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 paleoslope, 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.

C11C-0823 0830h POSTER

Spatial Patterns of Frozen vs. Sliding Basal Conditions of the Northeastern Laurentide Ice Sheet

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Cosmogenic exposure (CE) dating and glacial-geologic mapping along northeastern Baffin Island, Arctic Canada, indicate sharp contrasts in Laurentide Ice Sheet (LIS) basal flow dynamics during the last glaciation. Northeastern Baffin Island is characterized by glacially-scoured fiords with inter-fiord landscapes that exhibit advanced bedrock weathering characteristics. CE ages of erratics indicate that both the fiords and inter-fiord regions were covered by the LIS during the last glaciation. However, CE ages of bedrock in both settings indicate that while the fiords held erosive ice, adjacent plateaux were covered by non-erosive and presumably frozen-bedded ice. This contemporaneous juxtaposition of sliding and non-sliding ice suggests that ice streams may have drained the northeastern LIS during the last glaciation. The sharpness of the boundary between eroded and uneroded bedrock, in places <1 km, and the longitudinal elevation gradient of this boundary, which decreases seaward, help to constrain ice sheet geometry. Differentially-weathered landscapes, like those along northeastern Baffin Island, may be good locations to study bed conditions of former "fixed" ice streams. In addition, these ice streams of the past provide possible analogues for the basal flow dynamics of contemporary "fixed" ice streams.

C11C-0824 0830h POSTER

Reversal of ice-stream surface slope: constraints from a simple model.

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Here we use a simple model to examine the conditions for which an ice shelf, once grounded on a sill, will develop an ice-air surface slope reversal. Such reversals are of interest because subglacial water flow is sensitive to the potential gradient from the ice-air surface slope and so is strongly affected by the slope reversal. We use a non-dimensional, 1-d model of the coupled mass and momentum balance of ice flowing over a transition from a subglacial lake to a flat bedrock sill and then to an ice shelf. The model produces slope reversals for reasonable parameter values. Two key paramters are dimensionless numbers which measure the importance to ice flow of thickness gradients and basal drag, respectively; the prescribed boundary conditions are also of import. Strong positive feedbacks are suggested by these results. For potential subglacial lakes, ice-sheet thinning or cooling favor development of surface-slope reversals that contribute to lake trapping. Similarly sticky spots may produce surface-slope reversal, water diversion and increased flow resistance. Conversely ice-stream thickening or warming favor loss of surface-slope reversals, throughflow of basal meltwater with both lubricating and warming effects, and loss of subglacial lakes and sticky spots.

C11C-0825 0830h POSTER

Hercules Dome - An Overview From the US-ITASE Deep Radar

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Hercules Dome (86°S, 105°W) is an elongated, approximately 100 m local rise in the ice surface topography between the Horlick and Thiel Mts. about 400 Km from S. Pole and 100 Km up-flow from "The Bottleneck" linking the East and West Antarctic Ice Sheets. It was first identified by the USGS from USN aerial photographs taken in 1959-60 and further delineated by the SPRI-NSF-TUD airborne aerial radio echo sounding program in 1967-79. The Ice Core Working Group identified Hercules Dome in reports dating from the late 1980's as a possible site for a deep ice core because of its location at the boundary between the East and West Antarctic Ice Sheets where it may have the possibility of showing changes in the WAIS over the last 200,000 years. Recent interest has been rekindled because of the US-ITASE traverse which has provided the first ground-based observations of the area. We completed 120 km of radar profiling in an elongated grid pattern approximately 5 by 50 Km and roughly perpendicular to the main ITASE traverse route from Byrd to South Pole. Bed topography and internal stratigraphy down to 70% of the ice thickness is well-depicted in these surveys and we have picked the bed and a number of prominent, continuous internal layers from these profiles. These data reveal that Hercules Dome is approximately centered over a bedrock low, possibly a basin, some 30-50 Km in extent. The greatest ice thickness under the dome area is 2800 meters with bedrock elevations 200 meters below sea level. Within 15 to 25 Km in each of the directions surveyed, the bed rises 900 to 1400 meters from the low under the dome. Internal stratigraphy is well-behaved throughout the dome region in contrast to nearby areas along the traverse route which show marked disruptions of internal layers (Welch et al., this session). Although model studies will be required to explore details more fully, it appears that ice flow in the vicinity of the dome has not undergone major changes throughout at least the period of time represented by the upper 2000 meters of ice thickness. Other US-ITASE experiments should soon be providing additional glaciological information on Hercules Dome including modern accumulation rates, shallow radar, ice core chemistry and surface velocity.

URL: http://www.stolaf.edu/other/cegsic/itase/

C11C-0826 0830h POSTER

Radar evidence for stability of the Ross/Amundsen ice flow divide of the West Antarctic ice sheet.

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The marine-based West Antarctic ice sheet is likely the dominant contributor to past and possibly future rapid sea level changes. West Antarctic ice primarily flows westward to the Ross Sea, northward to the Amundsen Sea, and eastward to the Weddell Sea. Observations of dramatic thinning at the grounding lines of the Pine Island and Thwaites glaciers suggest that presently the Amundsen Sea catchment may be well out of balance. The Ross Sea catchment is currently in balance to within measurement uncertainty, although its grounding line has retreated by approximately 1000 km since the last glacial maximum, approximately 15,000 years ago. Such large-scale changes of the ice sheet margin configuration may also be expressed by movement of the divide that separates the flow of ice into these two catchments. Recovering a history of any such divide migration through the Holocene may shed light on the Ross-side retreat history, or alternatively, a recently activated migration may provide information about the current Amundsen Sea catchment imbalance. Ross/Amundsen flow divide migration is of particular interest since this is the site chosen for the second WAISCORES deep ice core. During 1999/2000, we conducted a series of airborne radar surveys of the Ross/Amundsen flow divide region with the objective of detecting stratigraphy patterns indicative of flow divide migration. The surveys consisted of continuous radar profiles along 12 curvilinear paths that follow local ice flow direction while maintaining constant terrain clearance. Such along-flow surveys facilitate flow-band modeling studies for quantitative determination of divide stability and or migration. Each of these approximately 120 km long lines were surveyed twice, once with equipment parameters set to optimize maximum ice penetration (for deep layer and bed detection) and once with settings to optimize near-surface resolution of stratigraphy (for enhanced temporal resolution). Imaged stratigraphy in the upper half of the ice column gives a record of the flow divide position over the past approximately 4 ka. We will discuss this evidence for relative stability of the divide position and its implications for post-glacial retreat of the West Antarctic ice sheet.

