Cryosphere

C11A MCC: 3004 Monday 0800h

The Roles of Permafrost in Climate Change: Archive, Translator, and Facilitator I *(joint with A, B, H, PP, GC)*

Presiding: **F E Nelson,** University of Delaware**; P Camill,** Carleton College

C11A-01 0800h INVITED

European Mountain Permafrost: Recent Near Surface Thermal Responses

Charles Harris[1] (+44-29-2087-4336; harrisc@cardiff.ac.uk)

Ketil Isaksen[2] (+47-2296-3267; ketil.isaksen@mi.no)

Johan Ludvig Sollid[3] (j.l.sollid@geo.uio.no)

Daniel Vonder Mühll[4] (Daniel.VonderMuehll@UniBas.ch)

Stephan Gruber[5] (stgruber@geo.unizh.ch)

[1]Cardiff University, School of Earth, Ocean and Planetary Sciences, Cardiff CF10 3YE, United Kingdom

[2]Norwegian Meteorological Institute, P.O.Box 43 Blindern, Oslo N-0313, Norway

[3]University of Oslo, Department of Physical Geography, P.O. Box 1042, Blindern, Oslo N-0316, Norway

[4]University of Basel, Petersgraben 35/3, Basel CH-4051, Switzerland

[5]University of Zurich - Irchel, Department of Physical Geography, Winterthurerstrasse 190, Zurich CH-8057, Switzerland

Geothermal measurements from the European PACE borehole network are firstly briefly reviewed. The network comprises six permafrost boreholes extending to at least 100 m depth in bedrock and forming a latitudinal transect from the European Alps, through the Scandinavian mountains to Svalbard. Near surface thermal regimes are first described, and active layer depths are shown to increase significantly with decreasing latitude. All boreholes show non-linear thermal profiles with near-surface warm-side temperature deviations from the deeper thermal gradient. First approximation estimates, based on curvature within the borehole thermal profiles, indicate a maximum ground surface warming of +1°C in Svalbard, considered to relate to thermal changes in the last 100 yr. In mainland Scandinavia, surface warming decreases southwards, being +0.6°C at Tarfalaryggen, Sweden and +0.5°C at Juvasshöe, Norway. In the European Alps, the steeper topography and greater influence of aspect leads to greater variation in thermal profiles, with estimated warming ranging from +0.8°C to +0.5°C. However, three-dimensional thermal modeling is necessary, particularly in the steep Alpine terrain before these thermal profiles can be interpreted with more confidence. The northernmost PACE borehole is located at Janssonhaugen, Svalbard at an altitude of 270 m a.s.l.. Morphologically the site is a sandstone bedrock remnant in a broad valley. Precipitation is low and wind action prevents significant snow accumulation. Data since 1999 indicate rapid warming at this arctic location apparently related to atmospheric temperatures. In most of the remaining boreholes, temperatures are strongly influenced by winter snow cover. However, the thermal response of Alpine boreholes to high summer temperatures in 2003 is reported and potential environmental impacts of such extreme events briefly discussed.

C11A-02 0815h

Permafrost: An International Approach to 21th Century Challenges

Jerry Brown (1-508-457-4982; jerrybrown@igc.org)

International Permafrost Association, P. O. Box 7, Woods Hole, MA 02543, United States

