C11A-05 0900h INVITED

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

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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

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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.

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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

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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.

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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

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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

Nino Southern Oscillation, both controlling the heat and moisture delivered to the U.S. Pacific coast. The existence of a significant "Snow Gun" effect presents two challenges to snow and glacier mass balance modeling. Firstly, the link between amplification of orographic precipitation and the temporal evolution of ocean-climate oscillations indicates that prediction of future mass balance trends requires consideration of the timing and amplitude of such oscillations. Only recently have ocean-atmosphere models begun to realistically produce such temporal variability. Secondly, the steepening snow mass-balance elevation-gradient associated with the "Snow Gun" implies greater spatial variability in balance with warming. In a warming climate, orographic processes at a scale finer that the highest resolution RCM (>20km grid) become increasingly important and predictions based on lower elevations become increasingly inaccurate for higher elevations. Therefore, thermodynamic interaction between atmospheric heat, moisture and topography must be included in downscaling techniques. In order to demonstrate the importance of the thermodynamic downscaling in mass balance predictions, we nest a high-resolution (100m grid), coupled Orographic Precipitation and Surface Energy balance Model (OPSEM) into the RegC2.5 RCM (40 km grid) and compare results. We apply this nesting technique to Mt. Shasta, California, an area of high topography (4000m) relative to its RegCM2.5 grid elevation (1289m). These models compute average April snow volume under present and doubled-present Atmospheric CO2 concentrations. While the RegCM2.5 regional model predicts an 83% decrease in April SWE, OPSEM predicts a 16% increase. These results indicate that thermodynamic interactions between the atmosphere and topography at sub- RCM grid resolution must be considered in mass balance models.

C11B-0807 0830h POSTER

Snow and ice-core stable isotopes time series and precipitation in Altai Mountains (Siberia)

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The Altai's glaciers provide information on internal and external hydrological cycles over the Eurasia, storing long-term records of fresh water transport from Atlantic and Pacific Oceans and the Central Asia closed drainage basin. The 22 m firn-ice cores and 3 m snow pits from the Belukha firn Plateau (4109 - 4115 m) were used to recover climatic records through physical and stable isotopes analysis. Well preserved seasonal δ^2H and δ^{18}O signals exist in the snow firn records with the mean of oxygen isotope ratios of -13.6$^o/_{oo}$. Three distinct data on moisture origin were clustered, i.e., Atlantic, Pacific Oceans and internal central Asian drainage basin. Two thirds of annual accumulation was formed by oceanic precipitation and more than half in annual accumulation has isotopic ratios corresponding to evaporation over the northern Atlantic Ocean. The δD-δ^{18}O relationship associated with Atlantic moisture source varied slightly during the year with intercept range from 8.8 in winter to 12.0 in spring and with almost unchangeable during the year deuterium excess of 10$^o/_{oo}$. The contribution of precipitation transferred from the Pacific Ocean, which has smallest deuterium excess (4.6$^o/_{oo}$, comprises on average 16% in annual accumulation with maximum in summer (up to 21%) and minimum of 8% in spring. The low d-excess was associated with the high atmospheric moisture saturation over the ocean during formation of precipitation. The mean and absolute values of δ^{18}O for records related to Pacific Ocean origin are the highest among three clusters (-9$^o/_{oo}$) that associated with highest air temperature during precipitation. The internal moisture source provides the largest portion of precipitation to Altai glaciers in the spring (up to 42%) and the minimum contribution during winter. The linear transfer function between mean air temperature and the isotopic composition in accumulated precipitation originating from the same external or internal moisture source was developed at the seasonal temporal scale.

