The Circumpolar Active Layer Monitoring (CALM) Program: Data Collection, Management, and Dissemination Strategies

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Abstract

The Circumpolar Active Layer Monitoring (CALM) program, established in the early 1990s, was designed to observe temporal and spatial variability of the active layer, near-surface permafrost parameters, and their response to changes and variations in climatic conditions. CALM is the world's primary source of information about the active layer. Auxiliary information includes air temperature, soil moisture, soil temperature at different depth, snow cover, soil composition, and landscape characterization and frost heave and thaw subsidence. Metadata include detailed site descriptions and photographs for each site. Several groups of sites have been used to create regional maps of active-layer thickness. CALM data are distributed through the program's website (www.udel.edu/Geography/calm), and are also archived in and distributed through the Frozen Ground Data Center at the University of Colorado. This paper provides details about the nature, availability, and uses of data from the CALM network
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Keywords: Active layer; Data analysis; Data archive; Polar regions; Permafrost; Sampling design

Introduction

The Circumpolar Active Layer Monitoring (CALM) program is a network of sites at which data about active-layer thickness (ALT) and dynamics are collected. CALM was established in the 1990s to observe and detect the long-term response of the active layer and near-surface permafrost to changes in climate. CALM is among the international permafrost community's first large-scale efforts to construct a coordinated monitoring program capable of producing data sets suitable for evaluating the effects of climate change. Together with the IPA's Thermal State of Permafrost program, CALM comprises GTN-P, the Global Terrestrial Network for Permafrost. The CALM network's history and organizational structure are reported in Brown et al. (2000) and Nelson et al. (2004).

CALM is currently administered through the University of Delaware (UDel) Department of Geography. Analysis, archiving, and distribution of CALM's long-term observations are integral components of the project. Collected measurements are provided by participants to the CALM office at UDel, where they are subsequently incorporated into several databases. The data are distributed through the program's website, and through data products produced by the Frozen Ground Data Center at the University of Colorado. This paper provides details about the nature, availability, and uses of data from the CALM network. Scientific results are presented regularly at national and international meetings, and have been published widely in international scientific journals and symposia proceedings. Several edited volumes focused on the CALM program have been published to date (Brown et al., 2000; Nelson ed.; 2004a, 2004b). Several paper focused on CALM appear elsewhere in these proceedings.

Distribution of Sites

The distribution of CALM observational sites in the Northern Hemisphere is shown in Figure 1. The CALM network incorporates sites in Arctic, sub-Arctic, Antarctic, and mountainous regions. Several sites constitute longitudinal and latitudinal transects across northwestern North America, Europe and the Nordic region, and northeastern and northwestern Russia. Sites in Europe, China, Mongolia, and Kazakhstan provide high-elevation locations. About 70% of the sites are located in Arctic and Subarctic lowlands underlain by continuous permafrost. Discontinuous and mountainous permafrost areas contain respectively 20% and 11% of sites. The distribution of sites is not uniform, a circumstance attributable to historical circumstances and logistical constraints. The sites were established in regions of extensive economic activity and/or in areas of long-term climatic, permafrost, and ecosystem research. This logistically driven approach to site selection was adopted to insure regularity and periodicity of measurements. Assessment of the representativeness of the CALM network with respect to climatic and environmental conditions is currently in progress, and initial results were reported by Anisimov et al. (2007).

Monitoring Procedures

Three methods are used to determine the thickness of the active layer: 1) Mechanical probing using a graduated metal rod; 2) temperature measurements; 3) frost/thaw tubes.

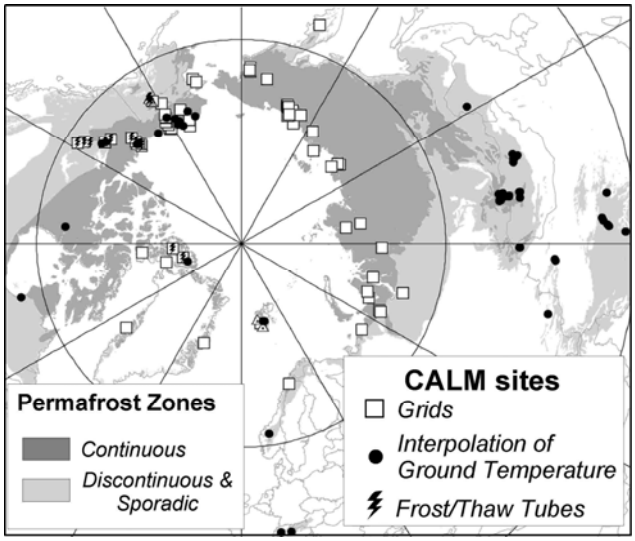

Figure 1. Permafrost distribution and location of CALM sites in the Northern Hemisphere. Sites are grouped according to active-layer monitoring methods.

