Gravimetric Soil Moisture Protocols

Purpose

To measure soil water content by mass

Overview

Students collect soil samples with a trowel or auger and weigh them, dry them, and then weigh them again. The soil water content is determined by calculating the difference between the wet sample mass and the dry sample mass.

Student Outcomes

Students will be able to collect soil samples from the field, then measure their soil moisture, record and report soil moisture data.

Students will be able to relate soil moisture measurements to the physical and chemical properties of the soil.

Science Concepts

Earth and Space Sciences

Earth materials are solid rocks, soil, water, biota, and the gases of the atmosphere.

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.

Soils consist of minerals (less than 2 mm), organic material, air and water.

Water circulates through soil changing the properties of both the soil and the water.

Physical Sciences

Objects have observable properties.

Relate mass, volume and density.

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

5-10 minutes preparation before sampling

10-15 minutes to collect samples*

5 minutes to weigh wet samples

5 minutes to weigh dry samples

Samples dry under heating lamps for 2 days or in a drying oven overnight.

*Some sample collection methods may require additional time

Level

All

Frequency

Daily or every two-to-three days. Alternatively, twelve or more times per year for the same site at daily, weekly or monthly intervals.

Materials and Tools

Soil Drying Method (select method most appropriate):
1) 250 Watt infrared heating lamp, 1 or 2 bulbs, that reach temperatures of 65 – 90 °C for 2-3 days)
2) Soil drying oven or other oven capable of maintaining a temperature not exceeding 105 °C Thermometer capable of measuring to 110 °C (only if using a drying oven)

Balance or scale with 0.1 g sensitivity (600 g capacity recommended, 400 g minimum capacity required)

Hot pad or oven mitt

Soil sample containers:
Sealable plastic bags (e.g. zip lock bag) OR
Soil sample cans or other metal cans such as empty and clean cat food, tuna or small pineapple cans

Plastic wrap and rubber bands to seal cans without lids

Meter stick

Trowel

Ruler marked in millimeters

Permanent markers to label soil containers

Compass

GLOBE Science Log (notebook)

Site Definition Sheet

Depending on the specific *soil moisture protocol, additional materials may be necessary:*

Star Pattern:

Soil Moisture Data Sheet - Star Pattern

6 soil collection containers (sealable soil sample cans, jars or plastic bags)

Transect Pattern:

Soil Moisture Data Sheet - Transect Pattern

50 meter tape or 50 meter rope marked every 5 meters

13 soil collection containers (sealable soil sample cans, jars or plastic bags)

Depth Profile:

Soil Moisture Data Sheet - Depth Profile

Auger

5 soil collection containers (sealable soil sample cans, jars or plastic bags)

Preparation

Choose and define a soil moisture site.

Weigh each soil sample container (cans or bags); weigh cans without lids

Label each plastic bag and/or can with its mass, date, site location and sample number

Prerequisites

None

Gravimetric Soil Moisture Protocol Introduction

Soil acts like a sponge spread across the land surface. It absorbs rain and snowmelt, slows runoff and helps control flooding. The absorbed water is held on the surface of soil particles and in pore spaces among soil particles. This water is available for use by plants. Some of this water evaporates back into the air; some drains through the soil into groundwater. Absorbent soils, like those found in wetlands, soak up floodwaters and release them slowly, preventing damaging runoff. Soils that are *saturated* with water have no available space to hold additional water because all the voids and pores are full of water, and therefore causing new rainfall to flow over the surface (also known as runoff) to low lying areas. This valuable environmental indicator also helps to estimate the soil-water balance – the pattern of how much water is stored in a soil over a year.

In order for most plants to grow, they need a place to take root, water, and nutrients. Generally, the nutrients come from dissolved soil minerals and organic matter and are carried to plants by soil water. Sometimes water flowing downward through the soil removes chemicals and nutrients from upper soil layers and deposits them deeper in the ground. The process by which materials are removed from the soil by water is known as *leaching*. Leached materials may be held in lower layers of the soil or may stay in the water and flow into rivers, lakes, and groundwater.

Water is an important element in the weathering processes that break rocks apart to form soil. For example, in cold climates, water in cracks will freeze and expand, causing rocks to break apart. When water melts and flows away, it moves broken rock parts with it. This *freeze-thaw* action is a primary soil builder. In tropical climates, water breaks rocks apart and helps to form soil particles and minerals by dissolving the rock.

Soil water also supports the decay of dead plants and animals into soil organic matter but only when oxygen from the air is present. In some places, the soil is so waterlogged that oxygen is excluded and plant and animal remains are preserved for centuries because of their slow rate of decomposition.

Some of the water stored in the soil evaporates back into the atmosphere. This evaporation cools the soil and increases the relative humidity of the air, sometimes affecting local weather and climate. The amount of water in the soil also affects soil temperature. Because liquid water has a higher *heat capacity* than either air or soil, more heat is required to

increase the temperature of moist soil. Similarly, more "cold" is required to decrease the temperature of moist soil. The net effect is that water in soil decreases the rate of soil warming and cooling.

Teacher Support

Preparation

Before beginning the *Soil Moisture Protocol*, have students complete the Site Definition Sheet. Have students weigh soil sample containers, sealable bags or cans (without the lids) in advance and write the mass on each container with a permanent marker. Mark each container with an identifying number. Have students follow the step-by-step processes as described in the field and lab guides (based on the data collection method selected) in preparing and weighing the sample containers, collecting the sample and determining the sample can volume.

Frequency of Measurement

Soil moisture data should be collected at a single site close enough to a school so that these data can be collected for at least 12 regularly spaced intervals. Students may want to coordinate their soil moisture sampling times with the collection of other GLOBE measurements that may affect soil moisture, such as precipitation.

If students identify an annual pattern of precipitation at their school, then they may want to collect soil moisture samples when the soil changes from wet to dry conditions. For example, if the school receives rain in early March followed by less rain in May, students could do a 12-week study from March though May. If the rainy season is spread out, students might do a study taking samples every 2 weeks for 24 weeks, or even a monthly sample throughout the year.