C11B-0808 0830h POSTER

Surface Temperature Lapse Rates and Regional Temperature Variability on the Prince of Wales Icefield, Ellesmere Island, Canada

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Surface temperature variability, net annual mass balance, and seasonal snow isotopic ratios were monitored from May 2001 to April 2003 in an array of 25 sites on the Prince of Wales Icefield, Ellesmere Island, Canada. The observational network spans the entire Icefield, an area of 180 km by 120 km, with a maximum elevation of 2020 m in the vicinity of the ice divide. Sites on the eastern margin descend to sea level, while the western margin terminates terrestrially at 450 to 620 m elevation. Hourly, daily, and monthly average temperatures from the spatial array provide a tremendous record of surface temperature lapse rates and mesoscale temperature variability on the Icefield. Observed lapse rates in the two-year record appear to have modes that are indicative of both synoptic and regional conditions, with an average rate of cooling of 4–5^{o}C/km. This is less than the moist- or dry-adiabatic lapse rates that are adopted for extrapolations of sea-level temperature to higher altitudes, with important implications for modeling snow and ice melt. We also examine systematic variations in the standard deviation of monthly and daily temperature, important free parameters in methods that are presently in use for glacier mass balance modeling.

C11B-0809 0830h POSTER

Climate Variability in West Antarctica Derived from Marine Aerosol Species from ITASE Firn/Ice Cores

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Marine aerosol species (sodium, chloride, magnesium, sulfate) from 13 high-resolution ice cores covering the last approximately 200 years from the Pine Island-Thwaites and Ross drainage systems and the South Pole are used to examine climate variability in West Antarctica. The large-scale spatial distribution of the ice cores improves characterization of the source regions and pathways of marine aerosols into West Antarctica. The Ross Sea is the dominant source region for marine aerosols in the study area, and the dominant pathway is across the Ross Ice Shelf. Factors contributing to the amount of marine aerosols transported inland are strength and positioning of low pressure systems, sea-ice extent, and wind strength. Associations of the sodium time-series with sea level pressure are investigated using the National Centers for Environmental Prediction (NCEP) data reanalysis, the Southern Oscillation Index (SOI), and Trans-Polar Index (TPI). Sea-ice associations are explored by correlating sea-ice extent with the marine aerosol time-series, and wind strength is investigated using a circumpolar vortex index and the NCEP meridional and zonal wind fields. The associations demonstrate that West Antarctic climate is extremely dynamic, with regional differences in the mechanisms driving marine aerosol variability.

C11B-0810 0830h POSTER

Do Trees Tell the Same Story as Glaciers? Reconstructing Drought in Glacier National Park, Montana Since AD 1540

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Glacier National Park has well-documented, extensive glacial recession from the end of the Little Ice Age (LIA) to the present. However, information is lacking on climatic variability and trends prior to the LIA. Since relatively little research on this topic exists, we constructed eight tree-ring chronologies for the examination of natural modes of variability and the influence of climatic drivers on glacial recession since AD 1540. We created a simple water balance model, representative of biological drought, using local climate station data. This model was then reconstructed using tree-ring chronologies. The reconstruction had an $R^2{}_a$=0.49 when validated with standard statistical procedures. As well, the chronologies also exhibit general correspondence with regional river flow and historically documented patterns of drought, which indicates that our reconstruction effectively reflects climatic variability over the entire 460-year record. The June July August drought reconstruction provides evidence for multi-decadal and centennial modes of variability that are inconsistent throughout the length of the record. In addition, the records of glacial recession indicate rapid retreat and ablation during periods of high summer drought. For instance, the Grinnell, Sperry, Jackson and Agassiz glaciers decreased to 50-68% of their original sizes between 1917-1945, at rates of up to 100 m/yr. During this same period, our reconstructions indicate the most extreme drought, in both duration and severity, of this 460-year period. The reconstruction provides insights into the role of drought as a driver of glacial dynamics during the LIA.

