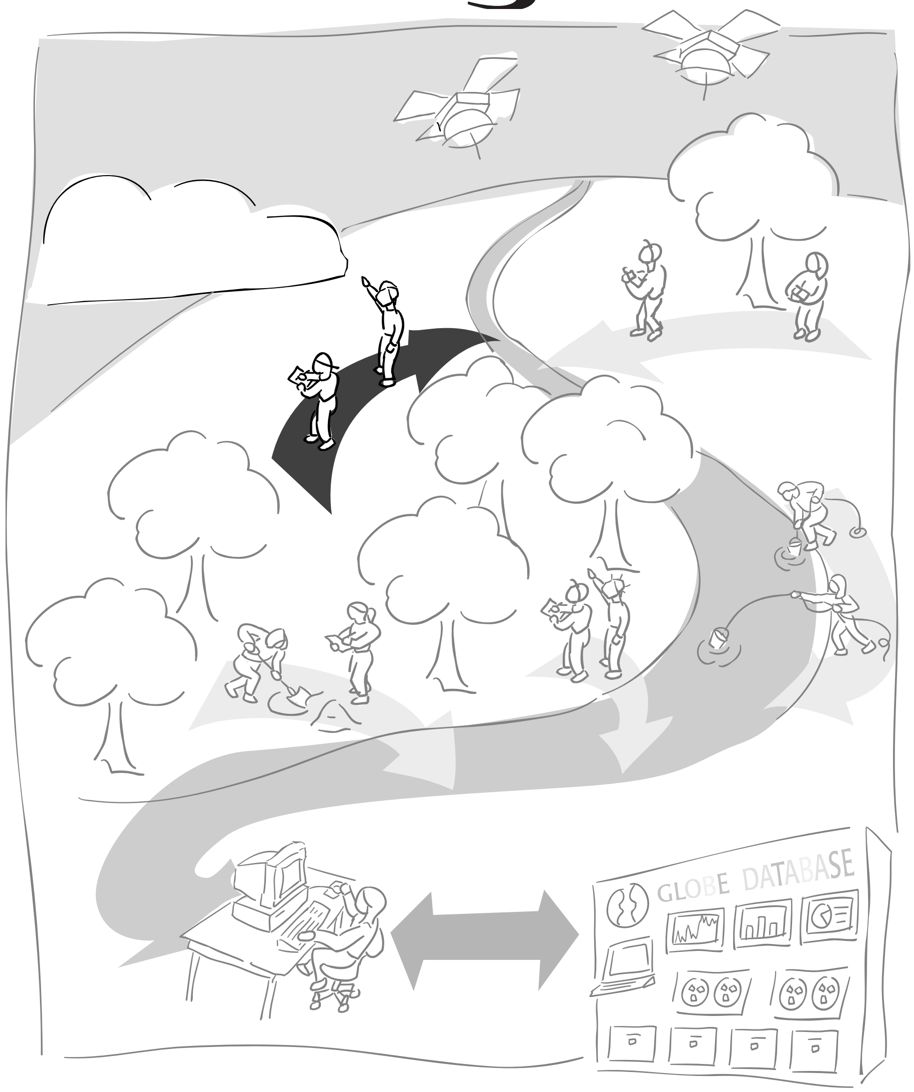
Atmosphere Investigation



A GLOBE® Learning Investigation

Atmosphere Investigation at a Glance

Protocols

Daily measurements within one hour of local solar noon:
- precipitation (rain or snow) including precipitation pH
- maximum and minimum temperature for the last 24 hours
  - (if using a Digital Multi-Day Max/Min thermometer this can be read at anytime of day)

At least one measurement per day:
- cloud cover and type and contrail cover and type
- aerosols
- water vapor
- relative humidity
- snow pack
- current temperature
- surface temperature
- ozone

Suggested Sequence of Activities

- Read the *Introduction*, especially the sections *What Measurements Are Taken* and *Getting Started*.
- Read the brief description of the learning activities at the beginning of the *Learning Activities* section.
- Review the protocols and plan which measurements your students will take; feel free to start with an easily sustained level of effort and then expand.
- Order any new or replacement instruments required.
- Cloud measurements are the easiest place to start and are required for several other protocols; do these activities with your students before beginning cloud observations:
  - *Observing, Describing, and Identifying Clouds*
  - *Estimating Cloud Cover: A Simulation*
- Install the instrument shelter which is required for taking air temperature measurements.
- Check the calibrations of your instruments (thermometers and barometer or altimeter).
- Have students define their Atmosphere Study Site and submit site definition data to GLOBE.
- Install your rain gauge and barometer or altimeter and plan out measurement logistics (such as where will required instruments and materials stay, timing and time requirements, etc.).
- Choose which *Atmosphere Data Sheets* your students will use and copy them.
- Copy the *Field Guides* for the protocols your students will follow.
- Teach students how to take the measurements following the *Field Guides,* record their readings on the *Data Sheet(s)*, and report data to GLOBE.
- Transfer to the students as much responsibility as practical for taking measurements and reporting data.
- Have students look at their data and comparable data from other schools.
- Engage students in inquiry and help middle and secondary students conduct student research projects using the *Looking at the Data* sections of the protocols.

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* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Appendix

Introduction

Scientists are investigating the atmosphere. They want to understand and predict:

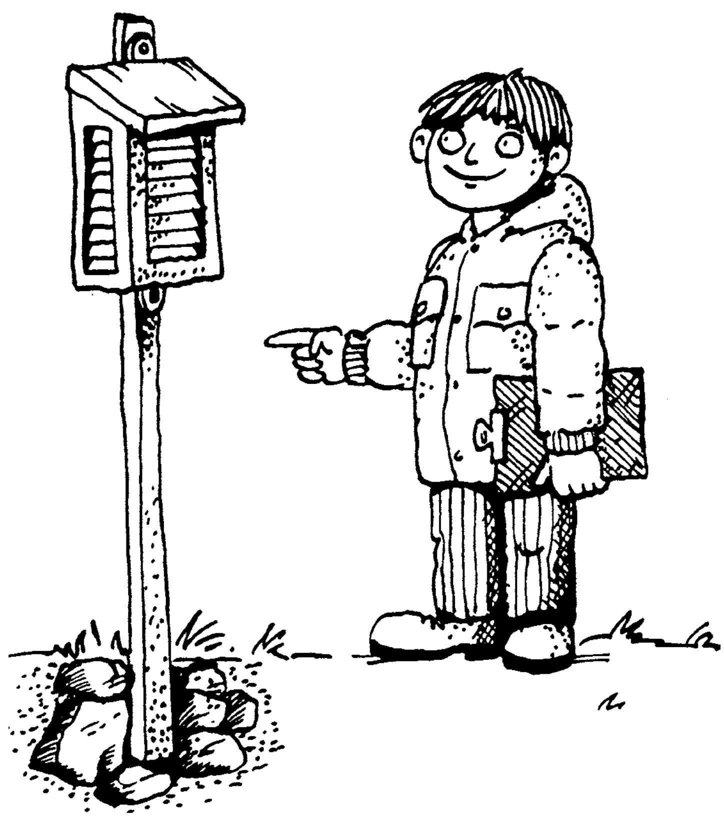
- Weather (the air temperature, rain, snow, relative humidity, cloud conditions, and atmospheric pressure and the coming and going of storms);
- Climate (the average and extreme conditions of the atmosphere);
- Energy Budget (Land-Atmosphere interactions); and
- Atmospheric Composition (the trace gases and particles in the air).

Each of these characteristics of the atmosphere affects us and our environment. What we wear and what we can do outside today depend on weather. Is it raining? Snowing? Sunny? Cold?

How we build our homes and schools, what crops we grow, what animals and plants naturally live around us all depend on climate. Does rain come mainly in winter or summer or every day? Do we get frost or snow? How long do dry spells last?

The composition of the atmosphere affects how our air looks and feels and how far we can see. On days when clouds don't completely cover the sky, does the sky look blue or milky? Does it ever have a brown tint? Do sunsets have lots of red color? All these are dependent on the composition of our air.

GLOBE scientists want several types of atmosphere data from schools to help in their investigations. As a GLOBE student, you can do research on the atmosphere, too. You can investigate your local weather, climate, and atmospheric composition and how these vary from place to place, season to season, and year to year. You will learn more about the air around you.



Why Investigate the Atmosphere?

We humans may live on land, but we live and move and breathe in the atmosphere. The atmosphere gives us the oxygen we breathe and carries off the carbon dioxide we exhale. The atmosphere filters out most harmful forms of sunlight and traps outgoing heat from Earth's surface. The atmosphere transports energy from the equator to the poles making the whole planet more liveable and brings the moisture evaporated from lakes and oceans to the dry land so that we have water to drink and to sustain our agriculture. We are creatures of the atmosphere and depend on its temperature, structure, composition and the moisture it carries.

Weather

On a day-to-day basis, we want to know many things about the weather we will encounter today. For example, we might like to know what the air temperature will be and whether it will rain so we can decide what type of clothes to wear; whether we need to take an umbrella with us when we go outside; or if we need to wear a hat and sunscreen to protect us from the sun's ultraviolet rays. We want to be sure the air we breathe is good for us. We want warnings so that we may protect ourselves and our property from severe storms.

Climate

We also want information about the atmosphere on a longer term basis. Farmers need to know if their crops will get enough rain. Ski resorts need to know if enough snow will fall. Insurance underwriters for areas struck by hurricanes would like to know how many hurricanes to expect in a given year and how strong they will be when they make landfall. Nearly everyone would like to know what the weather is going to be not only tomorrow or the next day, but next week, and what the climate will be six months, a year, or even ten years from now!

People have long said, "Everyone complains about the weather, but no one does anything about it." Today, scientists are working hard to understand and predict the full range of atmospheric phenomena, from storms to ozone. Atmospheric scientists study not only what is going on with the atmosphere today, but why it was a certain way in the past and what it will be like in the future. While controlling the weather is generally beyond human ability, the collective effects of human activity influence weather, climate, and atmospheric composition.

Scientific understanding of the atmosphere and the ability to forecast its future state grows through the application of fundamental laws and extensive observations. Since we care about the atmosphere on scales ranging from the individual farm to the entire globe and on timescales from a few minutes in severe storms to decades for the climate, vast quantities of data are needed.

Scientists Need GLOBE Data

People often think that scientists know what is happening in all parts of the world, but this is far from true. There are many regions where scientists have only the most general understanding of environmental factors such as air temperature and precipitation. Even in regions where there seems to be an abundance of data, scientists still do not know how much precipitation and temperature vary over relatively short distances. Official weather monitoring stations have contributed much data for a century or more in some locations while satellite technology has given us pictures of large areas every 30 minutes and global images at least twice daily for decades. Some areas have special monitors of atmospheric gases, and increasingly, airports monitor winds, not only at the ground, but up to heights of several kilometers. Despite all these wonderful efforts, there are gaps in coverage. The atmosphere varies significantly within these gaps, and GLOBE student measurements can improve the coverage for many types of observations.

Atmospheric conditions have an important impact on the types of plants and animals that live in a certain area, and even on the kind of soil that forms there. The measurements that students take for the GLOBE *Atmosphere Investigation* are important to scientists who study weather, climate, land cover, phenology, ecology, biology, hydrology, and soil.

The Big Picture

The Nature of the Atmosphere

Earth's atmosphere is a thin layer of gases composed of about 78% nitrogen, 21% oxygen, and 1% other gases (including argon, water vapor, carbon dioxide, and ozone). There are also solid and liquid particles called aerosols suspended in this layer. The atmosphere is held to the planet by gravity with the result that atmospheric pressure and density decrease with height above Earth's surface. See Figure AT-I-1.

Temperature also varies with height in the atmosphere (Figure AT-I-2), but in a more complex way than pressure and density. About half the sunlight shining on Earth passes all the way through the atmosphere and warms the surface. The warm ground then heats the air at the surface. Temperature generally decreases to heights of 8 to 15 km, depending on latitude. This defines the lower atmosphere or *troposphere* where most weather happens.

Ultraviolet sunlight is absorbed by oxygen to form the ozone layer and is also absorbed by ozone itself. This absorption warms the middle atmosphere, causing the temperature to rise with height from the top of the lower atmosphere to 50 km (the *stratosphere*) and then to fall with height to roughly 80 km (the *mesosphere*). Above this height, in the *thermosphere*, the density of the air is so reduced that many different phenomena begin to be important. At these heights, absorption of x-rays and extreme ultraviolet light from the sun ionizes the gases of the atmosphere and heats the air. The ions are affected by Earth's magnetic field and also by the solar wind. At great distances from the planet's surface, the atmosphere trails off into the *interplanetary medium*. The density of the atmosphere decreases until it is the same as that of interplanetary space.

There are differences in the atmosphere at different latitudes as well as different heights. The intensity of sunlight at Earth's surface varies with latitude. Sunlight is most intense in the tropics and least intense near the poles. The tropics are heated more than the poles, and the atmosphere along with the oceans transport heat from the equator toward the poles. The result is a large scale circulation of the atmosphere which is described in the *Earth As A System* chapter.

Through the motion of the atmosphere, all the different places on Earth are connected together on timescales of hours to days to months. Changes in one part of the world result in changes in other areas.

Figure AT-I-1

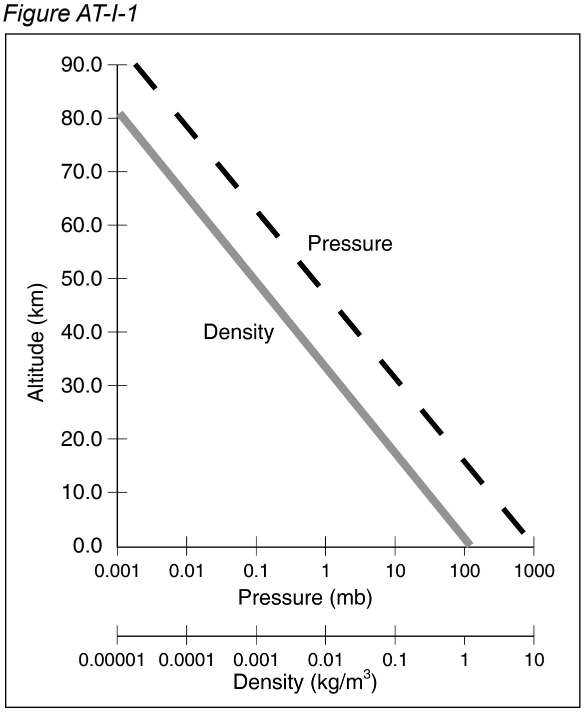
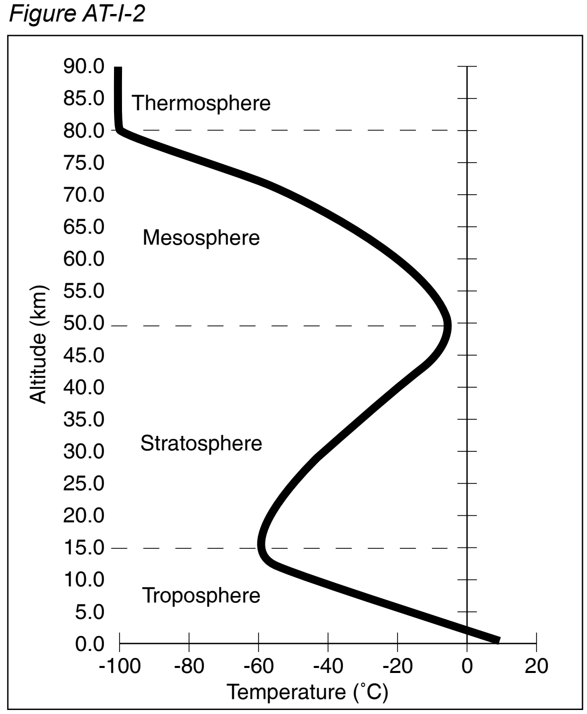


Figure AT-I-2



Weather and Climate, the Atmosphere Over Time

Weather and climate are not the same. By *weather* we mean what is happening in the atmosphere today, tomorrow, or even next week. By *climate* we mean weather averages, variability, and extremes over time. For example, in a certain city the current temperature may be 25° C; this is weather. If instead we were to look at the weather records for the past 30 years, we might find that the average temperature in that city on that particular day is 18° C (this is climate). We also might find that over this 30-year period the temperature in this city has ranged from as high as 30˚C to as low as 12˚C on that particular day. Therefore, the present temperature of 25˚C is not unusual.

When we study the history of Earth's climate, we notice that temperature and precipitation in any given region vary over time and that the composition of the atmosphere has changed. For example, images from certain satellites show that great rivers used to run through the Egyptian Desert. We also know that thousands of years ago, glaciers were present in places like New York City where today air conditioning is routinely used to cope with summer heat. If Earth was so different in the past, can we predict what might happen in the future? Predicting climate is a major goal of Earth Science today.

GLOBE Measurements

What Measurements Are Taken?

Different GLOBE measurements are useful in investigating weather, climate, and atmospheric composition.

Weather

- Cloud Cover and Type
- Contrail Cover and Type
- Barometric Pressure
- Relative Humidity
- Water Vapor
- Precipitation
- Maximum, Minimum, and Current Temperatures
- Surface Temperature
- Wind speed and direction (if you have automated equipment)

Climate

- Cloud Cover and Type
- Contrail Cover and Type
- Aerosol Optical Thickness
- Relative Humidity
- Precipitation
- Water Vapor
- Maximum, Minimum, and Current Temperatures
- Surface Temperature
- Wind speed and direction (if you have automated equipment)

Complemented by:

- Soil Temperature
- Soil Moisture
- Green-Up
- Green-Down

Atmospheric Composition

- Aerosol Optical Thickness
- Water Vapor
- Relative Humidity
- Precipitation (pH)
- Surface Ozone

Supported by measurements of:
Clouds, Barometric Pressure, Wind Direction, and Current Temperature.

Individual Measurements

Cloud Cover and Type

Clouds play an important role in Earth's weather and climate. Clouds also obscure (block out) the ground when the Earth is viewed from space. Therefore, satellites cannot observe the ground when it is cloudy and that can affect many scientific investigations, such as surface temperature.

Contrail Cover and Type

When a jet aircraft passes through a portion of the atmosphere having just the right combination of moisture and temperature it will form a linear cloud. These are known as contrails, or condensation trails. In some areas, jet traffic is causing a noticeable increase in cloudiness, which may affect both weather and climate. As part of the GLOBE *Cloud Protocols*, students use their eyes to determine the percentage of the sky that contrail's cover. They also count the contrails and categorize them into three types as given in the protocol. By quantifying the contrails present in the sky, students provide critical information needed to study how much of an affect these contrails are actually having on the weather that we experience.

Aerosol Optical Thickness

Small airborne liquid and solid particles, called aerosols, in the atmosphere affect whether the sky looks blue or milky, clear or hazy. They also influence the amount of sunlight that reaches Earth's surface. Using a sun photometer and a voltmeter to measure the intensity of sunlight reaching the surface, GLOBE students and scientists can determine aerosol amounts (aerosol optical thickness). Satellites infer this property of the atmosphere using remote sensing, while ground-based observations provide direct measurements to determine aerosol concentration. These two types of data complement one another, and student measurements can add greatly to the few ground-based professional monitoring stations currently collecting aerosol data.

Water Vapor

Water vapor in the atmosphere varies considerably in time and from place to place. These variations are related to both weather and climate. Clouds are formed from water vapor. Water vapor is the primary greenhouse gas that helps control temperatures in the lower atmosphere and on Earth's surface. Although the presence of water vapor near Earth's surface is easily discernible in the form of clouds and relative humidity, there are still many questions about atmospheric water vapor. Using a handheld GLOBE/GIFTS water vapor instrument to measure the intensity of the sunlight reaching the surface in specific wavelengths, GLOBE students and scientists can determine the amount of atmospheric water vapor present. Despite its importance, the global distribution and temporal variability of water vapor is not well known. Therefore, student measurements will be useful to scientists as they work to learn more about atmospheric water vapor.

Relative Humidity

The amount of water vapor in the air compared to the maximum amount of water vapor air at the same temperature and pressure can hold is referred to as relative humidity and is expressed as a percentage. Satellites can sense the amount of water in the atmosphere, but generally these measurements are averages over large regions ($\geq$10s of kilometers). Humidity may vary over much a smaller distances. Using either a sling psychrometer or a digital hygrometer to measure relative humidity, GLOBE students can expand the total set of humidity data and help scientists to gain a better understanding of its variations on small scales.

Precipitation

Rain and snow vary significantly over distances less than 10 km. In order to understand the local, regional, and global water cycles, we must know how much precipitation falls at many different locations around the world. Student observations using rain gauges and snow boards help provide improved sampling of rain and snow amounts and support improved understanding of weather and climate.

In addition to measuring the amount of precipitation, GLOBE students measure the pH of rain and melted snow. Knowing the pH of precipitation that falls in a particular area is often essential to understanding the pH of the soil and water bodies in that area. Student pH measurements establish a local basis for tracking changes in the input of acidity to the environment and can help scientists better map the fate of atmospheric chemicals.

Temperature

Air temperature varies throughout the day in response to direct solar heating and from day to day as weather systems move around the globe. Average air temperature also changes with the seasons. Scientists want to know both the extremes of temperature and the average temperature for time periods ranging from 24 hours to a month, a year, or longer. GLOBE students measure maximum and minimum temperatures for a 24-hour period beginning and ending within one hour of local solar noon. Scientists studying the climate of our planet are interested in finding out if the temperature at different places is changing, and if so, what patterns can be seen in these changes. Local temperature measurements, such as those taken by GLOBE students, aid scientists in answering these and other important questions regarding Earth's climate. Human settlement combined with variations in elevation and distance from water bodies produce local variations in temperature and GLOBE schools provide valuable detail for understanding changes even if there are official weather stations nearby.

There are a variety of options for measuring air temperature. The preferred method is to use a digital multi-day max/min thermometer as described in the *Digital Multi-Day Max/Min/ Current Air and Soil Temperatures Protocol*. This thermometer logs six days of maximum and minimum temperature data and has a soil probe that allows you to also collect soil temperatures. A U-shaped liquid-filled or digital single-day max/min thermometer can also be used as described in the *Max/Min/Current Air Temperature Protocol,* and must be read and reset everyday in order to obtain a continuous temperature record. Additionally, automated devises that log data may be utilized as described in the *Automated Soil and Air Temperature Monitoring Protocol* and *Automated Weather Station Protocols* that are available in the electronic version of the *Teacher's Guide.*

Surface Temperature

Described scientifically, surface temperature is the radiating temperature of the ground surface. Knowledge of surface temperatures is key to studying the energy cycle – the transfer of heat in your surrounding environment. The transfer of heat between the different components of the environment occurs at their boundaries, and surface temperature measurements provide the temperatures at these boundaries. Therefore, measurements of surface temperature help to relate air, soil, and water temperatures and contribute critically to the study of the energy cycle. Students can take surface temperature readings using a hand-held Infrared Thermometer (IRT). Measurements of surface temperatures are essential for climate studies, comparison with satellite data and to improve the understanding of the global energy balance.

Surface Ozone

Ozone (O_3) is a highly reactive gas present in the air around us. Knowing the amount of ozone in the air is important for understanding the chemistry of the atmosphere and its effect on the health of plants and animals, including us. Ozone concentrations are measured in units of parts per billion (ppb) and can vary over small spatial scales. Local measurements are required for scientists to track these local variations in ozone concentrations in the atmosphere. GLOBE scientists have developed a straightforward technique for students to measure ozone at their schools by exposing chemically treated strips to the air and measure their change in color with a hand-held reader. These student observations complement and extend the limited number of ozone monitoring stations currently in existence.

Where are measurements taken?

Atmosphere measurements are taken at the Atmosphere Study Site. This site is usually located on school grounds and should be within easy walking distance of your classroom so that students can take data daily in a minimum of time. Generally, the more open the site the better. Significant obstructions should be avoided, including trees and buildings near the instruments.

If your school does not have a suitable ground level location for safe, permanent installation of atmosphere instruments, use of roof sites and automated equipment can be considered. However, roof sites are not suitable for the *Surface Temperature Protocol*! Consult the *Optional Protocols* in this chapter for more guidance.

When are measurements taken?

The GLOBE atmosphere measurements should be taken on a daily basis, at specific times of day. See Figure AT-I-3. Taking daily measurements at the same time of day, allows easier comparison of measurements over the year and around the world. For GLOBE, many atmospheric observations should be made within one hour of local solar noon, and readings of daily total precipitation and maximum and minimum temperature are only acceptable if they are made within this 2-hour time period. Each of these measurements covers a roughly 24-hour period beginning within one hour of local solar noon on one day and continuing to within one hour of local solar noon on the next day. See Table AT-I-1.

Cloud and contrail observations, relative humidity readings, surface temperature, and current temperature measurements are also taken within one hour of local solar noon, but these observations can be reported for other times of day as well.

The digital multi-day max/min thermometer may be read at any time provided that it was reset within one hour of local solar noon.

Automated measurements are collected continuously at 15-minute intervals. This enables useful measurement of wind speed.

Local solar noon is the key time for taking GLOBE atmosphere measurements. See the section on how to calculate solar noon. Does this mean that only classes that meet at that time can participate? No! Because these measurements do not require much time to take, students from classes that meet earlier or later in the day can be assigned to take measurements during their lunch break or during a mid-day recess.

Solar Noon

Solar noon is the term used by GLOBE for the time when the sun appears to have reached its highest point in the sky during the day. An astronomer, for example, would refer to the same time as *local apparent noon*. Solar noon generally is not the same

Figure AT-I-3

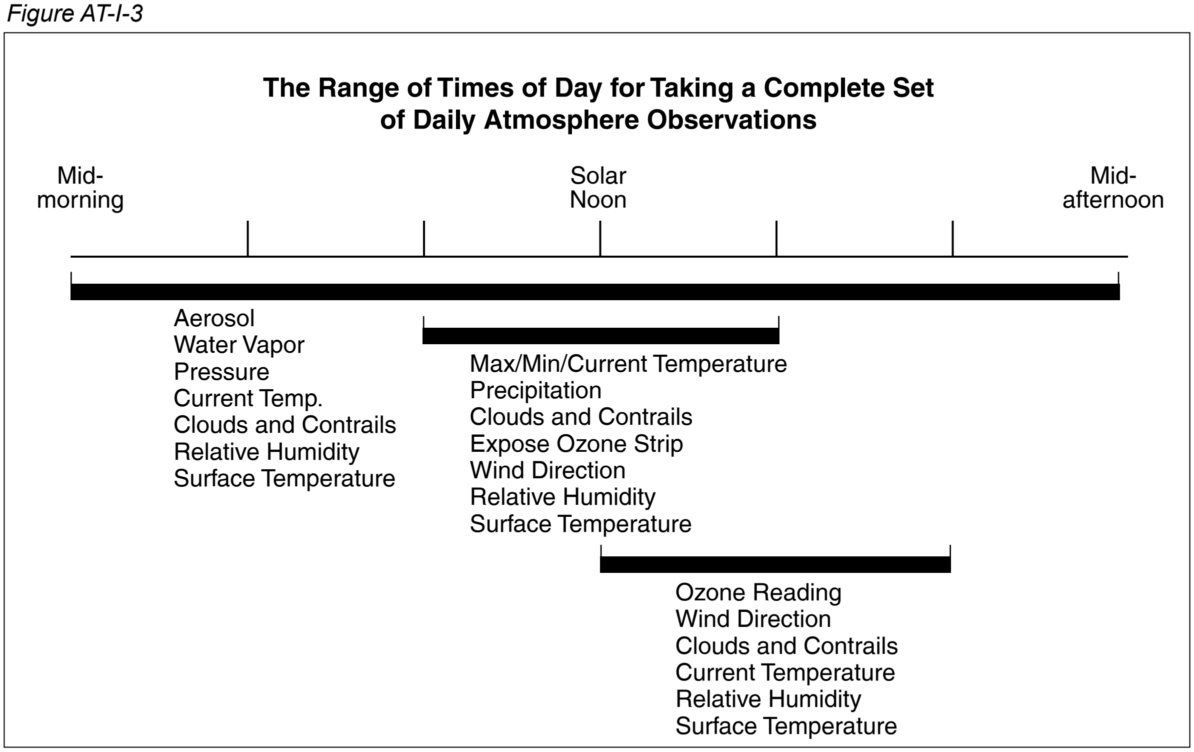


Table AT-I-1

Measurement	Taken within one hour of local solar noon	Other times measurements may be taken
Cloud Cover and Type Contrail Cover and Type	Yes	Required in support of aerosols, water vapor, surface temperature, ozone, and water transparency measurements; additional times are acceptable
Aerosols Water Vapor	Variable. Ideal time varies with location and season	When the sun is at least 30° above the horizon or at local solar noon when the sun doesn't reach 30° above the horizon; additional times are acceptable
Relative Humidity	Yes for the psychrometer; the digital hygrometer reading may be reported up to one hour later at the same time as the ozone measurement	Additional times are acceptable. Required in support of aerosols, water vapor, and ozone.
Precipitation	Yes	No
Current Temperature	Yes	Required for comparison with soil temperature measurements and in support of aerosols, water vapor, ozone, and relative humidity measurements; additional times are acceptable
Surface Temperature	Not required	Important for comparisons with soil and current temperature measurements
Maximum and Minimum Temperature	Yes	No
Barometric Pressure	Not required	Within one hour of aerosols and water vapor measurements if they are taken; otherwise as convenient
Ozone	The observation is started at this time and completed one hour later	Other one-hour periods are acceptable in addition to the near-noon measurement

as noon on your clock. The time of local solar noon depends on your location within your time zone, the time of year, and whether or not daylight savings time is in effect. Solar noon does occur, however, half-way between sunrise and sunset when the sun crosses the horizon. It is the point during the day when shadows are the shortest.

An easy way to determine local solar noon is to find a newspaper from your town or one nearby that gives times of sunrise and sunset and to calculate the average of these times. First, convert both times to 24-hour clock times by adding 12 to any p.m. times, then add the two times and divide by two. This is the time of solar noon. See Table AT-I-2.

Table AT-I-2

Example:	**1**	**2**	**3**	**4**
Sunrise (am or 24-hour clock are the same)	7:02 a.m.	6:58 a.m.	7:03 a.m.	6:32 a.m.
Sunset	5:43 p.m.	5:46 p.m.	8:09 p.m.	5:03 p.m.
Sunset (24-hour clock)	17:43	17:46	20:09	17:03
Sunrise + Sunset	24 hr 45 min	23 hr 104 min	27 hr 12 min	23 hr 35 min
Equivalent (so that the number of hours is even)	(unchanged)	24 hr 44 min	26 hr 72 min	22 hr 95 min
Divide by 2	12 hr 22.5 min	12 hr 22 min	13 hr 36 min	11 hr 47.5 min
Local Solar Noon (rounded to the nearest minute	12:23 p.m.	12:22 p.m.	1:36 p.m. or 13:36	11:48 a.m.

Note that this is an example of doing arithmetic in base 60.

How many students should be involved?

A single student can take any of the atmosphere measurements. However, it is a good idea to have a small group of students take readings so they can check each other. It also helps to have a partner to write down readings as they are made. Aerosols and water vapor measurements are difficult for one person to take alone. GLOBE recommends teams of 3 students as ideal for taking most measurements.

Many observations can either be taken by the group as a whole, or can be taken individually and then compared. If the readings are taken individually, the group must remember to empty the rain gauge and reset the thermometer only when all students are finished.

Ideally, pH measurements are taken by three different groups of students using three different samples of rain or melted snow. In all cases, taking three measurements is expected. These three results are averaged and compared as part of data quality control.

Rotating groups through the class (or classes) on a periodic basis will give all students an opportunity to participate. Having multiple groups take precipitation or maximum and minimum temperature measurements at different times on the same day is discouraged because it opens the door to confusion in emptying the rain gauge, resetting the 1-day maximum/minimum thermometer, and reporting the data.

The estimates of cloud type, cloud cover, contrail type, and contrail cover are *subjective* measurements, so the more students involved in this task, the better. Each student should take his or her own readings; then, students should come to an agreement as a group. Do not be surprised if your students initially have difficulty with these estimates. Even seasoned weather observers debate which type of cloud they are seeing, or exactly how much of the sky is covered by clouds. As your students get used to these observations, they will begin to recognize the more subtle distinctions in cloud types.

How long does it take to do the measurements?

The amount of time required to take the atmosphere measurements will vary depending on the location of your Atmosphere Study Site(s), how many students are on the team taking the data, student age and familiarity with the measurements, and the actual conditions encountered on a given day. See Table AT-I-3.

Getting Started

You and your students can investigate the atmosphere at your own study site and cooperate with scientists and other students to monitor the global environment. The atmosphere is one critical component of the global environment, and you can help compile a global database of

Table AT-I-3

Measurement	Approximate Time required (in minutes)
Cloud and contrail cover and type	10
Aerosols including supporting measurements	15 - 30
Water Vapor including supporting measurements	15 - 30
Aerosols and water vapor combined including supporting measurements	20 - 40
Relative Humidity	5 - 10
Precipitation	5 - 10
Precipitation pH using meter including calibration	10
Handling of snow samples in the classroom for snow or snow pack water equivalent	5
Snow water equivalent once the snow has melted	5
1-day maximum, minimum, and current temperature	5
Multi-day max/min/current air and soil temperature	5 - 10
Surface temperature including supporting measurements	10 - 20
Ozone deploying the strip and taking supporting measurements	10
Ozone reading the strip and taking supporting measurements	10 - 15
Entire set of local solar noon measurements: clouds and contrails, relative humidity, precipitation amount and pH, max/min/current temperature, surface temperature, and deploying the ozone strip*	15 - 25

*Taking aerosols or water vapor with this set should only add 5-10 minutes each.

atmospheric measurements that will aid in the long-term understanding of how the atmosphere is changing.

Keep a permanent record of your GLOBE data at your school. The atmospheric data that students gather should not only be submitted to the GLOBE data server, but should also be recorded permanently in the GLOBE Data Log for the school. A notebook of the *Data Sheets* filled in by the students can serve this purpose. See the *Implementation Guide* chapter for a description of the Data Log and its importance. Students should take pride in the fact that they are contributing to a long-term atmospheric data set at their school.

As your local data set grows, you should engage students in looking at their data. Each protocol of this chapter includes a *Looking At the Data* section, which outlines how to judge whether the data are reasonable and describes what scientists look for in data of this type. Most of them also contain a sample student investigation using data from the protocol. Review these sections for ideas on how to use GLOBE data for student learning about weather.

You and your students can approach the study of the atmosphere in many different ways, but three major themes that can be studied using the measurements you take in GLOBE are: weather, climate, and atmospheric composition. The sections below describe how the GLOBE *Atmosphere Protocols* contribute to an understanding of each of these areas that may be part of your curriculum.

Weather

Perhaps your students study weather. If so, their GLOBE work can become an integral part of this learning. By "weather" we mean the current condition and short-term changes in the atmosphere. Students may be familiar with weather reports and forecasts, and you could introduce the GLOBE protocols by asking them to explain what they think "weather" means. They will probably mention things like the temperature, whether it's raining or snowing, whether it's cloudy, whether it's windy and the direction of the wind. Some students may also mention barometric pressure, cloud types, and humidity. All of these are aspects of what meteorologists mean by "weather," and all can be measured in GLOBE. Thus, by doing GLOBE measurements, your students can begin to measure, monitor, study, track and forecast the weather.

Here is a suggested sequence for introducing GLOBE measurements through the study of weather.

1. Cloud and contrail measurements are the easiest place to start. They require only a cloud chart and the human eye. Two learning activities are good to do before beginning the actual cloud cover and cloud type protocols:
   - *Observing, Describing, and Identifying Clouds*
   - *Estimating Cloud Cover: A Simulation*
2. In order to submit your cloud cover and cloud type observations, you need to define an Atmosphere Study Site and submit site definition data to GLOBE. You may want do this before you set up the instrument shelter, so that if you experience delays in getting your shelter set up, you can still define your site and submit your cloud data.
3. You also can begin taking aerosols, water vapor, relative humidity, surface temperature, and barometric pressure readings without having the instrument shelter.
4. Current temperature measurements can also be taken without the instrument shelter. When you are able to install the instrument shelter you will be able to take and submit daily maximum and minimum air temperature measurements.
5. Taking and submitting liquid precipitation measurements requires the installation of a rain gauge on a post, but you can measure snow depth, liquid equivalent, and pH without the installation of the rain gauge.
6. If you use certain automated weather stations, you can add wind speed and direction to your set of GLOBE data following optional protocols.
7. You must check the calibrations of your instruments (thermometers, barometer or altimeter, sling psychrometer) before you begin.

Try your hand at forecasting. One interesting way for students to use the data they collect is to try to make weather forecasts using their own data and to compare their forecasts to those of professional meteorologists. Who is more accurate? What data are most helpful in making a prediction? What additional data do the professionals use that are not available to students? There are many interesting questions that can be pursued.

Climate

Climate is another major topic that your students may study and that can be explored using GLOBE measurements and data. "Climate" is the long-term trend of the atmosphere and other variable aspects of the environment. There is an old saying, "Climate is what you expect. Weather is what you get." Climate refers to averages and extremes of temperature, clouds, precipitation, relative humidity and their annual patterns.

Through looking at GLOBE data from their own school and from other sites around the world, students can begin to gain an appreciation for climate patterns and what causes them. They can notice seasonal trends, variations based on latitude, and variations based on proximity to large bodies of water. By using the GLOBE student data archive, students can compare the climate of their school, nearby schools, and schools in widely varying spots around the globe.

Students can take it as a challenge to build a long-term database that describes the climate of their locality. Most newspapers publish monthly summaries of the weather and compare them to climatic expectations. If not, then consult the meteorologist at your local airport or radio/TV station. These climatologies can provide the basis for interesting discussions of what is "normal" for your locale. Has it been a wetter than normal month? Hotter? Cooler? Cloudier? Using their GLOBE data and local climatic information, students can begin to answer these questions and think about how their climate may be changing.

To study climate your students will use the same atmosphere protocols as for weather, except they need not measure or look up barometric pressure. Routine measurements of daily amounts of precipitation and maximum and minimum air temperatures are critical for climate study. Measurements of soil temperature and moisture and of phenology are also important in studying climate. The temperature of water bodies and when they are dry or frozen are also useful. Students can think about and debate which of the GLOBE measurements are most important for describing the climate.

In order to study climate using GLOBE measurements, you will want your students to access data from other schools using the GLOBE Web site. GLOBE provides graphing tools online and the ability to download a school's data as a table that can be imported into other data analysis programs such as a spreadsheet.

Atmospheric Composition

Perhaps your students study the composition of the atmosphere. They can use three of the GLOBE *Atmosphere Protocols* – *Aerosols, Water Vapor* and *Surface Ozone* – to enhance their study. These can also be considered aspects of the weather and climate. Aerosols and water vapor affect visibility and the passage of sunlight and heat through the atmosphere while ozone levels have short and long term effects on plant and animal life and long term effects on all materials exposed to the atmosphere.

These protocols can be carried out without the installation of any permanent equipment, so even if you cannot install an instrument shelter and a rain gauge, you can still do these three measurements. However, for the *Surface Ozone Protocol* you will need to measure cloud and contrail cover and type, wind direction, and current temperature (using the alternative protocol that does not require the instrument shelter). For the *Aerosols* and *Water Vapor Protocols* you will need to record cloud and contrail cover and type, relative humidity, and current temperature, and may measure barometric pressure or obtain values from other sources or from GLOBE.

Getting Ready

To prepare yourself to lead students through an atmosphere investigation using GLOBE, read the introductory sections of the *Atmosphere* chapter of the GLOBE *Teacher's Guide*. Familiarize yourself with the scientific background information provided. Then take a look at the sections *What Measurements are Taken.* Decide which theme or set of questions your students should pursue and which measurements are appropriate for their study. Think about how to introduce GLOBE to your students as an opportunity for them to participate with scientists and other students in monitoring the global environment, and think about what projects and analyses your students can accomplish as they approach the atmosphere through the lens of weather, climate, or atmospheric composition.

If age appropriate, copy and distribute to students the section of the chapter entitled *Why Investigate the Atmosphere* in order to give them an understanding of why each measurement is scientifically important. Discuss the importance of both a global and a detailed local database to understand the environment and how they can contribute to this by submitting consistent accurate data to GLOBE. Engage the students in asking questions they can answer through taking and looking at data.

Review the specific protocols and plan which measurements your students will take. Feel free to start with an easily sustained level of effort that supports your educational objectives and then expand.

Obtain the instruments you will need and calibrate them if necessary. Set up your instrument shelter and rain gauge if you will be measuring maximum and minimum temperature and liquid precipitation.

Make photocopies of all the *Data Sheets* and field guides that students will need.

Prepare a notebook to serve as your school's Data Book.

Then, begin doing the GLOBE *Atmosphere Investigation!*

Educational Objectives

Students participating in the activities presented in this chapter should gain scientific inquiry abilities and understanding of a number of scientific concepts. These abilities include the use of a variety of specific instruments and techniques to take measurements and analyze the resulting data along with general approaches to inquiry. The Scientific Inquiry Abilities listed in the grey box are based on the assumption that the teacher has completed the protocol including the *Looking At the Data* section. If this section is not used, not all of the Inquiry Abilities will be covered. The Science Concepts included are outlined in the United States National Science Education Standards as recommended by the US National Research Council and include those for Earth and Space Science and Physical Science. The Geography Concepts are taken from the National Geography Standards prepared by the National Education Standards Project. Additional Enrichment Concepts specific to the atmosphere measurements have been included as well. The gray box at the beginning of each protocol or learning activity gives the key scientific concepts and scientific inquiry abilities covered. The following tables provide a summary indicating which concepts and abilities are covered in which protocols or learning activities.

	Basic Protocols				Adv. Protocols	
National Science Education Standards	Clouds	Humidity	Precip.	Temp.	Aerosols	Ozone
Earth and Space Science Concepts						
Weather can be described by quantitative measurements		■	■	■		■
Weather can be described by qualitative observations	■					
Weather changes from day to day and season to season	■	■	■	■		■
Weather varies on local, regional, and global spatial scales	■	■	■	■		■
Clouds form by condensation of water vapor in the atmosphere	■					
Clouds affect weather and climate	■					
Precipitation forms by condensation of water vapor in the atmosphere		■	■			
The atmosphere has different properties at different altitudes	■					
Water vapor is added to the atmosphere through evaporation and transpiration from plants	■	■				
The atmosphere is composed of different gases and aerosols					■	■
The sun is a major source of energy for changes in the atmosphere					■	
The diurnal and seasonal motion of the sun across the sky can be observed and described					■	
The water vapor content of the atmosphere is limited by pressure and temperature		■				
Condensation and evaporation affect the heat balance of the atmosphere		■				
Materials from human societies affect the chemical cycles of Earth						■
Dynamic processes such as Earth's rotation influence energy transfer from the sun to Earth						
The atmosphere has changed its composition over time						
Water circulates through the crust, oceans, and atmosphere						
Global patterns of atmospheric circulation influence local weather						
Oceans have a major affect on global climate						
Solar insolation drives atmospheric and ocean circulation						
The sun is the major source of energy for Earth surface processes						
The sun is the major source of energy at Earth's surface						
Solar isolation drives atmospheric and ocean circulation						
Physical Science Concepts						
Materials exist in different states – solid, liquid and gas	■	■	■			
Heat transfer occurs by radiation, conduction, and convection						
Substances expand and contract as they are heated and cooled						
Light radiation interacts with matter						
The sun is a major source of energy on the Earth's surface						
Energy is transferred in many ways						
Heat moves from warmer to cooler objects						
Light/ radiation interacts with matter						
The sun is a major source of energy for changes on the Earth's surface						
Energy is conserved						
Life Science Concepts						
Sunlight is the major source of energy for ecosystems						
Energy for life drives mainly from the sun						
General Science Concepts						
Scale models help us to understand concepts						
Visual models help us to analyze and interpret data						

* See the electronic version of the complete *Teacher's Guide* on CD-ROM or GLOBE Web site.

Adv. Protocols		Learning Activities											
Water Vap.	Surface Temp	Estimate Cloud Cover	Cloud Watch.	Observe Clouds	Study Instr. Shelter*	Build a Thermo-meter*	Draw Visuals*	Use Visuals*	Contour Map*	Make a Sundial	Hazy Skies	Air Mass	Model ppv*
■		■											
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	Basic Protocols				Adv. Protocols	
National Science Education Standards	Clouds	Humidity	Precip.	Temp.	Aerosols	Ozone
Geography Concepts						
The temperature variability of a location affects the characteristics of Earth's physical geographic system				■		
The nature and extent of cloud cover affects the characteristics of Earth's physical geographic system	■					
The nature and extent of precipitation affects the characteristics of Earth's physical geographic system			■			
Human activities can modify the physical environment					■	
Water vapor in the atmosphere affects the characteristics of Earth's physical geographic system		■				
Measurements of atmospheric variables help to describe the physical characteristics of an environment						
The physical characteristics of a location depend on its latitude and relation to incident solar radiation						
Geographic visualizations help to organize information about places, environments, and people						
The concentration of water vapor varies significantly from place to place, and depends on altitude, latitude, and climate						

* See the electronic version of the complete *Teacher's Guide* on CD-ROM or GLOBE Web site.

Adv. Protocols		Learning Activities											
Water Vap.	Surface Temp	Estimate Cloud Cover	Cloud Watch.	Observe Clouds	Study Instr. Shelter*	Build a Thermo-meter*	Draw Visuals*	Use Visuals*	Contour Map*	Make a Sundial	Hazy Skies	Air Mass	Model ppv*
	■												
	■					■							
	■	■	■	■									
	■												
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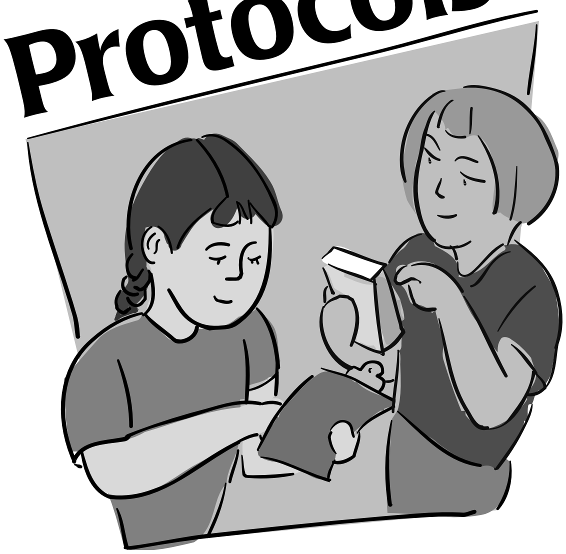
■													

	Basic Protocols				Adv. Protocols			
National Science Inquiry Standards	Clouds	Humidity	Precip.	Temp.	Aerosols	Ozone	Water Vapor	Surface Temp.
General Scientific Inquiry Abilities								
Use appropriate tools and techniques								
Construct a scientific instrument or model								
Identify answerable questions								
Design and conduct scientific investigations								
Use appropriate mathematics to analyze data								
Develop descriptions and explanations using evidence								
Recognize and analyze alternative explanations								
Communicate procedures and explanations								
Specific Scientific Inquiry Abilities								
Use a thermometer to measure temperature								
Use a cloud chart to identify cloud type								
Estimate cloud cover								
Use a rain gauge to measure rainfall and rain equivalent of snow								
Use pH paper, pens, or meters to measure pH								
Use meter sticks to measure snow depth								
Use a sun photometer and voltmeter to measure the amount of direct sunlight								
Use ozone strips and a strip reader to measure in situ ozone concentrations								
Use a weather vane to identify wind direction								
Use a barometer or altimeter to measure barometric pressure								
Use a hygrometer or sling psychrometer to measure relative humidity								
Use instrument to measure atmosphere water vapor content								
Use an infrared thermometer								

	Learning Activities										
Estimate Cloud Cover	Cloud Watch	Observe Clouds	Study Instrument Shelter*	Build a Thermo-meter*	Draw Visuals*	Use Visuals*	Contour Map*	Make a Sundial	Hazy Skies	Air Mass	Model ppv*

Protocols



Instrument Construction, Site Selection, and Set-Up

Selecting a convenient site is critical for daily data collection.

Cloud Protocols

Students estimate the amount of cloud and contrail cover, observe which types of clouds are visible, and count the number of each type of contrail.

Aerosols Protocol

Students use a red/green sun photometer to measure the amount of sunlight reaching the ground when clouds do not cover the sun.

Water Vapor Protocol

Students use a near-infrared sun photometer to measure the amount of sunlight reaching the ground at wavelengths that are correlated to water vapor.

Relative Humidity Protocol

Students measure the relative humidity using either a digital hygrometer or a sling psychrometer.

Precipitation Protocols

Students measure daily rainfall using a rain gauge, daily snowfall using a snow board, total snow accumulation on the ground, the equivalent depth of rain for both new snow and snow pack, and use techniques from the *Hydrology Investigation* to measure pH of rain and melted snow.

Digital Multi-Day Max/Min/Current Air and Soil Temperature

Students use a digital multi-day maximum/minimum thermometer mounted in their instrument shelter to measure the maximum and minimum air and soil temperatures for up to six previous 24-hour periods.

Maximum, Minimum, and Current Temperature Protocol

Students use a maximum/minimum thermometer mounted in their instrument shelter to measure current temperature and the maximum and minimum temperatures for the previous 24 hours. Students also may collect current temperature only.

Surface Temperature Protocol

Students use an infrared thermometer (IRT) to measure the temperature of Earth's surface.

Ozone Protocol

Students expose a chemically sensitive strip to the air for an hour and determine the amount of ozone present using an ozone strip reader.

*Optional Automated Weather Station Protocols**

Students use an automated weather station to measure barometric pressure, relative humidity, rain rate and amount, air temperature, and wind speed and direction every 15 minutes.

*Optional Barometric Pressure Protocol**

Students use an aneroid barometer to measure barometric pressure in support of the *Aerosols* and *Water Vapor Protocols.*

*Optional Automated Soil and Air Temperature Monitoring Protocol **

Students use a data logger and temperature sensors to measure air temperature and soil temperature at 5, 10, and 50 centimeter depths every 15 minutes for extended time periods.

*Optional AWS Weather Net Protocol**

Students define their school's AWS Weather Net station as a GLOBE Atmosphere Study Site and arrange for GLOBE to retrieve a copy of the data from their station to include in the GLOBE data archive.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Instrument Construction

Instructions for Building an Instrument Shelter

The GLOBE Instrument Shelter should be constructed of approximately 2 cm thick White Pine or similar wood and painted white, inside and out. A lock should be installed to prevent tampering with the instruments. Mounting blocks should be installed on the interior to insure that the max/min thermometer does not touch the back wall. The parts should be screwed together or glued and nailed. The plans are specified in metric units. Therefore, you may need to make minor adjustments to dimensions depending on the local standard dimensions of wood in your region.

It is easier to purchase prefabricated louvered panels, and they are usually available for purchase. The primary criteria for constructing louvres is that they provide for ventilation of the instrument shelter while preventing sunlight and rain from entering directly. To prevent sunlight from entering the shelter we suggest that each louvre slat overlap slightly with adjacent slats. See Figure AT-IC-1. There should also be a gap between slats of approximately 1 cm, and the slat angle should be roughly 50-60 degrees from horizontal. For shelter mounting instructions, see Figure AT-IC-8.

Figure AT-IC-1: Instrument Shelter

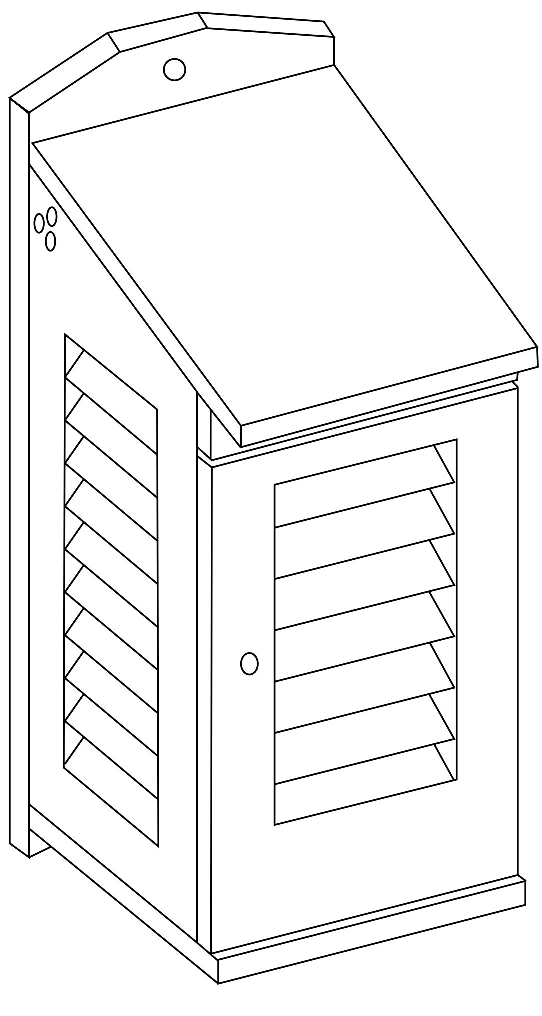


Figure AT-IC-2: Instrument Shelter Dimensions

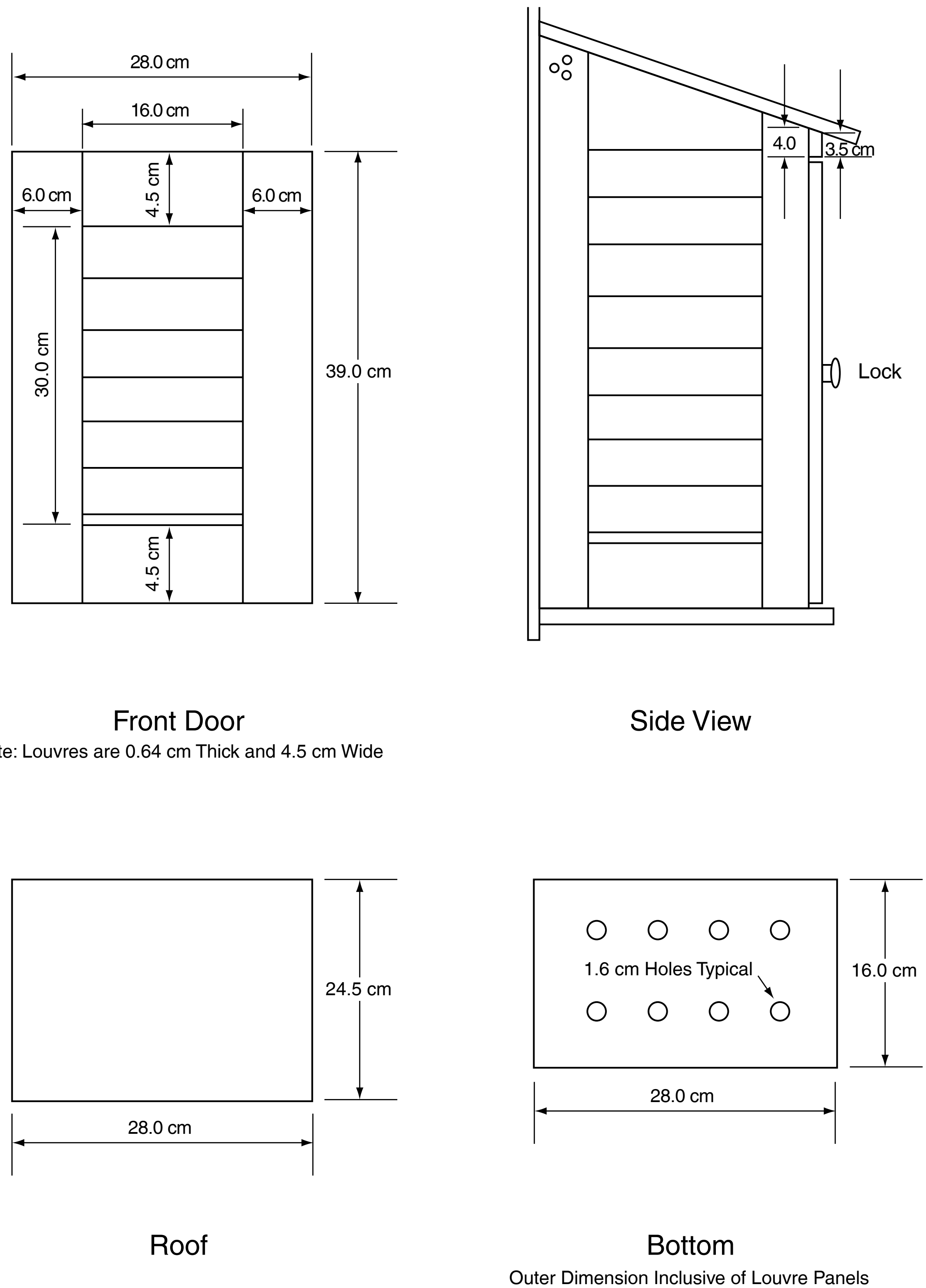
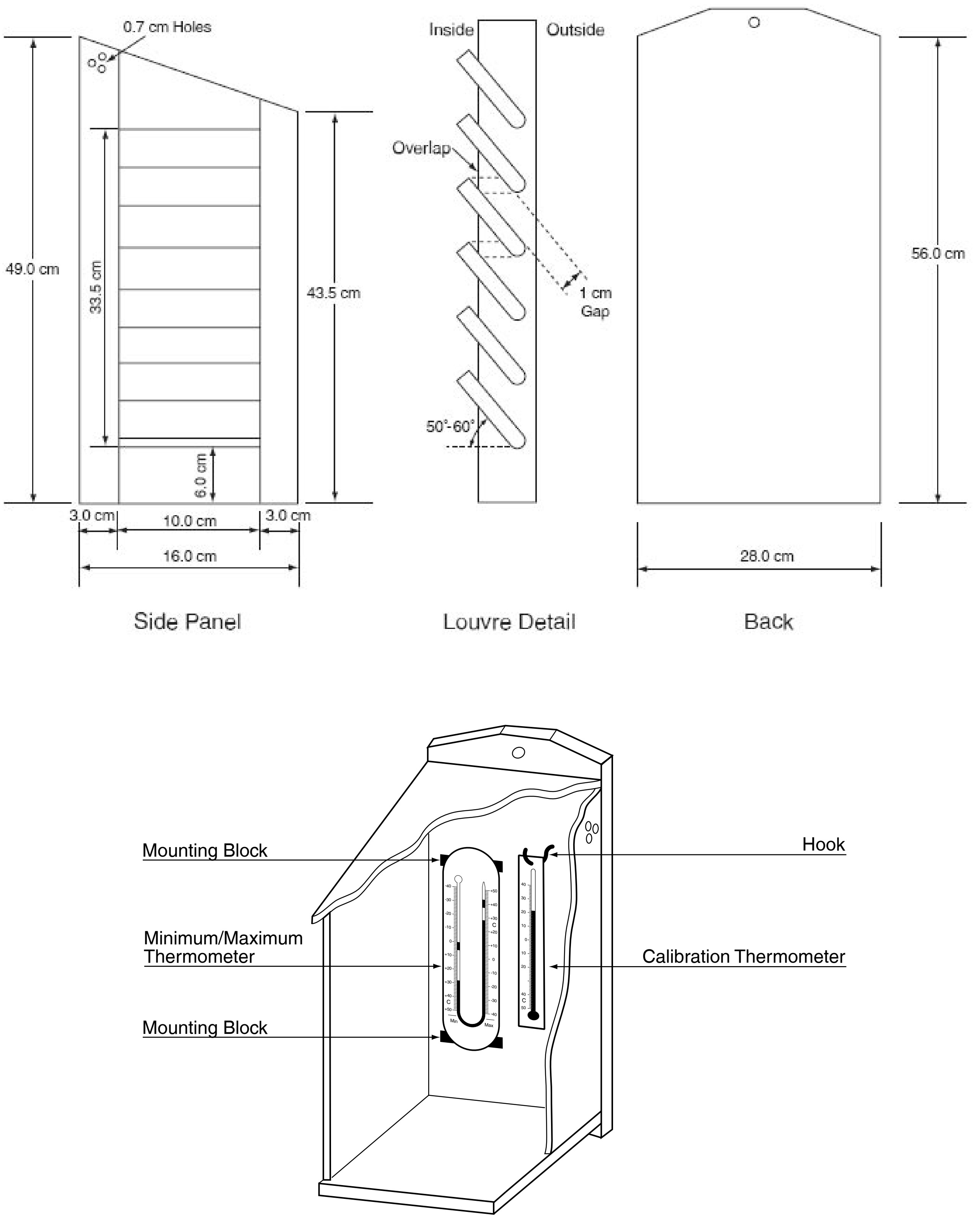


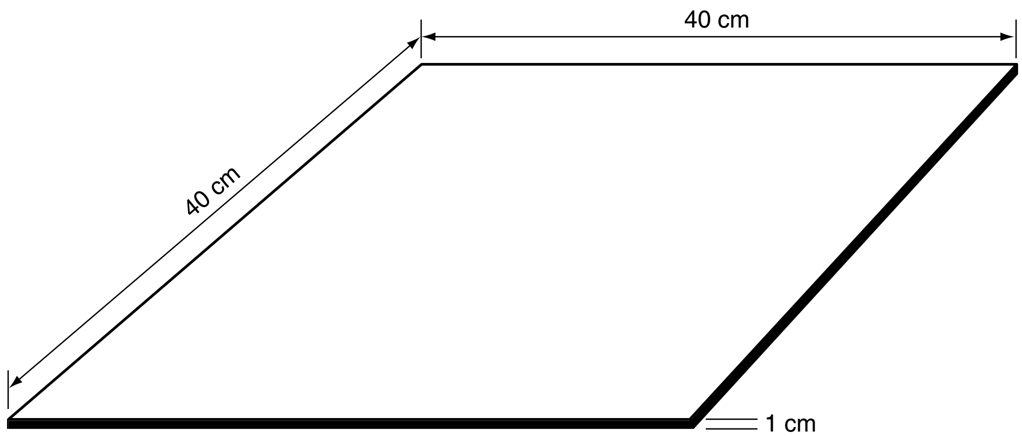
Figure AT-IC-3



Instructions for Constructing a Snowboard

A snowboard is a thin, flat surface that rests on top of earlier layers of snow. New snow falls on top of it and can be measured with a meter stick. The board should be made of plywood about 1 cm thick. It must be light enough so that the existing snow will support its weight. It should be at least 40 cm by 40 cm in area so that more than one snow depth measurement can be made and so that samples may be collected for both snow water equivalent and snow pH. The snowboard must be painted white. A flag will be needed to mark the location of the snowboard so that it can be found following a fresh snowfall.

Figure AT-IC-4: Snowboard Dimensions



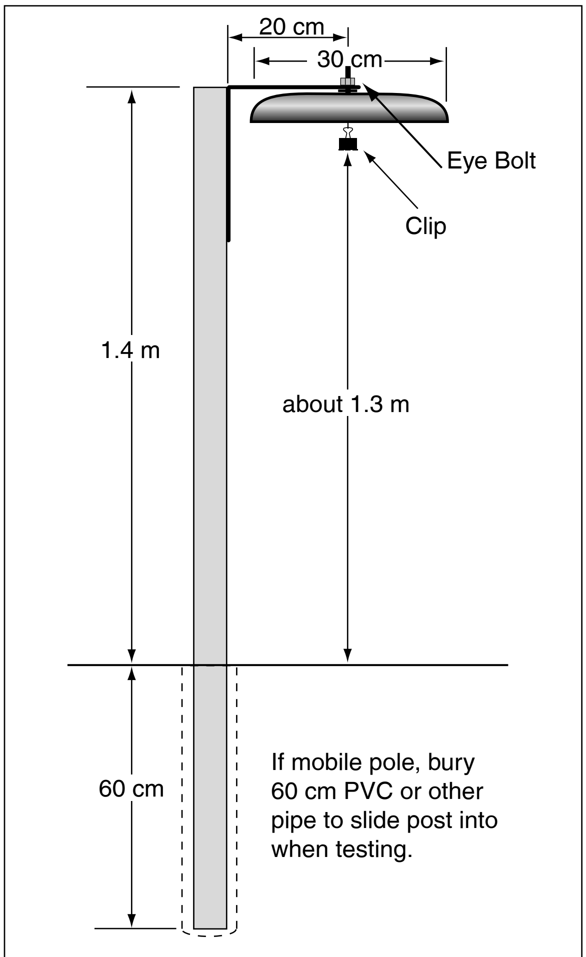
Constructing the Ozone Measurement Station

Materials

The materials needed to construct the Ozone Measurement Station can be purchased at a local hardware store.

1 Plastic Disk for a roof guard – 30 cm diameter (e.g., frisbee, plastic bucket lid)
1 Corner Bracket – 20 cm (8")
1 Eye Bolt – 1 cm x 5 cm (3/8" x 2")
2 Rubber Washers – 1 cm (3/8")
1 4 Links of 1 cm (3/8") stainless steel chain
1 Binder Clip – 3 cm (1 1/4")
1 Can light colored rust-protective enamel paint
1 2 m (6'8") sturdy pole or treated wooden post

Figure AT-IC-5



Directions for Construction

1. Spray-paint all metal pieces with light-colored, rust-resistant paint.
2. Place one washer on the eye bolt.
3. Place the 30-cm plastic disk on top of the eye bolt with the convex side facing up (so rain water will run off).
4. Place the eye bolt through the drilled hole of the bracket. Put on the second washer and secure it with a nut.
5. Attach the other side of the bracket to a 2 meter post or pole and place 60 cm securely into the ground or attach it to a mobile pole that fits into a 60 cm-long section of PVC or other pipe buried in the ground. See Figure AT-IC-5.

Making the Chain Clip

1. Use needle nose pliers to open one link on the end of the chain to slide over the eye bolt and use the pliers to close the open link.
2. Open the link on the opposite end of the chain and attach it to one handle of the 3 cm (1 1/4") binder clip. Close the link securely.
3. When you are ready to expose the ozone strip, place it in the binder clip.

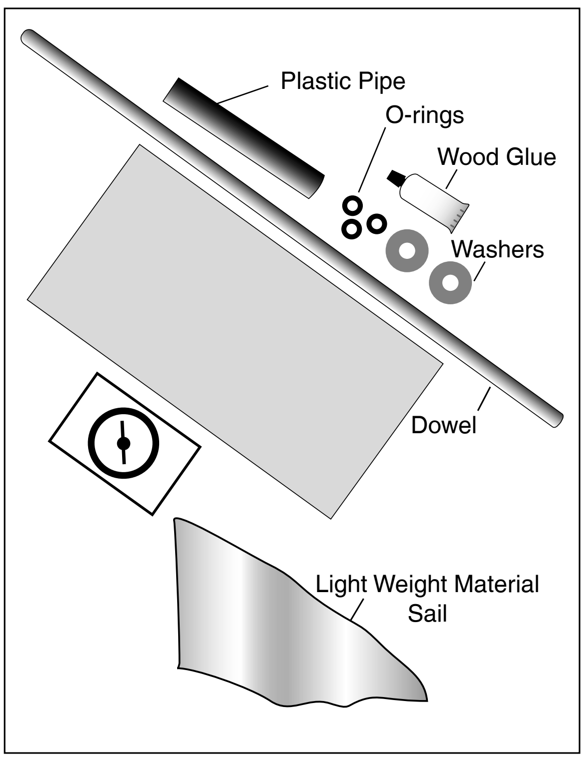
The ozone measurement station is designed to provide some protection from rain and snow for the ozone test strip. The chain with the chemical strip should be long enough that the ozone test strip hangs in the open air below the plastic disk and short enough that the wind cannot make the strip swing out from under the plastic disk which is serving as a roof.

Constructing a Wind Direction Instrument

Materials

1 Scrap piece of pine – approximately 5 cm x 15 cm x 60 cm for base
1 Dowel
3 O-rings – to fit snugly on dowel
2 Wide flat washers – with the inner diameter of the dowel
1 15 cm piece of plastic pipe
1 Package of letters and numbers or paint
1 Compass
1 Scrap piece of very light weight material (nylon, plastic, etc.) to cut right triangle wind sail (roughly 15 cm x 25 cm)
2 Pieces of waxed dental floss or nylon thread to tie sail
1 Drill with spade bit – for drilling hole for dowel
1 15 cm piece of self-adhesive velcro
1 Container of wood glue

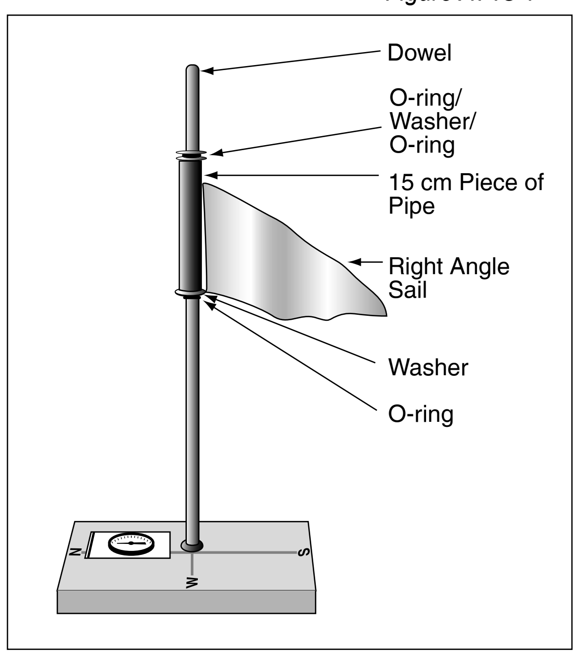
Figure AT-IC-6



Directions for Construction

1. Draw lines through the center of the wood (one going end to end and one going from side to side) and place letters on the grid N, S, E and W.
2. Drill hole the same diameter as your dowel, almost all the way through the center of block of wood.
3. Cut dowel to 60 cm in length and lightly sand both ends.
4. Glue one end of the dowel in the hole.
5. Roll one O-ring down approximately 25 cm from the top of the dowel.
6. Place steel flat washer on top of the O-ring.
7. Place 15 cm long piece of plastic pipe on top of the flat washer.
8. Place a second O-ring 0.5 cm above the pipe.
9. Place a washer on top of the O-ring and the third O-ring on top of the washer.
10. Cut out right angle sail and attach it to the pipe with nylon thread or waxed dental floss.
11. Attach Velcro to wood and back of compass and line N on the compass up with N on the line of the wooden block. (N on the wood should be true North and not magnetic North, so be sure to adjust for your magnetic declination.) If you are not familiar with the difference between North and magnetic north, see the *GPS Investigation* for help.

Figure AT-IC-7



Frequently Asked Questions

1. Does our instrument shelter have to have slats?

It is important that air be able to pass freely into and out of the instrument shelter so that the thermometer measures the ambient air temperature. The slats on the instrument shelter allow air to move through the shelter, but also help to keep out rain, snow, and blowing debris. Just putting holes in the walls of the shelter will let in more rain or snow than the slats will. So yes, it is very important for the instrument shelter to have slats. For more insight to the characteristics of the instrument shelter, see the Learning Activity on *Studying the Instrument Shelter*.

2. Why does the instrument shelter have to be white?

The role of the instrument shelter is to protect the thermometers from direct sunlight, as well as from precipitation and flying debris. However, we want to make sure that the instrument shelter itself doesn't affect the air temperature being measured. That is, we want the air temperature inside the shelter to be the same as the air temperature in the shade outside the shelter. This means that we want a shelter that won't absorb a lot of sunlight and heat up more than its surroundings. By making the shelter white, most of the sunlight that hits the shelter is reflected away. For more insight to the characteristics of the instrument shelter, see the Learning Activity on *Studying the Instrument Shelter*.

3. Must our snowboard be made of plywood?

Plywood is best, but other light woods may be used. Metal is not appropriate as it can warm up too much in sunlight and melt the initial snow of a day time snowfall. The key is that the snowboard is light enough to be placed on the surface of the snow and not sink into the snowpack.

Site Selection and Set-up

Choosing the location for your Atmospheric Study Site and correctly setting up your rain gauge, instrument shelter, and ozone measurement station are critical to your successful implementation of this investigation. Atmosphere measurements are taken frequently, so students need to be able to get to the site and return in a short amount of time.

The ideal site for taking atmospheric measurements is open, away from trees, buildings and other structures. The open area helps because nothing blocks precipitation creating rain or snow shadows, air is free to flow around the instruments, heat from individual buildings doesn't affect the data significantly, and most of the sky can be seen. In choosing your site, some compromise may be necessary between the ideal for scientific observations and the logistical constraints of the school grounds and their surroundings. The key to ensuring the value of your students' data is to document the nature of your Atmosphere Study Site and its surroundings.

Figure AT-IC-9 shows the ideal site. Trees, buildings, and other structures are all at least four times as far away as they are tall. For example, if your site is surrounded by trees or buildings that are 10 meters tall, place your instruments at least 40 meters from these trees. At such distances, trees, bushes, or buildings can be useful by breaking the wind and actually make your rainfall and snowfall readings more accurate

Cloud, Contrail, and Aerosol Observations

Measurements of cloud and contrail amounts, cloud type, and aerosols require an unobstructed view of the sky but do not require the installation of any equipment. The middle of a sports field is an excellent location. The site where you take your cloud, contrail, and aerosol measurements does not have to be the same as the location of your rain gauge, hygrometer, ozone measurement station, and instrument shelter. If you choose to take cloud, contrail, and aerosol observations from a separate site located more than 100 m from the shelter, define two Atmosphere Study Sites and report the data from the different protocols separately. To pick a good spot from which to take these measurements, simply walk around your school until you come to an area where you have the most unobstructed view of the sky. If you live in a city, you may not be able to find a completely unobstructed view of the sky. Choose the most open site available.

For sites that have substantial obstacles such as tall trees or large buildings which prevent a view of the entire sky, it will be helpful to take three observations of cloud and contrail cover and cloud and contrail type, spaced 5 minutes apart. In these situations, report to GLOBE the average cloud and contrail cover and all cloud types observed, rather than a single observation.

Precipitation, Relative Humidity, Temperature, and Ozone Instrument Placement

The ideal placement for both the rain gauge (and/or snowboard) and the instrument shelter, which will house the thermometers and digital hygrometer instrument, is a flat, open area with a natural (e.g., grassy) surface. Avoid building roofs and paved or concrete surfaces if at all possible; these can become hotter than a grassy surface and may affect instrument readings. Hard surfaces can cause errors in precipitation measurements due to splash-in. Also avoid placing the instruments on steep slopes or in sheltered hollows unless such terrain represents the surrounding area.

Measurements of soil moisture and temperature are much more valuable to scientists and more usable in student research projects if data on precipitation and air temperature are available from a site that is within 100 meters of the Soil Moisture or Soil Temperature Study Site. These soil measurements involve digging, placing instruments in the ground, taking samples of soil, and sticking soil thermometers in the ground. If it is possible for your school to take these soil measurements, even if you don't plan to do so for several years, you should take into consideration the requirements for the *Soil Moisture* and *Soil Temperature Protocols* given in the *Soil Investigation.*

Rain Gauge Placement

Since wind is one of the greatest causes of error in rain gauge measurements, the best placement for the rain gauge is on a post as low to the ground as practical. Wind blowing across the top of the gauge creates an effect that causes raindrops to be deflected around the gauge. Because wind speed generally increases with height above the ground, the lower the rain gauge, the less effect the wind should have on it. In Figure AT-IC-8, note that the instrument shelter and the rain gauge are mounted on separate posts. The top of the rain gauge is about 0.5 meters above the ground and is located 4.0 meters away from the instrument shelter so that the shelter does not block rain from collecting in the gauge.

If it is not practical to place the rain gauge and instrument shelter on separate posts, they may be mounted on a single post, with the rain gauge mounted on the opposite side from the shelter. Regardless of whether the rain gauge shares a post with the instrument shelter or is mounted on its own post, make sure the top of the rain gauge is about 10 cm higher than the top of the post, to avoid splash-in of rain from the post top. If possible, cut the top of the post at a 45˚ angle sloping away from the rain gauge so that drops will splash away from the gauge.

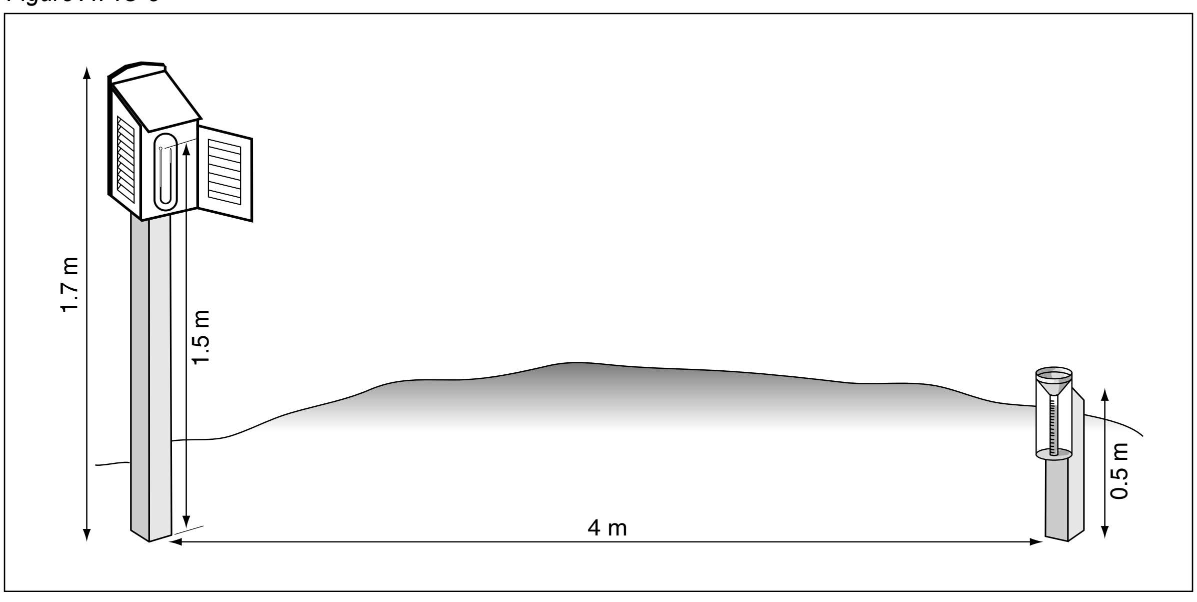
Snowboard Placement

Place the snowboard on relatively level ground where the snow depth best represents the average depth of the surrounding area. For a hillside, use the slope with an exposure away from the sun (this means a northerly exposure in the Northern Hemisphere and a southerly exposure in the Southern Hemisphere). The site should be free from trees, buildings, and other obstructions that may affect wind flow or the melting of snow. Remember that after each new snow fall, the snowboard will be moved to a new, undisturbed location. Also remember to place a flag where the snowboard is located so that you can find it following a snow fall.

Instrument Shelter and Thermometer Placement

The instrument shelter should be mounted so that the maximum-minimum thermometer mounted inside is 1.5 meters above the ground (or 0.6 meters above the average maximum snow depth). This will help prevent heat from the ground from affecting your temperature reading. The instrument shelter should be mounted on the side of the post that faces away from the equator. That is, the instrument shelter should be placed on the north-facing side of the post in the

Figure AT-IC-8



Northern Hemisphere, and on the south-facing side of the post in the Southern Hemisphere. This placement helps protect the thermometer from direct sunlight when the shelter door is opened to take a reading.

The post on which the instrument shelter is mounted should be secured in the ground as firmly as possible. This will help minimize vibrations caused by strong winds which may cause the indicators in the maximum/minimum thermometer to move. Locking the instrument shelter is customary to prevent tampering with the thermometer between readings.

The shelter protects the thermometer from radiation from the sun, sky, ground, and surrounding objects, but allows air to flow through so the air temperature inside the shelter is the same as the air temperature outside the shelter. Mount the maximum/minimum thermometer in the instrument shelter so that there is air flow all around the thermometer case. This is usually accomplished by using blocks or spacers between the thermometer and the rear wall of the shelter. See Figure AT-IC-3. No part of the thermometer should touch the walls, floor, or ceiling of the shelter.

The probe of the digital multi-day maximum/minimum thermometer should hang in the air in the air inside the shelter and not touch the walls. The read-out unit may be mounted on the back wall.

Ozone Measurement Station

The measurement station is mounted on a permanent post and located in an open area to allow air to flow freely around the chemical strip. It should be located near the GLOBE Instrument Shelter to enable students to collect required current temperature data easily. Thus, the Ozone Measurement Station is part of the Atmosphere Study Site.

The unit that holds the chemical test strip should be attached to a 5-cm diameter by 2-meter long wooden pole. Once the pole is permanently placed 60 cm into the ground, the top of the monitoring station will be at 1.4 meters above ground placing the chemical strip at about 1.3 meters above the ground. This will place the paper clip that holds the ozone sensitive strip at a good height for middle grade students. The pole may be shorter to locate the monitoring station at a convenient level for younger students or they can stand on the same step stool used to put their eyes level with the maximum/minimum thermometer in the instrument shelter. The plastic disk protects the chemically sensitive strip from light rain or snow.

Security of Your Instruments

Some schools have reported vandalism problems at their GLOBE study sites, particularly with the rain gauge and the instrument shelter. Each school must determine what security measures work best for them. Some schools place their instrument shelter in a very prominent place where the whole community can appreciate it and keep a watch on it. Other schools have put fences around their atmosphere sites. This is perfectly acceptable, providing that the fencing does not interfere in any way with the instruments. This means that a fenced enclosure must be large enough so that the rain gauge is completely free from obstruction. A fenced enclosure should not have a top of any kind, even a fenced top, as this will interfere with precipitation measurements. If there is simply no secure area around your school where instruments can safely be left outside for extended periods of time, there are alternate GLOBE protocols that you can use for measuring current temperature, and the ozone measurement station may be portable.

Documenting Your Atmosphere Study Site

To start reporting atmosphere measurements to GLOBE, you must define your Atmosphere Study Site in the GLOBE data system. To enable your students to get a quick start, you may initially define the site by giving it a name and assigning it the same coordinates as your school location. Later, when you have measured the latitude, longitude, and elevation using a GPS receiver, you can edit the study site definition to supply this information. There are many other characteristics of your study site which may be important to various data users. These include the heights of your rain gauge, maximum/minimum thermometer, ozone test strip hanger, the slope at your site and the slope's direction, and any ways in which your site differs from ideal conditions. All of these items may be added when you edit the site description.

At many GLOBE schools the ideal atmosphere study site doesn't exist. Scientists can still make good use of the data from these schools, but information is needed about all the ways in which your site is not ideal. This information is called metadata and is reported as part of the Atmosphere Study Site definition. It is important for scientists to know any local conditions which could affect the temperature at the instrument shelter, the amount of rain reaching the rain gage or snow accumulating on the snowboard, the ability of students to see the whole sky, etc.

What might affect temperature readings?

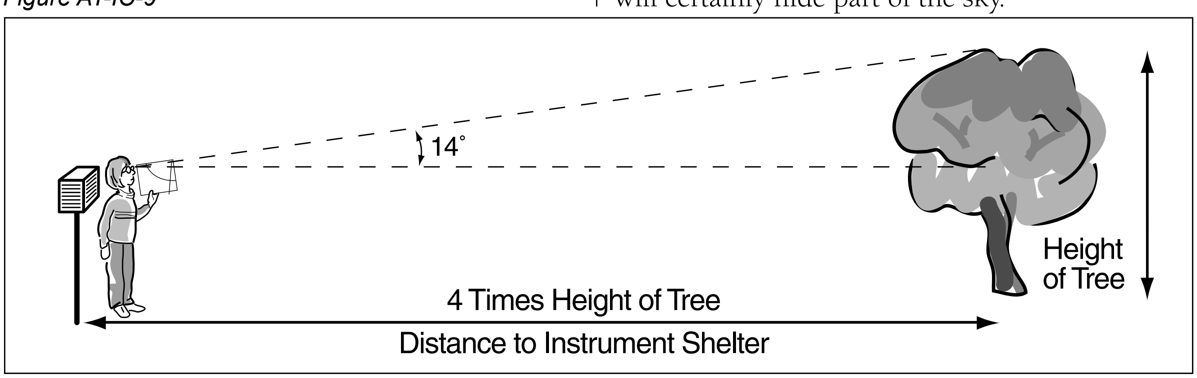
Buildings that are heated or cooled put out heat. If a building is within 10 meters of the instrument shelter, this should be noted in your metadata. Surfaces such as pavement and bricks absorb sunlight and radiate heat into the surrounding air as they warm. If the instrument shelter is mounted on a paved surface or a roof, a good description of this surface should be reported including the material of which the surface is made and its color. The desired surface under the atmosphere shelter is grass. If the natural surface cover in your area is generally bare soil because you live in a arid or semi-arid region, this should be reported as well.

What might affect precipitation or cloud observations?

Both the amount of precipitation collected and the amount of the sky that can be seen are affected by buildings, trees, hills, etc. surrounding the Atmosphere Study Site. For GLOBE, any obstacle which is four times as far away as it is tall is not a problem. Obstacles that are closer need to be reported as part of your site definition.

If you look at the top of an obstacle through a clinometer, and it is exactly four times as far away as it is tall, the angle you read will be 14˚. Every obstacle at an angle greater than 14˚ is too close and should be reported as part of your site description unless it is not a substantial object. For instance, a 7 meter tall flag pole 7 meters away that is ten centimeters in diameter won't significantly affect your measurements while a 20 meter tall tree 40 meters away may create a bit of a wind break and will certainly hide part of the sky.

Figure AT-IC-9



Documenting Your Atmosphere Study Site

Field Guide

Task

To describe and locate your Atmosphere Study Site

What You Need

- ❑ *Atmosphere Site Definition Sheet*
- ❑ *GPS Protocol Field Guide*
- ❑ Compass
- ❑ Pen or pencil
- ❑ GPS Receiver
- ❑ 50-meter Tape
- ❑ Clinometer
- ❑ Camera

In the Field

1. Fill in the information on the top of your *Atmosphere Site Definition Sheet.*
2. Locate your Atmosphere Study Site following the *GPS Protocol Field Guide.*
3. Describe all obstacles surrounding your site. (A building, tree, etc. is an obstacle if when you sight its top through a clinometer, the angle is > 14˚.)
4. Describe any buildings or walls closer to your site than 10 meters.
5. If you recorded any trees or buildings in steps 3 or 4, take photographs of the surroundings of your site looking North, East, South, and West. Identify the number of the picture for each photograph on your *Atmosphere Site Definition Sheet.*
6. Choose a partner whose eyes are at the same height as yours.
7. Ask them to stand 5 meters away from you going up hill on the steepest slope at your site.
8. Look at their eyes through the clinometer and record the angle. This is the slope at your site.
9. Record the compass direction to your partner.

   If you have installed a rain gauge, ozone measurement station, or instrument shelter at your site, do the following steps:

10. Measure the height of the top of the rain gauge above the ground in centimeters.
11. Measure the height of the bulb of the maximum-minimum thermometer above the ground in centimeters.
12. Measure the height of the clamp for the ozone strip above the ground in centimeters.
13. Record the type of ground cover that is under the instrument shelter.

Frequently Asked Questions

1. Is it okay to put our rain gauge and instrument shelter in a fenced area?

This is fine, as long as the fence doesn't block the rain gauge or cause rain to splash into the gauge.

2. We live in a city where there is not a good area on the school grounds to place our rain gauge and instrument shelter. Can we put these instruments on the roof of the school?

Although this is not the best location for weather instruments, if your choice is between putting the instruments on the roof or not participating in the Atmosphere Investigation, put the instruments on the roof. This has several disadvantages, both to students and scientists.

- Someone will need daily access to the roof to take the readings unless automated equipment is used.
- At the height of even a single-story building, the wind effect on your rain gauge is going to be worse than it would be on the ground.
- You must take care that structures on the roof don't block the rain gauge.
- The roof of a building is likely to be much warmer than its surroundings. The heat coming off the roof is likely to affect your temperature measurements. One way to cut down on this effect may be to put some kind of material like artificial or real grass down on the area underneath your instrument shelter.
- By putting the weather instruments on the roof, the measurements made will not be easily comparable to schools where the instruments are located on the ground. However, this does not mean that the measurements aren't useful. Eventually your school will develop a data record that will show if there are any changes in precipitation or temperature over time.

For cloud and aerosols observations, the roof can be an excellent location if your school is among the tallest buildings around.

Any time you are unable to strictly follow the protocol for placing your instruments, be sure to make a note of this in your site description. This way other students and scientists who use your data will be aware that there are special circumstances.

3. Is it okay to mount our instrument shelter on a tree?

While this may seem to be a reasonable place for the shelter, since a tree will protect the thermometer from sun and precipitation, a tree is NOT a good place for the instrument shelter. Why? Because a tree is a living thing. This means that in the process of making food and growing, a tree gives off heat and moisture that may affect your temperature reading. Also, a large tree may provide too much shelter and not allow wind to flow freely through the instrument shelter.

4. We can't find a location on the school grounds which is four times as far from the school building as the height of the building. What should we do?

It is often difficult to find an IDEAL location for the atmosphere instruments on your school grounds. Place the instruments in as good a location as possible. Remember to complete the *Atmosphere Site Definition Sheet,* and report the metadata about your site to the GLOBE Data Archive as part of defining your Atmosphere Study Site.

5. Can we put our rain gauge on the ground?

To minimize effects of the wind, placing the rain gauge at ground level will help reduce errors, but whether or not this is a good idea in practice depends on several factors. Most of all, the rain gauge must be stable. You don't want to just place it on a surface where it may get blown over by the wind or accidentally knocked over. That is, even if you want to put your rain gauge at ground level, you must still be certain that it is firmly attached to a post that will keep the gauge upright. Another consideration is the type of surface on which you are placing the gauge. A hard surface, such as concrete or asphalt, may increase the chance that rain will splash into the gauge from the ground. In this case, it would be best to have the top of the gauge at least 50 centimeters above the ground. However, if the surface is a porous natural surface, the gauge can be placed very close to the ground with little problem of splash-in.

6. We don't have a manufactured rain gauge. Can we use a soft drink bottle or some other kind of container?

The challenge with using a container other than a manufactured rain gauge that meets GLOBE specifications is obtaining an accurate measurement that is comparable to other data. Accurate measurements of rainfall involve more than just putting a ruler in a container and measuring the depth of rainwater. In addition, most containers are not straight-sided making it difficult to get consistent measurements. All of these difficulties indicate that the best possible container to measure rainfall is a gauge that meets the GLOBE specifications.

If you must use something other than an official rain gauge, please make a note of this as part of your Atmosphere Study Site definition.

The first requirement of a homemade rain gauge is that the top opening be round, level when it is mounted and have a diameter that meets GLOBE specifications. You should follow a special procedure to obtain the depth of rain that has fallen. Measure the diameter of your container's top opening in centimeters. After rain has accumulated in the gauge, pour it into the 100 mL graduated cylinder that you use in the hydrology and soil protocols. Measure the volume of rain that has collected in mL (which are equal to cubic centimeters). If more than 100 mL of rain has accumulated, fill the graduated cylinder to the 100 mL mark, empty it into a clean container and fill it again. Add up the volumes you measure in this way to get the total volume. The depth of rainfall is calculated as shown in the box below:

Report the value to the nearest tenth of a millimeter. Be sure to use a container that will not affect the pH of the rain water and use a clean graduated cylinder to measure the volume.

7. Why does the instrument shelter have to face away from the equator?

When you go outside on a sunny day, it is quickly obvious that you feel much warmer standing in direct sunshine than standing in the shade. For GLOBE temperature measurements, we want to measure the temperature of the air, without the influence of direct sunshine. In order to get an accurate measurement of air temperature, we need to make sure that the thermometer is protected from direct sunshine. This means that in the Northern Hemisphere the instrument shelter should face north, and in the Southern Hemisphere the instrument shelter should face south. In this way, sunlight will not shine directly onto the instruments in the shelter when the shelter door is opened to take a reading.

8. Mounting the instrument shelter so that our maximum-minimum thermometer is 1.5 meters off the ground makes it difficult for our youngest students to read the thermometer. Can we place it lower to the ground?

In the same way that placing the instrument shelter too close to a building or tree can influence temperature readings, placing the instrument shelter too close to the ground can influence the temperature reading. As the

$$\text{Radius of rain gauge opening (cm)} = \frac{\text{Diameter of rain gauge opening (cm)}}{2}$$

$$\text{Area of the rain gauge opening (cm}^2\text{)} = \text{ x [Radius of rain gauge opening (cm)]}^2$$

$$\text{Rain Depth (mm)} = 10\ \frac{\text{mm}}{\text{cm}} \times \frac{\text{Volume of rain (mL or cm}^3\text{)}}{\text{Area of the rain gauge (cm}^2\text{)}}$$

ground heats up during the day, it emits more energy. By putting the instrument shelter about 1.5 meters from the ground, the heat from the ground has a chance to dissipate into the atmosphere, so that we end up measuring air temperature and not ground temperature. For smaller students, provide a sturdy step (or set of steps) that will allow them to be at eye-level with the thermometer so that they can read it accurately.

9. The mountains around our school partially block our view of the sky. What should we do?
In some cases, schools on hillsides or in valleys may have mountains or hills that block at least part of the horizon. Treat the surrounding hills or mountains as obstacles and describe them in your metadata. Use the clinometer to measure the angle when you are looking at the hilltops or ridge lines and include this in your description. In this situation, also remember that local solar noon is the time when the sun is at the highest point in the sky that it will reach today. The time of apparent sunset and sunrise may be affected by the surrounding terrain, and so, you cannot simply average the times of local sunrise and sunset that you observe to calculate local solar noon.

10. The conditions at our Atmosphere Study Site have changed; what should we do?
You should report the new conditions to GLOBE using the "edit a study site" feature. Be sure to choose the setting indicating that you are reporting a change rather than supplying missing data or correcting data. It is important that the date you report be the first day when conditions changed or the day when you first observed the change. The metadata you enter will be associated with all data reported for this site beginning with this date.

11. We don't have access to a GPS receiver at present to define the location of our Atmosphere Study Site; what should we do?
You should define your Atmosphere Study Site and choose for its location the coordinates of your school. Later, when you have access to a GPS receiver, use it to measure the latitude, longitude, and elevation of your site and report these data to GLOBE by editing the definition of your Site. Information about obstacles, the heights of the various instruments, etc. can also be reported after data collection and reporting have begun by editing the definition of your Site.

Cloud Protocols

Purpose

To observe the type and cover of clouds including contrails

Overview

Students observe which of ten types of clouds and how many of three types of contrails are visible and how much of the sky is covered by clouds (other than contrails) and how much is covered by contrails.

Student Outcomes

Students learn how to make estimates from observations and how to categorize specific clouds following general descriptions for the categories.

Students learn the meteorological concepts of cloud heights, types, and cloud cover and learn the ten basic cloud types.

Science Concepts

Earth and Space Science

Weather can be described by qualitative observations.

Weather changes from day to day and over the seasons.

Weather varies on local, regional, and global spatial scales.

Clouds form by condensation of water vapor in the atmosphere.

Clouds affect weather and climate.

The atmosphere has different properties at different altitudes.

Water vapor is added to the atmosphere by evaporation from Earth's surface and transpiration from plants.

Physical Science

Materials exist in different states – solid, liquid, and gas.

Geography

The nature and extent of cloud cover affects the characteristics of the physical geographic system.

Scientific Inquiry Abilities

Use a Cloud Chart to classify cloud types.

Estimate cloud cover.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

10 minutes

Level

All

Frequency

Daily within one hour of local solar noon

In support of ozone and aerosol measurements

At the time of a satellite overpass

Additional times are welcome.

Materials and Tools

Atmosphere Investigation Data Sheet or *Cloud Data Sheet*

GLOBE Cloud Chart

Observing Cloud Type (in the *Appendix*)

Prerequisites

None

Cloud Protocols – Introduction

Clouds and the Atmosphere

Water in the environment can be a solid (ice and snow), a liquid, or a gas (water vapor). As water moves from place to place it can melt, freeze, evaporate, or condense. These changes happen as the water is warmed or cooled.

Water in the atmosphere exists in all three phases (solid, liquid, gas) and changes phase depending on temperature and pressure. Like most other gases that make up the atmosphere, water vapor is invisible to the human eye. However, unlike most other gases in our atmosphere, under the right conditions water vapor can change from a gas into solid particles or liquid drops. If temperatures are above freezing, the water vapor will condense into water droplets. If temperatures are below freezing, as they always are high in the atmosphere, tiny ice crystals may form instead. When a large number of water droplets or ice crystals are present, they block light enough for us to see them – they form clouds. So, clouds tell us something about air temperature and water up in the sky. They also affect the amount of sunlight reaching the ground and how far we can see.

In the troposphere, the lowest part of the atmosphere, temperature decreases with increasing altitude. As ice crystals form at high altitudes, they are often blown away from the region where they formed by the strong winds of the jet streams. Through this process of formation and movement ice crystals often merge into larger crystals and then begin to fall. These falling or windblown crystals create streaks, which we see as wispy clouds. These streaks are often curved by the wind, which can blow at different velocities at different altitudes.

Other types of clouds are blown about by the wind, too. Updrafts help form towering clouds; downdrafts tend to create clear spaces between clouds. Horizontal winds move clouds from place to place. Clouds that form over lakes and oceans are blown over the dryer land, bringing precipitation. Strong winds high in the atmosphere sometimes blow the tops off clouds creating anvil shapes or carrying ice crystals far downwind to clear areas.

Ice crystals and water drops scatter light differently. Thick clouds absorb more sunlight than thin ones. The types of clouds, phases of water, and amount of clouds, ice, and water drops all affect the amount of sunlight that comes through the atmosphere to warm Earth's surface. Clouds also affect how easily heat from the surface can escape through the atmosphere back to space.

By observing clouds, we can get information about temperature, moisture, and wind conditions in different places in the atmosphere. This information helps in predicting the weather. Observations of clouds also help us know how much sunlight is reaching the ground and how easily heat from the ground and lower atmosphere can escape, and this information is important in understanding climate.

Clouds and Weather

Which types of clouds you see often depends on the weather conditions you are experiencing or will soon experience. Some clouds form only in fair weather, while others bring showers or thunderstorms. The types of clouds present provide important information about vertical movement at different heights in the atmosphere. By paying attention to the clouds, soon you will be able to use cloud formation to forecast the weather!

Cloud types may indicate a trend in the weather pattern. For example, altocumulus clouds are often the first indicator that showers may occur later in the day. In middle latitudes, one can often see the advance of a warm front by watching the cloud types change from cirrus to cirrostratus. Later on, as the front gets closer, the clouds thicken and lower, becoming altostratus. As precipitation begins, the altostratus clouds become nimbostratus, immediately before the front passes your location.

Cloud types are an important sign of the processes that are occurring in the atmosphere. Clouds indicate that moist air is moving upward, and precipitation can only happen when this occurs. Clouds often provide the first signal that bad weather is coming, although not all clouds are associated with bad weather.

Clouds and Climate

Clouds play a complex role in climate. They are the source of precipitation, affect the amount of energy from the sun that reaches Earth's surface, and insulate Earth's surface and lower atmosphere.

At any given time, over half of Earth's surface is shadowed by clouds. Clouds reflect some of the sunlight away from Earth, keeping the planet cooler than it would be otherwise. At the same time, clouds absorb some of the heat energy given off by Earth's surface and release some of this heat back toward the ground, keeping Earth's surface warmer than it would be otherwise. Satellite measurements have shown that, on average, the cooling effect of clouds is larger than their warming effect. Scientists calculate that if clouds never formed in Earth's atmosphere, our planet would be over 20˚ C warmer on average.

Conditions on Earth affect the amount and types of clouds that form overhead. This helps to shape local climate. For example, in rain forests, the trees release large amounts of water vapor. As daily heating causes the air to rise, clouds form and intense rainstorms occur. Over three-quarters of the water in tropical rain forests is recycled in this way and cloud cover is almost complete for most of the year. In contrast, in a desert there is no surface source of moisture and clear conditions are typical. These clear conditions allow for more heating by sunlight and larger maximum temperatures. In both cases, the local climate – precipitation and temperature – is tied to cloud conditions.

Human activities also can affect cloud conditions. One specific and obvious example is the formation of contrails, or condensation trails. These are the linear clouds formed when a jet aircraft passes through a portion of the atmosphere having the right combination of moisture and temperature. The jet exhaust contains some water vapor as well as small particles – aerosols – that provide condensation nuclei that help ice crystals begin to form. In some areas, jet traffic is causing a noticeable change in cloudiness, which may affect both weather and climate.

How will cloud conditions change if Earth's surface becomes warmer on average? If the surface water of oceans and lakes warms, more water will evaporate. This should increase the total amount of water in the atmosphere and the amount of cloud cover, but what type of clouds will form? Will the increase in clouds happen mostly at high altitudes or low altitudes? Clouds at all altitudes reflect sunlight helping to cool Earth's surface, but high clouds release less heat to space and thus warm the surface more than low clouds. So, the changes in surface temperatures may depend on how cloud conditions change.

Many official sources of weather observations are now using automated equipment to observe clouds. These automated measurement systems do not take cloud type observations. This makes cloud observations by GLOBE students and other amateur weather observers unique as a data source. Since 1960, scientists have also used satellites to observe clouds. These observations began with simple pictures of clouds, but more advanced techniques are always being added. Scientists are working to develop automated methods to infer cloud types from visible and infrared weather satellite images. This task is hard, and observations from the ground are needed for comparison. Contrail detection from space is especially challenging, since many contrails are too narrow to see in satellite images. Accurate cloud type observations from GLOBE students are an important source of these ground-based observations.

Teacher Support

Every one looks at clouds. Children often stare up and imagine that they see the shapes of various objects in the sky. In GLOBE, students will be shifting what they look for in the sky to some specific, scientifically meaningful properties – cloud type and cover. A great habit to develop is looking up at the sky every time you go outdoors. Pay attention to what is going on in the atmosphere. You might be surprised at how much is happening!

Students take cloud observations with their eyes. The only equipment needed is the GLOBE Cloud Chart, so these protocols are easy to get started, but identifying cloud cover and cloud types is a skill. Students will get better with practice; the more frequently you and your students take cloud observations, the more comfortable you will become with these measurements, and the better will be the quality of your data.

With the advent of automated weather stations which only have instruments capable of viewing clouds at heights up to 3,000 to 4,000 meters, many middle and high clouds, including contrails, are no longer observable. The GLOBE cloud observations will provide a useful data set, continuing visual observations that have been collected for over 100 years that are now being replaced with automated observations.

Good questions to help students start determining the best place to take their measurements would be:

Where on the school grounds would you see the most clouds? Where would you see the least?

As you walk around the school grounds, have the students draw a map of the area. The youngest students could just sketch the main features, such as the school building(s), parking lots, playgrounds, etc. Older students should fill in more detail, such as what the playground surface is (e.g. paved, grassy, or bare ground). Have them note any streams or ponds and indicate areas of trees. They could measure how much of the sky is hidden by buildings and trees using the clinometer and techniques given in *Documenting Your Atmosphere Study Site*. The goal is to have a drawing of the school grounds so that students understand why the site for cloud observations was chosen. Each year, the new class of students can repeat this mapping to gain this understanding.

Measurement Hints

Cloud Cover

Cloud cover is a subjective estimate, but an important scientific one. Meteorologists and climate scientists must have accurate cloud cover observations to correctly account for the amount of solar radiation which is reflected or absorbed before sunlight reaches Earth's surface, and the amount of radiation coming up from Earth's surface and lower atmosphere which is reflected or absorbed before it can escape to space.

As the Learning Activity *Estimating Cloud Cover* makes clear, the human eye tends to overestimate the percentage of the sky covered by clouds. Having students do this activity is the best first step to taking accurate measurements. The other key to accuracy for cloud cover is to have students observe the entire sky that is visible from your Atmosphere Study Site.

Once students begin to take cloud cover observations, it is important that the observations be done by small groups in which a consensus can be achieved. One useful way to do the observation is to divide the sky into four quadrants, estimate the fractional coverage in each quadrant, and then find the average. This can be done using decimal values, or fractions, depending on students' mathematical abilities. The biggest discrepancies will usually occur for borderline situations, where one category is close to another. Cloud cover categories are given in Table AT-CL-1.

As students become more expert in this measurement, they will begin to realize that clouds are three dimensional and have thickness. As one looks toward the horizon, the sky can appear to be more cloud covered than it really is because the spaces between clouds are hidden from view. This effect is more pronounced for low clouds than for middle and high clouds (these categories are discussed under *Cloud Type*). It is also more of an issue for cumulus clouds than for stratus clouds. If when

Table AT-CL-1

Percentage	If less than	If greater than or equal to
10%	Clear	Isolated
25%	Isolated	Scattered
50%	Scattered	Broken
90%	Broken	Overcast

looking directly overhead students see a pattern of cloud cover with individual puffs or long rolls of cloud separated by clear areas, and the general appearance of the clouds is similar looking toward the horizon, it is reasonable to infer that there are spaces between these clouds as well and the cloud cover is not 100% toward the horizon.

This protocol includes a category of "No Clouds" which should be reported whenever there are no clouds visible in the sky and a category "Obscured Sky". This condition is to be reported when weather phenomena restrict the observer's ability to clearly see and identify the clouds and contrails in the sky. There are ten possible reportable obscurations. If your students have difficulty seeing the clouds and contrails in more than one-quarter of the sky, they will not report cloud or contrail cover using one of the normal categories, rather, they should report that the sky is Obscured, and then report one (or more) of the obscuring phenomena that are responsible for the limited visibility of the sky. Metadata should be reported for cloud and contrail cover for the part of the sky that is visible if the sky is only partially obscured. The obscuring phenomena are defined below.

- **Fog**
  Fog is a collection of small water droplets which is based at the ground, and restricts visibility along the ground and above it. Stratus clouds are often associated with fog. In coastal areas, mountains, and valleys, fog may be prevalent during the midday GLOBE observations. This category will include ice fog or diamond dust which is prevalent in cloud-free weather at high latitudes.
- **Smoke**
  Smoke particles, from forest fires or other sources, often severely restrict visibility along and above the ground. If smoke is present, there will be a distinct odor of smoke, distinguishing it from haze or fog.
- **Haze**
  Haze is caused by a collection of very small water droplets, or aerosols (which may be water droplets, pollutants or natural dust particles suspended in the atmosphere), which collectively give the sky a reddish, brown, yellowish, or white tint. Smog would be placed in this category. GLOBE has a new *Aerosols Protocol* for teachers who wish to learn more about haze and its causes. Most of the time measurable haze is present, clouds will still be observable. This category is only checked when the haze is so extreme that clouds cannot be seen.
- **Volcanic Ash**
  One of the greatest natural sources of aerosols in the atmosphere occurs when a volcano erupts. In such cases, it is conceivable that schools may have ash falling, or other restrictions to visibility (perhaps a plume overhead).
- **Dust**
  Wind will often pick up dust (small soil particles – clay and silt) and transport them thousands of kilometers. If the sky cannot be discerned because of dust falling or blowing, please report this category. Severe duststorms may restrict visibility at some locations, and they would be reported in this category as well, for example, if students cannot go outdoors because of a severe duststorm, the sky would be reported as obscured and dust would be the reason.
- **Sand**
  Blowing or suspended sand, or sandstorms, generally require stronger winds than dust events, but they can

make it just as difficult for observers to see the sky.

- **Spray –** (also called sea spray)
  Near large bodies of water, strong winds may suspend drops of water which will be sufficient to reduce the visibility so that the sky cannot be clearly discerned. This category generally is restricted to the area immediately adjacent to the coast, once inland, salt particles may be suspended after the water drops evaporate, leaving aerosols behind.
- **Heavy Rain**
  If rain is falling intensely at the time of the observation, the sky may not be visible. Even though it may seem overcast, if you cannot see the entire sky, you should report the sky as obscured, and heavy rain being the cause.
- **Heavy Snow**
  Snow may also fall at rates sufficient to prevent the observer's clear view of the sky and cloud cover.
- **Blowing Snow –** In the event the wind is blowing with sufficient strength to lift fallen snow off the ground, it may prevent observation of the sky. If blizzard conditions are occurring (strong winds and snow is still falling intensely), both of these last two categories should be reported.

Contrail Cover

The same technique of dividing the sky into four quadrants described above for cloud cover can also be used in the estimate of contrail cover. One single persistent contrail crossing the sky covers less than 1% of the sky (see *Estimating Cloud Cover Learning Activity*). Therefore, counting contrails can also be a good tool in the estimation. When the sky is obscured, as described above, contrail cover measurements cannot be taken.

Remember contrail cover is measured separately from cloud cover. So when you estimate cloud cover, you should not include contrails. When you observe contrails that overlap with clouds, you should report this in the metadata.

Cloud Type

Cloud type is a qualitative measurement. The GLOBE Cloud Chart, the cloud quiz on the GLOBE Web site, and other cloud information attainable in textbooks and from online sources may be useful in helping students learn the many different ways clouds can appear. However, two-dimensional images look quite different compared to actual sky observations, which are three-dimensional, and there is no substitute for experience in taking cloud observations.

The cloud type system is organized into 3 categories depending on the height or altitude of the base of the cloud. High clouds (cirro- or cirrus) are universally composed of ice crystals, and hence are more delicate in appearance. Because they are farther from the observer, they will also appear smaller than other cloud types, in general. The wispy trails often seen in high clouds are ice crystals falling and subliming (turning from a solid into a gas). Generally, the sun can be seen through high clouds and the ice particles in cirrostratus clouds scatter the sunlight to form a bright ring, called a halo, around the sun.

Middle clouds always begin with the prefix *alto-* and are predominantly comprised of water droplets. They may contain some ice. Sometimes the sun can be seen through these clouds as well, but without a ring.

Low clouds are closest to the observer, and they will often appear to be quite large in comparison to higher clouds. They may be much darker, appearing more gray than high or middle clouds. Low clouds may extend to much higher altitudes, which can be seen when there are clear gaps between the clouds.

Once this basic distinction is clear to you (high/middle/low), the next thing to decide is the shape or form of the cloud. If the cloud feature is a fairly uniform layer, it will be a stratiform, stratus-type cloud. Most clouds that have shape or forms such as puffs, rolls, bands, or tufts, are cumuliform, from the cumulus family. Finally, if a cloud is producing precipitation (which the observer can see), it must have nimbus in its name. The wispy shapes produced by ice clouds almost always occur at high altitudes and so they are called by the same name as high clouds – cirro- or cirrus. By performing the *Cloud Watch Learning Activity* from time to time with your students, you (and they) will gain more confidence in their ability to identify the cloud types in a complex sky!

Contrail Type

Contrails generally occur at high levels like cirro- or cirrus clouds. However, as human-induced clouds, contrails are reported in a separate category. There are three types of contrails for students to classify. These are:

- *Short-lived* – contrails that disappear shortly and form short line segments in the sky that fade out as the distance away from the airplane that created them increases.
- *Persistent Non-Spreading* – these contrails remain long after the airplane that made them has left the area. They form long, generally straight, lines of approximately constant width across the sky. These contrails are no wider then your index finger held at arm's length.
- *Persistent Spreading* – these contrails also remain long after the airplane that made them has left the area. They form long streaks that have widened with time since the plane passed. These contrails are wider than your index finger held at arm's length. This type is the only type that can currently be seen in satellite imagery; and only when they are wider than four fingers held at arm's length. Therefore, noting the equivalent finger width of these contrails in the metadata will be very useful for the scientists.

Refer to the Web site of the contrail team for additional pictures of the various contrail types.

Short-lived contrails form when the air at the elevation of the airplane is somewhat moist. Persistent contrails form when the air at the elevation of the airplane is very moist, and are more likely to affect climate than short-lived contrails are.

Student Preparation

The estimates of cloud type and cloud cover are *subjective* measurements, so involving several students in this task is good. Each student should take his or her own readings; then, students should come to an agreement as a group. Do not be surprised if your students initially have difficulty with these estimates. Even seasoned weather observers debate which type of cloud they are seeing, or exactly how much of the sky is covered by clouds. As your students get used to these observations, they will begin to recognize the subtle differences in cloud types.

Here are two effective ways to help train your students to take the most accurate cloud observations possible:

1. Practice cloud type observing by taking the GLOBE cloud quiz, available from the Resource Room of the GLOBE Web server, or by spending a lot of time looking at and identifying examples of the predominant cloud types for your location;
2. Do the following Learning Activities from the GLOBE *Atmosphere Teacher's Guide*
   - *Estimating Cloud Cover*
   - *Observing, Describing and Identifying Clouds*
   - *Cloud Watch*

These activities are designed to give students plenty of opportunities to gain proficiency in identifying cloud type and cloud cover.

Sometimes there may be disagreement among students taking observations of clouds, and the process of students coming to a consensus is an important part of the scientific discovery process. However, it may be useful to include some commentary in the Metadata section of your *Data Sheet.*

Practicing simulations with classmates will help build students' confidence. Be sure to have them check the entire sky. One of the best ways to do this is with groups of four students, standing back-to-back, one facing north, one east, one south, and one west. Now, each student is responsible for estimating the amount of cloud from the horizon to directly overhead in their quadrant.

Make sure they are all defining their quadrant in the same way. Once each student has an estimate (use 10% increments, or fractions like eighths or tenths), take the average of the four estimates by summing them and dividing by 4. This method will be particularly useful when you have a difficult sky that leads to different estimates among group members.

The following tip may help your students determine the heights of cumulus clouds. Have them extend their arm away from their shoulder parallel to the ground, and align their fingers with the cloud feature they are observing. A good rule of thumb to use is that if the individual puffs, rolls, waves, etc., of the clouds are smaller than one finger width, they are cirrocumulus. If they are not as wide as two fingers, but wider than one finger, it is most likely an altocumulus. If wider than two fingers, it will be cumulus (look for isolated puffs), stratocumulus (clouds are wider than tall, and there are many, perhaps elongated in bands), or cumulonimbus (with precipitation).

For distinguishing the different heights of stratus clouds, remember the following. Cirrostratus is the only cloud type which can produce a halo around the sun or moon. The halo will have all the rainbow colors in it. Altostratus will produce a thinly veiled sun or moon, and will often be darker in appearance, a medium gray color. Stratus will usually be very gray and often very low to the ground. Fog is actually a stratus cloud at zero altitude.

Here are some questions that students may be thinking about (or asking) as they take cloud observations:

What kind of sky do I see?
What kind of sky do other students from nearby schools see?
Should they be the same?

Cloud cover in particular can be a very local phenomenon, and therefore cloud type may vary significantly from one place to another nearby. When viewed as an aggregate for a large grouping of GLOBE schools, cloud observations become more useful. Also, local cloud observations are important to several other GLOBE protocols.

Questions for Further Discussion

Do cloud patterns change during the year? How?

Does the amount of cloud cover affect the local temperature?

How reliable are local weather forecasts based on cloud type observations alone? Can they be improved by using other GLOBE measurements?

Do cloud conditions and phenomena that block our view of the sky influence the types of vegetation and soil in our area? If so, how?

How do our cloud observations compare with satellite images of clouds?

Are contrails often seen in the local area? Why or why not?

Are the types of clouds and contrails you observe related?

How do the clouds you see relate to nearby mountains, lakes, large rivers, bays, or the ocean?

Cloud Cover and Contrail Cover Protocol

Field Guide

Task

Observe how much of the sky is covered by clouds and contrails.

What You Need

❑ *Atmosphere Investigation Data Sheet* OR *Cloud Data Sheet* OR *Ozone Data Sheet* OR *Aerosol Data Sheet*

In the Field

1. Complete the top section of your *Data Sheet*.
2. Look at the sky in every direction.
3. Estimate how much of the sky is covered by clouds that are not contrails.
4. Record which cloud classification best matches what you see.
5. Record which contrail classification best matches how much of the sky is covered by contrails.

Cloud Cover Classifications	*Contrail Classifications*
No Clouds The sky is cloudless; there are no clouds visible.	**None** There are no contrails visible.
Clear Clouds are present but cover less than one-tenth (or 10%) of the sky.	**0-10 %** Contrails are present but cover less than one-tenth (or 10%) of the sky.
Isolated Clouds Clouds cover between one-tenth (10%) and one-fourth (25%) of the sky.	**10-25 %** Contrails cover between one-tenth (10%) and one-fourth (25%) of the sky.
Scattered Clouds Clouds cover between one-fourth (25%) and one-half (50%) of the sky.	**25-50%** Contrails cover between one-fourth (25%) and one-half (50%) of the sky.
Broken Clouds Clouds cover between one-half (50%) and nine-tenths (90%) of the sky.	**> 50%** Contrails cover more than one-half (50%) of the sky.
Overcast Clouds cover more than nine-tenths (90%) of the sky.	
Obscured Clouds and contrails cannot be observed because more than one-fourth (25%) of the sky cannot be seen clearly.	

