

Engaging Alaska Communities and Students in Cryospheric Research

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1 Introduction

Permafrost is defined as ground materials that remain below 0 °C (32 °F) for 2 or more years. Permafrost forms when the ground cools enough in winter to produce a frozen layer that remains frozen throughout the following summer. The active layer (the soil near ground surface that thaws each summer) and the thickness of permafrost depend on local climatic conditions up to about 1,000 m thick, vegetation cover, soil type and moisture content, and any effects from the heat flow at the Earth's core.

The Permafrost/Active Layer Monitoring (PALM) Program is a research project that monitors the permafrost temperature of ground and the depth of the active layer in regions of permafrost and seasonal frost. Information learned from this research will help us understand the thermal state of permafrost and its effect on the natural environment and local ecosystems. Data recorded now will be the baseline for studies in the future, which makes this a long-term project. We hope to collect data for many years so that we can track how permafrost and the active layer change over time. To gather the data, we have established monitoring sites near communities throughout the permafrost and seasonal frost region in Alaska and other countries where ground is frozen. Students and teachers in the local

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schools participate in the program by reading measurements at the monitoring sites, recording data, comparing data online with other schools, and discussing what they learn. Classroom lessons on permafrost have been developed for students of all grade levels. The lessons, combined with activities at the measuring sites, offer students hands-on scientific experience and an opportunity to see the connection between science and research.

As part of this project, we developed a protocol for teachers around the world: GLOBE Seasons and Biomes Project. The GLOBE project will help to provide high-resolution spatial distribution of the thermal state of permafrost and will improve the general knowledge of Earth's climatic pattern; it also offers an opportunity for students to take part in understanding climatic systems. This project highlights the interaction between permafrost, the active layer, hydrology, and the climate system of the cryosphere, and provides a strong educational outreach program involving remote communities.

To ensure scientific integrity, all of the monitoring instruments have been installed by scientists, who select the sites representative of the surrounding biome and thermal conditions. The PALM Program is a unique opportunity for collaboration, in that it (1) uses scientifically accurate instruments, (2) is led and supervised by scientists who set up instrumentation and check data quality, (3) has a teacher/student-organized observation network, and (4) increases the spatial scale of monitoring sites that cover all the northern communities involved.

Most of the monitoring sites are located in remote communities, where the majority of residents depend on a subsistence lifestyle. Changes in climate, length of seasons, and permafrost conditions directly affect natural resources and subsistence activities. Changes in permafrost conditions affect local ecosystems and hydrological regimes and can influence the severity of natural disasters.

In addition to extending our knowledge of the environment of the cryosphere, the program involves school-age students. Several students have been using data from this research for their school projects and have been inspired to continue their studies. Data gathered from these stations are shared with other schools and made available to the public through the program's website (<http://www.uaf.edu/permafrost>). Increasingly, communities are becoming interested in this project, not only for its educational benefits but also for its implications for disasters such as mudslides, loss of food-storage capability in frozen ground, and water pipes bursting from ground freezing at lower depths. Challenges in education outreach include the high cost (dollars and time) of reaching remote study sites scattered all over the vast Alaska landscape and designing instructional materials that help students understand the science concepts behind the long-term study of permafrost and the active layer. In addition to scientific measurement protocols and learning activity development, a superhero—TunnelMan—has been created for instructional purposes. TunnelMan's adventures have been produced and made available on videos, the project's website, and YouTube. Through this project, students in remote communities learn science in a way that is meaningful to their daily lives. In addition, they experience research participation within a larger scientific community, expanding their worldview.

2 Motivation and Rationale of the Project

2.1 Scientific Viewpoint

Permafrost regions occupy about one-quarter of Earth's land surface. Permafrost is one of the most important components of the terrestrial system of the cryosphere, and this physical element of the landscape is one of the most sensitive to climatic change. Therefore, observing the interactions between permafrost and other components of the system of these regions (the climate, hydrology, biogeochemistry, vegetation), especially during a period of possible climatic warming, is among the most important aspects of cryosphere research. The changing properties of permafrost play an important role in driving the ecosystem balance and affect carbon and water cycles (Oechel et al. 2000). Additionally, structures built on or near ice-rich permafrost can suffer severe damage from thaw-induced ground settling, which will accelerate if mean annual temperatures continue to rise (Osterkamp et al. 2000; Romanovsky and Osterkamp 2001). Within the sensitive permafrost region, the discontinuous permafrost zone is the most likely to respond to climatic warming. Most rural communities in Alaska are located in this zone. Throughout the circumpolar North, boreal forest widely overlaps the area of discontinuous permafrost (Péwé 1975). Thermal conditions of discontinuous permafrost are quite unstable, as the ground is close to thawing, with temperatures often hovering at -1 °C or warmer.

Table 1 is an overview of the principal permafrost monitoring programs in the circumpolar North, with major findings and results summarized. Most notable is the evidence of a warming trend, even with few permafrost monitoring sites.

3 Implementation and Timeline

3.1 Approach

The majority of Alaska communities included in this project are located in remote areas, without road access. Air transportation is typically used to reach these communities, but this mode of travel was not ideal at the beginning of the program when equipment was needed to establish each monitoring station. To establish a monitoring station, a borehole, casing pipes, and drill equipment are needed. This technical part of establishing a station presented some difficulties. Each monitoring station requires the drilling of a 3–6 m deep borehole for measuring ground temperatures and a 1 and 5 m deep borehole for monitoring the seasonal/active layer. The remote location of most villages created the necessity, and therefore a great opportunity, for developing a portable, lightweight, small-diameter drill system. Such a portable

Table 1 Recent trends in permafrost temperatures measured at different locations (Romanovsky et al. 2002)

Country	Region	Permafrost temperature trends	References
USA	Trans-Alaska pipeline route (20 m), 1983–2000	+0.6 to +1.5 °C	Romanovsky and Osterkamp (2001)
	Barrow Permafrost Observatory (15 m), 1950–2001	+1 °C	Our ongoing research
Russia	East Siberia (1.6–3.2 m), 1960–1992	+0.03 °C/year	Our ongoing research
	North of West Siberia (10 m), 1980–1990	+0.3 to +0.7 °C	Pavlov (1994)
	European North of Russia, continuous permafrost zone (6 m), 1973–1992	+1.6 to +2.8 °C	Pavlov (1994)
Canada	Northern Mackenzie basin (28 m), 1990–2000	+0.1 °C/year	GSC data
	Central Mackenzie basin (15 m), 1985–2000	+0.03 °C/year	GSC data
	Alert (15 m), 1995–2000	+0.15 °C/year	Geological Survey of Canada (GSC) data

drill system is strongly affected by the grain size of frozen materials, which was problematic since permafrost conditions and local geology vary greatly among the different locations. Though a design for augers and coring bits (mechanical properties) for fine-grained frozen soils had already been well developed, drilling in frozen gravel, boulders, and glacial sediments is extremely difficult, even when using heavier track-mounted hydraulic drill systems, and required a different drill system. We developed a method of drilling through frozen gravel using a portable drill system. More than 250 monitoring sites have been established.

