IP31A MC: 125 Wednesday 0830h

Monitoring an Evolving Cryosphere: The 25th Anniversary of the National Snow and Ice Data Center II *(joint with A, H, OS, GC)*

***Presiding:* A Nolin,** CIRES/NSIDC**; T Scambos,** CIRES/NSIDC

IP31A-01 0835h INVITED

Elevation Changes of Some of Canada's Major Ice Caps

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In an effort to understand the current mass balance of the major Canadian ice caps, we conducted precise airborne laser surveys in spring of 1995 and 2000 using NASA's Airborne Topographic Mapper (ATM). The objective was to compare elevations in each year and determine the amount of thinning that occurred in the intervening five-year period. In general, most of the individual ice caps or groups of ice caps in a specific region exhibit an inverse relationship between elevation and thinning rate. The areas of lowest elevation showed the most thinning, while the higher portions of the ice caps appear to either be thinning less, or in some cases thickening. The same appears to be true for latitude, with the more southern ice caps showing greater thinning rates than the colder ones further north. Barnes Ice Cap on Baffin Island exhibited the most substantial thinning at about 1 m/yr in its lower regions. Nearby Penny Ice Cap also thinned by about 0.5 m/yr at its lower elevations. In the more northern regions, while some thinning was observed, it was not quite as large in magnitude as that of Barnes and Penny ice caps. On nearly all of the ice caps there was slight thickening (less than 10 cm/yr) at the highest elevations. In general, the magnitude of the observed changes is consistent with what might be expected from recent temperature and precipitation anomalies in the region.

IP31A-02 0855h

Recent Climate Variability in the Canadian Arctic: Implications for Ice Caps

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The climate of the Canadian Arctic determines response in ice cap and glacier mass balance. Our ability to predict mass balance change depends on understanding the relationship between climate variability and ice caps. This paper investigates climate variability in the Canadian Arctic, established by analyzing temperature records from a 1977-1999 WMO coastal weather station dataset, the NCEP-NCAR Reanalysis temperature dataset, and 1948-2000 precipitation records from the Meteorological Service of Canada. Temperature analyses are extrapolated from coastal weather stations to ice cap elevations by comparing the WMO temperature dataset to the NCEP-NCAR Reanalysis at 1000 hPa and then calculating environmental lapse rates based on NCEP-NCAR Reanalysis temperature values at 850, 700, and 500 hPa. Temperature and precipitation anomalies from 1995-1999 are discussed in detail to provide explanations for ice cap elevation changes measured by the Arctic Ice Mapping (AIM) laser altimetry/GPS measurements of 1995 and 2000.

IP31A-03 0910h

Ice Sheet Temperature Records Satellite and In Situ Data from Antarctica and Greenland

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Recently completed decadal-length surface temperature records from Antarctica and Greenland are providing insights into the challenge of detecting climate change. Ice and snow cover at high latitudes influence the global climate system by reflecting much of the incoming solar energy back to space. An expected consequence of global warming is a decrease in area covered by snow and ice and an increase in Earth's absorption of solar radiation. Models have predicted that the effects of climate warming may be amplified at high latitudes; thinning of the Greenland ice sheet margins and the breakup of Antarctic Peninsula ice shelves suggest this process may have begun.

Satellite data provide an excellent means of observing climate parameters across both long temporal and remote spatial domains but calibration and validation of their data remains a challenge. Infrared sensors can provide excellent temperature information but cloud cover and calibration remain as problems. Passive-microwave sensors can obtain data during the long polar night and through clouds but have calibration issues and a much lower spatial resolution. Automatic weather stations are generally spatially- and temporally-restricted and may have long gaps due to equipment failure. Stable isotopes of oxygen and hydrogen from ice sheet locations provide another means of determining temperature variations with time but are challenging to calibrate to observed temperatures and also represent restricted areas. This presentation will discuss these issues and elaborate on the development and limitations of composite satellite, automatic weather station, and proxy temperature data from selected sites in Antarctica and Greenland.

