# Frost Tube Protocol



## Purpose

To monitor the timing and depth of soil freezing at a GLOBE Frost Tube site.

## Overview

Students will construct a Frost Tube that is inserted into a hole in undisturbed and uncompacted soil. During the cold months, students measure the depth to which water in the Frost Tube has frozen. This indicates the depth to which surrounding soil is frozen.

## Student Outcomes

Students will be able to observe when water in the Frost Tube freezes, then collect, enter, and analyze these data. Starting with data collection in the fall, students will examine how soil freezing relates to air and soil temperatures and snow cover, which coincide with changes in seasons. Students can communicate results with other GLOBE schools and compare the timing and depth of freezing in different biomes around the world. Using Frost Tube data, students can predict the timing and depth of freezing for upcoming seasons (advanced).

### *Science Concepts*

*Earth and Space Sciences*

Some regions of the world have freeze/thaw cycles and these occur seasonally. Other regions do not have these cycles as the soil never freezes or thaws.

Water infiltrates into the soil and freezes at certain depths during the seasonal cycles.

Depending on the geographical location of the soil being tested, some water in soil may never thaw or freeze.

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

The depth of snow and/ or organic material (moss, leaf litter, etc) can impact how deep soil freezes.

*Life Sciences*

The temperature of the soil will impact the type of life growing on and in it and how it grows. (Organisms' functions relate to their environment.)

The type of vegetation growing on soil can influence how deep soil freezes and thaws as well as the rate at which it freezes and thaws. (Organisms change the environment in which they live.)

*Scientific Inquiry Abilities*

Use appropriate tools and techniques including mathematics to gather, analyze, and interpret data.

Develop descriptions and predictions using evidence.

Recognize and analyze alternative explanations.

Communicate procedures and explanations.

## Time

Construction of Frost Tube: 1 - 2 hours

Selection of site, set up and installation of Frost Tube: 1 - 2 hours

Measure Frost Depth: 5 minutes

## Level

All

## Frequency

Depth of frozen ground is measured at the same time of day once a week beginning when air temperatures approach freezing (0°C).

## Materials and Tools

- ❑ *Frost Tube Site Definition Field Guide*
- ❑ *Frost Tube Site Definition Sheet*
- ❑ *Frost Tube Field Guide at Air Temperatures Warmer Than -20 C*

- ❑ *Frost Tube Field Guide at Air Temperatures Colder Than -20 C*
- ❑ *Frost Tube Data Sheet*
- ❑ *GPS Protocol Field Guide* (if using a new site)
- ❑ *GPS Protocol Data Sheet* (if using a new site)
- ❑ GPS receiver (if using a new site)
- ❑ Soil probe or tile probe (needed once for installation)
- ❑ Frost Tube (see *Instrument Construction and Installation* for instructions on how to construct and install a Frost Tube)

### *Preparation*

Select a site for installing your Frost Tube. Ideally, the site should be in relatively undisturbed and uncompacted soil in native vegetation and within 30 meters of your Atmosphere study site if you have one. **Check with appropriate authorities for safety in digging in soil at the selected site.**

Obtain a GPS reading of the Frost Tube Protocol study site.

### *Prerequisites*

GLOBE *GPS Protocol*

*Recommended*

GLOBE *Soil Temperature Protocol*
GLOBE *Soil Characterization Protocol*
GLOBE *Atmosphere Protocol (Air and Soil Temperature;* **Surface Temperature, Solid** *Precipitation)*

# Introduction

### *Why Study Frozen Ground?*

The depth and timing of seasonally frozen ground affects hydrology, construction, plant growth, agriculture, soil processes, and even burials. Because frost depth is closely linked to both air and soil temperatures, Frost Tube measurements indicate when air temperature remains below freezing, causing soils to freeze from the surface down. Frozen soil indicates soil temperatures of zero degrees Celsius (0°C) or below. Therefore, Frost Tube measurements indicate soil temperature without the need for a themometer.

Monitoring the timing and depth of soil freezing and thawing helps students and scientists to understand how soil temperature is changing over time. The temperature of the soil is an important measurement to understand because it affects microclimate, plant growth, the timing of budburst or leaf fall, the rate of decomposition of organic material, and other chemical, physical, and biological processes that take place in the soil. In a climate-determined biome, the pattern of soil temperature within each season is consistent. Specifically, the mean (average) summer soil temperature, mean winter soil temperature, and mean annual soil temperature stays relatively constant from year to year. However, if a change in mean summer, winter, or annual soil temperature occurs from one year to the next, it could be due to some significant change in the surrounding environment such as an increase in air temperature or some type of disturbance such as deforestation, removal of the insulating soil surface, or urbanization (see the GLOBE *Soil Temperature Protocol* for more information about soil temperature). If soil temperatures warm, the depth of soil freezing may decrease and the time of freezing will be delayed. For this reason, monitoring the depth and timing of soil freezing helps scientists to investigate changing soil temperatures and identify the effect of **climate change** or other disturbances on ecosystems and biomes.

The pedosphere Frost Tube Protocol allows GLOBE students and scientists to see what part of the soil freezes and when the freezing starts and ends in different parts of the world.

At mid-latitudes and mid-elevations on the Earth, parts of the soil near the surface freeze in the winter. In these locations, frost conditions are an important factor in predicting runoff from rain and snowmelt. Snow cover tends to insulate the ground, slowing the timing and decreasing the depth of freezing. When water in soils freeze, it expands, causing frost heave. Additionally, when soils thaw, the frozen water melts, causing cavities and potholes. Transportation authorities use frost depth to establish weight loads on roadways, since frozen road beds are solid load-bearing surfaces. Studying frozen ground helps communities construct roadways that are less susceptible to frost heave, saving time and resources. Farmers and gardeners consider the date and depth of frost while determining when to plant. Builders consider frost depth to determine where to bury pipes and install foundations.

Center http://nsidc.org/cgi-bin/words/word.pl?permafrost).

Permafrost zones occupy up to 24 percent of the exposed land area of the Northern Hemisphere (Figure 1). Permafrost of various temperatures and continuity also exists in mountainous areas, due to the cold climate at high elevations. Subsea permafrost, which formed during the last glacial period with low sea levels, is also common within the vast continental shelves of the Arctic Ocean. Subsea permafrost is slowly thawing at many locations.


Figure 1. *Permafrost extent in the Northern Hemisphere*

(Map from Brown et al., 1997 modified by UNEP/GRID)

Studying the timing and depth of ground freezing in mid-latitudes and mid-elevations helps communities plan for climate change impacts.

In northern and southern latitudes and at high elevations, where air temperatures rise above freezing for a few months of the year, the ground surface temporarily thaws before freezing again after the arrival of cooler weather. Historically, these cold climates have **permafrost,** earth materials that remain at or below 0°C for at least two consecutive years (http://www.uspermafrost.org/glossary.php). Permafrost exists where summer heating fails to reach the base of the layer of frozen ground (National Snow and Ice Data

One of the indications of permafrost presence is "patterned ground" (Figure 2), which include large polygon shaped features called "pingos." Pingos form when the soil freezes and thaws over many seasons, creating an ice core that is being pushed up by groundwater.