For the most part, we used snowmobiles to reach remote locations during spring months. Snowmobile travel took place in the spring of 2007, 2008, 2009 and 2013. We visited 93 communities, traveling 12,000 km (7,500 miles) to set up monitoring sites. We used trails between communities—winter trails, dog-mushing trails, the Iditarod trail, and the Iron Dog trail—but not always. Most of the time we had to break trail. In the forest, snow was deep and it was difficult to make trails because of trees, but on the tundra, hardpacked trails made travel easier. This snowmobile-travel campaign was greatly successful, both logistically and socially. Most rural communities in Alaska and Canada are not visited by scientists, and when it occurs, visitors usually arrive and depart by airplane. Snowmobiles are an important means of transportation in remote areas and people find them interesting, especially teenagers and other school-age kids. We arrived on new snowmobiles from far away, having driven great distances. That had a strong impact on local people and got the program off to a good start. In 2011, we visited southeast Alaska communities by small boat to establish monitoring stations. We traveled the Inside Passage (fjords) to reach these 23 communities. Arriving by boat had a similar impact as arriving by snowmobile.

After a monitoring station is established, we visit communities again, traveling by snowmobile, boat, or airplane. It is important to revisit schools and maintain the strong connection with students and communities. Presently, almost all Alaska communities are in the PALM Program network, which is not only important for filling the scientific data gap but also important for furthering good relationships with teachers. Many rural schools experience high teacher turnover. Usually, however, our teacher connection remains in the PALM Program network if the teacher stays in Alaska. Throughout the year, we maintain regular communication and provide ongoing follow-up support with teachers at all schools near the permafrost monitoring stations that we have installed. We send out newsletters via e-mail monthly and correspond by e-mail or speak by phone with teachers daily. We also maintain a blog (updated almost daily) and a Twitter site on the PALM Program website.

3.2 Classroom Activities and Lessons

The classroom activities developed for the Permafrost/Active Layer Monitoring Program are differentiated by age group. Multi-age classrooms, in which older and younger students work together on science and math subjects, are common in rural Alaska. In many rural Alaska districts, students of all ages must pass “End of Level Tests of Attainment” before moving on to instruction in more advanced scientific concepts.

For this reason, a “spiraling” method was used to develop the permafrost curriculum, introducing advanced concepts in small doses for early levels and then building them in complexity for higher levels. Progressive levels of instruction concerning permafrost geophysics and related use of remote sensing start with basic principles and concepts (Levels I and II), build to earth processes and cycles of geomorphology (Levels III and IV), and conclude with atmosphere–ocean–land interactions, feedbacks, and energy transfer (Levels V and VI). Levels I and II correspond to grade equivalent K–4, Levels III and IV to grade equivalent 5–8, and Levels V and VI to grade equivalent 9–12.

Classroom lessons provide the framework for offering instruction. Online lectures, multimedia activities, “TunnelMan” videos, and online comic strip booklets are designed to give teachers instructing multi-age classrooms the flexibility to supplement classroom lessons when needed. The online scientist mentorship is designed specifically for teachers in geographically isolated rural villages in Alaska. Through online scientist mentorship, teachers have their questions answered and rural teachers are supplied with auxiliary resources (designed within and outside of the PALM Program) that augment permafrost instruction.

The program (1) offers teachers unique opportunities to integrate research and education by providing students a chance to work with and learn from experienced permafrost scientists; (2) provides classroom lessons on permafrost and the active layer, an important part of Alaska geosciences; and (3) distributes by DVD and



Fig. 1 Permafrost monitoring sites

through Internet an entertaining educational movie series called “TunnelMan.” Educational activities include the following:

1. To help students understand permafrost and its impact on the environment, permafrost monitoring sites are established and boreholes are drilled. Scientists introduce the project and guide student discussion, focusing on the question, “Why do we need to monitor permafrost?” (Fig. 1)
2. To demonstrate scientific methodology, design, and fieldwork, frost tubes are installed, data loggers are set up, and scientists calibrate temperature sensors with assistance from students. Students and teachers explore the following questions with scientists’ guidance: “What kind of sensors and instruments are we using?” and “How do these instruments work for us?” We provide teachers with a set of classroom lessons (Figs. 2 and 3).
3. About a year after monitoring stations are established, during the scientists’ return visit to the communities, a second set of lessons to explore the temperature



Fig. 2 Students watch borehole installation (*left*) and experience communicating with the data logger via laptop computer (*right*)



Fig. 3 Students prepare ice bath for calibration process (*left*) and set up sensor length for different depths (*right*)

data is developed in partnership with the teachers. After 1 year of data collection, students use the data to investigate permafrost and frozen ground, climate change impact on permafrost stability, and methods of monitoring changes in permafrost. Teachers download the data and use an MS Excel spreadsheet to plot monthly profiles, calculate the average temperature for each depth, and estimate active layer thickness. At this point, students focus on the following questions: “What is going on in our village?” “What will most likely happen in the future in our village?”

4. A model predicting changes in local permafrost is developed and used by students in the classroom. Students share data, comparing their data with that from different monitoring sites all over the world. Our hope is that by this point, students will understand many of the issues related to permafrost and related effects on the world around them. Teachers supplement the curriculum with an entertaining and instructional movie, “TunnelMan” (Figs. 4 and 5).
5. For students in the upper grades and for national park visitors, more-advanced classroom lectures/demonstrations are available, which offer opportunities for



Fig. 4 Demonstrating to students the seasonal variations of ground temperature using obtained data



Fig. 5 Students measure active layer depth (*left*) and look at physical details of frozen soil composition (*right*)

deeper and more complex understanding of the interactions between permafrost and climate change. One example of the effects of natural phenomena is the impact of forest (or tundra) fires on permafrost. Fire has a strong impact on permafrost degradation; fires burn away the insulation layer, which changes the thermal condition of the permafrost. Students measure and simulate the impact that wildfires of varying severity have on permafrost.

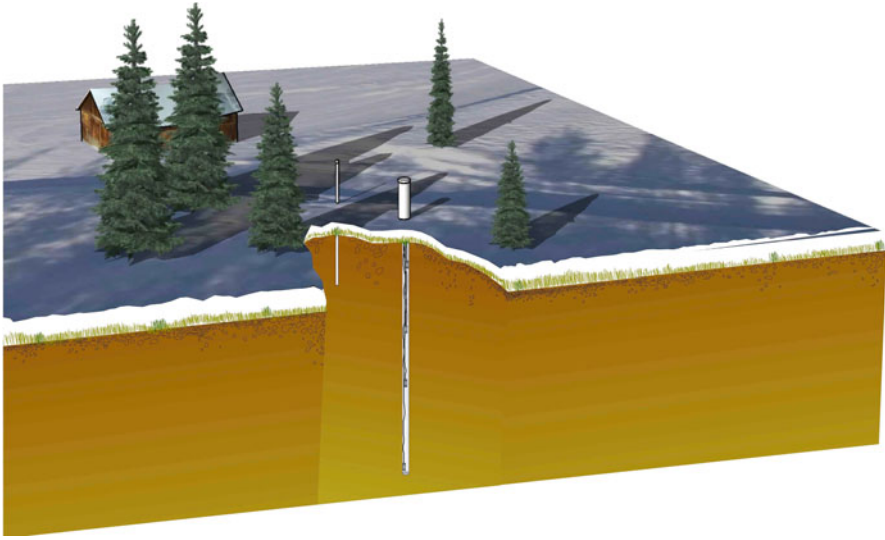


Fig. 6 Temperature monitoring station and frost tube

For maintenance purposes and educational outreach, the majority of our monitoring sites are located at or near schools or national park headquarters. This arrangement allows easier accessibility to equipment, provides educational opportunities by involving students and teachers in research, and facilitates data collection. A map of Alaska shows the locations of the communities (Fig. 1). Figure 6 shows a diagram of installed instruments. Permafrost temperatures are shown for three communities in Fig. 7. The trumpet curve (named for its shape) in these graphs are determined by soil temperature points at certain depths during a year. The ground temperature variations show seasonal changes near ground surface.

