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Large ice masses do not break off hanging glaciers without prior characteristic changes in appearance and movement. Formation of deep crevasses, and cracked ice near the glacier base are indications of a pending breakoff event. An empirical power-law fit is routinely used to predict the time of failure. The recognition and assessment of ice avalanche hazards from hanging glaciers largely relies on these facts. Several remarkable properties of the acceleration phase prior to failure can be described with a model system based on damage mechanics. The empirical formula used to predict failure time is obtained, which allows a physical interpretation of the empirical parameters. The solution reveals that two parameters of the empirical formula are related. This considerably reduces the complexity of predicting the time of failure. Characteristic length and time scales seem to be universal quantities of the failure process in hanging glaciers. The numerical values $t_f = 550$ days and $s_f = 55$ m are obtained by analyzing survey data from 15 break-off events. Measured ice velocities prior to break-off exhibit oscillations which can be described as log-periodic corrections to the leading velocity singularity. The exact cause for these oscillations is still unclear, but dynamical crack interactions or damage reduction due to healing are likely explanation.

URL: http://gi.alaska.edu/˜luthi/

C11D-0859 0830h POSTER

Modelling of the ice-shelf rifting around Hemmen Ice Rise, prior to the calving of iceberg A38.

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The calving of icebergs from the Ronne Ice Shelf is controlled mainly by the propagation of rifts originating from Hemmen Ice Rise (HIR) and d'Orville Coast. Using interferometric radar images collected by ERS-1, ERS-2 and Radarsat-1, we observe the evolution of rifts near Hemmen Ice Rise, prior to the large calving event of October 13th 1998, which resulted in the formation of iceberg A38. Using LEFM models combined with INSAR, Larour (in press 2003) showed that the propagation of those rifts is linked to their opening rate. The opening rate is inferred from the velocity field on each flank of a rift. Therefore, an accurate modelling of the ice-shelf flow is required to predict the evolution of the rifts prior to calving. Forward modelling of the ice-shelf flow by MacAyeal and others (1998) showed that softening along the ice-shelf margins and the presence of melange in between the rifts are key factors influencing the ice flow around Hemmen Ice Rise. Here we use a control method based on MacAyeal (1992) and Rommelaere and others (1997) to infer the distribution of the flow parameter and ice thickness on Ronne Ice Shelf to best match a velocity map from INSAR. The residual misfit between model and INSAR is reduced +-30m/a on the ice shelf. We then apply this parameter selection to run an ice-shelf flow model, coupled with LEFM, to predict the evolution of rifts. The results compare well with satellite observation. We thank the California Institude of Technology for making this study possible.

C11E MCC: 3004 Monday 1020h

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

Presiding: **N I Shiklomanov,** University of Delaware**; W R Eisner,** University of Cincinnati

C11E-01 1020h INVITED

The Role of Permafrost-Affected Soils in Climate Change

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Whereas permafrost-affected soils comprise 20% of the global land area, they contain an estimated 42% of the global soil carbon pool. In the Northern Hemisphere, dramatic increases in winter and spring air temperature since 1970 have been accompanied by increases in the seasonal thaw layer, warming of permafrost, and a possible shift in Arctic Tundra from being a net sink to a net source for atmospheric CO2. There are several challenges in determining C pools in permafrost-affected soils, including large small-scale variability due to patterned ground, mixing of organic C into the subsoil by cryoturbation, the presence of large amounts of C in the permafrost at depths > 1 m, and the difficulties in scaling up from the pedon to the landscape or regional level. Cryopedologists are addressing these challenges through specially adapted field techniques including the use of ground-penetrating radar and satellite imagery. Some issues, however, will require development of international methodological protocol to ensure that results can be compared between regions, within the circumarctic, and between hemispheres.