The layer of soil above permafrost that seasonally freezes and thaws is called the **active layer**. The GLOBE Frost Tube Protocol is used to monitor depth and timing of freezing of the active layer in places with permafrost. When students monitor depth of freezing, they are measuring the depth from the ground surface, not from the frozen permafrost below. In soils with permafrost, as the air temperature warms and the ice in the upper soil horizons

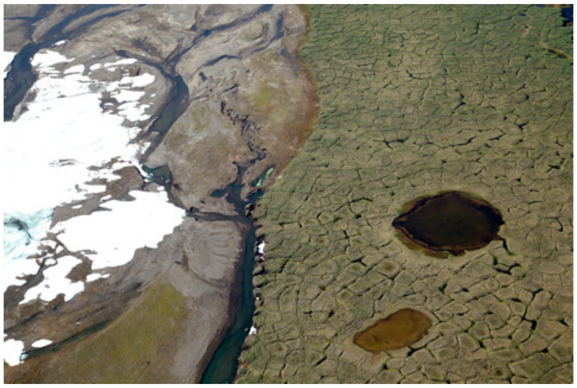

Figure 2. *Patterned Ground*
(http://www.uspermafrost.org/glossary.php)

melts, the melted water moves through the soil and freezes again as it reaches the permafrost layer; the soil then begins to freeze from the bottom up. The Frost Tube will show this process.

The thickness of the active layer depends on local climate, vegetation cover, soil properties, and heat within the Earth. As air temperatures cool (e.g. fall going into winter) the layer of freezing in the soil increases but is affected by variables such as snow depth and the thickness of the vegetative layer.

Like in temperate climates, thick layers of snow and/or vegetation will insulate the soil and prevent it from freezing until later in the winter. Heavy snowfall early in the year that persists will delay ground freezing. The maximum freeze in undisturbed soil generally occurs in late winter or early spring when air temperatures are starting to warm up. In the same way, the depth of thawing in permafrost areas is usually deepest at the end of the summer or even after the first few surface frosts in early autumn.

As the soil surface is impacted from disturbances such as changes in hydrology, building roads, urbanization, cutting trees, or mining peat moss, the insulating properties of the soil surface are removed and more heat and light move into the soil, increasing its temperature and causing frozen layers to thaw. The water and minerals collect and are frozen again from the top down during winter.

In cold climates with permafrost, large amounts of frozen organic matter (dead plants and animals) are affected by air temperature. If permafrost thaws, the organic matter decomposes, releasing greenhouse gases such as carbon dioxide and methane, while further warming the air. In northern and southern latitudes and at high elevations, studying frozen ground in the active layer helps students and scientists explore the interactions of thawing permafrost and climate change.

### *What is a Frost Tube?*

The instrument used to measure the depth and timing of the freezing of the ground is called a Frost Tube. This instrument is easily made and installed in undisturbed soil near your school. Installation is best done in summer/fall when soil is not frozen. A soil probe (also called tile probe) can be used to create a hole the same size as the Frost Tube to prevent disturbing the soil.

The Frost Tube consists of two tubes nested together (Figures 3, 4):

Inner tube - 2 meter section of 6-7 mm clear plastic tubing marked in 5 cm increments holding colored water.

Outer tube - 2 meter section of a 20 mm (outer diameter) PVC tube sealed, plugged, or capped on the bottom, with a removable cap at the top.

When inserted in a pre-probed hole in the ground, 1 meter of the Frost Tube sits below ground and one meter is above ground. The cap on top prevents snow, water, and debris from entering. The inner tube with colored water shows where ice has formed underground and soil temperature is 0°C or colder.

Students measure the depth of freezing as the ground cools. Depth of Freezing = distance in the Frost Tube (inner tube) from the soil surface to the boundary between the ice layer and unfrozen colored water. This boundary represents the depth of freezing measured from the soil surface to the underlying unfrozen soil.

To take a frost depth measurement, lift the inner tube and measure the depth between the ground surface line marked as 0 cm and the boundary between ice and colored liquid water.