6. If the sky is Obscured, record what is blocking your view of the sky. Report as many of the following as you observe.

• Fog	• Smoke	• Haze	• Volcanic Ash	• Dust
• Sand	• Spray	• Heavy Rain	• Heavy Snow	• Blowing Snow

Cloud Type and Contrail Type Protocol
Field Guide

Task

To see which of the ten types of clouds and how many of each of the three types of contrails are visible

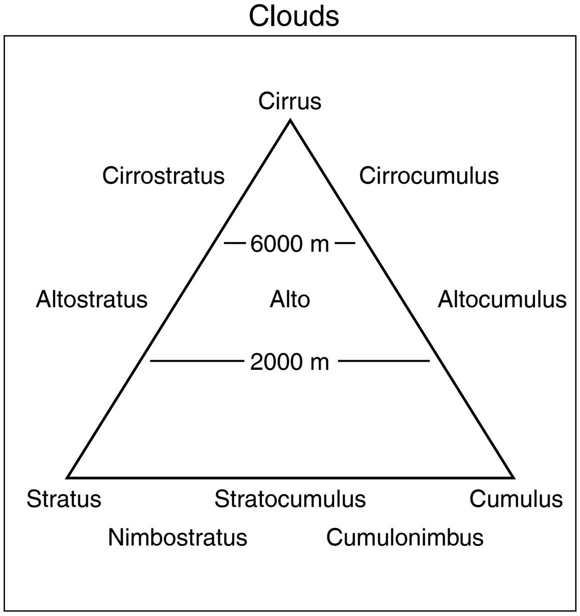
What You Need

- ❑ *Atmosphere Investigation Data Sheet* OR
  Cloud Data Sheet OR
  Ozone Data Sheet OR
  Aerosol Data Sheet
- ❑ *Observing Cloud Type* (in *Appendix*)
- ❑ GLOBE Cloud Chart

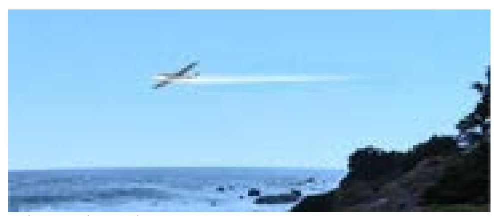
In the Field

1. Look at all the clouds in the sky, look in all directions, including directly overhead. Be careful not to look directly at the sun.
2. Identify the types of clouds that you see using the GLOBE cloud chart and the definitions found in *Observing Cloud Type.*
3. Check the box on your *Data Sheet* for each and every cloud type you see.
4. There are three types of contrails. Record the number of each type you see.

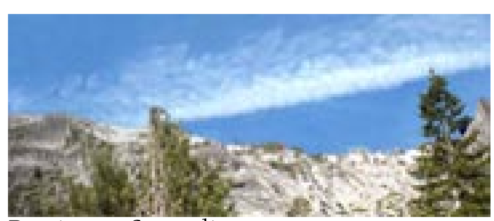
Clouds



Contrails


Short-lived


Persistent Non-Spreading


Persistent Spreading

Frequently Asked Questions

1. Why do we have to report cloud cover observations even if there are no clouds?
It is just as important for scientists to know when there are no clouds in the sky as when there are clouds. Please always report the cloud cover, even on a beautiful day with blue sky! How could you accurately calculate average cloud cover if data were always missing for completely clear days? Also be aware that clear sky is the easiest measurement from the ground, but the hardest to determine with confidence from satellite imagery.

2. Can't an instrument be designed to measure cloud cover?
Yes, in fact, lasers are used to measure this and the instrument is called a ceilometer. Ceilometers measure the portion of the sky covered by clouds, but they are very expensive. Furthermore, many of the ceilometers in use today only provide accurate estimates of cloud cover up to heights of about 3.5 kilometers, which makes them useless for most middle clouds and all high clouds. Cloud cover is an aggregate of all clouds at all levels, and human observations are still the best way to measure this from the ground. Also, ceilometers take only a single point or profile measurement that may not be representative of the overall cloud cover.

3. Is there any way to make sure that our observations are accurate, since there is no instrument to calibrate?
These data are important, and practice will help you to become proficient in estimating cloud cover. You can compare your own observations with nearby neighbors' observations, and compare them with "official" observations, too, to learn how accurate your own observations are, but remember that on some days the cloud conditions will be different even over short distances and they may change in minutes. If you do them diligently every day, you should become very comfortable with your efforts!

4. We have trouble figuring out if we are correct when we call a certain cloud one of the ten types. How do we know if we are correct?
You can't know for sure. The most important thing to do is to practice identifying cloud types as often as you can. If you have access to the World Wide Web, you can take the Interactive GLOBE cloud quiz, which you will find online as part of the GLOBE Web site. Also, you may wish to obtain another copy of the GLOBE Cloud Chart, cut it up, and make flash cards to help quiz your classmates.

5. Is this cloud type observation system in GLOBE unique or new in some way?
This system is the same one that meteorologists have been using for two hundred years. Many scientists report becoming interested in science because they started to observe the sky and note how it was different (in terms of cloud types) from one day to another. The scientific basis of this cloud type observing system has not changed substantially since it was first devised. The systematic breakdown of clouds into ten basic types was motivated, at least in part, by the classification of species of living things into the Animal and Plant Kingdoms by biologists. In fact, meteorologists often further divide the cloud types into other specific variations within each cloud type. *Castellanus* refers to castle-like turrets in a cloud formation, an indicator that the atmosphere is becoming unstable, perhaps foretelling precipitation. *Lenticularis* means lens-shaped, a cloud often formed over high mountains. And cumulus are often separated into *humilis* (fair weather, puffy) or *congestus* (towering, heaped like cauliflower, very tall).

6. What do I report if only part of the sky is obscured, but I can determine cloud types for part of the sky?
If more than one-quarter of the total sky is obscured, report 'obscured', and report the cloud types that you see in metadata. If less than one-quarter of the total sky is obscured, record the cloud cover and cloud types and state in the metadata how much of the sky is obscured.

7. I am not sure whether what I see is cirrus or old, spreading contrails?
At some point the distinction between the two cannot be made. In this situation, please report cirrus, but also note in your comments that the cirrus looks like it may have started from a contrail.

Cloud Protocol – Looking At Your Data

Are the data reasonable?

Given the subjective nature of cloud observations, it can be very difficult to determine if they are reasonable.

The internal consistency of the observations can be used to determine whether cloud type and cover data are reasonable. For instance, if there is overcast cloud cover with stratus, stratocumulus, or nimbostratus clouds, reports of alto or cirro cloud types would be unlikely as observers on the ground would not be able to see higher altitude clouds through the thick lower cloud cover. Another example would be reports of only cirrus clouds with overcast skies; cirrus clouds are only very rarely present in the amounts needed to cover 90% of the sky. The same is true for cumulus clouds as there must be breaks between the clouds for them to be cumulus (rather than stratocumulus).

What do scientists look for in these data?

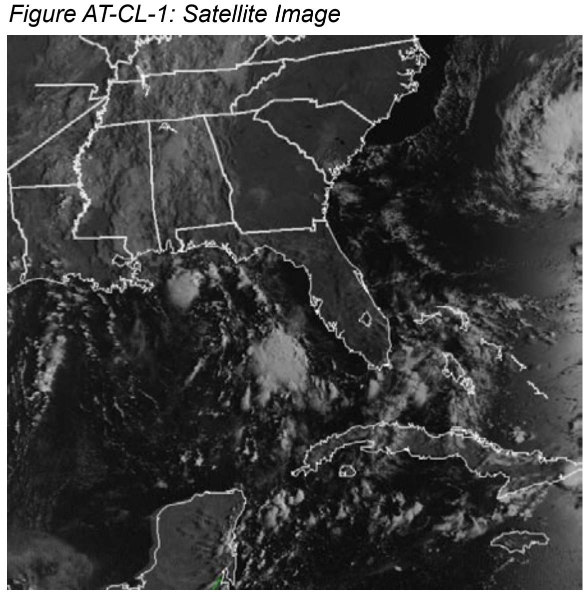
Many official weather observing stations across the world have effectively stopped taking cloud observations. National meteorological organizations have two primary reasons for this change. First, weather satellites are constantly monitoring Earth's surface and atmosphere, and we have become much better at determining cloud cover from satellite pictures in recent years. Second, many weather stations are taking their observations using automated instruments. These instruments cannot determine cloud type, and are often limited in their ability to distinguish middle and high cloud layers. The automated instruments can only sense clouds up to about 3.6 km in altitude and many cloud types are too high for most of these *ceilometers* to see them. So, they can only see half of the cloud types (cumulus, cumulonimbus, stratus, stratocumulus, and nimbostratus).

Clouds have been observed and associated with weather changes for centuries; in fact our cloud classification system is over 200 years old. The changes that you observe in the clouds help meteorologists to forecast the weather. By watching a clear sky change to a sky with isolated cumulus clouds, which may grow to scattered cumulus and broken cumulonimbus clouds, you can expect that thundershowers may begin soon. When an overcast stratus cloud thins out to stratocumulus, you might expect clearer weather to follow. Climate scientists like to watch cloud changes over long periods of time, to see if there is an increase or decrease in cloud cover or a change in type.

Since the early 1960's, meteorologists have had weather satellite pictures that can be used to see clouds (generally shown as white areas on satellite pictures), such as Figure AT-CL-1, a visible photograph from the NOAA 15 polar-orbiting weather satellite of the Gulf of Mexico, near the southeastern United States. Clouds are seen over the waters to the west of Florida, in the Bahamas and on the eastern edge of the picture, off the coast of North Carolina. The land areas of the southeastern United States are fairly clear along the Atlantic Ocean, but further to the west we see some clouds that are not as bright. This tells meteorologists that these clouds are probably lower and/or not as thick as the bright white ones in this mid-afternoon picture.

Scientists who work with satellite data need good surface observations of clouds to provide what is called ground truth for their satellite observations. These observations are important because they help meteorologists to understand

Figure AT-CL-1: Satellite Image



how accurate their satellite observations continue to be. In general, the more GLOBE schools that produce cloud observations, the better for scientists who wish to use these data, because they can assess how accurate and consistent the observations are by making such comparisons.

Satellite photographs do not always give scientists a clear idea of which cloud types are present. This is particularly true for contrails, which are often too narrow to be seen from space. For this reason, it is important for scientists to be able to find areas of low, middle, and high clouds, since each cloud layer will have different abilities to block sunlight and trap infrared radiation.

Let's look at some maps to see how we might proceed with such investigations. Figure AT-CL-2 shows some cloud cover observations for a spring day in 2001 over part of the United States and Canada, near the Great Lakes. The Great Lakes are large bodies of water that provide ample moisture to the atmosphere through evaporation. High levels of water vapor often lead to cloudy skies. The weather map for that day will also be useful to understand what type of cloud systems were present for that day since, in general, air must be rising to produce clouds and low pressure systems and fronts are the most likely areas for clouds to form.

Note the large number of gray boxes near the center of the state of Ohio in the map above. From the map legend, we see that these indicate areas of overcast skies. There are a few stations nearby that are not overcast, including one observation of an obscured sky, one broken, and one scattered. Perhaps a storm system is affecting a fairly large area of northern Ohio and western Pennsylvania. To the west of this area, the observations are mostly of clear skies. The same is true on the far eastern edge of the map, where skies are also mostly clear. Note how similar the cloud type observations are to each other within a region.

Each cloud cover observation also contains a cloud type observation, where students identify each of the ten possible cloud types present. Making a map of such observations would be very complicated, since there are so many possible combinations. GLOBE maps of cloud cover are drawn by dividing all cloud types into their height categories – low, middle, and high – and combinations of these. See Figure AT-CL-3.

Let's concentrate on eastern Ohio once again. Note that almost all of the observations are red, with a couple of green squares, a couple of blue squares, and one purple square. The map legend shows that red squares are low clouds (L), green squares are middle clouds (M), and blue squares are high clouds (H). The purple square is for an observation of low and high clouds (L+H) combined. Once again, the cloud observations are generally similar to each other, with most GLOBE schools reporting that low clouds were present.

If you look to the eastern edge of the map, there are many schools reporting high clouds, middle and high clouds, or low and high clouds. Perhaps these schools are in the path of a storm system that is moving their way from eastern Ohio.

An Example of a Student Research Investigation

Designing an Investigation

Natalie has always been interested in clouds. She is always drawing them and making shapes out of them in her mind. Natalie is one of the students in her class who volunteers to take GLOBE Atmosphere measurements and really likes to observe the clouds. Natalie decides to make her own cloud chart for the class, using cotton balls, white paper, blue construction paper, and glue. Her teacher decides to make that a class project, and they make a beautiful display board with cloud cover examples on it (from the *Estimating Cloud Cover Learning Activity*), and pictures of each of the ten cloud types.

Natalie wonders if the sky that she sees is the same sky that others see at nearby schools. The class decides to compare their cloud observations each day to those of two other schools in their area, another elementary school and a middle school. Some of the children think that it is a game that has to be won by finding the most cloud types, but that is quickly corrected by the teacher. She tells the students that they are collecting data that scientists will be using in research work, and that it is important that they do this job well. It does not take long for the students to all pitch in and do a good job collecting their observations.

Collecting and Analyzing Data

After they have made their cloud observations for about three weeks, the students use the GLOBE visualization tool to find other nearby schools with many cloud observations. They decide to limit their search to schools within 50 km of their school and they find 7 other schools. One of the students has a big sister that goes to a middle school they found, and another attended a different elementary school last year, so they choose those two schools.

The students decide to compare data first by printing out maps for each day for cloud cover and cloud type. Using these maps, they make an observation that the cloud cover observations at the nearby schools are not always the same as theirs.. In particular, the other elementary school, which is near the mountains, seems to have more cloud cover and more observations of cumulus clouds than Natalie's school. They decide that this will be a good investigation. The middle school reports cloud observations similar to theirs.

The students read about mountain weather and discover that in mountain areas there usually are more clouds, because as the air is blown across the mountains it has to rise, and rising air often leads to cloud formation. Because strong upward motions form the clouds, they tend to be cumulus and even cumulonimbus clouds. This seems to explain what they are seeing, and Mrs. Jones suggests that they test this explanation.

The students expect to find that GLOBE schools near the mountains have more cloud cover and more observations of cumulus clouds than other nearby schools farther away from the mountains.

After examining data for an entire year, the students find the following data for 240 observations:

	Natalie's school	**Mountain View school**
No clouds	15	10
Clear	33	27
Isolated	18	14
Scattered	32	35
Broken	64	66
Overcast	71	79
Obscured Sky	7	9

It is clear indeed that the Mountain View school has more overcast days and fewer clear days (or days with no clouds) than Natalie's school. The students are happy that they have been able to test their explanation with observations.

Future Research

Another curiosity they observe, with their teacher's help, is the larger number of observations of low cloud (23 more days with low cloud types at Mountain View School than Natalie's school), and they wonder if they are cumulonimbus or cumulus clouds? They also wonder if the Mountain View school has more precipitation than Natalie's school, if they have more cumulonimbus clouds. The students are eager to begin their next investigation!

Figure AT-CL-2

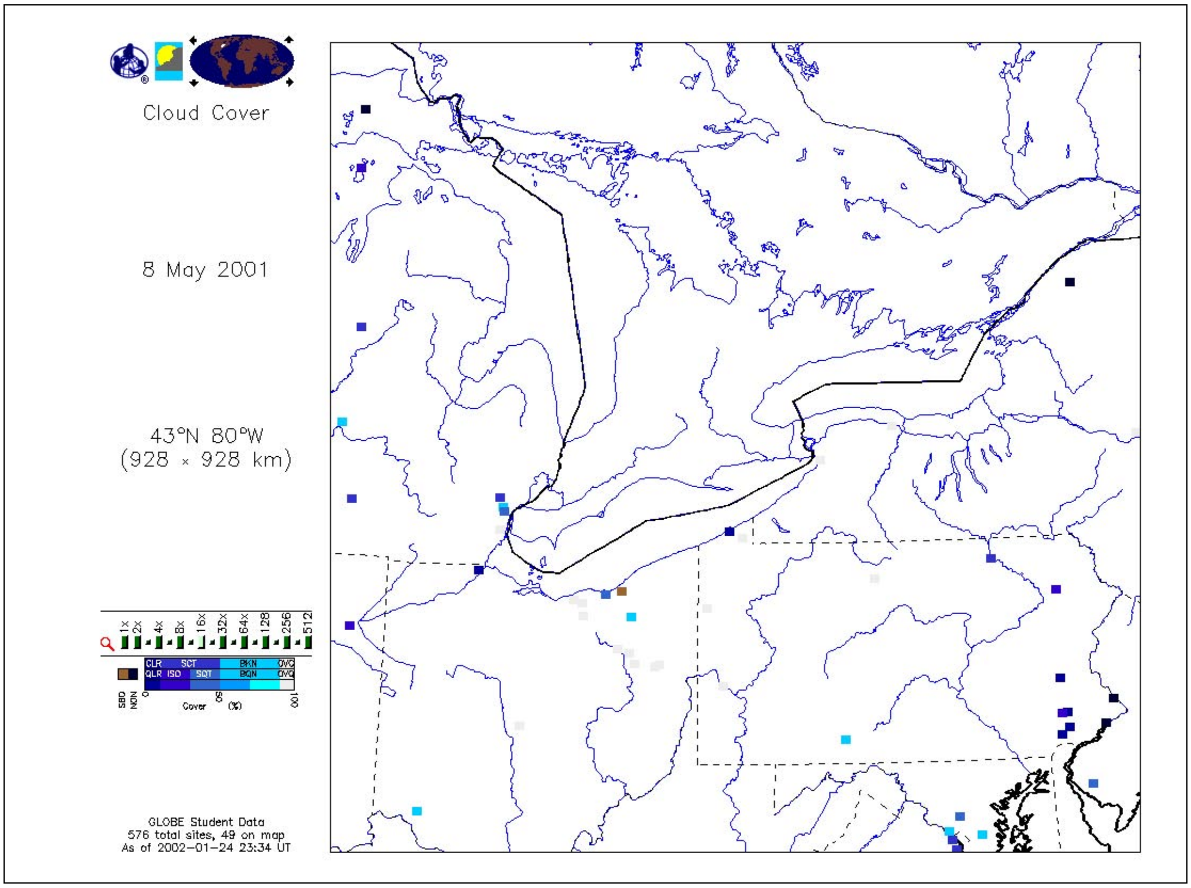
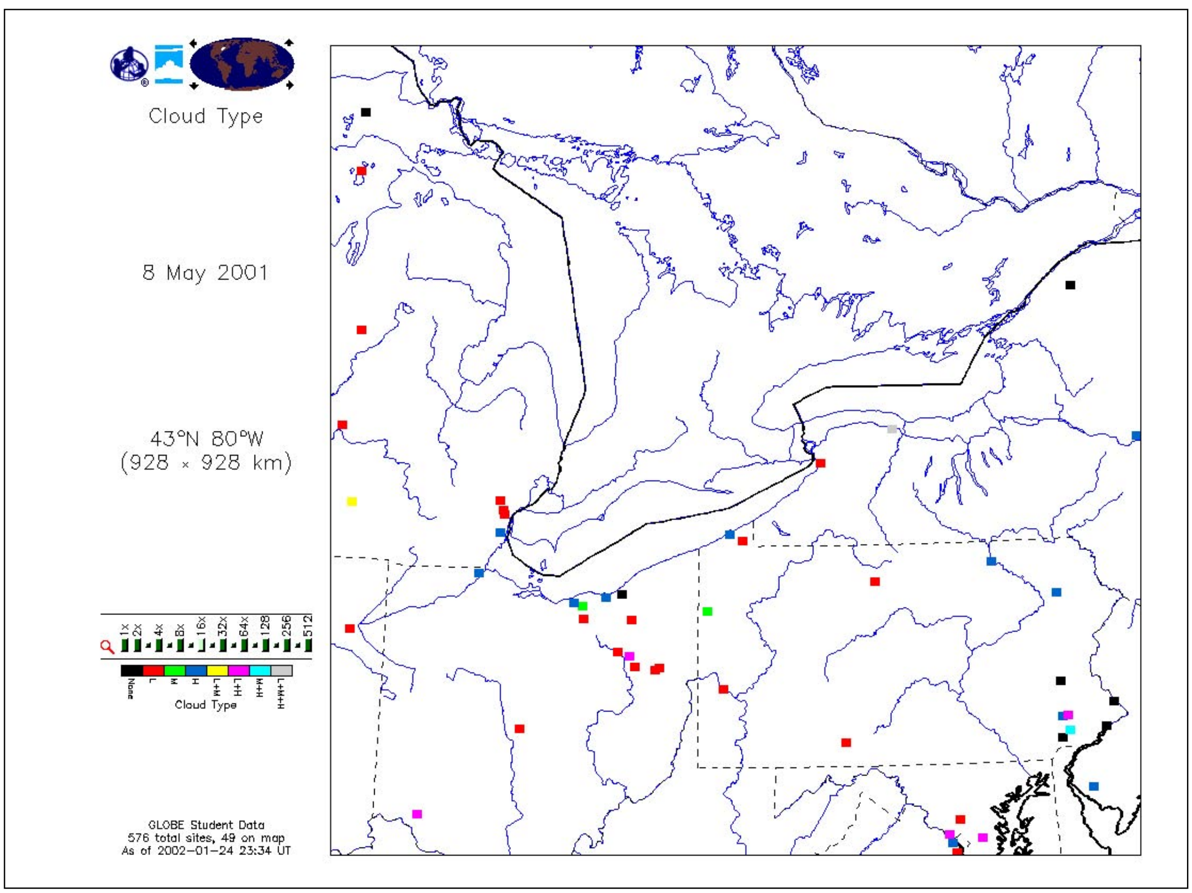


Figure AT-CL-3



Aerosols Protocol

Purpose

To measure the aerosol optical thickness of the atmosphere (how much of the sun's light is scattered or absorbed by particles suspended in the air)

Overview

Students point a GLOBE sun photometer at the sun and record the largest voltage reading they obtain on a digital voltmeter connected to the photometer. Students observe sky conditions near the sun, perform the *Cloud, Optional Barometric Pressure* (optional) and *Relative Humidity Protocols*, and measure current air temperature.

Student Outcomes

Students understand the concept that the atmosphere prevents all of the sun's light from reaching Earth's surface and they learn what causes hazy skies.

Science Concepts

Earth and Space Science

- The atmosphere is composed of different gases and aerosols.
- The sun is the major source of energy for changes in the atmosphere.
- The diurnal and seasonal motion of the sun across the sky can be observed and described.

Geography

- Human activities can modify the physical environment.

Atmosphere Enrichment

- Aerosols decrease the amount of solar energy reaching Earth's surface.
- Aerosols in the atmosphere increase haze, decrease visibility, and affect air quality.

Scientific Inquiry Abilities

- Use a sun photometer and voltmeter to measure the amount of direct sunlight.
- Identify answerable questions.
- Design and conduct scientific investigations.
- Use appropriate mathematics to analyze data.
- Develop descriptions and explanations using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures and explanations.

Time

15-30 minutes to collect data

Level

Middle and Secondary

Frequency

Every day, weather permitting

Materials and Tools

- Calibrated and aligned GLOBE sun photometer
- Digital voltmeter
- Watch, preferably digital (or GPS receiver)
- Thermometer
- Hygrometer or Sling psychrometer
- GLOBE Cloud Chart
- Barometer (optional)
- *Aerosols Data Sheet*

Preparation

Practice using a digital voltmeter.

Prerequisites

Cloud, Relative Humidity, and *Optional Barometric Pressure* (optional) *Protocols*

Ability to measure current air temperature

Aerosols Protocol – Introduction

Background

The atmosphere is composed of molecules of gas and small solid and liquid particles suspended in the air, called aerosols. Some aerosols are naturally produced from volcanoes, sea spray, sand, or wind-driven erosion of surface soil. Some aerosols are a result of human activity, such as dust from agricultural activities, smoke from burning biomass and fossil fuels and photochemically induced smog due primarily to vehicle emissions. Drops and ice crystals that form when water vapor freezes or condenses are also aerosols.

Most aerosols are in the troposphere, but large volcanic eruptions can inject aerosols and trace gases much higher into the stratosphere. Aerosols in the stratosphere may remain for years while in the troposphere, precipitation and interactions with Earth's surface remove aerosols in ten days or less.

Aerosols are too small to be individually visible, but you can often see their combined effect when the sky is hazy or looks dirty. Brilliant orange skies at sunrise and sunset may also be indicators that aerosols are present.

Aerosols influence our weather and climate because they affect the amount of sunlight reaching Earth's surface. Volcanic aerosols in the stratosphere have changed surface air temperatures around the world for years at a time. Biomass burning causes large local increases in aerosol concentrations that can affect regional weather. Taken together with other atmospheric measurements, aerosol measurements help scientists to better understand and predict climate and to understand atmospheric chemistry.

Aerosol concentrations vary significantly with location and time. There are seasonal and diurnal variations as well as unpredictable changes due to events such as large dust storms and volcanic eruptions. Aerosols are highly mobile; they can cross oceans and mountain ranges. It is generally agreed that, because of higher concentrations of aerosols, skies in many parts of the world are hazier than they were one or two centuries ago, even in rural areas.

Aerosol optical thickness (AOT, also called aerosol optical depth) is a measure of the extent to which aerosols affect the passage of sunlight through the atmosphere. The larger the optical thickness at a particular wavelength, the less light of that wavelength reaches Earth's surface. Measurements of aerosol optical thickness at more than one wavelength can provide important information about the concentration, size distribution, and variability of aerosols in the atmosphere. This information is needed for climate studies, for comparison with satellite data and to understand the global distribution and variability of aerosols.

Investigating Aerosols

Scientists have many questions regarding aerosols. How do aerosol concentrations change with the seasons? How are aerosol concentrations related to the weather and climate? How does smoke from large forest fires affect sunlight reaching Earth's surface? How long do volcanic emissions stay in the atmosphere and where do they go? How is air pollution related to aerosols? How do large industrial facilities and agricultural activities affect aerosols? How do aerosols affect a satellite's view of Earth's surface? Global measurements are needed to monitor the present distribution of aerosols and to track events that alter aerosol concentrations. Their study can lead to a better understanding of Earth's climate and how it is changing.

By reporting measurements regularly, you can provide scientists with the data they need and you can start to answer some questions about aerosols for your own data collection site. You may even observe plumes of aerosols originating thousands of kilometers away as they pass through your area. By building a data record that extends across several seasons and includes data from many locations, GLOBE can help scientists learn more about the global distribution of aerosols.

Teacher Support

Understanding Measurements of Aerosols

Aerosol measurements are best understood in the context of the other GLOBE atmospheric measurements. There may be observable relationships between aerosols and temperature, cloud cover, relative humidity, and precipitation. Certainly, aerosols vary seasonally. Thus, it is helpful to approach this topic as part of a "big picture" of the atmosphere and its properties.

An introduction to the concepts of solar elevation angle and relative air mass is essential to understanding these measurements. The Learning Activities *Making a Sundial* and *Calculating Relative Air Mass* describe activities to measure these values. Advanced-level students with appropriate mathematics backgrounds can calculate their own value for aerosol optical thickness using the *Looking at the Data* section. They can then compare their calculations to the value calculated by the GLOBE Data Server.

The GLOBE Sun Photometer

The GLOBE sun photometer has two channels, each of which is sensitive to a particular wavelength of light — green light at about 505 nanometers (nm) and red light at about 625 nm. Green light is near the peak sensitivity of the human eye; hence, a visibly hazy sky is likely to have a large aerosol optical thickness at this wavelength. Red light is more sensitive to larger aerosols. Data from a single channel enables the calculation of AOT in a particular wavelength range but it does not provide information about the size distribution of aerosols. Combining data from more than one channel provides information on size distribution. Knowing the size distribution helps identify the source of the aerosols.

Measurements taken with the GLOBE sun photometer are in units of volts. These values must be converted to aerosol optical thickness. Since the calculations require mathematics (logarithmic and exponential functions) that are appropriate only for high school students taking a pre-calculus mathematics course, the GLOBE Data Server will perform the calculations based on the voltage readings submitted by students and return a value of optical thickness for students to use. There is a *Looking at the Data* section for advanced students that includes the equation for converting sun photometer measurements into aerosol optical thickness. A typical aerosol optical thickness value for visible light in clear air is roughly 0.1. A very clear sky may have an AOT at green-light wavelengths of 0.05 or less. Very hazy skies can have AOTs of 0.5 or greater.

It may be easier to understand the concept of optical thickness when it is expressed in terms of the percentage of light that is transmitted through the atmosphere, according to this formula:

$$\text{percent transmission} = 100 \times e^{-a}$$

where a is optical thickness at a particular wavelength. This calculation gives the percentage of light at a particular wavelength that would be transmitted through the atmosphere if the sun were directly overhead. For an optical thickness of 0.10, the percent transmission is about 90.5%.

For students who are not yet comfortable with exponential functions, Table AT-AE-1 gives percent transmission as a function of optical thickness.

Table AT-AE-1

Optical Thickness	Percent Transmission
0.10	90.5%
0.20	81.9%
0.30	74.1%
0.40	67.0%
0.50	60.7%
0.60	54.9%
0.75	47.2%
1.00	36.8%
1.25	28.7%
1.50	22.3%
2.00	13.5%
2.50	8.2%
3.00	5.0%
3.50	3.0%
4.00	1.8%
5.00	0.7%

Where and When to Take Sun Photometer Measurements

The logical place to take sun photometer measurements is the same place where you do your cloud observations and other atmosphere protocols. If you take measurements at some other place, you need to define it as an additional Atmosphere Study Site.

Ideally, aerosol measurements should be made in the morning when the solar elevation angle is at least 30 degrees. This is because, generally, the air in the morning is less turbulent than air near noon when the sun is high in the sky, or in the afternoon, especially in the heat of summer. The less turbulent the air, the easier it is to obtain reliable measurements. During the winter in temperate and higher latitudes, the relative air mass at your location may always be greater than 2. You can still take measurements, but you should take them as close to solar noon as possible. Although you should try to take measurements during optimum conditions, it is OK to take and report measurements whenever it is convenient and you have an unobstructed view of the sun.

If you wish to collect sun photometer data that support ground validation efforts for Earth-observing spacecraft, you may need to take measurements at specific times, corresponding to spacecraft overflights of your observing site. For more information about this activity, please contact the GLOBE Science Team.

Instrument Care and Maintenance

Your GLOBE sun photometer is a simple and rugged device with no easily breakable parts. However, you must take care of it in order to take accurate measurements. Here are some things you should do (and not do) to make sure your sun photometer performs reliably over long periods of time.

1. Do *not* drop your photometer.
2. *Protect* your sun photometer from dirt and dust by storing it in a sealed plastic bag (such as a plastic sandwich bag) when you are not using it.
3. *Do not* expose your sun photometer to extremely hot or cold temperatures by leaving it in the sun or on a radiator or by leaving it outside.
4. *Keep* your sun photometer turned off when it is not in use.
5. *Check* the battery voltage every few months. See *Checking and Changing Your GLOBE Sun Photometer Battery*. Your sun photometer uses very little power when you take measurements, so the battery should last for many months of normal use. If you accidentally leave the photometer turned on for hours or days when you are not using it, check the battery before taking additional measurements and replace it if necessary.
6. *Do not* modify the electronics inside your sun photometer in any way. The calibration of your instrument depends critically on retaining the original components on the circuit board.
7. *Do not* enlarge the hole(s) in the case through which sunlight enters your sun photometer. The calibration of your sun photometer and the interpretation of its measurements are based on the size of this hole. If you change it, your measurements will no longer be valid.

With a little care, your sun photometer will work reliably for many years. Although the GLOBE Science Team might ask you to return your sun photometer for recalibration, under normal conditions no periodic recalibration is necessary. If your instrument appears not to be working correctly, consult with GLOBE before doing anything else.

Checking and Changing Your GLOBE Sun Photometer Battery

At least every three months, check the voltage of the battery in your sun photometer and replace the battery if necessary. If your sun photometer has a built-in digital voltmeter and a "low battery" indicator appears, or if the voltages from your instrument appear erratic, replace the battery at once. (See the *Checking and Changing Your GLOBE Sun Photometer Battery Lab Guide* for Instructions.) Replacing the battery will not change the calibration of your instrument and measurements made with the old battery will be OK as long as you replace the old battery before its voltage falls below 7.5 V.

Checking and Changing Your GLOBE Sun Photometer Battery
Lab Guide

Task
Check the battery in the sun photometer and replace it if necessary.

What You Need
- ❑ Small Phillips-head screwdriver
- ❑ Voltmeter
- ❑ Any standard, new 9 V battery if the old battery needs replacing (rechargeable batteries are not recommended for this instrument)

In the Lab
1. Open the case by removing the four screws in the cover.

   Do not remove the printed circuit board or disturb the electronics in any way.

   Do not touch the front surface of the LED detectors (the round green and red devices on the front of the printed circuit board).

2. With the instrument turned on, use a voltmeter to measure the voltage across the two connectors on the battery holder.

   Note that new 9-volt batteries typically produce voltages greater than 9 V, and can even produce voltages in excess of 10 V.

3. If the voltage is less than 7.5 V, replace the battery. Any standard 9 V battery is OK. Alkaline batteries are more expensive than other types and are not required. Note that the connectors on the + and -terminals are different, so the battery will fit in its holder only one way. Rechargeable batteries are not recommended for this instrument.

4. When you are done, check the operation of your sun photometer by letting sunlight shine on the LED detectors. You do not have to replace the cover while you are performing this test. Whenever an LED is not shadowed, you should see a voltage substantially larger than the "dark" voltage.

5. When you are sure the photometer is working, replace the cover. If your sun photometer has a foam strip on the lid, make sure the cover is oriented so this strip pushes against the top of the printed circuit board. Tighten the screws until they are snug, but do not force them.

If you want to convince yourself that replacing the battery has not changed the calibration of your instrument, wait for a clear day. Make a few measurements right before and right after you change the battery. These measurements should be consistent as long as the old battery voltage was not significantly less than 7.5 V.

Student Preparation

1. Prior to implementing this protocol, it will be helpful to spend a few minutes in your classroom or lab practicing how to use a digital voltmeter. When the voltmeter is connected to a circuit that is not producing a voltage signal, the digital display may indicate the presence of a small voltage (perhaps a few millivolts). This is normal operation, but it may be confusing to students who are expecting to see a voltage of 0.0 V. (**Note:** If your sun photometer has a built-in voltmeter, you do not need a separate digital voltmeter to take measurements. However, if you have a separate digital voltmeter, this is still a useful activity.)
2. In order to calculate aerosol optical thickness from your measurements, GLOBE must know the true barometric pressure (the station pressure) at your site when you took your measurements. The preferred source for local barometric pressure is an online or broadcast weather source for your area (such as the National Weather Service in the U.S.). See the *Optional Barometric Pressure Protocol*. Locating such a source should be part of student preparation for this protocol. If an online source is not available, there are other options discussed in *Getting Ready to Take Measurements,* below. Almost always, barometric pressure is reported adjusted to what it would be at sea level. This enables meteorologists to draw weather maps over terrain with varying elevation. GLOBE uses the elevation data from your site definition to adjust the sea level pressure you report to the station pressure needed to calculate AOT.
3. Current air temperature and relative humidity are also helpful supporting information for this protocol. Have students practice these measurements as well. See the *Digital Multi-Day Max/Min Current Temperature Protocol Field Guide,* steps 1-5 of the *Maximum, Minimum and Current Temperature Protocol Field Guide,* steps 1-4 of the *Digital Single-Day Maximum and Minimum Temperature Protocol Field Guide* or the *Current Air Temperature Protocol Field Guide* and the *Relative Humidity Protocol.*
4. The presence of thin, high (cirrus) clouds in front of the sun will affect sun photometer readings. This is why it is important that students gain some experience in identifying clouds, especially cirrus clouds, as described in the *Cloud Protocols*.
5. It is especially important to take sun photometer measurements in the prescribed way and under acceptable sky conditions. A *Classroom Preparation Guide* is provided to help you prepare. It describes in detail the steps required to take and record a measurement, along with the reasons for each step. It parallels the *Field Guide* that simply lists the steps in order without explanation. As part of their preparation for this protocol, students should study the *Classroom Preparation Guide* to make sure they understand the critical parts of each step.

Questions for Further Investigation

To what extent is AOT related to other atmospheric variables — temperature, cloud type and cover, precipitation, relative humidity, barometric pressure, and ozone concentration?

How does AOT relate to the appearance of a distant landmark or to the color of the sky?

Does AOT vary with site elevation? If so, how?

How does AOT vary as surroundings change from urban to rural?

How does AOT vary with the seasons?

Aerosols Protocol

Classroom Preparation Guide

Task

Record the maximum voltage reading that can be obtained by pointing your photometer at the sun.

Record the precise time of your measurement.

Observe and record cloud conditions, current air temperature, and relative humidity.

What You Need

- ❑ Calibrated and aligned GLOBE sun photometer
- ❑ Digital voltmeter (if your sun photometer does not have a built-in voltmeter)
- ❑ Watch, preferably digital or GPS receiver
- ❑ *Aerosols Data Sheet*
- ❑ GLOBE Cloud Chart
- ❑ Barometer (optional)
- ❑ Thermometer
- ❑ Hygrometer or sling psychrometer
- ❑ *Field Guides* for cloud, relative humidity and one air temperature protocol
- ❑ Pencil or pen

Getting Ready To Take Measurements

In order for the Science Team to interpret measurements made with your sun photometer, you must provide the longitude, latitude, and elevation of your observing site, as required for other GLOBE measurements. You do this once, when you define an Atmosphere Study Site. Other values and observations must be provided along with each measurement, as shown on the data entry form. The purpose of this section is to give you the information you need to complete the data entry.

Time

It is important to report accurately the time at which you take a measurement because the Science Team needs to calculate solar position at your site and that calculation depends on time. The GLOBE standard for reporting time is UT, which can be calculated from local clock time based on your time zone and the time of year. For this protocol, it is absolutely essential to convert local time to UT correctly; be especially careful when your local time is summer ("daylight savings") time. For example, you must add 5 hours to convert Eastern Standard Time to UT, but only 4 hours to convert Eastern Daylight Time to UT.

Time should be reported at least to the nearest 30 seconds. A digital watch or clock is easier to use than an analog one, but in either case you must set your timepiece against a reliable standard. The time accuracy requirements for this protocol are stricter than for the other GLOBE protocols. However, it is not difficult to set your clock or watch to meet this standard. You can get time online at www.time.gov. In many places, you can get an automated local time report by phone from a local radio or TV station. Your GPS receiver will report UT. In some places, you can buy a clock that sets itself automatically by detecting radio signals from a government-sponsored official time source. (In the U.S., for example, this so-called "atomic clock" signal is broadcast over station WWBV.)

It might be tempting to use the time stored in your computer as a standard. However, this is not a good idea, as (perhaps surprisingly) computer clocks are often not very accurate, and they must be set periodically according to a reliable standard. Note that some computer operating systems will automatically switch your computer clock back and forth between standard and summer ("daylight savings") time. You should be aware of when this change occurs if you need to manually convert time from your local clock time to UT.

The preferred time of day for reporting sun photometer measurements at most latitudes, during most of the year, is mid-morning. However, it is acceptable to take these measurements any time during the day between mid-morning and mid-afternoon. No matter what time you take measurements, be sure to report UT as accurately as possible, as noted above. The Science Team understands that it may be most convenient to take these measurements at the same time you collect your other atmospheric data. Measurements should be made at a relative air mass of no more than 2 whenever possible. (Refer to the Learning Activity that discusses relative air mass. A relative air mass of 2 corresponds to a solar elevation angle of 30 degrees.) During the winter in temperate and higher latitudes, the relative air mass at your location may always be greater than 2. You can still take measurements, but you should take them as close to solar noon as possible.

If you are taking sun photometer measurements in support of ground validation activities for Earth-observing spacecraft, then the measurement times will be based on the times of spacecraft overflights of your observing site.

Sky Conditions

When you record sun photometer measurements, you should also record other information about the sky, including cloud cover and cloud type, sky color, and your own assessment of how clear or hazy the sky is.

Sky color and clarity are subjective measurements but, with practice, you can learn to be consistent in your own observations. For example, you can easily learn to recognize the bright blue clear sky associated with low aerosol optical thickness. As the aerosol concentration increases, the sky color changes to a lighter blue color. It may appear milky rather than clear. In some places, especially in and near urban areas, the sky can have a brownish or yellowish tint due to air pollution (primarily particulates and NO_2).

When there are obvious reasons for high values of aerosol optical thickness, the Science Team needs to know about them. This is why you are also asked to comment about why you think the sky is hazy. It could be due to urban air pollution, a volcanic eruption, or dust from agricultural activity, for example.

Sun photometer measurements can be interpreted properly only when the sun is not obscured by clouds. This does not mean that the sky must by completely clear, but only that there must be no clouds in the vicinity of the sun. This is not necessarily a simple decision. It is easy to determine whether low- and mid-altitude clouds are near the sun, but cirrus clouds pose a more difficult problem. These clouds are often thin and may not appear to block a significant amount of sunlight. However, even very thin cirrus clouds can affect sun photometer measurements. For this reason, if you observe cirrus clouds earlier or later in the day relative to when you report measurements, you should note this fact on your data entry form.

Another difficult situation occurs in typical summer weather, especially near large urban areas. In this environment, very hazy skies and hot humid weather often make it difficult to distinguish cloud boundaries. Such conditions can produce relatively large values of aerosol optical thickness (any value greater than about 0.3-0.5) that may not represent the actual state of the atmosphere. It is important to describe such conditions whenever you report measurements.

To get a better idea of where cloud boundaries are, you can observe the sky through orange or red sunglasses, or through a sheet of translucent orange or red plastic. These colors filter out blue skylight and make clouds more distinct.

Never look directly at the sun, even through colored sunglasses or plastic sheets! This can damage your eyes.

Fog is another potential problem. It can make things look hazy. But fog (a stratus cloud at ground level) is not the same as atmospheric haze from aerosols. Conditions where the sun is shining through even light fog are unsuitable for taking sun photometer measurements. In many locations fog dissipates before mid-morning, so it will not affect your measurements.

Whenever you try to determine sky conditions before taking sun photometer measurements, you must block the sun itself with a book, a sheet of paper, a building or tree, or some other object. A sensible rule is that if you can see any shadows at all on the ground, you should not try to look at the sun. If in doubt, or if you believe you cannot determine sky conditions near the sun, do not take a measurement!

Temperature

The electronics in your GLOBE sun photometer, and especially its LED detectors, are temperature-sensitive. This means that the output will change under the same sunlight conditions as the sun photometer warms and cools. Therefore, it is important to maintain your sun photometer at approximately room temperature. To alert the Science Team to potential problems with temperature, we ask that you report air temperature along with your sun photometer measurements.

If you are taking sun photometer measurements at the same time you record temperature data from your weather station, you can use that current temperature. Otherwise, you must measure the air temperature separately. The preferred way to obtain air temperature values is to take them following the GLOBE *Temperature Protocols* using a thermometer that meets GLOBE standards mounted in an appropriate weather shelter. Alternatively, a value can be obtained from an online source or from a thermometer that does not necessarily meet GLOBE standards. Non-GLOBE temperature values should be reported as metadata on the *Data Sheet,* and not in the air temperature field.

In terms of instrument performance, the relevant temperature is not necessarily the outside temperature, but air temperature inside your sun photometer's case. Newer GLOBE sun photometers include a built-in sensor that monitors air temperature inside the instrument, near the LED detectors. These instruments have a rotary switch on the top of the case rather than a green/red channel toggle switch. If your sun photometer includes this feature, there is a place to report case temperature on the *Data Sheet*. The temperature, in degrees Celsius, is 100 times the voltage displayed on the voltmeter when the "T" channel is selected. For example, a voltage reading of 0.225 V corresponds to a temperature of 22.5° C. Ideally, this temperature should be in the low 20's.

There are some steps you should take to minimize temperature sensitivity problems. Keep your sun photometer inside, at room temperature, and bring it outside only when you are ready to take a measurement. In the winter, transport it to your observing site under your coat, for example, to keep it warm. In very hot or very cold weather, you can wrap the instrument in an insulating material such as an insulated sandwich bag, a towel, or pieces of plastic foam. In the summer, keep your instrument shielded from direct sunlight whenever you are not actually taking a measurement. You should practice taking and recording measurements so that an entire set of voltage measurements should take no more than two or three minutes.

Relative Humidity

Relative humidity is a useful addition to the *Aerosols Protocol* metadata because high (or low) values of relative humidity are often associated with high (or low) aerosol optical thickness values. There is a *Relative Humidity Protocol* available for this measurement, which requires a digital hygrometer or sling psychrometer, but it is also OK to use an online or broadcast value from within an hour of your sun photometer measurements. Online values should only be reported as comments while values you obtain following the *Relative Humidity Protocol* are valid GLOBE data and may be reported as such.

Barometric Pressure

Unlike the previous values described in this section, the station pressure at your observing site is *required* in order to calculate aerosol optical thickness. Unless your site is very close to sea level, the barometric pressure reported on weather broadcasts, in your local newspaper, and on the Web is not station pressure. Why? Because in such reports, the true barometric pressure has been adjusted to what it would be at sea level. This enables meteorologists to construct pressure maps that show the movement of air masses over large areas, independent of the varying elevation of the ground. Barometric pressure decreases roughly 1 mbar for every 10 meters of increased elevation. (See Figure AT-I-1 and the *Optional Barometric Pressure Protocol*.)

As noted above, the preferred source of barometric pressure is an online or broadcast value for your area. A second option is to leave the barometric pressure field blank. In this case, GLOBE will fill in the barometric pressure using a computer-generated model value. If you have calibrated your classroom barometer on a regular basis so that it gives sea level pressure and have confidence in that calibration, you may report a reading from your barometer. However, typical classroom aneroid barometers must be calibrated regularly as described in the *Optional Barometric Pressure Protocol*. At higher elevations, it may not be possible to calibrate your classroom barometer to give an equivalent sea level value.

In the Field

It is much easier for two people to take and record measurements than for one person working alone. If you can work as a team, divide up the tasks and go through several practice runs before you start recording real measurements.

1. Connect a digital voltmeter to the output jacks of your sun photometer.

   If your sun photometer has a built-in digital voltmeter, you can skip this step. If you need a separate voltmeter, do not use an analog voltmeter, which cannot be read accurately enough to be suitable for this task. Be sure to put the red lead in the red jack and the black lead in the black jack.

2. Turn the digital voltmeter and sun photometer on.

   If your sun photometer has a built-in digital voltmeter, the same switch turns on both the meter and the sun photometer and you do not need to worry about selecting an appropriate voltage range.

   If you are using an external voltmeter, select an appropriate DC volts range. Be careful not to use an AC volts setting. The appropriate range setting depends on your voltmeter. If it has a 2 V (volts) or 2000 mV (millivolts) setting, try that first. If your photometer produces more than 2 V, use the next higher range, often 20 V. Some voltmeters have auto-ranging capability, which means that there is only one DC volts setting and the voltmeter automatically selects an appropriate voltage range. If you are using an auto-ranging voltmeter, make sure you understand how to read voltages in this range.

   Note that if a digital voltmeter is connected to your sun photometer when the photometer is turned off, you will get unpredictable readings on the voltmeter, rather than the value of 0 V you might expect. This is normal behavior for digital voltmeters. Erratic voltage readings will also occur if the battery in your sun photometer is too low to power the electronics. When you turn your sun photometer on, and it is working properly, the voltmeter should produce a stable reading of no more than a few millivolts indoors or if the sun is not shining on a detector, or a value in the range of roughly 0.5-2 V when sunlight is shining on the detector.

3. If your sun photometer has a rotary switch on the top of the case, select the “T” setting and record the voltage.

   Multiply the voltage reading times 100 and record this value.

4. Select the green channel on your sun photometer (because the GLOBE data entry page asks for the green channel first).

5. Hold the instrument in front of you about chest-high or, if possible, sit down and brace the instrument against your knees, a chair back, railing, or some other fixed object. Find the spot made by the sun as it shines through the front alignment bracket.

   Here is an important safety rule:
   Under no circumstances should you hold the sun photometer at eye level and try to “sight” along the alignment brackets!

   Adjust the pointing of your instrument until the spot of sunlight shining through the front alignment bracket shines on the rear alignment bracket.

6. Adjust the pointing until the sunlight spot is centered over the appropriate colored dot on the rear alignment bracket. Record this value on your *Data Sheet.*

   Your sun photometer case will have either one or two round holes on the front of the case. If it has one hole, the rear alignment bracket will have two colored alignment dots - one green and one red. The sunlight spot must be centered around the green dot when you are taking green-channel measurements and around the red dot if you are taking red-channel measurements. If your sun photometer has two holes, the rear alignment bracket will have one blue alignment dot. The sunlight spot must be centered around this dot regardless of whether you are taking green- or red-channel measurements.

   When you adjust the pointing of your photometer so that the sunlight spot is centered around the alignment dot, the sunlight shining through the aperture hole(s) on the front of the case is centered over the LED detector(s) inside the case. It takes a little practice to learn how to center the sunlight spot over the alignment dot. Be sure the pointing is stable before you record voltages. It may help to steady your instrument against a chair, post, or other stationary object. The entire measurement process should not take more than 15 or 20 seconds for each reading of each channel. Be sure to record all the digits displayed on your voltmeter.

   Unless the sky is very hazy, or unless you are taking measurements late in the afternoon or early in the morning, the voltage should increase to more than 0.5 V. If you are using an auto-ranging voltmeter, the range will change automatically when you point your photometer directly at the sun (from a range appropriate for displaying the dark voltage to a range appropriate for displaying the sunlight voltage).

   Small movements of the sun photometer will cause the voltage to vary by a few millivolts. Even when your sun photometer is completely still and properly aligned with the sun, the voltage will still vary a little. This is due to fluctuations in the atmosphere itself. The hazier the atmosphere, the larger these fluctuations. Do not try to average the voltmeter readings. It is important to record only the maximum voltage you obtain during a few seconds of measurement time, starting only after the pointing of your instrument has been stabilized. There is a slight time delay between the time when the voltage output from your instrument changes and when that change is reflected in the digital reading. With a little practice, you can learn to compensate for this time delay.

7. Record the time at which you observed the maximum voltage as accurately and precisely as possible. An accuracy of 15-30 seconds is required.
8. While still pointing your sun photometer at the sun, cover the aperture with your finger to block all light from entering the case. Take a voltage reading and record this dark voltage reading on your *Data Sheet*.

   Note that the dark voltage **must** be reported as volts rather than millivolts, regardless of the range setting of your digital voltmeter. It is critical to report both the dark voltage and sunlight voltage in units of volts. It is important to record the dark voltage accurately, reporting all the digits displayed on your voltmeter. The dark voltage should be less than .020 V (20 mV). Depending on the characteristics of your instrument and the range setting of your voltmeter, the dark voltage may display as 0 V If so, report 0.000 V for the dark voltage.
9. Select the other channel (the red one, assuming you have started with the green channel) and repeat steps 6-8.

   After you gain experience with your sun photometer, it will be unnecessary to repeat step 8 after every sunlight voltage measurement. Indeed, the dark voltages should not change during a set of measurements. If this value changes by more than a millivolt or so, it means that your instrument is getting too hot or cold during the measurement and you need to develop a measurement strategy that prevents this from happening.
10. Repeat steps 4-9 at least twice and no more than four times.

    This will give you between three and five pairs of green/red measurements in all. It is a good idea to be consistent about the order in which you record measurements; you should record green, red, green, red, green, red, green, red, green, red.

    The time between measurements is not critical as long as you record the time accurately. However, as noted above, you should try to minimize the total time required to collect a set of measurements. Remember that your measurements will not be accurate if your sun photometer is significantly colder or warmer than room temperature.
11. If your sun photometer has a rotary switch on the top of the case, select the “T” setting and record the voltage.

    Multiply the voltage reading times 100 and record this value.
12. Turn off both the sun photometer and the voltmeter (if your instrument does not have a built-in digital voltmeter).

    You can disconnect a separate voltmeter or leave it plugged into the output jacks, depending on whether your class uses the voltmeter for other purposes.
13. Note any clouds in the vicinity of the sun in the *Comments* section of the *Aerosols Data Sheet*. Be sure to note the type of clouds by using the GLOBE Cloud Chart.
14. Do the *Cloud Protocols* and record your observations on the *Aerosols Data Sheet*.
15. Do the *Relative Humidity Protocol* and record your observations on the *Aerosols Data Sheet.*
16. Read and record the current temperature to the nearest 0.5˚ C following one of the air temperature protocols.

    There are four *Field Guides* from which to choose listed in the *Student Preparation Guide.* Be careful not to touch or breathe on the thermometer.
17. Complete the rest of the *Aerosols Data Sheet*. This may be done back in the classroom.

Aerosols Protocol
Field Guide

Task

Record the maximum voltage reading that can be obtained by pointing your photometer at the sun.

Record the precise time of your measurement.

Observe and record cloud conditions, current air temperature, and relative humidity

What You Need

- ❑ Calibrated and aligned GLOBE sun photometer
- ❑ Digital voltmeter
- ❑ Watch, preferably digital or GPS receiver
- ❑ *Aerosols Data Sheet*
- ❑ GLOBE Cloud Chart
- ❑ Barometer (optional)
- ❑ Thermometer
- ❑ Hygrometer or sling psychrometer
- ❑ *Field Guides* for cloud, relative humidity and one air temperature protocol
- ❑ Pencil or pen

In the Field

1. Connect a digital voltmeter to the output jacks of your sun photometer. (Skip this step if your sun photometer has a built-in digital voltmeter.)
2. Turn the digital voltmeter and sun photometer on.
3. If your sun photometer has a rotary switch on the top of the case, select the "T" setting and record 100 times this voltage.
4. Select the green channel.
5. Face the sun and point the sun photometer at the sun. (Do not look directly at the sun!)
6. Adjust the pointing until you see the maximum voltage in your digital voltmeter. Record this value on your *Data Sheet*.
7. Record the time at which you observed the maximum voltage as accurately as possible, to the nearest 15 seconds.
8. While still pointing your sun photometer at the sun, cover the aperture with your finger to block all light from entering the case. Take a voltage reading and record this dark voltage reading on your *Data Sheet*.
9. Select the red channel (assuming you have started with the green channel) and repeat steps 6-8.
10. Repeat steps 3-9 at least twice and not more than four times.
11. If your sun photometer has a rotary switch on the top of the case, select the "T" setting and record 100 times this voltage.
12. Turn off both the sun photometer and the voltmeter.
13. Note any clouds in the vicinity of the sun in the comments (metadata) section. Be sure to note the types of clouds by using the GLOBE Cloud Chart.
14. Do the *Cloud Protocols* and record your observations on the *Aerosols Data Sheet*.
15. Do the *Relative Humidity Protocol* and record your observations on the *Aerosols Data Sheet.*
16. Read and record the current temperature to the nearest 0.5° C following one of the air temperature protocols.
17. Complete the rest of the *Aerosols Data Sheet*.

Frequently Asked Questions

1. What is a sun photometer and what does it measure?

A sun photometer is a type of light meter that measures the amount of sunlight. Most sun photometers measure the amount of sunlight for a narrow range of colors or wavelengths. All sun photometers should measure only the sunlight arriving directly from the sun and not the sunlight scattered from air molecules and aerosols. Therefore a sun photometer is pointed directly at the sun and the light is collected through a small aperture (hole or opening) that greatly restricts the amount of scattered sunlight that reaches the instrument's detector(s).

2. The GLOBE sun photometer uses a light-emitting diode (LED) as a sunlight detector. What is an LED?

A light-emitting diode is a semiconductor device that emits light when an electrical current flows through it. The actual device is a tiny chip only a fraction of a millimeter in diameter. In the GLOBE sun photometer, this chip is housed in an epoxy housing about 5 mm in diameter. You can find these devices in a wide range of electronic instruments and consumer products. The physical process that causes LEDs to emit light also works the other way around: if light shines on an LED, it produces a very small current. The electronics in your sun photometer amplifies this current and converts it to a voltage.

Generally, the wavelength of light detected by an LED is shorter than the wavelength of light emitted by the same LED. For example, certain red LEDs are relatively good detectors of orange light. The LED in the GLOBE sun photometer emits green light with a peak value at about 565 nm. It detects light with a peak at about 525 nm, which is a little farther toward the blue part of the light spectrum.

3. What is the field of view of a sun photometer, and why is it important?

The equation that describes theoretically how to interpret sun photometer measurements requires that the instrument should see only direct light from the sun – that is, light that follows a straight line path from the sun to the light detector. This requirement can be met only approximately in practice because all sun photometers will see some scattered light from the sky around the sun.

The cone of light a sun photometer's detector sees is called its field of view, and it is desirable to have this cone as narrow as possible. The GLOBE sun photometer's field of view is about 2.5 degrees, which GLOBE scientists have concluded is a reasonable compromise between the theoretical ideal and practical considerations in building a handheld instrument. The basic trade-off is that the smaller the field of view, the harder the instrument is to point accurately at the sun. Very expensive sun photometers, with motors and electronics to align the detector with the sun, typically have fields of view of 1 degree or less. Studies have shown that the error introduced by somewhat larger fields of view is negligible for the conditions under which a GLOBE sun photometer should be used.

4. How important is it to keep the sun photometer from getting hot or cold while I'm taking measurements?

The LED detector in your sun photometer is temperature-sensitive, so its output is slightly influenced by its temperature. Therefore, it is very important to protect your instrument from getting too hot in the summer or too cold in the winter. In the summer, it is essential to keep the instrument case out of direct sunlight when you are not actually taking a measurement. In the winter, it is essential to keep the instrument warm – you can tuck it under your coat between measurements.

Never leave your sun photometer outside for extended periods of time. The sun photometer case itself provides some protection from temperature changes that can affect the electronics inside. (This is why newer GLOBE sun photometers have a built-in temperature sensor to monitor the air temperature inside the case, near the detectors.) If you follow these precautions and take your measurements as quickly as possible, then your measurements will be acceptable.

In extreme conditions (winter or summer), you should consider making an insulating housing for your sun photometer. You can use styrofoam or other foam plastic. Cut holes for the on/off switch and the sunlight aperture(s), and a channel for sunlight to get from the front alignment bracket to the target on the back bracket. The hole for a sunlight aperture should be no smaller in diameter than the thickness of the insulating material itself, and in no case should it be smaller than about 1 cm.

5. I dropped my sun photometer. What should I do now?
Fortunately, the components inside your sun photometer are virtually indestructible, so they should have survived being dropped. Check the case for cracks. Even if the case is cracked, you should still be OK. Just tape over the cracks — use something opaque, such as duct tape. Open the case and make sure that everything looks OK. In particular, make sure that the battery is still firmly attached to the terminals on the battery holder.

If the alignment brackets have moved or are loose as a result of the fall, then your sun photometer should be returned to the GLOBE Science Team for realignment and recalibration.

6. How do I know if my sun photometer is working properly?
When you turn your sun photometer on without pointing it at the sun, you should measure a voltage in the range of no more than 20 mV. On some instruments, dark voltages are less than 1 mV. When you point your instrument directly at the sun, the voltage should increase to a value in the range of about 0.5-2.0 V. Only in very hazy conditions, late in the afternoon, or early in the morning, should you see a sunlight voltage less than 0.5 V. If you do not see the expected voltages, then your sun photometer is not working.

The most likely reason for a sun photometer not to work is that the battery is too weak to power the electronics. If you suspect this is the case, then test the battery voltage and replace it according to the instructions given in *Checking Your GLOBE Sun Photometer Battery*. Remember that a dead or very low battery will not produce a sunlight voltage of 0 V, but will instead cause your voltmeter to display erratic values. If you still believe you have a problem, contact GLOBE for help.

7. What does it mean to calibrate a sun photometer?
A sun photometer is considered to be calibrated if its extraterrestrial constant is known. This is the voltage you would measure with your sun photometer if there were no atmosphere between you and the sun. As an exercise, you could think about pointing your sun photometer at the sun from the open cargo bay of the Space Shuttle as it orbits Earth above the atmosphere. The voltage you measure would be your instrument's extraterrestrial constant. This value depends primarily on the wavelength at which your sun photometer detects light and also on the distance between Earth and the sun. (This distance varies slightly because Earth follows a slightly elliptical, rather than a circular, path around the sun.)

Note that if you really could use a sun photometer outside Earth's atmosphere, you would not have to worry about limiting the field of view. Why? Because outside the atmosphere there are no air molecules or aerosols to scatter sunlight. Hence, your sun photometer will see only direct sunlight.

As a practical matter, sun photometers must be calibrated by inferring the extraterrestrial constant from measurements made at Earth's surface. This is called the "Langley plot" method. These measurements are difficult to take at low elevation sites with variable weather. GLOBE sun photometers are calibrated against reference instruments that have been calibrated using measurements taken at Mauna Loa Observatory, which is widely accepted as one of the best locations for such work.

It is an interesting project to make your own Langley plot calibrations and compare the results with the calibration assigned to your sun photometer. If you would like to do this, contact GLOBE for additional help.

8. Can I make my own sun photometer?

You can purchase a sun photometer kit. Constructing a sun photometer involves soldering some electronic components, which is a skill students need to learn under supervision by someone who has done it before. You can start taking measurements as soon as you have assembled your instrument. However, at some point, you must send your sun photometer to the GLOBE Science Team for calibration before your data can be accepted into the GLOBE Data Archive.

9. How often must I take sun photometer measurements?

The protocol asks that you take measurements every day, weather permitting. In some parts of the world, it is possible to go many days without having weather suitable for taking these measurements. It is highly desirable to have a plan for taking measurements on weekends and during holiday breaks (especially during extended summer holidays).

10. How can I tell whether the sky is clear enough to take sun photometer measurements?

The basic rule is that the sun must not be blocked by clouds during a measurement. It is OK to have clouds near the sun. This can be a difficult decision, because you are never supposed to look directly at the sun. You can look at the sky near the sun by blocking the sun with a book or notebook. An even better idea is to use the comer of a building to block the sun. It is very helpful to wear sunglasses when you make these decisions because they protect your eyes from UV radiation. Orange-tinted sunglasses will help you see faint clouds that might otherwise be invisible.

If you have concerns about a measurement, note them in the *Comments* section of the *Aerosols Data Sheet* when you report the measurement. Thin cirrus clouds are notoriously difficult to detect, but they can dramatically affect sun photometer measurements. If you see cirrus clouds in the hours before or after a measurement, be sure to include that in your sky description.

11. What are aerosols?

Aerosols are liquid or solid particles suspended in air. They range in size from a fraction of a micrometer to a few hundred micrometers. They include smoke, bacteria, salt, pollen, dust, various pollutants, ice, and tiny droplets of water. These particles interact with and scatter sunlight. The degree to which they affect sunlight depends on the wavelength of the light and the size of the aerosols. This kind of particle-light interaction is called Mie scattering, named after the German physicist Gustav Mie, who published the first detailed mathematical description of this phenomenon in the early part of the twentieth century.

12. What is optical thickness?

Optical thickness (or optical depth) describes how much light passes through a material. The amount of light transmitted can be quite small (less than a fraction of 1%) or very large (nearly 100%). The greater the optical thickness, the less light passes through the material. As applied to the atmosphere, aerosol optical thickness (AOT) describes the extent to which aerosols impede the direct transmission of sunlight of a certain wavelength through the atmosphere. In a very clear sky, AOT can have values of 0.05 (about 95% transmission) or less. Very hazy or smoky skies can have AOT values in excess of 1.0 (about 39% transmission).

Percent transmission through the atmosphere is an alternate way to describe the same phenomenon. There is a simple relationship between AOT and transmission expressed as a percentage:

$$\text{transmission (\%)} = 100 \times e^{(-AOT)}$$

Refer to Table AT-AH-1 to see the percent transmission for several values of AOT. Any scientific calculator should have an e^x function key. Try to reproduce one or more of the examples in this table to check if you understand how to use a calculator to convert AOT to percent transmission.

13. What is Beer's Law?

August Beer was a nineteenth-century German physicist who worked in the field of optics. He developed the principle known as Beer's

Law, which explains how the intensity of a beam of light is reduced as it passes through different media. Other nineteenth-century physicists also examined this law and applied it to the transmission of sunlight through the atmosphere. Hence, the equation used to describe how sun photometers work is usually referred to as the Beer/Lambert/Bouguer law. As applied to a sun photometer, Beer's Law is

$$V_o = V(r/r_o)^2 \exp\{-m[AOT + Rayleigh(p/p_o)]\}$$

Where r/r_o is Earth-sun distance in astronomical units, m is the relative air mass, AOT is the aerosol optical thickness, Rayleigh is the optical thickness due to Rayleigh scattering, and p/p_o is the ratio of current atmospheric pressure to standard atmospheric pressure (1013.25 mbar). You need to be comfortable with exponential and logarithmic functions before you use this formula to make your own calculations of aerosol optical thickness. Also, you need to know your sun photometer's calibration constants – one value of V_o for each of the two channels – and the Rayleigh coefficients corresponding to each wavelength. If you would like to do this calculation on your own, you will need to obtain the calibration constants and Rayleigh coefficients from GLOBE.

14. What is relative air mass (m)?
Relative air mass (m) is a measure of the amount of atmosphere through which a beam of sunlight travels. At any location or elevation, the relative air mass is 1 when the Sun is directly overhead at solar noon. (**Note:** At any latitude greater than about 23.5 degrees, north or south, the sun is never directly overhead, so the sun can never be observed through a relative air mass of 1.

A simplified formula for relative air mass is

$$m = \frac{1}{\sin(\text{elevation})}$$

where "elevation" is the angle of the sun above the horizon. This calculation is sufficiently accurate for relative air masses up to about 2. Larger values require a more complicated formula that corrects for the curvature of Earth's surface.

15. What is Rayleigh scattering?
Molecules of air scatter sunlight. Air molecules scatter ultraviolet and blue wavelengths much more efficiently than red and infrared wavelengths. (This is why the sky is blue.) This process was first described in the nineteenth century by the Nobel-prize-winning British physicist John William Strutt, the third Baron Rayleigh.

16. How accurate are aerosol measurements made with the GLOBE sun photometer?
The accuracy of sun photometer measurements has been studied for decades by atmospheric scientists, and it remains a topic of some debate. There are some inherent limitations to measuring atmospheric aerosols from Earth's surface, and there are also some limitations imposed by the design of the GLOBE sun photometer.

Measurements made carefully according to the protocols should be accurate to within less than about 0.02 AOT units. For very clear skies, with AOT values of perhaps less than 0.05, this is a significant percentage error. However, even operational "professional" sun photometers claim accuracies of no better than 0.01 AOT units. Thus, the accuracy of measurements made carefully with a GLOBE sun photometer are comparable to measurements made with other sun photometers.

Unlike some other GLOBE measurements, there is no easily accessible standard against which to check the accuracy of AOT calculations. GLOBE aerosol measurements will be subjected to scrutiny by the GLOBE Science Team and others for the foreseeable future. Nevertheless, it is fair to say that GLOBE aerosol measurements can achieve a level of accuracy that can be extremely useful to the atmospheric science community.

17. Will scientists really be interested in my aerosol measurements?
The answer to this question is an only slightly qualified "Yes." Comparatively few sun photometers are in use around the world. Since recent studies have shown that aerosols can block considerable sunlight, thus causing a cooling effect on Earth's climate, there is renewed interest in sun photometer measurements.

Upcoming Earth-monitoring satellite missions will focus on global characteristics of the atmosphere and its constituents. It is essential that reliable ground- based data measurements be available to calibrate satellite instruments and validate their measurements.

GLOBE schools provide the potential to establish a global aerosol monitoring network that is otherwise unattainable. On a regional scale, there is essentially no comprehensive monitoring of aerosols produced naturally by water vapor, naturally occurring forest and brush fires, dust, pollen, gases emitted by plants and trees, sea salt, and volcanic eruptions. The same is true for monitoring aerosols produced by automobile emissions, coal-burning power plants, intentional burning of forests and rangelands, certain industrial and mining operations, and dust from unpaved roads and agricultural fields. Again, GLOBE schools provide the potential for addressing these topics.

Here's the qualification to the "Yes." In most situations, aerosol measurements must be taken in the same place for many months, and even for years, in order to have lasting scientific interest. It is sometimes difficult to keep in mind the long-term value of taking the same measurements day after day. (This is not just a problem for aerosol measurements, of course.) In the case of aerosols, persistence is especially important due to the long time scales required to observe and analyze significant changes in the atmosphere.

What about ground validation measurements for space-based measurements? In this case, even a few accurate ground-based measurements can be valuable. However, it is still important to establish as long a data collection record as possible. This will give scientists confidence in your work, and will establish an aerosol "baseline" for your observing site, against which to evaluate unusual conditions when they occur.

So, the conclusion is: If you follow the protocols and provide careful measurements (especially during the summer), then there is no doubt that scientists will value your contribution now and in the future.

Aerosols Protocol – Looking At the Data

Are the data reasonable?

Perhaps your first thought about determining whether your data are reasonable would be to consider the voltages measured using your sun photometer. This is not as easy as it might seem! A sun photometer converts light from the sun to a voltage; this is what you measure and report to GLOBE. The relationship between the intensity of the light and the voltage produced is determined by the sensitivity of the detectors in your sun photometer (a green or red light emitting diode) and the gain provided by your sun photometer's battery-powered amplifier. This relationship is different for every GLOBE sun photometer, so each instrument has its own calibration constants (one for each of the two channels) that allow aerosol optical thickness to be calculated from the voltages you report.

The GLOBE sun photometer produces a small output voltage even when the sun is not shining on the detector. This "dark voltage," should be small, but how small? GLOBE performs some range checks on both the sunlight and dark voltages. However, reasonable voltages fall within a wide range of values. In some cases, your sun photometer's dark voltage may be only a few tenths of a millivolt. If so, it may display as 0 when you are using a 2 V (or 2000 mV) range setting on your digital voltmeter.

So, it is not easy to predict what "reasonable" voltages are for your sun photometer. However, after you have done the Aerosol Protocol a few times, you will get a good sense of what dark voltages your instrument produces and what sunlight voltages to expect under certain sky conditions. Remember that, generally, these ranges will be different for the green and red channels because of the differences in the detector responses and electronics.

It is much easier to determine whether the aerosol optical thicknesses calculated from your measurements at green and red wavelengths are reasonable. Table AT-AE-2 gives some typical ranges for aerosol optical thickness (AOT).

Table AT-AE-2

Sky condition	Green channel	Red channel
Extremely clear	0.03-0.05	0.02-0.03
Clear	0.05-0.10	0.03-0.07
Somewhat hazy	0.10-0.25	0.07-0.20
Hazy	0.25-0.5	0.02-0.40
Extremely hazy	>0.5	>0.4

The relationship between these numerical values and the sky clarity description (required as part of your data reporting) are only approximate, and may vary depending on local conditions.

Note that red AOT values are typically less than green AOT values. This is due to the fact that typical aerosols scatter green light more efficiently than red light. (The larger the AOT, the more light is being scattered away from the direct beam of sunlight that reaches your sun photometer's detector.) If the red AOT is larger than the green, it is not necessarily wrong, but it is an unusual enough occurrence that it should trigger a closer examination of the conditions under which the measurements were taken.

What do scientists look for in these data?

As noted above, green AOT values are usually higher than red AOT values. When the Science Team looks at your data, they will check that the relationship between the two channels appears reasonable.

The *Aerosols Protocol* requires that you report at least three sets of sun photometer measurements taken within the span of a few minutes. Assuming that you are pointing your sun photometer carefully and consistently toward the sun, differences among the three voltages for each channel are a measure only of the variations in the atmosphere at the time you are taking your measurements. If the differences are large, it may mean that clouds are drifting across the sun while you are taking measurements.

Scientists will also look carefully at cloud cover and type reports and will compare the AOT values calculated from the voltage measurements with reports of sky color and clarity. Cirrus clouds are of particular concern, as they can greatly reduce the transmission of sunlight even when they are almost invisible.

AOT tends to vary seasonally. Warm and humid days in temperate and equatorial climates can produce photochemical smog, especially in urban areas. Consequently, AOT tends to be higher in the summer than in the winter. This seasonal cycle can be difficult to find in GLOBE data, as many GLOBE schools do not report data during summer vacations. Figure AT-AE-1 shows some aerosol data from East Lincoln High School, Denver, NC, USA. Students made some measurements through the spring of 2000 and another class restarted the measurement program in the fall of 2000. Some of the values (especially the very low values) appear to be in error. Although it appears to be the case that warm weather produces higher AOT values, the lack of summertime measurements means that this conclusion cannot really be supported by these limited data.

Note also in Figure AT-AE-1 that there are some very high AOT values recorded in 1999. There are several possible explanations for these values. One possibility is, of course, that these data represent actual very hazy conditions. Another possibility is that students were initially unfamiliar with the sun photometer and recorded sunlight voltages that were too low (which will lead to AOT values that are too high). A third possibility is that there were some clouds between the observer and the sun. The AOT values themselves do not help us choose among these possibilities. The additional information scientists need to make decisions about the quality of sun photometer measurements can be obtained only by looking at all the measurements and their accompanying metadata.

One of the most exciting opportunities for students working with the *Aerosols Protocol* is to compare their measurements with other ground- and satellite-based measurements. Such comparisons can serve both as a check on GLOBE measurements and on the performance of other sun photometers. One source of aerosol data is the Aerosol Robotic Network (AERONET), managed by NASA's Goddard Space Flight Center. This ground-based network has about 100 sun photometers in operation at various locations around the world. The AERONET sun photometers are automated, solar-powered instruments. Their advantage is that they can operate unattended even in remote locations, broadcasting the results of their pre-programmed measurements to satellites, which then beam data to a central ground station for processing. The primary disadvantage of these automated devices is that there is no human observer to make decisions about whether a sun photometer measurement should be made at a particular time. Algorithms are applied to "screen" the measurements for cloud contamination. However, these algorithms are not perfect. They may, for example, suffer from the same lack of ability to distinguish thin cirrus clouds as ground-based observers. Thus, comparisons of automated and manual measurements provide a fascinating and extremely important check on the performance of both systems.

Figure AT-AE-2 shows a comparison of GLOBE sun photometer data with data from AERONET sun photometers. (AERONET data are publicly available online.) AERONET makes measurements every few minutes throughout the day. The GLOBE data sometimes fall near the lower range of AERONET values within a day. A more detailed examination of these data with an expanded time scale (to look at individual days) would clarify the relationship between these two datasets; this would make an excellent student project.

Figure AT-AE-3 shows comparisons between AOT values derived from the MODIS satellite and measurements made by students at East Lincoln High School, Denver, North Carolina, USA. (The MODIS data points are connected with solid lines, but this is only to make the data easier to follow; there is no reason to expect that missing MODIS data would fall along the lines.) Note that the GLOBE data again tend to cluster near the lower MODIS AOT values.

Some of the MODIS values in Figure AT-AE-3 seem very high. Figure AT-AE-4 offers some insight

Figure AT-AE-1: Sun Photometer Data (minimum AOT from a set of three) from East Lincoln High School, Denver, NC,

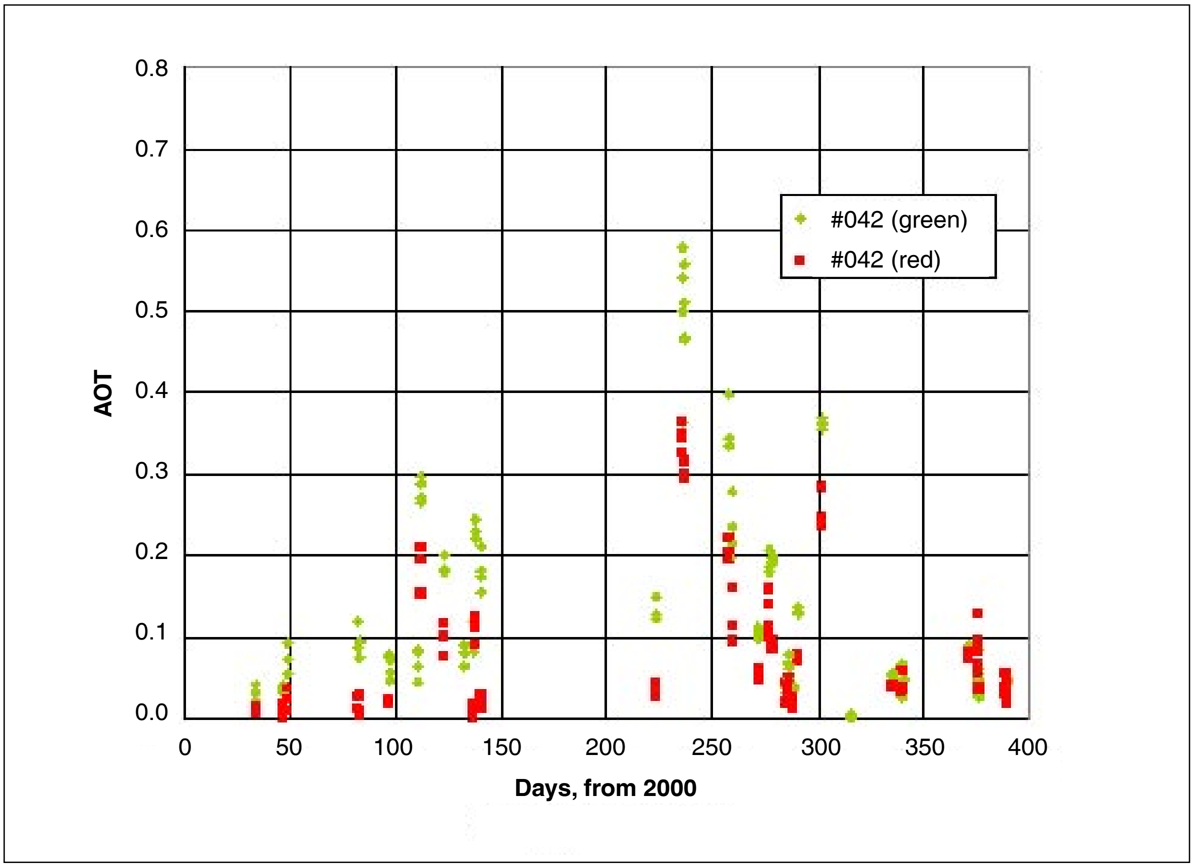


Figure AT-AE-2: Comparison of GLOBE Sun Photometer Measurements Made at Drexel University, Philadelphia, Pennsylvania, USA, with a Nearby AERONET Sun Photometer

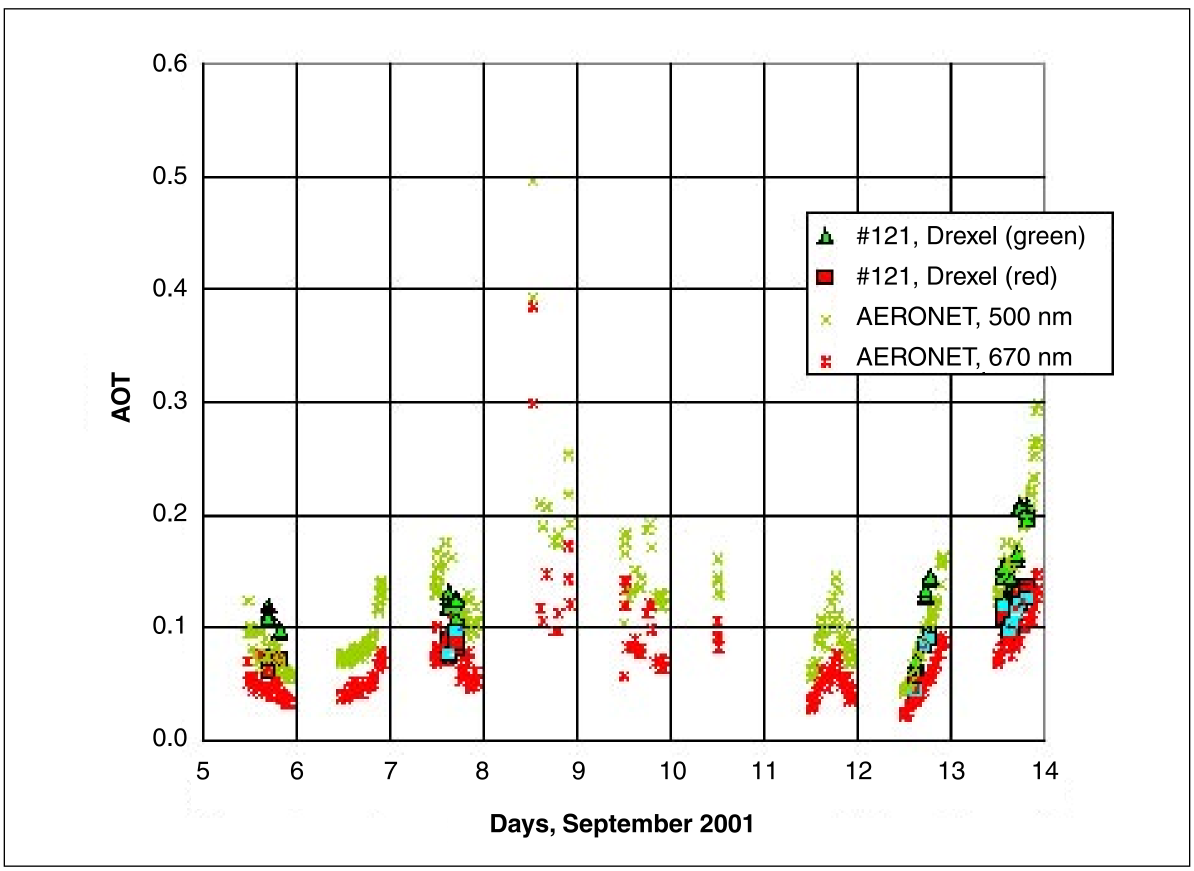


Figure AT-AE-3: Comparison of MODIS Data and GLOBE Sun Photometer Measurements Made at East Lincoln High School, Denver, NC, USA.

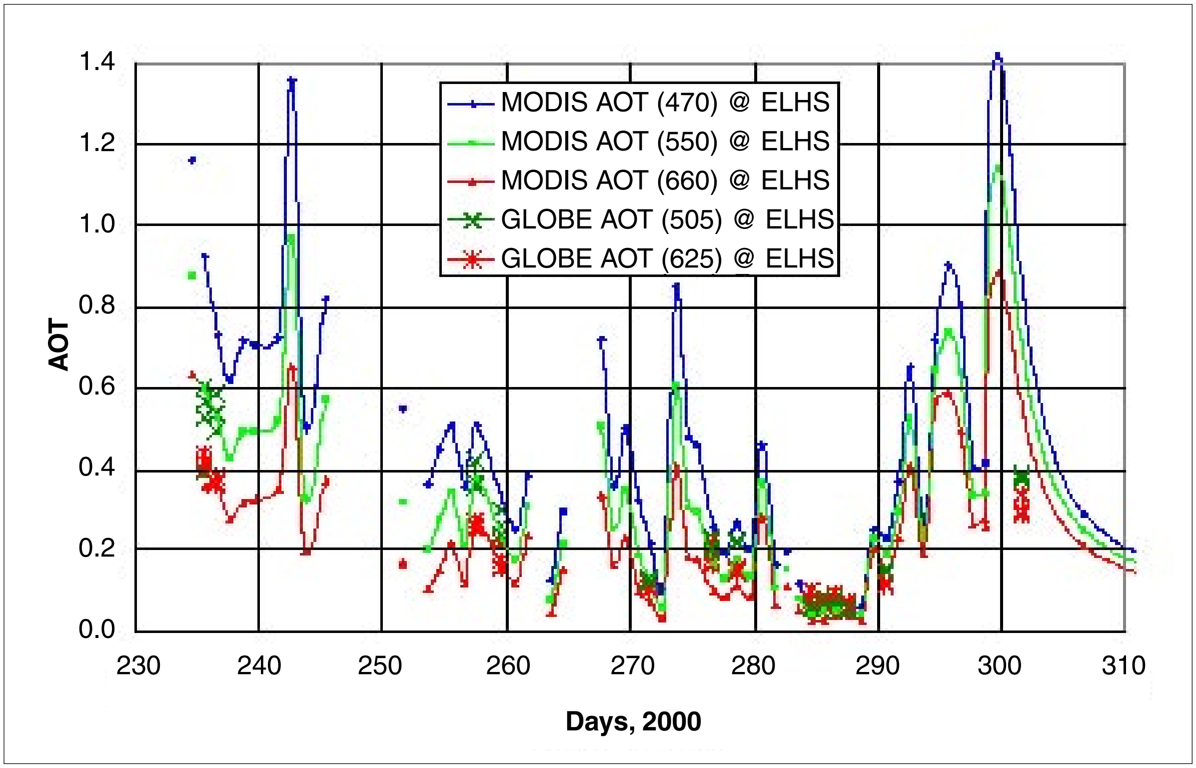
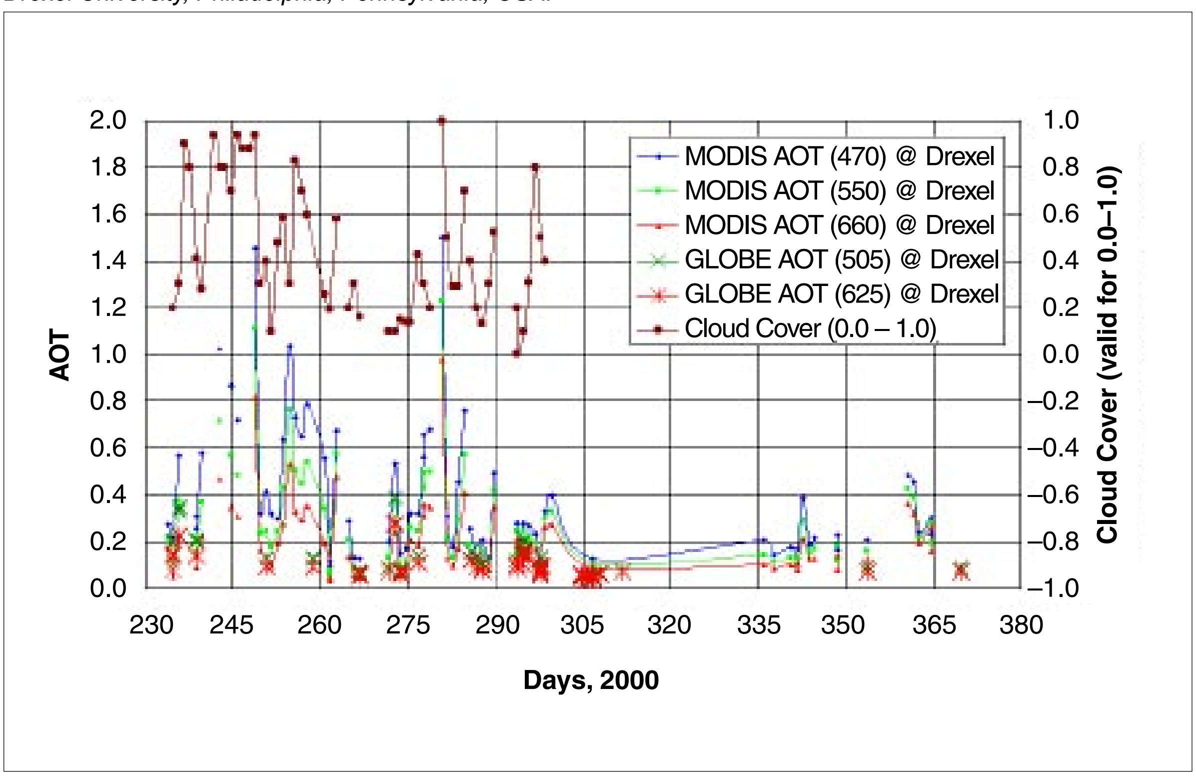


Figure AT-AE-4: Comparison of MODIS Data, GLOBE Sun Photometer Measurements, and Cloud Cover at Drexel University, Philadelphia, Pennsylvania, USA.



into why this might be so. These measurements from Drexel University include the percentage of daytime cloud cover. Clearly, some of the very high MODIS AOT values are associated with cloudy days. Drexel University is located in an urban area with a mixture of water (two rivers flow through Philadelphia), residential and commercial urban development, and green space (a large park). This kind of complicated surface is the most difficult for data reduction algorithms to analyze and the results shown in Figure AT-AE-4 may indicate problems with cloud discrimination over complicated surfaces. Whatever the explanation, Figures AT-AE-3 and AT-AE-4 show clearly the importance of carefully reporting metadata that define the conditions under which sun photometer measurements are taken.

When GLOBE student sun photometer measurements are taken carefully, data such as shown in Figures AT-AE-2, AT-AE-3 and AT-AE-4 can provide valuable information for scientists who are involved in understanding the global distribution of aerosols. The ability of human observers to characterize the circumstances and quality of their measurements provides an opportunity that unattended and satellite-based instruments can never match.

Locally, aerosol optical thickness can be influenced by air quality, season, relative humidity, natural and human-caused events such as volcanoes, forest fires and biomass burning, agricultural activity, windblown dust, and sea spray. All these connections provide many possible sources for student research projects.

Calculating Aerosol Optical Thickness (Advanced Students Only)

When you report voltage measurements from your sun photometer to GLOBE, the aerosol optical thickness (AOT) is calculated and reported. This calculation is too complicated for most GLOBE students to do on their own. However, if you are familiar with logarithmic and exponential equations, you can calculate AOT yourself using the following formula:

$$AOT = \frac{[\ln(V_o/R^2) - \ln(V - V_{dark}) - a_R(p/p_o)m]}{m}$$

Where:

ln is the natural (base *e*) logarithm

V_o is the calibration constant for your sun photometer. Each channel (red and green) has its own constant, which you can obtain from the GLOBE Web site.

R is the Earth-sun distance expressed in astronomical units (AU). The average Earth-sun distance is 1 AU. This value varies over the course of a year because the Earth's orbit around the sun is not circular. An approximate formula for R is:

$$R = \frac{(1 - \varepsilon^2)}{[1 + \varepsilon \cos(360^\circ \cdot d/365)]}$$

Where ε is the eccentricity of the Earth's orbit, approximately equal to 0.0167, and d is the day of the year. (Eccentricity is a measure of the amount by which the Earth's orbit differs from a circle.) Note that this equation predicts that the minimum value for R occurs at the beginning of the year. The actual minimum Earth-sun distance occurs, in fact, in early January but not on January 1.

V and V_{dark} are the sunlight and dark voltage from your sun photometer.

a_R is the contribution to optical thickness of molecular (Rayleigh) scattering of light in the atmosphere. For the red channel a_R is about 0.05793 and for the green channel it is about 0.13813.

p is the station pressure (the actual barometric pressure) at the time of the measurement.

p_o is standard sea level atmospheric pressure (1013.25 millibars).

m is the relative air mass. Its approximate value is:

m= 1/sin(solar elevation angle)

where solar elevation angle can be obtained from the *Making a Sundial Learning Activity* or by using a clinometer.

When GLOBE calculates AOT, it uses a series of equations to more accurately calculate the Earth-sun distance. For relative air mass, it uses those same astronomical equations to calculate solar position from your longitude and latitude and the time at which you took your measurement. Then it uses the calculated solar elevation angle to calculate relative air mass, using an equation that takes into account the curvature of Earth's atmosphere and the refraction (bending) of light rays as they pass through the atmosphere.

As a consequence of using these more complicated equations, GLOBE's AOT values will not agree exactly with the calculation described here. The smaller the AOT, the greater the difference is likely to be. Consider this example:

Date: July 7, 1999

Sun photometer calibration constant (V_o): 2.073 V

Solar elevation angle: 41°

Station pressure: 1016.0 millibars

Dark voltage: 0.003 V

Sunlight voltage: 1.389 V

Sun photometer channel: green

July 7, 2001, is the 188 th day of the year, so:

$R = (1 – 0.0167^2)/[1 + 0.0167 \bullet \cos(360^o \bullet 188/365)] = 1.0166$

The relative air mass is:

$m=1/\sin(41^o) = 1.5243$

Then, aerosol optical thickness is:

$AOT = [\ln(V_o/R^2) - \ln(V - V_{dark}) - a_R(p/p_o)m]/m$

$\ln(V_o) = \ln (2.073/1.01662^2) = \ln(2.00585) = 0.6960$

$\ln(1.389-0.003) = \ln(1.386) = 0.3264$

$a_R(p/p_o)m = (0.1381)(1016/1013.25)(1.5243) = 0.2111$

$AOT = (0.6960 - 0.3264 - 0.2111)/1.5243 = 0.1040$

GLOBE's calculated AOT value for these data is 0.1039, a difference small enough to ignore for these measurements.

In some situations, your AOT value may not agree this well with GLOBE's value. For example, if the solar elevation angle you observe with your solar gnomon is different from the value calculated by GLOBE – then the relative air mass calculated from your observed solar elevation angle will not be accurate. This will cause the AOT calculation to be in error.

AOT can be expressed as the percent of sunlight at a particular wavelength that reaches the Earth's surface after passing through a relative air mass of 1. For this example with the green channel,

% transmission = $100 \bullet e^{-AOT} = 100 \bullet e^{-0.1040} = 90.1\%$

Water Vapor Protocol

Purpose

To measure the total precipitable water vapor (column water vapor) in the atmosphere above an observer's site

Overview

Students point a GLOBE/GIFTS water vapor instrument at the sun and record the voltage readings from a digital voltmeter. Students observe sky conditions near the Sun and perform the *Cloud Protocols.*

Student Outcomes

Students understand the concept that the atmosphere prevents some of the sun's light from reaching Earth's surface, how water vapor measurements relate to the hydrologic cycle, and how greenhouse gases, such as water vapor, play an important role in weather and climate.

Science Concepts

Earth and Space Sciences

- Weather can be described by measurable quantities.
- Weather changes from day to day.
- Weather changes over the seasons.
- The atmosphere changes over time.
- Clouds formed by the condensation of water vapor affect weather and climate.
- Water circulates through the biosphere, lithosphere, atmosphere and hydrosphere (water cycle).
- Global patterns of atmospheric circulation influence local weather.
- Oceans have major effects on global climate.
- Solar insolation drives atmospheric and ocean circulation.

Physical Sciences

- Light/radiation interacts with matter.
- The Sun is a major source of energy for changes on the Earth's surface.

Geography

- The concentration of water vapor varies significantly from place to place, and depends on latitude, climate, and elevation.

Scientific Inquiry Abilities

Use an instrument to measure atmospheric water vapor content.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Time

15-30 minutes to collect data

Level

Middle and Secondary

Frequency

Every day, weather permitting

Materials and Tools

- Calibrated GLOBE/GIFTS water vapor instrument
- Watch, preferably digital (or GPS receiver)
- GLOBE Cloud Chart
- Thermometer
- Digital hygrometer or sling psychrometer (optional)
- Barometer (optional)
- *Water Vapor Data Sheet*

Preparation

Determine online source for barometric pressure values (if not using GLOBE protocols).

Prerequisites

Cloud, Optional Barometric Pressure (optional), and *Relative Humidity Protocols*

Ability to measure current air temperature

Haziness and sky color observations as described in the *Aerosols Protocol*

Water Vapor Protocol – Introduction

Background

Water vapor in the atmosphere varies considerably in time and from place to place. These variations are related to both weather and climate. Clouds are formed from water vapor. Water vapor is the primary greenhouse gas that helps control temperatures in the lower atmosphere. The interactions of water vapor with other constituents of the atmosphere are complex and global in scope.

Using the *Relative Humidity Protocol*, you measure the amount of water vapor near Earth's surface, but how much water vapor is in the whole column of air above you? Using this protocol enables you to answer this question. It also will help scientists answer these questions:

How is water vapor distributed around the world?

How does it vary over time?

Are the total amount of water vapor in the atmosphere and its distribution changing?

Changes in water vapor amount and distribution would affect cloud formation, weather, and climate.

Despite its importance, the global distribution and temporal variability of water vapor is not well known. As with other global measurements, scientists use satellite-based observing systems to study atmospheric water vapor. A primary motivation for conducting this protocol is to provide measurements to help support the GIFTS (Geosynchronous Imaging Fourier Transform Spectrometer) instrument, part of NASA' s New Millennium Program IOMI (Indian Ocean METOC Imager) spacecraft. GIFTS will observe weather patterns, atmospheric temperature, water vapor content and distribution, and the concentration of certain other atmospheric gases. From its geostationary orbit high above Earth, GIFTS will provide unprecedented detail about the spatial and temporal variability of these quantities.

As helpful as satellite-based measurements are to an improved understanding of the global distribution of water vapor, ground-based measurements are still needed. For example, when GIFTS views the Earth/atmosphere system from space, its spatial resolution (one pixel) is about 4 km x 4 km. At this level of resolution scientists can track storm systems, since large systems have dimensions on the order of hundreds or thousands of kilometers. However, smaller scale phenomena, such as individual cumulus clouds, cannot be resolved. Ground-based measurements provide a way to study such small scale phenomena, complementing the satellite observations. Ground-based observations also help scientists by making possible comparisons of atmospheric properties calculated independently from satellite and ground-based data.

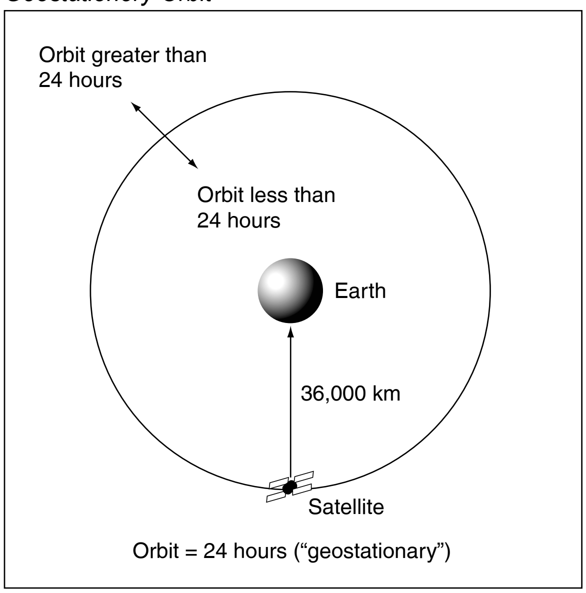
Investigating Water Vapor

By reporting water vapor measurements regularly, you provide scientists with some of the data they need to better understand the global distribution of water vapor, and you learn about the atmospheric water vapor that is over your own observing site. While all water vapor data are beneficial, data that can be compared directly with satellite-based measurements are especially valuable. In some cases, ground-based measurements should be timed to coincide with the passage of Earth-observing satellites over your site. This is true for spacecraft in NASA' s Earth Observing System (EOS) program, for example, as they are in near-polar sunsynchronous orbits and pass over or near virtually all sites on Earth's surface every day at specific and predictable times.

Instruments such as GIFTS are in geostationary orbits around the equator. The altitude of these circular orbits (nearly 36,000 km above Earth's surface) is chosen so that their orbital periods are equal to one day. If a satellite orbits in the equatorial plane, it maintains a fixed position over the same place on Earth's equator (hence the "geostationary" designation). Figure AT-WV-1 shows a geostationary orbit. The diameter of the orbit is roughly to scale with the diameter of Earth.

A vantage point above Earth's equator allows spacecraft instruments to take virtually continuous measurements of a specific portion of Earth's surface and atmosphere. Some measurements require the observed region to be in sunlight, but other measurements can be made at any time. If there is a geostationary satellite observing your region, it will almost always be useful to take ground-based measurements at any time during the day. Because of the seasonal variability of water vapor, it is important to build a water vapor data record that extends across several seasons. Long-term records are more valuable for scientists, and they will give you a better understanding of your own local environment.

Figure AT-WV-1: Satellite Orbiting Earth in Geostationery Orbit



Teacher Support

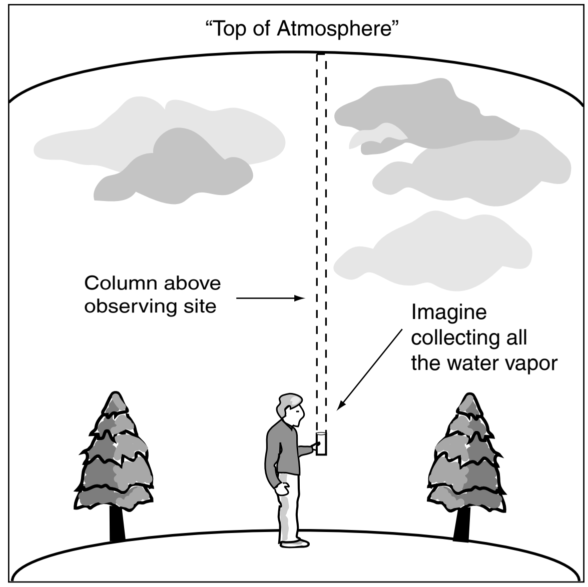
Understanding Measurements of Water Vapor

Imagine a column of atmosphere above an observing site (see Figure AT-WV-2). This column will contain all the atmospheric constituents, including water vapor. Now imagine collecting all the water vapor in the column, transforming it into liquid form, and bringing it down to the ground. The thickness of the layer of water is typically a few centimeters and is known as precipitable water (PW). The unit for expressing PW is cm (of water).

One way of measuring water vapor is to examine how it affects the transmission of sunlight through the atmosphere. Water vapor (molecules of H_2O in their gas phase) absorbs sunlight in specific wavelength bands, including two bands in the near-infrared part of the solar spectrum. This absorption reduces the amount of sunlight reaching Earth's surface at those wavelengths.

Figure AT-WV-3 shows three sets of data. One is the distribution of solar energy as a function of wavelength just outside Earth's atmosphere.

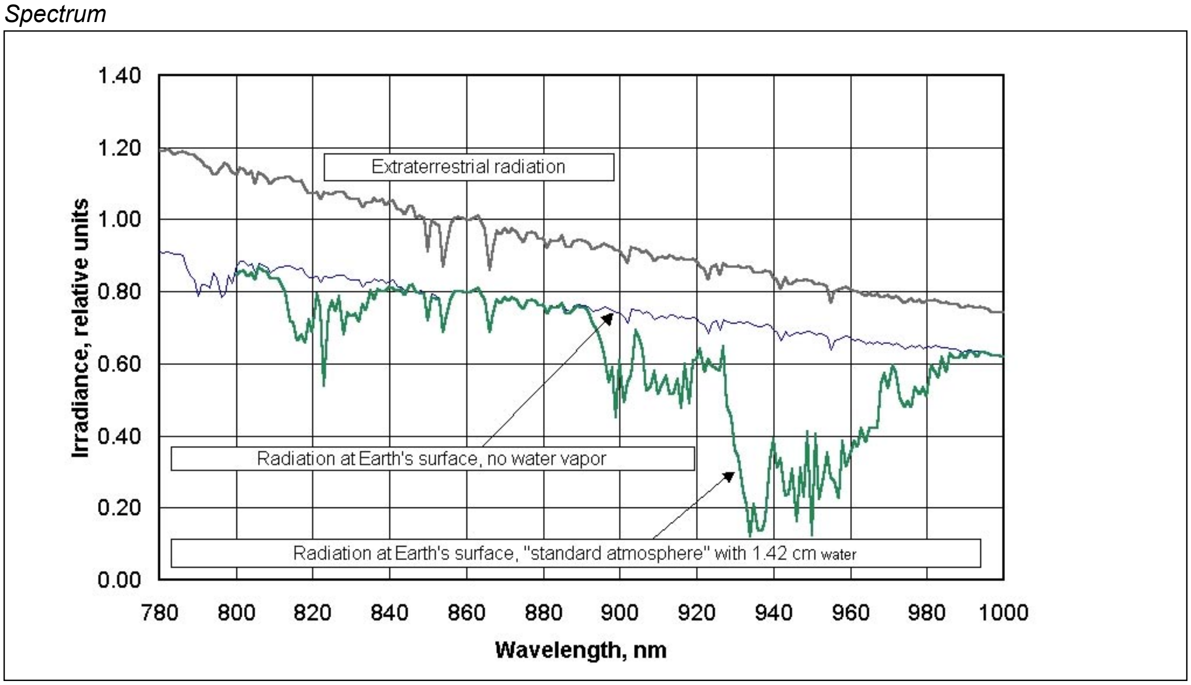
Figure AT-WV-2: Column Above Observer's Head



The second is the distribution of solar energy on Earth's surface assuming an atmosphere with no water vapor. The third is the distribution of solar energy with a "standard atmosphere" containing an average amount of PW. As the amount of PW increases, the amount of solar energy reaching Earth's surface at these wavelengths decreases.

Now suppose that two detectors respond to sunlight at different wavelengths – one at a

Figure AT-WV-3: Radiation at the Top of the Atmosphere and at Earth's Surface, in the Near-IR part of the Solar Spectrum



wavelength within a water vapor absorption band (at about 940 nm) and one just outside this band (at about 870 nm). Assuming the position of the sun relative to the observer doesn't change, the amount of light seen by the detector for the wavelength outside the band will not change if the amount of atmospheric water vapor changes. However, the detector for the wavelength inside the band will respond to changes in the amount of water vapor. Hence, the ratio of the response of two such detectors will change with the amount of water vapor, and can be used as a measure of the water vapor amount.

PW is related to other properties of the atmosphere, including those described in other GLOBE *Atmosphere Protocols*. It varies hourly, daily, seasonally, and geographically. Hence, it is helpful to consider water vapor as part of a broader discussion of the atmosphere and its properties. Ideally, water vapor measurements should be taken over an extended period of time to observe seasonal effects. The measurements will make more sense if they are combined with other GLOBE atmosphere observations, including the basic meteorological protocols and aerosols. In fact, some of these other protocols can be used to provide the metadata that must be reported along with the water vapor instrument data.

The GLOBE/GIFTS Water Vapor Instrument

The GLOBE/GIFTS water vapor instrument is based on the same principle as the GLOBE sun photometer for monitoring aerosols. They both use light emitting diodes (LEDs) to measure the strength of sunlight in select wavelengths. While the GLOBE sun photometer detects visible light in the green and red part of the spectrum, the water vapor instrument detects infrared rather than visible light. This instrument concept was first developed and described in the scientific literature by a member of the *Water Vapor Protocol* Science Team [Mims, Forrest M. III, Sun photometer with light-emitting diodes as spectrally selective detectors, *Applied Optics*, 31, 6965-6967, 1992]. Since that time, Mims has regularly collected water vapor data at Geronimo Creek Observatory in Seguin, Texas, USA [Mims, Forrest M. III, An inexpensive and stable LED sun photometer for measuring the water vapor column over South Texas from 1990 to 2001, *Geophys, Research Letter,* **29**, 13 pp, 20-1–20-4, 2002].

Figure AT-WV-4: The GLOBE/GIFTS Water Vapor Instrument

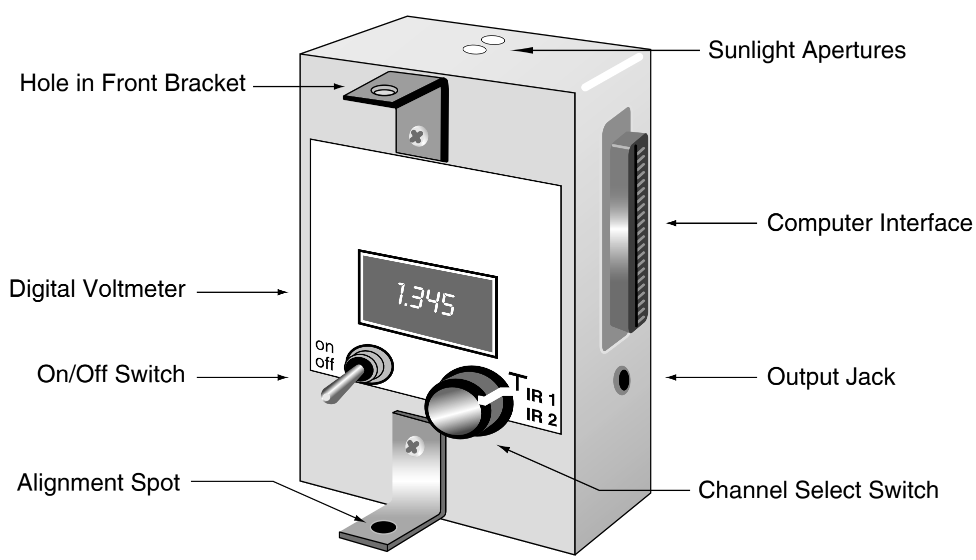
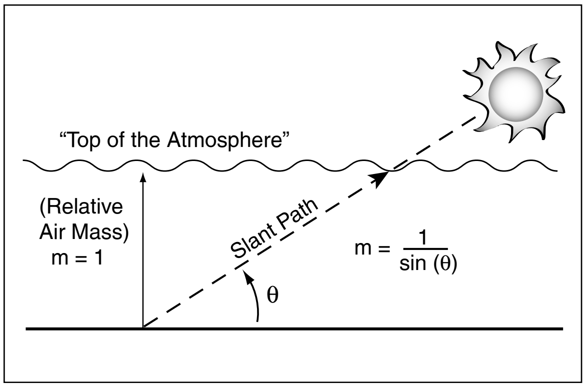


Figure AT-WV-5: Viewing the Sun Through the Atmosphere



Measurements taken with the GLOBE/GIFTS water vapor instrument are in units of volts. These values must be converted into PW using calibration data that have been determined for each instrument. The calibrations require access to specialized equipment and data that cannot be duplicated by students in the lab or in the field. The PW calculations are done by the GLOBE Data Server when data are reported and the calculated values are returned for students to use.

The standard unit for measuring water vapor is cm of water in a vertical column of atmosphere directly above the observer. However, in all areas outside the tropics, the sun is never directly overhead. So, in general, your instrument will view the sun through a slanted path, known as the slant path, as illustrated in Figure AT-WV-5. The ratio between the slant path and the shortest distance between you and the "top" of the atmosphere (directly overhead) is called the relative air mass (m). The smaller the solar elevation angle, θ, the longer the slant path and the larger the relative air mass. An approximate relationship between the solar elevation angle and relative air mass, that is valid when the sun is not near the horizon, is

$$m = \frac{1}{\sin(\theta)}$$

To compensate for the fact that your instrument is measuring the water vapor through a longer portion of the atmosphere along the slant path, the water vapor detected by your instrument (the slant path water vapor) is divided by the relative air mass to estimate the amount of water vapor in the vertical column of atmosphere directly over your head, PW, according to the formula:

$$PW = \frac{\text{(slant path PW)}}{m}$$

This process assumes that the distribution of water vapor with height along the slant path is the same as that in the column directly over your head.

Where and When to Take Water Vapor Measurements

The logical place to take water vapor measurements is in the same place where you do the *Cloud Protocols* (and, hopefully, the *Aerosols Protocol,* too). If you take measurements at some other site, you need to define it as an additional Atmosphere Study Site.

The basic meteorological conditions for using the GLOBE/GIFTS water vapor instrument are the same as for the GLOBE sun photometer: You must have an unobstructed view of the sun that is not blocked by clouds. Also, you should have an overall view of the sky that allows you to take reasonable cloud type and cover, sky color, and haziness observations. If your view of the sky is severely restricted (as it might be at urban sites, for example), you will need to note the restrictions in your study site definition.

The decision about when you should take water vapor measurements depends on whether you wish to associate your measurements with a particular satellite instrument and, if so, the kind of orbit of that satellite. For most orbits, including the near-polar sunsynchronous orbits of many Earth-observing satellites, measurements need to be timed to coincide with overflights of your site. NASA's current major Earth-observing sun-synchronous satellites fly over in mid morning or early afternoon. The precise times at which they fly over your observing site are readily available online. For instruments in geostationary orbits (such as GIFTS), or if you are not associating your measurements with specific satellite measurements, you can take measurements any time during the day. For developing a long-term record of water vapor over your observing site, it is helpful to take measurements at about the same time every day.

Instrument Care and Maintenance

Your GLOBE/GIFTS water vapor instrument is simple and rugged, with no easily breakable parts. However, you must take care of it in order to take accurate measurements. Here are some things you should do and not do to ensure your water vapor instrument performs reliably over long periods of time.

1. Do not drop your instrument.
2. Protect your instrument from dirt and dust by storing it in a sealed plastic bag when you are not using it.
3. Do not expose your instrument to extremely hot or cold temperatures - for example, by leaving it in the sun or on a radiator, or by leaving it outside.
4. Keep your instrument turned off when not in use.
5. Check the battery voltage every few months. See *Checking and Changing Your GLOBE/GIFTS Water Vapor Instrument's Battery*. This instrument uses very little power, so the battery should last for many months of normal use. If you accidentally leave your instrument turned on for hours or days when you are not using it, check the battery before taking additional measurements and replace it if necessary.
6. Do not modify the electronics inside your water vapor instrument in any way. The calibration of your instrument depends critically on retaining the original components on the circuit board.
7. Do not enlarge the holes in the case through which sunlight enters your water vapor instrument. The calibration of your instrument and the interpretation of its measurements are based on the size of these holes. If you change them, your instrument will no longer be calibrated and even if a new calibration is obtained, your instrument may be useless.

   With a little care, this instrument will work reliably for many years. If it appears not to be working correctly, consult with GLOBE before doing anything else.

Checking and Changing Your GLOBE/GIFTS Water Vapor Instrument's Battery

Every three months or so, or right away if you accidentally leave your instrument turned on for an extended period of time, check the charge on the battery and replace it if necessary. See the *Checking and Changing Your GLOBE Sun Photometer Battery Lab Guide* (in the *Aerosols Protocol*) for instructions. Replacing the battery will not change the calibration of your instrument and measurements made with the old battery will be OK as long as you replace it before its voltage falls below 7.5 V.

Suggestions for Student and Classroom Preparation

Science Background

This measurement should be useful as a hands-on activity for any course that addresses the atmosphere, weather and climate, the hydrologic cycle, or Earth as a system. Prior to implementing this protocol, it will be helpful to provide an introduction to electromagnetic radiation and the solar spectrum, including ultraviolet, visible, and infrared energy from the sun (material in the GLOBE Remote Sensing Video may prove helpful). It is important for students to understand that the light visible to the human eye spans only a very small portion of the solar spectrum and that light at other wavelengths has significant effects on humans and the environment.

If you have access in the classroom to an electronic device that is controlled by a remote IR controller, it may be helpful to experiment with this device. How do we know IR light (radiation) is really there? Does it appear to behave like "light" even though we can't see it? What will block the IR signal from the controller? What will allow its passage?

You should spend some time in your classroom familiarizing your students with the water vapor instrument, including reading the digital voltmeter on the top of the case. In the classroom, the voltages displayed on the voltmeter will be small, only a few millivolts. If you can point the instrument at the sun, even through a closed window, you will get much higher values.

Metadata and Other Auxiliary Data

The auxiliary data and metadata for the *Water Vapor Protocol* include those required for the GLOBE *Aerosols Protocol* along with relative humidity. Some of these are based on qualitative observations:

- Cloud cover and type, including contrails
- Sky color and clarity

Others are quantitative values:

- Current air temperature
- Barometric pressure
- Relative humidity

Depending on which GLOBE protocols you are already doing, you will need to organize sources for some or all of these observations and measurements. The requirements are described in detail in the *Classroom Preparation Guide*. In some cases, GLOBE protocols are available.

Additional Considerations

1. The presence of thin, high clouds (cirrus) is a problem for water vapor and other direct sun measurements because these clouds are often difficult to see and can significantly affect the amount of sunlight transmitted through the atmosphere. So, students need to gain experience with cloud observations.
2. Students should practice pointing the water vapor instrument at the sun before trying to record actual data. They should confirm that the maximum voltage is observed on the digital voltmeter when the round circle of sunlight shining through the front alignment bracket is centered over the colored dot on the rear bracket. (If this is not true, please notify the Science Team.) Practice sessions conducted outdoors, and whenever several students are trying to learn how to use the equipment, will take significantly longer than the actual time needed for one or two experienced observers to collect a set of measurements. During this time, the temperature inside your water vapor instrument can rise or fall by several degrees, depending on the ambient air temperature. You should avoid actually reporting measurements made during practice sessions.
3. It is important to take measurements in the prescribed way and under acceptable sky conditions. Because the numerical results will probably have little meaning to students, at least until they have recorded these data for a while, it is especially important to follow protocols carefully and consult with the Science Team if you have questions.

