



Permafrost Monitoring in the Central Alaska Network

Protocol Narrative, Version 1.0

Natural Resource Report NPS/CAKN/NRR—2018/1760



ON THE COVER

Oblique aerial view of ice wedges exposed in bluffs alongside Toklat River, Denali National Park and Preserve, Alaska.
NPS photo.

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Natural Resource Report NPS/CAKN/NRR—2018/1760

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Abstract

The three national park units which comprise the National Park Service Inventory and Monitoring Program's Central Alaska Network (CAKN: Wrangell-St. Elias, Denali, and Yukon-Charley Rivers) are underlain by permafrost—ground that remains at or below 0°C for at least two, but typically many, years. Much of that permafrost, however, is geographically discontinuous, thin, and close to the melting point of water. Under the warming conditions that characterize these parks, permafrost thaw is likely to have significant impacts on the landscapes of these parks. These impacts may include development of thermokarst, landslides and slumping, changes in hydrology and vegetation, growth and/or drainage of lakes, enhanced release of greenhouse gases, and decay of characteristic permafrost features like pingos and rock glaciers.

The CAKN permafrost monitoring program is designed to monitor a subset of these changes over multiple decades, and focuses on tracking changes in the thermal and physical state of permafrost. Collected data will contribute directly to the Global Terrestrial Network for Permafrost, the primary international permafrost monitoring program. Thermal changes will be monitored with a broad network of shallow (<3 m) soil temperature measurements, and also with temperature measurements from a single deep (29-70 m) borehole adjacent to each park. These measurements will mostly be conducted in collaboration with existing monitoring programs to leverage existing resources. Physical changes will be monitored with a network of active layer thickness measurements that use late-summer mechanical probing to determine maximum thaw depth on fine-grained permafrost soils. The thaw depth measurements will be co-located with survey-grade differential global positioning system (dGPS) surveys of soil surface elevation to detect thaw-related subsidence. These physical changes will be conducted in grids or transects at sites selected to take advantage of previous studies, to maximize logistical/resource efficiency, and to represent areas expected to change most rapidly in coming decades.

Many of the landscape-scale impacts of permafrost thaw are already monitored by the Arctic Network, but CAKN will monitor changes in one permafrost landform that is uniquely abundant in WRST: rock glaciers. The areal extent, surface elevations, and velocities of a well-studied rock glacier in the central Wrangells will be measured every 6th year. Opportunities for monitoring of other important permafrost changes, particularly including carbon cycling and thermokarst development, are not included in this protocol but will be considered for future studies. Sustainable inclusion of such work in the protocol itself would require a stable source of additional funds, but shorter-term opportunistic and collaborative research is an ongoing goal of the broader permafrost monitoring program.

Acknowledgments

Thanks to Maggie MacCluskie, Vladimir Romanovsky, Dave Schirokauer, Ted Schuur, Pam Sousanes, and Dave Swanson for helpful discussion and review of early versions of this protocol. Thanks also to colleagues who completed early work on permafrost in the CAKN parks, including Guy Adema, Chris Arp, Ken Carle, Kathryn Crummer, M. Torre Jorgenson, Michael Mahala, Karen Oakley, Tom Osterkamp, Santosh Panda, James Sickman, Trey Simmons, Christian Trucco, Jason Vogel, and Larrisa Yocum. I gratefully acknowledge the contributions of peer-reviewers Elchin Jafarov, Dmitri Nicolsky, Sergey Marchenko, and Joel Reynolds.

1. Introduction

1.1 Background

The Central Alaska Network (CAKN) is part of the National Park Service (NPS) Inventory and Monitoring (I&M) Program. The Inventory and Monitoring Program is the result of the 1998 National Parks Omnibus Management Act. This act directs NPS to “establish baseline [resource] information and to provide information on the long-term trends in the condition of National Park System resources.”

To accomplish this task, the NPS has grouped parks into 32 networks based upon broad ecological similarities. CAKN (Figure 1), one of four networks in Alaska, is composed of three conservation units: Wrangell-St. Elias National Park and Preserve (WRST), Denali National Park and Preserve (DENA), and Yukon-Charley Rivers National Preserve (YUCH).

The lands encompassed by CAKN are vast: the three park units within this network contain over 88,000 km² (21.7 million acres) and span an area that is around 780 km (485 miles) from east to west and around 660 km (410 miles) from north to south. Based on area, NPS land within this single network represents one-fourth of all the land in the National Park Service system. Elevations range from sea level to nearly 6200 m (1890'), and encompass a number of physiographic and climatic regions, including 12 of Alaska's 32 ecoregions (Nowacki et al. 2002). Biomes range from boreal to maritime with a substantial transition zone. Most of WRST and DENA and all of YUCH have a continental climates (relatively low precipitation, long extremely cold winters, and short hot summers), while the south side of the Alaska Range in DENA and the coastal areas of WRST have a maritime climate (cool wet summers, relatively mild winters with extensive snowfall).

Each network has developed and prioritized a suite of “vital signs” for long-term monitoring (MacCluskie et al. 2005). The primary goals of vital signs monitoring are to:

1. Determine status and trends in selected indicators of the condition of park ecosystems to allow managers to make better- informed decisions and to work more effectively with other agencies and individuals for the benefit of park resources.
2. Provide early warning of abnormal conditions and impairment of selected resources to help develop effective mitigation measures and reduce costs of management.
3. Provide data to better understand the dynamic nature and condition of park ecosystems and to provide reference points for comparisons with other altered environments.
4. Provide data to meet certain legal and congressional mandates related to natural resource protection and visitor enjoyment.
5. Provide a means of measuring progress towards performance goals.

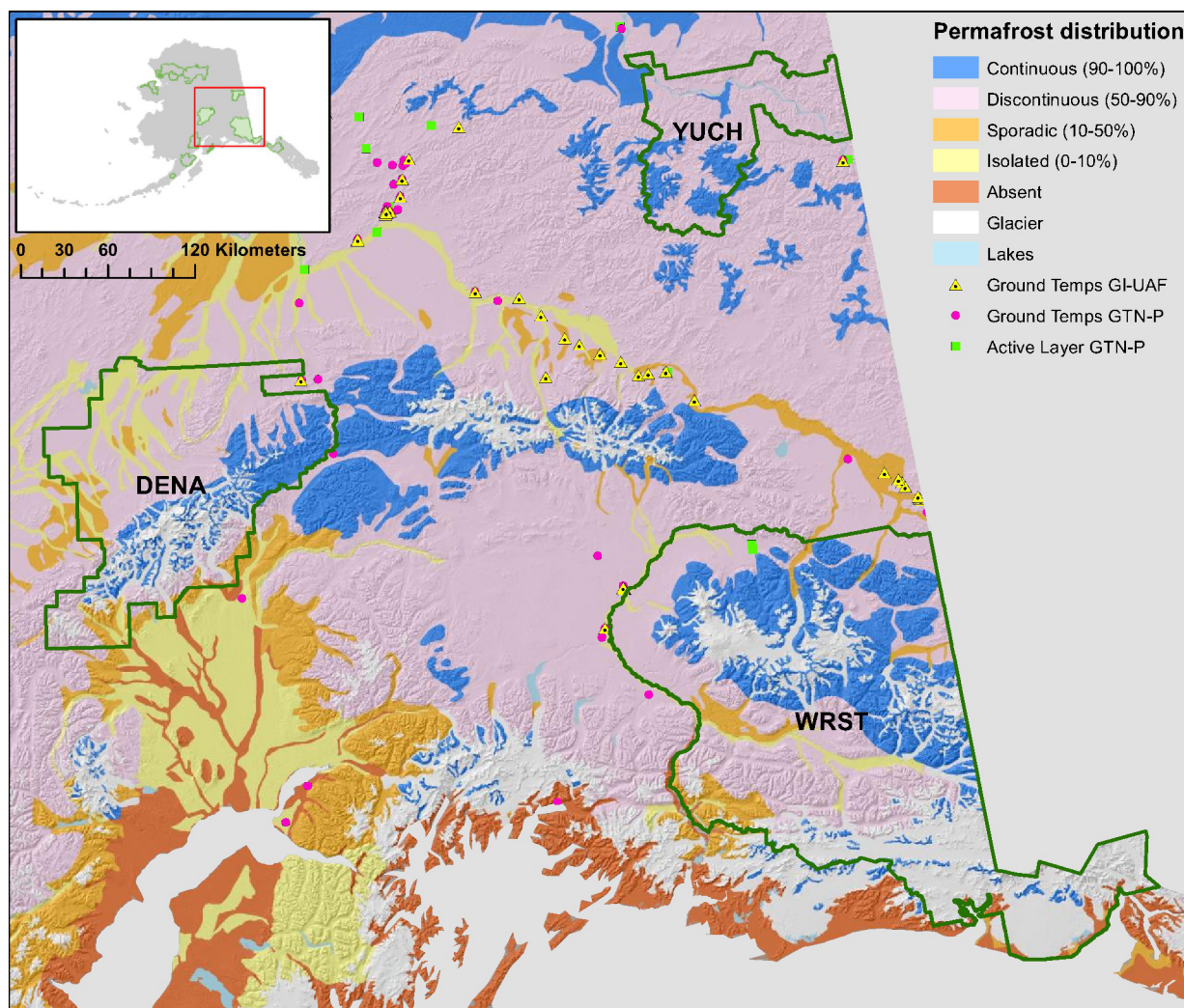


Figure 1. Permafrost distribution in the National Park Service Central Alaska Network (CAKN): Wrangell-St. Elias National Park and Preserve (WRST), Denali National Park and Preserve (DENA), and Yukon-Charley Rivers National Preserve (YUCH). At this scale, permafrost is considered continuous where it underlies 90-100% of the landscape (blue shading), discontinuous (50-90%, purple), sporadic (10-50%, orange), and isolated (0-10%, yellow). Glacier cover in white. Distribution from Jorgenson et al. 2008b. To provide context for this protocol, existing non-NPS permafrost measurement installations (some of which are not currently active) are shown with yellow, red, and green symbols.

Because CAKN parks are relatively pristine and unstudied, vital signs in the CAKN monitoring program focus on measures of general ecological structure and function and, in so doing, emphasize goals #1, #3, and #4 from the list above. While many long-term ecological monitoring programs have focused on local-scale anthropogenic causes of change, direct human effects tend to be more limited in our systems. However, scientists are already observing changes in high-latitude ecosystems due to climate warming; moreover, arctic and subarctic environments may be especially vulnerable to even slight shifts in temperature regimes. The relatively untouched nature of these vast parklands thus provides the CAKN with important baselines against which to measure and evaluate the direction and magnitude of changes brought about by human influences on regional and global scales.

Permafrost has been identified as one of the vital signs of environmental condition that will be monitored over the long term in CAKN (MacCluskie 2005). It is one of a group of physical drivers of habitat condition that also includes climate, hydrology, seasonal snow cover, glaciers, fire, flooding, landslides and avalanches, and disturbances related to tectonics (earthquakes and volcanoes). Many of the topics that appear in this list are linked by their role in the water cycle. Temperature is critical in the hydrological cycle because of the thermal thresholds that determine melting and evaporation, and this is especially true of permafrost. Permafrost is defined as ground (soil or rock, plus any included ice or organic material) that remains at or below 0 °C for at least two consecutive years (van Everdingen 2005). The presence, extent, and character of permafrost soils strongly influence a variety of landscape processes with both local (Osterkamp et al. 2009) and global (Schuur et al. 2015b) consequences, and it is therefore important to monitor changes in these attributes.

