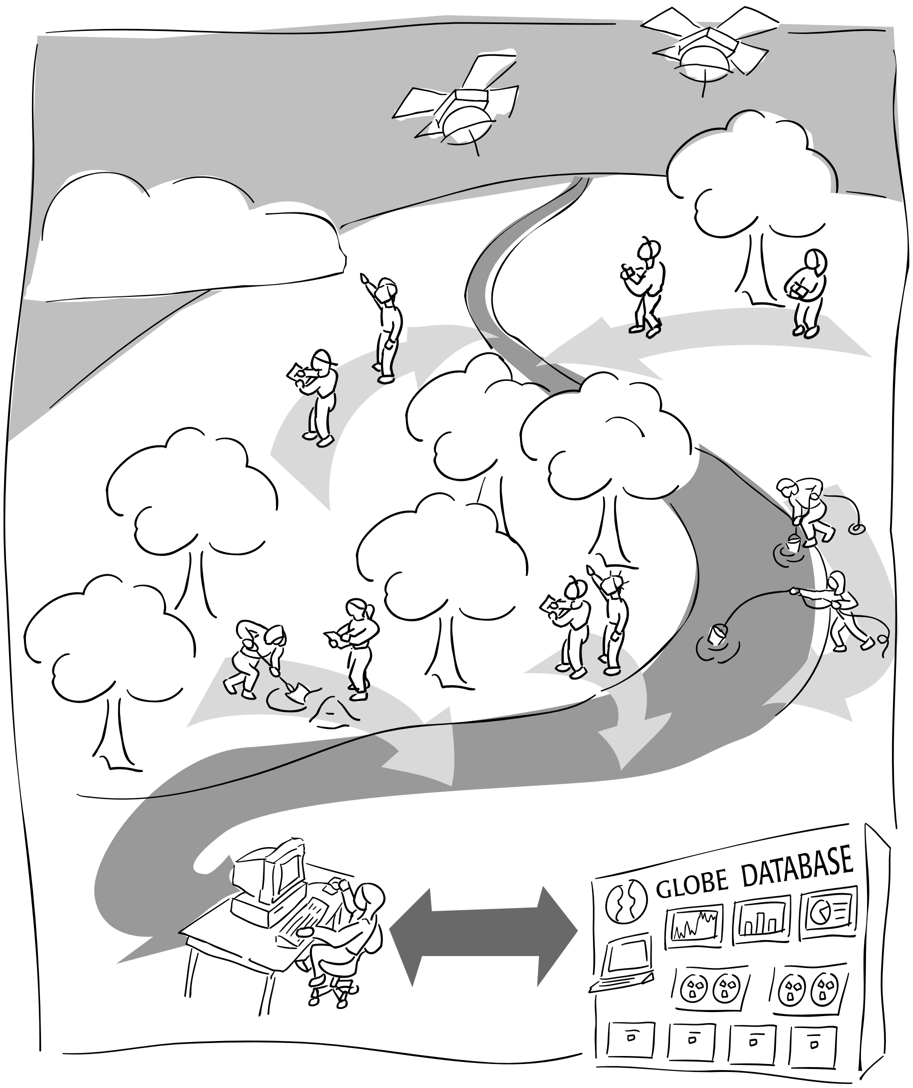
Toolkit



for the GLOBE® Teachers' Guide

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How to Publicize GLOBE in Your Community

The GLOBE program is a partnership among the U.S. Federal Government, the University Corporation for Atmospheric Research, other countries, U.S. state and local governments, schools, and the private sector. Outreach activities can help promote local interest in and support for your school's GLOBE Program activities. This section includes outreach ideas, tips on writing a press release and working with the media and sample press releases and articles. These materials are intended to be a starting point. To achieve the best results, adapt them to your school and community. Also, encourage your students to develop their own outreach activities.

GLOBE School Outreach Ideas

- Hold a GLOBE Open House and invite local citizens (e.g. parents, school superintendents, city officials, other government officials, and environmental clubs) and the media to join students in taking scientific measurements and observations. Allow the students to demonstrate how they report the data via the Internet. Discuss the online, graphic visualizations of the GLOBE student data and let the students explain how their work contributed to the image and to their understanding of Earth's environment. See *Working with the Media* in this section.
- Schedule a school assembly or meeting with parents and teachers to recognize the GLOBE teacher and students. Students can make presentations of their data and research investigation and talk about what they have learned.
- Help the students organize a GLOBE "Speakers Bureau" and seek opportunities to address local business and civic organizations. Students can demonstrate what they are learning about science, the environment and technology.
- Invite professionals in the environmental, science, geography and technology fields to meet with GLOBE students. This will help the students to see the value of their work beyond the classroom while also helping these professionals learn more about GLOBE.
- Have GLOBE students submit articles and photographs to the local newspaper. The local newspaper may want to feature GLOBE student observations regularly on their education or "kids" pages. Local television stations may be interested in including GLOBE data in their nightly weather reports or science and education features.
- Show the GLOBE video to small groups to help provide the overview of the program or let your students make their own GLOBE video or slide show.

Working With The Media

If you are contacted by the media or decide to seek media coverage of your GLOBE Program activities, the following hints may be helpful. Your local government or school public affairs office also might offer guidance.

Developing Your Message and Knowing Your Subject Matter

Take some time to decide exactly what it is you want the media to say about your GLOBE Program activities. Are you looking for coverage of a particular event, such as a GLOBE Open House, or are you hoping for a general feature story on the school activities? See *Writing a GLOBE News Release* and be sure to check the updated GLOBE Program information at www.globe.gov so that you can provide accurate answers to questions such as, "How many schools and how many countries are involved?" Also, if you are uncertain about any aspect of the program, send an email message to: info@globe.gov and you will receive a prompt response.

Invitations

You may choose to invite just one local paper or television station to visit your school at a particular time, or you can hold an event to which you invite all local media. The single invitation is easier to conduct and reporters and editors are more likely to be attracted to an "exclusive." Multiple invitations require more preparation and work in carrying out, but can produce wider coverage of your GLOBE Program activities. Including dignitaries with the students may broaden media interest, yet students are "the story." The choice of a single or multiple invitation well may depend on how much interest your news media has in GLOBE when you approach them.

Establishing Key Media Contacts

If you, your principal, or a GLOBE parent knows someone in a news organization, contact that individual first. If you don't have an inside contact, call the switchboard and ask for the name of reporters who cover environment, science, education or technology issues. Spend a few minutes on the phone explaining GLOBE and indicate that you will be sending additional materials, in the form of a brochure or press release or if you are planning a special event. Captivate their interest so that they will want to accept an invitation to visit your students. If they seem disinterested or rushed, try again after a few weeks or, better yet, ask if there is someone else in the office they would suggest to contact.

Timing Your Contacts

Reporters need at least one week advance notice for special events, preferably two weeks. Follow up your press release with a phone call. Don't be afraid to call the day before to confirm attendance.

Planning Your Event

To ensure good turn-out, time your event to begin no earlier than 10:00 a.m. Make sure there is plenty of open space for cameras and microphones. Check with the news organizations ahead of time to see if they need access to electrical outlets or have other special needs. When a reporter arrives for an event, make sure someone is responsible for greeting the reporter and introducing the reporter to the principal, the GLOBE teacher, students, and any VIPs in attendance. Prepare a press package for each reporter with another copy of the press release, print-outs of GLOBE visualizations, a copy of the event agenda, and any other materials that help describe your GLOBE Program.

Follow-up

After a media visit to your GLOBE school, call the news organization to make sure they have all the information they need. If there are significant inaccuracies in the story, you should politely notify the news organization of the errors.

Figure TK-1: A Sample Newspaper Story on GLOBE

Students collect data for GLOBE program

By MARY BARKER
Chronicle staff writer

An elementary science program in Grand Haven Schools not only teaches students valuable research methods, it also has them providing science data being used around the world by scientists studying the environment.

GRAND HAVEN

Griffin Elementary sixth-grade science teacher Roberta Cramer was the first to put her students to work measuring longitude, latitude and elevation with a Global Positioning System device, which uses relays from satellites in orbit above the earth.

The Global Learning and Observations to Benefit the Environment program, or GLOBE, is a hands-on project where students work under the guidance of GLOBE-trained teachers to make environmental observations and measurements and report them to a central processing facility.

Cramer's students record minimum, maximum and average daily temperatures 11 a.m. each day. The students also take note of the cloud cover and precipitation at that time. Water temperatures and acidity also are analyzed. The information is then sent through the Internet information highway to educators and scientists all over the world who are studying the environment.

Global images generated from the data are sent back to students for study.

Cramer said scientists for years have been retrieving information about the environment from satellite photographs. The data being collected by students around the world is being used as a way to verify the accuracy of the satellite images.

The Global Learning and Observations to Benefit the Environment program, or GLOBE, is a hands-on project where students work under the guidance of GLOBE-trained teachers to make environmental observations and measurements.

"The bottom line is students are learning science research, which is basically simple. It's a matter of accuracy and collecting data over a long period of time," Cramer said.

"This is a hands-on activity with far-reaching implications for scientists all over the world," Cramer said. "It isn't often that kids are doing science that will be used by other scientists. That is what makes this program unique."

Before they could get down to the business of collecting information and sending it around the globe, students at Griffin Elementary spent a lot of time choosing a research site to locate the weather station built and donated by Rick Fuller, a Griffin Elementary parent.

Science methodology was introduced while choos ing the site with a grid system approach to rating po tential locations based on a variety of criteria.

"They were asked to document their method o choosing a site and to reflect in writing on how an why the chose the site," Cramer said.

In the fall, while waiting for the measuring equip ment to arrive, students learned about cloud cove and maintained a science journal. Accuracy in re cording observations was stressed, Cramer said.

The special Global Positioning System device wil travel to Rosy Mound, Ferry, Central, Robinson an Peach Plains elementaries as well as the Junior Hig School and Community Education, where student will collect similar information and send it off to sci entists.

Students at various elementary levels will partici pate. For example, second-graders can measure ai temperatures and fifth-graders can sample loca plant and animal life; first-graders will record clou cover and sixth-graders will analyze water quality.

From there the device will be sent to another dis trict until next year when Grand Haven students wil repeat their effort at being part of the global picture

GLOBE is managed by a team of agencies heade by the National Oceanic and Atmospheric Adminis tration. Other agencies are: the National Aeronautic and Space Administration, the National Scienc Foundation, the Environmental Protection Agenc and the Departments of Education and State.

The leadership also includes the Office on Envi ronmental Policy and the Office of Science an Technology Policy in the President's Executive Of fice.

Figure TK-2: A Sample Newspaper Story on GLOBE

Project spurs student growth

By Edward Patenaude
Telegram & Gazette Staff

DUDLEY — A hands-on program that joins students, educators, and scientists in studying the global environment is a big hit with ninth-graders at Shepherd Hill Regional High School.

"I call it real science," says lead teacher Anthony R. Surozenski. "We've made a three-year commitment."

The science department at the district high school is providing day-by-day weather and related information for scientists affiliated with Global Learning and Observations to Benefit the Environment in Boulder, Co.

While students in Surozenski's ninth-grade science class are doing most of the work, checking information at a weather station, a soil moisture reading site, and a hydrology location, the program is open to the community. "We could use some help on weekends and during vacations," Surozenski says.

The weather and soil stations are on the Shepherd Hill campus, and water readings are made near a culvert connecting Mosquito and Wallace ponds on Dudley-Oxford Road, about a mile from the school.

'WE'RE NOT ALONE'

"It does not take very long to learn what has to be done nor does it take long to do the actual recording of data," said Surozenski, calling for assistance because readings must be taken between 11 a.m. and noon every day of the year.

"We've been working with this program since April," Surozenski said. "We're not alone. There are 1,600 (schools) in the United States and other countries gathering information so scientists can get a better understanding of the environment."

Edward Fox, 14, measures the height of a tree outside Shepherd Hill with a clinometer.

Students in last year's freshman science class walked the hilltop campus, identifying areas that might be used for ongoing weather and moisture readings and biometrics, the statistical study of biological data.

Information is forwarded via the Internet to Boulder, where it can be accessed by research scientists. Shepherd Hill readings are fixed to a 15-kilometer square that covers a region from Webster Lake westerly to the Quinebaug River, and includes most of the ponds, and a lot of woodlands and open areas in Dudley. The information is matched to reports from other schools and locations by the 100 scientists participating in the program. It is anticipated that data will improve understanding of the earth.

Students have established a land cover site near a corner of the Dudley-Oxford Road school. They recently checked tree leaf growth above a given section to determine the amount of sunlight that reaches the ground. The tests will record plant growth through the four seasons.

