Introduction

The great value of the learning activities in *Exploring the Connections* is the opportunity they provide for students to integrate their knowledge from different GLOBE investigations and other studies. Students will synthesize a great deal of information and will be able to communicate a whole picture of what they have learned.

The learning activities in this section teach a new way of looking at the Earth – as a living system. Students learn to identify the parts of the system and the processes that connect them at the local, regional, and global scales. As GLOBE students become the experts in their study sites, they can be regarded as valuable sources of information to the scientific community. Since Earth system science is a relatively new discipline, students perceive their study areas in ways that even local scientists may not have.

Summary of Learning Activities

In *Exploring the Connections*, students develop their skills to represent their thinking visually, by diagramming – a powerful tool that can be used in any discipline. They diagram and describe their study site as an Earth system for other GLOBE schools. They begin with concrete, specific observations and move toward abstraction as they work through the activities. Students first observe their study site as a set of components and interactions, and they make lists of those interactions. They annotate a photograph of the study site, writing brief descriptions of the interactions they have observed. Then, based on those annotations, they make a semi-representational diagram of the study site. Students discover real evidence of the interactions among components by studying graphs of GLOBE data from their study site. They then compare their individual diagrams and work together to create a class diagram and study site description that they can share with others. Cooperative learning, discussion, and analysis of diagrams help all students develop their thinking and communication skills.

Each student and each class will develop a somewhat different diagram, and that is expected and encouraged. There are no right or wrong answers in the diagramming process, only exploration, discovery, consideration, expression, and reflection. The teacher's task is to guide the student in making her or his best diagram, one that expresses the student's own ideas most clearly and completely. Diagramming may bring out some students' strengths in both content and skills that may not have been apparent before. In order to help teachers direct the students in the process of diagramming, a guide, *Diagramming Earth as a System,* is included in this introductory section.

Many interactions among Earth system components at the local scale are the same as those at the regional and global scales. Once students understand their study site as a system, they can more easily comprehend ways in which their region and the whole Earth operate as systems.

In activities at the regional scale, students identify and delineate the boundaries of a region for study as an Earth system. Different kinds and sizes of regions lend themselves to this study. Going through the identification process reflects and strengthens students' understanding of what makes a system, as students must justify their choice of regional boundaries. Once they have identified their region, they consider what enters and leaves it, its inputs and outputs, and the implications of changes in those inputs and outputs.

Expanding their scope to the global scale, students identify specific means and pathways – related to wind and water – by which their region is connected to others across the globe. They identify major components of the Earth system at the global scale, trace the pathway of water throughout the system's major components, and make a diagram of the pathway as an example of interconnectedness at the global scale.

Activities Are Organized by Scale

Activities are organized in three parts according to scale: local, regional, and global scales. The titles of the sections reflect these scales as follows: *Local Connections, Regional Connections, and Global Connections.*

Local Connections: How Can We Represent Our Study Site as a System to Other GLOBE Schools?

LC1: *Connecting the Parts of the Study Site*

LC2: *Representing the Study Site in a Diagram*

LC3: *Using Graphs to Show Connections*

LC4: *Diagramming the Study Site for Others*

LC5: *Comparing the Study Site to One in Another Region*

Regional Connections: In What Ways Is Our Region an Open System?

RC1: *Defining Regional Boundaries*

RC2: *Effects of Inputs and Outputs on a Region*

Global Connections: How Can We Describe the Earth as a System?

GC1: *Your Regional to Global Connection*

GC2: *Components of the Earth System Working Together*

Implementation Considerations

Curriculum

Teachers can conduct these learning activities in the context of biology, chemistry, Earth science, human or physical geography, meteorology, or oceanography. Writing and visual skills are integral parts of the activities.

Sequence

The activities have been designed to be done in sequence, and it is strongly recommended that teachers take students through the activities that way, particularly within each section. However, if necessary, each of the activities can stand alone.

Student Groups

Much of the work involved in the activities can be done either individually or in groups. The general pattern in these activities is that students work alone, then in groups, then as a class. If students do their initial work individually, the teacher will have the means of assessing prior knowledge. The teacher may wish to assign individual work periodically to test progress and comprehension.

Student Misconceptions

It has become clear in recent years that it is critical for teachers to discover and deal with student misconceptions about material being covered. If that step is neglected, students will retain their misconceptions and will not absorb the new material. Students' ideas are connected as a web; students will hold on to their previous ideas until they have a complete new set. These learning activities are designed so that initial discussions, student work, and student self-assessments will help to expose misconceptions. Teachers can use those products as a baseline for instruction.

Some specific student misconceptions students have about systems are known. From the American Association for the Advancement of Science, Project 2061, *Benchmarks for Science Literacy*: "Children tend to think of the properties of a system as belonging to individual parts of it rather than as arising from the interaction of its parts. A system property that arises from interaction of parts is therefore a difficult idea." (p. 262). This "difficult idea" is addressed at the very start of these learning activities. In Activity LC1, students list interconnections among the major components of their study site, making predictions about how the characteristics of one component might change if the characteristics of another component were to change. In LC2 and LC4, they develop diagrams of these interconnections. In RC2, students again make predictions about how components of a system might change if another component were to change, this time at the regional scale.

From *Benchmarks for Science Literacy*: "Also children often think of a system only as something that is made and therefore as obviously defined. This notion contrasts with the scientific view of systems as being defined with particular purposes in mind….(p. 262). Help in addressing this misconception can be found in Activity RC2, in which students identify and define their own region for study as a system.

Special Note

Scientists use the terms "atmosphere" for air, "hydrosphere" for bodies of water, "pedosphere" for soil, and "biosphere" for all living things. Pedosphere in particular may be an unfamiliar term. These terms are introduced in the second activity of the local scale section; teachers may wish to introduce them sooner or later than that.

Alignments to other GLOBE Learning Activities

Alignments to Local Connections Activities

All the activities listed below reinforce the concept that components of the Earth system change each other through their interactions. This concept, central to the activities in this section is key to an understanding of systems.

Hydrology Investigation: *Water Walk*

This activity helps students become familiar with the Earth's bodies of water and the differences in characteristics of water. Students learn that the characteristics of bodies of water are closely related to the characteristics of the surrounding land.

Hydrology Investigation: *The pH Game*

Students learn that the level of pH influences the vegetation and wildlife in a site, and is itself influenced by different factors in the rocks and soil, human activities, the atmosphere (precipitation), and the amount of water in the landscape.

Soil Investigation: *Just Passing Through*

Students develop an understanding of some of the relationships between water and soils of different types.