C11C-0827 0830h POSTER

InSAR observations of Ice Stream A: dispensing with the surface parallel flow assumption

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To date InSAR obvservations of ice flow have used pairs or triplets of observations from both ascending and descending satellite orbits. Employing the surface parallel flow assumption together with a digital elevation model (DEM) has been the only means to derive three dimensional ice flow. We present a new method of deriving 3-D flow from InSAR observations alone, by using multiple crossing orbits close to the South Pole, as acquired during the left-looking Radarsat Antarctic Mapping Project (RAMP) in the fall of 1997. We present the technique and compare our three dimensional results to conventional ascending/descending surface parallel flow assumption results, particularly in regard to vertical ice motion. Our study is centered on Ice Stream A, West Antarctica, giving us an insight into the implications for ice sheet and ice stream velocity mapping.

C11C-0828 0830h POSTER

Velocities along Byrd Glacier, East Antarctica, derived from Automatic Feature Tracking

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Automatic feature tracking techniques are applied to recently acquired ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery in order to determine the velocity field of Byrd Glacier, East Antarctica. The software IMCORR tracks the displacement of surface features (crevasses, drift mounds) in time sequential images, to produce the velocity field. Due to its high resolution, ASTER imagery is ideally suited for detecting small features changes. The produced result is a dense array of velocity vectors, which allows more thorough characterization of glacier dynamics. Byrd Glacier drains approximately 20.5 km3 of ice into the Ross Ice Shelf every year. Previous studies have determined ice velocities for Byrd Glacier by using photogrammetry, field measurements and manual feature tracking. The most recent velocity data is from 1986 and, as evident in the West Antarctic ice streams, substantial changes in velocity can occur on decadal time scales. The application of ASTER-based velocities fills this time lapse, and increased temporal resolution allows for a more complete analysis of Byrd Glacier. The ASTER-derived ice velocities are used in updating mass balance and force budget calculations to assess the stability of Byrd Glacier. Ice thickness information from BEDMAP, surface slopes from the OSU-DEM and a compilation of accumulation rates are used to complete the calculations.

C11C-0829 0830h POSTER

Glaciers of Larsen B embayment area show marked speed-up since shelf collapse

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Satellite images spanning the period before, during, and after the break-up of the Larsen B ice shelf in March, 2002, show a flow speed increase of several glaciers feeding the now-disintegrated shelf area. Further, the rate of speed-up increased in the months after shelf collapse. Landsat 7 band 8 images (15m pixel size) from 27 Jan 2000, 06 Dec 2001, 06 Apr 2002, 18 Dec 2002, and 20 Feb 2003 were used in an image correlation feature-tracking algorithm to gather the ice motion data along flow centerlines. Crane Glacier, a glacier near Caution Point peninsula, and the Hektoria-Green-Evans glacier system all showed evidence of speed-up. Leppard Glacier, feeding into the remaining southern section of the Larsen B shelf, showed no change in speed over the period. Speeds in the lower portions of the Crane Glacier (for example) increased from 1.7 m/day (27 Jan 2000 to 06 Apr 2002) to 3.1 m/day (06 Apr 2002 to 18 Dec 2002) and then 4.1 m/day (18 Dec 2002 to 20 Feb 2003). Leppard Glacier's lower trunk remained at 1.2 m/day through the same period. Errors in flow speeds are no worse than 10% for the shortest time-interval pair, and much better for other pairs, due to excellent image co-registration on stationary rock features flanking the glaciers. Measurements across all image pairs give consistent results. The results imply:

that ice shelf removal has a significant, rapid effect on feeder glacier flow; that the removal of the ice shelf directly affects glacier force balance; and that climate-related shelf removal for other shelves fed by larger ice streams will likely result in a rapid speed-up of those glaciers and a change in the mass balance of the adjacent ice sheet.

URL: http://nsidc.org/agdc

C11C-0830 0830h POSTER

Airborne Radar Sounding Studies of a Subglacial "Lake" Near South Pole Station, Antarctica

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Radar ice sounding transects have revealed what appears to be a subglacial lake beneath 2800 meters of ice 10.5 kilometers from the South Pole. It has been proposed that sterile drilling be tested at this lake, a location accessible from the existing South Pole Station. Not only would this allow for techniques to be tested before risking contamination of Lake Vostok, but there is also the possibility of finding exotic microorganisms in a permafrost-like bed. Other workers have concluded that the lake is frozen by analyzing temperature measurements in the South Pole ice and extrapolating a base temperature at the "lake" using several different models. Here, we attempt to determine the material of the lake by extracting its properties through a complete solution to the radar equation. The radar equation accounts for all the factors that influence the returned echo strength, including radar system parameters and propagation effects. The largest unknown quantity is the ice loss, which depends on the temperature and impurities throughout the ice. For this analysis, we use temperature profiles corresponding to both a frozen and a liquid base and several possible dielectric loss models to compute ice loss. The strength of the returned echo is also affected by the material making up the "lake" and its roughness. The reflection coefficients calculated for a temperature profile allowing melt are not consistent with a glacier/liquid-water interface, thus implying that this "lake" is indeed frozen. Further analysis of the reflection coefficients indicates that they correspond to impure ice, and local topography suggests that this feature is possibly an ancient lake.