Whereas glaciers are easily discernible to the human eye and satellites, permafrost terrains and their physical components are not easily detected from the surface without supplemental knowledge and measurements. In the Northern Hemisphere, approximately 17 million km^2 of exposed land contains some extent of permafrost or ground that remains frozen for more than two years. The vast majority, or 11 million km^2, of permafrost terrain has temperatures of 5° C or below, with perennially frozen ground underlying essentially all ground surfaces to considerable depths. Permafrost in the remaining regions, including mid-latitude mountains, is both warmer and is spatially variable (discontinuous). As climate warms the uppermost permafrost is subjected to increase thaw with resulting ground subsidence, accelerated erosion, and related biogeochemical modifications. The challenging questions to geocryologists, modelers and the public relate to the rate of change and the spatial variability of the projected thaw, particularly in the warmer zones where actual areal and subareal distribution of permafrost is poorly known. An international network of active layer measurements and borehole sites now exists under the Global Climate Observing System (GCOS), but requires additional sites for representative coverage. This Global Terrestrial Network for Permafrost (GTN-P) is coordinated by the 24-member, International Permafrost Association. At the Eighth International Conference on Permafrost (ICOP) in Zurich in July 2003, the IPA Council agreed on the scope of new activities for the next five years, many of which will be undertaken in cooperation with other international organizations (e.g. WCRP/CliC; ICSI, IASC, SCAR, IGU, IUGS). Examples of the activities of the IPA Working Groups are:
1. Antarctic Permafrost and Periglacial Environments (active layer processes, maps, database).
2. Coastal and Offshore Permafrost (sediment and organic transfers, subsea permafrost dynamics).
3. Cryosol (Antarctic soil map, soil database).
4. Glacier and Permafrost Hazards in High Mountains (interaction of ice and permafrost on slopes).
5. Isotopes and Geochemistry of Permafrost (paleoreconstruction, modern processes).
6. Mapping and Modelling of Mountain Permafrost (standardize map legends and maps, multi-dimensional models).
7. Periglacial Processes and Environments (past and present processes, field manual of measurements).
8. Permafrost and Climate (monitoring, impact assessments, inter-comparisons of models).
9. Permafrost Astrobiology (survivability of life on planets and analogous Earth environments).
10. Permafrost Engineering (case studies, climate impacts on infrastructure).
The Data Committee facilitates recovery of data, web access, and CD data production. These activities will provide added insight into past, present and future occurrences and responses of permafrost to climate change. They can contribute to activities of the International Polar Year. Results will be reported at the Ninth ICOP in Fairbanks, Alaska, in summer 2008. Current information is available on the IPA web site and in annual issues of *Frozen Ground*.

C11A-03 0830h

Effects of Freeze/Thaw Index, Air Temperature, and Snow Cover on Seasonal Freeze and Thaw Depths in Russia

Oliver W. Frauenfeld[1] ((303) 735-0247; oliverf@kryos.colorado.edu)

Tingjun Zhang[1] (tzhang@nsidc.org)

Roger G. Barry[1] (rbarry@kryos.colorado.edu)

David Gilichinsky[2] (gilichin@issp.serpukhov.su)

Andrew J. Etringer[1] (etringer@nsidc.org)

[1]National Snow and Ice Data Center/CIRES, University of Colorado 449 UCB, Boulder, CO 80309-0449, United States

[2]Soil Cryology Laboratory, Institute of Physico-Chemical and Biological Problems in Soil Sciences, Russian Academy of Sciences, Pushchino 142290, Russian Federation

Seasonal freezing and thawing processes in cold regions play an exceedingly important role in ecosystem diversity, productivity, and the Arctic hydrological system in general. Long-term changes in seasonal freeze and thaw depths are also important indicators of climate change. Only sparse observational measurements of seasonal freeze and thaw depths are available in permafrost and seasonally frozen ground regions. However, soil temperature data are more readily and widely measured. Using mean monthly soil temperature data for 240 stations located throughout Russia for 1930--1990, we have devised an interpolation method that determines the depth of the 0°C isotherm based on soil temperature data measured at various depths between 0.2 m and 3.2 m. This methodology works remarkably well and we are subsequently able to work with a greatly improved sample size of stations. A comprehensive evaluation of these new data's long-term trends in Russia indicates that, in permafrost regions, active layer depths have been steadily increasing. In the period 1956-1990 the active layer exhibited a statistically significant deepening by 11 cm. The changes in seasonally frozen ground are even greater: the depth of the freezing layer has exhibited a statistically significant decrease, resulting in 33 cm less frozen ground in 1990 than in 1956. Exploring potential causes for these changes–freeze and thaw index, air temperature, and snow cover–we are able to assess potential forcings of the observed changes. Multiple regression reveals that freezing index, the combined duration and magnitude of below-freezing temperatures during the freezing season, has the greatest influence on the seasonal freeze depth. Similarly, mean annual air temperature is also significantly related to freeze depth, as is average snow depth. Analyses exploring causes for the observed changes in active layer depth show that measures of air temperature–the thaw index and mean annual air temperature–significantly influence the active layer, as does the previous winter's snow cover. In general these changes indicate that, as temperatures have been increasing globally in recent decades, permafrost is thawing to a greater depth during the warm season while less of the ground in non-permafrost regions is freezing during the cold season. The changes in active layer depth and seasonal freezing depth seem to be related to changes in air temperature as well as snow cover. Potential direct consequences of these trends are increased river runoff and changes in discharge throughout the Russian Arctic drainage basin.