The number of sampling times can always be increased, but students should try to sample the wet, intermediate and dry times surrounding major wet periods. Sampling once or twice a week all year will definitely provide students with valuable insights into patterns of soil moisture.

Additionally, students may want to investigate

the SMAP Block Pattern Soil Moisture Protocol; this allows students to collect soil moisture data in coordination with the SMAP satellite overpass.

Measurement Procedures

Locating a soil moisture site

Soil moisture is influenced by precipitation and soil characteristics; therefore, if possible soil moisture data should be collected near the rain gauge (if your school is collecting precipitation data). Additional considerations are to avoid an area that is artificially watered (sprinklers or irrigation systems), and preferably in an area that is flat, uniform in surface character, and not under trees or shrub canopy.

Lab work

The lab work (the weighing and drying several repetitions until the sample is dry) should be conducted over the next day or two and the data entered into the GLOBE database. It is important to try to collect the soil moisture samples at approximately the same time every day in order to ensure consistency, meaning that if soil moisture samples are collected in the morning hours try to always collect soil moisture samples in the morning.

It is important for students to place soil samples in well-sealed zip lock bags or sample cans and weigh the samples as soon as possible after collecting them (cans should be weighed without lids). If samples dry out even a little before being weighed, the soil moisture data may not be accurate.

Samples should be dried and weighed several times until the mass of the soil and container (bag or can) does not change. This will indicate that the soil sample can be considered dry. If the mass has changed, even slightly, continue drying and weighing the sample and container until the mass does not change. The difference in the mass before and after drying equals the mass of water that was present in the soil at the time of collection. Scientists call this the *gravimetric* technique, which means a measurement by weighing.

The ratio of the mass of water to the mass of dry soil is the *soil water content* (also known as *gravimetric soil moisture content*). The mass of water is divided by the dry

soil mass to get a normalized value for soil water content. This normalized value can be compared with other measurements on other days even though the size of the soil samples may vary from one day to the next. It also permits valid comparisons among different sites.

Drying the sample

Once the soil sample container (sample can or bag) with soil is brought back to the classroom, weigh the bag or the can (without the lid) and soil. This will be the wet weight of soil plus container. After the wet weight has been recorded the soil must be dried completely. Depending on the intended drying method there are slightly different procedures:

Heating lamps: Open the ziplock bag and place under the heating lamp(s). If you collected soil in a can place the can under the heating lamp(s) without the lid. Note the initial drying time. If the soil was moist or wet at the time of collection the drying time may be longer than if the soil was dry. Weigh the bag with soil after 12 to 24 hours and then every 4 to 6 hours after that. When the mass of the soil and bag or can doesn't change it can be considered dry.

Soil (or other) oven: Place the can (without the lid) into the oven. Record the oven temperature and time. If the soil was moist or wet at the time of collection the drying time may be longer than if the soil was dry. Weigh the can with soil after 8 to 12 hours and then every 2 to 4 hours after that. When the mass of the soil and can doesn't change it can be considered dry. Do not dry soil in a ziplock bag in an oven.

Soil Moisture Sampling Protocols

The *Gravimetric Soil Moisture Protocol* offers three choices for sampling: *the Star Pattern*, *the Transect Pattern*, and *the Depth Profile*. The purpose of these sampling patterns is to avoid digging in the same place twice. Choose the sampling pattern that best complements the other GLOBE measurements students are taking, as well as educational objectives and students' research interests.

1. *The Star Pattern* involves collecting soil samples from 12 different locations at twelve different time periods in a 2 m x 2 m star-shaped area. For each of the 12 locations, three spots are chosen within 25 cm of each other. Samples from the top 5 cm and from 10 cm deep are collected at each of the three spots, for a total of 6 samples at each location on the star. This sampling method can be easily coordinated with the *Soil Temperature Protocol*, whereby students collect their soil temperature measurements at the same depths and locations as the soil moisture measurements.

2. *The Transect Pattern* requires an open space of at least 50 m length. Thirteen samples are collected from the top 5 cm of soil. This pattern allows students to see spatial variations in surface soil moisture measurements. It is also useful for comparison with soil moisture data collected remotely from satellites or aircraft. These remote measurement techniques sense moisture contained in the top 5 cm of soil and their measurements are averaged over areas of 100's of square meters or more.

3. *The Depth Profile* involves taking a sample of the top 5 cm and the use of an auger to take soil samples at depths of 10 cm, 30 cm, 60 cm, and 90 cm. Using an auger takes a bit of extra time, but this effort gathers valuable data and complements the *Soil Characterization Protocol* and the *Optional Automated Air and Soil Temperature Monitoring Protocol*.

Gravimetric soil moisture sampling disturbs the natural state of the soil, so students should never sample twice from the same spot within a period of several years. They can either offset the transect or shift the center of their star pattern within a 10 m diameter area. If the dried soil is returned to the sample sites after the measurements are completed, the same site can be reused after the area has had time for the soil to recover.

Managing Materials

Make sure that soil sample containers (cans and sealable or zip lock bags) can be tightly sealed to prevent moisture from evaporating. Soil cans may rust unless they are thoroughly dried after each use.

If you must use labels on the containers, make sure that they will not come off during the oven drying process.

Remember that lids must be removed from cans for drying, so weigh containers without their lids.

Balances and scales should be placed on flat surfaces and calibrated before each use.

Choose sample cans that are small enough to weigh less than 600 grams when filled with soil.

Dried soil samples should be returned to the soil moisture site to help restore it for measurements in future years.

Managing Students

Soil moisture samples can be collected most efficiently by small groups of students: one to four students. These same students or a few additional students can do the _Soil Temperature Protocol_ or the _Surface Temperature Protocol_ at the same time if these additional data will be collected. If the soil moisture samples are collected within one hour of local solar noon, students can also take the appropriate atmosphere measurements at the same time. If not, it is useful to have students read but not empty the rain gauge and record this value so that one knows how much of the day's rain fell before the sample was taken.

