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
- Barometer
- *Water Vapor Data Sheet*

Preparation

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

Prerequisites

Cloud, Barometric Pressure, 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.

As helpful as satellite-based measurements are to an improved understanding of the global distribution of water vapor, ground-based measurements are still needed. 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.

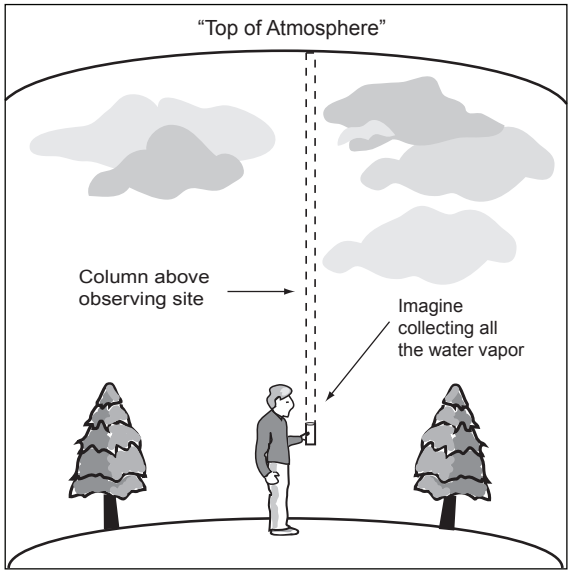
Teacher Support

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

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



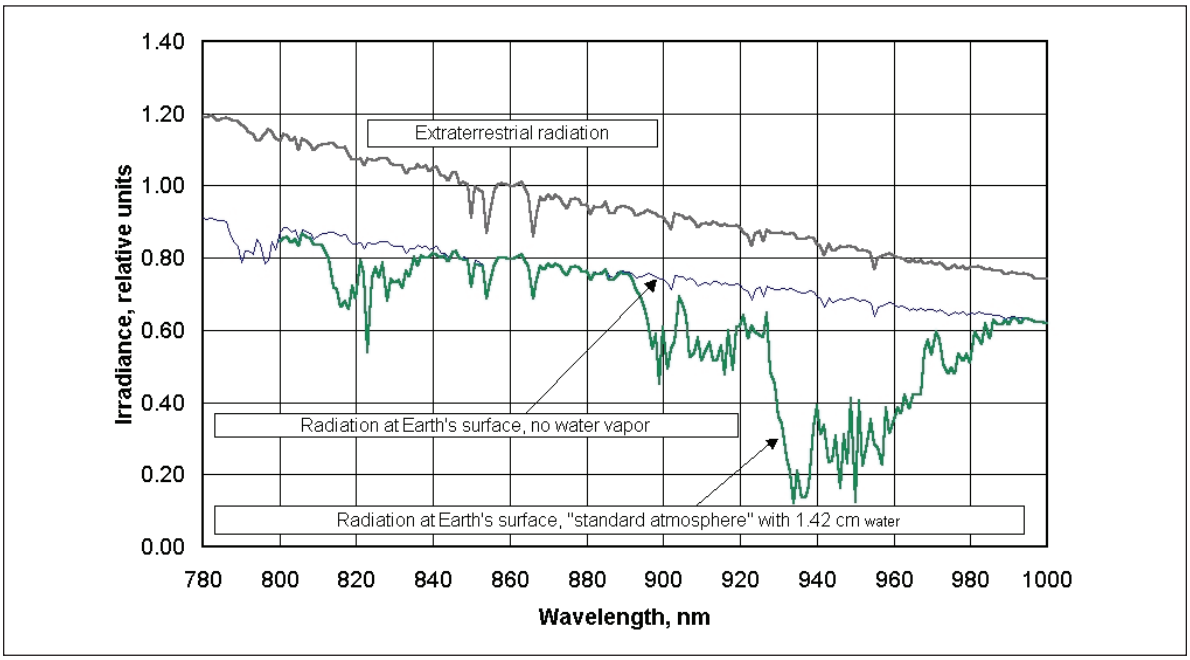
solar spectrum. This absorption reduces the amount of sunlight reaching Earth's surface at those wavelengths.

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. 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 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.

