SMAP Soil Moisture Measurement Protocol

Purpose

To obtain *in situ* measurements of soil moisture that are consistent with soil moisture measurements from NASA's Soil Moisture Active Passive (SMAP) satellite.

SMAP Soil Moisture Protocol -- Introduction

SMAP is a NASA satellite launched on 31 January 2015 to create global soil moisture maps every 3 days. It measures the amount of water in the top 5 centimeters of the soil and provides a volumetric soil moisture measurement. This protocol is a guide to making *in situ* volumetric soil moisture measurements that can help validate SMAP's soil moisture estimates taken from space. To do this, the SMAP team will compare the GLOBE *in situ* soil moisture measurements with the satellite measurements to determine how close or how far apart they are to each other. If they agree, then the SMAP team can have confidence that the satellite measurements are correct. To support this effort, SMAP initiated a 7-month-long soil moisture measurement campaign that began on 1 October 2015 and that will end on 30 April 2016.

The SMAP team will provide feedback to schools that enter 15 or more measurements to the GLOBE database. The SMAP team will have monthly webinars highlighting schools and countries collecting soil moisture data following the SMAP protocol.

Overview of the Measurement

There are two types of *in situ* moisture measurements: gravimetric (by weight) and volumetric (by volume). Gravimetric soil moisture measurement is the standard *in situ* method for determining the amount of water in the soil. In this SMAP protocol, students will take gravimetric measurements and convert them to volumetric measurements to ensure consistency with SMAP.

Volumetric soil moisture is the volume of water in a given volume of soil, and it is calculated by determining: 1) gravimetric soil moisture, and 2) sample bulk density and then 3) multiplying them. The equations to do this are provided below.

Gravimetric soil moisture is the mass of water in the soil divided by the mass of the soil. This measurement is calculated by collecting a soil sample in a sealable bag, weighing it, drying it, and then weighing it again. The difference between the wet sample mass and the dry sample mass is the mass of the water in the soil. Gravimetric soil moisture is calculated every time a soil sample is collected.

Sample builk density is the ratio of the dry mass of a soil sample to its volume. Bulk density increases with compaction, and tends to increase with depth. This soil property is calculated by collecting a soil sample in a can. The soil sample is transferred to a sealable bag and then weight and dried, and then weighed again in order to determine the dry weight of the soil. The volume of the can is measured and sample bulk density is then calculated by taking the ratio of the dry soil mass to the volume of the can. Sample bulk density should not change considerably across a small sampling area; therefore, it will only be calculated for every tenth soil sample collected. The bulk density value will then be applied to the current sample as well as to the previous nine samples collected to determine their volumetric soil moisture.

Task

Students collect a soil sample in a sealable bag and then weigh it, dry it, and then weigh it again. If the soil moisture sample was collected in a can, students will transfer the contents into a new bag, and then weigh it, dry it, and then weigh it again, and also measure the

volume of the can. The gravimetric and volumetric soil moisture calculations are then determined based on the wet mass, dry mass, container mass, and volume of the can.

Time

- 5-10 minutes preparation before sampling
- 5-10 minutes to collect samples
- 5 minutes to weigh wet samples
- 5 minutes to weigh dry samples
- 5 minutes to measure the volume of the can
- 5 minutes to report the data

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

Frequency of Measurement

SMAP makes estimates of soil moisture for the same spot on Earth every 3 days at approximately 6:00 a.m. local time. Ideally, your school will collect soil moisture as close as possible to 6:00 a.m. +/- 3 hours local time (e.g. 9:00 a.m.) on SMAP morning overpass days. Measurements outside of this day-and-time window are also useful; however, they are more difficult to compare directly with SMAP. The online NASA Satellite Predictor Tool, which is available at https://cloudsway2.larc.nasa.gov/cgi-bin/predict/predict.cgi, identifies when SMAP will be flying overhead based on latitude and longitude. Students should collect one soil moisture sample on collection days. Data should be submitted to the GLOBE science database as soon as drying of the samples is done. It is important to try to collect the soil moisture samples at approximately the same time every collection day in order to ensure consistency.