A *Classroom Preparation Guide* is provided to help you prepare for implementing this protocol. It describes in detail the steps involved in recording a complete set of measurements, along with some discussion for each step. It parallels the *Field Guide* that simply lists the steps in order with no further explanation. As part of their preparation for this protocol, students and teachers should study the *Classroom Preparation Guide* to make sure they understand each step.

Questions for Further Investigation

What kinds of weather conditions and climates are associated with high (low) PW?

To what extent is water vapor related to other atmosphere variables such as aerosol optical thickness, temperature, cloud type and cover, precipitation, relative humidity, dewpoint temperature, barometric pressure, or ozone concentration?

Can observations of PW improve your weather forecasts?

Water Vapor Protocol

Classroom Preparation Guide

This section includes a detailed step-by-step discussion about how to collect water vapor data, with information about and explanations for each step. The data collection steps are keyed to the *Water Vapor Protocol Data Collection Field Guide*, in which the same steps are listed, without explanation.

Tasks

- Record a set of maximum voltage readings obtained by pointing your water vapor instrument at the sun.
- Record the precise time of your measurements.
- Observe and record meteorological, cloud, and sky conditions.

What You Need

- ❑ GLOBE/GIFTS water vapor instrument
- ❑ *Water Vapor Data Sheet*
- ❑ Watch, preferably digital, or GPS receiver
- ❑ Digital hygrometer or sling psychrometer
- ❑ Pen or pencil
- ❑ GLOBE Cloud Chart
- ❑ Barometer (optional)
- ❑ Thermometer
- ❑ *Field Guides* for *Cloud, Air Temperature, Relative Humidity Protocols* (optional) and *Optional Barometric Pressure Protocol* (optional)

Getting Ready To Make Measurements

Site Description (see the Instrument Construction, Site Selection and Set-Up Protocol)

In order to report water vapor measurements you must have a defined atmosphere site at which to make observations. If your school has not established an *Atmosphere Study Site*, you will need to define one following the *Instrument Construction, Site Selection, and Set-Up Protocol*.

The site description needs to be done only once unless, of course, you change the location of the site or add an additional site. Interpretation of your measurements requires knowledge of the longitude, latitude, and elevation of your observing site.

The basic condition for taking water vapor measurements is that you must have an unobstructed view of the sun and a view of the sky that allows you to make reasonable cloud cover and type estimates. These measurements can be done in an urban setting.

Metadata

Metadata are data about data and supplement your actual data. They are important because they help scientists interpret your measurements. Some of the metadata (such as barometric station pressure) can be collected in the classroom just before or after your measurements.

Types of Metadata:

1. Barometric pressure *(Optional Barometric Pressure Protocol* **available)**

Accurate barometric pressure values are important. Sources for barometric pressure are, in order of preference:

1. Online or broadcast data from a nearby official weather station.
2. Printed values from a reliable source.
3. Measurements from a classroom barometer.

Note: If you use option #1 or option #2 then **do not** enter the value in the "Barometric Pressure" field on the *Water Vapor Data Sheet*, instead report this value in the *Comments* section of the *Data Sheet*. If option #3 is used the relative humidity value should be entered in the "Barometric Pressure" field on the *Water Vapor Data Sheet*.

In many parts of the world, accurate barometric pressure values are readily available online, and are therefore preferable.

Many U.S. newspapers publish a daily weather almanac that gives weather information for the previous day, including barometric pressure. Use the value closest to the time of your data collection. For example, if barometric pressure is given at noon, this would be the value to use for most water vapor measurements. Depending on whether pressure is rising, steady or falling, it is reasonable to interpolate between noontime and early morning or late afternoon values (6:00 am and 6:00 p.m. local time are often given in addition to 12:00 noon).

In the U.S., the pressure may need to be converted from inches of mercury to millibars (hectopascals), which is the international and GLOBE standard:

pressure (mbar or hectopascals) = pressure (inches of Hg) * 33.864 (mbar/inch of Hg)

It is sufficient to report barometric pressure to the nearest millibar.

2. Current air temperature (protocols available)

Because the electronics in your GLOBE water vapor instrument, and especially its detectors, are temperature-sensitive, the Science Team asks that you report air temperature along with your water vapor measurements. GLOBE provides four ways to measure current air temperature.

1. *Digital Multi-Day Max/Min Current Temperature Field Guide*
2. Steps 1-5 of the *Maximum, Minimum and Current Temperature Protocol Field Guide*
3. Steps 1-4 of the *Digital Single-Day Maximum and Minimum Temperature Protocol Field Guide*
4. *Current Air Temperature Protocol Field Guide*

3. Temperature inside your water vapor instrument case

In terms of instrument performance, what really matters is not the outside air temperature itself, but the temperature inside the instrument case. Your water vapor instrument is fitted with an electronic temperature sensor that is located next to the sunlight detectors. You can display the voltage reading from this sensor by selecting the "T" position for the rotary switch. The output from the sensor is 10 mV per degree C. So, the temperature is 100 times the "T" voltage reading. For example, if the reading is 0.224 V, then the temperature inside the case is 22.4 °C. You should record this value once at the beginning of a set of measurements and again at the end.

For the most accurate measurements, it is important to maintain the air inside the case at approximately room temperature — in the low 20's. There are some simple steps you can take to minimize temperature sensitivity problems. Keep your water vapor instrument inside and bring it outside only when you are ready to take measurements. In the winter, transport it to the observing site under your coat or in an insulated bag. In the summer, transport it in a small picnic cooler. You can construct an insulating shell for your instrument from rigid foam plastic sheets (Styrofoam) held together with aluminum tape. Especially in the summer, keep your instrument shielded from direct sunlight whenever you are not actually taking a measurement.

4. Time

It is important to report accurately the time at which you take measurements because calculations of solar position at your site depend critically on time. The GLOBE standard for reporting time is always UT, which can be calculated from local clock time, your time zone and time of year (required for areas that implement daylight sayings time). It is essential to convert local time to UT correctly. Be especially careful if you switch from standard to daylight savings time, or vice versa. For example, you must add 5 hours to convert Eastern Standard Time (EST) to UT, but only 4 hours to convert Eastern Daylight Time (EDT) to UT. A one-hour error can produce results that look OK but that are, wrong. If you have a GPS receiver, you can obtain UT directly from it.

Time should be reported to an accuracy of no less than the nearest 30 seconds. A digital watch or clock that displays seconds is easier to use than an analog one, but in either case you must set your timepiece against a reliable standard. Even an analog wristwatch can be read to the nearest 15 seconds if it has one-minute marks on its dial. The time accuracy requirements for this and the related *Aerosols Protocol* are stricter than for most other GLOBE protocols.

It is not difficult to set your clock or watch accurately enough to meet the standards required for this protocol. You can get time online or from a handheld GPS receiver. In many parts of the world, you can buy a clock that sets itself automatically by detecting a radio signal from an institution that maintains a reference clock.

It may be tempting to use the clock maintained by your computer as a standard. However, this is not a good idea, as computer clocks are often inaccurate, and they should be reset periodically according to a reliable standard. Note that modern computer operating systems will automatically switch your computer clock back and forth between standard and daylight savings time.

Water vapor measurements can be taken any time during the day. Indeed, it is an interesting project to study the variation of water vapor during the day. However, the water vapor instrument will give the most reliable readings when you take measurements between mid-morning and mid-afternoon. In temperate and higher latitudes, with low maximum solar elevation angles, you should take measurements near solar noon if possible, especially in the winter.

If you are taking measurements that correspond to satellite overflights, then the times of those overflights determine when measurements should be taken. How closely must your measurements match the time of the overflight to be useful? This is a question that should be discussed with scientists working with the space-based instruments. In general, the times should match within just a few minutes. However, it is always better to collect data than not, even if you cannot time the measurements precisely with satellite overflights.

5. Relative humidity (*Relative Humidity Protocol* **available)**
Relative humidity is reported as a whole number, in percent. Relative humidity and temperature are used to calculate the dewpoint temperature, which is empirically related to PW. (See *Looking at the Data.*) There are two options for reporting relative humidity, with the first being highly preferred:

1. Obtain a relative humidity reading by doing the *Relative Humidity Protocol.* Report this reading in the "Relative Humidity" field on the *Water Vapor Data Sheet.*
2. If you do not have access to a digital hygrometer or sling psychrometer that meets GLOBE specifications, you may obtain a relative humidity reading from an online or broadcast source. In this case **do not** fill in the "Relative Humidity" field on the *Water Vapor Data Sheet.* Instead report this value in the *Comments* section of the *Data Sheet.*

6. Cloud observations (*Cloud Protocols* **available)**
Water vapor measurements can be interpreted properly only when the sun is not obscured by clouds. This does not mean that the sky must be completely clear, but only that there must be no clouds in the vicinity of the sun. This may not always be a simple determination. It is easy to determine whether low- and mid-altitude clouds are near the sun, but cirrus clouds can pose a challenge. They are often thin and may not appear to block a significant amount of sunlight. However cirrus clouds can affect PW measurements even when they are invisible to the human eye. Remember that the water vapor instrument detects light in the infrared part of the solar spectrum, so the fact that cirrus clouds may be only faintly visible to humans does not mean they are not absorbing infrared sunlight.

Another difficult situation occurs in typical summer weather, especially near large urban areas. In this environment, polluted skies and humid conditions may make it difficult to distinguish cloud boundaries. It is important to describe such conditions whenever you report measurements. Observing the sky (away from the sun!) through orange or red sunglasses or a plastic filter will make cloud boundaries easier to see.

Whenever you try to determine cloud conditions in the vicinity of the sun, you must block the sun itself with a book, a sheet of paper, a building or tree, or some other object. A sensible rule is that if you can see even faint shadows on the ground, you should not try to look directly at the sun. If in doubt, or if you believe you cannot determine sky conditions near the sun, then do not take a measurement.

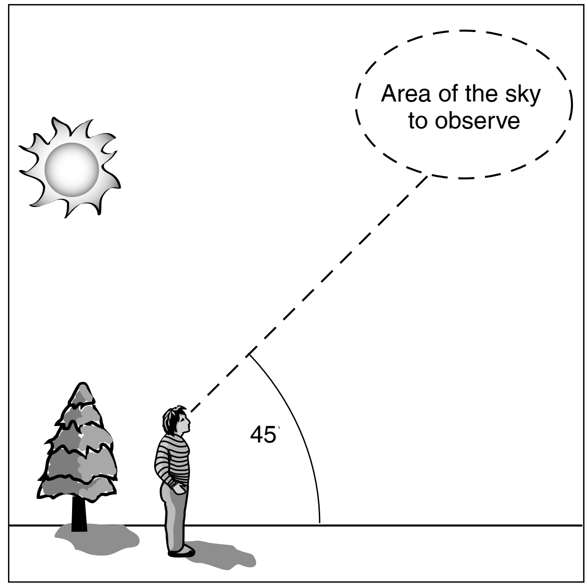
Safety Reminder: Never look directly at the sun, even through colored sunglasses or plastic filters. This can seriously damage your eyes!

Cloud condition reports should follow the *Cloud Protocols.* The categories given on the *Water Vapor Data Sheet* are described in these protocols.

7. Sky conditions

Sky conditions include sky color and clarity. These are subjective observations but, with practice, you can learn to be consistent in your interpretations. For example, you can easily learn to recognize the clear deep blue sky that is associated with clean air and low relative humidity. With higher humidity and increasing pollution, the sky color changes to a lighter blue. It may appear milky rather than clear. In some places, especially in and near urban areas, the sky can have a brownish or yellowish tint due to air pollution (primarily particulates and NO_2).

Figure AT-WV-6: Area of the Sky to Observe



To determine sky color, look at the sky in a direction *away* from the sun. That is, your shadow should be directly in front of you. Sky color is generally lighter near the horizon. For this reason, you should be consistent about basing your observation on the sky at an elevation angle of about 45° above the horizon. If this part of the sky is cloudy, use the nearest part of the sky for which you can determine the color.

You can determine sky clarity by using a distant object – a tall building or mountain range, for example – as a reference. When this object appears sharply defined in its natural colors, then the sky is clear. As the object becomes less distinct, then there are probably more water vapor and aerosols in the atmosphere. However, please note that this method of determining haziness is more directly related to horizontal visibility, which may not always be an accurate indicator of the condition of the atmosphere above your site.

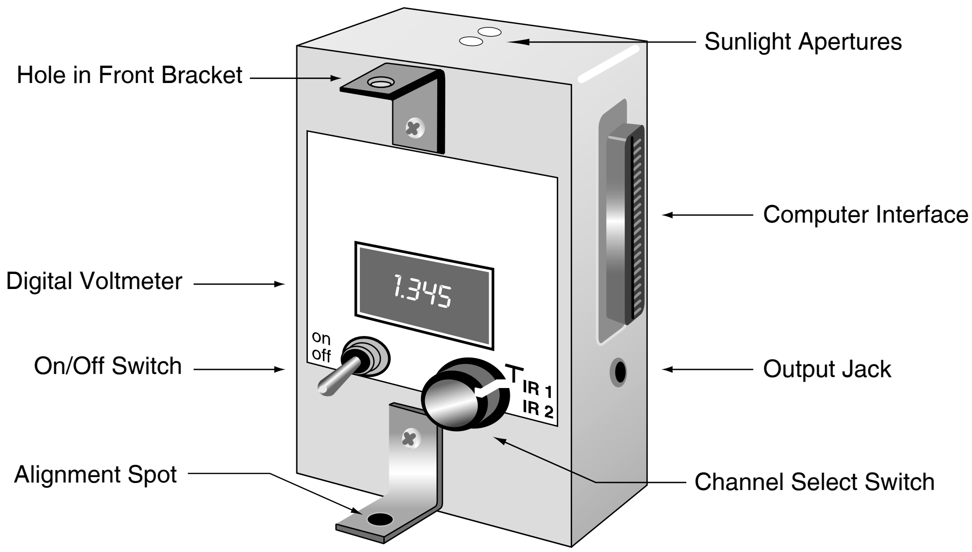
When there are obvious reasons for unusual sky conditions, the users of your data need to know about them. Urban pollution, dust, and smoke are examples of conditions that need to be reported in the *Comments* section of the *Data Sheet.*

8. Spacecraft overflight information

As an optional part of the *Water Vapor Protocol,* you can collect data at times that coincide with spacecraft overflights of your observing site. This may be important for spacecraft in low-altitude orbits, but not important for spacecraft in high-altitude geostationary orbits, such as GIFTS. Information about spacecraft overflights, including overflight time and the peak spacecraft elevation angle over your site, can be obtained online at: http://earthobservatory.nasa.gov/MissionControl/overpass.html. It is even possible to find overflight information for spacecraft not listed by name on this Web site. (Contact the Science Team for more information.) Because the water vapor measurement involves viewing the Sun, only daytime overflights are of interest. For any day, you should always select the daytime overflight corresponding to the largest value of the peak spacecraft elevation angle. When this value is 90˚, the spacecraft is flying directly over your site. When you are taking a measurement to correspond with a satellite overflights, please record the Satellite/instrument name, time of overflight, and the Max elevation angle on your *Water Vapor Data Sheet*.

Data Collection

Figure AT-WV-7: Parts of the GLOBE/GIFTS Water Vapor Instrument



In the Classroom

You should be familiar with the parts of the GLOBE/GIFTS Water Vapor Instrument, as shown in Figure AT-WV-7. Make sure you have all required materials and, if you are working as a team, that each team member understands her or his role. This is especially important if several different students participate in these measurements on a rotating basis. Information about using the computer interface can be obtained from the Science Team.

Practice runs can be made inside by pointing your instrument at the sun through a window – even a closed window. (Actual measurements should not be made through a closed window!) The water vapor instrument should be at room temperature – about 20-25˚ C – before collecting data. Place the instrument in an insulated container before you take it outside.

In the Field

It is easier for two people to collect these data than it is for one person working alone. If you are not familiar with this protocol, divide up the tasks and go through several practice runs outside before you start recording real data with your water vapor instrument. Remember that these practice runs may result in your instrument being exposed for a relatively long time to hot or cold weather. Before you take "real" measurements, you must be sure your instrument has returned to room temperature, as described in item 3 in the Metadata section of *Getting Ready To Take Measurements*.

Explanation of Field Guide Steps for Data Collection:

1. Turn your instrument on.
2. Hold the instrument in front of you in a position where you can read the digital voltmeter and can comfortably keep the sun spot shining through the front alignment bracket aligned on the rear alignment dot.

   It will be helpful to brace the instrument against your knees, a chair back, railing, or some other fixed object.
3. Set the rotary switch to T, read the voltage, multiply this reading by 100, and record the value under "case temperature" on your *Water Vapor Data Sheet.*

   This reading represents the air temperature near the LED detectors inside your instrument. For the most accurate results, this temperature should be in the range 20-25˚ C.
4. Set the rotary switch to IR1.

   The *Data Entry Form* asks for measurements in the order IR1 then IR2. Always take measurements in this order.
5. Adjust the pointing of your instrument until the spot of sunlight coming through the front alignment bracket is centered on the colored alignment spot on the rear bracket.

   During the next 10-15 seconds, observe the voltage displayed on the meter and record the maximum voltage in the "sunlight voltage" column of your *Data Sheet.* The voltages will fluctuate by a few millivolts even when you hold your instrument perfectly steady. This is due to real fluctuations in the atmosphere. Do not try to "average" these fluctuating voltages. Also, be sure to record all the digits displayed on the meter: 1.732 rather than 1.73, for example.
6. Record the time at which you took the measurement as accurately as possible.

   Include seconds. An accuracy of 15-30 seconds is required. This is possible even with an analog watch that has been set to a reliable standard.
7. While still pointing your instrument at the sun, cover the sunlight apertures with your finger to block all light from entering the case. Record this reading in the "dark voltage" column on the *Data Sheet.*
8. Select the IR2 channel and repeat steps 5-7.
9. Repeat steps 4-8 at least two and as many as four more times.

   This will give between three and five pairs of IR1/IR2 measurements. Remember that it is important to be consistent about the order in which you collect these data: IR1, IR2, IR1, IR2, IR1, IR2. The time between measurements is not critical as long as you record the time accurately. However, especially in hot or cold weather, it is important to minimize the total measurement time in order to keep the temperature inside your instrument case close to room temperature. A set of up to five pairs of measurements should take no longer than two or three minutes to collect (20-30 seconds per voltage value). The *Water Vapor Data Sheet* has space for up to five pairs of measurements; taking more than three pairs is helpful, but not required.

10. Set the rotary switch to T, read the voltage, multiply this reading by 100, and record the value under "case temperature" on your *Water Vapor Data Sheet.*

11. Turn off your water vapor instrument.

12. Note any clouds in the vicinity of the sun in the *Comments* section of your *Water Vapor Data Sheet.* Be sure to note the type of clouds by using the *GLOBE Cloud Chart*.

13. Do the *Cloud Protocols* and record your observations on the *Water Vapor Data Sheet*.

14. Read and record the current air temperature to the nearest 0.5˚ C following one of the air temperature protocols. Be careful not to touch or breathe on the thermometer.

    Use one of the protocols listed in item 2. in the first part of this *Classroom Preparation Guide.*

15. Perform the *Relative Humidity Protocol* and record the results on the *Water Vapor Data Sheet.*

    If you do not have an acceptable digital hygrometer or sling psychrometer available, then do not fill in the "Relative Humidity" fields on your data *Water Vapor Data Sheet*. Instead report a relative humidity value from a reliable online source in the *Comments* section of the *Water Vapor Data Sheet*.

16. Complete the *Water Vapor Data Sheet*.

    This includes reporting a barometric pressure value (preferably from an online source reported in the *Comments* section) as described above, and filling in any additional comments.

Water Vapor Protocol Data Collection

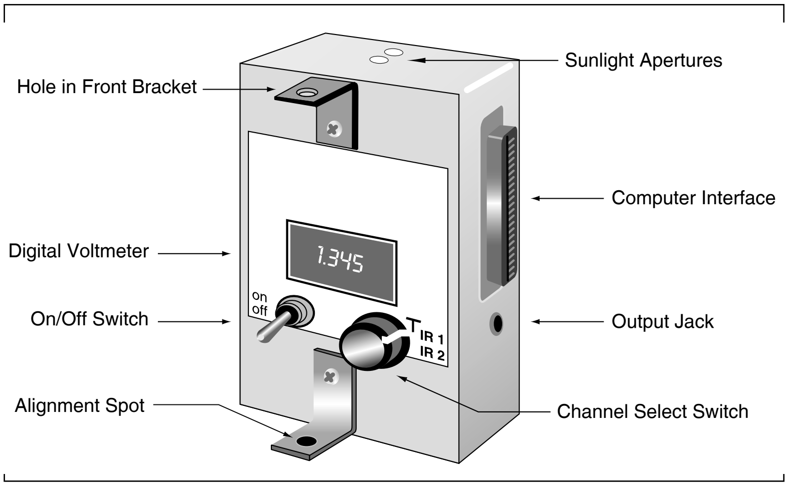
Field Guide

Task

- Record a set of maximum voltage readings obtained by pointing your water vapor instrument at the sun.
- Record the precise time of your measurements.
- Observe and record meteorological, cloud, and sky conditions.

What You Need

- ❑ GLOBE/GIFTS water vapor instrument
- ❑ *Water Vapor Data Sheet*
- ❑ Watch, preferably digital, or GPS receiver
- ❑ Digital hygrometer or sling psychrometer (optional)
- ❑ Pen or pencil
- ❑ GLOBE cloud chart
- ❑ Barometer (optional)
- ❑ Thermometer
- ❑ *Field Guides* for *Cloud, Air Temperature, Relative Humidity Protocols* (optional) and *Optional Barometric Pressure Protocol* (optional)



In the Field

1. Turn your instrument on.
2. Hold the instrument in front of you in a position where you can read the digital panel meter and can comfortably keep the sun spot shining through the front alignment bracket aligned on the rear alignment dot.
3. Set the rotary switch to T, read the voltage and multiply this reading by 100 and record it under case temperature on your *Water Vapor Data Sheet.*
4. Set the rotary switch to IR1.
5. Adjust the aim of your instrument until the spot of sunlight coming through the front alignment bracket is centered on the colored alignment dot on the rear bracket. Wait 2-3 seconds. Then, always keeping the spot of sunlight centered on the alignment dot, observe the voltage displayed on the voltmeter during the next 10-15 seconds and record the maximum voltage in the "sunlight voltage" column of your *Water Vapor Data Sheet.*
6. Record the time at which you took the measurement as accurately and precisely as possible.

7. While still pointing your instrument at the sun, cover the sunlight apertures with your finger to block all light from entering the case. Record this reading in the "dark voltage" column on the *Data Sheet.*
8. Set the rotary switch to IR2 and repeat steps 5-7.
9. Repeat steps 4-8 at least two and no more than five more times.
10. Set the rotary switch to T, read the voltage and multiply this reading by 100 and record it under case temperature on your *Water Vapor Data Sheet.*
11. Turn off your instrument.
12. Note any clouds in the vicinity of the sun in the *Comments* section of the *Water Vapor Data Sheet.* Be sure to note the type of clouds by using the GLOBE Cloud Chart.
13. Do the *Cloud Protocols* and record your observations on the *Water Vapor Data Sheet*.
14. Read and record the current air temperature to the nearest 0.5˚ C following one of the air temperature protocols. Be careful not to touch or breathe on the thermometer.
15. Perform the *Relative Humidity Protocol* and record the results on the *Water Vapor Data Sheet*.
16. Complete the *Water Vapor Data Sheet*.

Frequently Asked Questions

1. The GLOBE/GIFTS water vapor instrument uses light-emitting diodes (LEDs) as sunlight detectors. What is an LED?

A light-emitting diode is a semiconductor device that emits light when an electrical current flows through it. The actual device is a tiny chip only a fraction of a millimeter in diameter. The chip will be housed in either a small metal case with a flat glass cover about 5 mm in diameter, or an epoxy cylinder about 5 mm in diameter.

The physical process that causes LEDs to emit light also works the other way around. When light shines on an LED, it produces a very small current. The electronics in your water vapor instrument amplify this current and convert it to a voltage.

LEDs are found in a wide range of electronic instruments and consumer products. The most familiar LEDs emit visible light — red, yellow, green, or blue. The LEDs in your water vapor instrument emit (and respond to) infrared light. This radiation is invisible to the human eye. LED transmitters and detectors are commonly used in the familiar handheld remote control devices often included with consumer electronics devices such as TVs and audio equipment.

2. What does the GLOBE/GIFTS water vapor instrument measure?

As noted in Question 1, sunlight striking the detectors in your instrument causes a very small current to flow. Each detector responds to sunlight over a different narrow band of infrared wavelengths. When the current is amplified it produces a voltage that is proportional to the amount of light striking the detector within that wavelength band. Water vapor absorbs sunlight traveling through the atmosphere in one of the wavelength bands, but not the other. Your instrument is calibrated so that the amount of water vapor in the atmosphere can be related to the ratio of voltages from the two channels.

3. What is the field of view of the GLOBE/GIFTS water vapor instrument and why is it important?

The water vapor instrument is a sun photometer. The equation that describes theoretically how to interpret sun photometer measurements requires that the instrument should see only direct light from the sun — that is, light that follows a straight-line path from the sun to the light detector. This requirement can be met only approximately because all sun photometers see some scattered light from the sky around the sun.

The cone of light that a sun photometer's detector sees is called its field of view, and it is desirable to have this cone as narrow as possible. The GLOBE/GIFTS water vapor instrument's field of view is about 2.5 degrees, which is a reasonable compromise between desires for accuracy and practical considerations that arise in building a handheld instrument. The basic trade-off is that the smaller the field of view, the harder the instrument is to point accurately at the sun. Very expensive sun photometers, with motors and electronics to align the detector with the sun, can have fields of view of 1 degree or less. However, studies have shown that the error introduced by somewhat larger fields of view is negligible for the conditions under which the GLOBE/GIFTS water vapor instrument should be used.

4. How important is it to keep the water vapor instrument from getting hot or cold while I'm taking measurements?

The LED detectors in your instrument are temperature-sensitive, so their output is slightly influenced by their temperature. Therefore, it is important to protect your instrument from getting too hot or too cold. Keep it inside, at room temperature, when you are not actually collecting data. Never leave your instrument outside or in direct sunlight for extended periods of time. When you are collecting data, the important temperature is not the outside air temperature, but the air temperature inside the case. You can monitor the case temperature by selecting the "T" channel on your instrument. (Multiply the voltage reading by 100 to get the temperature in degrees C.) This temperature should be in the low 20's. If the temperature is in this range when you start taking measurements, and if you work as quickly as possible, the temperature inside the case should not change by more than a degree or two and you can minimize undesirable temperature effects.

5. I dropped my water vapor instrument. What should I do now?

Fortunately, the components inside your water vapor instruments are very rugged, so they should survive being dropped. If you have made an insulated housing for your instrument, then it will be very well protected. However, you should still check the case for cracks. Even if the case is cracked, it may still be OK. Just tape over the cracks using something opaque, such as duct tape or aluminum tape. Open the case and make sure that everything looks OK. In particular, make sure that the battery is still firmly attached to its connector. If the alignment brackets have moved or are loose as a result of the fall, your instrument should be returned to the Science Team for recalibration.

6. How do I know if my water vapor instrument is working properly?

When you turn your water vapor instrument on without pointing it at the sun, you should measure a small DC voltage no larger than a few millivolts. When you point your instrument directly at the sun, the voltage should increase to a value in the range of about 0.5 to 2 V. If you do not observe such voltage changes when you point your instrument at the sun, then it is not working.

The most likely reason for a water vapor instrument to stop working is that the battery is too weak to power the electronics. As indicated in the procedure for changing the battery (see the *Aerosols Protocol*), you should replace the battery if its voltage (with your instrument turned on) is less than 7.5 V. You should check the battery three or four times per year unless you know your instrument has inadvertently been left on for an extended period of time.

Changing the battery will not affect the calibration of your instrument. If you replace the battery and your instrument still appears not to work, contact GLOBE for help.

7. Can I make my own water vapor instrument?

Yes. You can purchase a basic GLOBE/GIFTS water vapor instrument kit. Constructing this device involves soldering some electronic components, which is a skill students need to learn from someone who has done it before. You can start taking measurements as soon as you have assembled your instrument. However, at some point, you must send your water vapor instrument to the GLOBE Science Team for calibration before your data can be accepted into the GLOBE Data Archive.

8. How accurate are measurements taken with the GLOBE water vapor instrument?

This is a difficult question whose answer is the subject of ongoing research. Unlike some other GLOBE measurements, there is no accepted reference standard against which these measurements can be compared. All measurements of total atmospheric water vapor content are subject to errors and uncertainties. Calibration of the GLOBE/GIFTS water vapor instrument depends on measurements made with other techniques. Therefore, its accuracy depends on the accuracy of these other techniques. Other sun-photometer based measurements of water vapor do not claim accuracies better than 10%. Although this seems like a large error, it is sufficient to be useful for improved understanding of the distribution and transport of water vapor.

9. How is total precipitable water vapor related to atmospheric properties measurable at the ground?

Practically by definition, it is not possible to infer precipitable water (PW) directly and accurately from other measurements made on the ground. If that were possible, we wouldn't need a water vapor instrument! However, atmospheric scientists have long understood that there is an approximate relationship between PW and the surface dewpoint temperature — the air temperature at which relative humidity would be 100%. About 40 years ago, C. H. Reitan [Surface Dew Point and Water Vapor Aloft, J. *Applied Meteorology 2,* 776-779, 1963] derived an empirical relationship:

$$\ln(PW) = 0.1102 + 0.0614T_d$$

where ln(PW) is the natural logarithm of the precipitable water in centimeters and T_d is the dewpoint temperature in degrees Celsius. Because the relationship between PW and dewpoint temperature is only approximate, it cannot substitute for an actual measurement of PW. Testing this relationship is a good research project for advanced secondary school students.

10. Can my GLOBE/GIFTS water vapor instrument be used to measure aerosol optical thickness at infrared wavelengths?

This question might occur to you if you are also doing the GLOBE *Aerosols Protocol*. The GLOBE/GIFTS water vapor instrument is nothing more than a sun photometer that has been calibrated in a particular way to determine atmospheric water vapor. However, it can also be calibrated as a sun photometer that can be used to determine aerosol optical thickness at two near-IR wavelengths. You can continue to use the same instrument to measure water vapor, too. Typically, you will not be able to do this calibration yourself. If you are interested in this project, which is well worth doing, please contact the Science Team.

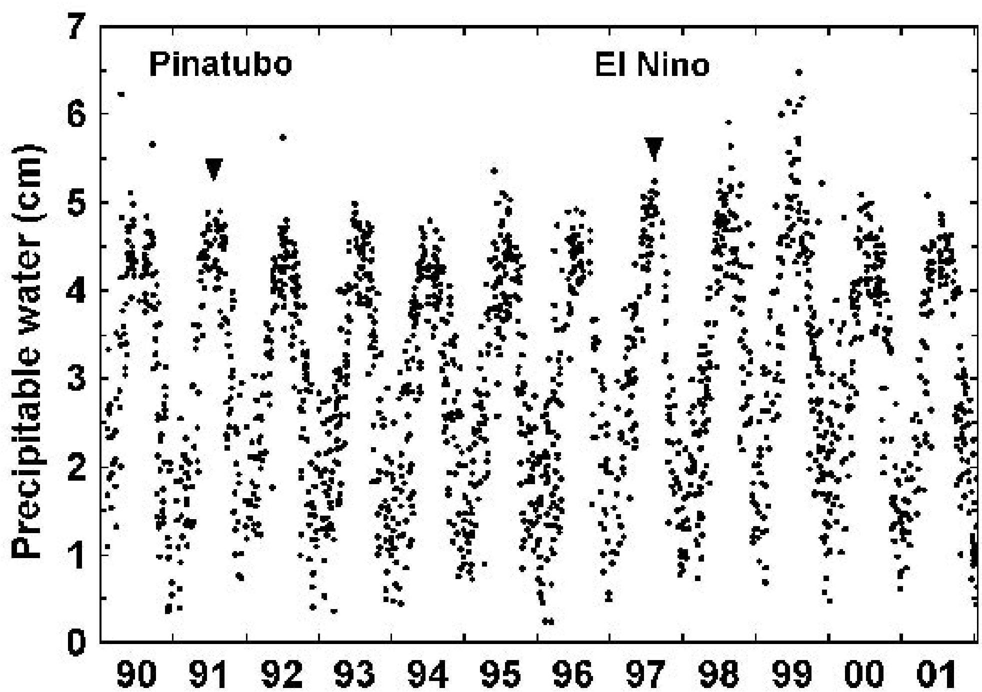
Water Vapor Protocol – Looking at the Data

Voltage readings from the GLOBE/GIFTS water vapor instrument should be in the range of 0.5 to 2.0 V, and dark current readings should be only a few millivolts. Large differences among a set of three to five voltage readings for IR1 or IR2 may indicate that there were cirrus or other clouds moving across the sun during observations.

Typically, precipitable water (PW) varies between a few tenths of a centimeter and several centimeters. At high elevation sites in arid climates, PW can approach 0. PW is only rarely above 6 cm. Much larger values may indicate that cirrus clouds were in front of the sun during the measurement. If a particular instrument regularly produces PW values outside the normal range, it indicates that something is wrong with the instrument (e.g., the battery needs to be changed or the instrument needs recalibration). Negative values of PW are physically impossible and indicate serious problems with the instrument or with the observer's understanding of how to collect data.

In temperate climates, the dominant feature of PW is its strong seasonal cycle. This can be seen in a 12-year record of PW measurements made with an LED-based instrument similar to the GLOBE/GIFTS instrument by Forrest Mims at his observatory in Seguin, Texas, USA. [See Mims, Forrest M. III, An inexpensive and stable LED sun photometer for measuring the water vapor column over South Texas from 1990 to 2001, *Geophys. Res. Lett. 29,*13, pp 20-1– 20-4,2002.] It is clear from Figure AT-WV-8 that PW values are higher in the summer than in the winter. PW measurements made by students in temperate climates should exhibit this seasonal cycle. Note that major volcano eruptions, such as Mt. Pinatubo, and El Nino events can influence the seasonal PW cycle. Measurements made in other climates, such as tropical regions that have wet and dry seasons, should have PW cycles that are related to these seasons. PW values at high-elevation observing sites will be smaller than those for sites nearer to sea level. (Unlike barometric pressure, for example, and like aerosol optical thickness, PW values are not "normalized" to sea level; they represent the actual amount of water vapor in the atmosphere above the observing site.)

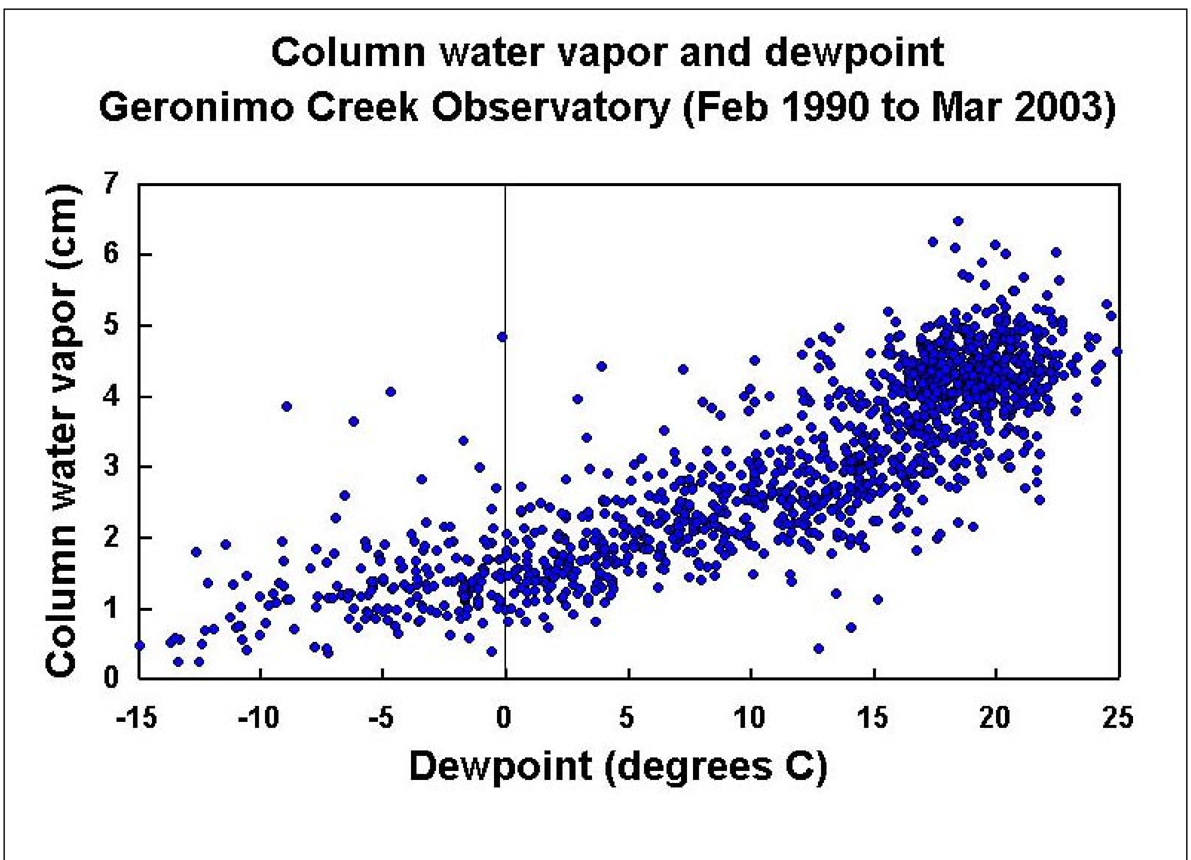
Figure AT-WV-8: Seasonal Variation of PW at Geronimo Creek Observatory, Seguin, Texas, USA



It might seem reasonable to expect PW to be related to relative humidity. Actually, the correlation between the amount of water vapor in the entire atmosphere and relative humidity – a measurement made near Earth's surface – is quite poor. However, under many conditions, PW is related to a another surface meteorological parameter: dewpoint temperature. This is the temperature at which relative humidity would be 100%. So, when relative humidity is less than 100%, the dewpoint temperature is less than the air temperature. This is discussed further in the *Relative Humidity Protocol*. The dewpoint temperature is not usually a regular part of "popular" weather reports, but is provided on the GLOBE Web site. Figure AT-WV-9 shows PW versus dewpoint temperature for data collected over 13 years by Forrest Mims at Geronimo Creek Observatory, Seguin, TX, USA.

Although the relationship between PW and dewpoint is interesting, it is clear from Figure AT-WV-9 that you cannot use dewpoint as a replacement for actual measurements of atmospheric water vapor. (Otherwise, there would be no reason for this protocol!) The relationship between dewpoint and water vapor breaks down when the weather is changing rapidly – when a cold front is passing, for example.

Figure AT-WV-9



Optional Barometric Pressure Protocol

Purpose

To measure air pressure

Overview

Students record atmospheric pressure using a barometer or altimeter.

Student Outcomes

Students gain an understanding that barometric or altimeter pressure varies and its increase or decrease indicates an upcoming change in the weather.

Students learn that the air has weight.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and over the seasons.

Weather varies on local, regional, and global spatial scales.

Atmosphere Enrichment

Air pressure is a measure of the weight of the atmosphere per unit area.

Changes in barometric pressure can be used to help predict weather.

Scientific Inquiry Abilities

Use a barometer or altimeter to measure barometric pressure.

Identify answerable questions.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Communicate procedures, descriptions, and predictions.

Time

5 minutes

Level

All

Frequency

Daily within one hour of local solar noon or at roughly the same time as the aerosol measurement if used as atmospheric pressure value for the *Aerosols Protocol*

Materials and Tools

Aneroid barometer or altimeter

Atmosphere Investigation Data Sheet

Prerequisites

None

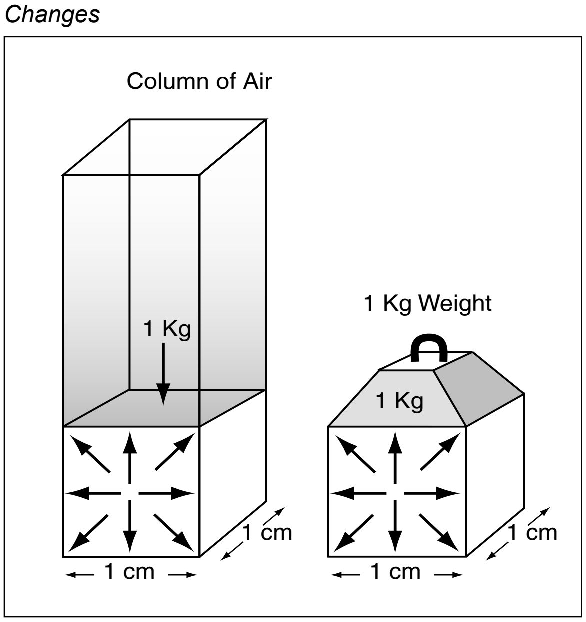
Optional Barometric Pressure Protocol – Introduction

Air is made up of molecules of nitrogen, oxygen, argon, water vapor, carbon dioxide, and other gases. Because these gases have mass, air is pulled toward the center of Earth by gravity. This force is what gives us weight, and the air also has weight. The greater the mass of air in a column above a specific area on the ground, the more weight the air has.

Pressure is defined as the force acting on a unit of area. Atmospheric pressure is the weight (force) of the air pushing on each unit of surface area on the ground. (A unit of area could be a square meter or a square centimeter – in other words, a unit in which area is measured.) Earth's atmospheric pressure is about 1 Kg/cm^2.

What is happening with atmospheric or barometric pressure? Think of a small cube of air sitting on Earth's surface. Above it, there is a column of air being pulled toward the surface by gravity. The force on the top of your cube of air is equal to the weight of the column of air above. The air in your cube transmits that force in all directions, pushing down on Earth's surface and horizontally on all the surrounding air. See Figure AT-PR-1. This is the atmospheric or barometric pressure, which is measured following this protocol.

Figure AT-PR-1: A Column of Air with Pressure Changes



You can think of this as being similar to the air in a ball. When you blow up a ball, you fill it with air until there is enough pressure to give the ball the bounce you want. The air inside the ball pushes on the surface by the same amount in all directions. When you put pressure on one place on the ball by hitting or kicking it, the air inside spreads that pressure in all directions, too.

Hundreds of years ago, scientists such as Galileo, Evangelista Torricelli, and Benjamin Franklin wondered about how changes of atmospheric pressure from day to day related to variations in the weather patterns they saw. Benjamin Franklin, for example, has been credited with observations that related the movement of low pressure systems (storms) along the northeastern coast of the United States, by comparing weather observations in his diary in Philadelphia with those of his friends in New York City and Boston.

Meteorologists have long known that high pressure generally brings fair weather, and low pressure is associated with "bad weather" - although most meteorologists tend to like "bad weather" because that is when the weather is most interesting!

A "falling barometer" is generally considered to be an indication of worsening weather. A "rising barometer" often indicates improving weather.

Daily observations of barometric pressure will be useful to you as you study other meteorological observations. You may note how changes in pressure readings from one day to the next are related to the kinds of weather observations discussed above. In particular, you may begin to notice how your cloud type and cloud cover observations are related to pressure recordings, how higher values of precipitation are related to low pressure, and that during spells of dry weather, the barometer will give high readings.

There are two ways that barometric pressures are generally expressed. One way is as barometric station pressure, the actual pressure experienced at a site. Since barometric pressure varies with elevation, it is difficult to track the movement of weather fronts by comparing station pressure values from sites at different elevations. Therefore, pressures are commonly expressed as sea level pressures, which represent the equivalent pressure that would be experienced if a site was located at sea level. Converting to sea level pressure involves applying a correction that compensates for the effect of the elevation of a site on the station pressure. Therefore, when sea level pressures at various sites are compared, the elevations of the sites are not pertinent and changes in pressure are direct reflections of the affects of weather fronts.

Interpretation of the aerosols, ozone, and water vapor measurements requires knowledge of atmospheric pressure, either from your barometer or from another reliable source.

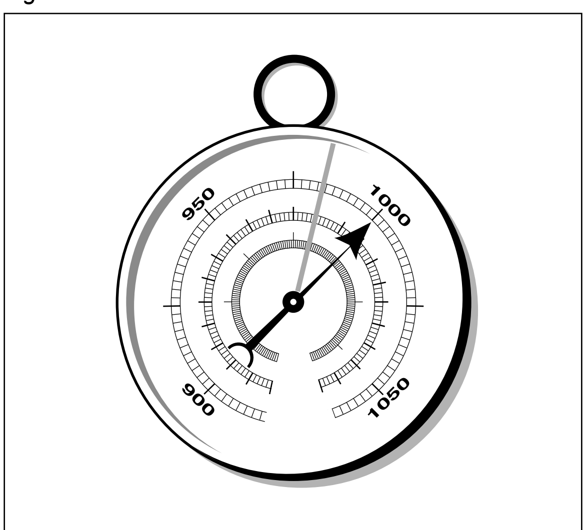
Teacher Support

The Aneroid Barometer and Altimeter

A device that can be used to measure atmospheric pressure is called a *barometer*.

The standard way of measuring pressure is to use a very sensitive mercury barometer, but these are expensive and mercury is poisonous. In order to make pressure measurements more accessible, the *aneroid barometer* was developed. Figure AT-PR-2 shows a typical aneroid barometer.

Figure AT-PR-2: Aneroid Barometer



The barometer contains an expandable bellows. The bellows changes size as air pressure changes. When air pressure is high, the bellows is compressed, and when air pressure is low, the bellows expands. Because the bellows is attached to a needle that moves across a scale, the barometer reading changes as the air pressure changes.

Most standard aneroid barometers will be useful for schools at elevations below 500 m; for higher elevation stations, an altimeter that also provides barometric pressure readings is recommended. Meteorologists typically convert air pressure values at weather stations to sea level pressure, so that the horizontal pressure variations that are important to wind and weather patterns can be seen more easily. More information is provided in *Calibrating Your Barometer*.

Units of Atmospheric Pressure

Scientists who use mercury barometers report atmospheric pressure as the height of a column of mercury (in mm), with an average value at sea level of 760 mm of mercury. Another unit of measurement for atmospheric pressure, the Pascal, relates to the notion that pressure is a measure of force per unit area. Standard sea level pressure is 101,325 Pascals (Pa), or 1013 hectopascals (hPa) (1hPa = 100 Pa). Hectopascals and millibars (mbar) are equivalent units of measure. The unit millibar is derived from the force unit of dynes per square centimeter. Typical values of air pressure for locations near sea level vary from about 960 mbar for extremely stormy conditions to about 1050 mbar for strong high pressure conditions.

As you go up in altitude, there is less air above you. Less air means less mass and less weight pushing down on the surface. So atmospheric pressure decreases as you go up in the atmosphere, and high elevation locations have lower air pressure values than low elevation locations. A good approximation of this is that for every 100 meters higher you go in the atmosphere, pressure will decrease by about 10 mbar. This works well up to about 3,000 meters above sea level. If your elevation above sea level were 1,000 meters, your normal pressure range would be roughly 860 to 950 mbar.

How to Place the Aneroid Barometer or Altimeter

In GLOBE we use a standard aneroid barometer or an altimeter. It should be mounted securely on a wall in the classroom, since air pressure is equal inside and outside the building. It should not rattle or shake back and forth. It should be mounted at eye level on the wall so that students can read it accurately. The barometer must first be calibrated against a standard value, either by calling a local government agency for assistance, or by following the instructions given in *Calibrating Your Barometer*. Your barometer should be recalibrated at least every six months.

Questions for Further Investigation

After recording your pressure readings for a month, make a graph of your pressure observations and also plot the daily precipitation. Do you see a relationship between these observations?

Is there any relationship between your data from the *Cloud Protocols* and barometric pressure?

Use pressure data from several GLOBE schools adjusted to sea level pressure to see if you can locate where high and low pressure areas are for a given day. How well do your findings compare with weather maps from your local newspaper or any other source?

Calibrating Your Barometer

When your barometer arrives, it most likely will have been calibrated at the factory. But it is necessary to calibrate the barometer yourself before you install the instrument. First, inspect your barometer; it will most likely have two different scales, one in millibars (or hectopascals) and one in millimeters (or centimeters) of mercury. All of your measurements for GLOBE should be taken in millibars or hectopascals (remember, these are equivalent).

There is a needle that can be set to the current reading each day – you should do this each day after you take your pressure reading. When you take tomorrow's reading, your barometer's set needle will read yesterday's value, and you can instantly compare to see whether pressure is higher or lower now than the day before!

To calibrate your barometer, you will have to find a local reliable weather information source, which provides measurements of pressure. A weather service or weather bureau office, agricultural extension office, newspaper, radio, or television station may be useful here.

Be sure that the reading is expressed as a sea level pressure. If the units of this pressure reading are not millibars or hectopascals you will need to convert the reading using the factors given below.

Conversion of Pressure Units

What if my units of pressure are not given to me in millibars or hectopascals?

This is quite likely in many locations, depending on the source of the calibration information. Use the table below to change the units of pressure to millibars from the units given.

Convert from	Multiply by this factor
Inches of mercury	33.86
Centimeters of mercury	13.33
Millimeters of mercury	1.333
Kilopascals	10
Pascals	0.01

Once you have obtained an accurate sea level pressure reading in millibars or hectopascals, reset your barometer to this pressure reading using a small set screw on the back of the barometer (this should only be done by the teacher!).

The barometer will then display the sea level pressure at your site accurately, within the limits of the scale on the barometer. If you move the barometer to a site with a different elevation you will need to calibrate the barometer based on a sea level pressure for that site.

Optional Barometric Pressure Protocol

Field Guide

Task

Measure the barometric pressure.

Reset the "set needle" to today's reading of barometric pressure.

What You Need

- ❑ A properly mounted aneroid barometer or altimeter
- ❑ *Atmosphere Investigation Data Sheet* or *Aerosols Data Sheet* or *Ozone Data Sheet* or *Water Vapor Data Sheet*
- ❑ Pen or pencil

In the Classroom

1. Record the time and date on the *Atmosphere Data Sheet.* (Skip this step if you are using the *Aerosols, Ozone,* or *Water Vapor Data Sheet.*)
2. Tap gently on the glass cover of the aneroid barometer to stabilize the needle.
3. Read the barometer to the nearest 0.1 millibar (or hectopascal).
4. Record this reading as the current pressure.
5. Set the "set needle" to the current pressure.

Frequently Asked Questions

1. If we missed reading the barometric pressure for a day or more (over the weekend, holiday, vacation, etc.), can we still report the pressure today?

Yes, you are only reporting today's pressure, so please report it as often as possible.

2. I really don't understand the difference between barometric station pressure and sea level pressure.

Since weather stations are spread all over the world at many elevations, and since pressure decreases rapidly with elevation, meteorologists need a way to map horizontal pressure patterns using a constant reference altitude. The easiest way to do this is to convert all observed pressure values to sea level pressure. In GLOBE barometric pressures are reported as sea level pressures but can be accessed and visualized as either sea level or station pressures, as the database is capable of making corrections to compensate for elevation changes.

3. In the 2002 version of the *Optional Barometric Pressure Protocol* **directed us to report pressure values to GLOBE as Station pressures. Why has this changed?**

GLOBE originally asked for pressure values as station pressures since this is the form that they are used in to analyze Aerosols data. However, we realized that this negates the educational benefits of looking at sea level pressures, which are direct indicators of the movement of storm systems. Using station pressures also makes obtaining calibration readings difficult since these readings are typically expressed as sea level pressures. Therefore, we have changed to sea level pressure as the standard way for expressing barometric pressures in GLOBE.

4. What if I want to convert a sea level pressure to a station pressure?

To convert a sea level pressure to a station pressure you will need to know your elevation above sea level (See the GPS Protocol) and the current temperature at your location. The temperature can be estimated if you do not have a measurement of it.

This conversion relates to one of the first lessons of atmospheric science, namely the concept that pressure decreases exponentially with altitude and that this decrease is characterized by a distance called the scale height. Some advanced students may wish to pursue this further using atmospheric science textbooks. What follows is the formula for the conversion and the origin of the constant involved, which is the scale height.

$$\text{Station pressure} = \text{Sea level pressure} \times e^{-\text{elevation} / (\text{temperature} \times 29.263)}$$

where:

Station pressure = the barometric pressure at your elevation in millibars (hectopascals)

Sea level pressure = the equivalent pressure at sea level in millibars (hectopascals)

elevation = the elevation of the station in meters

temperature = current temperature in degrees Kelvin (°K)

temperature (°K) = temperature (°C) + 273.15

the constant 29.263 is in units of meters per degree Kelvin (meters/°K)

$$29.263\ (\text{m}/^\circ\text{K}) = \frac{1000\ (\text{g/kg}) \times R}{M_{air} \times g}$$

R is the molar gas constant (= 8.314 Joules per mole per degree Kelvin)

1000 is to convert kilograms to grams (1 Joule = 1 kg m^2/sec)

M_{air} is the molecular weight of air (= 28.97 grams per mole)

g is the acceleration of gravity at Earth's surface (= 9.807 kg per second per second)

If you multiply this constant (29.263) by a temperature of 0° C, you get a value of 7993 meters or approximately 8 km. This is the scale height of Earth's atmosphere under average conditions (as given in the U. S. Standard Atmosphere).

A simplified conversion, which should only be used for stations at elevations below a few hundred meters, is:

Station pressure = Sea level pressure – (elevation/9.2)

The correction factor of 9.2 in the above formula is very nearly the change in elevation (vertically) that will correspond to a 1 millibar change in pressure, as given in the U. S. Standard Atmosphere.

5. Why do we have to reset the "set needle" each day?

The set needle is used to identify the previous pressure reading. Using it, you can instantly compare the current pressure reading to the previous one. For example, if the pressure is lower today than yesterday, you might ask yourself if the weather is stormier?

6. How accurate are these pressure readings, compared to those that might be taken with mercury barometers?

Today's aneroid barometers are not as accurate, in general, as well-made mercury barometers. There are some electronic barometers that have very accurate measurements, but the relatively inexpensive instruments that meet GLOBE specifications have all the necessary accuracy for our pressure measurements (about 3 to 4 mbar).

7. Why does pressure always decrease with height in the atmosphere?

Because pressure is a measure of the mass of the atmosphere above you (air does have mass!), as your elevation increases, there is less air above you, so pressure is less.

8. Why do high altitude GLOBE schools have to use an altimeter?

Most aneroid barometers are designed to be used near sea level. Altimeters are special aneroid barometers designed to be used at higher altitudes (including aircraft). At an altitude of 500 m above sea level, we would expect atmospheric pressure to be no greater than 1000 mbar and down to as low as 900 mbar for intense storms. Most aneroid barometers, however, have 950 mbar as the lowest possible measurement.

Relative Humidity Protocol

Purpose

To measure relative humidity at an Atmosphere Study Site

Overview

Sling Psychrometer: Students check that the sling psychrometer has water in it to wet the bulb of one of the thermometers and read the temperature of the dry bulb thermometer. Then they sling the thermometers around for 3 minutes and read the wet bulb temperature. Relative humidity is determined from the wet and dry bulb temperature readings using a table or slide calculator.

Digital Hygrometer: Students place the digital hygrometer in the instrument shelter and return to read the value after at least 30 minutes.

Student Outcomes

Students learn to quantify humidity and that there is a limit to the amount of water vapor which the air can hold.

Students gain insight into why rain drops and snow flakes form and why there is precipitation.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and over the seasons.

Weather varies on local, regional, and global spatial scales.

Water vapor content of the atmosphere is limited by temperature and pressure.

Water vapor is added to the atmosphere by evaporation from Earth's surface and transpiration from plants.

Precipitation forms by condensation of water vapor in the atmosphere.

Condensation and evaporation affect the heat balance of the atmosphere.

Physical Science

Materials exist in different states.

Geography

Water vapor in the atmosphere affects the characteristics of the physical geographic system.

Scientific Inquiry Abilities

Use a hygrometer or sling psychrometer to measure relative humidity.

Use a thermometer to measure temperature.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

5 minutes (digital hygrometer)
10 minutes (sling psychrometer)

Level

All

Frequency

Daily, preferably within one hour of local solar noon

Materials and Tools

Digital Hygrometer

Instrument shelter
Thermometer
Watch
Atmosphere Investigation Data Sheet

Sling Psychrometer

Instrument shelter
Calibration thermometer
Psychrometric chart
Watch or timer
Bottle of distilled water
Atmosphere Investigation Data Sheet

Prerequisites

None

Relative Humidity Protocol – Introduction

The atmosphere is made up a mixture of gases, one of which is water vapor. Water vapor is added to the atmosphere through evaporation and transpiration and removed when it condenses or freezes and precipitates. *Humidity* is the amount of water vapor present in the atmosphere. *Relative humidity (RH)* refers to this amount relative to the amount of water vapor in the atmosphere when the air is *saturated*.

The air is saturated when the liquid and gaseous forms of water are in balance at a given temperature. At saturation, relative humidity is 100%. When the relative humidity is over 100%, the air is *supersaturated* and the water vapor will condense or freeze to form new liquid water droplets or ice crystals.

$$RH = \frac{\text{amount of water vapor in the air}}{\text{amount of water vapor in the air at saturation}}$$

The amount of water vapor that may be present in the air at saturation depends upon the air temperature. The amount of water vapor that can exist in air at saturation increases as temperature increases. Table AT-RH-1 shows the relationship between temperature, saturation, and relative humidity. From this example you can see that if the temperature changes relative humidity can change even if the amount of water vapor in the air remains the same.

On a calm, clear day, air temperature tends to rise from sunrise until mid-afternoon and then fall until the following sunrise. If the amount of moisture in the air remains essentially the same during the course of the day, relative humidity will vary inversely with the temperature. That is, relative humidity will decrease from morning until mid-afternoon and rise again through the evening. See Figure AT-RH-1.

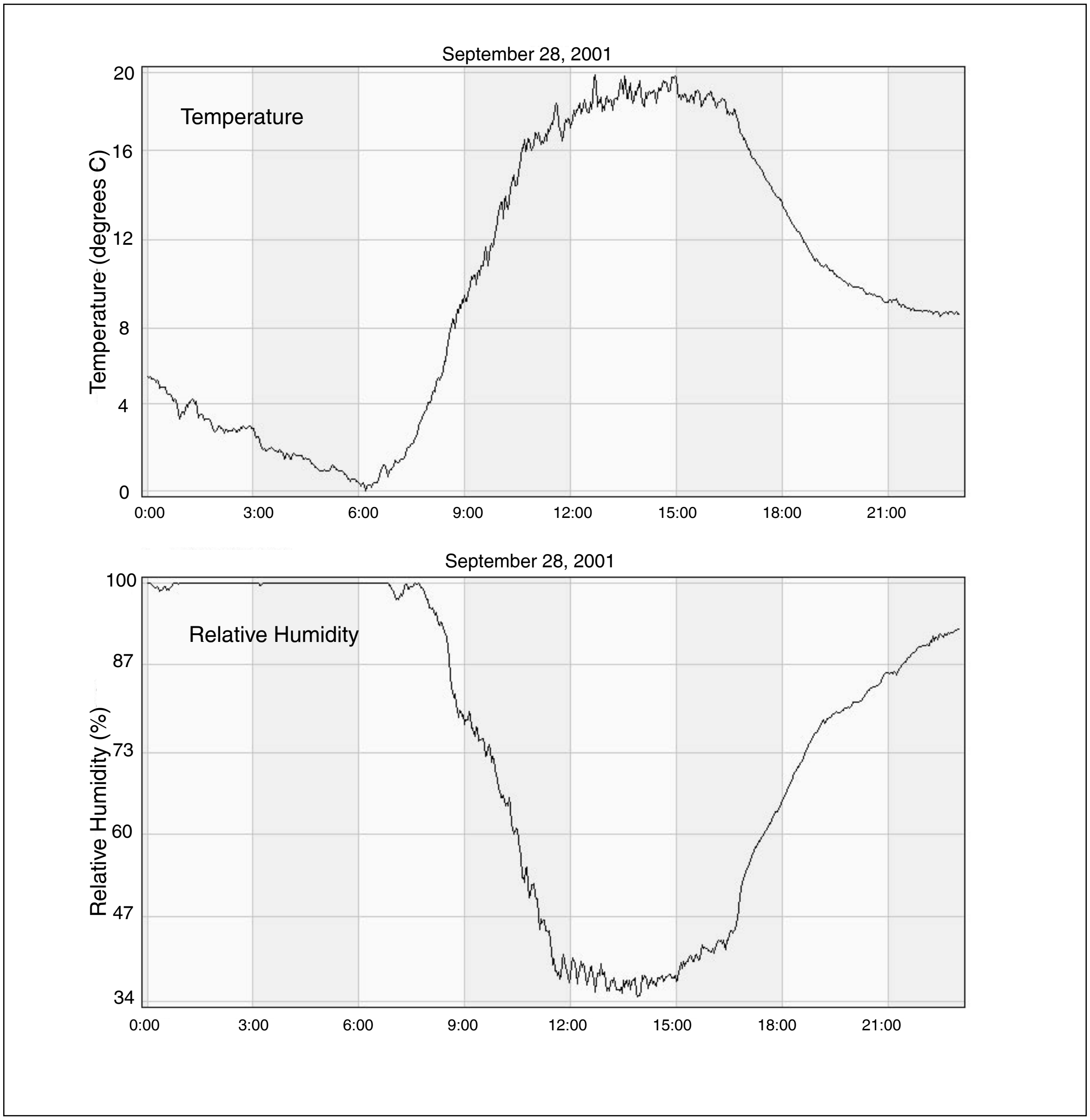
Water vapor in the atmosphere is an important part of the hydrologic cycle, and taking relative humidity measurements helps us to understand how rapidly water is moving from Earth's surface to the atmosphere and back again. By measuring water vapor in the atmosphere, the climate of a given location may be classified as arid (dry) or humid (moist). Relative humidity influences when clouds will form and precipitation will fall, therefore the amount of water in the atmosphere is important in determining the weather and climate of an area.

Relative humidity also affects the heating and cooling of the air. Since water has a significantly higher *heat capacity* than air, small amounts of water vapor can make considerable changes to the rate at which an air mass changes temperature. This accounts for the rapid cooling at night in the desert where the relative humidity is low, and the relatively slow nighttime cooling in more humid areas.

Table AT-RH-1

Air Temperature (°C)	Water Vapor Present in air (g/m³)	Water Vapor Present at Saturation (g/m³)	Relative Humidity
30	9	30	9 ÷30 * 100 = 30%
20	9	17	9 ÷ 17 * 100 = 53%
10	9	9	9 ÷ 9 * 100 = 100%

Figure AT-RH-1



Welcome Introduction Protocols Learning Activities Appendix

Teacher Support

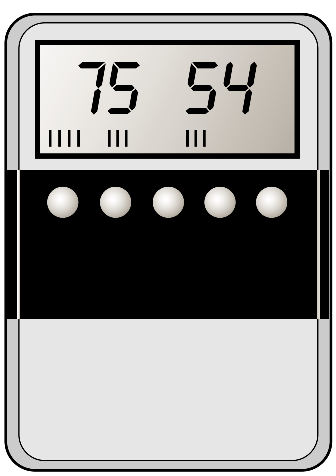
Digital Hygrometer

The hygrometer is a meteorological instrument with a long history. Initial hygrometers used human or other strands of hair, which when bundled, respond sensitively to moisture in the atmosphere (Perhaps some of you have experienced this yourself!) Using ceramic and metallic compounds, digital hygrometers which measure electrical resistance can also measure humidity over a wide range, thus making them ideal instruments for schools that cannot easily accommodate the difficulties of using the sling psychrometer for the humidity observations. No matter which instrument is used, the relative humidity observations will be useful to scientists.

Care must be taken to avoid exposure to condensation. If condensation occurs or is expected to occur during the time that the instrument will be exposed to the air in the instrument shelter, please do not place it outside. Rather, report a reading of 100% and enter comments "condensation occurring" in the metadata , which will indicate an inference, rather than a measurement, of relative humidity. An example of a digital hygrometer is shown in Figure AT-RH-2.

Most digital hygrometers may not be left in the instrument shelter during periods of condensation (precipitation or fog). Therefore, the instrument will have to be set out in the shelter at least 30 minutes before the local solar noon observations are begun. If you are also doing the ozone protocol, a convenient time to place the hygrometer in the shelter may be at the time you expose the ozone strip outside (which is one hour before your ozone observation is made).

Figure AT-RH-2: Digital Hygrometer



Some hygrometers have stands that can be used to place the instrument on the floor of the shelter. Some hygrometers may be probes that attach to external electronic devices, in this case place the probe in the shelter so that the sensor portion is not in contact with the sides of the shelter. After the hygrometer has been in the shelter at least 30 minutes, read the value of relative humidity to the nearest 1% on the digital display. Be sure that the "max" or "min" indicators are not lit, as this will indicate that the instrument is set to show the maximum or minimum value, not the actual value. Enter the reading on the *Data Entry Sheet* while you also enter your cloud, temperature and precipitation observations, and report the data to GLOBE.

No calibration is necessary for the instrument, until the calibration certificate that comes with it expires. Please send the instrument back to the factory for recalibration at the interval that the manufacturer recommends (usually two years).

Measurement Logistics

The digital hygrometer can be ruined by condensation within the instrument. For this reason, it should not be left out in the instrument shelter except in extremely dry locations and seasons. It must be kept inside in dry conditions and left outside only long enough to obtain a good measurement. If your building is not climate controlled, store the instrument in an air tight container with rice, wheat berries, or some other item which readily absorbs water from the air and keeps the air in the container dry. Don't forget to change the absorbing substance periodically

The instrument takes some time (roughly 30 minutes) to adjust to outside conditions. This presents a logistics challenge. Generally, the daily measurements of temperature, precipitation, and clouds can all be accomplished within 15 minutes, so the hygrometer will need to be placed outside during one visit to the Atmosphere Study Site and read during a later visit.

If you are taking ozone measurements, you will have a similar situation in that students come to the Atmosphere Study Site and expose an ozone strip and then come to the site one hour later to read the strip. One approach is to put the hygrometer in the instrument shelter when the ozone strip is exposed and to read it when the ozone strip is read. A reading of current temperature must be taken when the digital hygrometer is read and is also required when the ozone strip is read, so with this approach one current temperature reading will serve to support the interpretation of both the ozone and relative humidity measurements.

If precipitation or fog is occurring or imminent, do not take the hygrometer outside. Instead, report a reading of 100% on your Data Entry Sheet, and enter comments stating that the air is saturated, so the relative humidity is approximated.

Storing the Hygrometer

The hygrometer observation can be taken every day, but if the instrument will not be used for an extended time (i.e., one week or more), it may be desirable to remove the batteries. Always be sure that the instrument does not remain in the instrument shelter or anyplace else where it will be exposed to condensation, or will get wet.

Sling Psychrometer

The sling psychrometer is an instrument that consists of two thermometers attached to a sturdy housing, which can be whirled by hand. On one side, the "dry-bulb" thermometer measures the air temperature. On the other side, the "wet-bulb" thermometer (with a wick attached to the bottom of the thermometer) will be used to measure the temperature of air which is cooling by evaporation. Both thermometers show temperature decreasing as you go from bottom to top. The purpose of the measurement is find how much cooling by evaporation can take place at the time of the observation. The larger the difference between the dry-bulb temperature and wet-bulb temperature, the drier the air is. Using the air temperature and the wet-bulb temperature, the relative humidity can be determined easily. A scale for determining relative humidity is often found mounted to the instrument, or you may use an external psychrometric chart, which will come with the sling psychrometer. The standard sling psychrometer is shown in Figure AT-RH-3.

Before using your sling psychrometer, make sure that the columns of colored fluid are continuous because the columns may sometimes separate into segments during shipping. If there are gaps in the liquid column, grasp the thermometer by the case, making sure the thermometer is in an upright position, and shake the case until the liquid forms a continuous column. Do not press against the stem of the thermometer as this could cause breakage. You may need to tap the bottom of the thermometer against the palm of your hand as well. Each thermometer should also be calibrated against the calibration thermometer before use, and once every three months.

Questions for Further Investigation

How are *your* relative humidity observations related to air temperature?

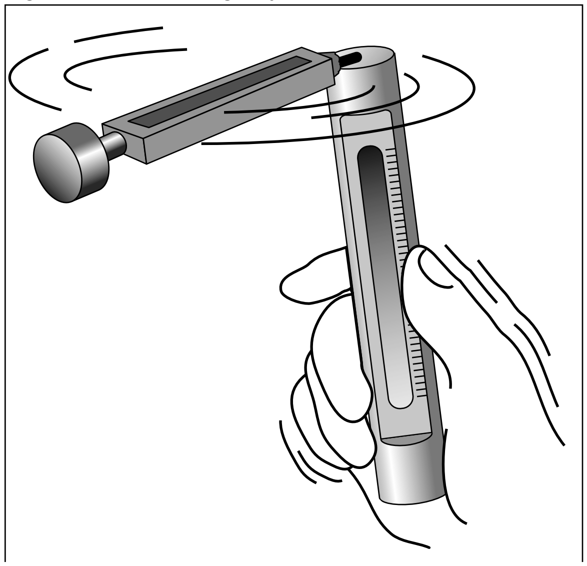
Can you find other GLOBE sites at your latitude which are closer to or further from large bodies of water? Do you see any systematic differences in relative humidity between your location and the others?

Does relative humidity affect any non-atmosphere parts of your local environment? How?

At what time of day will relative humidity normally be at a maximum? At a minimum?

Are your relative humidity and phrenology measurements related?

Figure AT-RH-3: Sling Psychrometer



Digital Hygrometer
Field Guide

Task

Find the relative humidity using a digital hygrometer.

What You Need

- ❑ Digital hygrometer
- ❑ *Atmosphere Investigation Data Sheet* OR *Ozone Data Sheet*
- ❑ Watch or timer
- ❑ A thermometer properly installed in an Instrument Shelter

In the Field

1. Place the hygrometer in the instrument shelter. (Unless it is very dry, do not leave the hygrometer in the shelter overnight!)
2. After at least 30 minutes, read the relative humidity, and note the instrument used.
3. Read the current temperature (if your reading is not being taken at the same time as the daily reading of maximum, minimum, and current temperature).
4. Return the hygrometer to the classroom, and store it in a dry place.

Sling Psychrometer
Field Guide

Task
Find the relative humidity by measuring the temperatures of wet bulb and dry bulb thermometers.

What You Need
- ❑ Sling psychrometer
- ❑ Watch or timer
- ❑ A psychrometric chart or scale
- ❑ *Atmosphere Investigation Data Sheet* OR *Ozone Data Sheet*

In the Field
1. Stand far enough away from other people and the instrument shelter so you will not hit them with the psychrometer. Stand in the shade if possible with your back to the sun. If there is no shade near the shelter, move to a shady spot nearby, but not too close to trees or buildings.
2. Keep the sling psychrometer as far away as possible from your body to prevent body heat from changing the temperature readings. This is very important in cold weather. Do not touch or breathe on the temperature-sensing parts of the thermometer as this, too, may affect the reading.
3. Open the sling psychrometer case by pulling out the slider, which contains the two thermometers.
4. Wait three minutes to allow the thermometer to read the current air temperature and then read the current dry bulb temperature to 0.5˚ C using the thermometer with no wick attached. Make sure your eyes are level with the instrument.
5. Record the dry bulb temperature.
6. Check to be sure that there is still distilled water in the reservoir, and that the wick is wet. If it is dry, add distilled water to the reservoir.
7. Sling the psychrometer for 3 minutes
8. Let the psychrometer stop whirling on its own! Do not stop it with your hand or other object.
9. Read the wet bulb temperature to 0.5˚ C (from the thermometer with the wick attached).
10. Record the wet bulb temperature.
11. Determine the relative humidity using a psychrometric chart or the sliding scale found on the cases of some psychrometers. You may also leave this blank as GLOBE can calculate relative humidity from your wet and dry bulb temperatures.
12. When you are done with the instrument, close it up and return it to the shelter properly.

Frequently Asked Questions

1. Why do you have two different methods of measuring relative humidity?

Two methods are used to try to provide an incentive for the teacher and student to make a determination about how much time is desired taking the observations. One is more complex (and fun) than the other. Observations from either method are equally valuable to the GLOBE program and scientists, in general.

2. How come we have to take the hygrometer inside each day, and bring it out to the weather shelter 30 minutes before we make our local solar noon observations?

The sensitive electronics inside the hygrometer cannot be exposed to condensation for long periods of time, so it is best to avoid all situations when condensation may be expected. If fog or persistent rainfall is occurring at the time of observation, it is best not to take the hygrometer outside; rather, the observer should report a relative humidity of 100%, but also should make a comment in the metadata that the observation was inferred based on visible condensation in the air (rain or fog).

3. I see the definitions for wet-bulb and dry-bulb temperature; what is the dew point temperature?

The dew point temperature is the temperature to which air must be cooled to achieve saturation (relative humidity = 100%) given its current water content. Dew point is a measure of the actual water vapor content. On calm clear days followed by calm clear nights, the temperature will fall rapidly towards the dew point. Unless dew forms, if the air temperature reaches the dew point temperature, fog may form. Once dew or fog forms, the dew point temperature will fall, because there is less water vapor in the air.

4. Why can't we use the sling psychrometer below freezing?

The relationship between evaporation rate and temperature is more complicated below freezing than above freezing, so the sling psychrometer will not be as practical. More expensive models that have greater ranges are available, but are beyond the reach of the expected school budgets for instruments. We recommend the use of a hygrometer for locations that have frequent temperatures below freezing.

5. How accurate are these relative humidity readings, compared to those that might be taken with more expensive instruments?

The hygrometer will report relative humidity with an accuracy range of 2-4%, within the desired 5% figure. The sling psychrometer reports temperature to within an accuracy of approximately 0.5° C; provided the calibration on the thermometers is maintained, this also ensures accuracy better than 5% over the most common range of values of relative humidity, between 20-95%.

Relative Humidity Protocol – Looking At the Data

Are the data reasonable?

To determine if the relative humidity data you collect are reasonable, it is important that you know what to expect the values for relative humidity to be.

Relative humidity is inversely dependent on temperature. This means that for a given air mass, as temperature rises, relative humidity falls, as long as the amount of water vapor contained in the air remains the same. If your relative humidity observations are taken at local solar noon, near the warmest part of the day, you will be measuring relative humidity when it is likely to be near its minimum value for the day.

When relative humidity reaches 100%, the air is said to be *saturated*. For air at a given temperature and pressure, any additional water vapor added to the air will condense as rain drops (or freeze as ice particles if the air is cold enough). For clouds to form, the air must be saturated.

Dew point temperature is another measure of humidity. The dew point is the temperature at which condensation begins to occur for air with a given water vapor content at a given pressure. While the relative humidity changes with temperature, the dew point remains constant because the water vapor content is not changing. When you look at the dew point temperature, remember that it will always be less than the air temperature, unless the air is saturated, in which case they are equal. If you measure relative humidity several times during the same day, the dew point temperature should remain the same unless a weather front has moved through the area.

Determination of the dew point temperature from the air temperature and relative humidity is a complicated calculation that the GLOBE server will do automatically for you so that visualizations and tables of dew point temperatures may be examined.

These points are illustrated in figure AT-RH-4, which shows hourly values of air temperature, dew point temperature, and relative humidity for a three-day period at Tallahassee Florida, USA. The temperature scale is shown on the left hand axis.

These data were collected using a data logger and an automated weather station at Florida State University, a GLOBE school. Local solar noon at Tallahassee is very near 1800 UTC each day (near the time of maximum temperature). Note that the temperature (shown in red) has a maximum value slightly higher than the previous day, and that in each case, it corresponds to the same time that the relative humidity (shown in green) is at its minimum. The relative humidity is at its maximum in the early morning (near 1200 UTC), when the temperature is at its lowest. Note how the dew point temperature (shown in blue) and air temperature are very close to each other at this time. These observations all indicate that the data appear to be reasonable.

Your relative humidity data should always be provided as a percentage between 0 and 100%. Your dew point temperature should always be less than or equal to your current temperature observations. Most importantly, unless your observations are taken during fog or precipitation events, your relative humidity should be less than 100%.

What do scientists look for in these data?

Scientists look at trends in relative humidity over different time periods. For instance, changes during a day may be related to sea breezes in coastal areas. In GLOBE, relative humidity usually is taken only once per day, near local solar noon. So with GLOBE data scientists examine trends in relative humidity over periods of days.

Scientists use relative humidity changes to forecast the weather. For example, they might look at temperature, relative humidity, and dew point to predict the likelihood of showers on a given day. In Figure AT-RH-4, note that the local solar noon relative humidity value increased by a small amount each day. This indicates a gradually moistening environment. That observation is more clearly shown by the dew point temperature values that have an upward trend throughout the period. Note that unlike temperature and relative humidity, the dew point temperature does not exhibit a strong diurnal cycle.

Figure AT-RH-5 shows a graph of temperature and relative humidity data for Norfork Elementary School in Arkansas, USA. These data vary considerably from day to day. Let's try to understand the data better by first focusing on the axes. On the abscissa, or x-axis, time begins on 1 October 2000 and ends in September 2001, so nearly one year of data are plotted. Data are available for each day with few missing observations; even weekends are included! Now examine the ordinates, or y-axes (there are two of them). On the left, we find the scale for temperature, and on the right, we find the scale for relative humidity.

It is difficult to see that the temperature versus relative humidity relationship we described earlier exists here, but we can smooth such data to illustrate the relationship. The next figure (AT-RH-6) shows a smoothed graph using 5-day running averages of the data. To calculate a 5-day running average, you average the values for today, the two previous days, and the two following days.

Now the relationship can be seen more clearly. In the winter with cold mid-day temperatures, the relative humidity is often above 60%, but in summer the relative humidity is only rarely above 60%. This can also be used as a consistency check, to help to ensure your data are reasonable. These observations may also be used to examine the influence of temperature on relative humidity, when actual water vapor content does not change very much.

We can of course observe the progression of temperature throughout the year, with the coldest temperatures in December and January. Note how the relative humidity is a near maximum for many of these winter days! There can of course be dry days during winter months as well, and scientists use relative humidity monitoring to classify air masses. These air mass identifications help meteorologists identify and monitor frontal systems and provide useful weather forecasts. Climatologists also use relative humidity to classify climates for various locations.

One of the main climatic controls that scientists recognize is how close a location is to a large body of water, such as a sea or ocean. Let's look at two GLOBE schools' humidity data to see if we recognize such a relationship. We will use the dew point temperature rather than the relative humidity here, to examine only the affect of water vapor content. Relative humidity, remember, includes both water vapor effects, and temperature effects.

Figure AT-RH-7 illustrates observations from two schools in Europe, the Istituto Tecnico Industriale Fermi, in Naples, Italy, and the Hermann Lietz-Schule Haubinda in Germany. Remember that the dew point temperature will illustrate only how the water vapor content of the air at a weather station changes over time. The graph illustrates a plot of three months of observations from winter 2001 (January through March), and on every day for which observations were taken from these two schools, you can see how the dew point temperature at Naples, located on the Mediterranean Sea, was much higher than the dew point at Haubinda, located far inland.

Although elevation, latitude, and air motion (the other major climatic controls) may help to explain some of these differences, how close a station is to large bodies of water will play a large role, in general, due to the large amount of evaporation that takes place in coastal regions. A useful project for GLOBE coastal schools is to compare the dew point values calculated from their data with those from a school at roughly the same latitude and elevation that is well inland from the same body of water. Is the relationship similar?

It is interesting to see how relative humidity is related to other meteorological variables. Naturally, as evaporation increases, relative humidity increases. So, we would expect to find a relationship with cloud cover, since clouds require a relative humidity at their altitudes of 100%. We measure relative humidity near the ground, not at the cloud base, but in general, relative humidity increases with altitude up to

Figure AT-RH-4

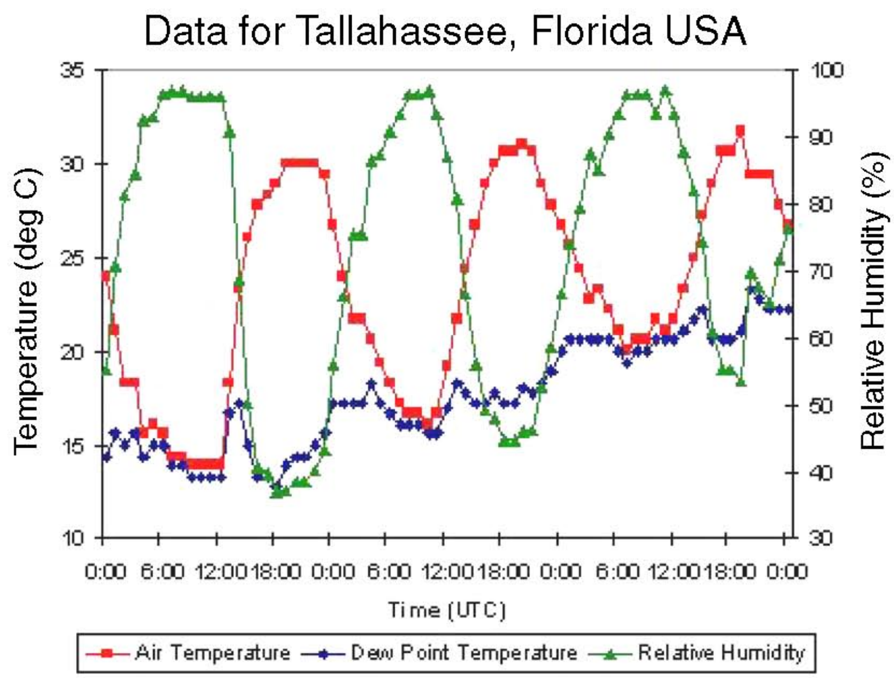


Figure AT-RH-5

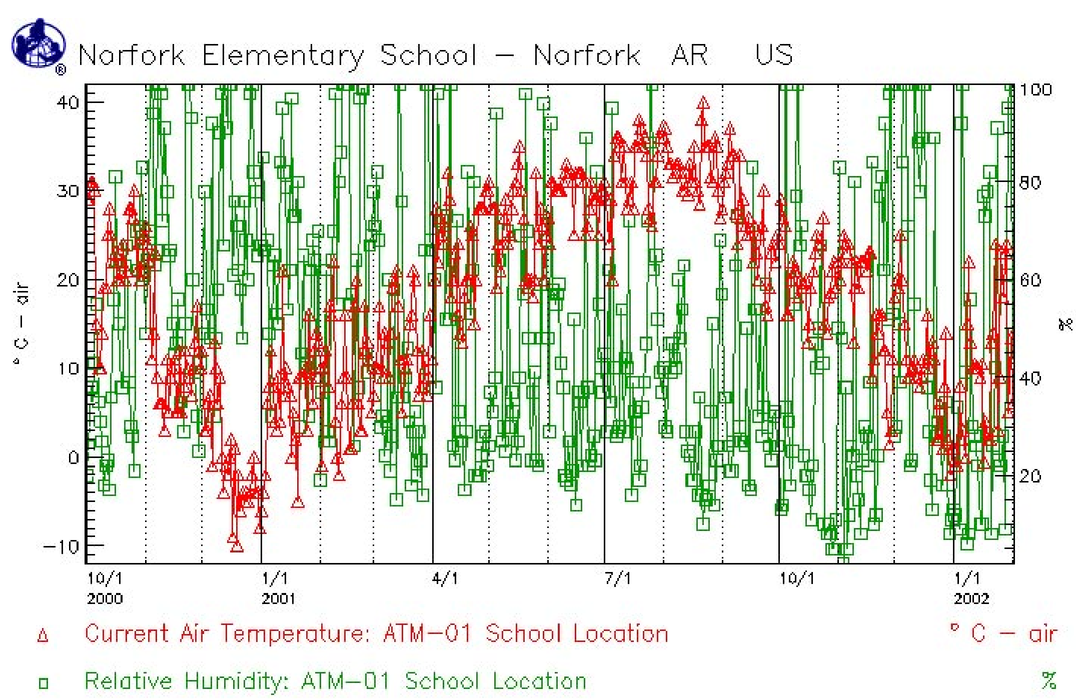


Figure AT-RH-6

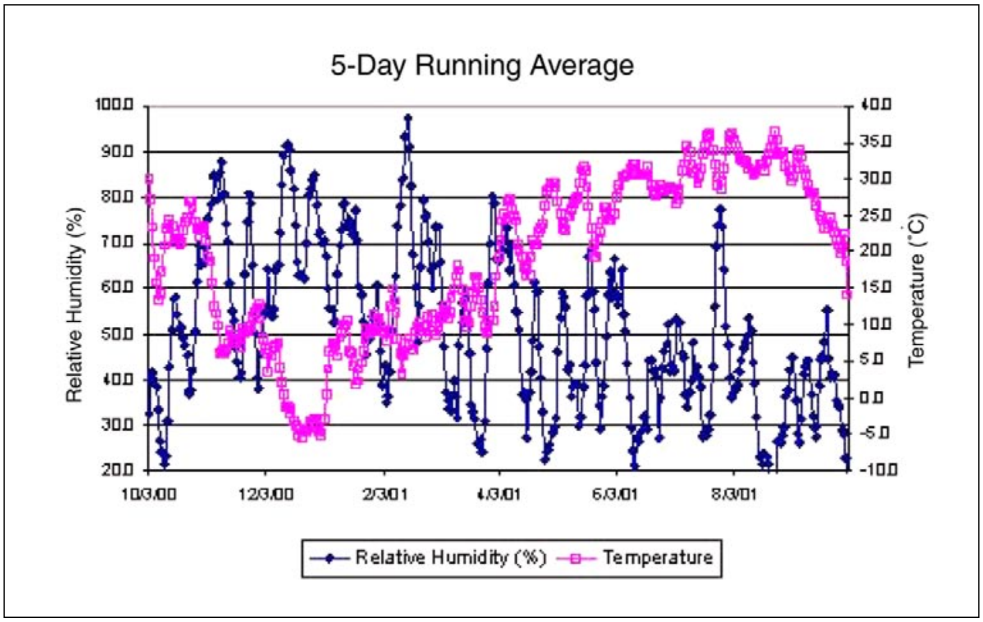


Figure AT-RH-7

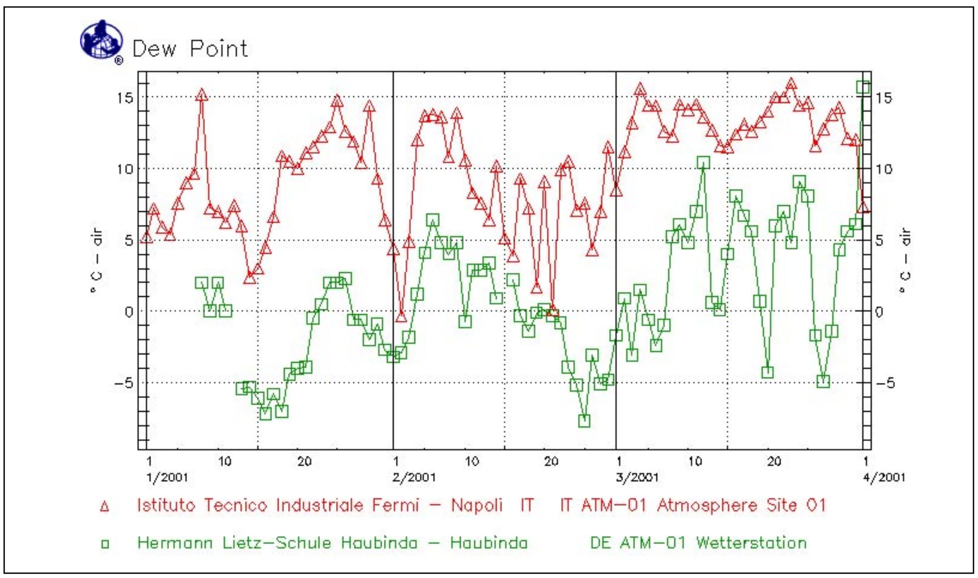
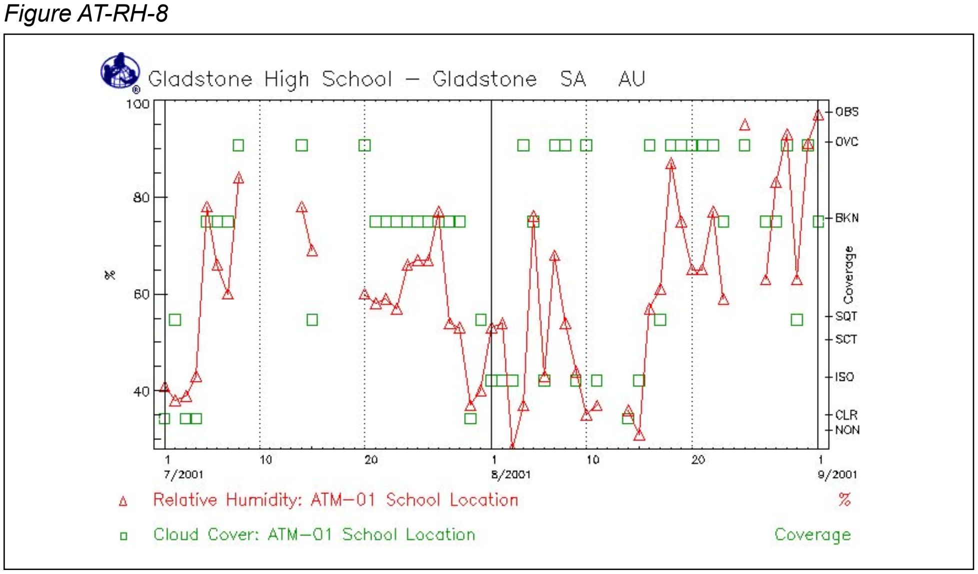


Figure AT-RH-8



100% at the base of the clouds. This is true for low clouds, in particular. Figure AT-RH-8 shows a plot of relative humidity and cloud cover from Gladstone High School in South Australia for July and August of 2001 (during winter). Note that on this graph relative humidity is shown as a red graph with connected lines, and the cloud cover is indicated as a single square for each day's cloud cover observation. There are several days when the relative humidity is at or below 50%, and on each of these days, the cloud cover was clear or isolated. Only when the relative humidity approaches 60% was scattered cloud cover observed in these two months. Broken and overcast skies occurred only when the relative humidity was greater than 50%. The relationship is not perfect, but for most days it is clear that when relative humidity is high, cloud cover is more likely to be high than not.

You can test the hypothesis that there is a relationship between cloud cover and relative humidity for a school like Gladstone by averaging the relative humidity for all days for various cloud covers. Let's test the hypothesis that on average as relative humidity increases, cloud cover also increases. Using data from Gladstone as an example, let's compute the average relative humidity for the scattered cloud cover days and the isolated cloud cover days. These calculations are shown in the box below.

Based on these limited observations, our hypothesis has been supported. In general scientists would want to use equal numbers of days for such tests and comparisons, and also would want to use at least 30 observations for each. You could do this for all your cloud cover and relative humidity observations to see how well this relationship holds for your location.

An Example of a Student Research Investigation

Designing an Investigation

Heikki, a student at Juuan Lukio/Poikolan Koulu in Juuka, Finland has been taking relative humidity measurements along with other students at his school. In studying climate, his teacher mentioned the moderating effect on air temperature of nearby large water bodies. When he asks questions about how this works, his teacher mentions that evaporation from the water causes higher levels of relative humidity and that it takes more energy to heat or cool moist air than dry air.

Heikki decides that this would make a good investigation. He wonders if relative humidity values from inland schools will be lower on average than the values from a coastal school. After looking at the GLOBE archive he selects three inland schools and one coastal school. He also decides to only look at data from late spring and early summer when ice will not be covering the water body. Table AT-RH-2 shows the data he found for these four schools.

Scattered Cloud Cover

$$\frac{38 + 68 + 41 + 62 + 64}{5} = 54.6\%$$ average relative humidity for scattered cloud cover days

Isolated Cloud Cover

$$\frac{54 + 55 + 27 + 42 + 43 + 36 + 31}{7} = 41.1\%$$ average relative humidity for isolated cloud cover days

Table AT-RH-2. Relative Humidity at GLOBE Schools from Heikki's Sample

Date	Juuka Inland	Ammansaari Inland	Utajarvi Inland	02600 Espoo Coastal
5/10/01	32	77	49	39
5/11/01	39	57	39	32
5/12/01	46	57	50	32
5/13/01	68	94	65	48
5/14/01	77	80	42	35
5/15/01	33	78	61	49
5/16/01	30	53	33	33
5/17/01	30	45	38	97
5/18/01	46	98	83	96
5/19/01	56	97	87	83
5/20/01	56	98	89	71
5/21/01	54	85	81	81
5/22/01	41	70	54	39
5/23/01	95	100	74	78
5/24/01	39	65	58	41
5/25/01	39	80	50	46
5/26/01	41	66	49	37
5/27/01	43	74	50	52
5/28/01	51	88	74	38
5/29/01	50	73	63	50
5/30/01	53	52	40	45
5/31/01	32	45	33	38
6/1/01	23	35	29	42
6/2/01	28	33	32	52
6/3/01	—	38	31	58
6/4/01	33	46	70	36
6/5/01	51	88	85	53
6/6/01	25	48	49	38
6/7/01	30	51	44	38
6/8/01	46	60	71	73
6/9/01	57	97	63	97
6/10/01	90	92	84	70
6/11/01	41	62	67	65
6/12/01	72	63	77	96
6/13/01	84	87	89	97
6/14/01	48	92	67	90
6/15/01	32	74	47	56
6/16/01	43	77	63	52
6/17/01	39	67	42	97
6/18/01	49	74	50	63
6/19/01	47	57	41	97
6/20/01	39	44	29	97
6/21/01	85	61	52	97
6/22/01	78	59	64	90
6/23/01	41	35	39	58
6/24/01	29	39	33	46
6/25/01	34	55	34	—
6/26/01	46	57	46	48
6/27/01	39	55	38	66
6/28/01	33	60	37	56
6/29/01	39	53	36	63
6/30/01	37	76	66	65
7/1/01	33	51	58	76
7/2/01	65	85	65	61
7/3/01	41	60	65	47
7/4/01	38	53	49	44
7/5/01	39	99	89	41
7/6/01	35	62	47	58
7/7/01	46	—	56	47
7/8/01	51	70	52	60
7/9/01	41	59	59	48
7/10/01	51	92	63	58
7/11/01	62	89	75	69
7/12/01	54	70	62	60
7/13/01	82	68	65	53
Avg. RH	47.3	67.6	56.0	60.0
Days highest	2	35	5	21

Collecting and Analyzing Data

Heikki calculates the average relative humidity for each of these schools by adding up all values reported for this time period from each school and dividing the sum by the number of days for which data were reported. His results are given on the next-to-last line of Table AT-RH-2.

Heikki asks a younger student if she would figure out whether the coastal school has higher relative humidity than the inland schools. She decides to look at which school reported the largest value for relative humidity each day and to count how many days each school's value was highest. She noticed that some days, only three schools reported data, so she skipped those days. Her results are given on the last line of Table 1.

Heikki is quite surprised to find that both the younger student's approach and his found that one of the inland schools had the *highest* relative humidity overall for this time period. The coastal school was only second highest.

Heikki concludes that there are clearly exceptions to the general rule about how relative humidity varies between coastal and inland schools. His teacher asks what more he could do to investigate the. The teacher tells Heikki that he could look for more schools in Finland with the relevant data, look for sets of inland and coastal schools from another country, or try to learn more about the geography of the school which had higher relative humidity than the coastal school in his study.

The teacher points out that Heikki's investigation did not examine the moderating effect of relative humidity on air temperature, nor did his investigation include the effects of altitude. They agree that Heikki will do a study of this as part of a group investigation with several of his classmates. The group discusses the concept they are going to study and decides that they will compare the difference between maximum and minimum air temperature for each day with the relative humidity data. Since the maximum and minimum air temperatures cover a 24-hour period that begins one day and ends the next, the group concludes that they will compare with the average relative humidity for each two-day pair. These data comparisons are shown in Table AT-RH-3.

Table AT-RH-3

Date (2001)	Juuka		Ammansaari		Utajarvi		02600 Espoo	
	Average 2-day RH (°C)	Temp. Range (%)	Average 2-day RH (°C)	Temp. Range (%)	Average 2-day RH (°C)	Temp. Range (%)	Average 2-day RH (°C)	Temp. Range (%)
10-May		17.0		10.5		0.7		
11-May	35.5	9.0	67.0	9.0	44.0	8.8	35.5	15.1
12-May	42.5	5.1	57.0	4.0	44.5	2.2	32.0	18.0
13-May	57.0	5.0	75.5	6.0	57.5	1.5	40.0	8.5
14-May	72.5	5.0	87.0	5.5	53.5		41.5	18.3
15-May	55.0	10.2	79.0	6.0	51.5		42.0	16.6
16-May	31.5	14.9	65.5	10.0	47.0	1.7	41.0	19.9
17-May	30.0	18.1	49.0	14.0	35.5		65.0	12.5
18-May	38.0	8.0	71.5	12.5	60.5	12.2	96.5	10.5
19-May	51.0	5.5	97.5	2.5	85.0	5.1	89.5	8.7
20-May	56.0	5.5	97.5	6.0	88.0	7.0	77.0	7.5
21-May	55.0	9.0	91.5	4.0	85.0	3.6	76.0	5.6
22-May	47.5	4.0	77.5	3.5	67.5	6.9	60.0	14.9
23-May	68.0	10.0	85.0	6.0	64.0	7.4	58.5	16.9
24-May	67.0	9.6	82.5	7.5	66.0	9.0	59.5	12.3
25-May	39.0	7.2	72.5	7.5	54.0	5.8	43.5	9.6
26-May	40.0	6.2	73.0	4.5	49.5	3.5	41.5	15.7
27-May	42.0	8.1	70.0	4.0	49.5	8.5	44.5	14.5
28-May	47.0	9.6	81.0	4.5	62.0	7.8	45.0	12.2
29-May	50.5	4.9	80.5	4.0	68.5	3.4	44.0	8.1
30-May	51.5	6.3	62.5	4.0	51.5	8.9	47.5	12.0
31-May	42.5	12.0	48.5	10.5	36.5	14.0	41.5	14.4
1-Jun	27.5	15.4	40.0	8.0	31.0	15.3	40.0	19.3
2-Jun	25.5	16.3	34.0	12.0	30.5	11.4	47.0	17.4
3-Jun			35.5	9.0	31.5	16.8	55.0	9.9
4-Jun		14.9	42.0	10.0	50.5	9.7	47.0	17.5
5-Jun	42.0	10.4	67.0	10.5	77.5	7.4	44.5	17.2
6-Jun	38.0	16.8	68.0	14.5	67.0	13.6	45.5	16.8
7-Jun	27.5	12.4	49.5	8.5	46.5	7.2	38.0	16.8
8-Jun	38.0	9.8	55.5	6.5	57.5	10.0	55.5	
9-Jun	51.5	8.0	78.5	7.0	67.0	7.0	85.0	5.3
10-Jun	73.5	10.1	94.5	7.5	73.5	6.1	83.5	10.9

Date (2001)	Juuka Average 2-day RH (%)	Juuka Temp. Range (°C)	Ammansaari Average 2-day RH (%)	Ammansaari Temp. Range (°C)	Utajarvi Average 2-day RH (%)	Utajarvi Temp. Range (°C)	02600 Espoo Average 2-day RH (%)	02600 Espoo Temp. Range (°C)
11-Jun	65.5	9.6	77.0	9.5	75.5	10.6	67.5	11.0
12-Jun	56.5	6.1	62.5	6.0	72.0	5.2	80.5	6.7
13-Jun	78.0	5.6	75.0	8.5	83.0	6.8	96.5	5.0
14-Jun	66.0	12.5	89.5	8.5	78.0	6.8	93.5	4.7
15-Jun	40.0	15.5	83.0	8.5	57.0	11.5	73.0	16.8
16-Jun	37.5	13.5	75.5	7.0	55.0	12.0	54.0	18.2
17-Jun	41.0	12.8	72.0	9.0	52.5	14.0	74.5	12.3
18-Jun	44.0	6.7	70.5	8.5	46.0	8.4	80.0	12.3
19-Jun	48.0	8.2	65.5	9.0	45.5	8.8	80.0	2.4
20-Jun	43.0	9.6	50.5	9.5	35.0	10.5	97.0	2.5
21-Jun	62.0	7.3	52.5	9.0	40.5	7.9	97.0	3.7
22-Jun	81.5	4.1	60.0	7.0	58.0	3.2	93.5	10.7
23-Jun	59.5	9.2	47.0	8.0	51.5	6.7	74.0	
24-Jun	35.0	14.8	37.0	10.5	36.0	14.5	52.0	
25-Jun	31.5	13.0	47.0	7.5	33.5	16.6		
26-Jun	40.0	15.5	56.0	12.0	40.0	14.5		
27-Jun	42.5	15.2	56.0	9.5	42.0	13.1	57.0	14.7
28-Jun	36.0	12.9	57.5	6.5	37.5	11.5	61.0	13.8
29-Jun	36.0	9.7	56.5	9.0	36.5	10.3	59.5	14.4
30-Jun	38.0	9.0	64.5	9.0	51.0	5.2	64.0	9.5
1-Jul	35.0	14.6	63.5	10.5	62.0	8.2	70.5	10.8
2-Jul	49.0	11.2	68.0	9.0	61.5	7.8	68.5	6.3
3-Jul	53.0	10.4	72.5	7.5	65.0	11.3	54.0	14.1
4-Jul	39.5	8.0	56.5	6.5	57.0	7.1	45.5	15.4
5-Jul	38.5	16.0	76.0	10.5	69.0	7.2	42.5	10.5
6-Jul	37.0	13.2	80.5	9.0	68.0	13.1	49.5	14.0
7-Jul	40.5	18.8			51.5	14.2		
8-Jul	48.5	10.1		8.5	54.0	15.7		
9-Jul	46.0	12.4	64.5	8.5	55.5	13.2	54.0	12.0
10-Jul	46.0	15.1	75.5	9.5	61.0	9.9	53.0	2.5
11-Jul	56.5	5.7	90.5	7.5	69.0	6.5	63.5	6.3
12-Jul	58.0	9.0	79.5	6.5	68.5	8.3	64.5	5.0
13-Jul	68.0	12.3	69.0	10.0	63.5	8.4	56.5	7.9

Figure AT-RH-9: Average Temperature Range Plotted as a Function of Average Relative Humidity for Schools in the Study Sample

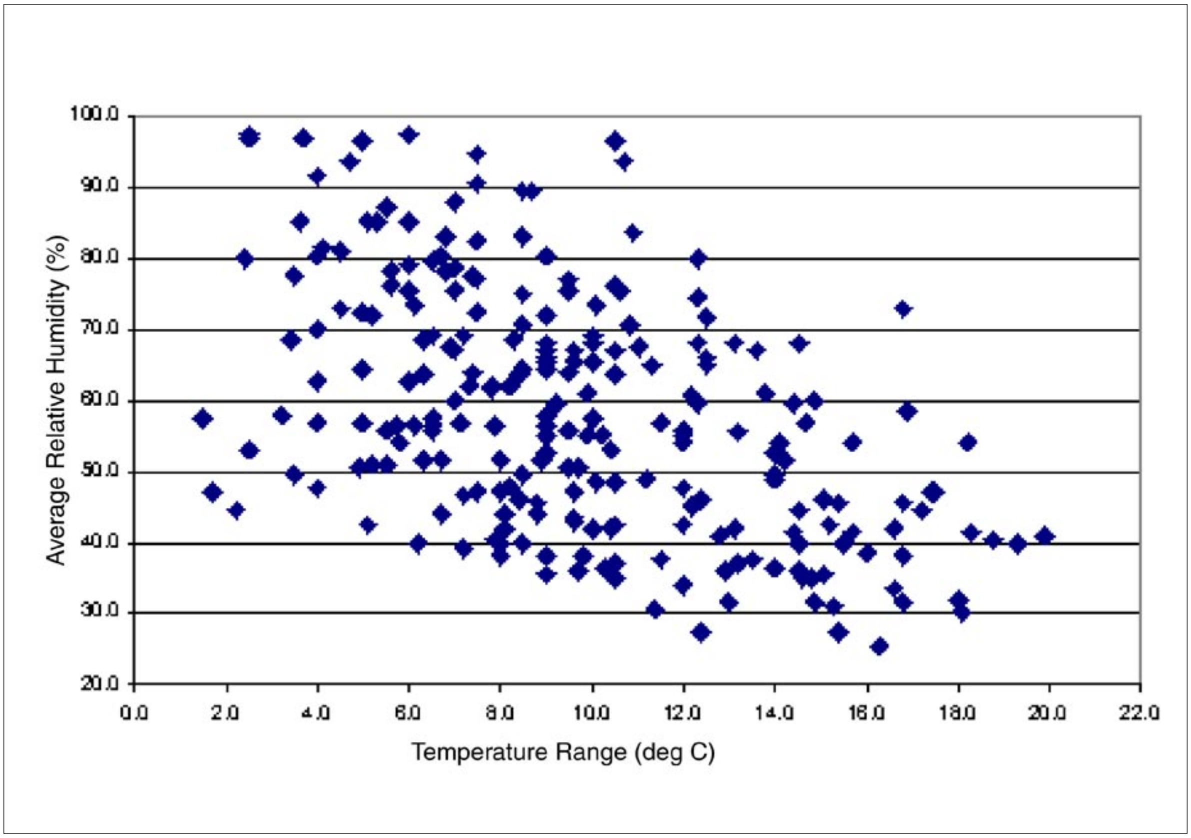
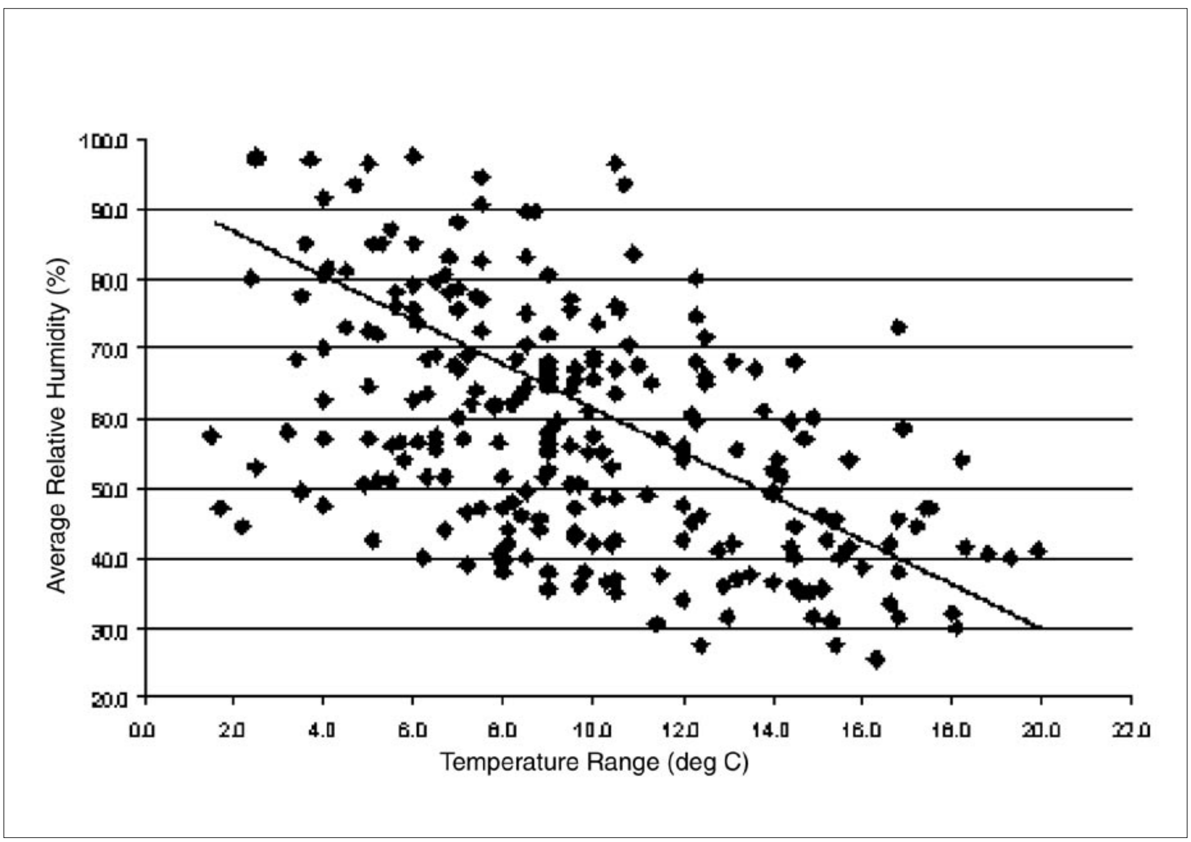


Figure AT-RH-10



Communicating Results

The students calculate temperature range for each day for each school and then graph all the points together with temperature range on the y-axis and relative humidity on the x-axis. Figure AT-RH-9 shows the result.

The students can see that for low temperature ranges (for example, less than about 4˚C), the average relative humidity reported is generally above 45%, and as the temperature ranges get larger, lower relative humidity values are reported. In fact, for high temperature ranges (greater than 16˚C), only one observation of relative humidity greater than 70% is reported, all the remaining observations are less than 60%. So, there indeed does appear to be a good relationship between these datasets.

This relationship is an inverse relationship, because as one variable increases, the other variable tends to decrease. If we tried to develop a line that best fits the data points, which might be used to try to forecast relative humidity from the temperature range, it might look like the line shown in Figure AT-RH-10. This line is called a least squares fit line, and it measures the best "straight-line" representation of the data that are plotted.

Future Research

The results are so encouraging that Heikki decides next to investigate the effects of altitude to see if he can explain his surprising results from the first experiment, and to look further at other geographic areas to see if the conclusions here are the same as his findings. He looks forward to the results from these investigations and the possible international collaborations to which they may lead.

Precipitation Protocols

Purpose

To determine the amount of moisture input to the local environment by measuring rain and snowfall and to measure the pH of precipitation

Overview

Students use a rain gauge and a snowboard to measure the daily amount of precipitation that has occurred. Students measure the depth and rain equivalent of each day's snow and of the total snowpack. Special pH measuring techniques for precipitation are used to determine the pH of rain and melted snow.

Student Outcomes

Students will understand that precipitation is measured in depth and this depth is assumed to apply to a large area, that precipitation has a pH that can vary, and that snow is an input of water to the surface just like rain and each snowfall is equivalent to some amount of rainfall.

Science Concepts

Earth and Space Science

- Weather can be described by quantitative measurements.
- Weather changes from day to day and over the seasons.
- Weather varies on local, regional, and global spatial scales.
- Precipitation forms by condensation of water vapor in the atmosphere.

Physical Science

- Materials exist in different states.

Geography

- The nature and extent of precipitation affects the characteristics of the physical geographic system.

Scientific Inquiry Abilities

- Use a rain gauge to measure rainfall and rain equivalent of snow.
- Use pH paper, pen, or meter to measure pH.
- Use meter sticks to measure snow depth.
- Identify answerable questions.
- Design and conduct scientific investigations.
- Use appropriate mathematics to analyze data.
- Develop descriptions and explanations using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures and explanations.

Time

In the field: 5 minutes for rain,
10-15 minutes for snow

In the lab: 5 minutes for snow rain equivalent
5 minutes for pH

Maintenance: 10 minutes weekly for cleaning the rain gauge

Level

All

Frequency

Daily within one hour of local solar noon

Materials and Tools

- Installed rain gauge
- Snowboard
- Clean containers for pH samples 100 mL or larger
- Two or three containers for snow samples
- Carpenter's level
- Meter stick
- pH paper OR meter and pH buffers
- Salt and salt card or tweezers
- Sampling jar with lid
- 300 mL beakers or cups
- Tweezers
- Stirring rods or spoon
- Latex gloves
- *Atmosphere Investigation Data Sheet*
- Distilled water for cleaning rain gauge

Preparation	***Prerequisites***
Install the rain gauge. Construct a snowboard. Read and be familiar with the *Hydrology Investigation pH Protocol.*	None

Precipitation Protocols – Introduction

Earth is the only planet in our solar system where significant amounts of liquid water flow on the surface. All life depends on water. The water in the atmosphere, which plays an essential role in determining the weather, is part of the larger hydrologic cycle. In this cycle, water evaporates from the oceans and land into the atmosphere, falls back to the surface as precipitation, and returns to the sea on the surface in rivers and streams, and underground. Through this process, energy and chemicals are transported from place to place shaping our climate, giving us storms, and putting salt in our oceans and seas.

Precipitation refers to all forms of liquid or solid water that fall from the atmosphere and reach Earth's surface. Liquid precipitation includes rainfall and drizzle; solid precipitation includes snow, ice pellets, and hail. How much precipitation falls in a region, when it falls within the year, whether it falls as rain or snow, and the amount that falls in individual events helps define the climate of that region. When water is scarce, deserts occur. When there is plenty of water, there may be an abundance of plant growth. Winter rains are associated with Mediterranean climates. The water supply for many great rivers is the melting of the snow pack high in the mountains. Knowing how much precipitation falls and how much and when snow melts is key to understanding local and global climate.

When we study the history of Earth's climate, we notice that precipitation in all regions changes over time. For example, satellite images show that great rivers used to run through the Sahara Desert. There is scientific evidence that a shallow sea once covered much of the United States. All of these changes happened long before people lived in these regions. What changes are happening now?

Scientists do not have a very good idea of how much of the water cycle is made up of snowfall. Although the depth of snowfall can be measured using a relatively simple instrument (a meter stick), making accurate measurements is somewhat difficult because of the tendency of snow to blow around. In addition, not all snowfalls of the same depth contain the same amount of water. If you have ever lived in a place where there is snow, then you know that some snowfalls are light and fluffy (and don't make very good snowballs!), and some are heavy and wet (and are great for making snow people). In order to get an accurate idea of how much water is tied up in snowfall we need to measure both the depth and the rain equivalent of snow.

The atmosphere contains small amounts of many different chemicals. Some are in the form of gases but others are small particles suspended in the air called aerosols. These gases and particles are picked up in raindrops and snowflakes and we can't measure them all, but many of them change precipitation pH, which can be measured easily. The pH of the precipitation helps determine the effect of rainfall and snowfall on soil, vegetation, lakes, and streams.

Some rainstorms and snowstorms are big, covering whole regions, while others may be only 10 km across or even smaller. Within a storm, the amount of precipitation that falls and its pH vary from one place to another and may change during the course of the storm. It is not practical to catch and measure every raindrop or snowflake. We have to be content with samples collected in different places, but with more samples, our overall data on precipitation becomes more accurate. Every GLOBE school improves the knowledge of precipitation in its surrounding area!