Like all the Inventory and Monitoring Program vital signs, this permafrost monitoring program is built around a monitoring protocol that guides the long-term collection of data to detect and describe changes in key variables. That protocol, which is described by this narrative report, by a companion report summarizing pertinent Data Quality Standards, and by a set of Standard Operating Procedures (SOPs), is meant to be sustainably executed over many decades. The core objectives of this protocol have therefore been designed to survive reasonably foreseeable changes in technology, NPS staffing, and funding. The protocol has also been designed to be consistent with, and comparable if not identical in methodology to, existing permafrost monitoring protocols in use at this time. Examples consulted for this purpose include Circumpolar Active-Layer Monitoring (CALM Program): description and data (Brown 1973), the International Permafrost Association's 2008 *Manual for monitoring and reporting permafrost measurements*, the United States Geological Survey's *DOI/GTN-P Climate-Station Data, Quality Assurance, and Control Procedures* (Clow and Urban 2012), and the NPS *Permafrost monitoring protocol for the Arctic Network: Narrative* (Swanson 2013). Revisions to the protocol will be necessary as these changes occur, but will be adopted in consistent pursuit of these core objectives. The permafrost monitoring program can pursue shorter-term opportunities to expand upon the measurements described in this protocol as collaborative opportunities emerge, but such activities are not the focus of this protocol narrative.

1.2 Rationale for monitoring permafrost

Permafrost is neither ubiquitous, nor uniformly distributed, within the CAKN parks. The geographic continuity of permafrost, which is widespread within the Arctic and boreal regions of the Northern Hemisphere, is controlled to a large extent by the surface energy balance and thus varies strongly across climatic gradients—most notably with latitude. Compared with permafrost in the continuous zone, which among Alaskan parklands is found mostly within the Arctic Network (comprising Cape Krusenstern National Monument, Noatak National Preserve, Gates of the Arctic National Park and Preserve, Kobuk Valley National Park, and Bering Land Bridge National Preserve; Swanson 2017), permafrost distribution in the CAKN parks is less spatially complete. Most of the CAKN parks are mapped, at least at the broadest scale of circumboreal permafrost maps, as *discontinuous* (covers 50-90% of the landscape). In the latest detailed Alaska-specific permafrost distribution map, permafrost ranges from *absent* in the southern coastal portion of WRST, through *isolated* (0-10% of the landscape) in major river valleys of WRST and DENA and *sporadic* (10-50%) in some lowlands of

WRST and DENA, to *discontinuous* (common in all parks) and *continuous* (90-100%) at the highest elevation portions of all three parks (Figure 1).

Within those zones, permafrost distribution is further constrained by other factors including glaciers and fire. Glaciers, though composed primarily of ice, are generally not considered to be permafrost features (van Everdingen 2005). Though this distinction is partly one of history and convenience, it is also strictly correct for a majority of the glaciers in WRST and DENA (YUCH contains no glaciers). This is so because most glaciers in those parks are temperate glaciers, meaning that the ice and firn within them reaches the pressure-melting point of water at the end of every melt season (Cogley et al. 2011). In other words, they are not *below* freezing on a year-round basis, as permafrost must be (perhaps with minor exceptions at the thin margins of glaciers in the coldest areas of these parks). Because glaciers occupy large fractions of WRST (34.8%) and, to a lesser extent, DENA (15.0%), and are biased in their distribution towards colder portions of the landscape (Figure 1), they therefore provide an important limit on the formation of permafrost in those parks (Loso et al. 2014).

Permafrost distribution is also affected by fire, which hastens permafrost degradation by removing the shading and insulating effects of overlying vegetation, allowing greater warming of the soil surface in summertime. Increased incidence and severity of wildfires in Alaskan forests and peatlands in recent decades has been linked to climatic change, and may provide a positive feedback for permafrost degradation because fires burn more deeply and severely in non-permafrost soils (Turetsky 2010). All three CAKN parks experience natural fires, and permafrost distribution is therefore influenced by changes in this disturbance regime.

Permafrost in the CAKN parks is very susceptible to change (Osterkamp and Romanovsky 1999). This susceptibility, which has strong potential consequences for ecosystems and infrastructure in the parks, is a function largely of the temperature of the permafrost. Permafrost is maintained by a climate with cold mean annual temperatures. Mean annual ground temperatures in permafrost are generally a few degrees warmer than mean annual air temperatures (Brown 1973). Thus for permafrost to exist, mean annual air temperatures must generally be below freezing. During the period 1971-2000, mean annual air temperatures in CAKN ranged from about below -12 °C in the highest mountains to above +3 °C near the coast, with most in the -4 °C to -1 °C range and the colder values evident only in the highest-elevation areas (Figure 2). Compared with permafrost areas further to the north, these soil temperatures are very close to the melting point of water.

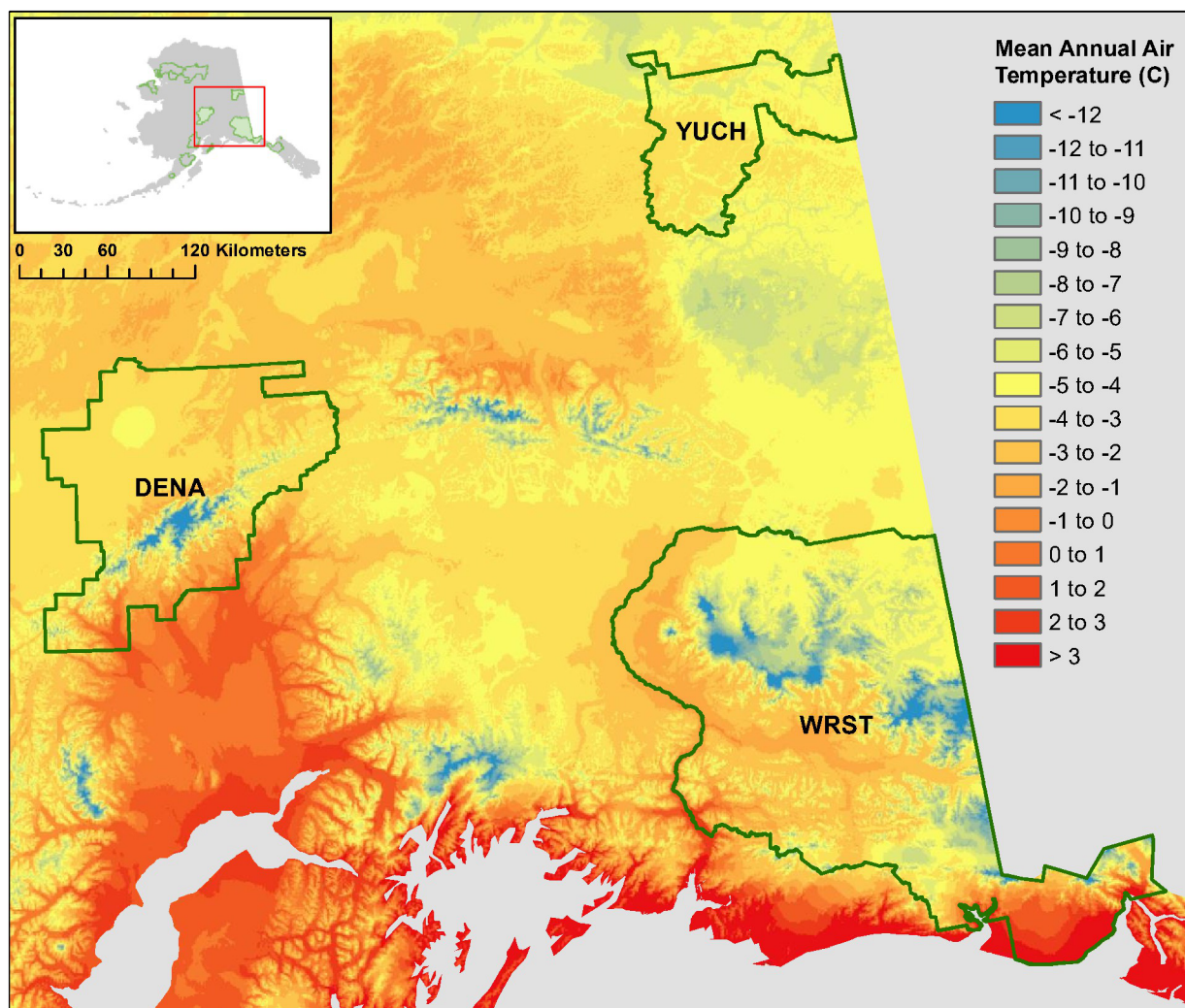


Figure 2. Mean 1971-2000 annual temperatures in CAKN (PRISM Climate Group 2009).

Climatic warming is underway, and likely to continue in CAKN (SNAP 2013). Predictions based on the best available global circulation models (Figure 3) are that mean annual temperatures in CAKN will warm over the next half-century by 1.5-3.0 °C, with the least warming near the coast and the greatest at the northern edges of DENA and YUCH. Although the details of these model predictions reflect substantial uncertainty in both the emissions and the climatic response, three general points are relatively insensitive to those errors: 1) warming is expected to continue, 2) warming will likely be greater in the northern portions of state, and 3) the warming is generally comparable in magnitude (but opposite in sign) to the mean annual air temperatures (Figure 2). These points imply the significant possibility that permafrost will become unstable and begin to thaw at many CAKN sites over the coming decades. This prediction, which is supported by focused permafrost modeling undertaken in DENA and WRST (Panda et al. 2016a, 2016b), justifies the convention—in this report—of referring to monitored changes as those related to permafrost thaw, though the protocol can equally well track changes related to unexpected cooling.

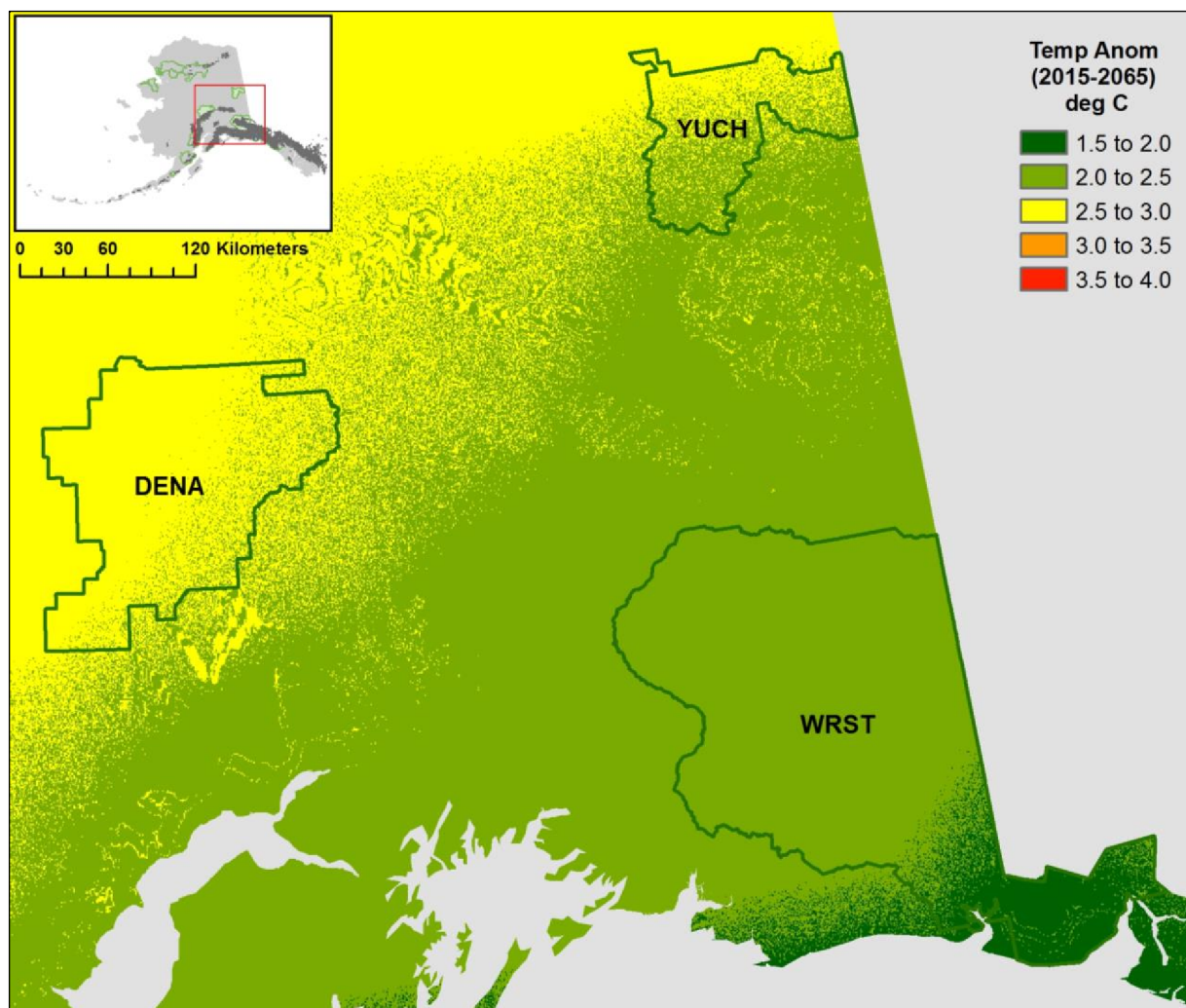


Figure 3. Temperature anomalies predicted for the next 50 years. Predicted warming, from the Scenarios Network for Alaska and Arctic Planning (SNAP 2013), is downscaled from the average output of five global climate models. Models are driven by the A1B emission scenario, a moderate estimate of greenhouse gas emissions and other forcing agents that impact global climate (IPCC SRES 2000). The basic spatial pattern is similar under other scenarios, but with greater or less magnitude of warming.