Level

All.

Prerequisites

None.

Managing Students

Soil moisture samples can be collected most efficiently by small groups of students: one to four students.

Materials and Tools

❑ *Site Definition Sheet*

❑ *Soil Moisture Data Sheet – SMAP Block Pattern*

❑ 500 mL graduated cylinder

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

❑ Sealable plastic bags

❑ 4 sampling cans (for example, empty and cleaned small cat food, tuna, or pineapple cans without a lip; cans with a lip impact the volume of the can). (NOTE: Use caution, can edges may be sharp.)

❑ Plastic wrap to seal the cans and rubber bands to hold the wrap around. Alternatively, soil sample cans with lids may be used; however, they are not ideal.

❑ Permanent marker for writing on sealable plastic bags and/or sample cans, and a pen or pencil to write your measurements.

❑ A heating lamp that can reach a sustained temperature of 60–90˚ C (for 2 or 3 days), such as a 250-watt infrared food heating lamp (with one or two bulbs) or a room heating lamp. Alternatively, a soil drying oven may be used; however, it is not required. (Any other safe heating source will work as long as the temperature can be sustained for 2 days and can reach 60–90˚ C; for example, a room heating lamp). If you have access to a soil drying oven, you may dry the sample, as described in the Gravimetric Soil Moisture Lab Guide. (NOTE: Do not dry soil in plastic bags in a soil drying oven.)

❑ Hot pads or oven mitts for handling dried soil samples, if using a drying oven.

- ❑ Meter stick
- ❑ Ruler marked in millimeters
- ❑ Trowel
- ❑ Hammer
- ❑ Wood block

Managing Materials

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

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

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

Initial Setup:

1. Join the SMAP community on the GLOBE website.
2. Select your site and complete the soil moisture section of the Site Definition Sheet. (NOTE: If you do not have a GPS to determine the latitude and longitude of your site, you can go to Google Earth and note the approximate coordinates for your sample location.)
3. Determine when SMAP will overfly your site in the morning and decide upon the sampling schedule by entering the date and the latitude and longitude of the soil moisture site into the online NASA Satellite Predictor Tool. This online tool will provide overpass information for the site such as Date, Time (GMT/UT), Distance from instrument track, and whether the instrument is ascending or descending (see Figure 1). This information will help teachers and students best determine when the satellite instrument track will be closest for useful data collection.
4. Define the sampling pattern. The SMAP Soil Moisture Protocol suggests using the SMAP Block Pattern for sampling (see Figure 2). The purpose of this sampling pattern is to systematically avoid collecting samples in the same place twice during a year. The SMAP Block Pattern layout consists of:
   - Using the meter stick to lay out a 3x3 meter square area that is flat, uniform in surface character, not under tree or shrub canopy, relatively free of rocks, and not artificially irrigated.

