C52B-04 1645h

Surface and Bottom Morphology of Petermann Gletscher's Floating Tongue in Northwestern Greenland

Konrad Steffen[1] (1-303-492-4524; Konrad.Steffen@colorado.edu); Eric Rignot[2] (1-818-354-1640; eric@adelie.jpl.nasa.gov); Russell Huff[1] (1-303-492-6881; russell.huff@colorado.edu); Nicolas Cullen[1] (1-303-492-6881; cullenn@cires.colorado.edu); Craig Stewart[3] (+44-1223-221621; cste@bas.ac.uk); Adrian Jenkins[3] (+44-1223-221493; ajen@bas.ac.uk)

[1] Cooperative Institute for Research in Environmental Science, University of Colorado, Campus Box 216, Boulder, CO 80309-0216, United States

[2] Jet Propulsion Laboratory, Mail Stop 300-235, 4800 Oak Grove Drive, Pasadena, CA 91109-8099, United States

[3] British Antarctic Survey, High Cross, Madingley Road, Cambridge CB3 0ET, United Kingdom

Petermann Gletscher is the largest and most influential outlet glacier in central northern Greenland. Located at 81 N, 60 W, it drains an area of 71,580 km2, with a discharge of 12 cubic km of ice per year into the Arctic Ocean. Remote sensing results suggest that its ice discharge exceeds that required to maintain the ice sheet interior in a state of mass equilibrium by 63 percent, and its grounding line is retreating at a rate which indicates ice thinning at nearly one meter per year. Its floating ice tongue is only a few meters above sea level at the ice front, hence highly vulnerable to ice thinning.

A detailed field campaign was carried out in May and June 2002 on the floating ice tongue of the Petermann Gletscher, which will allow for the first time field observations to be integrated with remote sensing data. The experiments were done close to the grounding line, the most crucial part of the glacier. Bottom melt rates were estimated using a novel phase-sensitive radar sounding system developed by the British Antarctic Survey. The surface energy balance was measured with automated micrometeorological stations, and surface melt rates were monitored continuously with sonic height instruments throughout the summer. Tidal constituents were measured close to the grounding line to characterize tides using a GPS receiver. We will report first results from this field expedition, including interesting surface morphological features, ground penetrating radar profiles showing surface and bottom topography of a small region of the floating tongue, and possibly bottom melt rates derived by the phase sensitive radar.

C61A MCC: 130 Saturday 0830h

Glaciers and Ice Sheets II *(joint with A, H, GC, PP)*

Presiding: **S Marshall,** University of Calgary**; T Murray,** University of Leeds

C61A-01 0835h

Englacial Water Flow - The Absence of Röthlisberger Conduits

Andrew G Fountain[1] (503-725-3386; andrew@pdx.edu)

Robert W Jacobel[2] (jacobel@stolaf.edu)

Robert B Schlichting[3] (rbs@imagina.com)

Peter Jansson[4] (pete@natgeo.su.se)

Sara Frodin[1]

[1] Departments of Geology and Geology, Portland State University, Portland, OR 97207, United States

[2] Department of Physics, Saint Olaf College, Northfield, MN 55057, United States

[3] Cleveland High School, 3400 SE 26th Avenue, Portland, OR 97202, United States

[4] Department of Physical Geography and Quaternary Geology, University of Stockholm, Stockholm SE-106 91, Sweden

We investigated the englacial hydrology of Storglaciären, a polythermal glacier in northern Sweden, to provide empirical data to test models of englacial water movement proposed by Röthlisberger and others. Our investigations included both ice-penetrating radar surveys and boreholes drilled to provide direct access. In two cases englacial channels were first identified in radar surveys, which determined the channel position to within approximately one-meter. Radar surveys also identified isolated water-filled cavities, confirmed by drilling, within the surface cold layer. Radar results are described in more detail in a companion paper by Jacobel et al., (this session).

