The Circumpolar Active Layer Monitoring (CALM III) Network

Long-Term Observations on the Climate-Active Layer-Permafrost System

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INTRODUCTION

Widespread and systematic changes in the thickness of the active layer (the seasonally thawed layer of ground above permafrost), if accompanied by penetration of thaw into the upper layers of ice-rich permafrost, could have profound effects on the flux of greenhouse gases, on human infrastructure in cold regions, and on landscape processes. It is therefore critical that observational and analytical procedures be conducted over extended periods to assess trends and detect cumulative changes in active-layer dynamics over long periods. Establishment of long-term time series of thaw measurements at fixed locations and across diverse landscapes and regions are required to identify scales of spatial variation, detect temporal trends, and validate models.

Northern Hemisphere sites in the CALM III program operate as part of the Arctic Observing Network (AON) supported by NSF. CALM III is integrated closely with the TSP ("Thermal State of Permafrost") program, and considerable emphasis is being placed on making borehole and active-layer observations in close proximity.

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 International Permafrost Association's Thermal State of Permafrost program, CALM comprises GTN-P, the Global Terrestrial Network for Permafrost. CALM is currently administered through the Geography Departments of George Washington University and the University of Delaware. Data are distributed through the AON's data program, through CALM's web site, and through data products produced by the Frozen Ground Data Center at the University of Colorado.

