Clouds Protocol
Featuring Satellite Comparison

Purpose
To observe the type, cover, and opacity of clouds including contrails and compare the view from the ground to that from space.

Overview
Students observe which types of clouds are visible, how much of the sky is covered by clouds, and the opacity of clouds. They also report on surface and sky conditions, information complementary to the satellite view.

Student Outcomes
Students learn how to make estimates from observations and how to categorize and classify clouds' properties following general descriptions and instructions.

Students learn the meteorological concepts of cloud height, cloud cover, and visual opacity, and learn basic cloud types.

Students gain confidence in interpretation and analysis of satellite data.

Science Concepts
Earth and Space Science
- Observations of weather conditions can be used to describe patterns over time.
- Typical weather conditions can be predicted during particular seasons.
- Weather data can be used to describe climates in different regions of the world.
- Cloud data can provide evidence regarding the complex interactions of air masses that result in changes in weather conditions.
- Clouds form by condensation of water vapor in the atmosphere.
- The atmosphere has different properties at different altitudes.
- Energy that flows into and out of Earth's System can result in changes in climate.

Physical Science
- Materials exist in different states: solid, liquid, and gas.
- Waves are reflected, absorbed, and transmitted through various materials.

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.
- Ask questions and define problems.
- Plan and carry out investigations.
- Analyze and interpret data.
- Use mathematics and computational thinking.
- Engage in argument from evidence.
- Obtain, evaluate, and communicate information.

Time
10 minutes

Level
All

Frequency
- At the time of a satellite overpass
- Standard GLOBE protocol - daily, within one hour of local solar noon
- To complement aerosol, surface temperature, and ozone measurements
- Additional times are welcome

Materials and Tools
- Cloud Data Sheet
  Or Data Entry – Mobile App
  Or GLOBE Observer – Mobile App
- GLOBE Cloud Chart
- GLOBE eTraining Slides (Click Download Module under "Clouds")
- Cloud Protocol Field Guides
- Contrail Formation Guide

Preparation
- Select study site
- Practice identifying clouds and related parameters using the GLOBE Cloud Chart, eTraining resources, and Learning Activities.

Prerequisites
None

Cloud Protocol – Introduction & Science Background

Why Observe Clouds?

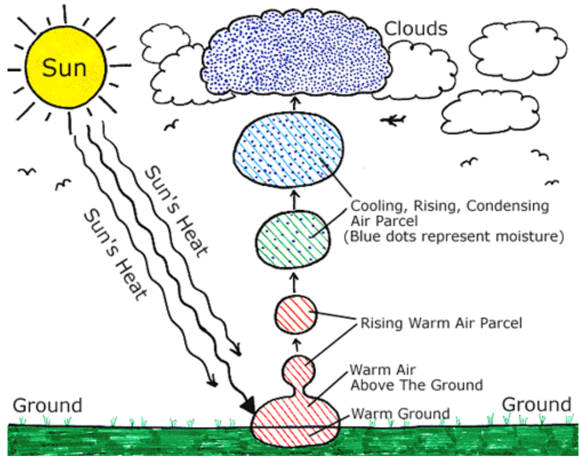
Clouds are a familiar part of our human environment. Clouds affect our daily plans, and even children pay attention to them from a young age because of the many shapes they can take. Clouds are a key factor influencing local weather as well as the Earth's climate system. They affect the temperature and energy balance of the Earth and play a large role in controlling the planet's long-term climate.

By observing clouds, we can get information about temperature, moisture, and wind conditions at different heights 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 to space. Clouds play a central role in controlling the exchange of heat in the atmosphere and changes in clouds over time can have significant climate impacts.

To understand the impact of clouds over time, satellites observe the planet's clouds and energy from space. Data from multiple research and weather satellites have made and continue to make significant contributions to our understanding of clouds. Ensuring that satellite instruments are accurate is very important. Scientists conduct experiments to study clouds and the Earth's energy using instruments on aircraft and at ground stations for comparison with satellite observations. This process is called validation, or sometimes "ground truth." Measurements from these experiments test the accuracy of satellite derived cloud detections and cloud type, height, and thickness estimates. Cloud observations made by people, such as GLOBE participants, are also an important part of this ground truth activity and contribute to our larger understanding of the role clouds play in our weather and climate.

Clouds and the Atmosphere

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



Cloud Formation Schematic, NCSU climate K-12 education
https://climate.ncsu.edu/edu/k12/.cloudformation

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 ice 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 together, they form a visible cloud. So, clouds tell us something about air temperature and water up in the sky, related to weather. They also affect the amount of sunlight reaching the ground and how much heat is escaping back to space, related to 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. Specific cloud types can indicate a trend in the weather. For example, in middle latitudes, one can often see the advance of a warm front by watching the cloud types change from cirrus to cirrostratus.

High Level Cloud Type	Associated Weather
Cirrus	Fair/pleasant weather, change within 24 hours
Cirrostratus	12-24 hours before precipitation
Cirrocumulus	Winter/cold/fair weather, tropics - approaching hurricane
Mid-Level Cloud Type	**Associated Weather**
Altostratus	Form ahead of storms
Altocumulus	Humid morning can form into thunderstorms
Low Level Cloud Type	**Associated Weather**
Stratus	Can become nimbostratus, light mist/drizzle
Cumulus	Convective, can grow into cumulonimbus
Stratocumulus	Precipitation rare, can turn to nimbostratus
Nimbostratus	Light to moderate precipitation
Cumulonimbus	Severe weather and heavy precipitation
Fog	Reduced visibility at ground level

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.