Boreholes were drilled using a hot-water system and a permanent drop in water level from the surface indicated interception of an englacial channel. After connection a submersible camera was lowered to image the geometry and orientation of the channel and to measure the water flow speed. Tracers were also injected to estimate connectivity between holes as well as flow speeds. Over two field seasons, we drilled 43 holes for a total distance of 3.7 km and down to depths of 200 m. Englacial channels were intercepted in 31 (72%) holes at depths between 10 and 158 m. In no instance did we encounter a Röthlisberger-type conduit. Instead we intersected steeply sloping crevasse-like features with nominal widths of 1 - 10 cm. Tracers and pressure variations revealed that the boreholes were englacially connected across 10s of meters despite connection depths that differed by 10 m or more. When flow could be detected, it was laminar with flow speeds between 0.1 - 1 cm s^{-1}.

From these results, we believe that crevasse-like features are the main conveyors of englacial water and form a fracture-like network consisting of numerous pathways, similar to a fracture network in rock rather than the traditional view of a few melt-enlarged conduits in ice. Classic Röthlisberger-type conduits are probably a special case of the flow system occurring only where flow paths converge to create discharges sufficient to initiate turbulent flow and melt-enlargement. Such locations would be limited to the glacier margins and near the terminal margin. These results counter current notions of englacial water flow and have profound consequences for past interpretation of data gained from boreholes and for understanding of water flow through glaciers.

C61A-02 0850h INVITED

Ice-sheet Hydrology and the Deglaciation of North America

Gwenn E. Flowers[1] (flowers@geop.ubc.ca)

Garry K.C. Clarke[1] (clarke@geop.ubc.ca)

Dave H.D. Hildes[1] (hildes@geop.ubc.ca)

[1] Department of Earth and Ocean Sciences, University of British Columbia, 2219 Main Mall, Vancouver, BC V6T 1Z4, Canada

Geophysical, geological, and paleoceanographic records provide clues that basal hydrology was an important influence on the history and dynamics of the Laurentide ice sheet, particularly during deglaciation. Water at the bed of a glacier facilitates basal motion (through sliding and bed deformation), which is believed to have exerted a controlling influence on the geometry of the ice sheet and the activity of its surge lobes. This has motivated various parameterizations of hydrology in large-scale dynamical models of the Laurentide ice sheet. We propose a physically-based distributed model of ice-sheet hydrology that includes groundwater transport coupled to a more efficient drainage system at the ice–bed interface. Groundwater transport rates are largely determined by the local geology, while basal flow rates are a function of the temporally-variable drainage morphology. Driven by ice-sheet geometry and meltwater production, the hydrology model determines spatial distributions of basal water volume, pressure, and flux. These variables illuminate areas disposed to subglacial water storage and basal flow enhancement. Explicit treatment of the basal water system enables us to explore and quantify the feedbacks of hydrology on Laurentide ice-sheet dynamics during the last deglaciation.

C61A-03 0905h

Real-time Hydrologic Observations of Hidden Creek Lake Jökulhlaups, Kennicott Glacier, Alaska

Joseph S Walder[1] (360-993-8948; jswalder@usgs.gov)

Suzanne P Anderson[2] (spa@emerald.ucsc.edu)

Robert S Anderson[2] (rsand@earthsci.ucsc.edu)

Andrew G Fountain[3] (fountaina@pdx.edu)

[1] US Geological Survey, 1300 SE Cardinal Ct., Bldg. 10, Suite 100, Vancouver, WA 98683, United States

[2] Univ. of California, Santa Cruz, Dept. of Earth Sciences, UCSC, Santa Cruz, CA 95064, United States

[3] Portland State University, Geology Dept. P.O. Box 751, Portland, OR 97207, United States