Teacher Support

Precipitation Measurements and Sampling

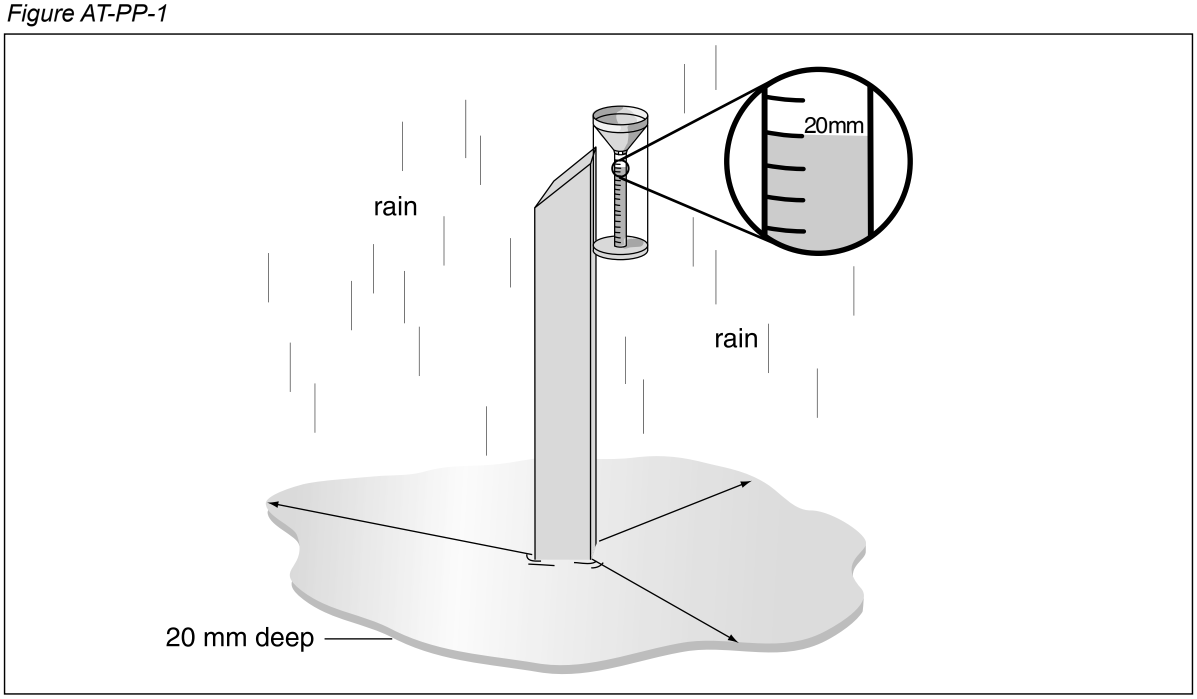
Scientists who model the hydrologic cycle need to know the total amount or volume of water that falls from the atmosphere to Earth's surface. When meteorologists and others measure precipitation they measure the depth of rain or snow that has fallen in a given amount of time. Rain gauge measurements, such as those done by GLOBE students, sample the amount of precipitation that falls. To get the total amount, you assume that the same depth of water fell over the area surrounding the rain gauge. See Figure AT-PP-1. If there is only one rain gauge in a region, this area can be quite large; the larger the area, the poorer the assumption. As more schools and others measure precipitation depth, the area represented by each measurement gets smaller and our knowledge of this part of the hydrologic cycle improves.

Measuring just the depth of snowfall isn't enough to enable you to know how much water is falling on the surface. Anyone who is experienced with snow knows that some snowfalls are light, powdery and relatively dry. Other snowfalls are heavy and wet. To determine the rain equivalent of a given snowfall, we need to collect a known quantity of snow and melt it.

Just as we can't just put a big bucket outside and then use a meter stick to measure the depth of rainfall; We can't just go out, collect a bucketful of snow and melt it. We need to collect snow to melt in a container of known size. The best way to determine the liquid water equivalent of snow is to use the outer cylinder of your rain gauge as your collection devise. By pushing the large cylinder straight down through the snow you will collect snow with an instrument of a known size.

Water moves through every living plant and animal. Chemicals in rainwater can have important effects on the land and water ecosystems. As water condenses into raindrops, some chemicals in the atmosphere dissolve in them and are carried to the surface with the rain. Aerosols (particles suspended in the air) also become attached to both raindrops and snowflakes and are washed out of the atmosphere by precipitation. Scientists call these processes wet deposition because through these processes precipitation deposits chemicals on Earth's surface.

Figure AT-PP-1



Scientists want to know how much of every possible chemical is deposited; GLOBE students can provide some help by measuring the most important chemical property of the precipitation, pH. The pH of water is altered as it moves through the environment. When water first condenses in the atmosphere, its pH is very close to neutral (7.0). Then, gases and particles from the atmosphere dissolve in the water droplets. This usually lowers the pH, making the droplets more acidic, but in regions where soil pH is high (8.0 or higher), the pH may increase as soil particles blown into the air are incorporated in raindrops. Normal precipitation in clear air is slightly acidic, having a pH of about 5.6. This is due to carbon dioxide (CO_2) and nitrogen in Earth's atmosphere. As water flows over the land surface or though the soil, the pH is changed by dissolving chemicals from the surface or soil.

Burning of some fuels releases gases (generally nitrogen or sulfur oxides) into the atmosphere that dissolve in water droplets and make precipitation more acidic. If the pH of rainfall is below 5.6 it is regarded as acid precipitation, and over a long period of time, it can directly harm plants. The most serious effect of acid precipitation, however, is weakening plants so that they become more susceptible to stresses such as cold, disease, insects, and drought. Acidic precipitation also leaches nutrients out of the soil and can release soluble aluminum ions from the soil, which can damage tree roots. If these aluminum ions are washed into lakes and streams they can harm many kinds of fish. In addition to being harmful to life forms, acid precipitation can damage structures. Acid precipitation is known to increase corrosion of metals and contributes to the destruction of stone structures and statues. In many regions of the world famous buildings and sculptures are deteriorating at increased rates.

The changes that can be studied using GLOBE precipitation data are those happening on shorter time scales of days to years. What is the seasonal variation in precipitation? When and how fast does snow melt and make its water available to the environment? Is this year particularly wet or dry for our location? What is the pH of precipitation and how does it vary? These are some of the questions that interest scientists and can be researched by GLOBE students.

Measurement Issues

Daily measurement of rain is desired. This provides a full picture of the pattern of rainfall and precipitation pH at your school and also ensures that the rain gauge is checked daily for debris, bird droppings, etc. GLOBE permits reporting of rain accumulations for up to 7 days, but as the number of days increases, the accuracy of the measurement decreases. Some of the water may evaporate from the rain gauge, especially when it's warm, samples may become contaminated, and the amount and pH readings may be for a combination of storms and weather systems. Despite these issues, there is considerable value in knowing the total input of water to your local environment over time, and so, reports of the total rainfall over several days are important when your students are unable to take daily readings.

It is important to report zero when there is no rain. If a school only reports rain when there is rain in the gauge, users of the data don't know what happened on the other days and this may make the data useless. Sometimes rain is spilled from the gauge before a reading is taken. In this case, always report "M" (missing) as the amount. This indicates to scientists using GLOBE data that there was rainfall for this day (or period of days) but an accurate reading was not obtained. If less than half a millimeter of rain is in the gauge, report "T" (trace) as the amount. See Table AT-PP-1.

It is important to take daily readings of snowfall. However, if this is not possible then the number of days since the last reading must be reported to GLOBE, along with the next reading. For example, say that you cleared the snowboard on Friday, but missed measurements on Saturday and Sunday. If you then measure snowfall on the board on Monday, you would report the total amount of new snow on the board, and enter "3" for the number of days that the snow accumulated. Even if you think you know that all of the snow fell on Sunday night, you must still report that your measurement on Monday

Table AT-PP-1: Reporting Precipitation

Type of Event	Report to GLOBE the # of days since your last measurement AND……
No rainfall	0
Rainfall > 0.5 mm with no problems reading the gauge	The rainfall amount in your rain gauge
Very small amount of rain < 0.5 mm	T (for Trace)
Spilled rain gauge before measurement could be made; gauge post fell over; etc	M (for Missing)

is the accumulation of 3 days. As with the rain gauge, accidents do happen and there may be a day when the snowboard has blown away or has been cleared before a measurement can be taken. In this case you should enter the letter "M" (for missing) for the daily snowfall amount. It is important that you record a missing value in these cases rather than a zero. Although it is a common mistake to substitute zero for missing values, this can lead to erroneous analyses of the data later on. However, only enter the letter "M" if the snowfall measurement is truly lost. That is, don't enter "M" for days when snow was accumulating on the snowboard. For example, when snowfall was read on Friday and Monday, but allowed to accumulate on Saturday and Sunday. DO NOT report "M" for the snowfall values for Saturday and Sunday. These values are not missing; they are included in the total snowfall reported on Monday.

Even if no new snow has fallen on your snowboard in the past 24 hours, you should take a daily measurement of the total depth of snow on the ground. This observation can give scientists information about how quickly snow is melting or sublimating (going from a solid form to a gas without first turning into a liquid).

In addition to measuring the amount of rainfall (and the rain equivalent for snow) you should measure the pH of the rain or melted snow using either pH paper or a pH meter. Special considerations must be made because most precipitation has low conductivity and both pH paper and pH meters do not perform well for low conductivity samples. Adding salt crystals to the rain or melted snow will increase the conductivity to an appropriate level. You can use either large salt crystals (0.5 mm to 2.0 mm in diameter) or finely ground "table" salt (with crystals less than 0.5 mm in diameter), as shown in Figure AT-PP-2. If you choose to use "table" salt you will use a *salt card* to measure the proper amount of salt. A *salt card* is an index card or clean piece of paper that contains two circles, one with a diameter of 4 mm and another with a diameter of 5 mm. You can create a *salt card* by either drawing two such circles on an index card or clean piece of paper or tracing or photocopying Figure AT-PP-3 onto a clean piece of paper. Large salt crystals are added using tweezers.

Figure AT-PP-2: Two Sizes of Salt Crystals

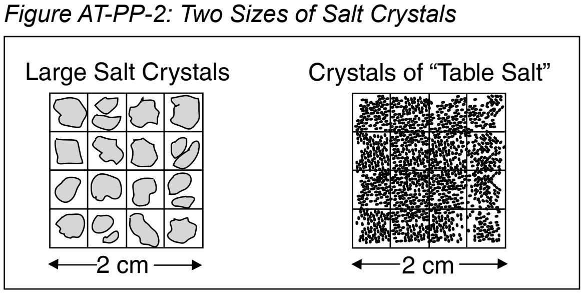
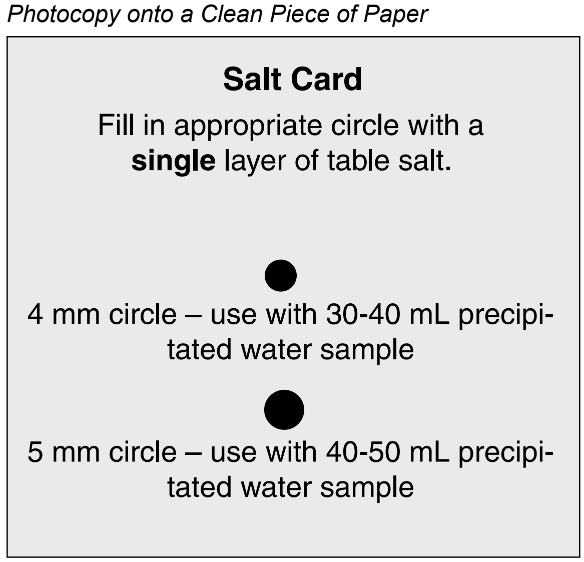


Figure AT-PP-3: Example Salt Card to Trace or Photocopy onto a Clean Piece of Paper



Student Preparation

Liquid Precipitation

Prior to the actual placement of the rain gauge, take a walk with students around the school grounds to locate the best places to put the gauge. Good questions to help get students started determining the best places to set up the rain gauge would be:

- Where would you put a rain gauge to catch the most rain? Why? (A clever student may answer that the place to catch the most rain would be under a downspout where the gauge could collect the rain running off of the roof of a building!)
- Is the place where you would catch the most rain the best place for the rain gauge? Why? (Remember that your data should be representative of the surrounding area.)

As you walk around the school grounds, have the students draw a map of the area. Younger students can just sketch the main features, such as the school building(s), parking lots, playgrounds, etc. Older students should fill in more details such as what the playground surface is (e.g. paved, grassy, or bare ground). The goal is to have a drawing of the school grounds so that when a decision is made on where to locate the weather instruments, students can locate them on their map. This will allow the students to give a good physical description of the area surrounding their instruments. In subsequent years, new classes of students can repeat this mapping exercise to note any changes in the school grounds and to understand why a specific location was chosen.

Observing and making a map of the area around the rain gauge contributes to four key elements of good scientific practice. First, the maps should be included in the student's individual Science Logs as part of students' documentation of their personal observations and notes. Second, a consensus map should be included in the school's Data Book along with the *Data Sheets*. Data about the conditions under which measurements are made is important metadata – data about data – and should be retained in each school's records. Third, GLOBE site definition sheets and data entry forms provide space for metadata to be entered as comments. Scientists must communicate all information about their observations that is needed for others to use their data. Fourth, all scientists should approach any measurement with some skepticism and ask themselves questions such as, "What could be influencing my observations and giving me inaccurate or unrepresentative data?"

Solid Precipitation

Prior to the first snowfall in your area, take a walk with students around the school grounds to locate the best places to measure the depth of snow. They should find an area away from buildings, trees, and other objects that may affect the depth of snow. Of course, like rainfall, there are small-scale variations in snowfall depth. A few questions to ask students to help them decide on the best place to measure snow are:

- Is the area of the rain gauge a good place to measure snowfall? Why or why not?
- Do you think different kinds of surfaces (e.g. grass, concrete, etc.) affect how much snow will accumulate in a particular place?
- What differences do you think you would see in snowfall depth over a large flat area compared to a very hilly area?
- How likely is it that someone will disturb the snow in this area by walking through it or by shoveling snow? Will salt or sand from nearby walkways or streets contaminate this location?

The water equivalent measurements of new snow and snow pack tie the rain and snow data together as elements of the hydrologic cycle. Discuss with students the concepts that there is a rain equivalent of snow, that snow is water stored on Earth's surface, and the reasons why the samples of snow must be taken in the careful manner required by the protocols. Students who understand the concepts of sampling rain and how snow measurements relate to rain measurements should be more careful and confident in taking data.

Questions for Further Investigation

When does your area get precipitation? Why?

What would happen if you got only half the normal amount of precipitation in a given year? How would the effects vary depending on when within the year there was less precipitation?

What would happen if you got double the normal amount of precipitation in a given year? How would the effects vary depending on when within the year there was more precipitation?

Is the amount of precipitation you get at your school the same or different from the amount measured at the five nearest GLOBE schools? What causes these differences or similarities?

Where do snow storms and rain storms come from before reaching your area?

Does precipitation pH vary from storm to storm? Why?

How do the amount and timing of precipitation relate to budburst and other phenology measurements?

How do the amount and timing of precipitation in your area relate to land cover?

How does the pH of precipitation relate to soil pH and the pH of nearby water bodies?

Instrument Maintenance and Calibration

Maintenance

Even if it has not rained, you should check your rain gauge daily to make sure that it is free of debris (windblown leaves, twigs, papers, etc.). Some birds seem to like sitting on the edge of the rain gauge and may leave droppings behind! Approximately once each month the rain gauge should be thoroughly cleaned with water and a bottle brush (or equivalent). This is to clean out any mold, mildew, or other things that may start to grow in the gauge. In very humid regions the gauge may need scrubbing more often; in dry areas you may only need to scrub the gauge once every two or three months (although dry debris should still be removed daily). Never use soap or detergent when cleaning the rain gauge because the residue will contaminate your precipitation pH measurements.

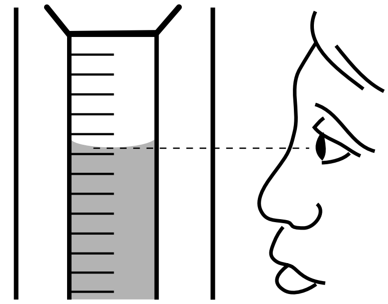
Bring the rain gauge indoors when the temperature falls below freezing. This will prevent the measuring tube from cracking. However, if you are in a transition season where temperatures can range from below freezing to above freezing during a 24-hour measurement period and both rain and snow are possible, you can leave the large overflow tube outside without the small measuring tube and funnel. This part of the rain gauge is less likely to crack. Any precipitation that falls into the large overflow tube can be brought indoors and poured into the small tube for accurate measurement.

Little maintenance is needed for the snowboard. The main things are to make sure the snowboard is cleared off after each measurement, and to check the board occasionally to make sure it has not warped.

Calibration

To ensure that your rain gauge is level, you simply need to put a carpenter's level across the top of the funnel of the gauge in two directions. A carpenter's level is a straight piece of board that has small glass tubes running in one or more directions. Each glass tube has markings on it, and an air bubble inside.

Rainfall Protocol
Field Guide



Task

Measure the amount of rain that has collected in your rain gauge.

Measure the pH of the rain.

Prepare the rain gauge to collect more rain.

What You Need

- ❑ A properly sited and mounted rain gauge
- ❑ Clean sampling jar with cover for pH measurement samples
- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Appropriate *Precipitation pH Lab Guide*
- ❑ Pen or pencil

In the Field

1. Read the level of the water in your rain gauge; be sure your eyes are level with the water in the measuring tube. Read the level at the bottom of the meniscus.
2. Record the rainfall amount to the nearest one-tenth of a millimeter.

   If there is no water in the rain gauge report 0.0 mm.

   If there is less than 0.5 mm, record "T" for trace.

   If you spill any water before measuring the amount of rain, record "M" for missing as the amount. (If you have only spilled a little, record the amount not spilled as metadata.)
3. Pour the water into the sampling jar and cover it for the pH measurement.
4. If there is water in the overflow tube:
   a. Remove the measuring tube from the overflow tube.
   b. Read the level of water in the measuring tube holding it so that your eyes are level with the meniscus.
   c. Record the amount to the nearest one-tenth of a millimeter.
   d. Pour the water from the measuring tube into the container for the pH measurement.
   e. Pour water from the overflow tube into the measuring tube.
   f. Repeat steps b through e until the overflow tube is empty.
   g. Add your measurements and record the sum as the rainfall amount.
5. Record the number of days rain has accumulated in the gauge. (The number of days since the rain gauge was last checked and emptied.)
6. Perform the appropriate *Precipitation pH Lab Guide* (depending on which type of pH measuring device and salt you are using).
7. Dry the rain gauge and remount it on its post.

Solid Precipitation Protocol

Field Guide

Task

Measure the amount of new snow that has collected on your snowboard.

Measure the total depth of snow on the ground.

Obtain samples of new snow and snowpack for pH measurement.

Obtain samples of new snow and snowpack to determine the water equivalent.

Prepare the snowboard to collect more snow.

What You Need

- ❑ A meter stick (or a longer measurement pole if snow accumulates to more than a meter in depth
- ❑ Snowboard
- ❑ A straight-sided container
- ❑ The overflow tube from your rain gauge
- ❑ Two clean sampling jars with covers for the pH samples
- ❑ A container for the snowpack rain equivalent sample
- ❑ Something flat and clean to slide under inverted containers
- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Pen or pencil
- ❑ Labels for snow samples

In the Field

1. Insert the measuring stick vertically into the snow until it rests on the ground. Be careful not to mistake an ice layer or crusted snow for the ground. Read and record the depth of the snowpack.
2. Repeat the measurement in at least two more places where the snow is least affected by drifting.
3. Report all three of these numbers as the total snowfall. If the snowpack is so small that a depth cannot be read, record the letter "T" (for trace) for total snowpack.
4. After a new snow has fallen on earlier snow, gently insert the measuring stick vertically into the snow until it touches the snowboard. Read and record the depth of new snow. If no new snow has fallen, record 0.0 as the depth of new snow.
5. If there is new snow, take at least two more measurements at different spots on the snowboard.
6. Report these numbers as the depth of new snow. If the snowfall is so small that a depth cannot be read, record the letter "T" (for trace) for new snow. If the snow on the snowboard has been disturbed before you can take an accurate measurement, report "M" for missing.
7. Record the number of days since the last reading of snow on the snowboard.

Taking Samples for the Lab

8. After you have measured the depth of new snow on the snowboard and of the snowpack, take a straight-sided container (such as the overflow tube from the rain gauge), and hold it straight up and down over the snowpack, well away from the snowboard. Choose a place where the snow has not been disturbed. Push the container down until it almost touches the ground.
9. Slide something flat and clean under the container just above the ground and turn the container right side up. Be sure not to lose any snow.
10. Save this sample in a clean container, cover it, label it "snowpack pH".
11. Take the overflow tube from the rain gauge, and hold it straight up and down over the snow away from the snowboard. Choose a place where the snow has not been disturbed. Push the tube down until it touches the ground.
12. Save this sample in your tube or another container, cover it, label it "snowpack rain equivalent".
13. Hold a straight-sided container straight up and down over the snowboard. Push the container down until it almost touches the board's surface.
14. Slide something flat and clean under the container just above the board and turn the container right side up.
15. Save this sample in a clean container, cover it, label it "new snow pH".
16. Hold the overflow tube from your rain gauge straight up and down over the snowboard. Push the tube down until it touches the board's surface. Slip something flat under the tube and turn it right side up OR hold the tube to the board and flip the board and tube over. Be sure not to lose any snow.
17. Save this sample in your overflow tube or another container, cover it, label it "new snow rain equivalent", and take it inside with you.
18. Once you have taken your samples, place the snowboard on top of existing undisturbed snow. Push the snowboard gently into the snow so that its surface is even with the surface of the snow. Place a flag or other marker nearby to help you locate the snowboard after the next snowfall.
19. Take your labeled samples inside to melt and measure.

Solid Precipitation Protocol
Lab Guide

Task

Determine the liquid water equivalent of new snow fall and total snowpack.

Determine the pH of the new snow and the snowpack.

What You Need

- ❑ Samples from the field (pH and rain equivalent for new snow and snowpack)
- ❑ The small measuring tube from your rain gauge
- ❑ Appropriate *Precipitation pH Lab Guide*
- ❑ *Atmosphere Investigation Data Sheet*

In the Lab

1. Once your snow samples are indoors, allow them to melt. Be sure they are covered to prevent evaporation.
2. Pour the melt water from the “new snow” sample into the measuring tube of the rain gauge (you may want to use the rain gauge funnel to help).
3. Read and record the rain equivalent in millimeters to the nearest 10th of a millimeter.
4. If there is more water than can fit into the measuring tube, empty the tube and repeat steps 2 and 3 and add the amounts.
5. Record this as the rain equivalent on your *Data Sheet.*
6. Pour melted snow water back into the sample jar.
7. Perform the appropriate *Precipitation pH Lab Guide* (depending on which type of pH measuring device and salt you are using) on the pH sample.
8. Repeat steps 2-7 for the “snowpack” sample.

Precipitation pH Using pH Paper and Large Salt Crystals
Lab Guide

Task
Measure the pH of your precipitation using pH paper and large salt crystals.

What You Need
- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Large salt crystals (0.5 mm to 2.0 mm in diameter)
- ❑ Tweezers
- ❑ Stirring rod or spoon
- ❑ pH paper
- ❑ 3 Clean 100 mL beakers or cups
- ❑ Covered sample jar containing at least 30 mL of rain or melted snow
- ❑ Latex gloves
- ❑ Pen or pencil
- ❑ Distilled water in wash bottle

In the Field
1. Pour a 50 mL (or less if you do not have 50 mL) sample of rain or melted snow from your sample jar into a clean beaker. You must have at least 30 mL of sample to measure pH.
2. Put on latex gloves.
3. Use tweezers to add one salt crystal into the beaker.
4. Stir the beaker's contents thoroughly with stirring rod or spoon until salt is dissolved.
5. Follow the instructions that came with the pH paper to measure the pH of the sample. Record the pH value on your *Data Sheet*.
6. If you have at least 30 mL of rain or snow left in your sample jar then repeat steps 1-5. Otherwise, repeat step 5. Continue until you have collected a total of 3 pH measurements.
7. Calculate the average of the 3 pH measurements and record on your *Data Sheet*.
8. Check to make sure that each measurement is within 1.0 pH unit of the average. If they are not within 1.0 unit of the average, then repeat the measurements. If your measurements are still not within 1.0 pH units of the average, discuss possible problems with your teacher.
9. Discard used pH paper in a waste container and rinse the beakers and sample jar three times with distilled water.

Precipitation pH Using pH Paper and "Table" Salt
Lab Guide

Task
Measure the pH of your precipitation using pH paper and "table" salt.

What You Need
- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Finely ground "table" salt (crystals less than 0.5 mm in diameter)
- ❑ *Salt card* consisting of 4 mm and 5 mm circles drawn on a card or piece of paper
- ❑ Stirring rod or spoon
- ❑ pH paper
- ❑ 3 clean 100 mL beakers or cups
- ❑ Covered sample jar containing at least 30 mL of rain or melted snow
- ❑ Latex gloves
- ❑ Pen or pencil
- ❑ Distilled water in wash bottle

In the Field
1. Pour a 50 mL (or less if you do not have 50 mL) sample of rain or melted snow from your sample jar into a clean beaker. You must have at least 30 mL of sample to measure pH.
2. Put on latex gloves.
3. Sprinkle salt onto the appropriate circle on your *salt card*. If your rain or melted snow sample is 40-50 mL, use the large 5 mm circle on the *salt card*. If your rain or melted snow sample is 30-40 mL, use the small 4 mm circle.
4. Fill the appropriate circle with a **single** layer of salt. Remove any excess salt from the *salt card*.
5. Pour the salt covering the circle on your *salt card* into the beaker.
6. Stir the beaker's contents thoroughly with stirring rod or spoon until salt is dissolved.
7. Follow the instructions that came with the pH paper to measure the pH of the sample. Record the pH value on your *Data Sheet*.
8. If you have at least 30 mL of rain or snow left in your sample jar then repeat steps 1-7. Otherwise, repeat step 7. Continue until you have collected a total of 3 pH measurements.
9. Calculate the average of the 3 pH measurements and record on your *Data Sheet*.
10. Check to make sure that each measurement is within 1.0 pH unit of the average. If they are not within 1.0 unit of the average, then repeat the measurements. If your measurements are still not within 1.0 pH units of the average, discuss possible problems with your teacher.
11. Discard used pH paper in a waste container and rinse the beakers and sample jar three times with distilled water.

Precipitation pH Using pH Meter and Large Salt Crystals

Lab Guide

Task

Measure the pH of your precipitation using a pH meter and large salt crystals.

What You Need

- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Tweezers
- ❑ Large salt crystals
- ❑ Pen or pencil
- ❑ pH meter
- ❑ pH buffers 4, 7, and 10
- ❑ 3 Clean 100 mL beakers or cups (0.5 mm to 2.0 mm in diameter)
- ❑ Covered sample jar containing at least 30 mL of rain or melted snow
- ❑ Latex gloves
- ❑ Distilled water in wash bottle

In the Field

1. Put on latex gloves.
2. Calibrate your pH meter according to the instrument instructions, using the pH buffers. Be sure to use enough standard to completely cover the tip of the electrode.
3. Rinse electrode *thoroughly* with distilled water. Any remaining standard can contaminate your sample.
4. Pour a 50 mL (or less if you do not have 50 mL) sample of rain or melted snow from your sample jar into a clean beaker. You must have at least 30 mL of sample to measure pH.
5. Use tweezers to add one salt crystal to the beaker.
6. Stir the beaker's contents thoroughly with stirring rod or spoon until salt is dissolved.
7. Follow the instructions that came with the pH meter to measure the pH of the sample and record the measurement on your *Data Sheet*. (**Note**: the electrode must be completely covered with sample water).
8. If you have at least 30 mL of rain or snow left in your sample jar then repeat steps 4-7. Otherwise, repeat step 7. Continue until you have collected a total of 3 pH measurements.
9. Calculate the average of the 3 pH measurements and record on your *Data Sheet*.
10. Check to make sure that each measurement is within 0.2 pH units of the average. If they are not with 0.2 units of the average, repeat the measurements. If your measurements are still not within 0.2 pH units of the average, discuss possible problems with your teacher.
11. Rinse the beakers and sample jar three times with distilled water.

Precipitation pH Using pH Meter and "Table" Salt

Lab Guide

Task

Measure the pH of your precipitation using a pH meter and "table" salt.

What You Need

- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Finely ground "table" salt (crystals less than 0.5 mm in diameter)
- ❑ Salt card consisting of 4 mm and 5 mm circles drawn on a card or piece of paper
- ❑ Stirring rod or spoon
- ❑ pH meter
- ❑ pH buffers 4, 7, and 10
- ❑ 3 clean 100 mL beakers or cups
- ❑ Covered sample jar containing at least 30 mL of rain or melted snow
- ❑ Latex gloves
- ❑ Pen or pencil
- ❑ Distilled water in wash bottle

In the Field

1. Put on latex gloves.
2. Calibrate your pH meter according to the instrument instructions, using the pH buffers. Be sure to use enough standard to completely cover the tip of the electrode.
3. Rinse electrode *thoroughly* with distilled water. Any remaining standard can contaminate your sample.
4. Pour a 50 mL (or less if you do not have 50 mL) sample of rain or melted snow from your sample jar into a clean beaker. You must have at least 30 mL of sample to measure pH.
5. Sprinkle salt onto the appropriate circle on your *salt card*. If your rain or melted snow sample is 40-50 mL, use the large 5 mm circle of the *salt card*. If your rain or melted snow sample is 30-40 mL, use the small 4 mm circle.
6. Fill the appropriate circle with a **single** layer of salt. Remove any excess salt from the *salt card*.
7. Pour the salt covering the circle on your *salt card* into the beaker.
8. Stir the beaker's contents thoroughly with stirring rod or spoon until salt is dissolved.
9. Follow the instructions that came with the pH meter to measure the pH of the sample and record the measurement on your *Data Sheet*. (**Note:** the electrode must be completely covered with sample water)
10. If you have at least 30 mL of rain or snow left in your sample jar then repeat steps 4-9. Otherwise, repeat step 9. Continue until you have collected a total of 3 pH measurements.
11. Calculate the average of the 3 pH measurements and record on your *Data Sheet*.
12. Check to make sure that each measurement is within 0.2 pH units of the average. If they are not with 0.2 units of the average, repeat the measurements. If your measurements are still not within 0.2 pH units of the average, discuss possible problems with your teacher.
13. Rinse the beakers and sample jar three times with distilled water.

Frequently Asked Questions

1. Why do we have to check the rain gauge every day, even if we know it hasn't rained?
The problem with containers like a rain gauge is that they tend to collect more than just rain. Leaves, dirt, and other debris can quickly spoil the rain gauge as a scientific instrument. This debris can block the funnel, causing rainwater to flow out of the gauge. Even if the debris isn't large enough to block the funnel, it may become mixed in with the rainwater and affect the level of precipitation you read or the pH reading. Therefore, it is important that you check the gauge daily to make sure it is free of dust and debris.

2. What is solar noon, and how do we figure out when it is in our area?
Local solar noon is a term used by scientists to indicate the time of day when the sun has reached its highest point in the sky in your particular location. The easiest way to determine local solar noon is to find out the exact times of sunrise and sunset in your area, calculate the total number of hours of daylight between those times, divide the number of daylight hours by two, and add that number to the time of sunrise. See the examples in *Solar Noon* in the section on *Measurement Logistics*.

3. When should we put our snowboard down?
The nice thing about the snowboard is that you don't have to anticipate the first snowfall. The snowboard doesn't have to go out until you already have snow on the ground. The purpose of the snowboard is to provide a barrier between old snow and new snow, so that you can measure the depth, liquid water equivalent, and pH of new snowfall.

4. Can we leave the overflow tube of our rain gauge out as a snow catcher?
Unfortunately, this won't work. Snow blows around too much to get an accurate measure of its depth using a rain gauge. Plus, we need to get several measurements of snow depth and average them to get a more accurate measure of the depth of snow in a region. However, on days where the temperature will be both above and below freezing, leave the overflow tube out to catch both rain and snow. The snow on these days is usually wet and heavy and doesn't blow as much and melts before local solar noon. You can measure the water in the overflow tube to get the rain equivalent of the snow plus any rainfall.

5. What do we do if the depth of new snow or snowpack is greater than the depth of our container?
Compact the snow in the container. If there is too much snow to fit in the container, push the container as far down as it will go and then pull it out.

If the snow stays in the container, empty it into a separate container which can be of any shape; or

If the snow does not come up with the container, use a small shovel or similar tool to dig the snow out of the column made by the container. Put all the snow in a separate container which can be of any shape.

Then push your straight-sided container further down in the snow continuing the hole where your first sample was taken, and repeat these steps until you have a sample that goes from the surface of the snow to the ground or the snowboard.

6. The snow protocol asks for up to four samples to be taken for pH measurements, and we only have one overflow tube; what can we do?
The pH samples do not need to be taken using the overflow tube. Any straight-sided container will do provided it is clean and will not contaminate the pH reading of the snow. Sometimes pH changes during a rain or snow storm and GLOBE wants the pH of the total precipitation that has fallen in the past day. The important points in sampling are:

1. avoid collecting snow that could be contaminated by contact with the snowboard or another surface and
2. collect a uniform column of snow that will represent the snow from the entire snowfall.

The overflow tube from the rain gauge is used in collecting the "new snow" and "snowpack" samples so that you can measure the rain equivalent using the measuring tube from the rain gauge. If you only have one rain gauge, first collect the snowpack sample and empty the contents of the overflow tube into another container and label it. Then reuse the overflow tube to collect the sample from the snowboard. If you do not wish to use the rain gauge, then you should do the following.

1. Use straight-sided containers instead of the overflow tube.
2. Take the samples and melt them in the same way.
3. Using your 100 mL or 500 mL graduated cylinders, pour the sample into the graduated cylinder and measure the volume as accurately as possible (± 1 mL in the 100 mL cylinder and ± 5 mL in the 500 mL cylinder).
4. Determine the area of the opening of the straight-sided container. If it is round, measure the diameter and calculate the area as follows:

$$\text{Radius} = \frac{\text{Diameter}}{2}$$

$$\text{Area (cm}^2\text{)} = \Pi \times (\text{radius})^2$$

Or if it is rectangular, measure the width and length of the opening and calculate the area as follows:

$$\text{Area (cm}^2\text{)} = \text{Width (cm)} \times \text{Length (cm)}$$

5. Calculate the rain equivalent depth of the melt water as follows:

$$\text{Depth (mm)} = \frac{\text{Volume of melt water (mL} = \text{cm}^3\text{)}}{\text{Area (cm}^2\text{)}} \times 10 \text{ (mm/cm)}$$

Note that milliliters are equivalent to cubic centimeters. Calculate the depth to the nearest 0.1 mm.

7. What should we do if we are likely to get both rain and snow during certain times of year?

There are many places where transition times (from Autumn to Winter, and then from Winter to Spring) mean that temperature can fluctuate above and below freezing over relatively short times. Once there is a chance that overnight temperatures will be below freezing, bring the funnel top and measuring tube of the rain gauge indoors. Leave the overflow tube in place at your Atmosphere Study Site. The narrow measuring tube is much more likely to crack if ice forms in it after a rainfall than is the larger overflow tube. The overflow tube will be able to catch any rain or snow that falls.

In some cases, you may get a snowfall that melts before your usual measurement time. If this happens, you can't report a new snow depth, but you can report as metadata that there was snow on the ground but it melted before a measurement was made.

Bring the measuring tube outside with you and use it to measure the amount of rain plus melted snow present in your overflow tube. If the water in your overflow tube all fell as rain, report it as rain. If the water in your overflow tube is all from snow which has melted, report it as the water equivalent of new snow, and report the new snow depth as "M" for missing and the snowpack depth on the ground as whatever value you measure (including 0.0 in many cases). If the water in your overflow tube is a mix of rain and melted snow or you don't know which it is, report it as rain and include in your comments that the sample included or may have included melted snow.

8. Snow fell overnight, but it melted before it was time to take the GLOBE Atmosphere measurements. What should we report as our data?

It is possible that an overnight snowfall may melt before the daily precipitation measurement is made. If you have left the overflow tube of your rain gauge outside, you can still report the liquid water equivalent of your snowfall. Note in your comments that your sample for liquid equivalent of new snow was collected in this way. Enter "M" for Daily Depth of New Snow and explain the circumstance in your comments.

9. New snow has fallen in the last day, but a significant amount of it blew away before we could measure it. What should we report as our data?

Report "M" for Daily Depth of New Snow and explain the circumstance in your comments. You should still report the total depth, rain equivalent, and pH of the snowpack if there is still any snow on the ground.

9. What is the best way to mark the location of our snowboard so we can find it after a new snowfall?

There are many ways in which you can do this. For example, you can place a flag in the ground next to the snowboard to help you locate the board. Or you could even attach a flag to the board itself (although you need to do this in such a way that it won't be unstable and tilt the board over on its side). Some ski resorts mount a pipe in a snowboard. The pipe can be marked with a permanent marking pen in millimeters and centimeters so that it not only helps you find the board, but also acts as a measuring stick to determine the depth of new snow.

10. If we know a new snowfall will melt before it is time to take our GLOBE measurements, should we try to take a measurement earlier in the day (for example, as soon as we get to school)?

If you have the time, it would be great to take a new snowfall measurement early in the day, particularly if warmer temperatures or high winds are forecast for later in the day and you think the snow may melt before solar noon. However, for consistency in the GLOBE archives, you still need to take snow measurements at solar noon. Record as metadata the time you took the earlier snowfall measurement, and the depth of the snow at that time. If you take snow measurements in the morning, make sure not to clear off the snowboard so that you can come back later in the day and take your solar noon measurements.

Precipitation Protocols – Looking At the Data

Are the data reasonable?

Precipitation can vary widely, even over short distances. So, in judging whether precipitation data are reasonable, common sense must be your guide. For example, if you lived in the state of Hawaii, it would be helpful to know that the record amount of rainfall received in the state in a 24-hour time period is about 965 mm. Figure AT-PP-4 from the National Climatic Data Center (NCDC) in Asheville, North Carolina in the U.S.A., shows you the maximum amount of precipitation received in each state of the U.S. in a 24 hour time period. In many areas, the maximum amount of precipitation was the result of a tropical storm or hurricane that hit that region

We can also find the total yearly precipitation for the wettest places in the world from the U.S. National Climatic Data Center, as shown in Table AT-PP-4.

*Figure AT-PP-4: Record Maximum 24-hour Precipitation (mm) through 1998 (*estimated)*

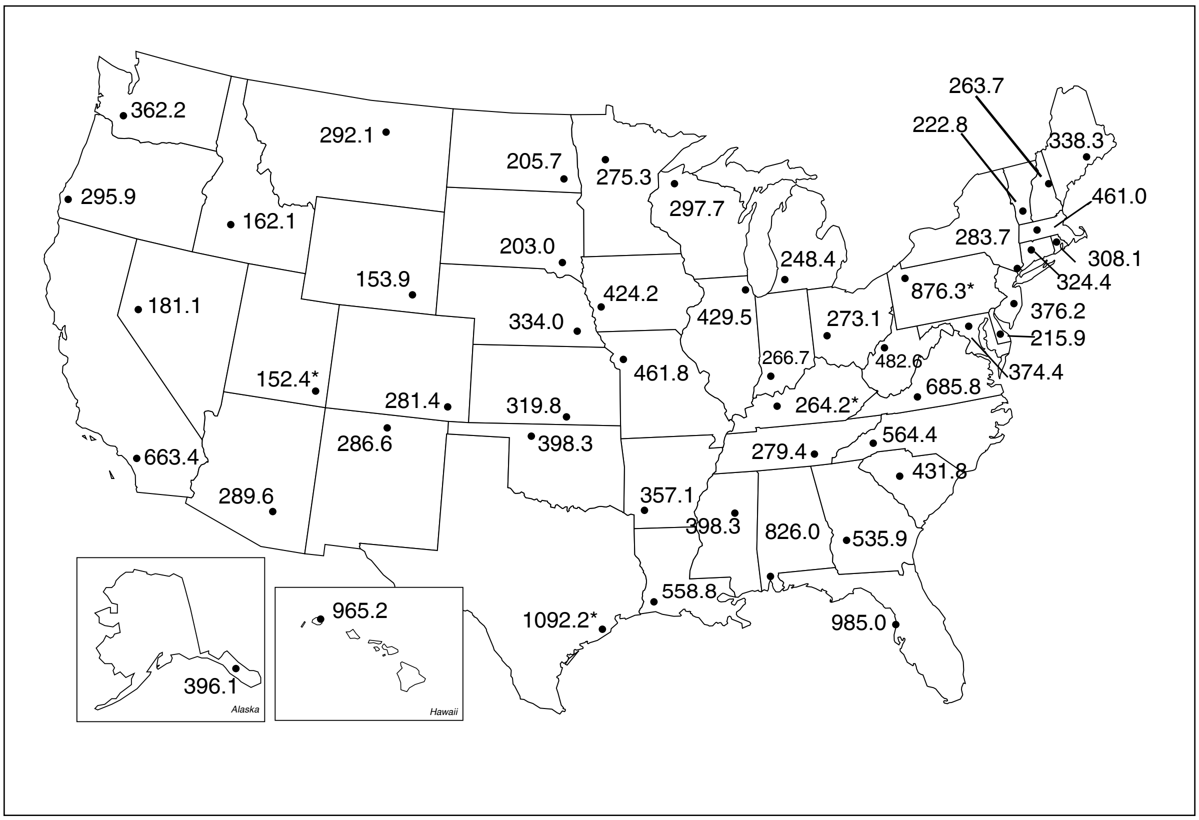


Table AT-PP-2

Continent	Highest Average (mm)	Place	Elevation (Meters)	Years of Record
South America	13299 *+	Lloro, Colombia	158.5	# 29
Asia	11872 *	Mawsynram, India	1401.2	38
Oceania	11684 *	Mt. Waialeale, Kauai, Hawaii, USA	1569.1	30
Africa	10287	Debundscha, Cameroon	9.1	32
South America	8992 +	Quibdo, Colombia	36.6	16
Australia	8636	Bellenden Ker, Queensland	1555.1	9
North America	6502	Henderson Lake, British Colombia, Canada	3.7	14
Europe	4648	Crkvica, Bosnia-Hercegovina	1017.1	22

**The value given is the continents's highest and possibly the world's highest depending on measurement practices, procedures, and period of record variations.*

+ The official greatest average annual precipitation for South America is 899.2 cm at Quibdo, Columbia. The 1329.9 cm average at Lloro, Columbia is an estimated amount.

 # Approximate elevation

A possible check on the reasonableness of data for an area is to compare with data from other nearby GLOBE schools or other sources of precipitation data. Figure AT-PP-5 shows 18 months of data for two schools in Croatia that are reasonably close to one another. Although you expect to see some variations in day-to-day precipitation, the overall patterns and amount of precipitation over time are similar.

In order to determine if precipitation pH data are reasonable, it helps to understand a little about the natural variability of the pH of normal precipitation. Because of naturally occurring carbon dioxide, sulfur dioxide and nitrogen oxides in the atmosphere, normal precipitation is somewhat acidic. Even in regions where there is little human activity, normal rainfall has a pH of about 5.6. However, some human activities can release much larger quantities of these and other gases into the atmosphere than would occur naturally. Once released into the atmosphere, these gases can react with other constituents of the air to form chemical compounds such as nitric acid and sulfuric acid that dissolve easily in water. The resulting water droplets will have pH values less than 5.6. These droplets can be carried long distances by prevailing winds, returning to Earth's surface as acid rain, snow, or fog. Sea spray, soil particles, and other substances can be swept up into the air and incorporated in water droplets. Many of these substances also change the pH of precipitation.

Figure AT-PP-6 shows the variation in average precipitation pH across the U.S.A. during 1999. This map shows us that average precipitation pH across the U.S.A. varies between about 4.2 and 5.6. The pH of individual precipitation events may be well outside this range, but it gives an indication of the approximate range of the average precipitation pH for this part of the world.

Figure AT-PP-7 is a graph of precipitation pH measurements from a GLOBE school in California, U.S.A. over a 5-month period of time, and shows that most of the measurements are between a pH of 6 and 7, but there is one data point with a pH of 9. If the pH was measured using pH paper, the variation of 1 pH unit is the same as the accuracy of the measurement method.

There are at least two possible explanations for an unusually high or low measurement of precipitation pH. One is that there was something different in the air that resulted in this unusual pH – for example, a dust storm, a forest fire, or some other phenomenon. A second explanation is that the pH pen or meter was not properly

Figure AT-PP-5

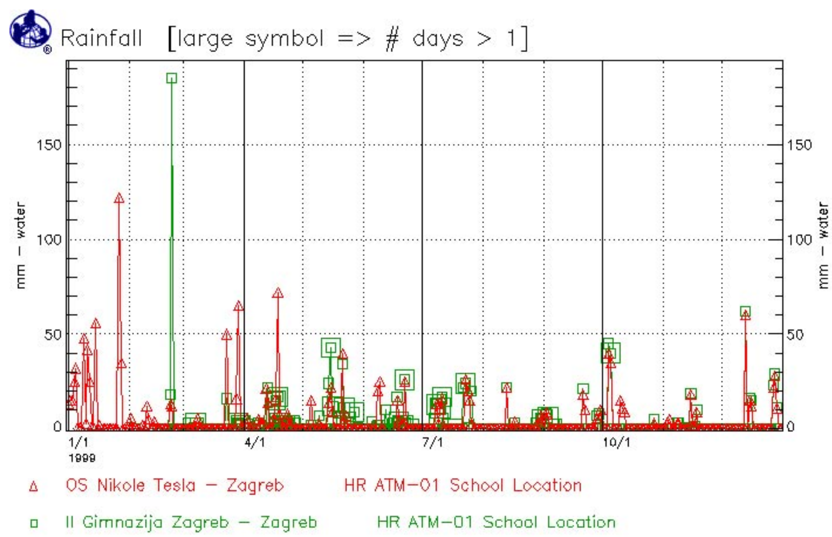


Figure AT-PP-6

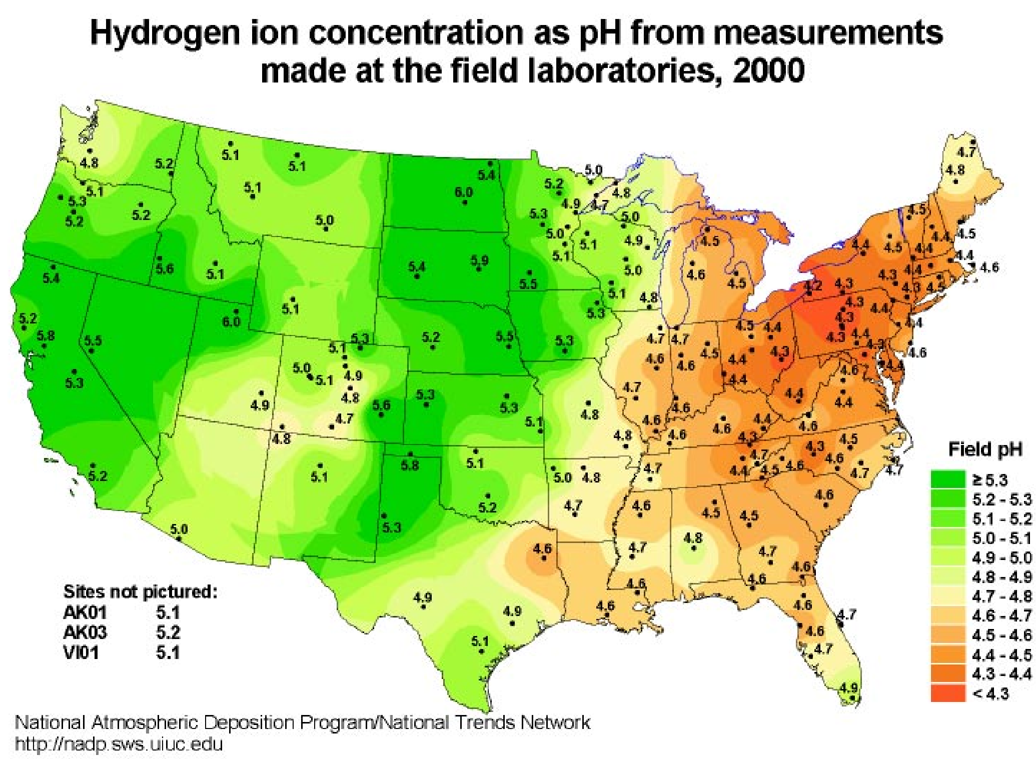


Figure AT-PP-7

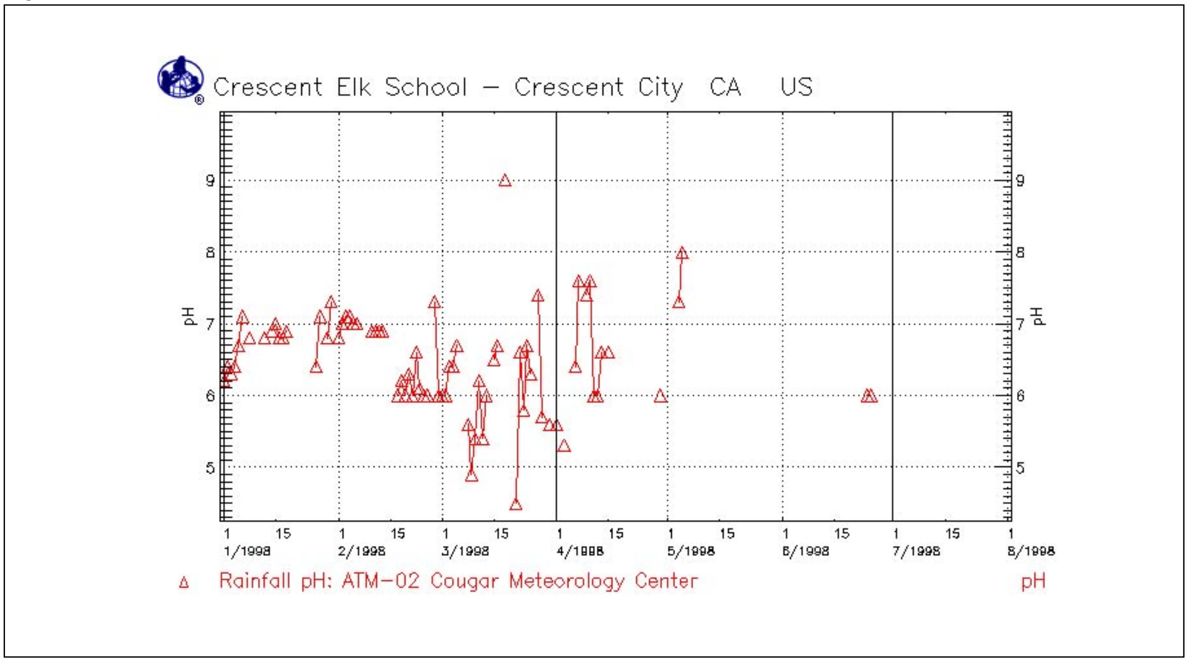
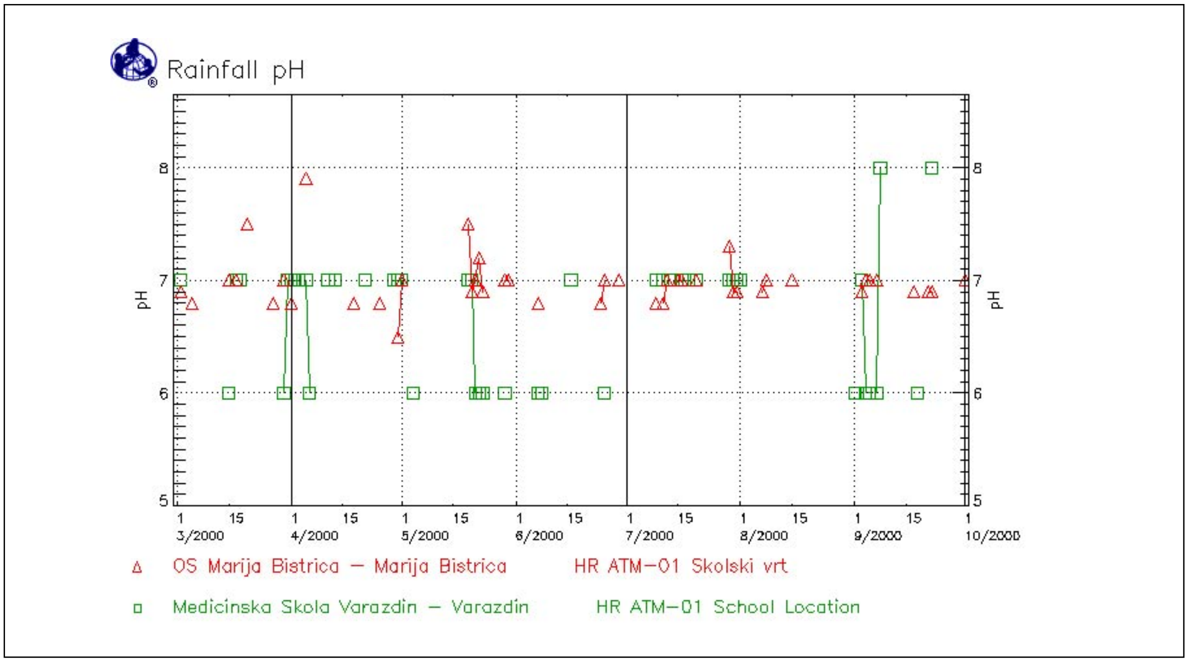


Figure AT-PP-8



calibrated or the pH paper had gone bad and the measurement is in error. The jump to 9.0 above is unusual and one should look at the comments reported by the school to better assess what was happening.

Comparison of data from schools that are reasonably close to one another shows variations of approximately 1 pH unit between these two schools. See Figure AT-PP-8. Given that all the data from Madecinska Skola are 6.0, 7.0, or 8.0, they were probably taken using pH paper, and this difference is reasonable. Both schools have occasionally higher pH readings that may be due to localized events affecting their rainfall. See Figures AT-PP-7 and AT-PP-8.

What do scientists look for in these data?

Scientists use precipitation data in their investigations of weather, climate, and atmospheric composition. In studying weather and climate, scientists may focus on individual rain events, patterns and average totals for precipitation over the year. Those concerned with atmospheric composition will look for how often there is enough rain or snow to wash trace gases and aerosols out of the air. Precipitation data are also useful for practical applications involving irrigation and water management.

In studies of weather, scientists may look at how much rain fell as part of a tropical storm or hurricane. They might also look at how much rain was associated with a particular level of flooding. This study could easily include data from many GLOBE schools in a region in combination with precipitation data from official weather stations.

Scientists trying to improve techniques for measuring average rainfall over large areas would compare data for specific days with the values they calculate from satellite or weather radar data. Each technique – rain gauge, satellite sensor, and radar – measures something different about the rain and has different limitations. So, comparing the different types of data can help improve techniques or provide a more accurate determination of how much precipitation actually occurred over an area.

Climate scientists look for different patterns in the data. What regions are the wettest? How little rain falls in deserts? What are the patterns of rainfall during the year? Climate scientists are particularly interested in how the total amounts and patterns of precipitation change over the years. Are rain events becoming more numerous? Are storms producing larger amounts of precipitation on average? Is the timing of rain during the year shifting?

As students, you can also learn about your climate by examining GLOBE precipitation data. For example, a student at Kingsburg High School in California, USA may hypothesize that the rainy season in northern California occurs at a different time of year than the rainy season in Benin, West Africa. To test this hypothesis, the student could search the GLOBE database for schools in Benin, and then compare the rainfall patterns from measurements made at their school in California to measurements made at one or more schools in Benin. Figure AT-PP-9 is an example of a comparison of two schools' rainfall records.

An initial look at this graph indicates that the rainy seasons in California and Benin do occur at different times of year. During this time period Benin received most of its rain between April and November, where as Kingsburg, California received most of its rainfall between January and April. To have more confidence in this conclusion we would need many more years of data.

As another example, students at Juuan Lukio/ Poikolan Koulu in Finland, in looking at a graph of rainfall and liquid water equivalent of snowfall may determine that their school receives most of its precipitation as snowfall. See Figure AT-PP-10.

Some simple calculations can be done with precipitation data. One of the most useful quantities that scientists use in looking at precipitation patterns is to look at the total amount of precipitation a given location receives in a certain time period (e.g., a week, a month, a season). To calculate these totals, students simply sum the precipitation data for a site for the time period desired

Figure AT-PP-11 is a comparison of rainfall over 11 days in March of 1999 between Ecopolis Center Junior Eco Club in Tokyo, Japan and Konigliches Athenaum Eupen in Eupen, Belgium.

We can obtain the actual numerical data for this time period for these two locations from the GLOBE archive:

GLOBE Data from Ecopolis Center Junior Eco Club, Tokyo, Japan from 03/05/1999 - 03/15/1999

Precipitation Rain

YYYYMMDD	LATITUDE	LONGITUDE	ELEVATN	SCHOOL	SITEID	RAINAMT	PH_RA	M
19990315	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.0	-99.0	0
19990314	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.0	-99.0	0
19990313	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.0	-99.0	0
19990312	35.4100	139.4000	10.0	RHG2H7U	ATM-01	3.0	4.7	3
19990311	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.0	-99.0	0
19990310	35.4100	139.4000	10.0	RHG2H7U	ATM-01	7.7	4.1	3
19990309	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.2	-99.0	0
19990308	35.4100	139.4000	10.0	RHG2H7U	ATM-01	12.0	5.1	3
19990307	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.0	-99.0	0
19990306	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.0	-99.0	0
19990305	35.4100	139.4000	10.0	RHG2H7U	ATM-01	0.8	6.1	3

GLOBE Data from Konigliches Athenaum Eupen, Eupen, Belgium from 03/05/1999 - 03/15/1999

Precipitation Rain

YYYYMMDD	LATITUDE	LONGITUDE	ELEVATN	SCHOOL	SITEID	RAINAMT	PH_RA	M
19990315	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.0	-99.0	0
19990314	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.0	-99.0	0
19990313	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.0	-99.0	0
19990312	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.0	-99.0	0
19990311	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.2	-99.0	0
19990310	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.0	-99.0	0
19990309	50.6292	6.0262	290.0	Tec1tGH	ATM-01	1.2	-99.0	0
19990308	50.6292	6.0262	290.0	Tec1tGH	ATM-01	1.6	-99.0	0
19990307	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.4	-99.0	0
19990306	50.6292	6.0262	290.0	Tec1tGH	ATM-01	4.2	-99.0	0
19990305	50.6292	6.0262	290.0	Tec1tGH	ATM-01	0.4	-99.0	0

We can calculate the total amount of rainfall each location received between 5 March and 15 March by adding up the rainfall each day (including those days that received zero rainfall)

For Ecopolis Center Junior Eco Club, Tokyo, Japan

0 + 0 + 0 + 3.0 + 0 + 7.7 + 0.2 + 12.0 + 0 + 0 + 0.8 = 23.7 mm

For Konigliches Athenaum Eupen, Eupen, Belgium

0 + 0 + 0 + 0 + 0.2 + 0 + 1.2 + 1.6 + 0.4 = 3.4 mm

We have now confirmed with calculations what we suspected by looking at the graph, the school in Japan received much more rainfall during this time period than did the school in Belgium. This large difference in the amount of rainfall between the school in Japan and the school in Belgium leads to many questions, for example: What is the total yearly rainfall at these two locations? What kinds of plants grow in these two locations? What kind of springtime weather do these places experience?

Student researchers should consider comparing precipitation totals, averages, and extremes between different schools or locations. You can compare monthly total precipitation from one year to another and look at the pattern in these totals over the year.

Precipitation data are important in understanding patterns of plant growth and the cycling of water in the environment. See *Green-Up Protocol Looking At the Data*. In some places, knowing the amount of precipitation is important for managing scarce water supplies. For instance, operators of dams may release more or less water through their dams depending on rainfall or snowmelt.

The actual input of water to the ground and water bodies (streams, rivers, lakes, etc.) is important for use in both plant growth and water resources studies. With rain this input is immediate, but with snow the amount of water produced when the snow melts is more crucial to know than the amount of snow that falls. If a location receives enough snow to build up a snow pack, a series of GLOBE measurements of the rain equivalent of new snow and snow pack can be taken to help with these studies.

For example, a school collects the data shown in the Table AT-PP-3.

Table AT-PP-3

Date	Days of Accumulation	New Snow (mm)	Rain Equivalent (mm) R_{NEW}	Snow Pack (mm)	Rain Equivalent (mm) R_{PACK}
12/10/99	1	0	0.0	0	0.0
12/12/99	1	0	0.0	0	0.0
12/13/99	1	0	0.0	0	0.0
12/14/99	1	10	1.5	10	1.5
12/15/99	1	110	5.5	120	7.0
12/16/99	1	5	1.0	110	7.5
12/17/99	1	0	0.0	110	7.5
12/18/99	1	75	8.7	180	16.0
12/19/99	1	30	M	200	M
12/20/99	1	30	3.0	200	18.0
12/21/99	1	0	M	185	M
12/22/99	1	0	M	185	M
12/23/99	1	0	0.0	180	17.0
12/24/99	1	—	M	180	M
12/25/99	1	—	M	190	M
12/26/99	1	—	M	200	M
12/27/99	1	178	22.4	335	39.5
12/28/99	1	—	M	320	39.0
12/29/99	1	8	0.5	320	39.0
12/30/99	1	33	M	350	M
12/31/99	1	28	5.5	360	48.0

From these data, these students can calculate the amount of water released into the environment. This calculation is:

Release amount (mm) = R_{NEW}(today) + R_{PACK} (yesterday) - R_{PACK} (today)

So for December 18, the release amount, stated as the equivalent depth of rain, was:

$$8.7 + 7.5 - 16.0 = 0.2 \text{ mm}$$

If there is no new snow between two dates, the release amount is simply the difference of the rain equivalent of the snow pack on the two days.

Some scientists studying climate investigate the interaction of sunlight with Earth's surface. For these investigations the presence or absence of snow on the ground is important. In their analyses, these scientists examine where and when there is snow on Earth's surface and often relate this information to satellite data. Students may ask how many days a year is there snow on the ground? What are the first and last days of the year when there is snow the ground?

Precipitation is a major way in which trace gases and aerosols are removed from the air. Most of this removal happens at the beginning of a storm; the first few millimeters of rain or centimeters of snow cleans the air. Scientists investigating atmospheric composition are interested in how often precipitation events occur that are large enough to remove trace gases and aerosols. Scientists are also interested in how much of an area experienced rain or snow because a localized storm only affects a small area, leaving the composition of the surrounding air largely unchanged. For this, they may look at cloud data (nimbostratus versus cumulonimbus clouds precipitation) or data from nearby GLOBE schools.

When looking at precipitation pH data, most interest is in the short-term average of precipitation pH and the trend of precipitation pH over time. A single reading of a very high or very low precipitation pH may not be significant, however, if over a period of time the precipitation pH continues to be either very high or very low, scientists begin to worry about the effects on local ecosystems.

Effects of very high pH precipitation on ecosystems have not been studied as much as the effects of low pH precipitation ("acid rain"). Some plants and animals can tolerate relatively high levels of acidity, where others may be very sensitive to even small decreases in pH. The effects of acid precipitation are usually seen the most in water bodies such as streams and lakes, or in wetlands such as marshes. The land cover and soils surrounding them also affect the pH of water flowing into these habitats. As water with low pH flows through soils, aluminum is released from the soils and this can cause additional stress in the environment. Thus, when scientists examine data on precipitation pH, they particularly look for values that are low over a long period of time. Scientists studying watersheds will look at precipitation pH along with soil pH and prevalent types of vegetation and land cover in their efforts to understand what is controlling or influencing the pH of water bodies.

Figure AT-PP-12 shows the precipitation pH for two schools in the Czech Republic from January 1998 through July 2001. The first thing we note from this graph is that neither school received precipitation that is very acidic. The lowest precipitation pH that either school reports is about 4, and this value is not common. The second thing we notice is that there doesn't appear to be an overall trend in precipitation pH over time at either school. That is, it doesn't appear that from early 1998 until the middle of 2001 there has been a steady increase or decrease in the pH of precipitation at these two locations. The next thing that scientists would want to explore after looking at the data from these two schools is to try to understand the differences in precipitation pH at these locations. Why is the precipitation pH at Gymnazium Dr. A. Hrdlicky systematically higher than at Zalkadni, and what does that mean for the ecosystems in these areas?

Two Examples of Student Research Investigations – Example 1: Rainfall Amount

Forming a Hypothesis

A student from CEG Adjohoun School in Adjohoun, Benin has been comparing GLOBE temperature measurements made at his school with other schools around Benin. He notices that during the time period from May through June of 2001 the average temperature measured at his school is typically somewhat greater than it is at another GLOBE school in Avrankou, Benin. See Figure AT-PP-13.

Looking at this graph makes the student wonder if this type of pattern is true for other GLOBE measurements. To begin his research, the student hypothesizes that;

Average rainfall in Adjohoun is greater than in Avrankou during the period of May through June of 2001.

Collecting and Analyzing Data

Data for rainfall have already been collected at both of these schools, so the first thing this student does is to graph the data. See Figure AT-PP-14.

After looking at the graph, the student decides that he really needs to create a data table with the values from this graph in order to determine if the average amount of rainfall received at Adjohoun really is greater than the rainfall received at Avrankou. He can easily retrieve the data from the GLOBE archives for each school, then save the information in one of several ways: by printing the table from the computer; by cutting and pasting the data into a spreadsheet; or by copying the data down on a sheet of paper by hand.

Next, the student needs to decide on a timescale to look at the rainfall data. He knows that daily rainfall varies a lot and in some cases he doesn't have daily values of rainfall, but has accumulated rainfall. He initially decides to calculate the total rainfall for this two-month period for both sites. To do this he adds up all the precipitation amounts for a given site.

He creates a table of the data:

Month	Rainfall Adjohoun (mm)	Rainfall at at Avrankou (mm)
April	124.4	162.0
May	118.2	282.7
June	161.3	193.8

The student finds that for Adjohoun, the rainfall for May and June of 2001 is 279.5 mm. His calculations show that during this same time period Avrankou received 476.5 mm of rain. Based on these sums the student concludes that, at least for these two months, Adjohoun received less rainfall than Avrankou, and his original hypothesis is not supported by these data.

Communicating Results

The student then presents an oral report to his teacher and class on his research. He explains to them his hypothesis and how he carried out his research. He shows them the data he has used and the calculations he has made. In addition, he discusses with the class what further research might be done, such as looking at a longer data record (perhaps for several years).

Example 2: Precipitation pH

Forming a Hypothesis

Students from Zakladni Skola – Ekolog, Praktikum in Jicin, Czech Republic have been taking measurements of precipitation and precipitation pH for a number of years. Several students decide to analyze these two data sets to see if there is a connection between the amount of rainfall received and the pH of the rainfall.

The students' first task is to choose a time period for their study, and then graph the data. The graph of rainfall amount and rainfall pH for two and a half years is shown in Figure AT-PP-15. Based on their examination of this graph, the students formulate the hypothesis that; As the amount of precipitation increases, the pH of the precipitation decreases.

Collecting and Analyzing Data

The first step in testing this hypothesis is to gather the data from the GLOBE archives. The data can be saved by printing the table from the computer, cutting and pasting the table into a spreadsheet, or copying down the values by hand. The students only need the data for those days where both rainfall and rainfall pH are reported.

The students then must decide how to analyze the data. In this case, they decide to group rainfall amounts and calculate the average pH for each group. They put the rainfall data into groups from 0.1 - 4.9 mm of rainfall, 5.0 - 9.9 mm, 10.0 - 14.9 mm, and so on. Then they calculate the average pH for each of these groups, and look for any trend in pH values as rainfall amounts increase. The following table gives their results:

Rainfall amount (mm)	Number of data points	Average pH
0.1 – 4.9	202	4.59
5.0 – 9.9	56	4.53
10.0 – 14.9	29	4.44
15.0 – 19.9	3	4.50
20.0 – 24.5	6	4.55
25.0 – 29.9	4	4.40
30.0 – 34.9	1	4.00
40.0 – 44.9	2	4.65
95.0 – 99.9	1	4.30

Notice that the students have started their rainfall amount with 0.1 mm instead of 0.0. This is because if the rainfall amount is zero, there can't be any pH value of rainfall. Also notice that the table of rainfall amounts isn't continuous (that is, some categories are missing) because there were no rainfall amounts in the data archive between those values.

The students decide from their calculations that there are too few data points in the rainfall categories above 14.9 mm for those calculations to be reliable. They focus instead only on the first 3 categories from their table.

Rainfall amount (mm)	Number of data points	Average pH
0.1 – 4.9	202	4.59
5.0 – 9.9	56	4.53
10.0 – 14.9	29	4.44

From these three points, there does seem to be some trend – there is an indication that the pH of the rainfall is slightly more acidic when more rain falls. This is an interesting result, and appears to support the students' hypothesis.

Communicating Results

The students decide to submit their research to a science fair. They create a poster that contains information about their hypothesis, the steps they took in doing their research, their data, calculations, and results. On their poster the students note that before they could positively conclude that rainfall pH decreases as the amount of rainfall increases, they would want to do some further calculations.

Future Research

The students would like to have a longer data record so that perhaps they would have more data at higher values of rainfall. They would also break the data up into smaller groupings, perhaps from 0.1-1.0 mm, 1.1-2.0 mm, and so on. If they find that their hypothesis is confirmed, the students could explore other variables, such as wind direction, length of rainfall event, or other parameters they think might be important, to determine why the pH decreases with increasing rainfall amounts.

The students also wonder if the pH value of rainfall changes during a single rain event. They propose that further study could be carried out by an experiment using the techniques they learned in the GLOBE protocols. In this case, however, the students propose that rather than collecting rainfall for 24 hours and then measuring the pH, they would set up an experiment on a rainy school day. The students would collect samples once every hour throughout the school day, and measure the pH of the rain for each hour of the rainfall event. They would then plot their data and see if there is a change in the pH of the rain as the storm goes on.

Figure AT-PP-9

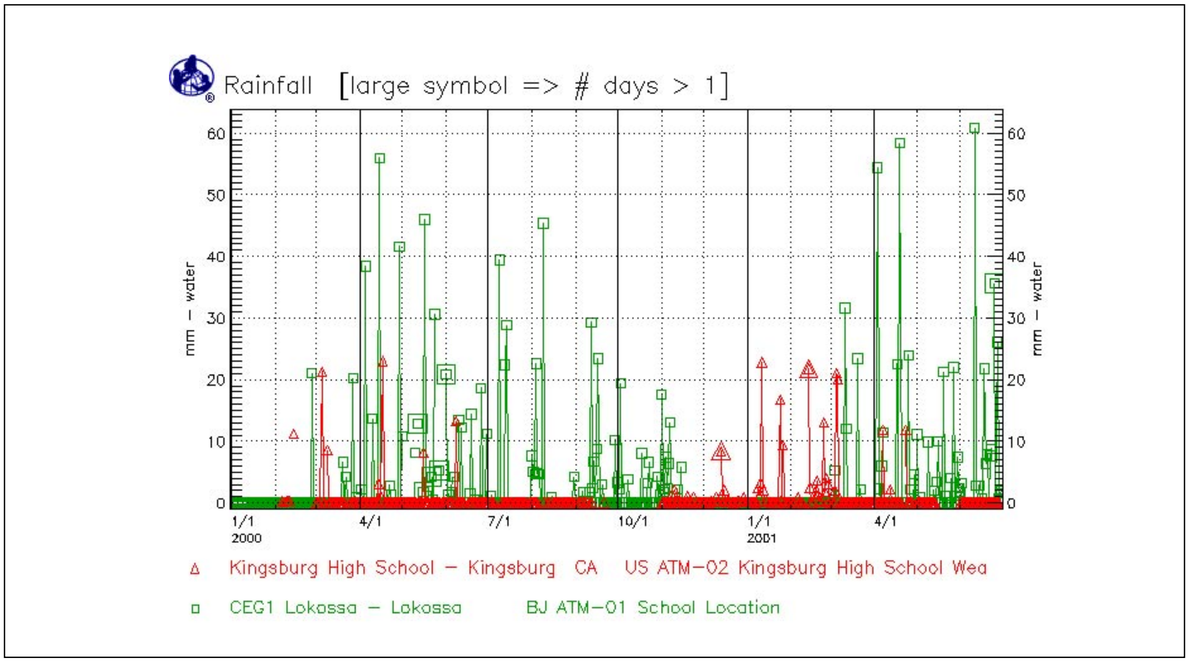


Figure AT-PP-10

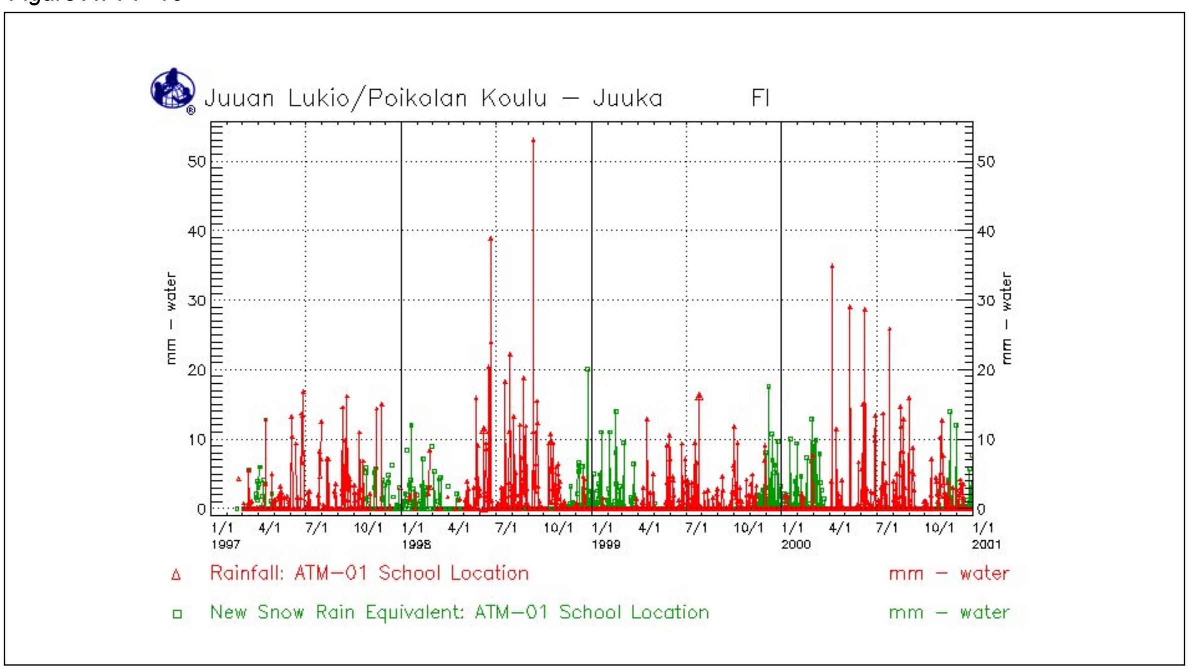


Figure AT-PP-11

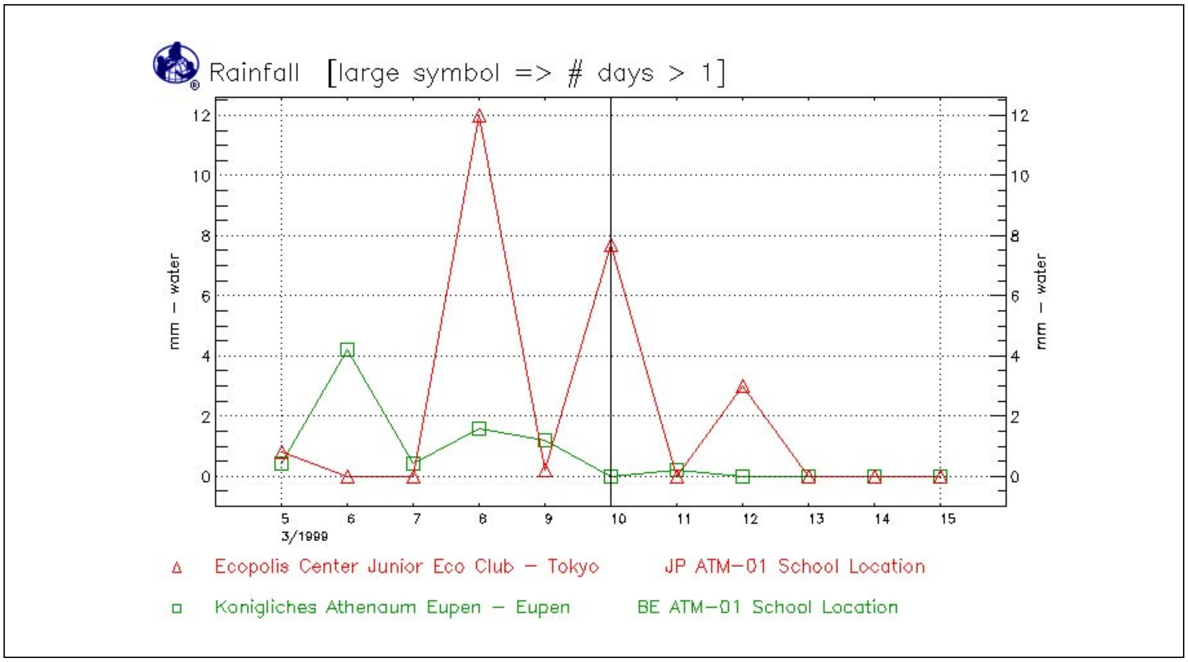


Figure AT-PP-12

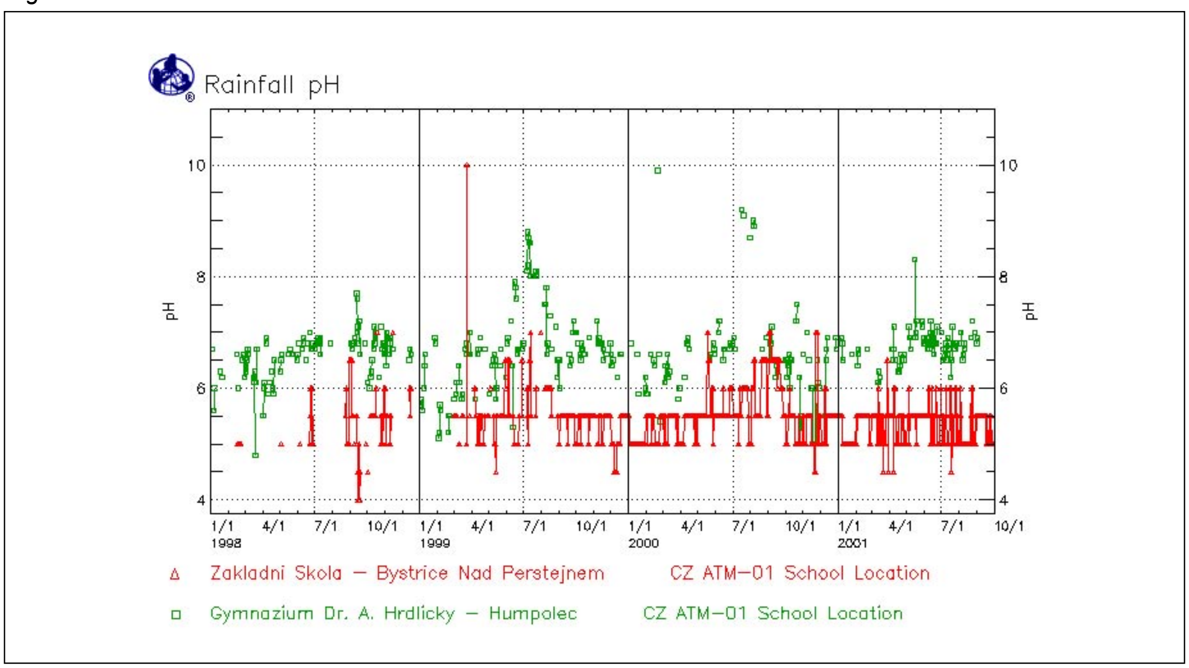


Figure AT-PP-13

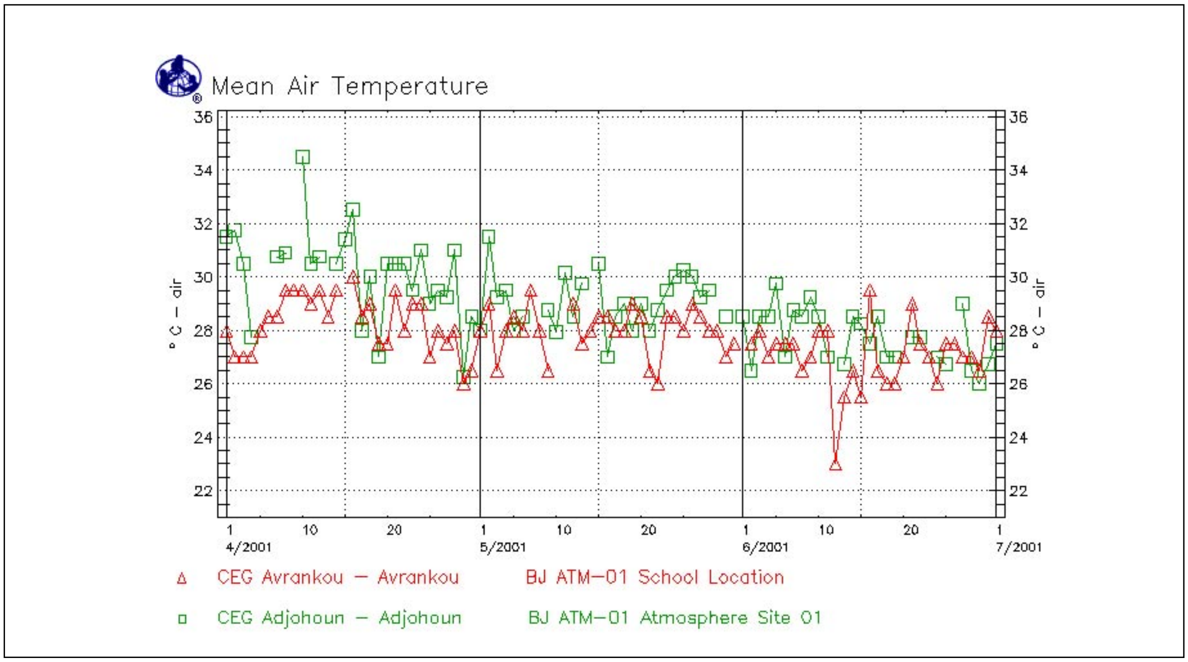


Figure AT-PP-14

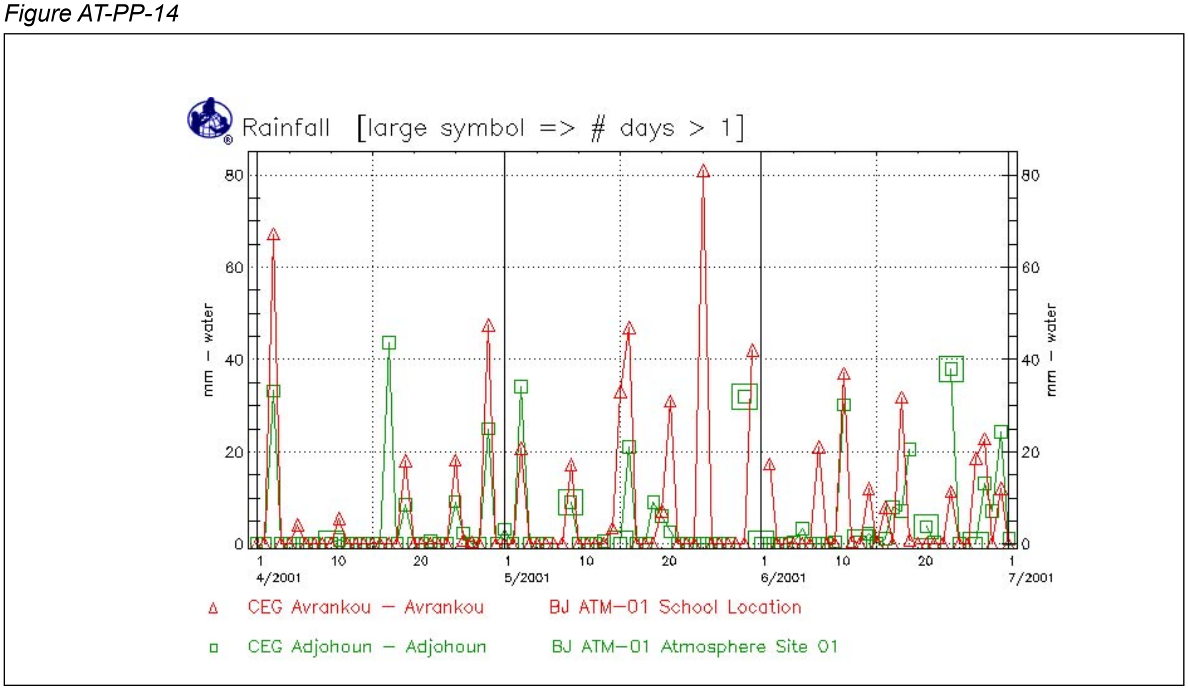
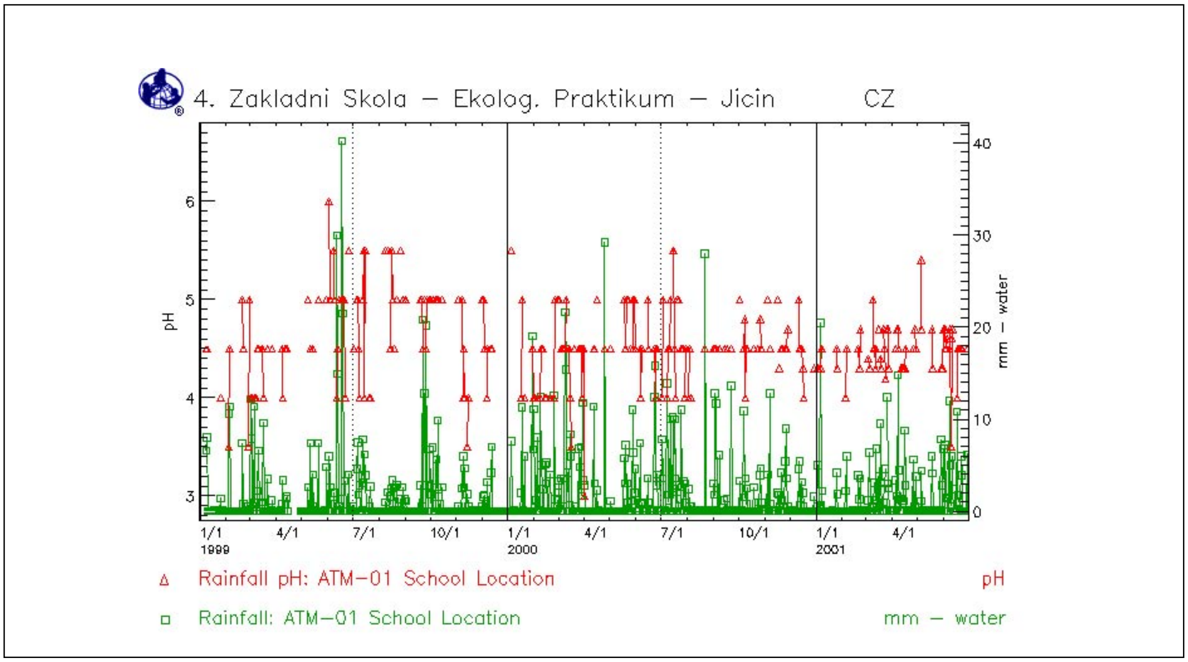


Figure AT-PP-15



Maximum, Minimum, and Current Temperature Protocol

Purpose
To measure air (and optionally soil) temperature within one hour of solar noon and the maximum and minimum air temperatures for the previous 24 hours

Overview
Students read the current, maximum, and minimum temperatures from a thermometer and then reset the maximum and minimum indicators to start a new 24-hour measurement period.

Student Outcomes
Students will learn to read minimum, maximum, and current temperatures using a U-shaped thermometer, understand diurnal and annual temperature variations, and recognize factors that influence atmospheric temperatures.

Science Concepts
Earth and Space Science

- Weather can be described by quantitative measurements.
- Weather changes from day to day and over the seasons.
- Weather varies on local, regional, and global spatial scales.

Geography

- The temperature variability of a location affects the characteristics of Earth's physical geographic system.

Scientific Inquiry Abilities
- Use a thermometer to measure temperature.
- Identify answerable questions.
- Design and conduct scientific investigations.
- Use appropriate mathematics to analyze data.
- Develop descriptions and explanations using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures and explanations.

Time
5 minutes

Level
All

Frequency
Daily within one hour of local solar noon

Materials and Tools
- Instrument shelter
- Installed maximum/minimum thermometer
- Calibration thermometer
- *Atmosphere Investigation Data Sheet*

Preparation
Set up the instrument shelter.

Calibrate and install the maximum/minimum thermometer.

Review how to read the maximum/minimum thermometer.

Prerequisites
None

Maximum, Minimum, and Current Temperature Protocol – Introduction

Temperature and Weather

Have you noticed that the daily weather forecasts are not always correct? This is partly because scientists are still trying to learn more about how our atmosphere works. Measurements of air temperature, and particularly how air temperature changes as storms pass by, are important to help scientists better understand our atmosphere from day to day. This understanding will enable meteorologists to accurately predict the weather for the next day, or even for the next week.

Measurements of air temperature are also important in understanding precipitation. Whether precipitation falls as rain, sleet, snow, or freezing rain depends on the air temperature. Air temperature also affects the amount of moisture that will evaporate and the relative humidity of the atmosphere. Moisture evaporated from land and water bodies into the atmosphere helps to fuel storms and greatly affects our weather.

Temperature and Climate

Is this an unusually warm year? Is Earth getting warmer as some scientists have predicted? Is the average temperature at your school changing because of local changes in land cover? To answer these and other questions about Earth's climate measurements are needed of daily maximum and minimum air and soil temperatures, month by month, year after year.

Generally, cities are warmer than the land areas surrounding them. As cities grow, temperatures may get warmer due to the expansion of paved areas and concrete buildings. An understanding of local variations in warming and cooling helps scientists to determine if there is a global change in average surface air temperature. Data from observations in many different environments, from the country to the inner city, are needed to study these changes in Earth's climate.

Scientists studying Earth's climate are looking for patterns of temperature change at different latitudes and longitudes. That is, are all places on Earth getting warmer or colder at the same rate? Computer models predict that if Earth's climate is changing due to the effect of greenhouse gases on air temperature, more warming will take place in the polar regions than in the tropics (although the polar regions will remain colder than the tropics). Models also predict that average nighttime temperatures will increase more than average daytime temperature and that an increase in temperatures will be more apparent in the winter than in the summer.

Evaluating model predictions of Earth's changing climate requires an enormous amount of data taken in many places on Earth over long periods of time. Measurements of daily atmosphere maximum and minimum temperature by GLOBE schools all over the world can help all of us improve our understanding of climate.

Temperature and Atmospheric Composition

Many of the chemical reactions that take place between trace gases in the atmosphere are affected by temperature. In some cases such as several of the reactions involved in the formation of ozone, the rate of the reaction depends on temperature. The presence of water vapor, water droplets, and ice crystals also plays a role in the chemistry of the atmosphere.

To understand weather, climate, and atmospheric composition, measurements of surface and air temperature are required. GLOBE measurements of air temperature near the ground are particularly useful because these data are hard to obtain except by reading carefully placed thermometers.

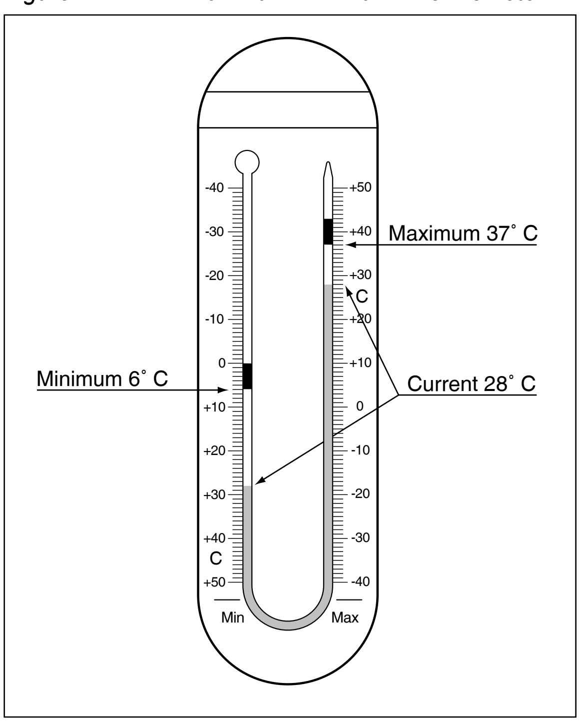
Teacher Support

Maximum/Minimum Thermometer

There are two instruments available to take daily measurements of maximum and minimum temperature. One is a liquid-filled thermometer and the second is a digital thermometer. The digital thermometer is also available with a soil probe that can be buried in the ground so that soil temperatures can also be measured. The use of these instruments is described in this protocol. There is also another type of max/min thermometer, called a digital multi-day max/min thermometer, which logs temperatures for six days, and is described in the *Digital Multi-Day Max/Min/ Current Air and Soil Temperatures Protocol.*

The liquid-filled maximum/minimum thermometer is a horseshoe-shaped tube with two indicators that show the maximum and minimum temperatures that have occurred since they were reset. See Figure AT-MM-1. On the maximum side, the temperature scale is such that temperature increases as you go from bottom to top (as with typical household thermometers). On the minimum side, however, the scale shows temperature decreasing as you go from bottom to top.

Figure AT-MM-1: Maximum/Minimum Thermometer



Most of the liquid in the thermometer is in the bulb which is at the top of the minimum side. As the temperature increases, the expansion of the liquid in the bulb pushes the mercury down on the minimum side and up on the maximum side. The indicator at the top of the mercury column on the maximum side of the thermometer is pushed upward. When the temperature drops, the column of mercury moves in the opposite direction, but the indicator on the maximum side remains in place indicating the highest temperature reached. As the temperature decreases, the mercury column rises on the minimum side of the thermometer until it reaches the indicator pin on the minimum side. Then, if the temperature continues to decrease, it pushes this indicator upward. When the temperature again increases, the indicator on the minimum side remains in place to indicate the lowest temperature reached.

The liquid-filled maximum/minimum thermometer is different from the type of thermometer familiar to most students. Thus, most students will benefit from practice in reading this type of thermometer prior to taking data in the field. This practice can be accomplished in several ways. You can hang the maximum/minimum thermometer in the classroom for a period of time and ask students to read it each day as they come in. Alternatively, you can copy the drawing of the maximum/minimum thermometer given in the *Appendix*, draw in a mercury column and the two indicators (which should be of a length equal to about 8˚ C) and ask the students to read the current, maximum, and minimum temperatures indicated on each drawing. Along these same lines, you could ask the students to make their own drawings showing specified current, maximum, and minimum temperatures.

The digital thermometer records and displays temperatures in 0.1˚ C increments. The sensor for reading air temperature is located inside the housing of the instrument. The thermometer is also available with an optional second sensor attached to a three meter long cord. This second sensor can be buried in the ground to measure soil temperature. If you are going to be taking both air and soil measurements it is important that you correctly label the sections of the display screen that apply to each sensor. This can be done by sticking two pieces of tape, labeled 'AIR' and SOIL', on the plastic casing of the thermometer to the right side of the display screen.

Instrument Maintenance

The instrument shelter should be kept clean both inside and outside. Dust, debris, and spider webs should be removed from the inside of the shelter with a clean, dry cloth. The outside of the shelter may be lightly washed with water to remove debris, but try to avoid getting too much water inside the shelter. If the outside of the shelter becomes very dirty, it should be repainted white.

Thermometer Calibration

If you are using the liquid-filled maximum/minimum thermometer, then approximately every three months you should check the calibration of your maximum/minimum thermometer against your calibration thermometer. If they disagree, recalibrate the thermometer. Roughly once a week, check that both sides of the maximum/minimum thermometer read the same. If they don't, recalibrate the thermometer.

If you are using a digital thermometer it is important that you calibrate it using a calibration thermometer. This calibration is done by comparing readings from the two thermometers and calculating the offsets that account for the difference between the digital thermometer readings and the true temperature. When the instrument is first set up both the air and soil sensors are calibrated following the *Digital Single-Day Max/Min Thermometer Sensor Calibration Field Guide*. Then every six months a check is made to see if the soil sensor is operating acceptably by comparing the temperatures that it is reporting to temperatures measured with a soil probe thermometer following the *Digital Single-Day Max/Min Thermometer Soil Sensor Error Check Field Guide*. If the difference between the digital soil sensor readings and the soil probe thermometer readings is greater than 2˚ C in magnitude than the digital soil sensor is dug out and both the air and soil sensors are recalibrated. If the difference is 2˚ C or more, the soil probe can be left buried and just the air sensor recalibrated.

Helpful Hints

Remind students that the mercury pushes the *bottom* of the indicators until the maximum or minimum temperatures are reached. Therefore, students should remember to read the maximum and minimum temperatures from the *bottom* (the end closest to the mercury column) of the indicators. To help students remember to read the bottom of the indicators, remind them that they are reading the highest point the mercury reached since the pins were reset.

If your thermometer has a Fahrenheit scale, paint over it so that students will not read it by mistake. One of the most common errors in the temperature data in the GLOBE data base is the reporting of temperature read in degrees Fahrenheit as if it were a reading in degrees Celsius. Before using the maximum/minimum thermometer, make sure that the column of mercury is continuous. Jarring during shipping can sometimes cause the mercury to separate into segments. If there are gaps in the mercury column, follow the instructions given in the *Frequently Asked Questions* section.

Questions for Further Investigation

When does temperature change the most from day to day?

What are the latitudes and elevations of other GLOBE schools with atmosphere temperature data similar to yours?

How does vegetation in your area respond to changing temperature?

Is your local environment affected more by average temperature or temperature extremes?

Thermometer Calibration

Lab Guide

Task

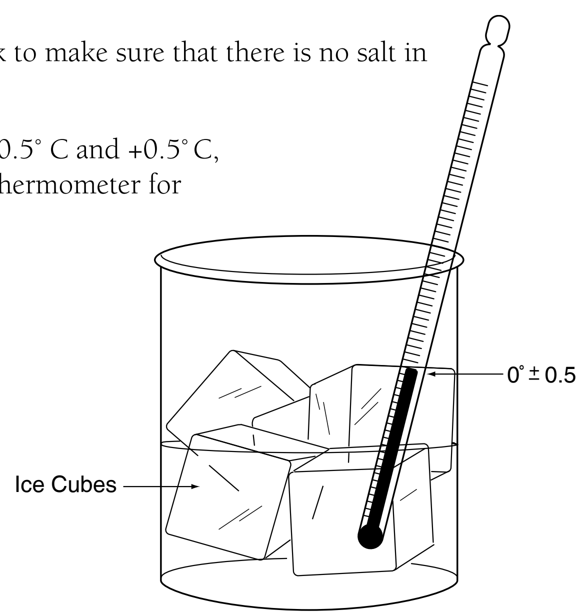
Check the calibration of the calibration thermometer.

What You Need

- ❑ Calibration thermometer
- ❑ Clean container at least 250 mL in size
- ❑ Crushed ice
- ❑ Water (distilled is ideal, but the key is that the water is not salty)

In the Lab

1. Prepare a mixture of fresh water and crushed ice with more ice than water in your container.
2. Put the calibration thermometer into the ice-water bath. The bulb of the thermometer must be in the water.
3. Allow the ice-water bath and thermometer to sit for 10 to 15 minutes.
4. Gently move the thermometer around in the ice-water bath so that it will be thoroughly cooled.
5. Read the thermometer. If it reads between -0.5˚ C and +0.5˚ C, the thermometer is fine.
6. If the thermometer reads greater than +0.5˚ C, check to make sure that there is more ice than water in your ice-water bath.
7. If the thermometer reads less than -0.5˚ C, check to make sure that there is no salt in your ice-water bath.
8. If the thermometer still does not read between -0.5˚ C and +0.5˚ C, replace the thermometer. If you have used this thermometer for measurements report this to GLOBE.



Maximum/Minimum Thermometer Calibration

Field Guide

Task

Check the calibration of the maximum/minimum thermometer.

Adjust the maximum/minimum thermometer if necessary.

What You Need

- ❑ Calibration thermometer that has been checked following the instructions in the *Thermometer Calibration Lab Guide*
- ❑ *Atmosphere Investigation Data Sheet*

In the Field

Day 1

Hang the calibration thermometer in the instrument shelter so that the bulb of the thermometer is not touching any surface.

Day 2

1. After reading the current, maximum, and minimum temperatures on the maximum/minimum thermometer, read the temperature on the calibration thermometer to the nearest 0.5˚ C.
2. Compare this reading with the current temperature from both the maximum and the minimum sides of the maximum/minimum thermometer.
3. If these readings are within +/- 0.5˚ C of the reading on the calibration thermometer, note in your metadata that the calibration of the maximum/minimum thermometer is good and complete the *Maximum, Minimum, and Current Temperature Protocol*.
4. If the current temperature reading from either side of the maximum/minimum thermometer is not within +/- 0.5˚ C of the reading on the calibration thermometer, proceed with the following steps:
5. Record the current temperatures from both the maximum and minimum sides of the maximum/minimum thermometer and the temperature reading of the calibration thermometer as comments for today on the *Atmosphere Investigation Data Sheet*. (Report all three temperatures.)
6. Leave the calibration thermometer hanging in the instrument shelter.
7. Remove the maximum/minimum thermometer from the instrument shelter. Do not touch the bulb of this thermometer. Keep the thermometer out of direct sunlight.
8. Loosen the screw so that the scales on the thermometer can move.
9. Slide the scales so that the current temperature reading agrees with the calibration thermometer reading.
10. Tighten the screw so that the scales are locked in place once more.
11. Remount the maximum/minimum thermometer in the instrument shelter and reset the indicators to the top of the mercury on both sides.
12. Record and report only the current temperature for today using the value from the calibration thermometer.
13. Record in your metadata for today that the thermometer required recalibration.

Maximum, Minimum, and Current Temperature Protocol

Field Guide

Task

Measure the current, maximum, and minimum air temperatures.

Reset the maximum and minimum indicators to start the next 24-hour measurement.

What You Need

- ❑ A properly sited instrument shelter
- ❑ A properly calibrated and installed maximum/minimum thermometer
- ❑ *Atmosphere Investigation Data Sheet*
- ❑ Pen or pencil

In the Field

1. Record the time and date on the *Atmosphere Investigation Data Sheet.*
2. Open the instrument shelter being careful not to touch or breathe on the thermometer.
3. Position yourself so that your eye is level with the mercury in the thermometer.
4. Read the level of the mercury on the maximum side of the thermometer to the nearest 0.5° C.
5. Record this reading as the current temperature.
6. Read the bottom of the indicator on the maximum side of the thermometer to the nearest 0.5° C.
7. Record this reading as the maximum temperature.
8. Read the bottom of the indicator on the minimum side of the thermometer to the nearest 0.5° C. Remember that the temperature scale is upside down.
9. Record this reading as the minimum temperature.
10. Use the magnet to gently move the maximum and minimum indicators down until they just touch the mercury.
11. Close the instrument shelter.

Digital Single-Day Max/Min Thermometer Sensor Calibration

Field Guide

Task

Calculate the air and soils sensor correction offset used to adjust for instrument accuracy errors.

What You Need

- ❑ Calibration thermometer that has been checked following the instructions in the *Thermometer Calibration Lab Guide*
- ❑ *Digital Max/Min Thermometer Calibration Data Sheet*

Note: If you plan on performing only air temperature measurements, or are only recalibrating the air sensor, skip the portions of this field guide that pertain to the soil sensor.

In the Field

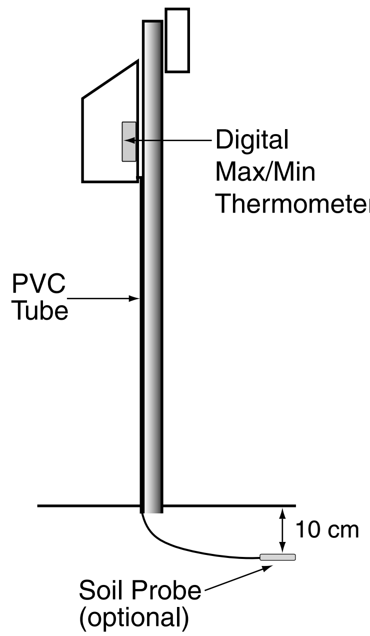
1. Open the door to the instrument shelter and hang the calibration thermometer, the digital thermometer, and the soil sensor in the instrument shelter so that they have air flow all around them and do not contact the sides of the shelter.
2. Close the door to the instrument shelter.
3. Wait at least an hour and then open the door to the instrument shelter. Make sure that your digital thermometer is displaying the current temperature(s) (Neither 'MAX' or 'MIN' symbols should be displayed on the screen. If they are, press the *MAX/MIN* button until they disappear).
4. Read the temperatures reported by the air sensor and the soil sensor of the digital thermometer and record them on your *Digital Max/Min Thermometer Calibration and Reset Data Sheet.*
5. Close the door of the instrument shelter.
6. Repeat steps 2 to 5 four more times, waiting at least one hour between each set of readings. Try to space out the five sets of readings over as much of a day as possible.
7. Report your calibration data to the GLOBE Web site.

Digital Max/Min Thermometer Installation

Field Guide

Task

Install the digital thermometer at your Atmosphere Study Site.



What You Need

- ❑ GLOBE instrument shelter (specifications are given in the *GLOBE Instrument List* in the *Toolkit* section)
- ❑ Drill with 12 mm spade bit (if doing soil measurements)
- ❑ String or wire ties
- ❑ 120 cm X 2.5 cm PVC pipe (optional)
- ❑ Digging tools (if doing soil measurements)

In the Field

1. Mount the digital thermometer housing to the rear wall of your instrument shelter. The housing should be placed so that the digital display may be easily read.
2. If you are not going to be taking soil temperature measurements, store the soil sensor (if your thermometer has one) and it's cable neatly in a corner of the shelter where it will be out of the way and skip the following steps. Otherwise, proceed to step 3.
3. If necessary, drill a 12 mm hole, using a drill with a spade bit, in the bottom of the instrument shelter, near the back. Feed the soil sensor probe through the hole, leaving as much cable as possible inside the shelter. You may wish to feed the sensor and wire through a thin PVC pipe that will serve to protect the wire.
4. Choose a site to place the soil temperature probe nearby on the equatorward side (sunny-side) of the mounting post for the instrument shelter. Data collected from soil in unshaded locations are preferred. Comments in your site definition should include the amount of shade that the soil surface above the probe will experience during a year.
5. Dig a hole to a depth of a little over 10 cm in depth at the chosen location.
6. Push the probe horizontally into the side of the hole at a depth of 10 cm. Use a nail or steel pin, with a slightly smaller diameter than the probe, to pilot an opening for the probe if needed.
7. Refill the hole with the soil that you removed.
8. Neatly secure all extra cable for the soil sensor using string or wire ties. Keep as much of the excess cable as possible within the shelter.

Digital Single-Day Maximum and Minimum Temperature Protocol

Field Guide

Task

Measure the current, maximum, and minimum air temperatures from the digital single-day thermometer.

Measure the current, maximum, and minimum soil temperatures from the digital single-day thermometer (optional).

Reset the digital thermometer to start the next 24-hour measurement.

What You Need

- ❑ A properly sited instrument shelter
- ❑ A properly calibrated and installed digital single-day max/min thermometer
- ❑ An accurate watch or other device that tells time
- ❑ An appropriate *Data Sheet*
- ❑ Pen or pencil

Note: Make sure that the digital thermometer is reading in Celsius units. If it is not, press the ˚C/˚F button to switch to Celsius units.

In the Field

1. Within an hour of local solar noon, open the instrument shelter being careful not to breathe on the thermometer.
2. Record the time and date on your *Data Sheet* in both local and UT time. **Note:** GLOBE Web site entry should be UT time.
3. Make sure that your thermometer is displaying the current temperature(s) (Neither 'MAX' or 'MIN' symbols should be displayed on the screen. If they are, press the *MAX/MIN* button until they disappear).
4. Record the current air temperature on your *Data Sheet*. If you are taking soil readings, also record the soil temperature.
5. Press the *MAX/MIN* button once.
6. Maximum temperature reading(s) will now be displayed along with the 'MAX' symbol on the display screen.
7. Record the maximum air temperature on your *Data Sheet*. If you are taking soil readings, also record the maximum soil temperature.
8. Press the *MAX/MIN* button a second time.
9. Minimum temperature reading(s) will now be displayed along with the 'MIN' symbol on the display screen.
10. Record the minimum air temperature on your data sheet. If you are taking soil readings, also record the minimum soil temperature.
11. Press and hold the *MAX/MIN* button for one second. This will reset your thermometer.
12. Close the instrument shelter.

Digital Single-Day Max/Min Thermometer Soil Sensor Error Check

Field Guide

Task

Check the accuracy of the soil sensor to see whether or not it needs to be dug out and recalibrated.

What You Need

- ❑ Soil probe thermometer from *Soil Temperature Protocol.*
- ❑ *Digital Max/Min Thermometer Calibration Data Sheet*

In the Field

1. Calibrate a soil probe thermometer following the *Calibrating the Soil Thermometer Lab Guide of the Soil Temperature Protocol.*
2. Open the door to the instrument shelter.
3. Select a place about 15 cm from the location of the soil temperature probe.
4. Measure the soil temperature at a depth of 10 cm at this spot following the *Soil Temperature Protocol.*
5. Record this temperature in the 'Soil Sensor Error Check' section of your *Digital Max/Min Thermometer Calibration and Reset Data Sheet.*
6. Make sure that your digital thermometer is displaying the current temperature(s) (Neither 'MAX' or 'MIN' symbols should be displayed on the screen. If they are, press the *MAX/MIN* button until they disappear).
7. Read the temperature reported by the soil sensor of the digital thermometer and record it on your *Data Sheet*.
8. Close the door of the instrument shelter.
9. Repeat steps 2 to 8 four more times, waiting one hour between measurements.
10. Calculate the average of the soil thermometer readings.
11. Calculate the average of the digital soil sensor readings.
12. Calculate the soil sensor error by subtracting the average of the five digital soil sensor readings (from step 10) from the average of the five soil sensor readings (from step 11)
13. If the absolute value of the soil sensor error is greater than or equal to two 2˚ C, then dig-out this sensor and recalibrate both the air and soil sensors following the *Digital Single-Day Max/ Min Thermometer Sensor Calibration.* Otherwise leave the digital soil sensor in the ground and recalibrate only the air sensor.

Frequently Asked Questions

1. If we missed reading the maximum/minimum thermometer for a day or more (over the weekend, holiday, vacation, etc.), can we still report the temperature for today?
You can and should report the current temperature. You may not report the maximum and minimum temperatures as they are the maximum and minimum temperatures for more than one day. Reset the indicators and tomorrow you can report the maximum, minimum, and current temperatures.

2. What should we do if our maximum/minimum thermometer does not agree with the calibration thermometer and we can not adjust the scales so that they agree?
This is rare, but there are some maximum/minimum thermometers that cannot be calibrated successfully. In this case, contact the supplier or manufacturer, explain that the calibration of the thermometer is off, and request a new thermometer.

3. What do we do if there are air bubbles in our thermometer?
For your thermometer to function properly, there must be no air bubble in the column of liquid in the thermometer and in the maximum/minimum thermometer there should be no gaps in the column of mercury. There are many techniques for reconnecting the columns of liquid in thermometers. One technique is to tap the upright thermometer casing against your hand. Do not press against the stem of the thermometer as this could cause breakage. Gently shaking or tapping the thermometer casing is much more effective in removing the gaps in the mercury than trying to heat or cool the thermometer.

Another technique is to attach a string securely to the top of the thermometer. Stand in a clear, open space, and swing the thermometer in a circle so that the centrifugal force pushes the liquid together. In the case of the maximum/minimum thermometer which has mercury in it, this procedure should be done by the teacher and not the students.

If repeated tries do not succeed in reconnecting the column of liquid, obtain a replacement thermometer from the manufacturer or supplier.

4. Can we take maximum and minimum temperature readings without using a thermometer containing mercury?
The way the horseshoe-shaped maximum/minimum thermometer works is only possible using two different liquids, one of which must be mercury. To take these data without using a thermometer with mercury you must use an electronic temperature sensor that remembers the maximum and minimum temperatures or that stores its readings using a data logger. See the *Optional Protocols* given in the on-line version of this *Teacher's Guide*.

5. The maximum temperature reading on our thermometer today is less than the current temperature reading yesterday. Is this wrong?
Yes, this is a problem if the difference is more than 0.5˚ C. Sometimes the maximum indicator slips. Report your readings anyway so that GLOBE can track these errors. If this problem occurs often (more than one day in 20 or 5% of the time), check to see that your instrument shelter is mounted firmly and securely and that there are no routine sources of vibration shaking the shelter. If your shelter is securely mounted and there are no sources of vibration, contact the supplier and replace your maximum/minimum thermometer and also inform GLOBE of your problem.

If the difference is just 0.5˚ C, this is not a problem, but be sure that you are always reading the thermometer with your eyes level with the mercury. Differences between two observers of 0.5˚ C are acceptable.

6. The minimum temperature reading on our thermometer today is greater than the current temperature reading yesterday. Is this wrong?
See the answer to question 5.

Maximum, Minimum, and Current Air Temperature – Looking At the Data

Are the data reasonable?

Air temperature varies throughout a 24-hour period. In some places there may be large daily changes in temperature, while in others this variation may be quite small. Figure AT-MM-2 shows a graph of air temperature over the course of a day with measurements taken every 15 minutes. You can see on this graph the current($T_{current}$), maximum (T_{max}), and minimum (T_{min}) temperatures for this day. You will use your horse-shoe-shaped thermometer to record the maximum and minimum temperatures so that you only need to read the thermometer once each day, within one hour of local solar noon.

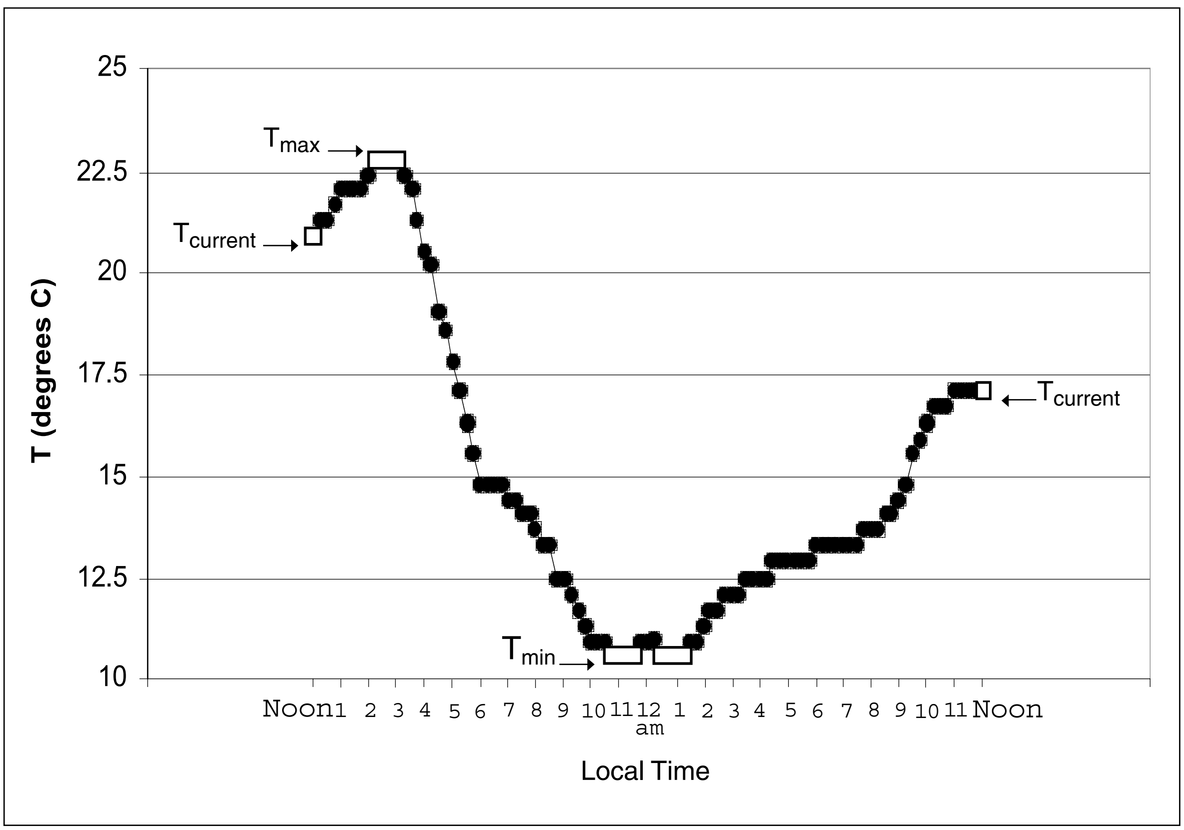
By definition T_{max} must be the highest temperature for this time period and T_{min} must be the lowest.

Therefore,

$$T_{max} \geq T_{current} \quad \text{and} \quad T_{min} \leq T_{current}$$

for $T_{current}$ at both the beginning and the end of the 24-hour period. If these inequalities are not true, then something is wrong with the T_{max} or the T_{min} for this day.

