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Global Terrestrial Network for Permafrost (GTNet-P): permafrost monitoring contributing to global climate observations

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Abstract: Active layer and permafrost thermal state have been identified as key cryospheric variables for monitoring through the World Meteorological Organization's Global Climate Observing System. An international network, the Global Terrestrial Network for Permafrost (GTNet-P), has been established under the Global Climate Observing System and is being developed by the International Permafrost Association. The active layer component, the Circumpolar Active Layer Monitoring (CALM) program, is already in place. Global Terrestrial Network for Permafrost organizational efforts are thus focused on the development of the permafrost temperature monitoring program, where Canada contributes actively through the Geological Survey of Canada's membership on the International Permafrost Association organization and implementation committee. Although several regional permafrost borehole temperature networks exist, a globally comprehensive network for ground temperature measurements is required to provide long-term field observations essential for the detection of the climate change signal, for the assessment of its impact on permafrost, and for indications of spatial variability across the permafrost regions.

Résumé : Les états thermiques de la couche active et du pergélisol ont été reconnus comme variables cryosphériques clés pour la surveillance dans le cadre du Système mondial d'observation du climat de l'Organisation météorologique mondiale. Un réseau international, le réseau mondial terrestre pour le pergélisol (GTNet-P), a été établi dans le cadre du Système mondial d'observation du climat et est en voie de développement par l'Association internationale du pergélisol. La composante couche active, soit le programme circumpolaire de surveillance de la couche active (CALM), est déjà en place. Les efforts visant à organiser le réseau mondial terrestre pour le pergélisol sont donc centrés sur l'élaboration d'un programme de surveillance de la température du pergélisol auquel le Canada contribue activement par la participation de la Commission géologique du Canada au comité d'organisation et de mise en oeuvre de l'Association internationale du pergélisol. Bien qu'il existe plusieurs réseaux régionaux de surveillance du pergélisol dans des sondages, un réseau de mesure de la température du sol à l'échelle du globe est nécessaire pour obtenir les observations de terrain à long terme qui sont essentielles aux fins de la détection du changement climatique, de l'évaluation de son incidence sur le pergélisol et de l'obtention d'indications quant à sa variabilité spatiale dans les régions pergélisolées.

INTRODUCTION

Climate warming is expected to be greatest over high latitudes and permafrost areas will be among the most heavily affected. About 25% of the land mass of the northern hemisphere (Fig. 1) is underlain by permafrost, including large regions of Canada, China, Russia, and Alaska, and with smaller permafrost areas in mountain chains of many other countries in both the northern and southern hemisphere (Brown et al., 1997; Zhang et al., 1999). Over half of the world's permafrost is at temperatures a few degrees below 0°C. General Circulation Models (e.g. Flato et al., in press) predict increases in mean annual air temperature of up to several degrees in high latitudes in response to a doubling of CO_2 (Fig. 1). Variations in permafrost conditions can be a sensitive indicator of climate change and climate variability (Lachenbruch et al., 1988; Osterkamp and Romanovsky, 1999). Moreover, warming and thawing of perennially frozen ground has important implications for many landscape processes and hazards such as increased terrain, slope, and coastal instability (Dyke et al., 1997; Dyke and Brooks, in press). These changes as well as associated alterations to surface hydrology, ground water regimes, and surface vegetation have consequent socio-economic impacts for ecosystems, infrastructure, and development (Michel and van Everdingen, 1994; Couture et al., 2000). Climate warming in permafrost regions will also affect the carbon cycle through changes in greenhouse gas sources and sinks associated with thawing or burning of permafrost-affected peatlands (Robinson and Moore, 2000). In addition, large amounts of methane are presently stored in the permafrost region as gas hydrates and their slow decomposition in response to climate warming may have large potential positive feedbacks (Taylor, 1999; Smith, in press).