Few glacier outburst floods (jökulhlaups) have been monitored in detail as they occur. Hidden Creek Lake (HCL), an ice-marginal lake impounded by Kennicott Glacier, Wrangell Mountains, Alaska, fills annually to a volume of about 20 to 30 million m^3 and then drains subglacially within about 2 to 3 days. In 1999, we measured lake-surface elevation, ice-dam deformation, and discharge in the Kennicott River (which drains the glacier) during the HCL outburst floods. In 2000 we collected comparable data beginning 3 weeks before lake drainage, and also measured flow in Hidden Creek, the main source of HCL water. Sources and sinks were in balance; any leakage from HCL prior to the 2000 jökulhlaup was too small to resolve. An important complication revealed by the deformation data was water storage in a "wedge" beneath the ice dam. During the 3 weeks before drainage in 2000, at least 1/3 of the total input to HCL went into the subglacial "wedge". The HCL outflow hydrograph was determined from lake-level records, basin hypsometry, and measured downdrop of the ice dam. In both 1999 and 2000, about 20% of the total water volume was stored in the subglacial "wedge". Both hydrographs were considerably more symmetrical about the peak than the canonical jökulhlaup hydrograph commonly mentioned in the literature. The relatively long tail on the outflow hydrograph may have been due to the fact that the entire lake had to evacuate through the subglacial "wedge", which became progressively more constricted with time. The flood hydrograph measured near the glacier terminus (16 km from the lake) is also fairly symmetrical. The flood peak in both years occurred about 12 h after the peak in the outflow hydrograph, implying a mean transit time of about 0.4 m/s. Integrated flood volume and lake volume agree fairly well in both years. Water-quality measurements are difficult to interpret: suspended sediment concentration in flood water peaked about 12 h before discharge, and the chemistry of flood waters is not readily explained by any sort of simple mixing models. As the HCL outburst flood progresses, Donoho Falls Lake–a normally dry ice-marginal basin that fills and drains during the HCL jökulhlaup–filled with water whose chemistry was closer to that of the background flow in Kennicott River than to HCL water, suggesting that the outburst flood created high subglacial water pressure that impeded normal drainage and even caused flow direction locally to reverse. Water levels recorded in boreholes also indicate the HCL jökulhlaup caused widespread disturbance in the glacier's pre-existing drainage system.

C61A-04 0920h

Hydraulics of Supraglacial Outburst Floods

Garry K. C. Clarke (1-604-822-3602; clarke@eos.ubc.ca)

University of British Columbia, Earth and Ocean Sciences, 6339 Stores Road, Vancouver, BC V6T 1Z4, Canada

A substantial literature exists describing observations and theory of subglacial outburst floods. Episodic floods from the Grímsvötn reservoir within the Vatnajökull ice cap of Iceland are especially well documented and have inspired some of the most influential theoretical developments. Much of this work is focused on physical processes and hazard prediction and applications to paleohydrology are uncommon. In contrast to subglacial outburst floods, the study of supraglacial outbursts is in an early stage of development. Such events are extremely rare and therefore challenging to study, yet supraglacial release is a conceivable mechanism for some of the great floods of the Pleistocene era, for which no modern analogues exist. For most of these reservoirs there are no data to distinguish whether the flood mechanism was supraglacial or subglacial so that, in addition to relevant but poorly constrained variables such as water temperature, the release mechanism itself is uncertain. A recent contribution by *Raymond and Noll* [2000] marks the first attempt to identify the controlling processes and encapsulate them in a physical model. However the work relies on a simplifying "bottleneck" assumption that is likely to be inappropriate when applied to the very long flood channels that would be required for supraglacial outburst floods from huge proglacial lakes of the Pleistocene and early Holocene epochs. Thus no existing models are appropriate for paleohydraulic comparisons of subglacial and supraglacial outbursts. Here I present a new model of supraglacial outburst flooding that is rooted in the Spring-Hutter formalism and does not suffer from the bottleneck assumption. Interesting complications arise such as the possibility of a spatially migrating spillway and overflow from the outlet channel onto the ice sheet surface.

C61A-05 0935h

Glacier Instability, Rapid Glacier Lake Growth and Related Hazards at Belvedere Glacier, Macugnaga, Italy

Christian Huggel[1] (+41 1 635 51 75; chuggel@geo.unizh.ch); Andreas Kaeaeb[1] (+41 1 635 51 75; kaeaeb@geo.unizh.ch); Wilfried Haeberli[1] (+41 1 635 51 75; haeberli@geo.unizh.ch); Gianni Mortara[2] (+39 011 3977 251; g.mortara@irpi.to.cnr.it); Marta Chiarle[2] (+39 011 3977 251; m.chiarle@irpi.to.cnr.it); Fulvio Epifani[3] (+39 3335 6045 513; fulvio.epifani@tin.it)

