Soil Temperature Protocol

Purpose
To measure near-surface soil temperatures

Overview
Students measure soil temperatures at 5 cm and 10 cm depths using a soil thermometer.

Student Outcomes
Students will be able to perform a soil thermometer calibration, carry out soil temperature measurements accurately and precisely and record and report soil temperature data. Students will be able to relate soil temperature measurements to the physical and chemical properties of soil.

Science Concepts

Earth and Space Sciences

- Soils have properties of color, texture, structure, consistence, density, pH, fertility; they support the growth of many types of plants.
- The surface of Earth changes.
- Water circulates through soil changing the properties of both the soil and the water.

Physical Sciences

- Objects have observable properties.
- Energy is conserved.
- Heat moves from warmer to colder objects.

Scientific Inquiry Abilities

- Identify answerable questions.
- Design and conduct an investigation.
- Use appropriate tools and techniques including mathematics to gather, analyze, and interpret data.
- Develop descriptions and explanations, predictions and models using evidence.
- Communicate procedures and explanations.

Time
10-15 minutes

Level
All

Frequency
Soil temperature measurements can be taken daily or weekly. Seasonal measurements are taken every three months at 2-3 hour intervals for two consecutive days (*diurnal cycle* measurement).

Materials and Tools
- Dial or digital soil thermometer
- 12 cm nail or spike
- 500-mL beaker
- Hammer
- Spacers (for limiting soil thermometer insertion depth)
- Calibration thermometer
- Wrench for adjusting dial soil thermometer
- Watch
- GLOBE Science Log(s)
- *Soil Temperature Data Sheet*

Preparation
Make spacers so that soil thermometer is inserted to the proper depths.

Prerequisites
None

Soil Temperature Protocol – Introduction

Soil temperature is an easy measurement to take and the data collected are useful to scientists and students. The temperature of the soil affects climate, plant growth, the timing of budburst or leaf fall, the rate of decomposition of organic wastes and other chemical, physical, and biological processes that take place in the soil.

The temperature of soil is directly linked to the temperature of the atmosphere because soil is an insulator for heat flowing between the solid earth and the atmosphere. For example, on a sunny day, soil will absorb energy from the sun and its temperature will rise. At night, the soil will release the heat to the air having a direct and observable affect on air temperature.

Soil temperatures can be relatively cool in the summer or relatively warm in the winter. Soil temperatures can range from 50˚ C for near-surface summer desert soils (warmer than the maximum air temperature) to values below freezing in the winter.

Soil temperature has a significant effect on the budding and growth rates of plants. For, example, as soil temperatures increase, chemical reactions speed up and cause seeds to sprout. Farmers use soil temperature data to predict when to plant crops.

Soil temperature also determines the life cycles of small creatures that live in the soil. For example, hibernating animals and insects emerge from the ground according to soil temperature.

Soil temperature also determines whether water in the soil will be in a liquid, gaseous, or frozen state. The amount and state of water in the soil affects the characteristics of each soil horizon in a soil profile. For example, in cold soils there is less decomposition of organic matter because the microorganisms function at a slower rate, resulting in a dark colored soil. Intense heating in tropical climates causes increased weathering and the production of iron oxides, giving these soils a reddish color. In Northern and Southern latitudes and at high elevations, some soil layers are permanently frozen and are known as *permafrost*. Melting permafrost alters soil structure and horizon thickness, and causes damage to plant roots. At mid-latitudes and mid-elevations, near-surface soil freezes in the winter. Soil moisture evaporates from soil surfaces. The amount of evaporation depends on the vapor pressure of the water in the soil, and this depends on temperature. Once the moisture evaporates, it adds to the humidity of the air, affecting the climate.

Understanding how soils heat and cool helps to predict the length of growing seasons for plants, the types of plants and animals that can live in the soil, and the input of humidity into the atmosphere. The amount of moisture in the soil affects the rate at which the soil heats and cools. Wet soils heat slower than dry soils because the water in the pore spaces between the soil particles absorbs more heat than air.

Soil temperature data can be used to make predictions about how the ecosystem will be affected by warming or cooling global temperatures. Scientists use soil temperature data in their research on topics varying from pest control to climate change. By collecting soil temperature data, GLOBE students make a significant contribution to the understanding of our environment.

Teacher Support

Preparation

Before students collect data and once every three months thereafter, have students calibrate the soil thermometer following the *Calibrating the Soil Thermometer Lab Guide*. This will ensure that the students' measurements are accurate.

To ensure that students take soil temperature measurements at the correct depths, have them use spacers when they insert the thermometer into the ground. These spacers are easily made according to the following procedures. See Figure SO-TE-1.

5 cm Measurement

1. Measure 7 cm up from the tip of the soil thermometer and mark this spot. (Note that the location of the temperature sensor is typically 2 cm above the tip of the thermometer.)
2. Measure the distance from the base of the soil thermometer dial to the 7 cm mark.
3. Make a spacer by cutting a piece of plastic tubing or wood to this length. (If using wood, drill a hole through the center of the block).
4. Insert the soil thermometer through the spacer. 7 cm of the thermometer should be sticking out of the bottom of the spacer.
5. Label this spacer *5 cm Measurement*.

10 cm Measurement

1. Measure 12 cm up from the tip of the soil thermometer and mark this spot.
2. Measure the distance from the base of the soil thermometer dial to the 12 cm mark.
3. Make a spacer by cutting a piece of plastic tubing or wood to this length. (If using wood, drill a hole through the center of the block).
4. Insert the soil thermometer through the spacer. 12 cm of the thermometer should be sticking out of the bottom of the spacer.
5. Label this spacer *10 cm Measurement*.

Alternatively, students can mark their thermometers so they will be inserted to the proper depth in the soil. Thermometers can be marked with a permanent marker. The thermometer should be marked 7 cm from the tip to get a 5 cm measurement and 12 cm from the tip to get a 10 cm measurement.