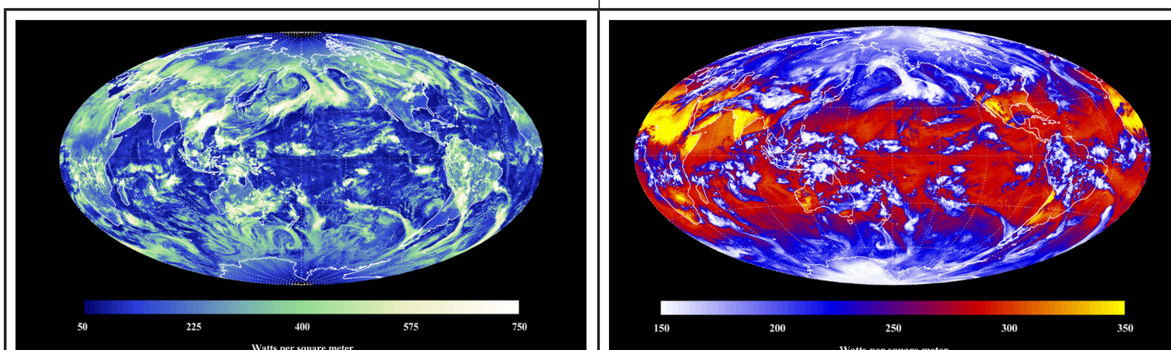
Cloud type is a visible sign of the processes that are occurring in the atmosphere and provides important information about vertical movement at different heights in the atmosphere. Most clouds indicate that moist air is moving upward, and precipitation can only happen when this occurs. By paying attention to the clouds, soon you may be able to use cloud observations to forecast the 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, about 70% of the Earth's surface is covered 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 5˚ C warmer on average.

Ice crystals and water drops scatter light differently. Thick clouds absorb more sunlight than thin ones. The types of clouds, phases of water, and the amount of clouds, ice, and



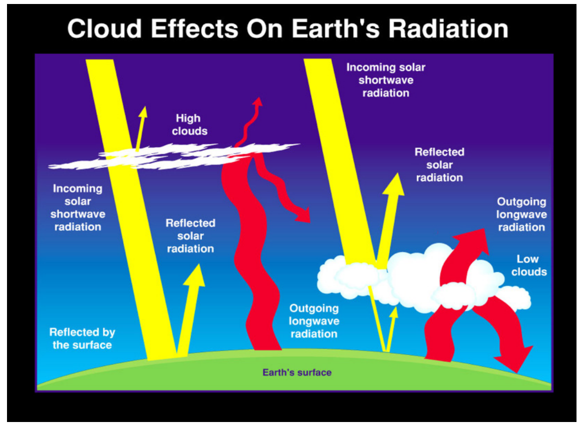
These global scale composite images show where more or less shortwave radiant energy (light) is reflected back into space (left), and where more or less longwave radiant energy (heat) is emitted to space (right). These measurements were acquired by the CERES instrument, flying aboard NASA's Aqua satellite, on March 18, 2011.

water drops all affect the amount of sunlight that comes through the atmosphere to warm Earth's surface. Cloud temperature also affects how much of the emitted heat from the surface is returned from the atmosphere back to the ground.

Conditions on Earth's surface 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. For most of the year, the sky is almost completely covered by clouds. 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 higher maximum temperatures. In both cases, the local climate – precipitation and temperature – is tied to cloud conditions (formation and type).

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 water vapor as well as small particles – aerosols – that provide condensation nuclei for the water vapor to condense onto and help ice crystals begin to form. In some areas, jet traffic causes a noticeable change in cloudiness, which may affect both weather and climate.

How will clouds 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 and 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. The interaction of clouds and surface temperature is a complex and scientists are currently researching how this process will unfold in the future.



NASA Langley Research Center
http://visibleearth.nasa.gov/view.php?id=54219

Cloud Measurement

Many official sources of weather observation programs are now using automated equipment to observe clouds. 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 developed. Scientists are working to develop automated methods to infer cloud types from visible and infrared satellite images. This task is complex, 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 property observations from GLOBE students are an important source of these ground-based observations.

From Space

Measuring the energy (radiation) emitted by the Earth is straightforward. One simply collects the energy that leaves a certain place on Earth (the field of view) and travels to the location of the spacecraft sensor. This energy (voltage) then has to be converted to a meaningful quantity through a complicated process of calibration and inversion which requires highly accurate instrumentation,

Measuring clouds from space is more of a challenge. It is done by remotely sensing (obtaining information without being in contact with the subject) the energy which is given off within a defined area (as above). Once that is done, however, all sorts of logic and thresholds have to be applied to determine whether what the satellite saw was a cloud or not. This complication is due in large part to the fact that the satellite is attempting to detect clouds against a highly variable background (land/ocean, snow/ice, dry/wet ground, vegetated/un-vegetated areas, urban/rural, etc.). In contrast, detection of the presence (though not necessarily identification) of clouds is very simple from the surface, because one views them against the uniform background of space - or of "blue sky." This is one reason why observations of clouds are helpful to scientists: a widely distributed network of observers who can tell for sure whether (and also what kind of) clouds were present within a given satellite footprint provides an independent data source for validation. This kind of ground truth information then helps fine tune the logic and thresholds so that detection methods can be improved, even in areas where there are no observers.