[1]Glaciology and Geomorphodynamics Group, Dep. of Geography, University of Zurich, Winterthurerstr. 190 , Zuerich, ZH 8057, Switzerland

[2]Consiglio Nazionale delle Ricerche, Istituto per la protezione Idrogeologica nel Bacino Padano, Strada delle Cacce 73, Torino, TO 10135, Italy

[3]Studio Geologico, F. Epifani, Via XX Settembre 73, Arona, NO 28041, Italy

Starting in summer 2000, Belvedere Glacier, near Macugnaga, Italian Alps, developed an extraordinary change in flow, geometry and surface appearance. A surge-type flow acceleration started in the lower parts of the Monte-Rosa east face, leading to strong crevassing and deformation of Belvedere Glacier, accompanied by bulging of its orographic right margin. In September 2001, a small supraglacial lake developed on the glacier. High water pressure and accelerated movement lasted into winter 2001/2002. The ice, in places, started to override moraines from the Little Ice Age. In late spring and early summer 2002, the supraglacial lake grew at extraordinary rates reaching a maximum area of more than 150'000 m^2 by end of June. The evolution of such a large supraglacial lake, a rather unique feature in the Alps, was probably enabled by changes in the subglacial drainage system in the course of the surge-like developments with high water pressure in the glacier.

At the end of June, an enhanced growth of the lake level with a rise of about 1 m per day was observed such that the supraglacial lake became a urgent hazard problem for the community of Macugnaga. Emergency measures had to be taken by the Italian Civil Protection. The authors thereby acted as the official expert advisers. Temporal evacuations were ordered and a permanent monitoring and alarm system was installed. Pumps with a maximum output of 1 m^3/s were brought to the lake. Bathymetric studies yielded a maximum lake depth of 55 m and a volume of 3.3 millions of cubic meters of water. Aerial photography of 1995, 1999, September 2001 and October 2001 was used to calculate ice flow velocities and changes in surface altitude. Compared to the period of 1995 to 1999, the flow accelerated by about five times in 2001 (max. speeds up to 200 m/yr). Surface uplift measured was about 10-15 m/yr. The results of the photogrammetric studies were used to evaluate different possible lake-outburst scenarios, in particular overtopping and failure of ice dam with catastrophic subglacial drainage. In consideration of the current bathymetric studies and ice thickness measurements from the 1980ies, it was assumed that the floatation equilibrium was possibly reached by end of June. In case of an ice dam, the maximum discharge of a related subglacial drainage was estimated at 200 m^3/s, probably involving a large debris flow. Extension and nature of thermokarst processes of the lake/ice interface are currently studied by repeated bathymetric measurements and adaption of corresponding models. In July/August 2002, geodetic ice flow velocity measurements showed that the enhanced flow velocities have decreased probably indicat ing the end of the surge-like movement.

In conclusion, the developments at Macugnaga are an excellent example illustrating the need for inte grated hazard assessments in consideration of complex process chains. The current situation requires studies on different aspects, such as rock instabilities, glacier dynamics and hydrology, geomorphody namics, and mitigation-construction planning.

C61A-06 0950h INVITED

Rapid Wastage of Alaska Glaciers: Preliminary Links to Alaska Climatology.

Anthony A Arendt[1] (907-474-7443; arendta@gi.alaksa.edu)

Keith A Echelmeyer[1] (907-474-7477; kechel@gi.alaska.edu)

William D Harrison[1] (907-474-7706; harrison@gi.alaska.edu)

Virginia B Valentine[1] (907-474-7455; by@gi.alaska.edu)

[1]Geophysical Institute, University of Alaska 903 Koyukuk Drive PO Box 757320, Fairbanks, AK 99775

Our laser altimetry measurements suggest that most of Alaska's glaciers have thinned from the mid-1950s to the mid-1990s (the "early period"), at a rate of about -0.5 m/year, or 0.14±0.04 mm/year sea level equivalent. Repeat measurements from the mid-1990s to 2000-2001 (the "recent period") suggest the rate of thinning and contribution to sea level rise has more than doubled. These measurements show that glaciers in Alaska may be contributing up to one-half of the sea level rise attributed to all mountain glaciers on Earth.