DISTRIBUTION OF ARCTIC SITES

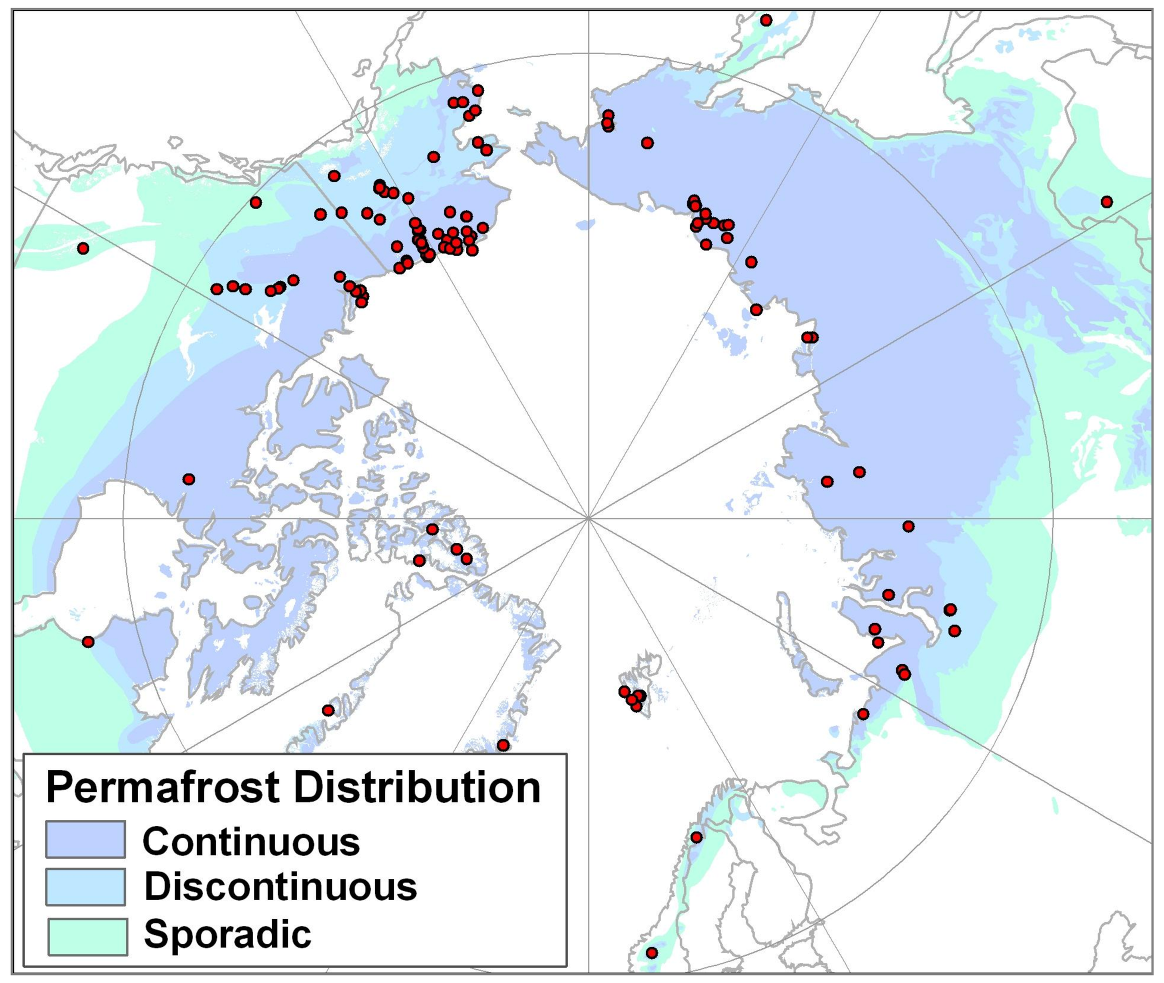


Figure 1. *Permafrost distribution and location of CALM sites in the Northern Hemisphere.*

The distribution of CALM observational sites in the Northern