The method-specific measurement procedure adopted by the CALM program is described in detail at the CALM web site (www.udel.edu/Geography/calm) and by Brown et al., (2000). At 86 of the sites, the active layer is measured by mechanical probing on regular grids of sampling points ranging from 10×10 m to 1000×1000 m. The time of probing varies from mid-August to the end of September, i.e., when thaw depth is at or near the maximum. More frequent measurements are made at some sites and in some years. The gridded sampling design allows for analysis of intra- and inter-site spatial variability and yields information useful for examining interrelations between physical and biological parameters. Grids are established at undisturbed locations, characteristic of dominant environmental conditions. Their size varies depending on site geometry, and the level of natural variability of surface and subsurface conditions. In general, 10×10 m to 100×100m size grids are established within relatively homogeneous landscape units. Several sites contain a number of grids representing various landscape units within the area. The 100×100 m to 1000× 1000 m grids usually encompass several characteristic landscapes within the area. CALM adopts a systematic sampling scheme for thaw depth measurements on most grids. The effectiveness of this sampling strategy has been investigated extensively and compared with alternative designs (Nelson et al., 1999). The systematic sampling design involves annual replicate measurement at regularly spaced grid nodes. With a few exceptions, each 10, 100, and 1000 m -side grid contains 121 nodes distributed evenly at 1, 10, and 100 m spacing respectively. At some grid nodes thaw depth measurements are not possible due to deep water, roads, or gravel pads. These missing data points are not reported.

At 87 of the sites, active-layer thickness is determined exclusively by interpretation of ground temperature measurements, obtained by an array of thermistors distributed vertically from the ground surface downward into the permafrost (Romanovsky and Osterkamp 1997, Romanovsky et al. 2003). This method is primarily used in mountain regions and areas with deep (>1.5 m) annual thaw propagation, where spatially oriented measurements by probing are impossible. The depth and spacing of thermistor installation depends on local conditions and the needs of individual research projects.

Liquid- or sand-filled thaw tubes (Nixon and Taylor 1998; Nixon, 2000) are employed in 11 Canadian and 3 Alaska sites. When read periodically, frost tubes provide information about seasonal progression of thaw and maximum seasonal thaw. However, as with temperature measurements, thaw tubes do not provide the information on local variability. Individual thaw tube measurements are highly dependent on location of installation. To address this deficiency, thaw tube measurements are complemented by grid sampling of the active layer.

Data Availability

One of CALM's primary objectives is to develop coherent, quality-controlled datasets of long-term observations on the active layer and upper permafrost, suitable for assessing changes in polar terrestrial ecosystems. At present, the CALM database consists of annual submissions from 168 sites, and includes ALT, soil temperature and moisture (where available), and heave/subsidence data (where available). The majority of available data are distributed through the CALM website maintained by the University of Delaware's Department of Geography. (www.udel.edu/Geography/calm). The web-based summary table contains average ALT at all stations for all years, and is linked to metadata and individual data sets. The following subsections provide a brief inventory of available data for specific geographic regions.