Here we examine patterns in the thinning rates of Alaska glaciers, and relate these to regional climate data, in search of causes for widespread glacier thinning. We analyze observational mean surface air temperature and precipitation data from 24 weather stations in Alaska, with continuous records dating to 1950. Preliminary results show temperatures in Alaska have increased by about 2.0°C over the last 50 years, while there has been a slight increase in precipitation. Temperature increases were greater in the winter season than in the summer: mean summer (June-July-August) temperatures during recent period measurements were only 0.4°C higher than those during early period measurements.

We observed large increases in thinning rates of many glaciers along southern coastal regions of Alaska, where many large ice masses descend to sea level, and where precipitation rates are high. However, climate data do not show a marked increase in temperature or decrease in precipitation for these regions. In fact, temperature records show the greatest increases in temperature occurred in interior Alaska, even though our measurements show a slightly positive trend in the mass balance of interior glaciers. We suspect that coastal climate monitoring stations located near sea level may not be representative of conditions in high mountain regions of southern Alaska.

Does rapid thinning of Alaska's glaciers suggest a change in climate that has not been measured by existing climate monitoring stations? We will investigate this question by using a degree-day mass balance model, driven by temperature and precipitation data from the nearest climate station, to simulate the cumulative net balance of a sample of glaciers in our study. The model output will be compared with average glacier-wide thickness changes (corrected for flow-derived changes in elevation) determined from altimetry. We will then tune the temperature and precipitation fields to match model output to our observations, and estimate potential changes in climate that would have caused the increase in thinning rates we observed.

C61A-07 1030h

Glacier Sliding With Cavitation Over Irregular Beds

Christian Schoof

Department of Earth and Ocean Sciences, University of British Columbia, 6339 Stores Road, Vancouver, BC V6T 1ZA, Canada

Pressurised subglacial water affects the sliding of glaciers over hard beds through the process of cavitation. In particular, it is widely recognised that sliding velocities depend not only on shear stress but also on the difference p_e between overburden and drainage pressures. However, the precise form which such a sliding law should take is unclear, and many modellers opt for a heuristic power-law $u_b = C\tau_b^n p_e^{-m}$. Here we show how Iken's (J. Glaciol., 27, 407-422) notion of a 'critical pressure' at which sliding becomes unstable can be re-interpreted as an upper bound on the amount basal shear stress which a hard bed can support. Such an upper bound clearly contradicts the sliding law above. Motivated by the need to construct a more realistic sliding law which is not in conflict with Iken's bound, we present an analysis of hard bed sliding in the presence of cavitation which extends Fowler's (Proc. R. Soc. L. Ser. A., 407, 147–170) treatment to the case of irregular beds with many different bump sizes. Our results imply that generalised power-law sliding laws should not be used indiscriminately, particularly when discussing surge-type glacier flow. Furthermore, our results highlight the need to incorporate improved drainage models into the theory of hard bed sliding.

C61A-08 1045h

Multiple Continuous Differential GPS Records of Surface Speed on the Bench Glacier, Alaska

Robert S. Anderson[1] (831-459-3342; rsand@es.ucsc.edu)

Shad O'Neel[2] (303-497-8041; shad@unavco.ucar.edu)

Suzanne P. Anderson[1] (831-459-5827; spa@es.ucsc.edu)

Mike G. Loso[1] (831-459-2551; mloso@es.ucsc.edu)

[1]University of California, Santa Cruz, Department of Earth Sciences UCSC, Santa Cruz, CA 95064, United States