The profile in Fig. 7a (Wainwright) shows typical seasonal variation for soil temperature in a northern part of Alaska. Zero annual amplitude permafrost temperature is about -7°C at 10 m below ground surface. Permafrost is colder and stable, with a shallow active layer (less than 1 m). Figure 7b shows a unique profile near the mouth of the Yukon River (Emmonak). Permafrost is presently 14 m thick, and it is possible that warm Yukon River groundwater flows underneath it, creating a strong gradient in soil temperature. Figure 7c shows a typical soil profile in Interior Alaska. This graph of soil temperature at Pearl Creek Elementary School in Fairbanks shows that the depth of no seasonal change is 2.5 m (8 ft) below ground surface. The depth is much shallower here because the temperature is close to the thawing point with almost no trend (straight up profiles). The reason for the shallow amplitude is due to heat transferred by phase change (latent heat transfer). The summer line in the Fairbanks graph shows that ground surface is above freezing, but at only 1 m (3 ft) below ground surface, the line crosses the 0°C (32°F) point. Beneath this point, soil is frozen. Most of the year, the upper layer is frozen too, but this layer thaws

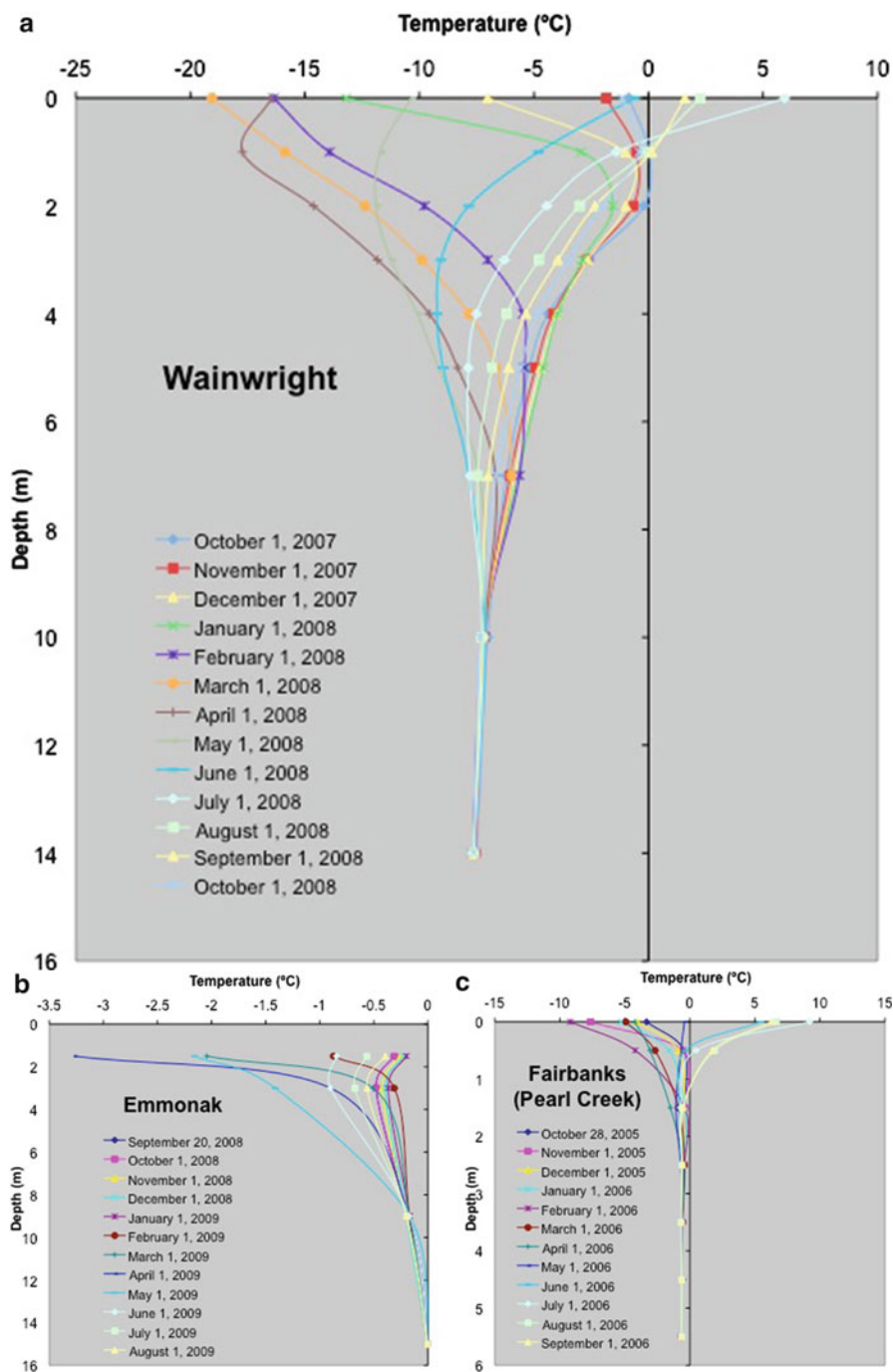


Fig. 7 Examples of permafrost temperature profiles from villages (a) Wainwright, (b) Emmonak, (c) Fairbanks



Fig. 8 Screenshot from TunnelMan Episode 1

each summer (the active layer). The main mechanism of ground temperature change is conduction. It takes time for heat to penetrate the ground. Deeper ground does not respond as quickly as ground surface. In the middle of winter (February), the ground surface is very cold, but the cold has not reached deeper underground yet. April is the coldest time of year 1 m (3 ft) below ground. Usually by then, there are lots of sunshine and half the snow has melted. It is possibly the most beautiful time in Alaska. Only 1 m below ground, however, it is the coldest time of the year, and pipes may freeze unless they are heated.

3.3 Video as Instruction Activity: TunnelMan Series

For public lectures and classroom instruction, classical methods of presentations (e.g., using PowerPoint) work well, but the video series “TunnelMan” has proven to be one of the most effective teaching tools for students (Fig. 8). This video series appeals to students in general, but it is especially successful at holding the attention of students who have attention-deficit challenges. TunnelMan, our underground superhero, helps explain permafrost and the soil temperature monitoring program in a movie, each lasting 4–6 min. The educational viewpoints of each episode are discussed after the video is shown. An important point here is that, presently, most villages in Alaska have no radio or television stations, but they do have Internet access. Most students have an

iPod type of music/video device. These environments are excellent for teaching, as young people are looking for cool video or music entertainment.