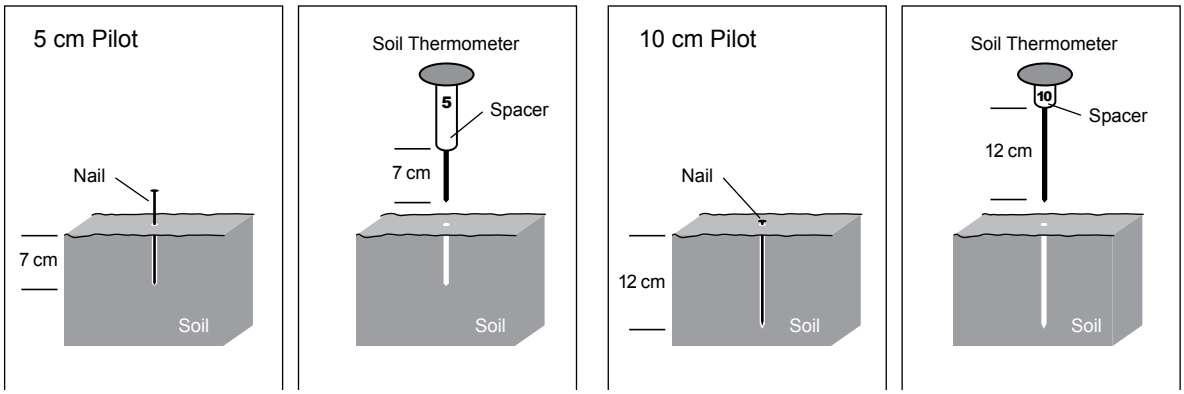
Site Selection

Soil temperature data are collected in the vicinity of the Atmosphere Study Site or the Soil Moisture Study Site.

Managing Materials

The soil temperature measurement requires inexpensive equipment. Consider buying three soil thermometers. Since the data are collected in triplicate, having three thermometers reduces the data collection time. This may allow collection of data daily

Figure SO-TE-1: Making Spacers for Your Soil Thermometer



– data collected more often are more useful for research and in the classroom.

Soil thermometers will break if students try to force them into the ground. It is advisable to have the students make pilot holes first with something sturdy like a large nail unless the soil is soft (i.e., loose or friable). Mark the nail for the pilot hole with a permanent marker or by scribing with a hacksaw at 5 cm, 7 cm, 10 cm, and 12 cm.

The soil thermometers should not be left permanently in the ground. The soil thermometers are not sealed to protect them against moisture, so it is not a good idea to leave them outside when not in use. (See the *Optional Automated Soil and Air Temperature Monitoring Protocol* or *Digital Multi-Day Max/Min/Current Air and Soil Temperature Protocol* for probes that can be left in the ground.)

Managing Students

Two or three students collect soil temperature data.

Frequency of Measurement

Soil temperature data are collected daily or weekly. Every three months, on two consecutive days, students should take measurements at least 5 times each day at intervals of approximately two to three hours following the *Soil Temperature Protocol – Diurnal Cycle Measurement Field Guide*. While a full daily cycle is typically 24 hours – the intention here is to capture the daytime part of this cycle.

Measurement Procedures

After selecting an appropriate site, a pilot hole is made to a depth of 5 cm and the temperature probe is inserted and read after 2-3 minutes. The pilot hole is then deepened to 10 cm and the temperature probe is again inserted and read after the temperature reading stabilizes. This process is repeated twice more within 25 cm of the original measurement and should take a total of about 20 minutes. Students measure the soil temperature three times at depths of 5 cm and 10 cm.

The three measurements taken at the same depth within 25 cm should be similar. If one data point is anomalous (very different from the others), scientists using the data may question whether it is valid. Students should note in the metadata any reasons they suspect there may be an *anomaly*.

Soil temperature measurements can be used to begin quantitative GLOBE measurements on the school grounds before an atmosphere shelter is established. Equipment is taken outside for the measurements and then brought back to the classroom avoiding security issues.

Supporting Activities

Encourage students to examine the relationship between soil temperature and soil characteristics.

Have students compare soil temperatures to air and water temperatures.

Have students examine seasonal soil temperature fluctuations.

Have students describe or draw a graph of how they would expect soil temperatures to change at different depths. Students should explain why they have drawn the graphs as they have. They then compare their graphs to actual data from the GLOBE Website visualizations. Have students discuss other variables that might be affecting the soil temperature pattern.

Have students do the *Surface Temperature Protocol* in the *Atmosphere Investigation*. In this protocol, students measure surface temperatures. These measurements can be related to soil temperatures.

Questions For Further Investigation

Is soil temperature or air temperature warmer at local solar noon?

How warm must soil get in your area before seeds sprout?

To what depth does your soil freeze?

How are other GLOBE measurements related to soil temperature?

Are the time of maximum air temperature and the time of maximum soil temperature at a 10 cm depth constant throughout the year?

Calibrating the Soil Thermometer

Lab Guide

Task

Calibrate the soil thermometer.

What You Need

- ❑ Soil thermometer
- ❑ Calibration thermometer (determined to be accurate to ± 0.5˚ C using the ice bath method described in the *Atmosphere Investigation*)
- ❑ 500-mL beaker
- ❑ Water
- ❑ Wrench that fits nut on soil thermometer
- ❑ Science Log

In the Lab

1. Pour about 250 mL of water at room temperature into a beaker.
2. Place both the calibration thermometer and the soil thermometer into the water.
3. Check that the water covers at least the lower 4 cm of both thermometers. Add more water if needed.
4. Wait 2 minutes.
5. Read the temperatures from both thermometers.
6. If the temperature difference between the thermometers is less than 2˚ C, stop; your soil thermometer is calibrated.
7. If the temperature difference is greater than 2˚ C, wait two more minutes.
8. If the temperature difference is still greater than 2˚ C, adjust the soil thermometer by turning the calibration nut at the base of the dial with the wrench until the soil thermometer reading matches the calibration thermometer.

Soil Temperature Protocol

Field Guide

Task

Measure soil and air temperature.

What You Need

- ❑ *Soil Temperature Data Sheet*
- ❑ Soil Thermometer
- ❑ Thermometer spacers
- ❑ 12 cm or longer nail marked at 5 cm, 7 cm, 10 cm and 12 cm from its point (if soil is firm or extra firm)
- ❑ Watch
- ❑ Science Log
- ❑ Pen or pencil
- ❑ Hammer (if soil is extra firm)

In the Field

1. Fill in the top portion of the *Soil Temperature Data Sheet*.
2. Locate your sampling point (If soil is soft, skip step 3).
3. Use the nail to make a 5 cm deep pilot hole for the thermometer. If the soil is extra firm and you have to use a hammer, make the hole 7 cm deep. Pull the nail out carefully, disturbing the soil as little as possible. Twisting as you pull may help. If the soil cracks or bulges up, move 25 cm and try again.
4. Insert the thermometer through the longer spacer so that 7 cm of the probe extends below the bottom of the guide. The dial should be against the top of the spacer.
5. Gently push the thermometer into the soil.
6. Wait 2 minutes. Record the temperature and time in your Science Log.
7. Wait 1 minute. Record the temperature and time in your Science Log.
8. If the 2 readings are within 1.0˚ C of each other, record this value and the time on the *Soil Temperature Data Sheet* as Sample 1, 5 cm reading. If the 2 temperatures are not within 1.0˚ C, continue taking temperature readings at 1-minute intervals until 2 consecutive readings are within 1.0˚ C.
9. Remove the thermometer from the hole. (If the soil is soft, skip step 10.)
10. Use the nail to deepen the hole to 10 cm. If you have to use a hammer, deepen the hole to 12 cm.