C11A-04 0845h

Establishing Permafrost Temperature Data Reanalysis

Vladimir E Romanovsky[1] (1-907-474-7459; ffver@uaf.edu)

Tatiana S Sazonova[1] (1-907-474-5321; ftts1@uaf.edu)

Gennagy S Tipenko[1] (1-907-474-5321; ffgst@uaf.edu)

[1]Geophysical Institute UAF, 903 Koyukuk Dr POB 757320, Fairbanks, AK 99775, United States

Permafrost has received much attention recently because surface temperatures are rising in most permafrost areas of the earth, bringing permafrost to the edge of widespread thawing and degradation. The thawing of permafrost that already occurs at the southern limits of the permafrost zone can generate dramatic changes in ecosystems and in infrastructure performance. All observed and predicted changes in permafrost stress the necessity to monitor its dynamics (particularly its temperature) for timely assessment and predictions of the possible negative impacts of permafrost degradation on ecosystems and infrastructure. The effects of human-induced disturbances will also be enhanced with climate warming. Permafrost temperature data reanalysis should be included as a very important component in the recently developing within the Global Terrestrial Network for Permafrost (GTN-P) of GCOS/GTOS WMO system for comprehensive monitoring of permafrost temperatures. In this modeling method that was developed at the Permafrost Lab of the Geophysical Institute, University of Alaska Fairbanks, variations in the air temperature and snow cover thickness and properties are the driving forces of the permafrost temperature dynamics. The model is calibrated for a specific site using measured permafrost and active layer temperatures (usually several years of available data are used) and data from the closest meteorological station for the same time interval. The calibrated model can then be applied to the entire period of meteorological records at this station, producing a time series of permafrost temperature changes. The same calibrated model can be applied for predictions of the future permafrost dynamics when some future climate change scenario is used as input data. The historical permafrost data from the Barrow Permafrost Observatory provide a unique opportunity to independently test our model and modeling results. One of the best examples of such historical data set is the permafrost temperature data that were obtained during the 1950s and early 1960s by Max Brewer of USGS in Barrow region. Those measurements were of very high quality, with a precision of generally 0.01œC. A specific numerical model for the Barrow permafrost temperature regime was developed in 1997 at the GI Permafrost Lab. The model was calibrated using data from shallow (down to one meter) soil temperatures obtained by Ken Hinkel at a Barrow site with surface conditions similar to the Brewer site. No data from the Brewer sites were used for the calibration. The daily air temperatures and snow cover thickness during the entire period of measurements (1924-2001) at the Barrow meteorological station were used as input data for this calibrated model. As a result, a time series of daily ground temperatures for the depths between 0 and 200 meters were obtained. To compare calculated temperatures with measured data, we used the time interval between September 1951 and October 1952, when weekly measurements were available. The results of this comparison were much better than expected. For the entire period, which covers more than one year, the differences between calculated and measured permafrost temperatures were typically smaller than 0.3œC in the depth interval between 2 and 18 meters. They practically never exceeded 1œC in the upper two meters of soil and permafrost. The same approach of permafrost temperature data reanalysis was used for many other sites in Alaska and in the Russian Arctic and Sub-Arctic. The results of reconstruction of the permafrost temperature dynamics in 20th century and forecasts for the 21st century based on this approach for the Fairbanks, Barrow, Yakutsk, Tiksi, and Vorkuta sites will be presented.