C11B-0811 0830h POSTER

Melting of small Arctic ice caps observed from ERS scatterometer time series

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Time series of active microwave backscatter data from the ERS Wind Scatterometers are used to demonstrate (1) the timing of melt onset can be observed over small ice caps, as well as the major ice sheets and multi-year sea ice; and (2) temporally integrated backscatter reduction (R) is strongly correlated with total annual positive-degree-days (PDD), as measured at four automated weather stations on the surface of the Greenland Ice Sheet. The latter is particularly interesting because unlike melt onset, R is a measure of melt processes integrated over an entire ablation season. Both methods work owing to the well-known sharp decrease in radar backscatter triggered by the appearance of liquid water in a glacier snowpack. Melt onset and R are determined for 14 small Arctic ice caps from 1992-2000. Interannual and regional variability in the timing of melt onset are comparable, averaging 33+9 and 38+13 days, respectively. Regional variability in R exceeds interannual variability, averaging 906+164 and 309+130 dB·d, respectively. The brevity of the derived nine-year records limits their statistical testing for trend. However, their qualitative interpretation suggests that the timing of melt onset is more variable for Arctic ice caps than for sea ice, and the intensity of summer surface melting increased by about 20% in the 1990's.

C11B-0812 0830h POSTER

Variability in Synoptic Circulation and Accumulation and Ablation Events in the Canadian Rockies, 1953-2003

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Through an automated synoptic classification system, the authors investigate the trends and variability of significant accumulation and ablation events in the Canadian Rockies. Using a statistical analogue approach validated from field data collected for the past 3 mass balance seasons at the Haig Glacier, Kananaskis Country, Alberta, frequency of occurrence is examined for synoptic types which dominate the accumulation and melt regimes of a continental glacier. Annual and decadal variability in accumulation and ablation events are described and future applications are outlined.

C11B-0813 0830h POSTER

Recent Changes of the Mass Balance of a Small Glacier in the Colorado Front Range

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Estimates of mass balance for 2003 are used in conjunction with historical records of mass balance, photographs and remotely sensed images to document changes in the mass balance and area of Arapaho Glacier for the period 1970 to 2003. Arapaho Glacier is one of 14 small glaciers located on the east side of the Continental Divide in the Colorado Front Range. There are also hundreds of semi-permanent snow patches in the area. Changes in the mass of glaciers and snow patches can provide information about how the regional water balance changes with climate. Measurements of snow accumulation and summer balance at Arapaho Glacier were made every 2 to 3 weeks between May and October of the 2003 season. These frequent measurements allow the close relationship between glacier regime and local climate conditions to be studied. In particular, the date when mass balance changes from positive to negative can be determined. In 2003, this change occurred in the first week of August. Glacier runoff after this date represents a release of water from long-term storage as glacier ice to the regional hydrological system. Estimates of glacier area and accumulation area ratio were made from photogrammetric interpretation of oblique terrestrial photographs and remote sensing data. Changes in glacier area are used with mass balance records to estimate changes in glacier volume over previous decades and to interpret these changes in terms of sensitivity to climate change.

C11B-0814 0830h POSTER

Measured Climate Induced Volume Changes of Three Glaciers and Current Glacier-Climate Response Prediction