Supporting Activities

To introduce students to the concepts that soil holds water, that there are many variables affecting how much water soil holds, and that water quality is affected as it passes through the soil, have them do the _Just Passing Though Learning Activity_.

To help students better understand the concept of soil water content, have them do the _Soils as Sponges Learning Activity_.

Questions For Further Investigation

What other GLOBE schools have patterns of soil moisture similar to yours?

How many weeks of the year is your soil relatively wet or relatively dry?

Does soil moisture change during the winter?

Which areas around your school are usually dry or wet? Why?

Which holds the most water: clay, sand, or silt? Why?

Does the type of land cover affect the amount of water that enters the soil? Does it affect the rate at which soil dries out following a rainstorm?

How are soil moisture and relative humidity related?

How are soil moisture and soil, surface and air temperature related?

How does the porosity of a soil horizon relate to the amount of water that horizon can hold?

How does soil water content change from one horizon to another in the same profile?

What happens to the downward flow of water if there is a coarse textured (sandy) horizon overlying a horizon with high clay content? What happens to water flow if a clayey horizon is found over a sandy horizon?

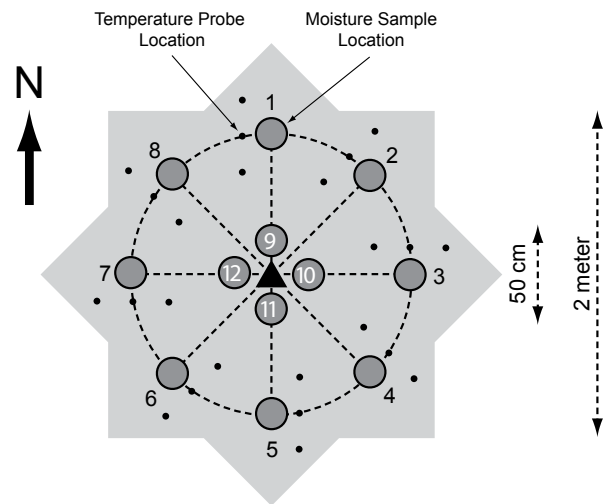# Star Pattern Soil Moisture Protocol
Field Guide

Task

Collect soil moisture samples at depths of 0-5 cm and 10 cm.

What You Need

❑ *Soil Moisture Data Sheet – Star Pattern*

❑ Compass (to locate sampling point)

❑ Trowel

❑ 6 soil sample containers (sealable bags or cans) weighed and labeled with their mass and container number

❑ Meter stick

❑ Ruler marked in millimeters

❑ Science Log

❑ Pen or pencil

In the Field

1. Complete the top portion of the *Soil Moisture Data Sheet – Star Pattern*.

2. Locate your sampling point on the star and cut or pull away any grass or groundcover.

3. Dig a hole 10-15 cm in diameter down to 5 cm. Leave the soil loose in the hole.

4. Remove from the loose soil any rocks larger than a pea (about 5 mm), large roots, worms, grubs, and other animals.

5. Use a trowel to fill a soil container with at least 100 g of the loose soil.

6. Immediately seal the container to hold in the moisture.

7. Record the container mass and number on the *Data Sheet* next to Sample 1, 0-5 cm.

8. Remove all of the soil from the hole down to a depth of 8 cm.

9. In a clean container, collect a soil sample that contains the soil between 8 and 12 cm. Remember to remove rocks, large roots, and animals. Seal the container.

10. Record the container mass and number on the *Data Sheet* next to Sample 1, 10 cm.

11. Return remaining soil to the hole.

12. Repeat steps 3 – 11 twice in new holes within 25 cm of the original sample point filling the other four cans and recording the container numbers and masses for samples 2 and 3 at both depths. You should have six containers of soil taken from three holes.

13. Dry samples according to the Gravimetric Soil Moisture Protocol Lab Guide.


Transect Soil Moisture Protocol
Field Guide

Task

Collect soil moisture samples at a depth of 0-5 cm along a 50 meter transect.

What You Need

- ❑ *Soil Moisture Data Sheet – Transect Pattern*
- ❑ Trowels (1 per student group)
- ❑ 13 sample containers (sealable bags or cans) labeled with mass and a container number
- ❑ 50 meter tape or 50 meter rope marked every 5 meters
- ❑ Rulers marked in millimeters (1 per student group)
- ❑ Science Log
- ❑ Pen or pencil
- ❑ Compass
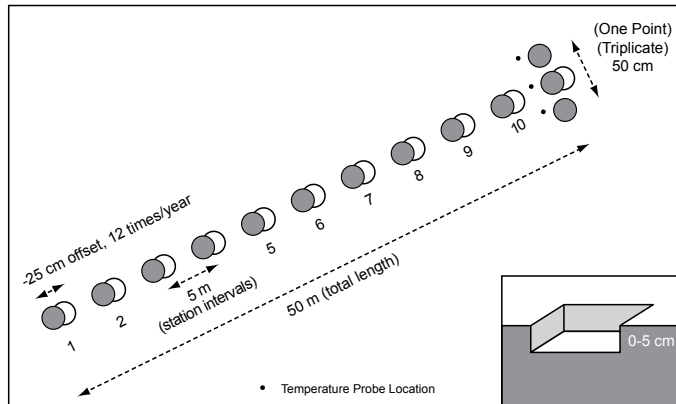
In the Field

1. Complete the top portion of the *Soil Moisture Data Sheet – Transect Pattern* including taking a compass reading along the transect line.

2. Stretch out the rope or measuring tape along the transect you will measure.

3. Locate your sampling point along the transect. Sample points should be every 5 meters along the transect, plus 2 extra samples taken at one end of the transect within 25 cm of the end point. Sample points should be numbered starting with Sample 1 at the beginning of the transect.

4. Cut or pull away any grass or groundcover above your sample point.

5. Dig a hole 10-15 cm in diameter down to 5 cm. Leave this soil loose in the hole.

6. Remove from the loose soil any rocks larger than a pea (about 5 mm), large roots, worms, grubs, and other animals.

7. Use your trowel to fill a soil container with at least 100 g of the loose soil.

8. Immediately seal the container to hold in the moisture.

9. Record the container number, mass, and distance to the start point of the transect on the *Data Sheet* next to the appropriate Sample Number.