The Shepherd Hill program has been mostly outside to date, but it will become an in-class activity as the weather turns cold, Surozenski said. While important and part of the process, field readings will be limited. "We'll be into the computer end of it when we can't get outside."

The program has been well accepted by the school's science classes, Surozenski says. There's a sense of accomplishment, the knowledge by students that activities will improve understanding of the planet. There's generally interesting information to share, according to Surozenski. For example, more than 3 inches of rain fell Oct. 21, and tests of water quality in the town ponds has generally been within acceptable pH levels.

Although a ninth-grade study, the volunteer aspect of the study is open to anyone in the community. There were a few gaps in the summer 1995 readings, but scout groups and others came to the fore, Surozenski said.

Debra Warms and her two sons, Christopher, a fifth-grader, and Jonathan, a fourth-grader, assumed responsibility for readings through the second week in July. Her husband, Kurt, is the leader of a Cub Scout pack just getting reorganized and Surozenski sought help, Debra Warms said. "He ended up with us," she said. "We enjoyed going up there."

'HANDS-ON APPROACH'

Surozenski and about 20 students were in a wooded section behind the school yesterday afternoon. The ninth-graders, mostly from the Charlton side of the two-town district, said the Globe science project offers a hands-on approach to science.

"It is a lot of fun because the information can be used in so many great ways," Tony Almeida said.

Enthusiasm for the project has brought Almeida to school on weekends, Surozenski said. Almeida and his parents, Sandra and Joseph A. Jr., are among the volunteers who visit the Dudley-Oxford Road campus when the school is closed.

Science is interesting but the outdoor sessions add a dimension to the school day, Jessica Beesley said. Zoe Ferris offered a similar note. Besides this, good grades are likely, she predicted.

"It's hands-on experience, not like sitting in a classroom," Andrea Bardier said while drawing measurements on a form.

Writing a GLOBE News Release

Five points are important to a good news release: **Who, What, When, Where** and **Why.** If possible, a sixth, **How**, should be included. It is important to get all these points in the first sentence or two. Use short words and write short sentences and short paragraphs. Two sentences make a good paragraph in a news release. Almost every news release can be written on one or two typewritten pages.

Remember

- Always give exact date, time, and location of your event, including the location for media parking and specific entrance information.
- Provide at least a two- or three-sentence description of the overall GLOBE Program, including information on the number of schools and countries involved. (Check www.globe.gov for up-to-date information.)
- Check every point of your release for accuracy. Never guess on dates, times, places, or spelling of names.
- Put school contact person and phone number at the top corner of the release, and print the release on school letterhead.

Figure TK-3: A Sample Press Release

Sample Press Release

Contact Name
phone number
email address
School

LOCAL STUDENTS ASSIST WORLD SCIENTISTS COLLECT ENVIRONMENTAL DATA

Students at **(NAME OF SCHOOL)** are joining an international network of young people taking scientific measurements of Earth systems and sharing their observations with other students and scientists around the world using state-of-the-art technology systems.

(NAME OF SCHOOL) is joining the GLOBE Program, an international environmental science and education partnership. GLOBE students are contributing to a better understanding of the planet by making regular research observations at thousands of locations around the world and sharing their information via the Internet.

(Teacher's Name) attended a workshop with GLOBE scientists and educators for instruction on the measurement procedures and the GLOBE computer technology system.

(INSERT GLOBE TEACHER QUOTE)

Students will select a study site near the school where they will take regular measurements of various atmospheric, hydrological, biological, and geological features. The students will then send their findings via the Internet to a GLOBE data processing facility. Their data will be combined with input from other GLOBE schools around the world and with other science sources, such as satellite imagery, to create dynamic, online images of Earth. The GLOBE student data are available to the general public on the World Wide Web at www.globe.gov.

The GLOBE Program is jointly funded and coordinated by the National Aeronautics and Space Administration and the National Science Foundation and with help from the U.S. Department of State. GLOBE is operated on behalf of NASA by the University Corporation for Atmospheric Research. **(Insert: Local support for GLOBE activities is being provided by ...)**

For more information, contact **(Insert GLOBE Teacher Name and phone number)**

Introduction to Remote Sensing

Introduction

All of us perceive the environment with our senses. Some senses require us to come in contact with what we are sensing - we touch and taste. Some senses allow us to perceive objects at a distance - we see and hear. In this second case, we are sensing objects or phenomena that are remote from our eyes or ears - we are doing remote sensing. By using the microscope, telescope, camera and film, microphone, amplifier, and speaker, and video camera and television we expand our remote sensing capabilities. These technologies allow us to see farther, to observe finer details, and to perceive fainter signals than our unaided senses.

Our remote sensing capabilities come in a mobile package complete with an energy source and data processing and storage facilities - we turn our heads to gaze in different directions, move to get a better view or to hear more clearly, make decisions based on what we sense, and remember sights and sounds. To see more of the environment around us, we can climb a ladder, a tree, or a hill and gain a wider view. Until the advent of hot-air balloons in the last century, these were the only ways for humans to get a bird's eye view of the Earth. With the invention of cameras in the mid- 1800s, people began to make aerial photographs from balloons. One of the first balloon photographs was of Boston, Massachusetts, USA, taken in 1860 from 1200 feet above the city. A particularly intriguing photograph was taken of the 1906 San Francisco earthquake and fire using an array of 17 kites moored to a boat anchored in San Francisco Bay!

Prior to 1960, the most widely used remote sensing systems were based on the camera, although infrared film and radar had been developed and used during World War II. Space-based remote sensing began in 1960 with the launch of the first Television Infrared Observation Satellite (TIROS I). The TIROS series of satellites initially focused on providing images of clouds and were the predecessors of the present National Oceanic and Atmospheric Administration (NOAA) polar-orbiting weather satellites. The first remote sensing satellite focused on the land surface was the Earth Resources Technology Satellite (ERTS I) launched by the National Aeronautics and Space Administration (NASA) in July 1972. Later, this satellite was renamed Landsat I, and became the first of a series of Landsat satellites designed to image and map land surface features. Today, there are dozens of environmental satellites launched and operated by various countries and multinational organizations.

Initially, the costs associated with these technologies restricted their use to large government and private organizations. More recently, the power of desktop computing and the proliferation of satellites from many countries have opened this frontier to people everywhere. Now, small colleges and businesses, elementary and secondary schools, land planners, environmental groups, and even individuals make use of satellite remote sensing technology.

Various images derived by remote sensing techniques appear throughout this guide. Some look like photographs – indeed some are photographs. The *Blue Marble*, perhaps the most famous image of the Earth from space, is a photograph taken by Apollo 17 astronauts on their journey to the Moon in December 1972. See Figure TK-4. Other images may look to you like abstract paintings. Today, most remote sensing images are not photographs; they are digital images sensed on solid-state detectors and converted to numbers which are transmitted, stored, and displayed by computers. The remote sensing instruments on Landsat produce this type of digital image. Wherever possible, each GLOBE school is provided with an image of its GLOBE Study Site taken from a Landsat satellite by an instrument named Thematic Mapper (TM).

Figure TK-4: The Blue Marble–Photograph taken from Apollo 17, December 1972

Source: NASA

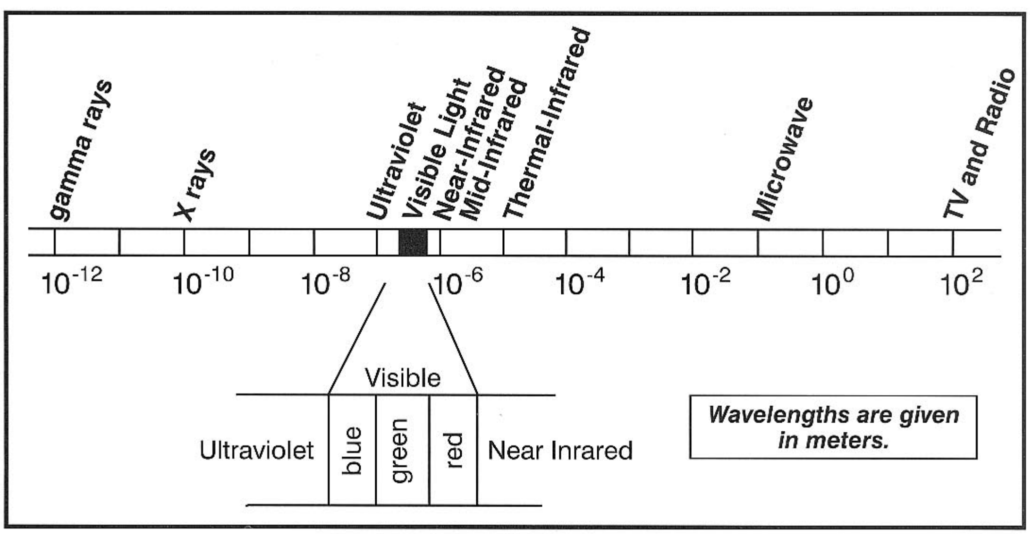
What Properties of a GLOBE Study Site Does the Thematic Mapper Measure?

The TM's sensors record visible and infrared (IR) sunlight that is reflected from the Earth outward into space. Thematic Mapper also includes sensors that detect IR radiation or light that is emitted by the Earth, but this part of TM's capabilities are not used in GLOBE.

Visible light is *electromagnetic radiation* or *light waves* that can be detected by our principle remote sensing capability, the human eye. It is said that the human eye provides us with about 90% of the information we receive about our environment. Visible light, however, is only a small part of a very large continuum of light waves. See Figure TK-5. This radiation forms a continuous spectrum in which the differing waves are characterized by their wavelengths. Wavelengths are commonly measured in one of two units, the micron (micrometer, µm), where 1 µm = 1 x 10^{-6} m (0.000001 m), or the nanometer (nm) where 1 nm = 1 x 10^{-9} m (0.000000001 m). The shortest wavelengths are associated with gamma rays, whose wavelengths are about 10^{-6} µm, while at the long end of the scale, radio and TV waves have wavelengths of 10^{+8} µm (=100 meters). Visible light lies close to the middle of this spectrum with violet light being the shortest wavelength, and red light the longest. Measured in nanometers, the wavelengths of visible light range from 400 nm for violet to 700 nm for red.

On either side of the wavelength *band* of visible radiation are other wavelengths of value in remote sensing. At wavelengths just longer than visible light are the three bands of infrared light–near,

Figure TK-5: Wavelengths of Electromagnetic Radiation



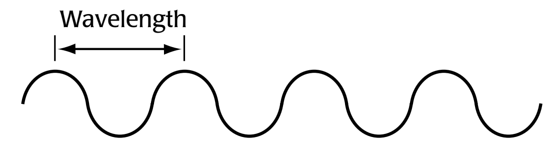
Source: GLOBE

Wavelengths of visible light:

Blue visible light: 4.5 x 10^{-7} meters
Green visible light: 5.5 x 10^{-7} meters
Red visible light: 6.5 x 10^{-7} meters

The labeled wavelengths in the electromagnetic spectrum diagram are the center of a range (or band) of wavelengths for that type of wave. The types of waves are not clearly separated. Think about a rainbow with its bands of red, orange, yellow, green, blue, and violet light. The colors of the visible light waves blend into one another. For our purposes, we will use the labeled wavelength (center of the range) in the diagram.

Figure TK-6: Wavelength



Wavelength is defined as the distance between two successive crests (or troughs) in a wave, as shown above.

When you think of wavelengths of radiation you can think of ocean waves. Wavelengths are measured from the crest of one wave to the crest of the next. Think of waves you have seen on lakes or the ocean. How far apart were the crests of those waves?

middle, and thermal. The image of the GLOBE Study Site is provided in TM's three visible bands (blue, green, and red), one near IR band, and one of its two middle IR bands. These visible and infrared data are used to assess extent and the health of crops, forests, and other forms of vegetative cover.

