SMAP Soil Moisture Measurement Protocol

Purpose

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

Overview

Students collect a soil sample in a sealable bag and weigh, dry, and weigh it again. If the soil moisture sample was collected in a can, students will transfer the contents into a new bag, weigh it, dry it, then weigh it again and also measure the volume of the can. The gravimetric and volumetric soil moisture are calculated from the wet mass, dry mass, bag mass, and volume of the can.

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.

Student soil moisture data will contribute to the interpretation of data from the NASA Soil Moisture Active Passive (SMAP) Mission.

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.

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
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 data

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

Level

All

Frequency of Measurement

SMAP makes estimates of soil moisture for the same spot on Earth every 2-3 days at approximately 6:00 AM 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 this day and time window are also useful but are more difficult to compare directly with SMAP data. The online SMAP overpass calculator, available at http://smap_op.apps.nsidc.org, identifies when SMAP will be flying overhead based on latitude and longitude. Students should collect one soil moisture sample on collection days. The weighing, drying, and weighing again steps should be done over the next few days. Data should be submitted to

the GLOBE science database as soon as possible. It is important to try to collect the soil moisture samples at approximately the same time every collection day in order to ensure consistency.

Materials and Tools

- A heating lamp that can reach a sustained 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 maybe used, but is not required*
- A balance or scale with 0.1 g sensitivity (600 g capacity recommended, 400 g minimum capacity required)
- Sealable plastic bags (e.g., zip lock bag)
- Small, shallow cans (empty and cleaned small cat food, tuna, or pineapple cans without a lip**. Note: edges may be sharp)
- Plastic wrap to seal the cans
- Rubber bands to hold the plastic wrap around the can. (Alternatively, soil sample cans with lids may be used but are not ideal)
- Site Definition Sheet
- *Soil Moisture Data Sheet – Box Pattern*
- Trowel
- A meter stick
- A ruler marked in millimeters
- A pen or pencil and permanent markers to label the soil containers
- Compass
- GLOBE Science Log (notebook)
- GPS receiver for site definition

Preparation

Decide upon the sampling frequency and method.

Weigh each soil sample container without its lid and record its mass and container number on the container.

Choose and define a soil moisture site.

Prerequisites

None

*Any other safe heating source will work as long as temperature can be sustained for 2 days and reach 60-90 °C (e.g. 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 using a can (do not dry soil in plastic bags in a soil drying oven).

**Cans with a lip will impact the volume of the can

SMAP Soil Moisture Protocol – Introduction

SMAP is a NASA satellite launched on Jan. 31, 2015 to create global soil moisture maps every 3 days. It measures the amount of water in the top 5 centimeters of soil and provides a volumetric soil moisture measurement. This protocol is a guide to making in situ volumetric soil moisture measurements that will 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 far apart they are to each other. If they agree well then the SMAP team can have confidence that the satellite measurements are correct. To support this effort, SMAP has initiated a 7-month-long soil moisture measurement campaign beginning on October 1, 2015 and ending on April 30 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* soil 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 to ensure consistency with SMAP.

Volumetric soil moisture is the volume of water in a given volume of soil and is calculated by

determining 1) gravimetric soil moisture and 2) sample bulk density and then 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, drying, 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 bulk density is the ratio of the dry mass of a soil sample to its volume. This soil property is calculated by collecting a soil sample in a can. The soil sample is transferred to a sealable bag and weighed, dried, and then weighed again 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 can volume. 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 the nine other samples to determine their volumetric soil moisture.

Managing Materials

Make sure that soil sample containers (cans and sealable 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 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 Preparation:

1. 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 SMAP Overpass Calculator 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 image 1). This information will help teachers and students best determine when the satellite instrument track will be closest for useful data collection.
2. Select your site and complete the soil moisture section of the *Site Definition Sheet*.