C11C-0831 0830h POSTER

What can Subglacial Sediment Tell us About the Underlying Geology and the Dynamic of the West-Antarctic Ice Sheet?

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The West-Antarctic Ice Sheet (WAIS) is the second largest ice sheet in the world. Its dynamic is extensively studied due to the proposed threat of rapid disintegration and associated sea level rise (Mercer, 1971). Most of its ice drains through a few fast flowing (> 100 m/yr) ice streams and outlet glaciers. Subglacial conditions in particular the distribution of basal water and the availability of subglacial sediment plays an important role for their location and extent. Subglacial geology in particular the distribution of sedimentary basin fill, providing material for a lubricating subglacial till layer, may pose a limit on the inland extent of the fast flowing ice stream. Subglacial volcanism and associated elevated geothermal heat fluxes may provide crucial subglacial melt water for ice stream lubrication. We have studied sediment from the base of the WAIS to elucidate questions about the existence of subglacial volcanism and to determine the provenance of the subglacial sediment. Within this study we measured clay mineralogy, sand petrography, magnetic and geochemical properties of subglacial and englacial sediment from different locations in the Ross Sea-catchment area of the WAIS. Our samples come from Whillans-, Kamb- and Bindschadler Ice Stream as well as from Siple Dome, Crary Ice Rise and Byrd Station. Most of our sediment samples represent samples of subglacial till, which in earlier studies have been characterized as reworked marine sediment of Cenozoic age. The englacial sediment samples come from basal ice. Our study so far has found no positive evidence for the existence of subglacial volcanism beneath the WAIS. The mineralogy as well as the REE-pattern of our samples correspond better with a crustal source for the sediment than Cenozoic basalts. The isotopic composition of our samples (Nd/Sm, Rb/Sr) show differences between individual ice streams locations as well as differences between different grain size fractions. TDM-ages range from 900 Ma to 1800 Ma; ENd between -4 to -12 and 87Sr/86Sr 0.715 to 0.735. Our preliminary geochemical results so far point to rocks from outcrops in the upstream areas of the individual ice streams as provenance for their sediment (Horlick Mountains and Whitmore Mountains) with a possibly small East-Antarctic component.

C11C-0832 0830h POSTER

A 3-D Thermomechanical Ice-Sheet Model: Preliminary Simulation of the Antarctic Ice Sheet With the Goldsby-Kohlstedt vs. Glen Flow Laws

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We have developed a 3-D coupled time- and temperature-dependent ice-sheet model (still in preliminary form) in which the Goldsby-Kohlstedt (2001) and Glen flow laws can be employed interchangeably. D. Goldsby and D. Kohlstedt found that the constitutive equation for ice is best represented as a nonlinear combination of 4 terms, representing (i) dislocation climb (for which the stress exponent n = 4), (ii) grain size-dependent grain boundary sliding (GBS)-accomodated basal slip (n = 1.8), (iii) basal slip-accommodated GBS (n = 2.4), and (iv) diffusional flow (n = 1). Each term is similar in form to Glen's flow law, but the 4 creep processes are characterized by differing values of material parameter, activation energy, stress exponent, etc. We have verified our model by reproducing the results of EISMINT experiment A, as summarized in Table 4 of Payne et al. (2000), for the case of Glen's flow law. In addition, new analytical solutions have been derived (by E.L.B.) for the cases of (i) a time-dependent, isothermal, circular ice sheet on a flat bed with a mass balance of zero, having all mass concentrated in a delta function at the origin at time zero, and (ii) a coupled time- and temperature-dependent circular ice sheet on a flat bed, with a non-zero distribution of mass balance. In both cases, the ice rheology is represented by Glen's flow law. We find that our model reproduces these analytical solutions, which provide a means for verifying the correctness of thermomechanical ice-sheet models without resorting to intercomparison exercises (e.g., Huybrecht et al., 1996; Payne et al., 2000). The cause of the "spoked" patterns of simulated basal melting that are characteristic of time-dependent temperature-coupled ice-sheet models with idealized geometries consisting of circular ice caps on flat beds has been identified (see e.g. Payne et al., 2000), and a method for resolving this problem has been developed (by J.A.K.-B.). Comparisons of the Goldsby-Kohlstedt vs. Glen flow laws have been carried out for the time evolution of idealized circular ice sheets on flat beds. Preliminary time- and temperature-dependent simulations of the Antarctic ice sheet using the Goldsby-Kohlstedt vs. Glen flow laws will be summarized. References: Goldsby, D.L., and D.L. Kohlstedt. 2001. Superplastic deformation of ice: experimental observations. J. Geophys. Res., 106(B6), 11017-11030. Huybrecht, P., T. Payne, and The EISMINT Intercomparison Group. 1996. The EISMINT benchmarks for testing ice-sheet models. Ann. Glaciol., 23, 1-12. Payne, A.J., and 10 others. 2000. Results from the EISMINT model intercomparisons: the effects of thermomechanical coupling. J. Glaciol., 46(153), 227-238.