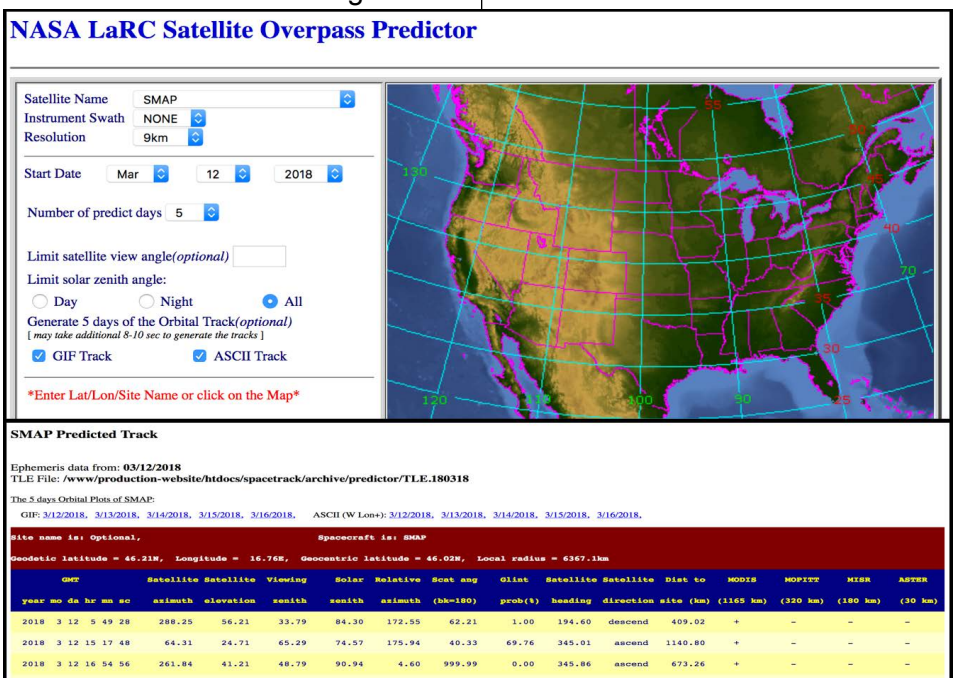

Figure 1. NASA Satellite Predictor Tool displaying example for the Osnovna Skola Varazdin in, Croatia. The most important information in this tool, for this protocol, are Date with GMT Time, Satellite Direction, and Distance to Site.

- Marking the four corners of this Block Pattern Sample area with rocks or other markers. The first sample will be taken at the northwest corner of the 3x3 meter area. The second sampling day, another sample will be collected 25 centimeters away from the previous sample and along the same row, following the pattern as displayed in Figure 2.
- Sampling 25 centimeters apart, starting from one corner and finishing in the opposite corner of the 3x3 meter grid. Students should take one sample each time a collection is done. Each sample should include soil from the top 5 centimeters. (NOTE: Soil moisture sampling disturbs the natural state of the soil, so students should never sample twice from the same point. Students should not sample soils that are frozen or have snow/ice on top of the soil; however, they should make note of such observations. Students can choose a different pattern; however, two samples should not be taken within less than 25 centimeters of one another during a year.)

5. Use the ruler to measure 5 centimeters from the tip of the trowel and mark it with a permanent marker. This is to ensure that you collect soil samples at a depth of 5 centimeters, which is the depth that SMAP can measure.

Preparation Before Sampling:

1. Collect required equipment.
2. Calibrate the balance or scale according to the manufacturer's directions. If you are using an electronic balance, check that the balance is measuring in grams and is zeroed properly.
3. Weigh the sealable plastic bags and sample cans (without their lids). (NOTE: You may wish to weigh and label sealable bags, or cans, for multiple measurement days at the same time.)
4. With a permanent marker, label each sealable plastic bag with its mass, sample collection date, site name or number (whatever you have determined that to be), and label each can with its mass (sample cans can be reused, so make a note of the sample collection date and site name or number).
5. Print a copy of the *Soil Moisture Data Sheet – SMAP Block Pattern*.