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



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. See a diagram of the GLOBE/GIFTS Water Vapor instrument in Figure Figure AT-WV-4. 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].

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

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

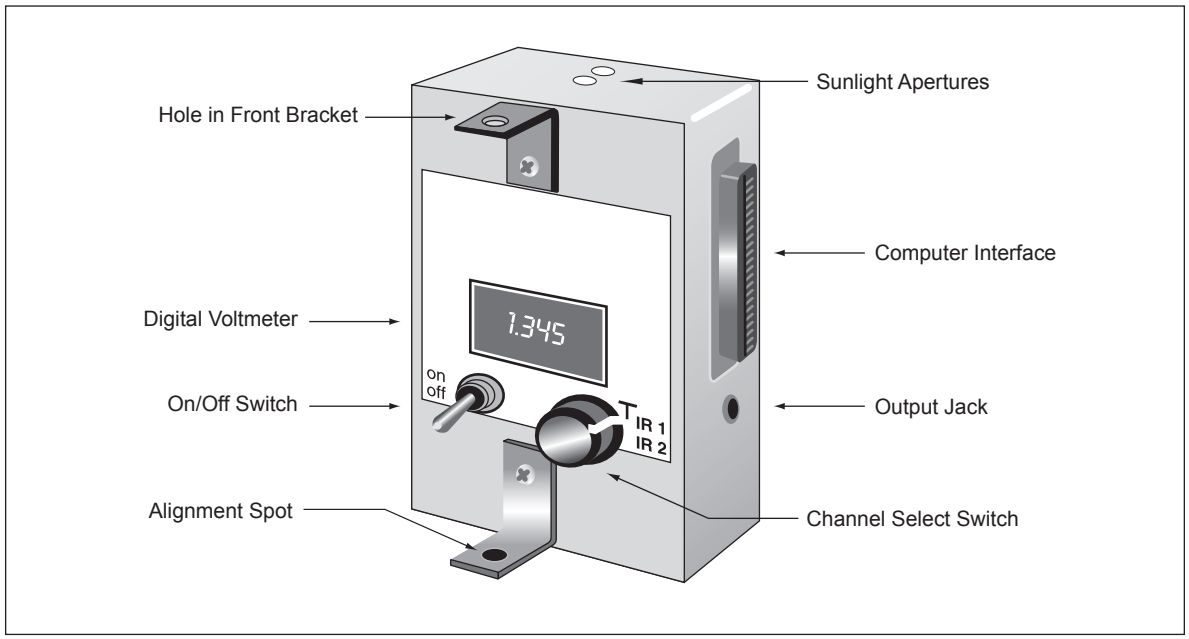
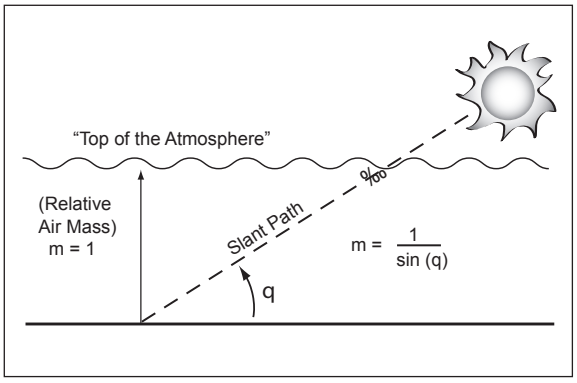


Figure AT-WV-5: Viewing the Sun Through the Atmosphere



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 sun-synchronous orbits of many Earth-observing satellites, measurements need to be timed to coincide with overflights of your site. The S'COOL satellite overpass calculator (http://scool.larc.nasa.gov/en_rover_overpass.html) provides overpass times for Aqua NPP, both very relevant to water vapor measurements. 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; this video is located at: http://www.globe.gov/teaching-and-learning/materials/globe-videos). 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
- ❑ Thermometer
- ❑ Field Guides for *Cloud*, *Air Temperature*, *Relative Humidity* Protocols and *Barometric Pressure Protocol*

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 (*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.