Teacher Support

Many teachers and students are familiar with clouds and day-to-day weather, but may be hesitant when it comes to identifying cloud types and classifying cloud cover and cloud visual opacity at different altitude levels or exactly "matching" satellite data. Observers will gain confidence with practice, seeing patterns and building recognition. Remember that the Cloud Protocol and ground observations from students are helpful because conditions visible from the ground will not always match the conclusions drawn from a satellite view. That is where the interesting learning can take place (for scientists and for students). Also note that the satellite derived cloud data uses slightly different parameters (cloud height, temperature, and water phase) to align to ground observations, so identifying the exact cloud type within a level (i.e. cirrus vs cirrostratus) is not the primary focus.

Advanced Preparation

The Cloud Protocol asks students to identify 12 main types of clouds and related parameters. While there are many types of clouds, identifying these main types, their cover, and their opacity provides crucial information about clouds in that region at that specific time.

At any given moment clouds cover ~70% of the Earth and are always changing. Ground observations provide an important piece of the puzzle and perspective (looking up) when trying to understand the role that clouds play in our Earth's weather and climate.

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

1. Practice cloud type observing using the dichotomous key, an interactive web tool, or by spending time looking at and identifying examples of the predominant cloud types for your location. Reviewing pictures from the previous school year or taking pictures to develop a local cloud atlas can also be helpful.
2. Guide your students through the following learning activities from the GLOBE Atmosphere Investigation on Clouds:
    a. Cloud Watch
    b. Estimating Cloud Cover
    c. Observing, Describing and Identifying Clouds

These activities are designed to give students plenty of opportunities to gain proficiency in identifying cloud type, cloud cover, cloud visual opacity, and data comparison and analysis.

Additional learning resources and media can be found on the Cloud Protocol Page.

Before formally reporting, have students discuss in their own words what they observe in their sky.

Site Definition and Mapping

A site needs to be defined for each observation area. Refer to Selecting and Documenting Your Atmosphere Study Site. Certain information is required for site definition, including latitude, longitude, elevation, and thermometer type. (Note: Selecting "Other" does allow an observer to enter temperature data, but it is strongly recommended that temperature data be collected using a GLOBE certified instrument and in accordance with the Air Temperature Protocol). If you are conducting the Cloud Protocol from multiple sites, each site needs a unique site definition.

When to Observe Clouds

Cloud observations can be taken at any time! The Cloud Protocol is designed to be flexible and fit into your schedule whenever it works for you.

Suggested Observation Times:

- Corresponding to satellite observations, to provide NASA with ground validation and comparison data as well as receive satellite data for interpretation in your classroom.
    - NASA satellite data are pulled from a collection of satellites and instruments. This means the frequency at which you match to a specific satellite or instrument may vary. Check an Overpass Schedule.
- Daily, within one hour of local solar noon, to align with other GLOBE protocol data collection times.
- In support of ozone and aerosol measurements, to provide direct and indirect complementary atmospheric data.
- Additional times are welcome, as they contribute to local investigations as well as building the GLOBE Cloud database.

Preparing for the Field

First, select and define one or more study sites.

- ***Students should also apply sunscreen and insect repellent as necessary. DO NOT look directly at the sun when making cloud observations.***

Depending on the age of your students and the goal of participation, it is helpful to print the overpass times for orbiting satellites or write them on the board for the students. Overpass schedules are accurate up to two weeks in advance; over longer periods atmospheric drag and orbital maneuvers may change the satellites orbit.

> ***Teacher Tip***
>
> *Prepare an observation kit with a clip-board and:*
>
> - *A GLOBE Cloud Chart*
> - *Cloud Protocol Field Guides*
> - *A Cloud Data Sheet (laminating the data sheet helps with durabil-ity and re-use)*
> - *A pen or pencil*

After students have become comfortable with the protocol, you can divide the class into protocol roles or teams (data collection and observation, data reporting, data analysis, etc.) changing weekly or biweekly. The model can be enhanced with an "expert" role, in which older students or students who have mastered the protocol can return to train new students.

Managing Students in the Field/ What to Observe

Use the Cloud Data Sheet to guide observation and data collection in the field.

- ***Students should never look directly at the sun!***

> ***Teacher Tip***
>
> *Starting at the bottom of the data sheet, have students observe surface conditions and their surroundings first, then move to "What is in Your Sky."*

Instruct students to look at most of the sky that they can see. Anything above an angle of ~14 degrees is to be included in the observation. Below that, along the horizon, clouds are too far away to correctly identify, and also don't correspond to the satellite view of your area. Here's a tip for how to estimate this 14-degree angle: hold out your arms in a "V," so that your hands are at about the level of the top of your head. That gives you the approximate angle of the sky to view.

This photo shows observers estimating 14 degrees above the horizon by placing their hands in a "V" at about head height. The area between their hands, above them, is their observation area.

> ***Teacher Tip***
>
> *Have students work in teams, as practicing with classmates will help build students' confidence. One useful way to do the observation is to have four students stand with their backs together, dividing the sky into four quadrants for which they can more easily determine cloud cover and type. Now each student is responsible for estimating the amount of cloud cover in their quadrant (from 14 degrees to directly overhead). Help students to be sure they are clear on the boundaries of their quadrant. Once each student has an estimate of cloud cover (use 10% increments, or fractions like eighths or tenths), take the average of the four estimates by summing them and dividing by 4. Repeat this to estimate the cloud cover at each level. This method will be particularly useful when you have a difficult sky that leads to different estimates among group members. Have students discuss and record the cloud types they observed. Having students work in teams will make outdoor observation go quicker.*

After all students have collected cloud data, teachers can gauge students' confidence. If there is disagreement or uncertainty, gather the students and have them discuss and use evidence based statements in order to develop a unified report. 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. When students agree on cloud identification, cover, opacity, and related parameters, enter the data online.