11. Replace the long spacer with the shorter one so that 12 cm of the thermometer extends below the bottom of the spacer. Insert the thermometer in the same hole. Gently push down until the thermometer tip is 12 cm below the surface.

12. Wait 2 minutes. Record the temperature and time in your Science Log.

13. Wait 1 minute. Record the temperature and time in your Science Log.

14. If the 2 readings are within 1.0˚ C of each other, record this value and time on the *Soil Temperature Data Sheet* as Sample 1, 10 cm reading. If the 2 temperatures are not within 1.0˚ C, continue taking temperature readings at 1-minute intervals until 2 consecutive readings are within 1.0˚ C.

15. Repeat steps 2 – 14 for 2 other holes 25 cm away from the first hole. Record these data on the *Soil Temperature Data Sheet* as Sample 2, 5 and 10 cm and Sample 3, 5 and 10 cm.
    Note: These three sets of measurements must all be made within 20 minutes.

16. If possible, read and record the current air temperature from the thermometer in the instrument shelter or by following the *Current Temperature Protocol* in the *Atmosphere Investigation*.

17. Wipe clean all the equipment.

Soil Temperature Protocol - Diurnal Cycle Measurement

Field Guide

Task

Measure soil and air temperature at least five times a day for two days.

What You Need

- ❑ *Soil Temperature Data Sheet – Diurnal Cycle*
- ❑ Soil thermometer
- ❑ Soil Thermometer spacers
- ❑ 12 cm or longer nail marked at 5 cm, 7 cm, 10 cm and 12 cm from its point (if soil is not soft)
- ❑ Hammer (if soil is extra firm)
- ❑ Watch
- ❑ Pen or pencil
- ❑ Science Log (notebook)
- ❑ Thermometer (for current air temperature)

In the Field

1. Fill in the top portion of the *Soil Temperature Data Sheet* and choose your first sampling point. Proceed to step 3 if soil is firm, or go to step 4. (Remember that you will be repeating steps 2-15 at least four more times.)
2. Locate your next sampling point 10 cm from your previous measurements. See Figure SO-TE-2. (If soil is soft, skip to step 4).
3. Use the nail to make a pilot hole 5 cm deep for the thermometer. If the ground is extra firm and you have to use a hammer, make the hole 7 cm deep. Pull the nail out carefully, disturbing the soil as little as possible. Twisting as you pull may help. If the soil cracks or bulges up, offset 10 cm and try again.
4. Insert the thermometer through the longer spacer so that 7 cm of the thermometer extends below the bottom of the guide. The dial should be against the top of the spacer.
5. Gently push the thermometer into the soil.
6. Wait 2 minutes. Record the temperature and time in your Science Log.
7. Wait 1 minute. Record the temperature and time in your Science Log.
8. If the 2 readings are within 1.0˚ C of each other, record this value and the time on the *Soil Temperature Data Sheet* for the current sample, 5 cm reading. If the 2 temperatures are not within 1.0˚ C, continue taking temperature readings at 1-minute intervals until 2 consecutive readings are within 1.0˚ C.
9. Remove the thermometer from the hole (If the soil is soft, skip step 10).

10. Use the nail to deepen the hole to 10 cm. If you have to use a hammer, deepen the hole to 12 cm.

11. Replace the long spacer with the short one so that 12 cm of the thermometer extends below the bottom of the spacer. Insert the thermometer in the same hole. Gently push down until the thermometer tip is 12 cm below the surface.

12. Wait 2 minutes. Record the temperature and time in your Science Log.

13. Wait 1 minute. Record the temperature and time in your Science Log.

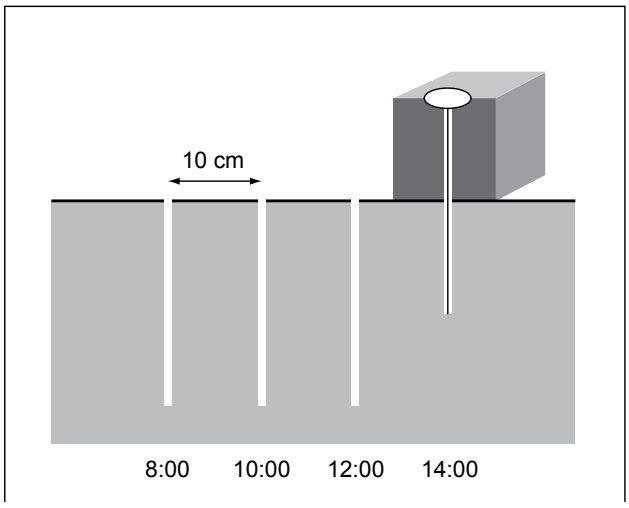
14. If the 2 readings are within 1.0˚ C of each other, record this value and time on the *Soil Temperature Data Sheet* for the current sample, 10 cm reading. If the 2 temperatures are not within 1.0˚ C, continue taking temperature readings at 1-minute intervals until 2 consecutive readings are within 1.0˚ C.

15. Read and record the current air temperature from the thermometer in the instrument shelter by following the *Current Temperature Protocol* in the *Atmosphere Investigation*. The *Soil Temperature Data Sheet* allows students to plot their diurnal soil temperature data.

16. Repeat steps 2-15 every 2 to 3 hours for at least 5 measurement times. See Figure SO-TE-2. Note that the times in figure are suggestions only. Choose times that work with your schedule.

17. The next day, repeat steps 2-16. Note that you will need a new *Soil Temperature Data Sheet* for the second day.

Figure SO-TE-2: Soil Temperature: Layout of Diurnal Observation



Soil Temperature Protocol – Looking at the Data

Are the Data Reasonable?