Many teachers working with the program's curricula, such as Mr. Robert Stagg from the Aquarian Charter School in the Anchorage School District and Ms. Carol Cologie from Crawford Elementary in the Fairbanks North Star Borough School District, use "TunnelMan" videos in their classrooms. Opinions of the "TunnelMan" series as a teaching tool have been encouraging. Comments include, from Stagg, "Tunnel Man is the best! I think that if I had to model my teaching after anyone it would be after Kenji!" and from Cologie, "Kenji Yoshikawa's permafrost tunnel tour, and his video of TunnelMan—that's the way I like to teach! You know, I like to model what Kenji does, teaching through humor and making things real."

According to Mr. Bill Streever of the *Alaska Dispatch*, who reviewed teacher comment sheets in preparation for a news article, the following comment from an unnamed teacher in a rural Alaska village is typical: "December 2nd the frost tube read 34 and the snow depth was 40 cm. The grade 8 students can't wait until it's their turn to go out and take the measurements, even when it's very cold outside."

In the *Alaska Dispatch* article, Streever concludes:

And here is another key point that both Professor Kenji Yoshikawa and TunnelMan bring to the villages: Village kids matter. A scientist from Japan thinks village kids matter enough to justify 3,500 miles by snow machine. Whether or not they become scientists, students know this: A Japanese man came on a snowmachine with a message of enthusiasm and a hands-on approach to life and left behind a permafrost observatory and, even more importantly, a sense that what happens right here matters, that this isolated village is not alone in a warming world.

3.3.1 TunnelMan Episode 1: Ice on Permafrost

This first episode of TunnelMan is a story, a process-type movie. After TunnelMan emerges from an ancient permafrost tunnel, he explains about ice (ice wedges) in frozen ground. Animation and music (Alicia Keys' "No One") are important aspects. In 2008, this song was popular among teenage students and its lyrics help with explanation. At the same time, educationally, we are concerned with thawing of ice-rich permafrost. Dry permafrost or frozen bedrock also exists in Alaska, but they are not of concern since their thawing would not undermine structures. Almost all infrastructure damage from thawing ice-rich permafrost is due to inadequate building design for the conditions. At the kickoff of this series in 2008, the video worked great in all of the communities and in university permafrost classes including in Russia, Germany, Japan, Spain, Argentina, England, and Norway. It seemed, though, that this movie was not cool enough for boys (mainly high school senior students) and was hard to watch repeatedly.

3.3.2 TunnelMan Episode 2: Hop-Pop TunnelMan

After releasing Episode 1, we tried to focus on including the favorite music of teenagers and making the videos captivating enough to watch repeatedly. The topic of Episode 2 is permafrost monitoring, that is why it is important to monitor

temperature. We chose music with a rap beat and changed images and topics faster for students who might not understand the contents at a single viewing. We created original tunes with a rap beat and scientific lyrics. Screen shots are ten times longer than in Episode 1, but are compressed into 4 min of show time. Some of the words are slang that is not generally used in classroom instruction, which could be a problem in certain schools or with elementary-age students. Using slang was successful for catching the attention of most teenage students. Some students even downloaded and installed this episode on their own device.

3.3.3 TunnelMan Episode 3: Active Layer Monitoring

Episode 3 is probably the favorite of teachers, though not of students, because of the song “Volare” by the Gipsy Kings, popular in the late 1980s, the teacher’s generation. The contents of this episode are classic, more like a typical educational video: how to install the monitoring equipment, what can be observed, the importance of the frost tube, etc. This is an instructional video that aids the teacher somewhat. Since there are many educational videos online today, we felt that this approach was not exactly our aim. However, the episode served well in teaching about frost tubes and other equipment, all explained within 3 min.

3.3.4 TunnelMan Episode 4: Geomorphology

Episode 4 music returns to rap beat and combines a classical movie idea (*Wizard of Oz*). This combination seems to appeal to all generations, even with the switch to rap beat. The purpose of this video is to help viewers understand permafrost and cold region landforms, especially those landforms near the students’ communities. After watching Episode 4, some students have developed an interest in flying over their village to see the landforms, which means that part of the production has been successful. Still, we feel that using a different media or class lesson to increase their knowledge of periglacial geomorphology and landscapes is beneficial.

3.3.5 TunnelMan Episode 5: Permafrost and Climate Chronology

Episode 5 is the last episode in the TunnelMan series and released in June 2012. This episode explains the last 140,000 years of Earth’s climate and permafrost history. Key goals of this video are to help students understand that climate is always changing (never stays the same) and that most of the permafrost in Alaska was established during the last glaciation (e.g., that thawing occurred during the last inter-glaciations). During the last glaciation, humans migrated across Beringia from Asia, becoming the ancestors of Alaska Natives. Filming for this episode was done at Africa’s Rift Valley (the cradle of humankind), Western China, the Peruvian Andes, and several Alaska locations.

We also developed several videos related to our program: “-40 °C World,” “Ice Fog,” “Snowmobile Trips in This Program,” “Boat Trips for Southeast Alaska,”

“Mongolian Borehole Hunting,” “Peruvian Andes Permafrost Drilling,” and “Kilimanjaro Trip.” Our Kilimanjaro permafrost expedition was a successful trip that included total four science teachers and four students from Alaska. We traveled in 2010, 2012 to the summit of Kilimanjaro. More than 700 questions arrived by e-mail during this expedition from 95 countries. Our fellow travelers, the students and teachers from Alaska, were helping to answer all questions during the ascent of the mountain.

3.4 Manga: TunnelMan Cartoon

The Japanese cartoon, Manga, is becoming popular in the USA, including the rural communities of Alaska. This cartoon idea presents a great media opportunity for Alaska Native students. We developed “TunnelMan Return in 2058,” a 32-page Manga story (Fig. 9a, b). This story takes place in Alaska in year 2058 (following International Polar Year). People are looking for proof of climate change, likely in temperature. Our 50-year-old vintage instrument, installed in 2008, helps the world to understand world climate. We hope this message underscores the importance of the program’s work and helps us avoid vandalism of existing monitoring stations. All of the contents of our work are available on <http://www.uaf.edu/permafrost>.

3.5 Active Layer Monitoring

Unlike permafrost monitoring, the frost tube program is much more dynamic and active to students. A frost tube is an instrument that measures when and how deeply soil freezes. Frost tubes are made of three tubes that fit inside each other. The innermost tube is marked every 5 cm and filled with colored water; it fits inside a radiant heat tube (sealed on the bottom), which fits inside a PVC pipe, open on both ends (Figs. 10 and 11). The innermost tube of the frost tube is about 12 mm in diameter. When inserted in the hole drilled in the ground (with a drill hole), the frost tube’s underground end reaches to the deepest level of frost or to the permafrost layer. The aboveground end (about 1 m long) is capped to prevent air temperature from influencing the underground temperature reading and to keep snow and water out. The innermost tube with colored water shows where ice has formed underground. We lift this tube out from the two outer tubes and note at what depth the ice has formed. It is easy to see the boundary between ice and unfrozen water, because the ice looks clear and the water looks colored. During frost heaves, only the outermost tube is affected. Students can monitor the timing and depth of freezing in soil at a frost tube site.