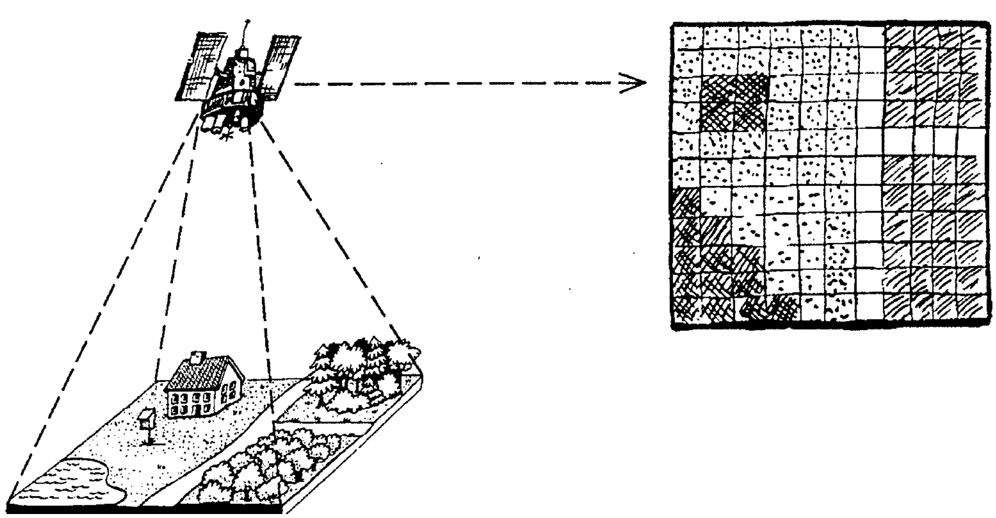
In each band, the TM measures the intensity of light reaching its detector from a specific place on the Earth and records this intensity as a number ranging from 0 to 255. In the binary or base 2 system of counting, it takes eight digits or places to count up to 255 and since each binary digit is referred to as a bit, TM is said to provide eight-bit data. The detectors and optics of TM were constructed so that from the 705 km orbital altitude of Landsat, the specific place reflecting light into an individual detector is 30 m by 30 m on the Earth's surface. Because of this, TM is described as having a spatial resolution of 30 m. Objects on the surface which are smaller than 30 m will be averaged together with their surroundings in the intensities measured and cannot be directly seen in a TM image.

Satellite Images

A picture of a large area of the Earth's surface can be produced by assembling the intensities measured for many adjacent 30 m by 30 m areas. If you look at a computer or television screen or at a pictures in a newspaper or comic book through a magnifying glass you will see small individual dots of color. Our eyes normally see this array of dots as a continuous image. Each of the dots is a picture element or pixel. To produce a digital image using TM data, a computer uses each intensity value to determine the brightness of one pixel on its screen. When fully displayed, each pixel in an image on the computer screen corresponds to a particular location on the Earth. This concept can be observed in the *blockiness* that is apparent when one blows up or zooms in to view a digital image more closely. See Figure TK-8.

Figures TK-9 through TK-12 show several satellite views of approximately the same area, the Pease International Tradeport in Portsmouth, New Hampshire, USA at several different spatial

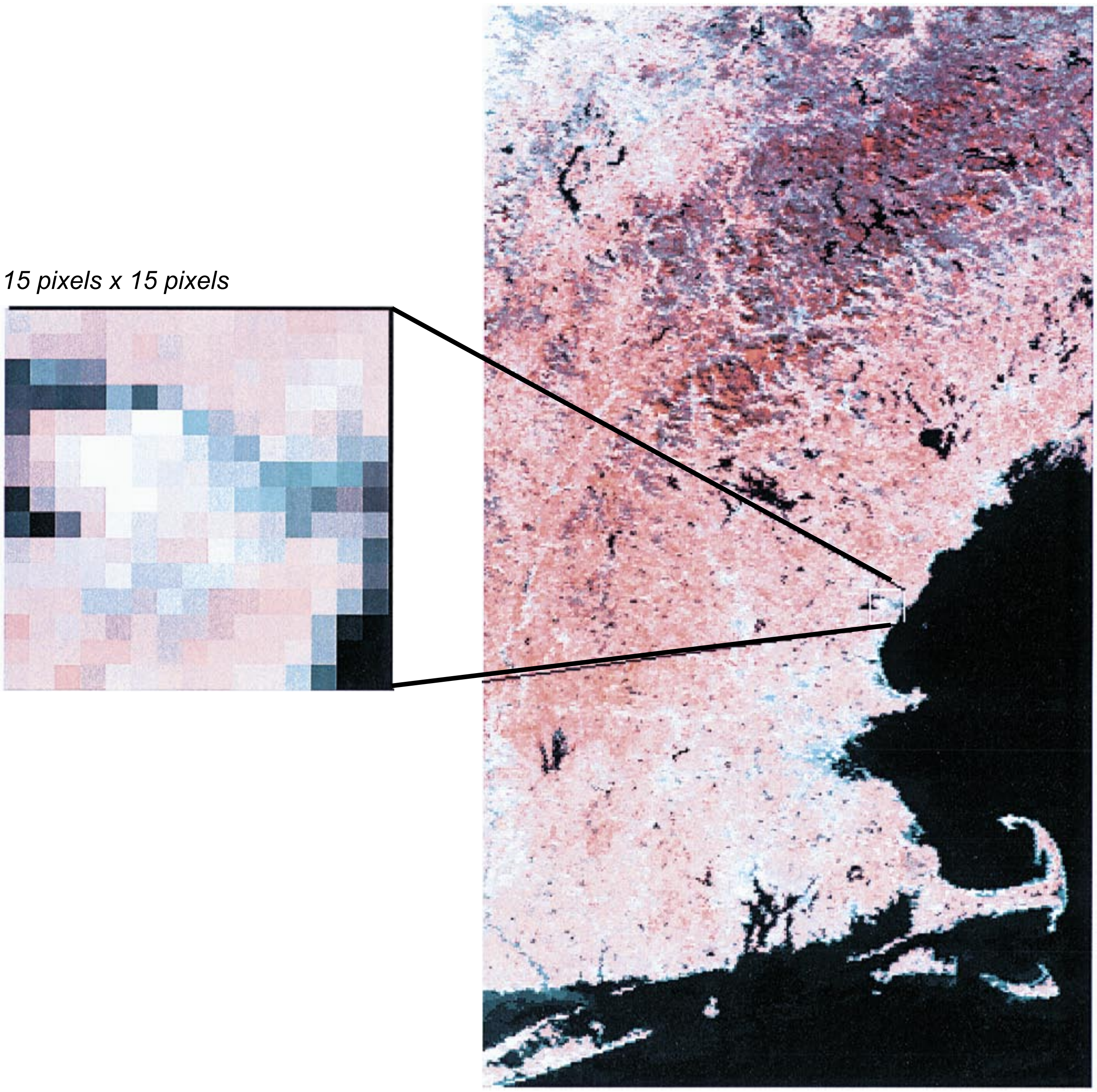
Figure TK-7: Gridded Landscape



This represents how a satellite views the earth's land cover as a group of equal size units placed on a landscape. Each unit is called a pixel. Source: Jan Smolik 1996 TEREZA Association for Environmental Education, Czech Republic

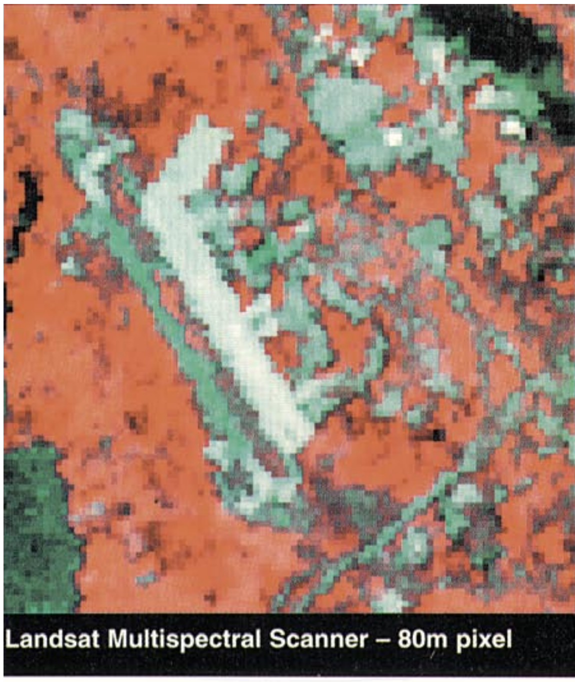
Figure TK-8: AVHRR Image

15 pixels x 15 pixels



Source: NASA

A false color infrared image of New England from the Advanced Very High Resolution Radiometer (AVHRR) sensor aboard a NOAA polar orbiting satellite. Each pixel in this scene is approximately 1.1 km on a side. The enlarged section shows a 15 pixel by 15 pixel area which is roughly the size as a GLOBE Study Site and which includes roughly the same section of Portsmouth, N.H., as Figures TK-9 through TK-12. The brightest pixels in this enlarged section represent the runway and apron area used to park aircraft and service vehicles



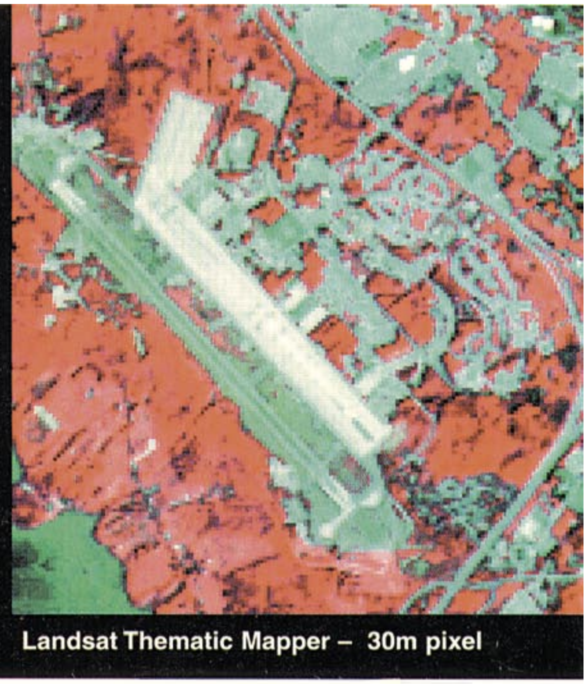


Figure TK-9
This Landsat Thematic Mapper Image shows the same area as Figure TK-8 with the 80 m resolution Multispectral Scanner flown aboard the first five Landsat satellites. In this view, the parking area is seen, but few other ground details are visible.

Figure TK-10
The Landsat Thematic Mapper Image of the same area as Figures TK-8 and TK-9 with 30 m. In this view, main roads are visible. These data have a high enough resolution to see features as small as a house. They are preferred for many types of ecological and environmental studies as they have both high spatial and spectral resolution.

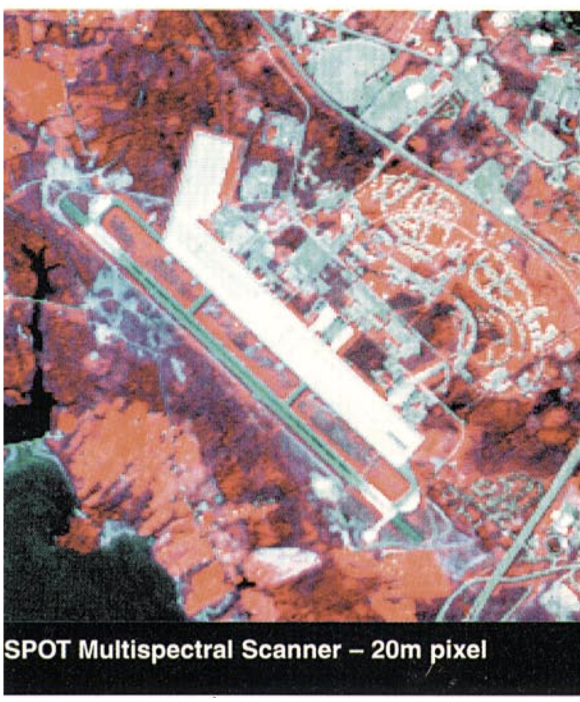


Figure TK-11
Pease, N.H. at the 20 m resolution of the French SPOT satellite's Multispectral Scanner. In this view, secondary roads and structures can be seen.

Figure TK-12
Pease, N.H. at the 10 m resolution of the French SPOT satellite's Panchromatic imager.

Source: Used with permission of the Earth Day Forest Watch Program, University of New Hampshire, Dr. Barry Rock and Mr. Gary Lauten

Figure TK-13: Land-water area of Canberra, Australia, viewed in the near-infrared band only. Note that the water appears black. Source: EROS Data Center

resolutions to demonstrate the effect of pixel size on image quality.

As the size of a pixel decreases, the amount of information needed to make an image of the same size area on the ground increases. Limitations in computer storage can make it impractical to use high resolution data when studying very large areas. The purpose of an investigation must therefore be considered when deciding which satellite or other remote sensor(s) to use. For GLOBE the 30 m by 30 m pixel size of Landsat is most appropriate. With this pixel size, the 15 km by 15 km area of a GLOBE Study Site can be covered by an image of 512 pixels by 512 pixels. Storing each TM band of such an image requires 256k bytes of memory and five bands fit nicely on a single floppy disk.