10. Continue to collect a sample at each sampling point along the transect. Remember to remove rocks, large roots, and animals. Seal each container and record the sample number and distance from the start point of the transect on the *Data Sheet*.

    Including the extra 2 samples taken near the end point, you should have 13 containers of soil taken from along your transect.

11. Dry samples according to the Gravimetric Soil Moisture Protocol Lab Guide.

# Depth Profile Soil Moisture Protocol
Field Guide

Task

Collect soil moisture samples at depths of 0-5 cm, 10 cm, 30 cm, 60 cm and 90 cm.

What You Need

❑ *Soil Moisture Data Sheet – Depth Profile*

❑ Compass (to locate sampling point)

❑ Trowel

❑ Auger

❑ Meter stick

❑ Five soil sample containers (sealable bags or cans) weighed and labeled with their mass and a container number

❑ Science Log

❑ Pen or pencil

In the Field

1. Complete the top portion of the *Soil Moisture Data Sheet – Depth Profile*.

2. Locate your sampling point on the star and cut and pull away any grass or groundcover. See *Star Pattern Soil Moisture Field Guide*.

3. With the trowel, dig a hole 10-15 cm in diameter down to 5 cm. Leave this soil loose in the hole.

4. Remove from the loose soil any rocks larger than a pea (about 5 mm), large roots, worms, and other animals.

5. Use your trowel to fill your soil container with at least 100 g of the loose soil.

6. Immediately seal the container to hold in the moisture.

7. Record the container number and mass on the *Data Sheet* next to Sample Depth 0-5 cm.

8. Use the auger or trowel to remove all of the soil from the hole down to a depth of 8 cm.

9. In a clean container, collect a soil sample that contains the soil between 8 and 12 cm deep. Remove rocks, large roots and animals. Seal the container.

10. Record the container number and mass on the *Data Sheet* next to Sample Depth 10 cm.

11. Continue to auger down to obtain samples centered at 30, 60, and 90 cm. Record the container numbers and mass values on the *Data Sheet*.

12. You should have 5 containers of soil taken from 1 hole. Return the remaining soil to the hole – last soil out, first in.

13. Dry samples according to the Gravimetric Soil Moisture Protocol Lab Guide.
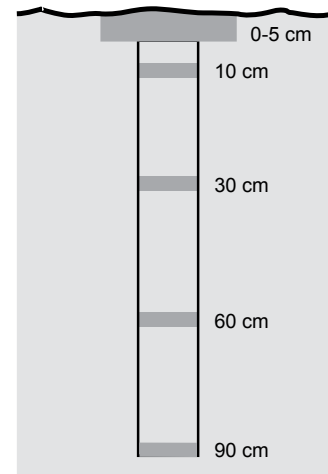
Gravimetric Soil Moisture Protocol
Lab Guide

Task

Weigh soil moisture samples, dry them completely, and weigh them again.

What You Need

❑ Heating lamp(s) or soil drying oven

❑ Thermometer capable of measuring to 110˚ C (if using a soil drying oven)

❑ Balance or scale with 0.1 g sensitivity and at least 400 g capacity (600 g recommended)

❑ Soil samples in containers, sealable bags or cans, depending on drying method

❑ Appropriate soil moisture data sheet (Star, Transect, Depth Profile)

❑ Science Log

❑ Pen or pencil

In the Lab

1. Calibrate the balance according to the manufacturer's directions. In your science log, record the standard mass used to calibrate the balance. If using an electronic balance, check that the balance is measuring in grams and is zeroed properly.

2. Shake the sample bag to move soil to one end of the bag.Fold the bag so the soil can occupy as little space as possible and it can be placed entirely on the scale to measure the wet mass of the soil sample and bag (figure 1).

Figure 1, determine wet mass of soil sample and bag

3. Record the mass to the nearest 0.1 g as the Wet Mass next to the appropriate sample container number on the *Soil Moisture Data Sheet*. (Be sure to select the data sheet that corresponds to your collection method: Star Pattern, Transect Pattern, or Depth Profile.)

4. Open bag(s) and dry beneath a 250 watt heating lamp (figure 2). If using a drying oven place the sample can in the oven without the lid (Do not place bags in oven).

5. Determine when the sample is dry by weighing the bag or can and sample, reheating for a few more hours and then weighing the sample again. When the mass of the sample does not change it can be considered dry.
   [**Note:** drying times vary based on drying method and soil water content; heating lamps may take 2-3 days to dry soil in a zip lock bag. Drying ovens should dry soil in a can overnight.]

Figure 2, drying soil under heating lamp

6. Carefully remove the bag and soil sample from beneath the heating lamp (or can from the oven) when the samples are dry.

7. Determine the mass of the dry soil sample (figure 3) and record it next to the appropriate container number on the *Data Sheet.*

8. Repeat steps for each soil sample.

Note: Dried soil should be returned to the site to fill in holes so site may be used in future years.

Figure 3, determine dry mass of soil sample and bag

Frequently Asked Questions

1. What should students do if they forgot to weigh the empty soil containers before filling them with samples in the field?

The soil collection containers can be weighed at the end of the soil moisture protocols after emptying the dried soil and cleaning the containers thoroughly. Remember that any dried soil left in the container will lead to an inaccurate container mass.

2. What should students do if the soil is frozen?

Take soil moisture measurements during times when the soil is thawed.

3. What should students do if the site was accidentally watered?

Take the data as usual, but check the flag on the *Data Sheet* to indicate artificially watered site. These data are still useful, and depending on conditions, the soil moisture may be affected by the watering for several days. If a large area, > 1 km^2 within 3 km of your site is irrigated, record this as metadata and report it to GLOBE. This is important for interpretation of observations.

4. What should students do if the soil is snow covered?

If the soil is not frozen, brush off the snow and proceed with the sample collection.