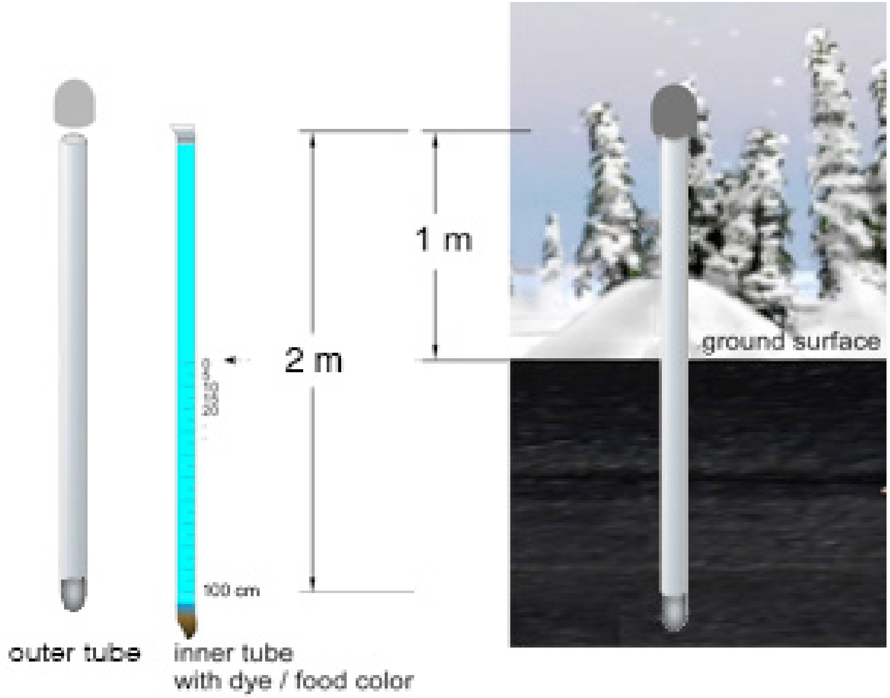


Figure 3. *Components of a Frost Tube*

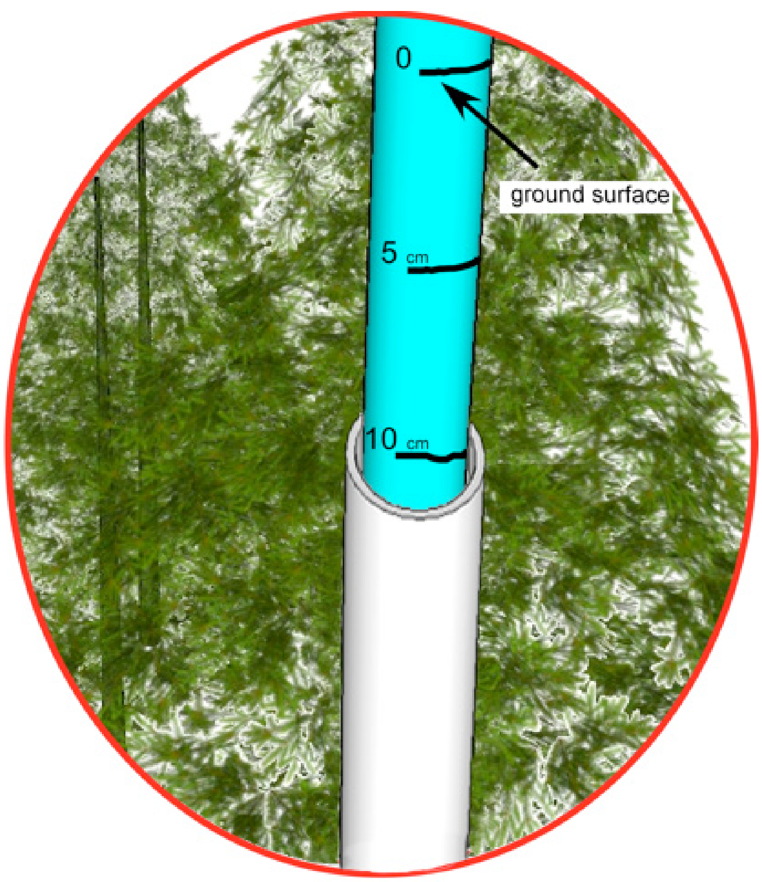


Figure 4. *Another view of the Frost Tube showing inner outer tubes*

# Instrument Construction and Installation

## Instructions for Making and Installing a Frost Tube to Measure Depth of Frozen Ground

### *Materials*

- ☐ Inner tube: 6 - 7 mm diameter (1/4" outside diameter) clear tubing, at least 2 m long
- ☐ Outer tube: 20 mm diameter (1/2" inside diameter) PVC tube, at least 2 m long
- ☐ 1 PVC cap to fit on 20 mm PVC tube
- ☐ 1 PVC end plug or cap, for the bottom of the 20 mm (1/2") PVC tube (epoxy putty may be used if cap is too large)
- ☐ PVC Cement
- ☐ Gas burner, alcohol lamp, or lighter to seal inner tube
- ☐ Pliers for pinching heated inner tube
- ☐ Gloves for applying PVC cement
- ☐ Food coloring and water
- ☐ Bowl for mixing food coloring with water
- ☐ Wash bottle with spout or funnel
- ☐ Black waterproof marker
- ☐ Meter stick with cm markings
- ☐ Soil probe or steel rod, 20  mm or 3/4" diameter, 1.5 m (60") in length.
- ☐ Flag
- ☐ *Frost Tube Site Definition Data Sheet*

### *Directions for Construction*

The Frost Tube consists of two layers:

- The innermost tube is a piece of clear tubing sealed on both ends, which holds colored water.
- The outermost tube is a piece PVC pipe, sealed with a PVC end plug secured with PVC cement on bottom and fitted with a removable cap on top.

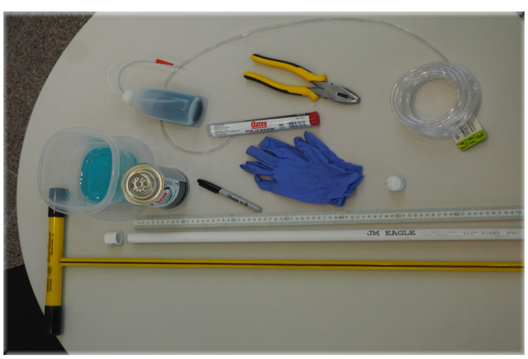


Figure 1a. *Parts of Frost Tube*

Figure 1b. *Assembled Frost Tube*

1. Estimate the below-ground length of the Frost Tube.

   *In areas of seasonally frozen ground:* The length of the Frost Tube should be a little longer than the depth to which the ground freezes in winter.  The suggested length is 2 meters (1 meter above and 1 meter below the ground surface).  Frost and thaw depth tables for your area will help you estimate the length.

   - At your site, pound or turn the probe vertically into the ground until you reach 1 meter or the estimated depth.  You may need to push the probe deeper in sandy soils, which tend to have deeper frost penetration. Mark the hole with a flag.

*In high latitudes and altitudes with permafrost:* The below-ground length of the Frost Tube depends on the depth of the active layer. Permafrost can be variable, so probing the ground is necessary.

- Check the thickness of the active layer using a steel stick or rod (thaw probe) at the end of the summer. Write down this depth.
- Pound the probe into the ground until you hit permafrost. It will feel like you have hit rock or something very hard. Your Frost Tube should extend to this depth. Flag this location for later installation.

2. Determine the length of the entire Frost Tube by adding 1 meter to the estimated below-ground length. Cut both tubes (inner and outer tubes) to the final length. Write this down on the *Frost Tube Site Definition Data Sheet*. The height of 1 m above ground allows the top of the Frost Tube to stick out of the snow (in most areas), be protected from runoff and animals, and be accessible.

3. Use a PVC end plug or cap to seal the bottom of the outer tube. A plug fits inside the tube, while a plug fits over the outside of the tube. Following the manufacturer's instructions and wearing gloves (latex, vinyl, or nitrile), coat the bottom 1 cm of the outer tube with the PVC cement and place the cap or plug. If you have wet soils, epoxy putty as a

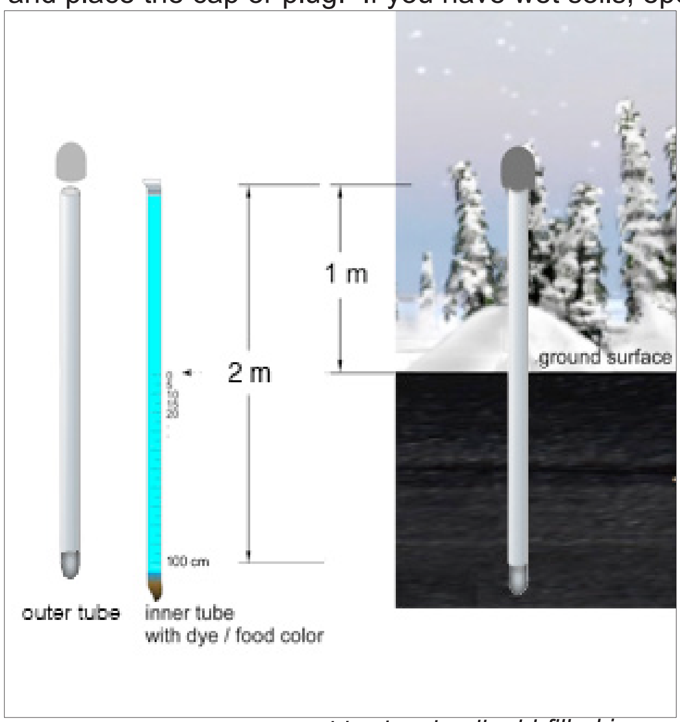


Figure 2. *Frost Tube assembly showing liquid-filled inner tube (both ends sealed) and outer tube as well as the assembled frost tube placed in the ground.*

plug with a cap over will keep water from infiltrating into the tube. If using epoxy putty, allow it to cure (harden) according to the instructions from the manufacturer.

4. In a bowl, mix water and enough food coloring to make bright but transparent color. Using the wash bottle or a funnel, fill the clear tube with the colored water up to 15 cm from the top being careful to keep it from pouring out the other end. (Eventually you will seal both ends of the inner tube but for now leave both ends unsealed. If you seal one end, the water will not go into the tube since it will not displace the air present.)

5. Light the gas burner. **Use ventilation and be careful not to burn yourself**. Seal one end of the clear tubing by heating it with the burner and press the ends together with pliers. This becomes the bottom end. Make sure that the seal does not distort the bottom of the tubing so it slides easily down into the outer PVC tube. Make sure that you do not stretch the inner tube because it must be the same length as the outer tube.

6. Seal the top end of the clear (inner) tubing by heating it with the burner. **Use ventilation and be careful not to burn yourself**. Flatten this end so that it is just wider than the diameter of the outer tube, but can still fit under the cap. This way, the top of the clear (inner) tube can be retrieved for measuring depth of freezing (Figure 1b).

7. Slip the clear inner tube, now filled with the colored water and sealed on both ends, into the outer tube so that it extends to the sealed bottom of the outer tube.

