# Frost Tube Protocol

***Purpose***
To monitor the timing and depth of freezing in soil at a Frost Tube Site or a designated GLOBE Study 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 at which water in the Frost Tube has frozen, indicating that the surrounding soil has also frozen.

***Student Outcomes***
Students will be able to,

- Observe when water in the Frost Tube freezes
- Collect and analyze data related to freezing of soil to understand how soil temperature and moisture coincide with changes in seasons across different biomes.
- Examine relationships among air, soil and permafrost
- Communicate project results with other GLOBE schools
- Collaborate with other GLOBE schools (within your country or other countries)
- Share observations by submitting data to the GLOBE archive
- Compare the timing and depth of freezing in soils in different regions around the world
- 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

Visits to and from site: 10 minutes (5 minutes to the site and 5 minutes to return)
Time to read measurements: 5 minutes

***Level***
All

***Frequency***
Depth of frozen ground is measured at the same time of day (preferably within one hour of solar noon) 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 auger (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; precipitation)*

# Introduction
## *Why Study Frozen Ground?*

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 general, the pattern of soil temperature over the course of a year tends to stay about the same (e.g., the mean 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 due to global warming 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). Monitoring the timing and depth of soil freezing and thawing helps scientists to understand how the temperature of the soil is changing over time so that they can identify the effect of **climate change such as** warming or other disturbances on the ecosystem.

At mid-latitudes and mid-elevations on the Earth, parts of the soil near the surface freeze in the winter. In Northern and Southern latitudes and at high elevations, some soil layers/earth materials that remain at or below 0 C for at least two consecutive years are known as permafrost (http://www.uspermafrost.org/glossary.php). The soil 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. If, after some disturbance or because of climate change, the soil temperature over the year may be warmer, the depth of soil freezing may decrease, and the time of freezing may be delayed. Other parts of the environment will also be affected. In cold climates, large amounts of organic matter (dead plants and animals) are present in the soil and become locked up in the permafrost. As the permafrost thaws, the organic matter starts to decompose and greenhouse gases such as carbon dioxide and methane are released. An increase in greenhouse gases in the atmosphere leads to higher air temperatures, which leads to even warmer soil temperatures, more thawing of permafrost, and the release of even more greenhouse gases as more organic material decomposes. This positive feedback cycle continues to add to global warming once it starts. The surface layers over the soil become thinner and have less insulating ability, and trees that were growing over the frozen soil layers with high ice content fall over and look like a “drunken forest”. The types of vegetation will be affected by the changing hydrologic regimes.

## *What is Permafrost?*

**Permafrost** is a layer of soil or rock, at some depth beneath the surface, in which the temperature has been continuously below 0°C for at least two years or more; it exists where summer heating fails to reach the base of the layer of frozen ground (National Snow and Ice Data Center http://nsidc.org/cgi-bin/words/word.pl?permafrost ). In areas where air temperatures rise above freezing for a few months of the year, the ground surface may temporarily thaw before freezing again after the arrival of cooler weather. The layer of soil above permafrost that seasonally freezes and thaws is called the **active layer**. The thickness of permafrost and the active layer depend on local climate conditions, vegetation cover and soil properties as well as from heat within the Earth.

As air temperatures cool (e.g. fall going into winter) the layer of freezing in the soil should increase but other variables such as snow depth and the thickness of the vegetative layer will impact how much and how quickly freezing occurs. If the layer of snow and or vegetation is very thick, it will insulate the soil and prevent it from freezing until later in the winter. When there is heavy snowfall early in the year and it persists, it 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 frosts in early autumn.


Figure 1. *Permafrost extent in the Northern Hemisphere*
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

Permafrost zones occupy up to 24 per cent of the exposed land area of the Northern Hemisphere. Permafrost is also common within the vast continental shelves of the Arctic Ocean. This subsea permafrost formed during the last glacial period when global sea levels were more than 100 m lower than at present and the shelves were exposed to very harsh climate conditions. Subsea permafrost is slowly thawing at many locations. Permafrost of various temperatures and continuity also exists in mountainous areas, due to the cold climate at high elevations. (Permafrost extent in the Northern Hemisphere, June 2007 in *UNEP/GRID-Arendal Maps and Graphics Library*..)