From a local ecosystem perspective, the most important consequences of permafrost thaw are related to the presence of ice and water. Because permafrost is defined on thermal and temporal criteria, it can include a variety of materials, including mineral and organic soil, rock, and ice. Warming temperatures to some extent impacts all of these constituents, but the ice content of permafrost is especially important. Many permafrost soils contain visible ice inclusions (“ground ice”) in the form of ice wedges (networks of massive wedge-shaped, foliated ice bodies), segregated ice (layers or lenses), or pore ice (small, interstitial crystals). Therefore, permafrost thaw can trigger major changes in surface topography and hydrology, resulting in the formation of thermokarst landforms (Jorgenson et al. 2008a). Thermokarst landforms develop when ground ice melts and the remaining soil subsides into the space previously occupied by ice volume. Thermokarst is not ubiquitous within permafrost landscapes, however, and in a given area is dependent upon local soil characteristics, topography,

and geomorphology (Olefeldt et al. 2016; Shur and Jorgenson 2007). Globally, thermokarst impacts only about 20% of permafrost, and within CAKN parks, areas containing or susceptible to developing 10% or more coverage by thermokarst landforms are similarly limited (Figure 4; Olefeldt et al. 2016). In general, low-lying basins characterized by relatively poor drainage and fine-grained soils are the most susceptible to development of thermokarst landforms.

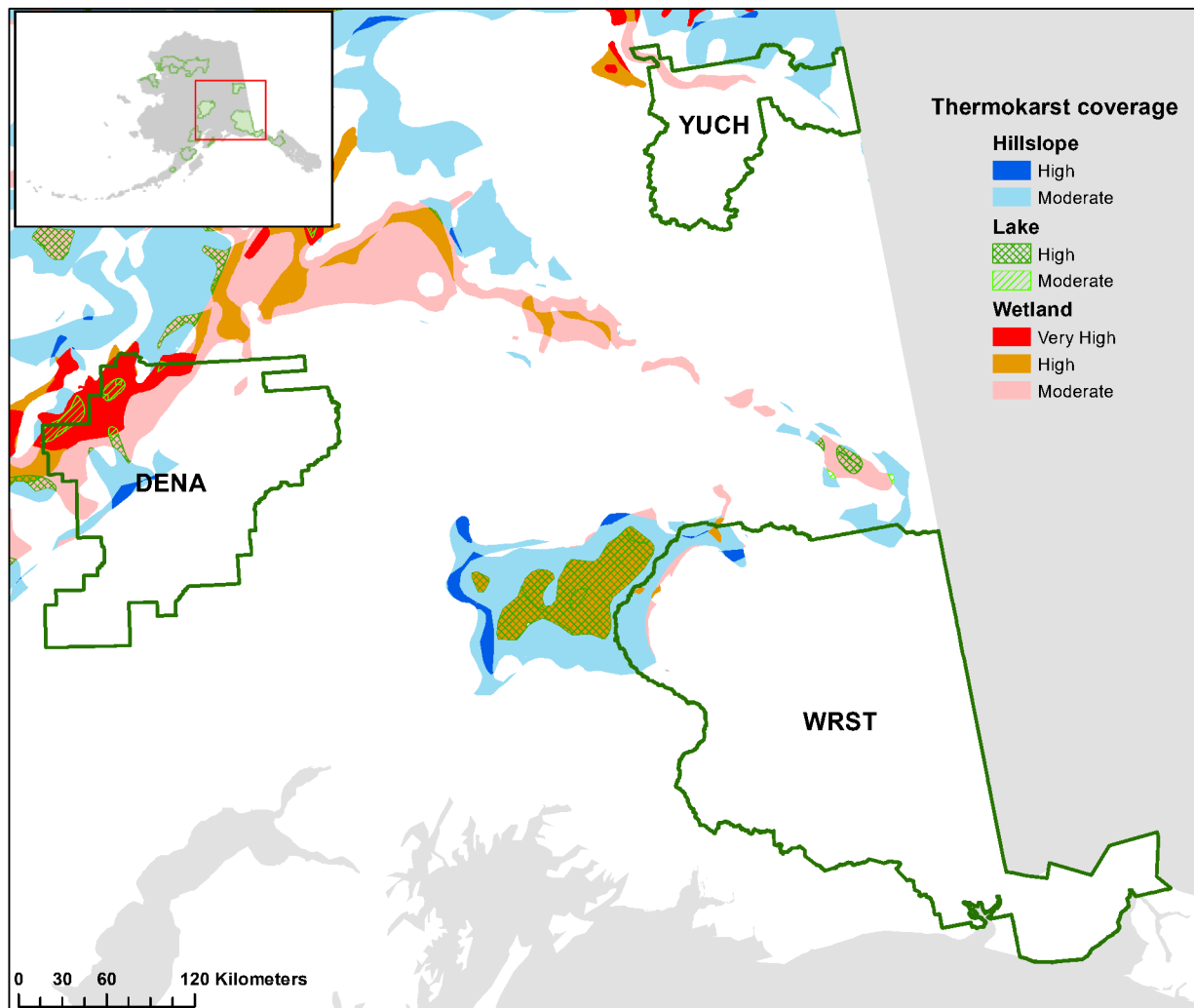


Figure 4. Distribution and regional coverage of thermokarst landscapes in CAKN parks. Thermokarst coverage is distinguished by landscape type (hillslope, lake, and wetland) and by expected degree of coverage, where 'very high' is 60-100% coverage, 'high' is 30-60%, and 'moderate' is 10-30%. More than one type can occur in a given area, so some polygons overlap. Coverage from Olefeldt et al. 2016.

Other local effects of permafrost thaw are even more limited in spatial extent, but can be dramatic (Jorgenson et al. 2001; Jorgenson and Osterkamp 2005). Thawing of permafrost can result in landslides, notably active-layer detachment failures (Lewkowicz and Harris 2005; Lewkowicz 2007) and retrogressive thaw slumps (Burn and Lewkowicz 1990; Lacelle et al. 2010; Swanson 2013). Subsidence causes new lake and pond basins to form and existing ones to enlarge, while growth of

gullies along thawing ice wedges can breach a lakeshore and abruptly drain the lake. Slumping and erosion as sediments thaw can shed large amounts of sediments into streams and lakes (Bowden et al. 2008; Lamoureux and Lafrenière 2009). Some unique permafrost landforms, like pingos (Mackay and Burn 2011) and rock glaciers (Haeberli et al. 2006), may—over long timescales—even be lost entirely.

Loss of permafrost has important hydrological implications. Subarctic soils are often wet due to perching of water on top of permafrost. Loss of permafrost in principle allows better soil drainage and more infiltration (Hinzman et al. 2003), although this effect is confounded by subsidence and consequent ponding. Degradation of ice wedges can reduce ponding of water in polygon centers and enhance runoff (Liljedahl et al. 2012). These various changes in hydrology and soil temperature are generally more common in the Arctic than in the Central Alaska Network, but wherever present they affect nutrient cycling and vegetation communities (Chapin et al. 1995).

Thaw of permafrost will also have global consequences through the release of methane and carbon dioxide. The carbon stock contained in permafrost soils reflects the accumulation of plants, animals, and soil organisms in perennially frozen soils over many thousands of years. Throughout the circumpolar permafrost zone, there are an estimated 1307 billion metric tons of C stored in the top 3 m of soil (Hugelius et al. 2014). If deeper permafrost soil is considered, another 500-700 billion metric tons of C could be held in frozen soils. As permafrost thaws, this carbon will have the opportunity to decompose and be released to the atmosphere as both carbon dioxide and methane. These gases have important positive feedbacks to global climate, and could be released in quantities sufficient in magnitude to have important implications beyond CAKN boundaries. Both the size of the organic C pool in permafrost and its rate of release to the atmosphere are therefore important to monitor if we wish to understand the consequences of permafrost thaw for future climate change.

1.3 Monitoring objectives

The indicators selected for measurement in the CAKN permafrost protocol were chosen to provide measurable indication of change while remaining achievable in light of the following considerations:

- Permafrost in the parks is mostly discontinuous, and the southern portion of WRST is mostly permafrost free.
- Due to the comparative rarity of thermokarst terrain, permafrost presence/absence is not uniformly detectable via remote sensing (satellite imagery, etc.).
- CAKN parks are large and far apart, and aside from areas adjacent to the few roads they are difficult to access.

Because permafrost is neither uniformly distributed nor amenable to efficient remote detection/field measurement, the permafrost protocol is strategically focused on careful measurement at a few discrete locations. Mapping the spatial extent of permafrost was discarded as an objective because of the difficulty of accurately determining permafrost presence/absence via remote sensing. Measurement of permafrost physical condition at a large number of widely dispersed, statistically representative sites (in a geographic sense) was also judged impractical on logistical/budgetary

grounds. The protocol is designed to leverage other programs through augmentation of existing measurements and/or through shared use of logistical assets. Finally, it is hoped that the collected data provide an attractive platform for collaborative work with outside scientists and institutions.

The CAKN permafrost protocol has two network-wide focus areas: 1) the thermal state of permafrost, and 2) the physical state of permafrost (Table 1). These measurements will contribute directly to the Global Terrestrial Network for Permafrost (GTN-P), the primary international program concerned with monitoring permafrost parameters (Christiansen 2012). We will also monitor changes in the dynamics of one rock glacier in WRST—a unique type of permafrost feature not included in other Alaskan long-term permafrost monitoring programs.

Table 1. Overview of proposed activities for the CAKN permafrost monitoring program. Prospective sites are mapped in Figure 5. Further details are provided in text and in the associated standard operating procedures.

Focus area	Objective	Unit	# sites WRST	# sites DENA	# sites YUCH	Frequency
Thermal state	Soil temperature	deg C	10	8	3	hourly
	Borehole temperature	deg C	1	1	1	annual
Physical state	Active layer thickness	m	5	4	4	every 3 yr
	Soil surface elevation	m asl	5	4	4	every 3 yr
Rock glacier	Areal extent	polygon	1	0	0	every 6 yr
	Surface elevations	m asl	1	0	0	every 6 yr
	Surface velocities	m/d	1	0	0	every 6 yr

The objectives of monitoring the thermal state of permafrost are to measure ground temperatures at a variety of sites within and near the permafrost zones of the three CAKN parks. Ground temperatures determine the presence or absence of permafrost, and over time the trends in these temperatures dictate the progress of permafrost thaw. The measurement sites have been selected to utilize existing installations and to collaborate with other agencies/institutions. Most temperature measurements will be made continuously at relatively shallow depths (0.5 – 2.0 m) in surface soils. Where possible, such measurements will be paired with soil moisture measurements on an opportunistic basis. In addition, annual re-measurement of the ground temperature profile will be made in a single deep (29-63 m) cased borehole at each park. Most of the measurements associated with this objective will be done in close collaboration with other research groups, most notably including the CAKN Climate Monitoring Vital Sign and the University of Alaska Geophysical Institute’s Permafrost Laboratory.