[2]UNAVCO, 3340 Mitchell Ln., Boulder, CO 80301, United States

Traditional measurement of glacier surface speed is labor intensive and weather-dependent. While it is thought that sliding speeds are tightly coupled to the subglacial hydrologic system, the nature of the connections requires further elucidation. We deployed 5 GPS receivers at 1 km intervals from the terminus into the accumulation area on the Bench Glacier, Chugach Range, Alaska, and a base station on a nearby bedrock ridge from mid-May through mid-July, 2002. Simultaneous measurement of the terminal stream discharge and air temperature allowed us to constrain meteorological forcing and to calculate the evolution of subglacial water storage. The 4-hour resolution ice surface velocity record reveals that departure from the low early season speeds of roughly 3-5 cm/d occurs progressively upglacier from JD 145 to JD 149; peak speeds were attained within about a week, and were 2-3-fold above background. This is in accord with optical surveying records from 1999 and 2000, although in 2002 the onset of anomalous motion is more subtle, progresses more rapidly upglacier (500-700 m/d) and is of longer duration. However, the stream responded very little to this sliding event; discharge remained at 1-2 m^3/s over this interval. In contrast, a high air temperature/melt event (JD 166-168) triggered simultaneous rapid motion (up to 30 cm/d) at all stakes except the highest. Stream discharge rose to 7 m^3/s within hours, and remained high, even after the termination of rapid sliding 3 days later. Total sliding during this event varied from 0.2 m at the terminus to 0.7 m at the ELA, while bed separation deduced from the vertical component is roughly one quarter of this. Motion becomes glacier surface-parallel within a week after the termination of sliding. Post-event speeds were consistently below the speeds of the more subtle early event.

We interpret this data as follows. In early season, poorly connected cavities prevent efficient subglacial drainage of the snowmelt inputs. Sub-glacial water pressure increases, eventually triggering the subtle sliding event. Cavity enlargement in this early event is insufficient to cause major changes in subglacial drainage, or to reduce the water pressure field. In this primed condition, the melt event enhanced basal water pressures, and triggered glacier-wide sliding. These speeds were sufficient to enlarge cavities to the degree that they interconnected, allowing water to begin to escape at rates that were greater than the melt inputs and therefore capable of reducing storage. Reduction of water pressures terminated sliding. Continuation of high water discharge at rates that exceeded melt inputs slowly reduced water storage, making later sliding events less likely.

C61A-09 1100h

Modeling the Transient Creep Behavior of Polycrystalline ice with an Elasto-viscoplastic Homogenization Scheme

Olivier Castelnau[1] (33-1-49-40-34-68; oc@lpmtm.univ-paris13.fr)

Rénald Brenner[1] (33-1-49-40-34-68; rb@lpmtm.univ-paris13.fr)

Maurine Montagnat[2] (maurine@lgge.obs.ujf-grenoble.fr)

Paul Duval[2] (33-4-76-82-42-67; duval@lgge.obs.ujf-grenoble.fr)

[1]LPMTM-CNRS, Université Paris 13, av. J.B. Clément, Villetaneuse 93430, France

[2]LGGE-CNRS, Université Joseph Fourier, rue Molière, BP 96, St. Martin d'Hères 38402, France

The flow of the large Greenland and Antarctica ice sheets is largely controlled by the rheology of the ice. Ice deforms *in-situ* at very high temperature as compared to the melting point ($T/T_f \geq 0.8$) and in a quasi-static regime that can be described by a non-linear viscoplastic constitutive relation. However, the interpretation of mechanical tests performed in the laboratory requires a better understanding of all creep regimes. Upon instantaneous loading, the stress is almost uniformly distributed inside the polycrystalline ice sample owing to the quasi-isotropic elastic behavior of ice crystals. But as deformation proceeds, the load is gradually transferred to the grains that are badly oriented for intracrystalline (dislocation) slip owing to the very large viscoplastic anisotropy of ice crystals. The decrease of strain rate during the transient creep by more than two orders of magnitude is associated with large directional internal stresses. Secondary creep has a rather short existence because it is immediately followed by the tertiary creep associated with discontinuous recrystallization that initiates systematically after 1.% total strain. This secondary creep regime is often considered as a stationary regime. Modeling the transient (up to the secondary) creep behavior of polycrystalline ice requires to account for the "long term memory effect" resulting from the elasto-viscoplastic coupling, together with the non-linear and strongly anisotropic viscoplastic behavior. This can be achieved

by the recently developed affine self-consistent homogenization scheme, which allows the description of the overall mechanical behavior of the aggregate with respect to the local elastic and viscoplastic behavior of the grains. Comparison of model results to a large set of experimental data will be given.