Our eyes can see in color as well as in black and white. If only one band of TM data is used to construct an image, it can be fully represented using 256 different shades of gray which our eye perceives as amounts of brightness. See Figures TK-12 and TK-13. The full range of colors we see can be produced by combining light of three different colors, for instance red, green, and blue on a computer screen or yellow, red, and blue when mixing paints. See Figure TK-14. On the computer screen or on a printed image, each pixel is produced by a combination of red, green, and blue. This allows us to view images of three different bands of TM data simultaneously. If we let the intensity of the red band of TM determine the amount of red in the corresponding pixel, the green band determine the amount of green, and the blue band the amount of blue, the resulting image will closely resemble what our eye would see looking down at the Earth's surface and is referred to as a visible image. Alternatively, the red portion of each pixel can be determined by the intensity of near IR light detected by TM, the green determined by the intensity of red light, and the blue determined by the intensity of green light to produce a *false color infrared* image roughly corresponding to IR sensitive camera film. Figure TK-15 shows such an image of a land and water area in Prague, the Czech Republic. Other band combinations are also possible, but in each case we are limited by the capability of our eyes to seeing at most three bands of TM in a single image.

Spectral Patterns

Let's consider what the different colors mean. When white sunlight (comprised of all colors) is incident on an object, some of the colors are absorbed and others are reflected. For example, an object that appears red is reflecting red light while absorbing all other colors. See Figure TK-16. If all incident light is reflected, the object appears white, whereas if all the light is absorbed, the object appears black.

The key to interpreting multispectral data is understanding the reflectance properties of different surfaces or objects viewed by the sensor. The tendency of an object to reflect or absorb solar radiation at different wavelengths gives rise to its *spectral pattern*. See Figure TK-14. Just as a person can be identified by his or her picture, spectral and spatial patterns can be combined to identify a remotely sensed object or surface feature. We can predict the spectral patterns of objects within the range of visible light, since this is the spectral region that we see. For example, we would predict the ocean to have a higher reflectance in blue spectral bands and the ocean appears blue in a visible image because most of the light entering the ocean is absorbed, while only the blue light is reflected. We would expect vegetation to have high reflectance in green because leaves are green, and so forth.

TM is not limited to detecting only in the visible range. Scientists have learned to interpret reflectance patterns outside the visible spectral region, and, in many instances, it is this invisible information that accounts for the power of multispectral imagery. Near infrared (NIR) radiation is almost completely absorbed by water, whereas land and particularly vegetation have high reflectance in the NIR region. Thus, the NIR bands are useful in differentiating land and water. In addition, the NIR bands are useful in locating and identifying different species of vegetation, and in determining whether or not particular plants healthy or diseased. Middle infrared (MIR) bands are sensitive to moisture content and, therefore, they are also useful in vegetation studies.

Satellite Orbits and Instruments and the Timing and Frequency of Observation

Another important aspect of satellite remote sensing is the frequency of coverage, that is, how often the satellite passes over a location on the Earth's surface. This is determined by the orbit in which the satellite is placed and the width of the area it images on the Earth's surface. The higher the orbital altitude, the longer the time required for the satellite to orbit the Earth. As a general rule, the smaller the size of the pixels in a remote sensing instrument, the narrower its field of view. The orbit of Landsat and the width of the TM image area were chosen to provide coverage of every place on the Earth's surface at least once every 16 days (except for small regions surrounding the poles which are never imaged).

The orbit was also chosen so that Landsat always passes overhead at the same local time each day. At the equator this time is about 9:45 am. Such orbits are called sun-synchronous. Sun angles, shadows and other such effects visible in TM images remain similar or vary slowly in predictable ways.

As the Earth progresses through the seasons, the reflectivity of the land surface changes principally due to changes in vegetation and the distribution of snow cover and sea ice. The changes in vegetation occur slowly as a result of seasonal changes in deciduous plants and the amount of moisture available to plants resulting from seasonal precipitation patterns.

Figure TK-14: Reflectance of Some Targets

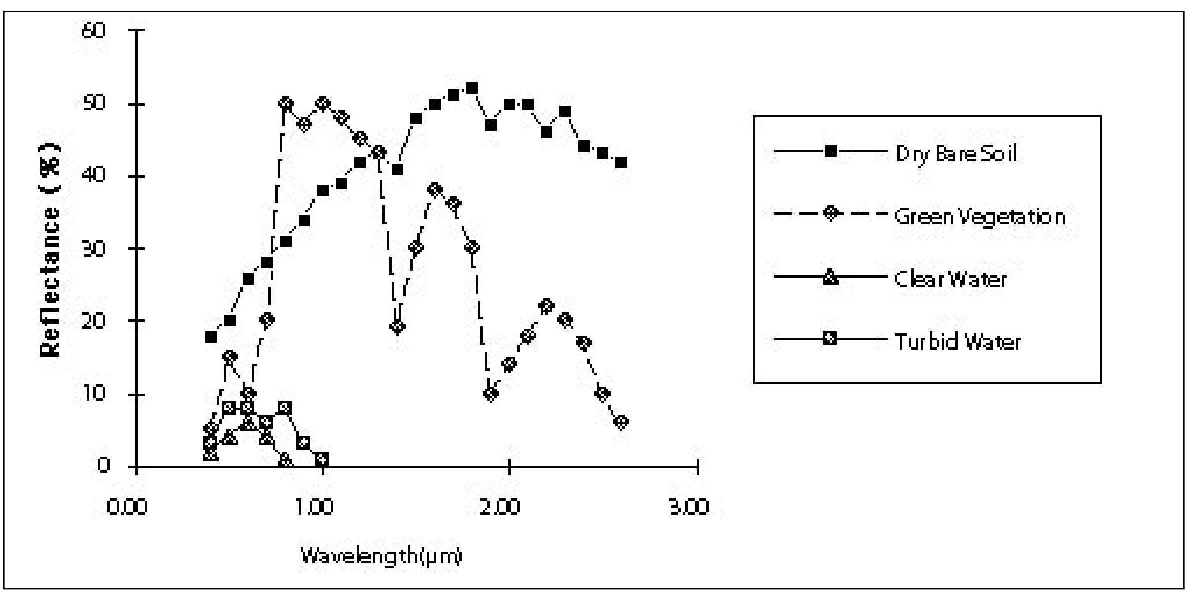


Figure TK-15: False Color Composite Image of Prague

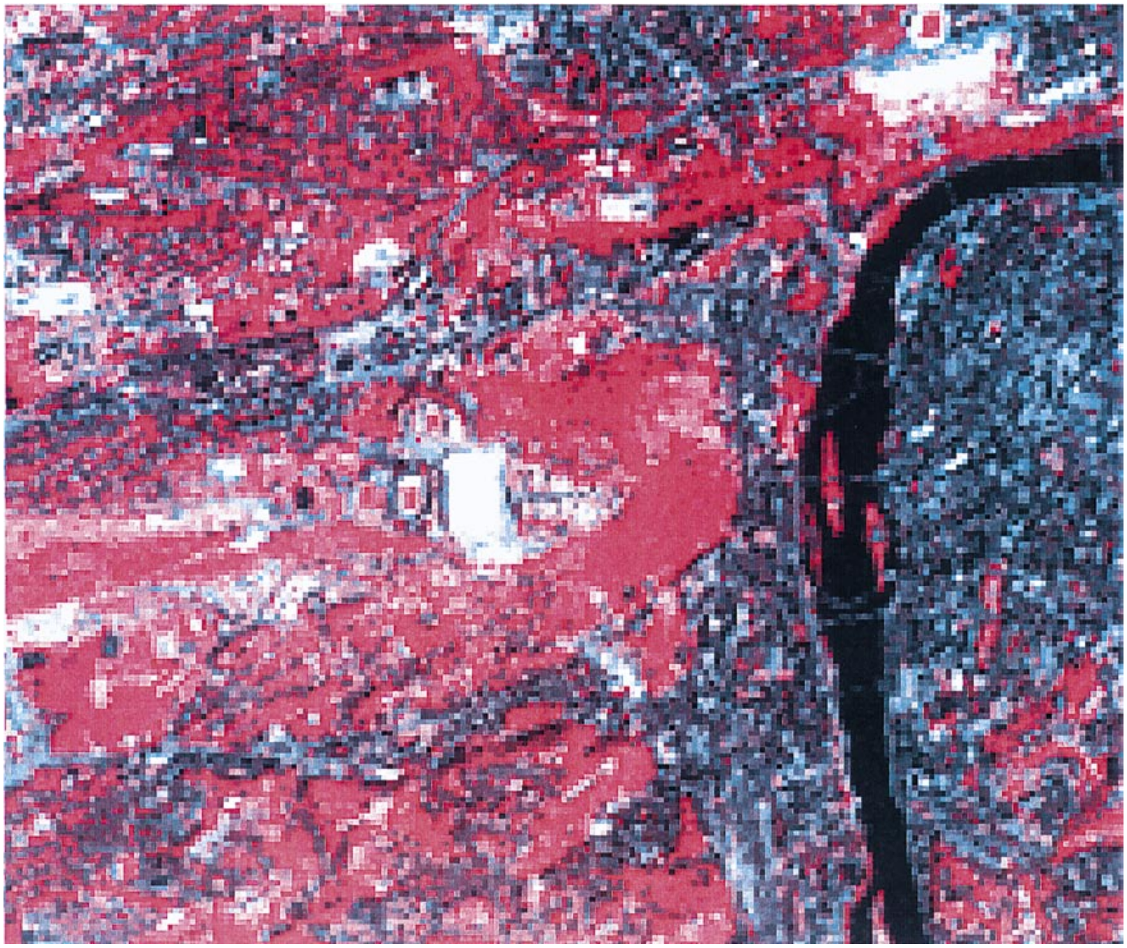
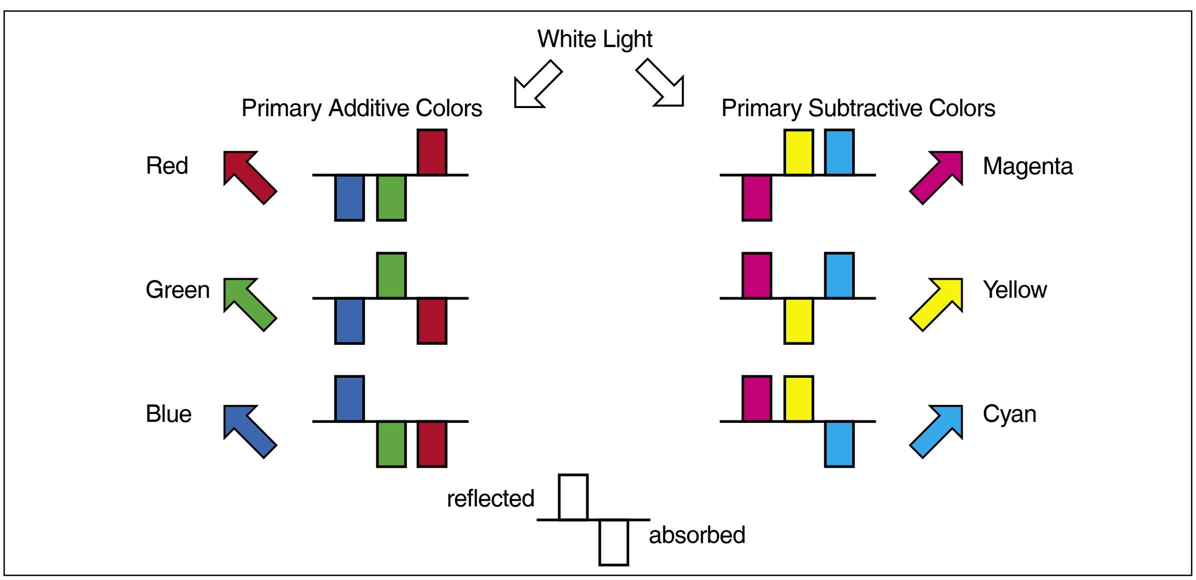


Figure TK-16: Visual Primary Additive and Secondary Subtractive Colors



Additive Primary and Secondary colors are produced when objects absorb and reflect different combinations of the colors found in white light. Source: GLOBE

GLOBE Measurements and Their Instruments

GLOBE environmental measurements are in five study areas: Atmosphere/Climate, Hydrology, Land Cover/Biology, Soils, and Phenology. The following pages summarize the current specifications for the instruments. The GLOBE measurements and instruments are differentiated by skill level.