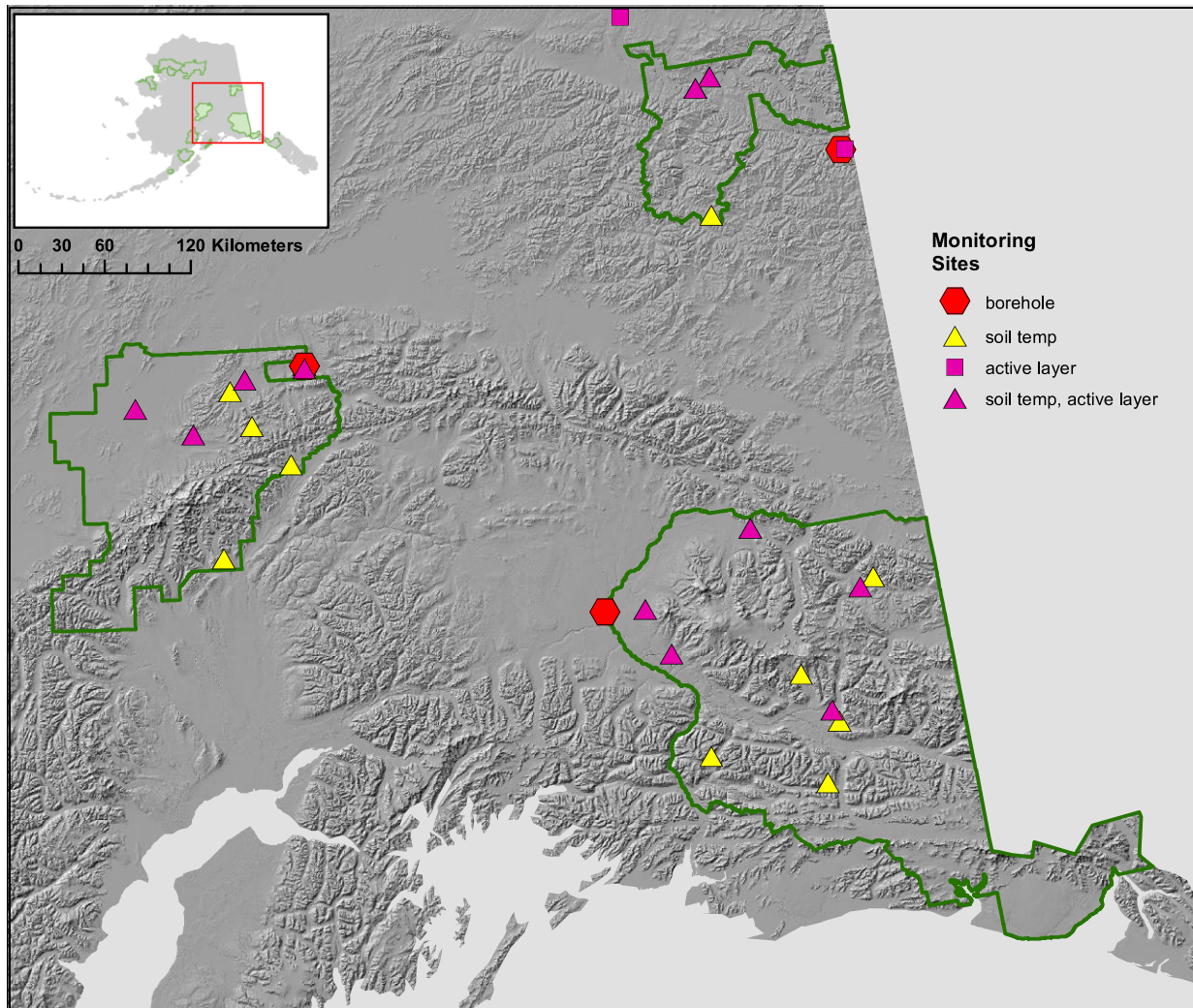


Figure 5. Proposed monitoring sites. Some include multiple measurements. Site list is expected to evolve over the first few years of the protocol.

The objectives of monitoring the physical state of permafrost are to determine the depth of the perennially frozen layer (active layer thickness) and the extent (if any) of associated soil surface subsidence. Active layer thickness is determined at the end of the melt season by probing in a series of points on a transect or grid. Soil surface elevation will be concurrently determined at each probing point using survey-grade dGPS or another survey method with comparable accuracy. Some of the sites proposed for active layer monitoring have been previously studied, and this program will update active layer measurements begun in 2003 at Toklat Basin in DENA (Schuur et al. 2015a), in 2012 at Andrew Flat in YUCH (Wells 2017), and in 2009 along the Tanada Lake Trail in WRST (Arp and Simmons 2012). Other measurements from those previous studies (vegetation, soil stratigraphy, etc.) are not formally included as part of this protocol, but may be included in future fieldwork if supported by collaboration and/or outside resources.

In WRST, we will monitor changes in surface elevation, areal extent, and flow velocity of the Sourdough Rock Glacier. Rock glaciers are classified as permafrost features, and the Sourdough

Rock Glacier is one well-studied member (Petersen et al. 2016) of a globally unique concentration of rock glaciers in the central Wrangell Mountains. A high concentration of rock glaciers is found in the central Wrangell Mountains, as attested by a relatively large number of studies that have focused on rock glaciers in this area (Bucki et al. 2004; Bucki and Echelmeyer 2004; Elconin 1995; Elconin and LaChappelle 1997; Haeberli et al. 2006; Petersen et al. 2016). This protocol conspicuously omits intensive monitoring of other landscape-scale permafrost features such as thermokarst and retrogressive thaw slumps, but these features are well-represented by other monitoring programs, most notably including the Permafrost Monitoring Program of the Arctic Network (Swanson 2017). In comparison, we are aware of no long-term rock glacier monitoring anywhere in North America.

General activities associated with each of these focus areas are summarized in Table 1, mapped in Figure 5, and described in a sample 6-year schedule in Table 2. Details are provided in Chapter 2, which describes the sampling design, field methods, and operational requirements of this protocol. Chapter 3 describes the data collection, management, archiving, and reporting practices associated with the protocol. Finally, Chapter 4 summarizes the procedure for updating this protocol.

Table 2. Proposed schedule for major fieldwork activities.

Activity	Park	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Soil temperature	All	Hourly continuous	Hourly continuous	Hourly continuous	Hourly continuous	Hourly continuous	Hourly continuous
Borehole temperature	All	1/yr	1/yr	1/yr	1/yr	1/yr	1/yr
Active layer thickness and soil surface elevation	WRST	1x	–	–	1x	–	–
	DENA	–	1x	–	–	1x	–
	YUCH	–	–	1x	–	–	1x
Rock Glacier extent and dynamics	WRST	1x	–	–	–	–	–

At some future date, additional focus areas may be added to this protocol if resources or collaborations make this possible. Most obvious in this regard would be addition of an additional focus area that considers the carbon content and budget of permafrost soils. This topic, while important, is presently beyond the scope and budget of this program. There is a possibility, however, that NPS could leverage ongoing work by outside collaborators (notably Northern Arizona University and the National Ecological Observatory Network [NEON]) already working at the Eight-Mile Lake site just outside DENA. Because the NEON site is just coming online at this writing, a potential long-term collaboration (or other potential foci) is not considered further in this narrative.

In addition to this summary narrative, the CAKN permafrost monitoring protocol includes a short report summarizing pertinent Data Quality Standards, and the Standard Operating Procedures (SOPs). The SOPs are published as short, individual documents that describe detailed methodology for every step of protocol implementation (Table 3).

Table 3. Standard Operating Procedures incorporated as part of the CAKN permafrost monitoring protocol. Each is published as a separate document.

SOP#	Title	Brief contents
1	Google Earth overview map preparation	Locations of sites; google earth data entry procedures; display protocols.
2	Soil temperature: sensor installation	Criteria for and locations of sites; choosing and fabricating sensors; field preparations; sensor and (as needed) datalogger installation and maintenance; soil profile characterization.
3	Soil temperature: data retrieval and management	Connecting to dataloggers and downloading data; data file maintenance and QC; metadata description; certification and publication procedures.
4	Borehole temperature: field methods	Locations of sites; field and equipment preparations; sensor/datalogger operation; measurement techniques.
5	Borehole: data retrieval and management	Downloading data; acquiring data from collaborators; data file maintenance and QC; metadata description; certification and publication procedures.
6	Active layer and surface elevation: field methods	Criteria for and locations of sites; monumentation; field and equipment preparations; probing techniques; GPS datalogger operation; data dictionaries.
7	Active layer and surface elevation: data processing and management	Downloading data; GPS processing; data file maintenance and QC; metadata description; certification and publication procedures.
8	Rock glacier: data collection	Contracting SfM (or) acquiring in-house NPS support; domain and flight planning; SfM processing guidelines; digitizing boundaries; DEM construction and differencing; COSI-Corr feature tracking.
9	Rock glacier: data processing and management	Digitizing glacier boundaries; DEM differencing; COSI-corr feature tracking; metadata description; certification and publication procedures.

2. Study design, methods, and operational requirements

2.1 Soil temperature

2.1.1 Sampling design

Soil temperatures will be measured in the uppermost (1-2 m) ground surface at a subset of existing remote automated weather stations (RAWS; **Table 4**). For maximum spatial representation of ground temperature changes, the protocol includes soil temperature measurements from all stations in the CAKN parks where temperature sensors are already installed, regardless of permafrost presence or absence (Hill and Sousanes 2015). For RAWS where permafrost is present, we will install and/or extend soil temperature sensor arrays with a goal of having the deepest temperature sensor at least 25 cm below the active layer, thus recording temperatures above and below the top of the perennially frozen layer. Over time, additional stand-alone soil temperature measurement stations may be added; three potential sites are listed with the RAWS in **Table 4**; no others are planned at this time.

Table 4. Locations and characteristics of existing weather stations slated for soil temperature measurements. Three sites being considered for standalone soil temperature monitoring are also listed.

Site	Park	Latitude	Longitude	Elevation (m)	Existing sensors?	Additional sensors?	Agency
Chicken Creek	WRST	62.1240	-141.8473	1597	yes	NO	NPS/CAKN
Chisana	WRST	62.0748	-142.0442	1012	NO	yes	NRCS ¹
Chititu	WRST	61.2736	-142.6209	1385	yes	yes	NPS/CAKN
Chetaslina	WRST	61.8500	-144.6667	715	NO	Yes	Standalone ²
Gates Glacier	WRST	61.6029	-143.0132	1237	yes	NO	NPS/CAKN
Klawasi	WRST	62.1470	-144.9280	937	NO	yes	NPS/FIRE
May Creek	WRST	61.3483	-142.6942	503	yes	NO	NRCS
Mentasta Fen	WRST	62.5500	-143.3667	984	NO	Yes	standalone
Tana Knob	WRST	60.9080	-142.9013	1140	yes	NO	NPS/CAKN
Tebay	WRST	61.1810	-144.3422	573	yes	NO	NPS/CAKN
Dunkle Hills	DENA	63.2675	-149.5392	808	yes	NO	NPS/CAKN
Eight Mile Lake	DENA	63.8831	-149.2536	780	yes	NO	NAU ³
McKinley River	DENA	63.6640	-151.6740	251	NO	yes	NPS/FIRE
Ruth Glacier	DENA	62.7097	-150.5397	1006	yes	NO	NPS/CAKN
Stampede	DENA	63.7478	-150.3281	549	yes	NO	NPS/CAKN
Toklat	DENA	63.5242	-150.0433	890	yes	NO	NPS/CAKN
Wigand	DENA	63.8142	-150.1094	1716	yes	yes	NPS/CAKN
Wonder Lake	DENA	63.4900	-150.8710	2038	yes	yes	NOAA ⁴
Andrew Flat	YUCH	65.3740	-142.8955	222	NO	Yes	standalone
Coal Creek	YUCH	65.3139	-143.1322	292	yes	yes	NPS/CAKN
Upper Charley	YUCH	64.5167	-143.2022	1114	yes	yes	NPS/CAKN

¹ Natural Resources and Conservation Service SNOTEL

² No current RAWS. Proposed for standalone soil temperature monitoring

³ Northern Arizona University, PI Ted Schuur

⁴ National Oceanic and Atmospheric Administration Climate Reference Network

2.1.2 Field methods

All soil temperatures will be measured on a continuous basis (typically hourly but at least every 4 hours, year-round) at one or more depths per site, and logged with automated data loggers that require only periodic (typically annual) maintenance. In most cases the data are delivered in real-time by telemetry, but at stations where telemetry is not installed or malfunctions, data will be downloaded during annual maintenance visits. Equipment deployed at each site will vary, and will be reflected (and updated, as necessary) in the SOPs and metadata for each site.