8. Place the cap on top of the outer tube.

### *Directions for Installation*

1. Return to the flagged location where you inserted the soil probe into the soil. Begin the *Frost Tube Site Definition Data Sheet*.

2. Insert the soil probe into the hole to the estimated depth. The hole should be just deep enough to accommodate the below-ground portion of the outer tube. If necessary, move the probe side to side and up and down to widen the hole.

3. Place the entire Frost Tube assembly into the hole. It should fit snugly in the hole and reach the estimated depth.

4. Mark the soil surface on the outer tube. Use a meter stick to measure the distance between the soil surface and the top of the outer tube. Subtract this measurement from the total length of the outer tube to get the below-ground depth of the Frost Tube. Record these lengths on the *Frost Tube Site Definition Data Sheet*.

5. Pull the inner clear tubing out and hold it close to the outer tube, lining up the top of the inner tube with the top of the outer tube. Clearly mark where the soil surface occurs with a permanent marker on the outside of the inner tube. Label the soil surface as 0 cm.

6. Lay the inner tube on a flat surface. Mark 5 cm increments from the 0 cm line to the bottom of the inner tubing using a meter stick and permanent marker. Write in the number next to every 10 cm interval (i.e., 10, 20, 30, 40, etc.). Place hash marks 1 cm apart so there are 4 evenly placed hash marks between each 5 cm mark (Figure 3).

7. Return the inner tubing to the installed outer tube of the Frost Tube assembly.

8. Cover the top of the Frost Tube with the PVC cap (*do not glue!*) to minimize the chance of snow, water, debris, and/or ambient air getting down inside (Figure 4). You may need to bend the top of the inner tube to get the cap to fit snugly.

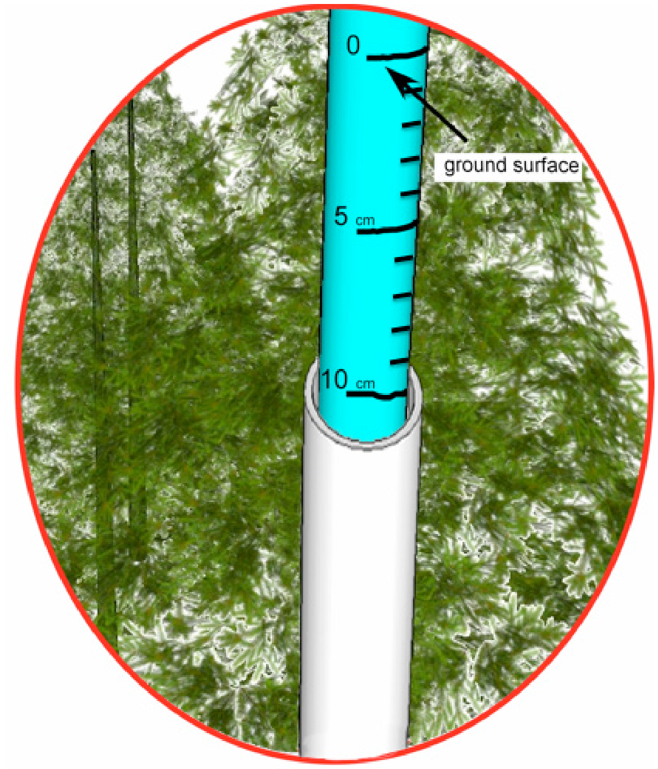


Figure 3. *Ground surface and 5 cm below-ground increments with 1 cm hash marks on inner tube*

Figure 4. *Assembled frost tube on left with a meter stick on the right*

# Teacher Support

## *The Big Picture*

The temperature of soil is linked to the temperature of the atmosphere. As air temperature increases or decreases, so does soil temperature. Depth of soil freezing is related to the length of time that air temperatures have been 0°C and colder. Pedosphere Frost Tube protocol is related to Earth System processes and atmosphere, biosphere, and pedosphere protocols.

The amount of heat that will be absorbed or released by the soil from and to the atmosphere depends on a number of factors including topography, vegetation cover, organic matter content, soil texture, soil moisture, and soil bulk density. In northern latitudes, a north facing slope will be colder and more likely to freeze than a south facing slope; the reverse is true in southern latitudes. The type of trees or other vegetation growing on the soil determines how much heat and light reach the soil below the vegetation canopy. A more open canopy will let more heat and light in than a closed canopy. A moss layer or organic matter in the soil acts as an insulator that slows the transfer of heat to and from the mineral parts of the soil. Wet soils heat more slowly than dry soils because the water in the pore spaces between the soil particles absorbs more heat than air. The denser the soil, the more heat is conducted through it. Thus, a sandy soil or a soil with a high bulk density will conduct heat faster than a clay or loamy soil with good structure and low bulk density. Students can investigate various factors that affect heat absorbed or released by soil, thereby affecting frost depth.

Monitoring the depth of soil freezing helps scientists and engineers understand how the temperature of the soil is changing over time as well as the local effects of climate change.

## *Who can do the Frost Tube Protocol?*

First, ask the following questions:

1. Do air temperatures reach freezing during some time of the year?
2. Does the soil freeze during part of the year?
3. Is there permafrost underlying soil in your area?

If you answer yes to any of these questions, then this protocol is a worthwhile investigation for your class. This protocol is a first step to helping students investigate relationships among air, soil, snow and permafrost (where it occurs).

## *Site Selection*

Ideally, the Frost Tube Study Site should be in relatively undisturbed and uncompacted soil in an area of native vegetation. Since the results for this protocol could be combined with temperature and precipitation data from a GLOBE Atmosphere Investigation, try to choose a site close to the Atmosphere study site, if you have one. It is best to locate your Frost Tube within a 5 minute walk from your school so it is relatively easy to access in cold weather.

**Check with the appropriate authorities for permission to install the Frost Tube at your proposed site and to locate it safely away from any buried cables or pipes.**

Be aware that nearby buildings, roads and even lakes or rivers may influence soil temperatures and affect the data you collect; carefully document this information on the *Frost Tube Site Definition Sheet*.

Many soils in northern latitudes were formed from glacial parent material. Hence, soils in this region may contain many large rocks that may make it difficult to dig or probe. When possible, locate an area with a minimum of rocks or use more robust equipment for inserting the Frost Tube, such as an auger or drill.

## *Measurement Considerations*

Frost Tube observations should be done by a minimum of two people per visit so one person can do the measurement while the other(s) hold the cap and record the data.

It is very important that Frost Tube measurements occur every week once the air temperature drops below freezing. Students need to collect measurements quickly and efficiently to reduce the effect of the surrounding air temperature on the Frost Tube. When students are finished making their observations, they must replace the top cap to keep snow, water, and ambient air out of the Frost Tube.

If snow is on the ground, students must take care to walk in a single path to prevent removing or compacting the snow near Frost Tube. Record snowpack in cm by taking three measurements with a meterstick following the first three steps of the **Solid Precipitation Field Guide**. The snowpack data can be recorded on the paper Frost Tube data sheet, but must be entered online as part of the atmosphere precipitation protocol.

In addition to snowpack, air temperature and surface temperature are optional measurements that students see on the **Frost Tube Data Sheet.** Refer to the **Air Temperature Field Guide** and the **Surface Temperature Field Guide.**

In areas with permafrost, the teacher should check the inner tube late in summer to determine maximum depth of thaw of the active layer (the layer above permafrost that seasonally freezes). If ice is present at the bottom of the inner tube, measure the distance from the soil surface to the ice boundary. Enter this data in the Comments section of the *Frost Tube Data Sheet*. NASA has conducted airborne and satellite missions to determine the depth of thaw. Students and teachers can compare local ground-based observations to airborne and satellite data.