Graphing soil temperature data is a useful way to determine temperature trends and variations. For example, the graphs for one year of soil temperatures at 5 cm and 10 cm depths at three locations covering a wide range of latitudes show some interesting trends. See Valdres, Norway (61.13˚ N, 8.59˚ E: Figure SO-TE-3), Cleveland, OH, USA (61.13 N, -81.56˚ W: Figure SO-TE-4), and Kanchanaburi, Thailand (14.49˚ N, 99.47˚ E: Figure SO-TE-5). These graphs indicate that soil temperatures at 5 cm and 10 cm depths follow similar patterns in variation over time.

Soil temperature data generally show daily and seasonal trends that are similar to air temperature. The next set of graphs shows soil temperature at 5 cm and mean air temperature for the same schools as the previous graphs. See Figures SO-TE-6, SO-TE-7, SO-TE-8. Note that the axis for air temperature is on the left and the axis for soil temperature is on the right.

The following questions can be asked to determine whether the data in the graphs are reasonable:

- At which depth is the soil temperature generally warmer? Is this true for all three locations? Is this true throughout the entire year?
- What is the relationship between soil temperature and air temperature? Is it the same for all three locations? Is it the same throughout the course of the year?
- Which temperature, air or soil, has a greater annual temperature range in the graphs shown?

Students can determine whether their data are reasonable by comparing with data from other schools and asking similar questions.

By looking at graphs of their soil and air measurements, students will get a better understanding of the temperature trends at their site. Graphing their soil temperature data is also useful to identify data points that do not make sense. These data points are referred to as *anomalies*. They can be the result of a natural phenomenon or a problem with the data collection procedure. Graphs also allow students to see annual or daily trends in the soil temperatures.

Questions students should ask when analyzing graphs of their soil temperature data include the following:

- What is the mean temperature?
- What is the range of the data (difference between maximum and minimum)?
- How variable are the data on different time scales (daily, weekly and monthly)?
- If a regular pattern is interrupted, is there a reason for this break in other data sets or in the metadata?
- Do the data represent a spatial or temporal average (Note that some scientists use equipment or data processing that automatically averages quantities such as temperature over longer time periods. In general, GLOBE data represent instantaneous measurements of a particular parameter)?

Following are some trends that students should notice in their soil temperature data:

- A correlation or similarity between the 5 and 10 cm soil temperature data.
- Soil temperature trends should appear similar to air temperature trends.

What Do Scientists Look for in the Data?

Scientists compare changes in soil temperature with soil characteristics to determine how different soils heat and cool. Since heat generally increases the speed of physical, chemical, and biological reactions, scientists use soil temperatures to predict the rate at which processes such as seed germination will occur.

Scientists are particularly interested in long-term soil temperature data. Comparing soil, air, and water temperatures over many years helps them to understand changes in global climate and the many processes related to it, such as soil and permafrost formation. Long-term data are needed to determine the persistence or trend of any observed changes.