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Small but hydrologically significant shifts in climate have affected the rates of glacier volume change at the three U.S. Geological Survey Benchmark glaciers. Rate changes are detected as inflections in the cumulative conventional and reference-surface mass-balances of Wolverine and Gulkana Glaciers in Alaska and South Cascade Glacier in Washington. The cumulative mass balances are robust and have recently been corroborated by geodetic determinations of glacier volume change. Furthermore, the four-decade length of record is unique for the western hemisphere. Balance trends at South Cascade Glacier in Washington are generally in the opposite sense compared with Wolverine Glacier in Alaska; NCEP correlation of winter balance with local winter temperatures is positive at 0.59 for Wolverine and -0.64 for South Cascade Glacier. At Wolverine Glacier, the negative trend of cumulative mass balances, since measurements began in 1965, was replaced by a growth trend $positivemassbalances$ during the late 1970s and 1980s. The positive mass-balance trend was driven by increased precipitation during the 1976/77 to 1989 period. At Gulkana Glacier, the cumulative mass-balance trend has been negative throughout its measurement history, but with rate-change inflection points that coincide with the interdecadal climate-regime shifts in the North Pacific indices. At South Cascade Glacier, the mass-loss trend, observed since measurements began in 1953, was replaced by a positive trend between 1970 and 1976 then became strongly and continuously negative until 1997 when the rate of loss generally decreased. Since 1989, the trends of the glaciers in Alaska have also been strongly negative. These loss rates are the highest rates in the entire record. The strongly negative trends during the 1990s agree with climate studies that suggest that the period since the 1989 regime shift has been unusual. Volume response time and reference surface balance are the current suggested methods for analyzing the response of glaciers to climate. Volume response times are relatively simple to determine and can be used to evaluate the temporal, areal, and volumetric affects of a climate change. However, the quasi-decadal period between the recent climate-regime shifts is several times less than the theoretical volume readjustment response times for the benchmark glaciers. If hydrologically significant climate shifts recur at quasi-decadal intervals and if most glaciers' volume-response times are several times longer $trueforallbutafewsmall, steepglaciers$, most medium and large glaciers are responding to the current climate and a fading series of regime shifts which, themselves, vary in magnitude. This confused history of driver trends prevent conventional balances from being simply correlated with climate. Reference-surface balances remove the dynamic response of glaciers from the balance trend by holding the surface area distribution constant. This effectively makes the reference surface balances directly correlated with the current climatic forcing. The challenging problem of predicting how a glacier will respond to real changes in climate may require a combination of the volume response time and reference surface mass balances applied to a long time-series of measured values that contain hydrologically significant variations.

C11B-0815 0830h POSTER

Glacier Evolution in the Altai Mountains, South-West Siberia, for the Last Half Century (with use of Geo-Informational Catalogue)

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To systemize and analyze the information for the period from 1835 to present on altitudinal distributions of glaciers, exposition, their numbers and surface areas in basins, volumes, genetic classification, location of lower and upper level of glaciers, average firn line position and main morphometric characteristics, DataBase on glacier dynamics in the Altai Mountains (AGDB) has been developed in ArcGIS Format [Tomsk State University, Russia]. Data from Glacier Catalogue [1962], topographic maps with the scale of 1:25000 and 1:50000 and air photos, which fixed glaciers' state on 1952, were digitized. Instrumental observational data on glacier tongue retreat from twenty glaciers since 1835, and radio-echo sounding measurements of 120 glacier volumes were also digitized in the AGDB. Modern state of Altai glaciers and their changes since 1952 were assessed from Resurs space images and partially from instrumental observations. Based on estimation from Resurs for the period from 1952 to 1998, the value of Altai glacier retreating was about 56.9 km2, i.e. 7.1 % of total area, varied from 4 % for valley glaciers to 16 % for glaciers of flat mountain tops. Retreat of 2-8 m per year was accompanied by their 10% mass loss. The slightest degradation occurred in inner (central) part of the glacier system, in the heads of river basins with large-scale glaciation, e.g., in the Katunski, Nothern-Chuiski and Southern-Chuiski ranges, amounting to 6.3%. These are the highest regions, reaching up to 4506 m., and 80% of Altai's glaciers are located there. In the river basins with relatively small-glacierized areas, at the peripheral regions, e.g., Kurai, Chihacheva ranges, the degradation reached its maximum values up to 22%.