Earth as a System Investigation: Seasons and Phenology: *What Can We Learn by Sharing Local Seasonal Markers with Other Schools Around the World?*

Teachers and students share seasonal marker observations, which are the various changes that mark transition points in the annual cycles of seasons. (Examples are the first snowfall, the beginning of monsoon rains, and the summer solstice.) Students compare GLOBE data with the observations they study. The activity promotes collaborations among GLOBE classes and helps teachers and students learn how to work with the GLOBE data system and GLOBEMail email. It also helps teachers and students learn how the protocols are interconnected.

All of the following activities strengthen the student's ability to compare the characteristics of Earth system study sites in different parts of the globe.

Soil Investigation: *Soil and My Backyard*

Student explore soil and soil properties, discovering the variability of soils and how they are formed.

Soil Investigation: *A Field View of Soil - Digging Around*

Students discover that variations in the landscape, such as in slope, shade, and plants, can affect soil properties, and that every soil is unique every place on Earth.

Earth as a System Investigation: Seasons and Phenology: *What Are Some Factors That Affect Seasonal Patterns?*

Students use GLOBE data and graphing tools to compare the influence of latitude, elevation, and geography on seasonal patterns.

Earth as a System Investigation Seasons and Phenology: *How Do Seasonal Temperature Patterns Vary Among Different Regions of the World?*

Students use GLOBE visualizations to display student data on maps and explore seasonal changes in regional and global temperature patterns across the Earth. They learn that temperatures vary from one location to another around the world and that local latitude, elevation and geography affect seasonal temperature patterns.

Alignments to Regional Connections Activities

Hydrology Investigation: *Model a Catchment Basin*

Watersheds provide useful boundaries for study of the Earth system, and this activity introduces students to their watershed and how it works. It also builds their skills of interpreting maps and images, as these are used to help construct a three-dimensional model of a watershed.

Alignments to Global Connections Activities

An Activity Guide accompanies the GLOBE Earth System Poster, *Exploring the Connections in a Typical Year.* The Guide describes how to help students explore patterns in the data displayed on the poster. Students find annual changes, relationships among types of data, and global patterns, and they make connections with GLOBE data.

Student Learning Goals and Alignment with National Standards, AAAS Project 2061 Benchmarks, and TIMMS

Student Learning Goals

Exploring the Connections accomplishes several goals at once. It teaches essential concepts and skills according to national standards; it introduces students to the new discipline of Earth system science; and it provides tools for students to construct an integrated conceptual framework for all their work with GLOBE. Just as Earth system scientists investigate relationships among several components of the Earth system and the scientific disciplines such as atmospheric science, oceanography, geology, and biology, devoted to them, so students investigate relationships among all GLOBE investigations. No one investigation is emphasized over any other. However, the design of this set of learning activities does allow students to discover and express their particular strengths in any given content area. Students also expand their abilities to demonstrate what they know in a variety of ways: verbally, visually, and in written form.

The objective for students in the Local Connections activities is to communicate to others the uniqueness of their study site as an Earth system. Teachers and students may also wish to describe their study site interactions to other audiences, such as policy makers.

The goal of Earth system science is to better understand the components and processes that shape the environment of the Earth, so that we can learn to understand our environment and make informed decisions to manage it. After going through these activities, students will have increased their understanding and will have developed their ability to make informed decisions about their environment. For example, they can review and analyze GLOBE measurements they and others have taken over time and consider whether or not any long-term changes are indicated. They can ponder the effects of those changes might be and how they should respond. Earth system science is a new scientific discipline, and as students teach others this new way of looking at the Earth, and they will learn it more thoroughly themselves.

Alignment with National Standards

The following table indicates the particular standards as described in the National Science Education Standards, addressed by each of the *Exploring the Connections Learning Activities*.

Student Learning Assessment

Assessment rubrics are included at the end of each learning activity. These can be used by the teacher to determine the extent to which students have understood the concepts and mastered the skills that were examined or used in the activity and to identify where there is still confusion. The assessments can also be used by the students to help them reinforce what they have learned and to identify areas of weakness.

Integrated problems are included in the appendix of this chapter that are designed to help the teacher assess if students can take the content material and skills they have learned through conducting the *Exploring the Connections Learning Activities* and apply them to other situations. Assessments have been developed for various levels of students.

Coverage for Exploring the Connections

National Science Education Standards	Learning Activity								
	LC1	LC2	LC3	LC4	LC5	RC1	RC2	GC1	GC2
Earth And Space Sciences									
Changes in Earth and Sky (K-4)									
Weather changes from day to day and over the seasons	■	■	■	■	■	■	■	■	■
Energy in the Earth System (9-12)									
The sun is the major source of energy at Earth's surface	■	■	■	■	■	■	■	■	■
Solar insolation drives atmospheric and ocean circulation	■	■	■	■	■	■	■	■	■
Geochemical Cycles (9-12)									
Each element moves among different reservoirs (biosphere, lithosphere, atmosphere, hydrosphere)	■	■	■	■	■	■	■	■	■
Physical Sciences									
Energy: Transfer and Conservation (5-8)									
Heat energy is transferred by conduction, convection and radiation	■	■	■	■	■	■	■	■	■
Heat moves from warmer to colder objects	■	■	■	■	■	■	■	■	■
Sun is a major source of energy for changes on the Earth's surface	■	■	■	■	■	■	■	■	■
Energy is conserved	■	■	■	■	■	■	■	■	■
Chemical Reactions (9-12)									
Chemical reactions take place in every part of the environment	■	■	■	■	■	■	■	■	■

Coverage for Exploring the Connections (continued)