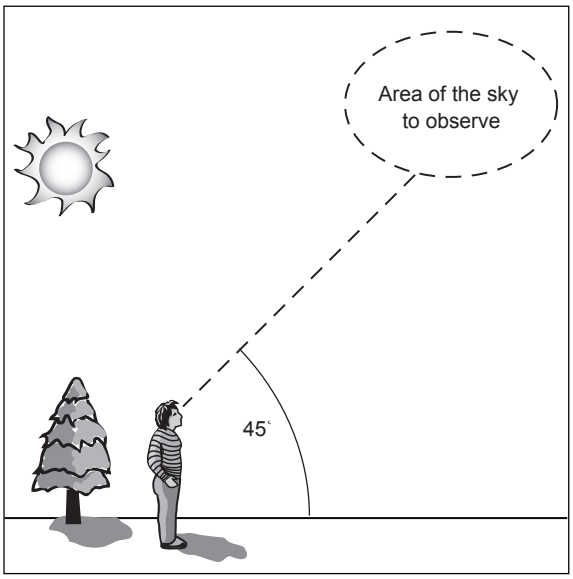
7. Sky conditions
Sky conditions include sky color and clarity. These are subjective observations but, with practice, you can learn to be consistent in your interpretations. For example, you can easily learn to recognize the clear deep blue sky that is associated with clean air and low relative humidity. 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).

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*.

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



8. Spacecraft overflight information

Collecting data during satellite overpass, when available, can add relevency to student field work. The S'COOL overpass calculator (http://scool.larc.nasa.gov/en_rover_overpass.html) will allow the user to calculate satellite overpass for Aqua and NPP, both very relevant to water vapor measurements. Because the water vapor measurement involves viewing the Sun, only daytime overflights are of interest. When you are taking a measurement to correspond with a satellite overflights, please record the Satellite/instrument name, time of overflight, and any additional information on your *Water Vapor Data Sheet*.

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.

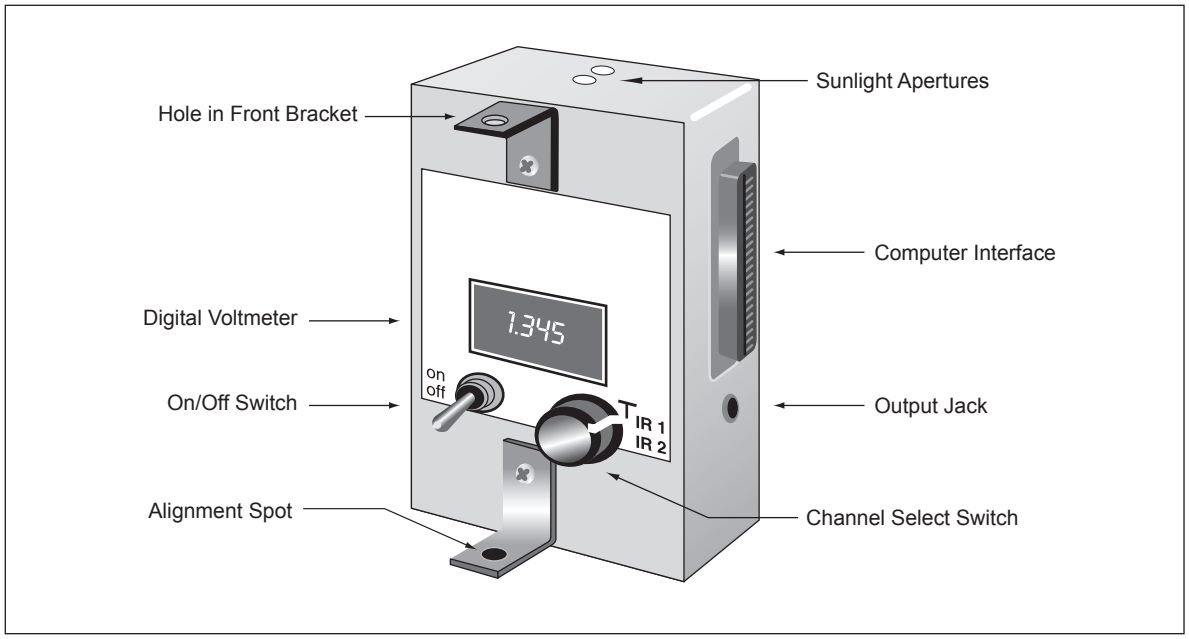
Practice runs can be made inside by pointing your instrument at the sun through a window – even a closed window. (Actual measurements should not be made through a closed window!) The water vapor instrument should be at room temperature – about 20-25˚ C – before collecting data. Place the instrument in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