### *Frequently Asked Questions*

1. Where is the deepest ice-water boundary in non-permafrost underlain areas?

The depth of where the colored water ends and clear water begins is used as an aid to read the ice-water boundary. However, sometimes when the water in the inner tubing freezes and thaws, the color or dye is pushed out of the frozen portion, and even when it thaws and refreezes, the color does not go back. Hence, students need to bend the tube to feel the presence of solid ice.

2. What is frost heave? Frost heave is the upward movement of soil when water in soil freezes and expands. As soils freeze and thaw, especially in the spring with colder nights and warmer days, ice can form. Over time, enough water accumulates and then freezes, expands, and pushes overlying material upwards. Frost heaves can damage roads, bridges, buildings, railroad tracks, and fences. When ice in soil thaws, water eventually drains out, and the soil may sink. Potholes in roads are an example of frost heave; water gets into pavement, freezes, expands, and causes cracking. After the ice thaws, vehicles compress the void left over by the water, causing a hole.

3. What do I do when the line marked as the soil surface is now above or below ground due to frost heave? If the Frost Tube has been heaved up, try to push it back down until it will not go further. If the Frost Tube has subsided, then leave it in place. Make a new line on the outer tube at the soil surface. Measure the length of the above-ground portion of the tube and record it on the *Frost Tube Site Definition Sheet*. Subtract the above ground-portion from the original length of the Frost Tube and record this as well. You will need to designate the Frost Tube as a new site with new measurements. Additionally, you will need to re-mark the tube. The Frost Tube may have to be reinstalled.

4. How deep should the Frost Tube be in areas that have sub-freezing air temperatures but no snow? Places with cold air temperatures without snow may have ground freezing deeper than 1 meter, requiring a Frost Tube that is 3 meters total length (1 meter above and 2 meters below ground).

5. Can I use other materials (than PVC) for the outer tube? There are two types of PVC: Schedule 40 and Schedule 80. The latter is much thicker and sturdier for rocky soils, but has a smaller amount of room for the inner tube. CPVC can be used, as it allows thermal transfer from the surrounding soil to the water in the inner tube, but it is brittle and will need to be replaced if it cracks.

6. Can I use a rubber plug on the bottom of the PVC tube? No. Rubber will crack and allow water and soil to get into the outer tube. Threaded cap plugs are available and PVC cement is recommended when installing the plug. If threaded cap plugs are not available, use epoxy putty to make a plug and place a PVC end cap over it, secured with PVC cement.

# Frost Tube Protocol – Looking at the Data

## Are the data reasonable?

The depth of freezing usually moves very slowly from the soil surface down (less than 1 cm per day). However, if air temperatures colder than 0°C persist early in winter and there is no snow cover, freezing could happen quickly in the top 5-10 cm of soil depending on soil water content. This typically happens in permafrost-underlain regions such as in Interior Alaska as well as in northern latitudes with sandy soils, where air and water can quickly penetrate greater depths.

Snow thickness is an important factor in ground freezing because of its insulating property. Different freezing depths could result in closely-placed Frost Tubes that have the same air temperature but different snow than warmer temperatures or more snow in another area. Coarse soils allow deeper penetration of frost because the larger particles will have larger pore spaces to allow cold air to penetrate.

Scientists consider the timing of soil freezing. Delay in ground freezing could be captured by Frost Tube data. Delay in ground freezing directly affects the degradation of the permafrost in northern latitudes.

Scientists use Frost Tube data to compare the differences in ground freezing timing and depths, which can be modeled once soil and snow conditions are known.

## Predicting Future Frost Depth

When winter comes, the ground freezes; as winter progresses, the frozen soil becomes thicker (Figure 5).

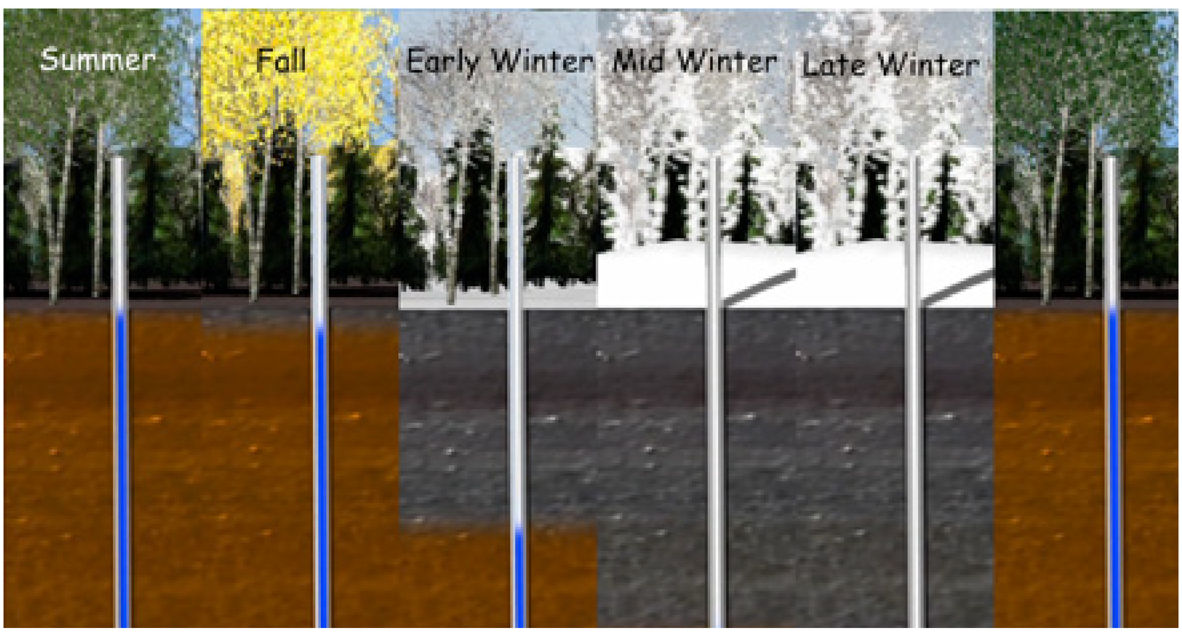


Figure 5. *Progression of freezing through the seasons. Frozen ice is shown as white and unfrozen water as blue in a Frost Tube.*

depths. For this reason, one factor that could make unreasonable data is the compaction or removal of snow near the Frost Tube.

## How do scientists use the data?

Frost Tube measurements are important because frost depth depends on air temperature, snow depth, and soil properties. Severe cold temperatures with little snow in one area could result in deeper soil freezing

Scientists are able to predict how thick the frozen soil will become using the following formula:

$$D = aF$$

**D** = depth of freezing

***a*** = thermal property coefficient

**F** = $\sqrt{\text{freezing degree days}}$

***a*** is the thermal property coefficient of the soil, which is influenced mainly by soil moisture, organic matter, and particle size. ***a*** varies between 1 to 5 and strongly depends on location. For example, ***a*** is 3 in saturated sandy material; 2.3 in dry silty material; 2 in organic material.

**F** is the square root of the number of freezing degree days (fdd) at the ground surface. Freezing degree days is a measure of how cold it has been and how long it has been cold. Another way to think about fdd is the accumulated daily average surface ground temperatures colder than 0˚C. The fdd unit is "°C days."