C11C-0833 0830h POSTER

Temperature dependence of the grain boundary migration in ice bicrystals

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The grain boundary (GB) migration plays a very important role in the texture and fabrics in the glacier and polar ice (Gow A. et al 1997). The study of the GB migration in bicrystalline samples permits the investigation of this complex phenomenon with more details. In this work, the GB movement under the influence of surface was studied in pure bicrystalline ice samples. The bicrystals having a $< 1010 >/60^0$ crystalline misorientation were annealed at -5^0C, -10^0C, -15^0C, -20^0C in a silicone oil bath for 170 days. The results obtained were analyzed using the GB movement equation with the Sun and Bauer configuration (Sun and Bauer 1972), driven by capillarity under the retarding effect produced by a diffusion-generated groove at the GB-surface intersection (Di Prinzio y Nasello 1998). Different temperatures GB mobility and the activation energy of the migration process were determined. The results were compared with the results obtained in grain growth in glacier ice.

C11C-0834 0830h POSTER

Study of the texture and fabric in the Taylor Dome ice core.

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A fully automated digital instrument for fabric analysis developed by Hansen and Wilen (2000) increases the quality and the quantity of c-axis fabric data from ice cores. The new data permit different mechanical and physical process in the ice cores to be studied statistically. Software tools are applied to analyze the textures and the fabrics in vertical and horizontal samples from Taylor Dome ice cores in the range 0 to 600 meters. The results show that the grain size increases with depth until the Holocene- Wisconsin boundary. The grain size distributions are very similar among all samples in the Taylor Dome ice core and the evolution of grain size in this depth range is consistent with the normal grain growth process. The samples exhibit correlation among nearest neighbors but their values are lower than the correlation in the GISP2 ice core, implying that polygonization and recrystallization are not particularly active, possibly because the temperature of the ice cores is lower than -40^oC (Alley, 1998). Hence, the results suggest that grain growth is the dominant mechanism to change the size of the grains. The samples exhibit a distinct band in the Schmidt Plot indicative of the stress state in the ice. On average, the maximum elongation direction of the crystal grains is oriented perpendicular to the band in the plot. The results from Taylor Dome are compared with other ice cores in order to understand the different mechanical processes in the ice.

C11C-0835 0830h POSTER

New Techniques: Muon Glaciology and Ultrasonic Logging

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The strain rate of cold glacial ice depends mainly on the stress tensor, temperature, grain size, and crystal habit. Lab measurements cannot be made at both the low stresses and low temperatures relevant to flow of cold glacial ice. Field studies with inclinometers measure only the horizontal components of flow. We have

developed a new method for measuring the 3D strain-rate field at -40° to -15°C, using the AMANDA neutrino-detecting array frozen into deep ice at South Pole. Each strain detector consists of a photomultiplier tube (PMT) in its pressure vessel. AMANDA has ~ 600 PMTs at depths 1500 to 2300 m in a ~ 0.02 km^3 volume. The coordinates of each PMT relative to a coordinate system moving down slope at 9 m yr^{-1} can be measured with s.d. < 1 m in 1 day by mapping trajectories of down-going cosmic-ray muons that pass through the array. The PMTs record the arrival times of the Cherenkov light emitted along the muon trajectory. Use of maximum likelihood for 10^5 muon tracks allows PMT positions to be determined; their positions are then updated at six-month intervals. We will report results of strain-rate measurements in three dimensions, made in 2000, 2001, and 2002 at $T \approx -30^\circ$C. Applying the same technique to the future 1 km^3 IceCube array, by averaging over subsets of the 5000 detectors, values of the strain-rate tensor as small as 3×10^{-5} yr^{-1} can be measured as a function of temperature and lateral position. The vertical strain rate due to snow accumulation, estimated to be $\sim 3 \times 10^{-5}$ yr^{-1}, can be measured and will serve as a check on the method. The second new method is designed to measure mean grain size in the ice surrounding a borehole. We will adapt an all-digital logging tool originally developed by Advanced Logic Technology (Luxembourg) for geophysics prospecting in rock boreholes. A 1.3 MHz transducer emits acoustic pulses horizontally into the ice in increments of 5° in azimuth and records the wave train back-scattered from grain boundaries. For fine-grained glacial ice, individual grains will not be resolved; instead, the amplitude of back-scattering as a function of time provides a measure of mean grain size. Data rate is $\sim$1 meter depth/minute. In addition, the logger can map borehole structure with 0.1 mm resolution. At depths down to $\sim$400 m, it measures air bubble concentrations, which can be related to local temperature at the time of firn close-off.

C11C-0836 0830h POSTER

Monitoring Polar Ice Change: First Results from GRACE

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The current state of ice mass imbalance in Antarctica and Greenland has significant implications for climate and global change. In this presentation, we discuss preliminary measurements of mass change in Antarctica and Greenland derived from GRACE measurements of the time-variable geoid. The measurements incorporate changes in ice mass due to combined accumulation and melting, effects of the Earth's continuing viscous response to past glacial loading, and leakage of other mass redistribution signals from adjoining regions. We compare these data with available model estimates of mass change, and we will discuss methods for combining the GRACE data with other geodetic measurements to isolate the contributions of time-variable accumulation, post glacial rebound and ice mass change. We will describe the characteristics of present-day mass imbalance and viscous rebound signals that are likely to be present in geodetic observations, and we will examine how to optimally combine time variable gravity from GRACE, altimeter measurements from ICEsat/GLAS, GPS measurements of vertical velocity, ice core measurements of compaction through time, radar-derived estimates of snow density and InSAR. We will discuss the strengths and limitations of combining different data sets.