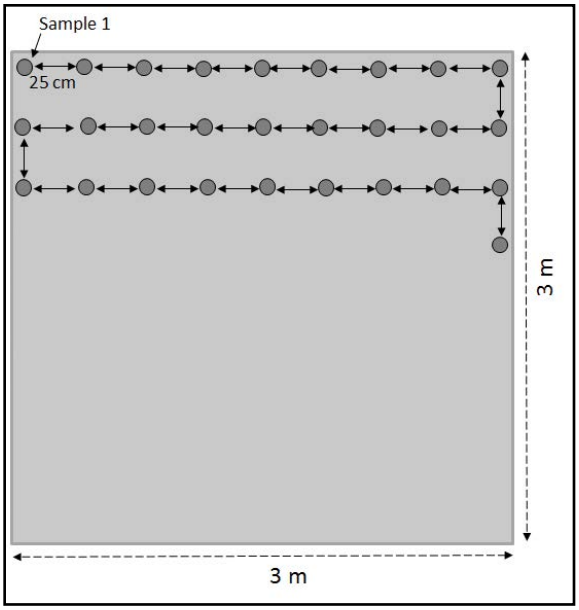

Figure 2. Diagram of the SMAP Block Pattern for collecting soil moisture data

Measurement Procedures

It is important for students to place soil samples in well-sealed containers and to weigh the samples as soon as possible after collecting them. If samples dry out even a little before being weighed, the soil moisture data will be not be accurate.

In the Field -- Preparation of the Soil Moisture Site

1. Complete the top portion of the *Soil Moisture Data Sheet – SMAP Block Pattern*.
2. Locate your sampling point within your site, 25 centimeters from the previous sample point, and cut or pull away any grass or ground cover.

In the Field – Sample Collection

Collect the soil sample.

a. Using a sealable bag:

- Dig the trowel 5 centimeters into the soil and place your sample into the pre-marked sealable bag (see Figure 3).
- Be sure to seal the bag well.

b. Using a tin can:

- Collect samples using a tin can every tenth sample. Alternatively, if you have a soil drying oven, collect all soil samples in a can and dry them in the over. (NOTE: Do not dry plastic bags in a soil drying oven.)
- Smooth the soil surface by scraping across it with your trowel
- Push the can all the way into the soil so that the bottom of the can is even with the ground surface (see Figure 4).
- Use the trowel to dig the filled sample can out of the soil by putting it underneath the can and lifting it out without spilling any of the sample in the can (see Figure 5).
- Level the top of the sample by scraping across it with the trowel. If a large rock or other object sticks out of the top of the sample, pull it out of your sample. Small rocks are part of the soil and can remain as part of the sample collected.
- Seal the sample by covering it with plastic wrap; use a rubber band to ensure that no moisture will evaporate from the sample before it is weighed. You can also use the can's lid; however, it is not recommended because dirt on the lip of the can will cause the lid to get stuck.
- If the soil is hard, place a wooden block on top of the can and pound it into the soil with a hammer (see Figure 6).
- If the soil is so hard that pounding it into the ground will bend the sample can, take a sample using a trowel and sealable bag and wait to take the can sample until the ground has softened.
- Place a flag or other marker in the spot from which the sample was taken so that it is clear where to take future samples.

In the Lab

1. Calibrate the balance according to the manufacturer's directions. If you are using an electronic balance, check that the balance is measuring in grams and is zeroed properly.

For each sample collected in the sealable bag:

2. Weigh the soil sample in the bag (see Figure 7). Record the mass to the nearest 0.1 g as the wet mass in box a on your *Soil Moisture Data Sheet – SMAP Block Pattern*.

3. Open the sample bag and, if necessary, roll the edges down to create a larger open area. If the soil sample is in clumps, break the clumps down with your hand outside the plastic bag (do not touch the soil sample directly).
4. Dry the sample by placing the open bag 20-40 centimeters underneath the 250-watt infrared heating bulb or your specific drying source (see Figure 8).
5. When the samples are dry, remove them from underneath the heating lamp and fill in drying time and drying method on the *Soil Moisture Data Sheet – SMAP Block Pattern*.*
6. Weigh the dry sample and bag and note the dry mass on the *Soil Moisture Data Sheet – SMAP Block Pattern* in box b.
7. Note the weight of the sealable bag on the *Soil Moisture Data Sheet – SMAP Block Pattern* in box d.

Figure 3. Place the soil in a sealable plastic bag.