Hemisphere is shown in Figure 1. The CALM network incorporates 185 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.

MONITORING PROCEDURES

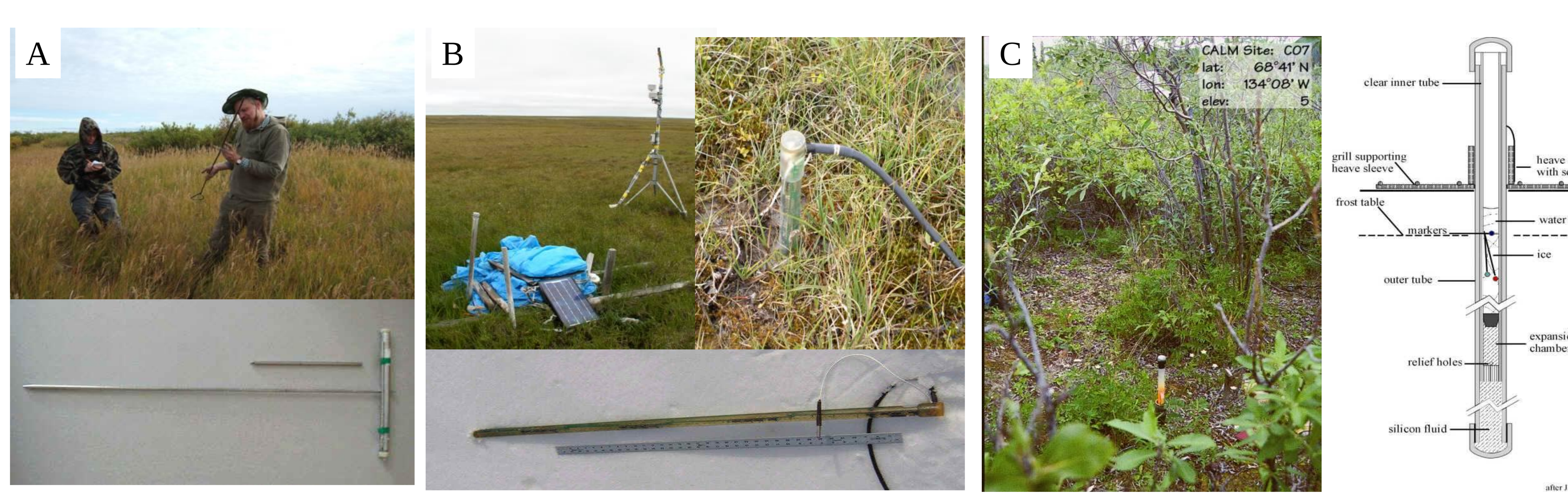
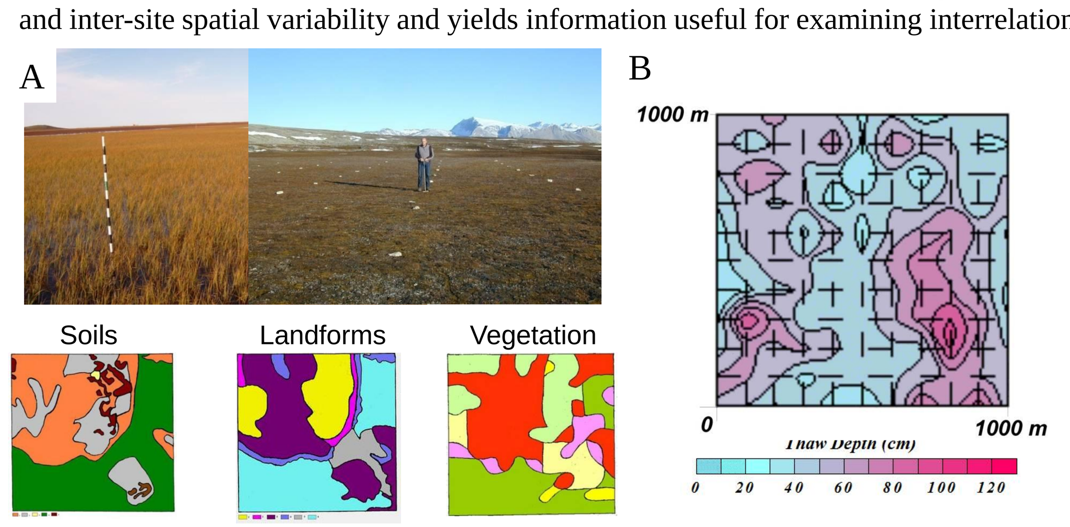