National Science Education Standards	Learning Activity								
	LC1	LC2	LC3	LC4	LC5	RC1	RC2	GC1	GC2
Life Sciences									
The Characteristics of Organisms (K-4)									
Organisms can only survive in environments where their needs are met	■	■	■	■	■	■	■		■
Earth has many different environments that support different combinations of organisms	■	■	■	■	■	■	■		■
Organisms and their Environments (K-4)									
Organisms' functions relate to their environment	■	■	■	■	■	■	■		■
Organisms change the environment in which they live	■	■	■	■	■	■	■		■
Humans can change natural environments	■	■	■	■	■	■	■		■
Life Cycles of Organisms (K-4)									
Plants and animals have life cycles	■	■	■	■	■	■	■		■
Structure and Function of Living Systems (5-8)									
Ecosystems demonstrate the complementary nature of structure and function	■	■	■	■	■	■	■		■
Regulation and Behavior (5-9 & 9-12)									
All organisms must be able to obtain and use resources while living in a constantly changing environment	■	■	■	■	■	■	■		■
Populations and Ecosystems (5-8)									
All populations living together and the physical factors with which they interact constitute an ecosystem	■	■	■	■	■	■	■		■
Populations of organisms can be categorized by the function they serve in the ecosystem	■	■	■	■	■	■	■		■
Sunlight is the major source of energy for ecosystems	■	■	■	■	■	■	■		■
The number of animals, plants and microorganisms an ecosystem can support depends on the available resources	■	■	■	■	■	■	■		■
The Interdependence of Organisms (9-12)									
Atoms and molecules cycle among the living and non living components of the ecosystem	■	■	■	■	■	■	■		■
Energy flows through ecosystems in one direction (photosynthesis-herbivores-carnivores-decomposers)	■	■	■	■	■	■	■		■
Organisms both cooperate and compete in ecosystems	■	■	■	■	■	■	■		■
The population of an ecosystem is limited by its resources	■	■	■	■	■	■	■		■
Humans can change ecosystem balance	■	■	■	■	■	■	■		■
Matter, Energy, and Organization in Living Systems (9-12)									
Energy for life derives mainly from the sun	■	■	■	■	■	■	■		■
Living systems require a continuous input of energy to maintain their chemical and physical organizations	■	■	■	■	■	■	■		■
The Behavior of Organisms (9-12)									
The interaction of organisms in an ecosystem have evolved together over time	■	■	■	■	■	■	■		■

Diagramming Earth as a System

Diagramming is a powerful way for your students to better understand Earth as a system. Diagrams enable students to embody their understandings in an illustration and to evolve their thinking as their diagrams encompass deeper understandings of the components and connections of Earth as a system. Further, diagrams provide you, the teacher, with a window on student understandings (and misunderstandings) as evidenced in their diagrams.

Using this process, students progress from literal drawings to more symbolic and abstract representations. This progression is a sign of learning, which results from students working over a few weeks to refine their diagrams as personal expressions and from students digesting the science concepts related to components and interconnections of Earth as a system.

Students draw their diagrams in the context of one or more visits to their GLOBE study sites. They base their drawings on their analysis of data from their own site and other sites throughout the world. As in the examples which follow, students should label their diagrams to designate the Earth system components and interconnections. Initially your students (especially elementary school students) might simply label components (such as tree, river, cloud). Over time, students can add labels showing some of the connections (such as "leaves fall and decompose, become part of the soil"). At the most advanced level of understanding, students use arrows, labels, and comments to illustrate systems (such as the full water cycle). Please refer to the description of Earth as a system at the beginning of this chapter.

As you work with your students, it may be helpful to consider diagramming in four phases, as described and illustrated on the pages that follow. In general, your students should progress from one phase to the next as their learning and understanding increase. Of course, individual student diagrams will differ, and older students may progress to abstract levels more quickly.

Discuss the literal illustration (Figure EA-EX-2) with your students. Ask them how they might simplify the illustration further in order to focus on the components, connections, and systems (Figure EA-EX-3). For example, instead of drawing many trees, students should draw just one tree. This forces students to decide which are the most important components, connections, and systems at their study site, that may be different at another study site. Although you might expect that more advanced understanding would lead to more complexity, in reality scientists often search for the simple essence of a system in order to understand it better.

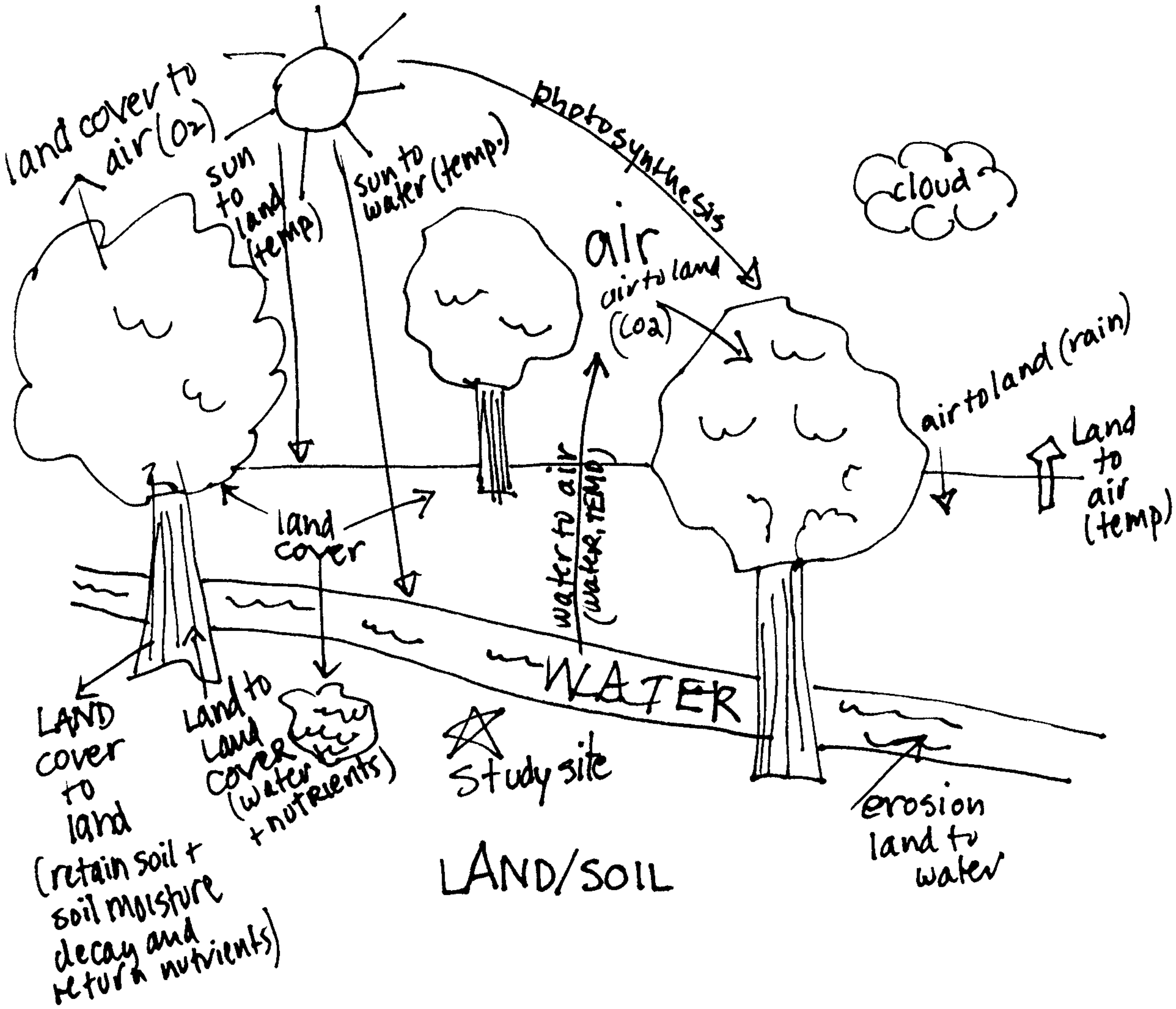
At the most advanced level, students move to a more abstract representation of the system. The example here (Figure EA-EX-4) reduces the diagram to the four major components of the Earth system (atmosphere, hydrosphere, pedosphere, and biosphere), with arrows showing the connections. This most simplified representation enables students to see the top-level view of Earth as a system. In reality, these broad domains and arrows imply underlying details. Such abstract representations embody a deeper understanding of the internal complexities of the full system.