Students measure the depth at which water in the frost tube has frozen once a week, to get an indication of when the surrounding soil has also frozen. Our large network of sites provides greater comparison of timing and depth of freezing in soils in different regions around Alaska and the world (Fig. 12). Working with

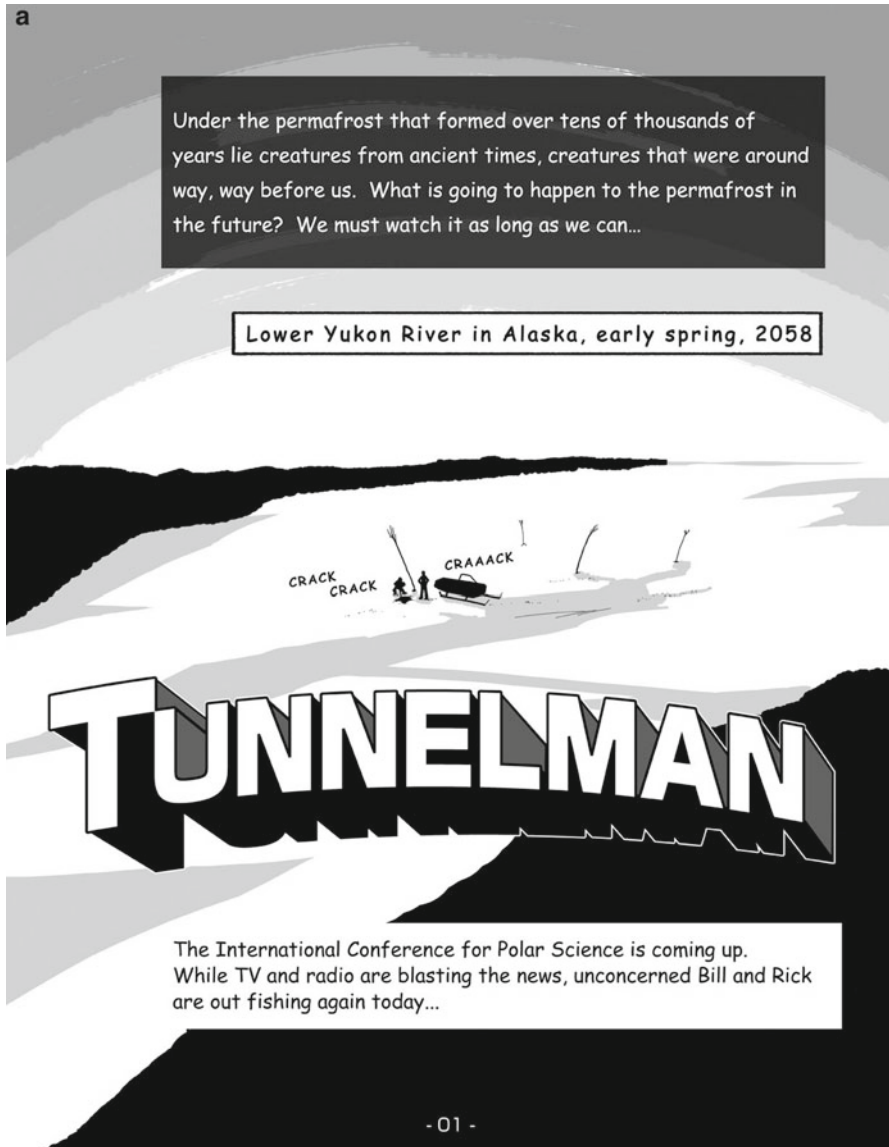


Fig. 9a Front (cover) page of our Manga (Japanese Cartoon) from TunnelMan Returns

temperature data, advanced students can predict the timing and depth of freezing for upcoming seasons or in a future scenario following climate change. The presence or absence of frozen ground has a strong effect on hydrology. Frozen soil acting as an impermeable layer affects water availability to root systems of plants and the recharge of groundwater reservoirs. A more-detailed description of the GLOBE frost tube protocol is found at GLOBE (2011).



Fig. 9b This story takes place in Alaska in year 2058 (following International Polar Year). People are looking for proof of climate change, likely our temperature monitoring network will be useful at the time

The frost tube program has been a great success in northern communities, because it is relatively easy to install, is cost efficient, and is a highly dynamic student activity. We installed a small one-channel data logger connected to an air temperature sensor next to the frost tube. From the surface temperature data, freezing degree days (freezing index) and thawing degree days (thawing index) as well as mean

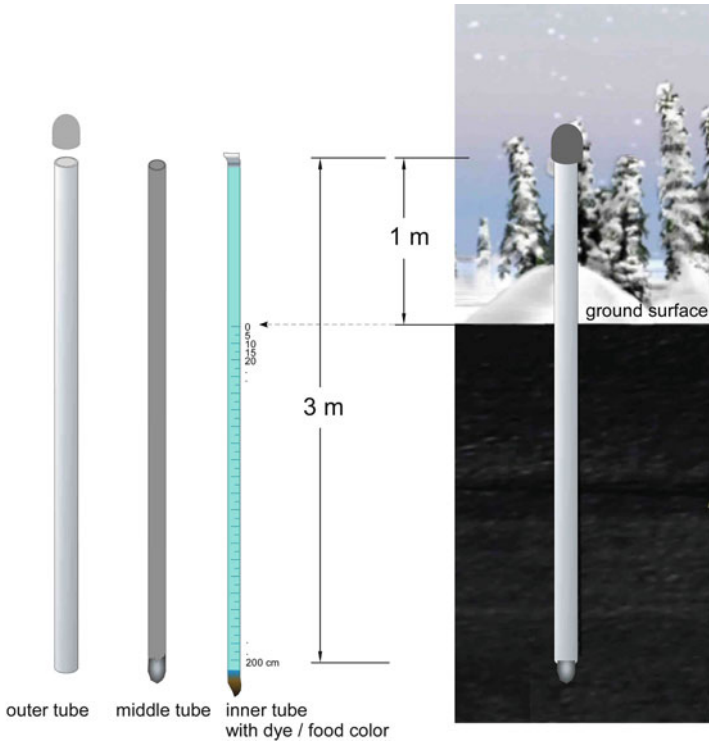


Fig. 10 Components of a frost tube

annual temperature can be calculated (Fig. 13). Examples of data collected are given in Fig. 14. These data could be used in a simple formula for predicting depth of freezing in the future.