The international community has committed to the development of a plan to contribute to global observations of the climate system, including observations of the atmosphere, oceans, hydrosphere, cryosphere, and terrestrial system. Permafrost is a key component of the cryosphere. In 1998, the International Permafrost Association (IPA) resolved to lead the development of a functional international network for permafrost monitoring (Brown, 1998). As a result, a Global Terrestrial Network for Permafrost (GTNet-P) was proposed and officially established in 1999 under the Global Climate Observing System (GCOS) and Global Terrestrial Observation System (GTOS) of the World Meteorological Organization

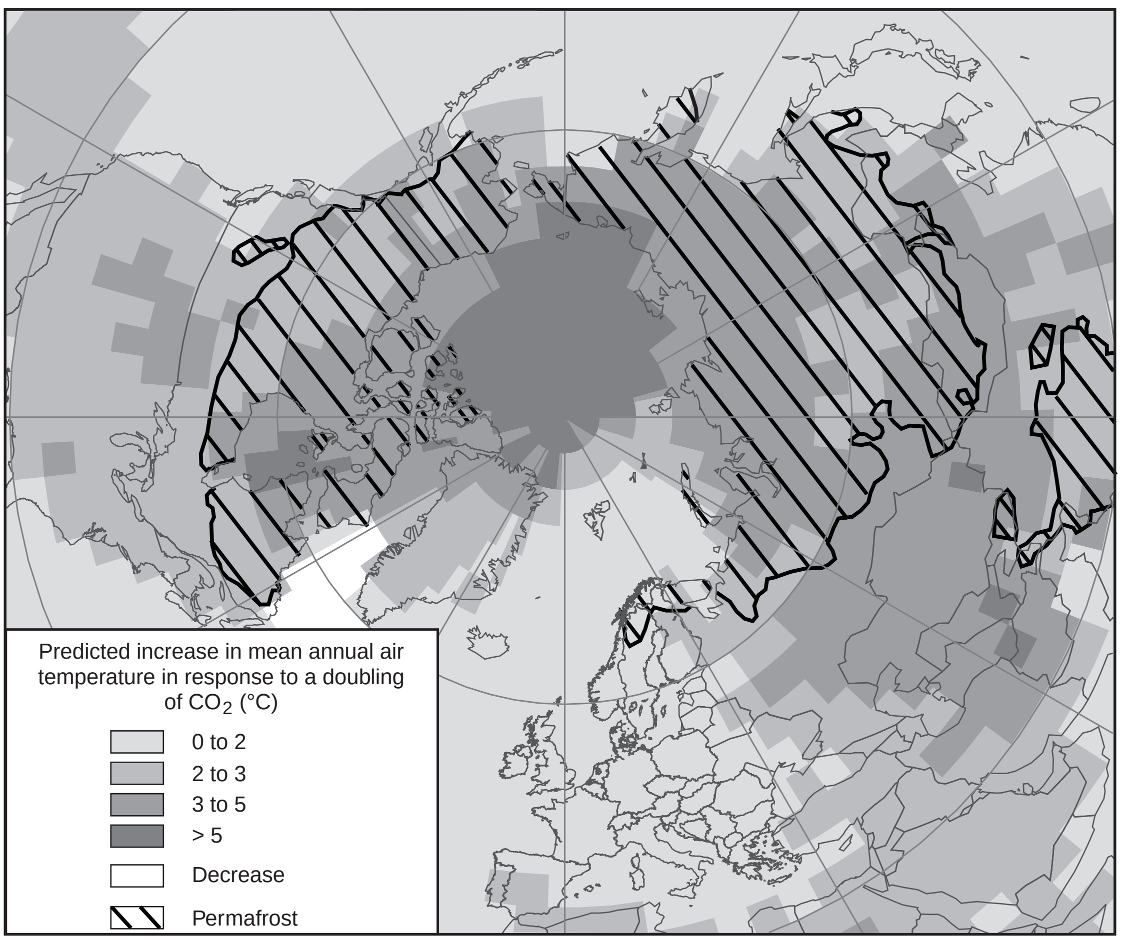

Figure 1. *Circumpolar permafrost distribution (*after *Brown et al., 1997) in the northern hemisphere and predicted change (2040 to 2060 minus 1975 to 1995) in mean annual air temperature in the circumpolar regions in response to doubling of CO_2 (Flato et al., in press).*

(WMO). The GTNet-P is a global network of permafrost observatories, designed most importantly to monitor changes in permafrost thermal state and in active layer. Such observatories will provide the long-term field observations essential for the detection of the terrestrial climate signal and of its spatial variability in permafrost, and for the assessment of the impacts of climate change on permafrost. Documentation of changing permafrost conditions also provides data for testing and improving cryospheric and general circulation models.