IP31A-04 0925h

Greenland Near Surface Temperature Model

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The climate of the Greenland ice sheet has become the focus of considerable attention in recent years due to suspected sensitivity to global climate change. The Greenland Climate Network (GC-Net) is a network of eighteen climate-monitoring stations distributed across Greenland to provide a long-term record for the assessment of Greenland's evolving climate. The objective of this analysis is to present a GIS based model of near surface monthly mean temperatures for the Greenland ice cap based on the temperature record produced by the GC-Net from January 1995 through July 2000. The confidence interval for the modeled temperature surface is of central importance to this analysis in order to compare the results with previous observations to assess climate change and variability. The two primary drivers for near surface temperature variability in Greenland measured at the monthly scale are annual variability in the radiation budget due primarily to changing solar geometry and location, primarily latitude and elevation. A simple linear model is proposed to predict monthly mean temperature of the form: Mean monthly temperature at month $t = b0 + b1\star\text{Latitude} + b2\star\text{Elevation} + b3\star X(t)$, $X(t)$ is a function of the month of the observation and is specified as $X(t) = 30 \sin(\text{Pi}(t-3)/8)$, when $2 < t < 11$ (March through October) and $X(t)$ is 1, 2, 3, 4 if t is November, December, January or February respectively. The model described above was estimated from the GC-Net data set using standard OLS regression and a high resolution DEM for Greenland. The model explains 89% of the wintertime variance in the monthly mean temperatures and 95% of the summer time variance. The 95% confidence interval for the model is 4.6 C for March through October and 4.9 C otherwise. The results will be discussed in detail for different seasons.

IP31A-05 0940h

On the Relationship Between Enhanced Flow in an Ice Sheet and Basal Topography

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Modeling studies suggest that it is possible to explain the existence of areas of enhanced flow through an increase in ice thickness, which induces enhanced internal deformation, without the need for invoking basal sliding in the model. Improvements in the accuracy and coverage of ice thickness and surface elevation data for the Greenland and Antarctic ice sheets have recently been published allowing this hypothesis to be examined using observational data. These new data sets have been used to investigate the relationship between basal topography and the onset of enhanced and/or streaming flow.

Balance velocities for Greenland and Antarctica have been calculated using the latest accumulation and ice thickness data and are used as a proxy for the dynamic regime of the ice mass. Onset areas were identified using a threshold for the acceleration of flow. These areas were mapped in relation to basal topography and, in particular, the location of bedrock depressions. Preliminary results indicate that a complex relationship exists and that bedrock depressions are not a necessary condition for the existence of areas of enhanced flow, although they appear to be associated with the majority of distinct onset areas. A thermal mechanism for a change in flow regime appears to be unlikely for those onset areas not associated with deeper, thicker ice. In Greenland, the northeast ice stream, which constitutes the only spatially extensive feature exhibiting enhanced flow, is clearly linked to a narrow, deep bedrock depression that extends as far as the upstream limit of the feature, close to the ice divide. The ice stream can be reproduced, within a model, based on a mechanism of enhanced internal deformation (due to the deeper ice within the bedrock depression) without the need for invoking basal sliding along its entire length.

IP31A-06 0955h

Rapid Glacier Thinning Along the Amundsen Coast, West Antarctica

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Together with the Pine Island glacier (PIG), the Thwaites (TG) and Smith (SG) glaciers are the principal drainage systems of the Amundsen Sea (AS) sector of the West Antarctic ice-sheet. We use satellite radar altimetry to show that a rapid thinning of ice has occurred along the AS coastline, and satellite radar interferometry (SRI) to show that the pattern of thinning was restricted to the fastest flowing sections of the outlet glaciers. Between 1991 and 2001, the TG and SG thinned by more than 25 and 45 m at their grounding lines, and a total of 157 cubic kilometres of ice was lost from the AS sector into the ocean. Using BEDMAP elevation data, we show that the thickness changes may have caused the PIG, TG and SG to retreat inland by over 8, 4 and 7 km respectively. This is in line with ours and other independent estimates of grounding line retreat rates derived from SRI. If the glaciers continue to thin at the present rates they will become afloat within 150-1500 years.

IP31A-07 1040h

On the Present-Day Mass Balance of the Antarctic Ice Sheet.