4 Some Outcomes of This Project

4.1 Permafrost Failure Impacts Rural Communities

The discontinuous permafrost region in Northwestern America is particularly sensitive to climatic change. Intense summer rain or extreme summer drying can accelerate rates of thermal erosion by changing the surface conditions in areas of ice-rich permafrost. The part of Yukon, Canada, and northwestern Alaska, both of which were covered by glaciers during the Last Glacial Maximum (LGM), are widely recognized as one of the most ice-rich (buried glacier ice in permafrost) and thaw-sensitive areas in the world. In particular, glaciated areas are prone to develop retrogressive thaw slumps from the thawing of buried glacial ice bodies. The volume of

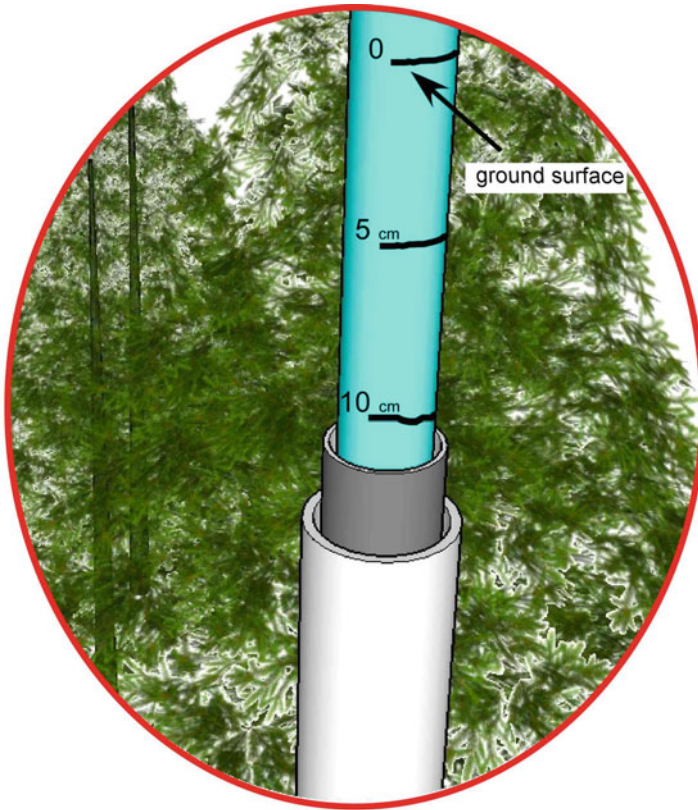


Fig. 11 Another view of the frost tube showing inner, middle, and outer tubes

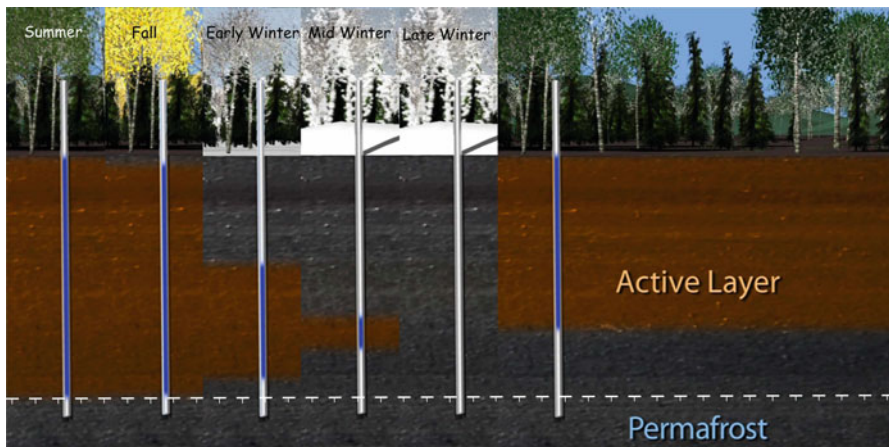


Fig. 12 Progression of freezing

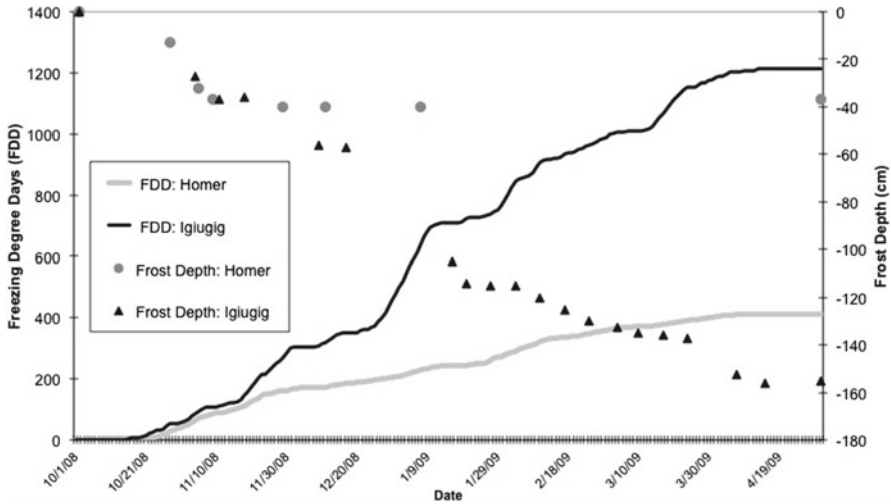


Fig. 13 Examples for freezing degree days and frost depths at Homer and Igiugig, Alaska

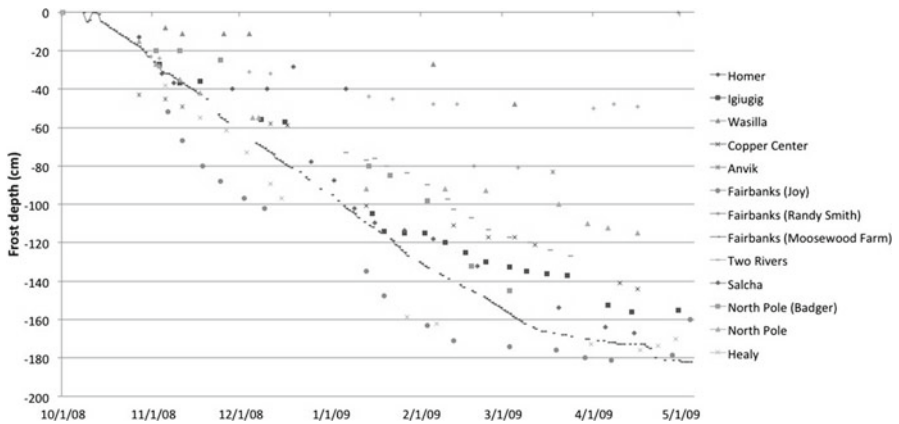


Fig. 14 Examples of frost tube measurements in rural communities, Alaska

sediment and ground ice eroded by retrogressive thaw slump activity has discharged large amounts of suspended sediments into marine or river systems (Fig. 15). Large quantities of suspended sediments have impacted drinking water sources for rural communities and may jeopardize critical fish-spawning habitat.