Data Collection

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



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

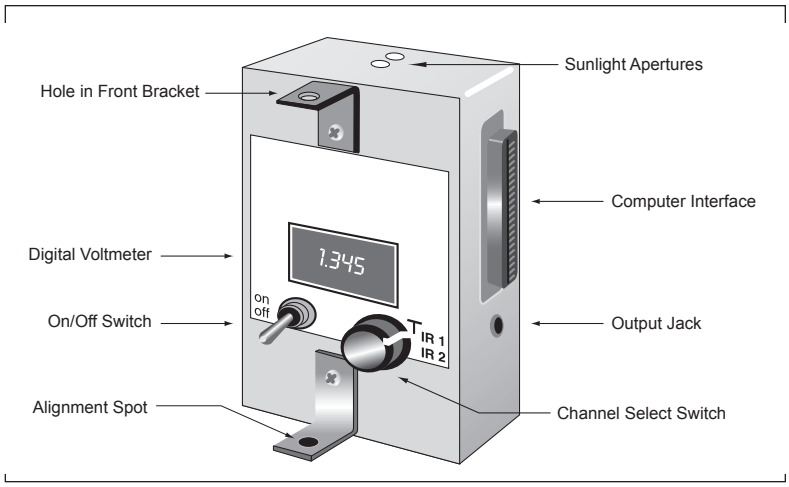
Field Guide

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
- ❑ Pen or pencil
- ❑ GLOBE cloud chart
- ❑ Barometer
- ❑ Thermometer
- ❑ Field Guides for *Cloud, Air Temperature, Relative Humidity Protocols* and *Barometric Pressure Protocol*



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.

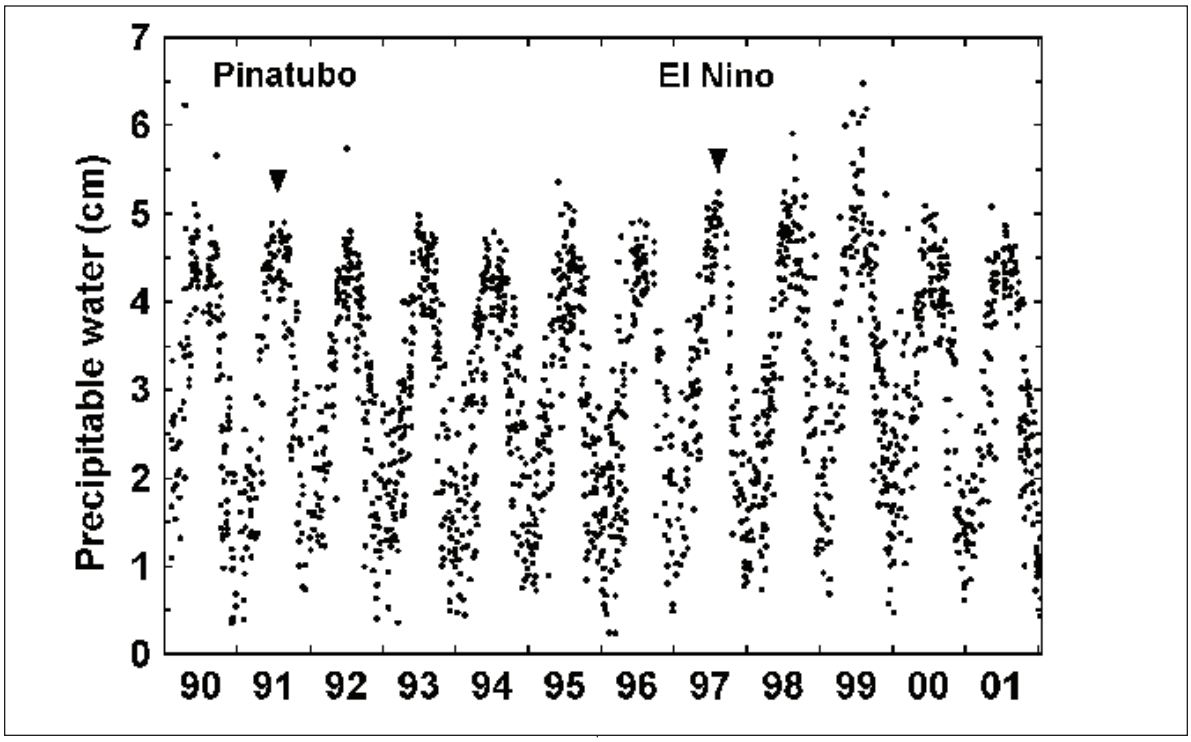
Water Vapor Protocol – Looking at the Data