Gravimetric Soil Moisture Protocol – Looking At the Data

Are the Data Reasonable?

The first step a scientist takes when examining soil moisture data is to calculate the Soil Water Content (SWC) for each sample using the formula:

$$\text{Soil Water Content} = \frac{\text{(Wet mass – Dry mass)}}{\text{(Dry mass – Container mass)}}$$

Soil water content typically ranges between 0.05 and 0.50 g/g (grams of water per gram of dry soil). Even soils in dry (desert) regions retain a small amount of water, although surface soils in these regions can fall below 0.05 g/g. Soils with high organic matter or high clay contents can hold large amounts of water, so it is possible to measure values above 0.50 g/g.

The amount of water a soil horizon can hold depends on the amount of pore space (porosity) available. Porosity can be calculated by using the example given in the *Looking At the Data* section of the *Soil Particle Density Protocol*.

Total porosity of a soil can range from as low as 25% in compacted soils to more than 60% in well aerated, high-organic-matter soils.

Looking at some examples helps to understand what different values of soil water content might mean.

Soil Water Content and Soil Particle Density

Consider an organic layer of soil with 50% spaces or voids between the soil particles with half of these spaces filled with water. A 100 cm^3 sample would contain 50 cm^3 of soil, 25 cm^3 of water, and 25 cm^3 of air. Typical densities of two different soils and the density of water can be used to illustrate the value of the soil particle density. The mass of the air is negligible and the air will be present in both the wet and dry samples.

Let's look at the sample data within the formula above:

Wet Mass = 100 g and the Dry Mass = 75 g; the container mass = 25 g

$$\text{Soil Water Content} = \frac{100\text{ g - }75\text{ g}}{75\text{ g - }25\text{ g}} = \frac{25\text{ g}}{50\text{ g}}$$

50 cm^3 of soil x 1.0 g/cm^3 soil particle density = 50 g soil

25 cm^3 of water x 1.0 g/cm^3 water density = 25 g water

In this case the Soil Water Content would be 25 g of water divided by 50 g of soil or 0.5 g/g.

Now consider a 100 cm^3 sample of a mineral soil with a particle density of 2.5 g/cm^3. Again the sample contains 50 cm^3 of soil, 25 cm^3 of water, and 25 cm^3 of air.

50 cm^3 of soil x 2.5 g/cm^3 soil particle density = 125 g soil

25 cm^3 of water x 1.0 g/cm^3 water density = 25 g water

In this case the Soil Water Content would be 25 g of water divided by 125 g of soil or 0.2 g/g.

Different soils with the same porosity and the same amount of water present can vary significantly in the value of Soil Water Content, and understanding whether the values measured are reasonable or not is easier if the soil characterization protocols have been done for a horizon.

Soils are expected to show an increase in water content after a rain or during snowmelt, if the soil is not frozen or saturated. Soils gradually dry out during times with little or no precipitation. How the soil dries at different depths depends on the properties of the soil in each horizon. In some cases, water enters the soil from below, when the water table rises. The water content in these soils may be more variable lower in the soil profile than at the surface.

If it rains, some of the rainfall is expected to soak or infiltrate into the ground and increase soil moisture. This infiltration starts happening immediately and can continue for several hours if water continues to be available from a steady rain or puddles. If infiltration continues until all the pore space is filled, then the soil becomes *saturated*. Most soils drain rapidly, usually within hours or days. The field capacity of a soil is the amount of water a soil will hold without downward drainage or redistribution.

As the ground dries from evaporation and transpiration, soil moisture decreases slowly, with the soils closer to the surface usually drying faster than deeper soils. Soil moisture decreases from field capacity to a water content known as the *wilting point*, (the point at which the soil holds the water too tightly for plants to take it up). Depending on the soil properties, soil temperature, air temperature, and relative humidity, it may take from days to weeks for the wilting point to be reached. A general picture of how soil water content changes in a single horizon with time is illustrated in Figure SO-GR-1, however, there are times when the actual data do not follow this pattern.

Moisture content is affected by rainfall variation and soil properties. In a soil profile some horizons retain more water and have a greater porosity than others, affecting the flow of water from one horizon to another.

For example, if a sandy horizon is located above a clayey horizon, water moving through the sandy horizon will enter the clayey horizon very slowly because of the difference between the large pores in the sandy soil and the very small pores in the clayey soil. The small pores act as a tight layer that only lets water move gradually, so that the sandy soil may actually be much wetter at a given time than the clay.

Examining graphs of data collected at three locations will help demonstrate the process to determine whether data are valid or not. The following graphs are used for this demonstration: Valdres, Norway (61.13 N, 8.59 E): Figure SO-GR-2, Stowe, Vermont, USA (44.48 N, 72.708 W): Figure SO-GR-3 and Norfork Arkansas, USA (36.19 N, 92.26 W): Figure SO-GR-4. Each data set includes rainfall, new snow rain equivalent, and soil moisture.

For the first two schools, the classes chose to take weekly measurements for three months. In this case, the protocol calls for taking measurements during periods when the soil moisture is changing. The students in Valdres, Norway knew from experience that melting winter snow would result in wet soils initially, then drying out gradually as summer approaches. Of course, near-surface soil moisture can also increase during spring rains (as happened on May 28 and later in July).

The students in Stowe, Vermont decided to monitor their soil moisture as it changed from dry summer conditions to wet fall conditions. Again, the near-surface soil moisture appears more variable, drying significantly for a short period early in October 2001. Conversely, the deeper 10 cm soil moisture shows fewer extreme changes.

The class in Norfork, Arkansas decided to take monthly measurements for 12 months to investigate the seasonal cycle of soil moisture in their area. Despite having precipitation off and on throughout the year, the soil moisture shows a gradual dry-down, particularly at the surface. The soil moisture at 10 cm shows less variation for most of the year.

