IP22A MC: Hall D Tuesday 1330h

Glacier Change: Rates and Resolution I *(joint with H, GC)*

Presiding: **J S Kargel,** United States Geological Survey**; D Hall,** NASA Goddard Space Flight Center

IP22A-0680 1330h POSTER

Observability of Antarctic Surface Temperature Variations on Decadal Time Scales, With High Spatial Resolution, Using Satellite Observations of Thermal Microwave Emission and Sparse Ground Measurements

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Knowledge of Antarctic surface temperature variations in space and time is presently based on instrumental records and interpretation of ice cores, both of which are, by practical necessity, sparse point measurements. The sufficiency of spatial sampling by such measurements remains uncertain. Spatially extensive satellite observations of 0.8 cm-wavelength (37 GHz) thermal emission can be interpreted in terms of snow surface temperature to address this problem, but such interpretation is presently limited in two important respects: (1) interpretation is restricted to regions of space and time near instrumental or other independent temperature data that are needed to infer an effective microwave emissivity; and (2) the record of suitable observations extends back only 22 years, a duration which is short compared to the timescale of many prospective temperature variations of interest.

The first limitation can be addressed by estimating long-term (centennial-scale) mean surface temperature independently from satellite observations of 4.5 cm-wavelength (6.7 GHz) emission. I present the essential physical and observational validation for this estimation, and show how, together with the shorter wavelength observations, the estimation can be used to characterize microwave emissivity at 0.8 cm-wavelength (for a simplified, though usefully approximate model in which firn properties are independent of depth within the range from which the shorter-wavelength emission originates). The second limitation can be addressed using emission observations at wavelengths longer than 0.8 cm - in particular, emission at 1.8 cm - and longer-wavelengths (i.e., frequencies of 19 GHz and lower) carries information on temperature variations on decadal scales. I present a simple calculation that shows how this occurs, and note approximate agreement of the calculation with recent results by Shuman and by Fahnestock and co-workers.

The underlying physics thus supports, in principle, the use of existing and prospective satellite microwave emission observations to characterize ice sheet temperature variations during a significant part of the 20th century - the key question is whether available accuracies compare well with the expected magnitudes of such temperature variations. I address this question using basic but modern geostatistical methods to estimate the accuracy of calibration of the satellite temperature estimates using sparse ground observations. From this follows directly an assessment of the observability of Antarctic surface temperature variations on decadal time scales, both with present data and with data likely to become available in the next decade.

IP22A-0681 1330h POSTER

Surface Temperature Increase of the Greenland Ice Sheet in Recent Years

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The annual mean air temperature for the central part of the Greenland ice sheet is 2 degrees Celsius warmer for the time period 1995-1999, as compared earlier station observations standardized to the 1951-1960 period. This annual mean temperature change decreases to approximately 1 degree Celsius for elevations between 1000-2000 m. The analysis is based on Greenland ice sheet automatic weather station (AWS) data. The National Centers for Environmental Prediction (NCEP) 30-year record of global analyses of atmospheric fields was compared with the more recent AWS measurements. The cumulative NCEP temperature deviations for the last six (1995-2000) years at sea level show strong warming for the entire ice sheet during the months April - June as compared to the 1970-1994 time period. The warming trends derived from the NCEP data sets are validated against AWS in situ measurements; Results will be presented for several elevation zones of the Greenland ice sheet.

IP22A-0682 1330h POSTER

Investigation of Changes in Active Glaciers at Small and Large Scales: Observations from Helheimgletscher, East Greenland, Compared to Results from Jakobshavn Isbræ, West Greenland

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Active outlet glaciers are the instability points in the Greenland Ice Shield. Study of ice dynamics, surface processes, productivity, advance/retreat, and elevation change requires a combination of satellite and field observations to cover a range of scales. Sufficient regional coverage is needed as much as detailed measurements of high-resolution ice-surface processes. We employ a suite of technologies, data, and methods.