The GTNet-P organizing committee is responsible for development, implementation, and management of the GTNet-P. The GTNet-P network consists of two components, 1) the existing Circumpolar Active Layer Monitoring (CALM) Program which focuses on active layer characteristics, and 2) a new borehole temperature network to focus on monitoring permafrost thermal state. This paper first briefly reviews GCOS and the CALM program, and then describes details of the development and status of the borehole temperature network.

INTERNATIONAL GLOBAL CLIMATE OBSERVING SYSTEM

The GCOS program was established in 1992 by the WMO, the International Oceanographic Commission (IOC), the United Nations Environmental Programme (UNEP), and the International Council of Scientific Unions (ICSU) to address the requirements for global observations for seasonal prediction and longer term climate change. Since the establishment of GCOS, the importance of systematic observations of the climate system has been given additional emphasis in the UN Framework Convention on Climate Change and by the 1998 Kyoto Conference. The main goals of GCOS are to characterize the current climate; to detect climate change, determine the rate of change and assist in attributing the causes of change; to determine climate forcing resulting from changing concentrations of greenhouse gases and other anthropogenic causes; to validate models and assist in prediction of the future climate; and to understand and quantify impacts of climate change on human activities and natural systems.

The GCOS program addresses all components of the climate system, including the cryosphere which collectively describes the portions of the Earth's surface where water is perennially or seasonally in a solid form (i.e. glaciers, ice caps, permafrost, sea ice, snow, and lake and river ice). The program is subdivided into three separate panels which look at atmospheric, terrestrial, and ocean observations; however, at the international level there is no separate panel for the cryosphere and it is split between the Global Terrestrial Observing System (GTOS) and the Global Ocean Observing System. Permafrost is examined under GTOS. In Canada, the development of the national plan for contributing to GCOS is proceeding on the basis of five separate components: atmosphere, oceans, hydrosphere, cryosphere and terrestrial systems. The key cryospheric variables identified by GCOS for permafrost are the active layer and permafrost thermal state (World Meteorlogical Organization, 1997).

The GCOS program will be built upon national programmes. The GCOS bodies co-ordinate and facilitate the national observing components in order to produce optimal data sets and information for use by the participating countries. The development of national programs is critical to ensure the continuation of existing networks as well as the expansion of activities, such as the addition of new sites to fill in regional or thematic gaps, and the establishment of central coordination and database management capability. This allows nations to support GCOS climate observational requirements and to better address their own national concerns. Canada, for example, has recently produced a draft national plan for its participation in GCOS (Rutherford, 1999).

ACTIVE LAYER MONITORING — THE CALM PROGRAM

The Circumpolar Active Layer Monitoring Program (CALM) was established by the International Permafrost Association in 1991 to obtain long-term active layer measurements. The active layer is the uppermost layer of the ground, which freezes and thaws seasonally and overlies permafrost. Important observations in the active layer include the maximum thickness of the seasonal thaw at the end of summer, and, when possible, a record of ground temperatures. The network has grown from an initial 15 sites to more than 80 sites located throughout the permafrost regions of the northern hemisphere (Fig. 2; Table 1). Methods employed at CALM sites to determine active layer thickness include probing, thaw tubes and temperature measurements (Fig. 3). Sites at which ground temperatures are measured may also form part of the permafrost thermal monitoring network. Maximum annual active layer thickness, and the method of its determination, are reported annually and posted on the CALM web site, maintained by the University of Cincinnati (http://www.geography.uc.edu/~kenhinke/CALM/index.html). The metadata, measurement protocols, site submission information, etc., are also available on the web site. Metadata for most sites are also available on the Circumpolar Active-Layer Permafrost System (CAPS) CD-ROM (International Permafrost Association, 1998). The United States National Science Foundation supports partial logistical expenses for the development of more than 20 Russian sites and the maintenance of the CALM web site.