The diagrams your students create serve multiple purposes. Most importantly, they help your students learn and develop their understanding of Earth as a system. Also, they provide you, as the teacher, with a powerful and convenient assessment tool, to see (literally) what your students are learning. In addition, diagrams are a vehicle of communication – they help your students (and scientists) share their own perceptions and models of Earth as a system. As such, each type of diagram serves its own purpose. There is no single correct diagram. It depends on what one wants to communicate. A literal diagram conveys the details of the particular site. An abstract diagram with arrows of different widths conveys relative quantities. And a highly simplified diagram with circles for the four major components conveys the top-level understanding of the system. You, your students, and scientists choose among the various types depending on what aspect of Earth as a system is to be communicated and focused on.

Figure EA-EX-1: Phase One – Photograph with Labels

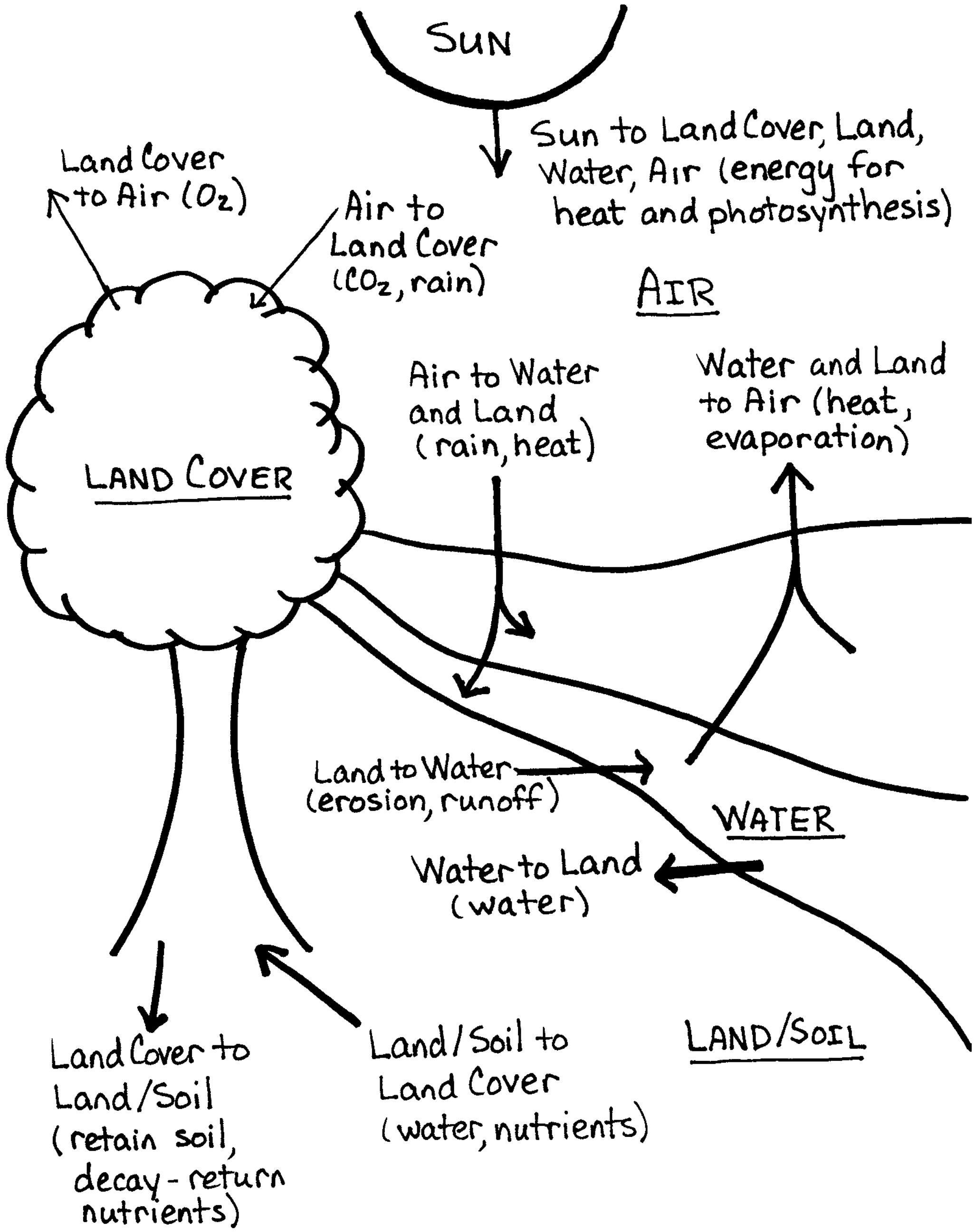
In this example (Figure EA-EX-1), students took a photograph of the study site (a stream flowing down the side of mountain), and then added labels with some descriptive comments. This approach is an easy way to get started, as the photographs are easy to use (requiring no drawing), the labeling can be done in the classroom, a set of photographs can show different aspects of the site, and the photos include many details that can lead to further discussion in the classroom. (You may want to take one or more photos to a local copy shop for overhead transparencies to support classroom discussions.)

Figure EA-EX-2: Phase Two – Literal Illustration



In this phase (Figure EA-EX-2), students move from the photo to illustration. Ideally, the illustration is done at the study site, while the students observe the site and pay close attention to what they see. By drawing in the field context, students are encouraged to notice more and more about their study site. When students add labels, including both the components (river, soil) and the interconnections (water from the river goes into the soil and then into the roots of the plants), they are summarizing what they see as important. If students put the labels on a clear transparency overlay, they can evolve their labels over time.