## *The Big Picture*

The temperature of soil is directly linked to the temperature of the atmosphere because soil is an insulator for heat flowing between the solid earth and the atmosphere. For example, on a sunny day, soil will absorb energy from the sun and its temperature will rise. At night, the soil will release the heat to the air having a direct and observable effect on air temperature. 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 bulk density, and soil moisture. A north facing slope will be colder and more likely to freeze than a south facing slope in northern 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 so that 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.

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 it's temperature and causing frozen layers to melt. As heat leaves the soil surface, the water and minerals in the soil freeze from the top down. However, as the air temperature warms and the ice in the upper soil horizons melts, the melted water moves through the soil and freezes again as it reaches the permafrost layer so that the soil begins to freeze from the bottom up.

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

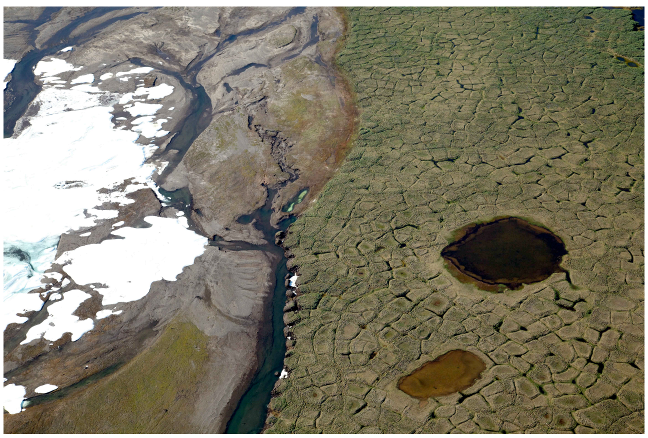

Figure 2. Patterned Ground
(http://www.uspermafrost.org/glossary.php)

## *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. The Frost Tube consists of a piece of 6-8 mm clear plastic tubing (inner tube) marked in 5 cm increments holding colored water that sits inside a 10 mm (outer diameter) radiant heat tube (middle tube) sealed on the bottom. This is placed inside a 12 mm CPVC pipe(outer tube), open on both ends