PERMAFROST THERMAL STATE — BOREHOLE TEMPERATURE MONITORING PROGRAM

Since the establishment of the GTNet-P in early 1999, the IPA organizing committee has focused its efforts on establishing the permafrost temperature monitoring program. This program will effectively consist of a globally comprehensive network of boreholes for ground temperature measurements. In permafrost, temperature-depth profiles are required, with the desired frequency of observations decreasing with depth (Riseborough and Burgess, 1996). For example,

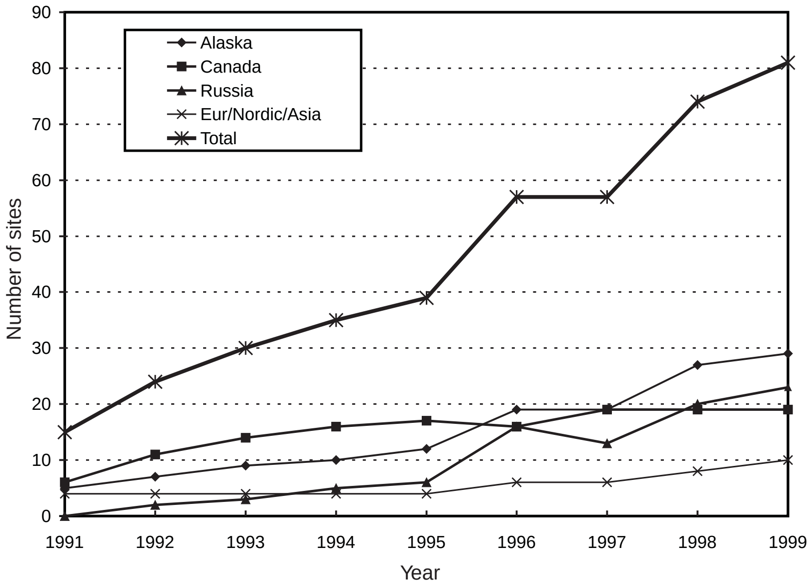

Figure 2.

Distribution of CALM sites by regions and number of sites over time.

Table 1. Summary of CALM and permafrost thermal monitoring sites by country (based on March 1999 compilation).

		Boreholes			
Country	**CALM sites**	**Surface 0–10 m**	**Shallow 10–25 m**	**Intermediate 25–125 m**	**Deep >125 m**
Austria-Russia	1				
Canada	20	9 (1)	36 (2)	14	3
China	2		3 (1)	12	1
Denmark-Greenland	3				
Germany-Russia	2				
Germany-Switzerland				1P	
Italy	3	1 (1)	1P	1P	
Italy-Antarctica		3			
Japan-Russia			5	2	
Kazakstan	1		3 (1)		1
Mongolia		1	3	6	
Norway				1P	
Norway-Svalbard				1P	
Poland-Svalbard	1				
Russia	21		22 (9)	11	15
Spain				1P	
Sweden	1			1P	
Sweden-Svalbard	1	2 (1)			
Switzerland	1		1P	6 (1) [2P]	
US-Alaska	25	4	1	22 (8)	21 (6)
US-Antarctica			1		1
US-Greenland					1

measurements are desirable several times throughout the year in the upper 5–15 m, where ground temperatures experience an annual temperature cycle (lagged and attenuated from the annual air temperature wave). At depths below the penetration of the annual wave (known as the depth of zero annual amplitude), and up to 50 m, annual observations are sufficient. Biennial or less frequent observations (5–10 year intervals) are acceptable at the greater depths (up to several hundred metres) where temperature changes very slowly. These temperature measurements are obtained through boreholes, using one of several types of thermistor sensor and measurement systems, e.g. through repeated logging of boreholes by lowering a single sensor probe or by permanent installation of a multisensor cable read manually or connected to a datalogger. The systems adopted have depended on several factors, such as borehole characteristics, desired depth increments, logistical considerations, compatibility with existing equipment, costs, etc.