Figure SO-TE-3

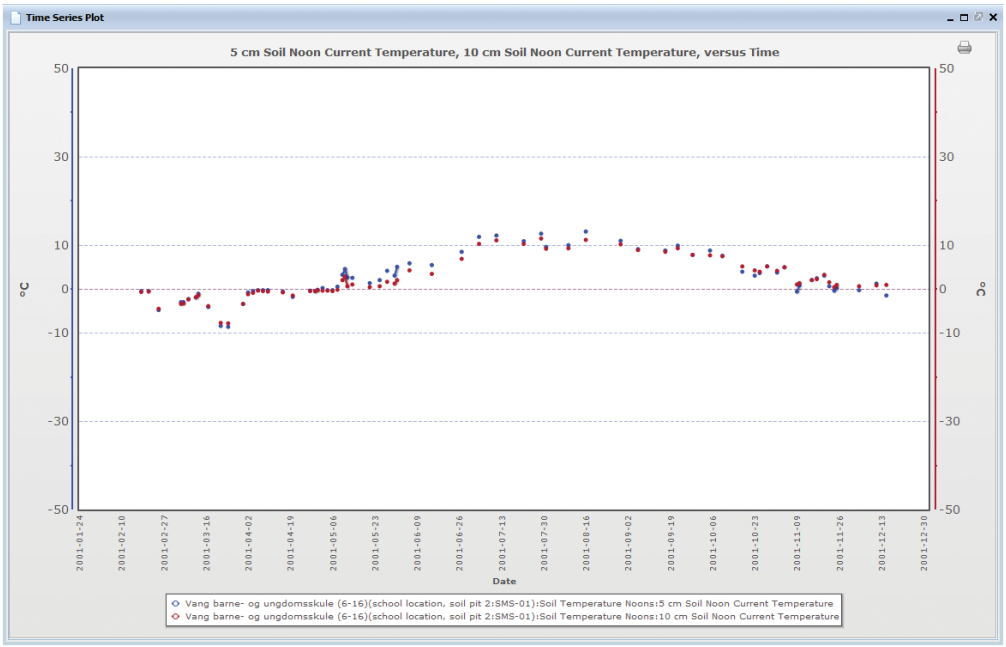


Figure SO-TE-4

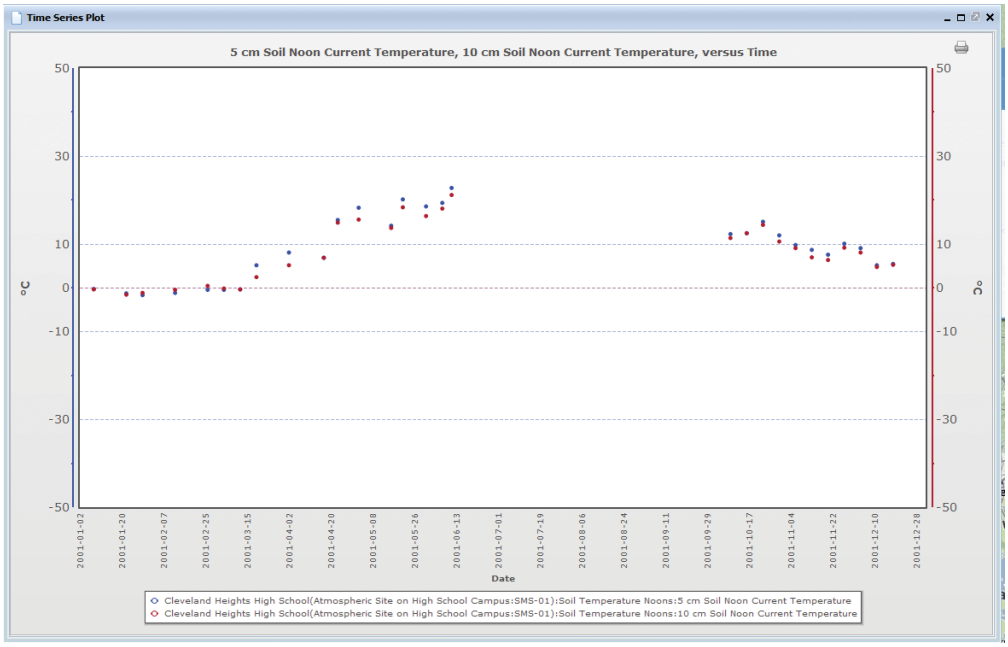


Figure SO-TE-5

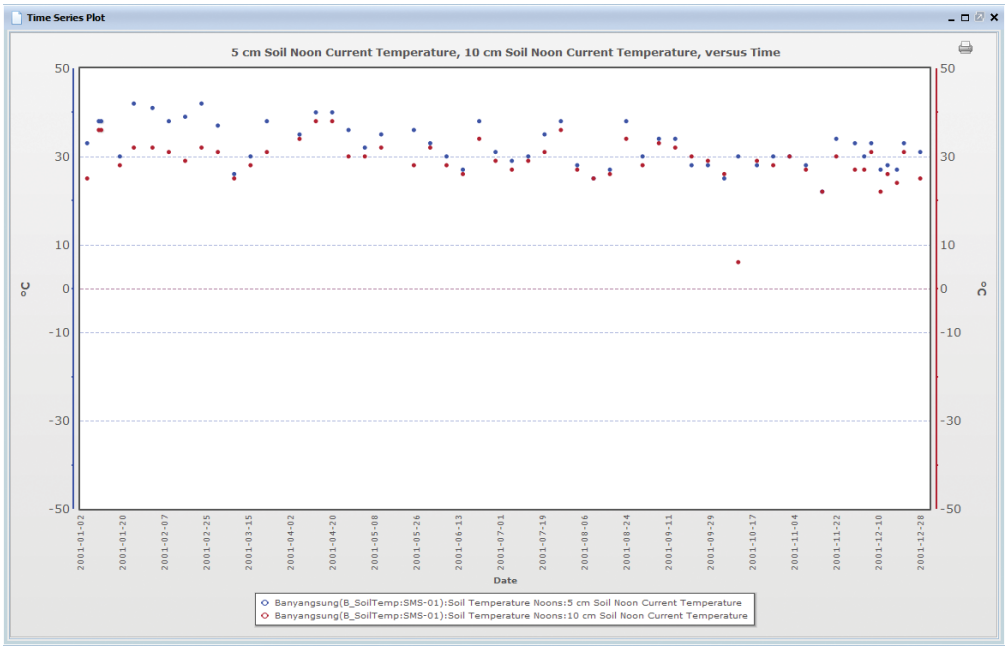


Figure SO-TE-6

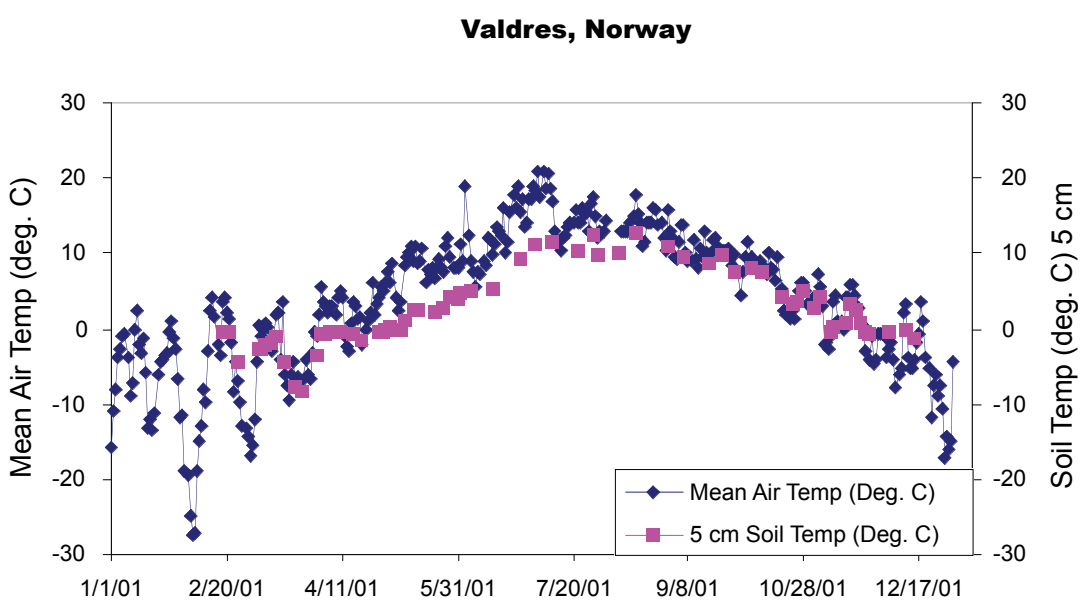


Figure SO-TE-7

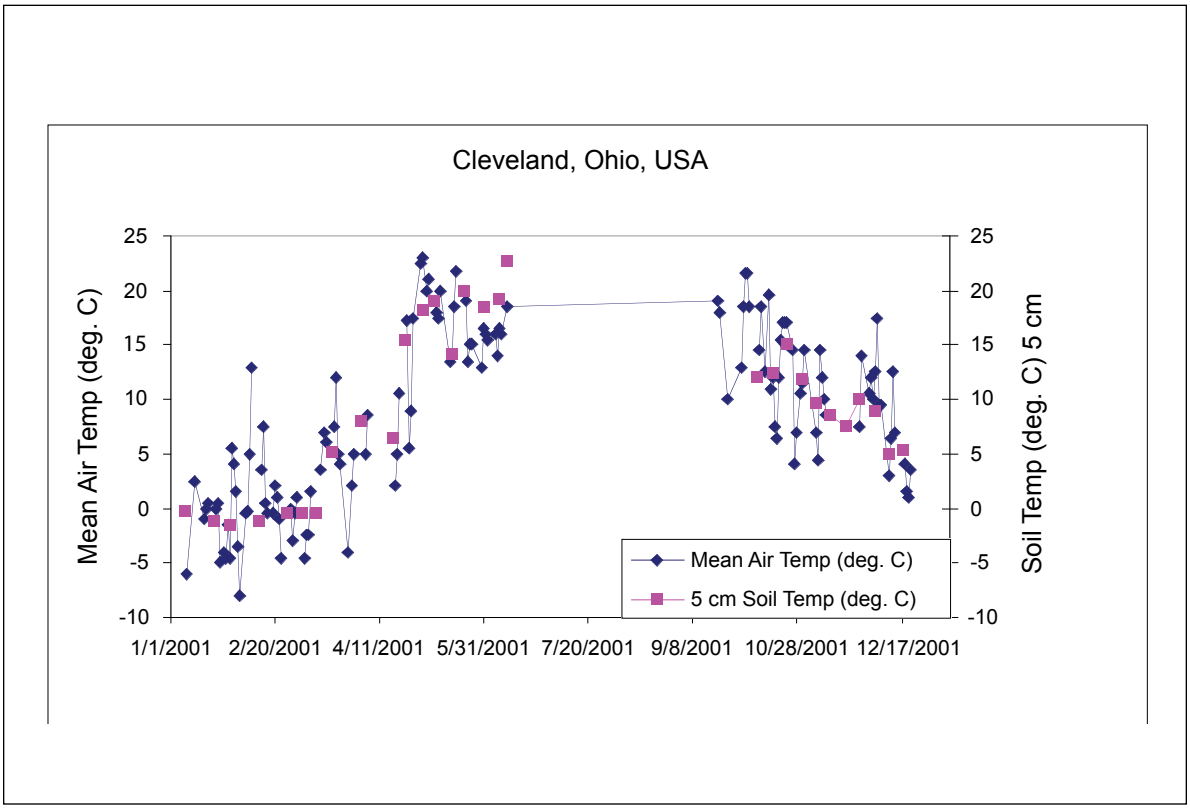
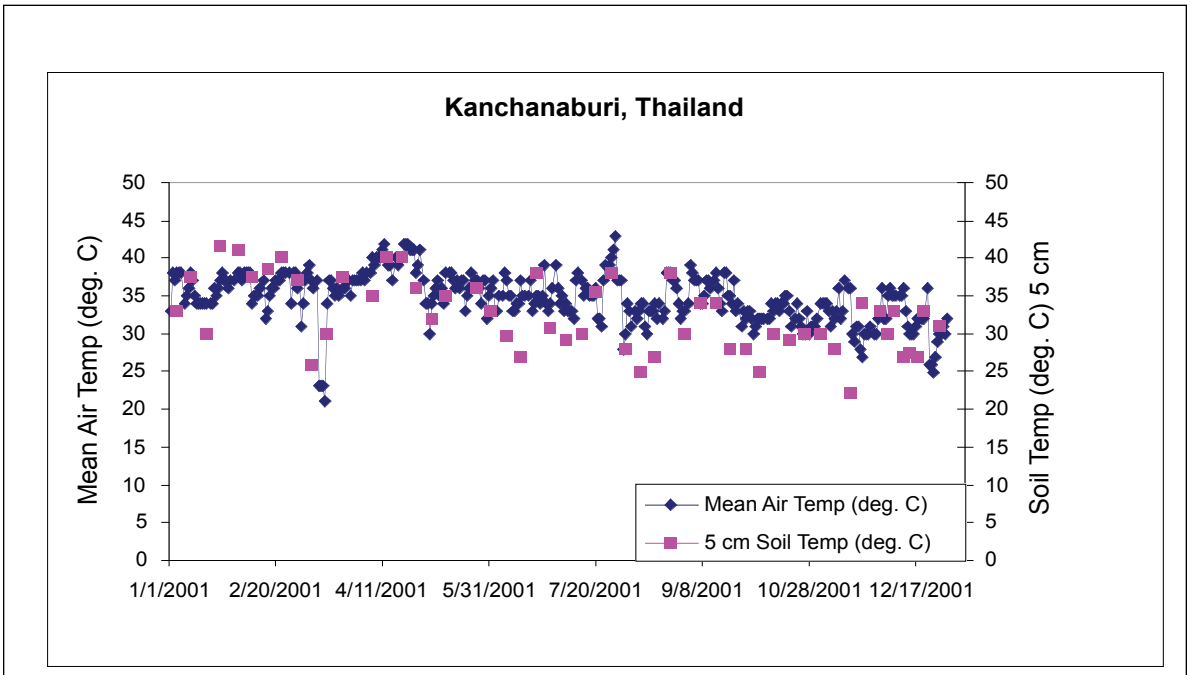


Figure SO-TE-8



Scientists also use ground observations together with models at different scales and with other data sets, such as satellite thermal infrared images to validate or extrapolate their understanding from one area to another.

An Example of a Student Research Project

Forming a Hypothesis

While looking at soil temperature data from a number of GLOBE schools, a group of students observed that at some schools the soil temperature at 5 cm was higher than the soil temperature at 10 cm but at other schools this pattern was reversed. The students wondered if this was random or if it was related to the time of year and air temperature. They looked at graphs of data from other GLOBE schools and decided to form a hypothesis based on their knowledge. Their hypothesis was: *Soil temperature at 5 cm depths will be greater (warmer) than soil temperature at 10 cm depths in the summer and less (colder) than soil temperature at 10 cm depths in the winter.*

Collecting Data