C61A-10 1115h

The Excess Diffusion of Stable Isotopes in Polycrystalline Ice

Alan W Rempel[1] (203-432-6616; alan.rempel@yale.edu)

J. S Wettlaufer[1,2] (john.wettlaufer@yale.edu)

[1]Department of Geology and Geophysics, Yale University, New Haven, CT 06520-8109

[2]Department of Physics, Yale University, New Haven, Ct 06520

Post-depositional processes must be taken into account when ice cores are used to infer the history of past climates. For example, the effects of diffusion in the firn are modeled and inverted to recover the original stable isotope ratios δ^{18}O and δD, which yield records of past temperature. Fortunately, beneath the level of pore close-off, post-depositional alteration is slowed considerably. Nevertheless, diffusion continues to smooth the isotope records, leading to the loss of seasonal and other high-frequency information. In fact, Johnsen and others (1999) found that the rate of diffusive smoothing in the Holocene ice sampled by the GRIP core is much faster than would be predicted by diffusion through solid ice alone. Nye (1998) argued that the presence of liquid veins at the boundaries of ice grains might explain this apparent “excess” diffusion. However, the analysis of Johnsen and others (2000) suggests that the required vein dimensions are unrealistically large. Here, we model the diffusion of stable isotopes in polycrystalline ice and show that the predictions of Nye (1998) and those of Johnsen and others (2000) represent two end-members in a spectrum of potential behavior. Our analysis ties together the two approaches and provides a rostrum for data analysis. In the Nye-model regime, the degree of excess diffusion depends on the wavelength of the isotopic signal. In the Johnsen-model regime, the rate of diffusive smoothing varies with the square of the grain size. We identify the physical characteristics that determine which of these asymptotic regimes more closely resembles the prevailing conditions and quantify the role of premelted liquid in the smoothing of isotopic signals. A deeper understanding of the processes by which the isotope records evolve will help to increase the accuracy and resolution of paleotemperature reconstructions.

S.J. Johnsen and others 1997 J. Geophys. Res. **102**, 26397.
S.J. Johnsen and others 2000 in: Physics of Ice Core Records, (ed. T. Hondoh) Hokkaido Univ. Press, 121.
J.F. Nye 1998 J. Glaciol. **44**, 467.

C61A-11 1130h

A Two-dimensional Model of Post-depositional Changes in Stable-Isotope Ratios in Polar Firn

Thomas A Neumann[1] (802-658-8706; taneuman@ess.washington.edu)

Edwin D Waddington[1] (edw@ess.washington.edu)

[1]Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195, United States

Stable-isotope ratios in precipitation are used as a proxy for the temperature above the inversion layer at the time of snow formation. We explore the possibility that the initial stable-isotopic ratios in snow may be modified by water-vapor exchange between pore-space vapor and the ice matrix.

We present a model which estimates the isotopic change of a two-dimensional section of firn through time. We model water-vapor motion through the firn as a result of diffusion along vapor-pressure gradients and of ventilation associated with air flow over the snow surface microtopography. Water vapor in firn pore spaces is a mixture of advected vapor from neighboring pores and vapor derived from sublimation of ice grains. We assume that stable isotopes do not fractionate upon sublimation and that ventilation continually advects air and water vapor through the firn. We calculate the mass of water vapor that changes phase (by either sublimation or condensation) in the firn through time. We also allow for water vapor loss to the atmosphere through advection. Our model inputs are the surface temperature, the firn microstructure (assumed constant), the isotopic composition of atmospheric water vapor, the relative humidity of the atmosphere, the mean wind speed and the microtopography of the firn.

Our model suggests that δ^{18}O can change by a few tenths of a part per mil per year. In high accumulation rate environments, surface snow is advected down through the ventilated zone before stable isotope ratios are modified significantly. However, post-depositional changes could be significant in low-accumulation-rate environments where snow remains within the near-surface ventilated zone for several years prior to deep burial. We also use this model to predict how the deuterium excess could change with time.