Measurement	Instrument	Skill Level
Atmosphere/Climate		
Cloud and Contrails Cover/Type	Cloud chart	All
Aerosols	Sun photometer, digital voltmeter	Middle, Secondary
Water Vapor	GLOBE/GIFTS Water Vapor Instrument	Middle, Secondary
Barometric Pressure*	Aneroid barometer or altimeter or digital barometer	All
Relative Humidity	Digital Hygrometer, Thermometer (calibration or Maximum/minimum)	All
	Sling Psychrometer, Instrument shelter, Calibration thermometer	All
Precipitation, Liquid	Rain gauge	All
Precipitation, Solid	Snowboard, Rain gauge, Snow depth pole	All
Precipitation pH	pH indicator paper	Primary
	pH meter, three pH buffers (7, 4, and 10)	Middle, Secondary
Digital Multi-day Maximum/ Minimum Air & Soil Temperatures Protocol	Digital Multi-day Maximum/ Minimum thermometer, Calibration thermometer, Soil thermometer, Instrument shelter	All
Air Temperature: Maximum, Minimum, and Current	Maximum/Minimum thermometer, Calibration thermometer, Instrument shelter	All

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

Measurement	Instrument	Skill Level
Surface Temperature	Infrared Thermometer (IRT)	Middle, Secondary
Surface Ozone	Ozone test strip scanner, ozone chemical test strips, ozone measurement station, sealable bags, wind direction device	All
Automated Weather Station Protocols*	Weather station with a data logger attached to a suitable computer, Calibration thermometer, Rain gauge	Middle, Secondary
Hydrology		
Transparency — Deep Water Sites Only	Secchi Disk, 5 m rope	All
Transparency — Surface Water	Turbidity tube	All
Water Temperature	Organic liquid-filled thermometer	All
Dissolved Oxygen	Dissolved oxygen kit	Middle, Secondary
Water pH	pH indicator paper	Primary
	pH meter, three pH buffers (7,4, and 10)	Middle, Secondary
Electrical Conductivity – Fresh Water Sites Only	Total dissolved solids (conductivity) tester, calibration solution	All
Salinity – Brackish and Salt Water Sites	Hydrometer, 500 mL clear plastic graduated cylinder, organic liquid-filled thermometer	All
Salinity Titration Method*– Brackish and Salt Water Sites	Salinity kit	Optional Middle, Secondary
Alkalinity	Water alkalinity kit	Middle, Secondary
Nitrate	Water Nitrate kit	Middle, Secondary
Freshwater Macroinvertebrates*	Latex gloves, clear plastic jars, small plastic vials, plastic squirt or spray bottles,20-mL bulb, basting syringes, eyedroppers, plastic or metal forceps, magnifying glasses	Middle, Secondary

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

Measurement	Instrument	Skill Level
Freshwater Macroinvertebrates* (cont)	or loupes, 5-L white buckets, white trays, sub-sampling tray, 0.5 mm sieve (or smaller), sieve between 2-5 m, locally-applicable macroinvertebrate identification keys, specimen bottles with preservation solution (70% ethanol) and tight lids (optional), 1 x 1 m quadrat (optional)	
Soil		
Soil Characterization – Field Slope, Horizon Depth, Structure, Color, Consistence, Texture, Carbonates	Clinometer, Camera, Meter stick, Color chart, Sample cans, Other containers, Shovel or Auger	All
Bulk Density	Metal sampling cans or other containers, Drying oven, Graduated cylinder, Sieve	All
Soil Particle Density	100 mL Volumetric or Erlenmeyer flask with stoppers, heat source, Thermometer, Balance	Middle, Secondary
Particle Size Distribution	500-ml graduated cylinders, Soil Dispersing Reagent (Sodium Hexametaphospate), 250 mL or larger containers, Thermometer, 100-mL graduated cylinder, meter stick	All
Soil pH	pH paper, meter and pH buffers, 100 mL beaker, balance	All
Soil Fertility	Soil NPK kit	Middle, Secondary
Soil Moisture	Balance, Meter stick, Drying oven (soils), Sample Cans, Other soil containers, Auger (depth sampling), 50 m tape measure (transect)	All
Soil Moisture Meter*	Soil moisture meter, Soil Moisture sensors, PVC piping	Optional, Secondary

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

Measurement	Instrument	Skill Level
Infiltration*	Dual ring infiltrometer	Optional, All
Soil Temperature	Soil thermometer	All
Automated Soil and Air Monitoring Protocol*	4-Channel data logger and software, 1 Air temperature sensor, 3 Soil temperature sensors, Data logger-to-computer interface cable, Watertight box, Desiccant, Instrument shelter	Optional Middle, Secondary
Digital Multi-Day Soil Temperatures Protocol*	Digital Multi-day Maximum/Minimum thermometer, Calibration thermometer, Soil thermometer	All
Automated Soil Moisture and Temperature Station Protocols*	Soil Moisture/ Temperature Station attached to a weather station with a data logger attached to a computer, Calibration thermometer	Middle, Secondary
Earth as a System		
Green-Up	Local plant identification guide, Compass, Camera, mm ruler	All
Green-Down	Local plant identification guide, Compass, Camera, GLOBE Plant Color Guide	All
Budburst	Local plant identification guide	All
Land Cover/Biology		
Land Cover Mapping	Remote sensing image, MultiSpec software (optional)	All
Species Identification	Dichotomous keys	All
Biometry Tree Circumference Tree Height Canopy Cover Ground Cover	Clinometer and densiometer (both may be student-made), 50 m tape measure	All
Biometry Grass Biomass	drying oven (plants)	All
GPS		
Latitude and Longitude of study sites	Global Positioning System receiver	All

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

Scientific Instruments for GLOBE Measurements

A number of instruments, supplies, and pieces of equipment are needed to conduct the GLOBE measurements properly. Many of these can be purchased from suppliers while some can be made by students or individuals in the school community. The GLOBE measurement protocols are broken into three types, depending on the degree of commitment to their support and expectations as to their training and implementation by GLOBE schools. These types are Basic, Advanced, and Optional. The following tables list the instruments needed for each type of measurement. GLOBE measurements are also differentiated by skill level. In the KIT Column of the following tables, P, M, and S indicate that an instrument is included in a primary (P), middle (M), or secondary (S) level kit. Each such kit includes the minimum set of instruments which most schools will need to purchase in order to do the **Basic** GLOBE protocols appropriate for their educational level. (A) indicates that the instrument is included in a kit for all advanced protocols. (E) indicates that purchase of this instrument is extra and that it is not included in a kit either because most schools should already have access to one, because schools in an area can reasonably share one instrument, or because the instrument is needed only if certain options within the GLOBE protocols are chosen. (C) indicates that the instrument can be constructed at the school or with local assistance.

Basic Measurements

Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
Cloud chart	E[1]	Cloud Cover/Type	All
Digital Hygrometer	P,M,S[2]	Relative Humidity	All
Sling Psychrometer	P,M,S[2]	Relative Humidity	All
Maximum/Minimum Thermometer (digital or U-shaped)	P,M,S	Air Temperature - Max/Min.and Current Temperature	All
Calibration thermometer (Organic liquid-filled thermometer)	P,M,S	Air Temperature, Relative Humidity, Water Temperature, Salinity, Soil Particle Size	All
Instrument Shelter	P,M,S,C	Air Temperature, Relative Humidity, Automated Soil and Air Temperature	All
Rain gauge	P,M,S	Precipitation, Liquid, Solid	All
Snowboard	M	Precipitation, Solid	All
Snow depth pole	E, C	Precipitation, Solid	All
pH indicator paper	P	Precip. pH, Water pH, Soil pH	Primary

[1] One copy provided to each GLOBE teacher at training.

[2] Only one of these instruments should be included in any one GLOBE kit.

Basic Measurements (continued)

Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
pH meter	M,S	Precip. pH, Water pH, Soil pH	Middle Secondary
pH 4, pH 7 and pH 10 buffers	M,S,C	Precip. pH, Water pH, Soil pH	Middle Secondary
Total dissolved solids (conductivity) tester	P,M,S[3]	Electrical Conductivity - Fresh water sites only	All
Calibration solution	P,M,S,C[3]	Electrical Conductivity - Fresh water sites only	All
Hydrometer	P,M,S[4]	Salinity — Brackish/salt water sites only	All
500 mL clear plastic graduated cylinder	P,M,S[4]	Salinity — Brackish/salt water sites only	All
Secchi Disk, Rope	E,C	Transparency — Deep water site only	All
Turbidity tube	C	Transparency — Shallow water site	All
Safety Equipment — Plastic gloves and goggles	A	Hydrology: Dissolved Oxygen, Alkalinity, Salinity Titration, Nitrate	Middle, Secondary
Remote sensing image data	See footnote[5]	Land Cover Mapping, Land Cover Change Detection	All
Dichotomous keys	E[6]	Species Identification, Green-Up, Green-Down	All
50 m tape measure	P,M,S	Site Layout, Tree Circumference, Tree Height	All
Compass	E	Land Cover Sample Sites Atmosphere and Soil Site Definitions, Green-up, Green-Down	All
Clinometer	E,C	Tree Height, Slope	All
Densiometer	C	Canopy Cover	All
Plant clippings drying	E	Grass Biomass	All

[3] Include in kit only for freshwater sites.

[4] Include in kit for brackish/salt water sites only.

[5] Remote sensing image data provided by GLOBE.

[6] Choose a dichotomous key appropriate to local vegetation; a generally applicable dichotomous key will be provided to each teacher at training.

oven Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
Dutch auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Sand auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Peat auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Bucket auger[7]	E	Soil: Profile, Bulk Density, Soil Moisture	All
Shovel	E	Soil: Profile, Bulk Density, Soil Moisture	All
Camera	E	Soil Profile, Land: Site Layout, Green-Up, Green-Down	All
Meter stick	E	Soil: Depth, Soil Moisture	All
Color chart	P,M,S	Soil Color	All
Distilled white vinegar	E	Soil: Free Carbonates	All
Acid squirt bottle	P,M,S	Soil: Free Carbonates	All
#10 sieve (2 mm mesh)	P,M,S	Soil: Bulk Density	All
Soil drying oven	E	Soil: Moisture, Bulk Density	All
Balance	E	Gravimetric Soil Moisture, Soil Bulk Density	All
Soil cans – 15	E,C	Gravimetric Soil Moisture Soil Bulk Density — Pit or surface method	All
Other soil containers	E	Gravimetric Soil Moisture, Bulk Density	All
100 mL graduated cylinder	P,M,S	Soil pH, Bulk Density	All
Garden trowel	E	Gravimetric Soil Moisture	All
Dual Ring Infiltrometer	E,C	Soil: Infiltration	All
Soil Thermometer	P,M,S	Soil: Temperature	All
Plant Color Guide	P,M,S	Green-Down	All
Global Positioning System receiver	E[8]	Latitude, longitude and elevation	All

[7] Select auger appropriate for local soil type.

[8] If you do not have access to a GPS receiver please contact your GLOBE Country Coordinator or, in the United States, the GLOBE Help Desk.

Basic Measurements (continued)

Instrument	KIT(P,M,S,E,A,M)	Measurement	Skill Level
Dissolved oxygen kit	A	Dissolved Oxygen	Middle, Secondary
Water alkalinity kit	A	Alkalinity	Middle, Secondary
Water nitrate kit	A	Hydrology: Nitrate	Middle, Secondary

Advanced Measurements

Instrument	KIT(P,M,S,E,A,C)	Measurement	Skill Level
Sun photometer	E	Aerosols	Middle, Secondary
GLOBE/GIFTS Water Vapor Instrument	E	Water Vapor	Middle, Secondary
Digital Voltmeter	E	Aerosols	Middle, Secondary
Aneroid Barometer	A	Barometric Pressure	All
Altimeter	A	Barometric Pressure	All
Infrared Thermometer	A	Surface Temperature	Middle, Secondary
Ozone test strip scanner	A	Surface Ozone	All
Ozone chemical test strips	A	Surface Ozone	All
Ozone Measurement Station	C	Surface Ozone	All
Sealable bags	E	Surface Ozone	All
Wind direction device	E, C	Surface Ozone	All
Hydrometer	A[9]	Soil: Particle Size	All
500 mL clear plastic graduated cylinder	A[9]	Soil: Particle Size	All
Dispersing solution	A	Soil: Particle Size	All
100 mL Erlenmeyer flask	A	Soil: Particle Density	All
Heat source	A	Soil: Particle Density	All
Soil NPK kit	A	Soil Fertility	Middle, Secondary
MultiSpec software	See footnote[10]	Unsupervised Clustering	Middle, Secondary

[9] Needed only if such equipment have not been purchased for salinity measurement (Basic Measurement - brackish/salt water sites only).