Figure AT-MM-2: Temperature Variation Over a 24-hour Period



Looking at a graph of these data, such as Figure AT-MM-3, makes it easy to check them visually.

Another check on the reasonableness of data from a single day is to compare them with data from near-by GLOBE schools or other sources of temperature data. Figure AT-MM-4 shows the data from a single day for 12 schools that are reasonably close to one another. Table AT-MM-1 gives the air temperature data for the schools shown in this figure. All the schools shown are in reasonable agreement.

What do people look for in these data?

In climate studies, scientists are interested in the average temperature over various time periods and in the extreme values. On most days, air temperature varies with the diurnal (daily) cycle of sunlight, and this variation is often larger than the change from day to day.

In many places, air temperature varies significantly as weather systems move across the region in a succession of cold fronts and warm fronts. The exact timing of these weather systems varies from year to year so comparing temperatures from the same day in different years is not a good indication of climate variation. To really be able to compare year-to-year changes, you must average over multiple weather systems. A month is long enough to average out the effects of individual storms, but not so long that seasonal variations are averaged out.

The average temperature for a day can be estimated by averaging the maximum and minimum temperatures for that day. Research has shown that this estimate is generally within 0.1˚ C of the actual average value. For the school we are considering on April 15, 1998:

$$T_{max} = 10.0^\circ C$$

$$T_{min} = 2.0^\circ C$$

$$T_{average} = \frac{T_{max} + T_{min}}{2} = \frac{10.0^\circ C + 2.0^\circ C}{2} = 6.0^\circ C$$

Table AT-MM-1: Data for the Schools Shown in Figure AT-MM-4 for April 15, 1998

MxTmp	MnTmp	CrTmp	Hour	Lat	Lon	Elev	Location of School
14.0	0.0	12.0	11	50.0477	14.4393	272	Praha 4, CZ
13.0	-1.0	12.0	12	49.7667	16.9167	273	Mohelnice, CZ
12.0	-1.0	8.0	10	50.1328	14.4035	322	Praha 8, CZ
12.0	3.0	12.0	11	50.0630	14.4340	272	Praha 4, CZ
11.2	0.9	11.0	9	50.4387	15.3523	868	Jicin,CZ
11.0	-4.0	10.0	11	48.9737	14.5027	395	Ceske Budejovice, CZ
11.0	2.0	9.0	10	49.9078	16.4218	460	Ceska Trebova, CZ
10.5	-1.2	10.2	11	49.9042	16.4432	350	Ceska Trebova, CZ
10.0	**2.0**	**9.0**	**11**	**49.5420**	**15.3537**	**518**	**Humpolec, CZ**
10.0	5.0	8.0	12	49.2080	16.6833	265	BRNO, CZ
10.0	0.0	8.0	11	49.5190	16.2600	570	Bystrice Nad Perstejnem, CZ
9.0	-2.0	9.0	11	49.3167	16.3417	485	Deblin, CZ

Figure AT-MM-3: Air Temperature Data for One Month from a GLOBE School

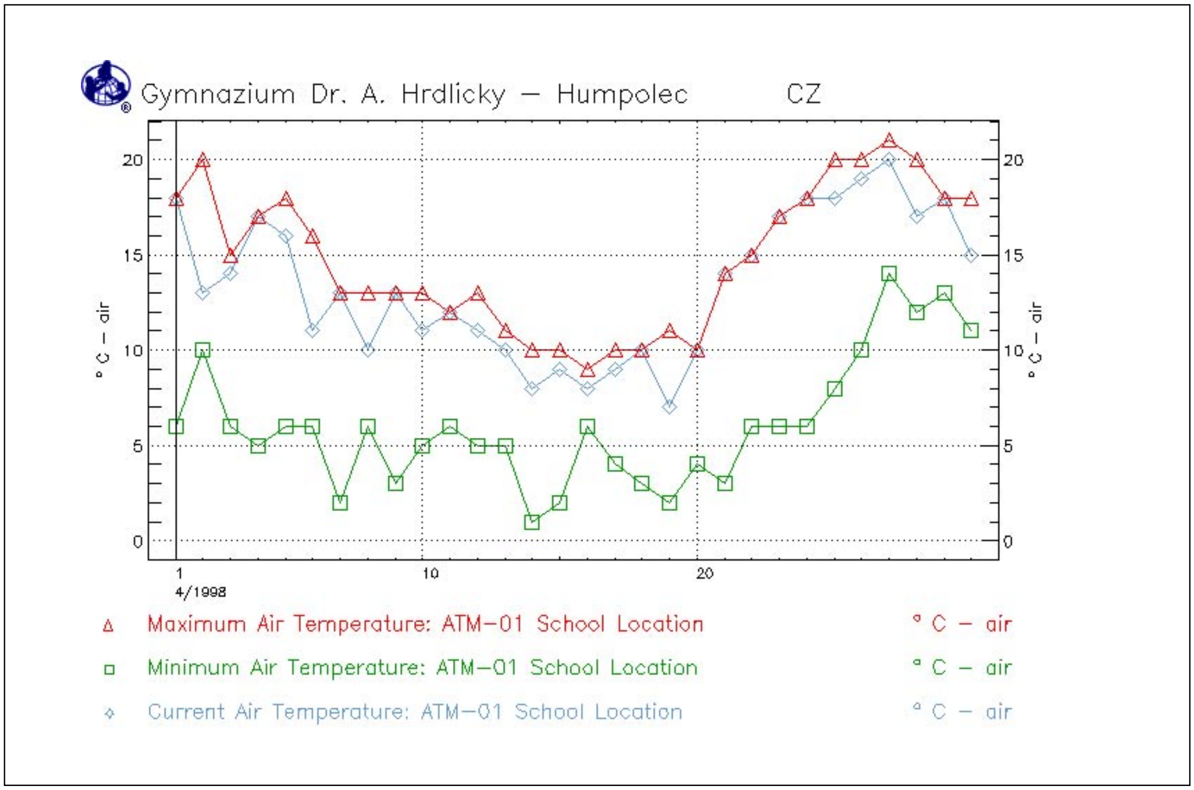
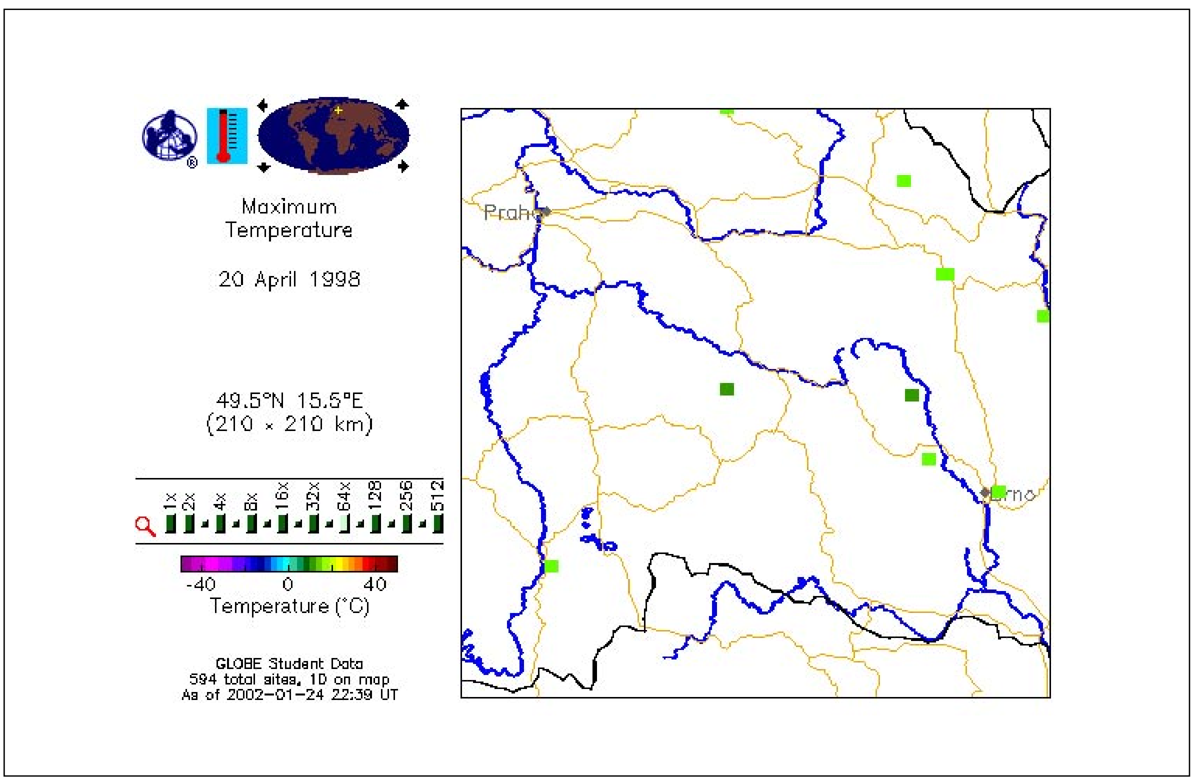


Figure AT-MM-4: GLOBE School Data for Maximum Temperature for a Single Day



The monthly average temperature can also be calculated by averaging the maximum and minimum temperatures for every day in the month. From the values in Table AT-MM-2, for Gymnazium Dr. A. Hrdlicky the monthly average air temperature for April 1998 is:

$$T_{average} \text{ (April 1998)} = 10.4° \text{ C.}$$

Most living things are sensitive to the extremes in temperature. This is particularly true when temperatures go below the freezing point of water (0.0° C). Looking at the minimum temperature curve in Figure AT-MM-3, it is easy to see that the temperature for this whole month never dipped below freezing. The lowest temperature measured was 1° C. The maximum temperature for the month was 21° C.

As student researchers, you should consider comparing temperatures, average temperatures, and temperature extremes between different schools or locations. You can compare monthly average temperatures from one year to another and look at the pattern of monthly average temperatures over the year. It is also interesting to look for the first and last days of the cold season when the minimum temperature is below freezing. A number of other sections in this Guide describe useful correlations of air temperature with other phenomena.

In comparing schools, remember that the atmosphere gets colder as elevation increases. Also, most large cities are warmer than the surrounding country side. This is called the urban heat island effect. Praha (Prague) is a large city. From the data in Table AT-MM-1 it is clear that the schools in Praha are at lower elevations as well as being in a city, and on this day they have the warmest maximum temperatures.

Table AT-MM-2: Temperature Data for April 1998

Date	Temperatures		
(yyyymmdd)	Current	Maximum	Minimum
19980430	15.0	18.0	11.0
19980429	18.0	18.0	13.0
19980428	17.0	20.0	12.0
19980427	20.0	21.0	14.0
19980426	19.0	20.0	10.0
19980425	18.0	20.0	8.0
19980424	18.0	18.0	6.0
19980423	17.0	17.0	6.0
19980422	15.0	15.0	6.0
19980421	14.0	14.0	3.0
19980420	10.0	10.0	4.0
19980419	7.0	11.0	2.0
19980418	10.0	10.0	3.0
19980417	9.0	10.0	4.0
19980416	8.0	9.0	6.0
19980415	9.0	10.0	2.0
19980414	8.0	10.0	1.0
19980413	10.0	11.0	5.0
19980412	11.0	13.0	5.0
19980411	12.0	12.0	6.0
19980410	11.0	13.0	5.0
19980409	13.0	13.0	3.0
19980408	10.0	13.0	6.0
19980407	13.0	13.0	2.0
19980406	11.0	16.0	6.0
19980405	16.0	18.0	6.0
19980404	17.0	17.0	5.0
19980403	14.0	15.0	6.0
19980402	13.0	20.0	10.0
19980401	18.0	18.0	6.0
Total		443.0	182.0

From Gymnasium Dr. A. Hrdlicky

An Example of a Student Research Investigation

Forming a Hypothesis

A student at a school in Humpolec, CZ looks at the visualizations of maximum temperature for several days in April 1998. She notices that the values for the schools in Praha are warmer than those for her school for a number of days. She asks if this could be true on average. As a simple starting point for her research she hypothesizes that: *Monthly average temperatures in Praha are warmer than in Humpolec.*

Collecting Data

Data have been collected by GLOBE schools in Praha for April 1998, so she decides to test her hypothesis using this month as her sample. She starts by identifying the GLOBE schools in Praha which have reported data for this time period. She finds five schools. Then she graphs the maximum, minimum, and current temperatures from each school and looks at the graphs to be sure that the data are of good quality. She decides that they are good enough for her project as she will be combining the data from all five schools.

Analyzing Data

As a first step in getting the data from these schools, she generates a plot of the maximum temperature data for April 1998 from her school and the schools in Praha. She then creates a data table with all the values for this graph. She saves this information either by printing the table from the computer, cutting and pasting the table into a spreadsheet, or copying down the values by hand. She does the same thing for the minimum temperatures. Now she calculates the average of all the maximum and minimum temperatures reported by the schools in Praha for this month. She gets a value of 12.6˚ C. Since this is greater than the value for her school of 10.4˚ C, her hypothesis is supported.

She wonders if averaging all the temperatures is correct, since on some days all five Praha schools provided data but on other days only one school reported. She decides to calculate the monthly average for each individual school and then average these five values. Her results for the five schools are 11.6˚ C, 12.1˚ C, 12.5˚ C, 13.0˚ C, and 14.4˚ C and the average of these values is 12.7˚ C which is in good agreement with the original average she calculated for Praha of 12.6˚ C.

She then proceeds to write-up her hypothesis, her procedure, and her conclusions and includes calculations she has done and graphs she has used or made. As a final note, she discusses additional tests of her hypothesis that she would like to investigate in the future including doing the comparison for April of another year or even doing the comparison for all months of the year 1998.

Further Data Analysis

If the student doing this project has been taught about square roots and some elementary statistics, she could go a bit further and examine the statistical errors in her calculations of monthly average temperatures. All of the schools involved in this example reported temperature to the nearest degree Celsius instead of to the nearest 0.5˚ C. How can she tell? Well she notices that all of the values reported have 0 in the tenths place. If readings were taken to the nearest half degree, there should be some values with 5 in the tenths place. So, given the accuracy of GLOBE instruments and the readings by the students, the error in the individual measurements is ± 1.0˚ C. The error in the average depends on the number of independent measurements included, so for each school the statistical error in the average is:

if N = number of measurements

$$\text{Error} = \pm\ 1^\circ\ \text{C} * \frac{\sqrt{\text{N}}}{\text{N}}$$

$$\text{Error} = \pm\ 1^\circ\ \text{C} * \frac{1}{\sqrt{\text{N}}}$$

For the schools with data for 22 or fewer days (and therefore 2 x 22 = 44 or fewer measurements), the error is approximately ± 0.2˚ C while for schools with more measurements the error is about ± 0.1˚ C. Given these statistical errors, the student concludes that the differences among the schools' monthly averages are larger than the errors and therefore statistically significant. This is true even among the schools in Praha. This strengthens her confidence that the hypothesis has been supported by the data because the monthly average temperature in Humpolec in April 1998 is lower than for any of the schools in Praha as well as being lower than the average of all data from Praha.

Advanced Data Analysis

A more advanced student would not calculate the statistical error using all the measurements from the five schools taken together because these data are not independent of one another. On a given day in Praha, the data from the five schools should be correlated because they are experiencing approximately the same weather. Realizing this, an advanced student decides to make two more checks on her conclusion.

First, she decides to calculate the average temperature for each day of April in Praha. For each day she sums the maximum and minimum temperatures from all schools which have data for that day and divides by the number of measurements reported. The results of this are given in the right-hand column of Table AT-MM-3. This process gives her average temperatures for 28 days in April and she averages these to get

Table AT-MM-3: Maximum and Minimum Temperature Data for Five Schools in Praha for April 1998

School:	Zakladni Skola, n.Inter.		Masarykova stredni skola chemicka		Zakladni Skola		Zakladni Skola Horackova		Gymnazium		Daily
Date	T_{max} °C	T_{min} °C	T_{max} °C	T_{min} °C	T_{max} °C	T_{min} °C	T_{max} °C	T_{min} °C	T_{max} °C	T_{min} °C	T_{avg} °C
4/1/1998	21	5	22	8	20	12	—	—	—	—	14.7
4/2/1998	17	12	20	11	19	9	—	—	—	—	14.7
4/3/1998	17	9	20	10	18	9	—	—	—	—	13.8
4/4/1998	19	11	—	—	18	7	—	—	—	—	13.8
4/5/1998	14	5	—	—	15	8	—	—	—	—	10.5
4/6/1998	14	4	—	—	18	8	—	—	—	—	11.0
4/7/1998	15	3	18	8	19	8	—	—	26	5	12.8
4/8/1998	14	4	—	—	17	9	—	—	—	—	11.0
4/9/1998	16	-1	—	—	16	8	—	—	—	—	9.8
4/10/1998	14	2	—	—	10	8	—	—	—	—	8.5
4/11/1998	14	2	—	—	14	7	—	—	—	—	9.3
4/12/1998	14	2	—	—	15	1	—	—	—	—	8.0
4/13/1998	—	—	—	—	15	4	—	—	—	—	9.5
4/14/1998	—	—	—	—	15	-8	—	—	—	—	3.5
4/15/1998	—	—	—	—	12	-1	14	0	12	3	6.7
4/16/1998	—	—	15	4	13	5	14	3	14	5	9.1
4/17/1998	—	—	15	5	17	7	13	1	14	2	9.3
4/18/1998	—	—	—	—	—	—	15	4	—	—	9.5
4/19/1998	—	—	—	—	—	—	—	—	—	—	
4/20/1998	—	—	—	—	—	—	—	—	—	—	
4/21/1998	17	8	21	5	—	—	16	4	16	2	11.1
4/22/1998	16	4	16	6	—	—	16	5	17	3	10.4
4/23/1998	17	4	21	9	—	—	20	5	21	3	12.5
4/24/1998	18	8	23	9	—	—	—	—	25	4	14.5
4/25/1998	20	7	—	—	19	8	—	—	—	—	13.5
4/26/1998	24	10	—	—	24	11	—	—	—	—	17.3
4/27/1998	24	10	—	—	25	12	—	—	26	10	17.8
4/28/1998	24	10	24	12	25	13	23	12	25	13	18.1
4/29/1998	25	9	22	15	20	13	22	12	21	12	17.1
4/30/1998	22	8	22	13	23	10	20	12	23	9	16.2
Total	396	136	259	115	407	168	173	58	240	71	333.7
Number of days	22	22	13	13	23	23	10	10	12	12	28
Average Max or Min	18.0	6.2	19.9	8.8	17.7	7.3	17.3	5.8	20.0	5.9	
Monthly T_{avg} °C	12.1		14.4		12.5		11.6		13.0		11.9
Statistical error (°C)	0.2		0.3		0.2		0.3		0.3		0.2

the monthly average temperature for Praha. The result is 11.9˚ C with a statistical error of ± 0.1˚ C, and this value is significantly lower than the other results. However, this monthly average is still significantly higher than that for Humpolec and the hypothesis is still confirmed.

Second, she notices that for two days, April 19 and 20, there is no data from any of the Praha schools. Were these abnormally cold or warm days which might bias the monthly average? Generally, Humpolec is close enough to Praha so that they experience similar periods of cold or warm weather as weather systems move through the Czech Republic. The student looks at the data from her school for these two days to get an indication of whether these were unusual days relative to the monthly average for April. The average temperatures for these two days were 7.0˚ C and 6.5˚ C, respectively. Both were significantly colder than the monthly average. Missing data for these two days could bias the monthly average for Praha, but by how much? To estimate this, the student decides to calculate the monthly average for Humpolec omitting these two days. The monthly average which one would obtain if data were missing for these two days is 10.7˚ C, 0.3˚ C higher than the actual average calculated. This is a significant effect, but it is not large enough to change the conclusion that average monthly temperature in Praha is higher than in Humpolec for the month of April 1998.

Explaining and Communicating Results

Knowing that average temperatures in Praha are higher than in Humpolec does not explain why this is the case. Pursuing this question is more challenging, but should be more rewarding. Two common effects could explain the systematic temperature differences observed – urban heat island effects and differences in elevation. A student might hypothesize that the warmer conditions in Praha compared to Humpolec are due to the difference in elevation. To test this hypothesis, the student would need to assemble data from schools in the Czech Republic at different elevations. For instance, Mohelnice and Jicin are both relatively small towns with Mohelnice at about the same elevation as Praha and Jicin at an elevation 350 meters higher than Humpolec. See Table AT-MM-2. If average temperatures in Mohelnice are about the same as those in Praha while the variation in average temperatures between Mohelnice, Humpolec, and Jincin are proportional to altitude, the hypothesis would be supported. Differences in latitude also affect average temperature. With an increase of 2˚ to 2.5˚ of latitude roughly equivalent to a 150 meter increase in elevation, the latitude effects should be significantly smaller than the elevation effects for these cities. Addressing questions such as this one is easier where there are many GLOBE schools consistently reporting data.

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Current Temperature

Purpose

To measure the current air temperature when an instrument shelter is not available

Overview

Current air temperature is measured using a thermometer held in the open air but in the shade for at least 3 minutes.

Student Outcomes

Science Concepts

Atmospheric Science

Weather can be described by quantitative measurements.

Weather changes over different time and spatial scales.

Weather changes over seasons.

Physical Science

Properties can be measured by tools.

Geography

Temperature variations affect the characteristics of Earth's physical geographic system.

Scientific Inquiry Abilities

Use a thermometer to measure temperature.

Time

5 minutes

Level

All

Frequency

As needed in support of other GLOBE measurements

Calibration every three months

Materials and Tools

Alcohol-filled thermometer (calibration thermometer or sling psychrometer)

A clock or watch

Rubber band and a piece of string (if calibration thermometer is used)

Data sheets

Preparation

Find a shady spot for your air temperature measurement.

Prerequisites

None

Teacher Support

This method should be used only when an instrument shelter is not available and a current temperature measurement is required in support of another GLOBE measurement. Remember to define the appropriate site for your measurements (i.e., if other atmosphere measurements are taken this is would be an Atmosphere Study Site, if soil temperature measurements are taken, this is a Soil Temperature Study Site, etc.).

Calibration and Quality Control

This measurement takes only a few minutes to complete. The main concern is to allow sufficient time for the thermometer to equilibrate to the temperature of the air, perhaps three to five minutes. In addition, the shady spot you use should not be adjacent to a building or other large structure, such as a tree. Try to maintain a distance at least 4 meters away from any such object, and take the measurement over a natural surface, such as vegetation, rather than concrete or paved walkways.

Your organic liquid-filled thermometer should be calibrated at least every three months as well as before its first use. Calibrate it following the instructions in the *Maximum, Minimum, and Current Temperatures Protocol.* The thermometers on your sling psychrometer should also be calibrated at least once every three months and before first use following the instructions in the *Relative Humidity Protocol.*

Current Air Temperature Protocol

Field Guide

Task

To measure current air temperature in support of other GLOBE measurements

What You Need

- ❑ String and rubber band and calibration thermometer OR Sling psychrometer
- ❑ *Data Sheet*
- ❑ Clock or watch
- ❑ Pen or pencil

In the Field

1. Tie one end of a piece of string securely to the end of the calibration thermometer and the other end to a rubber band.
2. Slip the rubber band around the wrist so that the thermometer is not broken if it is accidentally dropped on the ground.

   OR

   Use the dry bulb thermometer on your sling psychrometer.
3. Hold the thermometer at chest height, in the shade, and away from your body for three minutes.
4. At the end of three minutes, record the temperature reading in your science log
5. Hold the thermometer the same way for another minute.
6. At the end of the minute, record the temperature once again. If the temperature is within 0.5˚ C of the previous reading, record the reading on your *Data Sheet.*
7. If the two temperature readings differ by more than 0.5˚ C, repeat steps 5 and 6 again.
8. If two consecutive temperature readings are not within 0.5˚ C of one another after 7 minutes, record the last measurement on the *Data Sheet* and report your other four measurements in the comments section along with a note that your reading wasn't stable after 7 minutes.

Digital Multi-Day Max/ Min/Current Air and Soil Temperatures Protocol

Purpose

To record daily measurements of maximum, minimum, and current air and soil temperatures at a common site

Overview

One temperature probe is placed inside the instrument shelter while another is installed at a 10 cm depth in the soil. A digital thermometer is used to measure current temperatures as well as daily minimum and maximum temperatures. The daily minimum and maximum temperatures are stored by the instrument for a period of six days and need to be read and recorded within this span of time.

Student Outcomes

Students gain insight into the relationships between air and soil temperatures over time and learn to use a digital thermometer.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and season to season.

Weather varies on local, regional, and global spatial scales.

Geography

The variability of temperature of a location affects the characterization of Earth's physical geographic system.

Enrichment

Soil temperature varies with air temperature.

Soil temperature varies less than air temperature.

Scientific Inquiry Abilities

Use a digital max/min thermometer.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

10 minutes per measurement set

Level

All levels

Frequency

At least once every six days

Materials and Tools

Digital multi-day max/min thermometer

Instrument Shelter installed on a post

Digging tools (site setup only)

Calibration thermometer

Soil probe thermometer

Preparation

Set up the instrument shelter.

Calibrate and install the digital max/min thermometer.

Reset the digital max/min thermometer.

Review the *Soil Temperature Protocol*.

Prerequisites

None

Digital Multi-Day Max/Min Thermometer Introduction

The digital multi-day max/min thermometer is an electronic instrument used to measure the current temperature and record the maximum and minimum temperatures reached during multiple 24- hour periods. It has two identical temperature probes. One probe is used to measure air temperature and the other to measure soil temperature.

The instrument records and stores the highest and lowest temperatures reached over six successive 24-hour periods. The start and end times for these periods correspond to the time of day at which the instrument was initially reset by the user (the *time of reset*). The instrument is reset once when it is first setup and again whenever the battery is changed. For use in GLOBE, the *time of reset* should be as close as possible to local solar noon, thereby causing each 24-hour period to span from approximately local solar noon to local solar noon of consecutive days. The thermometer displays the maximum and minimum temperatures for the current day as well as for the previous five days as long as it is read at a time which is later than the time that the thermometer was initially reset (*time of reset*). If the thermometer is read after the *time of reset*, it will display the maximum and minimum temperatures for the previous six days.

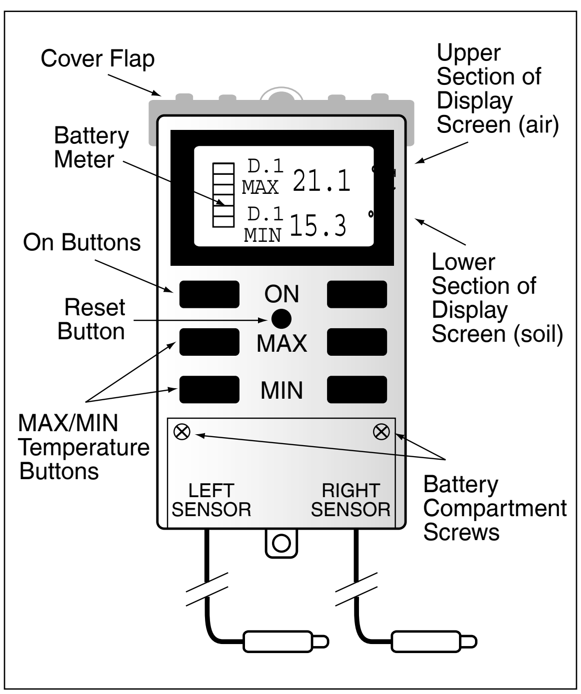


Figure AT-MU-1: Multi-Day Digital Max/Min Thermometer

The digital multi-day max/min thermometer is capable of measuring temperatures down to -20° C when run on a standard alkaline AA-size battery. Substitution of a lithium AA-size battery will allow the instrument to handle lower temperatures. Also, at low temperatures the digital display screen may become too dim to read, while the instrument is still recording temperatures.

Temperature Probes

The multi-day digital max/min thermometer has two sensor probes. Normally one probe will be used to measure air temperature while the other will be used to measure soil temperature. For the sake of consistency the probes should be placed as follows:

Left Sensor – air temperature,

Right Sensor – 10 cm depth in soil.

The display areas for the two sensors are labeled on the right side of the digital display screen for the instrument. The upper display area (which is for the left sensor) is labeled 'LF', while the lower display area (which is for the right sensor) is labeled 'RT'.

Hint: To help prevent confusion, label these display areas as 'air' and 'soil' respectively. This can be done by writing on a piece of tape attached to the left of the display screen.

Instrument Maintenance

The instrument shelter should be kept clean both inside and outside. Dust, debris, and spider webs should be removed from the inside of the shelter with a clean, dry cloth. The outside of the shelter may be lightly washed with water to remove debris, but try to avoid getting water inside the shelter. If the outside of the shelter becomes very dirty, it should be repainted white.

When the battery in the thermometer becomes low on power a low battery symbol will light. This symbol is located along the left side of the display screen and is shaped like a AA-size battery. Once this symbol becomes visible it is time to replace the battery. Follow the *Changing the Battery in the Digital Multi-Day Max/Min Thermometer Field Guide.*

Teacher Support

The instructions given in this protocol are specific to one brand of digital thermometer. They may be adapted to other equipment that meets the same specifications. If you have questions or require assistance with adapting these instructions to other instruments, contact the GLOBE Help Desk. The essential elements of this protocol, which must remain the same regardless of the equipment model, are the placement of the temperature probes and the +/- 0.5° C precision and accuracy of the temperature sensors.

Instructions for using alternative types of max/min thermometers are given in the *Single-Day Maximum, Minimum, and Current temperature Protocol*. The thermometers used in that protocol do not log data, so they need to be read and reset every day.

If your instrument shelter is in a location that makes it difficult to measure soil temperatures, or if you are only interested in taking air temperature measurements, it is acceptable to only take air measurements. To do so simply skip the portions of each field guide that pertain to the soil sensor.

Measurement Logistics

1. Review background in Atmosphere and Soil chapters.
2. Check a calibration thermometer following the *Thermometer Calibration Lab Guide*.
3. Calculate sensor correction offsets following the *Digital Multi-Day Max/Min Thermometer Sensor Calibration Field Guide*.
4. Install your digital multi-day max/min thermometer following the *Digital Multi-Day Max/Min Thermometer Installation Field Guide*.
5. Establish your *time of reset* by resetting the thermometer within one hour of local solar noon following the *Digital Multi-Day Max/Min Thermometer Reset Field Guide.*

6. Record current maximum and minimum temperatures following the *Digital Multi-Day Max/Min Temperature Protocol Field Guide* at least once every six days.
7. Record current temperatures following the *Digital Multi-Day Thermometer Current Temperature Protocol Field Guide* as desired.
8. Report your data to GLOBE.
9. Every six months, or whenever the battery is changed, check the accuracy of the soil probe following the *Digital Multi-Day Max/Min Thermometer Soil Sensor Error Check Field Guide*. If the magnitude of the soil sensor error that you calculate is two degrees Celsius or more, dig out the soil sensor and recalibrate both the soil and air sensors following the *Digital Multi-Day Max/Min Thermometer Sensor Calibration Field Guide*. If the magnitude of the soil sensor error that you calculate is less than two degrees Celsius, leave the soil sensor buried and recalibrate just the air sensor.
10. Engage students in looking at their data.

Calibration

Your digital thermometer must be calibrated before initial use. Every six months after installation and whenever the battery is changed the air sensor will need to be recalibrated and the soil sensor readings will need to be checked to see if the soil sensor needs to be dug out and recalibrated. These calibrations and checks are performed by comparing temperatures read by the two probes with readings from a calibration thermometer and the soil probe thermometer. See the *Soil Temperature Protocol*.

Helpful Hints

The goal of the calibrations is to obtain air and soil sensor correction offsets that account for differences between measured and actual temperatures. When you report your calibration data to the GLOBE database, the database automatically calculates these values and reports them to you. After you have completed your calibration and start entering temperature data to GLOBE, the database will automatically account for your correction offsets as your measurements are entered into the database. So, all the data in the GLOBE database have effectively been calibrated. However, take caution in accounting for the correction offsets when analyzing data not obtained from the GLOBE database (including data you have collected). DO NOT APPLY THE OFFSETS TO DATA REPORTED TO GLOBE.

Questions for Further Investigation

Which season has the greatest range of temperatures? Why?

How does the soil temperature range compare with the air temperature range?

What are the latitudes and elevations of other GLOBE schools with atmosphere and soil temperatures similar to yours?

What soil temperatures signal a new growing season in your area, as evidenced by new grass, weed growth and germination, or budburst?

Is your local environment affected more by average temperature or temperature extremes?

How does soil character affect soil temperature?

Thermometer Calibration

Lab Guide

Task

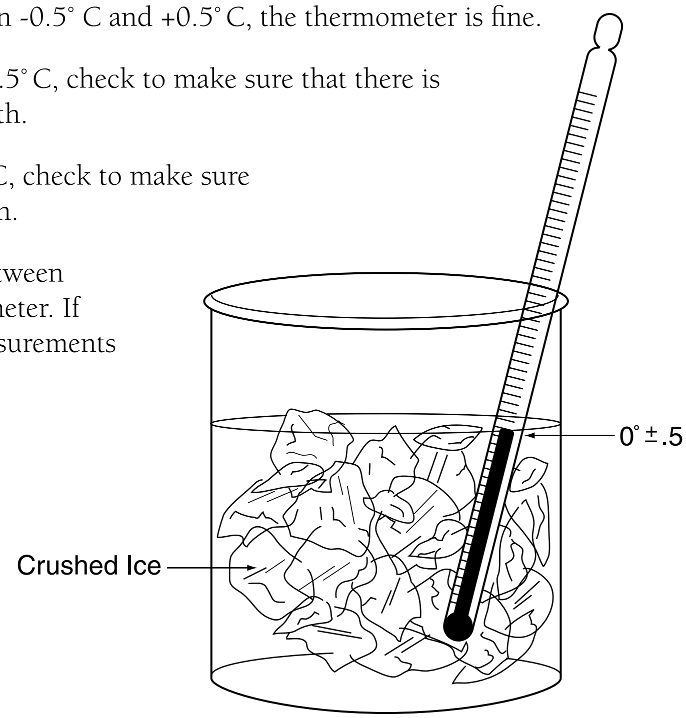
Check the calibration of the calibration thermometer.

What You Need

- ❑ Calibration thermometer
- ❑ Clean container at least 250 mL in size
- ❑ Crushed ice
- ❑ Water (distilled is ideal, but the key is that the water is not salty)

In the Lab

1. Prepare a mixture of fresh water and crushed ice with more ice than water in your container.
2. Put the calibration thermometer into the ice-water bath. The bulb of the thermometer must be in the water.
3. Allow the ice-water bath and thermometer to sit for 10 to 15 minutes.
4. Gently move the thermometer around in the ice-water bath so that it will be thoroughly cooled.
5. Read the thermometer. If it reads between -0.5˚ C and +0.5˚ C, the thermometer is fine.
6. If the thermometer reads greater than +0.5˚ C, check to make sure that there is more ice than water in your ice-water bath.
7. If the thermometer reads less than -0.5˚ C, check to make sure that there is no salt in your ice-water bath.
8. If the thermometer still does not read between -0.5˚ C and +0.5˚ C, replace the thermometer. If you have used this thermometer for measurements report this to GLOBE.



Digital Multi-Day Max/Min Thermometer Sensor Calibration

Field Guide

Task

Calculate the air and soil sensor correction offsets used to adjust for instrument accuracy errors.

What You Need

- ❑ Calibration thermometer that has been checked following the instructions in the *Thermometer Calibration Lab Guide*
- ❑ *Digital Max/Min Thermometer Calibration and Reset Data Sheet*

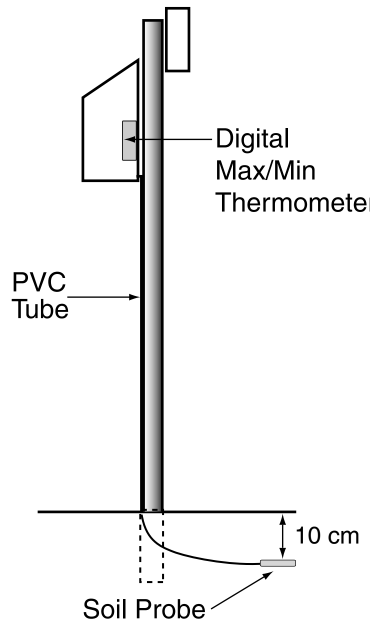
Note: If you are only recalibrating the air sensor, skip the portions of this field guide that pertain to the soil sensor.

In the Field

1. Open the door to the instrument shelter and hang the calibration thermometer and the two probes, both air and soil, in the instrument shelter so that they have air flow all around them and do not contact the sides of the shelter. Close the door to the instrument shelter.
2. Wait at least an hour and then open the door to the instrument shelter. Read the temperature from the calibration thermometer and record it to the nearest 0.5˚ C on your *Digital Max/Min Thermometer Calibration and Reset Data Sheet.*
3. Turn on the air temperature display of the digital multi-day max/min thermometer by pressing the air sensor ON button (upper left in button cluster). Read and record the current air temperature.
4. Turn on the soil temperature display of the digital multi-day max/min thermometer by pressing the soil sensor ON button (upper right in button cluster). Read and record the current soil temperature.
5. Close the cover flap of the digital thermometer and the door of the instrument shelter.
6. Repeat steps 2 to 5 four more times, waiting at least one hour between each set of readings. Try to space out the five sets of readings over as much of a day as possible.
7. Report your calibration data to GLOBE.

Digital Multi-Day Max/Min Thermometer Installation

Field Guide



Task

Install the digital thermometer at your Atmosphere Study Site.

What You Need

❑ Drill with 12 mm spade bit (if doing soil measurements)

❑ Digging tools (if doing soil measurements)

❑ String or wire ties

❑ GLOBE instrument shelter (specifications are given in the *GLOBE Instrument List* in the *Toolkit* section)

❑ 120 cm x 2.5 cm PVC pipe (optional)

In the Field

1. Mount the digital thermometer housing to the rear wall of your instrument shelter. The housing should be placed so that the digital display may be read easily.
2. Hang the probe labeled *Left Sensor* so that no part of it contacts the walls and there is airflow all around it. This can be done simply by hanging the rolled-up cable for this sensor from the top of the shelter, with the probe itself hanging below.
3. If you will not be taking soil measurements, store the right sensor and it's cable neatly in a corner of the shelter where it will be out of the way and skip the following steps.
4. If necessary drill a 12 mm hole, using a drill with a spade bit, in the bottom of the instrument shelter, near the back. Feed the right sensor probe through the hole, leaving as much cable as possible inside the shelter. You may wish to feed the sensor and wire through a thin PVC pipe that will then serve to protect the wire.
5. Choose a site to place the soil temperature probe nearby on the equatorward side (sunny-side) of the instrument shelter mounting post. Data collected from soil in unshaded locations are preferred. Comments in your site definition should include the amount of shade that the soil surface above the probe will experience during a year.
6. Dig a hole to a depth of a little over 10 cm at the chosen location.
7. Push the probe horizontally into the side of the hole at a depth of 10 cm. Use a nail or steel pin, with a slightly smaller diameter than the probe, to pilot an opening for the probe if needed.
8. Refill the hole with the soil that you removed.
9. Neatly secure all extra cable for the soil sensor using string or wire ties. Keep as much of the excess cable as possible within the shelter.

Digital Multi-Day Max/Min Thermometer Reset

Field Guide

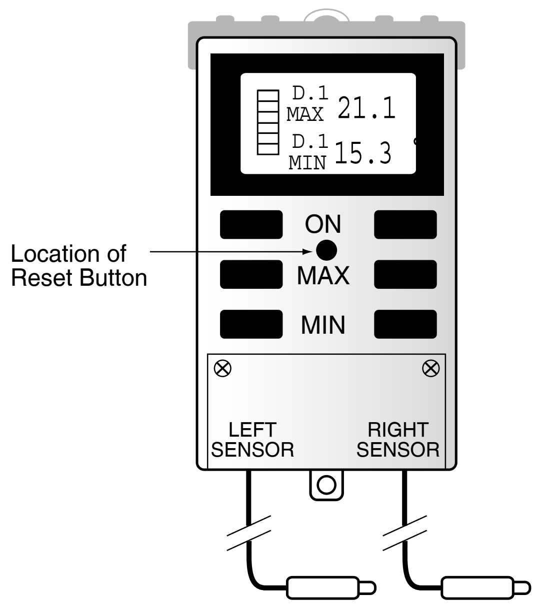
Task

Reset the digital multi-day thermometer to establish the *time of reset,* which serves as the starting and ending time for the 24-hour intervals over which the instrument records maximum and minimum temperatures.

Note: The thermometer should only be reset when it is setup, when the battery is changed, or if your *time of reset* becomes more than one hour from local solar noon.

What You Need

- ❑ Pen or nail
- ❑ *Digital Max/Min Thermometer Calibration and Reset Data Sheet*
- ❑ An accurate watch or other device that tells time



In the Field

1. Determine an appropriate *time of reset* that corresponds to the average time of local solar noon for your area. It is important that the *time of reset* is within one hour of local solar noon for every day that you will be taking measurements. If you find that this is not the case, then a new *time of reset* will need to be chosen and the instrument reset.
2. Go to the instrument shelter a little before your desired time of reset and open up the instrument shelter and the cover flap of the digital max/min thermometer.
3. At your desired time of reset, use a nail or the tip of a pen to press in and release the reset button, located as shown above.
4. The digital display screen will briefly flash and then begin reading the current temperature. The instrument has now been reset. Record the exact time of day, in the *Time of Reset* section of the *Digital Max/Min Thermometer Calibration and Reset Data Sheet*. This is your *time of reset*.
5. Report your *time of reset* and the date to GLOBE in both local and UT time.

Digital Multi-Day Maximum and Minimum Temperature Protocol

Field Guide

Task

Measure the daily maximum and minimum air temperatures for the past six days.

Measure the daily maximum and minimum soil temperatures for the past six days.

What You Need

- ❑ A properly sited instrument shelter
- ❑ A properly calibrated and installed digital multi-day max/min thermometer
- ❑ *Digital Multi-day Max/Min Thermometer Data Sheet*
- ❑ Pen or pencil
- ❑ An accurate watch or other device that tells time

In the Field

1. Maximum and minimum readings should be taken at least five minutes after your *time of reset*.
2. Open the instrument shelter and the cover flap of the digital max/min thermometer being careful not to breathe on or touch the air temperature sensor.
3. Record the time and date on your *Data Sheet* in both local and UT time. **Note:** GLOBE data entry should be UT time.
4. Turn the air temperature display of the thermometer on by pressing the air display ON button (upper left button labeled ON). **Note:** The temperature displayed will be the current air temperature.
5. Press the air sensor MAX button (middle left button labeled MAX) *twice*.
   Note: The reading that appears after you press the MAX button once is the highest temperature that has occurred since the last *time of reset,* and is not for a full 24-hour period. It should not be recorded.
6. You should see the MAX symbol displayed on the digital display screen to the left of the temperature reading with the symbol D.1 displayed above. Record this temperature on your *Data Sheet.*
7. Press the air senor MAX button again. The symbol D.2 should now be displayed in place of D.1. Record the accompanying temperature on your *Data Sheet.* Repeat this procedure to record data for as many of the past six days (D.1 – D.6) as needed.
8. To record minimum air temperatures repeat steps 5-7 pressing the air sensor MIN button (bottom left button labeled MIN) instead of the MAX button.
9. For the soil temperatures, repeat the above steps using the soil buttons on the right side and reading from the lower section of the display screen.
10. After all measurements have been taken close the cover flap of the instrument. It will shut off automatically after a short time.

Digital Multi-Day Max/Min Current Temperature Protocol
Field Guide

Task

Measure the current air temperature.

Measure the current soil temperature.

What You Need

- ❑ A properly sited instrument shelter
- ❑ A properly calibrated and installed digital multi-day max/min thermometer
- ❑ An accurate watch or other device that tells time
- ❑ Pen or pencil
- ❑ *Digital Multi-Day Max/Min Thermometer Data Sheet, Integrated 1-Day Data Sheet, Integrated 7-Day Data Sheet, Aerosols Data Sheet, Ozone Data Sheet,* or *Water Vapor Data Sheet*

In the Field

1. Open the instrument shelter and the cover flap of the digital max/min thermometer being careful not to breathe on or touch the air temperature sensor.
2. Record the time and date on your *Data Sheet.*
3. Turn the air temperature display on by pressing the air sensor ON button (upper left button labeled ON on the front of the instrument casing).
4. Read the current air temperature shown in the upper section of the digital display. Record this temperature on your *Data Sheet.*
5. If soil measurements are being taken, turn the soil temperature display on by pressing the soil sensor ON button (upper right button labeled ON).
6. Read the current soil temperature from the lower section of the digital display. Record this temperature on your *Data Sheet.*
7. After all measurements have been taken close the cover flap of the instrument. It will shut off automatically after a short time.

Digital Multi-Day Max/Min Current Soil Sensor Error Check

Lab and Field Guide

Task

Check the accuracy of the soil sensor to see if it needs to be dug out and recalibrated.

What You Need

- ❑ Soil probe thermometer from *Soil Temperature Protocol*
- ❑ *Digital Max/Min Thermometer Calibration and Reset Data Sheet*

In the Lab and Field

1. Calibrate a soil probe thermometer following the *Calibrating the Soil Thermometer Lab Guide* of the *Soil Temperature Protocol*.
2. Open the door to the instrument shelter.
3. Select an undisturbed place about 15 cm from the location of the soil temperature probe.
4. Measure the soil temperature at a depth of 10 cm at this spot following the *Soil Temperature Protocol Field Guide*.
5. Record this temperature in the Soil Sensor Error Check section of your *Digital Max/Min Thermometer Calibration and Reset Data Sheet*.
6. Turn on the soil temperature display of the digital multi-day max/min thermometer by pressing the soil sensor ON button (upper right button).
7. Read the temperature reported by the soil sensor of the digital thermometer and record it on your *Digital Max/Min Thermometer Calibration and Reset Data Sheet.*
8. Close the cover flap of the digital thermometer and the door of the instrument shelter.
9. Repeat steps 2 to 8 four more times, waiting at least one hour between measurements.
10. Calculate the average of the soil thermometer readings.
11. Calculate the average of the digital soil sensor readings.
12. Calculate the soil sensor error by subtracting the average of the five digital soil sensor readings (from step 10) from the average of the five soil sensor readings (from step 11)
13. If the absolute value of the soil sensor error is greater than or equal to 2° C, dig-out this sensor and recalibrate both the air and soil sensors following the *Digital Multi-Day Max/Min Thermometer Sensor Calibration Field Guide.* Otherwise, leave the digital soil sensor in the ground and recalibrate only the air sensor.

Changing the Battery in the Digital Multi-Day Max/Min Thermometer

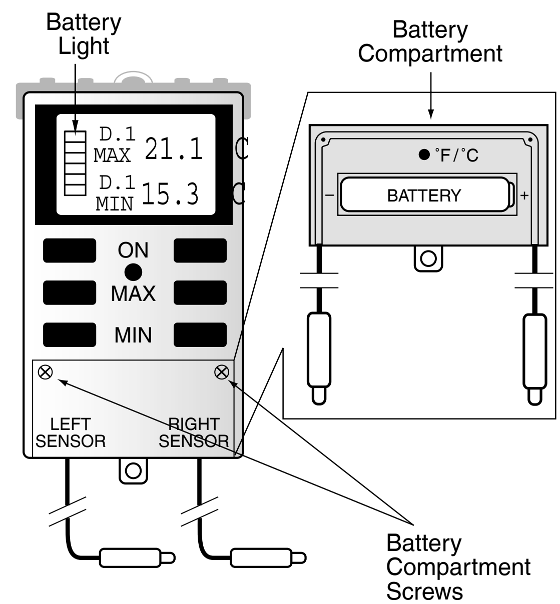
Field Guide

Task

Change the battery in the digital multi-day max/min thermometer.

What You Need

- ❑ A new AA-size battery
- ❑ A small Phillips head screwdriver



In the Field

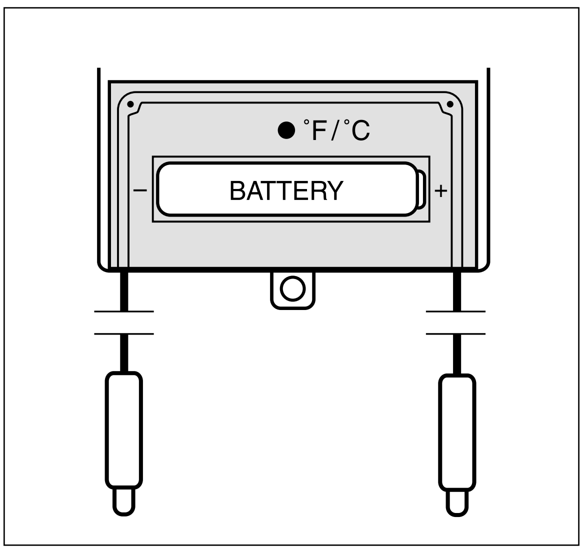
1. The battery is in the battery compartment in the lower section of the instrument casing.
2. Remove the two little screws located at the upper corners of the compartment cover and lift off the cover.
3. Change the battery, taking care to ensure correct polarity (negative end of battery contacting the spring).
4. Replace the compartment cover and secure with the two screws. After the battery has been changed be sure to recalibrate the instrument.
5. Recalibrate the air and soil sensors following the *Digital Multi-Day Max/Min Thermometer Sensor Calibration Field Guide*.
6. Reset the instrument using the *Resetting the Digital Multi-Day Max/Min Thermometer Field Guide*.

Frequently Asked Questions

1. What should I do if my digital max/min thermometer is reading temperatures in degrees Fahrenheit instead of Celsius?

You can change the units by pressing a small button located in the battery compartment. Open the battery compartment following the instructions given in the *Changing the Battery in the Digital Multi-Day Max/Min Thermometer Field Guide*. You should see a small round button, marked ˚F/˚C (see figure below). Turn on at least one of the sensors and press this button. You will see the measurement units change from Fahrenheit to Celsius. Close the battery compartment. Be sure always to have your instrument in Celsius mode when taking GLOBE measurements!

Figure AT-MU-2: Multi-Day Digital Max/Min Thermometer Battery Compartment with cover removed.



2. What if I find that as the time of local solar noon varies over the year it no longer is within an hour of my time of reset?

For your maximum and minimum temperature readings to be valid it is necessary for the *time of reset* to be within one hour of local solar noon. Reset your instrument using the *Digital Multi-Day Max/Min Thermometer Reset Field Guide* as close as possible to the time of local solar noon (within 15 minutes).

3. If I miss reading my maximum and minimum temperatures, can I still get the readings the next day?

The max/min temperatures stored in the instrument are updated every 24 hours at the *time of reset*. Therefore, these temperature values can be collected anytime from about 5 minutes after the *time of reset* on the desired day until 5 minutes before the *time of reset* on the next day. If you wait until after the time of reset on the 7th day, one day's data will be lost. However, if they are read on the next day, care must be taken to match temperatures read from the instrument to the days to which they correspond. Maximum and minimum temperatures displayed along with the D.1 symbol on the instrument display screen correspond to the current day when readings are being taken after *time of reset* (as recommended) and to the previous day when readings are being taken before the *time of reset*. See the following tables for clarification:

Readings taken AFTER time of reset (as recommended).

Digital Display			
Symbol:	D.1	D.2	D.3
Reading Corresponds to 24-hours Ending:	Today	Yesterday	2 days ago

Readings taken BEFORE time of reset

Digital Display			
Symbol:	D.1	D.2	D.3
Reading Corresponds to 24-hours Ending:	Yesterday	2 days ago	3 days ago

4. Can I read the thermometer in the morning before the time of reset?

If the thermometer is read in the morning, at least 5 minutes before the *time of reset*, it is possible to read the max/min temperatures for the past six days. However, the max/min temperatures for the current day cannot be read.

5. When I first press a MAX or MIN button, the instrument displays a reading which I am not supposed to record; what is this reading?

The reading displayed when you press a MIN or MAX button for the fist time is the minimum or maximum temperature for the on-going 24-hour period. Since this period is not finished, the reading may not be the final maximum or minimum temperature for the 24-hours. While it is not a valid data measurement that you report to GLOBE, it can be used for your own inquiry purposes.

6. How does the digital thermometer work?

The thermometer works by measuring the change in current running through a constant-voltage circuit in which the sensor probe serves as a resistor. As the temperature of the sensor changes, it's resistance changes. The change in current in the circuit is inversely proportional to the change in the sensor's resistance as described by Ohm's Law which explains that current is equal to voltage divided by resistance. So by measuring the current going through the circuit, and knowing the voltage, it is possible to calculate the resistance of the sensor. This is done by the instrument, which then reports the probe temperature corresponding to that level of resistance.

Automated Soil and Air Temperature Monitoring Protocol

Purpose

To continuously measure soil and air temperature at one site

Overview

Students install four temperature probes; three are placed in the soil at three different depths and one is placed in an instrument shelter. Students use a data logger to record readings from the probes every 15 minutes. Students transfer the data to their school computers for analysis and submission to the GLOBE database.

Student Outcomes

Students will be able to use automated monitoring equipment to measure soil and air temperatures. Students will be able to manipulate extensive multivariable data sets.

Students will be able to create spreadsheets and time-series graphs and use them for data analyses.

Science Concepts

Earth and Space Science

- Weather can be described by quantitative measurements.
- Weather changes from day to day and season to season.
- Weather varies on local, regional, and global spatial scales.
- Soil temperature varies with depth, soil moisture, and air temperature.
- Soil temperature varies less than air temperature.

Geography

- The temperature variability of a location affects the characteristics of Earth's physical geographic system.

Scientific Inquiry Abilities

- Use a data logger to measure temperature.
- Identify answerable questions.
- Design and conduct scientific investigations.
- Use appropriate mathematics to analyze data.
- Develop descriptions and explanations using evidence.
- Recognize and analyze alternative explanations.
- Communicate procedures and explanations.

Time

Set-up takes approximately 4 hours but may be spread over several days.

Data transfer - 10 minutes

Data analysis and submission to GLOBE – 30 minutes to 2 hours, depending on the amount of data and students' computing skills

Level

Middle, Secondary

Frequency

One-time set up

Battery needs to be changed yearly.

Data transfer, analysis, and submission to GLOBE - preferably weekly, but at least once per month

Materials and Tools

- 4-Channel data logger and software
- 1 air temperature sensor
- 3 soil temperature sensors
- Data logger/computer interface cable
- Watertight plastic box (~0.5 L volume)
- $CaSO_4$ or other desiccant (100 mL)
- 4 Strain-relief connectors
- Instrument shelter installed on a post
- Digging tools

Preparation

Review the Maximum, Minimum, and Current Air Temperature Protocol and *Soil Temperature Protocol.*

Prerequisites

None

Optional Automated Soil and Air Temperature Monitoring Protocol– Introduction

A data logger is an electronic device that automatically collects data at a predetermined sampling rate. Data loggers allow scientists and students to collect valuable environmental measurements in remote locations. They also collect data continuously allowing for consistent data collection and analysis. With a data logger, students are able to collect data during weekends and school breaks. Data loggers can collect data for up to 84 days without daily readings and thermometer calibrations.

Students who use data loggers contribute important data to a worldwide dataset of soil and air temperatures. Scientists' understanding of climate has been determined by their access to a large number of air temperature data, but soil temperature datasets are not as extensive. Students using data loggers will be making significant contributions to these datasets and to our understanding of soil science.

Teacher Support

Materials Management

The procedures described in this protocol are specific to a particular brand of data logger and its temperature probes and software. They may be adapted to other equipment, as long as they meet the GLOBE data logger specifications. If teachers and students plan to use different equipment, they should contact the GLOBE Help Desk to learn how to adapt this protocol to their equipment. The essential elements of this protocol, which must remain the same regardless of the equipment model, are the placement of the temperature probes and the +/-0.5 °C precision and accuracy of the temperature sensors.

An Onset Computer HOBO® 4-channel external data logger is used to record air and soil temperatures at an Atmosphere Study Site every 15 minutes on the quarter hour. The Onset HA-type sensors have a range of -40 to 100˚ C and an accuracy of 0.5˚ C. This works well for most surface and near-surface applications. This data logger has 4 channels. For consistency, the data logger must be connected as follows:

Ch.1 -Air Temperature;

Ch.2 -5 cm depth;

Ch.3 -10 cm depth;

Ch.4 -50 cm depth.

Condensation can damage the data logger so it needs to be kept in a watertight container free of high humidity. A plastic box with a tight sealing lid containing a desiccant, such as CaSO 4 , works well to absorb moisture and protect the logger.

Students may assemble their own watertight box. If they choose to do this, they must purchase a set of strain relief connectors (refer to step 2, in the *Data Logger Preparation Lab Guide)*. Students and teachers can make requests for these connectors with the GLOBE Help Desk (U.S. schools) or to with their Country Coordinators (all schools outside the U.S.).

Site Selection

For protection, the watertight data logger box should be kept out of direct sunlight and rain. The best place to install the soil data logger is inside a GLOBE instrument shelter. Students dig or auger a hole on the equator ward side (sunny-side) of the instrument shelter mounting post and place the probes at depths of 5 cm, 10 cm, and 50 cm. Data collected from soils in non-shaded locations are preferred. On their site definition sheets, students should comment on the amount of shade that the soil receives during the year.

Advance Preparation

Students should read the following sections in the BoxCar Pro® v.3.5+User's Manual: Installation, Launching HOBO® H8 loggers, Reading out data, Viewing your data, and Exporting data.

Students should complete the instrument assembly and software installation before they begin collecting data as detailed in the *Data Logger Preparation Lab Guide*.

Students should complete the Sensor Bias Test before they begin collecting data as detailed in the *Calibration and Lab Tests Lab Guide*. According to the Guide, students complete a Full Range Calibration and report it to GLOBE. The calibration and lab tests verify that the unit is working properly and provide an opportunity for students to practice using the logger before installing it in the field.

Students should install the data logger and sensors according to the instructions in the *Sensor Installation Field Guide*.

The science content for this protocol is the same as that for the *Maximum, Minimum and Current Air Temperature Protocol* and the *Soil Temperature Protocol*. Refer students to these sections for more background information.

Data Reporting

Students launch or initiate the data collection by following the *Data Logger Launching Lab or Field Guide*.

Students place the launched data logger in the instrument shelter and connect it to the temperature probes by following the *Data Logger Installation Field Guide*

Students download the stored data from the data logger and transfer them to a computer by following the *Data Collection Lab Guide*.

After collecting data, students re-launch and install the data logger in the instrument shelter by following the *Data Logger Launching Lab or Field Guide* and the *Data Logger Installation Field Guide*.

Students prepare their data for reporting and submit them to GLOBE by following the *Data Manipulation and Submission Lab Guide*.

Data should be transferred from the data logger in the field and sent to the GLOBE database every 1-2 weeks. Students should backup and save their .dtf raw data logger files.

The data logger may be unplugged and brought inside to download the data, but it is also possible to take a laptop computer or portable data caddy to the field and avoid disconnecting the logger.

Questions for Further Investigation

How do soil and air temperatures vary throughout the day?

How are soil temperature and air temperature related?

How are soil temperatures at different depths related?

How are changes in soil and air temperature affected by soil moisture?

How does soil texture affect soil temperature?

For influencing the timing of budburst and other phenologic changes in your area, are temperature averages or extremes more important?

Data Logger Preparation
Lab Guide

Task
Prepare and assemble the data logger and cables. Load the data logger software.

What You Need

Data Logger/Sensor Assembly

❑ H08-006-04 HOBO H8 4-Channel External

❑ TMC1-HA Wide-range temperature sensor, 0.3 m (1 ft) cable (1)

❑ TMC20-HA Wide-range temperature sensor, 6.1 m (20 ft) cable (3)

❑ Water tight box such as Rubbermaid #1 square sandwich box (~0.5 L volume)

❑ $CaSO_4$ or other dehydrating agent (100 mL)

❑ Strain-relief connectors (4)

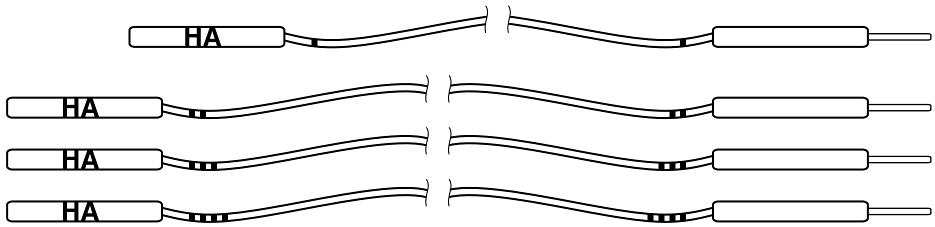
Computer interface

❑ BoxCar Pro® v.3.5+ or v.4.0 software

❑ PC or MAC computer interface cable

In the Lab

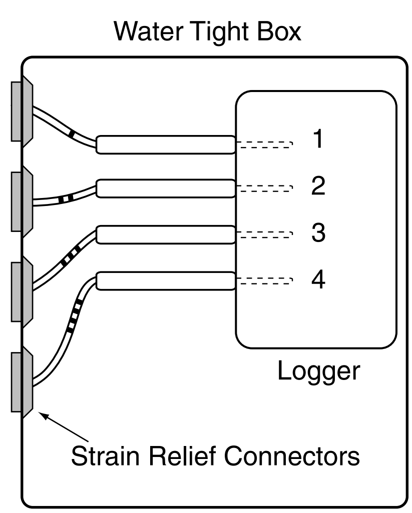
1. Use a permanent marker to mark BOTH ends of four TMC6-HA sensor cables. Place marks about 1 cm from the reinforced plug tip. Use 1,2,3 or 4 lines drawn completely around each cable. Label the short cable number 1.



2. Seal cables and data logger in a water-tight box

   Option A) Using strain relief connectors:

   - Drill or punch out four equally-spaced, 12 mm (1/2") holes in sidewall.
   - Install strain relief connectors, using a bit of silicon sealant around the threads.
   - Insert sensor cables through connectors and plug into appropriate data logger sockets.



Note: a set of strain relief connectors can be obtained by sending your mailing address to: the GLOBE Help Desk (U.S. schools) or your Country Coordinator (all other schools).

OR

Option B) Using wire ties and silicon sealant:

- Drill four equally-spaced, 5 mm (1/4”) holes in a sidewall.
- Insert sensor cables through the sidewall and plug into appropriate data logger sockets.
- Fasten wire ties snugly against inside wall.
- Fasten wire ties snugly against outside wall.
- Apply silicon sealant around wires and between wire ties and hole in the side wall.
- Let dry/cure for 24 hrs.

3. Load the Boxcar Pro software on your computer. If you are using a MAC, you must download the software from: www.onsetcomp.com/Support/2543_MacBCP.html
   - Follow the software installation instructions on page 1 of the BoxCar Pro® User’s Manual.
   - Connect the serial cable to a PC (9-pin, D-type) COM port OR to a MAC (8-pin, O-type) modem port.
   - Check the date and time on your computer to ensure that they are correct.
   - Run c:\Bxcrpro3\Bxcrpro.exe (default location) or double click on the BoxCar Pro® icon.

Note: Newer iMAC/G3 and G4 Apple computers with USB ports require additional cable adapters.

Calibration and Lab Tests

Lab Guide

Task

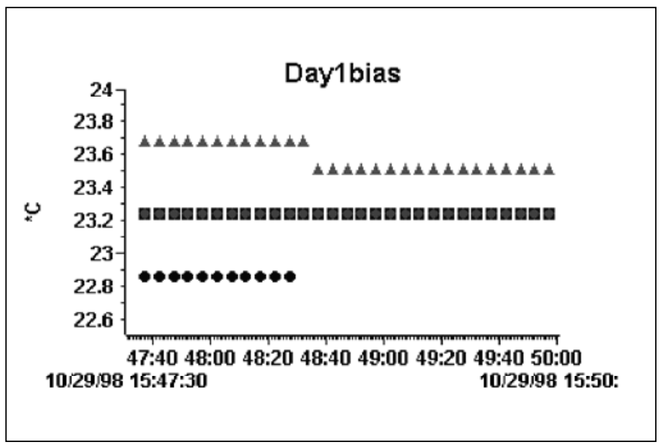
Verify that the data logger and sensors are operating normally.

What You Need

- ❑ Data logger assembly and cables
- ❑ Calibration thermometer
- ❑ Warm water (~50˚ C), Un-insulated cup, Ice

In the Lab

1. Record Sensor Bias – This test verifies that all four channels are recording the same approximate temperature by collecting data for a few minutes with all four sensors grouped together measuring air temperature. The bias or difference between each sensor should be less than 1˚ C.



   a. Plug each sensor into the appropriate socket and place all four sensor tips together and away from any sources of heat (like a sunny spot).

   b. Connect the logger to the serial cable.

   c. Confirm that your computer's clock is showing the current local time.

   d. Double click on the Boxcar® icon to run this software.

   e. Select "Launch" (Crtl L) under the "Logger" button on the main menu bar.

   f. Change the file "Description" from "TEST" to "Day1bias".

   g. Change the "Interval" to "6 sec"

   h. Select the "Start" button, message should indicate the "program" is being loaded.

   i. Wait 3 minutes. The data logger should be working!

   j. Select "Readout" (Crtl R) under the "Logger" button on the main menu bar.

   k. Screen should indicate the data is being "Downloaded", then prompt you for a filename. The default should be Day1bias.dtf

   l. Use View, Display Options to look at each temperature channel separately.

m. Record the average value from each channel in your GLOBE Science Log , they should be within 1° C of each other.

n. Make sure that you understand the time axis scale and that it is showing the correct time and date and how to save the data to an Excel file.

2. Full Range Calibration

a. Place the four temperature sensors in a half-full, non-insulated cup of warm water (~50° C).

b. Connect the logger to the serial cable.

c. Confirm that your computer's clock is showing the current local time.

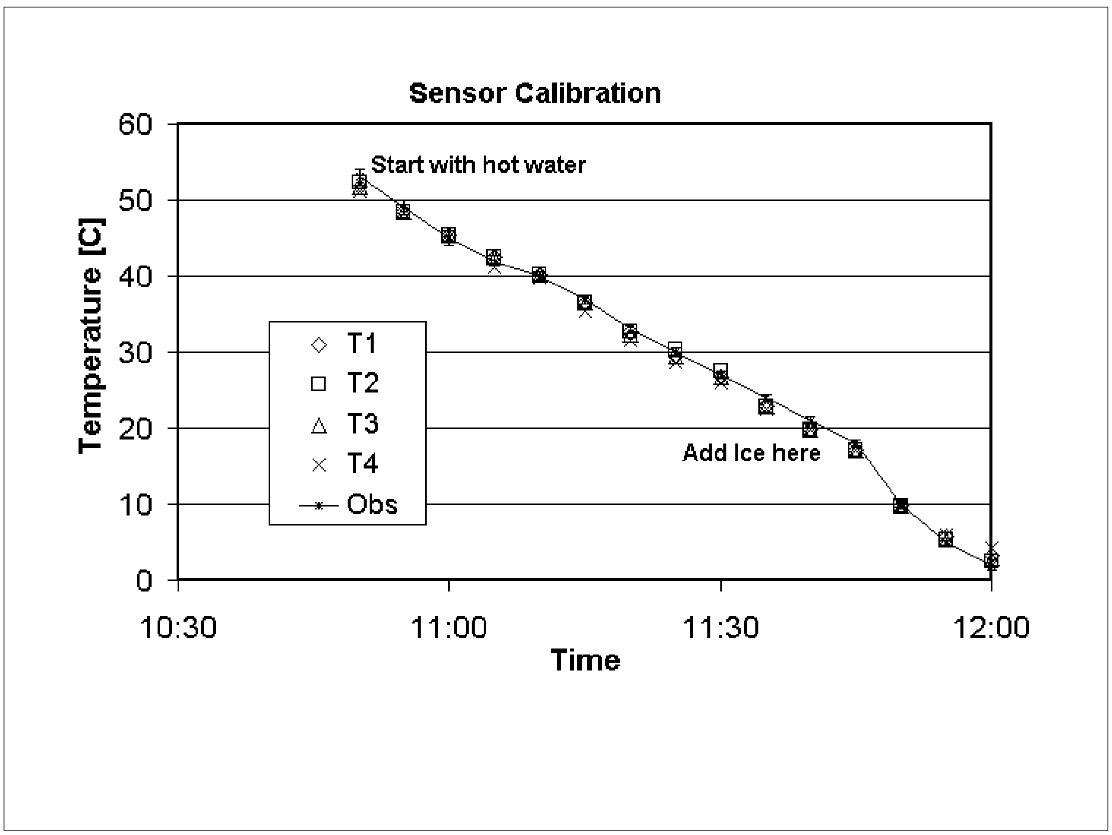
d. Select "Launch" under the "Logger" button on the main menu bar.

e. Set the file "Description" to "CAyymmdd", where yymmdd is today's year, month and day.

f. Set the "Interval" to "5 min" and launch the logger with a delayed start at the next regular 5 minute time mark (example: its now 10:17:00. So set the delayed start for 10:20:00).

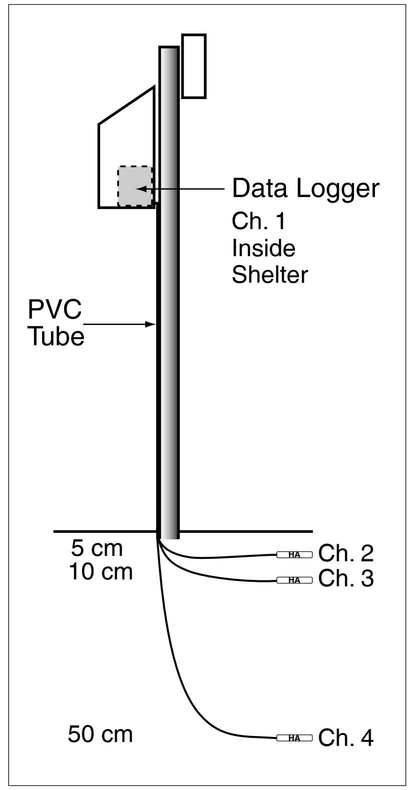
g. Record the calibration thermometer temperature every 5 min in conjunction with the loggers sampling time.

h. After the temperature change slows to 1° C/5 min, add ice cubes and continue until the water approaches freezing.



Sensor Installation

Field Guide



Task

Install the data logger and sensors at your atmosphere study site.

What You Need

- ❑ Meter stick
- ❑ Digging tools
- ❑ 120 cm x 2.5 cm PVC tube
- ❑ Data logger assembly and cables
- ❑ Drill with 12 mm spade bit
- ❑ Wire or brackets to secure PVC tube to post
- ❑ String or wire tie
- ❑ Desiccant

In the Field

1. Plan the installation. Make sure that the distance between your box and deepest sensor is less than 5.5 meters and that it is safe to dig a 50 cm deep hole.
2. Drill a 12 mm hole, if needed, through the bottom of your shelter, near the back.
3. Place the Data logger box inside the instrument shelter.
4. Use string or a wire tie to secure the air temperature sensor (#1) inside the instrument shelter.
5. Feed your 3 long cables through the 12 mm hole and pull them through the PVC tube (which protects the cables from excessive UV and animal bites). Plan on keeping any excess wire inside the shelter.
6. Secure the PVC tube to the shelter post.
7. Dig a hole 50 cm deep on the sunny (equatorward) side of the shelter post.
8. Push sensors horizontally into the side of the hole at 50 cm (#4), 10 cm (#3), and 5 cm (#2) depths, respectively. Use a nail or steel pin with a slightly smaller diameter to pilot these holes if the soil is hard.
9. Pour desiccant into a bag made of breathable fabric (e.g., cheese cloth or a cotton sock) and place it inside the watertight box so the air inside the box will be kept dry.
10. Seal the water tight box containing the data logger.

Data Logger Launching

Lab or Field Guide

Task

Launch your data logger for collecting diurnal soil and air temperature measurements.

What You Need

- ❑ Data logger disconnected from the four sensor cables
- ❑ *Data Logger Data Sheet*
- ❑ Computer: 386 or better, 4 Mb RAM, Windows 3.1 or later, 1 available COM (serial) port

In the Lab or Field

1. Make sure that your computer's clock is reading the correct local time.
2. Run the BoxCar® software
3. Connect the HOBO® 4-Channel External logger to the serial cable using the bottom and largest plug.
4. Select "Launch" (Ctrl L) under "Logger" button on the main menu bar.
5. You should see or select the following:
   a. Interval (duration) = 15 minutes (84 Days),
   b. Measurement: Channels 1-4 recording Temperature (both °F and °C). Without the sensors connected, the values will be different but should be relatively constant.
   c. Battery Level: full (replace the battery when level falls below 30%)
6. Select "Advanced Options".
7. You should see or select the following:
   a. Wrap-around when full (unchecked)
   b. Delayed Start (checked) Set to expected start time; Use this feature to start sampling times on the quarter hour, ex: XX:00:00, XX:15:00, XX:30:00, or XX:45:00. Select "am" or "pm".
8. Select "Enable/Disable Channels".
9. For Channels 1-4, you should see of select the following:
   a. -40 °F to +212 °F [TMC6-HA]. (checked)
   b. Select "Apply"
10. Select "Start".

Data Logger Installation
Field Guide

Task
Install the launched logger in the instrument shelter.

What You Need
- ❑ Launched data logger
- ❑ Desiccant
- ❑ *Data Logger Data Sheet*

In the Field
1. Open the door of the instrument shelter and uncap the empty data logger box.
2. Make sure that the logger and cable plugs are dry. Replace the desiccant as is necessary.
3. Carefully plug each sensor cable into the appropriate data logger channel. Make sure that each plug is fully inserted and seated in its jack.
   a. Plug cable #1 into jack #1 (air temperature sensor)
   b. Plug cable #2 into jack #2 (5 cm sensor)
   c. Plug cable #3 into jack #3 (10 cm sensor)
   d. Plug cable #4 into jack #4 (50 cm sensor)
4. Carefully seal the water-tight data logger box and place out of the way in the instrument shelter.
5. The data logger is now collecting data. We recommend you download the data weekly when school is in session or at least monthly during longer vacations.

Data Collection
Lab Guide

Task

Download the data stored in your data logger to your computer.

What You Need

- ❑ Data logger disconnected from the four sensor cables
- ❑ *Data Logger Data Sheet*
- ❑ Computer: 386 or better, 4 Mb RAM, Windows 3.1 or later, 1 available COM (serial) port

In the Lab

1. Make sure that your computer's clock is reading the correct local time.
2. Run BoxCar® software.
3. Connect the HOBO® 4-Channel External logger to the serial cable using the bottom and largest plug.
4. Select "Readout" (or Ctrl R) under the "Logger" button on the main menu bar.
5. You should see:
   a A pop-up box will indicate that the software is searching for the HOBO® data logger.
   b. A pop-up box will indicate that the data are being downloaded.
   c. A warning will be given if the data logger and shuttle clocks are unsynchronized.
   d. Battery Level: replace the battery after saving the data if the battery level falls below 30%.
   e. A "Save As" box.
6. Rename the data file (.dtf file) and save it. It is recommended to use a file name like "SSYYMMDD" where,
   a. "SS" is a two character school or site code and "YYMMDD" are the two digit values for year, month and day (i.e., 010315) for the date that you downloaded (READOUT) these data from your logger. Note: this BoxCar® software is limited to 8 character filenames.
   b. Make sure to select or take note of the output data directory.
7. Take time to preview the data using BoxCar's graphing capabilities.

Data Manipulation and Submission

Lab Guide

Task

Convert the data in the appropriate format for reporting to GLOBE.

What You Need

- ❑ Computer: 386 or better, 4 Mb RAM, Windows 3.1 or later, 1 available COM (serial) port
- ❑ BoxCar® software
- ❑ Excel or other spreadsheet software
- ❑ *Data Logger Data Sheet*

In the Lab

You should send in your data to GLOBE as often as you download your logger, which should be approximately weekly to monthly.

1. Double click on the BoxCar® icon to run this software.
2. Under “File” select “Open” and open the BoxCar® file (.dtf) that contains the data you are preparing to submit to GLOBE
3. Under “File” select “Export” and then “Excel” or the appropriate spreadsheet choice (or just select the “Excel” icon on the shortcut toolbar).
4. The “Export Set-Up” box will appear
5. Select all four channels that contain Celsius measurements by selecting each channel marked “Temperature [*C]” in the “Units” box (be sure to deselect the first default value which is marked “Temperature [*F]”).
6. Select “Export”.
7. Maintain the name as “SSYYMMDD.txt”
8. Select “OK”.
9. Launch Excel or other spreadsheet software.
10. Under “File” select “Open” and choose the file that contains your data (SSYYMMDD.txt).
11. Make sure to select “All Files (*.*)” under “Files of Type”.
12. Select “Open”.
13. The “Text Import Wizard” should be set to “Delimited”, “Start Import at Row 1”, “File origin Windows (ANSI).
14. Select “Finish” directly without passing through the intermediate steps. You should see one column of time data and four columns of temperature data with units of [*C].
15. Graph your data following the steps in *Looking at the Data*.
16. If you have any data points that are unquestionably bad, replace those values with a “B”.

17. If one of your sensors was not connected or not working, place an “X in the appropriate cells of your spreadsheet.
18. Select the whole first row that contains the titles (by clicking on “1”) and remove it, by selecting “Delete” under the “Edit” menu.
19. Format the whole first column that contains the time and date (by clicking on “A”) and choose “Cells” under the “Format” menu.
20. In the pop-up box that appears select “Custom” under “Category” and under “Type” enter yyyymmddhhmm. Hit “OK”. The date and time entries are now in the format required by GLOBE.
21. Select columns A,B,C and insert three new columns by selecting “Columns” under the “Insert” menu.
22. Scroll down to the last row of data.
23. Type “DLOG” in column A.
24. Enter your GLOBE School ID in column B.
25. Enter the GLOBE site type and number where the data logger is installed (atmosphere site = ATM-dd or soil moisture site = SMS-dd; e.g., ATM-01 or SMS-01) in column C.
26. Highlight the three cells containing “DLOG”, your GLOBE school ID, and the site type and number and select “Copy” under the “Edit” menu.
27. Highlight the first three columns in the second to last row of data and then use the following two keystrokes to highlight all the cells in columns A-C that contain data: “End”, “Shift Up Arrow”.
28. Select “Paste” under the “Edit” menu so that these three values are copied to the selected area of columns A-C.
29. Select column E and insert one new column by selecting “Columns” under the “Insert” menu.
30. Format the whole fifth column (by clicking on “E”) and choose “Cells” under the “Format” menu.
31. In the format cells “Number” pop-up box that appears, select “Text”. Move to the format cells “Alignment” tab and select “Right” within the “Horizontal” selection box. Hit “OK”
32. Scroll down to the last roll of data, if necessary.
33. In column E, enter the UT offset between your site and the prime meridian (UT_offset = UT_time – Local_time). This will be a constant unless there has been a local time shift (ie. day light savings) during the period of observation. Enter this value using a ±hhmm scheme (example: +0400 for a 4 hour offset for the East coast of the U.S. or –1030 for a –10 hour 30 minute offset for central Australia). Note, the sign of these offsets are opposite the standard value. Unfortunately, the coming and going of daylight savings varies by country. Please consult local authorities as to what local time you need to make this adjustment (or visit www.worldtimezone.com/daylight.htm)
34. Highlight the cell containing your offset and select “Copy” under the “Edit” menu.
35. Highlight the empty cell in column E in the second to last row and then use the following two keystrokes to highlight all the cells in column E that contain data: “End”, “Shift Up Arrow”.

36. Select "Paste" under the "Edit" menu so that this value is copied to the selected area of column E.
37. Save this document by selecting "Save As" under the "File" menu.
48. Change the name of this GLOBE formatted file to "DLYYMMDD.txt" (ignore the warning about file format generated by "Excel") and save as a tab-delimited text file.
39. You are now ready to send your data to GLOBE by email.
40. Launch your email program without quitting Excel.
41. In the "To:" field of your message enter "DATA@GLOBE.GOV".
42. In the "Subject:" field enter "DATA".
43. The first line of the text of your message must be "//AA". This tells the GLOBE server that the lines that follow will contain data.
44. Copy and paste the nine columns of the spreadsheet file that contains your logger data:
    a. Switch back to Excel or other spreadsheet and highlight the portion of the nine columns that contain information.
    b. Select "Copy" under the "Edit" menu.
    c. Switch back to your email program, put the cursor on the line below the "//AA" entry in the text portion of the message, and select "Paste" under the "Edit" menu. The whole table should now appear in the body of the email message.
45. After you insert the table with your data, type on the last line of your message "//ZZ". This tells the computer that there are no more data in your message. See an example of what your email should look like below.
46. Send the email to GLOBE.

Example of an email containing air and soil temperature data collected with a data logger

To: DATA@GLOBE.GOV

From: GLOBE_School@Somewhere.edu

Subject: DATA

//AA

DLOG	ZZUSTEST	ATM-01	200105141600	+0400	B	B	B	B
DLOG	ZZUSTEST	ATM-01	200105141615	+0400	24.79	24.79	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141630	+0400	24.79	24.79	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141645	+0400	24.79	24.79	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141700	+0400	24.79	24.79	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141715	+0400	24.79	24.4	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141730	+0400	24.79	24.4	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141745	+0400	24.79	24.4	24.79	24.79
DLOG	ZZUSTEST	ATM-01	200105141800	+0400	24.79	24.4	24.4	24.79
DLOG	ZZUSTEST	ATM-01	200105141815	+0400	24.79	24.4	X	24.79
DLOG	ZZUSTEST	ATM-01	200105141830	+0400	24.79	24.79	X	24.79
DLOG	ZZUSTEST	ATM-01	200105141845	+0400	24.79	24.79	X	24.79
DLOG	ZZUSTEST	ATM-01	200105141900	+0400	24.79	25.17	X	24.79
DLOG	ZZUSTEST	ATM-01	200105141915	+0400	24.79	25.17	X	24.79

//ZZ

Frequently Asked Questions

1. When I try to download the logger, there is no data. What happened?

This could happen if you did not complete a proper launch sequence prior to setting your logger in the field. Make sure you do not try to launch a data logger that has not been downloaded as all the data will be lost.

2. How do you tell if one of your sensors is not working?

The two most common problems are a broken wire or an open circuit, usually due to an animal bite or because the connection between plug and socket is not good. An open circuit will produce a very unrealistic value, which might vary slightly. Another warning sign is a reading that does not change. Contact Onset or the GLOBE help desk if you need help.

3. We did not get our logger to the field site for two days after it was launched, should we delete the data during this time period when we know the logger was not plugged in to our sensors?

Never delete rows of data - we want to know when you were attempting to collect data. However, if you have any data that are unquestionably bad, replace those values with a "B". If one of your sensors was missing or not putting out data, place an "X" in these cells of your data sheet.

4. We managed to plug our sensors into the wrong channels. What should we do?

If you are comfortable transposing the columns of data, you can do this in a spreadsheet program. Otherwise, send the .dtf and .txt files to jwash@hwr.arizona.edu with a description of the problem and I will correct it. In general, the daily range of the data should decrease from the air temperature to the 50 cm soil temperature.

5. When do bad data usually occur?

Bad data usually occur at the beginning or the end of your data record due to sampling while the sensors were disconnected.

6. We have submitted air temperature data from our data logger for a specific day(s) but the maximum and minimum air temperature values for that day(s) do not appear in our school's data archive. Why?

If there are three or more bad or missing data points for any 24 hour period (noon to noon), the GLOBE server does not calculate the daily maximum and minimum values for that day(s).

Key Definitions

Attenuation: to reduce in magnitude, to lessen

Conduction: transmission of heat (or electricity) through a substance.

Data Logger: a microcomputer capable of recording and storing both time and measurement data in the field. The only system maintenance required is to periodically download the stored data.

Desiccant: a substance such as calcium sulfide which will repeatedly absorb excess humidity after it is oven dried.

Diurnal: varying regularly throughout the day.

Energy balance: a conservative balance between incoming and outgoing energy components (solar, sensible heat, latent heat, soil heat) at a point, such as the Earth's surface.

Phase-shift: the period of a wave-like phenomena (ocean waves, sound waves) determines how far it is between adjacent peaks (maxima). A phase shift occurs when two waves have the same period but the maxima occur at different times.

Sinusoidal: like a sine wave; many radiation phenomena are greatest midday and least at night.

Surface Temperature Protocol

Purpose

To measure surface temperature

Overview

Surface temperature is measured with a hand-held Infrared Thermometer (IRT) that, when necessary, is wrapped in a thermal glove or has been placed outdoors for at least 30 minutes prior to data collection. The instrument is pointed at the ground to take surface temperature readings. *Cloud Protocols* are performed along with the *Surface Temperature Protocol*.

Student Outcomes

Students will learn to use an infrared thermometer, and understand how different surfaces radiate energy.

Science Concepts

Earth and Space Sciences

Clouds affect weather and climate.

The diurnal and seasonal motion of the sun across the sky can be observed and described.

Materials from human societies affect the chemical cycles of Earth.

The Sun is a major source of energy for Earth surface processes.

The Sun is a major source of energy at Earth's surface.

Solar isolation drives atmospheric and ocean circulation.

Physical Sciences

Heat transfer occurs by radiation, conduction, and convection.

Light radiation interacts with matter.

The sun is a major source of energy on the Earth's surface.

Energy is transferred in many ways.

Heat moves from warmer to colder objects.

Light/ radiation interacts with matter.

The Sun is a major source of energy for changes on Earth's surface.

Energy is conserved.

Life Sciences

Sunlight is the major source of energy for ecosystems.

Energy for life derives mainly from the Sun.

General Science

Visual models help us to analyze and interpret data.

Geography

The temperature variability of a location affects the characteristics of Earth's physical geographic system.

The nature and extent of cloud cover affects the characteristics of Earth's physical geographic system.

The nature and extent of precipitation affects the characteristics of Earth's physical geographic system.

Human activities can modify the physical environment.

Scientific Inquiry Abilities

Inquiry skills

Students will learn to use an infrared thermometer.

Use appropriate tools and techniques.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures, descriptions, and predictions.

Use a thermometer to measure temperature.

Use a cloud chart to identify cloud type.

Estimate cloud cover.

Use meter sticks to measure snow depth.

Time

10 – 20 minutes

Level

All

Frequency

Daily with other atmosphere measurements

On sunny days with few clouds for comparison with satellite observations.

When taking soil temperature measurements

When *Land Cover Sample Sites* are visited

Materials and Tools

Hand-held Infrared Thermometer (IRT)

Thermal Glove (use when the air temperature at the study site varies more than 5 degrees Celsius from the air temperature of where the IRT has been stored.)

Surface Temperature Data Sheet

GLOBE Cloud Chart

Ruler or meter stick

Watch

Pen or pencil

Preparation

Establish an Atmosphere Study Site OR

Establish a site where soil temperature is measured OR

Prepare to characterize Land Cover Sample Sites

Prerequisites

None

Surface Temperature Protocol – Introduction

As you explore your surrounding environment you will encounter objects that are at a variety of temperatures. For example, during the afternoon, areas that are exposed to direct sunlight will tend to be hotter than areas that are shaded. Within an area that is exposed to sunlight you may even notice certain objects are warmer or cooler than others. During the morning some objects, such as rocks, may take longer to warm up than their surroundings. Likewise at dusk these objects may take longer to cool.

Heat refers to the amount of thermal energy; it is transferred between objects in various ways. The rate at which energy is transferred to an object depends on its properties including the nature of its surface. The color of the object, the ratio of its mass to surface area, and the material of which it is composed all affect the transfer of energy.

The temperature of your surrounding environment is ever changing, and thermal energy is constantly being transferred among all the components of the environment. The temperature of the atmosphere will affect the temperature of Earth's surface, and likewise the temperature of Earth's surface will affect the temperature of the atmosphere.

The type of land cover present at Earth's surface will play a significant role in this relationship. What covers Earth's surface will help determine how much of the sun's energy that reaches the ground is retained by the surface or reflected back into the atmosphere. On a warm sunny day you can feel different levels of heat radiated from different types of land cover. On a warm day, where do you stand to keep cool? On a cold day, where do you go to keep warm?

Studying the transfer of heat in the environment – the energy cycle – is one key to understanding how the Earth system functions and may change in the future. The transfer of heat between the different components of the environment occurs at their boundaries. So, knowing the temperature at these boundaries is key. Surface temperature measurements provide these boundary temperatures. Therefore, measurements of surface temperature help to relate air, soil, and water temperatures and contribute critically to the study of the energy cycle. Relating land cover types to surface temperatures allows you to integrate multiple GLOBE investigation areas and truly study Earth as a system.

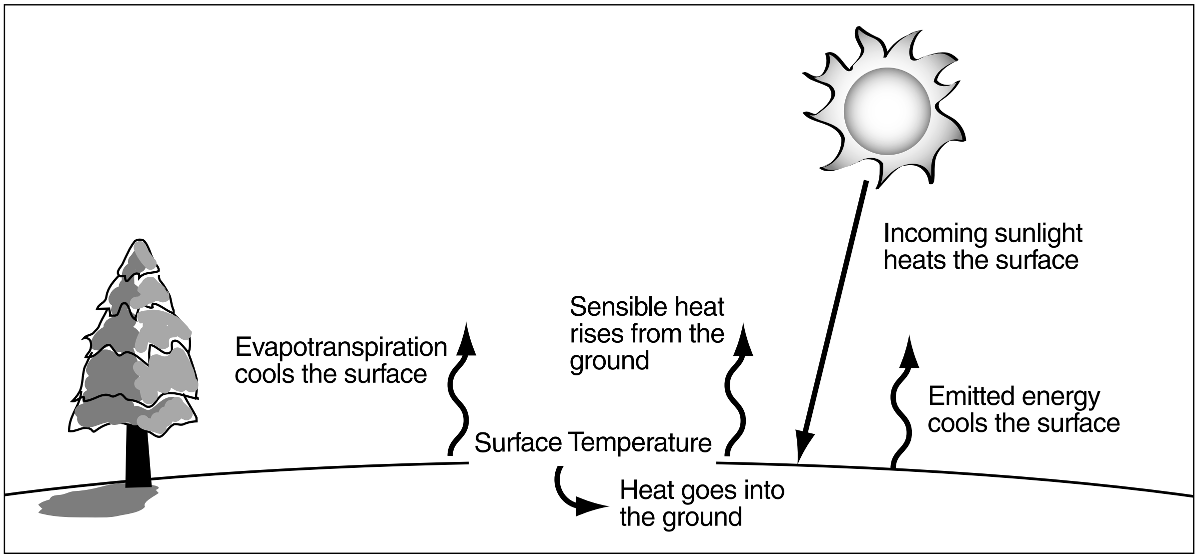
Your GLOBE measurements of surface temperatures will help climate studies and the understanding of the global energy cycle, both in combination with your other measurements and through comparisons with satellite data. See the *Earth As a System* chapter for more discussion of the energy cycle.

Surface temperature is an observation that is not normally taken by official weather agencies. There are three ways in which surface temperature is observed by scientists: 1. hand-held infrared thermometers similar to the one you use, 2. IRT instruments mounted on towers, and 3. observations from satellites. For most studies, individual scientists or groups of scientists take their own observations using the hand-held IRT instrument and tower mounted IRTs, then compare their observations with satellite imagery. In a couple of situations, organized efforts have been conducted to observe surface temperature continuously over a large area. For example, the state of Oklahoma (USA) has installed 70 IRTs on towers in its Mesonetwork of meteorological stations. These tower-mounted IRTs continuously take surface temperature observations over crop fields and rangeland. However, the total number of surface temperature observations taken around the world is relatively small. This is where GLOBE students can really help! By taking surface temperature observations, GLOBE schools have the potential to significantly add to our knowledge of Earth's surface temperature.

What is Surface Temperature?

Described scientifically, surface temperature is the radiating temperature of the ground surface including grass, bare soil, roads, sidewalks, buildings, and trees to name a few. Surface temperature can be observed using the electromagnetic spectrum. Every object emits electromagnetic energy according to its temperature. Hot objects emit

Figure AT-ST-1: Partitioning of the Sun's Energy as Related to Surface Temperature



shorter wavelength energy, while cooler objects emit longer wavelength energy. For example, the visible surface of the sun is approximately 5500° C. Its peak emission of energy is in the visible wavelengths of the spectrum, 0.4 µm to 0.7 µm. Earth's surface is much cooler and emits much longer wavelength energy. Most of its energy is emitted in the infrared, and consequently we call this part of the electromagnetic spectrum, centered around 10 µm, the thermal infrared. The Infrared Thermometer (IRT) used in this protocol measures the emitted electromagnetic energy from Earth's surface. The instrument converts this measurement into a temperature reading that is shown on the IRT's display area.

The Energy Cycle

The energy cycle describes the way in which the energy from the sun is partitioned into evapotranspiration and heating of Earth's surface. Scientifically, the energy cycle begins with incoming solar radiation. What happens to this radiation is affected by cloud cover, cloud type and by the albedo (reflectance) of Earth's surface.

At Earths surface, some of the solar energy evaporates water and some warms the surface. Heat from the surface flows into the ground and into the air if they are colder than the surface. The heat of vaporization of the water is released when and where the water condenses, often as clouds form. This is the main source of energy for storms.

At the heart of the energy cycle is surface temperature. All aspects of the energy budget contribute to or are affected by surface temperature.

The time of day affects the surface temperature. The surface temperature increases in the morning and peaks an hour or two after local solar noon. Incoming solar radiation is also greatest during the summer and least during the winter.

The amount of vegetation and moisture available at the surface affects the surface temperature also. When moisture is not available at the surface, such as in a desert or on a paved surface, there is no evaporation to cool the surface, and the temperature of the surface increases more during daylight.

The surface temperature affects the amount of long-wave (thermal) radiation going to space. The warmer the surface, the more energy it radiates.

In order to better understand heat in the environment, scientists take temperature measurements of many different environmental components at a variety of locations. These measurements include air temperature, surface land temperatures, surface water temperatures, and soil temperatures at various depths. You, as students, can do this as well by observing the surface temperature of different cover types at several locations, while also collecting air temperature, water temperature, and soil temperature. Scientists also measure the temperature of the atmosphere at various heights and the temperature of the ocean at different depths using satellite sensors, balloons, rockets, and buoys. Measurements at multiple heights in the air and depths in the waters are called soundings.

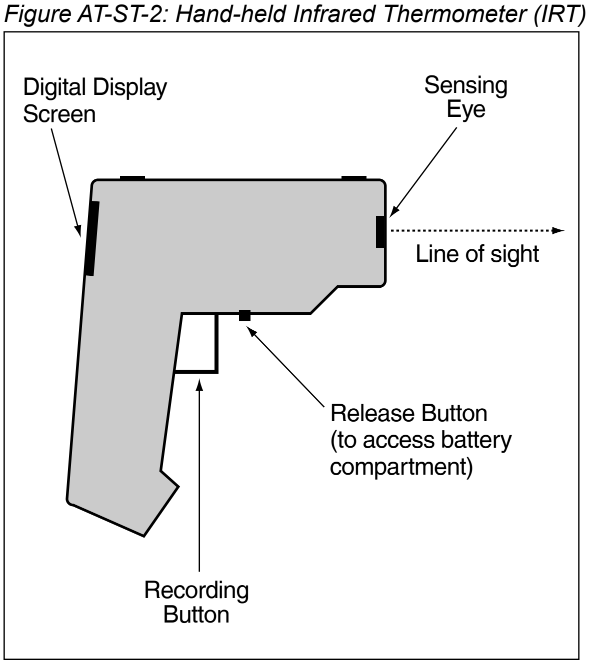
For more information about the energy budget and evapotranspiration please see the *Earth as a System Chapter.*

Teacher Support

Infrared Thermometer

An infrared thermometer (IRT) measures temperature by sensing the infrared radiation (light) coming from a surface. This instrument is sensitive to infrared radiation at wavelengths in the 8-14 μm range. It is not critical for students to understand how it works any more than they need to understand concepts about thermal expansion to use a conventional thermometer. With an the IRT (that, when necessary, is wrapped in a thermal glove or has been placed outdoors for at least 30 minutes prior to data collection), surface temperature measurements can be taken of a wide variety of surfaces including Earth's surface at GLOBE study sites.

Figure AT-ST-2: Hand-held Infrared Thermometer (IRT)



The instrument featured in this protocol is the ST20 Infrared Thermometer (IRT) by Raytek. This model is known to meet GLOBE Instrument Specifications (as found in the *Toolkit*). However, any IRT model instrument that meets the GLOBE Instrument Specifications can be used to take this measurement. You may need to adapt some of the instrument-specific details given in this protocol to suite your specific model instrument (be sure to consult directions provided by the manufacturer when doing so). However, the primary steps for taking Surface Temperature measurements, as outlined in the *Field Guide*, will remain the same regardless of the instrument used.

Thermal Glove -or- Place IRT Outdoors For At Least 30 Minutes

When the air temperature at your study site varies more than 5 degrees Celsius from the air temperature of where the IRT has been stored you need to do one of the following:

- Wrap the IRT in a Thermal Glove 'before' you go to your study site
  or
- Place the IRT outdoors for at least 30 minutes prior to data collection.

The purpose of the Thermal Glove or placement of the IRT outdoors for at least 30 minutes is to prevent inaccurate readings due to temporary thermal shock. Thermal shock is a phenomenon that occurs when the IRT instrument experiences a change in environmental temperature.

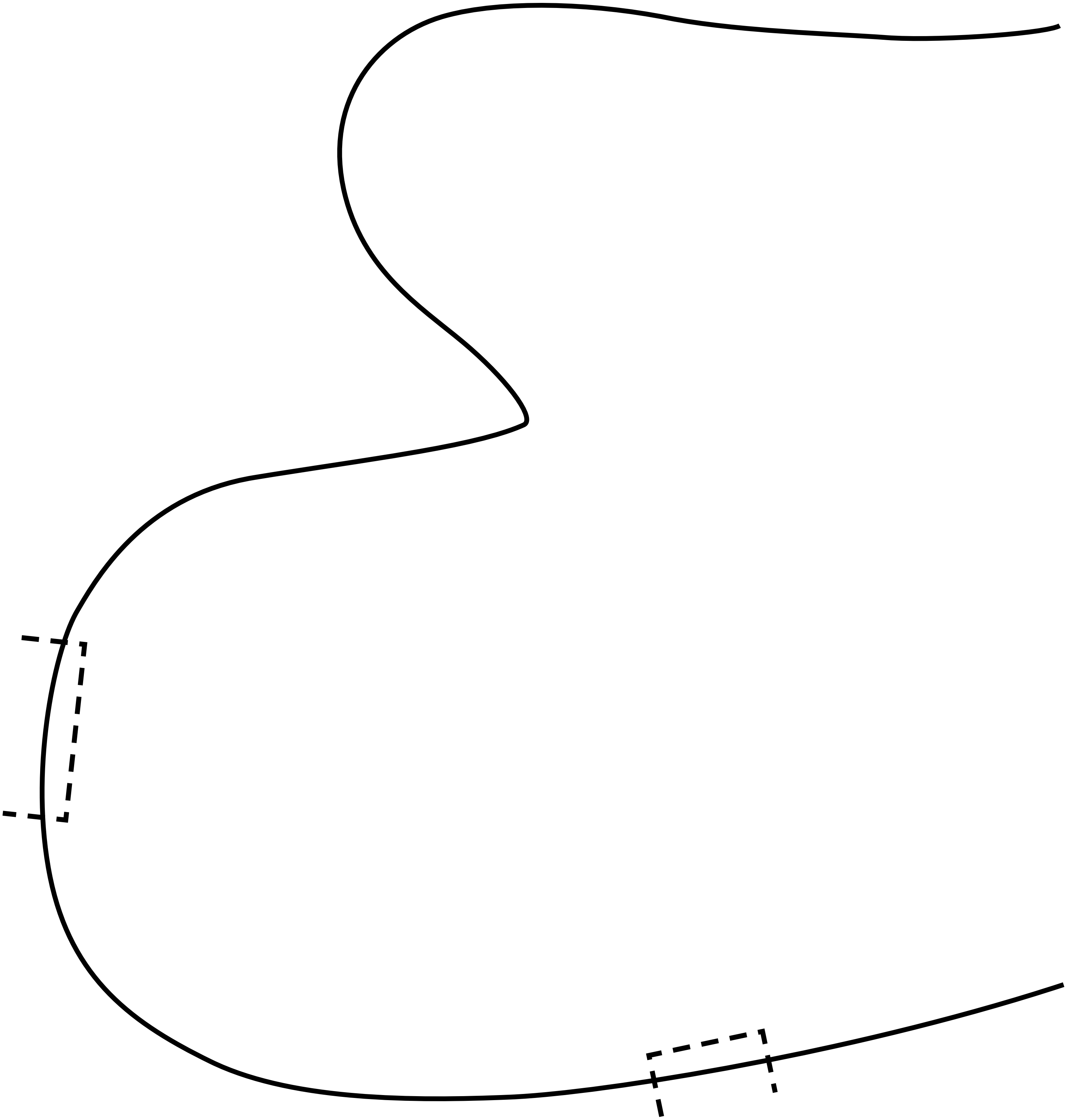
Also, the IRT wrapped in a thermal glove has been tested to work for 30 minutes.

The thermal glove is the invention of a very dedicated and highly respected secondary school teacher from St. Ursula Academy in Toledo, Ohio, USA who has been involved in our student-scientist, Earth observation research projects since August 2000. Thank you, Jackie Kane, for all your inspiration and hard work!

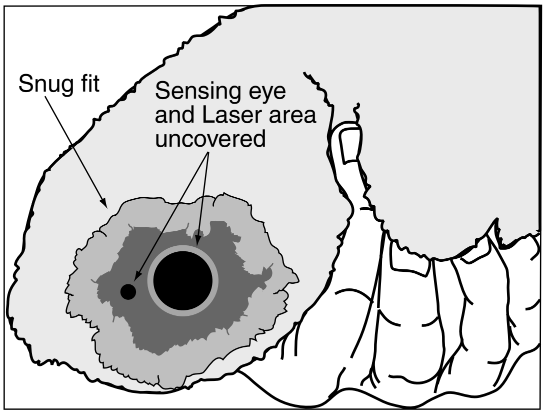
The thermal glove is made from a standard 'oven mitt'. An 'oven mitt' is a device that people put on their hand (like a mitten) to prevent burning when lifting hot items from an oven or a stove. The 'oven mitt' MUST be constructed of 100% terry cloth; inside and outside. An actual-size pattern of the thermal glove with hole designations for the IRT's sensing eye and digital display screen is shown on the following page. If you have any difficulties finding a 100% terry cloth 'oven mitt', please contact the Surface Temperature PI Team, and they will gladly send you a thermal glove. Contact information for the Surface Temperature PI Team is given on the *Meet the Scientists* Page of the GLOBE Web site.

Directions On How to Construct a Thermal Glove

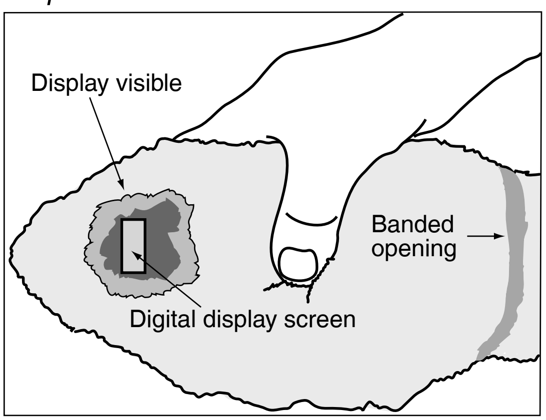
1. Purchase 1 'oven mitt' made of 100% terry cloth.
2. Lay your 'oven mitt' on the actual-size pattern shown on the following page and mark the areas on your 'oven mitt' where you will need to cut the 2 holes.
3. You will need very pointy, sharp, and sturdy scissors to poke through the 'oven mitt' and cut out the holes.
4. Cut out the 2 holes. These should be square shaped holes. The hole at the fingertip section should be approximately 3.5 centimeters. The other hole should be approximately 2 centimeters. It is better to error on the smaller side when cutting the holes. If a hole is cut too large it will allow airflow through the thermal glove which defeats the purpose of the thermal glove, so error on the smaller side! When you put your IRT into the 'oven mitt' then you can increase the holes if necessary.
5. Hold the 'oven mitt' so that the thumb points down.
6. Position the IRT instrument in the finger section of the 'oven mitt' with the sensing eye pointing out through the cut hole in the end of the finger section. Make sure the 'oven mitt' does not cover the sensing eye and laser areas of the IRT; however, also make sure that the IRT fits snugly against the front area of the 'oven mitt' to prevent air from flowing through the thermal glove. (Ignore the thumb section of the 'oven mitt').
7. Position the digital display screen so that it is visible from the upper cut hole (when the thumb is pointing downward.)
8. Make any cut adjustments to the 2 holes and reposition the IRT in the 'oven mitt' for hole-size verification.
9. Once the 2 holes are cut to specification, apply 'tacky glue' to all the seams that were cut. Let the glue dry overnight before you use the thermal glove in the field. The 'tacky glue' will seal the seams and stop them from unraveling.
10. Secure a sturdy rubber band around the loop located at the large bottom opening of the 'oven mitt'.
11. You now have a Thermal Glove that is ready for data collection and exploration – Have Fun!!



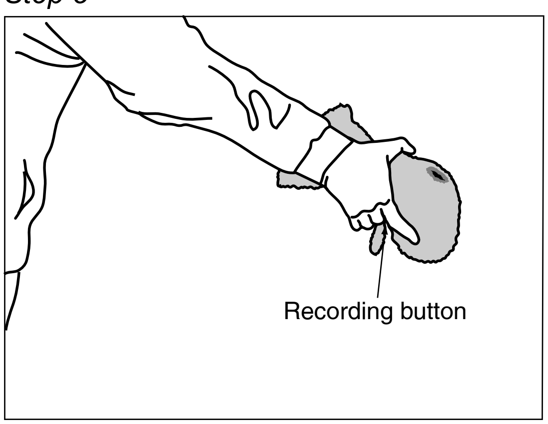
Step 2



Step 3 and 4



Step 5



Directions for Use of IRT with Thermal Glove:

1. Hold the thermal glove so the thumb points down.

2. Position the IRT in the finger section of the thermal glove with the sensing eye pointing out through the cut hole in the end of the finger section. Make sure the thermal glove does not cover the sensing eye and laser areas; however, also make sure that the IRT fits snugly against the front area of the thermal glove to prevent air from flowing through the glove. (Ignore the thumb section of the thermal glove).

3. Position the digital display screen so that it is visible in the upper cut hole (when the thumb is pointing downward.)

4. Take your hand out of the thermal glove and use a rubber band to tighten the thermal glove around the IRT handle at the large bottom opening of the thermal glove.

5. Operate the IRT from **outside** the thermal glove by placing your finger on the recording button and squeezing.

Thermal Glove Maintenance:

When needed, trim frayed edges of cut holes to avoid obstructing the sensing eye and laser area and digital display screen.

Understanding Measurements of Surface Temperature

Using other GLOBE protocols, your students can measure the air temperature and the soil temperature at several depths. With an IRT instrument (that, when necessary, is wrapped in a thermal glove or has been placed outdoors for at least 30 minutes prior to data collection) the air and soil temperature measurements can be complemented by measurements of the temperature at the surface rather than in the air or in the soil. This temperature at the surface is at the actual boundary between the atmosphere and the ground, and the resulting data are useful for understanding the transfer of heat to and from the ground. These data are also useful for comparison with satellite data, because some satellite instruments observe the ground and record surface temperature measurements in a way that is almost identical to how an IRT instrument measures surface temperature.

Instrument Maintenance

Be sure to follow all the manufacturer's instructions for proper maintenance of your Infrared Thermometer (IRT). This includes proper cleaning of the lens as accumulated particles can reduce the thermometer's accuracy by interfering with its optics. Take care not to damage the lens while cleaning it and DO NOT use solvents.

The digital readout of the IRT will display a battery icon when the battery becomes low. When you see this icon, it is time to check the battery and replace it if necessary. The battery is a 9V battery located in the handle of the instrument and can be accessed by pressing the release button (see Figure AT-ST-2) in front of the recording button and opening the handle. See the manufacturer's directions for more detailed instructions.

Make sure that your instrument is displaying temperature readings in degrees Celsius. If it is setup correctly, the temperature reading on the digital display screen will be followed by a "°C' symbol. If instead of this "°C ' symbol you see a "°F' then your thermometer is displaying temperature in degrees Fahrenheit and needs to be switched to display in Celsius. The instrument has a switch that allows you to change between Celsius and Fahrenheit readings. This switch is located above the battery and is accessed in the same manner as stated above. Again, consult manufacturer's directions for further detail. Because this switch is in the battery compartment, you do not have to worry that students will accidentally change this setting.

The calibration of your Infrared Thermometer (IRT) instrument should be checked once every year. To perform a check, prepare an ice water solution in a large beaker or bowl. Point the IRT instrument directly at the water with the end of the instrument approximately 5 cm away from the water; then press the recording button. If the instrument is reading correctly, the ice water measurement will read 0° C. If the reading of your instrument is not within –2 to 2° C , then the instrument is out of calibration.

If your instrument is not reading properly, check to see if the battery is low. If that is not the problem, check to see if the lens is dirty, and clean it if it is. If you are still not able to get the instrument to read properly, contact the manufacturer.

Site Selection

Surface temperature data are valuable for comparison with satellite observations and for use in combination with air and soil temperature measurements. The sites to use are *Land Cover Sample Sites, Atmosphere Study Sites,* and *Soil Moisture Study Sites.*

Picking and Describing a Good Surface Temperature Measurement Site for Comparisons With Satellite Data

A large, open, homogeneous site is required to compare your surface temperature observations with satellite data (for example, the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA' s EOS TERRA and AQUA satellites with 1 km spatial resolution and the Enhanced Thematic Mapper (ETM+) sensor on Landsat 7 with a thermal instrument of 60 meter spatial resolution).

A *Land Cover Sample Site* where the plants are less than a meter tall is an ideal site to take surface temperature. Land cover sites are required to be homogeneous over an area that is at least 90 meters x 90 meters. When your site meets these requirements, perform the *Land Cover Sample Site Protocol.*

Sites that are open and homogeneous, but less than 90 x 90 meters are also quite useful for surface temperature measurements, but they are not suitable for the *Land Cover Sample Site Protocol*. The site needs to be away from trees and buildings that create shadows on the land area, because the shadows will reduce the amount of sunlight absorbed by the ground and may cause significant variations in the surface temperature. The site can be a grassy area (like a football field), a parking lot (concrete or asphalt), bare soil, or an area containing shrubs.

If you choose a concrete or asphalt parking lot, there cannot be cars in the lot. If there are cars in the lot, then you have the same problem with shadows as you would with trees and buildings. If a section of your parking lot is the largest open, homogeneous area available, then designate that section as your Site and use the same section of the parking lot each time you collect surface temperature data.

If your site is greater than a 30 x 30 meters open, homogeneous area (but less than 90 x 90 meters), then this is wonderful. If your site is less than a 30 x 30 meters open, homogeneous area, then choose the largest open, homogeneous area available and designate it as your Site.

Many Atmosphere and Soil Moisture Study Sites will be useful for comparison with satellite data as they will be in open areas without buildings or other sources of shade.

Mark your site's boundaries appropriately (perhaps use GLOBE marker flags) if you can, so that students can reliably return to the exact location each time they collect surface temperature data.

If the site that you choose has already been defined as a *Land Cover Sample Site, Atmosphere Study Site, or Soil Moisture Study Site*, then you are ready to begin collecting and reporting surface temperature measurements. If your site has not been defined and is over 90 m x 90 m with homogeneous land cover, define your site as a *Land Cover Sample Site* following the *Land Cover Sample Site Protocol.* If your site has not been defined, and it is less than 90 x 90 meters, then define it as either an *Atmosphere Study Site,* or *Soil Moisture Study Site* depending on which will be most appropriate given the other measurements that you plan to take at the site.

When you define a new site for surface temperature, describe any unique permanent features of your site that would be likely to have an effect on Surface Temperature measurements in the *Comments* (metadata) field for the site definition. For example, site *is an asphalt parking lot that has yellow painted lines to mark the spaces and our school building as the boundary on the north side of the site*. Additional information about any temporary changes to the state of your site that relate to surface temperature readings can be recorded in the *Comments* field of your *Surface Temperature Data Sheet* when you take your measurements. For example, *site is covered with leaf litter today*.

When you report surface temperature data for the first time at a new site you will be asked to report some *Definition Data* regarding the size and ground cover type found at the site, as well as the model IRT you will be using at the site. Record this information at the top of your *Surface Temperature Data Sheet* the first time that you take measurements at the site.

You are encouraged to monitor the surface temperature at sites representing as many different land cover types as you can. The more sites that you monitor and for which you report data, the better the information will be for research. It is very exciting to monitor at least 2 sites with different land covers, so that you can observe and explore the changes in surface temperatures that occur due to the differences between these sites.

Helpful Hints

Some IRT units are equipped with a laser and backlight. You can choose whether or not to activate these. If you choose to put them on, a red laser beam will shine from the sensing eye area along the approximate line of sight of the instrument when the recording button is pressed. This will cause a red dot to appear where the surface temperature is being measured. A backlight for the digital display screen will remain lit for seven seconds after the recording button is pressed and released.

Using the laser can help you more accurately locate the point where you are measuring the surface temperature. However, it will also reduce battery life and could possibly be a distraction to students. It is imperative that the laser beam NOT be aimed directly at eyes or off surfaces where it could reflect into anyone's eyes. The laser and backlight option is controlled by a switch located above the battery in the battery compartment.

Questions for Further Investigation

How does surface temperature vary depending on whether the surface is in the sun or the shade? Does it matter whether the shade is from a tree, a shrub, or a cloud?

How does surface temperature compare with current air temperature? How does surface temperature compare with soil temperature at 5 cm and 10 cm?

How does surface temperature vary with land cover (e.g., bare soil, short grass, tall grass, concrete, asphalt, sand, forest litter)?

How does surface temperature vary with surface soil color?

How does the surface temperature of the ground, near the outside of the atmosphere shelter, compare with the current air temperature measured inside the shelter?

How does the surface temperature of the underside of a forest canopy compare with air temperature in the forest?

How does surface temperature change for different cover types (grass vs. asphalt for instance) on a cloudy day?

How does the time of year affect the surface temperature?

How does the surface temperature change for different cover types when it is wet versus when it is dry?

Surface Temperature Protocol
Field Guide

Task

Measure surface temperature.

What You Need

- ❑ *Surface Temperature Data Sheet*
- ❑ Hand-held Infrared Thermometer (IRT)
- ❑ Thermal Glove (use when the air temperature at the study site varies more than 5 degrees Celsius from the air temperature of where the IRT has been stored.)
- ❑ Ruler or Meter Stick, (if snow cover is present)
- ❑ Pencil or pen
- ❑ GLOBE Cloud Chart
- ❑ Accurate Watch

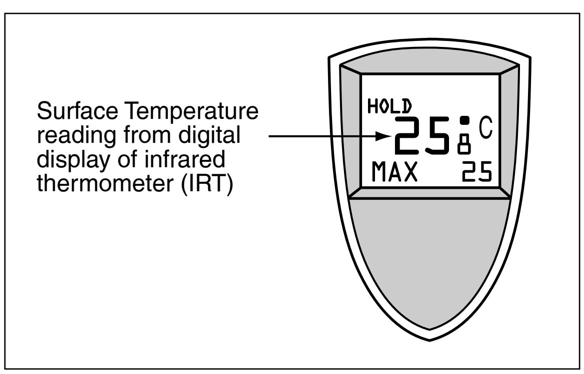
In The Field

1. When necessary, either wrap the IRT in a Thermal Glove before you go to your study site or place the IRT outdoors for at least 30 minutes prior to data collection. For more details, refer to the *Thermal Glove -or- Place IRT Outdoors For At Least 30 Minutes* section of this protocol.
2. Complete the top section of your *Surface Temperature Data Sheet* (fill out the *Supplemental Site Definition Data* section if you are taking Surface Temperature Measurements at a particular site for the first time, or if one of the values in that section has changed)
3. Take cloud observations following GLOBE *Cloud Protocols.*
4. If there is no snow on the ground anywhere in your Site, then check either "Wet" or "Dry" for the Site's Overall Surface Condition field on your *Surface Temperature Data Sheet.*
5. Check the box that corresponds to the method used to prevent the IRT from experiencing thermal shock.
6. Pick 9 Observation Spots that are in open areas within your site and are at least 5 meters apart. The Spots should also be away from trees and buildings that create a shadow on the land and in locations that have not been recently disturbed by people or animal traffic. (Note: It is best that you take readings at the 9 individual Observation Spots within seconds of each other.)
7. Go to one of the nine Observation Spots and stand so that you do not cast a shadow on the Spot.
8. Record the Current Time and its corresponding Universal Time (UT) on your S*urface Temperature Data Sheet.*

9. Hold the infrared thermometer (IRT) (wrapped in a Thermal Glove when necessary) with your arm extended straight out and point the instrument straight down at the ground.
10. Hold the IRT (wrapped in a Thermal Glove when necessary) as still as possible. Press and release the recording button. [You MUST release the recording button for the instrument to register and hold your spot's surface temperature.]
11. Read and record the surface temperature from the digital display screen located on the top of the IRT. (Note: Surface Temperature is recorded in Celsius to the nearest tenth degree, ie. 25.8)
12. Measure and record the snow depth in millimeters at the Observation Spot.
13. Repeat steps 7-12 at each of the remaining eight Observation Spots.
14. Record any other information that explains the environmental conditions of the day or site in the Comments field.

a. b.