To gather daily ground surface temperatures, schools can use a GLOBE digital max-min thermometer and place one sensor at the soil surface in the summer/fall during Frost Tube installation. They will average the maximum and minimum temperatures to get the daily average per day.

Cumulative fdd is calculated as a sum of the average daily degrees below freezing for a specified time period (10 days, month, season, etc.). (National Snow and Ice Data Center https://nsidc.org/cryosphere/glossary/term/freezing-degree-days).

By taking the square root of freezing degree days, F can be calculated. Multiplying F by a, the depth of freezing **D** can be predicted. The first step is calculating the freezing degree days.

## Calculating freezing degree days

The calculation of freezing degree days (fdd) at ground surface is used by scientists to estimate depth of freezing. For this method, students will need the daily average ground surface temperature data for their school. Ideally, collect ground temperature data from September 1st (if you live in the Northern Hemisphere) or April 1st (if you live in the Southern Hemisphere) up to and including the date when temperatures return to above freezing (0°C) consistently.

To calculate freezing degree days (fdd):

1. First, for each day, calculate the daily average ground surface temperature (Tavg) by averaging the daily maximum and minimum temperatures.

2. Starting with September 1 or April 1 (ideally), check to see if Tavg is less than 0˚ C. If it is, record this temperature in the fdd by day column (Table 1). If Tavg is greater than 0˚ C, record 0 in the fdd by day column. Go to the next day. Again, check to see if Tavg is less than 0˚C; if it is, add it to the temperature you recorded for the first and place the sum in the cumulative fdd column; if not, ignore it and carry down the prior day's cumulative fdd sum. Repeat this process for each subsequent day up the period when ground surface temperatures are consistently above freezing (i.e. until late spring). The sum of the daily average temperatures below 0 °C is the freezing degree days (fdd unit is "°C days"). Freezing degree days does not include minus (-) sign.

Table 1 shows example student data comparing two Alaskan communities. Homer, Alaska is located near the southern tip of the Kenai Peninsula on a bay that reaches into the Gulf of Alaska - an arm of the Pacific Ocean. Igiugig, Alaska is a small village on Illiamna Lake at the mouth of the Kvichak River. Although it has a similar latitude as Homer, its climate is colder.

| | Tavg (C) Homer | fdd by day Homer | fdd Cumulative Homer | Frost Depth (cm) Homer | Tavg (C) Igiugig | fdd by day Igiugig | fdd Cumulative Igiugig | Frost Depth (cm) Igiugig |
|---|---|---|---|---|---|---|---|---|
| 10/1/08 | 2 | 0 | 0 | | nd | nd | nd | |
| 10/2/08 | 1 | 0 | 0 | 0 | nd | nd | nd | 0 |
| 10/3/08 | 1 | 0 | 0 | | nd | nd | nd | |
| 10/4/08 | 0 | 0 | 0 | | nd | nd | nd | |
| 10/5/08 | 0 | 0 | 0 | | nd | nd | nd | |
| 10/6/08 | 0 | 0 | 0 | | nd | nd | nd | |
| 10/7/08 | -1 | 1 | 1 | | nd | nd | nd | |
| 10/8/08 | -1 | 1 | 2 | | nd | nd | nd | |
| 10/9/08 | -1 | 1 | 3 | | nd | nd | nd | |
| 10/10/08 | -1 | 1 | 4 | | nd | nd | nd | |
| 10/11/08 | 4 | 0 | 4 | | nd | nd | nd | |
| 10/12/08 | 2 | 0 | 4 | | nd | nd | nd | |
| 10/13/08 | 0 | 0 | 4 | | nd | nd | nd | |
| 10/14/08 | 0 | 0 | 4 | | nd | nd | nd | |
| 10/15/08 | 0 | 0 | 4 | | 2 | 0 | 0 | |
| 10/16/08 | 0 | 0 | 4 | | -2 | 2 | 2 | |
| 10/17/08 | 1 | 0 | 4 | | -4 | 4 | 6 | |
| 10/18/08 | 1 | 0 | 4 | | 2 | 0 | 6 | |
| 10/19/08 | 0 | 0 | 4 | | -2 | 2 | 8 | |
| 10/20/08 | -1 | 1 | 5 | | -4 | 4 | 12 | |
| 10/21/08 | -1 | 1 | 5 | | -2 | 2 | 14 | |
| 10/22/08 | -1 | 1 | 6 | | -6 | 6 | 20 | |
| 10/23/08 | -1 | 1 | 8 | | -6 | 6 | 26 | |
| 10/24/08 | -3 | 3 | 11 | | -7 | 7 | 33 | |
| 10/25/08 | -4 | 4 | 15 | | 0 | 0 | 33 | |
| 10/26/08 | -2 | 2 | 17 | | -4 | 4 | 37 | |
| 10/27/08 | | 4 | 21 | | -9 | 9 | 46 | |
| 10/28/08 | -7 | 7 | 28 | -13 | -9 | 9 | 55 | |
| 10/29/08 | -6 | 6 | 34 | | 0 | 0 | 55 | |
| 10/30/08 | -5 | 5 | 39 | | 2 | 0 | 55 | |
| 10/31/08 | -2 | 2 | 41 | | -4 | 4 | 59 | |
| 11/1/08 | -4 | 4 | 45 | | -3 | 3 | 62 | |
| 11/2/08 | -7 | 7 | 52 | | -5 | 5 | 67 | |
| 11/3/08 | -7 | 7 | 59 | | -11 | 11 | 78 | |
| 11/4/08 | -7 | 7 | 66 | | -10 | 10 | 88 | -27 |
| 11/5/08 | -4 | 4 | 70 | -32 | -7 | 7 | 95 | |
| 11/6/08 | -4 | 4 | 74 | | -4 | 4 | 99 | |
| 11/7/08 | -3 | 3 | 77 | | -7 | 7 | 106 | |
| 11/8/08 | -5 | 5 | 82 | | -2 | 2 | 108 | |
| 11/9/08 | -5 | 5 | 87 | -37 | 2 | 0 | 108 | |
| 11/10/08 | -1 | 1 | 88 | | 1 | 0 | 108 | |
| 11/11/08 | 0 | 0 | 88 | | -2 | 2 | 110 | -37 |
| 11/12/08 | -1 | 1 | 89 | | -3 | 3 | 113 | |
| 11/13/08 | -2 | 2 | 91 | | -5 | 5 | 118 | |
| 11/14/08 | -5 | 5 | 96 | | -4 | 4 | 122 | |
| 11/15/08 | -4 | 4 | 100 | | -1 | 1 | 123 | |
| 11/16/08 | -4 | 4 | 104 | | -4 | 4 | 127 | |
| 11/17/08 | -2 | 2 | 106 | | -7 | 7 | 134 | |
| 11/18/08 | -5 | 5 | 111 | | -11 | 11 | 145 | -36 |
| 11/19/08 | -7 | 7 | 118 | | -12 | 12 | 157 | |
| 11/20/08 | -8 | 8 | 126 | | -15 | 15 | 172 | |
| 11/21/08 | -5 | 5 | 131 | | -18 | 18 | 190 | |
| 11/22/08 | -7 | 7 | 138 | | -14 | 14 | 204 | |
| 11/23/08 | -8 | 8 | 146 | | -10 | 10 | 214 | |
| 11/24/08 | -3 | 3 | 149 | | 1 | 0 | 214 | |
| 11/25/08 | -2 | 2 | 151 | | -11 | 11 | 225 | |
| 11/26/08 | -3 | 3 | 154 | | -14 | 14 | 239 | |
| 11/27/08 | -4 | 4 | 158 | | -12 | 12 | 251 | |
| 11/28/08 | -2 | 2 | 160 | | -6 | 6 | 257 | |
| 11/29/08 | -1 | 1 | 161 | -40 | -10 | 10 | 267 | |
| 11/30/08 | -1 | 1 | 162 | | -21 | 21 | 288 | |
| 12/1/08 | -2 | 2 | 164 | | -13 | 13 | 301 | |
| | | | **CONTINUED ON ONLINE EXCEL SPREADSHEET** | | | | | |
| **5/1/09** | **4** | **0** | **411** | **-37** | **6** | **0** | **1212** | |

Table 1. Part of Excel Data Table showing surface temperature (Tavg), freezing degree days (fdd), and frost depth from 10/1/2008 until 5/1/2009 in Homer and Igiugig, Alaska. Students can use these data to practice figuring out freezing degree days based on ground surface temperatures or to calculate ***a*** in **D = *a*F**.