Alaska

At 30 out of 41 CALM-designated sites in Alaska periodic active layer observations are conducted on regular grids ranging from 10 m to 1000 m on a side. Geographically, grids are arranged in three north-south transects: (1) Fairbanks to the Beaufort Sea, along the Trans-Alaska Pipeline; (2) Ivotuk to Barrow (Chukchi Sea), and (3) Council and Kougarok, across the Seward Peninsula. These latitudinal transects, positioned from the Bering Sea eastward, encompass areas of steadily increasing continentality from west to east. For 25 of the grids, 10 or more years of consecutive active-layer data are available. These include seven sites with 1 km^2 grids (Hinkel and Nelson, 2003; Streletskiy et al. 2008), 15 1 ha grids, and three transects with thaw tubes. Two 1 km^2 grids in the Seward Peninsula (Council and Kougarok) and one near Ivotuk have data records dating to 1999. The 1 ha grid at Farmers Loop, north of Fairbanks was added to the network in 2005. Pre-1990 data are available for a series of 20 10×10 m Cold Region Research and Engineering Laboratory (CREEL) plots near Barrow (1962-1970, and 1991-2007) and two sites in interior Alaska (Perl Creek, 1969-2007, and Wickersham Dome, 1975-2007).

All grids have data loggers for monitoring air and soil temperatures at various depths. Several sites have installations for continuous monitoring of soil moisture. Detailed spatial characterization of topography and surface and subsurface conditions are available for each spatially heterogeneous 1 km^2 grid. These include DEMs, vegetation, soil, and landform characterization, and organic layer thickness. Annual spatial snow surveys have been conducted at the Barrow 1 km^2 grid, beginning in 1995. In 2000, spatially oriented monitoring of frost heave and thaw subsidence using Differential Global Positioning System (DGPS) was initiated at three sites representing broad landscape units, characteristic of the North Slope of Alaska (Little et al., 2003).

An additional eleven U.S. Geological Survey sites have been established near deep boreholes. At these sites active-layer thickness is determined by interpolation of ground temperature measurements. Data from these sites are currently being processed.

Canada

Of the 21 active CALM-designated sites in Canada, 15 are located along the latitudinal transect situated in the Mackenzie River Valley and operated by Federal government agencies: Geological Survey of Canada (Nixon et al. 2003) and Agriculture and Agri-Food Canada (Tarnocai 1995; Tarnocai et al. 2004). Several additional long-term, active-layer monitoring programs include CALM sites on the Arctic Islands (four sites), and two sites in the Hudson Bay region (Allard et al., 1995; Smith et al., 2001). The spatial active-layer observations on grids are conducted at 12 1 ha and one 1 km^2 grids. The most comprehensive data sets are available for eight 1 ha grids in the Mackenzie River Valley. The data include 10 or more years of active layer observations on grids and thaw tubes, spatial characterization of subsurface conditions (organic layer thickness, organic composition, mineral strata), and several annual snow surveys.

Nordic Region

The seven Nordic CALM sites are located in several areas surrounding the North Atlantic: two 1 ha grids in northeast Greenland at Zackenberg; one 1 ha grid in west Greenland on Disko Island (Christiansen 2004); 1 ha grid on the west coast of Svalbard at Kapp Linne (Akerman 1980); four transects constitute two sites at Calypostranda, Svalbard (Repelewska-Pekalowa & Pekalowa 2004); and an alpine-subarctic 1 ha grid in the vicinity of Abisko, northern Sweden. With the exception of Disko and one of the Calypostranda sites, the active layer record for the Nordic region grids is available for 10 or more years. The record for the Abisko site extends back to 1972 and includes thickness of active layer in different landscapes, mean monthly air temperature, and degree days of thawing. The Zackenberg database includes weekly active layer observations for the 1996-2006 thawing periods and snow thickness surveys for selected years.

Russia

Of the 41 CALM sites in Russia, 31 have continuous periodic active layer monitoring. The remaining 10 were either discontinued or are visited only sporadically. All Russian sites have grids ranging from 100 m^2 to 1 km^2. Several sites have supplemental transects that pre-date the establishment of CALM. The Russian CALM network extends from the European tundra of the Pechora and Vorkuta regions to West Siberia and the Lena Delta, eastward to the lower Kolyma River, and to Chukotka and Kamchatka. Most of these sites are within the continuous permafrost zone.

European North: Three 1 ha grids are located in the discontinuous permafrost region of the European tundra; Ayach-Yakha and Talnik near Vorkuta and Bolvansky in the Pechora lowlands (Mazhitova et al. 2004). Each site has 7 to 11 years of continuous active-layer record. The auxiliary data include detailed soil and vegetation characterization, soil temperature and soil moisture records. Since 1999, periodic, spatially oriented frost heave and ground subsidence measurements using optical leveling are conducted at the Ayach-Yakha site.