Because the students were located in a mid-latitude climate, they wanted to test their hypothesis with a school at a latitude similar to their own. The students chose Norfork Elementary School, Norfork, AR (36.20˚ N, 92.27˚ W), a mid-latitude school whose students had collected two years of soil temperature data (Figure SO-TE-9) and two years of air temperature data. The students plotted the soil temperature at 5 cm and 10 cm on the same graph to compare differences in these depths over the two years.

Analyzing Data

In looking at this graph, the students concluded that the data points were too close together to determine if their hypothesis was true or not. They decided to do some further data analysis. They began by subtracting the temperature at 10 cm from the temperature at 5 cm to calculate the temperature difference between the two depths. When the differences were negative, the deeper soil was warmer than the soil closer to the surface and when they got positive differences, the reverse was true. Then, they plotted the temperature differences over time to determine whether their hypothesis was correct.

Conclusions

From Figure SO-TE-10, the students could see that the negative values, representing times when the 10 cm soil was warmer than the 5 cm soil, occurred primarily in the fall (September, October and November) and winter (December, January, and February) months. However, there were many instances during the winter when the differences were positive, that is, the temperature at 5 cm was warmer than the temperature at 10 cm. Therefore, the students concluded that the data refuted their original hypothesis that soil temperatures at 10 cm would be warmer in the winter, as this was not always true.