At CAKN stations (Table 4), the equipment already installed by NPS physical scientists includes Campbell Scientific CR1000 dataloggers and Campbell Scientific 107 soil temperature probes. Sensors were typically installed at depths of 10, 20, and 50 cm but these vary from site to site. As described above, at least one additional 107 sensor will be added at sites that are believed to have permafrost. Our goal will be to position this additional sensor as deep as possible, but at least 25 cm below the approximate active layer depth.

At FIRE RAWS and NRCS SNOTEL sites (Table 4), new soil temperature sensors will need to be installed. The type of sensor installed will be determined in conjunction with the staff managing the stations, and may need to be adjusted for compatibility with existing equipment, but the goal will be closely match the sensor configuration at CAKN RAWS sites: 4 Campbell Scientific 107 soil sensors installed at the near subsurface, 50, 100, and >150 cm depth, with depth of last sensor adjusted if necessary to be at least 25 cm or more below the active layer depth.

The Eight Mile Lake and Wonder Lake sites (Table 4) are managed by Northern Arizona University and NOAA Climate Reference Network, respectively, and like most of the CAKN stations already have soil temperature measurements. If deeper temperature measurements are necessary to capture conditions below the active layer, we will work with those agencies (as at the FIRE RAWS sites) to install temperature sensors compatible with their equipment.

Should we choose to install new stand-alone soil temperature measurements at one or more sites not co-located with an existing weather station, we will install a simple system consisting of an Onset UX-120 datalogger and four Onset TMC soil temperature sensors at the standard depths described above. The datalogger runs simply off AAA batteries and will be housed in a waterproof box enclosure left on the soil surface. At all sites, regardless of installation type, we will complete a description of the soil profile at a site near (within ~25 m), and similar to, the site where ground temperatures are being monitored. We will use standard U.S. Department of Agriculture methods (Soil Survey Division Staff 1993) and complete this task during a maintenance visit within the first two years of operation. A soil profile description will be included as part of the metadata at each site.

2.1.3 Operational requirements

For all the existing weather stations, installation of the basic infrastructure (loggers, masts, power, telemetry, etc.) has already occurred. Some sites will require no additional installations, while others (as noted above) will require installation of new, or additional, soil temperature sensors. All sites will also require a soil profile description. Soil profiles and sensor installations will require only simple tools (shovels, soil drilling/boring tools). Profile descriptions and sensor installations will occur

during a single day's site visit by the permafrost principal investigator (PI) within the first two years of this protocol. To save on logistical costs, these visits will be scheduled to coincide with the timing of annual maintenance visits by each station's sponsoring agency. Permitting of these additional sensors at existing climate stations should be straightforward, but may require collaboration with cultural resources staff during ground disturbances.

Recurring annual maintenance of each station will typically occur on an annual basis and will not require participation by the PI unless troubleshooting of the soil sensors is required. Data will be downloaded and sensors visually checked (e.g. no animal damage, frost-jacking) at the time of these annual visits. Timing of these visits is not critical, and can occur anytime during the field season. In the case of new, standalone soil temperature measurements (four of which are tentatively planned at this time), installation and recurring annual maintenance would be scheduled and accomplished directly by the PI, and travel costs would likely fall solely upon the permafrost program. For this reason, new installations will be considered only for critical sites, and would to the extent possible be located within hiking distance of roads.

Because cooperators will complete maintenance of all but the stand-alone stations, costs associated with this objective are primarily associated with upfront costs of installation and then periodic replacement of failed sensors. New soil temperature sensors are approximately \$100 apiece, depending on specific configuration, and a stand-alone monitoring station can be built for about \$650. Travel to sites for initial installation and/or replacement of failed sensors will vary in cost, but will typically involve 2 days travel to/from the staging area for a given park and then aviation costs shared with the cooperating agency.

2.2 Borehole temperature

2.2.1 Sampling design

We will complement the network of shallow continuous soil temperature measurements with periodic (ideally annual) re-measurement of ground temperature profiles in a single deep cased borehole adjacent to each park (Figure 5): Gulkana (WRST), Healy (near Eight-Mile Lake, DENA), and Eagle (YUCH). Each of these boreholes already exists (Osterkamp 2003), and has a history of data collection that will inform our analysis going forward (Table 5). Deep borehole temperatures provide a systematic running mean of the air temperature history at the surface with less effect from seasonal trends or from the dynamics of vegetation change, surface disturbance, or hydrology change (Osterkamp and Romanovsky 1996).

Table 5. Locations and characteristics of deep boreholes utilized in the permafrost monitoring protocol.

Borehole	Borehole code*	Park	Latitude	Longitude	Elevation (m)	Depth (m)	Year established
Gulkana	US37	WRST	62.1669	-145.4707	479	70	1983
Healy	US40	DENA	63.8784	-149.2535	673	29	1985
Eagle	US35	YUCH	64.7784	-141.1802	267	63	1985

* from http://permafrost.gi.alaska.edu/sites_list

Deep borehole locations were chosen for accessibility to the road system, and were originally located outside of park boundaries in part because of permitting restrictions. No new boreholes will be drilled for this protocol.

2.2.2 Field methods

The three boreholes are already installed, and consist of ¾" metal casing filled with anti-freeze and capped. Re-measurement of temperatures within the casing at 1 m intervals will occur each summer. Ideal measurement time (for interannual comparability of measurements in the shallowest soils) would be late summer, but for the deeper (>3 m) portions of the borehole temperatures are unaffected by seasonal changes. For this reason, it is acceptable for the precise timing of these measurements to vary based upon logistical constraints.

Measurements are made with a single stainless steel temperature/data logger (Onset U12-015). The logger is pre-programmed to make measurements every second, and then is placed on the end of a measured steel cable that allows precise lowering of the logger in the hole. The lowering is paused every meter for 60 seconds, allowing equilibration with the borehole temperature before lowering to the next location. A complete measurement cycle requires less than 2 hours and requires a laptop equipped with Onset Hoboware Pro for programming of the logger and subsequent data download.

2.2.3 Operational requirements

As of this writing, the Gulkana and Healy boreholes are measured annually by an existing program funded and managed by Vladimir Romanovsky of the UAF Permafrost Laboratory. Through an agreement with Romanovsky, and utilizing consistent equipment and measurement protocols, NPS will take responsibility for continuation of annual measurements at the Eagle borehole, which has not been visited by UAF since 2009. No additional permitting will be required for ongoing maintenance of these boreholes.

Training of the PI in the proper measurement technique will require one site visit timed to include both the PI and personnel from the Permafrost Laboratory, probably at the Gulkana borehole within the first year of the protocol. Subsequent to that visit, UAF has offered to loan measurement equipment (temperature sensor/logger and lowering cable) to NPS for annual re-measurement of the Eagle borehole. To save on the cost of travel to Eagle, annual re-measurements at the Eagle borehole will likely be conducted in most years by the permanent YUCH ranger stationed at Eagle after training by the PI in year 2 of the protocol.

Should NPS choose to acquire the temperature logger and lowering cable, those equipment cost about \$1500. After the first two years of the project there will be no regular travel costs except where anomalous events change the pattern (e.g. hiring of a new ranger at YUCH, need to take on measurement responsibilities at one of the other sites, damage to a borehole, etc.).

2.3 Active layer thickness and soil surface elevation

2.3.1 Sampling design

In an area underlain by permafrost, active layer measurements quantify thickness of the near-surface layer that is subject each year to seasonal thawing and freezing (typically 0.3 to 1.5 m thick; van

Everdingen 2005). Concurrent surface elevation measurements allow precise detection of thaw-related surface subsidence (Little et al. 2003). We will measure active layer thickness and surface elevation at multiple points along transects/grids in each of several sites distributed throughout the CAKN parks. Several of the sites listed in Table 6 contain multiple transects—the plan is to re-measure all these sites. These measurements must be made in the latest portion of the melt season, generally between August 15 and September 15, a requirement that poses logistical challenges for measuring multiple sites with a single investigator. For this reason, the protocol prescribes re-measurements on a rotating basis, with sites within a given park re-measured every third year.

Table 6. Locations and characteristics of active layer/surface elevation monitoring sites.

Site	CALM code*	Park	Latitude	Longitude	Elevation (m)	Year established
Chisana	N/A	WRST	62.0748	-142.0442	1012	new
Chetaslina	N/A	WRST	61.8500	-144.6667	715	new
Klawasi	N/A	WRST	62.1470	-144.9280	937	new
May Creek	N/A	WRST	61.3483	-142.6942	503	new
Mentasta Fen	U40A	WRST	62.5500	-143.3667	984	2009
Eight-Mile Lake	N/A	DENA	63.8831	-149.2536	780	2003
McKinley River	N/A	DENA	63.6640	-151.6740	251	new
Wigand	N/A	DENA	63.8142	-150.1094	1716	2003
Wonder Lake	N/A	DENA	63.4900	-150.8710	2038	new
Andrew Flat	N/A	YUCH	65.3740	-142.8955	222	2012
Circle	U47	YUCH	65.8282	-144.0784	183	2009
Coal Creek	N/A	YUCH	65.3139	-143.1322	292	new
Eagle	U51	YUCH	64.7777	-141.1095	407	2009

* from <http://www2.gwu.edu/~calm/data/north.html>

Sites were selected to maximize available resources by either being adjacent to existing installations or at a limited number of additional high-priority sites (Table 6). Importantly, active layer measurement by the probing technique is only useful at sites with fine-grained soils, limiting the utility of some permafrost sites with clast-rich soils or shallow bedrock. At some of the selected sites the presence of permafrost is uncertain, and these would be deleted from the list if the initial visit determines that permafrost is absent. Similarly, additional sites could be added in the future, potentially with the alternative technique of using frost tubes to measure active layer thickness in rocky soils. Selected measurement sites will complement the existing global network of circumboreal active-layer measurements (CALM; Brown 1998). The CALM network is well-represented in Arctic Alaska, but has very few actively measured sites in the discontinuous permafrost zone of subarctic Alaska represented by the CAKN parks.

2.3.2 Field methods

Field methods for mechanical probing will closely follow the standard operating procedures utilized by the CALM network (Humlum and Matsuoka 2004). A metal thaw probe is inserted into the

ground to the point of resistance, with gentle up and down motions used to ensure that the probe reaches all the way through minor resistance within the thawed layer. The sound and feel of frozen ground is distinctive, and once reached the depth of the probe is measured at the ground surface, defined as the top of the organic soil layer, including (if present) live mosses and lichens. If standing water is present, probe depth is measured relative to the ground surface but water depth is also recorded.