C11E-02 1035h

ISOTOPIC VARIATIONS IN PERMAFROST ON THE NORTH SLOPE OF ALASKA

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Anadarko Petroleum Corporation, Maurer Technology, and the U.S. Department of Energy drilled the Hot Ice #1 borehole on the North Slope of Alaska during March/April of 2003. Its purpose was to explore for the possible occurrence of methane hydrates in the base of the thick permafrost zone present on the North Slope. The borehole reached a depth of 425 m, passing through the bottom of the permafrost at about 380 m. The entire hole was cored, with core recovery exceeding 90%. The bedrock geology consists of interbedded sequences of siltstone, conglomerate, sandstone, coal and shale with some bitumens and/or ice lenses. The borehole represents an ideal opportunity to study geochemical signals present in the North Slope permafrost. Thirty samples, obtained over the entire length of the core, were collected for isotopic analyses and are currently being analyzed at the Center for Isotope Geochemistry at the Lawrence Berkeley National Laboratory. The samples were chosen to best determine whether any broad isotopic trends exist within the permafrost. Measurements are being made of the hydrogen and oxygen isotope ratios of the ice and the carbon isotope ratios of carbon dioxide trapped in the permafrost. In addition, the carbon isotope ratios of any methane contained in the samples will also be determined. Preliminary results for the oxygen isotope compositions of the permafrost yield δ^{18}O values ranging from -18$^{o}/_{oo}$ to -22$^{o}/_{oo}$ with a general trend towards lower values in the deeper part of the core. The concentrations of the CO_2 in the samples (possibly representing dissolved inorganic carbon in the pore water?) range from 0.6 to 2.5 millimoles/liter with concentrations increasing with depth. The δ^{13}C values of the CO_2 range from -7$^{o}/_{oo}$ to -27$^{o}/_{oo}$ with the lowest values in the higher concentration, deeper samples. This trend is consistent with increasing inputs of CO_2 derived from hydrocarbons/hydrates with depth and may yield insight into the affecting methane hydrate formation within the permafrost.

C11E-03 1050h

Discontinuous Permafrost Thaw Accelerates in Boreal Peatlands During Late-20th Century Climate Warming

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Permafrost covers 25% of the land surface in the northern hemisphere, where mean annual ground temperature (MAGT) is less than 0^{o}C. A 1.4-5.8^{o}C warming in mean annual air temperature (MAAT) by 2100 will likely change the sign of MAAT and MAGT over most of the zone of discontinuous permafrost in the northern hemisphere, causing widespread permafrost thaw. However, there is little direct evidence documenting the magnitude of high-latitude warming and its impact on permafrost thaw. In this study, I examine rates of discontinuous permafrost thaw in the boreal peatlands of northern Manitoba, Canada, using a combination of tree-ring analyses to document thaw rates from 1941-1991 and direct measurements of permanent benchmarks established in 1995 and resurveyed in 2002. I use instrumented records of MAAT, mean winter snow depth, and duration of continuous snow pack from climate stations across northern Manitoba to analyze temporal and spatial trends in these variables and their potential impacts on thaw. I show that permafrost thaw in central Canadian peatlands has accelerated significantly since 1950, concurrent with a significant, late-20th-century average climate warming of +1.39^{o}C in this region. Projecting current warming trends to year 2100, I show that trends for north-central Canada are in good agreement with general circulation models, which suggest a 4-8^{o}C warming at high-latitudes. This magnitude of warming will likely eliminate most of the present range of discontinuous permafrost in central Canada by 2100.

C

C11E-04 1105h

Feedbacks in Climate - Permafrost - Vegetation System: Predictive Modeling Approach.