C11C-0837 0830h POSTER

Global Land Ice Measurements from Space (GLIMS) Database at NSIDC

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Global Land Ice Measurements from Space (GLIMS) is an international project tasked with surveying a majority of the world's estimated 160,000 glaciers with data collected by the Advanced Spaceborne Thermal Emission and reflection Radiometer (ASTER) instrument aboard the EOS Terra spacecraft and the Landsat Enhanced Thematic Mapper Plus (ETM+). With National Aeronautics and Space Administration (NASA) funding, the National Snow and Ice Data Center (NSIDC) has developed the GLIMS glacier database. The database includes temporal measurements of glacier length, area, boundaries, topography, surface velocity vectors, and snowline elevation. The database design, data transfer specification, and ingest module are complete. Simple user interfaces for data submission and ordering are being tested. We are working closely with the United States Geological Survey on the development of GLIMS analysis software called GLIMSView. New funding from NASA, expected to begin in the next few months, will include support to: populate the database with new analyses from the world- wide network of GLIMS Regional Centers, add historical observations from the Former Soviet Union and China, enhance the user interface with an open systems GIS approach to make the data available, and validate the utility and quality of the database for glaciological science through selected regional scientific assessments. This paper describes these recent developments and new plans for GLIMS. The GLIMS database will provide an easy-to-use and widely accessible service for the glaciological community and other users needing information about the world's glaciers. http://www.glims.org/ and http://nsidc.org/data/glims/

URL: http://www.glims.org/

C11C-0838 0830h POSTER

New Tools for Analyzing Glacier Changes From Space

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Efforts to compile a comprehensive global glacier inventory, such as that being undertaken by the Global Land Ice Measurements from Space (GLIMS) project, require ready access to high-resolution satellite imagery as well as tools for performing analyses on these data. In this paper we describe a study of ice extent and volume changes for the Petrov glacier system of the Akshiyrak Range in the interior Tien Shan of Central Asia. Glacier outlines were digitized from an orthorectified ASTER imagery using a freeware tool, GLIMSView. A digital elevation model (DEM) was extracted from an ASTER scene acquired in October 2002. From these results we determine ice area as a function of elevation using GIS tools. The resulting hypsography is then used in conjunction with field measurements of mass balance for another glacier in the same range to estimate the mass balance for the Petrov glacier as a function of observed equilibrium line altitude, and thus to predict how climate change will impact the hydrology of the region.

URL: http://glims.org

C11C-0839 0830h POSTER

An attempt to develop size distribution functions for the glaciers of the world.

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Glaciers play an important role in the Earth System. Inventories of glacier characteristics are needed to allow scientists and resource management agencies to predict runoff, detect climate change, understand changes in the earth's rotation, and estimate contributions to a changing sea level. Distributions of glacier surface area are critical input parameters to climate and hydrological models. Although thorough inventories exist for a few regions, many published inventories are incomplete, especially for small glaciers, while inventories for other regions do not exist. Using data from published inventories we derive probability distribution functions for glacier surface area at the mountain range, regional, and global scale. From these distribution functions, gaps in current inventories can be filled, and area-distribution functions can be estimated for regions where inventories do not currently exist.

C11C-0840 0830h POSTER

Persistent Patterns of Windborne Snow Re-distribution on an Antarctic Ice Rise: Implications for the Equilibrium Profile and Flow

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We show that layers observed using ground-penetrating radar over Lyddan Ice Rise, Antarctica are approximate isochrones. We use these layers to map persistent spatial (<1 km) variations in snow accumulation over the ice rise, and the pattern of ice flow around the summit region. We find that the ice-flow divide, which has remained static for several decades, is currently around 1 km away from the ice rise summit. The layers also show that major spatial variability in snow accumulation (>50% of the mean) is directly related to extremely subtle changes in surface slope (<1%), and that this spatial variability has been stable for several decades. This finding implies that, in addition the normal control on the equilibrium profile of the ice rise, i.e. the relationship between surface slope versus ice-flow, the equilibrium profile is also by the relationship between surface slope and accumulation rate. We investigate the interaction of these two effects using a 2-dimensional isothermal time-dependent ice sheet model. We find that in this case, the surface slope / accumulation rate relation is sufficiently weak, that in this case, a time-stable equilibrium profile does exist, and that such a relationship does not necessarily imply result in surface waves or dunes. However, the interaction between surface slope and accumulation does significantly modify the profile of the ice rise and displaces the position of the summit by around 1 km. We conclude that the position of the summit of Lyddan and similar ice rises and ice caps, is highly dependent on the local wind climatology and could be significantly affected by a change in the wind climatology. Such effects of wind modification of ice rise profiles may have particular importance for the interpretation of ice cores collected from ice rises and ice caps.

C11C-0841 0830h POSTER

WIND AND SURFACE TOPOGRAPHY AS A CAUSE OF STRATIGRAPHIC DEFORMATION IN WEST ANTARCTICA

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The stratigraphy of firn and ice in polar ice sheets is important for core site selection, and reveals information on the complex processes of flow, deformation and deposition. We are interested in how some of the deformation that we have observed with ground-based, 400-MHz ground-penetrating radar profiles evolves in the firn regime of West Antarctica. It has long been known that wind decreases deposition on downwind slopes and increases it on upwind slopes. What are not known are the degree to which this happens, and the stratigraphic consequences at depth. We discuss a 177 km profile recorded during the ITASE project that originated at Byrd Surface Camp, and whose westerly direction was within 30 degrees of alignment with the downglacier wind and also, with the direction of ice flow. The measured flow speeds of 11 m/a (at Byrd, upglacier) to 48 m/a (downglacier) indicate that the ice was in extension, so that compressive forces could not have caused the folding and pinching. We compare surface slopes with the total accumulation from 1988-1999 to show the degree to which wind diminished accumulation on the leeward slopes (facing downglacier) and increased it on the windward slopes (facing upglacier). The sensitivity of this process to slopes less than a few tenths of a degree is impressive. The strong deformation in the deeper firn stratigraphy is then seen to be apparent because it directly results from the spatial differences in accumulation rates. Some stratigraphic horizons dip as much as 16 m over a few km, and some horizons exhibit total depth changes of up to 30 m over

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about half the length of the profile. The spatial stability of many fold hinges with depth suggests that the upglacier migration of surface topography that results from the variable accumulation rates may be balanced by the ice flow. Other, deeper radar profiles acquired during ITASE show that the scale of the apparent folding greatly increases with depth.