[10] Downloadable from Purdue University http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/Index.html

Optional Measurements

Instrument	KIT(P,M,S,E,C)	Measurement	Skill Level
Salinity kit		Salinity — Titration Method	Optional, Middle, Secondary
Soil moisture sensors (4 required)		Soil Moisture Sensor	Optional, Secondary
Soil Moisture Meter		Soil Moisture Sensor	Optional, Secondary
PVC Pipe		Soil Moisture Sensor	Optional, Secondary
4-Channel data logger		Automated Soil and Air Temperature	Optional, Middle, Secondary
One air temperature sensor and three soil temperature sensors		Automated Soil and Air Temperature	Optional, Middle, Secondary
Water tight box		Automated Soil and Air Temperature	Optional, Middle, Secondary
Desiccant		Automated Soil and Air Temperature	Optional, Middle, Secondary
Automated Weather Station		Automated Weather Station	Optional, Middle, Secondary
Kicknet or D-net		Freshwater Macroinvertebrates	Optional, Middle, Secondary
Quadrat		Freshwater Macroinvertebrates	Optional, Middle, Secondary
Sieves		Freshwater Macroinvertebrates	Optional, Middle, Secondary

GLOBE Instrument Specifications

All GLOBE instrument specifications described below represent the minimum specifications necessary to collect scientifically valid data. GLOBE schools may use instruments that meet or exceed these specifications. For example, the GLOBE specifications for pH paper call for a range of 2 to 9 pH units. A pH paper with a range of 1 to 14 exceeds specifications and may be used by GLOBE schools.

Atmosphere/Climate

Cloud Cover/Type - All Skill Levels

Instrument Specifications: Cloud Chart

The GLOBE cloud chart shall display at least one visual example of each of the 10 basic cloud types - cirrus, cirrostratus, cirrocumulus, altostratus, altocumulus, cumulus, nimbostratus, stratus, cumulonimbus, stratocumulus. Sky cover will be visually estimated. The GLOBE Program will provide a cloud chart to each trained U.S. teacher and to each GLOBE Program Country Coordinator.

Aerosols – Middle, Secondary

Instrument Specifications: Sun Photometer

The GLOBE sun photometer has two optical/electronic channels, one with an effective aerosol optical thickness wavelength of 505 nm and the other with an effective AOT wavelength of 625 nm, where "effective aerosol optical thickness wavelength" is defined in Brooks, David R., and Forrest M. Mims III: Development of an inexpensive handheld LED-based Sun photometer for the GLOBE program. *J. Geophys. Res.* **106**(D5), 4733-4740, 2001. (That is, the algorithms presented in this paper are an integral part of the instrument specification.) The LED detectors for each channel must be obtained directly from the GLOBE Aerosols Science Team.

The detectors and their associated battery-powered electronics are housed in an enclosed plastic or metal box approximately 15 cm long by 5 cm high by 8 cm wide. The detectors must be mounted in a plane such that the LED chips themselves (embedded in a standard T-1-3/4 epoxy housing) are 12.5 cm from one end of the case and that end must contain a 5.5 mm (7/32") diameter sun aperture hole. The round end of the LED housing, which acts as a lens in usual LED applications, must be flattened and polished. There must be a clear line of site from this aperture hole to each detector. No internal light baffling is required.

Sunlight is aligned on the detectors through the use of two alignment brackets mounted on the outside of the case. Sunlight passes through a round hole in the front bracket and then shines upon two alignment marks on the rear bracket (one for each channel). When the sunlight spot is centered over an alignment mark, it should also be centered over the LED for the corresponding channel. (Alternate means of aligning the sun on the detectors are acceptable.)

The electronics consist of two low-power op-amp-based transimpedance amplifiers (or their functional equivalents) to convert the LED current to a voltage on the order of 1-2V in full sunlight. Noise, gain, temperature drift, and other op amp performance characteristics should be similar to that of Linear Technology LTC1050 or LTC1051 op amps. (Generic 741-type op amps or their dual equivalents are not suitable for this instrument.) Bypass capacitors should be included in the resistive feedback loops to prevent self-oscillation.

The sun photometer's output should be monitored either by attaching an external digital voltmeter to pin jacks mounted on the case, or through a built-in digital meter. A built-in meter should display at least three digits to the right of the decimal point for output in the 1-2V range.

Instrument Specifications: Digital Voltmeter

A digital voltmeter (or multimeter) with a DC volts setting that is either: (i) auto-ranging within the range 0-20VDC or (ii) manually selectable for range settings of 0-2VDC and 0-20VDC. For inputs of less than 10VDC (that is, up to 9.999V), the meter must display three digits to the right of the decimal point.

Water Vapor – Middle, Secondary

Instrument Specifications: GLOBE/GIFTS water vapor instrument

The GLOBE/GIFTS water vapor instrument is based on the same principle as and similar in design to the GLOBE sun photometer, the specifications for which are described in detail under Aerosols. Both use light emitting diodes (LEDs) to measure the strength of sunlight in select wavelengths. While the GLOBE sun photometer detects visible light in the green and red part of the spectrum, the water vapor instrument detects infrared rather than visible light. This instrument concept was first developed and described in the scientific literature by a member of the *Water Vapor* protocol Science Team [Mims, Forrest M. III, Sun photometer with light-emitting diodes as spectrally selective detectors, *Applied Optics*, **31**, 6965-6967, 1992].

The calibrations of the LEDs for this instrument require access to highly specialized equipment and data and they cannot be duplicated by students in the lab or in the field. These instruments can be obtained from the GLOBE Water Vapor Team.

Barometric Pressure – All Skill Levels

Instrument Specifications: Aneroid Barometer

The aneroid barometer must have a clear scale with a pressure range between 940 and 1060 millibars. The scale should be readable to the nearest whole millibar and have an accuracy of 3.5 millibars over its entire range. A set needle should be on the face of the barometer. The barometer must be calibratable. This barometer will be most useful for stations whose elevation is less than 500 meters above sea level. Schools at higher elevations will need to use an altimeter.

Instrument Specifications: Altimeter

An altimeter is a special type of aneroid barometer designed to provide heights (using standard temperature and pressure values), as well as true atmospheric pressure readings. The scale must be given in millibars and extend from 650 millibars to 1050 millibars. Accuracy must be 3.5 millibars over the range of the instrument. The altimeter must be calibratable. This instrument is for the measurement of atmospheric pressure at elevations over 500 m.

Instrument Specifications: Digital Barometric Pressure Sensor

Barometric pressure values may also be collected with a digital barometric pressure sensor. This sensor must have a pressure range of between 940 and 1060 mbars with one mbar resolution and an accuracy of 3.5 mbars over its entire range. Barometric pressures reported from the sensor must be station pressures.

Relative Humidity – All Skill Levels

Instrument Specifications: Digital Hygrometer

A digital hygrometer or sensor must provide a digital readout of relative humidity to the nearest 1%. Over a range of 20-95%, accuracy must be at least 5%.

The digital hygrometer should include a stand to allow the unit to be placed upright on the floor of the instrument shelter, while measurements are being taken. Calibration is done by the manufacturer and should be warranted for at least two years, with subsequent recalibration available. Batteries should be included. The unit should not be left outside on a daily basis.

Instrument Specifications: Sling Psychrometer

The wet bulb and dry bulb temperatures shall be measured with a sling psychrometer, which consists of two spirit-filled thermometers. The thermometers shall be readable only in degrees Celsius, with scales marked in increments of 1.0˚ C, and the scales must be capable of supporting temperature estimations to the nearest 0.5˚ C over a range of –1˚ C to 35˚ C. The psychrometer must be in a sturdy protective case or have spirit bulbs mounted on a rigid plate, and be provided with handle necessary for whirling or slinging. Thermometers must be factory calibrated to an accuracy of +1.0° C, which will provide relative humidity accuracy of 5%. Both scales should be adjustable for calibration, or the spirit bulbs replaceable. Each scale must be clearly marked to indicate Celsius. Siting and installation instructions are provided in the *Atmosphere Chapter*.

Instrument Specifications: Calibration Thermometer

The Calibration Thermometer described in Air Temperature may be used for this measurement.

Instrument Specifications: Maximum/Minimum Thermometer

The Maximum/Minimum Thermometer described in Air Temperature may be for this measurement.

Instrument Specifications: Instrument Shelter

The Instrument Shelter described in Air Temperature will be used for this measurement.

Surface Ozone – All Skill Levels

Instrument Specifications: Ozone Chemical Strips

The ozone chemical strips contain a solution of tin(II) chloride dihydrate and 1,5-diphenylcarbazide dissolved in reagent-grade acetone. When exposed to air, ozone reacts with the mixture and triggers a colorimetric reaction resulting in the formation of a pink color. Ground level ozone concentrations can be measured by quantifying the color change on an exposed chemical strip using an ozone optical reader.

Instrument Specifications: Ozone Test Strip Scanner

The ozone test strip optical reader operates as a simple spectrophotometer consisting of a light emitting diode (LED) emitting light near 540nm, and a photo diode that captures the reflected light off the exposed chemical test strip and converts it into an electrical voltage. The reader must be calibrated so that the voltage measured can be displayed as an ozone concentration in parts ozone per billion parts of air (ppb). Zero ozone level must be set by inserting an unexposed ozone test strip into the reader and storing the voltage produced. Any absorption at 540 nm above this value will be measured as a specific ozone concentration.

Instrument Specifications: Ozone Measuring Station

Directions for constructing an ozone measuring station are provided in the *Instrument Construction, Site Selection, and Set-Up* section of the *Atmosphere Chapter.*

Instrument Specifications: Wind Direction Instrument

Any device capable of displaying wind direction, such as weathervane. Directions for constructing a wind direction instrument are provided in the *Instrument Construction, Site Selection, and Set-Up* section of the *Atmosphere Chapter.*

Precipitation, Liquid - All Skill Levels

Instrument Specifications: Rain Gauge

Precipitation will be measured with a clear view plastic rain gauge with a collector that is at least 102 mm in diameter. The rain gauge must be at least 280 mm in height with a scale indicating rain collected of 0.2 mm or less on an inner clear cylinder. It must have the capacity to measure rainfall of 280 mm without overflowing. The shape of the outer part must also be cylindrical, and overflow from the inner cylinder shall be directed to the outer part of the rain gauge. The outer cylinder must be capable of being used in the inverted position to gather a snow sample for measurement of the water content of snow. The rain gauge must be provided with the necessary hardware for installation on a pole. Instructions for siting are provided in the GLOBE Program *Teacher's Guide.*

Instrument Specifications: Electronic Tipping Bucket

An electronic tipping bucket rain-measuring instrument may be used in conjunction with an automated weather station. The tipping bucket must have a resolution of at least 0.25 mm.

Precipitation, Solid - All Skill Levels

Instrument Specifications: Snowboard

The depth of daily snowfall will be measured with a plywood board, painted white, which is approximately 40 cm X 40 cm x at least 1 cm thick.

Instrument Specifications: Rain Gauge

The rain gauge described in Precipitation, Liquid will be used for this measurement.

Instrument Specifications: Snow Depth Pole

For snow depths less than 1 meter, a meter stick is recommended. When the snow is deeper than one meter, a snow depth pole is used. This can be made from a 2 meter pole by placing two meter sticks end to end on this pole.

Precipitation pH - All Skill Levels

The same instruments described in Hydrology: Water pH will be used for this measurement.

Air Temperature - All Skill Levels

Instrument Specifications: Digital Max/Min Thermometers

Digital max/min thermometers may be used. These must have either an accuracy of ± 0.5º Celsius or a precision of at least ± 0.5º Celsius and an error offset that is temperature independent. These thermometers can either be digital single-day max/min thermometers that are checked and reset each day or digital multi-day max/min thermometers that log temperature values for multiple days.

Digital multi-day max/min thermometers must be able to record max/min temperatures over 24-periods that can be set to begin and end within one hour of local solar noon.

Instrument Specifications: Liquid-filled Maximum/Minimum Thermometer

Air temperature can be measured with a U-shaped maximum/minimum thermometer. The maximum/minimum thermometer shall be readable only in degrees Celsius, with maximum and minimum scales marked in increments of 1.0˚ C, and the scales must be capable of supporting temperature estimations to the nearest 0.5˚ C. The thermometer must be in a sturdy protective case, and be provided with the necessary hardware for installation. It must be factory calibrated to an accuracy of +1.0˚ C. Both scales must be adjustable for calibration. Each scale must be clearly marked to indicate Celsius, and have indicators such as "+" and "-" on each scale to indicate direction of increasing and decreasing temperature. In addition, each scale must be clearly marked to identify which scale is maximum and which is minimum. Siting and installation instructions are provided in the GLOBE Program *Teacher's Guide*.