***Figure 2**. Three methods are used to determine the thickness of the active layer: A) Mechanical probing using a graduated metal rod; B) temperature measurements; C) frost/thaw tubes.*

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 (Figure 3). 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.



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.

Liquid- or sand-filled thaw tubes are employed at 11 Canadian and 3 Alaska sites.

Figure 3. *Examples of environmental attributes measured on CALM grids (A) and spatial scaling of active layer observations to local level (B)*

ACTIVE-LAYER THICKNESS TRENDS

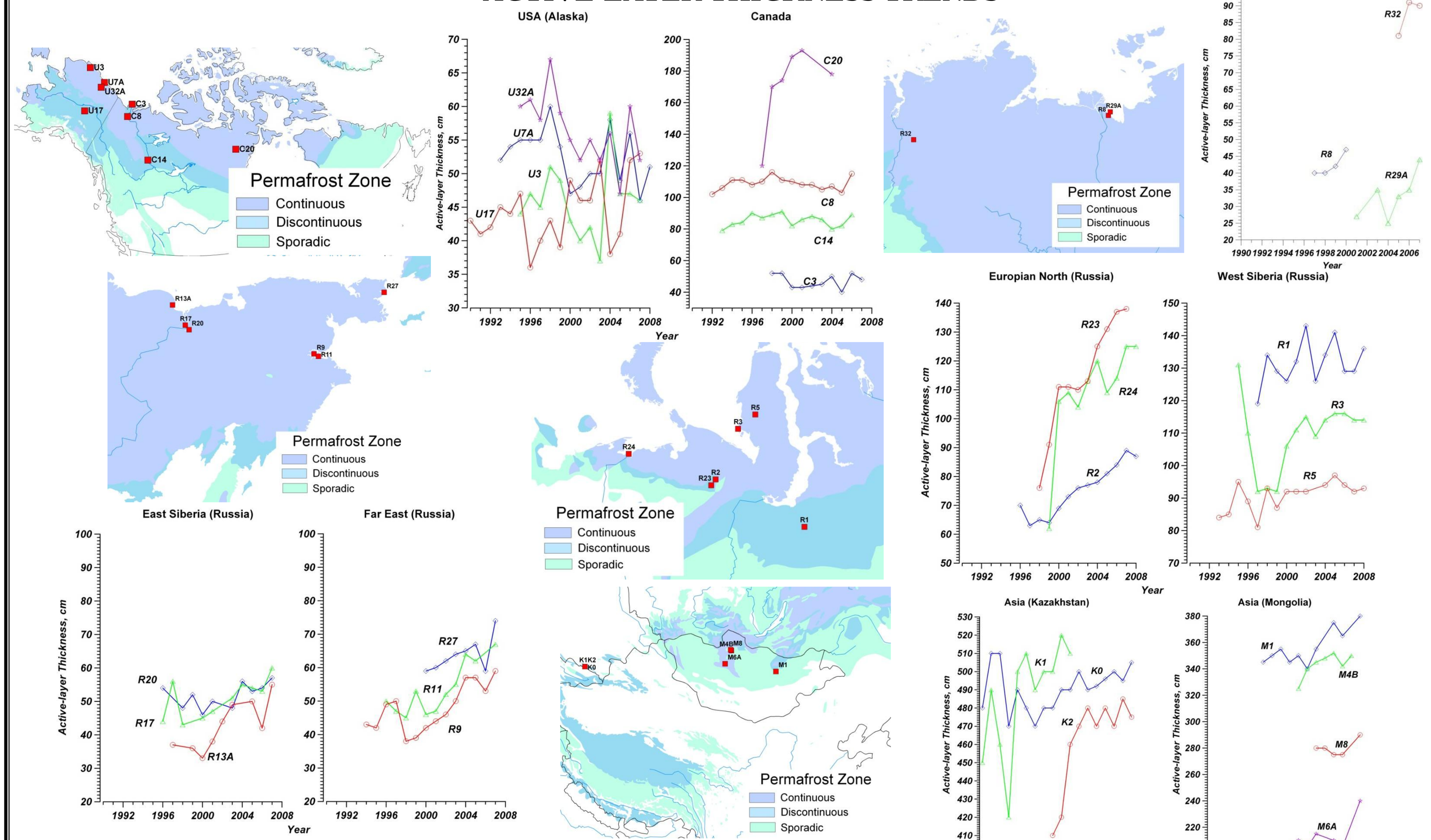


Figure 4. *Active-layer thickness trends for representative sites from several Arctic regions.*

REGIONAL ACTIVE-LAYER CHARACTERIZATION

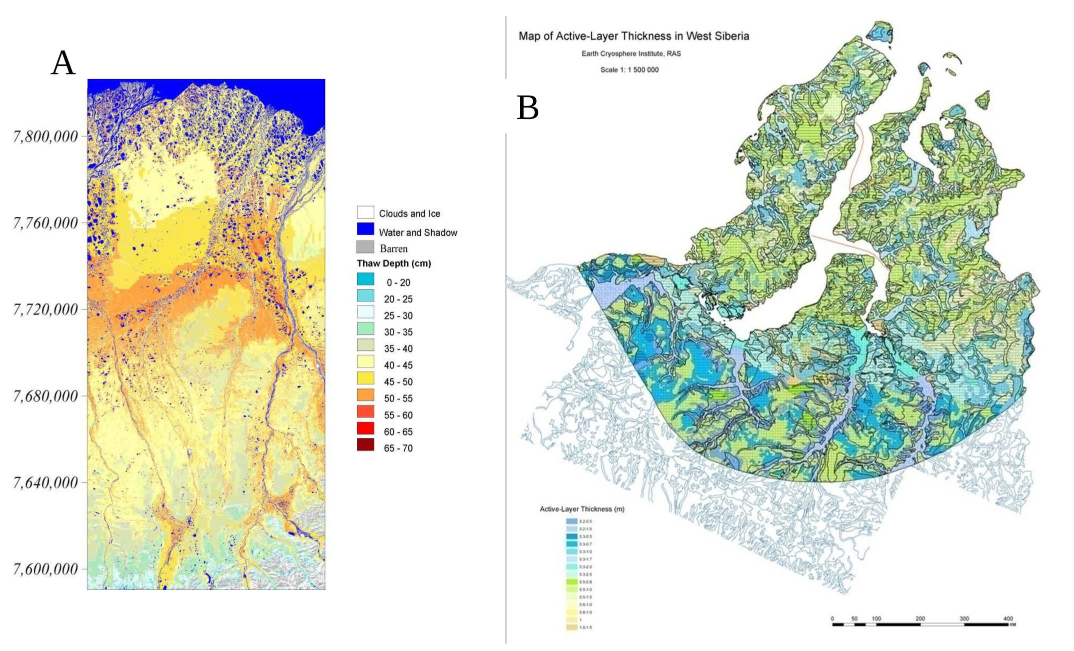


Figure 5. *Regional Active-Layer Characterization*

Several regions with large assemblages of sites and representative of high-latitude climatic/landscape gradients are suitable for spatial data integration. 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) depicting annual active layer thickness (***Figure 5 A***) and the probability of the active layer exceeding certain thresholds for the 27,000 km^2 Kuparuk Region in north-central Alaska. The second regional compilation is a detailed digital landscape and active-layer map of northern West Siberia (***Figure 5 B***) . 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.