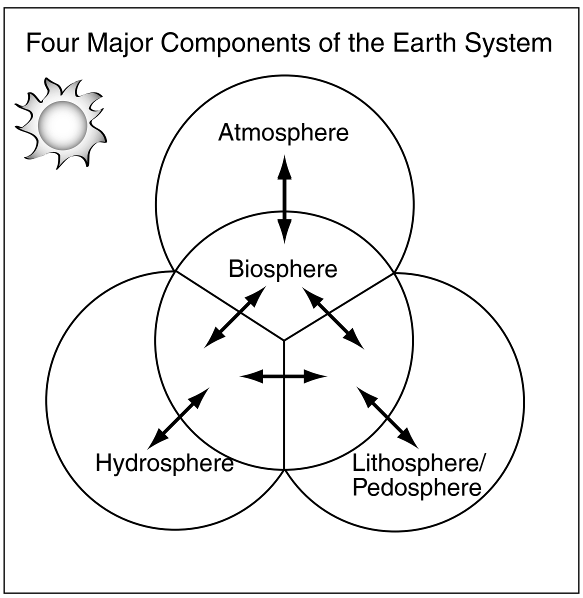
Figure EA-EX-3: Phase Three – Simplified Illustration



Drawing Conclusions from Graphed Data

In activity LC3, *Using Graphs to Show Connections*, we suggest using graphs to understand the connections between air temperature on one hand and either water temperature or soil temperature on the other. But drawing conclusions from graphed data is not always easy. So here we provide some suggestions on using graphs effectively to understand single variables and the relationships among variables.

Figure EA-EX-4: Phase Four – Abstract



Getting Oriented to the GLOBE Graphing Conventions

First, we should get oriented as to how the GLOBE graphs organize and present information. In this analysis we use only the line graphs produced by the GLOBE Web site. All these graphs have the same format. Before beginning analysis with the graphs, we should understand these format conventions.

Look at Figure EA-EX-5 and notice:

- The GLOBE icon at the upper left identifies this as a GLOBE graph.
- The name of the school that submitted the data appears at the top of the graph.
- The name of the GLOBE measurement being graphed appears at the bottom of the graph, e.g. Maximum Air Temperature.
- Left of the name of the measurement is the icon used to mark the data on the graph, e.g. a triangle.
- To the right of the measurement name is the unit of measurement, e.g. ˚C(elsius).
- The beginning date of the graph (month/ day/year) appears at the bottom left, e.g. 1/1/1998.
- The graph has dotted guidelines to help you read the data points in relation to the x- and y-axis scales.
- The GLOBE graphing program connects the observations with a line to make it easier to follow the trend of the data.

The graph has two axes. The x-axis (horizontal) has *time* increasing to the right. The scale on this axis increases by days or months, over one or more years. The y-axis (vertical) shows the range of values that the variable being graphed goes through over the time it was measured.

Figure EA-EX-5 shows the maximum air temperature at Reynolds Jr. Sr. High School over the course of a year. What information about the temperature at Reynolds Jr. Sr. High School can we get from this graph?

1. What time period does this graph cover? In this case it is one year, beginning with 1/1/98. (Count 3 months after 10/1 to find the end of the year.)
2. Next look at the frequency of observations. In this case it is about once a day, which indicates that the students took the temperature every day or so.
3. Then ask, "Do the data vary smoothly from one point to the next or do the points jump around?" In the case of Reynolds Jr. Sr. High School, the maximum daily temperature jumps up and down a lot. But how much?
4. We can estimate the daily maximum temperature variation by sketching a line to connect the highest points and another line to connect the lowest points. The difference between the "high line" and the "low line" shows the range of the daily maximum temperature change. This range may vary during the year. If it does, the high and low lines will move closer together or farther apart.
5. Next we want to consider how the daily maximum temperature *changes* over the entire period of time shown in the graph. What are the lowest and highest daily maximum temperatures and when do they occur? Here are three ways to find out:
   a. Just inspect the graph visually.
   b. Create a monthly average of the daily maximum temperature values and plot the monthly averages on the graph. Then inspect the pattern of averages.
   c. Take the maximum and minimum daily maximum temperature curves you drew in step 4 and average the values at different times of year. From this, estimate the maximum and minimum daily maximum temperature.

Through the use of the graph of the daily maximum temperatures at Reynolds Jr. Sr. High School in 1998 we have determined:

- the variation in the daily maximum temperatures and
- the seasonal range of the daily maximum temperatures.

But, this is based on information for only one year, 1998. Would the pattern hold up in other years?

We can also use line graphs of this kind to examine how two variables are related. For this, we need a graph with two variables, which is discussed in the next section.

Exploring Relationships Among Two Variables Using a Graph

One way to explore the relationship among two variables is to plot those variables on the same graph. But when reading such a graph we need to consider whether the variables are of the same kind or not. (By “same kind” we mean that they measure the same quantity in the same units. Air temperature and water temperature are the “same kind” of variable because they both measure temperature in ˚C. Soil pH and water pH are the “same kind” because they both measure acidity in pH units.)

Two Variables of the Same Kind

In Figure EA-EX-6, both sets of data are *temperatures* and both are measured in the *same units, ˚C*. Therefore, both the right and the left y-axes are scales of temperature in ˚C. Since the scales are the same, there is no problem comparing the two variables.

Let’s look at how the two temperatures (air and water) change over a long time (a year) and over a short time (a week or two).

Over the course of the year we see in the surface water temperatures the familiar seasonal cycle that we saw in the daily maximum air temperatures, shown also in Figure EA-EX-5. However, there are some differences.

1. The first difference is that the water temperature does not “vary” as much as the air temperature. You should be careful not to over-interpret this aspect of the graph. Air temperatures are measured every day and so they may appear to jump around more than water temperatures that are measured only once a week. You cannot tell how much water temperatures may have varied between observations.

   There also seems to be a relationship on shorter time scales between the surface water temperature and the daily maximum air temperature. Look, for example, at mid-March. During that time the daily maximum air temperatures are relatively low compared to the general trend of the air temperatures during the spring. At the same time the weekly surface water temperatures are also relatively low compared to the general trend of the temperatures during the spring. This particular example shows an effect which lasts a few weeks. If you now look more closely at the data through the year you will see that at times of relatively low or high surface water temperatures there are also relatively low or high daily maximum air temperatures.

2. There is another difference between the surface water temperature and the daily maximum surface air temperature when viewed through the year. The range of the water temperature is smaller than the range of the air temperature. Look carefully at the temperatures during the summer. The daily maximum air temperature is higher than the surface water temperature most of the summer. Now look carefully at the temperatures during the winter. The daily maximum air temperature and the surface water temperature are generally within the same range during the winter. As a result, the range of temperatures of the water through the year is smaller than the range of air temperatures.