SMAP Overflights Tool

Lat: 46.3000 Lon: 16.3333

Date: 08/24/2015 Time:

Compute 8 Day Coverage

8 day coverage starting 2015-08-24 00:00:00 Download Data

Date	GMT Time	Distance From Track	Ascending/Descending
2015-08-24	05:39:43	-127.01 KM	descending
2015-08-24	16:44:47	386.22 KM	ascending
2015-08-26	05:15:04	344.22 KM	descending
2015-08-26	16:20:49	-82.57 KM	ascending
2015-08-27	05:51:30	-349.49 KM	descending
2015-08-29	05:27:32	94.6 KM	descending
2015-08-29	16:32:56	164.45 KM	ascending
2015-08-31	16:08:25	-299.75 KM	ascending

Figure 1, SMAP Overflight Tool displaying dates, times in GMT (Universal Time), distance from SMAP instrument track, and whether instrument is ascending or descending for III. osnovna skola Varazdin, Croatia.

3. The SMAP Soil Moisture Protocol suggests using the SMAP block pattern for sampling (Figure 2). The purpose of this sampling pattern is to systematically avoid collecting samples in the same place twice during a year. To lay out a SMAP Block Pattern consists of:
   - Using the meter stick to lay out a 3 m x 3 m rectangular area that is flat, uniform in surface character, not under tree or shrub canopy, relatively free of rocks, and should not be artificially irrigated (unless it is located in a large field that is consistently irrigated).
   - 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 3 m x 3 m area. The second day, another sample will be collected 25 cm away along a row 25 cm from the previous, following the pattern as displayed in figure 2.
   - Soil samples are taken 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. Soil moisture sampling disturbs the natural state of the soil, so students should never sample twice from the same point within a period of a year. 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.
   - **Note:** you can choose a different pattern but two samples should not be taken within less than 25 cm of one another during a year.
4. Join the SMAP Community on the GLOBE website.
5. Use the ruler to measure 5 cm from the tip of the trowel and mark it with a permanent marker. This is done in order to ensure that you collect soil samples up to 5 cm in depth, which is the depth that SMAP can measure.

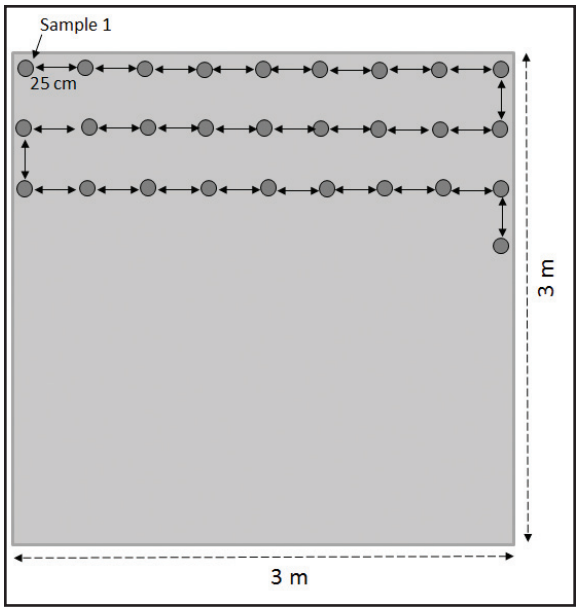


Figure 2, Diagram of the SMAP Block Pattern for collecting soil moisture data

Preparation Before Sampling:

1. Calibrate the balance or scale according to the manufacturer's directions. If using an electronic balance, check that the balance is measuring in grams and is zeroed properly.
2. Collect required equipment.
3. Weigh the sealable plastic bags and sample cans (without their lids). You may wish to weigh and label ziplock 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 location, and sample number and label each can with its mass and an identifying number (sample cans can be reused so make a note of the sample collection date and site location).
5. Print a copy of the *Soil Moisture Data Sheet – SMAP Block Pattern*.

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.

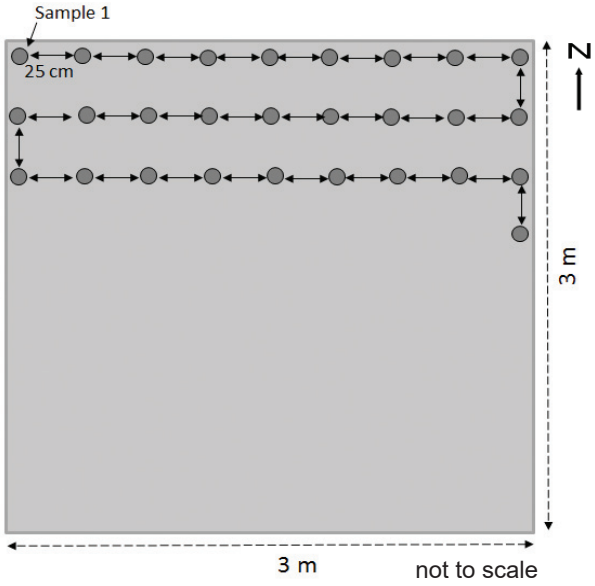
SMAP Block Pattern Soil Moisture Protocol