Several other regional maps are under construction.

TRANSIENT LAYER

The transient layer serves as a buffer between the active layer and permafrost ***Figures 6 & 7***. Significant ice segregation can occur within this layer during "cold" years, due predominantly to freezing from below during the autumn and winter. During most "warm" years the ice-rich transient layer protects underlying permafrost from thawing, although extreme summers may reduce its vertical extent significantly. Incremental segregation or melting of ice within the transient layer can, however, result in substantial heave or subsidence at the surface over decadal time scales. The thickness of the transient layer plays a crucial role in evaluating the potential response of the active-layer/permafrost system to climatic change, and for development of thermokarst processes. ***Figure 8*** shows the long-term behavior of ALT at Barrow, Alaska, thought to be related to transient layer dynamics.

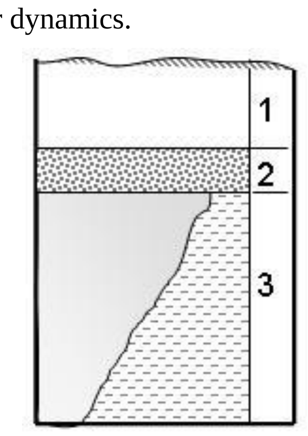


***Figure 6**. Schematic diagram of the three-layer model. (1): Active layer (seasonal freezing and thawing); (2) Transient layer with high- and quasi-uniform ice content and freezing/thawing at decadal to century scales; (3) Long-term permafrost (freezing and thawing at century to millennial scales), with spatially irregular ice content (e.g., ice wedges).*

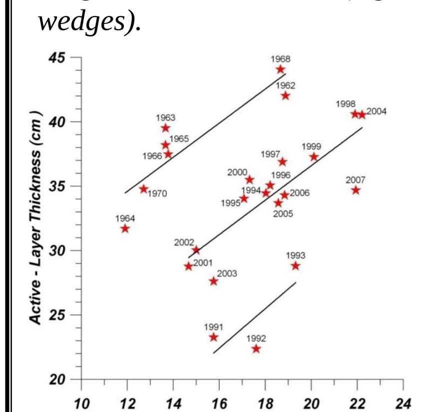


***Figure 8**. Plot of thawing degree-day accumulation vs. active-layer thickness in Barrow, AK during the periods 1962 and 1991-2007. "Best-fit" lines were computed separately for 1960s early 1990s, and subsequent years. A shift in the position of the upper surface of the transient layer is thought to be responsible for the large difference in thawing regimes between the periods.*

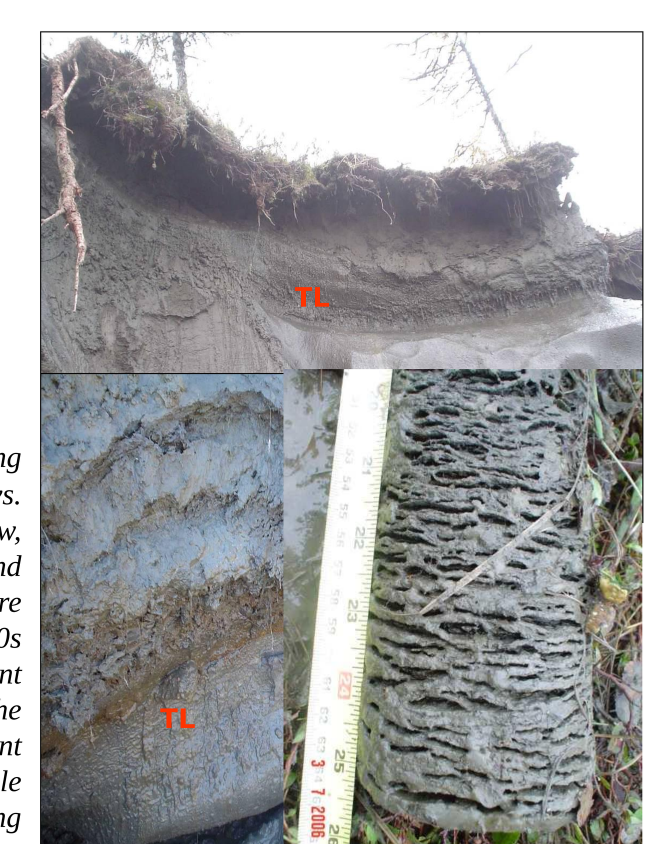


***Figure 7.** The transient layer is characterized by very ice-rich cryogenic textures. Volumetric moisture content observations, conducted at several Russian sites, indicate that the mean moisture content is 25% for the active layer and 55% for the transient layer .*

Field investigations involve using differential GPS ***(Figure 9)*** and traditional surveying to track interannual vertical movements associated with formation and ablation of ice near the permafrost table, and to investigate the relation between frost heave, thaw settlement, and active-layer thickness.