The above pictures show correct use of IRT, a) without a Thermal Glove and b) with Thermal Glove



Frequently Asked Questions

1. What should I do if the surface temperature reading I want to record disappears from the digital display screen before I am able to accurately read and record it?

The surface temperature reading will be displayed for seven seconds after you release the recording button of the IRT. If you are unable to read the temperature in this time, or are unsure of your reading, then retake the measurement at that Observation Spot according to the directions given in the *Field Guide*.

2. How should a dusting of snow be documented on the *Surface Temperature Data Sheet***?**

If there is snow of less than ten millimeters in depth on the ground then record the letter "T" in the snow depth section of your *Data Sheet* to indicate a dusting of snow. If there is snow of ten millimeters or more in depth then measure the depth of the snow pack in millimeters using your ruler or meter stick.

3. The *Surface Temperature Field Guide* **asks for measurements of cloud cover and snow depth, for which there are also separate GLOBE measurements. Would it be helpful to take these or any other GLOBE measurements along with Surface Temperature?**

Yes! Taking multiple types of measurements at the same site at the same time allows for greater insight into the state of the environment than a single measurement possibly could. Taking additional types of measurements to accompany your surface temperature readings allows you to study what factors may be affecting each individual reading. Surface temperature ties strongly to cloud cover, air temperature, soil moisture, soil characterization, and land cover type.

4. Is recording NO snow -or- NO clouds important?

Yes, reporting that there is no snow and/or no clouds is important! If there is no snow, please record a zero in all appropriate SNOW DEPTH fields. If there are no clouds in the sky, please check NO CLOUDS in the *Cloud Type* table on your *Surface Temperature Data Sheet.* The fact that there is no snow or no clouds present will directly impact your readings of surface temperature, so reporting this will help to explain your readings.

If you leave a blank in these fields, it will be confusing, because the scientists will never know if you forgot to take the data or if the measurement is zero. Also, your data for that day can not be used in research.

5. Can the Infrared Thermometer (IRT) Instrument be used for other types of temperature monitoring?

Yes. Some of its other uses are by meat packers to ensure that their refrigerators and freezers are kept at a specific temperature. Also, mechanics use this instrument to measure the temperature of a car's oil. And a teacher has shared with us that a janitor came into her classroom to check the temperature at different places around the room that helped to determine when the classroom's heating system was fixed.

6. The Field Guide says that we should take readings at 9 individual observation spots each time we go to the study site to take surface temperature measurements. Can we take fewer than 9 readings?

We strongly encourage you to take all 9 readings. The 9 points are needed by GLOBE scientists to create meaningful averages of your study site and to accurately compare your data to satellite data. The more readings that you take, the better your data is for the scientists! If your study site is less than 30 x 30 meters, we still strongly encourage you to take all 9 readings; however, we also understand that the 9 measurements may need to be closer than 5 meters apart. It is required that you take at least 3 readings to report data to GLOBE.

7. Can I use the IRT instrument to study the surface temperature of water?

Yes, the IRT instrument can be used to read the temperature of the surface of a water body. However, since it is not possible to follow the steps outlined in the *Surface Temperature Field Guide* over open water these values cannot be reported to GLOBE. However, they can be quite useful in studying the relationship between air and water temperatures, and can be included as metadata accompanying water temperature readings submitted to GLOBE.

8. When do I use the Thermal Glove?

Your Infrared Thermometer (IRT) should be wrapped in a Thermal Glove when the air temperature at your study site varies more than 5 degrees Celsius from the air temperature of where the IRT has been stored.

9. Should I round up to the nearest integer when recording the surface temperature measurement from the IRT digital display screen?

NO. The surface temperature measurement must be recorded to the nearest tenth degree, ie. 25.8.

Surface Temperature Protocol – Looking At the Data

Are the data reasonable?

There are many factors that influence the surface temperature reading including the land cover type, soil moisture content, cloudiness, and temperatures prior to your observation in addition to your location, time of day and day of year. Therefore, it will be more difficult to determine if your surface temperature data are reasonable.

As you become more familiar with your surface temperature readings at your site throughout the year, you will become familiar with what the temperature of different cover types may be. You will become trained as an observer and will be able to notice if there is an anomaly that occurs (a measurement that seems odd, compared to your other data) which will spark you to question that reading or area.

Sometimes the observations that you get may seem incorrect, but in fact, the observations may be telling you something interesting about how surfaces heat up and cool down. If asked, most people would say that an asphalt parking lot would be much warmer than a grass site. One GLOBE school in Michigan (USA) found the exact opposite temperatures on a sunny afternoon in early March. The grass was warmer than the asphalt site. In the case of these observations, the weather had been very cold all winter long. On the sunny day in question, the sun was able to warm up the grass while the asphalt parking lot retained the cold temperatures from winter for much longer. From summer through early fall on a sunny afternoon, an asphalt parking lot will be hotter than a grass site. However, during the winter through early spring on a sunny afternoon, the grass will heat up in the sun and be warmer than the parking lot.

Other times there may not be a scientific explanation for an errant surface temperature observation. For instance, you know that the ground is frozen because you can see ice; however, your IRT instrument records the ground as 40˚ C. This may lead you to ask if your IRT instrument is measuring accurately, if you made a mistake in data collection, or if something has changed within your Study Site. Scientists do this exact questioning of their observations, as well. If you think the IRT instrument may be misreading the temperature, refer to the *Instrument Maintenance* section above. The IRT may need a new battery, the lens may be dirty, or the instrument may be out of calibration.

So, get ready for some interesting and exciting learning about our planet's temperatures!

What do scientists look for in these data?

GLOBE scientists will be using student surface temperature observations in two ways. We will be using the surface temperatures recorded by GLOBE students to validate satellite algorithms that are used to record Earth's surface temperature. Satellite images give a synoptic view of the landscape that ground observations cannot. As stated above in the *Surface Temperature Protocol Introduction* section, Earth's surface emits electromagnetic energy according to its temperature. However, satellites observe Earth's emitted energy after it travels through the atmosphere. Greenhouse gases in the atmosphere, such as carbon dioxide and water vapor, absorb some of the energy emitted by Earth's surface and these gases emit energy at their own temperature which makes the satellite observation of Earth's surface temperature misleading. This atmospheric effect makes it difficult for scientists to use the surface temperature that is recorded by satellites. GLOBE students' surface temperature observations will allow us to determine if the satellite algorithms (equations) for surface temperature accurately account for the atmosphere's interference.

The second way that we will use the students' surface temperature data is to compare observations between different cover types to monitor the effect of land cover on the temperature of Earth. These observations will give us an understanding of the causes and extent of the urban heat island effect. We will compare grass sites' surface temperatures at urban vs. rural schools. The same comparison will be made with all the different land cover types between urban and rural locations.

The Urban Heat Island Effect

The urban heat island effect is a phenomenon where the change in the land from natural vegetation to parking lots and buildings can cause the temperature of the area to increase (Figure AT-ST-3). The central part of a city can be 5-10° C warmer than the surrounding countryside. Transpiration from vegetation including trees and grass cools the air. The energy from the sun that shines on the surface is used to evaporate water and is not available to heat up the ground. In contrast, parking lots, roads and buildings dry out under sunshine, and all of the incoming energy from the sun heats the surface warming it up more than it would otherwise. You may notice these temperature differences when you are taking your observations. (**Note:** The time of day and time of year may influence whether pavement is warmer than grass.)

Look at the image of surface temperature for Toledo, Ohio, USA, shown in Figure AT-ST-4. This image is from the Landsat 7 satellite taken on July 1, 2000 at approximately 11:00 am Local Time. Red areas are hot, and blue and purple areas are cooler. The hottest locations are sites with much pavement (concrete and asphalt), such as malls and the downtown area of Toledo. The cooler areas are the parks, that have many trees and the water in the Maumee River and Lake Erie.

An Example of a Student Research Investigation

Designing an Investigation

This is a simple investigation that can be performed using an IRT. Mikell Hedley's Research Methods class from Central Catholic High School in Toledo, Ohio, USA, investigated the properties of different land cover types that affect surface temperature. Within the boundaries of each site, they collected surface temperature readings at 4 different Observation Spots.

It was a sunny afternoon and the class decided to observe grass, asphalt, cement, and bare soil. Before going outside Mrs. Hedley asked her students to predict which areas would be warmest and coolest.

Student 1 – I know that my blacktop driveway gets really hot on a summer day. I think it's because it is black. So, asphalt will be warmest.

Teacher – Black surfaces absorb more sunlight than lighter surfaces, such as cement. We will see if you are right. What else is going on?

Student 2 – Don't plants give off water? In Biology class, we learned that plants give off water through photosynthesis. Because of this I think the grass will be coolest.

Figure AT-ST-3: Example Relationship between Land Cover and Temperature. Miller (1999)

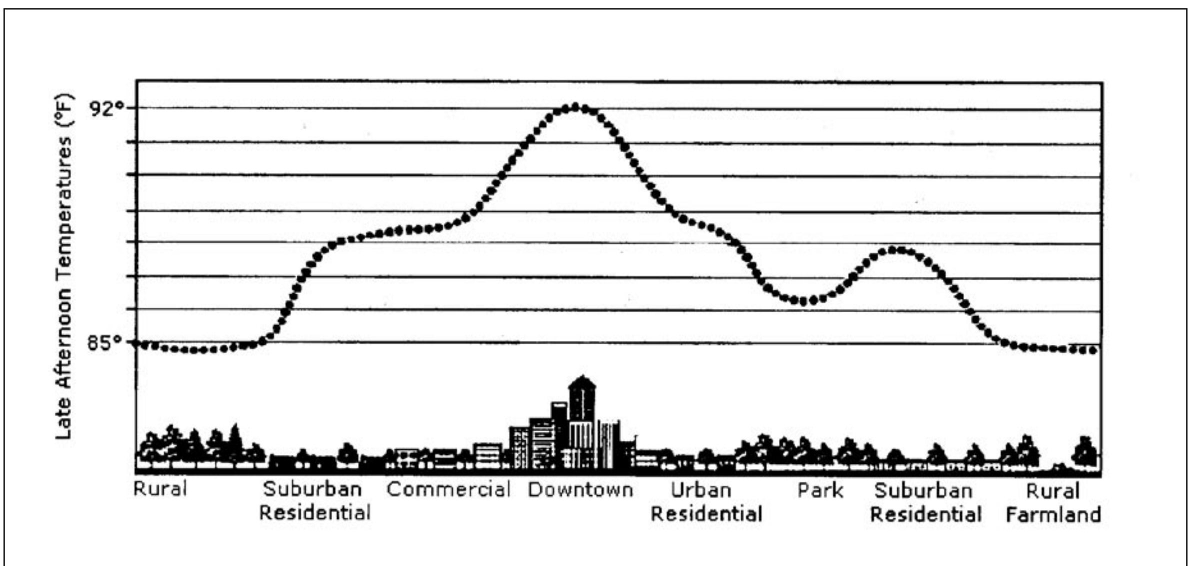
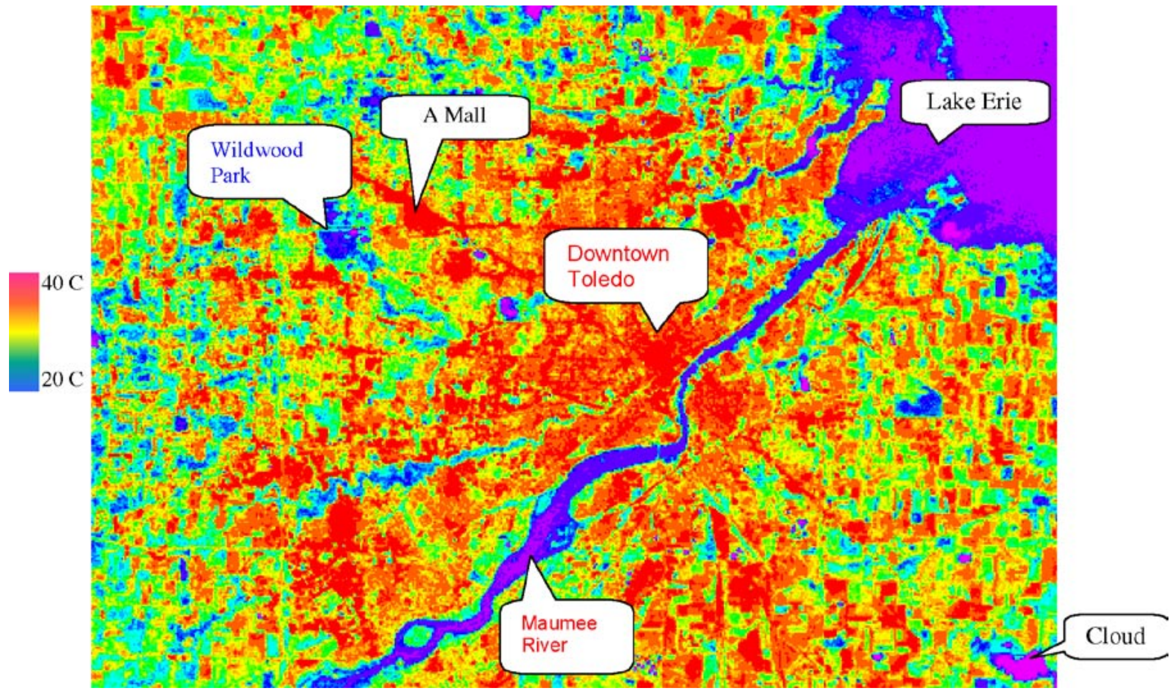


Figure AT-ST-4: Surface Temperature for Toledo, Ohio, USA



Teacher – Yes, plants are drawing water from the ground and transpiring it into the air. Evaporation cools, and, in transpiration liquid, water in the plant becomes water vapor in the air.

Student 3 – Asphalt, concrete, and bare soil are all massive and dense. I think it will take more heat to warm them up, but the grass is not so dense, so it will warm up more quickly and be the hottest.

Teacher – Let's go measure and test your predictions.

Table AT-ST-5 presents the results.

Table AT-ST-5: Surface Temperature Readings (˚C) at Areas with Different Types of Land Cover

Land Cover	Observation Spots			
	1	2	3	4
Grass	27.5	30.0	28.5	29.0
Asphalt	35.5	33.5	33.5	34.0
Cement	32.0	33.0	32.0	33.5
Bare Soil	30.0	31.0	33.0	31.5

These data show that the asphalt had the highest temperature while the grass had the lowest. So the predictions of Students 1 and 2 proved correct.

Surface Ozone Protocol

Purpose

To measure ozone concentrations at ground level

Overview

Students deploy a strip of paper that changes color in the presence of ozone. They use an ozone reader to determine the amount of ozone in ppb as indicated by the color change of the paper strip.

Student Outcomes

Students will learn to measure the concentrations of ground-level ozone in the atmosphere and to observe changes in the concentrations over time.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and over the seasons.

Weather varies on local, regional, and global spatial scales.

The atmosphere is made up of different gases and aerosols.

Materials from human societies affect the chemical cycles of the Earth.

Geography

Human activities can modify the physical environment.

Atmospheric Enrichment

The concentration of surface ozone varies over time.

Cloud cover, air temperature, wind direction and humidity affect ozone concentration.

Air quality is affected by the concentration of ozone present.

Scientific Inquiry Abilities

Use ozone strips and a strip reader to measure *in situ* ozone concentrations.

Use a weather vane to identify wind direction.

Identify answerable questions.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

Two five-minute time periods, one hour apart

Level

All

Frequency

Daily

Measurements starting within one hour of local solar noon are preferred.

Materials and Tools

Ozone Data Sheet

Clipboard

Pencil or pen

Chemical test strip in sealable plastic bag

Ozone Test Strip Scanner

Ozone Measurement Station

Device to measure wind direction

GLOBE Cloud Chart

Instrument Shelter with Thermometer

Sling Psychrometer OR Digital Hygrometer

Clock or watch

Preparation

Assemble and install Ozone Monitoring Station.

Assemble or obtain and install Wind Direction Instrument.

Prerequisites

Cloud Protocols

Relative Humidity Protocol

Maximum, Minimum and Current Temperature Protocol OR

Digital Multi-Day Max/Min/Current Air and Soil Temperature Protocol

Ozone Protocol – Introduction

Ozone is one of many gases in the air present in small amounts. These gases are called *trace gases*, and they play a role in the complex chemistry that determines the quality of the air we breathe. The amounts (concentrations) of these trace gases vary with time of day, from day to day, and from place to place. These variations are due to variations in the amounts of other gases from which trace gases are formed, and conditions such as air temperature. Monitoring the concentrations of trace gases is important for our understanding of air quality and how it is changing.

The oxygen molecule, consisting of two atoms of oxygen (O_2) (See Figure AT-SO-1) comprises 21% of Earth's atmosphere. Ozone, a molecule containing three oxygen atoms (O_3) (See Figure AT-SO-2) is present in much smaller amounts. Surface ozone can be produced when certain chemicals are released to the atmosphere and these chemicals react with each other in the presence of sunlight. Ozone is an important trace gas because it is very reactive, which means that it will easily 'stick' to, and react with all surfaces, including living tissue.

Ozone exists in both the stratosphere and troposphere; 90% of the ozone is found in the stratosphere, leaving a small amount in the troposphere. The ozone located in the stratosphere is often called 'good ozone' because it absorbs much of the sun's ultraviolet rays and protects the life forms on Earth. In contrast, the additional ozone that occurs in the troposphere is 'bad ozone' and is considered a pollutant. It is the main component of smog. Sometimes the term 'photochemical smog' is used, which is the correct term for pollution found near most urban areas. This type of smog is a product of chemical reactions in the atmosphere that take place only in the presence of sunlight.

Ozone is often one of the more abundant trace gases in the atmosphere and GLOBE students can measure it using simple chemical test strips. Collecting surface ozone data will provide a record of the amount of ground level ozone found in different geographic regions at different times. These data will help scientists understand how weather conditions influence the amount of ozone in the air. The GLOBE database will contribute valuable information for understanding how Earth's atmosphere may be changing.

Figure AT-SO-1: Oxygen Molecule

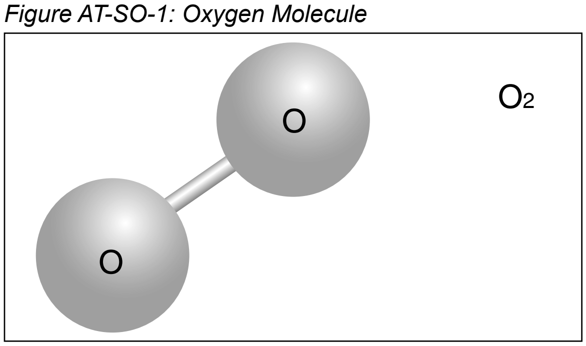
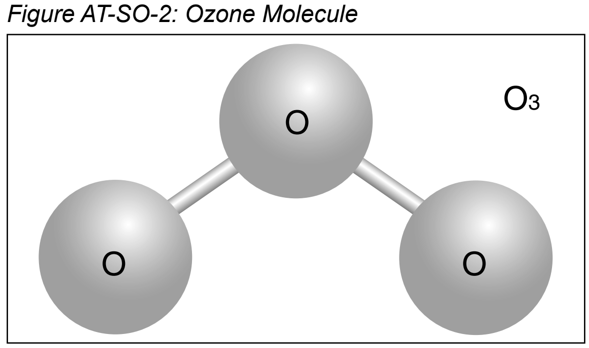


Figure AT-SO-2: Ozone Molecule



Teacher Support

The Measurement

The GLOBE surface ozone measurement is taken using a chemically sensitive strip that changes color in the presence of ozone. The more ozone present, the more change that will occur. The chemical strip is placed in the clip of the monitoring station preferably within one hour of local solar noon and left exposed to the air for one hour. It is then read using a scanner, which reads the strip more accurately and precisely than the eye, enhancing the scientific value of these data.

The amount of color change will increase if the strip is exposed to ozone for a longer period of time. Therefore, to ensure that GLOBE data are comparable around the world, the protocol specifies that the strip be exposed for only one hour and that the time it is exposed and the time it is read are reported to GLOBE to the nearest minute.

Placing the Chemical Strip

The chemical strip is exposed to outside air that is moving freely around the monitoring station. It is important to keep the strip in a closed plastic bag or pouch until it is placed in the monitoring station because once the strip is exposed it begins to react with any ozone that is present. When placing the strip, avoid touching the chemical on the strip to prevent contamination; however there is no danger should someone touch the strip.

Reading the Chemical Response

Reading of the chemically sensitive strip must be completed in the field. The team collecting the information records the level of response on the *Ozone Data Sheet.*

Determining the Level of Surface Ozone

The hand held scanner provides a more sensitive reading of the color of the ozone test strip than can be achieved with the naked eye. The scanner is designed to give a reading of ozone concentration in units of parts per billion. The correspondence between the color of the strip and the average concentration of ozone in the air during the time the strip was exposed assumes that the exposure was for just one hour.

Place the chemical strip into the thin slot on top of the scanner. Hold the edge of the chemical strip on the end with the words “Test Card”. The chemical side of the strip should face the display. Gently slide the strip into the slot on top of the scanner until the bottom of the strip touches the base of the scanner and won’t slide in any further. This places the circle with the chemical in the center of the end of the scanner. It will take a few seconds for the scanner to read the color change of the strip, and identify the ozone concentration in parts per billion.

Measurement Logistics

The need to expose the ozone strip for one hour may pose a logistical challenge. One approach to solve this is to expose the ozone strip at the same time that the daily atmosphere measurements of maximum, minimum, and current temperature, precipitation, relative humidity, and clouds are made within one hour of local solar noon. These measurements will then provide one set of the cloud and current temperature measurements required to support the ozone measurement. Students would also read wind direction at this time.

Just a few minutes before an hour has passed students need to go to the site to measure the concentration of ozone detected by the strip. At the same time, they will need to open the instrument shelter and read the current temperature, do the *Cloud Cover* and *Cloud Type Protocols*, and again observe the wind direction. Unusual weather conditions that may have affected the response of the strip are reported as comments or metadata. The students who read the ozone strip do not have to be the same students who exposed the strip. This gives you some flexibility to work within the constraints of the school day and student schedules.

The key to this two time measurement is to establish a clear schedule so that everyone involved knows what they are expected to do and when to do it. Design a system so students know when the hour is nearly finished, and return to the site to read and record the data.

Ozone concentrations often vary over the day. To build a consistent set of ozone readings that can be compared across many schools, the primary data set desired is of measurements for a one hour period that begins within one hour of local solar noon. This should require the least effort as noted above. If this timing will not work at your school or if you wish to take more than one ozone measurement a day, you may do this protocol at other times. These data may not be displayed on GLOBE visualizations of mid-day ozone values, but they will be included in the tables of data associated with your school and will be made available in graphs. The key is that the ozone strip is exposed for one hour and that clouds, current temperature, and wind direction are reported for both the beginning and end of this time period.

Scanner Use and Care

An ozone measuring hand-held scanner is used to measure the level of ozone present in the atmosphere. It is important to read the handheld scanner in a shaded area with the scanner placed on a level stable surface. Sunlight and motion can affect the scanner reading.

Placing the scanner inside the instrument shelter provides the level shaded surface needed to take the ozone measurement. The instrument should be inside the GLOBE Instrument Shelter for 5 minutes to allow it time to adjust to the outside conditions. During these 5 minutes, students should be recording cloud cover, temperature, and wind direction data. After recording these data, the students will return to the instrument shelter, turn on the scanner, and wait 30 seconds to allow the internal electronics to stabilize. The scanner will automatically turn off. Turn it back on immediately to calibrate the unexposed ozone test strip. These same steps should be repeated when the students return to the site to read the exposed ozone test strip. The scanner must be brought back into the classroom after calibrating the unexposed strip as well as after reading the exposed strip.

The ozone measuring hand-held scanner is a rugged instrument, but care must be taken to ensure accurate measurements.

1. Keep the scanner at room temperature and in its protective case to protect it from dirt and dust when it is not in use.
2. Go to RESET and reset the scanner each day to MODE 01
3. When the scanner is turned on to calibrate the unexposed strip or read the exposed strip, be careful not to accidentally touch or bump the two buttons on the edge of the scanner. If the buttons are touched without a strip in the scanner, the scanner will respond by trying to save a reading without a strip and you will not have an accurate ppb reading. The scanner will need to be recalibrated with an unexposed strip to reset the white paper reading.
4. The test strip scanner is sensitive to temperature changes. If the outside temperature is not within 5° C of the classroom temperature, the scanner should remain inside and the exposed strip should be brought back into the classroom to be read. The time it takes to bring the ozone strip from the monitoring station to the classroom will not significantly impact the ozone concentrations.
5. Turn the scanner off when it is not in use.
6. Do not drop the scanner.
7. Protect the scanner's electronics from water.
8. Change the three AAA batteries when the scanner indicates they have low power.

Supporting Measurements

Since the chemistry of trace gases in the atmosphere depends on the amount of sunlight present, students are asked to record the cloud cover and type when they expose the strip and when they read it. Many chemical reactions also depend on temperature and so students are asked to measure current temperature when the strip is exposed and read. Lastly, the amounts of trace gases present may vary considerably depending on what is upwind from your measurement site. Students also measure the wind direction at the beginning and end of the exposure period.

These supporting data can be compared to data collected from other schools in different locations. As students learn about the air they breathe, they should explore how weather conditions can affect the amount of ozone in the air around them. Comparing the data they gather with students from other regions of the world is an appropriate topic for student inquiry.

Note: If wind measurements are not available, data from the closest surface weather site (available on the Web) would be important to have in the analysis of the data (as well as for the analysis of other atmosphere protocol measurements). If data are taken from the Web, this fact should be noted in the metadata

Student Preparation.

Students need to be trained how to measure and record the surface ozone level. It will be important to the accuracy of the measurement that students are able to:

1. Work in cooperative groups of 2-4 students to gather, analyze, and discuss results.
2. Organize all materials needed to set up and take the measurement of surface ozone.
3. Follow a schedule to return to the ozone monitoring site 5-10 minutes before strip is to be read to take supporting measurements.
4. Identify and record the starting time when they expose the chemical strip, and accurately read the strip at the end of one hour.
5. Carry the chemically sensitive strip to the monitoring site in a plastic bag to control exposure time.
6. Read and follow the *Ozone Field Guide* instructions for placing and reading the ozone strip.
7. Read the current temperature from the maximum/minimum thermometer without altering the maximum and minimum settings.
8. Identify and record cloud type and cover using the *Cloud Protocols*.
9. Record data accurately and completely for reporting to GLOBE and for future graphing and analysis.
10. Record their observations in their individual GLOBE Science Logs.
11. Respond in their GLOBE Science Logs to a question that reveals the individual nature of their learning experience, share their responses with their team, discuss, and choose to add to their response as a result of their discussion without changing their original response.

Helpful Hints

Have a designated area to keep the clipboard with the *Data Sheet* to facilitate different teams working to record data. Keep the *Data Sheets* in a notebook so that they are not misplaced.

From time to time check the written record in the Data Book to ensure that it is complete and accurate.

Sometimes a chemical strip gets damaged while exposed to ambient air. If the chemical strip gets wet, the response will be marbled. Enter M for data for this day or time period. This will indicate that the measurement was taken, but it was contaminated.

If there is no response on the chemical strip, enter 0 to indicate no surface ozone is present.

Questions for Further Investigation

Is the amount of ozone you observe related to other atmosphere phenomena? Which ones? How?

How can you use your data collected over a period of time to predict future changes in the atmosphere?

What is the variability of ozone in the atmosphere daily? Seasonally? Annually?

Exposing the Ozone Test Strip
Field Guide

Task

Begin the measurement of surface ozone concentration.

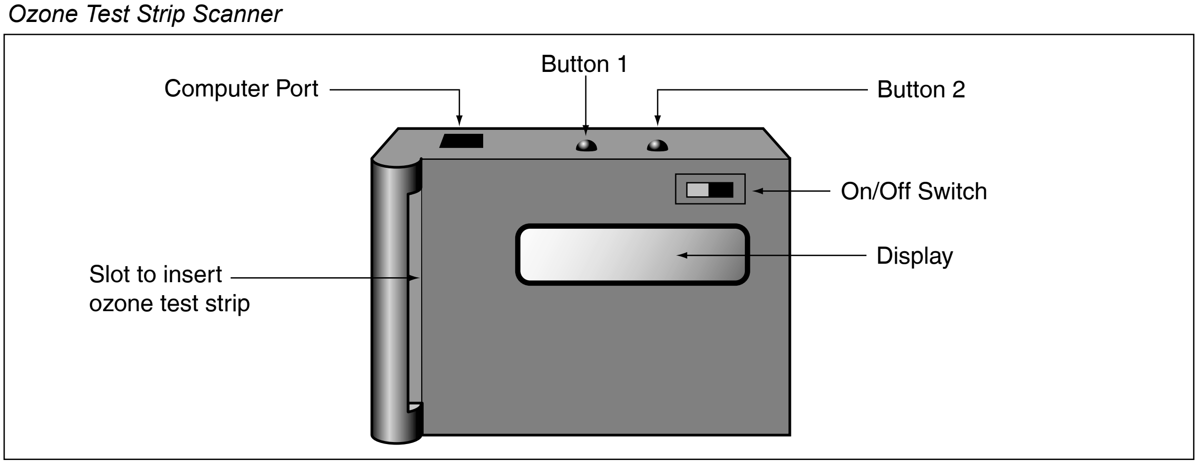
Record cloud conditions, current air temperature, wind direction, and relative humidity.

What You Need

- ❑ One Ozone Test Strip
- ❑ Plastic bag to carry the test strip to your site
- ❑ Ozone Test Strip Scanner
- ❑ Clipboard
- ❑ *Ozone Data Sheet*
- ❑ Pen or pencil
- ❑ Sling Psychrometer OR Digital Hygrometer
- ❑ *Measuring Wind Direction Field Guide*
- ❑ *Cloud Cover Field Guide*
- ❑ *Cloud Type Field Guide*
- ❑ *Sling Psychrometer Field Guide* OR *Digital Hygrometer Field Guide*
- ❑ GLOBE Cloud Chart
- ❑ Wind Direction Instrument
- ❑ Key to your instrument shelter
- ❑ A clock or watch accurate to the nearest minute

Note: If using the digital hygrometer to measure current relative humidity, it must be placed in the instrument shelter at least 30 minutes before calibrating and placing the unexposed ozone strip and gathering metadata.

Ozone Test Strip Scanner

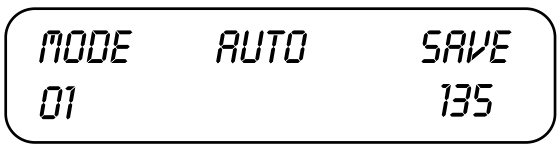


In the Field or Classroom

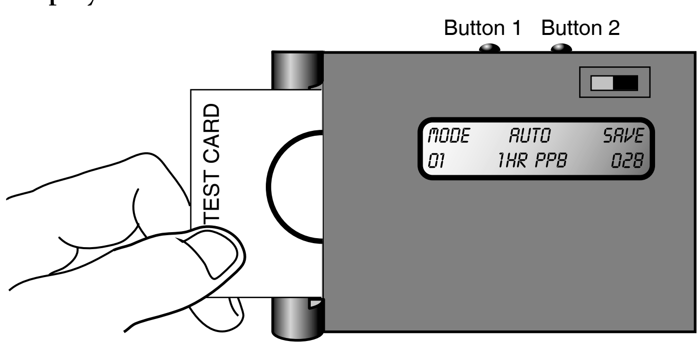
1. Fill out the top of the *Ozone Data Sheet.*
2. Remove a single ozone test strip from the plastic bag,
3. Record the date and starting time.

Calibrating the Scanner

4. Place the scanner on a steady surface out of direct sunlight, preferably inside your Instrument Shelter.
5. Turn on the scanner and you should see the following in the LCD readout. (Older scanners may display 170 for the number under SAVE and need to be recalibrated. Contact the GLOBE Help Desk for assistance.)



6. Place the unexposed ozone test strip into the scanner with the **chemical side facing toward the display.**



7. Press button 1 (left button) until you see SELECT> CALIB on the display.
8. Press button 2 (right button) and you will see 1 HR WHT = and fluctuating numbers. This is ok.
9. Press both buttons simultaneously to save unexposed strip reading.
10. Turn off the scanner, and remove the unexposed strip. (NOTE: turning off scanner before removing the strip will prevent accidentally changing the settings in the scanner)

In the Field

11. Place this ozone test strip in the clip on the monitoring station. Do not touch the chemical part of the strip at any time. (It is not harmful to you, but touching it may prevent you from getting an accurate measurement.) Record the time.
12. Determine cloud cover and cloud type following the *Cloud Cover* and *Cloud Type Protocols.*
13. Measure and record the current temperature on the thermometer in your instrument shelter (to the nearest 0.5° C).
14. Record the wind direction.
15. Measure and record the relative humidity using either a sling psychrometer or digital hygrometer.

Reading the Ozone Test Strip
Field Guide

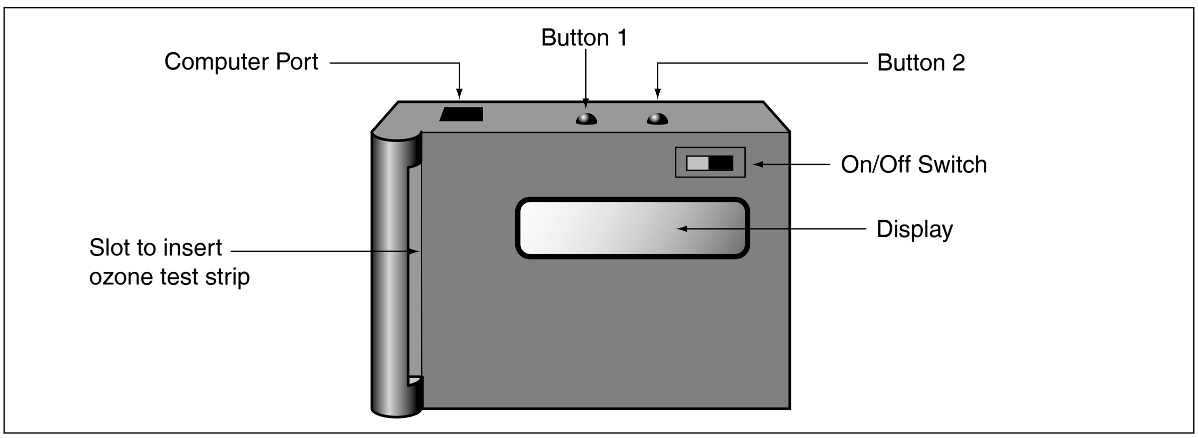
Task

Complete the measurement of surface ozone concentration after the ozone test strip has been exposed for one hour.

Record cloud conditions, current air temperature, wind direction, and relative humidity.

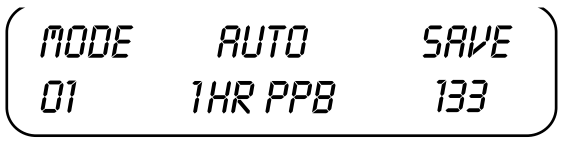
What You Need

- ❑ Ozone Test Strip Scanner
- ❑ Clipboard
- ❑ *Ozone Data Sheet*
- ❑ Pen or pencil
- ❑ GLOBE Cloud Chart
- ❑ Sling Psychrometer OR Digital Hygrometer
- ❑ *Cloud Cover Field Guide*
- ❑ *Cloud Type Field Guide*
- ❑ *Measuring Wind Direction Field Guide*
- ❑ *Sling Psychrometer Field Guide* OR *Digital Hygrometer Field Guide*
- ❑ Wind Direction Instrument
- ❑ Key to your instrument shelter
- ❑ A clock or watch accurate to the nearest minute



In the Field

1. Place the scanner in the instrument shelter and turn it on. Let it run 30 seconds to adjust to climate. (Do not touch any other buttons except the on/off switch if scanner turns off) You should see something like the following display:



2. Remove the test strip from the clip; be careful not to touch the chemical part of the strip.

In the Field or Classroom

3. Slide the strip into the slot on top of the scanner until the bottom of the strip touches the base of the scanner and won't slide in any further. The chemical part of the strip should face the display
4. The reading should stop fluctuating after 5-10 seconds. If it fluctuates between two numbers, choose the lower of the two readings after the test paper has been in the scanner for 10-15 seconds.
5. Record the ppb reading on your *Data Sheet* and turn scanner off. If the reading fluctuates between two numbers, choose the lower of the two readings after the test paper has been in the scanner for 5-10 seconds. Place the strip into a sealed plastic bag.
6. Record the time you read the ozone strip.
7. Determine cloud cover and cloud type following the *Cloud Cover and Cloud Type Field Guides.*
8. Read and record the current air temperature.
9. Determine and record the wind direction.
10. Measure and record the relative humidity using either a sling psychrometer or digital hygrometer.

Note: The new scanner model automatically turns itself off after a minute. If this happens, turn it back on to complete your task. It is not uncommon for the scanner to display more than one value, because of the nature of the electronics in the scanner and the color on the exposed strip is rarely completely uniform (although it may appear that way to the naked eye). It is common that the concentration shown in the display fluctuates among several values and eventually starts to increase the longer the strip remains in the unit. Because the measurement accuracy is 10 ppb, fluctuating numbers within a range of 1-5 ppb are acceptable. The goal of the *Ozone Protocol* is to be able to distinguish between values that are regarded as low (0-20 ppb), normal (30-50ppb) and high (>60 ppb).

Measuring Wind Direction
Field Guide

Task
Determine wind direction using Wind Direction Instrument.

What You Need

- ❑ Wind Direction Instrument
- ❑ Clipboard
- ❑ *Ozone Data Sheet*

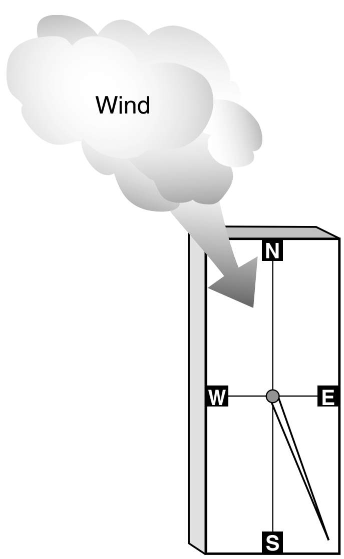
In the Field

1. Place your wind direction instrument on a table or bench so that it is about 1 meter off the ground.
2. Use the compass to find magnetic north and align the base of your model marked N to match true north.
3. Look at the wind sail to see if there is any wind blowing.
4. Put your right hand on your hip and your left arm out straight.
5. Turn your body so that your straight arm is pointing in the same direction as the wind sail. Your right elbow is now pointing in the direction of the wind.
6. Record this direction on your *Data Sheet.*

For example, if your wind sail is pointing south, your straight arm should be pointing south. In order for the wind sail to be pointing south, where does the wind have to be coming from? North.

Your straight arm is pointing where the wind is going, and the elbow of your bent arm is pointing in the direction where the wind is coming from, north. Winds are identified by the direction from which they are coming.

Wind is coming from the **northwest**



Wind sail is being blown towards **southeast.**

Frequently Asked Questions

1. What if the ozone strip does not change color after one hour?

If there is no color change, enter 0 on the data sheet, because it indicates that there is very little or no surface ozone present.

2. What if the ozone strip got wet due to rain or snow and the color is marbled, or the surface is not one complete color?

Your ozone measurement strip is contaminated or spoiled which means the data are not accurate. Report your data as M to the GLOBE Data Server. Note as a comment weather conditions which may have affected your results. Still measure the current temperature, cloud cover and cloud type and report them.

3. We are not in school on the weekend, how can we collect data?

Persistence in data collection is important, so work with your GLOBE team to arrange for a volunteer to bring one or two students to your Atmosphere Study Site on weekends and holidays if possible. Data from school days alone are still valuable, but for some schools weekends will have systematically different ozone levels.

4. Can the plastic disk and strip be placed on the weather station?

No. They should be on different posts.

5. Why is it important to take the temperature reading after recording the ozone level?

The strip will continue to respond to the gases in the air. So it is important to take the ozone reading and then the temperature reading.

6. Why is it important to record the wind direction, cloud cover and type, and current temperature before calibrating an unexposed strip or reading the exposed strip?

The scanner needs time to adjust to the outside conditions. If you return to the monitoring site 5-8 minutes before the hour you have to read the exposed strip, you can place the scanner in the instrument shelter, and record the cloud cover and type, wind direction, and current temperature reading while the scanner adjusts to the outside conditions. Remember that the strip will continue to respond to the gases in the air and it is important to read the response of the strip one hour after it was placed.

7. What are some common problems with using the test strip scanner and how can I fix them?

Problem 1: I don't know if my scanner is calibrated correctly

To check the calibration of the scanner, first turn the scanner on and reset it. Go to CALIB and place an unexposed strip in the Scanner. Push the right button, button #2, and let the scanner read the unexposed strip for 1 minute. Record the lowest and highest readings. A large range (> 5 ppb) between the lowest and highest readings, or a reading of 180 or higher indicates a scanner problem. Contact the Vender and return the scanner for repairs.

Problem 2: The reading under "SAVE" is a Range of Low Fluctuating Numbers

The scanner was calibrated without an unexposed strip. Push the left button, button #1, until CALIB shows on the LCD. Place an unexposed strip in the scanner, push the right button, button #2, and then hold both buttons down simultaneously to reset the calibration for an unexposed strip. The scanner should return to SAVE 170.

Problem 3: The LCD Reads 8HR PPB or AQI When the Scanner is Turned On

If settings have been changed the reading under SAVE will also be different. Someone has changed the SETTING categories in the scanner. Push the left button, button number 1 until SETTINGS appear on the LCD. Push the right button, button #2, and you will see DRATION = 8HR. Push the right button until you see DRATION = 1HR. Push the left button and it will show MEASURE = AQI. Push the right button until it scrolls to MEASURE = PPB and push the left button. Now push both buttons simultaneously to save the settings and return to the original screen on the LCD. It should read:

MODE	AUTO	SAVE
01	1HR PPB	170

8. Can I determine that there may be problems with my measurements based on my scanner's readings? If so, how can I diagnose and correct these problems?

Before taking measurements each day, it is beneficial to turn on the scanner and push the left button until "Reset" shows on the LCD, and push both buttons to reset the scanner to MODE 1. However, even resetting the scanner before using it each day may not prevent minor problems from occurring. Occasionally the response of the scanner indicates something has been changed within it, and resetting the scanner will not be enough to correct the problem. Some of these problems and their solutions are identified below.

Note: At the time of placing the strip and again when reading the exposed strip the following must be done:

- Scanner placed in ambient air for 4-5 minutes to allow it to acclimate to environmental conditions.
- Scanner turned on for one minute to enable it to stabilize, and when it shuts off immediately turn it back on, give it a few seconds to stabilize and then calibrate the unexposed or read the exposed strip.

Problem 1: The range of readings of an unexposed strip may indicate a problem with the scanner.

Solution: Turn on the scanner. Reset it. The correct Readings on the LCD are: MODE 01 1 HR PPB and 135 (if reads 168-170, the scanner needs updating, contact the GLOBE Help Desk). Place the unexposed strip in the scanner and push the left button until you read "CALIB". Push the right button and let the scanner read the unexposed strip for 1 minute. Record the lowest and highest readings. For example, the range of numbers may fluctuate, but the fluctuation is near or about 5 ppb. However, if the fluctuation has a much larger range than 5 numbers from the lowest number to the highest number, or the range of readings are higher than 180, contact the manufacturer to determine whether or not the scanner needs to be repaired.

Problem 2: Readings under "SAVE" are low, fluctuating numbers, when scanner is turned on.

Diagnosis: The scanner needs to be calibrated **with** an unexposed strip. Someone set the calibration without using a strip.

Solution: Push the left button until you reach "Calib". Place an unexposed chemical strip" into the scanner and push the right button to activate the reading of the **unexposed strip.** Hold both buttons down to lock in on the calibration. Before removing the unexposed strip, the reading under "SAVE" should be 000 or 001. If it goes higher than 001, calibrate the scanner again with the unexposed strip.

Problem 3: LCD reads 8 hr instead of 1 HR or AQI instead of PPB, when the scanner is turned

Diagnosis: Either of these readings will also affect the reading under SAVE. Someone has changed the "DATA" categories in the scanner.

Solution: Push the left button until you have "DATA".

Push the right button to read the first category under "DATA" then,

Push the left button to scan through the list of categories - until the LCD reads the category "GAS" - then push the right button to read the subcategories under "GAS " until it reads "ozone"

Push the left button again and it saves the category, "ozone" and scrolls to the next general data category called MEASURE=.

Push the right button until it shows PPB and push the left button to save it.

The scanner will automatically scroll to "DRATION" or the time the strip will be exposed.

Push the right button until the DRATION=1HR and push both buttons simultaneously to save the corrected "DATA" category settings.

Surface Ozone Measurement - Looking at the Data

Are the data reasonable?

Average surface ozone measurements can range from nearly 0 ppb to over 150 ppb (and even 200 ppb in extremely polluted conditions). Research has shown that different areas experience different levels of surface ozone depending upon time of year, location, and the level of hydrocarbons and nitrogen oxides in the air, since they are the precursors needed to produce ozone near Earth's surface.

Students taking daily measurements over several weeks should observe a range of ozone levels. Often, there is a gradual build-up over several days, and then concentrations drop over a shorter period of time. Students should take particular note of the wind direction and temperature over this several-week period along with the passage of weather fronts. Has the wind shifted? Are there days when there is a heavy overcast and the ozone levels show unusually low values? On a longer time scale, how do surface ozone measurements vary with season and from one year to another? Gaining experience with the variations in ozone concentration at your own site is the best way to judge whether individual measurements are reasonable.

Although surface ozone concentrations can be quite variable, there are some correlations that usually apply. Sunlight drives some of the chemical reactions in the atmosphere which lead to the formation of ozone. Therefore, it is reasonable to expect higher surface ozone concentrations in the summer than in the winter. In low latitudes, where the amount of sunlight is relatively constant (and high) throughout the year, highest surface ozone values are found most often if there is a seasonal source of the precursors needed to generate ozone. Thus, in many tropical areas, surface ozone levels will likely increase if there is a preferred time of the year when biomass burning takes place. This seasonality may be linked to the region's dry season, since it is easier to burn vegetation after it has dried out over a period of several weeks.

On shorter time scales, heavy cloud cover and low surface ozone concentrations are often observed at the same time. It is unlikely that high concentrations would be present if it is raining. When there is little or no wind, local concentrations of the chemicals leading to ozone formation can build up. Under these conditions, the ozone formed locally is not carried away and is not diluted with air from higher in the troposphere where ozone concentrations are generally lower. The chemical processes leading to ozone production happen more rapidly under warmer conditions.

What do people look for in these data?

Monthly data gathered at fixed times

One method of collecting data is to measure ozone every day for a specific period of time, usually for at least one month, and hopefully longer. An example of a 1-month data record is presented in Table AT-SO-1.

This is a typical data set that would be gathered by students at the same time every day. Plotting ozone concentration versus temperature does not reveal any strong correlation; for example, both the warmest day (11/1) and the coldest day (11/23) have the two highest ozone readings (55 and 46 ppb). There is, however, a general tendency for concentrations to be lower when the temperatures are colder: From the 10^{th} through the 25^{th}, temperatures are below 20˚ C and the ozone concentrations average 15 ppb. When the temperatures are >20˚ C *and* it is not raining, the average concentration is 38 ppb., more than twice as high as when it is relatively cool. The other very important factor in this analysis is the wind direction. When the wind is from the south or southwest, the average concentration is 41 ppb. For this particular data set, the wind direction appears to be the primary factor signaling higher concentrations. The reasons for this finding may be simple, or they may be complex. For example, is there a large metropolitan area located nearby and when the air is from the south, are you downwind of a large pollution

Table AT-SO-1 **Heart of Mary School–ppb Ozone and Metadata**

Date	ppb	Ending Temp	End Time	Cloud Type	Cloud Cover	Wind Direction (beginning/ ending)	Notes
11/1/00	55	28	12:50	Cirrostratus, Cumulonimbus	Broken	SW/SW	
11/7/00	19	26	12:30	Stratocumulus	Overcast	SW/SW	Heavy rain
11/8/00	12	26	12:25	Stratocumulus	Overcast	SE/SE	Light rain
11/9/00	35	24	12:25	None	No clouds	NW/NW	
11/10/00	13	14	12:15	None	No clouds	NW/NW	
11/11/00	15	16	12:25	None	No clouds	W/NW	
11/14/00	22	14	12:30	Cirrus	Scattered	NW/NW	
11/15/00	16	14	12:30	Cirrostratus	Scattered	NW/NW	
11/17/00	13	5	12:30	Cirrostratus	Overcast	NW/NW	31 mm of rain
11/20/00	14	14	12:40	None	No clouds	NW/NW	
11/21/00	13	9	12:25	None	No clouds	NW/NW	
11/22/00	16	12	12:45	Cirrostratus	Clear	NW/NW	
11/23/00	46	6	12:15	Nimbostratus	Overcast	S/S	
11/25/00	16	15	1:00	Nimbostratus	Overcast	W/W	
11/27/00	31	21	12:30	None	No clouds	SW/SW	
11/28/00	30	20	12:40	Cirrus	Overcast	SW/SW	
11/29/00	40	21	12:30	Cumulus	Clear	W/W	

source? Such an effect is often observed in the Los Angeles basin where highest concentrations of ozone are primarily found in the suburban areas downwind from the metropolitan area. Another reason may be due to the placement of the ozone monitoring site if, for example, there is an open field to the south and a forested region to the north. Ozone is destroyed as it comes in contact with leaves on a tree, so a fetch of air from the north in this case could be lowering the amount of ozone observed at the monitoring site. In this particular example, the metadata are extremely important for data interpretation.

An Example of a Student Research Investigation

Forming a Hypothesis

A student of Heart of Mary School in Alabama has decided to focus on the interconnections of atmospheric conditions on the level of surface ozone observed. She has decided to begin her research process by looking at the visualizations of measurements of the ozone level and current temperature at her school for the month of April. Her initial hypothesis is *the level of surface ozone produced is directly related to the current temperature.*

Collecting and Analyzing Data

Measuring surface ozone is a new protocol, but her school has several months of data they have gathered during the initial implementation of the new protocol. She decides to identify a month that is beginning to show increased levels of ozone to begin her analysis. There is an Air Quality Monitoring site near her school, which has been turned on since March, so she accesses the ozone levels measured by the professional equipment to be sure the data she has collected are of good quality. She finds her data fall within a range of ±10 ppb of the professional readings. Clearly, her data are good enough for her project.

She begins by organizing a spreadsheet of her ozone measurements, ending temperature, cloud type and cover, and the starting and ending wind direction by the dates the information was recorded. See Table AT-SO-3.

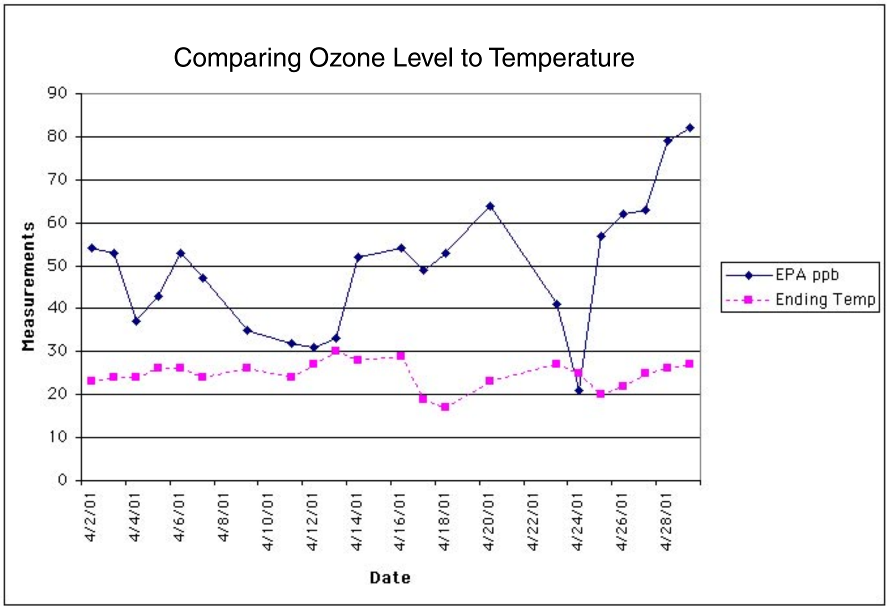
She generates a plot of the ozone measurements and considers measurements of 39 ppb and lower as low ozone levels and 60 ppb and higher relatively high ozone. She then graphs the ozone and

Heart of Mary School Ozone Measurement Levels and Metadata

Table AT-SO-2 *Taken at 17:30 UT Time*

Date	ppb	Ending Temp	Cloud Type	Cloud Cover	Wind Direction (beginning/ending)
4/2/01	54	23	Cirrus	Broken	SW/SW
4/3/01	53	24	Stratocumulus	Broken	NW/NW
4/4/01	37	24	Stratocumulus	Overcast	NW/NW
4/5/01	43	26	Cirrostratus	Broken	NW/NW
4/6/01	53	26	Cirrostratus	Broken	N/N
4/7/01	47	24	Cirrostratus	Broken	NE/NE
4/9/01	35	26	Cumulus	Broken	SW/SW
4/11/01	32	24	Altostratus	Broken	SW/SW
4/12/01	31	27	Cirrus	Scattered	SW/SW
4/13/01	33	30	Altocumulus, Cumulus	Broken	SW/SW
4/14/01	52	28	Cirrostratus, Cumulus	Broken	W/W
4/16/01	54	29	Altostratus,Cirrocumulus	Clear	NW/NW
4/17/01	49	19	None	Clear	N/N
4/18/01	53	17	None	Clear	N/N
4/20/01	64	23	None	Clear	S/SW
4/23/01	41	27	None	Clear	SW/SW
4/24/01	21	25	Cumululonimbus, Stratocumulus	Overcast	SW/SW
4/25/01	57	20	None	Clear	NW/NW
4/26/01	62	22	None	Clear	N/N
4/27/01	63	25	None	Clear	NW/NW
4/28/01	79	26	None	Clear	W/SE
4/29/01	82	27	Cirrus, Altostratus, Cirrocumulus	Broken	W/SE

Figure AT-SO-3



current temperature measurements. See Figure AT-SO-3.

While reviewing her data she realizes that there is a pattern on some days when the temperature goes up, the ozone level increases, and when it goes down the ozone level decreases. However, there are days when the temperature was equally high and the ozone level dropped dramatically. She knows her data are reasonable as she compared them with professional data, and wonders if she reorganizes her data by temperature will she be able to quickly identify the days with similar temperature that have different ozone levels. This might enable her to identify other factors influencing the level of ozone produced. See Table AT-SO-4.

She realizes that with clear conditions and an increase in temperature, the level of ozone is higher except for one day. Another observation she makes is that the presence of clouds influences the level of ozone observed regardless of the temperature, and on days with roughly the same temperature those with overcast sky conditions have lower levels of ozone. The general pattern of increasing temperatures with broken clouds still provides an increase in the level of ozone produced except for a couple of days when the temperature was high, few clouds, but the level of ozone was lower than similar days. The wind direction was different indicating that perhaps wind direction may influence the level of ozone. The wind directions at the beginning and ending of the observation periods are usually the same during this month except the two data points taken on April 28 and 29.

Further Analysis

Students could go a step further and determine the ratio of levels of ozone days by identifying patterns of ozone levels. Students would be able to determine whether or not the number of high ozone days is increasing or decreasing each month. The categories organized to calculate ratio might be: low levels of 39 ppb or lower, 40-49 ppb, 50-59 ppb, 60-69 ppb, 70-79 ppb and 80 ppb and higher. The following sample of ozone data from March through June demonstrates how ratio may be used to analyze monthly ozone patterns. See Table AT-SO-4.

At a glance the student can visually see patterns developing from March through June and also recognize the impact of inconsistent data upon their ability to accurately analyze changes occurring over time. They might relate this to problems scientists have with incomplete data records. She will observe that there are consistently days with low levels of ozone, but she can see that the levels of ozone are increasing each month. Upon realizing that June is not a complete data summary, she might question how missing data will impact any conclusions that might be made from the review of June's data.

Table AT-SO-3 **Heart of Mary School Ozone Measurements April 2001**

Temp.	ppb ozone	Cloud Type	Cloud Cover	Wind Direction
17	53	none	Clear	N/N
19	49	none	Clear	N/N
20	57	none	Clear	NW/NW
22	62	none	Clear	N/N
23	64	none	Clear	S/SW
23	54	Cirrus	Broken	SW/SW
24	53	Stratocumulus	Broken	NW/NW
24	47	Cirrostratus	Broken	NE/NE
24	37	Stratocumulus	Overcast	NW/NW
24	32	Altostratus	Broken	SW/SW
25	63	none	Clear	NW/NW
25	21	Cumululonimbus, Stratocumulus	Overcast	SW/SW
26	79	none	Clear	W/SE
26	53	Cirrostratus	Broken	N/N
26	43	Cirrostratus	Broken	NW/NW
26	35	Cumulus	Broken	SW/SW
27	82	Cirrus, Altostratus, Cirrocumulus	Broken	W/SE
27	41	none	Clear	SW/SW
27	31	Cirrus	Scattered	SW/SW
28	52	Cirrostatus, Cumulus	Broken	W/W
29	54	Altostratus, Cirrocumulus	Clear	NW/NW
30	33	Altocumulus, Cumulus	Broken	SW/SW

By reviewing the percentages for each category of ozone level, she will see the continuous increase in ozone levels and identify the general variability of ozone levels for a given period of time. See Table AT-SO-5. June's record demonstrates a void in the data, which makes it difficult to draw accurate conclusions.

Future Research

Another question raised by the student is how she might be able to identify a monthly pattern for ozone levels. She wonders if she calculates the temperature and ozone mean, for the four months, if the means will reflect a continuous increase or decrease in the level of ozone measured. Can a monthly ozone mean calculated for each month of the year provide information about the pattern of ozone levels? How do the patterns of ozone levels relate to seasonal changes during the year?

Identifying the ozone pattern in her area will provide insight into atmospheric conditions that influence ozone levels. Exploring the relationship between wind direction patterns and levels of ozone measured provides a different challenge, but can be very exciting. Using the GLOBE database, the student may choose another school in a town located approximately at the same latitude, but in a different geographic

Heart of Mary School-Observed Ozone Levels (ppb)
March through June

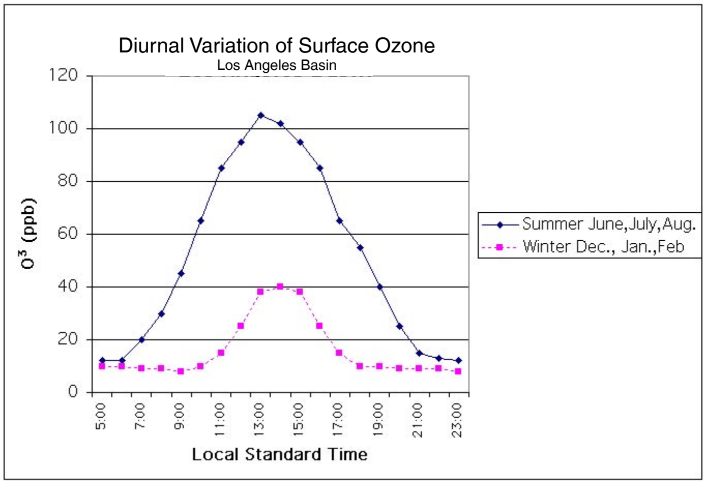
Table AT-SO-4 *Grouped by Category (level) of Ozone Concentration*

	March	April	May	June
	17	21	35	28
	24	31	37	25
	33	32	45	26
	33	33	46	30
	34	35	49	31
	36	37	50	40
	36	41	54	55
	40	43	56	67
	41	47	56	70
	41	49	57	76
	42	52	57	78
	44	53	58	87
	44	53	58	87
	45	53	59	88
	47	54	60	95
	47	54	62	
	48	57	63	
	50	62	66	
	56	63	66	
	60	64	69	
	74	79	71	
	74	82	74	
			74	
			74	
			86	
Days	**22**	**22**	**25**	**15**

Table AT-SO-5 ***Ratio of Ozone Levels for Four Months***

Month	March		April		May		June	
Total Number of Days with Ozone Measurements	22		22		25		15	
Category	Ratio	%	Ratio	%	Ratio	%	Ratio	%
< 40 ppb	7:22	32%	6:22	27%	2:25	8%	5:15	34%
40 – 49 ppb	10:22	45%	4:22	18%	3:25	12%	1:15	7%
50 – 59 ppb	2:22	9%	7:22	32%	9:25	36%	1:15	7%
60 – 69 ppb	1:22	5%	3:22	16%	6:25	24%	1:15	7%
70 – 79 ppb	2:22	9%	1:22	5%	4:25	16%	3:15	20%
> 80 ppb	0:22	0%	1:22	5%	1:25	4%	4:15	27%

Figure AT-SO-4



region to determine what other variables might influence the level of surface ozone produced. Posing and addressing additional questions is easier when GLOBE schools consistently report data. As demonstrated in this study, missing data makes it difficult to monitor how the atmosphere changes over time.

Studying Diurnal Variation of Surface Ozone and Validation of Data

Students may also want to investigate the diurnal variation of surface ozone. A typical set of diurnal ozone is shown in Figure AT-SO-4 for the Los Angeles basin. The two curves represent summertime (dashed line) and wintertime (solid line) concentrations plotted as a function of local time. From the difference in amplitude on the two curves, it is easy to see why the data set gathered by students would likely be more interesting in the summer, late spring or early autumn rather than in the middle of winter when lower ozone concentrations and less variability would be expected

Table AT-SO-6 summarizes two days of surface ozone measurements during times of when students would be available to take such measurements. This particular set of data was obtained at an operational EPA monitoring site so that the student measurements could be compared directly with the measurements using a calibrated ozone monitor that cost thousands of dollars. This is one comparison that has allowed GLOBE to determine the how well its measurement system performs in the field.

The goal of the surface ozone protocol is to obtain ozone concentrations with an accuracy of 10 ppb or better. From the data shown in Table AT-SO-6, we can see that the accuracy goal has been achieved in this test. On both days, the Zikua system showed higher concentrations in the afternoon although the diurnal difference was much greater on the second day. The EPA monitor confirmed the diurnal behavior and also measured a greater difference between the afternoon and morning of the 30th.

Table AT-SO-6

Date	Start Time	GLOBE Reading (ppb)	EPA Reading (ppB)
8/29/00	10:00	22	25
	12:00	28	31
	13:00	33	35
	14:00	31	39
	15:00	34	44
8/30/00	10:00	18	10
	11:00	23	25
	12:00	29	31
	13:00	35	38
	14:00	43	53
	15:00	60	59

AWS WeatherNet Protocol

Purpose

A school participating in the AWS WeatherNet Program arranges for transfer of data logged through AWS to GLOBE.

Overview

GLOBE schools participating in the AWS WeatherNet Program arrange for their data to be transferred automatically to GLOBE. A special GLOBE Atmosphere Study Site is defined for the school's AWS weather station, and this activates an automatic transfer of their AWS data to the GLOBE database.

Student Outcomes

Students can view data for their school that are continuous and show variations within a day. The data collected include wind speed and direction and pressure thereby supporting a more complete study of meteorology. Students pursue a more extensive set of research investigations.

Science Concepts and Scientific Inquiry Abilities

Science Concepts and *Scientific Inquiry Abilities* are gained through analyzing the data collected with the weather station. Refer to the *Looking at Your Data* sections of the protocols that correspond to the measurements taken with your AWS weather station for guidance on performing this data analysis. Consult the *Science Concepts* and *Scientific Inquiry Abilities* listed in the gray boxes for these protocols to learn about the science concepts and scientific inquiry abilities that will be gained.

Time

Approximately 15 minutes

Level

All

Frequency

Once

Materials and Tools

Weather station connected to the AWS WeatherNet Network

Atmosphere Site Definition Sheet

Preparation

Establish AWS WeatherNet system and obtain school ID.

Prerequisites

None

AWS Automated Weather Station Network

Using automated weather stations that record data can allow students to take environmental measurements at much shorter time intervals than collecting data by hand. The large volume of data that can be collected at uniform time intervals allows for the study of weather phenomena that can change quickly (such as wind) and so cannot be monitored through measurements taken with longer sampling periods.

A network of automated weather stations throughout the world collecting and reporting data to a central database would serve as an important resource for studying global weather patterns and tracking weather systems. AWS Convergence Technologies, Inc., operates a large private network of weather stations. An extension of this network is the WeatherNet for Education (www.weathernetclassroom.com), which involves schools and colleges in the study of weather and provides educational tools to aid in this study.

Teacher Support

AWS WeatherNet and GLOBE

AWS WeatherNet allows schools to use weather stations to collect and report atmospheric data. Since the function of AWS WeatherNet is inline with that of GLOBE, it is possible for a school to participate in both programs simultaneously. A GLOBE school that is participating in the AWS WeatherNet may have the data that they collect with AWS transferred automatically to the GLOBE database.

In order to accomplish this the school must define a GLOBE Atmosphere Study Site specifically for their AWS weather station. After this special site definition is completed, the data that the school reports to AWS will automatically be transferred over to the GLOBE database. The school should still continue to take additional GLOBE measurements not covered by AWS and report these to GLOBE.

Defining an Atmosphere Site for AWS Weather Station

To define a GLOBE site for AWS data you will need to complete an *Atmosphere Site Definition Sheet* for your AWS weather station. In addition to the standard information associated with a GLOBE Atmosphere Study Site that is recorded on this *Site Definition Sheet*, you include your AWS School ID.

After the *AWS Site Definition Sheet* is completed the site must be defined online using the Atmosphere site definition page available under the *Atmosphere* section of the *Data Entry* page of the GLOBE Web site. On this page you will need to follow the special instructions for reporting your site as an AWS WeatherNet station. This includes selecting a Thermometer type of "AWS WeatherNet Station" and reporting your AWS School ID to GLOBE.

Davis Weather Station Protocol

Purpose

To log atmosphere data using a Davis weather station

Overview

A weather station is setup to measure and record atmospheric measurements at 15 minute intervals. These measurements are transferred to your school's computer and then submitted to GLOBE via email data entry.

Student Outcomes

Students can view data for their school that are continuous and show variations within a day. The data collected includes wind speed and direction and pressure thereby supporting a more complete study of meteorology using GLOBE. Students pursue a more extensive set of research investigations.

Science Concepts

Earth and Space Science

- Weather can be described by quantitative measurements.
- Weather changes from day to day and season to season.
- Weather varies on local, regional, and global spatial scales.

Geography

- The temperature of variability of a location affects the characterization of Earth's physical geographic system.

Scientific Inquiry Abilities

Scientific inquiry abilities are gained through analyzing the data collected with the weather station. Refer to the *Looking at Your Data* sections of the protocols that correspond to the measurements taken with your weather station for guidance on performing this data analysis. Consult the *Scientific Inquiry Abilities* listed in the gray boxes for these protocols to learn about the inquiry abilities that will be gained.

Time

2 hours for site definition and set-up

15 minutes to use spreadsheet data entry to prepare and submit data to GLOBE periodically

Level

Middle and Secondary

Frequency

Data reporting approximately once every week

Materials and Tools

- Weather station with data logger
- Computer capable of running weather station software
- Calibration thermometer
- Rain gauge

Preparation

Set up the weather station.

Prerequisites

None

Automated Weather Stations

Using automated weather stations that record data can allow students to take environmental measurements at much shorter time intervals than collecting data by hand. The large volume of data that can be collected at uniform time intervals allows for the study of weather phenomena that can change quickly (such as wind) and so cannot be monitored through measurements taken with longer sampling periods.

The weather stations used in this protocol are manufactured by Davis Instruments (http://davisnet.com). These weather stations have a display screen that shows current weather readings, such as temperature, humidity, barometric pressure, wind speed and direction and rainfall, measured by sensors attached to the station either through cables, or wirelessly. The type of measurements taken depends on the model of weather station and the types of sensors purchased.

Besides displaying current readings on the display screen, the weather station also records data over a long period of time using a data logger. This data logger is sold in a kit that also includes software that lets you download the data onto your computer and visualize it, and is required for this protocol.

Once the data are downloaded from the weather station to your computer you can export them to a text file, ingest them to a spreadsheet program, and manipulate them to conform to the format required for GLOBE email data entry. Software is available for some models to export text files in GLOBE's email data entry format.

The following atmospheric data can be taken with this protocol and reported to GLOBE: average wind speed and direction over the 15-minute sampling interval, maximum wind speed and direction over the sampling interval, wind run integrated over the 15-minute period, temperature, relative humidity, barometric pressure, rain rate and total rainfall. Cloud, Snow, Precipitation pH, Aerosol, and Ozone measurements must still be done following the appropriate other protocols.

Measurement Logistics

1. Review background in the *Atmosphere Chapter*.
2. Setup the weather station console and connect to your computer according to manufacturer's directions.
3. Install your atmospheric weather sensors according to the *Weather Station Atmospheric Sensors Installation Field Guide*.
4. Define your measurement site as an atmosphere site with *Davis Weather Station* selected for thermometer type
5. Log readings at 15-minute intervals and transfer data to your computer according to the directions included with your software.
6. When you are ready to report the data to GLOBE (recommended once a week) export the data stored in your computer to a text file in the format for GLOBE email reporting following the *Logging and Reporting Weather Station Data Lab Guide*
7. Paste the text in this file into the body of an email and send it to GLOBE following email data entry instructions available in the "Data Entry" section of the GLOBE Web site.
8. Engage students in looking at the data.
9. Every year recalibrate your weather station.

Teacher Support

The instructions given in this protocol are specific to one brand of weather station. However, they may be adapted to other equipment that meets the same specifications. If you have questions or require assistance with adapting these instructions to other instruments, contact your Country Coordinator or in the US, the GLOBE Help Desk. The essential elements of this protocol, which must remain the same regardless of the equipment model, are the placement of the station, the precision and accuracy of the sensors, and the sampling interval.

When purchased, your Davis weather station is certified to be calibrated for one full year. After that there are two options for recalibration. The first option is to send it back to the manufacturer to be recalibrated for a fee (see your distributor for details). The second option is to recalibrate using the *GLOBE Recalibration Procedures* outlined in this protocol. Either option is acceptable, but one of the two must be completed so that your instrument continues to take accurate readings.

Before starting students on the installation of your weather station, review the material provided in the *Site Selection and Setup Protocol* for information on important considerations in selecting an area to take atmospheric measurements.

Data Recording

The GLOBE database requires weather station data logged at 15-minute intervals, so make sure that the sampling interval in your weather station is set to 15 minutes. Also, the read-out should happen on the quarter-hour (e.g., 10:00, 10:15, 10:30, 10:45, etc.) Ensure that measurements are being displayed and reported in the appropriate units (i.e., millimeters for rain, degrees Celsius for temperatures, percent for relative humidity, meters/second for wind speed, and kilometers for wind run).

The time associated with each data point reported to GLOBE needs to be in Universal Time (UT). If you choose to have your weather station set to local time you will need to make sure that you adjust the times reported to GLOBE.

Due to the quantity of data, weather station data is reported to GLOBE only via email data entry. Software provided by Davis may allow data to be exported directly into the correct GLOBE email data entry format (see *Frequently Asked Questions* for information on the availability of this software), using the "*Export Records (GLOBE Format)*" option from the *Browse* menu option in the export data pull-down menu. This software can automatically adjust the times to UT. If you have an older version of the software that does not have this option, export your data to a text file, import the text file into your spreadsheet program, manipulate the columns to match the requirements for email data entry, and cut and paste the resulting values into an email data entry message.

GLOBE Recalibration Procedures

The GLOBE recalibration procedures outlined in this protocol involve determining a correction offset for the tipping bucket and performing a check of the temperature sensor. The offset for tipping bucket is equivalent to the difference in the readings taken by the weather station and readings taken by a rain gauge, which serves as a calibration instrument of known accuracy. This correction offset helps account for drift in the readings taken by the tipping bucket that can occur over time. Once reported to GLOBE, this offset will be applied automatically to all subsequent data you report and the adjusted values are displayed on the GLOBE Web site. Do not report offsets to GLOBE and then apply them to the data yourself before submitting the data to GLOBE as this will cause the offsets to be applied twice!

For some of the measurements taken by the weather station, such as wind, there are no measurement protocols in GLOBE to use for calibration so there are no current methods available for their calibration.

The complete GLOBE weather station calibration consists of the following:

- Check the temperature sensor following the *Weather Station Temperature Sensor Recalibration Field Guide.*
- Calibrate the tipping bucket rain gauge following the *Weather Station Tipping Bucket Rain Gauge Recalibration Field Guide.*

Helpful Hints

- During set-up, be sure to choose the right value for the volume of your tipping bucket or all rain data will be in error.

Questions for Further Investigations

Are the patterns of weather variables over a day the same every day? What causes this?

Which season has the greatest range of temperatures? Why?

What are the latitudes and elevations of other GLOBE schools with annual precipitation and temperature patterns similar to yours?

Is your local environment affected more by average temperature or temperature extremes?

How do changes in wind speed and direction and pressure relate to changes in temperature and relative humidity and to the occurrence of rain?

Weather Station Atmospheric Sensors Installation

Field Guide

Task

Install the atmospheric sensors for your weather station.

What You Need

- ❑ The sensors that you are going to install
- ❑ The tools necessary to make the installation
- ❑ GLOBE site definition sheet
- ❑ Manufacturer's instructions
- ❑ Compass

Note: Actual installation may vary significantly depending on which sensors you are using and the location where you are installing them.

In the Field

1. Scout for a location(s) for the placement of your instrument shelter. If you are using an anemometer (to measure wind) that can be mounted separately from the rest of the sensor suite, consider mounting it in a different location. If the anemometer is attached to the rest of the sensors, then preferably mount them in a location most appropriate for the thermometer (step 4). If you are using wireless sensors, make sure that they are mounted close enough to your station console to allow for proper communication.
2. If possible, mount your sensor suite so that the temperature sensor is at a height of 1.5 meters above the ground (or 60 cm above average maximum snow depth), preferably in a flat open area with a natural surface (grassy in most places). Try to avoid having buildings within 10 meters.
3. If possible, mount the anemometer where it is above the height of nearby trees and buildings. If you mount it on top of a building, try to keep it at least 1.2 meters above the roofline.
4. Report your site definition data to the GLOBE Web site as an atmosphere site with *Davis Weather Station* selected for thermometer type.

Logging and Reporting Weather Station Data
Lab Guide

Task

Log and report data collected with your weather station.

What You Need

- ❑ A setup and operating weather station
- ❑ A suitable computer with email access

In the Field

1. Set your weather station to log data at 15 minute intervals on the quarter hour (e.g., 15:15).
2. Download your weather station data to your computer following the instructions for your weather station. **Note:** some weather stations can be set-up to transfer these data automatically.
3. Export a text file of your data. Save this file on your computer. (If your software has the ability to export a text file in the GLOBE email data entry format, skip to step 5).
4. Use spreadsheet or other software to edit the exported file into the GLOBE email data entry format. Save this spreadsheet file on your computer.
5. Copy and paste your data in GLOBE email data entry format into the body of a GLOBE email data entry message.

Weather Station Temperature Sensor Recalibration

Field Guide

Task

Compare the temperatures recorded by your weather station with readings from a calibration thermometer.

What You Need

- ❑ Calibration thermometer that has been checked following the instructions in the *Thermometer Calibration Lab Guide*
- ❑ *Weather Station Calibration Data Sheet*

In the Field

1. Hang the calibration thermometer in the shade within 30 cm of the temperature sensor of your weather station.
2. Wait three minutes and then read the temperature from the calibration thermometer as well as the temperature from your weather station. Wait one more minute to see if the calibration thermometer reading is changing. If it is, continue until it stops changing. If the digital display for your weather station is located well away from the calibration thermometer, this may require two students cooperating. Record these readings on your *Weather Station Calibration Data Sheet*.
3. Repeat step 2 four more times, waiting at least one hour between each set of readings. Try to space out the five sets of readings over as much of the day as possible.
4. Report your new calibration data to the GLOBE Web site.

Weather Station Tipping Bucket Rain Gauge Calibration

Field Guide

Task

Record a rain event (of 2 cm or more) with a rain gauge and then compare the rainfall measured with this rain gauge to the rainfall recorded by the tipping bucket of your weather station.

What You Need

- ❑ A rain gauge that meets GLOBE specifications
- ❑ *Weather Station Calibration Data Sheet*

In the Field

1. Hang the plastic rain gauge in an open area within 15 m of and at the same height as the tipping bucket of your weather station. Take caution to ensure that the plastic rain gauge is placed so that it will not interfere with, or be affected by, the weather station.
2. Wait for a rain event to occur and then take your reading for rainfall from the rain gauge, following the *Rainfall Protocol Field Guide*. If the rainfall reading is more than 2 cm, record it on your W*eather Station Calibration Data Sheet* and continue.
3. Add all the rainfall values recorded by your weather station for this rain event. Record this sum on your W*eather Station Calibration Data Sheet.*
4. Repeat this process for two other rain events.
5. Report your calibration data to the GLOBE Web site.

Frequently Asked Questions

1. What should I do if there is frozen precipitation that my weather station registers as rain?

Frozen precipitation and melting snow can cause the tipping bucket of your weather station to tip, and may therefore register as rainfall on your station. The tipping bucket is calibrated exclusively for rainfall so any measurements caused by frozen precipitation are erroneous. Please report any frozen precipitation in your metadata and if possible edit your data record to remove any rainfall readings that were caused by frozen precipitation before reporting data to GLOBE.

2. I am using a Davis weather station, but my software does not include the option to export GLOBE data. What can I do?

Davis is making the option to export GLOBE data available in updated versions of the software for their weather stations. These updated versions are available for download from the Davis Web site (http://davisnet.com). You can contact Davis to see if a version of the software that includes the export GLOBE function is available for your model weather station.

Atmosphere Investigation

Weather Station Calibration Data Sheet

School Name ___________________________________ Study Site: ATM-_______________________

Air Temperature Sensor Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Calibration Thermometer Reading (˚C)	Digital Temperature Sensor (˚C)
1					
2					
3					
4					
5					

Rain Gauge Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Rain Gauge Reading* (mm)	Digital Tipping Bucket Total Reading (mm)
1					
2					
3					
4					
5					

* must be greater than 20 mm for recalibration

RainWise Weather Station Protocol

Purpose

To log atmosphere data using a RainWise weather station

Overview

A weather station is setup to measure and record atmospheric measurements at 15 minute intervals. These measurements are transferred to your school's computer and then submitted to GLOBE via email data entry.

Student Outcomes

Students can view data for their school that are continuous and show variations within a day. The data collected includes wind speed and direction and pressure thereby supporting a more complete study of meteorology using GLOBE. Students pursue a more extensive set of research investigations.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and season to season.

Weather varies on local, regional, and global spatial scales.

Geography

The temperature of variability of a location affects the characterization of Earth's physical geographic system.

Scientific Inquiry Abilities

Scientific inquiry abilities are gained through analyzing the data collected with the weather station. Refer to the *Looking at Your Data* sections of the protocols that correspond to the measurements taken with your weather station for guidance on performing this data analysis. Consult the *Scientific Inquiry Abilities* listed in the gray boxes for these protocols to learn about the inquiry abilities that will be gained.

Time

2 hours for site definition and set-up

15 minutes to use spreadsheet data entry to prepare and submit data to GLOBE periodically

Level

Middle and Secondary

Frequency

Data reporting approximately once every week

Materials and Tools

Weather station with data logger

Computer capable of running weather station software

Calibration thermometer

Rain gauge

Preparation

Set up the weather station.

Prerequisites

None

Automated Weather Stations

Using automated weather stations that record data can allow students to take environmental measurements at much shorter time intervals than collecting data by hand. The large volume of data that can be collected at uniform time intervals allows for the study of weather phenomena that can change quickly (such as wind) and so cannot be monitored through measurements taken with longer sampling periods.

The weather stations used in this protocol are manufactured by RainWise Inc. (http://www.rainwise.com). These weather stations have a display screen that shows current weather readings, such as temperature, humidity, barometric pressure, wind speed and direction and rainfall, measured by sensors attached to the station either through cables, or wirelessly. The type of measurements taken depends on the model of weather station and the types of sensors purchased.

Besides displaying current readings on the display screen, the weather station also records data over a long period of time using a data logger. This data logger is sold in a kit that also includes software that lets you download the data onto your computer and visualize it, and is required for this protocol.

Once the data are downloaded from the weather station to your computer you can export them to a text file, ingest them to a spreadsheet program, and manipulate them to conform to the format required for GLOBE email data entry. Software is available for some models to export text files in GLOBE's email data entry format.

The following atmospheric data can be taken with this protocol and reported to GLOBE: average wind speed and direction over the 15-minute sampling interval, maximum wind speed and direction over the sampling interval, wind run integrated over the 15-minute period, temperature, relative humidity, barometric pressure, rain rate and total rainfall. Cloud, Snow, Precipitation pH, Aerosol, and Ozone measurements must still be done following the appropriate other protocols.

Measurement Logistics

1. Review background in the *Atmosphere Chapter*.
2. Setup the weather station console and connect to your computer according to manufacturer's directions.
3. Install your atmospheric weather sensors according to the *Weather Station Atmospheric Sensors Installation Field Guide*.
4. Define your measurement site as an atmosphere site with *RainWise Weather Station* selected for thermometer type
5. Log readings at 15-minute intervals and transfer data to your computer according to the directions included with your software.
6. When you are ready to report the data to GLOBE (recommended once a week) export the data stored in your computer to a text file in the format for GLOBE email reporting following the *Logging and Reporting Weather Station Data Lab Guide*
7. Paste the text in this file into the body of an email and send it to GLOBE following email data entry instructions available in the "Data Entry" section of the GLOBE Web site.
8. Engage students in looking at the data.
9. Every year recalibrate your weather station.

Teacher Support

The instructions given in this protocol are specific to one brand of weather station. However, they may be adapted to other equipment that meets the same specifications. If you have questions or require assistance with adapting these instructions to other instruments, contact your Country Coordinator or in the US, the GLOBE Help Desk. The essential elements of this protocol, which must remain the same regardless of the equipment model, are the placement of the station, the precision and accuracy of the sensors, and the sampling interval.

Once a year you should recalibrate your weather station using the GLOBE Recalibration Procedures outlined in this protocol. This will help assure the accuracy of the readings that you report to GLOBE.

Before starting students on the installation of your weather station, review the material provided in the *Site Selection and Setup Protocol* for information on important considerations in selecting an area to take atmospheric measurements.

Data Recording

The GLOBE database requires weather station data logged at 15-minute intervals, so make sure that the sampling interval in your weather station is set to 15 minutes. Also, the read-out should happen on the quarter-hour (e.g., 10:00, 10:15, 10:30, 10:45, etc.) Ensure that measurements are being displayed and reported in the appropriate units (i.e., millimeters for rain, degrees Celsius for temperatures, percent for relative humidity, meters/second for wind speed, and kilometers for wind run).

The time associated with each data point reported to GLOBE needs to be in Universal Time (UT). If you choose to have your weather station set to local time you will need to make sure that you adjust the times reported to GLOBE.

Due to the quantity of data, weather station data is reported to GLOBE only via email data entry. Software provided by RainWise may allow data to be exported directly into the correct GLOBE email data entry format (see *Frequently Asked Questions* for information on the availability of this software), using the "*Export Records (GLOBE Format)*" option from the *Browse* menu option in the export data pull-down menu. This software can automatically adjust the times to UT. If you have an older version of the software that does not have this option, export your data to a text file, import the text file into your spreadsheet program, manipulate the columns to match the requirements for email data entry, and cut and paste the resulting values into an email data entry message.

GLOBE Recalibration Procedures

The GLOBE recalibration procedures outlined in this protocol involve determining a correction offset for the tipping bucket and performing a check of the temperature sensor. The offset for tipping bucket is equivalent to the difference in the readings taken by the weather station and readings taken by a rain gauge, which serves as a calibration instrument of known accuracy. This correction offset helps account for drift in the readings taken by the tipping bucket that can occur over time. Once reported to GLOBE, this offset will be applied automatically to all subsequent data you report and the adjusted values are displayed on the GLOBE Web site. Do not report offsets to GLOBE and then apply them to the data yourself before submitting the data to GLOBE as this will cause the offsets to be applied twice!

For some of the measurements taken by the weather station, such as wind, there are no measurement protocols in GLOBE to use for calibration so there are no current methods available for their calibration.

The complete GLOBE weather station calibration consists of the following:

- Check the temperature sensor following the *Weather Station Temperature Sensor Recalibration Field Guide*.
- Calibrate the tipping bucket rain gauge following the *Weather Station Tipping Bucket Rain Gauge Recalibration Field Guide*.

Helpful Hints

- During set-up, be sure to choose the right value for the volume of your tipping bucket or all rain data will be in error.

Questions for Further Investigations

Are the patterns of weather variables over a day the same every day? What causes this?

Which season has the greatest range of temperatures? Why?

What are the latitudes and elevations of other GLOBE schools with annual precipitation and temperature patterns similar to yours?

Is your local environment affected more by average temperature or temperature extremes?

How do changes in wind speed and direction and pressure relate to changes in temperature and relative humidity and to the occurrence of rain?

Weather Station Atmospheric Sensors Installation
Field Guide

Task
Install the atmospheric sensors for your weather station.

What You Need
- ❑ The sensors that you are going to install
- ❑ Manufacturer's instructions
- ❑ The tools necessary to make the installation
- ❑ Compass
- ❑ GLOBE site definition sheet

Note: Actual installation may vary significantly depending on which sensors you are using and the location where you are installing them.

In the Field
1. Scout for a location(s) for the placement of your instrument shelter. If you are using an anemometer (to measure wind) that can be mounted separately from the rest of the sensor suite, consider mounting it in a different location. If the anemometer is attached to the rest of the sensors, then preferably mount them in a location most appropriate for the thermometer (step 4). If you are using wireless sensors, make sure that they are mounted close enough to your station console to allow for proper communication.
2. If possible, mount your sensor suite so that the temperature sensor is at a height of 1.5 meters above the ground (or 60 cm above average maximum snow depth), preferably in a flat open area with a natural surface (grassy in most places). Try to avoid having buildings within 10 meters.
3. If possible, mount the anemometer where it is above the height of nearby trees and buildings. If you mount it on top of a building, try to keep it at least 1.2 meters above the roofline.
4. Report your site definition data to the GLOBE Web site as an atmosphere site with *RainWise Weather Station* selected for thermometer type.

Logging and Reporting Weather Station Data

Lab Guide

Task

Log and report data collected with your weather station.

What You Need

- ❑ A setup and operating weather station
- ❑ A suitable computer with email access

In the Field

1. Set your weather station to log data at 15 minute intervals on the quarter hour (e.g., 15:15).
2. Download your weather station data to your computer following the instructions for your weather station. **Note:** some weather stations can be set-up to transfer these data automatically.
3. Export a text file of your data. Save this file on your computer. (If your software has the ability to export a text file in the GLOBE email data entry format, skip to step 5).
4. Use spreadsheet or other software to edit the exported file into the GLOBE email data entry format. Save this spreadsheet file on your computer.
5. Copy and paste your data in GLOBE email data entry format into the body of a GLOBE email data entry message.

Weather Station Temperature Sensor Recalibration

Field Guide

Task

Compare the temperatures recorded by your weather station with readings from a calibration thermometer.

What You Need

- ❑ Calibration thermometer that has been checked following the instructions in the *Thermometer Calibration Lab Guide*
- ❑ *Weather Station Calibration Data Sheet*

In the Field

1. Hang the calibration thermometer in the shade within 30 cm of the temperature sensor of your weather station.
2. Wait three minutes and then read the temperature from the calibration thermometer as well as the temperature from your weather station. Wait one more minute to see if the calibration thermometer reading is changing. If it is, continue until it stops changing. If the digital display for your weather station is located well away from the calibration thermometer, this may require two students cooperating. Record these readings on your *Weather Station Calibration Data Sheet*.
3. Repeat step 2 four more times, waiting at least one hour between each set of readings. Try to space out the five sets of readings over as much of the day as possible.
4. Report your new calibration data to the GLOBE Web site.

Weather Station Tipping Bucket Rain Gauge Calibration

Field Guide

Task

Record a rain event (of 2 cm or more) with a rain gauge and then compare the rainfall measured with this rain gauge to the rainfall recorded by the tipping bucket of your weather station.

What You Need

- ❑ A rain gauge that meets GLOBE specifications
- ❑ *Weather Station Calibration Data Sheet*

In the Field

1. Hang the plastic rain gauge in an open area within 15 m of and at the same height as the tipping bucket of your weather station. Take caution to ensure that the plastic rain gauge is placed so that it will not interfere with, or be affected by, the weather station.
2. Wait for a rain event to occur and then take your reading for rainfall from the rain gauge, following the *Rainfall Protocol Field Guide*. If the rainfall reading is more than 2 cm, record it on your W*eather Station Calibration Data Sheet* and continue.
3. Add all the rainfall values recorded by your weather station for this rain event. Record this sum on your W*eather Station Calibration Data Sheet.*
4. Repeat this process for two other rain events.
5. Report your calibration data to the GLOBE Web site.

Frequently Asked Questions

1. What should I do if there is frozen precipitation that my weather station registers as rain?

Frozen precipitation and melting snow can cause the tipping bucket of your weather station to tip, and may therefore register as rainfall on your station. The tipping bucket is calibrated exclusively for rainfall so any measurements caused by frozen precipitation are erroneous. Please report any frozen precipitation in your metadata and if possible edit your data record to remove any rainfall readings that were caused by frozen precipitation before reporting data to GLOBE.

2. I am using a RainWise weather station, but my software does not include the option to export GLOBE data. What can I do?

The *Virtual Weather Station* software packaged designed by Ambient, LLC, includes the option to export GLOBE data. This requires Version 12.06p14 or newer of this software. To download and install the latest version and user's manual, visit http://www.ambientweather.com/Products/Descriptions/Download.asp.

Atmosphere Investigation

Weather Station Calibration Data Sheet

School Name ______________________ Study Site: ATM-______________

Air Temperature Sensor Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Calibration Thermometer Reading (˚C)	Digital Temperature Sensor (°C)
1					
2					
3					
4					
5					

Rain Gauge Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Rain Gauge Reading* (mm)	Digital Tipping Bucket Total Reading (mm)
1					
2					
3					
4					
5					

* must be greater than 20 mm for recalibration

WeatherHawk Weather Station Protocol

Purpose

To log atmosphere data using a WeatherHawk™ weather station

Overview

A weather station is setup to measure and record atmospheric measurements at 15 minute intervals. These measurements are transferred to your school's computer and then submitted to GLOBE via email data entry.

Student Outcomes

Students can view data for their school that are continuous and show variations within a day. The data collected includes wind speed and direction and pressure thereby supporting a more complete study of meteorology using GLOBE. Students pursue a more extensive set of research investigations.

Science Concepts

Earth and Space Science

Weather can be described by quantitative measurements.

Weather changes from day to day and season to season.

Weather varies on local, regional, and global spatial scales.

Geography

The temperature of variability of a location affects the characterization of Earth's physical geographic system.

Scientific Inquiry Abilities

Scientific inquiry abilities are gained through analyzing the data collected with the weather station. Refer to the *Looking at Your Data* sections of the protocols that correspond to the measurements taken with your weather station for guidance on performing this data analysis. Consult the *Scientific Inquiry Abilities* listed in the gray boxes for these protocols to learn about the inquiry abilities that will be gained.

Time

2 hours for site definition and set-up

15 minutes to use spreadsheet data entry to prepare and submit data to GLOBE periodically

Level

Middle and Secondary

Frequency

Data reporting approximately once every week

Materials and Tools

Weather station with data logger

Computer capable of running weather station software

Calibration thermometer

Rain gauge

Preparation

Set up the weather station.

Prerequisites

None

Automated Weather Stations

Using automated weather stations that record data can allow students to take environmental measurements at much shorter time intervals than collecting data by hand. The large volume of data that can be collected at uniform time intervals allows for the study of weather phenomena that can change quickly (such as wind) and so cannot be monitored through measurements taken with longer sampling periods.

The weather stations used in this protocol are manufactured by WeatherHawk Inc. (http://www.WeatherHawk.com). These weather stations have a display screen that shows current weather readings, such as temperature, humidity, barometric pressure, wind speed and direction and rainfall, measured by sensors attached to the station either through cables, or wirelessly. The type of measurements taken depends on the model of weather station and the types of sensors purchased.

Besides displaying current readings on the display screen, the weather station also records data over a long period of time using a data logger. This data logger is sold in a kit that also includes software that lets you download the data onto your computer and visualize it, and is required for this protocol.

Once the data are downloaded from the weather station to your computer you can export them to a text file, ingest them to a spreadsheet program, and manipulate them to conform to the format required for GLOBE email data entry. Software is available for some models to export text files in GLOBE's email data entry format.

The following atmospheric data can be taken with this protocol and reported to GLOBE: average wind speed and direction over the 15-minute sampling interval, maximum wind speed and direction over the sampling interval, wind run integrated over the 15-minute period, temperature, relative humidity, barometric pressure, rain rate and total rainfall. Cloud, Snow, Precipitation pH, Aerosol, and Ozone measurements must still be done following the appropriate other protocols.

Measurement Logistics

1. Review background in the *Atmosphere Chapter*.
2. Setup the weather station console and connect to your computer according to manufacturer's directions.
3. Install your atmospheric weather sensors according to the *Weather Station Atmospheric Sensors Installation Field Guide*.
4. Define your measurement site as an atmosphere site with *WeatherHawk Weather Station* selected for thermometer type
5. Log readings at 15-minute intervals and transfer data to your computer according to the directions included with your software.
6. When you are ready to report the data to GLOBE (recommended once a week) export the data stored in your computer to a text file in the format for GLOBE email reporting following the *Logging and Reporting Weather Station Data Lab Guide*
7. Paste the text in this file into the body of an email and send it to GLOBE following email data entry instructions available in the "Data Entry" section of the GLOBE Web site.
8. Engage students in looking at the data.
9. Every year recalibrate your weather station.

Teacher Support

The instructions given in this protocol are specific to one brand of weather station. However, they may be adapted to other equipment that meets the same specifications. If you have questions or require assistance with adapting these instructions to other instruments, contact your Country Coordinator or in the US, the GLOBE Help Desk. The essential elements of this protocol, which must remain the same regardless of the equipment model, are the placement of the station, the precision and accuracy of the sensors, and the sampling interval.

Once a year you should recalibrate your weather station using the GLOBE Recalibration Procedures outlined in this protocol. This will help assure the accuracy of the readings that you report to GLOBE.

Before starting students on the installation of your weather station, review the material provided in the *Site Selection and Setup Protocol* for information on important considerations in selecting an area to take atmospheric measurements.

Data Recording

The GLOBE database requires weather station data logged at 15-minute intervals, so make sure that the sampling interval in your weather station is set to 15 minutes. Also, the read-out should happen on the quarter-hour (e.g., 10:00, 10:15, 10:30, 10:45, etc.) Ensure that measurements are being displayed and reported in the appropriate units (i.e., millimeters for rain, degrees Celsius for temperatures, percent for relative humidity, meters/second for wind speed, and kilometers for wind run).

The time associated with each data point reported to GLOBE needs to be in Universal Time (UT). If you choose to have your weather station set to local time you will need to make sure that you adjust the times reported to GLOBE.

Due to the quantity of data, weather station data is reported to GLOBE only via email data entry. Software provided by WeatherHawk may allow data to be exported directly into the correct GLOBE email data entry format (see *Frequently Asked Questions* for information on the availability of this software), using the "*Export Records (GLOBE Format)*" option from the *Browse* menu option in the export data pull-down menu. This software can automatically adjust the times to UT. If you have an older version of the software that does not have this option, export your data to a text file, import the text file into your spreadsheet program, manipulate the columns to match the requirements for email data entry, and cut and paste the resulting values into an email data entry message.

GLOBE Recalibration Procedures

The GLOBE recalibration procedures outlined in this protocol involve determining a correction offset for the tipping bucket and performing a check of the temperature sensor. The offset for tipping bucket is equivalent to the difference in the readings taken by the weather station and readings taken by a rain gauge, which serves as a calibration instrument of known accuracy. This correction offset helps account for drift in the readings taken by the tipping bucket that can occur over time. Once reported to GLOBE, this offset will be applied automatically to all subsequent data you report and the adjusted values are displayed on the GLOBE Web site. Do not report offsets to GLOBE and then apply them to the data yourself before submitting the data to GLOBE as this will cause the offsets to be applied twice!

For some of the measurements taken by the weather station, such as wind, there are no measurement protocols in GLOBE to use for calibration so there are no current methods available for their calibration.

The complete GLOBE weather station calibration consists of the following:

- Check the temperature sensor following the *Weather Station Temperature Sensor Recalibration Field Guide*.
- Calibrate the tipping bucket rain gauge following the *Weather Station Tipping Bucket Rain Gauge Recalibration Field Guide*.

Helpful Hints

- During set-up, be sure to choose the right value for the volume of your tipping bucket or all rain data will be in error.

Questions for Further Investigations

Are the patterns of weather variables over a day the same every day? What causes this?

Which season has the greatest range of temperatures? Why?

What are the latitudes and elevations of other GLOBE schools with annual precipitation and temperature patterns similar to yours?

Is your local environment affected more by average temperature or temperature extremes?

How do changes in wind speed and direction and pressure relate to changes in temperature and relative humidity and to the occurrence of rain?

Weather Station Atmospheric Sensors Installation

Field Guide

Task

Install the atmospheric sensors for your weather station.

What You Need

- ❑ The sensors that you are going to install
- ❑ The tools necessary to make the installation
- ❑ GLOBE site definition sheet
- ❑ Manufacturer's instructions
- ❑ Compass

Note: Actual installation may vary significantly depending on which sensors you are using and the location where you are installing them.

In the Field

1. Scout for a location(s) for the placement of your instrument shelter. If you are using an anemometer (to measure wind) that can be mounted separately from the rest of the sensor suite, consider mounting it in a different location. If the anemometer is attached to the rest of the sensors, then preferably mount them in a location most appropriate for the thermometer (step 4). If you are using wireless sensors, make sure that they are mounted close enough to your station console to allow for proper communication.
2. If possible, mount your sensor suite so that the temperature sensor is at a height of 1.5 meters above the ground (or 60 cm above average maximum snow depth), preferably in a flat open area with a natural surface (grassy in most places). Try to avoid having buildings within 10 meters.
3. If possible, mount the anemometer where it is above the height of nearby trees and buildings. If you mount it on top of a building, try to keep it at least 1.2 meters above the roofline.
4. Report your site definition data to the GLOBE Web site as an atmosphere site with *WeatherHawk Weather Station* selected for thermometer type.

Logging and Reporting Weather Station Data

Lab Guide

Task

Log and report data collected with your weather station.

What You Need

- ❑ A setup and operating weather station
- ❑ A suitable computer with email access

In the Field

1. Set your weather station to log data at 15 minute intervals on the quarter hour (e.g., 15:15).
2. Download your weather station data to your computer following the instructions for your weather station. **Note:** some weather stations can be set-up to transfer these data automatically.
3. Export a text file of your data. Save this file on your computer. (If your software has the ability to export a text file in the GLOBE email data entry format, skip to step 5).
4. Use spreadsheet or other software to edit the exported file into the GLOBE email data entry format. Save this spreadsheet file on your computer.
5. Copy and paste your data in GLOBE email data entry format into the body of a GLOBE email data entry message.

Weather Station Temperature Sensor Recalibration

Field Guide

Task

Compare the temperatures recorded by your weather station with readings from a calibration thermometer.

What You Need

- ❑ Calibration thermometer that has been checked following the instructions in the *Thermometer Calibration Lab Guide*
- ❑ *Weather Station Calibration Data Sheet*

In the Field

1. Hang the calibration thermometer in the shade within 30 cm of the temperature sensor of your weather station.
2. Wait three minutes and then read the temperature from the calibration thermometer as well as the temperature from your weather station. Wait one more minute to see if the calibration thermometer reading is changing. If it is, continue until it stops changing. If the digital display for your weather station is located well away from the calibration thermometer, this may require two students cooperating. Record these readings on your *Weather Station Calibration Data Sheet*.
3. Repeat step 2 four more times, waiting at least one hour between each set of readings. Try to space out the five sets of readings over as much of the day as possible.
4. Report your new calibration data to the GLOBE Web site.

Weather Station Tipping Bucket Rain Gauge Calibration

Field Guide

Task

Record a rain event (of 2 cm or more) with a rain gauge and then compare the rainfall measured with this rain gauge to the rainfall recorded by the tipping bucket of your weather station.

What You Need

- ❑ A rain gauge that meets GLOBE specifications
- ❑ *Weather Station Calibration Data Sheet*

In the Field

1. Hang the plastic rain gauge in an open area within 15 m of and at the same height as the tipping bucket of your weather station. Take caution to ensure that the plastic rain gauge is placed so that it will not interfere with, or be affected by, the weather station.
2. Wait for a rain event to occur and then take your reading for rainfall from the rain gauge, following the *Rainfall Protocol Field Guide*. If the rainfall reading is more than 2 cm, record it on your W*eather Station Calibration Data Sheet* and continue.
3. Add all the rainfall values recorded by your weather station for this rain event. Record this sum on your W*eather Station Calibration Data Sheet.*
4. Repeat this process for two other rain events.
5. Report your calibration data to the GLOBE Web site.

Frequently Asked Questions

1. What should I do if there is frozen precipitation that my weather station registers as rain?

Frozen precipitation and melting snow can cause the tipping bucket of your weather station to tip, and may therefore register as rainfall on your station. The tipping bucket is calibrated exclusively for rainfall so any measurements caused by frozen precipitation are erroneous. Please report any frozen precipitation in your metadata and if possible edit your data record to remove any rainfall readings that were caused by frozen precipitation before reporting data to GLOBE.

2. I am using a WeatherHawk weather station, but my software does not include the option to export GLOBE data. What can I do?

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Atmosphere Investigation
Weather Station Calibration Data Sheet

School Name ________________________________ Study Site: ATM-______________________

Air Temperature Sensor Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Calibration Thermometer Reading (˚C)	Digital Temperature Sensor (°C)
1					
2					
3					
4					
5					

Rain Gauge Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Rain Gauge Reading* (mm)	Digital Tipping Bucket Total Reading (mm)
1					
2					
3					
4					
5					

* must be greater than 20 mm for recalibration

Learning Activities Supporting, Taking, and Understanding Measurements

Observing, Describing, and Identifying Clouds

Students begin to learn cloud types and their names.

Estimating Cloud Cover: A Simulation

Students practice estimating how much of the sky is covered by clouds.

Cloud Watch

Students monitor clouds and weather to begin to understand the connections between the two.

Observing Visibility and Sky Color

Students observe sky color and learn to associate color with the presence or absence of aerosols.

Making a Sundial

Students study the movement of the sun during the day by making quantitative observations of the direction and length of the shadow cast by a stick (known as a solar gnomon).

Calculating Relative Air Mass

Students are introduced to the concepts of solar elevation angle and relative air mass and learn how to determine relative air mass from measurements of solar elevation angle.

*Studying the Instrument Shelter**

Students explore how the placement and design of instrument shelters can influence temperature measurements taken from thermometers located inside them.

*Building a Thermometer**

Students construct simple thermometers to understand how and why liquid-in-glass thermometers work.

*Constructing a Model of Parts Per Billion of Surface Ozone**

Students construct and compare cubes of different volumes to gain insight into small concentrations such as a part per million and a part per billion.

Learning Activities Supporting the Use of Visualizations to Look at Data

*Making a Contour Map**

Students construct one or more contour maps using GLOBE data.

*Draw Your Own Visualization**

Students draw a visualization and learn about all the design choices involved and how these choices affect what is communicated by the visualization.

*Learning to Use Visualizations: An Example With Elevation and Temperature**

Students use visualizations to explore the relation between elevation and temperature and begin learning how to make important patterns evident in visualizations.

* See the full e-guide version of the *Teacher's Guide* available on the GLOBE Web site and CD-ROM.

Observing, Describing, and Identifying Clouds

Purpose

To enable students to observe clouds, describe them in a common vocabulary, and compare their descriptions with the official cloud names

Overview

Students observe and sketch clouds, describing their forms. They will initially generate descriptions of a personal nature and then move toward building a more scientific vocabulary. They correlate their descriptions with the standard classifications using the ten cloud types identified for GLOBE. Each student develops a personal cloud booklet to be used in conjunction with the GLOBE Cloud Chart.

Student Outcomes

Students will be able to identify cloud types using standard cloud classification names.

Science Concepts

Earth and Space Science

Weather can be described by qualitative observations.

Weather changes from day to day and over the seasons.

Clouds form by condensation of water vapor in the atmosphere.

Geography

The nature and extent of cloud cover affects the characteristics of the physical geographic system.

Atmosphere Enrichment

Clouds are identified by their shape, altitude, composition, and precipitation characteristics.

Clouds help us to understand and predict the weather.

Scientific Inquiry Abilities

Identify answerable questions.

Use a Cloud Chart to classify cloud types.

Develop descriptions using evidence.

Communicate procedures, descriptions, and predictions.

Time

Two class periods. May be repeated on days when different kinds of clouds are present

Level

All

Materials and Tools

GLOBE Cloud Chart

Observing Cloud Type Sheets (in the Appendix)

GLOBE Science Log

Reference books containing cloud images

Still or video camera to photograph clouds (optional)

Preparation

Obtain cloud reference books and mark the appropriate pages.

Prerequisites

None

Background

Accurate weather forecasting starts with careful and consistent observations. The human eye represents one of the best (and least expensive) weather instruments. Much of what we know about the weather is a result of direct human observation conducted over thousands of years. Although being able to identify clouds is useful in itself, observing clouds on a regular basis and keeping track of the weather associated with certain kinds of clouds will show students the connection between cloud types and weather. Recognizing cloud types can help you predict the kind of weather to expect in the near future. We do not describe those connections here, but there are numerous weather books that can help you and your students make them. Inviting a local meteorologist to visit your class and to talk with the students is a sure way to stimulate interest in the relationship between clouds and weather patterns.

In this activity, we ask students to look carefully at clouds, sketch them, and describe them in their own words *before* using the official names. The activity can be repeated on different days when different kinds of clouds are present. In fact, if you can be spontaneous, it would be nice to take a break and do some outdoor "cloud work" whenever a new kind of cloud appears in the sky. Over time, students can build up a considerable familiarity with cloud types. If you cannot always take the students outside when interesting clouds appear, perhaps you can observe them through a window.

Students Develop a Personal Cloud Booklet

Students should develop, either in their GLOBE Science Logs or in separate cloud booklets, an individual, personal set of notes on clouds and cloud types. They should devote one page of their GLOBE Science Logs to each individual cloud type they identify. They can include not only their own observations and descriptions but also photographs of clouds that they take or that they clip from other sources. On any given day students may observe several kinds of clouds in the sky at the same time. If several types of clouds are present, they should record each of the types on a separate page of their GLOBE Science Logs.

Identifying and Classifying Clouds

The GLOBE protocol asks you to identify ten common types of clouds. The names used for the clouds are based on three factors: their *shape,* the *altitude* at which they occur, and whether they are *producing precipitation.*

1. Clouds come in three basic shapes:
   cumulus clouds (heaped and puffy)
   stratus clouds (layered)
   cirrus clouds (wispy)
2. Clouds occur in three altitude ranges (specifically, the altitude of the cloud base):
   High clouds (above 6,000 m), designated by "cirrus or cirro-"
   - Cirrus
   - Cirrocumulus
   - Cirrostratus

   Middle clouds (2,000 - 6,000 m), designated by "alto-"
   - Altocumulus
   - Altostratus

   Low clouds (below 2,000 m), no prefix
   - Stratus
   - Nimbostratus
   - Cumulus
   - Stratocumulus
   - Cumulonimbus

Note: While both cumulus and cumulonimbus clouds may have their bases starting below 2,000 m, they often grow thick enough to extend into the middle or even high range. Thus, they are often referred to as "clouds of vertical development." Only high clouds are wispy and so the term cirrus has become synonymous with wispy as well as referring to high clouds.

3. Clouds whose names incorporate the word "nimbus" or the prefix "nimbo-" are clouds from which precipitation is falling.
4. Contrails are linear clouds formed around small particles in jet aircraft exhaust.

These are indeed clouds, caused directly by human activity, and are of great interest to researchers. We distinguish three subtypes:

1. *Short-lived contrails:* obvious tail behind a plane; Do not remain after plane passes;
2. *Persistent, non-spreading contrails:* obvious contrails (linear, narrow features) that do not appear to dissipate significantly, or to show signs of spreading, and that remain long after the airplanes that created them have left the area; Each contrail subtends a narrow angle in the sky;
3. *Persistent, spreading contrails:* obvious linear cirrus-type clouds with a diffuse appearance; Each contrail subtends a wider angle in the sky.

Cloud Identification Tips

Several things are useful to know in identifying and naming clouds according to the official classifications:

Clouds that are wispy and high in the sky are always cirrus of one type or another. If the cirrus clouds contain waves or puffs, then they are cirrocumulus. If they form continuous layers that seem to cover the sky high up, they are cirrostratus. Contrails occur at high levels too, and are very linear cloud features.

Clouds at middle altitudes are designated by the prefix "alto-." If in layers, they are altostratus; if in heaps and puffy, they are altocumulus.

Clouds that form at low altitudes (below 2,000 m) are either of the cumulus or stratus family. Clouds in the cumulus family are puffy and heaped. Clouds in the stratus family form in layers or sheets that cover broad expanses of sky.

Low clouds that are dark, threatening and *actually producing rain* receive the designation "nimbus." Nimbostratus clouds cover the entire sky with broad sheets and produce steady rain. Nimbostratus clouds are larger horizontally than vertically. The rainfall associated with nimbostratus typically is low to moderate in intensity, but falls over a large area for an extended period of time. Cumulonimbus have dark bases and puffy tops, often anvil-shaped, and are sometimes called "thunderheads." They tend to produce heavy precipitation, typically accompanied by lightning and thunder.

Using Photography

It should not be hard to find photographs of clouds in books, charts, and magazines. However, the students will enjoy taking their own photographs of clouds. Introduce this as an activity after they have sketched and described clouds in their own words. Video photography of clouds in motion also presents a new perspective on cloud formation and behavior, particularly if you can use a tripod and time-lapse photography.

Part 1: Describing Clouds In Your Own Words

What To Do and How To Do It

1. Organize the students into two-person teams. Send them outside with their GLOBE Science Logs to an open location to observe the clouds. Each student should draw a detailed sketch of the clouds in the sky. If there are several different kinds of clouds present, they should sketch each specific kind on a separate page of their notebooks.
2. Each student should record the date and time of day and describe the appearance of the clouds next to the sketch. They should use as many words as necessary to describe the appearance of the clouds. Emphasize that there are no right or wrong answers and that they should use whatever words seem appropriate to them. Some possible student responses:
   Size: small, large, heavy, light, dense, thick
   Shape: fluffy, stringy, cottony, lumpy, torn, smooth, patchy, sheets, ragged, looks like a...
   Color: gray, black, white, silvery, milky
   Description: thunderclouds, menacing, threatening, gloomy, enveloping, beautiful, streaked, foggy, bubbly, scattered, moving, swirling
3. Upon returning to the class, pairs should join together to share descriptions. Ask each group of four to compile a "group list" of all the words they used to describe each cloud type they observed. They should select the words they think are the best ones for describing the clouds they saw.
4. Using the GLOBE Cloud Chart, students should match their sketches with one of the photographs and record the scientific name of the cloud type next to their sketch.

Part 2: Comparing Your Descriptions to the Official Descriptions

What To Do and How To Do It

1. (You may choose to postpone this discussion until the class has accumulated descriptions of several different kinds of clouds.)
   Initiate a class discussion. Ask one four-person group to draw a cloud sketch on the board and record the words their group used to describe the cloud. If several different clouds have been observed, have a different group do each type. Ask other groups to contribute additional words they used to describe these clouds.
   Ask the students to group the words they used into clusters that seem to go together. Ask them to name the specific features of the clouds (such as size, shape, color, altitude, or other features) to which these clusters refer. Do these clusters represent the main cloud features to which they think an observer should pay attention? Are there any cloud features that have not been included? What would they say is the basis of their system, that is, what features of clouds does it pay attention to?
2. Ask the students to indicate the "official" names for the clouds pictured on the board. Explain that the official system used to classify clouds relies upon three features of clouds: shape, altitude, and precipitation. Compare the official system to the classification system they developed on their own. What cloud features does each include and omit?
   Ask students which of their words they would use to describe each of these cloud families:
   stratus clouds
   cumulus clouds
   cirrus clouds
   nimbus clouds

3. Repeat the observation, sketching, and description of different cloud types on subsequent days as new clouds appear in your sky. Have students develop a separate page of their GLOBE Science Logs for each new cloud type they observe. Have them record both the official name of the cloud and their own preferred descriptions of it. Continue to discuss the basis for the official classification system.

Adaptations for Younger and Older Students

Younger students can describe clouds in terms of their basic family type: cirrus, cumulus, and stratus. They can also describe the height of the clouds: low, medium, or high; their shape: large or small; and their color: white, gray, or black.

Older students can correlate cloud types with the appearance of certain types of weather. See the *Cloud Watch Learning Activity*. Students also can pay attention to the sequence of cloud types over the course of several days and can investigate the factors that cause clouds to form.

This activity can present interesting possibilities for collaboration with an art teacher or a literature teacher, each of whom can contribute a different, perhaps nonscientific, perspective on the description of clouds.

Further Investigations

Examine the correlation between wind and clouds. Chart the wind direction and speed for each observable cloud type.

Explain the connection between the hydrologic cycle and atmospheric conditions.

Satellite and shuttle photos allow observations of the dynamics of our atmosphere and the examination of large-scale phenomena that are not possible from land. Use space-based imagery to predict weather or to track storms. Consider the merits and disadvantages of space images versus local meteorological information and data.

Track storms and clouds from a distance to aid in understanding local weather conditions. Use binoculars to study clouds and their formations from a distance. Use local maps to help identify the distance of landmarks and the speed at which clouds are moving.

Create cloud games to practice identification skills and concepts:

Cloud Game #1: Have each student create a set of 3” x 5” index cards that includes names of the ten cloud types. A second set of cards includes illustrations of each of the ten types. Pairs of students combine cards, turning them face down. Partners alternate turning over two cards at a time, attempting to locate a match. A successful match results in another turn. Play continues until all cards have been matched. The winner is the partner with the most matched pairs.

Cloud Game #2: Groups of students can generate questions about clouds: appearance, shape, altitude, and percentage of dominant cover. On a 3” x 5” index card write the statement as an answer. For example: “Scattered Clouds” is the answer to the question, “What is the cloud cover when between a tenth and a half of the sky is covered with clouds?” Divide the class into teams to play. Players respond to the answer cards in the form of a question (see above).

Estimating Cloud Cover: A Simulation

Purpose

To help students better understand percent cloud cover and to take more accurate cloud cover observations

Overview

Working in pairs or small groups, students use construction paper to simulate cloud cover. They estimate the percentage of cloud cover represented by torn pieces of paper on a contrasting background and assign a cloud cover classification to the simulations created by their classmates.