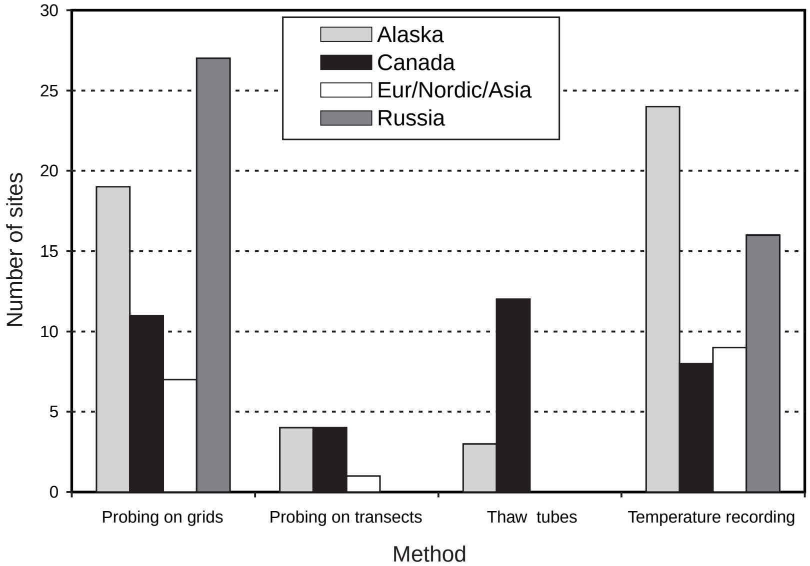

Figure 3.

Methods used to determine active layer thickness at CALM sites.

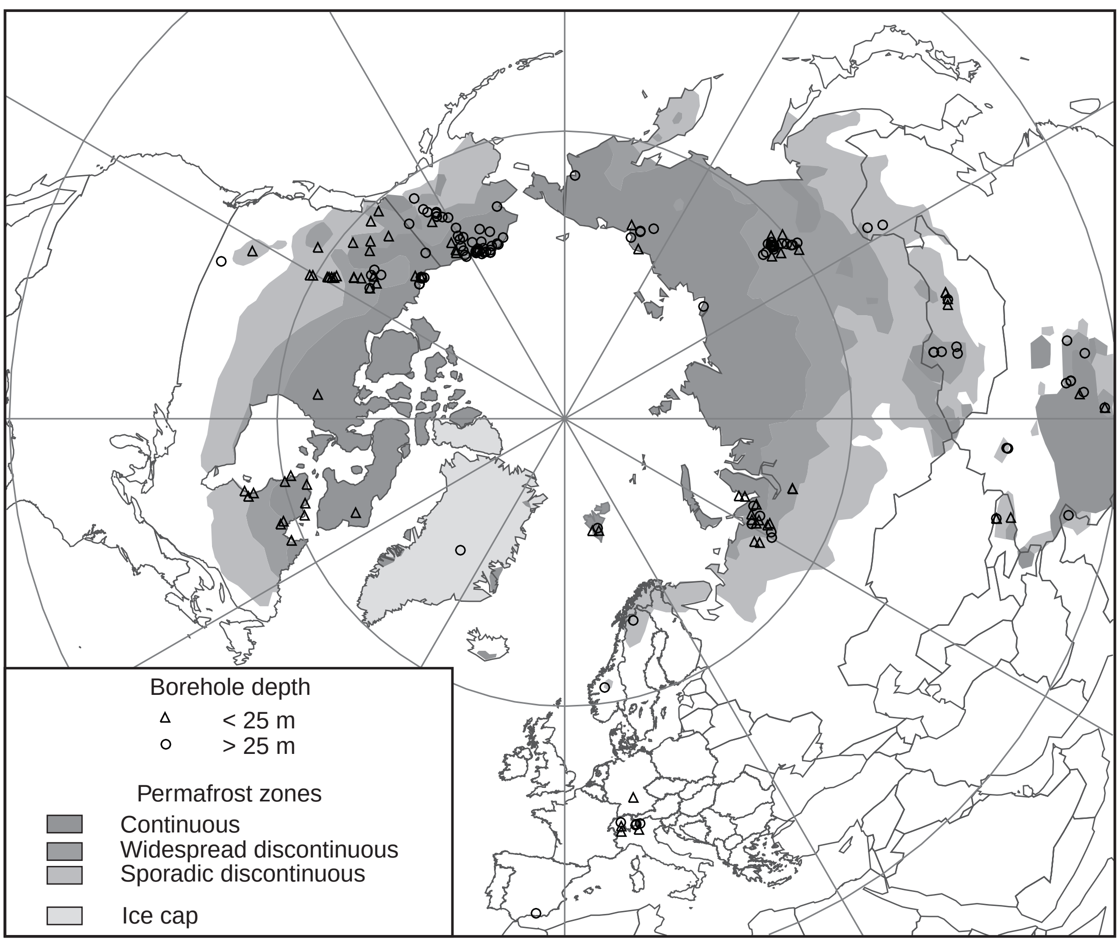

Figure 4. *Permafrost zones in the northern hemisphere (*after *Brown et al., 1997) and location of candidate boreholes for the borehole temperature monitoring component of the GTNet-P (based on March 1999 site compilation).*