Note: Enter one report for the whole class per observation. It can help to compile the agreed upon data on one data sheet for reference.

Observation Hints

This protocol includes a category of "No Clouds" which should be reported whenever there are no clouds visible in the sky. A "No Clouds" report is just as important as a "Clouds Observable" report in helping understand our Earth's system. If "Clouds Observable" is reported, follow the observation hints below.

Obscuration

An obscuration is a phenomenon that restricts your view of clouds and/or contrails. There are ten possible reportable obscurations. **An accurate GLOBE cloud observation cannot be made if an obscuration covers more than 25% of your sky.** In this case, students will not report cloud 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. In this situation you can enter comments about the section of sky that you can see and surface conditions, but you will not complete cloud data sections. The obscuring phenomena are defined below.

Fog – Fog is formed when water vapor near the ground condenses or freezes to form tiny droplets or crystals in the air. Fog usually develops when relative humidity is near 100%. Fog and stratus clouds are closely related. In coastal areas, mountains, and valleys, fog may be prevalent during 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 may 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 (pollutants or natural 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 an Aerosols Protocol for those who wish to learn more about haze and its causes. Typically, when 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 it thousands of kilometers. If the sky cannot be discerned because of dust falling or blowing, please report this category. Severe dust storms 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 dust storm, 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 is generally 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 are still falling intensely), both of these last two categories should be reported.

If you select an obscuration at the beginning of your Cloud Data Sheet, you will not fill out cloud type, cover, or opacity on low, mid, and high levels. You may continue to reporting Surface Conditions on the data sheet.

Overall Sky Conditions

Overall Sky Conditions include:

- Total Cloud Cover, for the observed sky above 14 degrees from the horizon;
- Sky Color, observed facing away from the Sun, **looking up** at the bluest part of the sky (usually ~ 45 degrees, halfway between the horizon and straight up); and
- Sky Visibility, observed along the x-axis or **looking across** the horizon at the clarity of a distant feature.

Overall Sky Conditions help frame your observation, providing more information about atmospheric conditions. For additional information and practice see the GLOBE Observing Visibility and Sky Color learning activity.

Cloud Cover

Your estimation of cloud cover is subjective, but scientifically important. 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 from Earth's surface and lower atmosphere

Cloud Cover Percentage (%)	Cloud Cover Category
0%	No Clouds
>0% to 10%	Few
>10% to 25%	Isolated
>25% to 50%	Scattered
>50% to 90%	Broken
>90%	Overcast

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.

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. Cloud cover categories are given in the Table above.

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 mid 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 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 concept is applicable when making a Total Cloud Cover Observation.

Cloud cover, in particular, can be a very local phenomenon, and therefore 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.

Cloud Type

Cloud type is a qualitative observation; clouds are fluid and do not always neatly match the categories humans have set up. The GLOBE Cloud Chart, dichotomous key, and other cloud information in textbooks and 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.

Clouds are organized into categories depending on the height or altitude of the base of the cloud, their shape or form, and whether or not the cloud is producing precipitation. **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 sublimating (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.

Mid-level 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 mid-level 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/mid/low), the next thing to decide is the shape or form of the cloud. If the cloud feature is a fairly uniform layer, it is 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 nimbo/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!

Teacher Tip

Identifying Cloud Height:

Meteorologists have developed methods of identifying the different cumuliform (cumulus-type) clouds based on the apparent size of the individual clouds. These tips can help your students identify clouds more accurately as well. Since cumuliform clouds often form in rows or fields across the sky, you will first need to identify a typical, individual cloud in the field. With your arm fully extended, does the average individual cloud appear smaller than the width of your thumb, larger than the width of your closed fist, or somewhere in between? The answer to this question will help you determine the cloud type. If the individual cloud is smaller than the width of your thumb, then it's most likely a high level cumulus cloud, or cirrocumulus. If the individual cloud is larger than the width of your closed fist, then it's probably a cumulus, and if the individual cloud is larger in width than your thumb but smaller in width than your closed fist, then it's probably an altocumulus.

This strategy is based on the fact that objects appear smaller the farther they are away from you.

Stratocumulus clouds are typically wider than a closed fist and wider than they are tall, and there are many perhaps elongated in bands; cumulonimbus clouds are also wider than a closed fist but much taller and produce precipitation.

For distinguishing the different heights of stratiform (stratus-type) clouds, remember the following: Cirrostratus is the only cloud type that 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, with the location of the Sun not visible.

Contrail Type

Contrails generally occur at high levels like cirro- or cirrus clouds. However, as human-induced clouds, the number of contrails are specifically reported. 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. They form when the air at the altitude at which the airplane is flying is only somewhat moist.

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 than your index finger held at arm's length. They form when the air at the altitude at which the airplane is flying is quite moist.

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, hastening condensation in very cold ambient air at the airplane's altitude. For this reason, they are most likely to affect climate. 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 about four fingers held at arm's length. Therefore, noting the equivalent finger width of these contrails in the metadata will be very useful for scientists.

The Contrail Formation Guide provides science, history, images, and other resources on contrails.

Cloud Visual Opacity

Opacity, or how much the clouds transmit or block light, is an important observation. We use opacity rather than thickness when studying the radiative effects of clouds. We are interested in how much sunlight they let through (opacity), not in how much vertical space they take up (thickness). We use three somewhat subjective categories to describe this:

Transparent; This describes thin clouds through which light passes easily, and through which you can even see blue sky. For example, cirrus clouds have a milky bluish-whitish appearance.