In 2004, a huge retrogressive thaw slump occurred at the upper stream of the Selawik River in Alaska. White fish is a major source of protein for those who live in the village of Selawik, and residents are concerned about the white fish resource. Since the ground failure in 2004, the village mayor, school principal, science teacher, and students have supported the PALM Program by sampling



Fig. 15 Retrogressive thaw slump near village of Selawik

suspended solid measurements. A similar problem occurred in 2005 at Kivalina, another village in Alaska. High, concentrated, suspended sediments are entering the intake of the village's drinking water system. Village water is drawn from the mouth of Wulik River, where several retrogressive thaw slumps have

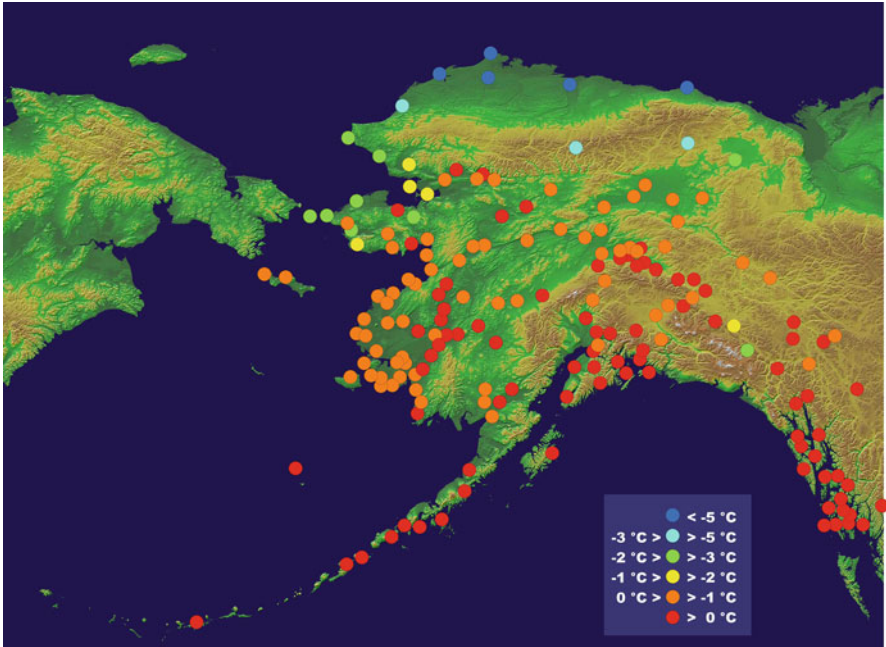


Fig. 16 Map of our monitoring network and the results from ground temperature distributions

occurred upstream. In general, permafrost-related hazards add to the interest in the PALM Program, and our program provided important information to the communities (Fig. 16).

4.2 Ice Cellar (*Sigluaqs*)

An ice cellar (called a *sigluaq*) is one of the smartest ideas of northern Natives. Mainly whaling communities have one or several ice cellars in the village. The meat stores well in this traditional natural freezer that makes use of permafrost; however, ice cellar temperature depends on permafrost temperature and climate. We monitored ice cellar/permafrost temperature with whaling captains and students of whaling villages such as Gambell, Savoonga, Little Diomed, Wales, Kivalina, Pt. Hope, Pt. Lay, Wainwright, Barrow, Nuiqsut, and Kaktovik. Reference measurements from Canada and Russia were employed. Most cellars are located 3–6 m below ground surface. That depth is still within the temperature seasonal fluctuation zone, which is usually -3 to -13 °C at cellars in Barrow (Fig. 17a). Climatic change has been suspected of compromising and causing damage to ice cellars in northern communities, with thaw and spoilage of meat a potential problem. Investigation of temperature regimes in these cellars is critically important for the continued well-being

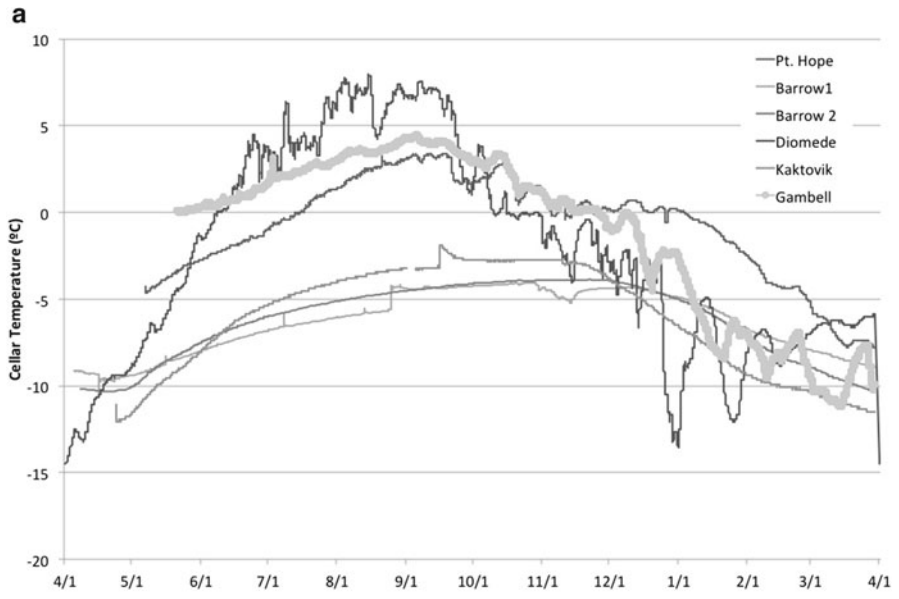


Fig. 17 Annual temperature of ice cellar (a) and cellar with whale meat (b)

of local communities. Long-term monitoring may yield useful climatic and permafrost information. This study shows that the temperature regime of ice cellars is quite different north and south of Point Hope. The primary use of ice cellars in northern communities (north of Point Hope) is storage of whale or other meat

(Fig. 17b). However, the primary use of ice cellars in southern communities (St. Lawrence Island, Diomedede Island, and the Seward Peninsula) is between November and May, mainly for fermentation of sea lion meat. The subsistence life of Alaska Natives and the permafrost temperature regime fit reasonably well in these areas. The temperature data is useful in local schools for class or independent student projects such as science fairs.

5 Evaluation

The Bering Strait School District (BSSD) was chosen as the district in which more in-depth curriculum research would be conducted, because teachers in this district already were trained in pilot testing protocol. When our program began, BSSD teachers recently had finished pilot testing several other lessons. Before teachers began pilot testing the permafrost curriculum, they attended permafrost program sessions at BSSD headquarters in Unalakleet, Alaska, as part of their broader BSSD mandatory district-wide in-service training (in August 2008 for new teachers and in October 2008 for returning teachers). Our program was invited to participate in an intensive 3-day workshop for teacher representatives from each of the BSSD's 15 schools (November 16–18, 2008). To keep costs manageable, two representatives from each BSSD school attended this workshop. These representatives were responsible for sharing the training with other teachers upon return to their schools.

During the workshop, we provided a detailed overview of permafrost geophysics, describing soil properties in the Arctic, heat transfer, and the moss insulation buffer zones between the atmosphere and the ground. We also took teachers on a field trip to a nearby school to show them a model of a permafrost monitoring station. During the field trip, we explained how teachers could determine permafrost temperature and permafrost active layer depth in each rural community. Pilot testing protocol required BSSD teachers to:

1. Retrieve all permafrost curriculum resources as they became available (classroom lessons on permafrost + interactive multimedia activities + other resources, such as the TunnelMan videos and comic strip booklets) from the PALM Program website
2. Implement the permafrost curriculum with indigenous students in multi-age classrooms in rural BSSD schools
3. Participate in associated permafrost curricular activities (online videoconference lectures + online scientist mentorship)
4. Review, comment on, and suggest revisions for all permafrost curriculum resources, sending comments monthly by FedEx or by e-mail to Yoshikawa (University of Alaska Fairbanks)

At each school site, two boreholes were drilled. Into one hole, a data logger was inserted, which gathers data that can be used to show slow change in permafrost over time. In the other hole, a frost tube was inserted that contains colored water.