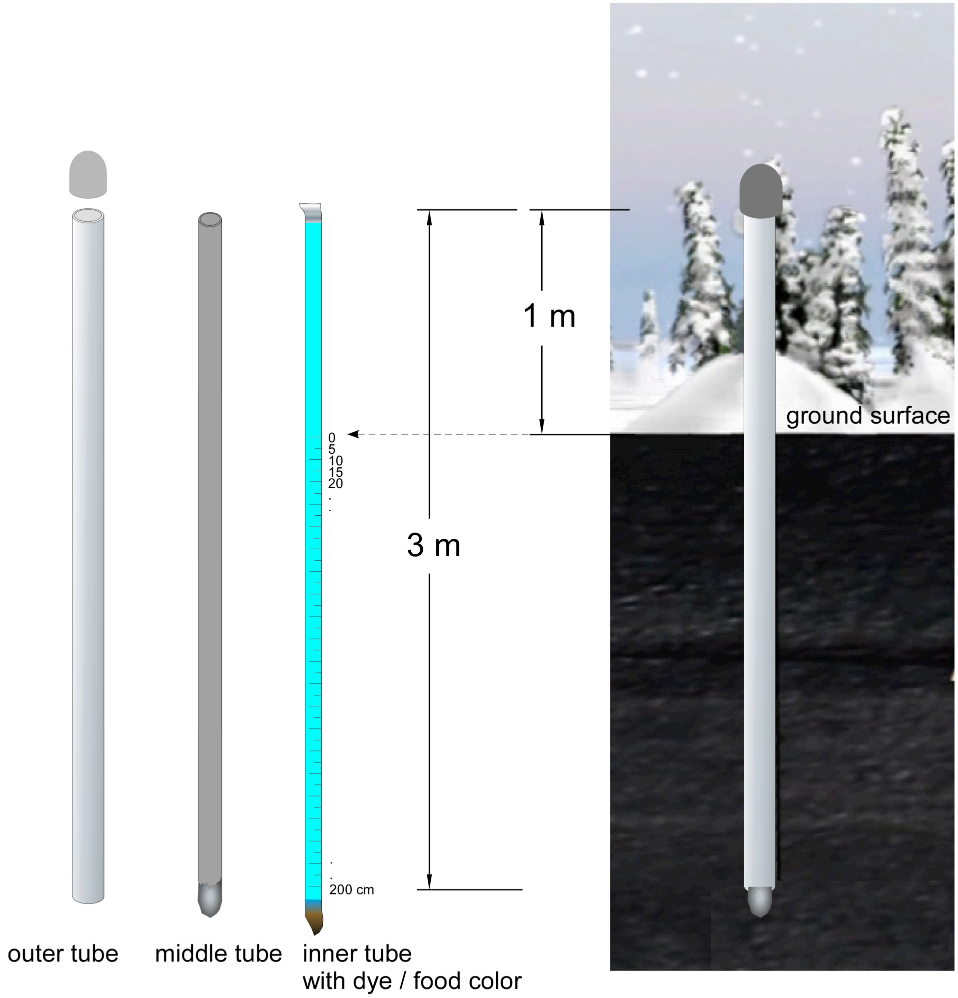


Figure 3. Components of a frost tube

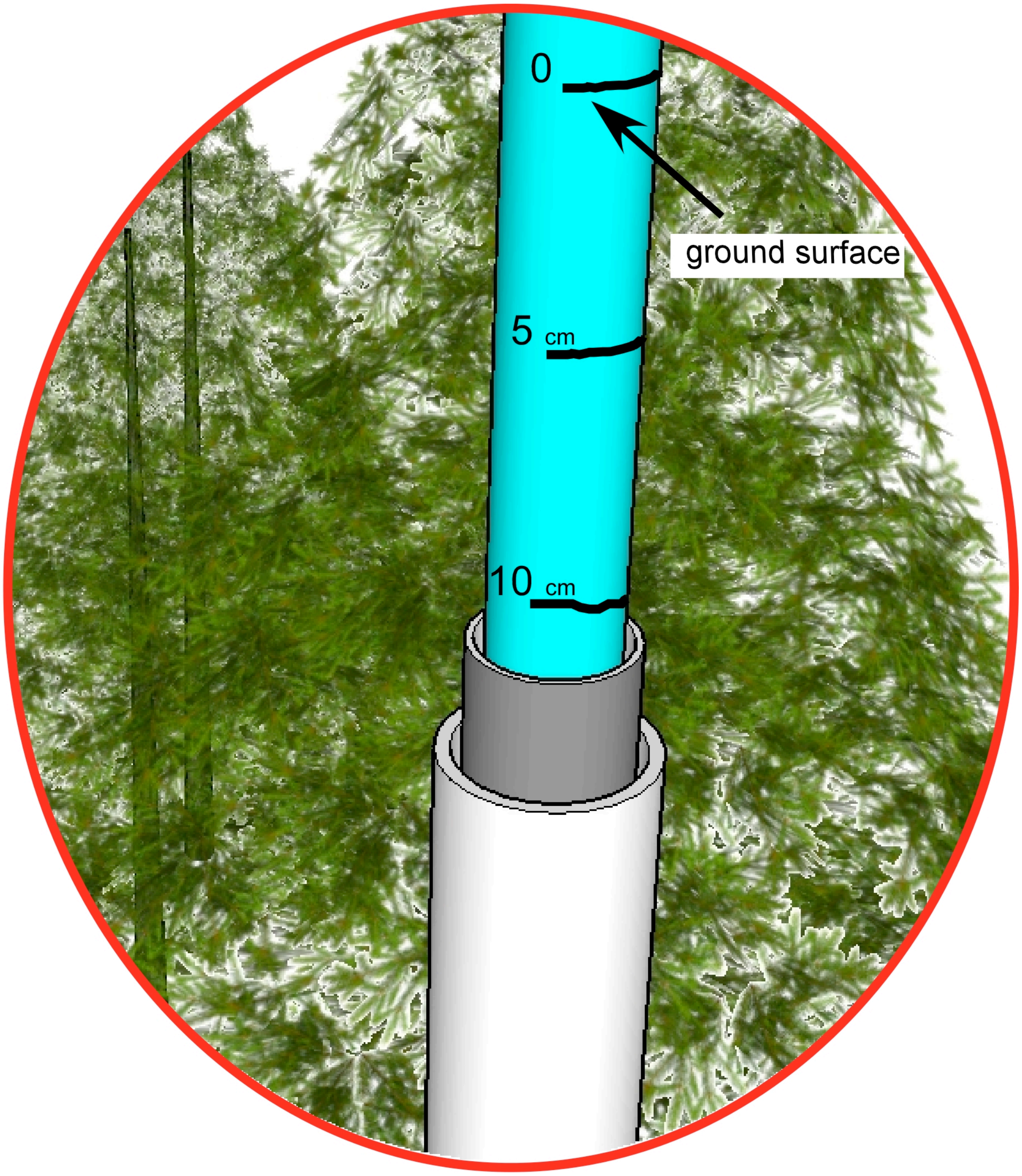


Figure 4. Another view of the frost tube showing inner, middle and outer tubes.

# Teacher Support

Depth of soil freezing is related to the length of time it has been cold above ground. That is why measuring the depth of freezing indicates the type of climate where they study is. Monitoring the depth of soil freezing helps scientists and engineers understand how the temperature of the soil is changing over time so that they can identify the effect of climate change.

When winter comes the ground freezes and the frozen soil becomes thicker as winter progresses.. How thick will it become?

*The depth of ground freezing depends on many different parameters, such as freezing degree days, soil moisture content, bulk density, grain particles, etc. This can be simplified by the following formula:*

**D** = **aF**

**D** = *depth of freezing*
**a** = *constant*
**F** = *√t (square root of t) = freezing degree days*

**F** *is the number of freezing degree days at the ground surface. Freezing degree days (fdd) is a measure of how cold it has been and how long it has been cold; the cumulative fdd is usually calculated as a sum of average daily degrees below freezing for a specified time period (10 days, month, season, etc.). (National Snow and Ice Data Center* [*http://nsidc.org/cgi-bin/words/word.pl?freezing%20degree-days*](http://nsidc.org/cgi-bin/words/word.pl?freezing%20degree-days) *)*

**a** *is a constant of the thermal property of the soil, soil moisture content and characteristics of frost heaving. Frost heaving is characterized by soil particle size.* **a** *varies between 1 to 5 and is usually around 2.7 but it strongly depends on location. For example, saturated sandy material is around 3. Dry silty material is about 2.3. Organic material would probably be around 2.*

*Using depth of soil freezing and freezing degree days we can figure out* **a**. *By knowing* **a** *and climactic conditions (#freezing degree days,* **F***) we can calculate the depth of freezing,* **D**. *If we know the frost depth and* **a** *then we can calculate freezing degree days. In this way scientists can better understand how the climate may be changing by gathering more data about soil freezing depth.*