Figure 9. *The position of the ground surface is monitored seasonally at the sites supported under CALM project. DGPS is used at the Alaskan sites in early June and late August to track both frost heave and thaw settlement.*

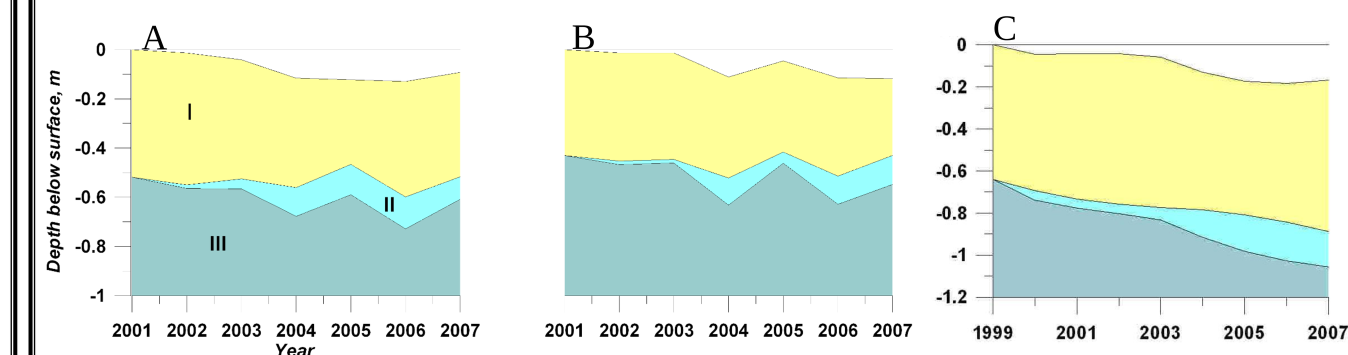


***Figure 10**. Annual changes in position of ground surface and ALT as measured by mechanical for representative of Alaska coastal plain (a), Alaska foothills (b) and European Russia (c) CALM sites. I- ALT measured by probing; II- ALT, corrected for ground subsidence; III-permafrost.*

The observed increase in active-layer thickness at East Siberian sites results in progressive degradation of the ice-rich transient layer. At several sites, the transient layer has degraded completely, causing thawing of deeper, perennially frozen layers. To obtain a preliminary estimate of the release of water from the thawing of upper permafrost, the difference in volumetric water content between the active and underlying transitional layers was considered. The 30% difference translates to a 3 mm-thick layer of water for each cm of thawed soil (***Figure 11***). The contribution of this flux to the total runoff, estimated by percentage of summer precipitation, can reach 20% during dry and warm summers (***Figure 12***).

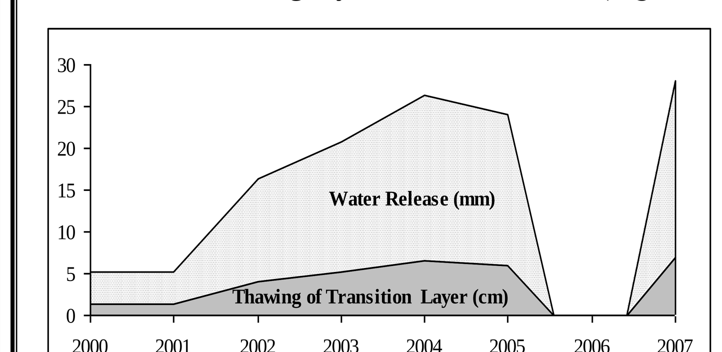


***Figure 11**. The relationship between thawing of the transient (transition) layer and water release from melting of ground ice.*