West Siberia: Eight active CALM sites are located in West Siberia. The core of the data sets consist of observations from two 1 ha grids at Mare Sale and Vaskiny Dachi in the continuous permafrost zone and 1km^2 Nadym grid in the discontinuous zone (Vasiliev et al., 2008). The active layer observations for Mare Sale are available since 1978, and for Nadym since 1972. The active layer record at the Vaskiny Dachi site dates to 1991. Pre-CALM (1993) observations were performed at the environmentally homogeneous 10 × 10 m plots, and along several transects incorporating the dominant landscape units. Each site has continuous soil temperature records of variable length and detailed spatial landscape, soil, and vegetation characterizations. An additional 1 ha site was established in the continuous permafrost zone in 2005 (Zepalov et al., 2008). During the summer of 2007 four grids were established in the discontinuous permafrost zone in landscapes inadequately represented by the Nadym grid. At present, these sites are in the process of being characterized and instrumented.

Central Siberia: In association with the GEWEX Asian Monsoon Experiment (GAME) program in the Siberian Arctic, a 1 km^2 CALM grid was established in 1997 near Tiksi, on the Lena River (Watanabe et al. 2003). The site-specific data base is available in the GAME Siberia website (http://www.hyarc.nagoya-u.ac.jp/game/siberia/index.html). Thaw depth measurements are also available for two 1 ha grids representing different landscapes of the Lena delta since 2004.

Lower Kolyma River: Beginning in 1996, a series of 15 1 ha grids spanning a distance of approximately 300 km was established to represent characteristic climatic and environmental conditions in the Kolyma-Indigirka lowlands on the northeast Eurasian tundra (Fyodorov-Davydov et al. 2004). At present, 11 sites are reporting data. Annual active-layer and soil temperature observations are carried out at the five most accessible sites situated in close proximity to the North-East Scientific Station in Cherskyi in the transitional

zone between taiga and tundra. Logistical problems led to some interruptions in observations at the remaining six sites. All sites have detailed descriptions of surface and subsurface conditions.

Chukotka and Kamchatka Peninsulas: Beginning in 1996, a Mt. Dionisy site was established on the Chukotka Peninsula. A new site was initiated at Lavrentia along the Chukchi Sea coast in 2000 (Zamalodchikov et al., 2004). Both sites consist of 1 ha grids. Annual soil moisture observations and detailed soil characterizations are available for Lavrentia site. Active layer records are also available for two 1 ha grids on Kamchatka since 2003.

Mongolia

The Mongolian network consists of a series of instrumented boreholes located in the arid land permafrost at the southern fringe of the Siberian permafrost zones. An original network of 12 sites (Sharkuu 2003) was expanded to 37 sites during the last 2–5 years. The majority of the new sites are located in the Hovsgol region. Seventeen boreholes were drilled, with depths ranging from 5 to 80 m and two deep boreholes from mid-1980s were instrumented for permafrost and active layer monitoring. An additional eight sites were instrumented for shallow ground temperature monitoring (Sharkhuu et.al., 2007). All sites report ground temperature and active layer thickness determined by interpolation of ground temperature profiles, obtained in late September and early October.

Mountain Permafrost Regions

Permafrost occurs in all mountainous regions of the high latitudes and is widespread at higher elevations in mid latitude mountain ranges, including the Qinghai-Tibet Plateau. The mountain permafrost is represented in the CALM data base by one site in Norway, one site in Svalbard (Isaksen et al., 2007), two sites in Switzerland (Harris et al. 2001), two sites in Kazakhstan (Marchenko et al., 2007) and six sites on Qinghai-Tibet Plateau, China (King et al., 2006). All sites consist of boreholes of variable depth. With the exception of Kazakhstan sites, only interpolated active layer values are reported annually.