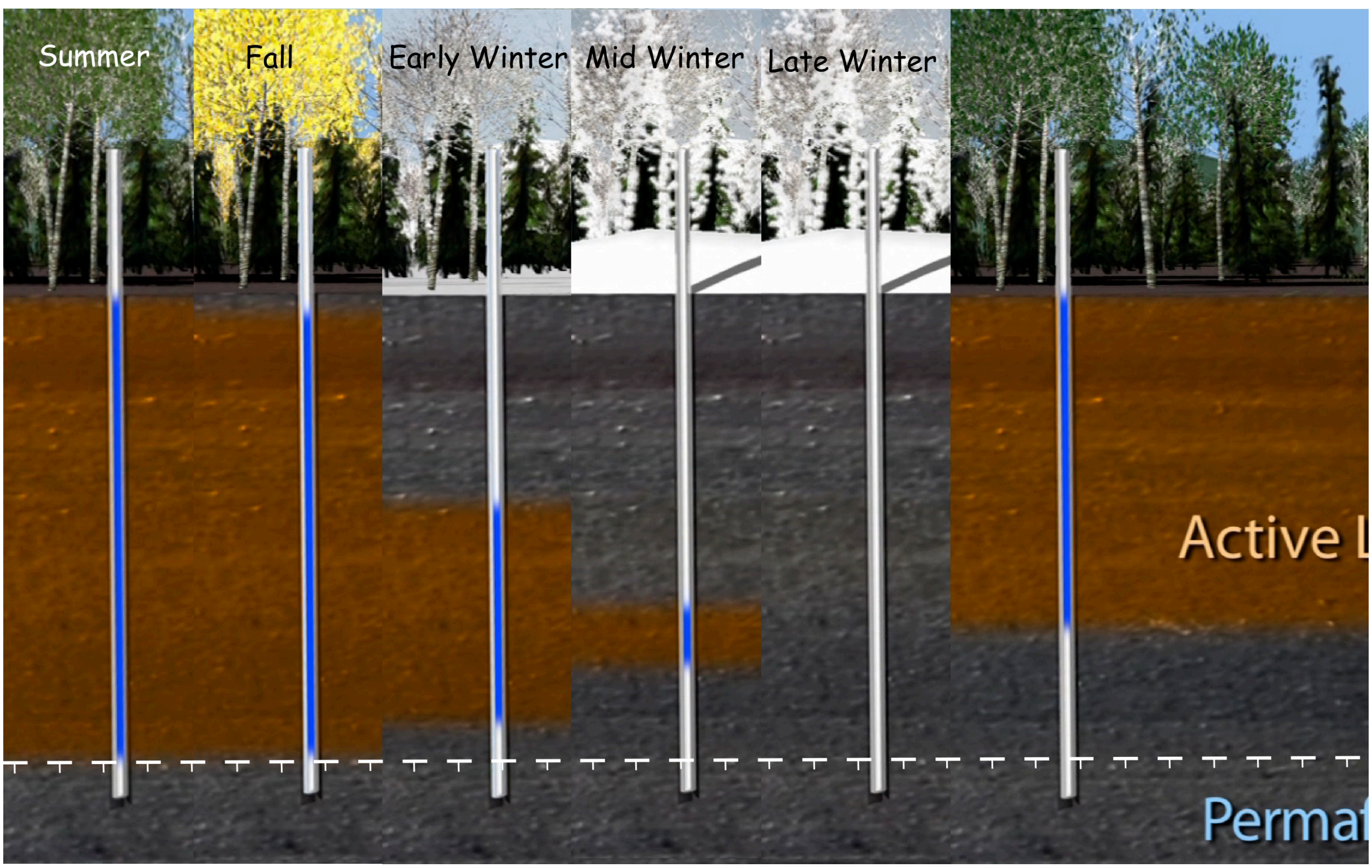

Figure 5. Progression of freezing

## *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 would also be best to locate your Frost Tube within a 5 minute walk from your school so it is relatively easy to access in cold weather.