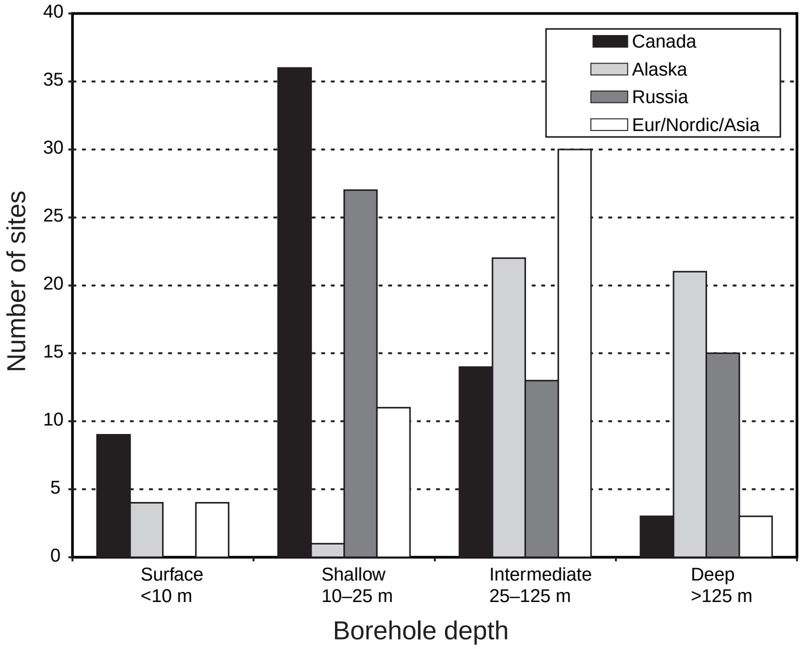

Figure 5.

Distribution of candidate boreholes in the four depth classes by region.

Many boreholes drilled for research, geotechnical, or resource exploration purposes in permafrost regions in the last two decades have been maintained as thermal monitoring sites. A survey conducted in early 1999 identified about 200 candidate boreholes in the circumpolar north (Fig. 4) for future long-term observations of permafrost temperatures and related climatic variables. The boreholes range from single sites, to transects or regional networks, and vary in depth from less than 5 m to over 125 m (Fig. 5; Table 1); several are co-located with CALM sites. Regional networks include those of the Geological Survey of Canada (GSC) in Mackenzie valley and Delta, the University of Alaska's Alaskan transect, the United States Geological Survey's deep boreholes in Northern Alaska and the European Community's Permafrost and Climate in Europe (PACE) project of nine permafrost boreholes in mountains from Spain and Italy to Svalbard.

Members of the GTNet-P committee have met several times since early 1999 to continue development of the program:

1) in April 1999 at the International Conference on Monitoring the Cryosphere in Pushchino, Russia;

2) in July 1999 during the International Union of Geodesy and Geophysics General Assembly in Birmingham, UK, where input was provided to the next report of the Terrestrial Observation Panel on Climate (TOPC) of GTOS;

3) in December 1999 at the fall American Geophysical Union Conference in San Francisco, U.S.A.;

4) in January 2000, in Ottawa, Canada, at the Canadian Permafrost Monitoring Network Workshop, held as part of Canada's efforts to develop a GCOS cryopshere plan (unpub. report, Meterological Service of Canada, Environment Canada, 1999) and sponsored by the GSC and Canada's Climate Change Action Fund; and most recently

5) in May 2000, in Pushchino, Russia, at the International Conference on Rhythms of Natural Processes in the Earth Cryosphere, where a GTNet-P status report was presented and a roundtable discussion held to solicit additional input.

A borehole metadata form has been developed and was distributed internationally in late 1999. Aproximately 75 additional candidate sites were identified including some in Mongolia, several regions in Russia, the Canadian High Arctic and Antarctica. It is expected that other sites will be nominated in the near future. Site selection criteria are being finalized. Protocols for borehole temperature data collection and submission are being developed, as well as the procedures for data dissemination and accessibility.