Translucent; This describes medium-thickness clouds that let some sunlight through, but through which you cannot see blue sky. There may be some milky bluish-white near the edges, and a very little bit of gray under the thickest parts, but these clouds are mostly a bright white.

Opaque; This describes thick clouds, which do not allow light to pass directly, although light can diffuse through them. Such thick clouds often look gray. When the sky is overcast, or when these clouds are in front of the Sun, it is impossible to tell where the Sun is.

Surface Conditions

Surface Conditions are an important part of the Cloud Protocol observations. When we look up, we are differentiating between a blue sky and mostly white clouds. When a satellite is trying to categorize clouds versus other geographical elements there are many more colors involved and it can sometimes be difficult to tell the difference between ice and snow or clouds. By reporting surface conditions, you are providing additional data to assist during analysis and satellite validation.

Student Preparation

Suggested sequence of events:

1. Conduct the Observing, Describing, and Identifying Clouds learning activity to correctly identify cloud observation parameters.
2. Identify research questions/hypotheses and the methods that will be used to answer these questions.
3. Map and define study site(s).
4. Conduct field data collection, followed by analysis, if necessary for identification.
5. Submit data to the GLOBE website.
6. Conduct data analysis.
7. Present student research.

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, as this relates Earth's radiation budget. 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 while clear sky is the easiest measurement from the ground, it is 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?

Yes! You will receive corresponding satellite overpass data. Different satellites will provide different types of information, and you may receive more than one set of information from the same place and time. By becoming familiar with the satellite data and comparing multiple images when you have the opportunity, you will learn and increase your confidence. In addition, practice will help you to become proficient. Remember that on some days the cloud conditions will be different even over short distances and they may change in minutes - so exact matches are not to be expected all the time.

4. We have trouble figuring out if we are correct when we call a certain cloud one of the 12 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 Internet, you can practice with a Dichotomous Key. You may also wish to print out the GLOBE Cloud Chart, cut it up, and make flash cards to help quiz your classmates.

Note that for the purposes of satellite comparison, the distinction between, for example, cirrus and cirrocumulus is not the focus. Both are high ice clouds to the satellite.

5. Is this cloud type observation system in GLOBE unique or new in some way?

The scientific basis of this cloud type observing system has not changed substantially since it was first devised (meterologists have been using the same categories for over 200 years). The systematic breakdown of clouds into twelve 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. Your ability to contribute this data is powerful because there can only be so many professional scientists or official ground sites, but GLOBE provides the abaility to have many sites all around the world all using the same careful system to collect more data. More data over a long periods allow us to see change and patterns over time.

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 comments. If less than one-quarter of the total sky is obscured, record the cloud cover and cloud types and state in the comments 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. Hint: a contrail would be reported as a cirrus cloud once it exceeds the width of four fingers, with your palm held up at arm's length. A persistent contrail would move to a persistent spreading contrail once it exceeds the width of one finger.

Cloud and Contrail Cover

Field Guide

NEVER look directly at the Sun!

Task

Observe how much of the sky is covered by clouds, including contrails. Choosing between these categories is easy at the extremes, but harder where they meet. Estimate what fraction of the sky is covered by clouds. One good way to do this is to have everyone in the class make an estimate, and then average all the answers.

When multiple cloud layers are present, we would like this information for each cloud layer as well as a total cloud cover.

What You Need

- ☐ Cloud Data Sheet
- ☐ GLOBE Cloud Chart
- ☐ GLOBE Data Entry options

In the Field

1. Complete the top section of your Data Sheet.
2. Look at the sky in every direction (above 14 degrees).
3. Estimate how much of the sky is covered by clouds and contrails.
4. Record the cloud/contrail cover for the overall sky, as well as each level.

Cloud Cover Classifications
No Clouds The sky is cloudless; no clouds are visible.
Few Clouds are present but cover less than one-tenth (or 10%) of the sky.
Isolated Clouds cover between one-tenth (10%) and one-fourth (25%) of the sky.
Scattered Clouds cover between one-fourth (25%) and one-half (50%) of the sky.
Broken Clouds cover between one-half (50%) and nine-tenths (90%) 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.

5. 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

Sky Color and Sky Visibility
Field Guide

NEVER look directly at the Sun!

Task

Classify sky color and sky visibility, the overall sky conditions. These parameters describe the sky itself; not any clouds that may be present.

Color and visibility help us understand the impact of aerosols in our atmosphere, parameters that also affect energy transport.

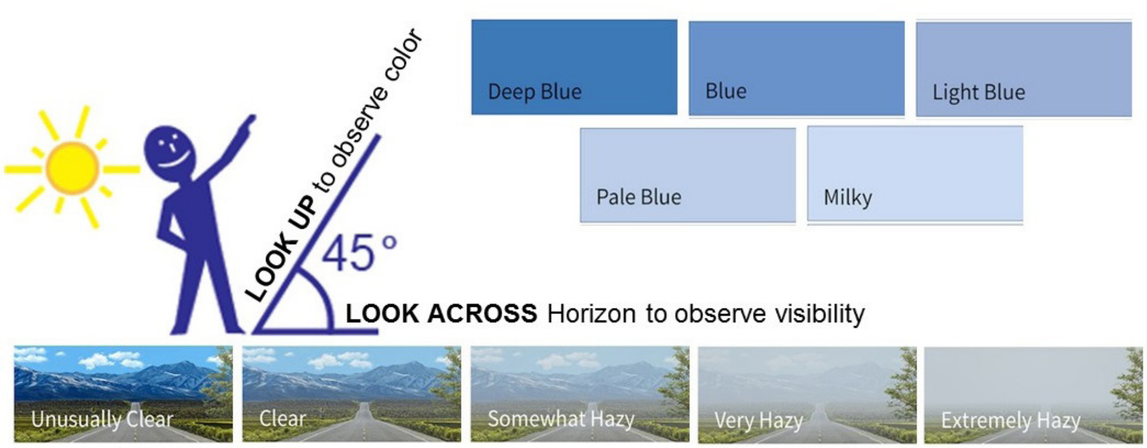
- These observations are only possible during the day, not at dusk or night.
- Sky color cannot be observed if view of the sky is obscured or if the sky has no clear patches (you cannot observe color if you have 50% cloud cover or greater).

