# Managing Permafrost Data: Past Approaches and Future Directions

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## Abstract

The International Permafrost Association (IPA) has a long history of data management. Notable achievements include the establishment of a Global Geocryological Data (GGD) system and the publication of the Circumpolar Active-layer Permafrost System (CAPS) compilations. At the same time, the IPA has struggled to maintain continual stewardship of permafrost and related data with sustained support. Activities as part of the International Polar Year will significantly increase data holdings and will required renewed emphasis on data description, preservation, and integration with other disciplines.

**Keywords:** data management; frozen ground; GGD; IPA; IPY; permafrost.

## Introduction

Permafrost and seasonally frozen ground data and information are critical for fundamental process understanding, environmental change detection, impact assessment, model validation, and engineering applications. The International Permafrost Association (IPA) has long emphasized the importance of these data and has encouraged ongoing data sharing and management through the Global Geocryological Data (GGD) system. The GGD is an internationally distributed system linking investigators and data centers around the world and was proposed by Barry et al. (1995). The World Data Center (WDC) for Glaciology at Boulder has historically acted as central node of the GGD and has published two compendiums of permafrost related data: *Circumpolar Active-Layer Permafrost System* (CAPS) Version 1 and the substantially updated Version 2 (IPA DIWG 1998, IPA SCDIC 2003).

Data advertised through the GGD and published on CAPS include information on borehole parameters, soil temperature, cryosols, and climatology as well as maps, metadata, and bibliographies. Data come from diverse international sources, but data produced by IPA projects have always been prominent in the collections. These products include benchmark maps such as the *Circum-Arctic Map of Permafrost and Ground-Ice Conditions* (Brown et al. 1998) as well as data and metadata from ongoing IPA programs such as the Global Terrestrial Network for Permafrost (GTN-P), the Arctic Coastal Dynamics (ACD) program, and the Antarctic Permafrost and Soils (ANTPAS) project. These IPA programs continue to produce important data with a burst of new activity in the International Polar Year (IPY). Another area of potential data growth is through satellite remote sensing.

While the GGD has succeeded in capturing and describing many important data resources, it has been an ad hoc activity without sustained support for ongoing data collection and stewardship. There is a critical need to sustain data stewardship activities throughout the entire data lifecycle. Note, data stewardship is a broader concept than data management. It can be defined as "all activities that preserve and improve the information content, accessibility, and usability of data and their associated metadata" (NRC 2008). Correspondingly, the concept of a data lifecycle reflects how data are continually evaluated, improved, and maintained for archiving until retired or discarded.

The GGD is linked to the broader IPY Data and Information Service (IPYDIS), which works with the Scientific Committee on Antarctic Research (SCAR) and International Arctic Science Committee (IASC) to establish a lasting polar data infrastructure. The IPA seeks to contribute to this international effort by capturing the burst of permafrost data collection during IPY, and ensuring the preservation of past data in a new CAPS Version 3 compilation. The IPA also seeks to develop a more sustainable data collection and stewardship strategy through linkages to other relevant international programs including the intergovernmental Group on Earth Observations (GEO).

## Global Geocryological Data

The need for a consistent and comprehensive permafrost data management has long been recognized. In 1983, the U.S. National Research Council called for greater coordination and a specialized permafrost data clearinghouse (NRC 1983). In 1988, the WDC for Glaciology at Boulder organized a workshop in Trondheim, Norway in conjunction with the Fifth International Conference on Permafrost (Barry & Brennan 1989). This workshop, coupled with a paper presented by Roger Barry (1988), led to the establishment of a Data and Information Working Group within the IPA and established the overall IPA data strategy. The strategy was refined based on an international survey of permafrost data holdings (Barry & Brennan 1993) and culminated in the establishment of the GGD and the first CAPS compilation for the Seventh International Conference on Permafrost, SICOP, in 1998. Furthermore, delegates to the SICOP International Conference recognized the importance of continuity in data and information activities, and the existing Working Group was reestablished as a permanent Standing Committee on Data Information and Communication (SCDIC) during the Twelfth IPA Council Meeting at SICOP in Yellowknife, Canada.