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Using interferometric observations combined with other data, we estimate the grounding-line fluxes of 18 of the largest glaciers draining West and East Antarctica with a precision better than ever before. The results are compared to accumulation in the interior of the basins to determine the state of mass balance of the glaciers. The major results are as follow: 1) Areas identified in prior studies as exhibiting a large positive mass balance - due to an erroneous knowledge of the grounding line - are in fact close to mass balance, if not loosing mass. 2) Glaciers not draining East Antarctica into the Ross or Filchner/Ronne ice shelves are remarkably close to a state of mass balance. 3) West Antarctica glaciers are close to a state of mass balance except for the Pine Island/Thwaites/Dotson glaciers sector which is significantly out of balance and thinning. 4) As the glaciers reach the ocean waters and become afloat, a large fraction of the ice is removed from the bottom, not from iceberg calving. This latter result emphasizes the fundamental importance of ice-ocean interactions in the overall mass balance of Antarctic ice and on the potential evolution of ice shelves and grounded ice in a warmer climate.

IP31A-08 1055h

High Resolution Airborne InSAR DEM of Bagley Ice Valley, South-central Alaska: Geodetic Validation with Airborne Laser Altimeter Data

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Bagley Ice Valley, in the St. Elias and Chugach Mountains of south-central Alaska, is an integral part of the largest connected glacierized terrain on the North American continent. From the flow divide between Mt. Logan and Mt. St. Elias, Bagley Ice Valley flows west-northwest for some 90 km down a slope of less than 1^o, at widths up to 15 km, to a saddle-gap where it turns south-west to become Bering Glacier.

During 4-13 September 2000, an airborne survey of Bagley Ice Valley was performed by Intermap Technologies, Inc., using their Star-3i X-band SAR interferometer. The resulting digital elevation model (DEM) covers an area of 3243 km^2. The DEM elevations are orthometric heights, in meters above the EGM96 geoid. The horizontal locations of the 10-m postings are with respect to the WGS84 ellipsoid. On 26 August 2000, 9 to 18 days prior to the Intermap Star-3i survey, a small-aircraft laser altimeter profile was acquired along the central flow line for validation. The laser altimeter data consists of elevations above the WGS84 ellipsoid and orthometric heights above GEOID99-Alaska. Assessment of the accuracy of the Intermap Star-3i DEM was made by comparison of both the DEM orthometric heights and elevations above the WGS84 ellipsoid with the laser altimeter data. Comparison of the orthometric heights showed an average difference of 5.4 ± 1.0 m (DEM surface higher). Comparison of elevations above the WGS84 ellipsoid showed an average difference of -0.77 ± 0.93 m (DEM surface lower). This indicates that the X-band Star-3i interferometer was penetrating the glacier surface by an expected small amount. The WGS84 comparison is well within the 3 m RMS accuracy quoted for GT-3 DEM products. Snow accumulation may have occurred, however, on Bagley Ice Valley between 26 August and 4-13 September 2000. This will be estimated using a mass balance model and used to correct the altimeter-derived surface heights.

The new DEM of Bagley Ice Valley will provide a reference surface of high accuracy for glaciological and geodetic research using ICEsat and small-aircraft laser altimeter profiling of this glaciologically important region of south-central Alaska.

IP31A-09 1110h INVITED

Glacier Monitoring: Opportunities, Accomplishments, and Limitations.

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Glaciers and ice caps, exclusive of the two major ice sheets, have been monitored for more than a century. Initially sparked by interest in the effect of glaciers on the landscape and their sensitive response to changes of climate, glacier study is now additionally motivated because of impacts on cold-regions ecology and hydrology as well as global sea-level rise. Glacier observations in many areas provide the only real data on climate change in the mountains. A substantial number of mass balance programs were initiated during the 1960s that improved our understanding of spatial and temporal changes in climate, and provided a basis for projecting future changes to glaciers and sea level. These results show a general increase in both snow accumulation and ice melting during the last 40 years (but with net wastage predominating), and a marked increase in the sensitivity of ice wastage to air temperature since the late 1980s. The World Data Center system provided unrestricted exchange of data among glaciologists during the cold war. The World Glacier Monitoring Service together with the National Snow and Ice Data Center and several individuals now provide ready access to glacier data. Remaining problems include inadequate access to digital data, a size bias to small glaciers, some traditional methodologies which limit the usefulness of the results, slow incorporation of new technologies, complexity of incorporating glacier dynamics in mass balance analysis, and insufficient attention by some investigators to reporting observational error. Perhaps the most difficult problems are the extension of limited data to the synthesis of broad regional or global conclusions, and a general dwindling of support for monitoring activities.