What You Need

- ☐ Cloud Data Sheet
- ☐ Color and Visibility reference on Cloud ID Chart or within the GLOBE Observer app
- ☐ GLOBE Data Entry options

In the Field

1. Complete the top section of your Data Sheet.
2. Look at the sky in every direction (above 14 degrees).
3. **Look Up** to observe sky color, reporting the shade that most closely matches your sky.
   - Turn your back to the Sun.
   - Observe the bluest part of your sky, which is usually around 45 degrees above the horizon.
4. **Look Across** to observe sky visibility.
   - Look at a landmark in the distance and estimate how visible it is under current sky conditions.
   - Try to use the same landmark every time.
5. Record sky color and sky visibility for the overall sky. This observation will not be taken on each level.



Cloud and Contrail Type

Field Guide

NEVER look directly at the Sun!

Task

To see which of the 12 types of clouds and how many of each of the three types of contrails are visible.

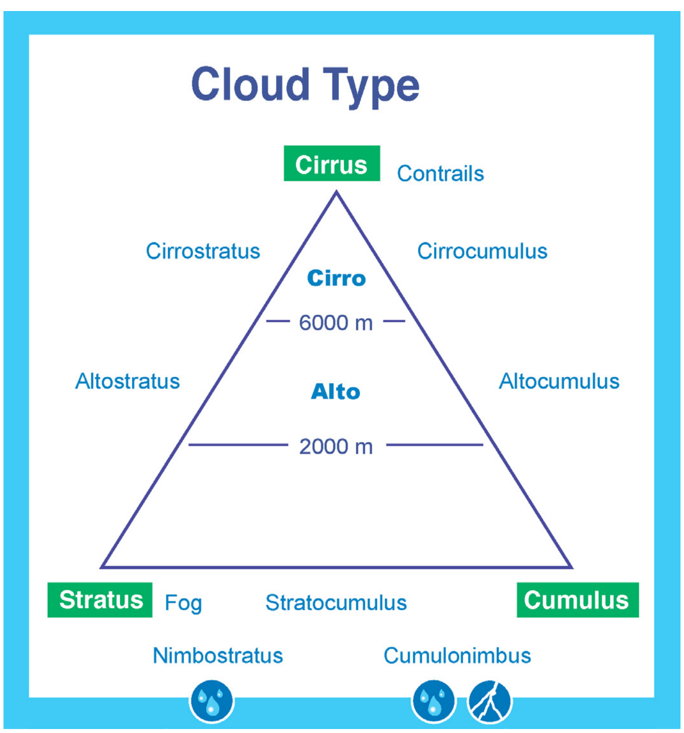
What You Need

- ☐ Cloud Data Sheet
- ☐ GLOBE Cloud Chart
- ☐ Observing Cloud Type Appendix
- ☐ Contrail Formation Guide
- ☐ GLOBE Data Entry options

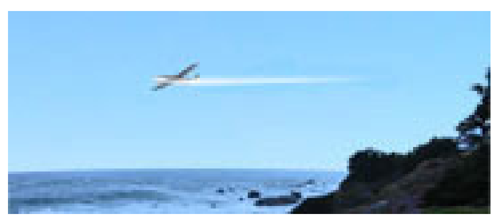
In the Field

1. Look at all the clouds in the sky, in all directions.
2. Identify the types of clouds that you see using the GLOBE Cloud Chart and the definitions found in Observing Cloud Type (shape and height).
3. Check the box on your Data Sheet for each and every cloud type you see on each level (low, mid, and high).
4. There are three types of contrails. Record the number of each type you see.

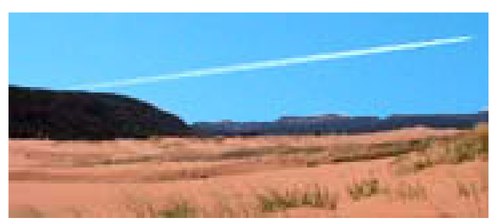
CLOUDS



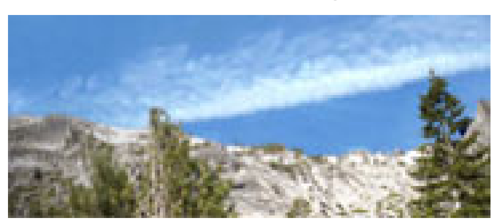
CONTRAILS



Short-lived



Persistent Non-Spreading



Persistent Spreading

Cloud and Contrail Visual Opacity
Field Guide

NEVER look directly at the Sun!