Because many soils in northern latitudes were formed from glacial parent material, soils in this region may contain many large rocks that may make it difficult to dig into. If possible, locate an area with a minimum of rocks or you may need to use more robust equipment for inserting the frost tube. **Check with the appropriate authorities for permission to dig 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 so carefully document this information on the *Frost Tube Site Definition Sheet*. If you live in an area of permafrost, check the clear tube late in summer to measure the distance from the soil surface to the boundary between water and ice at the bottom of the tube. Enter this data in the Comments/ metadata section of the *Frost Tube Data Sheet*.

## *Measurement Procedure*

It is highly desirable that these observations be done by a minimum of two people per visit.

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

- <u>Depth of Freezing</u> = distance in the Frost Tube (inner 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.

## *Managing Students*

It is very important that someone visits the Frost Tube site every week to take measurements once the air temperature drops below freezing. Students need to collect measurements quickly and efficiently to reduce the impact 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 cold air out of the assembly.

## *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. So bend the tube to detect or locate presence of ice.

## *Frost Tube Protocol – Looking at the Data*

**Are the data reasonable?**

The freezing front (boundary of ice and water interface) usually moves very slowly from the soil surface down (less than 1 cm per day). However if below freezing air temperatures persist and there is no snow cover, near surface soil depth freezing could happen quickly in the top 5-10 cm of soil early in the winter depending on soil water content and ambient air temperatures. This typically happens in permafrost underlain regions such as in Interior Alaska. In either case, freezing usually proceeds at increasing depths in most of the Alaska, but not southeast or Prince William Sound area.

**What do scientists look for in the data?**

Frost tube (depth) can tell many things. The maximum depth of freezing would be one of the important measurements for this. Ground freezing mostly depends on air temperature, snow depth, and soil properties. Severe winter conditions in one area could result in deeper soil freezing than warmer winter conditions in another area. Delay in ground freezing could be captured by frost tube data. Delay in ground freezing directly affects degradation of the permafrost in northern latitudes.

Also snow thickness is an important factor in ground freezing because of snow's insulating quality. Different freezing depths could result in areas with the same air temperature but with different snow depths

These differences in ground freezing depths can be simulated or modeled once soil conditions or characteristics (designated as "a" in the equation given earlier in the Teacher Support section), is calculated. Freezing degree days (accumulated daily average surface ground temperatures colder than 0 ˚C) increases until the end of the winter. Snow depth and air temperature affect freezing degree days (fdd) and ground-freezing depth. However "a" stays the same. Hence we can predict depth of freezing (D) using fdd. Depth of ground or soil freezing ("D" in equation) can be estimated from one year of frost tube data.

***Estimating soil frost depth: Calculating freezing degree days (FDD):***

The maximum depth of freezing depends on winter air temperature, snow thickness, soil moisture content, soil physical properties, such as grain size, pore space, mineral composition etc. Freezing degree days (fdd) at ground surface are a common measure of freezing depth estimation used by scientists. For this method, you will need the daily average ground surface temperature data for your school from September 1st (if you live in the northern hemisphere) or April first (if you live in the southern hemisphere) up to and including the date of when temperatures are above freezing ( 0 $^{o}$C).

To calculate freezing degree days:

1. First, for each day, calculate the daily average ground temperature (Tavg)
2. Starting with September 1 or April 1, check to see if Tavg is less than 0˚ C. If it is, record this temperature. If Tavg is greater than 0˚ C, ignore it. Go to the next day. Again, check to see if the (Tavg) is less than 0˚ C. If it is, add it to the temperature you recorded for the first. If not, again ignore it. Repeat this process for each subsequent day up to the day of no freezing (e.g. until late spring). The sum of the daily average negative

temperatures is your freezing degree days (fdd unit is “°C days”). But remove negative sign (-) from sum of the daily average of negative temperatures. Freezing degree days does not include minus (-) sign before number. Record values in the Table on your *Work Sheet.*