C11A-05 0900h INVITED

Widespread Degradation of Ice Wedges on the Arctic Coastal Plain in Northern Alaska in Response to the Recent Warmer Climate

Yuri Shur[1] (1-907-474-7067; ffys@uaf.edu)

M. Torre Jorgenson[2] (1-907-455-6777; tjorgenson@abrinc.com)

Erik R. Pullman[2]

[1]Department of Civil and Environmental Engineering University of Alaska Fairbanks, PO Box 755900, Fairbanks, AK 99775

[2]ABR, Inc, P.O. Box 80410, Fairbanks, AK 99708

The continuous permafrost on the Arctic Coastal Plain in northern Alaska has been considered stable because permafrost temperatures remain low, even with an increase of several degrees during the last decades. Ice wedges, however, are particularly susceptible to degradation because only a very thin layer of permafrost (the transient layer) exists between the ice and the bottom of the active layer. An increase in the active layer during unusually warm periods causes the thawing front to encounter the underlying ice wedges and initiate degradation. Field observations and photogrammetric analysis of 1945, 1979, and 2001 aerial photography indicate that there has been widespread degradation of the ice wedges on the Arctic Coastal Plain west of the Colville Delta over the recent 57-year period, and indications are that most of the degradation occurred during the last two decades. Field sampling at 46 polygonal troughs and their intersections showed that ice wedge degradation has been relatively recent as indicated by newly drowned vegetation. We found thermokarst was widespread on a variety of terrain conditions, but most prevalent on, ice-rich centers of old drained lake basins and alluvial-marine terraces, which have the greatest ice wedge development in the studied landscape. Ice wedges on these terrains typically occupy from 10 to 20 % of the upper permafrost. We attributed the natural degradation to warm weather during the last decades, because disturbance of the ground surface, which could have similar impact on ice wedges, was not evident. While, ice-wedge degradation probably has been periodically occurring at low rates over the preceding centuries, it has greatly accelerated during the last several decades. We identified six stages of ice-wedge degradation and stabilization. They include: (1) the loss of transient layer of upper permafrost above ice wedges, leading to enhanced nutrient availability and vegetative growth; (2) thawing of ice wedges and surface settlement; (3) accumulation of water in degrading troughs and killing of vegetation; (4) increased thawing of ice wedges under flooded conditions, which is often accompanied by lateral thermal erosion of ice-rich soil along polygon margins; (5) initial establishment of aquatic mosses and sedges; and (6) stabilization of the ice wedges through robust vegetative growth, accumulation of organic matter, and reestablishment of permanently frozen soil. The maximum depth of thaw settlement at ice wedge intersections, where degradation is greatest, reaches about 1.5 m. During re-stabilization, clear congelation ice often forms above ice wedges and pseudomorphs may form as a cast in deeper thawed portions of the ice wedges. The degradation of ice wedges greatly affects ecosystem properties by changing the micro-relief, causing inundation of the settling surface, altering vegetation, and enhancing methane production under anaerobic conditions. It remains uncertain, however, whether ice-wedge degradation can lead to development of larger thermokarst lakes. Development of waterbodies larger that the thermokarst pits at wedge intersections was not evident and evidence indicates that the degraded ice wedges stabilize before the central parts of polygons are substantially degraded.

C11A-06 0915h

Hydrological Changes in the Arctic in Response to a Changing Climate

Larry D. Hinzman[1] (1-907-474-7331; ffldh@uaf.edu); Douglas L. Kane[1] (1-907-474-7808; ffdlk@uaf.edu); James P. McNamara[2] (1-208-426-1354; JMCNAMAR@boisestate.edu); Matt A. Nolan[1] (1-907-474-2467; fnman@uaf.edu); Vladimir E. Romanovsky[3] (1-907-474-7459; ffver@uaf.edu); Daqing Yang[1] (1-907-474-2468; ffdy@uaf.edu); Kenji Yoshikawa[1] (1-907-474-6090; ffky@uaf.edu)