In addition to the probe depth, we will make an additional measurement of xyz position at each probe site using survey-grade dGPS. The antenna from the roving receiver will be mounted on a survey rod, the point of which will be held stationary at the ground surface (not inserted into the ground) at the same location as the probing occurred. Local benchmarks for each project site will be located and/or established during the first year of sampling at each site and will be used in all subsequent years for the dGPS base station receiver. Alternative survey techniques (total station, Structure from Motion [SfM], or terrestrial lidar) can be substituted in the future, but are not part of the protocol at this time.

The CALM protocol calls for replicate measurement points at each site, with the sampling regime being systematic and marked with semi-permanent tags for the purpose of precise re-measurement. CALM allows for use of either transects or grids or points at each measurement site, and the CAKN permafrost protocol may rely on both. In cases where prior measurements have already been made (Table 6), we will simply repeat the pre-existing sample scheme. At new sites, on the advice of Vladimir Romanovsky (pers. comm. 2017), we will establish 95 m long transects and make measurements every 5 m (for 20 total measurements). Care will be taken to minimize ground disturbance at these sites so that future measurements are not compromised by anthropogenic changes in vegetation or soil compaction.

2.3.3 Operational requirements

Active layer measurement sites require minimal installation: just selection of the sampling framework (transect or grid, and location), and installation of permanent corner/end markers to identify the site for subsequent re-measurement. In some cases sites have already been measured at least once, and these preparatory tasks are unneeded. Equipment for re-measurement campaigns includes the probe (thin rigid metal rod of less than 1 cm calibrated in 1 cm increments), a measurement tape, and a survey-grade dGPS receiver with associated base station and accessories. The first two items are already available to the PI, and the GPS equipment will be reserved and borrowed from the main GPS inventory at the AK Regional Office as needed. Costs for equipment are therefore minimal. Permitting for this portion of the protocol will require justification of permanent, inconspicuous ground-level plot markers; the purposely minimized ground disturbance should not pose a permitting challenge.

The main resources required for this project instead are related to travel and access for ongoing monitoring. With the plan of visiting sites at one park per year, re-visiting on a 3-year rotation, that implies a single campaign late in the summer of each year with associated travel. The practical logistical hubs for planned work are Eight-Mile Lake (DENA), Coal Creek (YUCH), and Gulkana (WRST). Fieldwork will be accomplished by a team of 2, including the PI and one assistant. Aviation

and travel costs will depend upon the park, the specific list of sites, and the chosen mechanism of transport, but will in part dictate any potential growth in the number of sites.

2.4 Rock Glacier extent and dynamics

2.4.1 Sampling design

Sourdough Rock Glacier is the informal name given to a large rock glacier on the south side of Sourdough Mountain, in the central Wrangells near McCarthy. The rock glacier has previously been studied by geophysicists interested in its similarity to geomorphic features on the surface of Mars (Petersen et al. 2016), and their results provide baseline information germane to this monitoring protocol. They mapped the surface and created a digital elevation model (DEM) using SfM, made an orthophotograph suitable for delineation of the areal extent (though they did not digitize the boundary), and they measured surface velocities using feature tracking (Figure 6). This particular glacier was selected because of this existing baseline information, because of its relative accessibility from the WRST community of McCarthy, and because its size (~3 km long), composition (~50 m thick mélange of ice and porphyritic dacite), and velocity (<2 m/yr) are considered roughly typical of the many other rock glaciers concentrated in this region.

Although a sample size of one rock glacier is poorly suited to drawing inferences about the full population of rock glaciers in WRST, or CAKN parks generally, it is a substantial advance over the present situation with no systematic long-term monitoring of rock glaciers despite uncertainty regarding their likely response to climatic change (Ødegård et al. 2003). Because rock glaciers evolve and flow more slowly than true glaciers (Haeberli et al. 2006), changes to the Sourdough Rock Glacier are expected to occur slowly so re-measurement of extent, surface elevation, and surface velocities will occur only every 6 years.

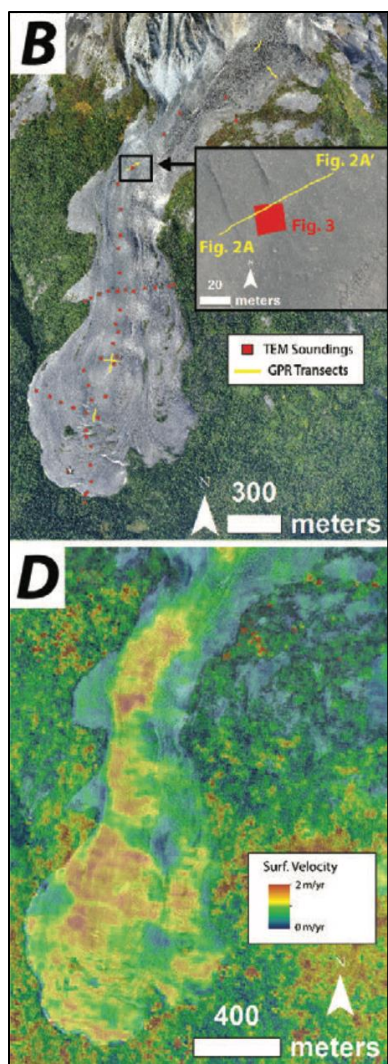


Figure 6. Orthophotograph (top panel) and velocities (bottom panel) of Sourdough Rock Glacier, excerpted from fig. 1 in Petersen et al. 2016.

2.4.2 Field methods

Every sixth year, late in the melt season during good weather, overlapping digital photographs of the entire areal extent of Sourdough Rock Glacier will be collected via either a contract or using DOI aircraft if the internal capacity exists. These photographs will be used by either the contractor or by NPS staff (using Agisoft Photoscan or similar software) to generate an orthophotograph and digital elevation model of the rock glacier surface. We will digitize the rock glacier boundary in ArcMap at 1:2000 scale in order to detect small changes. Concurrently, surface elevations over the entire rock glacier surface will be compared with previous surveys.

During the summer season of that same year, surface velocities will be measured. Surface velocities can be determined using feature tracking on repeat photography, and if cost-amenable we will use a second set of photographs to generate a surface-wide velocity map similar to that seen in Figure 6. Failing that, we will estimate velocities at a minimum of 5 sites along the centerline of the rock

glacier surface by installing temporary monuments on large stable boulders and measuring their positions a minimum of twice during the summer. The location coordinates, determined using survey-grade dGPS, will be differenced to determine velocity.

2.4.3 Operational requirements

This component of the protocol prescribes a flexible approach to gathering the required data. The most logistically simple strategy would be to contract out the gathering of digital photography on two occasions in every sixth year. The PI or another technician with experience analyzing geospatial data, could then digitize the glacier outline, analyze a DEM product, and use freely available feature tracking software (e.g. COSI-Corr; Leprince et al. 2007) to determine surface velocities. The contracted cost of SfM has declined rapidly in recent years and is likely to be manageable under the current budget, especially if a budget cycling approach is used to periodically enhance the program's available funds. NPS is also developing internal capacity (hardware, software, and expertise) to acquire and process SfM data, and may well be able to perform this task at an even lower project cost by the time of the next acquisition.

Alternatively, surface velocities can be calculated using traditional field methods (re-measurement of fixed monuments using survey-grade dGPS) to collapse the SfM collection to one epoch only. If this is done, velocity calculations would require approximately 2 days of fieldwork in the early season (to install and measure monuments), and another 2 days in the late season (to measure and demobilize). The field team would likely consist of 2 persons: the PI and one assistant, based out of McCarthy/Kennicott. Survey-grade GPS gear could be borrowed from AKRO, and monuments could be cheaply constructed from metal conduit at a cost of less than \$100. Permitting will be based on the type of sampling selected.

3. Data management

3.1 Overview

Data management for the permafrost monitoring program will proceed through an ongoing life cycle as shown in Figure 7 (NPS 2008). Major stages of the life cycle include data collection, data entry and import, quality control, data product documentation and archival, seasonal closeout, and dataset certification (Wilder 2005). Data analysis and reporting are separate from the data management cycle, but are a critical periodic component of this protocol and are included in the figure for completeness.

The Vital Sign principal investigator is responsible for the timely completion of all data collection and management tasks outlined in this protocol and summarized in Figure 7. The Network data manager maintains the hardware and software platform in support of the Vital Sign's data stream, provides for data security, accessibility and longevity, and gives technological support and guidance in all aspects of data management activities. The principal investigator and data manager are jointly responsible for dataset certification and publication.

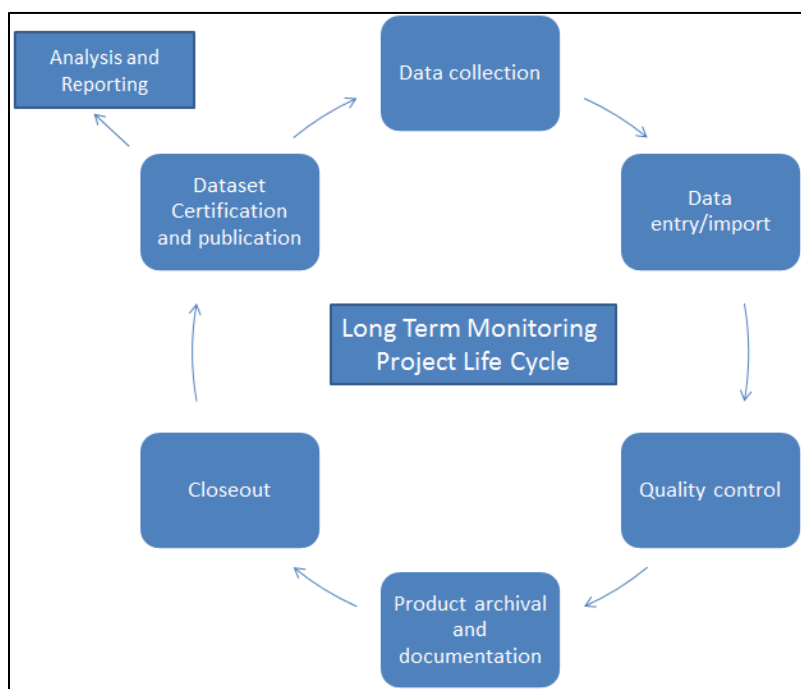


Figure 7. Long term monitoring project data management life cycle.

All phases of this data management process must comply with NPS standards. After a summary of applicable NPS standards, an overview of each component of the data management life cycle follows. As with the field methods, specific procedures are given in the Standard Operating Procedure (SOPs).

NPS Standards

The CAKN permafrost monitoring protocol will comply with all pertinent NPS standards for scientific data collection and dissemination. These are summarized here.

Director's Order #11A section 5.8: Data Integrity Standards outlines the NPS policy for accuracy, completeness, and review of scientific data (NPS 2005b):

"All information owners will maintain all official NPS records and data in a manner which meets the highest data integrity standards, including timeliness, accuracy and completeness (also see DO #19). Each information owner will take whatever steps necessary to ensure that NPS systems have sufficient data quality reviews and audits from both an internal system perspective, as well as externally thorough control reviews."

Director's Order #11B mandates a high level of information quality from the service's scientific programs (NPS 2005c):

"The National Park Service will ensure that information it releases will be developed from reliable data sources and will otherwise ensure information quality at each stage of information development. The NPS's methods for producing quality information will be made transparent, to the maximum extent practicable, through accurate documentation, use of appropriate internal and external review procedures, consultation with experts and users, and verification of the quality of the information disseminated to the public. The NPS will also keep users informed about corrections and revisions."

Information will be developed only from reliable data sources based on accepted practices and policies utilizing accepted methods for information collection and verification. It will be reproducible to the extent possible. Influential information will be produced with a high degree of transparency about data and methods."

Direction for managing physical and digital materials is in NPS Director's Order #11D (NPS 2012):

"The NPS has a strong business need for excellent records management, in that the Service's mission is to care for natural and cultural resources so that they are left "unimpaired" for future generations. This requirement for managing resources in perpetuity sets a high standard for record keeping. No resources can be managed well in the future without complete records of how they were managed in the past. Because the NPS manages some of America's most significant cultural and natural resources, the public also has a significant interest in our records. Section 1.9.2 of NPS Management Policies 2006 (NPS, 2006) states that the future of the Service depends on the availability, management, dissemination, and preservation of information, and directs the agency to implement professional quality programs to manage information resources."