All three of these are interesting data sets. Comparison with precipitation has helped

Figure SO-GR-1, Soil Water Content graph
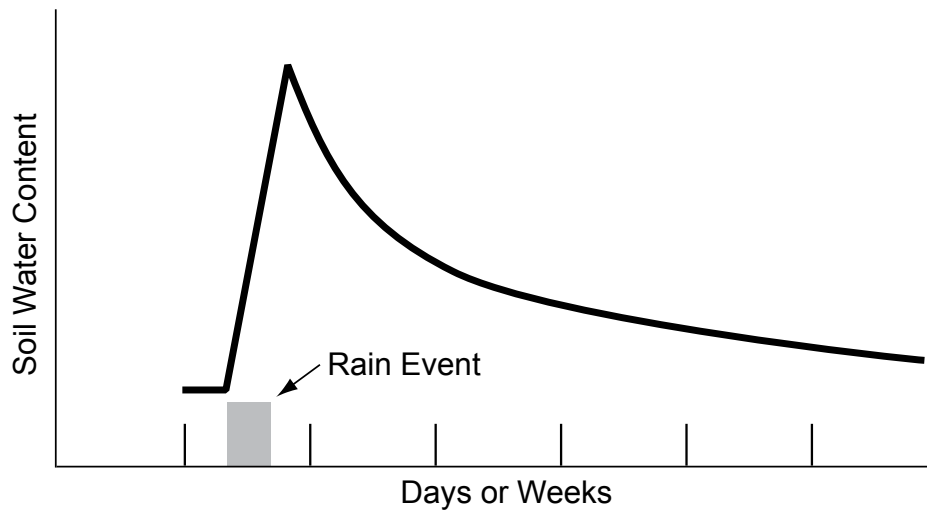
explain some of the variability while applying basic climatic knowledge has helped explain some of the longer-term trends. Knowing the soil characterization properties (texture, bulk and particle density, etc.) helps scientists and students understand more about how water is moving or stored in the soil.

What do scientists look for in the data?

Generally, scientists want to understand how water cycles through the local or regional environment. For example, they want to understand how precipitation and melting snow relate to increases in the water levels of streams, rivers, and lakes. Soil moisture measurements help to understand these processes. When soil moisture measurements are available for a whole profile, they can be used to predict floods, droughts, or the optimal timing for crop irrigation. Scientists also use soil moisture data with soil temperature, relative humidity and land cover data, to estimate the rate at which water is returned to the atmosphere through evaporation and transpiration.

Phenology scientists look at the effect of soil moisture on the annual cycles of plants, such as trees and annual grasses. In some forested regions, tree growth begins in the spring when the soil becomes moist and then stops during the summer when the soil becomes dry.

Scientists are interested in soil moisture changes over time. They are also interested in examining the regional or spatial patterns of soil moisture changes. Scientists focus on patterns rather than the absolute values of the measurements because soil moisture is a function of precipitation, soil texture, infiltration rate and local weather conditions.

Scientists would like to know the soil water content over large areas and ultimately they hope to use remote sensing data from satellites like the SMAP mission to help measure this. Ground-based soil moisture data are required in order to develop and assess the methods for estimating soil moisture from satellites. By contributing to GLOBE's soil moisture campaign, students are helping with this exciting scientific advance.

Figure SO-GR-2, Precipitation and soil moisture (5 and 10 cm) graph for Vang barne- og ungdomsskule, Norway
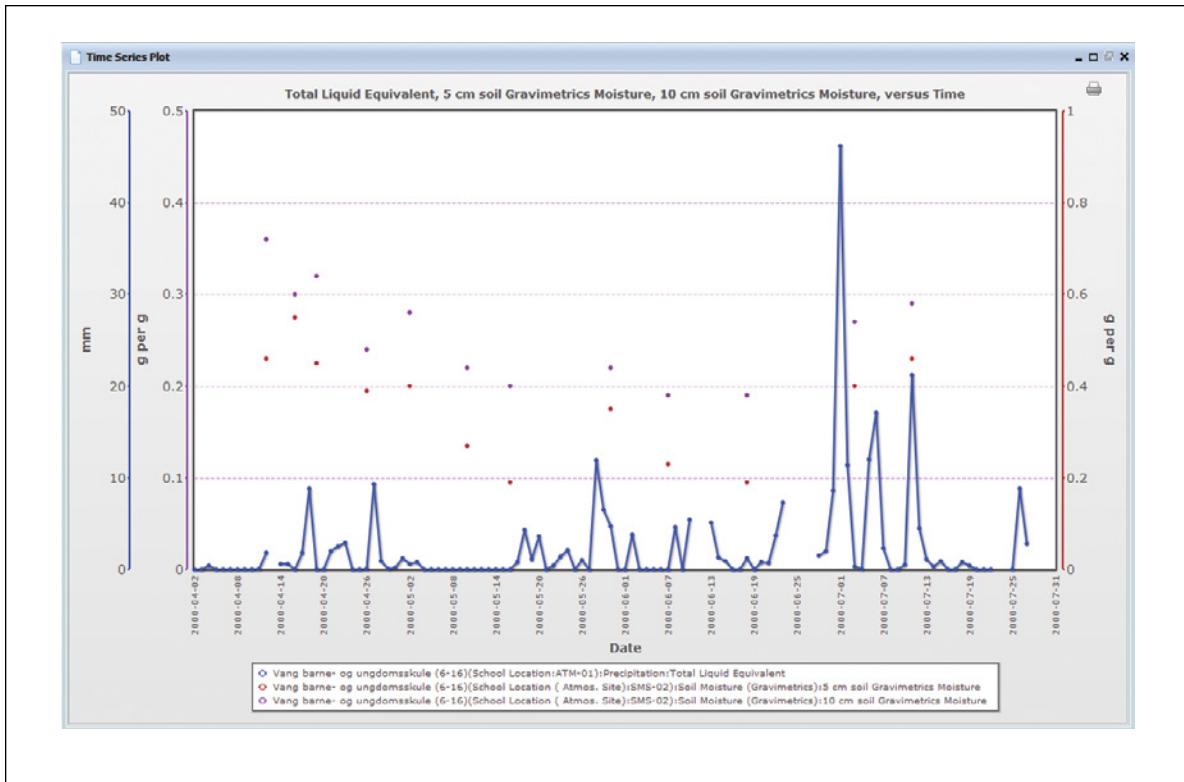