For each sample collected in a can:

8. Every tenth soil sample is taken with a can. Immediately transfer the soil from the can into a bag labeled with its container mass, container number, sample collection date, and site name or number. (NOTE: Be sure to transfer all of the soil, leaving nothing in the can, so that you will get an accurate measurement.)
9. Find the volume of the clean dry can using a graduated cylinder. Fill the graduated cylinder with water and record the initial volume. Due to water's adhesive property, water in a graduated cylinder forms a meniscus; be sure to record the volume from the bottom of the meniscus (see Figure 9). Clean off the rim of the graduated cylinder as well as the protective ring to avoid unaccounted water drops from entering the can.
10. Pour the water into the can until it fills the can to the brim. Make sure the water in the can has a flat surface (see Figure 10).
11. Record the final volume left in the graduated cylinder and use the equation below to find the volume of the can (V_{can}):

    $V_{can} = V_i - V_f$

    Where V_i is the initial volume in the graduated cylinder and V_f is the final volume.
12. If the water in the graduated cylinder does not fill the can entirely, then repeat Step 9 and Step 10 until the can is full. Record the first volume of the graduated cylinder as volume 1. Pour the water into the can. Fill the graduated cylinder again and record this value as initial volume 2. Repeat, if necessary, recording initial volume 3, etc. Fill the can to the brim and record the final volume of the graduated cylinder. Use the equation below to find the volume of the can:

    $V_{can} = V_1 + (V_{2\,i} - V_{2f})_f$

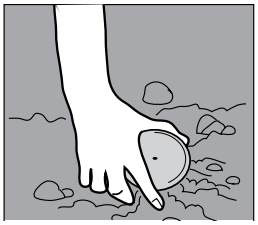
Figure 4. Push the sample can into the soil.


Figure 5. Use the trowel to dig up sample can.


Figure 6. Gently tap the sample can with a wood block and hammer.

13. Measure the volume of the can three times and record the results on the *Soil Moisture Data Sheet – SMAP Block Pattern*.
14. Perform Step 3through Step 7 for drying the sample that has been transferred to a sealable bag.

Note: If you have an oven, then do all soil collections and drying using sample cans. Measure sample bulk density for every tenth sample collected.

Figure 7. Determine the wet mass of the soil sample.

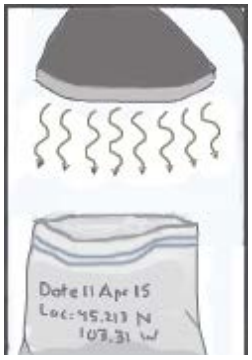

Figure 8. Dry the soil under a heating lamp.

Calculations

GLOBE Data Entry tools will calculate both gravimetric and volumetric soil moisture. However, it is important to understand the calculations:

1. *Gravimetric Soil Moisture* is the difference in the mass before and after drying, which equals the mass of water that was present in the soil. 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 allows valid comparisons among different sites. This measurement is calculated for every sample collected.

   a. To calculate gravimetric soil moisture the following information is needed:
   - Container Mass (g) [sealable plastic bag mass or sample can mass]
   - Wet Mass (g)
   - Dry Mass (g)

   b. Calculate the gravimetric soil moisture in grams using the following equation:

$$\text{Gravimetric Soil Moisture} = \frac{(\text{Wet Mass}) - (\text{Dry Mass})}{(\text{Dry Mass}) - (\text{Container Mass})}$$

Gravimetric Soil Moisture is in units g/g

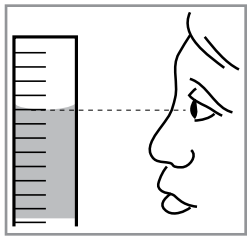
Figure 9. Read the meniscus.

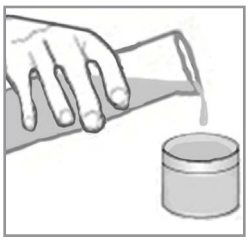
Figure 10. Measure the volume of sample can.

* Weigh the sample after drying it for the recommended 2-3 days. In order to determine if all the water has been removed, dry the sample for an additional period of time (one to several hours) and then weigh it again. If the mass of the sample has not changed, then the sample can be considered completely dry. If the mass has changed by 0.3 grams or more, then dry the sample for another day and weigh it again. Repeat this last part until there is no difference in mass.