The 1998 CAPS1 included 56 datasets and an additional 89 metadata descriptions for products held elsewhere around the world. In late 2002, the newly established Frozen Ground Data Center (FGDC) at the WDC for Glaciology at Boulder in collaboration with the International Arctic Research Center published the contents of CAPS online at the FGDC web site and began updating and adding to the CAPS collection to create CAPS Version 2. CAPS2 expanded the scope of CAPS by including data and information for seasonally frozen ground regions from in-situ measurements, satellite remote sensing, and model outputs and included data and metadata for more than 200 datasets. More comprehensive data documentation was also written.

Since the publication of CAPS2, the FGDC has published several other datasets. These additions include important historical data (Oberman & Kakunov 2004), maps (Sodnom & Yanshin 1990), and long-term, broad-scale time series of seasonally frozen soil parameters (Zhang et al. 2005). These products are available through the FGDC web site. Data will remain available until the next major media migration or system upgrade at the WDC, at which point the FGDC distribution will need to be retired, unless continued funding can be identified.

In many ways, the history of the GGD parallels the evolution of digital data management in general. Initial bibliographic efforts grew into data compilation and recording efforts. Standard metadata formats were created and implemented. Central catalogs describing distributed data were created. Media and distribution methods evolved.

In some ways the GGD was at the forefront of developments in data management. For example, CAPS1 included specific citations for all datasets and urged investigators to formally cite data use as they would any other publication. This practice is just now gaining wide spread acceptance as is evident in the IPY Data Policy and increasing acceptance of data citations by leading journals.

On the other hand, the GGD has been largely an ad hoc effort punctuated by intense activity around the CAPS compilations. This contrasts with the increasing recognition of the importance of continual data stewardship and full lifecycle data management (USGCRP 1999, NRC 2008). For example, part of the effort of updating CAPS was to try and contact the investigators and institutions holding the 89 GGD products described but not contained on CAPS1. Unfortunately, 45 of the 89 products were not readily accessible and may no longer be available. The potential loss of these data highlights the need for continued support of data management for the permafrost community.

The IPA through its SCDIC needs to evolve its data strategy and the general GGD system to more actively acquire current datasets, rescue data at risk of loss, ensure the planned migration of investigator held data to more permanent archives, and address the growth of data resulting from the burst of IPA activity as part of the IPY.

## IPA Programs and the IPY

A summary of the major IPA activities since its formation in 1983 is presented in these proceedings (Brown et al. 2008). In addition to mapping, bibliographic, and terminology projects, the main IPA focus has been on broad, coordinated international field programs. Individual national sponsors fund each program, but the field efforts are unified through IPA coordination of site documentation, data collection methods, and metadata descriptions. Each program has its own data management structure that can be considered a node of the GGD, while metadata should be broadly shared to facilitate discovery across the GGD. IPA programs include:

- The Global Terrestrial Network for Permafrost (GTN-P), which includes both boreholes and active layer sampling protocols.
- The Arctic Coastal Dynamics (ACD) project.
- Northern Circumpolar Soil Carbon Database (NSCD) (Tarnocai et al. 2007).

• Each IPA program is linked to IPY approved and coordinated projects including "Permafrost Observatory Project: A Contribution to the Thermal State of Permafrost" (IPY project #50), "Arctic Circum-Polar Coastal Observatory Network (ACCO-Net)" (IPY 90), "Antarctic and sub-Antarctic Permafrost, Periglacial and Soil Environments" (IPY 33), "Carbon Pools in Permafrost Regions" (IPY 373), and the Russian project, "Response of Arctic and Subarctic soils in a changing Earth: dynamic and frontier studies" (IPY 262).

*Global Terrestrial Network for Permafrost*

The GTN-P consists of two components: the Thermal State of Permafrost (TSP) and the Circumpolar Active Layer Monitoring Network (CALM) (Burgess et al. 2000). Together they are contributing to the Global Earth Observation System of Systems and the UN Framework Convention on Climate Change through the Global Terrestrial Observing System.