Figure SO-GR-3, Precipitation and soil moisture (5 and 10 cm) graph for Stowe Elementary School, VT, USA
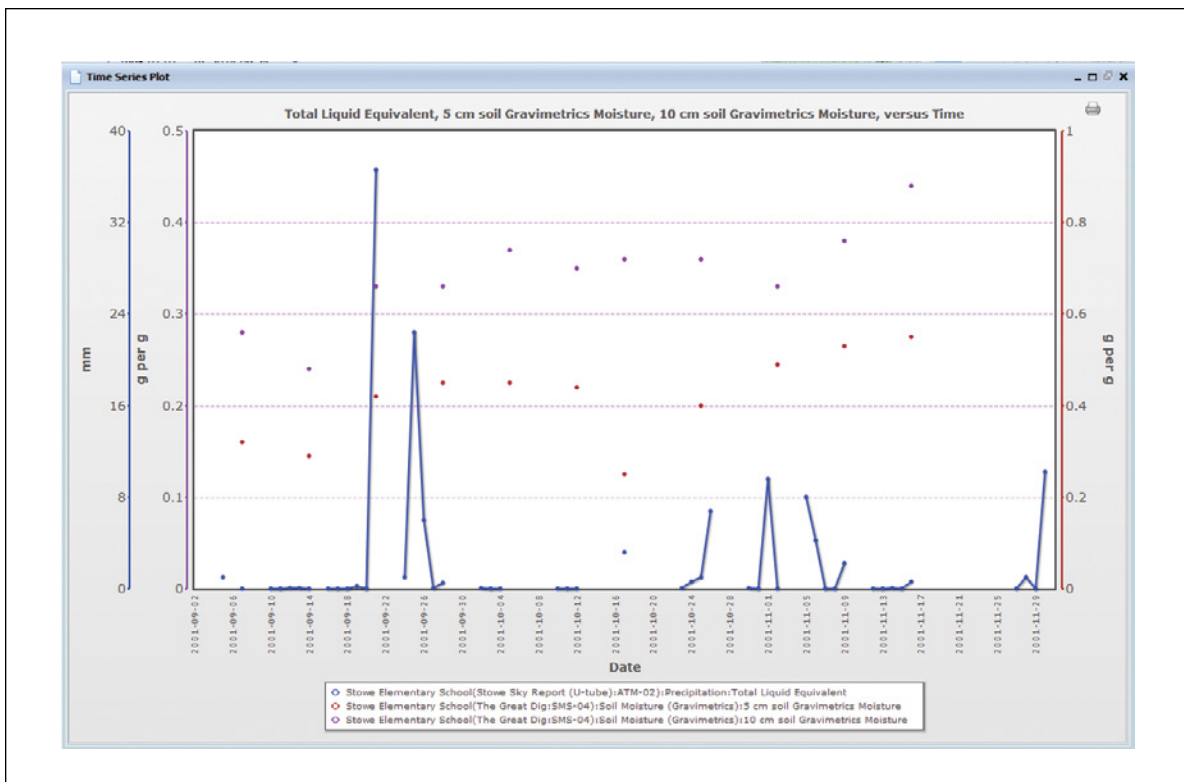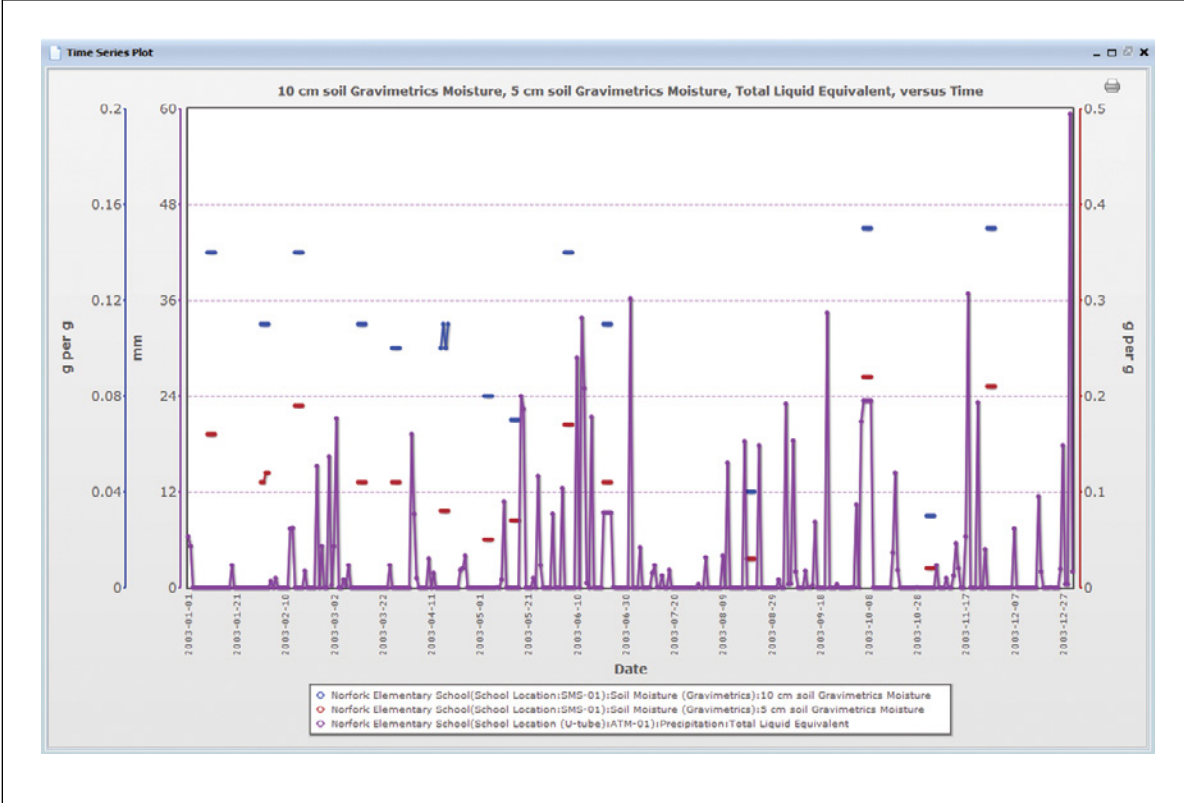
Figure SO-GR-4, Precipitation and soil moisture (5 and 10 cm) graph for Norfork Elementary School, AR, USA

An Example of a Student Research Project

Observations

Students at Stowe Elementary School in Vermont, USA collected ten gravimetric soil moisture samples over the autumn months (September-November). Figure SO-GR-3 shows a plot of their soil moisture and precipitation data.