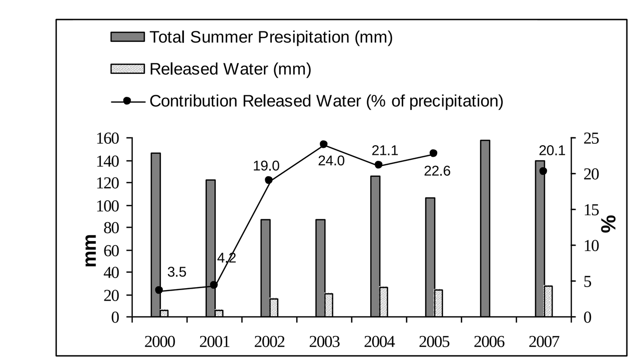
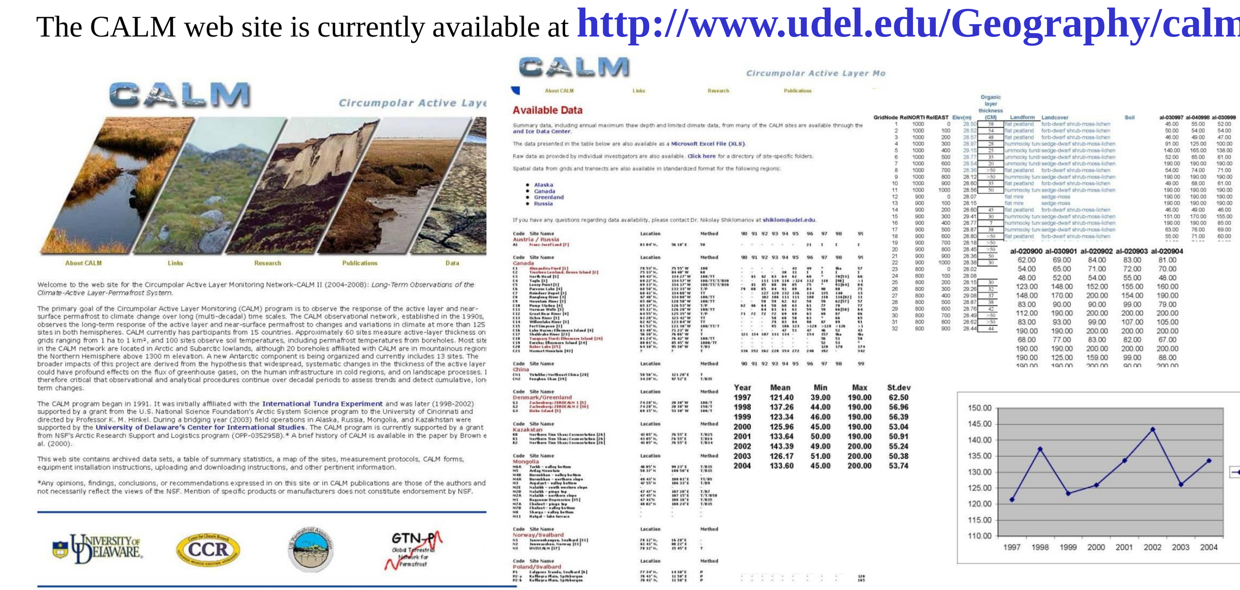


***Figure 11**. The contribution of the total annual water flux from the degrading transition layer, estimated by percentage of summer precipitation.*

CALM WEB SITE

The CALM web site is currently available at **http://www.udel.edu/Geography/calm/**



COLLABORATION

CALM is, in the first instance, a global-change program. Its change-detection function remains a critically important part of its mission. As part of this charge, the program is also concerned with differentiating between the impacts of long-term climate change and more localized anthropogenic effects.

CALM III continues existing partnerships and collaborations with other international organizations and programs, including GCOS/GTOS, CEON, CliC, ITEX, ICARP, IASC, and the ongoing IUGS Year of Planet Earth project. CALM made significant contributions to *International Polar Year 2007-08* as part of an integrated suite of IPA programs known collectively as *INPO*, the International Network of Permafrost Observatories. CALM was identified as a model program with respect to data harmonization in the recent U.S. National Research Council report *Toward an Integrated Arctic Observing Network*.

Reflecting its open, community-based structure, CALM III holds annual meetings and round-table discussions in connection with several major scientific conferences. The second CALM Workshop was held in Alaska during June 2008, immediately preceding the Ninth International Conference on Permafrost in Fairbanks.

ACKNOWLEDGMENTS

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