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Permafrost models driven by scenarios of climate change predict that reduction of the total (continuous) permafrost area in the northern hemisphere by 2030, 2050, and 2080 is likely to be 10%-18% (15%-25%); 15%-30% (20%-40%), and 20%-35% (25%-50%), respectively. Predicted changes of the seasonal thaw depth in the following three decades are relatively small, typically within 10%-15%. By the middle of the century thaw depth may increase on average by 15%-25%, and by 50% and more in the northernmost locations. By 2080 layer of seasonal thawing will become markedly thicker (by 30%-50% and more) all over the permafrost area. Vegetation above permafrost plays important role in regulating ground temperature and depth of seasonal thawing. In the warm period organic layer of peat, mosses, and lichens has low thermal conductivity and protects permafrost from thawing. Results from coupled climate - permafrost - vegetation model suggest that 5cm, 10cm, 15cm, and 20cm thick organic layer reduces seasonal thaw depth by 10%, 25%, 40%, and 60%, respectively, compared to bare ground. Enhanced growth of non-vascular plants under warmer climatic conditions may thus mitigate the effects of climatic warming on permafrost. Controlled experiments involving continuous localized warming at selected sites in the northern Europe and in Alaska indicate a multiyear tendency towards the replacement of mosses and lichens by vascular plants. In the long term climate-induced changes of vegetation may thus cause enhances warming and deeper seasonal thawing of the frozen ground ultimately leading to degradation of permafrost. Acknowledgement. This work is supported by the National Science Foundation of the Netherlands, grant # 047.011.2001.003.

C11E-05 1120h

The Circumpolar Arctic Vegetation Map: A tool for analysis of change in permafrost regions

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Arctic vegetation occurs beyond the northern limit of trees, in areas that have an Arctic climate and Arctic flora. Here we present an overview of the recently published Circumpolar Arctic Vegetation Map (CAVM), an area analysis of the vegetation map, and a discussion of its potential for analysis of change in the Arctic. Six countries have Arctic tundra vegetation, Canada, Greenland, Iceland, Russia, Norway (Svalbard), and the US (Total Arctic area = 7.1 million km2). Some treeless areas, such as most of Iceland and the Aluetian Islands are excluded from the map because they lack an Arctic climate. The

CAVM divides the Arctic into five bioclimate subzones, A thru E (Subzone A is the coldest and Subzone E is the warmest), based on a combination of summer temperature and vegetation. Fifteen vegetation types are mapped based on the dominant plant growth forms. More detailed, plant-community-level, information is contained in the database used to construct the map. The reverse side of the vegetation map has a false-color infrared image constructed from Advanced Very-High Resolution (AVHRR) satellite-derived raster data, and maps of bioclimate subzones, elevation, landscape types, lake cover, substrate chemistry, floristic provinces, the maximum normalized difference vegetation index (NDVI), and aboveground phytomass. The vegetation map was analyzed by vegetation type and biomass for each county, bioclimate subzone, and floristic province. Biomass distribution was analyzed by means of a correlation between aboveground phytomass and the normalized difference vegetation index (NDVI), a remote-sensing index of surface greenness. Biomass on zonal surfaces roughly doubles within each successively warmer subzone, from about 50 g m-2 in Subzone A to 800 g m2- in Subzone E. But the pattern of vegetation increase is highly variable, and depends on a number of other factors. The most important appears to be the glacial history of the landscape. Areas that were glaciated during the late-Pleistocene, such as Canada, Svalbard, and Greenland, do not show such strong increases in NDVI with temperature as do areas that were not glaciated. Abundant lakes and rocky surfaces limit the greenness of these recently glaciated surfaces. The highest NDVI and phytomass are found in non-glaciated regions of Alaska and Russia. Soil acidity also affects NDVI patterns. In Subzone D, where the NDVI/ soil acidity relationship has been studied most closely, NDVI is lower on nonacidic surfaces. This has been attributed to fewer shrubs and higher proportion of graminoids (more standing dead sedge leaves) in nonacidic areas. This trend is probably caused by generally drier soils, with less production, on limestone-derived soils. The trend is less clear in Subzone E because of fewer nonacidic surfaces, and the abundance of glacial lakes with low NDVI on the acidic shield areas of Canada. Time series analysis of trends in NDVI in Subzones C, D, and E in Alaska have shown a 17% increase in the NDVI over the 21-year record. The increases have been greatest in moist nonacidic tundra. Future analyses of the circumpolar database will be directed at examining which geographic regions and vegetation types have shown the strongest increases, and how these are correlated with temperature changes.