The CAKN permafrost monitoring protocol does not define the collection of sensitive data and requires no special handling procedures. The I&M Network will comply with all FOIA restrictions regarding the release of data as instructed in NPS Director's Order #66B (NPS 2005a).

3.2 Data collection

Data collected in the CAKN permafrost monitoring program may include raw/unprocessed data (field notes, raw datalogger files, etc.), products of intermediate processing (error-corrected data files, processing logs, etc.), and final certified data products (processed, quality-controlled data with associated metadata). The products do not require a database, and will be kept in a file based data management system. For convenience, CAKN permafrost monitoring program data deliverables can be subdivided, on the basis of data type and collection schedule, into four distinct categories: soil temperature (PRMst), borehole temperature (PRMbh), active layer thickness (PRMal), and rock glacier dynamics (PRMrg). Deliverables not particularly associated with any one of these categories are included as PRM. These deliverables, which collectively include graphic, tabular, and geospatial data types, are summarized by category in Table 7, and then described more thoroughly below.

Table 7. CAKN permafrost monitoring data deliverables schedule.

Identifier	Deliverable	Description	SOPs	Format	Schedule*	Viewable
PRM01	Study site locations	Generalized xyz locations of all current field measurement sites associated with the permafrost protocol.	1	Google Earth .kmz	Annual	Public
PRM02	Field notes	Scanned copies of all field notes collected during protocol activities in the previous year.	2,4,6	Scans .pdf	Annual	Internal
PRMst01	Soil temperature logger files	Raw logger files plus spreadsheet of soil temperature logger data. Spreadsheet will be annotated and QC'd.	2	Various + spreadsheet .xlsx	Annual + 1 yr	Internal
PRMst02	Certified soil temperature	Machine-readable table of hourly temperature measurements for each site/depth, with metadata.	3	Text file .csv	Annual + 1 yr	Public
PRMbh01	Borehole temperature logger files	Raw logger files plus spreadsheet of borehole temperature logger data. Spreadsheet will be annotated and QC'd.	4	.hobo + spreadsheet .xlsx	Annual + 1 yr	Internal
PRMbh02	Certified borehole temperature	Machine-readable table of annual temperature measurements for each site/depth, with metadata.	5	Text file .csv	Annual + 1 yr	Public

* '+1 yr' indicates permissible 12 month lag between data collection and delivery

Table 8 (continued). CAKN permafrost monitoring data deliverables schedule.

Identifier	Deliverable	Description	SOPs	Format	Schedule*	Viewable
PRMa01	Active layer survey files	Packaged electronic files from collection and processing of survey data. If using dGPS, files would include raw data files, data dictionary, processing logs, and processed differentially corrected locations.	6	Various	3 rd year + 1 yr	Internal
PRMa02	Certified active layer depths and positions	Machine-readable table of active layer (probing) depths, plus latitudes, longitudes, and elevations for all probed points, with metadata.	7	Text file .csv	3 rd year + 1 yr	Public
PRMrg01	Rock glacier survey files	Packaged electronic files from collection and processing of survey data. If using SfM, includes raw photographs, processing logs, and output. Also includes dGPS/COSI-Corr processing data.	8	Various	6 th year + 1 yr	Internal
PRMrg02	Certified rock glacier rasters	Orthophotographs, digital elevation models, and velocity maps, with metadata.	9	ArcMap .gdb	6 th year + 1 yr	Public

* '+1 yr' indicates permissible 12 month lag between data collection and delivery

Deliverable PRM01: Study site locations

This data product is meant primarily to fulfill an informational purpose for collaborators, the public, and other scientists interested in the scope of the permafrost monitoring protocol. It will consist of a single Google Earth .kmz file that contains the generalized locations of all study sites associated with the protocol. It is, in this respect, an updated and public-friendly version of Figure 5 in this document. “Generalized” means that all sites will be represented as points, even if they have detailed sub-information (transects, grids, polygon shapes) that is contained elsewhere in these data. None of the contents of this deliverable are meant to serve as certified data—this deliverable is better viewed as an outreach product, but is included in this list for completeness. Full instructions are contained in SOP 1. Schedule: Released as needed, but at least annually at the conclusion of the field season. Publicly viewable. Responsibility: PI.

Deliverable PRM02: Field notes

Though most of data collected within this protocol are digital, it is nevertheless best practice to keep field notes while conducting any fieldwork. Those notes may include some or all of the following: data, observations, equipment notes, start/stop times for sensors, participant and weather information, and other items. Regardless of content, all field notes associated with CAKN permafrost protocols will be scanned and uploaded to IRMA as an internal data product. Full instructions are contained in

SOPs 2, 4, and 6. Schedule: Released annually at the conclusion of the field season. Internally viewable. Responsibility: PI.

Deliverable PRMst01: Soil temperature logger files

Because soil temperatures will be collected from a variety of sensors and dataloggers, the particular format of digitally downloaded temperature logs will likely vary. But all native format logger files will be saved as an intermediate data product under this deliverable. All files will also be exported to tabular format and saved as worksheets within a single excel spreadsheet that permits annotation and QC. Full instructions are contained in SOP 2. Schedule: Released within 12 months of annual data download. Internally viewable. Responsibility: PI.

Deliverable PRMst02: Certified soil temperature

Following QC, all soil temperature files from the PRMst01 will be saved to a single machine-readable .csv file. That deliverable will contain depths, date/times, and hourly temperatures for all sites, and will be accompanied by metadata that provide full descriptions of sites, logger/sensor packages, errors, etc. Data will be organized in a manner compatible with similar datasets collected by USGS and UAF. Full instructions are contained in SOP 3. Schedule: Released within 12 months of annual data download. Publicly viewable. Responsibility: PI and DM (for certification).

Deliverable PRMb01: Borehole temperature logger files

All native format borehole logger files (probably .hobo) will be saved as an intermediate data product under this deliverable. All files will also be exported to tabular format and saved as worksheets within a single excel spreadsheet that permits annotation and QC. Full instructions are contained in SOP 4. Schedule: Released within 12 months of annual data collection. Internally viewable. Responsibility: PI.

Deliverable PRMb02: Certified borehole temperature

Following QC, all borehole temperature files from the PRMb01 will be saved to a single machine-readable .csv file. That deliverable will contain depths, date/times, and annual temperatures for all sites, and will be accompanied by metadata that provide full descriptions of sites, logger/sensor packages, errors, etc. Data will be organized in a manner compatible with similar datasets collected by USGS and UAF. Full instructions are contained in SOP 5. Schedule: Released within 12 months of annual data collection. Publicly viewable. Responsibility: PI and DM (for certification).

Deliverable PRMal01: Active layer survey files

The format of this deliverable will vary with technology chosen. Initially, it is envisioned that the data collection will involve survey grade gps that can, with use of an appropriate data dictionary, permit simultaneous collection of measured probe depths. In that scenario, the deliverable would include the data dictionary, the collected position data from both the rover and the base station gps units, the post-processing logs, and the processed (final corrected) xyz positions. If the technology changes (for instance to terrestrial lidar or SfM), the type of data deliverable contained within PRMal01 will change, along with the SOP. Full instructions are contained in SOP 6. Schedule: Released within 12 months of every 3rd year of data collection. Internally viewable. Responsibility: PI.

Deliverable PRMa02: Certified active layer depths and positions

Following QC, this deliverable will—regardless of technology used to collect the data—consist of a single machine-readable .csv file that contains x, y, z positions for the surface of all probe points, plus probe depths, for all sites. Accompanying metadata will identify sites, datums, collection techniques, errors and uncertainties, etc. Data will be organized in a manner compatible with similar datasets collected by USGS and UAF. Full instructions are contained in SOP 7. Schedule: Released within 12 months of every 3rd year of data collection. Publicly viewable. Responsibility: PI and DM (for certification).

Deliverable PRMrg01: Rock glacier survey files

The format of this deliverable will vary with technology chosen. Initially, it is envisioned that the data collection will involve two epochs of digital photo collection for processing using SfM. Whether acquired by a contractor or by NPS, the files archived under this deliverable should include raw photographs, raw gps and inertial position files, processing logs, and exported DEMs/orthophotographs. If the technology changes (for instance to lidar or SfM), the type of data deliverable contained within PRMrg01 will change, along with the SOP. Full instructions are contained in SOP 8. Schedule: Released within 12 months of every 6th year of data collection. Internally viewable. Responsibility: PI.

Deliverable PRMrg02: Certified rock glacier rasters

Following QC, this deliverable will—regardless of technology used to collect the data—consist of a rock glacier outline (.shp), a spatially aware digital elevation model (.grd or other), and a spatially aware orthophotograph (.tif or other). Each will be explicitly associated with known x, y, z positions referenced to an identified datum and with explicit confidence intervals. Accompanying metadata will identify datums, collection techniques, errors and uncertainties, etc. Full instructions are contained in SOP 9. Schedule: Released within 12 months of every 6th year of data collection. Publicly viewable. Responsibility: PI and DM (for certification).

3.3 Data entry/import

Data will be collected under this protocol in a variety of formats. All fieldwork will be accompanied by some amount of field notes, which will be promptly scanned, saved to a proper directory, and backed up to a network server within 48 hours of completion of any field efforts. Electronic data collected directly from automated data loggers (temp sensors, etc.) or from field survey devices (GPS units, etc.) will be promptly downloaded to an office computer, checked for completeness, filed in a proper directory, and backed up to a network server within 48 hours of collection, or as soon as possible thereafter.

Some of the data collected as part of this protocol be collected by partners. Borehole temperature data will be collected and shared by Vladimir Romanovsky and colleagues from the UAF Permafrost Laboratory (www.permafrostwatch.org). Much of the soil temperature data will be downloaded and shared by collaborators including the CAKN climate vital sign PI, NPS FIRE RAWS technicians, NRCS scientists, and NOAA scientists. Electronic data delivered by these or other project collaborators will be labeled with the source (person, method of delivery, and date), checked for

completeness, filed in a proper directory, and back up to a network server within 48 hours of receipt, or as soon as possible thereafter.

All files archived by the CAKN permafrost monitoring protocol, whether directly collected by CAKN staff or shared by collaborators, will be labeled “raw” and undergo no further changes (e.g. “filename_raw.xlsx”). Processing and quality control will always be done on duplicate files, marked with latest revision date (e.g. “filename_rev2017_04_24.xlsx”).

3.4 Quality control

Ensuring data quality is a high priority for the CAKN permafrost monitoring protocol. Quality control procedures focus on verifying data as well as identifying and correcting errors in final data products. Quality control safeguards include:

- Immediate (within 48 hour) checking of collected/downloaded data for completeness,
- Regular collection, scanning, and archiving of field notes to maintain a record of data collection abnormalities,
- Double data entry in the rare case of manually entered data,
- Regular checking of data for extreme or impossible values,
- Regular calibration of sensors on manufacturer recommended schedules,
- Graphical and visual exploratory data analysis,
- Statistical error or outlier identification, and
- Dataset certification.

The CAKN permafrost monitoring protocol plans for quality assurance by proactively deploying a system of administrative procedures including:

- Standard operating procedures designed to minimize the introduction of errors during data collection and processing,
- Regular PI and field assistant training,
- Regular dataset archiving and backup to prevent data loss or corruption,
- Application level data entry checks and business rule enforcement, and
- Periodic data quality audits and reports, including reporting on uncertainties associated with all measurements.