IP31A-10 1130h

The new 3D Austrian Glacier Inventory: Volume, Area, Altitude

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Of the 925 Austrian glaciers inventoried in 1969 many have disappeared since. A new, three-dimensional inventory is being elaborated based on aerial photographs of 1996 to 99 and on continuing radio-echo soundings of ice thickness. The 1969 inventory is being reprocessed with up to date techniques aiming at an accuracy of surface elevation of 0.7 m. Ortho-photo maps at a scale of 1:10.000 and digital elevation models with a 30 m grid are being produced of all glaciers of the new inventory and of the majority of the old one. Maps of surface elevation changes capture the remnants of the positive balances that prevailed up to 1982 on the tongues of some glaciers while most of them display sinking of the surfaces of the firn basins.

Ice thickness was determined by surface based radio-echo sounding for a limited number of glaciers comprising representative specimens of plateau, valley and cirque glaciers. Total volume will be determined from area-volume scaling, preliminary results giving a relatively high power of 1.45. Maximum depth was 275 m on a glacier of 18 km2 surface area.

Test glaciers show good agreement of 30 years volume changes with simultaneous direct mass balance determinations, approaching 1 m water equivalent losses throughout the past decade. Models of energy fluxes, mass balance and ice dynamics are applied in order to understand the climatic forcing of the 1969 to 99 changes of the glacier surfaces.

IP31A-11 1145h

Ice Dynamics During Svalbard Surges Using Satellite Radar Interferometry

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Svalbard surges are known to be of long duration and relatively low speed compared to surges in other regions. We present results from dual azimuth satellite radar interferometry that reveal ice dynamics during the 1990s surges of two Svalbard glaciers, Monacobreen and Fridtjovbreen. Surge initiation and termination were progressive, with approximately linear acceleration and deceleration. Surge initiation was more rapid than termination, which occurred over 4+ years. At both glaciers the velocity and strain rate increased by more than an order-of-magnitude during the surge and there was no indication at either of a surge front travelling downglacier. The spatial pattern of both velocity and strain rate was remarkably constant, and was probably controlled by bedrock features. From these results, and those published in the literature, we attempt to reconstruct a typical Svalbard surge cycle and compare this to published surge dynamics from other cluster regions, especially that of Variegated Glacier in Alaska. Surge dynamics at Svalbard glaciers are in marked contrast to the observed surge of Variegated Glacier, which started rapidly and terminated over a period of only a few days. At Variegated Glacier, the rapid velocity transitions are thought to result from switches in the basal hydrological system from a distributed high pressure linked cavity system to a lower volume and pressure system of tunnels. We argue that the strong contrast in dynamics between Svalbard and Alaskan surges suggest that there are at least two markedly different types of glacier surges. We further suggest that it is very unlikely that the same surge mechanisms are involved. This result has implications for studies of populations of surge-type glaciers that attempt to disentangle surge controls, especially if both mechanisms operate in some surge clusters.

IP32A MC: 125 Wednesday 1330h

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Presiding: **A Nolin**, CIRES/NSIDC; **T Scambos**, CIRES/NSIDC

IP32A-01 1330h INVITED

Featured Presentation: Sea Ice Datasets at NSIDC: From Yearbooks to Digital Catalogs

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There is no abstract available for this presentation.

IP32A-02 1350h

The North Pole Environmental Observatory

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The Arctic environment is changing. The North Pole Environmental Observatory (NPEO) was established as a type of program of long-term observations required to understand Arctic change. The North Pole region was chosen because it is central to observed changes, there is a reasonable past history of measurements, and there is often a large gap there in the coverage of surface measurements. NPEO has three main components, (1) an automated drifting station composed of several buoys to measure atmospheric, upper ocean, and ice variables, (2) a sub-surface mooring at the Pole measuring ocean properties and ice draft, and (3) an airborne hydrographic survey that provides a snapshot spatial description of upper ocean properties.

The first observatory was established at the Pole in April 2000 by aircraft flying out of Alert. The drifting station portion consisted of ocean ice and meteorological buoys. Over one year the drifting station passed south through Fram Strait and stopped operating in the Greenland Sea. The airborne hydrographic survey made 6 stations between Alert, the Pole, and beyond. The sub-surface mooring was not deployed. In 2001 the drifting station was similar, but the operation was expanded to deploy a 4000-m mooring at the Pole. The mooring includes current meters, C-T sensors, ADCP,