The TSP component of GTN-P consists of a network of boreholes, in which permafrost temperatures are measured. The network currently consists of over 300 boreholes with many new sites to be established during IPY. This network is built on a number of regional networks. Boreholes range in depth from a few meters to greater than 100 m with record lengths of up to three decades. Data collected from this network has provided important information on the change in permafrost temperature over time and are important contributions to major regional and global assessments (ACIA 2004, IPCC 2007, UNEP 2007).

TSP borehole metadata (site descriptions) and summary permafrost temperature data are accessible through the GTN-P web site hosted by the Geological Survey of Canada (GSC). A major goal for IPY is to provide a "snapshot" that describes the thermal state of permafrost for a specific time period. This snapshot can serve as a baseline for the assessment of the rate of change of permafrost conditions and can be used to validate climate model scenarios and to support process research to improve our understanding of permafrost dynamics.

Two national programs within the TSP project illustrate the project scope and its data management challenges. The TSP Norway project plans to establish the North Scandinavia Permafrost Observatory around 70°N, covering a transect from maritime northern Norway into northwestern Sweden and Finland. The Svalbard Nordenskiöld Land Permafrost Observatory around 78°N is already being established. Both observatories deliver borehole temperatures, active layer thickness, meteorological, and periglacial process data from different permafrost landforms. All these data will be organized in the NORPERM database located at the Norwegian Geological Survey. The aim is to also include earlier permafrost and periglacial data from all of Norway and Svalbard in the database. Data from NORPERM shall also be available to others through the GTN-P.

The Canadian Permafrost Monitoring Network coordinated by the GSC consists of over 100 monitoring sites maintained by government agencies and universities. Sites are largely concentrated in the western Arctic (Mackenzie Valley and Delta), northern Quebec, with a few sites in the high Arctic. During IPY, scientists intend to establish new monitoring sites in northern Manitoba, Yukon and Nunavut Territories as part of the TSP project.

The Canadian network maintains a web site that links to the GTN-P web site and provides access to metadata for both active layer and permafrost thermal monitoring sites and summary data. Linkages with the Canadian cryospheric community are through the Canadian Cryospheric Information Network. Canada's contribution to the IPY will be a standardized set of permafrost temperatures collected during IPY that will be compiled into a digital database to be released through the web site and as a CD publication.

The other major component of GTN-P, CALM, monitors active layer thickness and shallow ground temperature, and coordinates field experiments. The CALM network currently consists of more than 150 sites distributed throughout the Arctic and several mountain ranges of the mid-latitudes. Efforts to expand the number and capabilities of sites in the Southern Hemisphere (CALM-S) are underway through ANTPAS. Instrumentation and data-acquisition methods include monitoring the soil thermal and moisture regimes with automatic data loggers, mechanical probing of the seasonally thawed layer at specified spatial and temporal intervals, frost/thaw tubes, and a variety of instruments for measuring frost heave and thaw subsidence.

Data are transferred to the CALM data repository at the University of Delaware for archive and distribution through the CALM web site, which is linked to the GTN-P site and FGDC (Shiklomanov et al. 2008).

*Arctic Coastal Dynamics*

The ACD project of IASC and the IPA was created in 1999 to improve understanding of circum-Arctic coastal dynamics under the influence of environmental changes and geologic controls. ACD's international and ongoing effort to segment and classify the entire circum-Arctic coastline has resulted in a scalable GIS database of coastal geomorphological characteristics evaluated by regional experts. This detailed evaluation has been compiled into a geographic information system (GIS), which contains data on coastal morphology, composition, dominant processes, ground ice, and environmental forcing parameters such as wind speed, storm counts, melt season, and wave energy.

This information is available for over 1300 segments, covering the coastline of all eight regional seas of the Arctic Ocean. The coasts of the Barents, Kara, Laptev, East Siberian, Chukchi, and Beaufort Seas have been segmented, as has the coastline of Svalbard. The length of individual segments varies (median length is 38 km), but the segmentation format is scalable, allowing the adoption of future digital coastlines and the integration of additional, higher-resolution data. The data are available via an Internet map server and as a downloadable geodatabase at the ACD web site. Others with complementary datasets are encouraged to contribute to this growing data resource. Future development will include the incorporation of remote sensing into the geodatabase.