Task

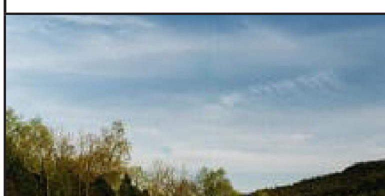
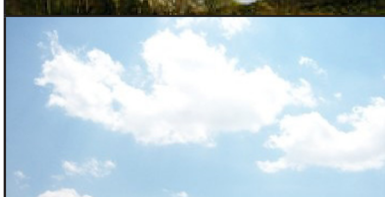
If clouds are present, observe how much sunlight they let through to the Earth surface, information on their opacity. Scientists use opacity rather than thickness because it means something different. When studying the radiative effects of clouds, we are interested in how much sunlight they let through (opacity), not in how much vertical space they take up (thickness).

What You Need

- ☐ Cloud Data Sheet
- ☐ GLOBE Cloud Chart
- ☐ GLOBE Data Entry options

In the Field

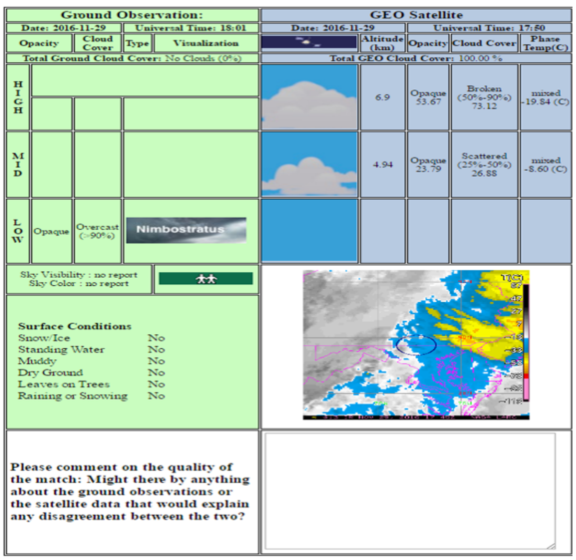
1. Estimate how much light the cloud is letting through to the Earth's surface.
2. Classify visual opacity for clouds on each level (low, mid, and high).
   - Reference your shadow for help:
     - Transparent clouds in front of the Sun - crisp shadow with clear edges
     - Translucent clouds in front of the Sun - less crisp shadow with edges starting to become fuzzy
     - Opaque clouds in front of the Sun - very fuzzy and difficult or impossible to see shadow
3. Record which opacity classification best matches what you observe on each level.

Visual Opacity Classification	
	**Transparent** This describes thin clouds through which light passes readily, and through which you can even see blue sky. Note the milky bluish-whitish appearance of the cirrus clouds (left).
	**Translucent** This describes medium-thickness clouds that let some sunlight through, but through which you cannot see blue sky. There may be some milky bluish-white near the edges, and bit of gray under the thickest parts, but these clouds are mostly bright white.
	**Opaque** This describes thick clouds which do not allow light to pass directly, although light can diffuse through them. Such thick clouds often look gray. When the sky is overcast, or when these clouds are in front of the Sun, it is impossible to tell the location of the Sun.

Cloud Protocol – Looking At Your Data

Retrieving Satellite and Match Data

Observers will receive a 'Match' email when their observation aligns to corresponding satellite data. The ground observation will be on the left side of the table (green) and the satellite observation and images will be on the right.



Ground Observation:					GEO Satellite				
Date: 2016-11-29		Universal Time: 18:01			Date: 2016-11-29		Universal Time: 17:50		
	Opacity	Cloud Cover	Type	Visualization		Altitude (km)	Opacity	Cloud Cover	Phase Temp(C)
Total Ground Cloud Cover: No Clouds (0%)					Total GEO Cloud Cover: 100.00 %				
HIGH						6.9	Opaque 53.67	Broken (50%-90%) 73.12	mixed -19.84 (C)
MID						4.94	Opaque 23.79	Scattered (25%-50%) 26.88	mixed -8.60 (C)
LOW	Opaque	Overcast (>90%)		Nimbostratus					
Sky Visibility : no report Sky Color : no report									
Surface Conditions Snow/Ice No Standing Water No Muddy No Dry Ground No Leaves on Trees No Raining or Snowing No									
Please comment on the quality of the match: Might there by anything about the ground observations or the satellite data that would explain any disagreement between the two?									

Sample NASA Satellite Match Table

> ***Teacher Tip***
>
> *Corresponding satellite data is not only accessible in your email, but you can also access your match link within the GLOBE Data Visualization System and the Explore Data link on the NASA satellite comparison support web pages.*

Context From Satellite Data

From above the Earth, satellite data and imagery provide information about clouds and characteristics on mid and high levels that may be obscured from the ground. With satellite information, you can see where your local weather fits into global patterns and phenomena.

Use your 'Match' email with satellite comparison data to:

- Reflect on your observation and consider any difficulties that you had when observing a tricky cloudscape.
- Help understand what may be the difference between ground perspective and satellite views.
- Guide student research investigations and prompt further questions.

Are the data reasonable?

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

The internal consistency of the observations can be used to determine whether cloud type, cover, and opacity 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. On the other hand, an example of an unreasonable report would be 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).

In addition, satellite matches can agree or point out discrepancies within your report. For example, if you reported clear skies and the satellite reported overcast, you would investigate further. In this case you might have snow and ice on the ground, registering as cold clouds to a satellite. We have also observed young students who sometimes classify a sky with uniform white stratus clouds as clear.

What do scientists look for in these data?

Many official weather observing stations across the world have effectively stopped taking individual 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 mid and high level cloud layers. The automated instruments can only sense clouds up to about 3.5 km in altitude and many cloud types are too high for most of these ceilometers to see them. So, they can only identify 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.