Field and Lab Guide

Task

Collect a surface soil sample for comparison to SMAP satellite data.

What You Need



- ❑ *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)
- ❑ zip lock bag
- ❑ 1 soil moisture sample can
- ❑ 1 soil moisture sample can lid or plastic wrap and rubber band for water tight covering of the can
- ❑ Permanent marker for writing on ziplock bags and/or sample cans
- ❑ 250 Watt infrared heating lamps that reach temperatures of 65 – 90˚ C (Soil drying oven is also an option)
- ❑ Thermometer capable of measuring to 110˚ C (if using a drying oven)
- ❑ Hot pads or oven mitts for handling dried soil samples
- ❑ Meter stick
- ❑ Ruler marked in millimeters
- ❑ Trowel
- ❑ Hammer
- ❑ Wood block
- ❑ Pen or pencil
- ❑ flag
- ❑ Science Log

In the Field – Preparation of the Soil Moisture Site

1. Complete the *Site Definition Sheet*.(if not already done).
2. Complete the top portion of the *Soil Moisture Data Sheet – SMAP Block Pattern*.
3. Locate your sampling point within your site, 25 cm from the previous sample point, and cut or pull away any grass or ground cover.

In the Field – Sample Collection

Collect the soil sample

Daily Measurements (using a sealable bag):

- dig the trowel 5 cm into the soil and place your sample into the pre-marked sealable bag (Figure 3).
- be sure to seal the bag well.

  Note: If you have a soil drying oven collect all soil samples in a can and dry samples in oven; do not dry plastic bags in a soil drying oven.

IFigure 3, placing soil in zip lock bag

Every 10th Sample (using a sample can)

- smooth the soil surface by scraping across it with you trowel
- push the can all the way into the soil so that the bottom of the can is even with the ground surface (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 (Figure 5).
- level the top of the sample by scraping across it with the trowel. If rock or other object sticks out of the top of the sample, return the sample to the ground, wipe the can clean and take a new sample. (In this case this second sample may be closer than 25 cm, but must be in undisturbed soil.)
- seal the sample using the can's lid or by covering it with plastic wrap and use a rubber band to ensure that no moisture will evaporate from the sample before it is weighed.
- if the soil is hard, place a wooden block on top of the can and pound it into the soil with a hammer (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.


Figure 4, pushing sample can into soil


Figure 5, use trowel to dig up sample can


Figure 6, gently tap sample can with wood block and hammer

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 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 (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 them 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 (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.

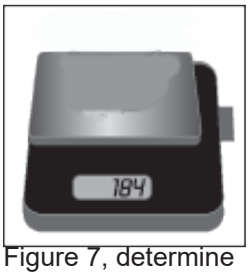


Figure 7, determine wet mass of soil sample and bag

Figure 8, drying soil under a heating lamp

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, and container number, sample collection date, and site name. (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. Because of 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 can has a flat surface (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.

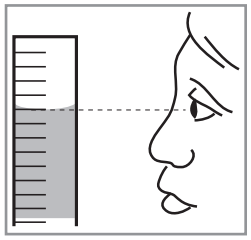


Figure 9, reading the meniscus


Figure 10, measure 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 (e.g. one to several hours) 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.

12. If the water in the graduated cylinder does not fill the can entirely, then repeat steps 9 and 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:

    $V_{can} = V_1 + V_2 - V_F$ or $V_{can} = V_1 + V_2 + V_3 - V_f$

13. Measure the volume of the can 3 times and record the results on the *Soil Moisture Data Sheet – SMAP Block Pattern*.
14. Perform steps #3-7 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.

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

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 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, surface, 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° 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: Keep 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.