Forming a Hypothesis

A common assumption is that soil moisture increases after a rainfall. While this tended to be the overall case for their surface soil moisture data, the students noticed that there were exceptions.

They predicted that these exceptions occurred when soil moisture samples were not collected immediately after precipitation events. The students felt that soil wetting and drying would take longer and require more rainfall at 10 cm depths than the near-surface soil. After looking at their data, the students decided to test the following hypothesis: *Soil moisture at the surface will increase if more than 10 mm of precipitation has fallen in the previous 5 days and soil moisture at 10 cm will increase if more than 20 mm of precipitation has fallen in the previous 10 days.*

Collecting Data

The students chose to analyze their data set first, and then look for other schools that had measured weekly near-surface soil moisture to see if they had similar relationships in their data. They separated into teams, one to analyze their data and the other to look for schools with at least 24 soil moisture observations and more than 100 precipitation observations in the same year. After printing the graph of their data, the students made a table of their data and downloaded it onto their computer.

Analyzing Data

One group of students used colored pencils to mark the five and ten-day periods that preceded each soil moisture observation and added the rainfall amounts for these times to get the total rainfall for each period. They organized their data into a new table, shown below (Table SO-GR-1). Another group of students calculated the change in soil moisture from one reading to the next and added this information to the table. Finally, the class decided whether the data supported their hypothesis or not. In a few cases, there was no change in soil moisture so they modified their original hypothesis to read, "…*soil moisture should increase or stay the same* …"

Table SO-GR-1: Stowe, VT 2001 Soil Moisture and Precipitation Data

Date	5-day Precip. Sum (cm)	5 cm Soil Moisture (g/g)	Change in Soil Moisture	Agree?	10-day Precip. Sum (cm)	10 cm Soil Moisture (g/g)	Change in Soil Moisture	Agree?
9/7/01	1.0	0.32			18.6	0.27		
9/14/01	0.2	0.28	-0.04	Y	1.2	0.24	-0.03	Y
9/21/01	36.8	0.42	0.14	Y	37.0	0.33	0.09	Y
9/28/01	30.0	0.45	0.03	Y	66.8	0.33	0	Y
10/5/01	0.5	0.45	0	Y	30.5	0.37	0.04	Y
10/12/01	17.8	0.44	-0.01	N	17.8	0.35	-0.02	Y
10/17/01	11.8	0.26	-0.18	N	29.6	0.35	0	Y
10/25/01	33.5	0.4	0.14	Y	36.7	0.36	0.01	Y
11/2/01	14.5	0.49	0.09	Y	22.3	0.33	-0.03	N
11/9/01	14.4	0.53	0.04	Y	24.0	0.38	0.05	Y
11/16/01	4.8	0.55	0.02	N	7.0	0.44	0.06	N
				70%				80%

Overall, the students' hypothesis was consistent with 70-80% of their observations. They considered the results to reformulate a better hypothesis. For example, they considered changing the surface precipitation threshold to 12 mm, or actually calculating the depth to which the soil would be wet based on the original soil moisture content and the amount of rain that had fallen. By carefully examining the situations where the hypothesis failed, they might learn more about soil moisture. For example, the surface data from 12 Oct. 2001 might be explained by the fact that all 17.8 mm fell on the first day of the 5-day period so it had time to evaporate or infiltrate into the ground. The students' hypothesis might not work on 16 Nov. 2001 because the weather was colder and the soil was approaching saturation.

Further Research

A similar analysis can be made of data from other schools. Table SO-GR-2 reveals results for springtime data collected in Valdres, Norway. The percentage correct in each column is the same as for the Stowe, VT data set. Students could look for other similarities or differences or try to find other locations around the world to see if this pattern is consistent. Although these students only looked at two years of data, they felt more confident about predicting the relationship between precipitation and soil moisture.

Table SO-GR-2: Valdres, NO 2000 Soil Moisture and Precipitation Data

Date	5-day Precip. Sum (cm)	5 cm Soil Moisture (g/g)	Change in Soil Moisture	Agree?	10-day Precip. Sum (cm)	10 cm Soil Moisture (g/g)	Change in Soil Moisture	Agree?
4/12/00	1.9	0.46			5	0.36		
4/16/00	5.5	0.55	0.09	N	5.6	0.3	-0.06	Y
4/19/00	11.2	0.45	-0.1	N	16.2	0.32	0.02	N
4/26/00	5.5	0.39	-0.06	Y	18.1	0.24	-0.08	Y
5/2/00	3	0.4	0.01	N	15.3	0.28	0.04	N
5/10/00	0	0.27	-0.13	Y	2.6	0.22	-0.06	Y
5/16/00	0	0.19	-0.08	Y	0	0.21	-0.01	Y
5/30/00	24.1	0.35	0.16	Y	28	0.22	0.01	Y
6/7/00	0	0.23	-0.12	Y	15	0.19	-0.03	Y
6/18/00	3.4	0.19	-0.04	Y	19	0.19	0	Y
7/3/00	68.5	0.4	0.21	Y	98.4	0.26	0.07	Y
7/11/00	24	0.46	0.06	Y	64.9	0.29	0.03	Y
				70%				80%