| | Tavg | FDD by day | FDD | frost depth | Tavg | FDD by day | FDD | frost depth |
|---|---|---|---|---|---|---|---|---|
| | Homer | Homer | Homer | Homer | Igiugig | Igiugig | Igiugig | 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 | 0 | 0 | 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 | | -6 | 6 | 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 | -6 | 6 | 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 | -5 | 5 | 45 | | -3 | 3 | 62 | |
| 11/2/08 | -6 | 6 | 52 | | -5 | 5 | 67 | |
| 11/3/08 | -7 | 7 | 59 | | -10 | 10 | 78 | |
| 11/4/08 | -7 | 7 | 66 | | -10 | 10 | 88 | -27 |
| 11/5/08 | -5 | 5 | 70 | -32 | -7 | 7 | 95 | |
| 11/6/08 | -3 | 3 | 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 | -3 | 3 | 91 | | -5 | 5 | 118 | |
| 11/14/08 | -4 | 4 | 96 | | -4 | 4 | 122 | |
| 11/15/08 | -4 | 4 | 100 | | -2 | 2 | 123 | |
| 11/16/08 | -5 | 5 | 104 | | -3 | 3 | 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 | -7 | 7 | 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 | -4 | 4 | 149 | | 1 | 0 | 214 | |
| 11/25/08 | -1 | 1 | 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 | -3 | 3 | 164 | | -13 | 13 | 301 | |
| 12/2/08 | -3 | 3 | 167 | | -3 | 3 | 304 | |
| 12/3/08 | -2 | 2 | 169 | | 1 | 0 | 304 | |
| 12/4/08 | -1 | 1 | 170 | | 2 | 0 | 304 | |
| 12/5/08 | 0 | 0 | 171 | | 2 | 0 | 304 | |
| 12/6/08 | 0 | 0 | 171 | | 1 | 0 | 304 | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 12/7/08 | 0 | 0 | 171 | | -1 | 1 | 305 | |
| 12/8/08 | 0 | 0 | 171 | | 0 | 0 | 305 | |

Excel Data Table of surface temperature and freezing degree days from 10/1/2008 until 5/1/2009 is provided as a separate document.

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

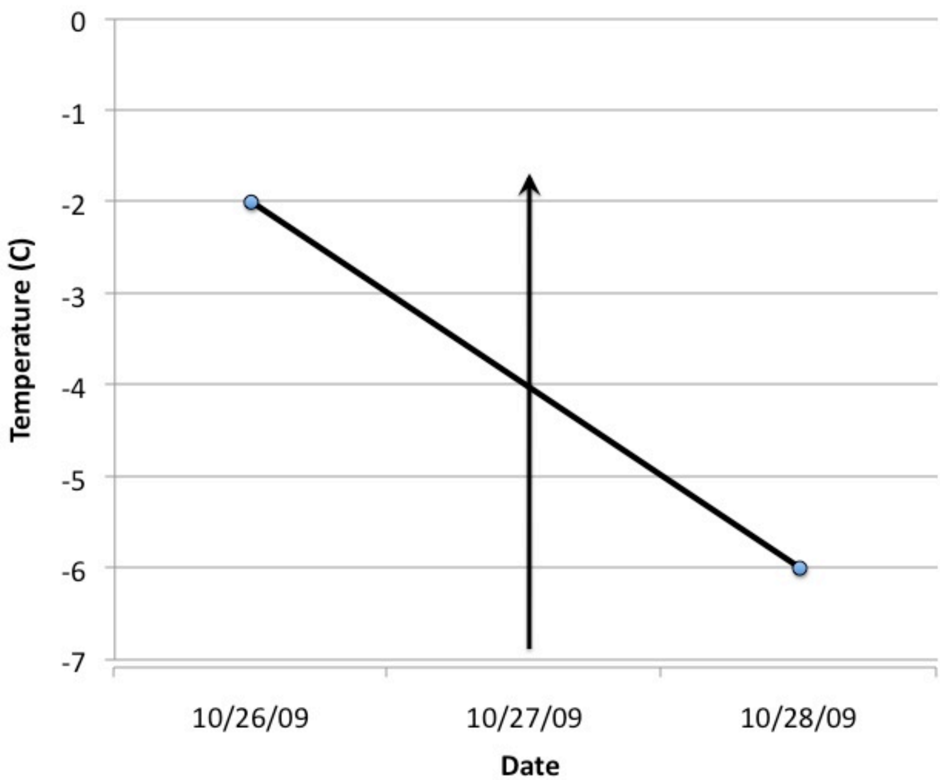


Figure 6. Estimate of missing datum for surface temperature on October 27, 2008, at Homer.