Two Variables of Different Kinds

Figure EA-EX-7 shows two variables that are of different kinds: temperature shown in ˚C and dissolved oxygen (DO) in mg/L. Therefore, the y-axis on the right side is different from that on the left side of the graph. Each y-axis has a data scale that covers the range of variation of the variable that is being plotted on the graph using that scale. On this graph the range of the surface water temperature is between -1˚ C and 25˚ C, the minimum and maximum on the y-axis scale. The range of the dissolved oxygen data, as seen

Figure EA-EX-5: Daily Maximum Air Temperature at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA for

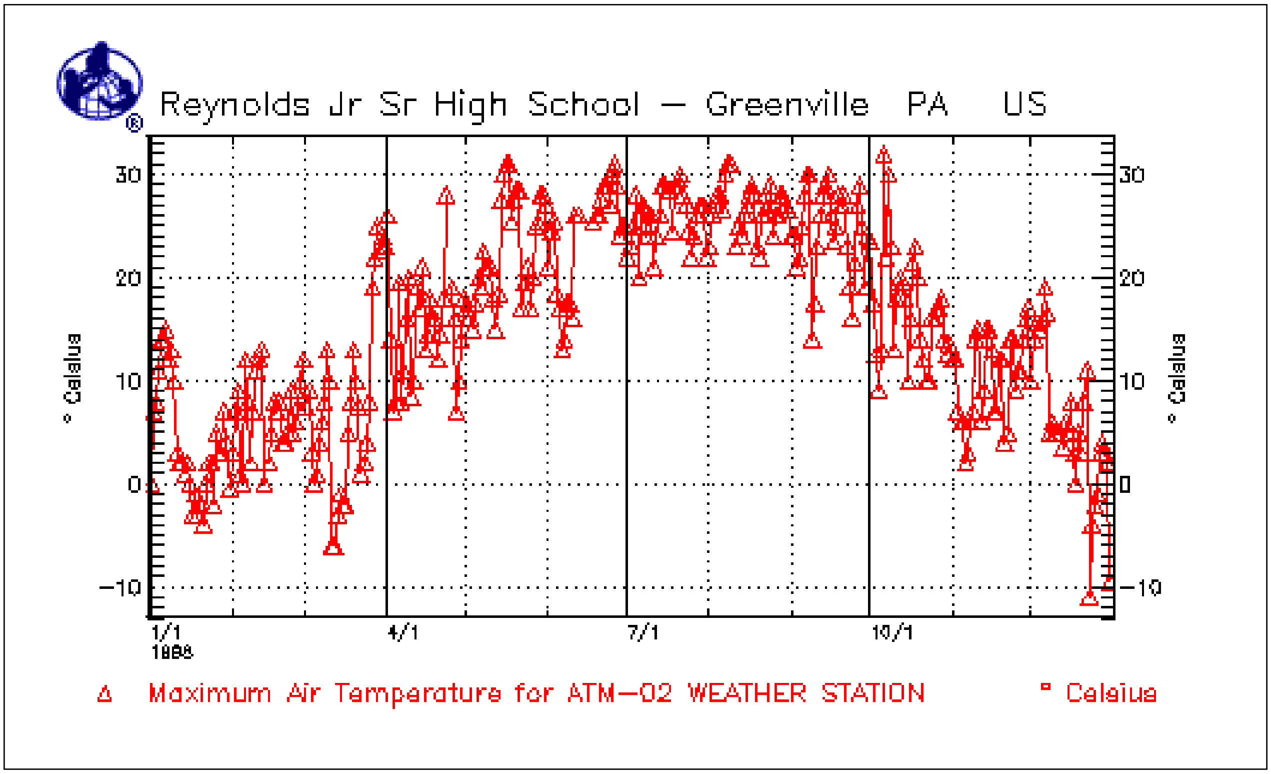


Figure EA-EX-6: Surface Water Temperature and Daily Maximum Air Temperature at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA for 1998