URL: http://www.geobotany.uaf.edu/cavm/draft0306/index.html

C11E-06 1135h

Mapping Active-Layer Thickness in an Urbanized Environment: The Barrow Urban Heat Island Study

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Local and global changes in the Arctic climate may have profound impacts on hydrology, soil stability, and infrastructure, such as roads, buildings, and water, gas, or oil pipelines. These changes will be manifested in large part through permafrost, which can influence virtually all physical, chemical, and biological processes occurring in the soil. The "Barrow Urban Heat Island Study" (BUHIS) is an ongoing project in northern Alaska that examines the effects of urbanization on air and soil temperatures in and around Barrow. At 4600 residents, Barrow is the largest native settlement in the circumarctic region and the northernmost urban area in the United States. Initiated in summer 2001, BUHIS is recording temperature and thaw depth at more than 60 locations throughout the village, the developing suburbs, and surrounding undisturbed tundra. This paper describes one part of study examining the active layer and anthropogenic influences on its thickness. Summer air and soil temperature data, together with digital vegetation and soil maps, are used as input to a modified Stefan solution to map depth of thaw over an area of 100 square kilometers that includes both the village of Barrow and the surrounding tundra. Maps representing end-of-summer conditions for 2001 provide the first spatial/temporal representation of active-layer variability within an urbanized area. Increasing urban development in Arctic regions is causing information about changes accompanying industrial development and urbanization to become more vital, particularly given the possibility of a warming climate.

C11E-07 1150h

Slope Relaxation in Thaw Lake Terrain, NW Alaska.

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Thaw-induced subsidence of the ground surface, localized in thaw lake basins, generates topographic relief of 1 to 20 m in regions of ice-rich permafrost. After lakes drain, basin relief is modified by gravity-driven slope processes and by re-inflation of the lake floor by peat accumulation and refreezing. Unlike slopes in temperate regions, where transport laws and rates have been estimated from measurements (eg., linear diffusion of topography and diffusion time constants), rates of slope relaxation over 10 - 10^4 y have not been measured in permafrost terrain. To investigate rates of permafrost slope relaxation, we conducted differential GPS surveys (resolution $\approx$ 1 cm) and constructed digital elevation models of bounding slopes for four lake basins ranging in age from modern (an actively expanding lake) to 10^4 y, located in ice-rich aeolian Pleistocene silt on the Seward Peninsula, NW Alaska. Timing of lake drainage, marking the onset of slope relaxation, is constrained by radiocarbon ages of basal terrestrial peat samples collected from permafrost cores and stratigraphic exposures. The resulting chronosequence of slopes, each developed in similar materials and from a similar initial state, is then used to investigate time evolution of hillslopes in permafrost. Preliminary results indicate that 1) Total thaw basin relief ranges from 10–18 m; 2) Before and immediately following lake drainage, slopes display irregular, slump-dominated profiles with angle 35–60°; 3) After lake drainage, mid slopes evolve toward smooth cross- sectional and along-slope profiles consistent with diffusive transport; 4) Upper slopes exhibit gentle diffusive profiles near divides, but are marked by laterally-discontinuous steep 1–2 m high ramparts where merging into mid slope, which persist in the oldest basins. 5) Lower slopes are marked by sharp breaks where toes meet reinflating flat basin floors. Comparisons between measured slopes and transport model predictions are consistent with the view that permafrost slopes are characterized by a mixture of linear diffusive and non-linear transport processes (eg., solifluction) that can maintain relief over long time periods.