C11B-0816 0830h POSTER

Paleothermometry via a Genetic Algorithm With an Application to GISP2 Borehole Data

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Borehole temperature-depth profiles of ice sheets contain information about local climate change stretching back more than a hundred thousand years to the Eemian. Surface temperature histories at the Greenland ice sheet drill sites, GRIP and GISP2, have been reconstructed in the literature using a Control Method (Cuffey et al., 1995) and an Inverse Monte Carlo method (Dahl-Jensen, et al., 1998). In contrast to previous inversion efforts, the flexibility of the proposed Genetic Algorithm based method makes it possible to easily incorporate other climate proxies obtained from the ice core itself as constraints into the inversion process either by augmenting the fitness function with appropriate penalty terms or by treating it as a multi-objective optimization problem. The Genetic Algorithm based surface temperature inversion is applied to synthetic borehole temperature profiles and the GISP2 borehole data. Comparisons between the reconstructed and prescribed temperature forcing in the synthetic cases demonstrate the robustness of the new inversion method. Inversion of GISP2 data shows that the retrodicted 40,000 year long surface temperature history obtained by the Genetic Algorithm agrees well with results of previous studies while using only minimal problem specific knowledge. The resulting surface temperature reconstruction is used as an independent calibration of the linear oxygen-isotope paleothermometer ($\delta^{18}O = \alpha T + \beta$) and yields a value for $\alpha = 0.360$ per mil $^{\circ}C^{-1}$ and $\beta = -23.9$ per mil. The Genetic Algorithm based inversion method enables a multi-proxy approach to ice sheet borehole temperature inversions which should improve the accuracy and resolution of surface temperature reconstructions and aid in the interpretation of very long $\delta^{18}O$ records from ice cores as a local temperature proxy.

C11B-0817 0830h POSTER

Significant glacial advance during Younger Dryas, Annapurna region, Nepal

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^{10}Be exposure ages of moraine boulders and glacially-carved bedrock walls in the Annapurna region of central Nepal show that small glaciers (<8 km_2) were at their maximum extent during the Younger Dryas cold period. Preliminary dates from several large glaciers also show advances during the Younger Dryas. Analyses of past and present small glacier ELAs (equilibrium line altitudes) and modern weather records also indicate that these glaciers require colder temperatures (on the order of 6°C cooler) to advance to their maximal positions with ELAs 400-1200 m below modern levels. Some valleys that once contained glaciers are now entirely below the summer snows and require cooling to fill with ice. The observation that Younger Dryas glacial advances may be as big or bigger than LGM (late glacial maximum) advances is unusual. However the Younger Dryas may have provided the necessary balance between cold temperatures and moderate precipitation. Other recent research on the timing of Himalayan glaciations have suggested that increased precipitation is the primary factor in glacial advance. The results of this study indicate that significant glacial advances cannot occur in this region if climate is either too arid (i.e. the LGM) or if precipitation is accompanied by too much warming (i.e. early Holocene).

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C11B-0818 0830h POSTER

Tien Shan glacier's recession since the end of 19th century and during last 60 years by land instrumental, aerial photo and satellite remote sensing data

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Tien Shan is one of the largest mountain systems in the World with glaciated area of more than 17,000 km^2 and counts a significant impact on distribution of water resources and hydroelectric potential in Central Asia. Tien Shan glaciers are the basic reserve for river flow in the extremely dry years, being the only renewable clear water resource in the region integrating four central Asian countries and western territory of China. The current research presents the estimation on area distribution, volume and temporal changes over 100 glaciers at the northern and central Tien Shan located in five different climatic and topographic basins. The response of glaciers to the warm/cool and wet/dry annual to decadal conditions has been evaluated by composition 1:25 000 and 1:100 000 scales DEMs developed on the time series repeated aerial photographs derived between 1943 and 1991 and high resolution SAR images from RADARSAT and ERS. In the process of satellite imagery and high-resolution DEM development, different topographic parameters for each node of the DEM grids (e.g. surface type, altitude, slope angles, slope aspect, slope curvature, etc.) were calculated. The Tien Shan glacier recession since 19th century estimated based on the Russian topographic survey data. Last decade glacier changes have been evaluated using high-resolution ASTER and Landsat-7 satellite, visible and infrared imagery coordinated with the in situ measurements. Radio-echo sounding measurements were used for assessment of glacier volumes changes. The global climatic and regional environmental changes during the last century adversely affected regime of the Tien Shan glaciers causing their large recession. Only between 1943 and 2003 Tien Shan glaciers lost about 30% in glacierized surface area. The largest glacier recession observed in the northern and central and eastern Tien Shan where glaciers retreated up to 3 km and their surface declined over 30 m.