Synthetic Aperture Radar (SAR) data are analyzed by application of geostatistical surface classification. Structural glaciology, an approach combining structural geology and continuum mechanics principles, promotes an understanding of ice-dynamical provinces, in particular of fast-moving glaciers, based on analysis of SAR data, videographic data, and GPS-registered photography. Microtopographic measurements of the ice surface (Glacier Roughness Sensor (GRS) data) provide subscale information for satellite data not otherwise obtainable. Changes in location and extension of surface provinces, including ablation areas, blue ice fields, sastrugi fields, and crevasse fields can be mapped and monitored. Largely due to logistical advantages, West Greenlandic glaciers have been favored by scientific expeditions in the past. While glaciers with the largest calving rate are located in West Greenland, significant mass discharge and elevation change is occurring also along the eastern margin of the inland ice. This summer (2001) we investigated Helheimgletscher and neighboring glaciers in the Sermilik area. Helheimgletscher is one of the most active East Greenlandic glaciers. It is distinguished as the glacier with the highest velocity and the largest calf-ice production in the area with maximal thinning rates along the East Greenlandic coast. While all other glaciers in the Sermilik area have been retreating, Helheimgletscher has experienced a substantial advance during the 20th century. Results from the Helheimgletscher data are compared to results from our work on Jakobshavn Isbræ (1996-1999, MICROTOP Expeditions).

IP22A-0683 1330h POSTER

Recent Changes in Surface Area of the Devon Ice Cap, Nunavut, Canada

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Identifying geometric changes of an ice cap over time provides insight into understanding the current behaviour of the ice mass and predicting the long-term response patterns to climate trends. Multi-temporal image data from 1960 and 1999 used to quantify recent changes in areal extent of the Devon ice cap, Nunavut reveal a net decrease in surface area over the last 40 years. Advance of the north-west margin however, highlights the variable response patterns characteristic of this ice cap. A DEM of the ice cap surface was employed to delineate drainage basin boundaries enabling changes to be examined on a regional scale. Balance ratios calculated from basin hypsometry for 4 selected drainage basins show high correlation (r2 = 0.898) with percent area change suggesting that topographic setting and position of the ELA strongly influences ice boundary dynamics. Changes detected in this study represent decadal scale response patterns to climate forcing however intermediate observations (or more frequent observations in the future) would be beneficial for separating short-term fluctuations from long term trends.

IP22A-0684 1330h POSTER

Satellite Monitoring of Melt on Mid-Latitude Mountain Glaciers: A Case Study in Alaska

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Satellite observations from high resolution visible images, synthetic aperture radar (SAR) and passive microwave instruments such as the Special Sensor Microwave/Imager (SSM/I) make it possible to assess glacier melting at a range of spatial and temporal scales. The mass balance of mid-latitude mountain glaciers integrates the effects of numerous climate factors that are often difficult to monitor in remote areas. Glacier melt (ablation) is an important component of the mass balance equation that can be monitored using a multi-sensor approach. Changes in late summer snowline altitude have been used to determine relative mass balance for 22 outlet glaciers on the Juneau Icefield starting with one of the earliest Landsat Multispectral Scanner (MSS) images (1973). Over the last 3 decades few cloud-free late summer images exist. Active and passive microwave satellite data help fill these gaps. An extensive collection of C-band (5.6 cm wavelength) SAR images of Alaskan glaciers has been developed at the Alaska SAR Facility. SAR data of the Juneau Icefield show clearly the spring melt onset and the progression of melt throughout the melt season. They are used to identify and understand later stages of snowpack metamorphism, snow disappearance, and surface refreeze. With care, winter SAR data can supplement high resolution visible data for snowline determination. High resolution visible images are available, at most, a few times per decade, and SAR images are available on a monthly to seasonal scale. Melt dynamics, however, have strong daily and weekly variations. Seasonal melt onset is identified with greater precision using regional passive microwave data. Frequent (twice daily) observations with 37 GHz SSM/I brightness temperatures and diurnal amplitude variations also enable study of the meteorological complexity of the melt onset process, refreeze timing, and diurnal melt dynamics. Measurements of regional melt onset and refreeze timing suggest a variable ablation season length that may have lengthened between 1988 and 1998. Late summer snowline observations show major altitude variation since 1973, with extremely low levels in 1986 and high levels in 1995. The high snowlines in 1995 may correspond with a regional increase in melt intensity observed in southeast Alaska. These three approaches to glacier monitoring show the importance of assessing the melt component of glacier mass balance at a variety of scales. Individual glaciers vary significantly, so it is valuable to incorporate the details into a regional view.