Next they calculated the freezing degree days for Igiugig. They calculated the freezing degree days of 411 FDD at Homer and 1212 FDD at Igiugig. Data show that the site with greater number of freezing degree days, had deeper ground freezing, 155 cm depth at Igiugig; and the site with less number of freezing degree days, Homer, had shallow ground freezing of 37cm depth. Also number of freezing degree days and frost depth indicated thicker (more) snow accumulated after November at Homer, that prevented further ground freezing, hence, ground temperature stayed near 0°C for the rest of the winter.

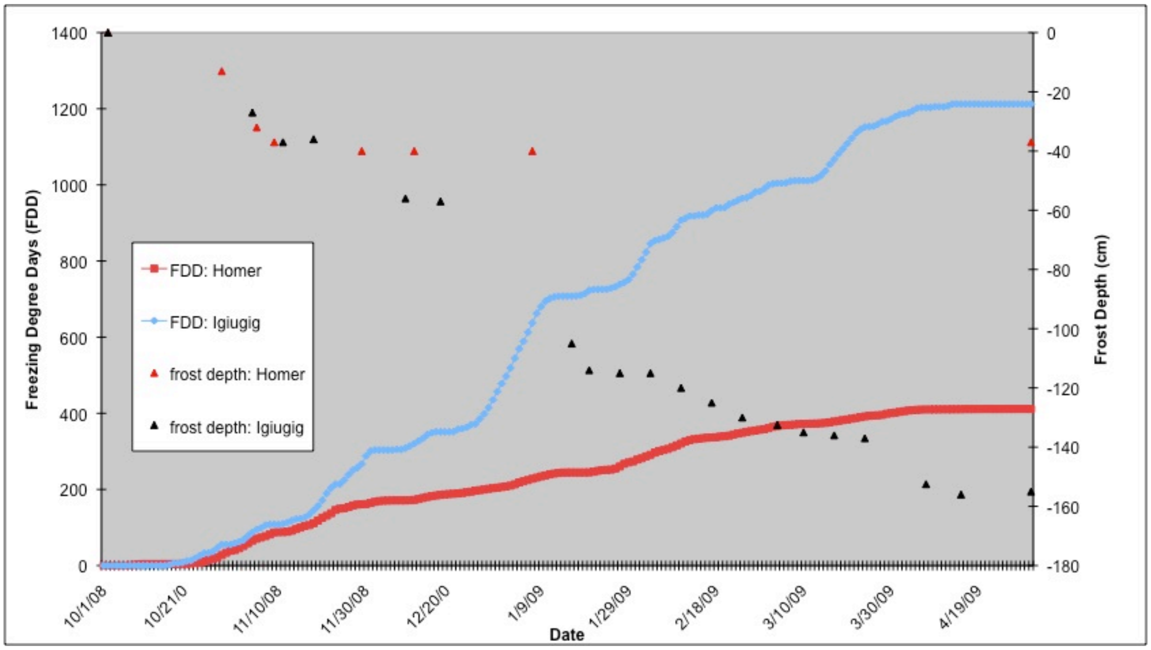


Figure 7. Freezing degree days and frost depths at Homer and Iguigig, Alaska

## *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 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?

## References


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

Permafrost extent in the Northern Hemisphere. (June 2007). In *UNEP/GRID-Arendal Maps and Graphics Library*. Retrieved 05:55, May 26, 2010 from http://maps.grida.no/go/graphic/permafrost-extent-in-the-northern-hemisphere