C11B-0819 0830h POSTER

Stratigraphic Transition into and out of a Snowball Glacial: Evidence from the Otavi Platform and Fransfontein Slope, Namibia

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Detailed lithostratigraphic studies on the transition from non diamictite to diamictite intervals within the Neoproterozoic are vital in evaluating the nature of presumed glacial events in the Snowball Earth hypothesis. To this goal we examined the fine-scale stratigraphic relationships of units above and below the Ghaub carbonate diamictite in the region of the Fransfontein paleslope, north central Namibia. Stratigraphic transitions here are marked by sediment gravity flow and ice rafted horizons that pass in a systematic way both into the Ghaub diamictite and out of the Ghaub diamictite. While distinct ice rafted horizons are indeed present within these transitional intervals the nature of inter-bedded sediment gravity flows (composite fining and coarsening) indicate a single ice advance and retreat cycle that bounds the massive to nearly structureless diamictite characteristic of the Ghaub glacial unit. Small-scale structures within the diamictite are indicative of localized shearing, localized production of silt sized matrix, and suppression of turbulent flow. These observations are consistent with a subglacial origin for portions of the Ghaub diamictite interval. Taken together the stratigraphic and sedimentologic observations on the slope setting are consistent with the Snowball Earth hypothesis of a single glacial episode preceded and succeeded by carbonate deposition.

C11C MCC: Level 2 Monday 0830h

Glaciers and Ice Sheets I Posters

(joint with G, H, OS, PP)

Presiding: **R W Jacobel,** St. Olaf College**; G Casassa,** CECS

C11C-0820 0830h POSTER

Hypsometry of the Greenland Ice Sheet Margin

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Ice sheet dynamics and melt are to a large degree dependent on the character of the ice sheet marginal zone. For Greenland this zone is up to about 100 km wide. This important zone is poorly represented in ice sheet models as these typically use a spatial grid with a 20-40 km grid-space. Both computer and data limitations prevent the reduction of the grid spacing, hence other methods have to be developed to represent ice sheet margins. Subgrid hypsometric parameterisation (area:elevation distribution functions) has already been used to resolve a substantial part of the grid resolution problem in ice sheet models for the inception stages. In order to capture topographic, dynamic and mass balance characteristics of the Greenland Ice Sheet peripheral region, we present a subgrid parameterisation of the elevation distribution of the ice sheet marginal zone through hypsometric terrain characterisation. High resolution (5x5km) Digital Elevation Models (DEMs) (Bamber et al., 2001; Scambos and Haran, 2002) of Greenland were used to obtain a topographic characterisation of ice marginal regions. Hypsometric curves of areas of 20x20km were reconstructed from these DEMs for the entire peripheral zone of the Greenland Ice Sheet. On the basis of these curves, specific classes of hypsometric functions were extracted to represent the variety in and homogeneity of ice surface and proglacial terrain topographic characteristics, ice flow dynamics and the type of ice margin (land-based versus calving). This major partitioning of the ice marginal zones into regions with similar dynamic and topographic characteristics, confirms that specific hypsometric functions can be used as subgrid parametrisation in ice sheet models. Since ice sheet models presently poorly represent iceberg calving, special consideration is directed towards a separate treatment of land-based and calving margins. Further, hypsometric parameterisation with added ablation curves (melt quantified per elevation) will not only provide a more accurate portrayal of ice-land distribution and topography of the ice sheet margin, but also disclose the mass balance signal and local response of glaciers to climate trends.