Instrument Specifications: Digital Temperature Sensor

Digital temperature sensors may also be used to monitor temperature. These must have either an accuracy of ± 0.5º Celsius or a precision of at least ± 0.5º Celsius and an error offset that is temperature independent.

Instrument Specifications: Calibration Thermometer

The maximum/minimum thermometer will be calibrated with a second thermometer which is an organic liquid-filled thermometer with a temperature range of -5˚ C to 50˚ C. The thermometer must be factory calibrated and tested with standards traceable to N.I.S.T (The National Institute of Standards and Technology - United States) to an accuracy of +0.5˚ C, with 0.5˚ C scale divisions. It must be supplied with a metal jacket with holes at the bulb end to allow for circulation and a hole at the top by which to hang the thermometer in the instrument shelter for calibration of the maximum/minimum thermometer.

Instrument Specifications: Instrument Shelter

An instrument shelter is required to house the maximum/minimum thermometer and the calibration thermometer to assure scientifically usable air temperature measurements. The instrument shelter must be constructed of a material with a thermal insulation value which equals or exceeds that of seasoned white pine wood (approximately 2.0 cm thick). It must be painted white with exterior grade paint. The shelter must be vented, and be large enough to allow air circulation around the thermometer. The inside dimensions must be at least 45 cm high, 24.0 cm wide, and 12.0 cm deep. The shelter must have a hinged door on the front, be louvered on the front and sides, and have holes in the bottom and holes at the uppermost part of the sides to increase ventilation if the louvers do not extend to the top of the sides. The door must contain a lock. The instrument shelter must be mountable onto a wall or post. The top of the shelter must slope downward toward the front. The parts of the shelter must be securely fastened to each other, either using screws or with nails and glue. Joints must be sealed with weather resistant caulking compound. Detailed instructions on constructing an instrument shelter are provided in the *Instrument Construction, Site Selection, and Set-Up* section of the *Atmosphere Chapter.*

Surface Temperature – Middle, Secondary

Instrument Specifications: Infrared Thermometer (IRT)

The Infrared thermometer should be a handheld instrument. It must have an accuracy of +/-1˚ C over a range of –32˚ C to 72˚ C.

Automated Weather Station– Optional, Middle, Secondary

Instrument Specifications: Automated Weather Station

A weather station must be attached to a data logger and computer, and be capable of logging data at 15-minute intervals. Data entry is simplified if the software for the weather station supports the option to "Export GLOBE Data".

The sensors attached to the weather station must meet the following specifications:

Temperature: Must have either an accuracy of ± 0.5º Celsius or a precision of at least ± 0.5º Celsius and an error offset that is temperature independent.

Barometric Pressure: Must have a pressure range of between 940 and 1060 mbars with one mbar resolution and an accuracy of 3.5 mbars over its entire range.

Relative Humidity: Must have a digital readout of relative humidity to the nearest 1%. Over a humidity range of 20-95%, accuracy must be at least 5%.

Rainfall: Must have a resolution of at least 0.25 mm.

Anemometer: Must have a precision of ± 5% and a range of at least 0-34 m/s

You may report data taken using any sensors that meet these specifications. In order to perform a weather station protocol and related email data entry these sensors must be attached to a weather station that is capable of logging data at 15-minute intervals.

If one or more of the sensors of your weather station do not meet the above specifications, you may still report data collected with the sensors that do meet specifications.

Hydrology

Water Temperature: - All Skill Levels

Instrument Specifications: Organic Liquid-filled Thermometer

The calibration thermometer or digital temperature sensor described in Air Temperature will be used for this measurement.

Transparency - All Skill Levels

Instrument Specifications: Secchi Disk Apparatus (for deep water sites only)

5 m length of rope and a disk with a diameter of 20 cm. The disk shall be colored with paint or other appropriate means such that alternate quadrants of each side are black and white. The disk must be made so that it will not be disfigured or damaged by repeated immersion in water, including sea water. It must be weighted such that it remains horizontal while it is lowered by the rope in the water.

Instrument Specifications: Turbidity Tube (for surface water)

Clear plastic tube, approximately 1.2 m long and 4.5 cm diameter with a white cap that fits securely on the end of the tube. The end cap must display a pattern consisting of alternating black and white quadrants on the side that is viewed by looking down the tube.

Water pH - All Skill Levels

Note: The instrument requirements for this measurement vary according to skill level. Please select the appropriate instrument for your students.

Skill Level - Primary

Instrument Specifications: pH Paper

The pH of standing water at this skill level will be measured with pH paper which can be purchased in strips or rolls. The pH paper must have an accuracy of at least ± 1.0 pH units, with a range of 2 to 9 pH units. For water samples with low conductivity the pH paper must be accurate in low conductivity levels.

Skill Level - Middle, Secondary

Instrument Specifications: pH Meter

The pH of standing water at this skill level will be measured with a pH meter. The pH meter must have an accuracy of 0.1 pH unit, and a range of pH 1 to pH 14, at temperatures from 0 C to 50 C. The device shall automatically compensate the reading when it is placed in solutions of differing temperature.

The pH meter must be capable of being calibrated using at least two known pH buffer solutions: pH 4, 7, or 10.

Skill Level - Middle, Secondary

Instrument Specifications: Buffers

pH buffer solutions are required to calibrate the pH pen and meter. The buffer solutions should have a value of pH 4.0, pH 7.0 and pH 10.0.

Dissolved Oxygen - Middle, Secondary Skill Levels

Instrument Specifications: Dissolved Oxygen Kit

A dissolved oxygen test kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Enables measurement of dissolved oxygen with an accuracy of at least +/- 1 mg/L
- Contains all the chemicals and special containers to perform this measurement based on the Winkler titration method. This method is described in *Standard Methods for the Examination of Water and Wastewater*, 19th edition, 1995, a publication of the American Public Health Association, Washington, DC.
- Contains clear instructions for using the kit to make this measurement using a procedure based on the Winkler titration method.

Alkalinity - Middle, Secondary Skill Levels

Instrument Specifications: Water Alkalinity Kit

A water alkalinity kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Enables measurement of total alkalinity with an accuracy of at least 6.8 mg/L as $CaCO_3$ (low range, under 136 mg/L), and 17 mg/L as $CaCO_3$ (high range, above 136 mg/L).
- Contains all chemicals and containers needed to perform the alkalinity titration, including: 1) Bromocresol green-methyl red indicator and scoop for adding the required amount to the sample, 2) sulfuric acid for titration, and method of delivering acid to sample to achieve the required accuracy, 3) measuring containers and bottles for titration. This method is described in 19th edition, 1995, a publication of the American Public Health Association, Washington, D.C.
- Contains clear instructions for using the kit to make this measurement, based on acid titration to a Bromocresol green-methyl red end point.
- Plastic gloves and safety goggles

Instrument Specifications: Safety Equipment

Plastic gloves and safety goggles must be used in making this measurement.

Electrical Conductivity (for fresh water sites) - All Skill Levels

Instrument Specifications: Electrode-type Total Dissolved Solids Tester (Conductivity Meter)

This device shall measure electrical conductivity of liquid solutions using two metal electrodes separated by a fixed distance. The device shall be designed to be hand-held, and battery powered, with no electrical power cord attached. The device shall employ a method to automatically compensate the indicated conductivity value relative to changes in the temperature of the solution. The measurement range shall be at least from 0-1990 microSiemens/cm, with a resolution of 10 microSiemens/cm, an accuracy of +/- 2% full scale, and an operating temperature of 0-50 C. The device shall be capable of calibration using a standard solution.

Instrument Specifications: Calibration Standard

A standardized solution of KCl and water or NaCl and water that has a conductivity of between 500 +/- 0.25% and 1500 +/- 0.25% microSiemens at 25C.

Salinity (for brackish and salt water sites) - All Skill Levels

Instrument Specifications: Hydrometer Method

The same instrument described in Soil Particle Size will be used for this measurement.

A 500 mL clear plastic cylinder and an organic liquid-filled thermometer for use with the hydrometer are required. The 500 mL cylinder for Soil Particle Size may be used. The calibration thermometer for Air Temperature may be used.

Instrument Specifications: Salinity Titration Method - Optional, Middle, Secondary Skill Levels

A salinity kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Range: 0 - 20 parts per thousand (ppt)*
- Smallest increment: 0.4 ppt
- Method/chemistry: chloride titration
- Approximate number of tests: 50
- Contains clear instructions for using this kit to make this measurement, based on the chloride titration method.

*Titrator must be refillable for use in higher salinity waters.

Nitrate - Middle, Secondary Skill Levels

Instrument Specifications: Water Nitrate Kit

A nitrate kit can be purchased. Teachers or manufacturers who wish to use or prepare another version should ensure that it also meets the following requirements:

- Range: 0 - 10 ppm NO_3-N (typical water) or a range with the highest concentration greater that what is typically observed for your water body (polluted water.)
- Smallest increment: 0.05 ppm NO_3-N for the range 0 -1 ppm NO_3-N; 0.5 ppm NO_3-N for the range 1 - 5 ppm NO_3-N; 1 ppm NO_3-N for the range 5 - 10 ppm NO_3-N; 2 ppm NO_3-N for concentrations greater than 10 ppm NO_3-N
- Contains clear instructions for using this kit to make this measurement.

Freshwater Macroinvertebrates – Optional, Middle, Secondary

Instrument Specifications: Kicknet

Must have dimensions of 1 m X 0.9 m, and made of 0.5 mm mesh netting.

Instrument Specifications: D-net

Must be a "D"-shape with a 40 cm long base, and made of 0.5 mm mesh netting.

Instrument Specifications: Quadrat

Must be a square with internal dimensions of 1 m X 1 m. Can be made from locally available materials.

Instrument Specifications: Sieves

There are two sieves required:

1. a sieve with mesh netting of 0.5 mm or smaller
2. a sieve with mesh netting of 2-5 mm

Soil Characterization

Soil Slope - All Skill Levels

Instrument Specifications: Clinometer

A clinometer as described in Land Cover specifications.

Soil Profile - All Skill Levels

Instrument Specifications: Camera

A camera with color film or digital camera.

Instrument Specifications: Meter Stick

A durable ruler with gradations every cm and mm.

Instrument Specifications: Soil Auger (optional)

See soil auger types listed under Soil Moisture.

Soil Structure - All Skill Levels

Instrument Specifications: None

Color - All Skill Levels

Instrument Specifications: Color Chart

A soil color chart designed especially for the GLOBE Program can be purchased. It contains at least 200 colors and uses the Munsell System of Color Notation. This flip chart is weather-resistant and has large color chips which are edge-mounted for ease of reading. The color range includes all hues found in the full set of International soil colors, yet provides a selected set of values and chroma to aid color identification for students. Manufacturers who wish to prepare another version should contact the GLOBE Program for the complete list of colors.

Soil Consistence - All Skill Levels

Instrument Specifications: None

Soil Texture- All Skill Levels

Instrument Specifications: None

Free Carbonates - All Skill Levels

Instrument Specifications: Vinegar

Distilled white vinegar. Household vinegar may be used.

Instrument Specifications: Acid Squirt Bottle

A bottle capable of safely holding at least 200 mL of acid is required.

Sample Preparation for Bulk Density, Particle Size, Soil pH, and Fertility Protocols - All Skill Levels

Instrument Specifications: Sieve

Number 10 sieve with 2 mm mesh attached to a frame.

Soil Bulk Density - All Skill Levels

Instrument Specifications: Graduated Cylinder -100 mL

Glass graduated cylinder with a capacity of 100 mL marked in 1 mL or smaller divisions, with graduations covering at least the range from 10 mL to 100 mL.

Instrument Specifications: Balance and Augers

The same balance and auger used for Gravimetric Soil Moisture will be used for Bulk Density.

Instrument Specifications: Soil Sample Cans and Other Soil Containers

Cans and containers should meet the same specifications as given for these items for Gravimetric Soil Moisture

Soil Particle Size - All Skill Levels

Instrument Specifications: Hydrometer

The hydrometer used should meet the following requirements:

- Calibrated to specific temperature for water and sample (e.g. 15.6 C / 15.6 C
- Range (specific gravity / no units): 1.0000 - 1.0700
- Smallest increment (no units): 0.0005

Instrument Specifications: Thermometer

The Calibration Thermometer described in Air Temperature will be used for this measurement.

Instrument Specifications: 500 mL Clear Plastic Graduated Cylinder

One 500 mL capacity plastic graduated cylinder, marked at least at the 500 mL level. Cylinder must be clear plastic, not frosted plastic and not glass.