2. *Soil Sample Bulk Density* is the ratio of the dry weight of the soil sample to its volume. It is calculated by collecting a soil sample in a can. The soil sample is weighed, dried, and then weighed again to determine the dry weight of the soil. The volume of the can is also measured and the sample bulk density is then calculated by taking the ratio of the dry weight of the soil to the volume of the can. This measurement is taken for every tenth sample.

   a. To calculate soil sample bulk density the following information is needed:
   - Sealable plastic bag mass (g)
   - Dry Mass (g)
   - Can volume (mL*)

   b. Calculate the soil sample bulk density in grams/milliliter* using the following equation

   $$\text{Soil Sample Bulk Density} = \frac{\text{(Mass of Dry Soil)}}{\text{(Can Volume)}}$$

   Soil Sample Bulk Density is measured in g/mL*
   Note: 1 mL = 1 cm^3 or cc

3. *Volumetric Soil Moisture* is the volume of water for a given volume of soil and is calculated by multiplying gravimetric soil moisture by sample bulk density. This measurement is calculated for every sample by using the sample bulk density from every tenth sample collected.

   a. The following information is needed to calculate volumetric soil moisture:
   - Soil Sample Bulk Density (g/cm^3)
   - Gravimetric Soil Moisture (g/g)

   b. Calculate volumetric soil moisture with the following equation:

   Volumetric Soil Moisture = (Gravimetric Soil Moisture) x (Soil Sample Bulk Density/ density of water**)

   Volumetric Soil Moisture is measured in cm^3/cm^3 (or cc/cc) *

   *The SMAP mission calculates volumetric soil moisture using cubic centimeters. One milliliter (1 mL) is equivalent to one cubic centimeter (1 cm^3). After calculating bulk density and volumetric soil moisture in milliliters (mL), you can easily convert to using cubic centimeters (cm^3) with a one to one ratio (1:1).

   **For this measurement, the density of water is always assumed to be 1 g/cm^3

Questions for Further Investigation

1. What other GLOBE schools have patterns of soil moisture similar to yours?
2. How many weeks of the year is your soil relatively wet or relatively dry?
3. Which areas around your school are usually dry or wet? Why?
4. Which holds the most water: clay, sand, or silt? Why?
5. 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?
6. How are soil moisture and relative humidity related?
7. How are soil moisture and soil and air temperatures related?

Frequently Asked Questions

Q: If we can collect soil moisture data only a few times, when will our data be most useful?

A: SMAP scientists hope that you will take a series of measurements so that they can see the change over time in their comparisons with the satellite data. If you can only collect data for a limited period, the most useful time is when soil moisture conditions are changing, in other words when soil is drying out or getting wetter.

Q: At our school, heating lamps may not be left on after hours; how can we dry our samples?

A: At the end of the school day turn off the heat lamps, and then turn them back on the next morning. It may take more than two days to fully dry the sample, but as long as the sample is fully dry when you weigh it, the measurement will be good.

Q: We are improvising a soil drying set-up; what guidance can you give us?

A: First, ensure that whatever you do it will not run the risk of fire. Also, at temperatures above 105^{o} C, some soil compounds other than water may evaporate from the sample, so it is important that your drying set-up never gets samples hotter than this temperature.

Q: The heat lamps melted our sealable plastic bags; what should we do?

A: Move the sample bags further away from the heat lamps in the future.

Q: We have had a long dry spell and our soil has been too hard to get a can into it for more than 10 measurement days; what should we do?

A: Keep taking samples with sealable bags and a trowel until the surface soil softens enough to get a can into it, then take the sample bulk density at the first opportunity. If you anticipate that a prolonged dry period is coming, take the sample bulk density (can sample) measurement even if it is sooner than the tenth measurement.

Q: Can we use a microwave to dry our samples?

A: Never use a microwave to dry your samples. This is extremely dangerous and can cause a fire.