Although the students found that their hypothesis was not true all of the time, the graph they made did confirm their idea that the 10 cm soil temperatures would be warmer than the 5 cm soil temperatures but only during the cooler months. To get a better view of this, the students generated a plot that showed the difference between 5 cm and 10 cm soil temperatures and mean air temperature. See Figure SO-TE-11. Note that the axis for soil temperature difference is on the left and the axis for air temperature is on the right. From this graph the students were able to conclude that at this site, air temperature must be low (< 5˚ C) for the soil temperature at 10 cm to be greater than the soil temperature at 5 cm. This conclusion made sense to the students. They reasoned that when the air temperature is warm, it warms the soil closer to the surface first, but when the air is cool, it will cool the soil closest to the surface first, leaving the more insulated deeper soil warmer.

Further Research

The students working on this project wondered if the relationship they observed would be the same in other parts of the world. They performed the same analysis on the soil and air temperature from two other schools, one in Norway, (Figure SO-TE-12) a much cooler climate, and one in Thailand, (Figure SO-TE-13) a much warmer climate.

The students saw from these graphs that the relationship between soil and air temperature that they observed in the data from Arkansas was similar to Norway's but not Thailand's. This led them to conclude that the climate and/or soil type of a region must affect this relationship. In particular, they speculated that many other warm and wet regions might not fit this pattern. The students were excited to collect enough data at their own school to study changes in 5 cm and 10 cm soil and air temperatures throughout the year.