Instrument Specifications: Dispersing Solution

Sodiumhexametaphosphate powder or a 10% solution of either sodiumhexametaphosphate or a detergent that does not produce suds.

Soil Particle Density – All Skill Levels

Instrument Specifications: 100 mL Erlenmeyer flask

A heat-resistant Erlenmeyer flask with a cap, capable of holding 100 mL of solution.

Instrument Specifications: Heat source

A heat source capable of bringing 100 mL of a water and soil solution to a gentle boil and maintaining this boil for at least 10 minutes.

Soil pH - All Skill Levels

Instrument Specifications: pH measurement devices

The same instruments described in Hydrology: Water pH will be used for this measurement.

Instrument Specifications: Graduated Cylinder -100 mL

The same instrument as described in Bulk Density will be used for this measurement.

Soil Fertility - Middle, Secondary Skill Levels

Instrument Specifications: Soil NPK (Macronutrients) Kit

The test kit must:

- Contain unit-dose reagents and containers needed to extract soil nutrients from 50 samples and to perform 50 tests of each: soil nitrogen; soil phosphorus; and soil potassium.
- Employ methods based on the Spurway extraction method, the zinc reduction/ chromotropic acid method for nitrogen, the ascorbic acid reduction method for phosphorus, and the sodium tetraphenylboron (turbidimetric) method for potassium.
- Contain clear instructions, including diagrams, for using the kit.
- Contain a water resistant color chart for interpreting the results of colorimetric tests and a turbidity chart for the turbidimetric test.

Soil Moisture

Gravimetric Soil Moisture - All Skill Levels

Instrument Specifications: Balance

This balance must have the capacity to weigh 300 grams with an accuracy of +/- 0.1 gram. It can be either mechanical or electronic. It is assumed that a balance is available locally, for example in a high school science laboratory.

Instrument Specifications: Drying Oven (soils)

Drying oven capable of holding a temperature of 95 C - 105 C for at least 10 hours or a temperature of 75 C - 95 C for 24 hours. The oven must be ventilated, and have interior dimension of at least 25 cm x 30 cm x 25 cm. It is assumed that an oven is available locally, for example in a high school science laboratory.

Instrument Specifications: Microwave Drying Oven

Any microwave oven compatible with school use.

Instrument Specifications: Soil Sample Cans

15 round sample tins. A metal container with a diameter 7 cm, and height 5 cm, with a removable cover is appropriate as are small round, cleaned food cans. Cans must be capable of having a small hole punched in their bottoms.

Instrument Specifications: Other Soil Containers

15 containers large enough to have soil samples transferred into them directly from an auger without loss of sample. Glass jars, plastic food containers with lids, or other containers that can be covered and that can hold the soil samples while they are dried in the drying oven selected.

Instrument Specifications: Dutch Auger For Combination Soils

Dutch (or Edelman) auger for combination soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Dutch Sand Auger

Auger designed for sandy soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Bucket Auger

Bucket (or Riverside) auger designed for hard and brittle soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Instrument Specifications: Peat Auger

Auger designed for peat soils with a head having the minimum dimensions of 7 cm wide and 18 cm long. The unit (head and shaft inclusive) should be at least 120 cm long in order to be suitable to dig a hole up to 1m deep. It should be of one piece welded construction.

Soil Moisture Sensor - Optional, Secondary Skill Level

Instrument Specifications: Soil Moisture Sensor

This should be a ceramic block sensor that uses an electrical resistance method for soil water matric potential measurement. One of the best ceramic block sensors is called a Watermark block and is the one recommended for this measurement.

Instrument Specifications: Soil Moisture Meter

There are two meters you might use. One is manufactured by Delmhorst and reads 0 to 100 (dry to wet). The other is made by Watermark and reads 0 to 200. Both are acceptable by the GLOBE data system. Please contact the GLOBE soil moisture science team if you have a different kind of sensor or meter.

Instrument Specifications: PVC Piping

The PVC pipe assists in placing the soil moisture sensors in the ground. It should be 90 cm in length and approximately 2 cm in diameter. Additional PVC piping is required to mark the location of the sensors. These should be 23 cm long with a diameter of approximately 5 cm. Four pieces of this material are required.

Infiltration — Optional, All Skill Levels

Instrument Specifications: Dual Ring Infiltrometer

Two concentric metal cylinders. The inner one must have a diameter of 10 cm to 25 cm. The outer one must have a diameter at least 10 cm larger than the inner cylinder. Both cylinders should be 10 to 15 cm high and open at both ends. Steel cans may be found which will work for this apparatus.

Soil Temperature

Soil Temperature- All Skill Levels

Instrument Specifications: Soil Thermometer

A 11 cm to 20 cm stainless steel probe, heavy-duty construction dial or digital thermometer with a range of at least -10 to 50 degrees C (Celsius scale required) and an accuracy of 1% full scale (over a range of no more than 200 degrees C) or better is required. The sensor should be in the bottom third of the probe. The sensor should give stable readings after less than 60 seconds in an isothermal bath. Batteries, if required, should be included. The sensor should be adjustable with the calibration procedure and achievable accuracy clearly stated. Dial thermometers must be sealed against fogging and be covered with shatterproof glass or plastic. Scale graduations of 1.0 degrees C and 0.1 degrees C are preferred for dial and digital thermometers, respectively. Glass stem thermometers are NOT acceptable.

Instrument Specifications: Digital Maximum and Minimum Thermometers

See *Digital Maximum and Minimum Thermometers* listed under Air Temperature.

Automated Soil and Air Monitoring – Optional, Middle, Secondary

Instrument Specifications: 4-Channel Data Logger

A self contained, programmable data logger capable of collecting and storing data from four temperature sensors (one air, possibly internal, and three soil - external channels). Data logger must be capable of collecting data at 15 and 60 minute intervals (sampling frequency) and storing at least 3750 measurements (time/date stamped) per channel (8kb capability is preferred) in nonvolatile memory. The time accuracy must be ±1 minute per week. The temperature must be recorded with at least 7 bits of resolution. The logger must be powered by a user-replaceable lithium-grade battery, with a continuous use lifetime of one year. It must have operational ranges of -20 to +70 degrees Celsius in a 0 - 95% relative humidity, non-condensing environment.

Instrument Specifications: Data Logger Computer Interface and Software

Computer interface cables and appropriate software for launching the logger and retrieving the data must be available. The computer interface must be MS WINDOWS compatible. MAC compatibility is desired but not essential. The software must allow the data to be exported as an ASCII text file and should provide some basic graphical display of the data.

Instrument Specifications: Air and Soil Temperature Sensors

Air temperature can be sensed internally if the response time is less than 15 minutes, otherwise, a short (0.3 meter) cable (and 4th external channel) must be available. The soil temperature sensors must be designed to work for years buried up to 1 meter deep in unsaturated soils. Their cables must be between 3 and 6 meters in length. All sensors and cables must be weather and sun-resistant since they will be deployed outside on a continuous basis. All sensors should have an accuracy of ± 0.5 degrees Celsius (at 20 degrees Celsius) and a range of -30 to +100 degrees Celsius.

Instrument Specifications: Watertight Box

Instructions for constructing a watertight box are provided in the *Automated Soil and Air Temperature monitoring Protocol.*

Instrument Specifications: Desiccant

100 mL of $CaSO_4$ or other dehydrating agent.

Instrument Specifications: Instrument Shelter

The Instrument Shelter described in Air Temperature will be used for this measurement.

Automated Soil Moisture and Temperature Stations – Optional, Middle, Secondary

Instrument Specifications: Automated Soil Moisture and Temperature Station

A soil moisture/temperature station must be attached to a weather station with a data logger attached to a computer, and be capable of logging data at 15-minute intervals. Data entry is simplified if the software for the weather station supports the option to "Export GLOBE Data". Ideally there will be four soil moisture sensors, three temperature sensors for soil, and one optional temperature sensor for air. However, you may use fewer sensors.

The sensors used with the soil moisture/temperature station must meet the following specifications:

Temperature: sensors must be designed to work for years buried up to 1 meter deep in unsaturated soils. Their cables must be between 3 and 6 meters in length. All sensors and cables must be weather and sun-resistant since they will be deployed outside on a continuous basis. All sensors should have an accuracy of ± 0.5 degrees Celsius (at 20 degrees Celsius) and a range of -30 to +100 degrees Celsius.

Soil Moisture: ceramic block sensors that use an electrical resistance method for soil water matric potential measurement. One of the best ceramic block sensors is called a Watermark block and is the one recommended for this measurement.

Land Cover/Biology

Land Cover - All Skill Levels

Instrument Specifications: Landsat Thematic Mapper (TM) Image, MultiSpec software.

The GLOBE Program will provide a TM image to all US schools. MultiSpec software is available for downloading from the Internet.

Species Identification - All Skill Levels

Instrument Specifications: Dichotomous Keys

Dichotomous keys for tree identification are not available from a central supplier; they need to be acquired locally.

Biometry

Layout of the Biology Site - All Skill Levels

Instrument Specifications: Tape Measure

50 m tape, graduated one side, marked in 2 mm or smaller units.

Tree Circumference - All Skill Levels

Instrument Specifications: Tape Measure

The tape measure described in Layout of the Biology Site will be used for this measurement.

Tree Height - All Skill Levels

Instrument Specifications: Tape Measure

The tape measure described in Layout of the Biology Site will be used for this measurement.

Instrument Specifications: Clinometer

The clinometer may be made by students from plans in the GLOBE Teacher's Guide, or may consist of a moveable dial within a metal case and lens viewer. For the moveable dial version, the scale must be graduated from 0-90° in 1° units.

Canopy Cover - All Skill Levels

Instrument Specifications: Densiometer

The densiometer may be made by students according to instructions in the GLOBE Teacher's Guide.

Ground Cover - All Skill Levels

Instrument Specifications: None

Grass Biomass - All Skill Levels

Instrument Specifications: Balance

This balance must have the capacity to weigh 300 grams with an accuracy of +/- 0.1 gram. It can be either mechanical or electronic. It is assumed that a balance is available locally, for example in a high school science laboratory.

Instrument Specifications: Drying Oven (plants)

This oven must be capable of holding samples at 50-70 C for up to two days and must be ventilated to allow moisture to escape. The interior dimensions of the oven must be at least 25 cm x 30 cm x 25 cm. It is assumed that an oven is available locally, for example in a high school science laboratory. The oven should be designed for drying biological samples or food and should not be a conventional cooking oven, which could present a fire hazard in this application.

Earth as a System

Green-Up – All Skill Levels

Instrument Specifications: Dichotomous Keys

Dichotomous keys for tree identification are not available from a central supplier; they need to be acquired locally.

Instrument Specifications: Camera

It is assumed that a camera with color film or digital camera is available locally.

Green-Down – All Skill Levels

Instrument Specifications: Plant Color Guide

A guide made of weather-resistant paper that contains reference color chips based on the Munsell System of Color Notation. The following colors should be displayed: 5G 8/4, 5G 7/4, 5G 6/2, 5G 4/2, 5GY 3/2, 5GY 4/8, 2.5Y 8/6, 2.5Y 8/12, 5YR 7/12, 5GY 7/12, 5GY 6/10, 5GY 5/10, 2.5Y 6/6, 5Y 8/4, 7.5YR 8/4, 7.5YR 6/4, 7.5YR 5/4, 7.5YR 3/4, 5R 3/4, 2.5R 4/2, 2.5R 4/4, 2.5R 4/6, 2.5R 4/8, 2.5R 4/12. Each color chip must be positioned near a cutout that allows color comparison between plant leaves and the reference chips.

Instrument Specifications: Local Plant Identification Guide

Local Plant Identification Guides for tree identification are not available from a central supplier; they need to be acquired locally.

Instrument Specifications: Camera

It is assumed that a camera with color film or digital camera is available locally.

Budburst - All Skill Levels

Instrument Specifications: Local Plant Identification Guide

Local Plant Identification Guides for tree identification are not available from a central supplier; they need to be acquired locally.

GPS

Latitude, Longitude and Elevation of GLOBE Study Sites - All Skill Levels

Instrument Specifications: Global Positioning System (GPS) Receiver

The instrument must be capable of:

- Preferably capable of expressing latitude and longitude in decimal degrees to the nearest 0.0001 degrees (may alternatively express in whole degrees, minutes and decimal minutes to the nearest 0.01 minutes, but this will require conversion before reporting readings to GLOBE) and
- Displaying time on screen in units of UT hours, minutes, and seconds,
- Using the WGS-84 map datum, and
- Displaying elevation in meters.