Student Outcomes

Students understand the difficulties of visually estimating the percentage of cloud cover and gain experience estimating cloud cover, evaluating the accuracy of estimates, and using fractions and percentages.

Science Concepts

Earth and Space Science

Clouds can be described by quantitative measurements.

Clouds change over different temporal and spatial scales.

Geography

The nature and extent of cloud cover affects the characteristics of the physical geographic system.

Scientific Inquiry Abilities

Estimate cloud cover.

Design and conduct scientific investigations.

Use appropriate mathematics to analyze data.

Communicate results and explanations.

Time

One class period

Level

All

Materials and Tools

Sheets of colored construction paper, one blue and one white per student

Glue stick, glue, or tape

Preparation

None

Prerequisites

Familiarity with fractions and percentages

Background

Even experienced observers have difficulty estimating cloud cover. This seems to derive, in part, from our tendency to underestimate the open space between objects in comparison to the space occupied by the objects themselves, in this case the clouds. Students have an opportunity to experience this perceptual bias themselves, to reflect on its consequences for their scientific work, and to devise strategies to improve their ability to estimate cloud cover.

What To Do and How To Do It

Introduce students to the idea of observing and quantifying cloud cover. Explain that they will simulate cloud cover using construction paper and estimate the amount of cloud cover represented by white scraps of paper on a blue background. Demonstrate the procedures covered in steps 3 - 6 below so that students understand how to proceed.

You may review the *Cloud Cover Protocol* with students before doing this learning activity or use the activity as a first step in presenting the protocol to students. Step 7 below requires you to explain the classification categories that are used – no clouds, clear, isolated, scattered, broken, and overcast.

1. Organize students into pairs.
2. Provide each pair with the necessary materials:
   - one sheet of light blue construction paper
   - one sheet of white construction paper divided into 10 equal segments
   - GLOBE Science Log
   - glue stick, glue, or tape.
3. Have each student pair choose a percentage of cloud cover that they wish to represent. They must choose a multiple of 10% (i.e. 20%, 30%, 60%, etc. not 5% or 95%). They should not reveal the percentage they have chosen to anyone else.
4. Have each pair cut their white paper so that it represents the percentage of cloud cover they have chosen. For example, if they have chosen 30%, they should cut out 30% of their white piece of paper and recycle the remaining 70%.
5. Students should then tear their white paper into irregular shapes to represent clouds.
6. Have students paste or tape the cloud pieces onto the blue paper, taking care not to overlap the pieces of white paper. On the back of the blue paper, record the percentage of cloud cover.
7. Have students take turns visiting each others' simulations and estimating the percentage of cloud cover. For each simulation they should classify the sky as "clear, isolated, scattered, broken, or overcast using Table AT-CO-1." They should then record their estimates in their GLOBE Science Log, using a table similar to that shown in Table AT-CO-2.

   Have all students visit all the simulations, or divide the class in some way so that students visit only some of the simulations.
8. When students complete their estimates of cloud cover, create a table on the board to compare the estimates with the actual percentages. See Table AT-CO-3.
9. Create a second table that compares correct classifications with incorrect classifications. See Table AT-CO-4.
10. Discuss with the class the accuracy of their estimates.
    Which were more accurate — the percentage estimates or the classifications?

Table AT-CO-1

Percentage	If less than	If greater or equal to
10%	Clear	Isolated
25%	Isolated	Scattered
50%	Scattered	Broken
90%	Broken	Overcast

Table AT-CO-2

Name	Estimated percent	Classification
Jon & Alice	40%	scattered
Juan & Jose	70%	broken

Table AT-CO-3

Name	Actual %	Underestimates	Correct estimates	Overestimates
Jon & Alice	60	4	5	12
Juan & Jose	70	6	9	6

Table AT-CO-4

Name	Correct classification	Classified too little cover	Classified correctly	Classified too much cover
Jon & Alice	Broken	4	9	8
Juan & Jose	Broken	7	12	2

Where did the greatest errors occur?

Can students come up with a quantitative measure of their collective accuracy?

Does the class have a tendency to overestimate or underestimate cloud cover?

What factors influenced the accuracy of the estimates (e.g. size of the clouds, clustering of the clouds in one part of the sky, the percentage of sky that was covered)?

Do students feel that making these estimates is something they have a talent for, or is it something that they can learn?

Where else might such spatial estimation skills be valuable?

Which cloud classifications were the easiest and most difficult to identify?

What strategies enabled students to correctly estimate cloud cover?

What strategies might produce more accurate classifications?

Observing Visibility and Sky Color

Purpose

To observe, document, and classify changes in visibility and sky color over time and to understand the relationship between sky color, visibility, and aerosols in the atmosphere

Student Outcomes

Students become aware of the changes in visibility and sky color due to particles suspended in the air.

Overview

Science Concepts

Earth and Space Science

The atmosphere is composed of different gases and aerosols.

Geography

Human activities can modify the physical environment, specifically air quality and the composition of the atmosphere.

Atmosphere Enrichment

Aerosols decrease the amount of solar energy reaching Earth's surface.

Aerosols in the atmosphere increase haze, decrease visibility, and affect air quality.

Scientific Inquiry Abilities

Identify answerable questions.

Observe and describe sky conditions.

Develop descriptions and explanations using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

Time

Initial observations: 20 minutes

Continued observations: 10 minutes

Level

All

Frequency

Initial observations: for five to ten days, days with limited cloud covered preferred

Continued observations: throughout the year, days with limited cloud covered preferred

Materials and Tools

Colored pencils or water-colored paint and brushes

White paper

Optional: camera or paint sample cards (from a local paint store)

Visibility and Sky Color Data Sheet

Visibility and Sky Color Summary Chart

Scissors and tape

Preparation

None

Prerequisites

Cloud Cover Protocol

Background

Why is a clear sky blue? The atmosphere consists primarily of molecules of oxygen and nitrogen. Sunlight bounces off these molecules, a process called scattering. Light with shorter wavelengths, at the blue end of the visible light spectrum, is scattered more efficiently than longer wavelengths. To an observer on the ground, this scattered light fills the entire sky and a clear sky appears blue.

However, there are also liquid and solid particles called aerosols suspended in the atmosphere. When there are relatively few aerosols, the sky appears clear. For example, a distant building or mountain peak appears clearly defined, with colors similar to what you would see if you were much closer to that distant object. On a very clear day, you would report the sky color as blue or deep blue and the sky condition as clear or unusually clear. Aerosols come from natural sources such as condensation and freezing water vapor, volcanoes, dust storms, and salt crystals evaporated from sea spray. They also come from human activities such as burning fossil fuels and biomass (e.g., wood, dung, dried leaves) and plowing or digging up soil. Aerosols are much bigger than gas molecules (they range in size from about 10^{-6} m (1 micron) to 10^{-7} m) and they scatter light from all visible wavelengths. Individual aerosols are too small to be visible to the human eye, but their presence affects the sky's appearance. As the aerosol concentration, and therefore scattering of sunlight, increases, the sky appears less blue. Haze is the visible effect of aerosols on the atmosphere; it is a qualitative condition you can observe. When aerosol concentrations are high, we say that the sky looks hazy. Aerosol concentrations can also be measured quantitatively.

Hazy skies appear pale blue or almost white. Depending on the type of aerosols present in the atmosphere, the sky may also appear brownish or yellowish. Scattering of visible light through a hazy sky affects horizontal visibility, so distant objects appear less distinct, with washed-out or distorted colors. Distant objects that are visible on a clear day may actually disappear on a hazy day. Aerosols, probably produced by urban smog, cause the haze evident in this picture of the Empire State Building in New York City. Over the past few decades, horizontal visibility has declined around the globe, on average, due to increasing aerosol concentrations. As a result, scenic vistas throughout the world have been obscured.

Photograph © Forrest M. Mims III. Used by permission. May be freely reproduced with acknowledgment.

Teacher Preparation

In this activity, your students will carefully observe the atmosphere over a period of days and record their observations. Through these direct observations they will develop an understanding that visibility and sky color are related and that both are due to the relative presence or absence of aerosols.

The students will classify the sky color using standard categories and will represent the sky color using paints or colored pencils. They also will record the visibility based on observation of a distant object such as a mountain or a building. It is not important that they observe every day, but they should try to sample a wide range of the visibility and sky conditions that occur at your location. They should try to observe on some very clear days, on some hazy days, and on some intermediate days. After they have observed and recorded examples of very clear days, very hazy days, and various conditions in between, the class will record their observations in a summary table and see whether or not a pattern emerges that relates visibility to sky color.

Visibility

By "visibility" we mean the clarity with which objects can be viewed through the intervening atmosphere. In order to judge visibility or the clarity of the atmosphere, students need to be able to look out at a distant scene, such as a distant building or a mountain or hillside. By looking at the same scene or object every day students will gradually develop a sense of whether the day is unusually clear, clear, somewhat hazy, very hazy, or extremely hazy. Only practice, lots of different examples, and discussion will make these categories clear. (No pun intended!)

Sky Color

Students are also asked to observe, classify, and represent the sky color. They will classify the sky color using the categories listed at the bottom of the data sheet. They represent the sky color in a drawing using paints or colored pencils. They could also try using photographs or color paint chips. As they make more observations, the students will become more confident of their classifications and more skillful in drawing the sky color.

Students may notice that the sky is often a different color in different parts of the sky. Near the horizon it is typically lighter due to the presence of aerosols. The darkest part of sky can often be seen about half way between the horizon and directly overhead, in the "anti- sun" direction – that is, when you look at the sky with your shadow in front of you. Students should try to locate the darkest (bluest) color of the sky and record it.

Correlation Between Visibility and Sky Color

One of the purposes of this activity is for students to realize that on the clearest days with the highest visibility the sky is a deep blue color, while on hazy days it appears milky. Changes in visibility and sky color are both due to changes in aerosol concentrations in the atmosphere. Because aerosols scatter sunlight, high aerosol concentrations make it harder to see distant objects and make the sky appear lighter. On clear days when aerosols are low, visibility is high and the sky is deep blue. But do not TELL students this; let them discover it by pooling the class observations in the *Visibility and Sky Color Summary Chart*. It *should* be the case that most of their observations will tend to fall along the main diagonal from upper left to lower right.

What To Do and How To Do It

1. Lead students through a discussion of aerosols, visibility, and sky color. Begin by asking them what they recall about times when the sky was very hazy. How was the visibility? How did they recognize that visibility was low? What color was the sky? When did this occur? What do they think caused it?
2. Continue by asking them to recall a time when the sky was very clear. What did it look like? What color? How was the visibility through the atmosphere? When did this very clear event occur? What was the weather like at that time? What do

they think caused the air to be so clear at that time?

3. If it has not already come up in discussion, discuss the role of aerosols in the creation of haze. Discuss local and regional sources of aerosols. Discuss, also, how aerosols such as dust can be transported from long distances and affect local conditions.
4. Explain that they will undertake an investigation of sky color and visibility. Introduce the *Visibility and Sky Color Data Sheet* and discuss how to use it. Take observations for as many days as necessary to obtain a full range of sky conditions in the data.
5. After the class has made a large number of observations, covering the entire range of sky conditions that occur in your area, bring the class together for a group discussion of the data. Engage the students in a discussion of the conditions that existed when they observed the clearest and their haziest skies. What was the weather like? What do they think accounted for the clearest and the haziest skies? When they had hazy skies, was the haze created by local, regional, or long-distance factors?
6. On the blackboard or on chart paper, create a chart similar to the *Visibility and Sky Color Summary Chart* shown. Invite students to contribute their data to the chart by placing a mark in the appropriate cross-classification cell to represent each of their observations.
7. When the chart has been populated with all of the student observations you should observe a diagonal trend in the data, from upper left to lower right. Ask students to explain why this trend exists. What is the common element that causes both low visibility and milky skies?
8. (Optional) Have each student or team create a "key" to help them make future observations. Select one sky color example for each level of visibility/sky color from "unusually clear" to "extremely hazy." Use these keys to standardize your observations of haze conditions. Students can continue to take observations throughout the year and note relationships to season, storms, time of day, temperature, wind direction and other conditions. Depending on students' ages, these color keys can be sky paintings, photographs, or paint color chips that can be obtained from stores that sell interior paint.

Student Preparation for Observing Visibility and Sky Color

Make these observations only on days when you can see the sky. Do not attempt to observe visibility and sky color on days that are overcast. For each day that you make an observation, record the date, the local time, your estimate of the visibility and your estimate of the sky color.

Both visibility and sky color are subjective classifications. That means you should expect some variation among observers and changes in your own classifications as you gain experience. As you gain experience in observing the atmosphere and the sky you may change your mind about some of your initial classifications. You may decide that what you originally classified as a deep blue sky you now consider to be merely "blue." Or, you may decide that what you thought was "somewhat hazy" was really "very hazy." Do not worry about this and do not go back and change your original observations. You can expect your skill in classifying to evolve and change. Gradually, you should gain confidence in your ability to classify consistently.

1. Estimate the visibility.

   Select some distant object – a mountain range, a building, or other object several kilometers away. Use this object as your "reference object" to judge visibility every day you make an observation. Take note of how distinctly you can see it and select one of the visibility categories below and record it on the *Visibility and Sky Color Data Sheet.*

   Unusually clear
   Clear
   Somewhat hazy
   Very hazy
   Extremely hazy

2. Observe the sky color.

   Now look at the sky and find the part of it that is the darkest color. When you do this activity, be sure not to look directly at the sun even if it is partially obscured by clouds. Select a category for the sky color from the list below and record it on the *Visibility and Sky Color Data Sheet*.

   Deep blue
   Blue
   Light blue
   Pale blue
   Milky

3. Paint or draw with colored pencils your best representation of the sky color in the "picture" box. You can also use paint color chips or photographs to represent sky color.

Questions for Understanding

1. When you see blue skies, what other weather conditions are likely to exist? What else would you observe on very clear days?
2. Are you aware of any daily patterns in sky color and visibility in your location? Is it usually hazier at certain times of day? What causes this?
3. How are sky color and haze related to weather?
4. Are sky color and haze at your location related to the amount of wind and the wind direction? If so, why?
5. Are sky color and haze at your location related to the time of the year? That is, are there seasonal patterns in your data?

Visibility and Sky Color Data Sheet

Observer(s): ____

____

Date	Local Time	Visibility (use categories below)	Sky Color		Comments: weather conditions, wind direction, etc.
			Category (see below)	**Draw the Color** *	

*Alternatively, you can give the name of a paint color, or you can refer to a photograph you have taken previously.

Visibility Categories	**Sky Color Categories**
Unusually clear	Deep blue
Clear	Blue
Somewhat hazy	Light blue
Very hazy	Pale blue
Extremely hazy	Milky

Visibility and Sky Color Summary Chart

Make a mark or an "x" in the cell of the chart where each observation falls.

Visibility/Sky Color	Deep blue	Blue	Light blue	Pale blue	Milky
Unusually clear					
Clear					
Somewhat hazy					
Very hazy					
Extremely hazy					

What do you notice about the pattern of observations?

How can you explain this pattern?

Making a Sundial

Purpose

Investigate the movement of the sun through the day and determine the time of local solar noon.

Overview

Students construct a sundial and use it to observe the movement of the sun through the sky over the course of a day by marking changes in the position of a shadow once each hour. Students determine the approximate time of solar noon at their school as indicated by the time of the shortest shadow. Students revisit the site on a subsequent day to estimate the time of day using their sundial.

Student Outcomes

Students will gain an understanding of the daily movement of the sun across the sky and experience conducting a set of simple, quantitative observations.

Science Concepts

Earth and Space Science

The diurnal and seasonal motion of the sun across the sky can be observed and described.

Geography

The physical characteristics of a location depends on its latitude and relation to incident solar radiation.

Scientific Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Construct a scientific instrument.

Develop explanations and predictions using evidence.

Communicate results and explanations.

Time

Hourly measurements lasting 5 minutes during one sunny school day; 15 minutes to revisit the sundial on subsequent days; time for classroom discussion

Level

Primary and Middle

Materials and Tools

Wooden dowel or similar pole at least 50 cm long

Shadow markers (flags, rocks, sticks, nails, etc.)

Meter stick

Preparation

None

Prerequisites

None

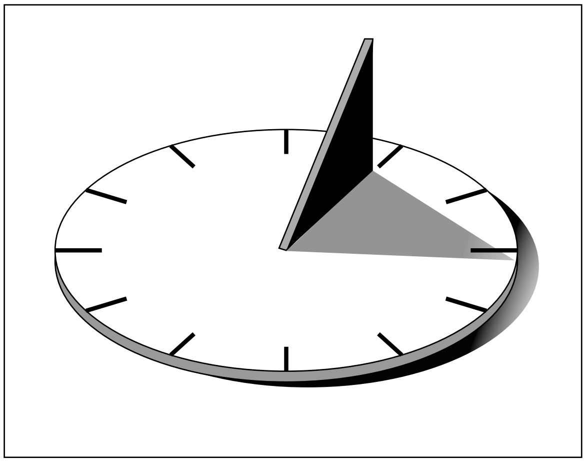
Background

Students may have noticed that when they arrive at school in the morning the sun is shining on one side of the school and when they leave in the afternoon it is shining on the other side. This occurs because the sun appears to travel across the sky each day.

Before the invention of clocks, people used this motion of the sun to determine the time by making sundials. Sundials are simply stationary vertical objects, such as a pole, placed on a flat surface. The pole is known as a *gnomon* (NO-mon) and the flat surface as a *dial*. As the sun travels through the sky, the length and position of the shadow cast on the *dial* by the *gnomon* change. The shadow is longest at sunrise and sunset and is shortest at local solar noon.

In this activity students will make a sundial by marking the position of the shadow cast by a gnomon every hour for one school day. They will return to their dial on a subsequent day to see if they can predict the time of day from the sundial they made.

Figure AT-SU-1



What To Do and How To Do It

1. Select a day that will be sunny for at least seven hours starting when school begins.
2. Take the students outside to a relatively flat spot on school grounds that will be out of the shadow of buildings and trees until the end of the school day. Place the pole in the ground making certain that it is perpendicular to the ground using a plumb bob (a piece of string with a weight on it) or a level. Measure and record the height from the ground to the top of the pole.
3. Have the students put a #1 on the first object (rock, flag, etc.) they will use to mark the position of the shadows. Ask the students to place the marker on the ground at the end of the shadow and to record the time from their watches.
4. The students should measure and record the distance from the base of the gnomon to the end of the shadow in the table provided. (Optional: have the students measure the angle as well using a compass.)
5. Have a few students visit the gnomon at least once an hour for the remainder of the school day. The students should measure the length of the shadow (and the optional angle), place a new numbered marker at the end of the shadow and record the time of day.
6. Ask the students to use the table to determine which marker is closest to the pole. This is the time of the shortest shadow and is the observation closest to solar noon. If you have the time, you could have the students take more frequent measurements around the time of this observation on the following day to get a better estimate of solar noon.

Figure AT-SU-2:

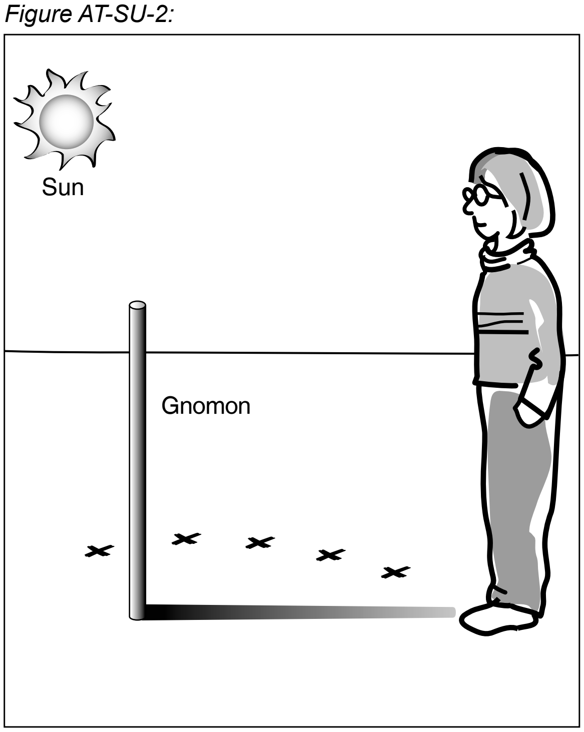
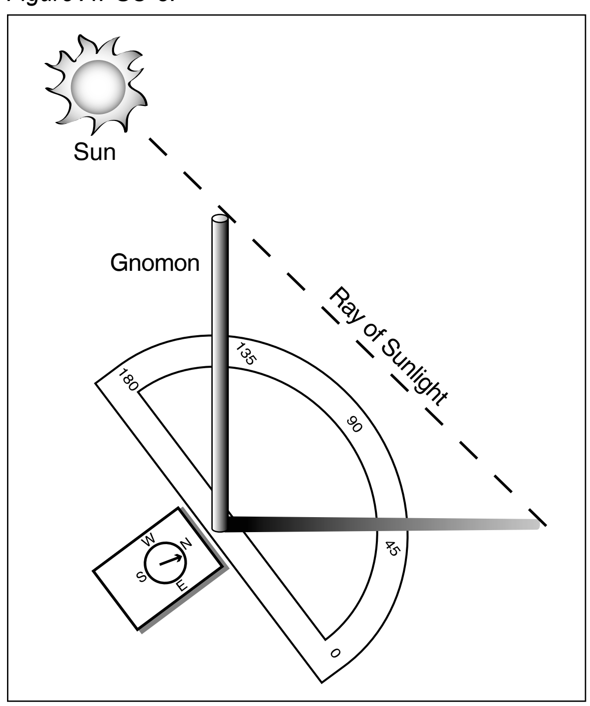


Figure AT-SU-3:



7. Visit the sundial on another day in the same week. The students should bring their completed tables. Have the students look at the shadow being cast by the pole and estimate from their tables what the time on their watches will be. Ask each student to write down his or her estimate. Have the students look at their watches to find out how close their estimates were.

Questions

1. What is the path of the sun as it moves across the sky?
2. Does the path of the sun across the sky and the pattern of the shadows from the gnomon on the dial change during the year? (The answer could form the basis for a hypothesis that the students could test experimentally.)

Adaptations for Older Students

Older students can observe the changing angle of the sun above the horizon. By measuring the height of the gnomon and the distance from the top of the pole to the end of the shadow (the hypotenuse of the triangle), students can determine the angle of the sun using simple geometry for similar triangles. Have the students add a column to the table and fill in the solar elevation angle for each time they placed a marker. When is the solar elevation the greatest? the smallest? Could they have predicted this from the length of the shadows?

Date ____________________

Description of Sundial Site ____

____

____

Weather Conditions ____

Height of the gnomon (pole) ____________

Marker #	Time	Length of shadow cast by the gnomon	Optional: Compass angle of the shadow

Estimated time of solar noon _________

Calculating Relative Air Mass

Purpose

To introduce students to the concept of relative air mass and demonstrate how solar elevation angle affects the intensity of sunlight that reaches an observer on the ground.

Overview

Students work in teams to calculate relative air mass using simple geometry.

Student Outcomes

Students understand the relationship of solar elevation angle to relative air mass.

Science Concepts

Earth and Space Science

Dynamic processes such as Earth's rotation influence energy transfer from the sun to Earth.

Atmosphere Enrichment

The path length of incident sunlight through the atmosphere (relative air mass) varies as a function of the solar elevation angle.

Scientific Inquiry Abilities

Identify answerable questions.

Use appropriate tools and techniques.

Use appropriate mathematics to analyze data.

Develop and construct models using evidence.

Communicate procedures and explanations.

Time

Morning elevation readings: 5 minutes each; sunny day is necessary

Calculating air mass: 20 minutes

Level

Middle and Secondary

Materials and Tools

Meter stick and/or tape measure marked in centimeters

Pole, at least 50 cm high, to be used as a solar gnomon (e.g. wooden dowel)

Calculating Relative Air Mass Data Sheet

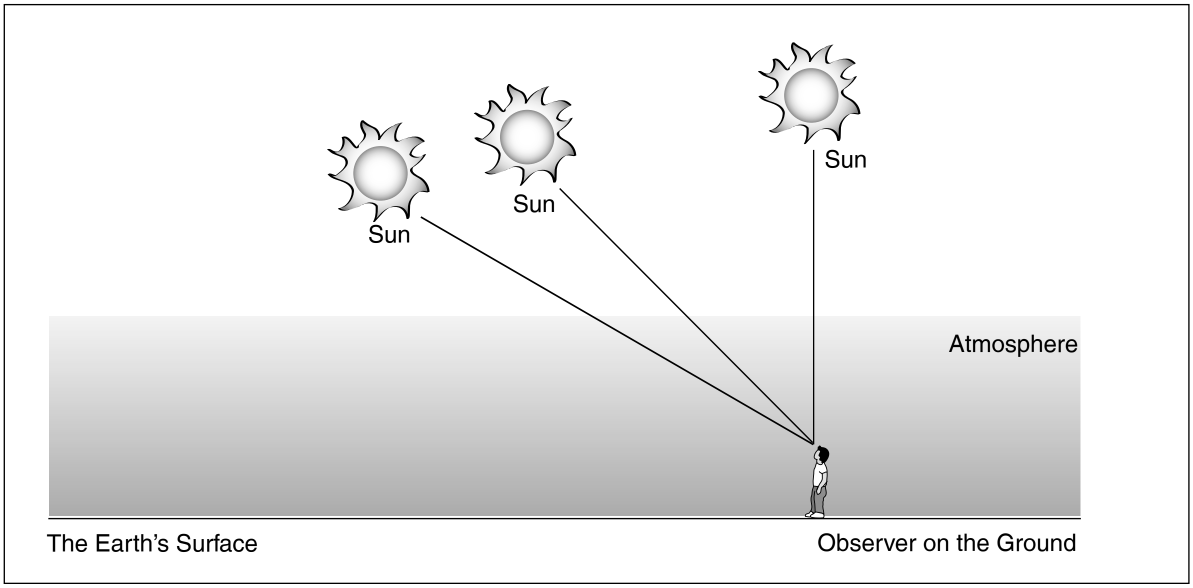
Preparation

None

Prerequisites

Making a Sundial (suggested for younger students)

Figure AT-AM-1



Teacher Support

Background

Relative air mass is a ratio indicating the amount of atmosphere that light must pass through before reaching an observer on the ground. When the sun is directly overhead, sunlight passes through the least amount of atmosphere to reach the ground. This is defined as a relative air mass of 1.0. In this case, the sun is 90˚ above the horizon. When the Sun is 30˚ above the horizon, sunlight passes through twice as much atmosphere to reach an observer on the ground, and the relative air mass is 2.0. Thus, the relative air mass is a function of the solar elevation angle.

In the *Aerosol Protocol*, the amount (the intensity) of sunlight reaching the instrument depends on the amount of atmosphere between the instrument and the sun as well as the amount of aerosol in the atmosphere. So, the relative air mass you calculate in this activity is important for interpreting data obtained using the GLOBE sun photometer. In *Looking At the Data* for the *Aerosol Protocol*, the technique is given for calculating aerosol optical thickness from the voltage readings of the photometer. This calculation requires knowing the relative air mass at the time of observation.

In order to help students understand how the solar elevation angle affects relative air mass, make some sketches on the board like those shown above or use an overhead projector to project the figure onto a board or wall. Invite students to use a meter stick to measure the distance from the top of the atmosphere to the observer for solar elevation angles of 90, 45, and 30 degrees. The students should see that as the elevation angle of the sun decreases, the pathlength of sunlight through the atmosphere increases. Have the students find the ratio of each pathlength to the 90 degree pathlength. These ratios are the relative pathlengths through the atmosphere and are the same as the relative air masses.

Relative air mass can be calculated in the field using the length of the shadow cast by a vertical pole. A pole used for this purpose is called a *solar gnomon*. In Figure AT-AM-2A, the pathlength through the atmosphere (p) is a function of the elevation angle (e). The distance from the ground to the top of the atmosphere (d) may be assumed to be constant.

As shown in Figure AT-AM-2B , sunlight shining on the solar gnomon casts a shadow creating a right triangle. The three sides of this triangle are: the height of the gnomon (h), the length of the pole's shadow on the ground (r), and the hypotenuse (c).

The solar elevation angle (∠e) is the same in the right triangles in both figures, making them similar triangles where the ratio of the hypotenuse to the side opposite ∠e is the same in both cases. Therefore you can determine relative air mass (p/d) by measuring the triangle formed by the solar gnomom and its shadow.

There are several ways to find relative air mass depending on the mathematical sophistication of your students. If your students only know arithmetic, have them measure c directly as suggested in the steps below.

Equation 1 Relative Air Mass = $\frac{c}{h}$

If your students know a bit of geometry and understand square roots, then you can measure the length of the shadow (r) and the height of the gnomon (h), and:

Equation 2 Relative Air Mass = $\frac{c}{h}$

$$= \sqrt{\frac{h^2 + r^2}{h^2}} \qquad = \sqrt{1 + \frac{r^2}{h^2}}$$

If your students understand trigonometric functions, you can measure ∠e, and:

Equation 3 sin(e)=h/c

Equation 4 Relative Air Mass = c/h = 1/sin(e)

Ask the students to speculate about how the relative air mass will affect the intensity of the sunlight that an observer on the ground would see. The important concept for the students to understand is that the longer the pathlength, the less sunlight shines through. This happens even in a clear atmosphere, as students can see by observing that sunlight is not as strong near sunrise and sunset as it is at noontime.

Also note that outside the tropics, the sun is never directly overhead and the relative air mass is always greater than one.

Students may ask why the sun looks redder at sunrise and sunset than at noontime. Sunlight's path through the atmosphere is longest at sunrise and sunset, so the number of gas molecules and particles that can scatter the sunlight is greatest at these times. The gases in the atmosphere scatter blue light more strongly than red light. At sunset, when the relative air mass is high, the orange and red color dominates because almost all the violet, blue, green, and yellow light has been scattered leaving only the red and orange hues (wavelengths). The relative amounts of different wavelengths in sunlight combined with the relative amount of scattering by gases in the atmosphere gives us our blue sky. During most of the day when we look at the sky and not at the sun, the light reaching our eyes is scattered sunlight, and blue is the predominant color. Aerosols in the sky tend to make the sky look less blue and more milky.

What To Do and How To Do It

1. Organize the class into working groups of three students per group.
2. Select a day that is sunny. Unless your school is at relatively high latitude (higher than ~ 50˚ N or S), this activity is best done before mid morning or after mid afternoon.
3. Find a flat site outside that will not be shaded during the activity. Place a solar gnomon (wooden dowel or other straight object) at least 50 cm in height in the ground. Use a string with a weight on the end or a level to make sure that the pole is perpendicular to the ground. Measure the length of the gnomon above the ground and record it on the *Calculating Relative Air Mass Work Sheet*. Next, measure the distance from the top of the pole to the end of the shadow. This is the hypotenuse of the triangle. Use a tape measure or a string to measure the distance. Have the three students in each group do this reading independently and record the readings on the *Calculating Relative Air Mass Work Sheet.*
4. Have students average the hypotenuse lengths.

Figure AT-AM-2A: Simple Model of Relative Air Mass

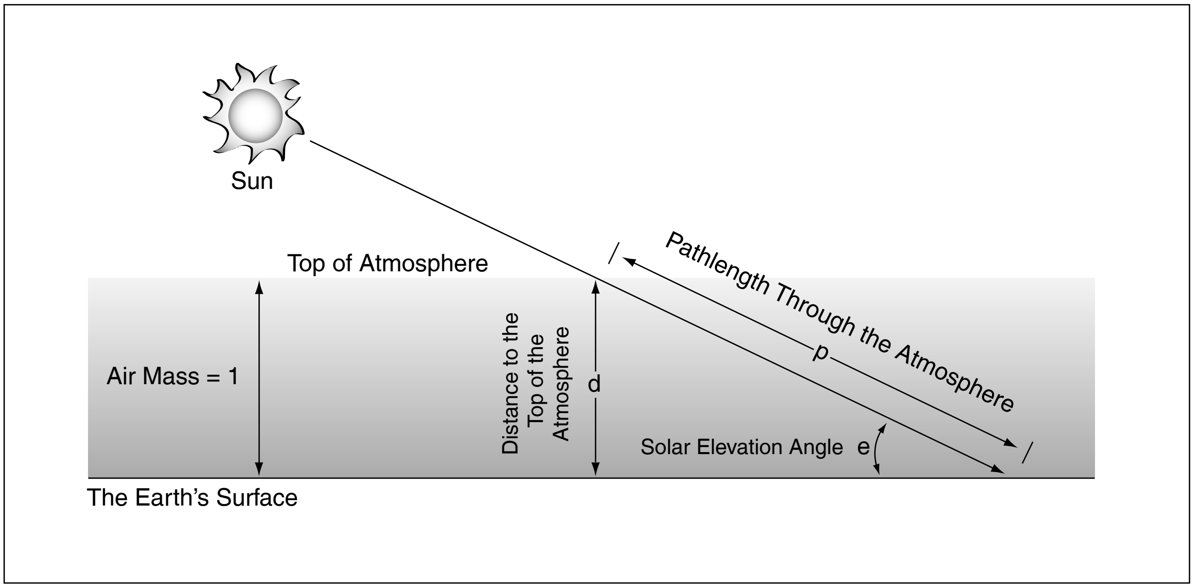
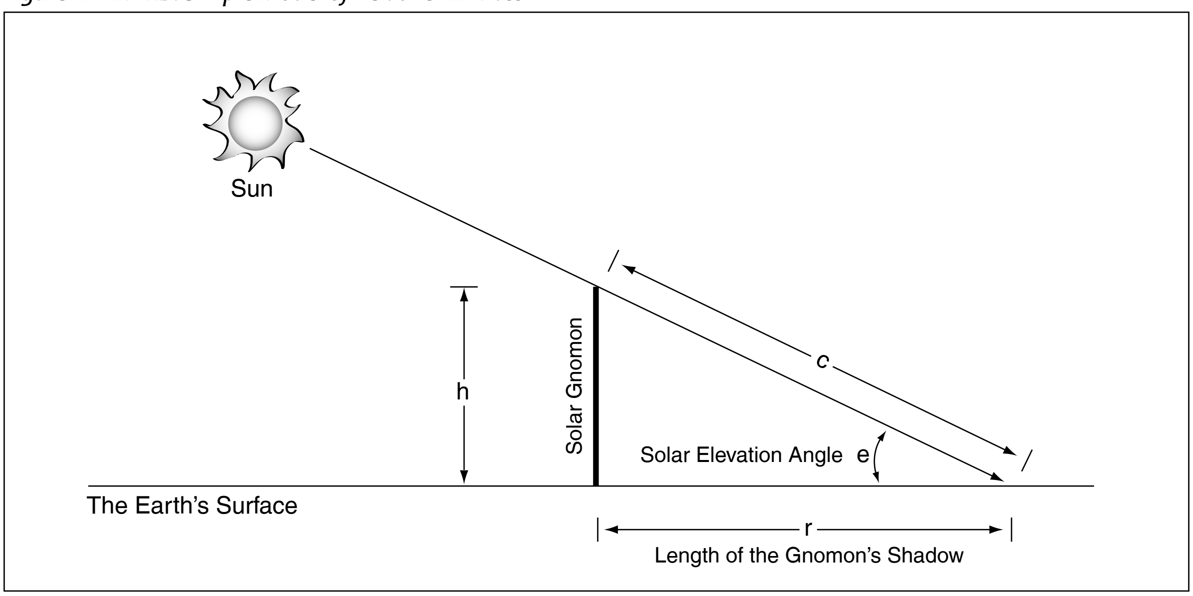


Figure AT-AM-2B: Simple Model of Relative Air Mass



Deriving Relative Air Mass

1. Calculate the relative air mass value for each of five days using Equations 1 or 2.
2. Ask students the following questions: How do you think the relative air mass readings might change if your readings were taken at different times throughout the day? How might relative air mass readings taken at the same time of the day, differ at different times of year?

Variations for Older Students

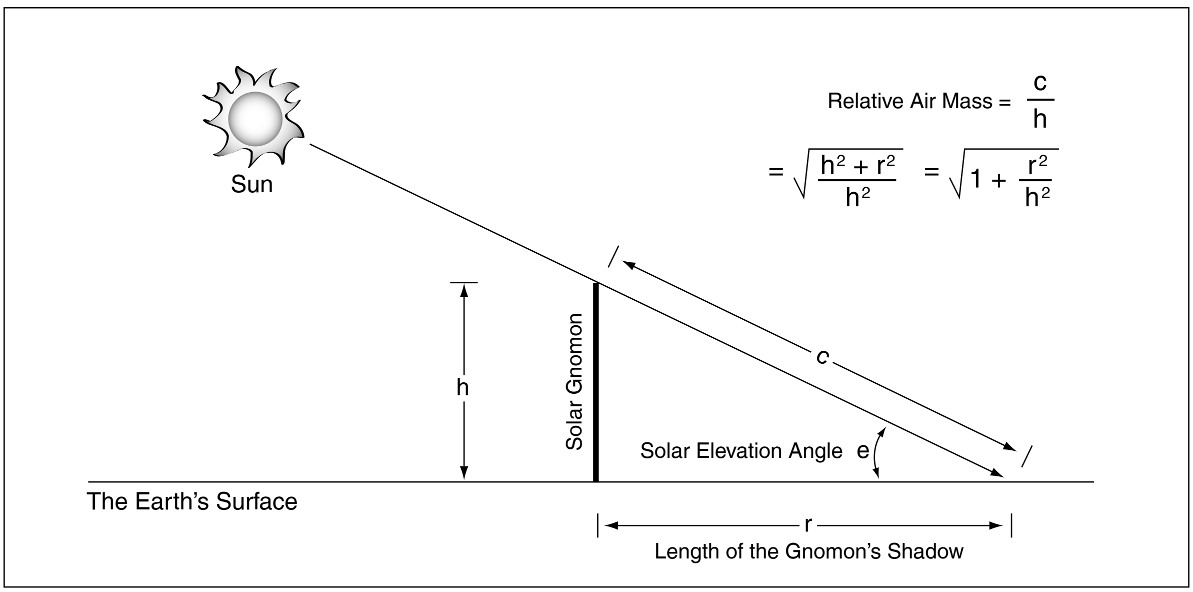
Have students measure and average the length of the shadow instead of the hypotenuse and calculate relative air mass using Equation 2.

Have students measure the solar elevation angle and use Equations 3 and 4 to calculate relative air mass.

Calculating Relative Air Mass
Data Sheet

1. During a day that will be sunny in the morning, set up a solar gnomon outside. Work in groups of three and measure the height of the gnomon and length of the hypotenuse of the triangle formed by the solar gnomon and the shadow it casts using a meter stick, or if the shadow is very long, a tape measure. Have another member of your group help you by holding the meter stick or tape measure at the top of the pole while you read the length at the end of the shadow. Have each member of your group make these measurements. Record the name of the student in your group and each of your measurements in the table below.

Student Name	Local Time	Universal Time	Pole Height (h)	Hypotenuse Length (c)
1.				
2.				
3.				
		Average		



2. Calculate the average hypotenuse length by taking the sum of the readings from the three partners and dividing by 3. Write the average hypotenuse length value for your group on the table above.

3. Calculate relative air mass (m) from the equation. $m = \frac{c}{h}$

4. How do you think the relative air mass reading might change if you took the measurement at different times throughout the day?

5. How might relative air mass readings taken at the same time of the day, but during different seasons differ? Explain.

Studying The Instrument Shelter

Purpose

To discover why the instrument shelter is built the way it is

Overview

Students construct shelters that have varying properties and place them in the same location or place similar shelters in different locations and compare temperature data taken in each shelter. Students should predict what will happen for each of the different shelter designs or placements and perform the steps of student research.

Student Outcomes

Students gain an understanding of GLOBE specifications for the instrument shelter and perform a guided inquiry project.

Science Concepts

Physical Science

Heat transfer occurs by radiation, conduction, and convection.

Geography

Measurements of atmospheric variables help to describe the physical characteristic of an environment.

Atmosphere Enrichment

Measurements of atmospheric temperature are affected by the design and location of the Instrument Shelter.

Scientific Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Develop explanations and predictions using evidence.

Communicate results and explanations.

Time

One class period for discussion of the shelter and design of an experiment. Two to three additional class periods to experiment with model shelters.

Level

All

Materials and Tools

At least one pair of cardboard instrument shelters for each property to be explored (e.g., cereal container, milk container, shoe box).

Two or more identical thermometers

Depending on the number of characteristics to be investigated, the following materials may be needed:

White paint and black paint (to investigate color)

Two paint brushes (if paint is used)

Heavy-duty scissors (necessary if the shelters must be made from sheets of cardboard and also to investigate the purpose of slits in the shelter)

Paper (to compare the effect of having shelters made of different materials)

Two or more thermometers per student group (depending on the number of properties to be tested at the same time)

String

One or more wooden posts, strong enough to be placed in the ground and hold the instrument shelter (shelters can be nailed onto the posts)

Nails (to attach shelters to the posts)

Hammer

Meter stick

The actual GLOBE instrument shelter (If the actual shelter is not available, students should have the picture and physical description of it given in *Instrument Construction, Site Selection, and Set-Up.*)

Preparation

None

Prerequisites

An assembled instrument shelter (highly desirable)

Background

While it may seem that air temperature is simple to measure, it is not necessarily easy for many people around the world to take measurements in precisely the same way so they can be compared with each other. Factors such as wind, sunlight, heat radiating from the ground or nearby walls, and moisture can affect a thermometer. So we must protect these instruments by placing them in a shelter built to a specific set of specifications that shields the thermometer from these different influences while allowing it to sense the air . In addition, where this shelter is placed and how the thermometer is placed inside of it are of critical importance.

By following a consistent approach to the construction and placement of GLOBE instrument shelters, scientists and students can be reasonably certain that the temperature differences reported from various areas over time are due to real differences in air temperature. Of course there are some inevitable variations from site to site and GLOBE permits some exceptions to the stringent requirements for placement of the instrument shelter provided these are documented through comments (also termed metadata) and reported to the GLOBE Data Archive.

What To Do and How To Do It

Day One

1. You should start the discussion by asking students to identify the major characteristics of the GLOBE instrument shelter that could influence the temperature inside it. These include:
   - The color of the shelter;
   - The slits in the sides of the shelter;
   - The materials of which the shelter is made.

   The discussion should turn to why the students think these characteristics are important.
2. The discussion of the physical characteristics of the shelter should be followed by a discussion of the placement of the shelter and the thermometer inside the shelter. Questions to ask are:
   - Why should the shelter be located away from buildings and trees?
   - Why should it be placed over a natural surface, such as grass?
   - Why should it be placed 1.5 meters above the ground?
   - Why should the shelter be oriented with the door facing north in the northern hemisphere and south in the southern hemisphere?
   - Why is the thermometer not supposed to touch the shelter?

Students should predict the effect that each of the above parameters has on the measurement of temperature (e.g., if the shelter is mounted above pavement instead of grass the temperatures measured will be greater). Then it will be time to test their predictions.

Day One/Day Two (depending on how long the discussions take)

1. Students should be divided into teams. The number of teams will be determined by the number of properties to be investigated, the availability of materials, and the number of students. Up to eight teams could be formed to explore the eight basic parameters discussed above. The more students can be allowed to decide what to investigate and how to investigate it, the closer they are coming to doing full student inquiry.
2. Each team should construct two shelters. This is a simple task if students use ready-made boxes such as oatmeal or shoe boxes, but will be more complicated if they must make shelters from sheets of cardboard.

   If shelters are made from sheets of cardboard, the actual design of the shelter (whether it is a cylinder, like an oatmeal box, or a rectangle, like a shoe box) is not as important as the fact that all shelters should be as close to the same design and size as possible. This is a key lesson in designing student research projects. You always want to keep as many factors the same as possible and choose one to change in a systematic way.

3. Each team should choose or is assigned a property to explore. For those investigating the physical properties of the shelter, further work on the shelter will be necessary. The following are possible alterations to shelters to study their properties:
   – Paint one shelter white and one black;
   – Make one shelter with slits and one without (paint both white);
   – If you are using ready-made boxes, then use white paper to construct a shelter of similar shape and size to the cardboard one. Paint the cardboard shelter white.
   Use a tin can and a box of the same size and shape.
4. Shelters should be mounted on posts near one another and at the same height above the ground unless a team is investigating the effect of shelter height or location. For most teams, the posts do not need to be more that a meter high. The team investigating shelter height above the ground should mount one shelter sitting on the ground and the other one on a post approximately 1.5 meters high.
5. Each team should be given two identical thermometers. Prior to placing the thermometers in their shelters, the students must make sure that the thermometers read the same temperature while indoors. If they do not, then they should switch thermometers to get a pair that do read the same or the students should note the difference between them and adjust their measurements accordingly. For instance, if thermometer A reads 18.0˚ C and thermometer B reads 19.5˚ C when they are next to each other in the classroom, then students should subtract 1.5˚ C from every reading taken with thermometer B during their experiment. Since this is a learning activity, it is not important that the thermometers be calibrated as they must be to take GLOBE data.

Day Three/Day Four

1. Choose a day that is mostly sunny and, ideally, slightly breezy. For most comparisons, you do not want an overcast, rainy, or snowy day.
2. Each team should record the starting temperature of their thermometers. (Again, these should be the same or the differences noted.)
3. Then the thermometers should be placed in the shelters in such a way that they do not touch the cardboard (or paper) surface (unless, of course, the group is exploring the effect of the thermometer touching the shelter wall). If ready-made cardboard boxes are used, the thermometer can be hung by a string from the top of the shelter.
4. Each team should take its two shelters (with thermometers in them) outside. The teams investigating the physical properties of the shelter (color, slits, material) should find an open area away from buildings, preferably an open field. Teams investigating the placement of the shelter will split into two subgroups. One group will place its shelter in an appropriate area (grassy area, away from buildings). The other group will place its shelter in a non-ideal location. That is, to investigate the effects of shelter placement, place:
   One shelter in an ideal location, one next to the sunny side of a building, one in the middle of a parking lot, or other paved or asphalt surface one shelter at 1.5 meters above the surface, one on the ground at the base of the post.
5. Students should record the temperature from each thermometer about five minutes after placing their shelters. They should then wait another five minutes

and record the temperatures again. Temperatures should continue to be recorded at approximately five minute intervals, until the temperatures in the shelters have stabilized and do not change over two successive readings. Note that this may not necessarily take the same amount of time for both shelters. That is, it may take one thermometer longer to reach the maximum temperature than the other. Therefore, it is important to check both thermometers.

6. Once the temperature has stabilized in both shelters, the students can bring their shelters and their recorded temperatures back to the classroom.
7. Each team should give a brief report of what it found to the entire class and then discuss their results.
8. Each team should write a brief report showing its recorded temperatures. The team should discuss its findings in terms of how the particular parameter investigated affects the temperature and provide any conclusions they can justify about why this is true.

Adaptations for Older Students

For older students: Older students can explore which of the parameters is most important by quantitatively comparing the results from the different pair comparisons. The may also test the combined effect of different changes by making more than two shelters in various categories.

For example, they could test the combined effects of color and ventilation by making one black and one white shelter without slits and one black and one white shelter with slits. They can also explore what effect different weather conditions have on their results. For instance, the experiment could be performed on both a clear day and an overcast day or a calm day and a windy day.

Students could also examine sets of three or more shelters. An example of this might be to place identical shelters next to a building, 5 meters from the building and 10 meters from the building; or there might be shelters with no slits, a few slits, and many slits.

Student Assessment

Students' understanding of the importance of the shelter design and placement can be assessed in terms of:

- The conclusions they draw in their oral and written reports;
- The understanding they show during the class discussions;
- Their ability to deal with such additional questions as: What would be the effect on the white shelter if it became covered with a heavy layer of dust?;
- The validity of the measurements they take.

Students' progress in inquiry can be assessed in terms of:

- Participation and creativity in experiment design;
- Use of math and being quantitative in their analysis;
- How logical is students' reasoning in reaching their conclusions;
- How students discuss and reason about possible extensions to the project.

Building a Thermometer

Purpose

To build an instrument that can be used to measure water temperature

Overview

Students will construct a soda-bottle thermometer, which is similar to the thermometer used by GLOBE schools. Both are based on the principle that most substances expand and contract as their temperature changes. This experiment also demonstrates the principle of heat transfer.

Student Outcomes

Student will understand why and how a standard thermometer works.

Science Concepts

Physical Science

Substances expand and contract as they are heated and cooled.

Geography

The temperature variability of a location affects the characteristics of the physical geographic system.

Scientific Inquiry Abilities

Identify answerable questions.
Design and conduct scientific investigations.
Construct a scientific instrument.
Develop explanations and predictions using evidence.
Communicate results and explanations.

Time

Two class periods

1. To do experiment - one class period
2. To discuss principles of expansion, contraction, and heat transfer through conduction and convection – 15 to 30 minutes
3. To record class data onto board or overhead and make graphs – 30 minutes
4. To have each group present to the class their results, ideas for other variables to test, and any problems that they encountered – 30 minutes

Level

Intermediate

Materials and Tools

(per group of students)

Ice
Water
One liter plastic soda bottle
Clear or white plastic drinking straw
Modeling clay. A one-pound block of modeling clay should be enough for 25 to 30 thermometers
Two 2-liter plastic soda bottles – the tops of these bottles need to be cut off
Scissors or knife to cut the top off the 2-liter plastic bottles
Food coloring (yellow does not work as well as red, blue, and green)
A watch or clock with a second hand
A metric ruler
A marker, grease pencil, or pen to mark the side of the straw
Building a Thermometer Activity Sheet

Preparation

Assemble materials.

Review principles of heat transfer.

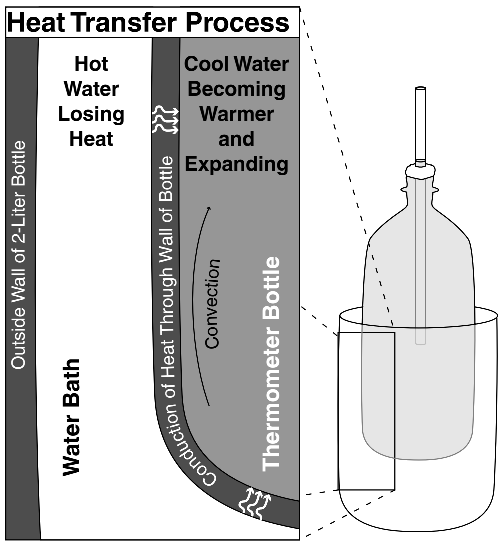
Prerequisites

Ability to make a graph

Background

Several scientific principles are at work in this activity. One is the principle of expansion and contraction. Most substances expand when heated and contract when cooled. Over the range of temperatures in this experiment, water too expands when heated and contracts when cooled. (As water approaches its freezing point, it again expands.)

Figure AT-TH-4



Substances expand when heated because their kinetic energy, or energy of movement, increases with temperature. The molecules move faster and spread farther apart, causing the material to expand. When the substance is cooled, molecular movement decreases and the substance contracts.

In the case of water, the coefficient of expansion is quite small, so the volume of the water increases by only a very small percentage. Nonetheless, because all of the increase in volume is channeled into the small-diameter straw, the expansion can be seen.

This experiment also illustrates heat transfer by conduction. Conduction occurs when energy is transferred from one molecule to the next by direct contact, such as when the metal handle of a pan becomes hot. Metals are good conductors of heat. Wood is a poor conductor. In this experiment, the warm water in the outer container transfers its heat by conduction through the plastic wall of the one-liter bottle to the water in the inner bottle.

Convection is the large-scale movement of a liquid or a gas which acts to redistribute heat throughout an entire volume. A common example of convection is water boiling in a pot. In this case, the water in contact with the bottom of the pot (where the heat source is) becomes heated and less dense than the water on top of it. This hot water rises, cooler water sinks and is then heated by contact with the bottom of the pot.

Preparation

This activity works well in teams of two or three students. Here are some job assignments and descriptions:

Student 1 Assembler – gathers materials and assembles the thermometer

Student 2 Timer/reporter – keeps track of 2-minute intervals when the experiment starts – makes marks on the straw showing how much the water has moved – measures the straw at the end of the experiment and tells the recorder the measurements – reports to the class the results of the experiment

Student 3 Recorder – records the measurements that the timer has made – also transfers the group's measurements onto the *Data Sheets.*

Make a copy of the *Building a Thermometer* Activity Sheet for each group of students.

The teacher should assemble materials before the class starts. If small groups are to be used, they should be assigned in advance. Students should bring in the 1-liter and 2-liter soda bottles. Allow a week or so to collect the necessary materials if students are supplying the bottles. Review the possible problems below before doing the experiment in class.

Be sure to understand the principles of heat transfer (conduction and convection) and the expansion and contraction of materials. Some examples of each in different situations would be helpful for a discussion. You may need to review how to measure in millimeters with the students.

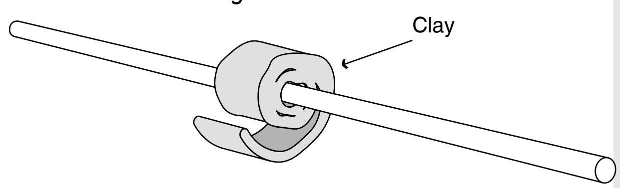
What To Do and How To Do It

This activity can be done as a demonstration but is probably more effective if students or groups of students make their own thermometers. These instructions also appear on the *Building a Thermometer* Activity Sheet in the *Appendix* which can be copied and distributed to students.

Building the Thermometer

1. Fill the 1-liter soda bottle to the very top of the lip with cold tap water.
2. Add four drops of food coloring. This makes the water line easier to see. Blue, green, or red work best.
3. Roll some modeling clay into a small ball about 25 mm in diameter. Then roll it out so that it forms a cylinder about the length and diameter of a pencil. Flatten the pencil-shaped clay into a thick ribbon. Wrap the ribbon around the mid-point of the straw. See Figure AT-TH-5.

Figure AT-TH-5



Team Data Sheet *measurements in millimeters*

2 minutes	
4 minutes	
6 minutes	
8 minutes	
10 minutes	

Class Data Sheet

	Group A	B	C	D	Average
2 minutes					
4 minutes					
6 minutes					
8 minutes					
10 minutes					

4. Place the straw into the bottle and use the clay to seal off the bottle. Be careful not to pinch the straw closed. You also do not want any holes or cracks in the clay that would allow water to escape. One half of the straw will be inside the bottle and one half will be outside the bottle. Press the clay plug into the neck of the bottle far enough to force the water level up into the straw so that it can be seen. See Figure AT-TH-6.

Experiment

1. Place the filled one-liter bottle (soda-bottle thermometer) into one two-liter plastic bottle container. Place a mark on the straw where you see the water line.
2. Fill the 2-liter container with hot tap water. Wait two minutes. Mark the straw at the water line. Repeat this marking every two minutes, for ten minutes. At the end of the ten minutes, use a ruler to measure the distance of each mark from the original water mark at the bottom of the straw. Record your measurements on the Team Data Sheet.

   Watch closely for any changes. Do you see any? Describe what you observe.
3. Put ice and cold water into the second two-liter container.
4. Place the thermometer bottle into the ice water. Record your observations.
5. What happens to the water level in the straw when the thermometer is placed in hot water? (Answer: It rises about 4 cm if there's a 25 degree C difference.)

   What happens to the water level when the thermometer is placed in cold water? (Answer: It falls.)
6. Explain why you think this is happening.
7. Using your answer to question 6, how does the maximum-minimum thermometer, used for the noon temperature measurements for GLOBE, work?
8. What are two other things (variables) that, if changed, might cause this experiment to work differently? (A few answers: the amount of water touching the soda-bottle thermometer, the temperature of the water, the size of the container, the diameter of the straw.)

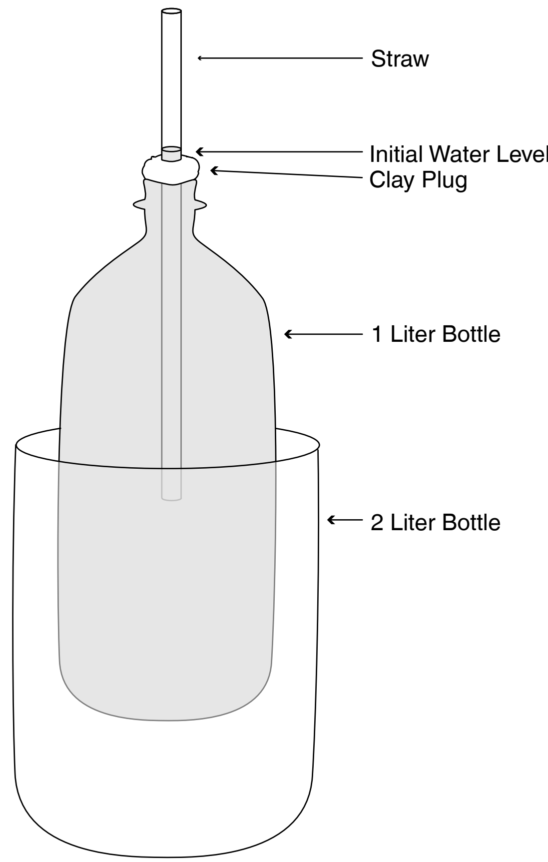


Figure AT-TH-6

9. Graph the measurements that you recorded on your team data sheet. The x-axis (horizontal) should be the time (in minutes) and the y-axis (vertical) should be your measurements from the original line before the hot water is added (in millimeters). Be sure to give your graph a title and to label the axes of the graph so that someone else could understand it.
10. Make a class data sheet on a chalkboard or on a sheet of poster paper. Record your data on the *Class Data Sheet*. Combine your data with that of your classmates to find the average movement of water for each two-minute time period.
11. Add the average figures for the movement of water to your graph. Be sure to label this new line. How is the graph of your measurements different from the graph of the class average?

12. Explain the graph. What story does your graph tell? Can you draw any conclusions?
13. Why might it be important to have more than one trial when you are drawing conclusions?

Possible Problems with the Experiment

- The seal with the modeling clay has cracks in it, allowing the water to escape
- If the 1-liter water bottle is not filled to the top, it takes a longer time for the water to move up the straw. Indeed, the water may not move up the straw at all.
- There is not enough of a temperature difference between the water in the 1-liter bottle and the water in the 2-liter bottle. A 25 degree Celsius or larger difference is optimum. If there is a smaller difference, you will not get very large movements on the straw. Hot tap water and cold tap water should have enough of a difference for the experiment to work.
- Students will forget to mark the beginning level in the straw. Be sure that they understand that the mark should be made immediately after placing the 1-liter bottle into the 2-liter bottle, before adding the hot water.
- If you have trouble getting or keeping ice in the classroom, you can omit this part of the experiment or show it as a demonstration.

Adaptations for Younger and Older Students

For younger students: Younger students can make the thermometer apparatus and observe the movement of the water in the straw, but not mark the water level at two-minute intervals. The teacher should cut the two-liter plastic container ahead of time.

For older students: Other variables could be tested, such as different size straws, larger or smaller containers for the hot water, or different size containers for the thermometers. The students could design their own experiment, conduct it, and present their findings to the class. They could calibrate their thermometer with a standard thermometer.

Further Investigations

1. Use a standard thermometer to measure the temperature of the water in the inside of the soda-bottle thermometer and compare it to the temperature of the water outside the thermometer. Does the amount of water movement in the straw change when there are different temperatures? Perform an experiment, keep records, and present your findings to the class.
2. Does the size of the containers affect the way the thermometer works? Design an experiment that tests this concept, do the experiment, and make a chart showing your results.
3. Go to the library and research what materials are used to make different thermometers. Be sure to find out the different principles on which they operate. Present your findings to the class.
4. Call the local weather offices or television or radio stations and see what type of thermometers are used there. Take a trip to visit the weather station. Take pictures and make a poster to share with your class.
5. Make thermometers using different diameters of straws and see if there are any differences. What do you think might have caused any differences you see? Would this have an effect on the construction of real thermometers?
6. Find out how scientists record the temperature at different depths of the ocean. On a map of the oceans, show the average water temperature. Make a chart to share with the class.

Student Assessment

Students should be able to answer the questions in the experiment on the student activity sheet. They should also be able to explain how a thermometer works in class or on a quiz.

Building a Thermometer Activity Sheet

Purpose

To help you understand how and why a liquid-in-glass thermometer works.

Overview

The soft drink bottle thermometer that you construct in this activity is similar to the thermometer you use in the GLOBE Instrument Shelter. However, there are differences. Both use liquids, but the liquids are different. Do you know what liquid is in the standard GLOBE thermometer? Also, the thermometer you will make has no degree markings. But the principles of operation are the same for both types of thermometers.

The thermometer you use for measurements and the instruments you will build are both based on the principle that substances expand and contract as their temperature changes.

This lab also demonstrates the principle of heat transfer. When a warm object is placed against a cold object heat is transferred from the warm object to the cold object by conduction. For example, in the winter if you place your bare hand on the fender of an automobile, your hand transfers heat to the metal by conduction.

Usually when you work in a job, you are part of a team. In this activity you will also be part of a team. Here are your job descriptions:

Student 1 – assembler - gathers materials and assembles the thermometer

Student 2 – timer/reporter - uses clock or watch to keep track of 2-minute intervals when the experiment starts - makes marks on the straw showing how much the water has moved - measures the straw at the end of the experiment and tells recorder the measurements - reports to the class the results of the experiment

Student 3 – recorder - records the measurements that the timer has made - also transfers the group's measurements onto the class chart

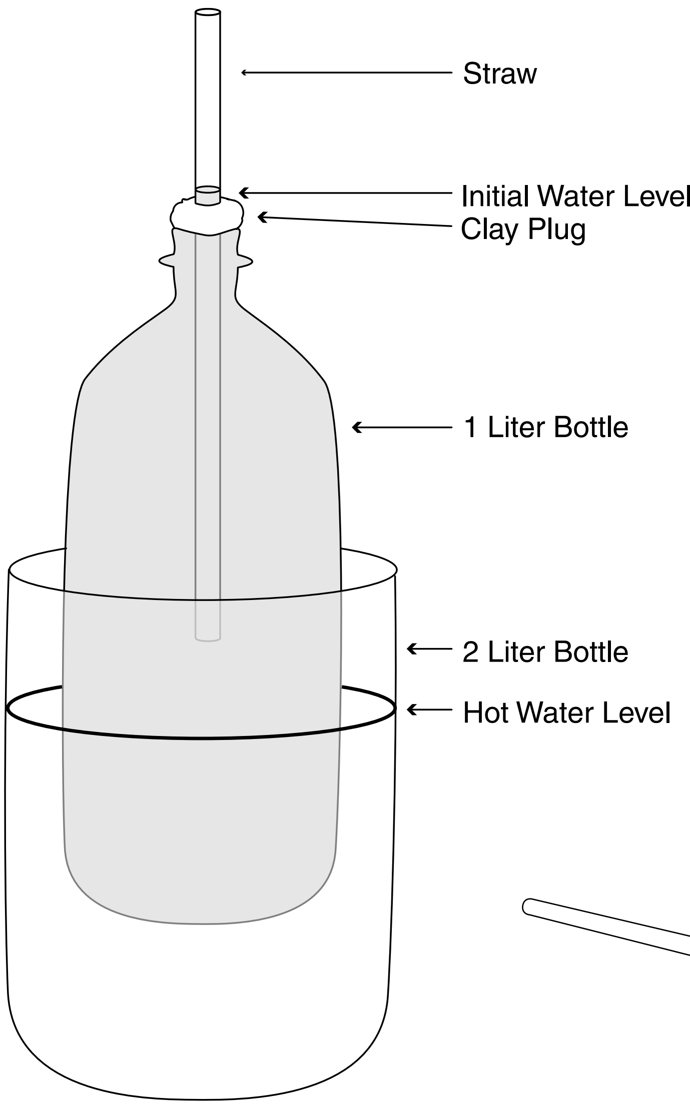
Materials and Tools

(per group of students)

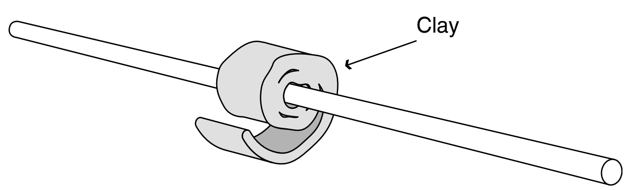
Ice
Water
One liter plastic soda bottle
Clear or white plastic drinking straw
Modeling clay (a ball about 25 mm in diameter)
Scissors or knife to cut the top off the two liter plastic bottle
2 two-liter plastic soda bottles - the top of the bottle needs to be cut off so that it is used as a container to hold water and the 1 liter plastic soda bottle
Food coloring (yellow doesn't work as well as red, blue, and green)
Watch or clock with second hand
Metric ruler
Marker, grease pencil, or pen to make marks on the side of the straw

Building the Thermometer

1. Fill the one liter soft drink bottle to the very top of the lip with cold tap water.
2. Add four drops of food coloring – this helps make the water line easier to see. Blue, green, or red work best.



3. Roll some modeling clay into a small ball about 25 mm in diameter. Then roll it out so that it forms a cylinder about the length and diameter of a pencil. Flatten the pencil-shaped clay into a thick ribbon. Wrap the ribbon around the midpoint of the straw.
4. Place the straw into the bottle and use the clay to seal off the bottle. In doing this, be careful not to pinch the straw closed. You also do not want any holes or cracks in the clay that would allow water to escape. One half of the straw will be inside the bottle and one half will be outside the bottle. Press the clay plug into the neck of the bottle far enough to force the water level up into the straw so that it can be seen.



Experiment

1. Place the filled one liter bottle (the soft drink bottle thermometer) into the empty two liter plastic bottle container. Place a mark on the straw where you see the water line.
2. Fill the two liter container with hot tap water. Wait two minutes. Mark the straw at the water line. Repeat this marking every two minutes, for ten minutes. At the end of ten minutes use a ruler to measure the distance of each mark from the original water mark at the bottom of the straw. Record your measurements in millimeters under “hot water” in the table below.

Team Data Sheet

Time	*Hot Water*	*Cold Water*
2 minutes		
4 minutes		
6 minutes		
8 minutes		
10 minutes		

Watch closely for any changes. Do you see any? Describe what you observe.

____

____

3. Put ice and cold water into the second two-liter container.
4. Place the thermometer bottle into the ice water. Record your observations in millimeters under "cold water" in the table above.

5. What happens to the water level in the straw when the thermometer is placed in hot water?

____

____

____

What happens to the water level in the straw when the thermometer is placed in cold water?

____

____

____

6. Explain why you think these changes happen.

____

____

____

7. Using your answers to question 6, how does the maximum-minimum thermometer used for the GLOBE measurements work?

8. What are two other things (variables) that, if changed, might cause this experiment to work differently?

9. Graph the measurements that you recorded in your team data sheet at step number 2. The x-axis (horizontal) should be the time (in minutes) and the y-axis (vertical) should be your measurements (in millimeters) from the original line before the hot water was added. Be sure to give your graph a title and to label the axes of the graph so that someone else could understand it.

10. Record your data on the *Class Data Sheet* on the board or as your teacher instructs. Combine your data with that of your classmates to find the average movement of water for each two-minute time period.

11. Add the average figures for the movement of water to your own graph. Be sure to label this new line. How is the graph of your measurements different from the graph of the class average?

12. Explain the graph. What story does your graph tell? Can you draw any conclusions?

13. Why might it be important to have more than one trial when you are drawing conclusions?

Cloud Watch

Purpose

To explore the connections between cloud type, cloud cover, and weather and stimulate student interest in taking cloud type observations

Overview

Students observe cloud type and coverage and weather conditions over a five-day period and correlate these observations. Students make and test predictions using these observations.

Student Outcomes

Students learn to draw inferences from observations and use them to make and test predictions.

Science Concepts

Earth and Space Science

Weather changes from day to day and over the seasons.

Clouds affect weather and climate.

Geography

The nature and extent of cloud cover affects the characteristics of the physical geographic system.

Atmosphere Enrichment

Clouds help us to understand and predict the weather.

Scientific Inquiry Abilities

Identify answerable questions.

Design and conduct scientific investigations.

Develop explanations and predictions using evidence.

Communicate results and explanations.

Time

Ten minutes, one to three times per day for five days; plus one-half to one class period for discussion

Level

All

Materials and Tools

GLOBE Cloud Charts

Preparation

None

Prerequisites

None

What To Do and How To Do It

Over a five-day period, students should carefully look at the clouds and write down what they see in their GLOBE Science Logs. If they do not yet know the names of the clouds, they can try to match them with the clouds on the cloud chart or they can write down what the clouds look like. It is best if they can check the sky three times per day: once in the morning (on the way to school); once at midday (around lunchtime); and once in the late afternoon or early evening (perhaps on the way home from school). The exact times of each observation are not critical, although it will help if the observations are made at roughly the same time each day. (For example, the morning observations should all be made around 8 a.m., rather than at 7 a.m. one day, and 10 a.m. the next day. The same is true for the noontime and afternoon or evening observations). If students can make only one observation, it is best to choose the one within one hour of local solar noon.

At the end of each day, students should also record the weather for that day. Was it a rainy morning and clear afternoon? Did it snow all day? Was it calm and humid? The students do not need to quantify their weather reports (i.e., they don't have to write down "21 millimeters of rain" or "79% relative humidity"), but should describe the weather as completely and clearly as possible.

As the students record their cloud and weather observations, they should look for any patterns. For example, are altocumulus clouds in the morning typically followed by afternoon thunderstorms? Are small puffy clouds in the morning or at mid-day ever associated with precipitation later in the day? Are isolated morning contrails followed by extensive cirrus or altocumulus clouds later in the day?

After a week of recording clouds and weather, ask students to use their observations to predict the weather. Can they predict in the morning what the afternoon weather will be? Can they predict the weather for the following day? Ask students to explain why they made the predictions they did. Have each student keep track of how well they do in forecasting the weather. They may develop a new respect for the difficulty of forecasting!

Frequently Asked Questions

What if the cloud and weather conditions are the same for five days in a row?

This can happen in some places and at certain times of year. If you need to move on to other topics, you can have students discuss their observations without making predictions and go on.

In predicting weather, predicting that tomorrow will be the same as today is known as a persistence forecast, and it is generally correct more than half the time. For a forecasting system to have skill it must be more accurate than a persistence forecast over a period of months and years.

Other approaches are to have students extend their observations beyond five days until they have observed a variety of cloud types and weather conditions. Sometimes weather patterns lock in place for a month or more, so you may have more success by having students resume taking measurements at a later date.

Constructing a Model of ppbv of Surface Ozone

Purpose

To construct a model that will provide students with a visual representation of parts per billion by volume of surface ozone in the air

Overview

Students will work in teams to construct cubes of different volumes and to compare them to get a feel for parts per million by volume and parts per billion by volume.

Student Outcomes

Students gain a feeling for the small quantities of gases, such as ozone, present in the Earth's atmosphere.

Science Concepts

Earth and Space Science

The atmosphere is made up of different gases and aerosols.

Atmosphere Enrichment

The concentration of surface ozone in the atmosphere is variable.

General

Scale models help us understand concepts.

Scientific Inquiry Abilities

Identify answerable questions.
Use appropriate tools and techniques.
Use appropriate mathematics to analyze data.
Develop and construct models using evidence.
Communicate procedures and explanations.

Time

Two to three class periods

Level

Middle and Secondary

Materials and Tools

Copies of cubic patterns to construct
Scissors
Clear tape
Metric rulers marked in mm
Meter sticks
Clear tape
Centimeter blocks to form cubes of different sizes
Model of Cubic Meter-Oaktag or cardboard with cm cube pattern, dowels, corner pieces, and tape or Velcro

Preparation

Copy sheets with patterns for students to construct models of different sized centimeter cubes.

Construct and display a model of one cubic meter.

Prerequisites

Ability to accurately measure in mm, cm, m

Ability to calculate the area of rectangle

Introduction

Scientists in every scientific field construct models to picture things that they cannot directly observe. Examples of such models are scale models of the solar system or of molecules and atoms. This activity focuses on constructing a model of chemical mixing ratios in parts per million by volume and parts per billion by volume. In *Hydrology*, the learning activity *Modeling Your Watershed* is another example of constructing a physical model to help understand the environment.

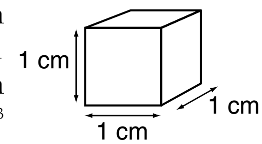
Student educational experiences may vary, so some instruction may be required to understand a model of parts per billion by volume (ppbv). The first activity is designed to provide a hands-on exploration of cubic centimeters and to teach students how the volume of a cube is calculated. It starts with a very basic model, in which students can directly see and count the component parts. The activity moves to a model in which some of the components are hidden and must be inferred or the model dismantled to reveal the components inside in order to determine the volume. This initial activity provides a common foundation from which a group of students may explore more complex cubic models of volume. Centimeter blocks may be used to demonstrate the volume of different sized cubes. In the event none are available, a pattern with directions for constructing cardboard models has been provided in the Appendix.

Students enter a classroom with varied mathematical backgrounds. To develop a common level of understanding, students may be introduced to cubic volume beginning with cubes having a height (h), width (w) and depth (d) of one centimeter. This will develop the rudimentary concept of a cubic centimeter as one unit.

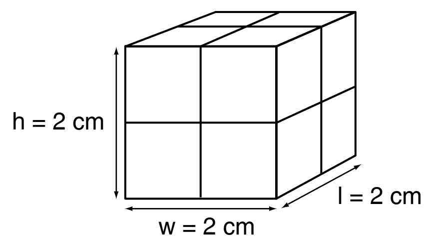
What To Do and How To Do It

Ask the class if they know what a part per billion is. Allow for a brief discussion, but expect this concept to be new to students.

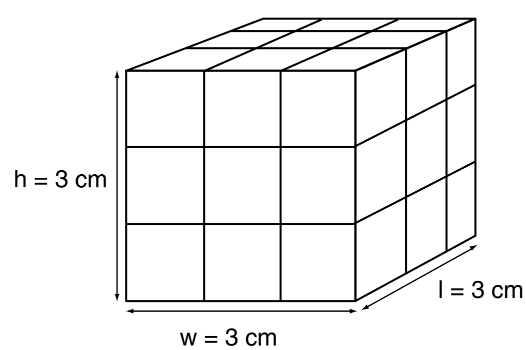
Have each team look at a one cm cube. Ask the students to measure and record the length, width and height of their cube. Define for the students that a cube with the dimensions 1 cm x 1 cm x 1 cm has a volume of 1 cubic centimeter, which can be written as 1 cm^3 (or 1 cc).



Have the groups of students assemble a cube 2 cm x 2 cm x 2 cm Ask them to determine the volume of this cube. Ask them to identify whether they counted, added, or multiplied to get their answer and let them briefly discuss their choices.



Have the groups of students assemble a cube 3 cm x 3 cm x 3 cm. Ask them to determine the volume of this cube. Ask them to identify whether they counted, added, or multiplied to get their answer, and let them briefly discuss their choices. Ask them if they would be willing to count or add to get the volume of a much larger cube.



Have the groups of students assemble a 5 cm x 5 cm x 5 cm cube. Ask them to determine the volume of this cube. Ask each group how they got the volume of their cube. The volume equals 125 cubic centimeters or 125 cm^3.

How many blocks within the cube can you see?

How many cubes do you think are not visible, but you know are inside the cube?

How can you calculate the volume of this cube?

How can you prove that your calculation of the volume of this cube is correct?

Introduce the cubic meter model. Have each group place a single one-cubic-centimeter cube on the cubic meter.

How many one cubic centimeter cubes does it take to fill a cubic meter? Answer: (1 million)

Explain to the students that the cube (one cubic centimeter) is one part per million by volume of the cubic meter.

Give the students a one-cubic-millimeter cube cut from cardboard. Have them place it in one of the cm cubes marked on the cubic meter.

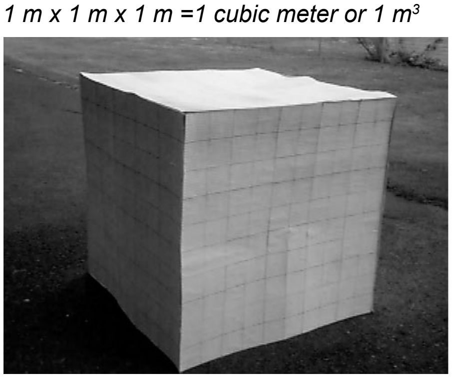
How many one cubic millimeter cubes will it take to fill a cubic centimeter? Answer (1 thousand)

How many to fill a cubic meter? Answer (1 billion)

Explain that this means that the 1 mm cube is one part per billion by volume of the cubic meter.

Inform the students that they will be (or are) measuring ozone concentrations of parts per billion by volume, and have the students discuss in their groups how one part per billion of a cubic meter relates to the concentration of ozone that they will be measuring. Have the groups share their ideas with the class.

Cubic Meter
1 m x 1 m x 1 m =1 cubic meter or 1 m^3



Student Sheet

The student sheet shows the steps to follow to determine the volume of a cube. These directions follow those in the *What To Do and How To Do It* section of the teacher's lesson plan. The students will need the cubic meter to complete the challenge section of the student sheet.

Extension Activity

In this extension of the ppb activity, students will represent the amount of ozone they measure in the atmosphere as a portion of the total volume of their classroom.

Materials

- Model of one cubic meter set up in classroom
- One set of metric blocks per team or copies of the patterns on thin cardboard
- Ozone data from your school or another local source such as a GLOBE school or a newspaper article
- Scissors and glue, to enable each team to make their own models for problem solving
- Student sheets to review and complete as a team after the lesson is introduced

Student Preparation

Organize the class in teams of 3-4 students and have each team decide who will be the recorder, facilitator, engineer and reporter. If possible, each student should be given the chance to play each role.

Provide each team facilitator with copies of the student sheets for each team member.

Provide each engineer with the materials and directions needed to construct models and to complete the problem-solving activities.

Recorder- takes notes for the team

Facilitator- gets the directions the team will be following and makes sure that everyone on the team understands the directions. This person also encourages all team members to share ideas and be involved in the processes used by the team.

Engineer- gets the materials and guides the construction of models.

Reporter- the spokesperson for the team and presents the team's work to the whole class.

What To Do and How To Do It

Have the students measure and calculate the volume of their classroom in cubic meters. Then, have them determine how many cubic millimeters they would need to physically represent the concentration of ozone in ppb they measured outside.

Procedure:

1. Measure the length, width, and height of the classroom in meters. Multiply the length x width x height to determine the total cubic meters of air in the classroom
2. Make a model of the parts per billion of surface ozone measured outside during that day for each cubic meter of air identified in the classroom. This is done by multiplying the amount of surface ozone in ppb outside by the number of cubic meters in the classroom.
3. Hang the parts per billion of ozone measured for each cubic meter of air in the classroom. This model will demonstrate the amount of ozone that would exist in a volume of atmosphere the size of the classroom. If you are not yet collecting ozone data, look up a daily ozone measurement for a nearby GLOBE school or look in the newspaper for a local ozone value.

   Example: Students have measured 20 ppbv as the concentration of ozone. The classroom is 6 meters wide by 9 meters long by 3 meters high for a volume of 6 x 9 x 3 = 162 m^3. 20 billionths of this volume is 3,240 mm^3 or 3.24 cm^3. So to represent the amount of ozone measured, the students would hang 3 cubic centimeter cubes and 240 cubic millimeter cubes or 3,240 cubic millimeter cubes. As an alternative, students could construct 20 cubes scaled to be 1 billionth the volume of the classroom (i.e., 6 mm x 9 mm x 3 mm).

Student Assessment

Rubric for assessing GLOBE Student Science Log

Checklist for team collaboration

Science Log Question: *You have been asked to explain your surface ozone measurement of 55 ppbv. Write a description of ppbv that will explain the measurement and give a visual image of how much a ppbv represents in the atmosphere.*

The sample rubric may be used to assess the student's response in the journal. It is assessed after students have shared and had time to add changes in their thinking as a result of their discussions. Provide the students with a copy of the sample rubric (or another model you may develop with the students to define the criteria for assessing their response.

Helpful Hints

Monitor team discussions and help them clarify points as they work through the above activities.

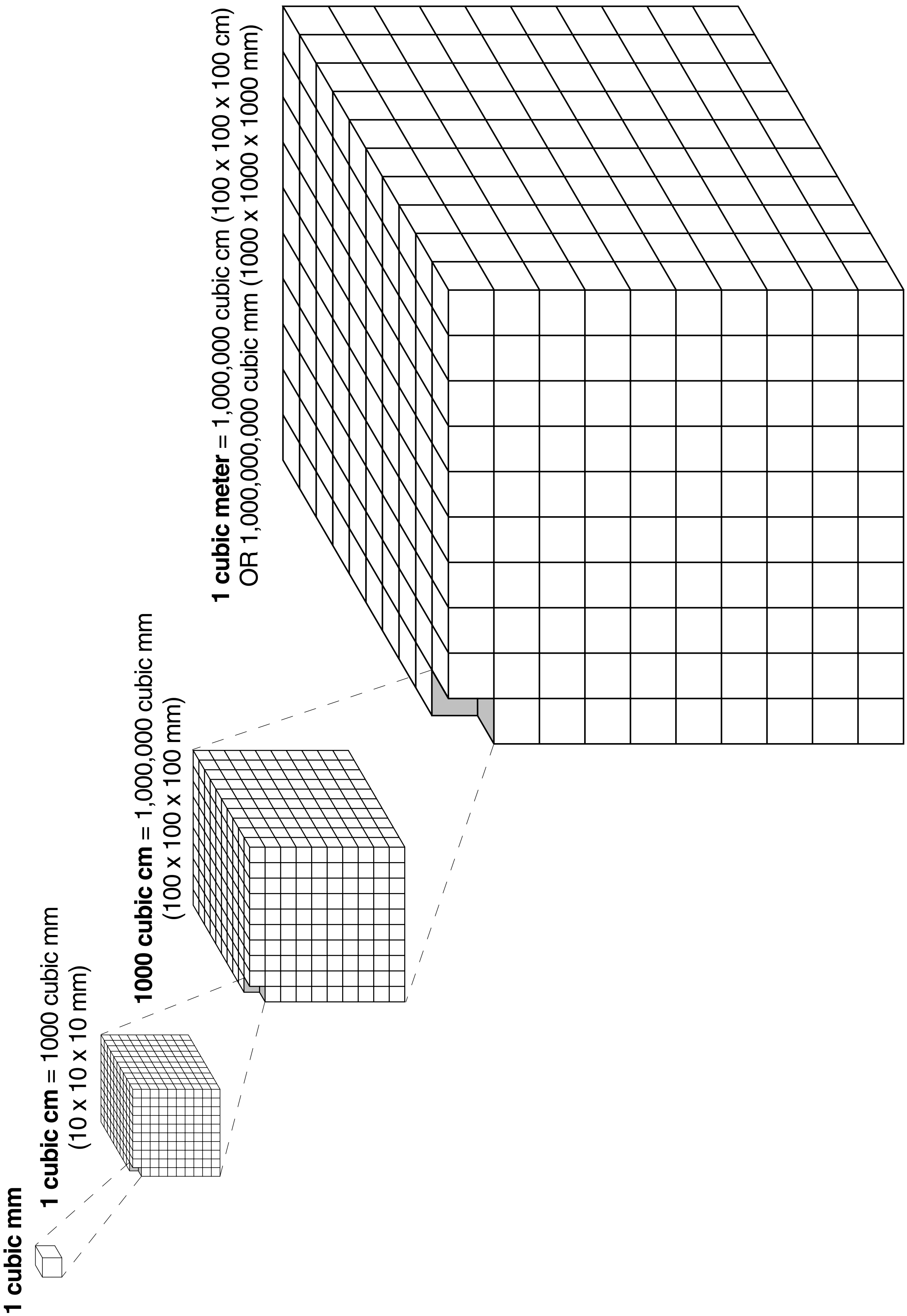
Frequently Asked Questions

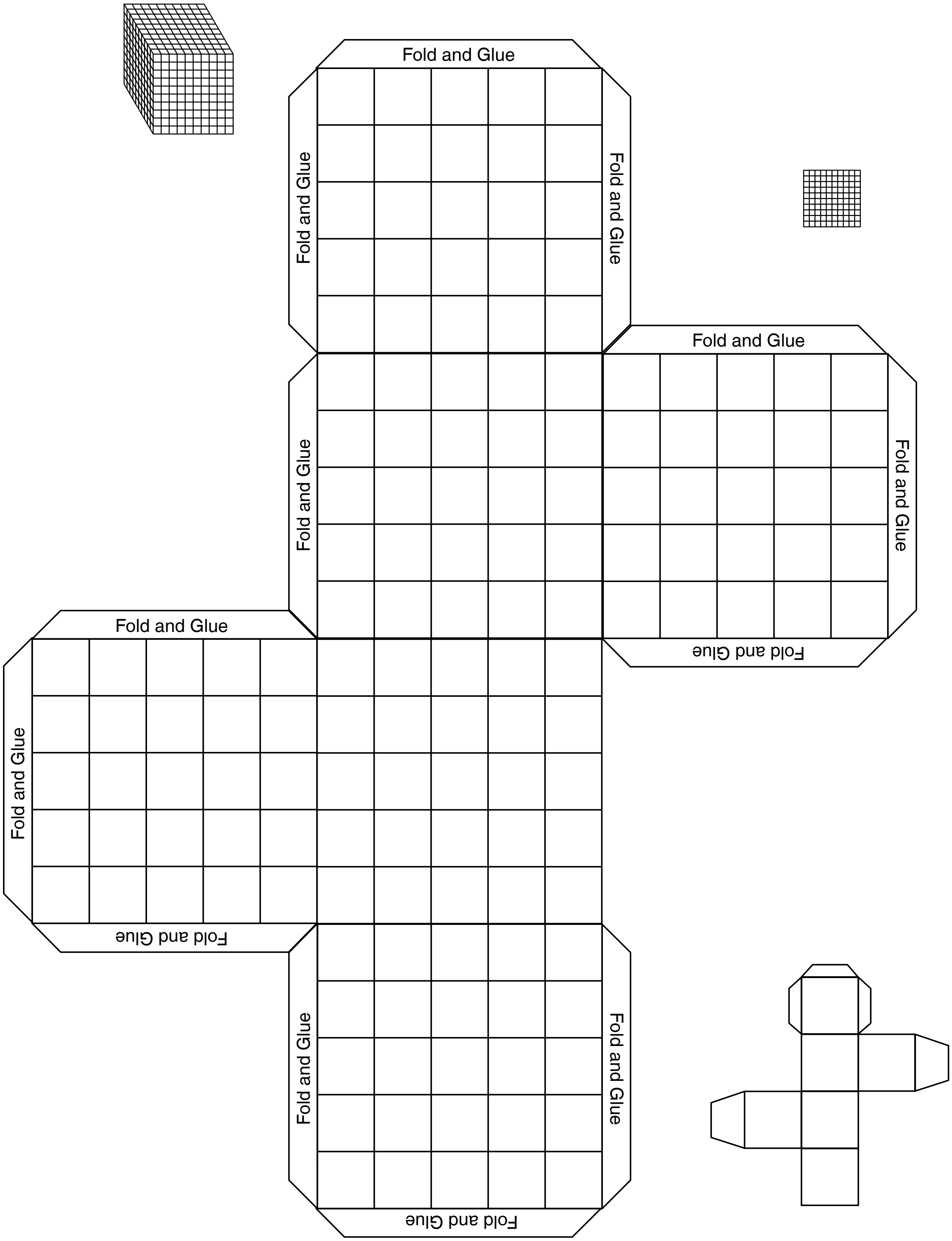
1. What is a safe level of surface ozone for us to breathe?

The U.S. Environmental Protection Agency has established as unhealthy an ozone concentration that exceeds 80 ppbv for eight hours or more.

2. Is there as much surface ozone inside our classroom as there is outside?

No, surface ozone would be more concentrated outside than inside the classroom. It is destroyed when it comes in contact with the building and other objects outside.


1 cubic mm
1 cubic cm = 1000 cubic mm
(10 x 10 x 10 mm)
1000 cubic cm = 1,000,000 cubic mm
(100 x 100 x 100 mm)
1 cubic meter = 1,000,000 cubic cm (100 x 100 x 100 cm)
OR 1,000,000,000 cubic mm (1000 x 1000 x 1000 mm)


Fold and Glue
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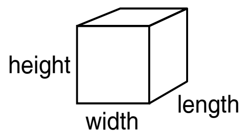
Constructing a Model of ppbv of Surface Ozone

Work Sheet

1. Look at the small cube. What is the length (l), width (w), and height (h) of the cube?



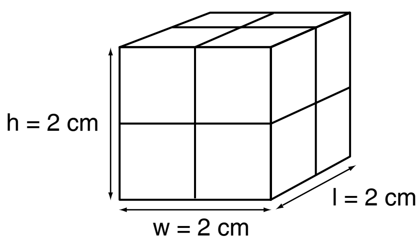
length = ________

width = ________

height = ________

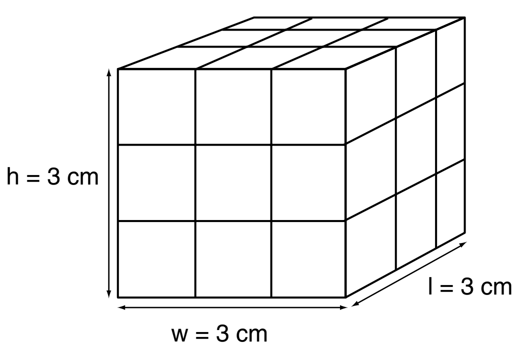
One cubic centimeter is written ______________

2. Make a 2 cm x 2 cm x 2 cm cube.
   a. Determine the volume of your cube.
   b. Tell how you determined the volume of your cube.



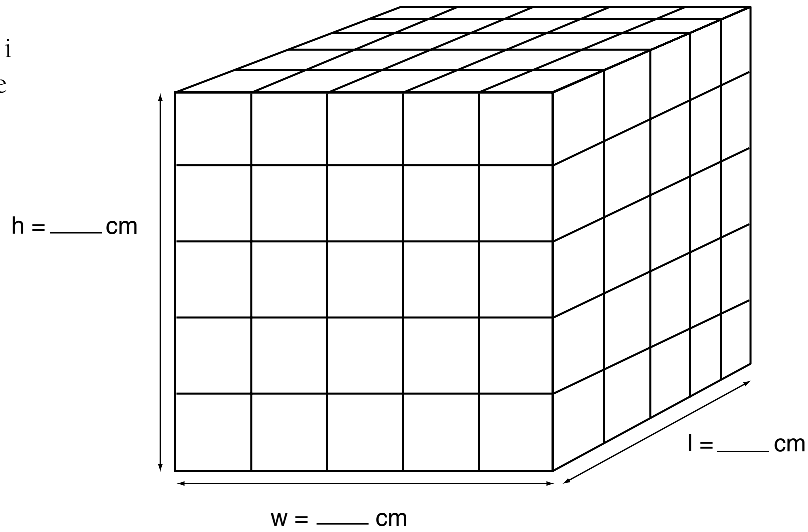
3. Make a 3 cm x 3 cm x 3 cm cube.
   a. Identify the volume of this cube.
   b. Tell how you determined the volume of your cube.

   Volume (V) = _______ cm^3



4. Build this cube and i
you find the volume

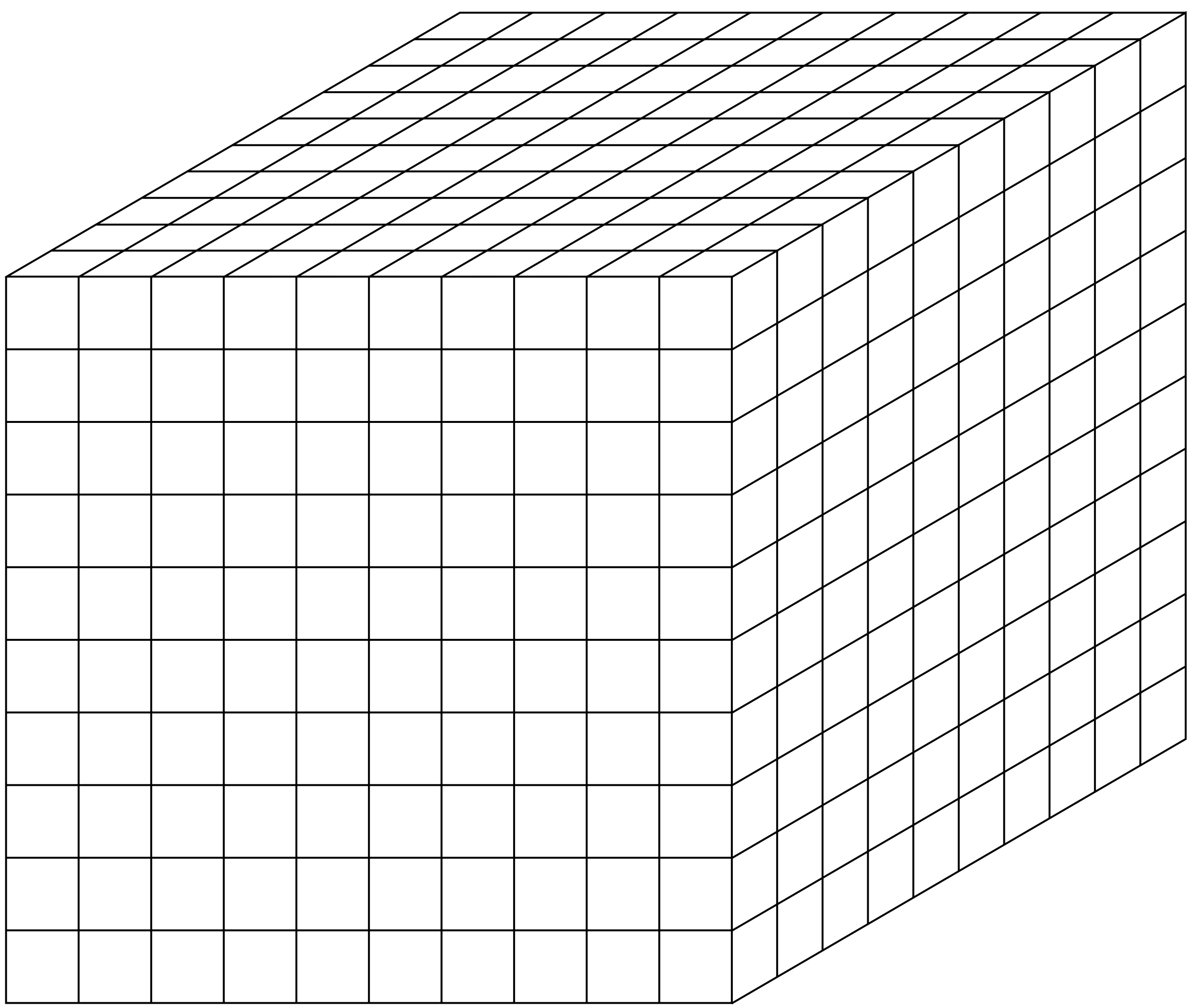
V= _______ cm^3



5. a. How many of the above cubes would fit into this cube? _______

b. What is the volume of this cube? _______ cm^3

c. Identify how you found the volume of this cube.



The Challenge

Work with your team to solve the following problems. Record the steps you use to solve your problems in the space below each question.

1. How many cubic centimeters fit into a cubic meter?

2. How many cubic millimeters fit in a cubic meter?

3. What is the volume of a cube that is 1 part per million by volume in a cubic meter?

4. What is the volume of a cube that is 1 part per billion in a cubic meter?

Making a Contour Map

Purpose

To learn how contour maps can be made by hand

Overview

Students plot data from GLOBE schools on a map with latitude and longitude lines and draw contours based on the values plotted.

Student Outcomes

Students gain an understanding of contour mapping.

Science Concepts

Geography

Geographic visualizations help organize information about places, environments, and people.

General

Visual models help us analyze and interpret data.

Scientific Inquiry Abilities

Identify answerable questions.

Use appropriate tools and techniques.

Use appropriate mathematics to analyze data.

Develop and construct models using evidence.

Communicate procedures and explanations.

Time

One class period

Level

Middle, Secondary

Materials and Tools

Pens or pencils (several colors optional)

Copy of the blank map

Preparation

Make a copy of the *Making a Contour Map Work Sheet* and the *Data Table* for each student or team

Prerequisites

None

Background

Contour maps are a useful way to visualize the spatial relationships among data and the spatial distribution of data values (e.g., where is it warmer or cooler, where did it rain and how much).

What To Do and How To Do It

1. Provide every student or team with a copy of the blank map and the table of data provided as part of this activity.
2. Discuss the map with the students to ensure that they recognize and understand the latitude and longitude lines shown and recognize that negative longitude is the same as West longitude and positive latitude is the same as North latitude.
3. Discuss with students the concept of a contour line. Emphasize that contour lines connect places on a map where a variable (e.g., mean air temperature) has the same value and that on one side of the line values would be above this value (e.g., 20˚ C) while on the other side of the line values would be below this value. Weather maps are good examples along with topographic maps, and both may be familiar to students.
4. Demonstrate how to plot the first value given for mean temperature on April 5, 2000, for Portola High School (the first row of the *Data Table*).

a. Locate longitude -120.5˚ (=120.5 W) that is mid way between the 120W longitude line and the first line to its left.
b. Trace along this line to latitude 39.8˚ (=39.8N) that is just below the 40N latitude line.
c. Write the value 8.0 at this spot on the map.

5. Have students plot the values for Mean Temperature for the first three schools in the *Data Table*.
6. Ask students to locate and mark the places on their maps where they estimate that the mean temperature would be 10˚ C and 20˚ C.
7. Discuss with students the point that with just three values plotted it is hard to know where the contour line should be drawn except between these three points.
8. Have students plot the values for the next three schools in the *Data Table* and extend their initial 10˚ C and 20˚ C marks to become contour lines.
9. Have students plot values for the next three schools and extend their contour lines as far as they think is reasonable given these nine data points.
10. Have students look at the values for the next three schools and ask them where they will go and if there is a problem plotting them. (There is a problem because these three schools are all in the same community and their values would probably be on top of one another on the map.) Let students decide how best to cope with this difficulty.
11. Have students plot the remaining values and add contour lines for 15˚ C and 25˚ C if they can.
12. Ask students if they could add a contour at 5˚ C. The discussion should bring out the point that since there are no schools with values below 5˚ C, there is no reason to suppose that any place on the map would have had a mean temperature this low on this day.

Extensions of Basic Learning Activity

Have students create a contour map using the total precipitation for April 2000 data. In this case with one school having a value more than five times as large as the school with the next most precipitation, even increments in the contour lines may not be appropriate. In mathematical terms, a linear interpolation between the values may not be a good approximation of the distribution of values.

Have students create a contour map using the cloud cover values for April 5, 2000. The contour lines should be those marking the boundary between cloud cover classifications (e.g., between scattered and broken or 50% cloud cover). In this case the data reports are not numbers but represent ranges. Students should discuss how this affects their placement of contour lines. Two schools (Birch Lane and Millview) reported data using the GLOBE 2000 categories; you may choose to have students omit these two schools for simplicity or discuss how to account for the different quantitative meaning of their data reports.

Have students create an elevation map by plotting the elevation data provided for the schools. Now the contours should show mountains and valleys. There are too few points provided to do this accurately. Discuss with students what would be their strategies for making a better elevation map using actual data. How many points do they think would be required? How closely should data points be located? Should they be collected on a regular grid? Could other GLOBE data help?

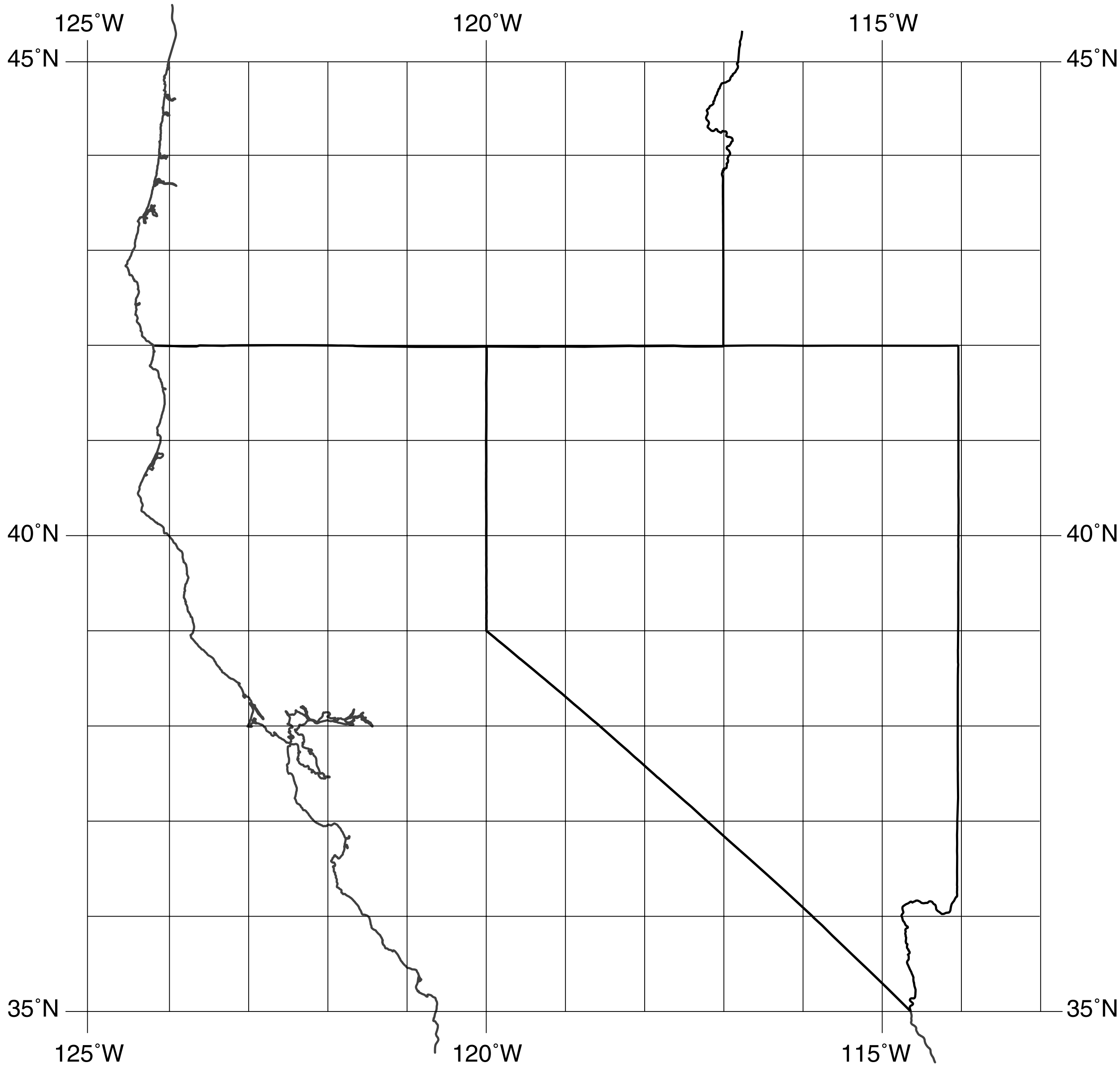
Have students find on the GLOBE Web site the explanation of how GLOBE contour map visualizations are done. They can read this explanation and then apply the formulas themselves on the Mean Air Temperature data in the *Data Table* and compare these results with the contour maps they did interpolating between points by eye.

Students may explore the relationship between elevation and temperature described in *Earth As A System*. Mean temperature values can be adjusted for differences in elevation and a new contour map drawn of what the values might have been if every school was at sea level. This concept is explained in the *Optional Barometric Pressure Protocol* for pressure but it may be extended to temperature as an exercise. Students should discuss the flaws in this approach as a form of scientific analysis and on which temperature data it might prove useful. The flaw is that the relationships between elevation and air temperature or latitude and air temperature are approximately correct for long-term averages in temperature and not for the values on a single day.

Student Assessment

Either of the first two items suggested as extensions to the basic learning activity may be assigned to assess overall student understanding and proficiency in making contour maps. Alternatively, a data table with different parameters can be assembled for this area from the GLOBE Web site and students assigned to make a contour map using these data.

Making a Contour Map Work Sheet



Data Table

Mean T (C) 5-Apr-00	Cloud Cover* 5-Apr-00	Total Precipitation April 2000 (mm)	Latitude (degrees)	Longitude (degrees)	Elevation (meters)	School Name and Location
8.0		7.2	39.8	-120.5	1500	Portola High School, Portola, CA, US
16.0	SCT	22.1	38.8	-120.9	454	Gold Trail School, Placerville, CA, US
21.0	BKN	0.0	38.0	-121.3	12	Lincoln Elementary School, Stockton, CA, US
15.3	OVQ	34.5	38.6	-121.7	16	Birch Lane Elementary School, Davis, CA, US
22.5	BKN		37.7	-120.9	18	Stroud Elementary School, Modesto, CA, US
15.5	SCT	70.8	38.0	-122.6	82	San Domenico School, San Anselmo, CA, US
12.0	CLR	32.6	37.8	-122.2	70	Piedmont Independent Learning High School, Piedmont, CA, US
14.0	SQT	44.9	37.0	-122.0	2408	Happy Valley Elementary School, Santa Cruz, CA, US
22.0	BKN	27.8	37.0	-120.1	91	Madera High School, Madera, CA, US
22.0	BQN	29.1	37.0	-120.0	106	Millview Elementary School, Madera, CA, US
20.5	BKN	27.2	37.0	-120.1	90	Berenda Elementary School, Madera, CA, US
26.0	BKN		37.1	-119.5	2408	Auberry Elementary, Auberry, CA, US
16.5	BKN		37.4	-118.4	1364	Round Valley Joint Elementary School District, Bishop, CA, US
12.5		452.0	41.8	-124.2	202	Crescent Elk School, Crescent City, CA, US
21.0	CLR		36.5	-119.6	77	Washington Elementary School, Kingsburg, CA, US
20.0	BKN	51.6	36.8	-119.9	70	Steinbeck Elementary School, Fresno, CA, US
		38.5	36.7	-119.7	81	John Burroughs Elementary School, Fresno, CA, US
19.8	SQT	8.1	36.3	-119.3	86	La Joya Middle School, Visalia, CA, US
		1.0	36.8	-121.7	60	North Monterey County High School, Castroville, CA,
12.0	CLR	24.7	43.5	-115.3	1307	Pine Elementary/Junior High School, Mountain Home, ID, US
19.0	CLR	11.0	36.6	-119.4	99	Reedley High School, Reedley, CA, US
	OBS	19.6	36.6	-121.9	150	Spanish Bay Academy, Pebble Beach, CA, US
	SCT	0.0	36.2	-115.2	637	Mabel Hoggard Magnet School, Las Vegas, NV, US
15.0	CLR		43.5	-116.6	862	South Middle School, Nampa, ID, US
		48.9	44.1	-123.2	192	Fairfield Elementary School, Eugene, OR, US

*Cover: Cloud Cover.

Cloud Cover Codes: (GLOBE 1 and 2): CLR=Clear (0-9%), SCT=Scattered (10-50%), BKN=Broken (51-90%), OVC=Overcast (91-100%). (GLOBE 2000): NON=No clouds (0% coverage), QLR=Clear (1-9%), ISO=Isolated (10-24%), SQT=Scattered (25-49%), BQN=Broken (50-89%), OVQ=Overcast (90-100%), OBS=Obscured Sky.

Draw Your Own Visualization

Purpose

To learn about visualizations by designing and drawing one.

Overview

Students draw a visualization based either on their interests and ideas about the world or based on actual GLOBE data. Students are asked to justify the design choices they make and to interpret the visualizations of their peers.

Student Outcomes

Students learn to identify and communicate important patterns in a dataset by drawing a visualization, and begin to interpret those patterns.

Students select and specify colors, units, and ranges of values to communicate data effectively in a visualization.

Science Concepts

General

Visual models help us analyze and interpret data.

Geography

Geographic visualizations help organize information about places, environments, and people.

Scientific Inquiry Abilities

Identify answerable questions.

Use appropriate tools and techniques.

Use appropriate mathematics to analyze data.

Develop and construct models using evidence.

Communicate procedures and explanations.

Time

One 45-minute class period

Level

Middle

Materials

Blank paper maps

Coloring media for each student: crayons, colored pencils, water paints, or pastels

Globes and atlases for students to consult when drawing their visualizations.

Preparation

Copy the blank paper map and Work Sheet for each student.

Prerequisites

None.

Background

We all use data all the time: for example, we might check out sports statistics or look at a weather map, or grade papers.

Data can be presented in many different ways. Sometimes data are presented in the form of numbers, as in tables of GLOBE measurements like precipitation or water quality. Tables of data offer precise values that are good for calculations or comparisons. However, tables of numbers can be difficult to understand at a glance, especially with large or complex scientific datasets.

Visualizations are a way to turn data into a picture to make it easier to understand. Visualizations help us begin to make sense of the data, find patterns within it, and use it to answer questions about the world. This activity is an introduction to visualization: a chance to design and draw one of your own on a topic that interests you.

A visualization can be designed in many different ways — there is not a single "right way" to draw a visualization. Authors make design choices in order to communicate something specific. A topographical map, for example, is one common way to show patterns of elevation; topographical maps use contour lines to show areas of equal elevation.

In this activity, you will use color as a way to illustrate patterns in data. The colors you use, and what each color represents, depends on what you want your visualization to show.

Four key questions to answer when creating a visualization are:

What is the *purpose* of the visualization?
Are you working with *numeric* or *categorical* data?
What *colors* will you use, and what do they represent?
What *geographic area* is being covered?

Purpose

A visualization is meant to communicate something to the people who look at it. For example, a weather map with temperature ranges in different colors helps to show weather patterns across the displayed region. The first step in designing a visualization is deciding what it is intended to communicate.

Type of Data/Units/Range of Values

The data shown in a visualization can be *numeric* or *categorical*.

With *numeric* data, the visualization shows a quantity of something: the number of bird species in different parts of the country, or the average noontime temperature in different parts of the world. To make it clear what the numbers mean, we specify *units of measure*. For example, temperature might be measured in degrees Celsius, Fahrenheit, or Kelvin.

To simplify the illustration of data and show patterns, one can divide numeric data into *ranges of values* and assign a color to each range. A temperature visualization might use one color for temperatures in the range -20˚C to 0˚C, and another color for temperatures in the range 0˚C to 20˚C. If exact values are not known, it is also possible to use *qualitative* values (descriptive words like high, middle, and low for cloud heights). Usually, numeric ranges are better to use because they are more precise and uniform; what is "warm" to one person might be "hot" to someone else, but everyone agrees on what 20˚C means.

Some visualizations show data that are not numeric at all: for example, the most popular sport in different cities ("hockey," "football," etc.) or types of land cover in different regions ("broadleaf evergreen forest," "desert," etc.). This type of data is called *categorical*. With categorical data, the visualization designer must decide whether to group similar categories to show patterns. For example, depending on the question the "favorite sport" visualization is designed to answer, it might be important to show each individual type of boating activity, or it might be simpler to group them all under the category "water sports."

Colors

Once the ranges or categories have been selected, the next step is to choose *colors* to represent them. Sometimes it is possible to choose colors that resemble the phenomenon being visualized (for example, in a visualization of land cover you may want to use green for forests). Using colors in this way helps to make the visualization easy to understand. Another strategy is to use a standard progression such as the colors of the rainbow, so that values that are close to each other look similar. For example, a temperature visualization might use blues and purples for cold temperatures and reds and oranges for hot temperatures. These visual techniques can help to make patterns in the data easier to recognize and comprehend.

In most hand-drawn visualizations, 4 to 6 colors are enough; too many colors complicate the picture and make it hard to read.

Geography and Scale

Many visualizations show data that are collected in different places: for example, a visualization might show average rainfall in different parts of the world. To show where the data come from, many visualizations are drawn on maps. Maps have *geographical elements* (e.g., continent outlines) to show spatial aspects of the data at a glance, like the location of wetlands near a bay. When you draw a visualization, it is important to start with a blank map that shows the part of the world that the data are from. It is also important to select a *scale* for the visualization: will it show July rainfall in a particular country, or around the world? The scale you select will depend on what data you have and what the visualization is intended to communicate.

Preparation

Hand out crayons (or other color media) to each student, and distribute the available globes or atlases.

Each student will also need a blank map on which to draw his or her visualization. A blank global map with country outlines is provided with this activity, and can be enlarged on a copier to show a particular continent or global region. For more local maps, you or the students can use the map generation facility on the GLOBE Web site.

What To Do and How To Do It

Go through the following four steps.

1. Introduction to visualizations
2. Students design and draw a visualization
3. Group discussion and interpretation
4. Class discussion

Step 1. Introduction to Visualizations

Begin with a discussion of why visualizations are important, both in science and in everyday life.

- Show samples of visualizations that the students may have seen recently in the local paper (e.g., a weather map), or ask students to find an example as homework.
- Use an atlas, which will often have many color visualizations of Earth and Earth science.
- Discuss why it is easier to understand the visualizations than a table of numbers. What does this visualization allow you to see at a glance that numbers would not? What types of interpretation does it support?
- Relate the discussion to an activity you plan for your class to do using GLOBE data: why would visualizations be helpful in that activity?

Tell students that they will be designing their own visualization in this activity. There are two ways to do this:

1. You can ask students to draw a visualization on a topic they are familiar with, mapping data they already know something about; or
2. Students can use measurements from the GLOBE program, such as air temperature, rainfall, or cloud cover.

If you choose 1, students have the opportunity to be creative and to connect the concept of visualization to something in which they are interested, potentially outside of science. For example, students might choose to draw a visualization about agricultural crops in various regions of the world or number of languages spoken in each country. If students are having trouble coming up with a topic they feel they have sufficient data to draw, talk to them and elicit from them ideas about data that are appropriate to represent spatially, guiding them to appropriate topics if necessary.

If you choose 2, students can begin to explore the concepts behind GLOBE measurements and understand an important step in data analysis – visualizing spatial data to detect patterns. If students do their visualization on a topic related to data they are or will be collecting, you may wish to view the visualizations on the GLOBE Web site as a class or have individual students do so. Once there, students can see how GLOBE data are drawn onto maps.

As you introduce the activity, explain to students that their job is to communicate a set of data in a way that makes it easy for others to understand. There is no "right" or "wrong" way to design a visualization. The students' design choices can make it easy or difficult for someone else to understand what they are trying to communicate.

Step 2. Students Design and Draw a Visualization

Give each student one of the blank maps you have prepared. Each student will select a topic and draw his or her own visualization.

The Work Sheet for this activity will step students through the decisions they need to make to design their own visualization as described in the *Background* section. As they work, you may want to offer some guidance.

- Students may need help in defining the purpose of their visualization, and in making design choices that allow them to communicate the data clearly (e.g., dividing numeric data into ranges and selecting colors).
- Encourage students to sketch their plans in pencil before they color them in, since students may focus on one value or range first and not save space for all the data.
- Students should be encouraged to complete their designs fairly quickly (approximately 15 minutes).
- The Work Sheet also asks students to look at their visualization and check their work to see if it is easy to understand. Students may need help in reflecting carefully on their drawings. As you work with individual students, refer to the Purpose statement on their Work Sheets. Based on that statement, ask them to think of questions about the data that their drawing would be useful in answering, and help them check to see whether it supports that analysis.

If only pencils are available, and not color media, students can use different patterns or symbols of shading to represent different areas.

Step 3. Peer Review

After the students are through drawing their visualizations, divide them into small groups. Ask students to interpret each other's visualizations within the group, deciding what each visualization is intended to communicate. How easy is it for students to understand the intent of the visualization, and what the colors represent? What design choices were helpful in communicating the data? What design choices might have offered better communication? Give students the opportunity to make modifications after this discussion, if needed, to improve their visualizations.

Step 4. Class Discussion

Bring the class together for a discussion of what makes a good visualization. If time allows, invite individual students to present their visualization or one they looked at within their group, and to say what aspects of the design made it easier or more difficult to understand. This discussion is a good opportunity to link the general tool of visualization to the GLOBE data that students are or will be working with, and to discuss how visualizations can make that data easier to analyze.

Further Investigations

Drawing visualizations can also be done as a group project by using a poster-sized blank visualization. This can be created by copying one of the blank visualizations onto an overhead, projecting it onto the wall, and then tracing that image onto poster board. These large visualizations are also well suited to class presentations because they can be seen by the whole class. Drawing a visualization as a group is a good way to conduct preliminary analysis of a set of GLOBE data.