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

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



observing site.)

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 Website. 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.

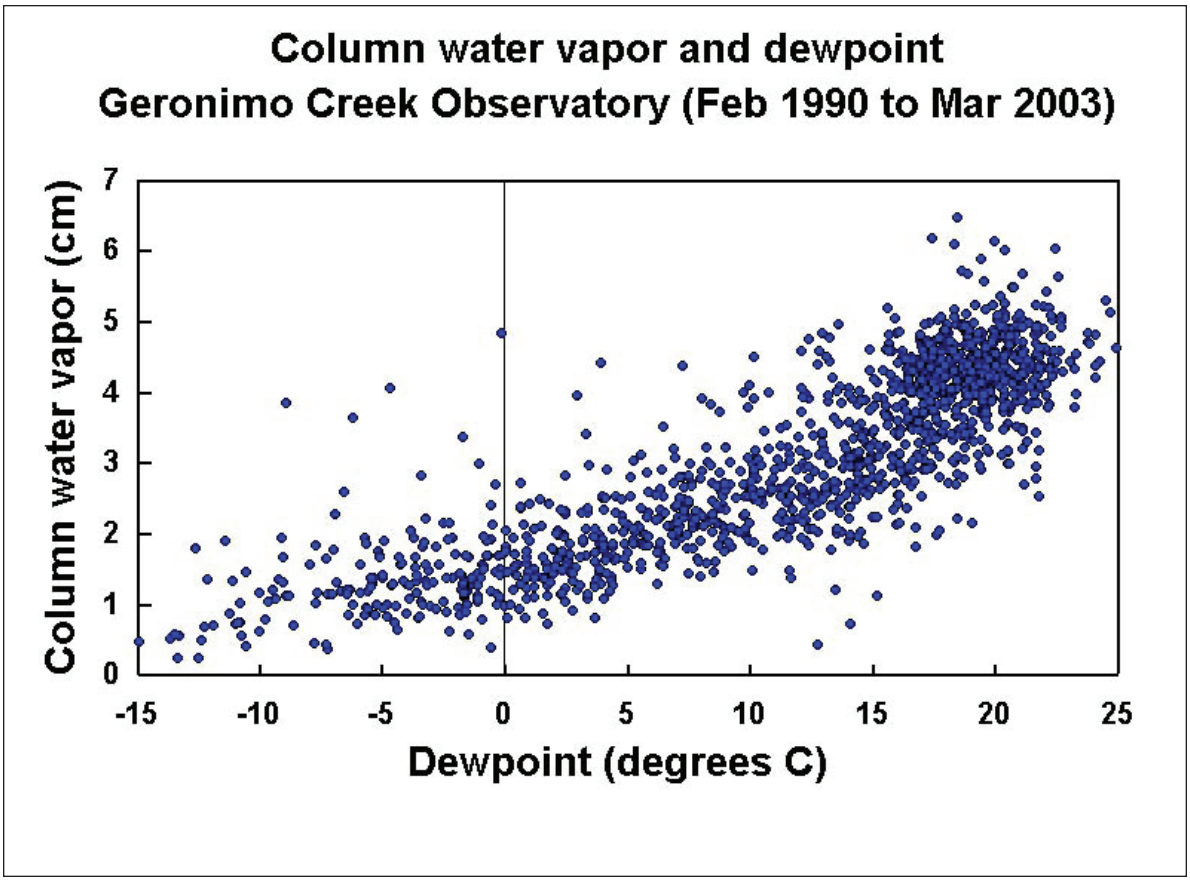



Figure AT-WV-9