The Canadian GCOS Permafrost Monitoring Network Workshop provided an important opportunity to discuss network requirement issues with a large national segment of the permafrost community. Several recommendations were identified at the workshop for the successful establishment and operation of a national network contributing to the development of GTNet-P including establishment of instrumentation protocols and data submission and dissemination. The recommendations are summarized in a workshop report to be released on the GSC's permafrost web page.

Most countries with permafrost currently lack a central agency with the clear mandate and necessary resources to organize, co-ordinate, and operate a national network. In fact, appropriate ministries in many countries with permafrost are unaware of the existence of the GTNet-P or of the importance of permafrost data for GCOS's mission. Thus there is a lack of resources for implementation, management, and continuing operation of national networks. Most existing efforts have been largely ad hoc. In addition, many existing boreholes are in remote and often inaccessible locations; hence, there are logistical and financial difficulties reaching sites on a regular basis. Observation deficiencies are most prominent in five countries, Russia, Mongolia, Kazakhstan, China, and Argentina. Regional gaps also exist elsewhere such as central Arctic and sub-Arctic Canada. Additional boreholes are required to ensure adequate coverage for a global observation network, but new holes are expensive to drill. At least 20 new holes are required initially in under-represented regions. The Secretary-General of the WMO will be sending letters to Foreign Ministries of countries with permafrost (or countries involved in permafrost monitoring) to request their commitment and continued support for GTNet-P–GCOS activities.

An international workshop will be held by the International Arctic Research Centre and the Geophysical Institute, University of Alaska Fairbanks, in June 2000 to focus on permafrost monitoring and data management with emphasis on Russia and Asian countries, as well as on finalizing measurement and reporting standards. The prerequisite for attendance will be metadata submissions and data preparation for selected sites. Some metadata for sites in these regions are currently available on the CAPS CD-ROM (International Permafrost Association, 1998).

The GSC currently supports the international data management for the GTNet-P borehole temperature monitoring program. A GTNet-P web page is under development on the GSC's Permafrost web site and the list of candidate boreholes has been posted (http://sts.gsc.nrcan.gc.ca/permafrost/gtn-p.htm). Metadata forms for the submission of new borehole sites are also available. Metadata for network sites will ultimately be accessible as well as regularly submitted data and protocols.

A major problem, especially in Russia, is that a substantial amount of useful historical data already exist, but these data are dispersed, generally not in a digital format compatible with current data management systems, and often have not been subjected to quality control procedures. To ensure that valuable records are not lost, these data need to be located, processed and archived in an accessible form. Resources are thus required for data rescue as well as data management. In Canada select data rescue efforts and web enabling of national databases have been initiated through support from the federal government's Climate Change Action Fund. GTNet-P data will be subsequently archived through the National Snow and Ice Data Centre, Boulder, Colorado, as part of the IPA's Global Geocryological database (International Permafrost Association, 1998) and the World Data Centre A for Glaciology.

FUTURE PLANS FOR THE BOREHOLE NETWORK

The next step is to formally select sites for the network. This will be done through evaluation of metadata for nominated sites and will begin at the June 2000 Alaskan workshop. Following site selection and protocol development, available data will be submitted. The metadata will be officially released as a GSC Open File. Summary data will also be provided on the GTNet-P web site. Data will be submitted annually (less frequently for deeper measurements) and annual summaries will be posted on the web site. A summary report on regional permafrost thermal conditions and recent changes for western arctic North America will be produced first. The Canadian portion will be incorporated into the permafrost component of the State of the Cryosphere report and web site, supported by CRYSYS (use of the **Cry**ospheric **Sys**tem to Monitor Global Change in Canada) and the Climate Change Action Fund. A five year summary report organized by regional editors is envisaged with the draft to be presented in 2003 at the Eighth International Permafrost Conference in Switzerland.

ACKNOWLEDGMENTS

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Relevant web sites:

GTNet-P: http://sts.gsc.nrcan.gc.ca/permafrost/gtn-p.htm
CALM:
http://www.geography.uc.edu/~kenhinke/CALM/index.html
IPA: http://www.geodata.soton.ac.uk/ipa/
PACE: http://www.cf.ac.uk/uwcc/earth/pace/
GSC - Permafrost: http://sts.gsc.nrcan.gc.ca/permafrost/