ACD represents the coastal component of the ongoing international effort to integrate existing and planned Arctic observatories into a coherent Sustained Arctic Observatory Network (SAON). In addition, ACD's IPY activity, ACCO-Net, integrates 17 Arctic coastal observatory projects with 24 ACD key sites into an extended network.

*Antarctic Permafrost and Soils*

The overall objective of ANTPAS is to develop an internationally coordinated, web-accessible, database and monitoring system on Antarctic permafrost and soils. Specific objectives are to:

1. Develop a web-accessible repository for permafrost and soils data.
2. Prepare thematic maps on Antarctic permafrost and soils.
3. Develop a system of boreholes providing data on permafrost and soils properties, past environmental change, and responses to climate change.
4. Develop a monitoring system recording active layer and periglacial process responses to climate change along selected environmental gradients.

With no centralized funding, ANTPAS progress is restricted to member activity within existing research programs. ANTPAS has developed a web site for publications and links to relevant databases (Objective 1).

Progress has been made on developing soil and permafrost maps (Objective 2), particularly for the Antarctic Peninsula and the Trans-Antarctic Mountain regions. The soil and permafrost data are to be stored, and made available through the web sites of the individual investigators with links to each database from the ANTPAS web site. ANTPAS Objectives 3 and 4 compliment the TSP and CALM projects in the Northern Hemisphere.

## Other Geocryological Data

*Satellite remote sensing*

Satellite remote sensing data are increasingly used for permafrost and seasonally frozen ground studies (Zhang et al. 2004, Duguay et al. 2005). Remote sensing of permafrost terrain and near-surface soil freeze/thaw cycles typically uses a combination of imaging in optical and thermal wavelengths, passive microwave remote sensing, and active microwave remote sensing using scatterometer and Synthetic Aperture Radar (SAR). Consequently, large amounts of valuable data can be generated.

Images and data from the orbiting visible and near-infrared sensors can be used to infer permafrost distribution (e.g., Anderson et al. 1984), active layer thickness, and various periglacial features (Leverington & Duguay 1996). LANDSAT data provide a high-resolution (15 m to 80 m), long (1972–present) time-series, useful to investigate changes in land surface morphology such as in rock glaciers, thaw lakes, and other periglacial phenomena. Land surface temperature is a key parameter for permafrost and seasonally frozen ground studies. The potential application of using land surface temperature products derived from visible and infrared sensors from 1980 to the present can be substantial (Zhang et al. 2004, Duguay et al. 2005). Remotely sensed land surface temperatures can be used to drive numerical models simulating the development of the active layer and thermal regime of permafrost or to estimate thawing index, which can be used to estimate active layer thickness.

SAR data has been used to map bottom fast ice that controls the preservation and development of subsea permafrost (Solomon et al. 2005). Data from passive microwave sensors dating from 1978 can be used to detect near-surface soil freeze-thaw status based on the spectral sensitivity of brightness temperatures to the state of water (liquid or solid) in soils. Zhang and Armstrong (2003) have provided the near-surface (<5 cm) soil freeze/thaw status derived from passive microwave satellite remote sensing data over the Arctic terrestrial drainage basin. Other near-surface soil freeze/thaw data products are also available but have not yet been archived.

Scatterometery can also be used to detect near-surface soil freeze/thaw status with relatively high spatial resolution. Attempts have been made to apply the differential interferometric synthetic aperture radar technique to monitor the surface deformation (frost heave and thaw settlement) due to the annual freeze/thaw cycle of the active layer over permafrost (Wang & Li 1999).

As satellite remote sensing techniques improve, more and better products will continue to be generated. It is essential to archive and distribute such data products.

*Periglacial process data*

Information on the movement and activity of different periglacial landforms derived from many different techniques including remote sensing, geophysical data such as resistivity and georadar, direct movement measurements, and snow distribution data are increasingly being collected; yet they are lacking coordinated data management arrangements. For example, the TSP Norway project is collecting significant periglacial process data. In another example, the FGDC at WDC for Glaciology at Boulder has received several offers of data on rock glaciers from independent investigators. Because these data are not part of a formal funded program at the WDC, it is difficult for the WDC to acquire the data.