Table 2 PALM (ACMP) Program student pre-/posttest Wilcoxon signed-rank analysis results (Larson et al. 2009, p. 28)

Year	Number of students	Average pretest	Pretest std. deviation	Average posttest	Posttest std. deviation	Average improvement	Z score	P
PY3	186	19.3 %	27.7 %	93.6 %	12.1 %	74.3 %	11.687	<0.001

During on-site Technology Workshops, we explained how students could measure the depth and rate of freezing and thawing by taking measurements during key moments in the fall, winter, and spring. We returned to the communities annually to help students download data from permafrost observatory data loggers. The mechanics of these large data download “dumps” were described, with an explanation of how they provide comprehensive information about permafrost temperature over the course of a year.

Following instructions outlined in the permafrost curriculum, BSSD students were able to perform various analyses on the data to determine the depth of the active layer and the time and rate of its freezing and thawing.

After pilot testing the permafrost curriculum in BSSD classrooms throughout the year, two representatives from each BSSD school met at University of Alaska Fairbanks to review their experiences and to share recommendations on all facets of the permafrost curriculum from other staff at their schools. At the culminating workshop, teachers from each BSSD school used student achievement scores (from this program-created pre- and posttests) to emphasize their revision suggestions.

The Wilcoxon signed-rank test was used to assess if statistically significant differences occurred between pre- and posttest scores. The Wilcoxon signed-rank test is a nonparametric test for the significance of the difference between the distributions of two related samples involving repeated measures or matched pairs. Like the *t* test for correlated samples, the Wilcoxon signed-rank test applies to two-sample designs involving repeated measures, matched pairs, or “before” and “after” measures. The Wilcoxon signed-rank test was used rather than a *t* test because this program’s pre- and posttest student data did not fit a normal distribution. An α -level of 0.01 was used to assess significance, meaning that the chances of obtaining a significant result when the underlying distributions were not significantly different are less than 1 %. External analyses of pre- and posttest results indicate that, overall, students’ average improvement was 74.3 % ($n=186$), a significant improvement ($Z=11.687$, $P<0.001$). The PALM Program, part of Arctic Climate Modeling Program (ACMP), student pre- and posttests administered provided data on growth in student knowledge and learning of climate science and inquiry/process skills. Students demonstrated an average increase in achievement of 74.9 %. An objective rubric was used to grade each pre- and posttest question. To ensure the validity of each score, two ACMP staff members individually assessed each pre- and posttest item. External analyses of pre- and posttest results show significant improvement in student Science, Technology, and Math (STM) knowledge and skills. “ACMP PY3” corresponds to the year the permafrost module (PALM) was used (Larson et al. 2009) (Table 2).

6 Summary

The intellectual merit of this program is that it will advance knowledge of our climatic system and the thermal state of permafrost as a complex process that is spatially and temporally quite variable. This is the first time that we have obtained a high-resolution spatial data set for Alaska and other permafrost regions. The climatic system of the cryosphere has an important influence on global climate. Monitoring the thermal state of permafrost by measuring borehole temperatures is one of the methods that can be used to understand climatic trends. The degradation of permafrost is triggered by the length of the active layer freezing period; that is, seasonal lengths are an important factor. Implicit in many of climatic change reports is the desire to develop a sustainable scientific infrastructure to address needs, among which is the establishment and maintenance of long-term observational networks. The Permafrost/Active Layer Monitoring Program provides opportunities for field experience and educational participation at levels ranging from elementary school to high school. The program will help to provide high-resolution spatial distribution of the thermal state of permafrost, especially in Alaska, and will improve the general knowledge of Earth's climatic pattern. The program also offers an opportunity for students to take part in understanding climatic systems. This project highlights the interaction between permafrost, the active layer, hydrology, and the climate system of the cryosphere, and provides a strong educational outreach program involving remote communities.

Overview

Background and Motivation

- The Permafrost/Active Layer Monitoring Program is an ongoing project that builds on work begun in 2005 to establish long-term permafrost and active layer monitoring sites adjacent to schools in Alaska and in the circumpolar permafrost region.
- About 200 schools in Alaska are involved in the project. The monitoring sites collect temperature measurement data on permafrost and the length and depth of the active layer.
- This information is important because changes in permafrost conditions affect local ecosystems and hydrological regimes and can influence the severity of natural disasters.

Innovations and Findings

- Changes in climate, length of seasons, and permafrost conditions directly impact natural resources and subsistence activities; thus, the information obtained from the monitoring sites has relevance to the communities and the students involved.

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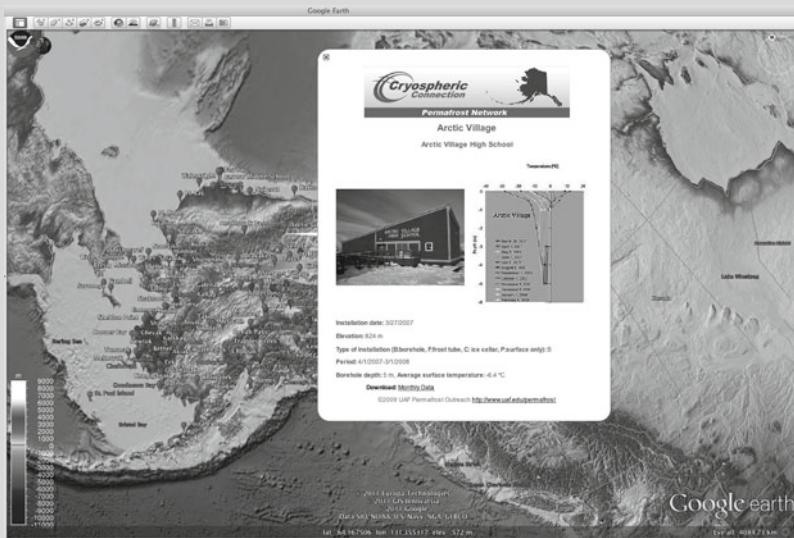


Fig. 18 Example of data archiving with Google Earth interface

- The data gathered from these stations are shared with other schools and made available to the public through the PALM Program website as well as by using Google Earth interface (Fig. 18).
- For public lectures and classroom instruction, the video series, “TunnelMan,” has proven to be one of the most effective teaching tools for students. This video series appeals to students in general, but it is especially successful at holding the attention of students who have attention-deficit challenges.

Implications for Wider Practice

- Obtained data sets are not only useful for class lessons but also very helpful for science community as well as engineering purposes as they relate to communities infrastructures.
- Pre- and post-assessments administered to students provide data on growth in student knowledge and learning of permafrost science and inquiry/process skills.
- About 200 points of temperature measurements sites reveal the thermal state of permafrost in Alaska. We have a better understanding of and more accurate information on the distribution of permafrost and thermal conditions of each community. In addition to extending our knowledge of the environment of the cryosphere, the program involves school-age students in hopes of inspiring a new generation of scientists to continue this study.

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