The basic activity defined in *What To Do and How To Do It* is a generic introduction to the language of visualization as a tool for interpreting and communicating data. The extensions below offer suggestions for specific analytic activities that you can choose based on your goals for this class.

- Ask each student to think of a question that their visualization can be used to answer: for example, "What city has the highest population density in the country?" Trade visualizations with another group, and ask them to use the visualization to answer the question. This activity reinforces the perception of visualizations as a tool for problem-solving.
- Ask each student to come up with a headline or caption for their visualization as it might appear in a newspaper, and then write the first several sentences of the story. For example, the caption on a weather map might be "Heat wave sweeps the West Coast!" This activity reinforces the perception of visualizations as a tool for communication of patterns in data.
- If you are using GLOBE data for this activity, add a class discussion in which you predict trends in the data you will be collecting based on this visualization. For example, you might want to predict how the visualization will change as data are collected over the year. This activity helps to establish the idea that visualizations will be useful in the work your class will be doing with GLOBE as you try to answer questions about the World throughout the year.

Resources

Blank maps can be designed on the GLOBE Web site and printed out for students. (From the GLOBE home page, select *Visualizations* and then *GLOBE Maps*. Under Other Options on the Maps page, you can choose *Create a blank map*.)

The *GLOBE Earth System Poster* offers good examples of color visualizations from Earth science data and the patterns that visualizations can show in large datasets.

The Internet has a large collection of scientific visualizations created by research organizations. Searching for the word "visualization" along with the name of an environmental science research organization can bring up a useful set of examples.

Draw Your Own Visualization

Work Sheet

Name____

In this activity, you will draw a visualization of something that interests you, using colors and a blank map. A visualization is a picture that makes a set of data easier to understand and may help you to recognize patterns within it. It is up to you to decide what data you want to communicate in this visualization.

This Work Sheet will step you through the process of designing a visualization. Remember, your design choices can make it easy or difficult for someone else to understand your visualization.

1. What is the *purpose* of your visualization? For example, you might want to show temperature patterns across the region, or the average height of trees in different regions. Write the purpose of your visualization here.

   ____
   ____
   ____
   ____
   ____

   On your blank map, give your visualization a title that communicates its purpose.

   ____

2. What *geographic area* is being covered by your visualization? Examples are: the whole world; Africa; your hometown. Write down the area your visualization covers here, and make sure you have a blank map that shows the correct region of the world.

   ____
   ____
   ____
   ____
   ____

3. Are your data numbers or categories? (circle one)

Data that are numbers are called numeric; data that are categories are called categorical.

4. For *numeric data, answer a and b; for categorical data, answer c.*

a. What are the *units of measure* (e.g., degrees Celsius, height in meters)?

____

b. What *ranges* will you show? Remember, a range groups similar data together by color so that patterns are easier to see. If you are mapping temperature, you might want to use ranges like *-20°C to 0°C* and *0°C to 20°C*. Write down the ranges you will show here, and skip to question 5.

____

____

____

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For *categorical data:*
c. What *values* will you show? For example, if you are showing ecosystems, values might include desert or rainforest. Write down the values you will show.

____

____

5. Now choose the *colors* you will use to represent each range or value. Remember that, if possible, it helps to use colors that mean something about the data (e.g., red for hot or green for forest) or that help illustrate a particular pattern (e.g., temperatures close to each other have similar colors). Write a description of the color scheme you picked and say why you picked it.

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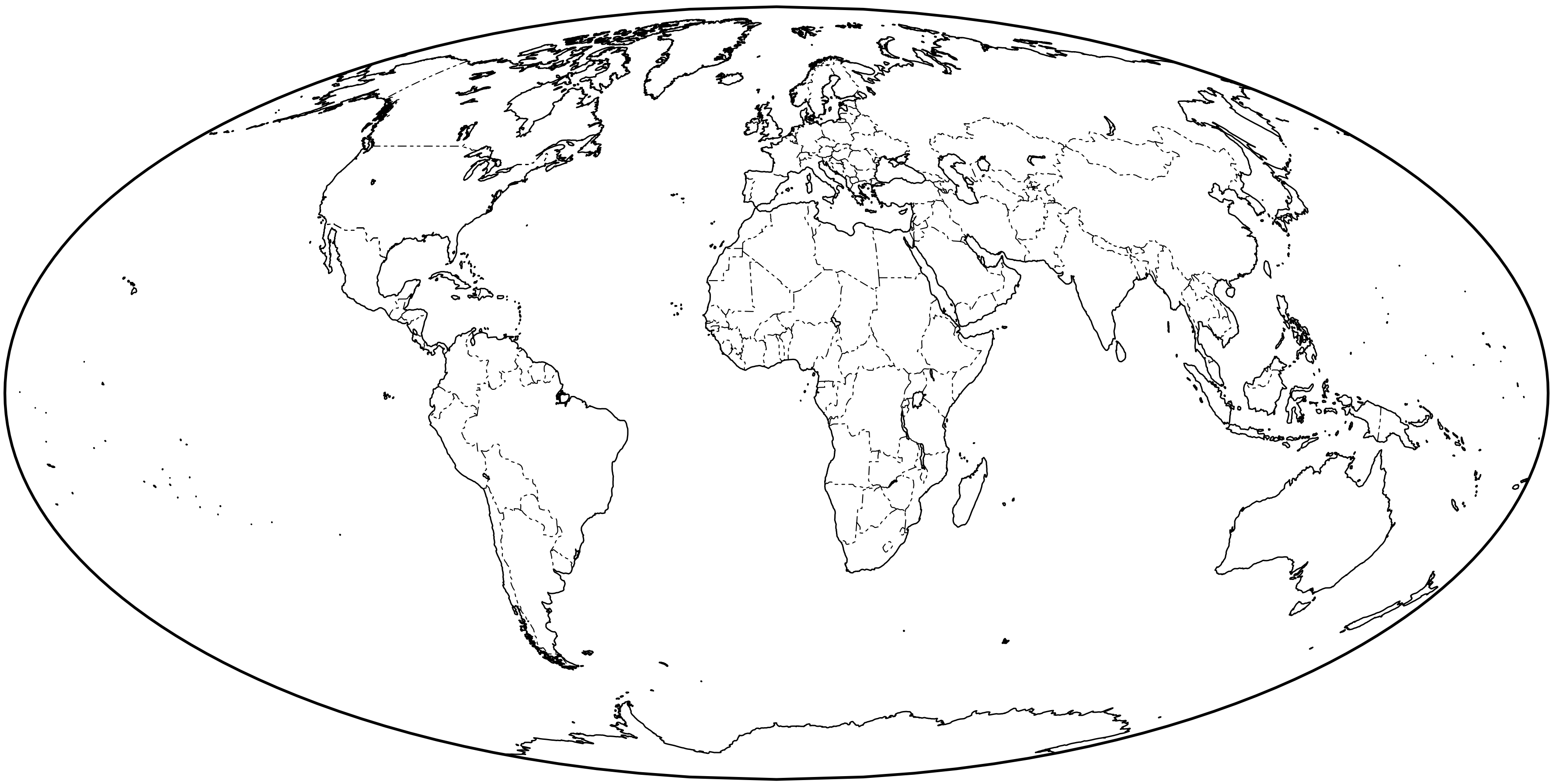
On your map, create a *legend* that shows each range or value, and next to it the color you will use.

6. Draw your visualization. Now pretend that you have never seen this visualization before. Would you be able to figure it out? Is everything clearly labeled and drawn? Revise your visualization if necessary.

Draw Your Own Visualization Work Sheet

*Name*______________________________

Title:______________________________

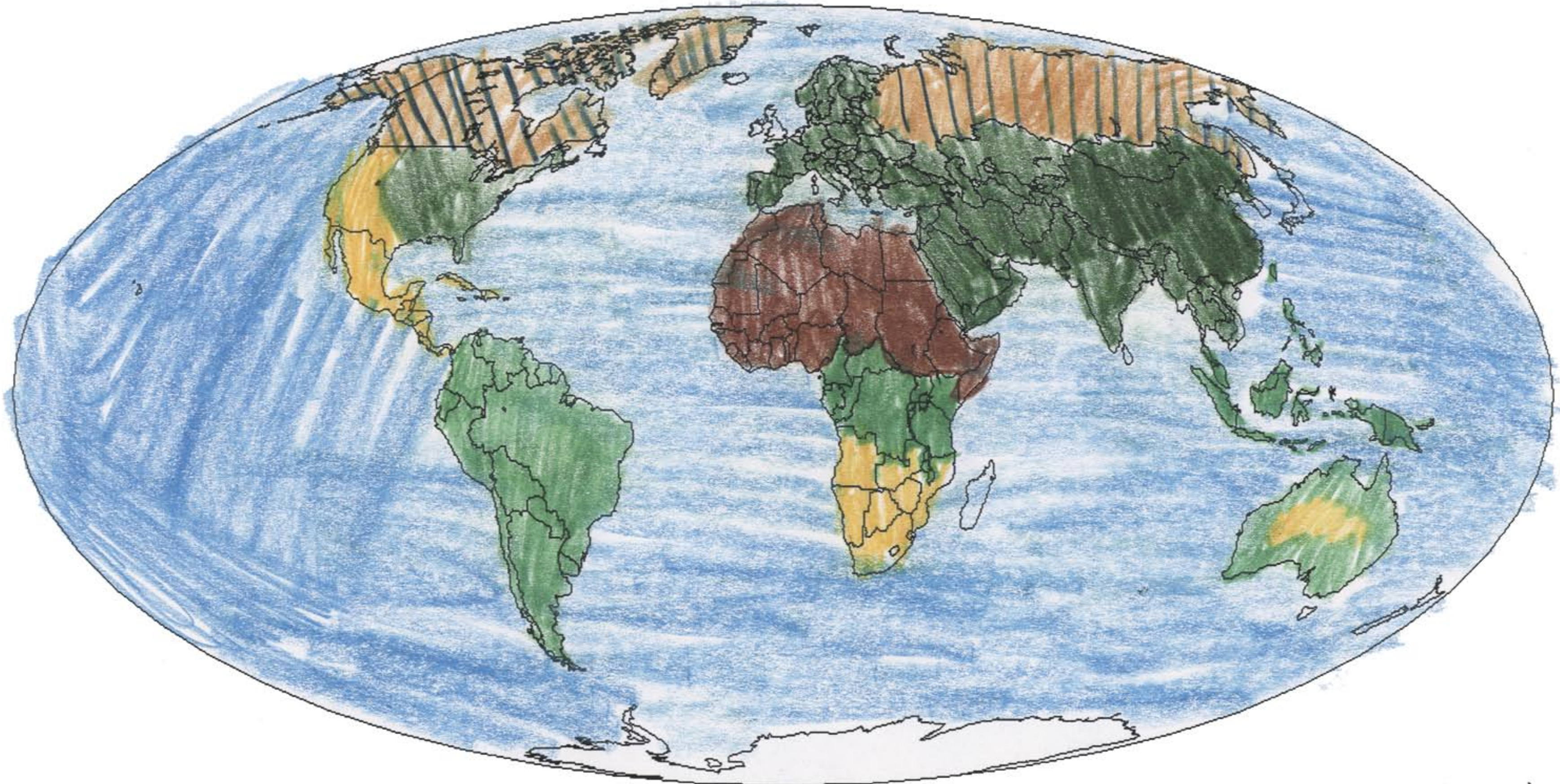


Color Legend

Draw Your Own Visualization Work Sheet

Name Eileen E.

Title: The 7 Bioms of the world.



Color Legend

Grassland | Decidious forest | ocean tagia | rain forest | degert | tundra

– When colors have lines of diff. colors on them the area is also inhabeted by that biom also

Draw Your Own Visualization
Rubric

For each criterion, evaluate student work using the following score levels and standards:

3 = Shows clear evidence of achieving or exceeding desired performance

2 = Mainly achieves desired performance

1 = Achieves some parts of the performance, buts needs improvement

0 = Fails to perform or performs in an inadequate way

1. Designing a visualization using the key elements of quantity, units and range (if numeric) and category (if categorical), as well as organization of colors used, geographic area, and scale.
   A. Color
      • Did the student choose colors that are clearly distinguishable from one another?
      • Are the colors organized in a reasonable way?

Score Level	Description
3	Colors are clearly distinguishable from one another; use of colors is organized and appropriate for the intended purpose. For example, if the student is illustrating a continuous set of data, colors are graduated; if the data are categorical, colors are chosen to show distinct categories. On the Work Sheet, the student's explanation of the color scheme demonstrates that it was a conscious, logical choice.
2	Colors are difficult to distinguish in some places and/or colors could be better organized to achieve the intended purpose. For example, in a visualization of temperature, colors are selected at random for each range or do not illustrate a gradual shift from hot to cold. The Work Sheet explanation has flaws.
1	Use or choice of colors is inappropriate or inconsistent; colors are not tied to ranges or categories of data. Work Sheet explanation is unclear.
0	Work is blank or incomplete.

B. Units and range of values

- Does the student's choice of unit match the quantity being visualized?
- Is the chosen range of values appropriate for the quantity being visualized?
- Are colors appropriately mapped into the chosen range?

Score Level	Description
3	Units are clearly stated and appropriate to the quantity being measured. Ranges of values are clearly stated and appropriate and values are generally divided into 4-6 ranges. Selected ranges or categories span the entire set of values; for example, an "other" category is included if necessary.
2	Work shows some understanding of the use of units and range of values in designing and drawing visualizations, but demonstrates need for improvement in one of the areas described above. For example, the unit chosen may not be entirely appropriate for the quantity being visualized, or the range of values chosen may leave large portions of the visualization blank.
1	Work shows a poor understanding of the use of units and range of values in designing and drawing visualizations, demonstrating a need for improvement in each area (e.g., units and value ranges).
0	Work is blank or incomplete. Units or ranges are not specified.

2. Using a visualization to communicate data.

A. Was the student able to highlight, interpret, and communicate patterns in the data?

Score Level	Description
3	The visualization overall serves as an effective tool to communicate the intended message or idea. Colors and ranges are selected to point out important patterns in the data. For example, in a population visualization, areas of highest population density are easy to identify.
2	The visualization overall communicates some aspects of the intended message or idea, but is unclear or ambiguous in some ways. For example, the visualization is clearly labeled, but chosen ranges mask some important patterns.
1	The visualization overall fails to communicate the intended message or idea and requires some basic revisions in order to serve as an effective communication tool.
0	The visualization is blank or incomplete or confusing so that no patterns can be recognized.

Learning to Use Visualizations:

An Example with Elevation and Temperature

Purpose

To introduce students to visualizations as a tool for scientific problem-solving, using elevation and temperature as an example.

Overview

In this learning activity, students use visualizations to make sense of elevation and temperature data and to explore the relationships between the two variables. Students color in visualizations of elevation and temperature so that important patterns in the data become evident. The relationship between the two quantities is studied by using them to compute the *lapse rate,* the rate at which temperature falls with increasing elevation.

Student Outcomes

Students can identify and communicate important patterns in a dataset by drawing a visualization, and can begin to interpret those patterns.

Students can analyze the correlation between two variables using visualization as a tool.

Science Concepts

General

Visual models help us analyze and interpret data.

Geography

Geographic visualizations help organize information about places, environments, and people.

Scientific Inquiry Abilities

Identify answerable questions.

Use appropriate tools and techniques.

Use appropriate mathematics to analyze data.

Develop and construct models using evidence.

Communicate procedures and explanations.

Time

One 45-minute class period, although extensions are suggested

Level

Middle, Secondary

Materials

Overhead projector and visualization overheads, or color copies of Figure AT-V-1

Copies of *Work Sheet* for all students

Rulers, crayons or colored pencils

Preparation

If you plan to do the extensions with GLOBE data, you may want to find appropriate schools in advance. See *Further Investigations.*

Prerequisites

Students should be familiar with computations using ratios. It is also helpful if students have some experience using visualizations (e.g., *Draw Your Own Visualization* activity in this chapter).

Background

Scientific visualizations of Earth systems appear in many places. Many newspapers include bright color visualizations of surface temperature and visualizations of the formation of an ozone hole have been featured on magazine covers. These visualizations help us to make sense of complicated scientific information. This learning activity will use visualizations in a similar way: showing patterns in scientific data and using that information to help solve a problem.

The first step in using a visualization is *getting oriented:* understanding how the visualization is organized and what it means, and connecting it to something you are familiar with (similar to the "You Are Here" arrow on a map). When you are presented with a new visualization, look for the following elements:

1. **Data characteristics including type, units, and time.** The *type* of the data is what real world value it represents. In the first visualization illustrated in Figure AT-V-1A, Earth Elevation and Ocean Depth, the data type is elevation in relation to sea level (for areas covered by land) and depth below sea level (for areas covered by water). The *units* are in meters, with positive values above sea level and negative values below sea level. The values refer to the average elevation in that area, so they are not the maximum values at each point. The *time* is when the data were collected. Time is an important element in the second visualization in Figure AT-V-1B (Surface Temperature: January 1987), since surface temperatures vary a great deal over the course of a year.
2. **Use of color.** The color scheme contains the colors that represent particular data values in a visualization: for instance, orange might represent temperatures between 20-30˚ C. The *legend* shows the arrangement of color and the range of values that each represents. Choosing a particular color scheme can help the visualization to point out patterns or emphasize a particular view of the data.

   The visualizations in Figure AT-V-1 use color in a strategic way. The colors are chosen to correspond to various natural phenomena. In the *Earth Elevation and Ocean Depth Visualization*, the depths of the ocean are shown in shades of blue. Most land is shown in shades of brown, with mountains shown in white. This type of color legend is useful for seeing global patterns, because the continuous data are now grouped and color-coded.

   Global patterns can be made easier to see by using *landmark values* that mark off the range at which certain phenomena occur. Landmark values are the points on a color scale where the representative value undergoes a distinctive change. For example, a landmark value might be 0˚C, where water freezes. Using colors to point out landmark values can make the visualization easier to understand.

   The *Surface Temperature Visualization* in Figure AT-V-1B makes use of the associations we have with particular colors. Warm colors (yellows, oranges and reds) are used to show temperatures above the freezing point of water, and cool colors (blues, purples) are used to show temperatures below the freezing point of water. The map's legend will always tell you what the colors represent.
3. **Geographical features.** The third element of a visualization is *geographical features,* which help to place the data spatially: what places on the Earth do these numbers describe? In Figure AT-V-1B, outlines of the continents let you see, for example, that Australia's temperatures near the coast are cooler than temperatures inland.
4. **Resolution.** The map's resolution is a measure of the smallest area in which two different values can be shown. For example, in the *Earth Elevation and Ocean Depth Visualization* each data value covers a 1˚ square area, so the resolution of the maps in Figure AT-V-1 is 1˚ by 1˚. This means that you can see

differences between elevations at 23° S and 24° S, but not between 23.1° S and 23°3 S.

In *Work Sheet* 1, which you will be using for this exercise, the data are represented in 3° by 3° squares, which means that each square covers a larger area and the image of the data is less precise. Because of this, calculations on data read from the map will only be approximate.

All of the above features give visualizations power, communicating information in ways that give us insight into the data and the world in order to solve problems. In this activity you will use visualizations to consider the relationship between elevation and temperature, and then estimate the lapse rate as we move from the coast of the Indian Ocean to the Himalaya Mountains.

The *lapse rate* is the rate at which the air temperature changes with an increase in elevation. If you have ever climbed a hill or mountain, you may have felt the decrease in temperature: it gets colder as you go up.

Scientists calculate the lapse rate as the rate at which temperature decreases as you go straight up into the air. The value comes from weather balloons carrying instruments that measure temperature, air pressure, and humidity, which are sent up into the atmosphere. The locations of these balloons are tracked and the information they collect (plus their position) is sent back to a ground station. Using measurements from such devices, and models of the weather, scientists have calculated a lapse rate as a theoretical constant of 9.8° C per km of elevation.

Actual lapse rate can differ from the theoretical constant for a number of complicated reasons. For example, the rate is different if air is humid rather than dry. If the soil is dry, no cooling near the surface occurs from evaporation. This can cause very warm temperatures near the surface, which rapidly cool as elevation is gained. Moist air changes temperature more slowly as the water condenses from it (and forms droplets or dew). The energy stored in the water vapor is released as it condenses, thus raising the temperature. As a result, the average lapse rate for moist air is only about 5.4° C per km; very different from the theoretical constant of 9.8° C per km.

Preparation

Hand out crayons (or other color media) to each student pair. Hand out a copy of the *Work Sheet*. Make a color transparency of Figure AT-V-1, or locate it on the Globe Web site for projecting in class.

What To Do and How To Do It

Do the following three steps.

1. Class discussion to orient students to the visualizations in Figure AT-V-1
2. Group analysis and problem-solving
3. Class discussion to reflect on the use of visualizations

Step 1. Class Discussion: Getting Oriented with Elevation and Temperature

This discussion will orient students to the use of visualizations. By looking at several visualizations of elevation and temperature, your students will learn their way around a visualization and be ready to do the second step, the problem-solving task.

Introduce the utility of visualization as a tool for making sense of data.

- Have students look at their *Work Sheets*, which contain visualizations they will color in. Each is a series of numbers in cells that represent an area of 3° x 3°. The first table shows the average elevation for each cell; the second shows the average temperature in July 1987 for each cell. It is hard to find patterns just by looking at this many numbers.

  This activity will use *color visualizations* to point out patterns in the data. Of course, visualizing the data with colors is only one alternative. For example, elevation can also be shown on topographic maps that use contour lines instead of colors.

Orient students to the visualizations by connecting the colors with phenomena in the world: what do these data really mean?

- On the Earth Elevation and Ocean Depth visualization (Figure AT-V-1A), ask your students to locate the regions that are colored in white, and discuss what those areas have in common. Students should realize that these areas have the highest elevation. Now, help them identify why those areas are so high: the obvious explanation will be that there are mountain ranges in those areas (e.g., the Andes in Peru, the Rockies in the US, and the Himalayas in Asia). However, in some cases elevation is due to thick ice sheets (e.g., Antarctica and Greenland).
- Students may initially be confused about exactly what the colors represent in this visualization. For example, students may be familiar with visualizations of temperature in the newspaper, so they may interpret blue as cold and red as hot. Some students may also interpret blue as water rather than ocean depth. Reinforce the importance of orienting to the visualization using the information found in legends and keys.
- Other confusing elements of many visualizations are resolution and projection. In Figure AT-V-1A, the *resolution* is 1˚ square. (In the *Work Sheet* visualizations that students will color and analyze, resolution is 3˚ x 3˚; it will be important for students to understand the implications of that for the precision of the data.) *Projection* is how the spherical shape of the Earth is shown on a flat space, causing distortions of size, shape, and distance. In Figure AT-V-1, the 1˚ squares are determined by regular grid spacing rather than depicting actual geographical features. The actual area of each square is variable depending on the latitude; this can be confusing at the poles, for example, where Antarctica appears as a large horizontal area. It may be useful to compare the size of the continent as depicted here with its projection on a globe.

Discuss strategic use of color in the visualizations.

- The idea of *landmark values* was introduced in the Background section and should be illustrated through discussion here. For example, the surface temperature map shows values below freezing (i.e., below 0˚ C), as shades of blue and values above freezing as shades of orange and red, making it easy to see at a glance where the temperatures are below freezing and where they are not.
- In the activity that follows, students will be coloring in the visualizations on their *Work Sheets*, using colors in ways that will help patterns to emerge from the data.

Step 2. Group Problem-Solving

The recommended group size for this activity is student pairs.

The student *Work Sheet* walks students through the process of selecting colors for their visualizations and coloring them in. The rubric section provides an example of how the completed visualizations might look.

The *Work Sheet* first asks students to select color schemes and color in the visualizations. The *Work Sheet* suggests that they use 1500 m as a "landmark value" as the height at which mountains begin. There are other possible values that could represent the minimum elevation of mountains, but using 1500 m works well with the particular data values in this visualization. For temperature, students will need to figure out the full range of temperatures represented (from a low of 1˚ C to a high of 36˚ C) and divide into four relatively equal ranges for their color scheme.

When students have colored the visualizations they are ready to use them for problem-solving: they will explore the relationship between change in elevation and change in temperature. In general, the change in temperature due to change in altitude is called the *lapse rate.* The Himalayas are a particularly good place to investigate this phenomenon since the changes are so dramatic. Students empirically derive the lapse rate by calculating the change that occurs between two points on the visualizations. The lapse rate calculation involves some use of ratios and negative numbers; students may need guidance with this calculation depending on their mathematical backgrounds. Make sure they understand that the elevation visualization uses a unit of *meters*, and the commonly accepted unit for lapse rate is ˚C per *kilometer*; students will therefore need to multiply their calculated ratio by 1000. The rate they compute will generally be a negative number, since temperature *decreases* as elevation *increases*. For many students, this is a confusing concept that may need to be illustrated for the class as a whole.

The answers that students get will vary depending on which cells they choose. Lapse rate values are likely to be lower than the commonly accepted average lapse rate of 9.8˚ C per km of elevation. The theoretical lapse rate is measured by sampling air temperature in vertical elevations above the Earth. By contrast, students are working with air temperatures at Earth's surface which are affected by a number of factors, including surface absorption of sunlight. For example, if you release a weather balloon at sea level, the temperature it will measure at an altitude of 1 km usually will be less than the ground level temperature on a nearby mountain at an elevation of 1 km.

Students are likely to need guidance in thinking through question 8, which asks them to speculate on why they may have calculated a different lapse rate than classmates who chose different cells. Many possible reasons are valid. The most important factor is the resolution of the cells: each cell contains the average elevation or temperature across a large area, and therefore the values are not nearly as precise as points going up a mountain. Lapse rate is also affected by environmental factors such as humidity, which is affected by proximity to the ocean. If students are confused, you may want to include these issues in class discussion.

Step 3. Class Discussion

Close the class period with a brief discussion of the utility of color visualizations for seeing patterns in data. This is a good opportunity to link the tool of visualization with the GLOBE data your students are collecting: what types of analysis might such a tool help you to conduct on particular GLOBE data? Can it help students to answer any questions about their local environment and how it relates to larger systems on Earth?

Further Investigations

These investigations offer ways to connect this activity to GLOBE data, and possibly to your own school.

1. Use the Visualizations page on the GLOBE Web site to investigate elevation-temperature relationships for GLOBE schools that have reported data, ideally finding a school to compare to your own. This comparison is best conducted with schools that report temperature data frequently, and that are at a latitude similar to yours (or to each other) but at very different elevations. Search first for schools that have reported at least 1000 data points for air temperature, and narrow the search using latitude restrictions on the search page. Using a broad search at the beginning can help locate two schools for possible comparison. Sorting the resulting list by latitude can help you visually inspect the list for good candidates. Select two schools and graph their temperatures, selecting *mean temperature* as a graph parameter. Visually inspect the graph to find a year that has a good set of temperatures reported for both schools and graph just that year.

   From the graph page, you can *show data* for one month. Students can get a table of mean temperatures for one month for each school, find the monthly average, and calculate the lapse rate between the two schools. Once again, the resulting lapse rate is likely to differ from either the theoretical average or from the rates calculated by students on the *Work Sheet* from Himalayan data. Actual lapse rate is affected by many factors; this is an opportunity to discuss local and global influences on local temperatures.

2. You can also compare elevation and temperature visually using the GLOBE Web site visualizations pages' *image spreadsheet*. After you have selected one or more schools to investigate, use the server to look at the map of one of the schools, then select *Image spreadsheet*. This will bring up a spreadsheet with the map in all four cells. Use the row selections to select either the *Mean Temperature* dataset or *Geophysical data* and Redraw. You will see temperature in one row and elevation/depth data in another row. The columns show different months, and you can select different values to see the relationship between elevation and temperature at different times.
3. Use the Visualizations page on the GLOBE Web Server to allow students to change the color scheme and range of a visualization. Any time you are looking at a GLOBE visualization, you have the option of changing the colorbar. Using this capability, students can experiment with a variety of landmark values and see the effects of different color schemes. For example, students can find the current global surface temperature map on the GLOBE Web site and change its color scheme to one consisting only of blues and reds, similar to the one in Figure AT-V-1B. Then students can change the landmark value between the colors. The visualization will be re-drawn so that the parts of the world that are warmer than the chosen landmark temperature are red and the parts that are colder are shown as blue.
4. Other GLOBE activities link well with this one. The *Draw Your Own Visualization* activity is useful before or after this one to give students the experience of designing their own visualizations. In addition, there are a number of other visualization activities in the *Earth as a System* chapter that build on the approach developed here.

Resources

Atlases generally contain useful collections of visualizations.

The GLOBE Web Server contains a wealth of visualizations, including 3D ones. In addition, there are many excellent visualization sites from scientific organizations such as NASA and NOAA where students can examine visualizations and analyze the underlying data.

The *Remote Sensing* portion of the *GLOBE Land Cover* video provides a good explanation of resolution, presenting an example of an airport shown at increasing resolutions until it becomes recognizable.

Learning To Use Visualizations
Work Sheet

Name____

In this activity, you will draw visualizations and use them to help understand the relationship between elevation and temperature.

Part A: Drawing Visualizations

The last page of this *Work Sheet* provides two charts of numbers: elevations (in meters) and temperatures (in ˚C). These numbers are *spatially distributed:* each represents the average value across a 3˚ x 3˚ block of land in South Asia (3˚ latitude by 3˚ longitude). Your first goal is to identify the approximate southern border of the Himalayas, the highest mountains on Earth, from these charts by turning each of them into a visualization that can help you answer the question.

1. Assign a color scheme for elevation. When you pick colors to help illustrate where the mountains begin, it is useful to use a *landmark value*. A landmark value is a point on a color scale where the value undergoes a distinctive change. In this example, use 1500 m as the landmark value that defines where mountains begin.

   Choose four colors for this visualization, and identify elevation ranges that each of them will represent. Make sure the landmark value of 1500 m is the border between two of them. You will want to make it obvious which cells are in the mountains and which aren't, so you should select very different colors—with a high degree of contrast—for values above and below 1500 m.

   Color in the scale below the elevation map.

2. Assign a color scheme for temperature. There isn't an obvious temperature value that indicates where mountains begin, so select your four ranges to be of equal size (i.e., the same number of degrees in each range). Again, create the color scale on the map to show what your chosen colors represent.

3. Color in the visualizations. Using the color schemes that you selected, color in the *Elevation* and *Temperature Visualizations*.

Part B: Orienting and Problem-Solving with Visualizations

4. On the *Elevation Visualization* draw the southern boundary of the Himalayas, following the outline of the squares.

5. The highest elevation on your map is 5,300 meters, but the highest mountain in the world (Mt. Everest) is 8,800 meters, and is located in the Himalayas on your map. Explain this by considering the map's *resolution*.

   ____
   ____
   ____
   ____
   ____

6. Can you draw the border of the Himalayas using just the *Temperature Visualization* on *Work Sheet 1*? Try it! How closely does this match the border you drew in question 4?

   Explain why it is possible to approximate the border of the mountain range just by using temperature data.

   ___

   ___

   ___

   ___

   ___

7. The rate at which temperature falls as you climb a mountain or go up in the lower atmosphere is called the *lapse rate*. To compute the lapse rate, pick two cells that are next to each other but have very different elevations. Find the corresponding temperature cells. Calculate the lapse rate as the change in temperature divided by the change in elevation.

   $$\frac{\Delta T}{\Delta E} = \frac{\text{change in temperature}}{\text{change in elevation}}$$

   You will get a negative number for either ΔT (the temperature dropping) or ΔE (the elevation dropping). For example, if the temperature map shows that Cell A is 4°C and Cell B is 16°C, and the elevation map shows that Cell A is 5200 m and Cell B is 2300 m, then the lapse rate is:

   $$\frac{\Delta T}{\Delta E} = \frac{4°C - 16°C}{5200m - 2300m} = \frac{-12°C}{2900\ m} = \frac{-.004°C}{1\ m} \times 1000\ m/km = -4\ °C/km$$

   This ratio means that for every kilometer you climb, the temperature decreases 4°C and therefore, every kilometer you climb down the temperature will increase by 4°C.

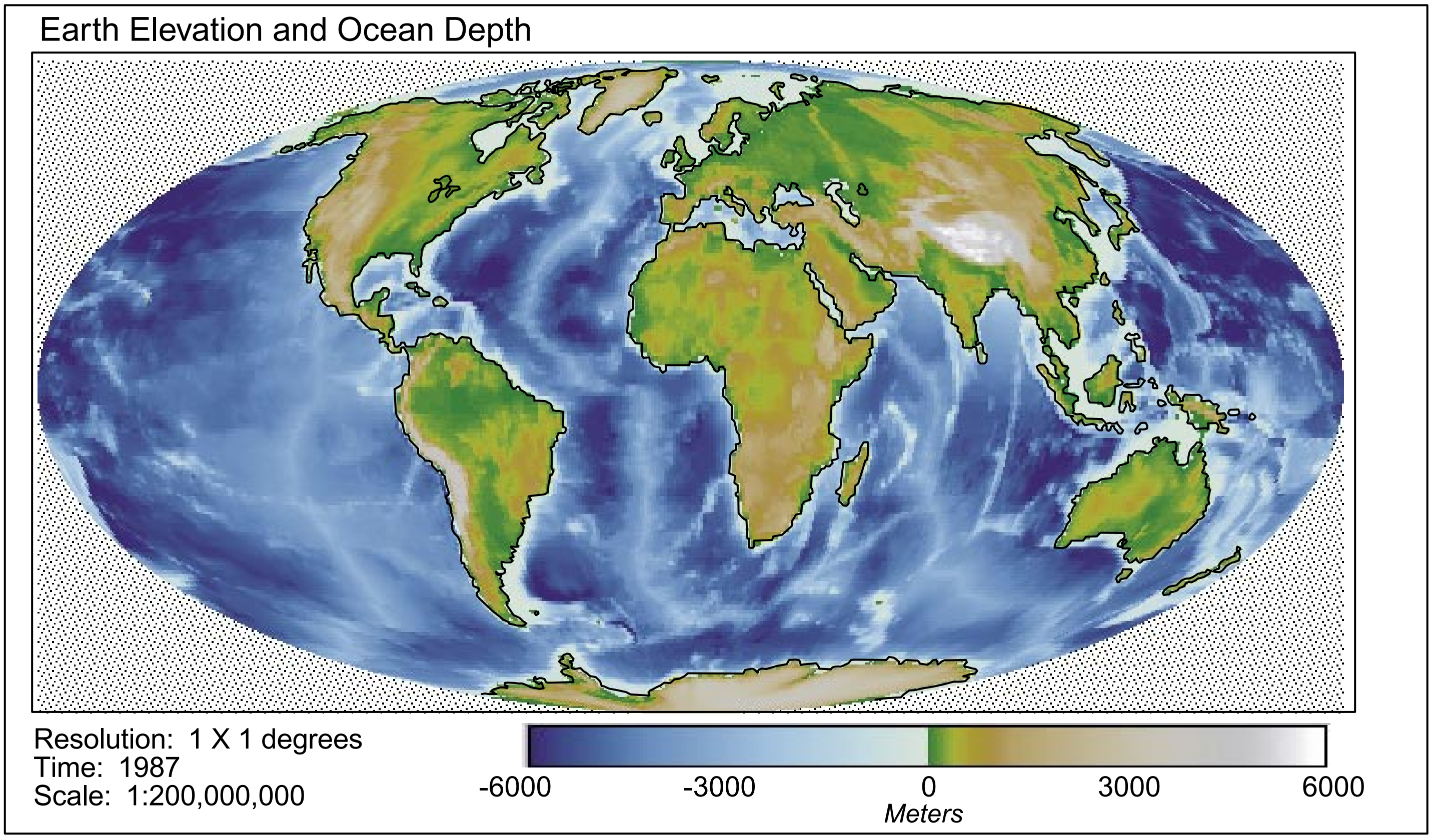
   Calculate the lapse rate for the two cells you chose:

   $$\frac{\Delta T}{\Delta E} =$$

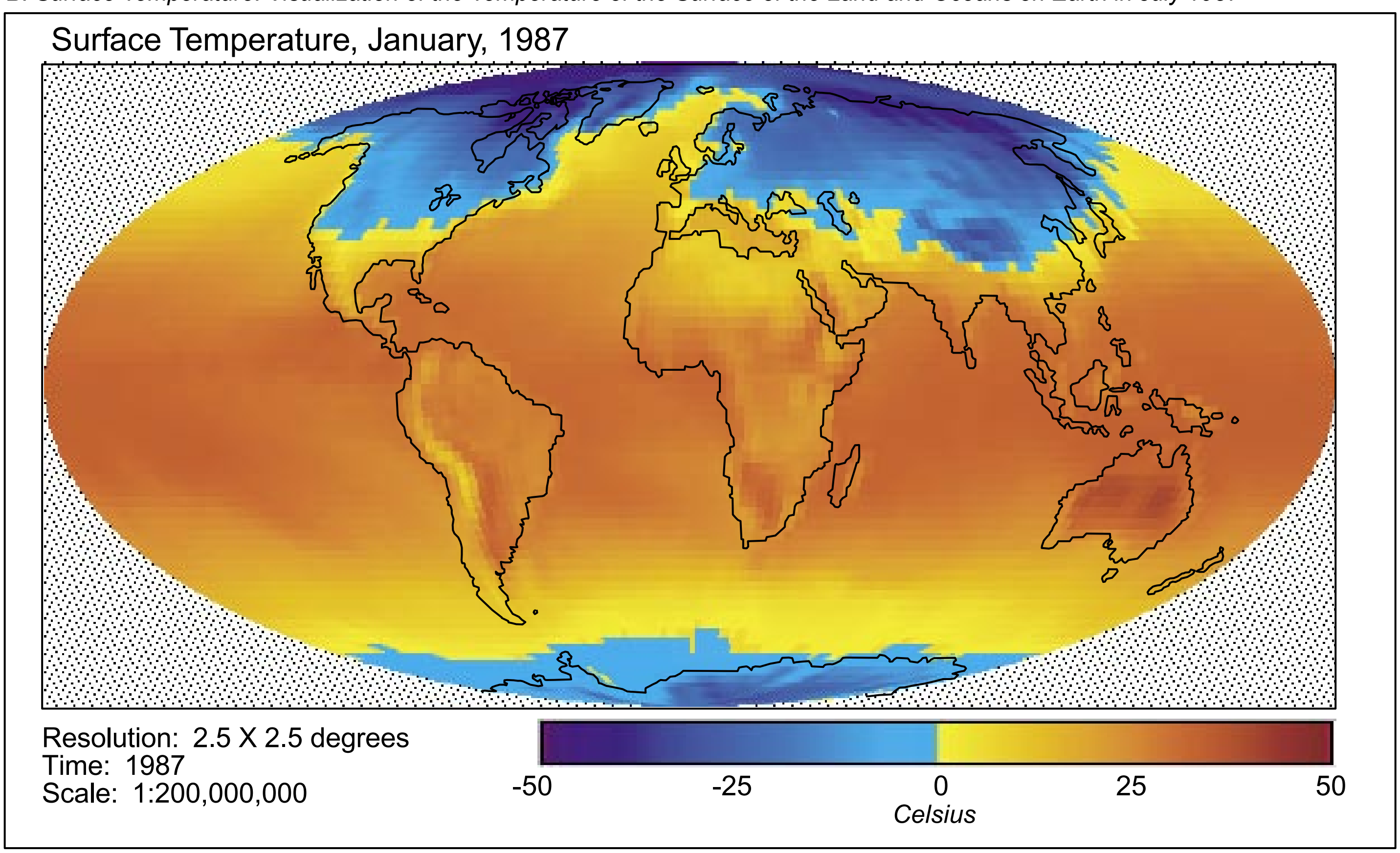
8. Compare your answer with another team. Did you get the same lapse rate? If your answers differ, what might be some reasons why?

Figure AT-V-1

A. Earth Elevation and Ocean Depth: Visualization of Earth Elevation Above and Below Sea Level



B. Surface Temperature: Visualization of the Temperature of the Surface of the Land and Oceans on Earth in July 1987



Learning To Use Visualizations Work Sheet

*Name*________________________________

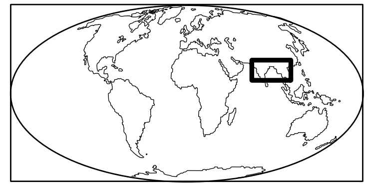
Units
Elevation: meters above sea level
Temperature: degrees Celsius

Scale
Kilometers
300 150 0 300 600

Resolution
3X3 degrees

Time
1987

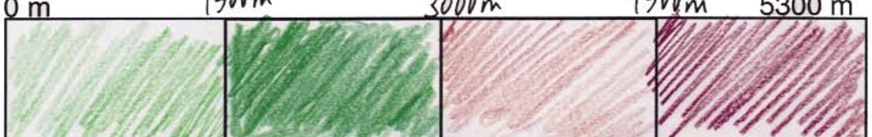
Location



Elevation of Land Above Sea Level (m)

2000	2900	2700	1800	1000	900	1100	1300	1900	2200	1400	1300	1300
2800	4300	3400	2100	2000	3100	4400	3800	3200	4000	3500	2100	1600
2100	2200	4400	5200	5300	5200	5300	5100	4900	4600	3900	2700	1500
700	200	1600	4300	5200	5200	5200	4900	4900	4800	4000	2000	800
200	200	300	500	2300	3900	4400	4000	2300	3400	3600	1600	900
100	400	400	300	200	100	100	300	800	1200	2100	1900	1000
100	200	400	500	500	400	0	200	600	1000	1400	1100	400
water	500	500	300	500	200	water	water	300	700	700	800	200
water	500	500	300	200	water	water	water	0	300	300	200	400
water	300	700	300	water	water	water	water	water	300	200	100	300
water	water	400	100	water	water	water	water	water	100	100	100	100

Color Scale



Surface Temperature: July, 1987 (°C)

25	19	15	17	19	22	25	25	25	23	24	26	26
19	6	4	15	22	22	18	17	16	16	17	21	26
16	6	1	5	8	8	5	5	9	10	11	14	21
24	26	17	7	4	5	7	7	6	7	9	13	21
34	36	33	25	16	10	8	9	11	12	11	15	23
35	34	32	32	29	23	20	19	20	20	16	17	22
32	30	27	28	27	27	27	27	24	23	20	20	22
water	27	25	26	28	28	water	water	26	24	22	22	25
water	26	24	26	26	water	water	water	29	25	24	24	26
water	28	24	26	water	water	water	water	water	27	26	25	25
water	water	27	24	water	water	water	water	water	27	27	27	26

Color Scale

Learning To Use Visualizations Work Sheet

*Name*______________________________

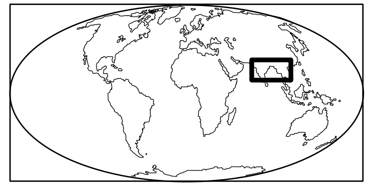
Units
Elevation: meters above sea level
Temperature: degrees Celsius

Scale
Kilometers
300 150 0 300 600

Resolution
3X3 degrees

Time
1987

Location



Average Elevation of Land Above Sea Level (m)

2000	2900	2700	1800	1000	900	1100	1300	1900	2200	1400	1300	1300
2800	4300	3400	2100	2000	3100	4400	3800	3200	4000	3500	2100	1600
2100	2200	4400	5200	5300	5200	5300	5100	4900	4600	3900	2700	1500
700	200	1600	4300	5200	5200	5200	4900	4900	4800	4000	2000	800
200	200	300	500	2300	3900	4400	4000	2300	3400	3600	1600	900
100	400	400	300	200	100	100	300	800	1200	2100	1900	1000
100	200	400	500	500	400	0	200	600	1000	1400	1100	400
water	500	500	300	500	200	water	water	300	700	700	800	200
water	500	500	300	200	water	water	water	0	300	300	200	400
water	300	700	300	water	water	water	water	water	300	200	100	300
water	water	400	100	water	water	water	water	water	100	100	100	100

Color Scale

0 m *Low land* *Mountains* 5300 m

Average Surface Temperature: July, 1987 (°C)

25	19	15	17	19	22	25	25	25	23	24	26	26
19	6	4	15	22	22	18	17	16	16	17	21	26
16	6	1	5	8	8	5	5	9	10	11	14	21
24	26	17	7	4	5	7	7	6	7	9	13	21
34	36	33	25	16	10	8	9	11	12	11	15	23
35	34	32	32	29	23	20	19	20	20	16	17	22
32	30	27	28	27	27	27	27	24	23	20	20	22
water	27	25	26	28	28	water	water	26	24	22	22	25
water	26	24	26	26	water	water	water	29	25	24	24	26
water	28	24	26	water	water	water	water	water	27	26	25	25
water	water	27	24	water	water	water	water	water	27	27	27	26

Color Scale

0°C 36°C

Learning to Use Visualizations
Rubric

For each of the criteria on the following pages, student work is to be evaluated using the score levels and standards below:

3 = Shows clear evidence of achieving or exceeding desired performance

2 = Mainly achieves desired performance

1 = Achieves some parts of the performance, but needs improvement

0 = Answer is blank, entirely arbitrary or inappropriate

1. Drawing visualizations

   A. Assigning landmark values and color scheme

Score Level	Description
3	Visualizations have useful color schemes that illuminate important patterns in the underlying data and incorporate landmark values, as evidenced by color legend. Color scheme for elevation visualization uses landmark value of 1500 m for mountains; color transition is significant at that point (see example). Color scheme for temperature visualization divides the range into four roughly equal segments or another sensible division.
2	Visualizations have easy-to-read color schemes, but the elevation color scheme fails to indicate a major transition at 1500 m or the temperature color scheme does not assign ranges evenly.
1	No landmark values are used; colors appear chosen at random.
0	Color key is blank or confusing.

   B. Coloring the visualization

Score Level	Description
3	Colors are assigned properly according to the color scheme in the key; visualization is neatly colored.
2	All cells with a numeric value are colored correctly, but work is messy, reducing the communicative power of the visualization.
1	Cells are colored incorrectly or so messily that accuracy cannot be determined.
0	Both visualizations are left blank, or they are not colored based on the assigned color schemes.

2. Orienting and problem-solving with visualizations
   A. Drawing the southern boundary of the Himalayas on the elevation visualization

Score Level	Description
3	Student work shows understanding of the problem and how to locate and use the appropriate information/data from the visualization to solve the problem. The student has clearly drawn in a southern boundary for the Himalayas, and this boundary appears to be selected by landmark or significant value color transition. See example.
2	Student work shows understanding of the problem, but may indicate some problems either in obtaining the appropriate data from the visualization OR in using the data to solve the problem. The student may have drawn a northern boundary, or drawn a boundary not based on landmark or significant color value transition.
1	Student work shows little understanding of the problem and/or how to solve it, but the work is attempted. May attempt to use the visualization to draw the boundary, but does not use a boundary based on landmark or significant color value transition, and has difficulty selecting a consistent boundary. Boundary appears to be drawn without use of color scale or numerical values in the squares.
0	The southern boundary is not drawn; evidence of student understanding of the problem and/or use of the visualization is missing.

B. Explaining the concept of resolution

Score Level	Description
3	An answer is given which displays clear understanding of the concept of resolution. Student states that the number in each square is an average of all the elevations in the square, rather than a high or low value, and therefore a high point such as Everest would be masked.
2	Answer displays understanding of differing ground heights and of resolution, but student does not state that the number in each square is an average of all the elevations in the square.
1	Response indicates some understanding of the concept of resolution, but is vague or does not connect the concept to the question asked.
0	Answer is blank, arbitrary or inappropriate.

C. Drawing the southern boundary of the Himalayas from the temperature visualization and comparing results to the elevation visualization

Score Level	Description
3	Student work shows understanding of the problem and how to locate and use the appropriate information/data from the visualization to solve the problem. The student has clearly drawn in a southern boundary for the Himalayas, and this boundary appears to be selected by landmark or significant value color transition. The student has written a short statement accurately describing how the boundaries on the temperature and elevation visualizations compare. See example of visualizations. Note that in this example, the boundaries are similar but not identical. This should be noted in the description, with explanation (for example, we would not expect a perfect correlation because many factors influence local temperatures besides elevation, and the resolution is too imprecise to expect exact transitions to be visible).
2	Student work shows understanding of the problem, but may indicate some problems either in obtaining the appropriate data from the visualization or in using the data to solve the problem. The student may have drawn a northern boundary, or drawn a boundary not based on landmark or significant color value transition. Some explanation is offered, but reasons for the differences are inaccurate or vague.
1	Student work shows little understanding of the problem and/or how to solve it, but the work is attempted. May attempt to use the visualization to draw the boundary, but does not use a boundary based on landmark or significant color value transition, and has difficulty selecting a consistent boundary. Explanation is inaccurate or missing.
0	The southern boundary is not drawn; evidence of student understanding of the problem and/or use of the visualization is missing.

D. Calculating the lapse rate and explaining differences

Score Level	Description
3	The lapse rate is correctly calculated and expressed in correct units (degrees C per kilometer). Students picked two cells that are next two each other and correctly computed the difference and the ratio. Explanation of differences draws on concepts of resolution or local factors that might influence lapse rate.
2	The lapse rate is correctly calculated but not expressed in correct units, or small errors in calculation have resulted in an incorrect answer. Explanation is attempted and indicates some understanding of lapse rate, but without noting specific factors that might explain the differences.
1	Lapse rate is calculated incorrectly; units are missing or incorrect; explanation is missing or incorrect.
0	Answer is blank, arbitrary or inappropriate.

Land, Water, and Air

Purpose

To help students understand that land and water heat and cool at different rates and that the properties of soil and water influence the heating of air above them

Overview

Students measure temperature change in soil, water and air as they are exposed to the heating action of the sun.

Time

Three to four hours total; one to two hours of actual time on task

Level

Intermediate and advanced

Key Concepts

Different substances, such as soil, water and air, transfer energy and heat at different rates

Skills

- Designing and conducting an experiment
- Measuring and recording data
- Organizing data in tables
- Graphing
- Working effectively in groups

Materials and Tools

(per group of students)

- Two plastic buckets at least 30 cm tall
- Centimeter ruler
- Six Thermometers
- A means to suspend thermometers over the buckets, such as string and dowels

Preparation

Arrange for an outdoor area in which to conduct the experiment. (This activity could be performed indoors by substituting a strong artificial light source for the sunlight.) This experiment gives the best results on a sunny, warm day. Divide the students into small working groups. You may want to demonstrate the activity first so that all students understand how to conduct the experiment.

Prerequisites

None

Background

One of the important reasons why we have different kinds of weather throughout the world is because land and water heat and cool at different rates.

For example, afternoon thunderstorms in Florida are often initiated by the fact that during the day the land heats up faster than the water does. (To understand more about this, students should research what causes sea breezes.) In parts of the world that experience monsoons (wind systems that reverse direction seasonally), the rainy part of the monsoon season is characterized by alternating periods of active (rainy) and non-active (not rainy) weather depending on whether the land is dry or wet.

Students may have observed a difference in the heating and cooling rates of land relative to water if they have ever run barefoot across a beach to the water in the middle of a warm, sunny afternoon. They probably remember how hot the land was and how cool and refreshing the water was. If they were at the beach until after sunset and walked barefoot across the beach to the water, they might remember that at this time of day, it is the beach that feels cool, while the water feels warm. Students can study this land/water difference with a simple experiment.

What To Do and How To Do It

Fill one bucket with soil to a depth of approximately 15 centimeters (cm). Fill the other bucket to the same depth with cool water (as from an outdoor faucet). Set both buckets out in the soil. In each bucket suspend a thermometer one cm above, one cm below, and eight cm below the surface. Try to position the thermometers so that the sunlight is not shining directly on the bulb or the glass tube (See the Water Temperature and the Soil Temperature protocols in the GLOBE Teacher's Guide for suggestions on collecting water and soil temperatures.). Allow time for the thermometer temperatures to stabilize. Record the initial thermometer readings.

Read the temperature of each thermometer at two minute intervals for twenty minutes. Remove thermometers and store properly. Then read the temperatures at one, two, and three hours.

Questions for Discussion

After the experiment has been completed, pose the following questions to students:

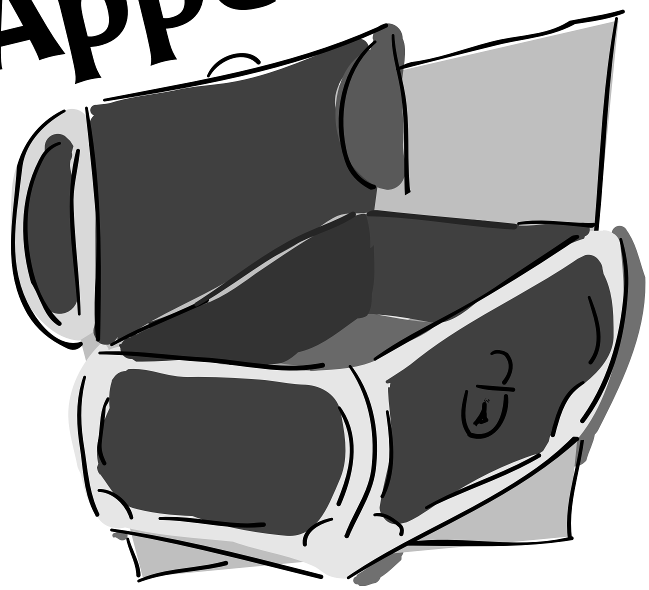
Is the temperature of the soil one cm below the surface warmer than it was when students set out the buckets three hours ago? Why?

Which temperature reading is higher at a depth of eight cm, that of the soil or that of the water? What conclusions can students draw from this experiment?

What students should have found was that the soil's surface was much warmer at one cm than that of the water at one cm. On the other hand, the water was warmer at a depth of 8 cm after three hours than the soil at a depth of eight cm. The temperatures at one cm above the surface should be higher for the soil than for the water.

Liquid water molecules move much more freely than the molecules that make up soil. Therefore, water can distribute heat throughout a greater volume than can soil. That is why, after three hours in the sun, the water in the bucket was warmer at s depth of eight cm than was the soil. After sunset, the heat absorbed by soil quickly escapes to the atmosphere, and the land cools rapidly. However, although water heats up more slowly than land, once it is heated it takes longer to cool. If students were to repeat the measurements several hours after sunset, they would find that the water temperature at one cm was still higher than that of the soil at one cm.

Appendix



Atmosphere Investigation

Site Definition Sheet

School Name: ______________________________ Class or Group Name: ________________________

Name(s) of student(s) filling in Site Definition Sheet: ____

____

Date: ____________________________ Check one: ❒ New Site ❒ Metadata Update

Site name (give your site a unique name): ____

Location: Latitude: ______________° ❒ N or ❒ S Longitude: ______________° ❒ E or ❒ W

Elevation: ___ meters

Source of Location Data (check one): ❒ GPS ❒ Other ______________________________________

Obstacles (Check one): ❒ No obstacles ❒ Obstacles (describe below)

(Obstacles are trees, buildings, etc. that appear above 14° elevation when viewed from the site.)

Description: ____

____

____

Buildings within 10 meters of your instrument shelter (Check one): ❒ No buildings ❒ Buildings (describe below)

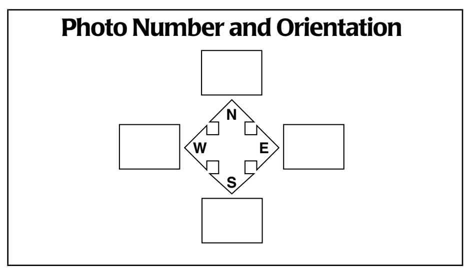
Description: ____

____

____

____

____



Other Site Data:

Steepest Slope: ______________________ Compass Angle (facing up slope): ____________________

Height of the top of the rain gauge: __________ cm

Height of the sensor or bulb of your max/min thermometer: __________cm

Height of the clip in your ozone measurement station: __________cm

Surface Cover under instrument shelter (Check one): ❒ Pavement ❒ Bare ground

❒ Short grass (< 10 cm) ❒ Long grass (> 10 cm) ❒ Sand ❒ Roof (describe below)

❒ Other (describe below)

Description: ____

____

Overall comments on the site (metadata): ____

____

____

____

Atmosphere Investigation

Clouds 1-Measurement Data Sheet

School Name: ____

Observer names: ____

____

Date: Year_____ Month______ Day______ Study Site: ATM-____________________

Local Time (hour:min):____________________ Universal Time (hour:min):____________________

Cloud Type

High (in the sky):

(Check all types seen)

❑ Cirrus

❑ Cirrocumulus

❑ Cirrostratus

Middle (of the sky):

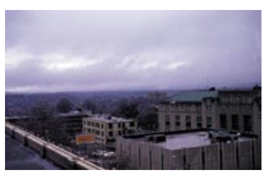
(Check all types seen)

❑ Altostratus

❑ Altocumulus

Low (in the sky):

(Check all types seen)



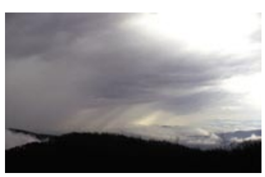
❑ Stratus

❑ Stratocumulus

❑ Cumulus

Rain or Snow Producing Clouds:

(Check all types seen)

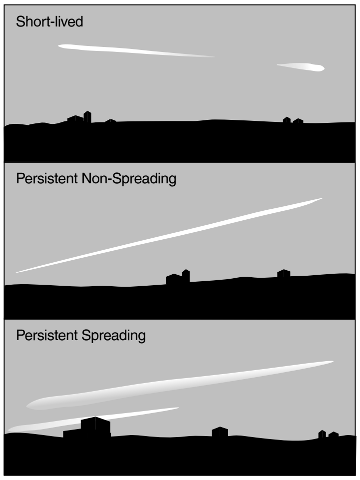


❑ Nimbostratus

❑ Cumulonimbus

School Name ______________________________ Study Site: ATM-____________

Contrail Type (Record the number of each type observed)



Short-lived Contrails
How many do you see? ________

Persistent Non-Spreading Contrails
How many do you see? ________

Persistent Spreading Contrails
How many do you see? ________

Three-quarters or More of the Sky is Visible:

Cloud Cover (Check One)


No Clouds
❑ 0%-No Clouds


Clear
❑ <10% Clouds


Isolated
❑ 10-25% Clouds


Scattered
❑ 25-50% Clouds


Broken
❑ 50-90% Clouds


Overcast
❑ >90%

Contrail Cover (Check one)

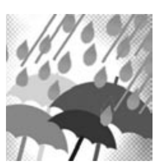
❑ No Contrails (0%) ❑ 0-10% ❑ 10-25% ❑ 25-50% ❑ >50%

View of more than one-quarter or more of the sky is blocked: Obscured ❑ Check here

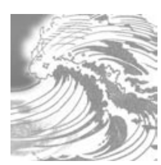
Why is the view of the sky blocked? (Check all that apply)

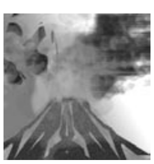

❑ Blowing Snow


❑ Heavy Snow


❑ Heavy Rain

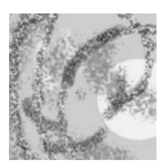

❑ Fog


❑ Spray


❑ Volcanic Ash


❑ Smoke


❑ Dust


❑ Sand


❑ Haze

Comments:____

____

Atmosphere Investigation

Clouds 7-Measurement Data Sheet

School Name ______________________________ Study Site: ATM-____________

Day of the week							
Date							
Local time (hour:min)							
Universal time (hour:min)							
Observer names							

Cloud Type *(Check all types seen)*

Cirrus	❒	❒	❒	❒	❒	❒	❒
Cirrocumulus	❒	❒	❒	❒	❒	❒	❒
Cirrostratus	❒	❒	❒	❒	❒	❒	❒
Altostratus	❒	❒	❒	❒	❒	❒	❒
Altocumulus	❒	❒	❒	❒	❒	❒	❒
Cumulus	❒	❒	❒	❒	❒	❒	❒
Nimbostratus	❒	❒	❒	❒	❒	❒	❒
Stratus	❒	❒	❒	❒	❒	❒	❒
Stratocumulus	❒	❒	❒	❒	❒	❒	❒
Cumulonimbus	❒	❒	❒	❒	❒	❒	❒

Contrail Type *(Record the number of each type observed)*

Short-lived							
Persistent Non-Spreading							
Persistent Spreading							

Cloud Cover *(Check one- if sky not obscured)*

No clouds (0%)	❒	❒	❒	❒	❒	❒	❒
Clear (0% - 10%)	❒	❒	❒	❒	❒	❒	❒
Isolated (10% - 25%)	❒	❒	❒	❒	❒	❒	❒
Scattered (25% - 50%)	❒	❒	❒	❒	❒	❒	❒
Broken (50% - 90%)	❒	❒	❒	❒	❒	❒	❒
Overcast (90% - 100%)	❒	❒	❒	❒	❒	❒	❒
Sky obscured	❒	❒	❒	❒	❒	❒	❒

School Name ________________________________ Study Site: ATM-____________

Contrail Cover *(Check one- if sky not obscured)*

None	❐	❐	❐	❐	❐	❐	❐
0-10%	❐	❐	❐	❐	❐	❐	❐
10-25%	❐	❐	❐	❐	❐	❐	❐
25-50%	❐	❐	❐	❐	❐	❐	❐
>50%	❐	❐	❐	❐	❐	❐	❐

If Sky Obscured *(Check all that apply)*

Fog	❐	❐	❐	❐	❐	❐	❐
Smoke	❐	❐	❐	❐	❐	❐	❐
Haze	❐	❐	❐	❐	❐	❐	❐
Volcanic ash	❐	❐	❐	❐	❐	❐	❐
Dust	❐	❐	❐	❐	❐	❐	❐
Sand	❐	❐	❐	❐	❐	❐	❐
Spray	❐	❐	❐	❐	❐	❐	❐
Heavy rain	❐	❐	❐	❐	❐	❐	❐
Heavy snow	❐	❐	❐	❐	❐	❐	❐
Blowing snow	❐	❐	❐	❐	❐	❐	❐

Comments:

Atmosphere Investigation

Integrated 1-Day Data Sheet

School Name: ______________________________

Observer names: ______________________________

____

Date: Year_____ Month______ Day______ Study Site: ATM-______________________

Local Time (hour:min):__________________ Universal Time (hour:min):__________________

Cloud Type *(Check all types seen)*

High:	❒ Cirrostratus	❒ Cirrus	❒ Cirrocumulus
Middle:	❒ Altostratus		❒ Altocumulus
Low:	❒ Stratus	❒ Stratocumulus	❒ Cumulus
Rain or Snow-Producing:	❒ Nimbostratus		❒ Cumulonimbus

Contrail Type *(Record the number of each type observed)*

Short-lived______ Persistent Non-Spreading______ Persistent Spreading______

Cloud Cover *(Check one- if sky not obscured)*

❒ No Clouds (0%) ❒ Clear (0% - 10%) ❒ Isolated (10% - 25%) ❒ Scattered (25% - 50%) ❒ Broken (50% - 90%) ❒ Overcast (90% - 100%) ❒ Sky obscured

Contrail Cover *(Check one- if sky not obscured)*

❒ None ❒ 0-10% ❒ 10-25% ❒ 25-50% ❒ >50%

If Sky Obscured *(Check all that apply)*

❒ Fog ❒ Smoke ❒ Haze ❒ Volcanic ash ❒ Dust ❒ Sand ❒ Spray ❒ Heavy rain
❒ Heavy snow ❒ Blowing snow

Barometric Station Pressure

Barometric Pressure (mbar): ____________________ ❒ Sea Level Pressure ❒ Station Pressure

Local Time (Hour:Min)*____________________

Universal Time (Hour:Min)*____________________

* If different from other measurements

Relative Humidity

Dry bulb temperature* (°C): ____________________

(note: Current air temp. and dry bulb temp. should be similar)

Wet bulb temperature* (°C): ____________________

* Sling Psychrometer only.

Relative Humidity (%): ____________________

School Name ______________________ Study Site: ATM-______________

Rainfall

Number of days rain has accumulated: ______________

Rainwater in rain gauge (mm)*: ______________

**Remember: enter 0.0 when there has been no rainfall.*
Record M for missing if there was rain and you weren't able to take an accurate reading.
Record T for trace if the amount of rainfall is less than 0.5 mm.

Snowfall

Daily: Number of days snow has accumulated on the snowboard: ______________

Depth of new snow on the snowboard* (mm):

Sample 1: __________ Sample 2: __________ Sample 3: __________

Snow Pack: Total snow accumulation on the ground (mm):

Sample 1: __________ Sample 2: __________ Sample 3: __________

Rain equivalent of:

1. New snow on the snow board (mm): ________ 2. Total snowpack on the ground (mm): ________

** Remember: Record 0 when there has been no snowfall.*
Record M for missing if there was snow and you weren't able to take an accurate reading.
Record T for trace amount of snowfall (too small to measure).

Precipitation pH

Measurement method for pH: ❒ paper ❒ meter

pH of the rain or melted snow:

Sample 1:________ Sample 2:________ Sample 3:________ Average: ________

pH of the melted snow pack:

Sample 1:________ Sample 2:________ Sample 3:________ Average: ________

Maximum, Minimum, and Current Temperatures

Current air temperature: (˚C) ______________

Maximum daily air temperature: (˚C) ______________

Minimum daily air temperature: (˚C) ______________

Current soil temperature: (˚C)*______________

Maximum daily soil temperature: (˚C)* ______________

Minimum daily soil temperature: (˚C)* ______________

*Note: Daily soil temperature measurements apply to those using a digital max/min thermometer with a soil probe.

Comments (Unusual conditions):

____

____

Atmosphere Investigation

Integrated 7-Day Data Sheet

School Name ______________________________ Study Site: ATM-_______________

Day of the week							
Date							
Local time (hour:min)							
Universal time (hour:min)							
Observer names							

Cloud Type *(Check all types seen)*

Cirrus	❐	❐	❐	❐	❐	❐	❐
Cirrocumulus	❐	❐	❐	❐	❐	❐	❐
Cirrostratus	❐	❐	❐	❐	❐	❐	❐
Altostratus	❐	❐	❐	❐	❐	❐	❐
Altocumulus	❐	❐	❐	❐	❐	❐	❐
Cumulus	❐	❐	❐	❐	❐	❐	❐
Nimbostratus	❐	❐	❐	❐	❐	❐	❐
Stratus	❐	❐	❐	❐	❐	❐	❐
Stratocumulus	❐	❐	❐	❐	❐	❐	❐
Cumulonimbus	❐	❐	❐	❐	❐	❐	❐

Contrail Type *(Record the number of each type observed)*

Short-lived							
Persistent Non-Spreading							
Persistent Spreading							

Cloud Cover *(Check one- if sky not obscured)*

No clouds (0%)	❐	❐	❐	❐	❐	❐	❐
Clear (0% - 10%)	❐	❐	❐	❐	❐	❐	❐
Isolated (10% - 25%)	❐	❐	❐	❐	❐	❐	❐
Scattered (25% - 50%)	❐	❐	❐	❐	❐	❐	❐
Broken (50% - 90%)	❐	❐	❐	❐	❐	❐	❐
Overcast (90% - 100%)	❐	❐	❐	❐	❐	❐	❐
Sky obscured	❐	❐	❐	❐	❐	❐	❐

Contrail Cover *(Check one- if sky not obscured)*

None	❐	❐	❐	❐	❐	❐	❐
0-10%	❐	❐	❐	❐	❐	❐	❐
10-25%	❐	❐	❐	❐	❐	❐	❐
25-50%	❐	❐	❐	❐	❐	❐	❐
>50%	❐	❐	❐	❐	❐	❐	❐

School Name ______________________________ Study Site: ATM-____________

If Sky Obscured (Check all that apply)

Fog	❒	❒	❒	❒	❒	❒	❒
Smoke	❒	❒	❒	❒	❒	❒	❒
Haze	❒	❒	❒	❒	❒	❒	❒
Volcanic ash	❒	❒	❒	❒	❒	❒	❒
Dust	❒	❒	❒	❒	❒	❒	❒
Sand	❒	❒	❒	❒	❒	❒	❒
Spray	❒	❒	❒	❒	❒	❒	❒
Heavy rain	❒	❒	❒	❒	❒	❒	❒
Heavy snow	❒	❒	❒	❒	❒	❒	❒
Blowing snow	❒	❒	❒	❒	❒	❒	❒

Barometric Pressure ❒ *Sea Level Pressure* ❒ *Station Pressure*

Barometric Pressure (mbar)							
Local Time (Hour:Min)*							
Universal Time (Hour:Min)*							

* If different from other measurements

Relative Humidity

Dry bulb temperature (˚C) - Sling Psychrometer							
Wet bulb temperature (˚C) - Sling Psychrometer							
Relative humidity (%)							

Rainfall

Number of days rain has accumulated							
Rainwater in rain gauge (mm)*							

** Remember: Record 0.0 when there has been no rainfall.*
Record M for missing if there was rain and you weren't able to take an accurate reading.
Record T for trace if the amount of rainfall is less than 0.5 mm.

Solid Precipitation

Total snowpack on the ground:

Depth sample 1 (mm)							
Depth sample 2 (mm)							
Depth sample 3 (mm)							

School Name ____ Study Site: ATM-__________________

Solid Precipitation *(continued)*

New snow on the snowboard:

Number of days snow has accumulated on the snowboard:							
Depth sample 1 (mm)*							
Depth sample 2 (mm)*							
Depth sample 3 (mm)*							

Rain Equivalent:

Rain equivalent of new snow on the snowboard (mm)							
Rain equivalent of total snow-pack on the ground (mm)							

** Remember: Record 0 when there has been no snowfall.*
Record M for missing if there was snow and you weren't able to take an accurate reading.
Record T for trace amount of snowfall (too small to measure).

Precipitation pH

Measurement method for pH: ❒ paper ❒ meter

pH of the rain or melted snow:

pH sample 1						
pH sample 2						
pH sample 3						
Average						

pH of the melted snowpack:

pH sample 1							
pH sample 2							
pH sample 3							
Average							

Maximum, Minimum, and Current Temperatures

Current air temperature: (°C)							
Maximum daily air temperature: (°C)							
Minimum daily air temperature: (°C)							
Current soil temperature: (°C)*							
Maximum daily soil temperature: (°C)*							
Minimum daily soil temperature: (°C)*							

*Note: Daily soil temperature measurements apply to those using a digital max/min thermometer with a soil probe.

Add Comments on the back of this sheet: (Unusual conditions - date your comments)

Atmosphere Investigation

Aerosols Data Sheet

School Name ______________________ Study Site: ATM-______________

Date : ______________

Observer names:____

____

For Satellite overflights on date of measurements:

Satellite/instrument name: ________ Time of overflight (UT): ________ Max elevation angle (deg): ____

Sun Photometer Instrument serial number: ________________

Case temperature before taking measurements (multiply voltage reading times 100) ________ ° C

Fill in the second-fifth columns of this table and report your data to GLOBE. GLOBE will provide you with calculated values for AOT, which you then record in the sixth column. If your sun photometer has a rotary switch with a "T" (case temperature) position, fill in 100 times the displayed value before and after your measurements.

Measurement Number[1]	**Local Time[2] (hrs:min:sec)**	**Universal Time[3] (hrs:min:sec)**	**Maximum Voltage in Sunlight[4] (volts)**	**Dark Voltage[5] (volts)**	**AOT[6] (cm)**
1 (green)					
1 (red)					
2 (green)					
2 (red)					
3 (green)					
3 (red)					
4 (green)					
4 (red)					
5 (green)					
5 (red)					

[1] At least three sets of measurements are required.

[2] Ideally, time should be reported to the nearest 15 seconds, using an accurately set timepiece.

[3] Be careful when converting local time to UT.

[4] Always report voltages with 3 digits to the right of the decimal point. For example, 1.773 rather than 1.77.

[5] Enter dark voltage in units of volts, not millivolts. For example, 0.003 V rather than 3 mV.

[6] These values are calculated from your data and provided by GLOBE.

Case temperature, after taking case measurements: (multiply voltage reading x 100):____________ °C

School Name ________________________________ Study Site: ATM-_______________

Cloud and contrail conditions (If sky not obscured, check the box for each cloud or contrail type you observe and check one box for cloud or contrail cover amount.)

Cloud Type *(Check all types seen)*

Cirrus	❒
Cirrostratus	❒
Cirrocumulus	❒
Altostratus	❒
Altocumulus	❒
Stratus	❒
Stratocumulus	❒
Cumulus	❒
Nimbostratus	❒
Cumulonimbus	❒

Contrail Type *(Record the number of each type observed)*

Short-lived _____

Persistent Non-Spreading _____

Persistent Spreading _____

Cloud Cover *(Check one- if sky not obscured)*

No clouds (0%)	❒
Clear (0% - 10%)	❒
Isolated (10 - 25%)	❒
Scattered (25% - 50%)	❒
Broken (50% - 90%)	❒
Overcast (90% - 100%)	❒
Sky Obscured	❒

Contrail Cover *(Check one- if sky not obscured)*

None	❒
0-10%	❒
10-25%	❒
25-50%	❒
>50%	❒

Sky Conditions

(Check one box in each table, as appropriate.
Sky conditions can be checked only if sky not obscured.)

Sky Color		Sky Clarity		Sky Obscured by	
Deep blue	❒	Unusually clear	❒	Fog	❒
Blue	❒	Clear	❒	Smoke	❒
Light blue	❒	Somewhat hazy	❒	Haze	❒
Pale blue	❒	Very hazy	❒	Volcanic ash	❒
Milky	❒	Extremely hazy	❒	Dust	❒
				Sand	❒
				Marine Spray	❒
				Strong rain	❒
				Strong snow	❒
				Blowing snow	❒

School Name ____ Study Site: ATM-_____________________

Current Air Temperature (obtained following GLOBE Protocol):_____ °C

Relative Humidity (obtained following GLOBE Protocol)

Dry bulb temperature* (°C):_________ Wet bulb temperature* (°C):_________

*Sling Psychrometer only. (Note: Current air temperature and dry bulb temperature should be similar.)

Relative Humidity (%): ________________

Barometric Pressure: ______________ mbar ❒ Sea Level Pressure ❒ Station Pressure

Select data source (check one):

❒ Online or broadcast source

❒ Aneroid barometer

❒ Other barometer

Comments: Describe conditions that could affect your measurements, such as urban smog, smoke from forest fires, blowing sand, or dust from agricultural activities. Also, include air temperature and relative humidity values that were obtained without following GLOBE protocols.

Atmosphere Investigation

Water Vapor Data Sheet

School Name ________________________________ Study Site: ATM-________________

Date on which the measurements were taken: ______________________________________

Observer names:____

For Satellite overflights on date of measurements (optional):

Satellite/instrument name: __________ Time of overflight (UT): ________

Max elevation angle (deg): __________

GLOBE/GIFTS Water Vapor Instrument serial number: ________________________________

Case temperature, before taking measurements: (multiply voltage reading x 100):____________ ˚C

Fill in the second-fifth columns of this table and report your data to GLOBE. GLOBE will provide you with calculated values for **Precipitable Water,** which you then record in the sixth column.

Measurement Number[1]	Local Time[2] (hrs:min:sec)	Universal Time[3] (hrs:min:sec)	Maximum Sunlight Voltage[4] (volts)	Dark Voltage[5] (volts)	Precipitable Water[6] (cm)
1 (IR1)					
1 (IR2)					
2 (IR1)					
2 (IR2)					
3 (IR1)					
3 (IR2)					
4 (IR1)					
4 (IR2)					
5 (IR1)					
5 (IR2)					

[1] At least three sets of measurements are required.
[2] Ideally, time should be reported to the nearest 15 seconds, using an accurately set timepiece.
[3] Always report voltages with 3 digits to the right of the decimal point. For example, 1.773 rather than 1.77.
[4] Enter dark voltage in units of volts, not millivolts. For example, 0.003 V rather than 3 mV.
[5] These values are provided by the GLOBE database and calculated from your data.

Case temperature, after taking measurements: (multiply voltage reading x 100):____________ ˚C

School Name ______________________________ Study Site: ATM-____________________

Cloud Type *(Check all types seen)*

Cirrus	❒
Cirrostratus	❒
Cirrocumulus	❒
Altostratus	❒
Altocumulus	❒
Stratus	❒
Stratocumulus	❒
Cumulus	❒
Nimbostratus	❒
Cumulonimbus	❒

Contrail Type *(Record the number of each type observed)*

Short-lived ______

Persistent Non-Spreading ______

Persistent Spreading ______

Cloud Cover *(Check one- if sky not obscured)*

No clouds (0%)	❒
Clear (0% - 10%)	❒
Isolated (10 - 25%)	❒
Scattered (25% - 50%)	❒
Broken (50% - 90%)	❒
Overcast (90% - 100%)	❒
Sky Obscured	❒

Contrail Cover *(Check one- if sky not obscured)*

None	❒
0-10%	❒
10-25%	❒
25-50%	❒
>50%	❒

Sky Color

Deep blue	❒
Blue	❒
Light blue	❒
Pale blue	❒
Milky	❒

Sky Clarity

Unusually clear	❒
Clear	❒
Somewhat hazy	❒
Very hazy	❒
Extremely hazy	❒

Sky Obscured *(check the box for each observed phenomenon*

Fog	❒
Smoke	❒
Haze	❒
Volcanic ash	❒
Dust	❒
Sand	❒
Spray	❒
Heavy rain	❒
Heavy snow	❒
Blowing snow	❒

School Name ________________________________ Study Site: ATM-________________

Current Air Temperature (if obtained following GLOBE Protocol)________ ˚C

Relative Humidity (if obtained following GLOBE Protocol)

Dry bulb temperature* (˚C):________Wet bulb temperature* (˚C):________

** Sling Psychrometer only. (Note: Current air temperature and dry bulb temperature should be similar)*

Relative Humidity (%):____________________

Barometric Pressure : __________ mbar ❐ Sea Level Pressure ❐ Station Pressure

Select data source (check one):

❐ Online or broadcast source

❐ Aneroid barometer

❐ Other barometer

Comments: Describe conditions that might affect sky clarity, such as urban smog, smoke from forest fires, blowing sand, or dust from agricultural activities. Also, include air temperature and relative humidity values that were obtained without following GLOBE protocols.

Digital Max/Min Thermometer Calibration and Reset

Data Sheet

School Name: ____________________ Study Site: ATM- __________

Observer Names: ____

____

Calibration

Thermometer Readings						
Reading Number	**Date** (Year/ Month/Day)	**Local Time** (Hour:Min)	**UT Time** (Hour:Min)	**Calibration thermometer readings (˚C)**	**Digital air sensor readings (˚C)**	**Digital soil sensor readings (˚C)**
1						
2						
3						
4						
5						

Time of Reset

Note: The thermometer should be reset only when it is first setup, after the battery is changed, or if the time of local solar noon drifts to more than one hour from your time of reset.

Date: Year__________ Month __________ Day __________

Local time (Hour:Min) ________ Universal time (Hour:Min) ________

Was the reset due to a battery change?________

Soil Sensor Error Check

Local time (hour/min) ________ Universal time (hour/min) ________

1. Soil probe thermometer from *Soil Temperature Protocol* readings (˚C):
   a. reading #1(˚C):________________
   b. reading #2(˚C):________________
   c. reading #3(˚C):________________
   d. reading #4(˚C):________________
   e. reading #5(˚C):________________
   total of the 5 readings (˚C):________________

2. Digital soil sensor readings:
   a. reading #1(˚C):________________
   b. reading #2(˚C):________________
   c. reading #3(˚C):________________
   d. reading #4(˚C):________________
   e. reading #5(˚C):________________
   total of the 5 readings(˚C):________________

3. Average of the 5 soil probe thermometer readings(˚C)
   [= the total of the five soil probe thermometer readings/5]:________________

4. Average of the 5 soil sensor readings(˚C)
   [= the total of the five soil sensor readings/5]: ________________

5. Soil sensor error (˚C) [= #4 – #3]: ________________

6. If the absolute value of the soil sensor error (#5) is greater than or equal to 2˚ C , then dig-out the sensor and recalibrate both the air and soil sensor following the *Digital Multi-Day Max/Min Thermometer Sensor Calibration Field Guide*. If the absolute value of the soil sensor error that you calculate is less than 2˚ C then leave the soil sensor buried and proceed to recalibrate just the air sensor.

Digital Multi-Day Maximum/ Minimum Thermometer
Data Sheet

School Name: ______________________ Study Site: ATM- __________

Observer Names: ____

____

Date: Year ________ Month ________ Day ________

Local time (hour:min)________ Universal time (hour:min) ________

Your *Time of Reset* in universal time (hour:min): ________

Current Temperatures

Air temperature (°C): ____________

Current soil temperature (°C): ____________

Maximum, Minimum Temperatures

Do not read the thermometer within 5 minutes of your *time of reset.*

	Label on Digital Display Screen					
	D1	D2	D3	D4	D5	D6
Maximum Air Temperature (°C)						
Minimum Air Temperature (°C)						
Maximum Soil Temperature (°C)						
Minimum Soil Temperature (°C)						
If you are reading thermometer AFTER your time of reset, Correspond to 24-hour Period Ending:	Today	Yesterday	Two days ago	Three days ago	Four days ago	Five days ago
If you are reading thermometer BEFORE your time of reset, Correspond to 24-hour Period Ending:	Yesterday	Two days ago	Three days ago	Four days ago	Five days ago	Six days ago

Atmosphere Investigation

Check after Data Entered onto Website ❐

Surface Temperature Data Sheet

School Name ______________________________ Study Site: ATM-________________

Date: ____________________

Observer names:____

____

Surface Temperature Supplemental Site Definition Data*

** To be filled out the first time taking Surface Temperature Measurements at a particular site, or if one of the values below has changed.*

Homogenous Site Size (Meters) – Check One

❐ = 90 x 90 (Land Cover Sample Site) ❐ = 30 x 30 ❐ < 30 X 30, specify size: ____ X ____

Cover Type – Check One
(If you are at a Land Cover Sample Site then check only the last box)

❐ Short Grass (less than 0.5 m in height)
❐ Tall Grass (0.5 m to 2 m in height)
❐ Barren Land
❐ Shrubs
❐ Dwarf Shrubs
❐ Concrete
❐ Asphalt
❐ Other Describe:____________________
❐ This is a Land Cover Sample Site

Manufacturer and model of IRT instrument used at this site:________________________

Cloud Type *(Check all types seen)*

Cirrus	❐
Cirrostratus	❐
Cirrocumulus	❐
Altostratus	❐
Altocumulus	❐
Stratus	❐
Stratocumulus	❐
Cumulus	❐
Nimbostratus	❐
Cumulonimbus	❐

Contrail Type *(Record the number of each type observed)*

Short-lived _____

Persistent Non-Spreading _____

Persistent Spreading _____

Cloud Cover *(Check one- if sky not obscured)*

No clouds (0%)	❐
Clear (0% - 10%)	❐
Isolated (10 - 25%)	❐
Scattered (25% - 50%)	❐
Broken (50% - 90%)	❐
Overcast (90% - 100%)	❐
Sky Obscured	❐

Contrail Cover *(Check one- if sky not obscured)*

None	❐
0-10%	❐
10-25%	❐
25-50%	❐
>50%	❐

Date:__________ School Name ________________________Study Site: ATM-______________________

If there is NO snow located on the ground anywhere in your Site, then check one.

Site's Overall Surface Condition: ❒ Wet ❒ Dry

Check which **Method Used to Prevent IRT from Experiencing Thermal Shock:**

☐ IRT was wrapped in Thermal Glove, then taken from storage location to study site

☐ IRT was placed outdoors for at least 30 minutes prior to data collection (No Thermal Glove used)

☐ IRT was taken directly from storage location to study site (No Thermal Glove used)

☐ Other method used, please describe: ____

Surface Temperature

Observation Spots	Local Time (hrs:mins)	Universal Time (hrs:mins)	Surface Temperature (example 25.8˚ C)	Snow Depth (mm)*
1	:	:		
2	:	:		
3	:	:		
4	:	:		
5	:	:		
6	:	:		
7	:	:		
8	:	:		
9	:	:		

*Record Snow Depth according to:

- If there is NO snow at this Observation Spot, then record "0" (zero).
- If there is snow LESS than ten millimeters in depth, then record the letter "T"
- If there is snow GREATER than ten millimeters in depth, then put your ruler or meter stick vertically into the snow at the spot where you just took your surface temperature reading, so that it penetrates all the way to the ground. Read and record the snow depth in millimeters.

Comments:

____

____

____

____

Atmosphere Investigation

Ozone Data Sheet

School Name ______________________________ Study Site: ATM-____________

Day of the week							
Date							
Observer names							

Ozone Strip Exposed

Local time (hour:min)							
Universal time (hour:min)							
Wind direction (N, NE, E, SE, S, SW, W, NW)							
Use values reported on Atmosphere Data Entry for clouds, contrails, current temperature, and relative humidity (Check the box)							
Current temperature (˚C)							
Dry bulb temperature (˚C) - Sling Psychrometer							
Wet bulb temperature (˚C) - Sling Psychrometer							
Relative humidity (%)							

Ozone Strip Read

Local time (hour:min)							
Universal time (hour:min)							
Ozone concentration* (parts per billion)							
Wind direction (N, NE, E, SE, S, SW, W, NW)							
Current temperature (˚C)							
Dry bulb temperature (˚C) - Sling Psychrometer							
Wet bulb temperature (˚C) - Sling Psychrometer							
Relative humidity (%)							

***Remember: enter M if the chemical strip gets damaged by snow or rain, or the response of the chemical is marbled.**

Comments: ____

School Name ____ Study Site: ATM-__________________

Ozone Strip Exposed Cloud Data

Day of the week							
Date							

Take cloud data from *Atmosphere Data Work Sheet*	❒	❒	❒	❒	❒	❒	❒

Cloud Type *(Check all types seen)*

Cirrus	❒	❒	❒	❒	❒	❒	❒
Cirrocumulus	❒	❒	❒	❒	❒	❒	❒
Cirrostratus	❒	❒	❒	❒	❒	❒	❒
Altostratus	❒	❒	❒	❒	❒	❒	❒
Altocumulus	❒	❒	❒	❒	❒	❒	❒
Cumulus	❒	❒	❒	❒	❒	❒	❒
Nimbostratus	❒	❒	❒	❒	❒	❒	❒
Stratus	❒	❒	❒	❒	❒	❒	❒
Stratocumulus	❒	❒	❒	❒	❒	❒	❒
Cumulonimbus	❒	❒	❒	❒	❒	❒	❒

Contrail Type *(Record the number of each type observed)*

Short-lived							
Persistent Non-Spreading							
Persistent Spreading							

Cloud Cover *(Check one- if sky not obscured)*

No clouds (0%)	❒	❒	❒	❒	❒	❒	❒
Clear (0% - 10%)	❒	❒	❒	❒	❒	❒	❒
Isolated (10% - 25%)	❒	❒	❒	❒	❒	❒	❒
Scattered (25% - 50%)	❒	❒	❒	❒	❒	❒	❒
Broken (50% - 90%)	❒	❒	❒	❒	❒	❒	❒
Overcast (90% - 100%)	❒	❒	❒	❒	❒	❒	❒
Sky obscured	❒	❒	❒	❒	❒	❒	❒

Contrail Cover *(Check one- if sky not obscured)*

None	❒	❒	❒	❒	❒	❒	❒
0-10%	❒	❒	❒	❒	❒	❒	❒
10-25%	❒	❒	❒	❒	❒	❒	❒
25-50%	❒	❒	❒	❒	❒	❒	❒
>50%	❒	❒	❒	❒	❒	❒	❒

School Name ______________________________ Study Site: ATM-__________

If Sky Obscured *(Check all that apply)*

Fog	❒	❒	❒	❒	❒	❒	❒
Smoke	❒	❒	❒	❒	❒	❒	❒
Haze	❒	❒	❒	❒	❒	❒	❒
Volcanic ash	❒	❒	❒	❒	❒	❒	❒
Dust	❒	❒	❒	❒	❒	❒	❒
Sand	❒	❒	❒	❒	❒	❒	❒
Spray	❒	❒	❒	❒	❒	❒	❒
Heavy rain	❒	❒	❒	❒	❒	❒	❒
Heavy snow	❒	❒	❒	❒	❒	❒	❒
Blowing snow	❒	❒	❒	❒	❒	❒	❒

Ozone Strip Read Cloud Data

Day of the week							
Date							

Cloud Type *(Check all types seen)*

Cirrus	❒	❒	❒	❒	❒	❒	❒
Cirrocumulus	❒	❒	❒	❒	❒	❒	❒
Cirrostratus	❒	❒	❒	❒	❒	❒	❒
Altostratus	❒	❒	❒	❒	❒	❒	❒
Altocumulus	❒	❒	❒	❒	❒	❒	❒
Cumulus	❒	❒	❒	❒	❒	❒	❒
Nimbostratus	❒	❒	❒	❒	❒	❒	❒
Stratus	❒	❒	❒	❒	❒	❒	❒
Stratocumulus	❒	❒	❒	❒	❒	❒	❒
Cumulonimbus	❒	❒	❒	❒	❒	❒	❒

Contrail Type *(Record the number of each type observed)*

Short-lived							
Persistent Non-Spreading							
Persistent Spreading							

School Name ______________________________ Study Site: ATM-______________

Cloud Cover (Check one- if sky not obscured)

No clouds (0%)	❐	❐	❐	❐	❐	❐	❐
Clear (0% - 10%)	❐	❐	❐	❐	❐	❐	❐
Isolated (10% - 25%)	❐	❐	❐	❐	❐	❐	❐
Scattered (25% - 50%)	❐	❐	❐	❐	❐	❐	❐
Broken (50% - 90%)	❐	❐	❐	❐	❐	❐	❐
Overcast (90% - 100%)	❐	❐	❐	❐	❐	❐	❐
Sky obscured	❐	❐	❐	❐	❐	❐	❐

Contrail Cover (Check one- if sky not obscured)

None	❐	❐	❐	❐	❐	❐	❐
0-10%	❐	❐	❐	❐	❐	❐	❐
10-25%	❐	❐	❐	❐	❐	❐	❐
25-50%	❐	❐	❐	❐	❐	❐	❐
>50%	❐	❐	❐	❐	❐	❐	❐

If Sky Obscured (Check all that apply)

Fog	❐	❐	❐	❐	❐	❐	❐
Smoke	❐	❐	❐	❐	❐	❐	❐
Haze	❐	❐	❐	❐	❐	❐	❐
Volcanic ash	❐	❐	❐	❐	❐	❐	❐
Dust	❐	❐	❐	❐	❐	❐	❐
Sand	❐	❐	❐	❐	❐	❐	❐
Spray	❐	❐	❐	❐	❐	❐	❐
Heavy rain	❐	❐	❐	❐	❐	❐	❐
Heavy snow	❐	❐	❐	❐	❐	❐	❐
Blowing snow	❐	❐	❐	❐	❐	❐	❐

Atmosphere Investigation
Weather Station Calibration Data Sheet

School Name ______________________________ Study Site: ATM-____________________

Air Temperature Sensor Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Calibration Thermometer Reading (˚C)	Digital Temperature Sensor (˚C)
1					
2					
3					
4					
5					

Rain Gauge Recalibration

Reading Number	Date (year/month/day)	Local time (hour:min)	Universal time (hour:min)	Rain Gauge Reading* (mm)	Digital Tipping Bucket Total Reading (mm)
1					
2					
3					
4					
5					

* must be greater than 20 mm for recalibration

Observing Cloud Type

There are five descriptive terms for the various types of clouds:

CIRRO or high clouds
ALTO or middle clouds
CUMULUS or white puffy clouds
STRATUS or layered clouds
NIMBUS or clouds from which precipitation is falling

The following ten types of clouds, named using the above terms, are to be used when reporting the cloud type for your area:

High Clouds

Cirrus

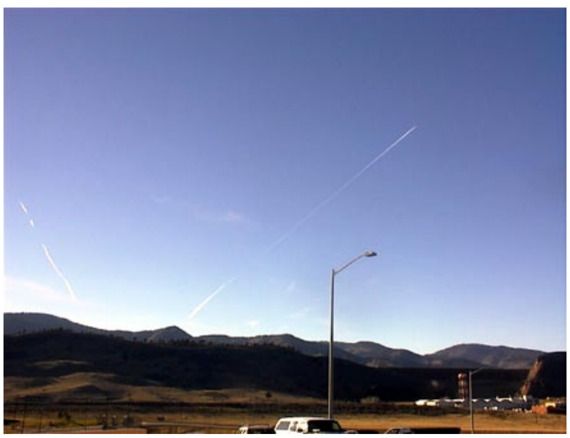
These clouds look like white delicate feathers. They are generally white wispy forms. They contain ice crystals.

Cirrocumulus

These clouds are thin white layers with a texture giving them the look of patches of cotton or ripples without shadows. They contain primarily ice crystals and perhaps some very cold water droplets.

Cirrostratus

These clouds are a thin, almost transparent, whitish layer made up of ice crystals. They may totally or partly cover the sky and can create a halo appearance around the sun.



Contrails

Short-lived Contrail

Note the short line of cloud above the lightpole. The airplane is barely visible in this photo but is at the front of the contrail

Persistent Contrails

These are very distinct contrails, and show a range from persistent non-spreading on the right to persistent spreading on the left. The most likely explanation for this photo is that all three airplanes followed about the same path, but that the winds high in the atmosphere are blowing from right to left, moving the older contrails to the left. The spreading of the left-most contrail indicates there is a fair amount of water vapor in the upper atmosphere.

Persistent, Spreading Contrails

This photo shows persistent, spreading contrails in an area of high air traffic. As above, it is likely that the planes are mostly following a similar path, but the contrails are being spread out by the wind. Note that all the contrails in this photo appear as wide or wider than those above, indicating that the presence of abundant water vapor in the atmosphere is allowing the contrails to spread. Also note the cloud near the middle of the photo, which looks like a regular cirrus cloud, but whose position makes it likely that this cloud actually originated from a contrail.

Middle Clouds

Altostratus

These clouds form a bluish or grayish veil that totally or partially covers the sky. The light of the sun can be seen through them but there is no halo effect.

Altocumulus

These clouds look like waves of the sea with white and gray coloring and shadows. They contain mostly water droplets and perhaps some ice crystals.

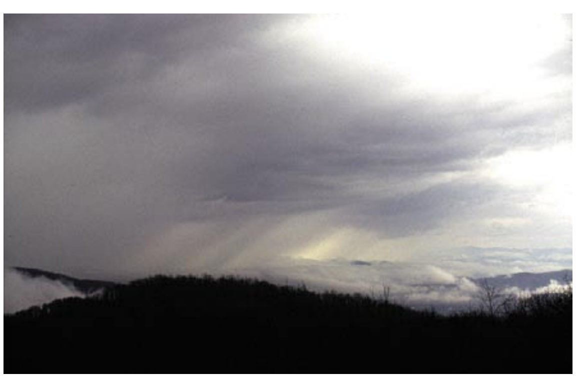
Low Clouds

Stratus

These clouds are gray and lie very close to the surface of the Earth. They usually look like a sheet layer but sometimes are found in patches. They rarely produce precipitation.

Stratocumulus

These clouds are a gray or whitish color. The bases of these clouds tend to be more round than flat. They can be formed from old stratus clouds or from cumulus clouds that are spreading out. Their tops also tend to be mostly flat.



Nimbostratus

This is a very dark and gray-colored cloud layer that blots out the light of the sun. It is massive and has a continuous fall of precipitation.

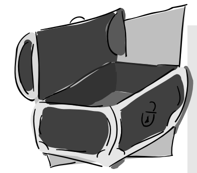
Cumulus

These clouds have a flat base and a dense, mound-shaped top that resembles a large cauliflower. Where the sun hits these clouds they are a brilliant white. The base tends to be a darker gray. They generally do not produce precipitation.

Cumulonimbus

These are large, heavy, and dense clouds. They have a generally flat, dark surface with very tall and large tops like the shape of a massive mountain or anvil. These clouds are often associated with lightning, thunder and sometimes hail. They may also produce tornados.

Glossary



Absolute Zero
The theoretical temperature at which matter has the least energy; the limit of how cold matter can get. If substances could be cooled to absolute zero they would not emit any electromagnetic radiation.

Absorption
Radiation retained by an object and converted to other forms of energy

Acid Rain
Rain having a pH lower than 5.6, the pH of water in equilibrium with the current concentration of carbon dioxide in the air

Aerosols
Liquid or solid particles suspended in the atmosphere. Their sizes generally have linear dimensions in the range of 100-1000 nanometers (nm).

Air Mass
A large volume of air (often covering thousands of square kilometers) with temperature and humidity characteristics that vary little horizontally

Albedo
The percentage of incoming radiation (usually visible light) reflected back to space from a planet or object, its surface, or its cloud layers

Altimeter
A barometer, normalized to standard pressure, temperature and density, used to measure altitude by measuring atmospheric pressure. Altitude is determined by assuming all changes in pressure are due to a change in height relative to sea level. Altimeters are adapted to work over wide ranges of height above sea level and used in GLOBE to measure barometric pressure at elevations above 500 meters.

Ambient Air
Air that is moving freely and not part of a specific perturbation to the surrounding atmosphere (e.g., not part of an exhaust plume, not smoke from a fire, not a dust cloud blown off a field)

Atmospheric Greenhouse Effect
Warming of a planet by the atmospheric absorption and re-emission of infrared radiation emitted from the surface of the planet by various gases in the atmosphere (i.e., *greenhouse gases*)

Barometer
An instrument used to measure atmospheric pressure

Biological Diversity (biodiversity)
The variety of life in all its forms, levels and combinations that coexist in an ecosystem. At different scales this includes ecosystem diversity, species diversity, and genetic diversity. The degree of biodiversity is often used as an indicator of the health of the environment.

Blowing Dust
Dust (soil particles smaller than sand) suspended in the air that reduces visibility, or obscures part or all of the sky

Blowing Sand
Sand suspended in the air that reduces visibility, or obscures part or all of the sky

Blowing Snow
Snow from the ground that the wind blows into the air that reduces visibility, or obscures part or all of the sky

Carbon Monoxide
Chemical compound of one oxygen atom and one carbon atom primarily produced as product of incomplete combustion (chemical symbol: CO)

Ceiling
The height of the base of the cloud layer that covers more than 50% of the sky

Ceilometer
An instrument used to determine the height of the cloud base, which helps to indicates cloud type

Celsius Scale
A temperature scale invented in 1742 by Swedish astronomer Anders Celsius. This scale defines the melting point of water ice as 0° C, and the boiling point of water as 100° C. Because of the 100-degree interval between these two points, this scale is sometimes called the "*centigrade scale*".

Chemical Test Strip
A piece of paper treated with special chemicals that show a color change when exposed to ozone

Cirriform
A cloud type formed of ice crystals at high altitudes (greater than 6 km above sea level)

Climate
Weather at a locality averaged over some time period, plus extremes in weather behavior during a time period

Cloud Cover
The percent of the sky covered by clouds

Compounds
Chemicals made of atoms from two or more elements

Concentration
The number of molecules of a specific gas in a unit volume relative to the sum of all the molecules in that volume, often reported as parts per million (ppm) or parts per billion (ppb)

Condensation
The change of phase of a substance from a vapor to a liquid. The process of condensation releases energy; this energy is known as latent heat

Conduction
The transfer of heat through collisions of the individual constituents of a substance (e.g., molecules, atoms) without the systematic movement of groups of these constituents. For example, if one end of a metal rod is heated, the heat will be conducted the length of the rod so that the other end will also increase in temperature. Conduction can occur in solids, liquids, or gases (but is generally most efficient in solids).

Convection
The transfer of heat by mass flow, that is, large scale motion within a liquid or a gas of groups of constituents (e.g. molecules, atoms) that are relatively warmer or cooler than their surroundings. In the atmosphere convection mostly refers to vertical motions brought about by warm air rising and cooler air sinking.

Cumuliform
A cloud type that is heaped, puffy, banded, or otherwise is characterized by rounded features particularly on the top and sides

Density (D)
The ratio of the mass (M) of a substance to its volume (V) (D = M/V)

Deposition
The process by which water vapor turns directly into ice on a surface without passing through the liquid phase

Dew Point Temperature
The temperature at which the water vapor begins to condense in air cooled at constant pressure. Dew Point Temperature is a measure of the amount of water vapor in air.

Diffuse Insolation
Solar radiation that reaches Earth's surface by being scattered or reflected by components of Earth's atmosphere (such as gases, clouds and aerosols)

Direct Insolation
Solar radiation that reaches Earth's surface by passing directly through the atmosphere without interacting with the components of Earth's atmosphere

Diurnal Cycle
Refers to the 24 hours of the day, and sometimes the changes that occur over that 24-hour time period

Drizzle
Slow falling liquid precipitation made up of droplets with diameters between 0.2 and 0.5 mm. Drizzle reduces visibility more than light rain because of the large numbers of very small drops

Dry Bulb Temperature
The temperature on one of two thermometers on a sling psychrometer; this temperature corresponds to the bulb which does not contain the water saturated wick

Ecosystem
A community of different species interacting with one another and with the chemical and physical factors making up their surroundings

El Niño
El Niño refers to a prolonged significant warming of surface waters in the central and eastern tropical Pacific Ocean and generally to the phenomena that accompany this warming.

Electromagnetic (EM) Radiation
Energy waves produced by oscillating or accelerating electric charges. EM waves have both electric and magnetic components. Unlike conduction and convection, EM waves do not need media like solids, liquids, or gases in order to transfer energy. Electromagnetic radiation can be arranged in a spectrum from very energetic short wavelengths (gamma rays, x-rays), to less energetic, very long wavelengths (microwaves and radio waves). Visible light is a small part of the electromagnetic spectrum that human eyes can see.

Elevation Angle
The angular distance between the horizon and an object in the sky, such as the sun. The *zenith angle* is 90˚ minus the elevation angle.

Evaporation
The phase change of a substance from a liquid to a gas

Evapotranspiration
The transfer and transformation of liquid water from soil to air by the combined processes of evaporation and transpiration by vegetation

Fahrenheit Scale
A temperature scale invented by the 18th century German physicist Daniel Gabriel Fahrenheit. This scale defines the melting point of water ice as 32˚ F and the boiling point of water as 212˚ F. The United States is the only major country in the world still commonly using the Fahrenheit scale.

Fog
A cloud in contact with Earth's surface

Force (F)
a push or pull

Freezing
The process of water changing phase from liquid to solid (ice)

Freezing Rain and Freezing Drizzle
Supercooled water drops that freeze when they come in contact with cold surfaces

Front
The narrow transition region between two distinct air masses. A front is a region of changing wind direction, changing surface air pressure, and often results in the development of clouds and precipitation.

Frost
The deposition of ice from water vapor in the atmosphere directly onto surfaces such as grass or windows

Geostationary
An object in orbit around Earth that stays above a certain location on the planet; the object is generally located directly above the Equator at a fixed longitude.

Greenhouse Gas
Any gas that causes heat to be retained in the atmosphere and thereby causes the average temperature of the atmosphere to increase. Greenhouse gases are strong absorbers of infrared radiation. Examples of significant greenhouse gases are water vapor, carbon dioxide, nitrous oxide, methane, and chlorofluorocarbons.

Gravity
The force of attraction among all matter (e.g., gravity pulls each of us toward Earth's center)

Greenwich Mean Time (GMT)
The same reference time as Universal Time (UT); the time at 0 degrees longitude (the prime meridian) that passes through Greenwich, England

Hail (also known as Hailstones)
Precipitation in the form of irregular balls of ice ranging in size from about 2 mm to 13 cm in diameter. The largest hailstones can only form in the most violent thunderstorms that have extremely strong updrafts (upward moving air).

Halo
The optical phenomenon caused when sunlight or moonlight is refracted through ice crystals, splitting the visible beam into its distinct colors. This occurs only with cirrostratus or thick cirrus clouds.

Haze
The reduction of visibility by aerosols in the atmosphere. Haze may cause the sky to appear milky white to yellowish, reddish, or brown, depending on whether the aerosol is wet or dry and depending on the size and nature of the particles which scatter the light.

Heat
The total energy of motion of all of the atoms and molecules that make up a substance

Heavy Rain
Rain falling at such a great rate (greater than 7.5 mm/hr) that it reduces visibility and obscures the view of the sky

Heavy Snow
Falling snow that reduces visibility to less than 400 meters and obscures the view of the sky

Hydrocarbons
Compounds composed primarily of carbon and hydrogen atoms. Gaseous hydrocarbons occur in the atmosphere, (e.g., the compounds in natural gas, chemical species given off naturally by plants, and compounds that result from by-products of the combustion process).

Hydrologic Cycle
The continuous flow of water through the Earth system. The hydrologic cycle is composed of reservoirs of water (such as ice caps, oceans, atmospheric humidity, and aquifers) and fluxes or flows of water (such as evaporation, precipitation, river flow, and iceberg calving).

Hygrometer
An instrument used to measure the relative humidity of air

Ice Pellets
Same as sleet

Infrared radiation
Light (electromagnetic radiation) with wavelengths ranging from just longer than visible light (0.7 micrometers) to just shorter than microwaves or radio waves (1000 micrometers). The amount of light thermally emitted by Earth's surface and lower atmosphere peaks at wavelengths near 10 micrometers, and light in this portion of the infrared wavelength range is often referred to as thermal infrared.

In situ
In place. Most of the atmospheric measurements in GLOBE, such as temperature and ozone, are taken *in situ*; however, many of these quantities can also be measured *remotely* through the use of special satellites.

Insolation
Incoming solar radiation

Interplanetary Medium
The space between the planets that contains electromagnetic radiation, electric and magnetic fields, ionized gas, neutral atoms, and microscopic dust particles. The characteristics of interplanetary space are primarily influenced by the sun and not by individual planets.

Inverse Relationship
When two variables are related to each other in an opposite way; for example, as one increases, the other decreases (e.g. $x = 1/y$)

Isobars
Lines on a map connecting points of equal pressure

Isotherms
Lines on a map connecting points of equal temperature

Kelvin Scale
A temperature scale named for British physicist William Thomson Kelvin who proposed it in 1848. One Kelvin degree is equivalent to one Celsius degree. However, zero on the Kelvin scale is defined to be the temperature at which molecular energy is a minimum, also

called “absolute zero”. The convention when writing temperatures in the Kelvin scale is to just use the letter K, omitting the degree symbol. Zero on the Kelvin scale corresponds to approximately –273˚ C.

La Niña
A period of anomalous cooling of sea-surface temperatures in the central and eastern tropical Pacific Ocean

Latent heat
The heat used or released when water changes phase between solid, liquid, and gas

Melting
The process of a substance changing phase from solid to liquid

Mesosphere
The third layer of the atmosphere above Earth’s surface, generally found between altitudes of 50 km and 80 85 km and characterized by temperature decreasing with altitude

Millibar
A unit of barometric pressure equivalent to one one-thousandth of a bar and equivalent to a hectopascal

Mixing Ratio
A scientific term often used synonymously with concentration. One example is the mass of water vapor in a sample of air divided by the total mass of air in the sample

Nitrogen Oxides
The family of compounds comprised of one or more nitrogen atoms and one or more oxygen atoms. Nitric oxide (NO) and Nitrogen dioxide (NO_2) are both primarily products of combustion whereas nitrous oxide (N_2O) is a primarily product of microbial activity in soils.

Optical thickness (also optical depth)
A measure of how much particles (aerosols) and gas molecules (air) impede the transmission of light through a gas at a specific wavelength. At an optical depth of one, the incoming light is attenuated to 1/e in intensity.

Ozone
A highly reactive gas composed of 3 oxygen atoms that exists in varying amounts in the troposphere and stratosphere. Ozone is found naturally in the atmosphere as a result of breaking apart oxygen molecules (O_2) into two oxygen atoms that combine with molecules of oxygen to form ozone (O_3).

Ozone Layer
The layer of the atmosphere in the stratosphere and lower mesosphere that absorbs most incoming ultraviolet radiation

Ozone Optical Scanner
An instrument used in GLOBE’s ozone protocol that measures the color change on the chemical test strips and interprets this change as an ozone concentration in units of ppb

Pascal
The unit of pressure equivalent to 1 Newton/meter-squared. 100 pascals equals one hectopascal which is a standard pressure unit used in GLOBE

pH Scale
The system used to specify the range of acidity or alkalinity of substances. On this scale, a substance with a pH of 7 is neutral. Substances with pH less than 7 are acidic; substances with pH greater than 7 are alkaline (or basic).

Phase Change
The change in a substance from one phase to another. Substances (elements and compounds) generally exist in one of three phases solid, liquid, and gas; For example, water vapor (gas) condensing into water (liquid). Substances undergoing phase changes take up or give off heat without changing temperature. (See Latent Heat)

Photolysis
The break-up of an atmospheric compound by light. For example, when ozone (O_3) is formed in the atmosphere, it can be split into atomic oxygen (O) and molecular oxygen (O_2) by ultraviolet sunlight.

Polar-Orbiting Satellite

An artificial satellite (spacecraft that orbits Earth) passing near or over the poles. This term usually refers to satellites in near-polar orbits that are designed so that their orbital plane maintains a constant angle (on average) with the line between the sun and Earth. These are called sun-synchronous satellites.

Pollutant

A trace gas or aerosol that contaminates the air

ppb

Parts per billion, a unit of measure of atmospheric trace gas concentration or mixing ratio; sometimes denoted ppbv (parts per billion by volume), which is how trace gas mixing ratios are normally defined.

Precipitable Water Vapor

The depth of a planet-wide layer of liquid water that would be formed if all the water vapor in a column of atmosphere were condensed onto Earth's surface. On average, the atmosphere contains about 2 centimeters of precipitable water vapor.

Precipitation

Water in solid or liquid form that falls to Earth's surface from the atmosphere

Precursor

A chemical necessary to reactions that form other compounds (e.g., nitric oxide is a precursor of ozone in the near-surface atmosphere)

Pressure

Force per unit area; for the atmosphere, it may be thought of as the weight of the column of air above a given area.

Radiation

See "*Electromagnetic Radiation*".

Rayleigh scattering

Scattering of sunlight by molecules in the atmosphere, named after the 19^{th} century British physicist John William Strutt, the third Baron Rayleigh.

Reactive Chemicals

Chemicals that will undergo chemical reactions in the atmosphere

Reflection

The process by which radiation incident upon an object is directed at some fixed angle away from that object

Relative Air Mass

The ratio of the amount of atmosphere between an observer and the sun relative to the amount of atmosphere directly overhead. Relative air mass is directly related to solar elevation angle.

Relative Humidity

A measure of the amount of water vapor in a sample of air compared to the amount contained in an air sample at the same pressure and temperature saturated with water vapor

Satellite

An object in orbit around a larger celestial body

Scattering

The process by which radiation interacting with a substance is deflected in all directions

Sea Level Pressure

Atmospheric pressure adjusted to the value that would be measured if the measurement location were at sea level

Sea Spray

Aerosols blown off the surface of a salt water body under windy conditions, which may produce obstructions to visibility

Seasonal Cycle

A periodic change in a variable that occurs in tandem with Earth's seasons

Sensible Heat

The heat associated with a change in temperature of a substance as distinct from the heat associated with a phase change

Shower

A type of precipitation event that is typically of short duration, or occurs with frequent changes of intensity

Sleet

Precipitation that at some point is in liquid form, but freezes before reaching the ground

Sling Psychrometer

A device consisting of two thermometers, one of which has a dry bulb and the other of which has a bulb that is kept wet. The difference between the wet and dry bulb temperatures is used to calculate relative humidity.

Smog

Air that contains a sufficient combination of aerosols from water and combustion to be visible. Aerosols in smog may be produced indirectly by reactions among the gases present in combustion exhaust. Smog originated as a term combining the words smoke and fog and may reduce visibility in a similar way.

Smoke

Air containing sufficient aerosols produced by combustion to be visible, which may reduce visibility or obstruct views of the sky

Solar Noon

The time at which the sun is at its highest point in the sky (zenith) during a day

Specific Heat

The amount of heat required to raise the temperature of 1 gram of a substance by 1° C

Squall

An intense or violent shower accompanied by strong, gusty winds

Station Pressure

The true atmospheric pressure, uncorrected to standard conditions at sea level. Weather reports generally give barometric pressure corrected to sea level, not station pressure.

Stratiform

A cloud comprised of a single or multiple horizontal layers; there is very little discernible structure to clouds of this type.

Stratosphere

The second layer of the atmosphere above Earth's surface, generally characterized by temperature increasing with altitude. The stratosphere begins at altitudes ranging from about 8 km in the polar regions to 1618 km in the tropics and extends to altitudes of about 50 km where there is a local maximum in atmospheric temperature. The stratosphere contains most of the ozone found in the atmosphere.

Sublimation

The transition of a substance directly from the solid phase to the gas phase

Sun Photometer

An instrument that measures the intensity of sunlight transmitted through the atmosphere within a narrow wavelength range

Supercooled Water

Water with a temperature that is below its freezing point but still in liquid form

Temperature

A measure of the *average* energy of motion of all the atoms and molecules that make up a substance

Temperature Inversion

An increase in temperature with height in the troposphere, usually associated with a very stable air mass. Normally, temperature in the troposphere increases with height. When and where temperature increases with height, vertical mixing of the atmosphere is greatly decreased. This leads to the trapping of aerosols and trace gases from the surface being contained in the air near the surface. It also causes the atmosphere to be stratified in horizontal layers in the stratosphere, hence the name of this atmospheric layer.

Thermosphere

The fourth layer of the atmosphere above Earth's surface. In the thermosphere, temperature increases greatly, ion concentrations become significant, and the dynamics of the atmosphere is virtually independent of the forces and phenomena associated with Earth's surface and lower atmosphere. Most of the ionosphere is contained within the thermosphere and above the thermosphere is interplanetary space.

Thunderstorm

A cumulonimbus cloud or family of cumulonimbus clouds that produce lightning, and therefore, thunder. Thunderstorms are not always accompanied by precipitation reaching the ground.

Trace Gas

Gases present in the atmosphere in very small quantities, always less than one-tenth of one percent

Transpiration

The process by which water vapor escapes into the atmosphere through open stomata on plant leaf surfaces

Tropical Cyclone

A low pressure system found in tropical latitudes which may develop into a tropical storm, hurricane, and other similarly intense storm

Troposphere

The lowest layer of the atmosphere where almost all weather occurs. The troposphere contains about 80% of the atmosphere's mass and is characterized by temperatures that normally decrease with altitude. The boundary of the troposphere and the stratosphere depends on latitude and season. It ranges from as low as 8 km over the poles to as high as 16-18 km in the tropics.

Ultraviolet

A part of the electromagnetic spectrum that is more energetic, and of shorter wavelengths than visible light; usually defined as radiation with wavelengths of 0.1 - 0.38 micrometers.

Universal Time (UT)

The time at 0 degrees longitude (the prime meridian); UT is the currently preferred term for this reference time, which is the same as GMT.

Visibility

The distance over which an observer can see and clearly identify an object

Visible Radiation

Light with wavelengths between about 0.38 and 0.7 micrometers that may be seen by humans. The sun emits its peak amount of energy in the visible portion of the electromagnetic spectrum.

Volcanic Ash

Small particles of minerals, rock and glass fragments ejected from volcanic eruptions. As aerosols they may reduce visibility or obscure a view of the sky. These particles often produce spectacular light scattering effects including colorful sunsets.

Water Cycle

See Hydrologic Cycle.

Water Vapor

The colorless, odorless, invisible, gaseous form of water in the atmosphere

Wavelength (of light)

A property of light that is inversely proportional to its frequency and describes the distance from one wave peak to the following wave peak. Visible light lies in the wavelength range from about 0.38 micrometers (violet) to 0.7 micrometers (red). The peak sensitivity of the human eye is to light at a wavelength of about 0.5 micrometers (green), near the response wavelength of the green channel of the GLOBE sun photometer.

Weather

The state of the atmosphere at a particular place and time. Weather includes variables such as temperature, barometric pressure, wind, cloudiness, precipitation, and relative humidity.

Wet Bulb Depression

The difference between the dry bulb and wet bulb temperature readings on a sling psychrometer

Wet Bulb Temperature

The temperature taken on a sling psychrometer from the thermometer with its bulb covered in a wet wick, after slinging or whirling the psychrometer for the prescribed amount of time

Wet Deposition

The depositing of gases or aerosols from the atmosphere on to Earth's surface through their incorporation in precipitation (rain drops, snowflakes, etc.). Sometimes the terms 'rain out' or 'wash out' are used in place of wet deposition.

Zenith Angle

The angular distance between an object in the sky, such as the sun, and an object directly overhead. Zenith angle is 90° minus the *elevation angle*