Southern Hemisphere

The Antarctic Permafrost and Soils (ANTPAS) program (Parsons et al., 2008) incorporates several sites known collectively as CALM-South (CALM-S). Periodic ground temperature monitoring at depths to 2.4 m is conducted at three sites in South Victoria Land, Antarctica and at two others on Livingston Island/South Shetland Islands (Hauck et al., 2007). Data are reported as interpolated maximum annual thaw depth. Detailed site descriptions are available at the ANTPAS website (http://erth.waikato.ac.nz/antpas/). Plans to expand ANTPAS /CALM-S by developing 12 to 15 sites distributed across environmental gradients from the Andes to the sub-Antarctic islands and through the Antarctic Peninsula and Transantarctic Mountains to the McMurdo Dry Valleys are currently under development (Bockheim, 2005).

Regional Active-Layer Characterization

Several regions with large assemblages of sites and representative of high-latitude climatic/landscape gradients are suitable for spatial data integration. Examples are the North West Siberia region (Yamal-Gydan Peninsulas), the Lower Kolyma River, north-central Alaska, and the Mackenzie River region (Canada). Each of these regions has been the subject of extensive geocryological research and contains information sufficient to facilitate regional-scale mapping.

At present, the CALM database contains two regional (broad-scale) active-layer maps compiled from data sampled from multiple sites. The first is a 14-year series of maps (1 km^2 resolution) of depicting annual active layer thickness and the probability of the active layer exceeding certain thresholds for the 27,000 km^2 Kuparuk Region in north-central Alaska (Shiklomanov and Nelson, 2002; Anisimov et al., 2002). The second regional compilation is a detailed digital landscape and active-layer map of northern West Siberia. The map was compiled in cooperation with the Earth Cryosphere Institute (Russia) and depicts a hierarchy of landscapes units, organic layer thickness, lithology, and the landscape-specific characteristic values of active-layer thickness. At present, the map is being refined and extended.

Several other regional maps are under construction, including an active-layer map for the Kolyma-Indigirka lowlands of Russia, a map of the North Atlantic region, and a map of the Barrow Peninsula on Alaska's North Slope.

Data Use for Models

Active-layer observations and auxiliary information from the CALM network provide an extensive circumpolar database, which has been used extensively to validate process-based geocryological (e.g., Oelke and Zhang, 2003; Shiklomanov et al., 2007) and hydrological (Rawlins et al., 2003) models. Obviously, data obtained from individual observational CALM sites should be used with caution for evaluating model-produced gridded fields, owing to possible discrepancies between the size of observation plots and those of model grid cells. It is well known that active-layer thickness and other near-surface permafrost parameters can be highly variable in time and space (e.g., Nelson et al., 1998, Shiklomanov and Nelson, 2002). Observational locations may not represent generalized conditions prescribed for the model's grid cells. The use of individual CALM grids or groups of grids representing the diversity of environmental conditions in particular regions can compensate somewhat for such deficiencies. The development and implementation of regional scaling approaches addresses the problem of discordance in resolution between empirical and simulation studies further, and facilitates development of procedures for assimilating geocryological data and modeling results. Shiklomanov et al. (2007) provided an example of a hierarchical approach for evaluating spatial permafrost models. The methodology incorporates empirical data from point locations and observational plots provided through the CALM

observational networks, provides regional characterization of permafrost conditions and can be extended with continental- and circumpolar-scale models.

Conclusion

CALM is the oldest and most comprehensive permafrost-oriented international global-change monitoring program, and has achieved considerable success in this role. Although the CALM network continues to grow in terms of the number of participating sites and the quantity and quality of observations, two outstanding data issues remain to be resolved. 1) Continuation of periodic measurements: This problem relates to difficulties associated with unattended operation of scientific equipment at remote locations and periodic accessibility of sites. For example, approximately one-fourth of Russian sites were discontinued during the last five years due to substantial increases in logistical costs. A large number of sites have suffered from equipment malfunction and vandalism. 2) The methodology of simple sharing of basic data, adopted by CALM in the late 1990s, does not entirely satisfy the growing needs of the increasingly international and interdisciplinary scientific community and general public. Newly developed web-based database and mapping applications provide more advanced and user-friendly vehicles for presenting and sharing geographically referenced information. The first step toward enhancing CALM's archival and dissemination strategies will be to prepare data for the upcoming Circumpolar Active-layer Permafrost System (CAPS) Version 3 database compilation developed by the Frozen Ground Data Center and Standing Committee for Data Information and Communication within the IPA (Parsons et al., 2008).

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