Figure SO-TE-9

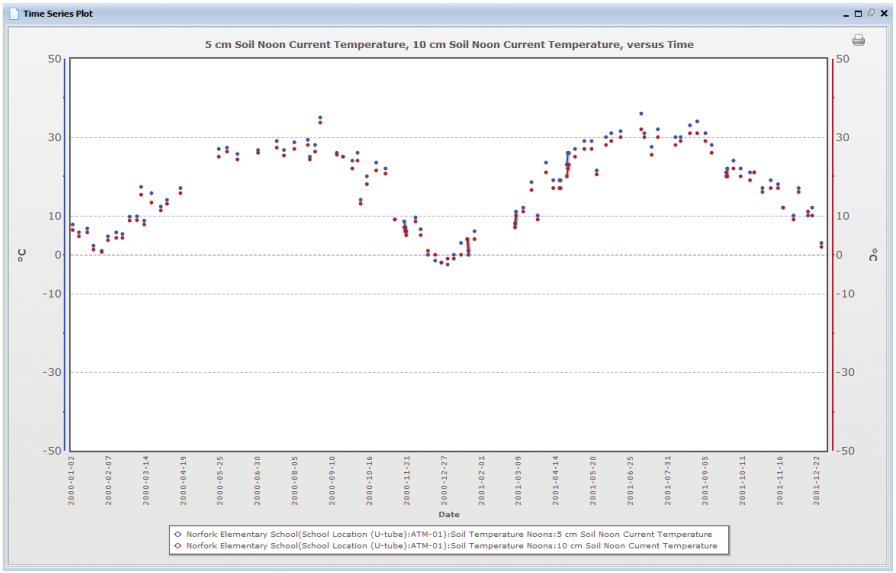


Figure SO-TE-10

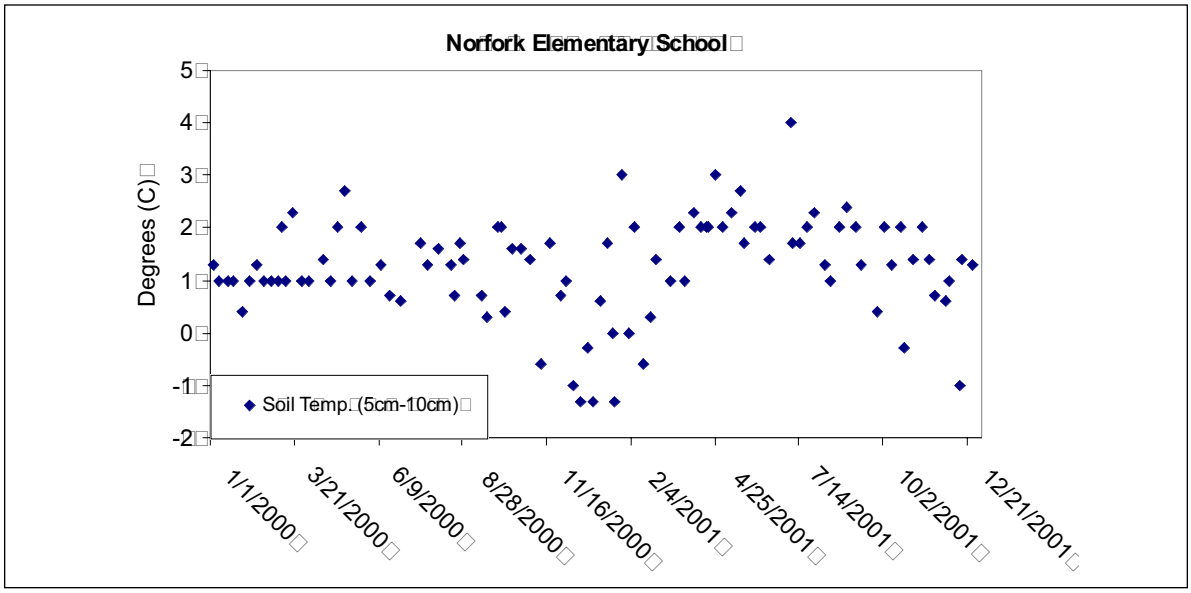


Figure SO-TE-11

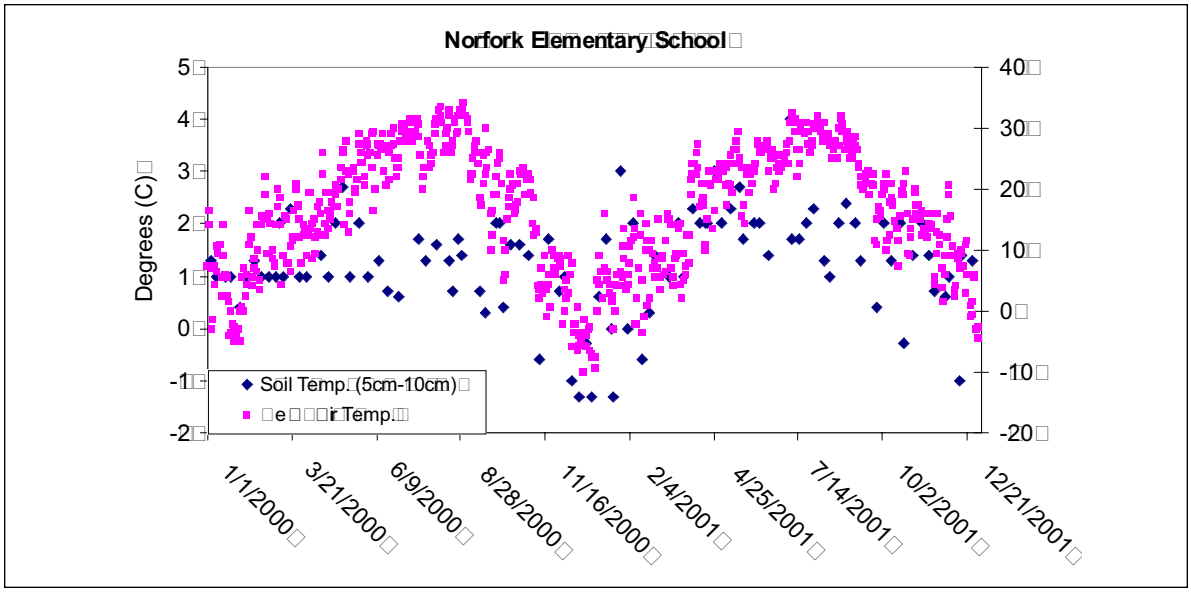


Figure SO-TE-12

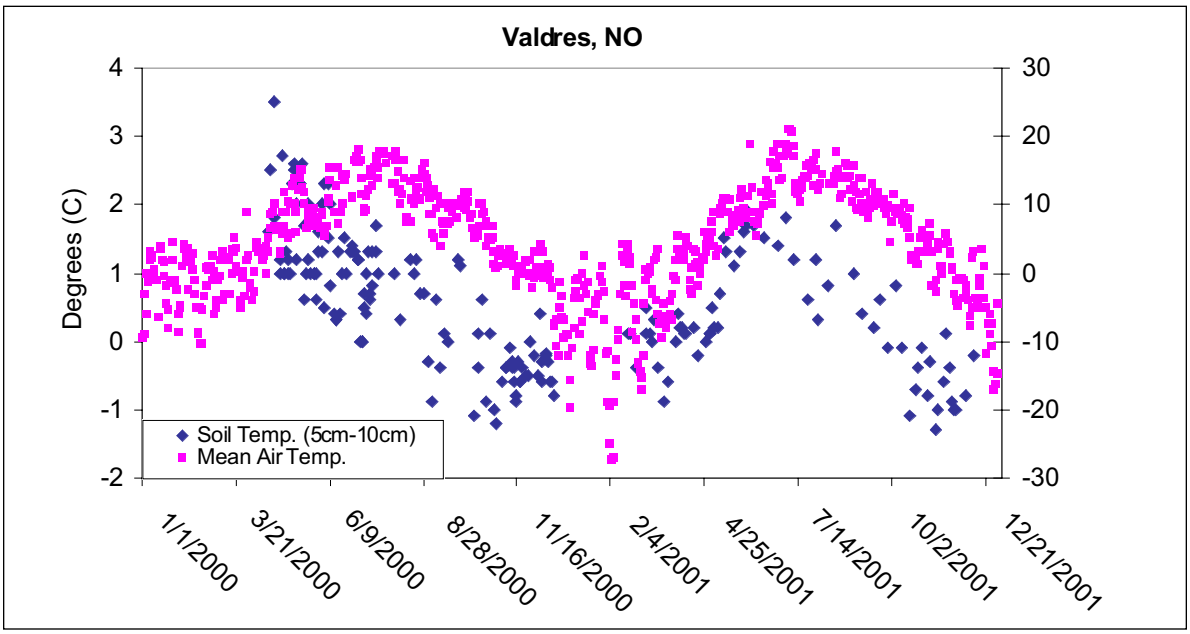
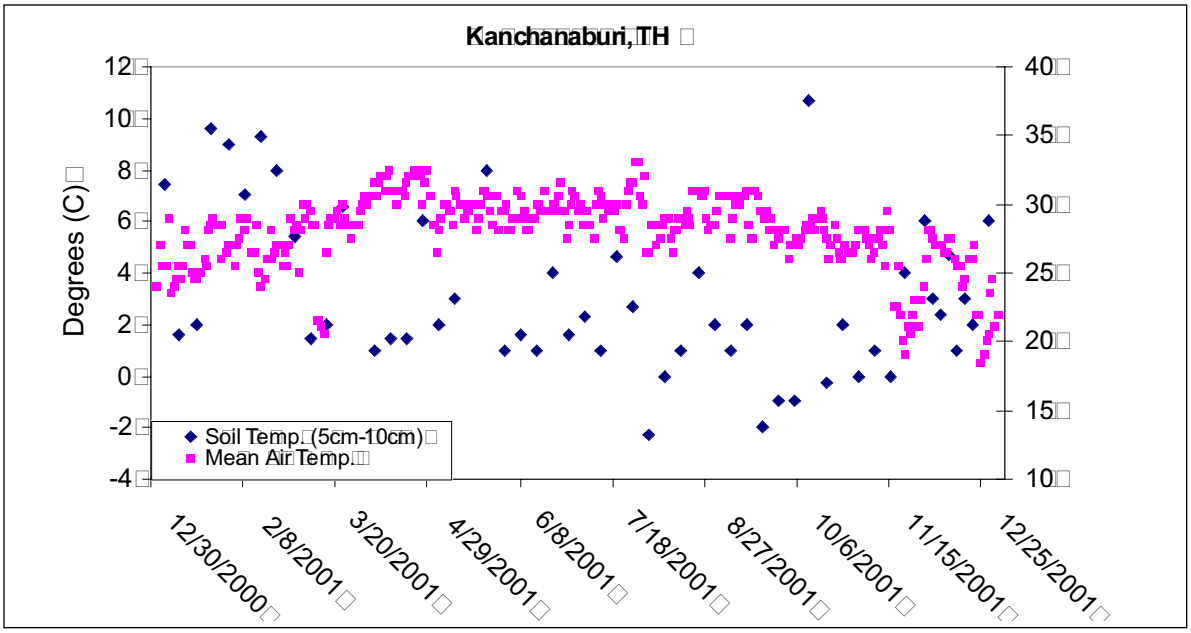



Figure SO-TE-13