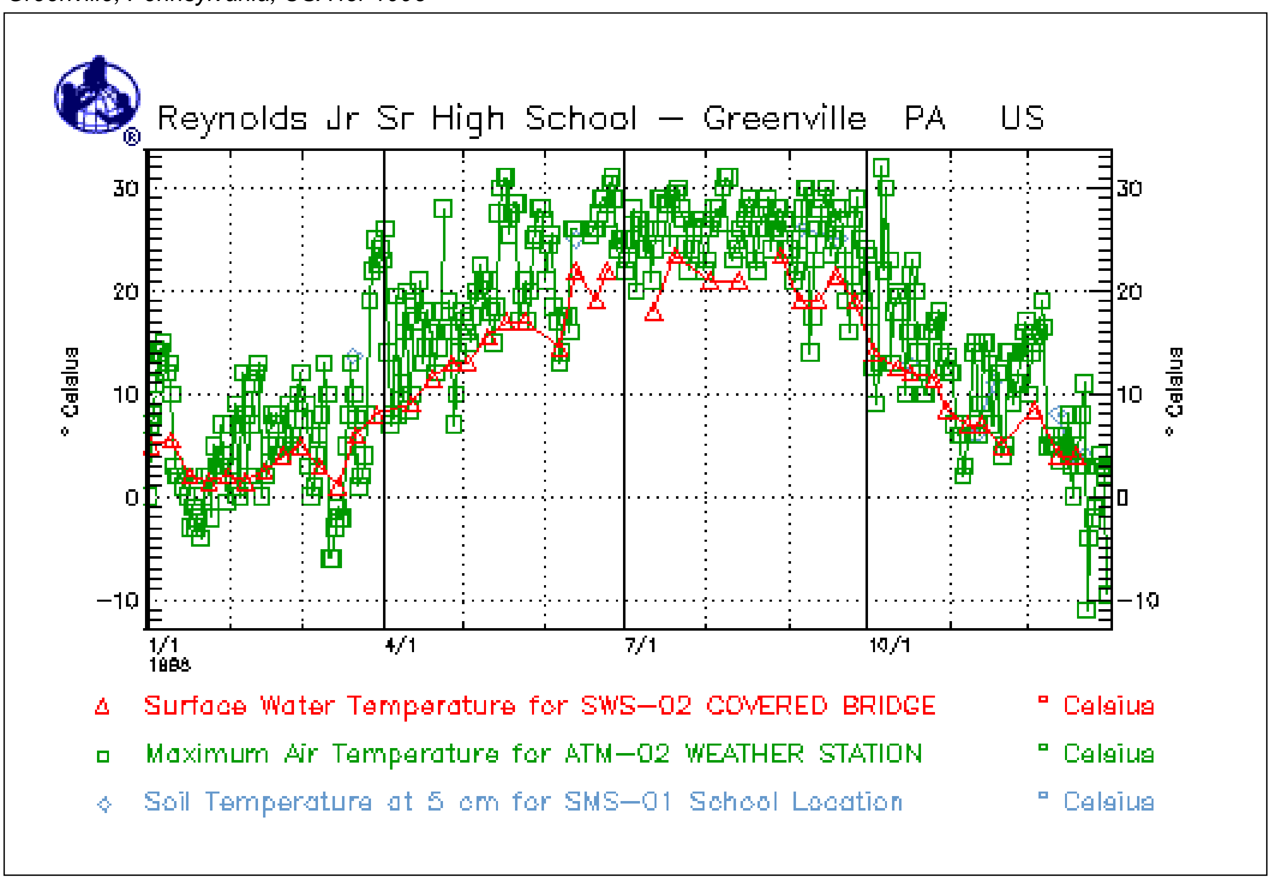


Figure EA-EX-7: Surface Water Temperature and Surface Water Dissolved Oxygen at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA for 1998

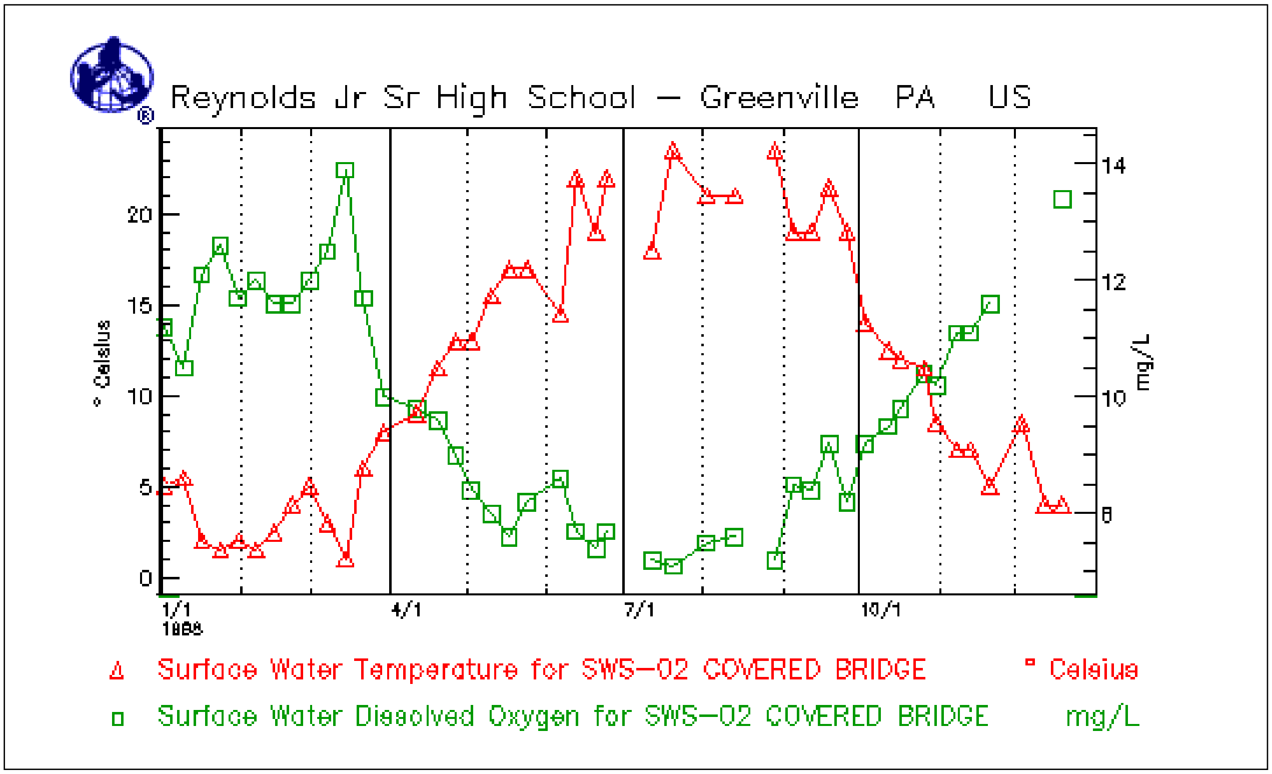
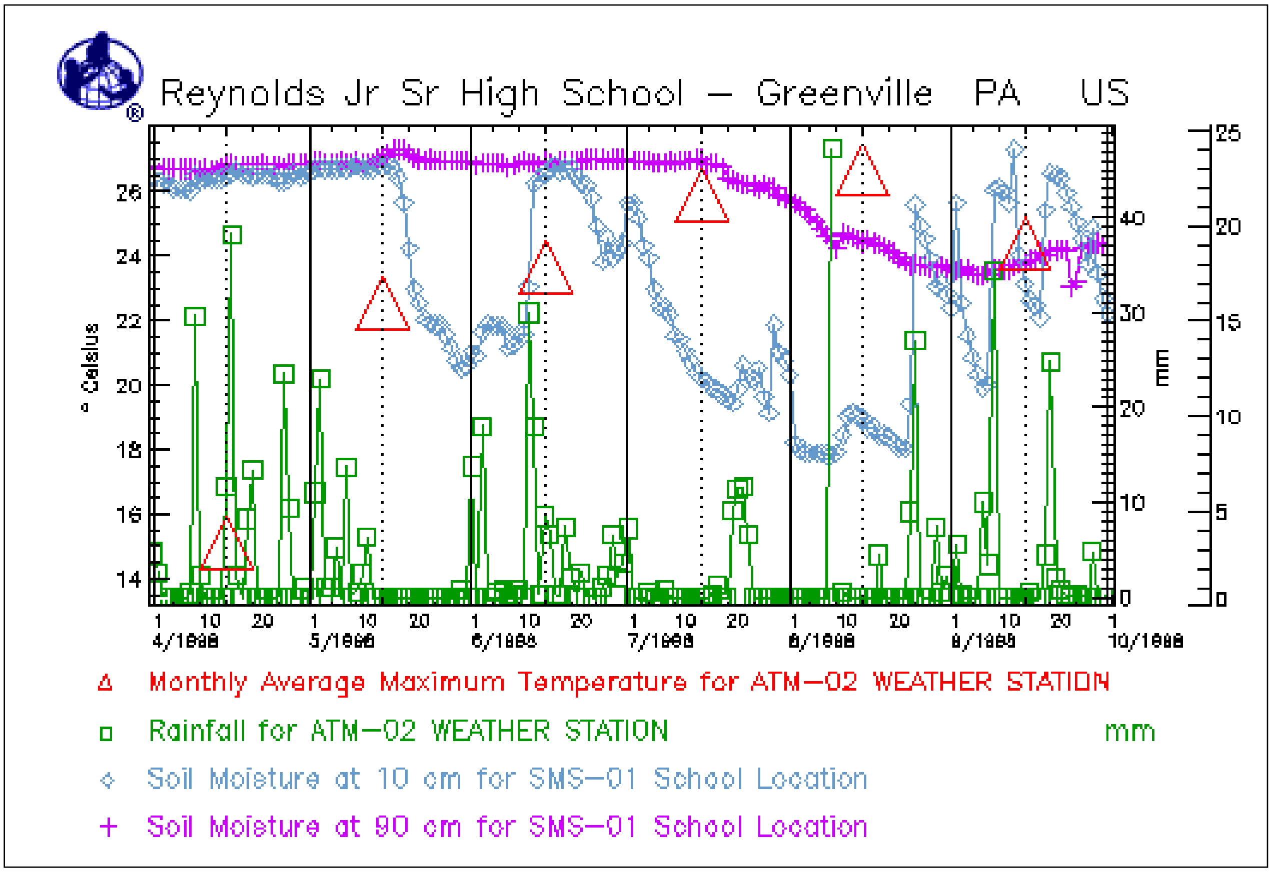