*Historical and other data*

There are a variety of other important geocryological data sources. Various national programs continue to produce important data outside the bounds of formal IPA programs. While some of these data are well managed and readily available, others need to be better described through formal metadata protocols, converted to digital formats, or migrated to new media. Some data are at risk as investigators retire or research programs end. Some data even need to be "rediscovered", such as those datasets advertised on CAPS that are no longer readily available.

Models are also increasingly important in characterizing and predicting geocryological processes, especially in a changing climate regime (e.g., Marchenko et al. 2008).

Preservation and distribution of significant model outputs will be a growing concern.

Finally, the IPA has often produced specialized bibliographies and these have also been featured on CAPS. The Cold Regions Bibliography Project continues this work with the *Bibliography on Cold Regions Science and Technology* (Tahirkheli 2008).

## Future Directions

The increased IPY field data collection, the increased application of remote sensing methods, and the growing need to integrate data across disciplines challenge the ad hoc nature of the GGD. To achieve the IPY goals of greater international collaboration and interdisciplinary research, it is insufficient to simply share basic metadata. Data must be provided in more consistent formats through more interoperable data exchange protocols. Open Geospatial Consortium (OGC) standards and technologies provide one approach to interoperable data sharing. Several information portals such as the Arctic Research Mapping Application and the Arctic Portal build off OGC technologies. Already, within the GGD, the ACD is providing its coastal segment database through an OGC map server, while the WDC for Glaciology provides the *Circum-Arctic Map of Permafrost* and other cryospheric data through several OGC protocols (WMS, WCS, WFS) (Maurer 2007). Users can then use these data and services to prepare their own maps, view regions and variables of interest, and compare data from different sources.

Another goal of IPY is to leave a legacy for future generations. This challenges the SCDIC and the GGD to develop a more continuous and sustainable data stewardship and preservation strategy. This applies not only to publicly available databases, but sufficient resources must also be committed for active data rescue activities. We should also recognize the value of the past CAPS compilations in providing data snapshots at periodic intervals. These snapshots can act as archival records that are, in essence, preserved simply through their broad and public distribution. IPY marks an important milestone for the IPA with a pulse of new data, and much of that data will be presented at the Ninth International Conference on Permafrost. The SCDIC hope to use this opportunity to create a new CAPS3 compilation. An excellent deadline and opportunity for broad distribution of CAPS3 is the large IPY closing conference in Oslo, Norway in June 2010. Table 1 summarizes some of the potential content.

As the SCDIC develops CAPS3, it must consider how CAPS can evolve as a preservation medium, as well as what data and information it will contain. Is it still appropriate to create physical media for public distribution (e.g., DVDs), or are other strategies such as the peer-to-peer based LOCKSS (Lots of Copies Keeps Stuff Safe) Program more appropriate? Documentation on CAPS3 should evolve to comply with the ISO standard Open Archival Information System Reference Model (CCSDS 2002, cf. Duerr et al. 2006). Finally, quality control procedures for the data compiled need to be determined. Historically, quality control was the responsibility of individual investigators and national programs, but CAPS3 compilers will want to ensure data are in suitably preserveable formats with adequate description of data uncertainties. CAPS3 can serve as benchmark in the development of a lasting polar data system.

Table 1. Initial CAPS3 data sources.

| Source | Description or Activity |
|---|---|
| GTN-P TSP | Temperature data from 300 designated boreholes |
| GTN-P CALM | Active layer data from 150 sites |
| ACD | 1331 coastal segments described in a geodatabase. |
| ANTPAS and TSP | Maps, thousands of soil profiles, and periglacial process data |
| NCSCD | Database of thousands of polygons with soil properties and carbon stocks |
| CAPS1 and CAPS2 | Updates to key products<br>Rescue of lost products |
| National programs | Identification, description, and acquisition of important products |
| Remote sensing & model output | Identification, description, and acquisition of important products |
| Other projects and investigators | Historical data and value added products such as maps, graphical presentations, analyses, etc. |
| Bibliographies | Monthly updates to the Cold Regions Bibliography |

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