C11E-08 1205h

CEON: A Circum-Arctic Environmental Observatories Network

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The concept of a terrestrial Circum-arctic Environmental Observatories Network (CEON) was introduced at Arctic Science Summit Week (ASSW) in 2000 at a meeting of the Forum of Arctic Research Operators (FARO: www.faro-arctic.org). CEON is conditioned by the need for increased international integration of research effort and the loss and/or danger of loss of continuous northern high latitude environmental observations. FARO has endorsed the CEON concept advocating that CEON be developed to promote environmental measurements and dissemination of these to Arctic researchers whilst encompassing and building on the strengths of existing arctic stations and environmental observatory networks. Since 2000, the CEON concept has increasingly received enthusiastic support from a variety of existing networks, disciplinary collaborations and research stations as well as endorsement from the the International Arctic Science Committee (IASC) (www.iasc.no). At ASSW 2002, a working group was formed to scope and develop the concept of CEON. Since then, presentations of the CEON concept have been made at meetings of various networks, research collaborations and polar research boards in Europe, Russia and the United States in order to make contact and collect feedback from potential CEON stakeholder and user groups. Presentations have focused on the necessity for the CEON initiative to meet and promote the needs of the participating research community, science administrators, policy makers, industry, education and indigenous communities. In doing so, it has been stressed that CEON should be seen as a network that facilitates and encourages environmental monitoring, which provides linkages between disciplines and existing networks and connectivity spanning regional to circumarctic and global scales. Following CEON presentations audiences have been asked to introduce their own bias in the development of CEON by providing feedback to the following question: "What would you do if you had the opportunity to conduct standardized long term, integrated measurements across all research stations and networks in the Arctic?" It is hoped that this approach will facilitate the development and scope of CEON based on the experience, needs and future directions envisaged by a broad range of potential CEON stakeholder and user groups. The CEON initiative should not be seen as duplicating prior or ongoing research effort, but an international partnership that aims at forming a logistic and research framework within which ongoing and future research can be oriented to cumulatively form and facilitate long-term research endeavors in the Arctic. Based on recent scoping and development activities and the convention of the first planning meeting in October 2003, this presentation recapitulates the enthusiastic support for the initiation of CEON and outlines a conceptual roadmap for its inception. This road map will include the formation of an interim multidisciplinary and international steering committee, an international workshop and a science implementation strategy. We invite your thoughts and ideas to facilitate the development of the CEON initiative.

URL: http://www.cevl.msu.edu/ael/projects/ceon.html

C12A MCC: Level 2 Monday 1330h

General Cryosphere Posters *(joint with ED)*

Presiding: **M W Williams,** University of Colorado

C12A-0860 1330h POSTER

Can we Trust Measurements of Turbulence on top of the Greenland Ice Sheet?

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The most important challenge to providing new insights into the workings of the atmosphere on the top of the Greenland ice sheet is to demonstrate that its weak and intermittent turbulence can be adequately characterized using existing instrumentation. To tackle this problem, very high temporal resolution measurements of turbulence at two heights near the surface were collected at Summit, Greenland over several field seasons. Two independent tests of stationarity on 1080 30-minute runs revealed that approximately 40% of observations are nonstationary. Nonstationary runs are characterized by periods with significant turbulent fluxes separated be extended inactive periods with little or no flux, with most of the flux during a run realized in small fractions (<25%) of the total time. However, spectral analyses of stationary runs show that velocity and temperature data, when non-dimensionalized with appropriate scaling parameters, reduce to a set of universal curves that are functions of z/L. To capture 99% of the turbulent heat flux in stable conditions sampling rates do not need to exceed 15 Hz, which is far less than the sampling frequency of 50 Hz used in this investigation. This is important as it shows that standard fast-response sensors close to the surface (2m) can capture the different scales of turbulent motion in this environment. For these measurements to be useful in other applications, such as establishing flux-profile relationships or energy budgets, the issue of stationarity must be addressed otherwise results may differ from those expected.

C12A-0861 1330h POSTER

Cyclone Occurrence in the Arctic: Coupling With Teleconnections and the Impacts on Ice Sheet Melt Cycles

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