[1]University of Alaska Fairbanks, Water and Environmental Research Center, Fairbanks, AK 99775-5860, United States

[2]Boise State University, Department of Geosciences, Boise, ID 83725-1535, United States

[3]University of Alaska Fairbanks, Geophysical Institute, Fairbanks, AK 99775-7320, United States

The broadest impacts of climate change to the terrestrial arctic regions will result through consequent effects of changing permafrost structure and extent. As the climate differentially warms in summer and winter, the permafrost will become warmer, the active layer (the layer of soil above the permafrost that annually experiences freeze and thaw) will become thicker, the lower boundary of permafrost will become shallower and permafrost extent will decrease in area. These simple structural changes will affect every aspect of the surface water and energy balances. As the active layer thickens, there is greater storage capacity for soil moisture and greater lags and decays are introduced into the hydrologic response times to precipitation. When the frozen ground is very close to the surface, the stream and river discharge peaks are higher and the base flow is lower. As permafrost becomes thinner, there can be more connections between surface and subsurface water. As permafrost extent decreases, there is more infiltration to groundwater. This has significant impacts on large and small scales. The timing of stream runoff will change, reducing the percentage of continental runoff released during the summer and increasing the proportion of winter runoff. This is already becoming evident in Siberian Rivers. As permafrost becomes thinner and is reduced in spatial extent, the proportions of groundwater in stream runoff will increase as the proportion of surface runoff decreases, increasing river alkalinity and electrical conductivity. This could impact mixing of fresh and saline waters, formation of the halocline and seawater chemistry. Other important impacts will occur due to changing basin geomorphology. Currently the drainage networks in arctic watersheds are quite immature as compared to the more well-developed stream networks of temperate regions. These stream channels are essentially frozen in place as the major flood events (predominantly snowmelt) occur when the soils and streambeds are frozen solid. As the active layer becomes thicker, there could be significantly increased sediment loads delivered to the ocean. Presently, most small streams (1,000 km2) in the Arctic are completely frozen from the bed to the surface when spring melt is initiated. However, in lower reaches of the rivers there are places where the channel is deep enough to prevent complete winter freezing. Break-up of the rivers differs dramatically in these places where the ice is not frozen fast to the bottom. Huge ice chunks are lifted by the flowing water, chewing up channels bottoms and sides and introducing massive sediments to the spring runoff.

C11A-07 0930h

Spatial variability of the active layer thickness: observations, analysis, and modeling.

Nikolay I. Shiklomanov[1] (302 831-1314; shiklom@udel.edu)

Frederick E Nelson[1] (302 831-0852; fnelson@udel.edu)

Kenneth Hinkel[2] (Kenneth.Hinkel@uc.edu)

Anna Klene[3] (klene@selway.umt.edu)

[1]Department of Geography, University of Delaware, Newark, DE 19716, United States

[2]Department of Geography,, University of Cincinnati, 401 Braunstein Hall,, Cincinnati, OH 45221, United States

[3]Department of Geography, The University of Montana, Social Science 203, Missoula, MT 59812, United States

The uppermost layer of seasonal thawing above permafrost (the active layer) is an important regulator of energy and mass fluxes between the surface and the atmosphere in the polar regions. A major difficulty in predicting and mapping active-layer thickness stems from its large spatial variability over a wide range of geographic scale, in response to many interacting climatic and terrestrial factors. Here we address the problem of spatial and temporal variability of active-layer thickness over a wide range of scales, and the landscape-specific effects of this variability in several environmental settings. Data from eight years of extensive, spatially oriented field investigations conducted in North-Central Alaska are used to examine regularities in thaw depth for several landscape types and to provide a comprehensive evaluation of spatial and temporal active-layer variability under contemporary climate. The results can be used to facilitate detailed characterization of active-layer thickness at small geographical scale, evaluation of currently available spatially-distributed permafrost models, and bridge a critical gap between models of climate-permafrost interactions and localized thaw depth measurements.