In order to calculate freezing degree days, students first examined the temperature data to see if any dates had missing data. They found only one (27 October, 2008) in Homer. For the missing temperature on that date, they looked at the mean temperature for the day before and after. To estimate the mean temperature on 27 October, they performed a linear interpolation, which is a technique often used by scientists to estimate the values of missing data. The graph below (Figure 6) shows the mean temperature data for 26 October (-2°C) and 28 October (-6°C). Students drew a line connecting these two points and then estimated the mean temperature for 27 October was -4°C. Students could have averaged the two temperatures as well.

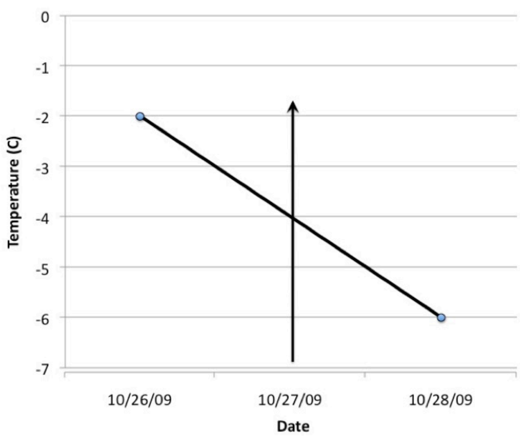


Figure 6. *Estimate of missing datum for surface temperature on 27 October, 2008, at Homer.*

Next, students calculated the freezing degree days for both Homer and Igiugig. They calculated the freezing degree days of 411°C days in Homer and 1212°C days in Igiugig. Data show that the site with greater number of freezing degree days, Igiugig, had deeper soil freezing (155 cm depth), and the site with less freezing degree days, Homer, had shallow soil freezing (37 cm depth).

To visualize how freezing advances from the soil surface over time, students constucted a frost depth profile graph. They put the 0 cm depth (soil surface) at the top right corner of the graph with increasing depths along the right y-axis to 180 cm (the depth of these frost tubes). They represented frost tube measurements with triangles. On this figure, they superimposed freezing degree data as a line graph. This shows that the number of freezing degree days increased as winter advanced.

Interestingly, the frost depth in Homer did not increase after November while the number of freezing degree days increased slowly. This led to additional research. Students investigated snowpack and learned that snow accumulated after November in Homer, which insulated the soil and prevented further soil freezing.

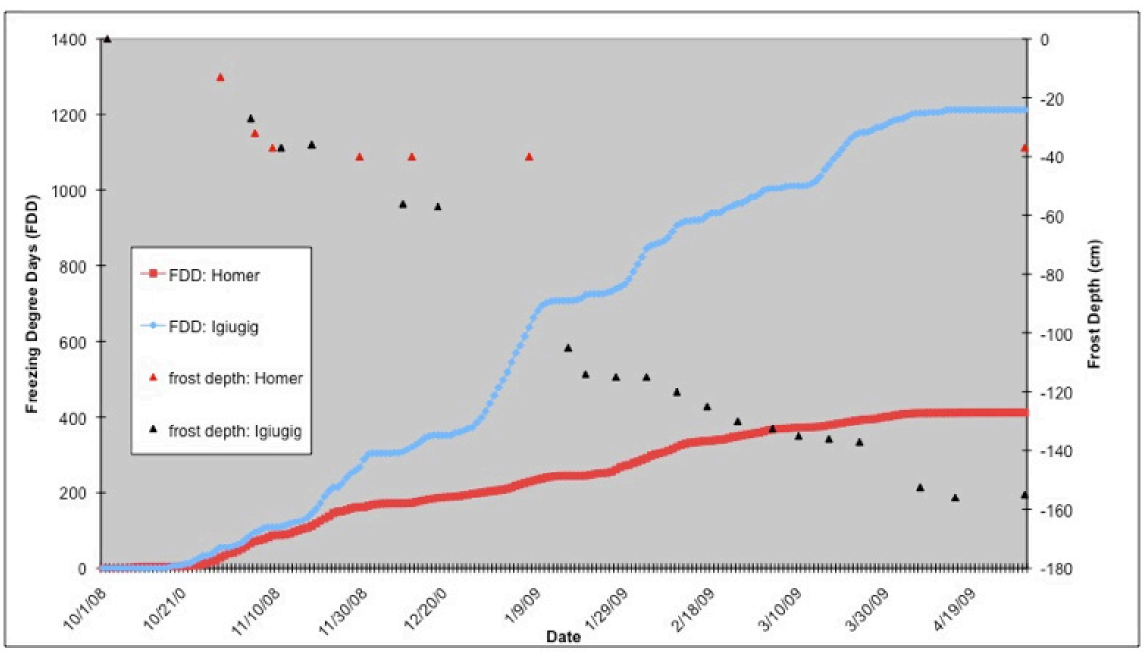


Figure 7. *Freezing degree days and frost depths at Homer and Iguigig, Alaska*

### *Questions for Further Investigation*

How will frost depth differ in different regions across the globe?

What would cause the timing and depth of freezing in soils to change from one year to another?

How does the timing and depth of freezing affect frost heave at your site?

How does the depth of freezing affect vegetation phenology in a particular region?

Is there any relationship between the freezing of the ground and freshwater ice seasonality?

What other parts of the ecosystem are affected by the timing and depth of soil freezing?

How does **F** (the square root of freezing degree days) in the equation **D** = ***a*F** vary for your site over time while **a** is constant?

How does depth of thaw at your site (in permafrost-underlain areas) compare to NASA airborne and satellite data?

### *Reference*

Brown, J., Ferrians, O.J.J., Heginbottom, J.A. and Melnikov, E.S. (1997). International Permafrost Association Circum-Arctic Map of Permafrost and Ground Ice Conditions, Scale 1:10,000,000. U.S. Geological Survey

# Frost Tube Site Definition

## Field Guide

### *Task*

To describe the site where the Frost Tube is located.

### *What You Need*

- □ GPS receiver
- □ *GPS Field Guide*
- □ *GPS Data Sheet*
- □ *Frost Tube Site Definition Sheet*
- □ Meter stick
- □ Pen or pencil
- □ Camera

### *In the Field*

1. Fill out the top part of the *Frost Tube Site Definition Sheet* (Coordinates, Source of Location Data, Site Type, and Cover Type). In the Air category, note that "thermometer type" is required. If there is no air temperature thermomter, select "no thermometer."