3.5 Product archival and documentation

Each specific data deliverable is ultimately archived and disseminated directly from the IRMA Data Store, the single authoritative source for CAKN products. Of these, only an overview map (PRM01) and the final certified data products are publicly available—the raw and intermediate products are maintained as internal products only (Table 7). Datasets approved via implied certification will be denoted with the word “certified” in their labels, directories, and metadata, and will kept separate from other uncertified files. Data will be stored in other locations as well, including I&M and/or local

servers, the Network file server, and in some cases on collaborative data-sharing websites. Under no circumstances will any mission-critical information reside solely on individual I&M staff computers whether they are assigned to monitoring personnel by the NPS or not. Project materials will be secured and available on I&M servers at all times. In the event that one of these data products ever diverges from that in the IRMA Data Store, the IRMA version should be considered authoritative. The data manager, in conjunction with IT staff at FAC and with the Network support office in Ft. Collins, CO is responsible for backups, security and longevity of monitoring data.

The IRMA Data Store is the primary organizational repository and publication platform for all information related to the CAKN permafrost monitoring program—not just data. A single master IRMA project reference (<https://irma.nps.gov/DataStore/Reference/Profile/2216593>) includes authoritative copies of the project protocol (including SOPs and other related documents), project reports and resource briefs, and project data (Figure 8). It is the joint responsibility of the PI and the data manager to keep the system of related IRMA Data Store references up to date, as described in SOPs 3, 5, 7, and 9, which describe the uploading of, and maintenance of, IRMA products.

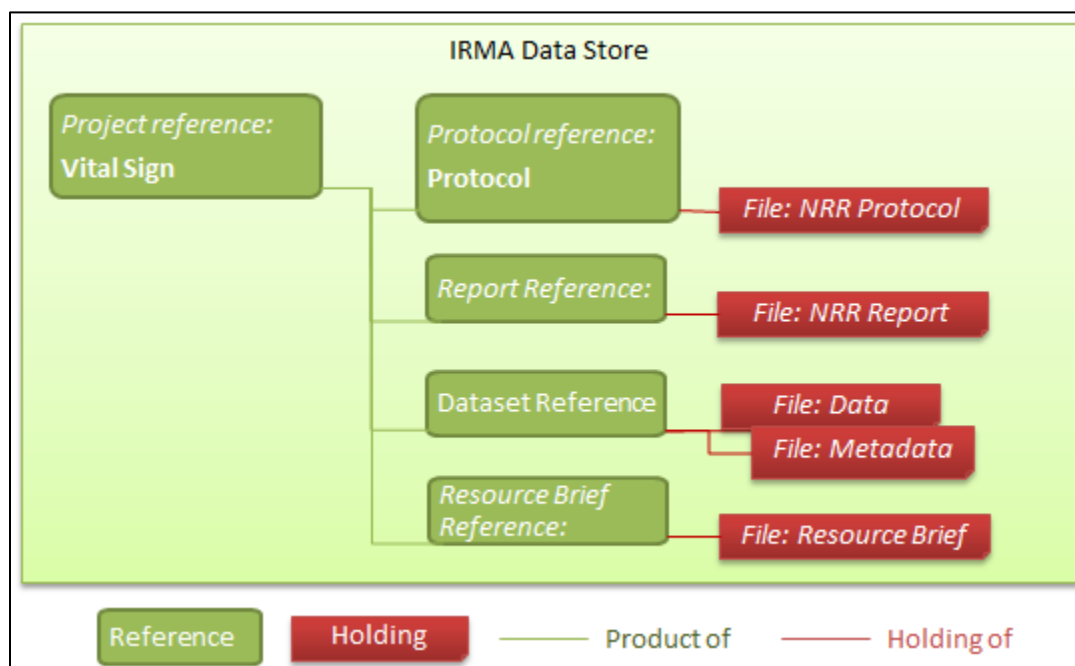


Figure 8. Standardized CAKN Project Reference architecture in the IRMA Data Store.

Line of Sight is the informal name given to the I&M program’s philosophy that every product should be inextricably linked in a traversable way to the standard operating procedure and protocol version that guided its collection (Figure 9). This custodial chain is maintained through each data deliverable’s metadata, which will refer to the particular protocol narrative and SOP versions that guided collection and processing of that data. All current and former protocol narratives and SOPs will be stored on the IRMA Data Store (only the most current version will be public), and revision logs within all those documents will provide a further description of the history and timing of

methodological revisions. A data consumer will therefore be reliably able to access a data record and discover the standard operating procedure version that defined its collection and processing.

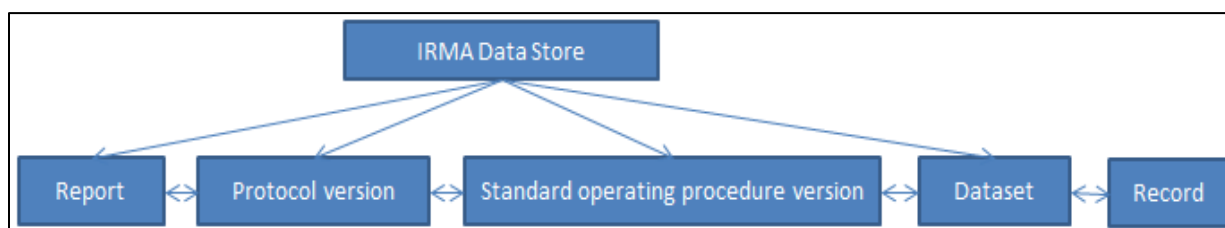


Figure 9. “Line of Sight”. Each informational component informs and is informed by other components. Discovery of one component leads to discovery of all other components in a formalized data management chain of custody.

All certified project datasets, including spatial and non-spatial data, are archived in the IRMA data store with metadata. The mandate for adequate metadata comes from Director’s Order #11A (NPS 2005b):

“All NPS data systems will develop data dictionaries and conform to available NPS organization-wide dictionaries. Geographic Information and Metadata must meet all Federal standards, DOI standards and NPS standards.”

Spatial metadata will be in [Federal Geographic Data Committee](#) (FGDC 1998) format. Tabular metadata will be developed in [Ecological Metadata Language](#) (Knowledge Network for Biocomplexity 2015a; Michener et al. 1997) using [Morpho](#) (Knowledge Network for Biocomplexity 2015b) or similar tool.

3.6 Closeout

Closeout is the part of the permafrost monitoring data management life cycle through which seasonal data collection files (deliverables) are archived in the IRMA Data Store. Closeout happens after a re-measurement cycle when data files have been collected, processed, and quality-controlled. The closeout schedule, described in Table 7, generally requires that all collected data types (whether internal or public and certified) be archived to IRMA within one year of collection. Closeout is complete when the IRMA Dataset’s holdings match the deliverables schedule (Figure 10). After closeout all permissions are removed from the seasonal IRMA Dataset reference except for the project leader and data manager. The dataset reference will then be linked to the main permafrost monitoring IRMA Project reference so that it becomes discoverable within the NPS. Procedures for public, certified datasets follow a similar schedule, and are described in the next section.

Protocol Narrative

Table 1 shows the field data deliverables that will be collected seasonally.

Table 1. Data deliverables schedule

Identifier	Deliverable
DS01	Field database file
DS02	Field data collection forms
DS03	Survey Photos
DS04	Tracklogs
DS05	Waypoints
DS06	NRDS Report

REFERENCE: 2173037

IRMA Portal Integrated Resource Management Applications

[Portal](#) > [Home](#) > [IRMA Applications](#) > [Data Store](#) > [Profile](#) >

Scientist, A. 2012. Title of remeasurement dataset. Dataset. National Park Service XXXX Inventory and Monitoring Program. Fairbanks, AK. Generic Dataset-2222131.

Reference Status as of 07/31/2015: Active
Visibility: Internal

Holdings
DS01 FieldDatabase.zip (.shp, 134kb)
DS02 Field data collection forms (pdf, 320kb)
DS03 SurveyPhotos-2011.zip (.jpg, Compressed archive, 300Mb)
DS04-05 Tracklogs-Waypoints.zip
DS06 NRDS Report (link)

Closeout is complete when the deliverables in the deliverables schedule are available in the IRMA Data Store

Figure 10. Data deliverables are defined in the monitoring protocol and archived in IRMA dataset references after each re-measurement cycle. Closeout is complete when the holdings in the dataset reference match the deliverables in the protocol's data deliverables schedule.

3.7 Dataset certification and publication

Certification is the phase of the data management life cycle where the principal investigator and data manager both formally confirm that a particular data deliverable is ready for analysis and public viewing. Certification, which affirms the scientific and technical integrity of the program that underlies the data deliverable, is implicit in the process of publishing a publicly viewable dataset. Raw and intermediate data deliverables are only internally accessible to NPS employees via the IRMA Data Store, unlike certified datasets that are by definition viewable at the public Permafrost Vital Sign web page that publishes the releasable contents of this reference via web services.

All certified datasets will be accompanied by metadata that summarize collection procedures, data quality, and other pertinent notes. Detailed certification procedures and metadata formats for each certified data deliverable are defined in the relevant SOPs, but in general the process of releasing a certified data deliverable on the IRMA Data Store indicates that the Principal Investigator and Data Manager both certify the following:

- The dataset is of sufficient quality that analyses may be performed on it and the results published.

- The protocol and pertinent standard operating procedures are current and up to date. The data deliverable is traceable, via the metadata, to the specific protocol and SOP versions that guided its collection (i.e., line of sight).
- Raw and intermediate data deliverables have been processed via documented quality control procedures, all closeout activities have been performed, and those products have been archived and documented appropriately within the Data Store.
- The dataset is published in a publicly accessible, machine-readable format appropriate for public consumption, and is accompanied by a complete metadata text file.
- The Vital Sign's IRMA Data Store cross-reference architecture is complete and up to date, and reflects inclusion of the new data.

Some of the data collected as part of this protocol will be shared with partners for release on collaborative databases. The borehole temperature data, for example, will be posted by the UAF Permafrost Laboratory (www.permafrostwatch.org) and also by the GTN-P (gtnpdatabase.org/boreholes). Annual thaw depths will also be shared with GTN-P (gtnpdatabase.org/activelayers) and with the CALM network (www2.gwu.edu/~calm/data/north.html). In all such cases, data will be shared only after certification and publishing on the IRMA Data Store—the authoritative source.

3.8 Analysis and reporting

Analysis and reporting of certified protocol data can take many forms, but the primary three internal tools for reporting are Resource Briefs, Natural Resource Reports, and Natural Resource Data Series reports. Resource Briefs are the primary outreach document for the CAKN permafrost monitoring program. The principal investigator will periodically revise any existing resource brief after new findings to reflect current understanding of the resource's trend and implications for park management. The cycle for these revisions can vary, but should in most cases occur at least every 5 years. Resource briefs are archived in the IRMA Data Store and then linked to the main Vital Sign Project reference as a product (Figure 8).

Natural Resource Reports (NRRs) provide comprehensive summaries and analysis of protocol data for a technical audience. All such reports, and any other reporting that include summaries or statistical analyses of protocol data will provide explicit links to the data and metadata on which they were based. As with the resource briefs, the schedule of NRRs can vary, but will be less often than once per year. Natural Resource Data Series (NRDS) reports may be issued in the interval between NRRs. NRDS reports are very limited in scope, and serve only to provide a public, narrative-formatted update of project data without engaging in trend analysis or interpretation.

Other reporting consistent with the goals of the CAKN permafrost monitoring program include journal articles, outreach videos, web and social media content, and book sections. All of these may, at times, be appropriate venues for dissemination of protocol data but they should, in every case,

reference the authoritative data source (the project reference at the IRMA Data Store) in the same manner as internal publications.

4. Protocol revision and archiving

All edits and amendments made to the protocol narrative and/or SOPs should be recorded in the revision history log table at the beginning of this document (for revisions to the narrative) and at the beginning of each SOP for SOP revisions. Users of this protocol should promptly notify the project manager of recommended edits or changes. The project manager will review and incorporate suggested changes as necessary, record these changes in the revision history log(s), and modify the date and version number on the title page of this document to reflect these changes. This protocol and any future versions will be archived in the CAKN SQL Server databases, database backup files, and in the IRMA data store. The most up-to-date protocol document will be available on the public network website.

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