C11A-08 0945h

Climate Change, Permafrost and Infrastructure: Task Force Report of the U.S. Arctic Research Commission

Lawson W. Brigham[1] (1-907-271-4577; usarc@acsalaska.net)

Frederick E. Nelson[2] (1-302-831-6654; fnelson@udel.edu)

[1]Alaska Office, U.S. Arctic Research Commission, 420 L Street, Suite 315, Anchorage, AK 99501, United States

[2]Department of Geography, University of Delaware, 207 Pearson Hall, Newark, DE 19716, United States

During 2002 the U.S. Arctic Research Commission chartered a task force on climate change, permafrost and infrastructure impacts. The task force was asked to identify key issues and research needs to foster a greater understanding of global change impacts on permafrost in the Arctic and their importance to natural and human systems. Permafrost was found to play three key roles in the context of climatic change: as a record keeper by functioning as a temperature archive; as a translator of climate change through subsidence and related impacts; and, as a facilitator of further change through its impacts on the global carbon cycle. Evidence of widespread warming of permafrost and observations of thawing have serious implications for Alaska's transportation network, for the trans-Alaska pipeline, and for nearly 100,000 Alaskans living in areas of permafrost. These impacts resulting from changing permafrost must be met by a timely, well-informed, and coordinated response by a host of federal and state organizations. Key task force findings include: requirements for a dedicated U.S. federal permafrost research program; data management needs; baseline permafrost mapping in Alaska; basic permafrost research focusing on process studies and modeling; and, applied permafrost research on design criteria and contaminants in permafrost environments. This report to the Commissioners makes specific recommendations to seven federal agencies, the State of Alaska, and the National Research Council. These recommendations will be incorporated in future Arctic research planning documents of the U.S. Arctic Research Commission.

C

C11B MCC: Level 2 Monday 0830h

Glacier-Climate Interactions I Posters

(joint with A, H, OS, PP)

Presiding: **S Marshall,** University of Calgary**; T G Casal,** Rosenstiel School of Marine and Atmospheric Science, University of Miami

C11B-0806 0830h POSTER

California's Snow Gun and its implications for mass balance predictions under greenhouse warming

Ian Howat[1] (ihowat@es.ucsc.edu)

Mark Snyder[1] (msnyder@es.ucsc.edu)

Slawek Tulaczyk[1] (stulaczyk@es.ucsc.edu)

Lisa Sloan[1] (lsloan@es.ucsc.edu)

[1]University of California, Santa Cruz, Earth Sciences, 1156 High St., Santa Cruz, CA 95064

Precipitation has received limited treatment in glacier and snowpack mass balance models, largely due to the poor resolution and confidence of precipitation predictions relative to temperature predictions derived from atmospheric models. Most snow and glacier mass balance models rely on statistical or lapse rate-based downscaling of general or regional circulation models (GCM's and RCM's), essentially decoupling sub-grid scale, orographically-driven evolution of atmospheric heat and moisture. Such models invariably predict large losses in the snow and ice volume under greenhouse warming. However, positive trends in the mass balance of glaciers in some warming maritime climates, as well as at high elevations of the Greenland Ice Sheet, suggest that increased precipitation may play an important role in snow- and glacier-climate interactions. Here, we present a half century of April snowpack data from the Sierra Nevada and Cascade mountains of California, USA. This high-density network of snow-course data indicates that a gain in winter snow accumulation at higher elevations has compensated loss in snow volume at lower elevations by over 50% and has led to glacier expansion on Mt. Shasta. These trends are concurrent with a region-wide increase in winter temperatures up to 2°C. They result from the orographic lifting and saturation of warmer, more humid air leading to increased precipitation at higher elevations. Previous studies have invoked such a "Snow Gun" effect to explain contemporaneous records of Tertiary ocean warming and rapid glacial expansion. A climatological context of the California's "snow gun" effect is elucidated by correlation between the elevation distribution of April SWE observations and the phase of the Pacific Decadal Oscillation and the El