C11C-0842 0830h POSTER

Layered Nature With Different Physical Properties Of Firn

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To better understand the formation mechanism of the layered structures in firn, we have introduced new methods to clarify the various physical properties relating to the firn-densification process; that is, the X-ray transmission method for detailed profile of density, the X-ray CT for the anisotropy of crystal shapes, the X-ray diffraction method for the crystallographic orientations of both 0002 and 11-20, and the open resonator method for the dielectric permittivity tensor at microwave frequency. These methods have been applied to the firn in both the Dome Fuji ice core from East Antarctica and the P96 ice core from Penny Ice Cap, Baffin Island, Canada. We have found by these measurements that (1) the crystal shapes elongated vertically near the surface turn into spherical ones with depth, (2) the layers with the preferential c axis orientations (fabrics) in vertical alternate with those in horizontal, (3) these preferential orientations gradually vary towards random ones with depth, but (4) there still exist the layered structures with different fabrics even at the close-off depth, and (5) the dielectric anisotropy, or the difference between the dielectric constants parallel and perpendicular to the core axis, decreases with depth. On the basis of these findings, we propose a grain-rotation mechanism during the firn-densification process, which well explains the finding (3). The finding (4) suggests that ice below the close-off depth is also composed of the layered structures with different fabrics. Since the difference in fabrics between layers increases by plastic deformation of grains below the close-off depth, the layered structures with different fabrics must be developed with depth.

C11C-0843 0830h POSTER

Fine-Resolution Mapping of Near-Surface Internal Layers

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Knowledge of the mass balance of the Greenland Ice Sheet is necessary to assess its contribution to the rising sea level. The accumulation rate of snow on ice sheets is an important variable in determining this mass balance and in interpreting data from ICESAT and CRYOSAT missions. Using a small number of ice pits and cores to determine accumulation rate is unreliable, due to the small number of samples. In order to reduce this uncertainty, we have developed a wideband radar to generate a continuous profile of the isochronous layers in the ice sheet. Such a profile can be used to estimate long-term accumulation rate with reduced uncertainty. We built a wideband FM-CW radar that operates from 500 to 2000 MHz with range resolution of about 10 cm. We used a YIG oscillator to generate this signal. Since FM radar performance is affected by any non-linearity in the YIG oscillator, we developed a method for correcting any non-linearity in the YIG oscillator by using it in a phase-locked loop configuration. We simulated the performance and built a prototype radar. We tested the radar during the 2003 field season at North GRIP, and collected data over a long transect of 5 km. We collected radar data in conjunction with detailed snow pit studies at several locations along the radar tracks. Also we extracted a 15 m core for isotope analysis. Our preliminary results show that we can map layers to a depth of about 150 m with about 10 cm resolution. We will present the design considerations, laboratory test results of radar performance, results from experiments at NGRIP and comparison of the radar data with information derived from snow pits.

C11C-0844 0830h POSTER

Recent Observations and Structural Analysis of Surge-Type Glaciers in the Glacier Bay Area

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The Chugach-St.-Elias Mountains in North America hold the largest non-polar connected glaciated area of the world. Most of its larger glaciers are surge-type glaciers. In the summer of 2003, we collected aerial photographic and GPS data over numerous glaciers in the eastern St. Elias Mountains, including the Glacier Bay area. Observed glaciers include Davidson, Casement, McBride, Riggs, Cushing, Carroll, Rendu, Tsirku, Grand Pacific, Melbern, Ferris, Margerie, Johns Hopkins, Lamplugh, Reid, Burroughs, Morse, Muir and Willard Glaciers, of which Carroll, Rendu, Ferris, Grand Pacific, Johns Hopkins and Margerie Glaciers are surge-type glaciers. Our approach utilizes a quantitative analysis of surface patterns, following the principles of structural geology for the analysis of brittle-deformation patterns (manifested in crevasses) and ductile deformation patterns (visible in folded moraines). First results will be presented.

C11C-0845 0830h POSTER

Comparative Analysis of Glaciers in the Chugach-St.-Elias Mountains

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The phenomenon of glacier surges has to date been studied for only relatively few examples. 136 of the 204 surge-type glaciers in North America listed by Post (1969) are located in the St. Elias Mountains. In August 2003 we increased our data inventory of observations on surge glaciers by collecting material for 19 glaciers in the Glacier Bay area and neighboring regions in the eastern St. Elias Mountains, including 6 surge-type glaciers (Carroll, Rendu, Ferris, Grand Pacific, Margerie, and Johns Hopkins Glaciers). Analyses utilize digital video and photographic data, satellite data and GPS data. Geostatistical classification parameters and algebraic parameters characteristic of surge motions are derived for selected glaciers. During the 1993-1995 surge of Bering Glacier the entire surface of Alaska's longest glacier was crevassed and could be segmented into several dynamic provinces, where patterns changed as the surge progressed and the affected areas expanded downglacier and upglacier, finally affecting the Bagley Ice Field. The middle moraine of Grand Pacific and Ferris Glaciers is pushed over to the Grand Pacific side, caused by a recent surge of the heavily crevassed Ferris Glacier. The front of Johns Hopkins Glacier advances, as its lower reaches are affected by a surge. The surge history of Bering Glacier goes back to the Holocene, whereas Carroll and Rendu Glaciers have surged only 3-4 times. These observations pose questions on the possible relationship between surge dynamics and climatic changes.