Figure EA-EX-8: Monthly Averages Maximum Temperature, Daily Precipitation, and Soil Moisture at 10 cm and 90 cm at Reynolds Jr. Sr. High School in Greenville, Pennsylvania, USA from April 1, 1998 to October 1, 1998.



on the right hand y-axis scale, is between 6.5 and 14.5 mg/L. In examining this graph, you can not compare the magnitudes or sizes of the changes in water temperature and DO because they are measured in different units. However, you *can* compare the *directions* of the changes in these variables and the *timing* of when changes occur.

In the example shown in EA-EX-7 we can look at two types of change: those that occur over the year and those that occur over shorter periods of time, on the order of a week.

Change over the year: We can see the seasonal cycle in the surface water temperatures as we noted earlier. We also can see a seasonal cycle in the dissolved oxygen, but it is dramatically different. Figure EA-EX-7 shows that the relationship between these two variables is *inverse*. Whenever the surface water temperatures are high, the dissolved oxygen content is low. Conversely, whenever the surface water temperature is low the dissolved oxygen content is high.

Short-term changes on the order of a week: In looking at shorter-term changes, we must note whether the data we are comparing were taken at the same time and location and whether data were taken at the same interval (i.e. once a day, once a week, once a month…). We can best compare data that are taken at the same time and location. In EA-EX-7 the data seem to have been taken at the same time, at about one week intervals. The data were taken at the same location, as noted in the key for the figure. In this case we also know that the Hydrology protocol calls for the measurement of these two quantities at the hydrology study site at one week intervals.

Note: Sometimes it is not possible to have data from the same time and location. In that case the graphs may show data at different intervals and possibly taken from different locations. Before analyzing the data you need to determine whether the locations and times are too far apart to make a useful comparison of the data, or whether some analysis can be done. If you determine that you can go ahead with the analysis, you must keep the differences in the data in mind when drawing any conclusions.

Now we can compare the surface water temperature and the surface water dissolved oxygen measurements on the shorter time scale. On this scale, too, it seems that if surface water temperature decreases, the surface water DO increases. This is seen most clearly in early to mid-March, where there is a large decrease in the surface water temperature (from about 5° C to 1° C), at the same time as there is a large increase in the surface water DO (from 12.1 to 13.8 mg/L). Similar short-term variations can be seen in early June and mid-November. However, there are also times when this relationship is not as clear, such as in July and mid-September.

Having detected this interesting inverse relationship we should now ask: "Is the evidence convincing enough to indicate a strong relationship between surface water temperature and surface water dissolved oxygen?" If so, then we have somehow to explain the data that are *inconsistent* with this conclusion. (One possible explanation is that there are other processes at work that might affect the surface water dissolved oxygen.) If we think that there is not enough evidence to draw a conclusion, then we might want to determine what we would need to do in order to draw a conclusion. One possibility is to conduct a laboratory experiment in which we can control other variables and then measure dissolved oxygen and temperature in water as we change the temperature. We will then get another graph of temperature and dissolved oxygen and will have to determine if the data show a relationship and if there are any inconsistencies. If there are inconsistencies with the conclusions we draw, they will have to be explained in a scientific manner.

Reading a Graph with Multiple Variables

Looking at a graph with multiple variables, Figure EA-EX-8, is similar to looking at a graph with two variables, just more complex. First, we follow steps 1-5 in the section "Graph with One Variable" for each of the variables in this new graph. Then we look at the different scales involved in the graph. Instead of looking at two scales on the y-axis, as we did when considering two variables, we now have to consider scales for each of the variables represented and match the correct scale with the correct variable. Sometimes one scale may serve for more than one variable.

In Figure EA-EX-8 some compromises were made to make the data more readable. First, the temperature data are shown as a monthly average, while the rainfall and soil moisture data are shown as daily values. While this does eliminate the possibility of comparing daily variations in temperature to daily changes in precipitation and soil moisture, it makes the graph easier to read. Consider if the daily maximum temperature data shown in Figure EA-EX-5 were put in the graph in Figure EA-EX-8. The overlapping of the data would make it difficult to read. Therefore, the monthly average maximum air temperature has been plotted.

The second compromise is that the x-axis no longer covers a whole year. Again, this change is to facilitate reading the graph. The period of time shown is April to October 1998. This is the time of interest, when the soil moisture is falling and is more responsive to changes in precipitation. During the rest of the year, the soil moisture at Reynolds Jr. Sr. High School is pretty constant at about 27% (this was determined by first looking at graphs of these variables that covered all of 1998). The graph was changed to cover this shorter period to make the graph easier to read and therefore facilitate analysis and the eventual drawing of conclusions.

There are many interesting relationships to examine on this graph. One is the relation between soil moisture at 10 cm and precipitation events. If you look closely at the graph, you can see that once the soil moisture drops below its winter maximum value, every time there is precipitation the soil moisture at 10 cm increases temporarily. In addition, you can see that the precipitation event occurs before or right at the beginning of the increase in soil moisture at 10 cm. This would indicate that the precipitation event occurs first and provides the water necessary to increase the soil moisture. Once the rain stops, the soil moisture at 10 cm begins to decrease.

In *Learning Activity LC3* in this chapter, students can work with this graph and others that they create at the GLOBE Web site to further investigate the relationships among the different components of the Earth system at their study site and at the study sites of other GLOBE schools.