IP22A-0685 1330h POSTER

Hubbard Glacier Will Block the Entrance to Russell Fiord, Alaska

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Hubbard Glacier, near Yakutat in southeastern Alaska, is about 120 kilometers long and is the largest tidewater calving glacier in Alaska. The persistent advance of Hubbard Glacier since 1895 or earlier eventually will close the entrance to Russell Fiord for hundreds of years into the future. Determining the rate of advance of Hubbard Glacier from short-term data is complicated by relatively large spatial variability across the width of the terminus and by a seasonal advance and retreat amplitude of almost 100 meters that is superimposed on the long-term advance of a few tens of meters per year. Spatial variability is largely addressed by evaluating width-averaged terminus positions that are expressed as glacier lengths. The effect of seasonal variations can be reduced by comparing terminus positions determined during similar parts of a year. Comparing approximately 50-year periods, the average rate of advance has accelerated from about 16 meters per year between 1895 and 1948 to about 26 meters

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per year between 1948 and 1998. During shorter periods, the advance is spatially and temporally erratic. For example, an average advance of 32 meters along the 6-kilometer-wide terminus facing Disenchantment Bay between August 1988 and July 1990 contrasts with an advance of 111 meters along the 2.8-kilometer-wide Russell Fiord terminus during the same period. The terminus facing Disenchantment Bay exhibited an extreme temporal rate change during the decade 1990-99; the rate of advance changed from an average of about 4 meters per year between July 1990 and July 1998 to the sharply contrasting rate of 149 meters per year between late July 1998 and early August 1999. This recently recognized erratic nature of short-term advance rates makes them unreliable as a basis for closure forecasts. Indeed, three published forecasts made during the 1990s have failed. The 100-year average advance rate is approximately 22 meters per year for most of the terminus and about 19 meters per year toward the closure point. Because Hubbard Glacier must advance about 300 meters across a narrow channel that is swept by severe tidal currents before it can block the entrance to Russell Fiord, normal glacier flow is not likely to cause a closure before 2020.

IP22A-0686 1330h POSTER

Glacier Inventory Update at Popocatpetl volcano, Mexico by Digital Photogrammetry: Documentation of Glacier Extinction

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Monitoring of glaciers at volcanoes at inter-tropical latitudes is very important for several reasons. Glacier fluctuations provide insights to the climate change in these latitudes. Also, inventory of glaciers at volcanoes allows evaluation of hazards during eruptive periods. However, glaciological work is a difficult task during eruptions and becomes hazardous to researchers. In this context, a tool such as digital photogrammetry helps in fast, accurate and safe updating of glacier inventories. Popocatpetl volcano's glaciers have been studied during the last decade but after the onset of the present eruption in late 1994 glaciological work has been very difficult and at the same time, very much needed for debris-flow-related risk assessment. Glacier tongues have retreated strongly for their size but have reached the maximum elevation they could before they started to decrease in volume by thinning. The morphology of the glaciers has changed from a lobed-hanging glacier to a chaotic series of elongated seracs of a range of dimensions and forms. They trend always perpendicular to the slope. Aerial photographs obtained on December 16, 2000 were processed by digital photogrammetry and the estimated total glaciated area resulted in 0.255 km2 (< 0.25 km2 correspond to Ventorrillo Glacier and the rest to Noroccidental Glacier). The decrease in glaciated area since the first inventory represents 72 % of the total area reported in 1958. This information allows to state that the current glacier retreat precludes their extinction. Studies made for the last 7 years of eruptive activity reveal a strong glacier retreat forced by global, regional, and local climate changes, as well as by volcanic activity.

IP22A-0687 1330h POSTER

Response Time for Glacier Mass Balance

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Interannual fluctuations in mass balance, since they do not involve the sluggish mechanism of ice flow, are sometimes considered the "undelayed" response of glaciers to climate forcing. However, nonzero mass balance is indicative of a *disequilibrium*, between present climate and present glacier state. Given a constant climate, this disequilibrium would decay, with a time constant similar to the glacier adjustment time. Taken together with the negative correlation between globally averaged values of temperature and mass balance, the increasingly negative balances of recent decades indicate a climate that is warming more rapidly than glaciers are capable of adjusting. A mass-balance response time on the order of decades is indicated for the global glacier inventory, but data quality limits the precision with which this parameter can be specified.

IP22B MC: Hall D Tuesday 1330h

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

Presiding: **G Scharfen,** CIRES/NSIDC**; R Weaver,** CIRES/NSIDC

IP22B-0688 1330h POSTER

Mapping Snow Grain Size and Albedo on the Greenland Ice Sheet Using an Imaging Spectrometer

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The Hyperion sensor is an imaging spectroradimeter with 220 spectral bands over the solar spectrum. The instrument is on-board NASA's Earth Observing-1 (EO-1) satellite and has acquired numerous images over the Greenland ice sheet. We use Hyperion spectral data from the range 0.98 - 1.06 microns to compute the scaled area of spectral absorption feature that is centered at 1.03 microns. The scaled area of this ice absorption feature is highly correlated with the optically-equivalent snow grain size and thus can be used to quantitatively estimate grain size for homogeneously snow-covered pixels under clear sky conditions. We present Hyperion-derived snow grain size estimates for several locations on the Greenland ice sheet. Furthermore, estimates of spectral albedo are derived by using these snow grain size estimates as input to a radiative transfer model. Broadband albedo is computed by direct integration of the spectral albedo values and then compared with concurrent in situ measurements of broadband albedo. Inferring albedo from measuring grain size is likely to be more accurate than albedo determinations from traditional methods.