Figure AT-CL-1: Satellite Image

Visible photograph - NOAA 15 polar-orbiting weather satellite of the Gulf of Mexico. 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

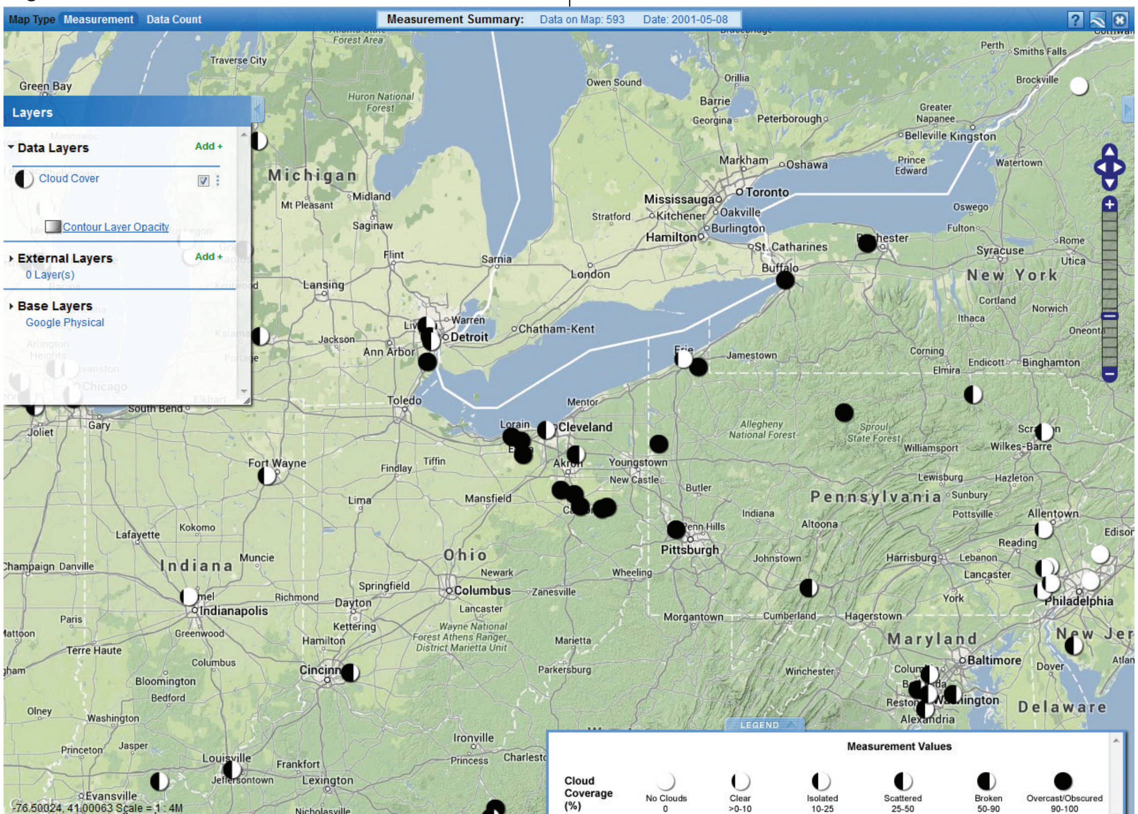
Since the early 1960s, meteorologists have had weather satellite pictures that can be used to see clouds (generally shown as white areas on satellite pictures), such as Figure AT- CL-1, a visible photograph from the NOAA 15 polar-orbiting weather satellite of the Gulf of Mexico, near the southeastern 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 how accurate their satellite observations continue to be. In general, the more GLOBE schools that report 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, mid, 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

Figure AT-CL-2



for clouds to form.

Note the large number of completely filled-in circles southwest of Cleveland, Ohio in the image. From the legend, we see that these completely filled-in circles indicate areas of overcast or obscured skies. There are a few stations nearby that are not overcast, including one observation of broken and one scattered. Perhaps a storm system is affecting a fairly large area of northern Ohio and western Pennsylvania. To the far eastern edge of the map, the observations are mostly of clear skies. Note how similar the cloud type observations are to each other within a region, confirming each other's data.

Questions for Further Discussion

Possible questions to explore in GLOBE Visualization:

Q: Do cloud patterns change during the year? How?

Try: Exploring "All Cloud Types" layer

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

Try: Exploring various "Contrail Coverage" layer

Q: Are the types of clouds and contrails you observe related?

Try: Exploring various "Cloud Types" and "Contrail Coverage"

Possible questions to explore with further measurements:

Q: Does the amount of cloud cover affect the local temperature?

Try: Adding Air Temperature protocols

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

Try: Adding air temperature, barometric pressure, precipitation, relative humidity, surface temperature, water vapor, and/or wind protocol(s)

Q: 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?

Try: Adding Biometry, Land Cover or Soils protocols

Possible questions to explore with outside information:

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

Try: Adding maps or satellite imagery

Q: How do your cloud observations compare with satellite images of clouds?

Try: Exploring NASA or NOAA resources

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 twelve 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 seven 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
Isolates	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!

Satellite Extension

Mrs. Jones recieves satellite match emails corresponding to the class's reports over the last three weeks. She prints out the match tabels along with the satellite imagery for the students to compart to GLOBE data visualization maps. The students compare the maps and identify the different school location using their latitude and longitude. Natalie observes that the schools' ground reports agree with the satellite cloud cover for corresponding days. She also comments that some schools were under the same storm clouds on some days, making the connection from their local area to the global weather pattern.