C11C-0846 0830h POSTER

Glaciological Field Measurements on the Bering Glacier, Alaska Summer 2003

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The Bering Glacier in the St.Elias/Chugach Mountains of South-central Alaska is one of the largest surging glaciers. It last surged in 1993 and 1995 with portions of its terminus advancing over 10 km. Since this time the terminus has retreated to near its pre-surge position. While the surge events attract significant attention, there is little known about the quiescent phase and the conditions prior to surging. Measurements made during this period could provide clues to the surge mechanism(s) such as evidence of melt water storage. During the summer of 2003 we made measurements of ice velocity, surface elevation and ice thickness along three transverse transects of the glacier. We reoccupied 19 locations on the glacier with survey grade GPS measurements. Ice velocities were calculated from these measurements and range from over 2 m/day to less than 10 cm/day. Many of the measurements were made at the locations of the USGS 1991 survey providing the opportunity to directly measure ice surface elevation change.

C11C-0847 0830h POSTER

Taku Glacier: Proglacial Deformation and Subglacial Erosion

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Taku Glacier has advanced about 7 km since 1890 and is continuing its advance today. Located in southeastern Alaska, this glacier flows from the Juneau Ice Field down to sea level. In the last several decades the glacier has bulldozed a berm of marine and fluvial sediments from the fjord bottom; this berm now separates the terminus from tidewater. The force of the advancing glacier is causing large-scale deformation within these sediments. In 2001, a series of thrust scarps began to form in front of a 200 m section of the terminus. These scarps were active for several months and produced a series of bulges that grew to be several meters in height above the surrounding sediments. Ground penetrating radar (GPR) was used to image the internal structure of these bulges. A trench dug into one of the proglacial ridges revealed that a >2 m clay/sand layer might have played an important role as a thrust zone during deformation. This layer could also be identified in the GPR returns.

Beside these scarp-formed bulges there are numerous indicators of the continued advance. Push moraines along the terminus range in height from 1 m to a towering 10 m. In some areas the advancing ice has dug into the sediments and has lifted the vegetation from below. We also observed up to 1 m thick debris freeze-on layers that, when exposed at the terminus, melt and contribute to the development of some moraines.

In addition to these observations we performed a series of radio echo-soundings over a grid that extends about 5 km upglacier. These data are compared with depth measurements made in 1989. Since then the glacier has advanced about 180 m. Within 1 km of the present terminus the glacier has deepened its bed by about 15 m, which indicates an erosion rate of about 1 my^{-1} in this

area. This rate agrees with the one observed over the past 100 years. Entrenchment plays an important role in the glacier's dynamics and needs to be taken into account when measuring volume changes.

C11C-0848 0830h POSTER

Flow Dynamics from Elevation Changes on the Malaspina-Seward Glacier System, Alaska-Yukon, using High Resolution Airborne and SRTM InSAR-Derived DEMs

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The Malaspina piedmont glacier, with an area of 2400 km^2 (Post and LaChapelle, 2000), includes the Agassiz and Marvine Glaciers to the west and east, respectively, of the central Seward Lobe. Upper Seward Glacier, mostly in Yukon, Canada, is a broad icefield that forms the main accumulation area of Malaspina Glacier. Mt. Irving nunatak divides Upper Seward into western and eastern halves. Lower Seward Glacier, mostly in Alaska, connects Upper Seward to Malaspina Glacier. The combined Malaspina-Seward glacier system, including all tributaries, has a total area of about 5,000 km^2 (Molnia, 2001). The glaciers of the Malaspina system are characterized by complex flow dynamics, including quasi-periodic surging and pulsating flow. High-resolution DEMs produced from airborne and spaceborne single-pass X-Band InSAR by Intermap Technologies, Inc. (August 2002) and the German Aerospace Center (from the NASA Shuttle Radar Topography Mission, February 2000), respectively, are used to derive short-term surface elevation changes. An adjustment for systematic error in the SRTM DEM is applied. Snow depth vs. altitude is estimated using the mass balance model of Tangborn (1999) on these glaciers from Sept. 1999 to Feb. 2000, and is used to adjust the SRTM DEM to a late summer 1999 level. During the 3-year 1999 to 2002 time period, the Seward Lobe of Malaspina thinned over its eastern half, while the western half thickened by about 10 $\pm$ 1 m on average. This suggests that the main flow direction has changed from southeast, the direction of a major surge in 1987-88 (A. Post, pers. comm.), to southwest. Surges in alternate directions have been hypothesized by A. Post (pers. comm.) as the cause of the intricately folded moraines on Malaspina Glacier. Marvine Glacier, which surged in 2000 (K. Echelmeyer, pers. comm.), shows thickening in its ablation area of up to 60 $\pm$ 1 m and thinning in its accumulation area of up to 60 $\pm$ 1 m. The 3-year mean surface lowering on Agassiz, Malaspina (Seward Lobe), Lower Seward, Marvine and Hayden Glaciers, including a -3.2 m adjustment of the SRTM heights for systematic error, was about 2.7 $\pm$ 1 m, or 0.9 $\pm$ 0.4 m yr^{-1}. References Molnia, B., Glaciers of Alaska, Alaska Geographic, 28 (2), 2001. Post, A., and E. LaChapelle, Glacier Ice, University of Washington Press, Seattle, 2000. Tangborn, W.V., A mass-balance model that uses low-altitude meterological observations and the altitude area of a glacier, Geograf. Ann., 81(A), 753-765, 1999.