IP22B-0689 1330h POSTER

Comparison of Snow Albedo from MISR, MODIS and AVHRR with ground-based observations on the Greenland Ice Sheet

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The surface albedo is an important climate parameter, as it controls the amount of solar radiation absorbed by the surface. For snow-covered surfaces, the albedo may be greater than 0.80, thereby allowing very little solar energy to be absorbed by the snowpack. As the snow ages and/or begins to melt, the albedo is reduced considerably, leading to enhanced absorption of solar radiation. Consequently, snow melt, comprises an unstable, positive feedback component of the climate system, which amplifies small pertubations to that system. Satellite remote sensing offers a means for measuring and monitoring the surface albedo of snow-covered areas. This study evaluates snow surface albedo retrievals from MISR, MODIS and AVHRR through comparisons with surface albedo measurements obtained in Greenland. Data from automatic weather stations, in addition to other in situ data collected during 2000 provide the ground-based measurements with which to compare coincident clear-sky satellite albedo retrievals. In general, agreements are good with the satellite data. However, satellite calibration and difficulties accurately representing the angular signature of the snow surface make it difficult to reach an albedo accuracy within 0.05.

IP22B-0690 1330h POSTER

The Radiation Paradox at Summit Camp, Greenland?

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Clouds play an enhanced role in governing surface radiation balances in the dry polar atmosphere, yet their frequency, thermodynamic properties and radiative properties are poorly understood over Greenland. In the dry snow regions of Greenland, a net warming effect is expected from cloud cover - the effect known as the radiation paradox. This research investigates the occurrence of the radiation paradox at Summit Camp, Greenland using data from two instruments that were installed during the summer 2001 field season. A whole sky imager captures a digital sky image, quantifying the cloud cover each minute. A ceilometer sounds the atmosphere with a laser pulse, monitoring cloud base height every 15 seconds. These high frequency measurements, together with a sophisticated surface radiation data set, constitute a new means for evaluating the net effect of clouds on the surface radiation budget over snow and ice. The ceilometer serves as a useful guide for partitioning the effects of clouds at different heights above the surface. Results will be presented focusing on the diurnal variability of the radiation paradox and its relationship with cloud height.

IP22B-0691 1330h POSTER

Controls on Surging in East Greenland Derived From a new Glacier Inventory

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Glacier surging is often classified as a distinct type of bimodal flow behaviour. Yet, studies of surging show a spectrum in surge behaviour, where initiation and termination, as well velocity development and periodicity can vary greatly from glacier to glacier. It is clearly possible that different classes of surge behaviour involve different controls on glacier flow. Environmental and glacial characteristics that distinguish surge-type from normal glaciers can serve as benchmark data to test surge theories and to identify boundary conditions for surging. Different regional glacier population analyses have revealed that surge potential is controlled by a combination of glacier geometry, local climate, thermal and substrate conditions. In this study we use the results of multivariate logit modelling of a surge cluster in central East Greenland and compare the controls on surging in this region to those found for other regions.

Central East Greenland is characterised by a variety of glacier types, such as small icecaps and valley glaciers, and large dissection glaciers draining local ice plateaux. Many of these are tidewater terminating and former surges have caused extreme calving events. For 258 local glaciers, of which 71 are of surge type, a suite of glacial and environmental factors were analysed. These data were collected from remotely sensed data (SAR ERS 1/2 and Landsat 7 images), aerial photographs and maps and were assembled in a GIS. This provides a baseline digital glacier inventory for East Greenland. Variables of interest are geologic controls (eg. physical properties), geometric controls (eg. glacier type, shape and complexity) and mass balance related properties. This study uses a range of variables previously tested for Svalbard surge controls (Jiskoot et al., 2000), and in addition focuses on variables representing glacier complexity, such as channel curvature, tributary arrangements and shape factors. Results show that geologic boundary conditions for surging vary greatly between cluster regions, whereas geometric controls show remarkable similarities. This study provides new insights into controls on ice dynamics and flow instabilities.

IP22B-0692 1330h POSTER

Autonomous Measurements of Ice Mass Balance

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