C11C-0821 0830h POSTER

Thinning of the Patagonian Icefields From Recent Laser Altimetry, SRTM and Earlier Cartographic Data

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The Northern and Southern Patagonia icefields of southern South America (NPI and SPI respectively), are one of the largest temperate glacier systems of mid-latitudes. The glaciers are fed by abundant precipitation of 1-11 m/yr water equivalent (w.e.) due to westerly air flow, and are affected by large ablation (>10 m/yr w.e.) and calving on fjords and freshwater lakes on the lower reaches, with an important east-west gradient. Outlet glaciers are known to be affected by generalized retreat and thinning over the past century, being explained by atmospheric warming and also decreased precipitation. Recently the 2000 Shuttle Radar Topography Mission (SRTM) data in combination with 1968, 1975 and 1995 cartographic data of Chile and Argentina and a few limited ground survey points have allowed the calculation of volume change for the largest 63 glaciers (Rignot et al., in press). Although SRTM data provide a complete coverage with a vertical precision of 7 m and a horizontal resolution of 90 m, the existing cartographic data do not map adequately the accumulation areas because of lack of stereoscopic coverage in the original aerial photographs used to compile the existing maps. In November/December 2002 two flights were made from Punta Arenas by the Centro de Estudios Científicos (CECS) aboard a Chilean Navy P-3 Orion aircraft, equipped with NASA sensors that included a scanning laser altimeter that yielded measurements of surface elevation to an accuracy of ± 0.2 m along a total 4000 km flight track over the glaciers. Surveys covered most of NPI and provided a partial coverage of SPI as well. These data provide a unique opportunity for computing glacier thickness changes over the ablation and accumulation areas. Here we provide preliminary computations of ice thickness changes between the existing cartographic data, limited ground surveys, SRTM data and the laser altimetry data at selected glaciers over SPI and NPI. The data confirm the thinning observed in recent years, with larger values at lower elevations. Preliminary results from the 2002 laser altimetry and 1975 topographic data (19 m vertical error) at the ablation areas (between 700 and 50 m a.s.l.) of San Quintín and Benito glaciers (NPI) show a thinning rate of 1.3 ± 0.7 m/yr and 3.6 ± 0.7 m/yr respectively. The comparison between SRTM and laser altimetry data at the NPI glaciers, yielded ice elevation changes smaller than the errors due to the short (2-year) time period involved. At the ablation area of Tyndall glacier (between 800 and 50 m a.s.l.) a thinning rate of 3.0 ± 0.7 /yr was obtained using the 2002 laser altimetry and the 1975 map data. We postulate that these large thinning rates cannot be explained only by warmer air temperature and decreased precipitation and suggest that ice dynamic effects are critically relevant.

C11C-0822 0830h POSTER

Intergrating Numerical Modeling and Field Observations with GIS to Determine the Paleotopography of the Fennoscandian Ice Sheet Through the Last Glacial Cycle.

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Major limitations in the successful use of ice sheet models for climate research arise from limited field data for model calibration. The end results may be unrealistic simulations of ice sheet inception, growth, and decay. There is, however, an abundance of empirical data in Fennoscandia that can be used to verify and refine a model of the Fennoscandian Ice Sheet (FIS) through the last glacial cycle. A high resolution, three-dimensional, thermomechanical model is being used to simulate the FIS through a glacial cycle while field evidence, such as end moraines, ice flow characteristics (e.g., flow orientation and magnitude), and cosmogenic dates, will be compiled into a Geographic Information Systems (GIS) database and used to verify the model results. Modeled simulations for the Last Glacial Maximum (LGM) and 1,000 year time slices are being statistically compared against field observations (digitized maps from prior research) using an iterative process in order to determine the "goodness of fit". The end results will be FIS reconfiguration maps illustrating the paleotopography and dynamics of the FIS during the inception, growth, and decay. As a result, the ice dynamics under which the geomorphic landforms were formed will be suggested, as well as a new reconstruction of the timing and dynamics of the advance of the FIS.