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Jökulhlaup triggering: Observations at Kennicott Glacier, Alaska

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Jökulhlaups, sudden releases of water impounded by a glacier, produce large floods unrelated to weather events. We draw on observations from 90 years of annual jökulhlaups from Hidden Creek Lake, Kennicott Glacier, Alaska and from detailed monitoring in 1999 and 2000, to examine conditions that trigger outburst floods. For the class of jökulhlaups caused by subglacial drainage, the trigger must be related to formation of subglacial conduits, a pivotal problem in glaciology. Hidden Creek Lake water level at drainage has declined over the last century, during which time the glacier has thinned. The water level trend is mirrored by a tendency toward earlier release dates in the summer. These observations suggest that a minimum threshold lake level must be exceeded for drainage to occur, and that this threshold is related to ice thickness. The release date varies by over a month, however, and lake level varies by as much as 10 m over spans of a few years, which indicates that more is involved than simple exceedance of a threshold. Kennicott Glacier impounds several other small lakes. In two summers with fairly complete observations of their behavior, these lakes drained in sequence from nearest to furthest from the terminus. More frequent observations have been made of drainage of one of these lakes: Erie Lake, located roughly the same distance from the terminus as Hidden Creek Lake, along a major tributary to the Kennicott Glacier, usually drains within days of Hidden Creek Lake. These patterns are consistent with a trigger that is related to glacier-wide evolution of the hydrologic system, rather than each drainage reflecting purely local conditions. Perhaps there is a linkage between timing of outbursts and seasonal upglacier extension of the subglacial conduit system. While we have no direct information on annual evolution of the conduit system at Kennicott Glacier, some have suggested that conduits and the snowline move upglacier in tandem. In 1999 and 2000, the snowline had retreated far upglacier, beyond Hidden Creek Lake, before it drained. Estimated melt rates in the days preceding Hidden Creek Lake outbursts, calculated with a degree day model, show no pattern: lake drainage has occurred during times of both low and high melt production. Jökulhlaup triggering appears to be controlled by a number of conditions, among them the height of the ice barrier, organization of the subglacial hydrologic system, and specific, probably transient, conditions within that system at the time of drainage.

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Water Flow through Widespread and Interconnected Void Spaces at Depth in a Temperate Glacier

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We present a suite of observations that suggest void spaces within the ice mass of Bench Glacier, Alaska are abundant, interconnected, and may offer an important means for englacial water storage and routing. During Spring of 2003, a grid of boreholes spaced 20 x 20 m were drilled to the bed of Bench Glacier, Chugach Mountains, Alaska. The boreholes extended 180 m to the bed of the glacier and totaled more than 3600 m within the 10^6 m^3 block of temperate ice. Each borehole was inspected by video camera multiple times during a four-week period. These video observations show that open, crevasse-shaped void spaces are common in the lower two thirds of the ice depth. Upward water flow with active refreezing was observed in association with the voids. Eventual upwelling of turbid water demonstrated a connection between the voids and the bed. Slug tests and monitored drilling experiments (presented in detail elsewhere) revealed numerous englacial connections between different boreholes of the grid. For example, during the drilling process changes in water level were observed in the partially-drilled borehole that were coincident with changes in extant boreholes. Together, these observations imply that void spaces in the glacier are widespread and interconnected over many 10s of meters. They do not appear to form an aborescent network of channels. Since the voids are apparently well connected to the bed, they provide an additional dimension to the subglacial hydrological system - a place to store and route water. Hence, englacial voids may be an important component of the glacier drainage system and the linkage between hydrology and sliding dynamics.

URL: http://research.gg.uwyo.edu/joelh/benchglacier

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Investigation of Subglacial and Englacial Hydrology Using Borehole Slug Tests; Bench Glacier, Alaska

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Slug tests have long been used to determine the hydraulic conductivity of aquifer formations in the immediate vicinity of monitoring wells. However, slug tests have rarely been used to help determine englacial and subglacial hydrological characteristics. A series of slug tests were performed on Bench Glacier, Alaska in order to characterize the subglacial and englacial hydrology. A total of 16 slug tests were performed over a period of one week in early June 2002, with an additional 20 slug tests performed over a period of 10 days in June 2003. The slug tests were performed at various times of the day in boreholes drilled to the bed of the glacier. During the 2002 field season, water levels were recorded in the slug hole and an adjacent hole approximately 10 meters away. In 2003, water levels were recorded in the slug hole and 5 adjacent holes (within a grid of 16 boreholes) located between 20 and 60 meters away. Responses to the slug of water varied from an overdamped, slow drain to an underdamped, oscillation of the borehole water level. Modeling of the amplitude and frequency for the underdamped response reveals information on the structure of the subglacial and englacial drainage systems, as well as provides constraints on the amount of water in the system. Analysis of the slug tests within the grid shows both temporal and spatial changes in the response and thus the system, providing insight into the development of the subglacial and englacial hydrologic systems.

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High-Resolution Surface Velocity Measurements by Combined GPS and Automated Optical Surveying

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Ongoing glacier dynamics research at Bench Glacier, Alaska requires not only detailed and accurate measurements of surface velocity and velocity gradients, but also a definitive means of distinguishing between surface uplift arising from vertical extension and uplift arising from englacial water storage. Hourly differential GPS measurements at 3 locations over a 1500 m reach of the glacier were combined with half-hourly automated measurements of a network of 24 optical survey targets distributed in a grid covering a 300 x 500 m region within the GPS profile. Data was acquired nearly continuously for an 18 day period on the optical survey grid and for over 4 months on the GPS profile. Resulting target trajectories are combined with additional measurements of vertical strain in a borehole to calculate all three components of surface velocity and their spatial gradients, and allow us to distinguish vertical extension from uplift at the bed. This information will be used with measurements of water pressure and velocity in a network of 24 boreholes to characterize the relationship between basal sliding, water pressure and water storage.