2. Use the GPS receiver and *GPS Field Guide* and *GPS Data Sheet* to identify the latitude, longitude and elevation.

3. Provide the date the Frost Tube was installed (this may be different than the date you define the site).

4. Record the height of the Frost Tube above ground, depth below ground, and total length.

5. Note whether there are any water bodies within 100 m of the Frost Tube site. If there are, record the direction and the distance.

6. Note the landscape position.

7. Describe the type of surface cover.

8. Describe any other information you think is important and enter it as a comment. For example, name the water body (if one is present) and whether there are human activities or structures within 100 m of the Frost Tube site. Also note the distance to the atmosphere site if applicable.

9. Standing by the Frost Tube, take four photographs in the four cardinal directions, North, South, East, and West. Pictures can be added later to the online site definition form.

# Frost Tube Protocol at Air Temperatures Warmer than –20˚C

## Field Guide

### *Task*

Observe and record the depth of freezing in the ground (where there is no permafrost) when air temperatures are warmer than – 20°C (determined by a GLOBE Atmosphere site nearby or from another reliable source).

*or*

Observe and record the depth of freezing in the ground's active layer (where there is permafrost) when air temperatures are warmer than – 20°C (determined by a GLOBE Atmosphere site nearby or from another reliable source).

### *What You Need*

- □ A properly installed Frost Tube
- □ *Frost Tube Data Sheet*
- □ Pen or pencil
- □ Meter stick

Students will measure the depth of freezing weekly, starting when air temperatures reach 0°C or colder.

- Depth of Freezing = distance in the inner tube of the Frost Tube from the soil surface to the boundary between the ice layer and unfrozen water. This represents the depth of freezing between the soil surface and the underlying unfrozen soil.

### *In the Field*

**First time only/getting started**

1. Complete the upper portion of your data sheet.

**Every visit**

1. Record the date on the *Frost Tube Data Sheet*.

2. If you have a GLOBE Atmosphere site nearby, record the current air temperature on the *Frost Tube Data Sheet*. Otherwise, consult a reliable source (e.g., local Weather Service station) for this information. If the air temperature is colder than -20° C then use the *Frost Tube Protocol for Temperatures Colder than -20 C Field Guide*. If the air temperature is warmer than -20° C then continue with the following procedure.

3. Walk to the Frost Tube site using the same path to reduce impact on the snow conditions.

4. Working quickly to reduce impact on the Frost Tube reading, remove the PVC cap and pull the inner tube (containing the colored water) out just far enough to note the depth of freezing or thawing. Be sure to hold the outer PVC pipe (outer tube) to prevent it from lifting out of the hole as well.

5. Determine the depth of freezing:

    - Locate the soil surface mark (0 cm) on the water-filled inner tubing. Hold the meter stick by the inner tube.

    - Find the boundary between the ice at the top of the clear tubing and the water below it. The ice appears relatively clear while the water is colored. (*Note: Sometimes the ice will be mottled with some color still left in it from the food coloring*. This happens when freezing occurs so quickly that some of the dye crystals are trapped in the ice.) There should still be a distinct boundary evident between such partially colored ice and the unfrozen water, which will have a homogeneous color.

    - Read off the depth of this boundary to the nearest centimeter (by holding meter stick by the inner tube.

6. Quickly return the clear tube to the structure and replace the PVC cap.

7. Record the depth of freezing on the *Frost Tube Data Sheet* and the observer names.

8. Repeat the measurements **once each week at the same time**, ideally within one hour of solar noon.

9. If possible, for each time the Frost Tube is read, note the current air temperature and depth of snowpack (if present) in three representative loacations at the Frost Tube site where there is minimal disturbance.

# Frost Tube Protocol at Air Temperatures Colder Than –20˚C

## Field Guide

### *Task*

Observe and record the depth of freezing in the ground's active layer (where there is permafrost) when air temperatures are colder than – 20°C (determined by a GLOBE Atmosphere site nearby or from another reliable source).

*or*

Observe and record the depth of freezing in the ground (where there is no permafrost) when air temperatures are colder than – 20° C (determined by a GLOBE Atmosphere site nearby or from another reliable source).

### *What You Need*

- ☐ A properly installed Frost Tube
- ☐ *Frost Tube Data Sheet*
- ☐ Pen or pencil
- ☐ Meter stick

Students will measure the depth of freezing as the ground cools.

- Depth of Freezing = distance in the Frost Tube from the soil surface to the boundary between the ice layer and unfrozen water in the inner tube. This represents the depth of freezing between the soil surface and the underlying unfrozen soil.

### *In the Field*

**First time only/getting started**

1. Complete the upper portion of your data sheet.

**Every visit**

1. Record the date on the *Frost Tube Data Sheet*.

2. If you have a GLOBE Atmosphere site nearby, record the current air temperature on the *Frost Tube Data Sheet*. Otherwise, consult a reliable source (e.g., local Weather Service station) for this information. If the air temperature is warmer than -20°C then use the *Frost Tube Protocol for Temperatures Warmer than -20 C Field Guide*. If the air temperature is colder than -20°C then continue with the following procedure.

3. Walk to the Frost Tube site using the same path to reduce impact on the snow conditions.

4. Use a meter stick to record the depth of snow in three undisturbed locations near the Frost Tube. Enter these data on the *Frost Tube Data Sheet*.

5. Working quickly to reduce impact of colder than -20° C temperatures, remove the PVC cap and pull the inner tube (containing the colored water) out just far enough to note the depth of freezing or thawing. Be sure to hold the outer PVC tube to prevent it from lifting

out of the hole as well.

6. Determine the depth of freezing:

- Locate the soil surface mark (0 cm) on the water-filled inner tubing. Hold the meter stick by this inner tube.

- Find the boundary between the ice at the top of the clear tubing and the water below it. The ice appears relatively clear while the water is colored. (*Note: Sometimes the ice will be mottled with some color still left in it from the food coloring*. This happens when freezing occurs so quickly that some of the dye crystals are trapped in the ice.) There should still be a distinct boundary evident between such partially colored ice and the unfrozen water, which will have a homogeneous color.

- Read off the depth of this boundary to the nearest centimeter (by holding the meter stick by the inner tube).

7. Record the depth of freezing on the *Frost Tube Data Sheet* and the observer names.

8. Because the extremely cold air temperature may cause some of the unfrozen water in the tube to freeze during the time it is pulled out of the assembly, you will need to remove the clear tubing from the Frost Tube and carry it inside to completely thaw it out for at least 24 hours. After removing the inner tubing, be sure to replace the cap on the outer PVC pipe.

9. The following day replace the clear tubing in the Frost Tube:

- Carefully coil up the tubing and place it under your coat before you go outside. This will help to reduce the influence of the cold air.

- Walk to the Frost Tube site, remove the cap and quickly place the clear tubing back into the Frost Tube. Replace the cap immediately.

- Note the date that the Frost Tube was removed for thawing out and the date it was replaced on the *Frost Tube Protocol Data Sheet* in the Comments section.

- Do not disturb the Frost Tube until it is time to take the next measurement.

10. Repeat the measurements **once each week at the same time**, ideally within one hour of solar noon. If the cold weather continues, you will need to repeat this procedure each time you read the Frost Tube (depth of freezing is observed and recorded).

11. If possible, for each time the Frost Tube is read, note the current air temperature and depth of snowpack (if present) in three representative loacations at the Frost Tube site where there is minimal disturbance.