C61A-12 1145h

Laborative studies of the diffusion rate of stable isotopes in firn

Annette Sjberg[1] (ansj9728@student.uu.se)

Veijo A Pohjola[1] (veijo.pohjola@geo.uu.se)

Harro A.J. Meijer[2] (harro@cio.phys.rug.nl)

[1]Department of Earth Sciences, Uppsala University, Villavgen 16, Uppsala S-752 36, Sweden

[2]Centre for Isotope Research, Groningen University, Nijenborgh 4, Groningen 9747 AG, Netherlands

The diffusion of stable isotopes of water (d18O and d2H) in ice and firn is a question of interest for ice core glaciology. The back-diffusion (or de-convolution) models used today can be improved by having better knowledge of the diffusivity within firn, and ice. This is a laboratory setup, where we study the diffusion rate of stable isotopes of water within a matrix of fabricated firn. The laboratory procedure is such that two bodies of isotopically different waters are frozen. Flakes are shaved of the ice, making firn grains. The density of this manually fabricated firn is approximately 500 kg / m3. The firn of the two isotopically different waters is then sandwiched in an isolated box held in a freezer. The thickness of the different layers are varied in the stack at the setup, the ice temperature and the ice density are held relatively constant. Samples of the stack are taken over consequent longer time periods. Both d18O and d2H of the water are analyzed, using isotope ratio mass spectrometry. Comparison the results of the diffusion experiment with diffusion models will tell if the measured diffusion rate is similar to theoretical diffusion rates, or not.

C62A MCC: Hall C Saturday 1330h

Glaciers and Ice Sheets III Posters

(joint with A, H, GC, PP)

Presiding: **T Murray,** University of Leeds**; W T Pfeffer,** University of Colorado

C62A-0902 1330h POSTER

Radar Studies of Englacial Water in Storglaciaren, Sweden

Robert W. Jacobel[1] ((507) 646-3124; jacobel@stolaf.edu)

Erin M. Peterson[1] ((507) 646-3124; petersoe@stolaf.edu)

Douglas R. Stone[1] ((507) 646-3124; stoned@stolaf.edu)

Andrew G. Fountain[2] ((503) 725-3386; bjaf@pdx.edu)

[1]Department of Physics, St. Olaf College, 1500 St. Olaf Ave., Northfield, MN 55057, United States

[2]Departments of Geology and Geography, Portland State University, 17 Cramer Hall, Portland, OR 97207, United States

We present results from a second season of ground-based ice-penetrating radar studies on Storglaciaren, a polythermal glacier in arctic Sweden. The purpose of this research is to investigate the morphology and hydraulics of englacial channels - a problem of central importance to understanding glacier movement. Previous work has for the most part been limited to theoretical studies with few observations. We used a multi-frequency ground-penetrating radar in conjunction with borehole video (see companion paper by Fountain, et al., this session) to image englacial water passages.

Coarse surveys were carried out in the ablation zone using an impulse radar at a frequency of 50 MHz to characterize the surface cold layer, and to search for promising sites where englacial water bodies might be imaged and located. Subsequent detailed grid surveys with a spacing of 2 meters were completed using both 50 and 100 MHz radars. Two sites were found where bright englacial echoes suggested a sloping water-filled feature with linear dimensions on the order of several meters. Boreholes were drilled at both sites and directly intersected each feature. The borehole video camera confirmed that both features were narrow (1-10 cm) channels carrying water at slow speeds. At a third site, radar surveys located a point-like reflector at a depth of 20 meters within the surface cold layer. The borehole camera revealed this to be an oblate water-filled cavity approximately half a meter in extent and not connected to the englacial hydraulic system.

Our radar surveys showed that success in imaging water bodies from multiple positions on the surface was dependent on the object size and orientation, as would be expected for an extended reflector with complex geometry. Like other surveys, we detected many reflectors in single profiles that could not be indentifed in multiple views, and thus the source could not be located precisely. Likewise, the borehole drill intersected a number of water-filled channels that were not resolved by the radar. This result confirms the difficulty of imaging and locating extended objects with a broad beam antenna. At the same time, the correspondence between borehole and radar results in those cases where channels were located, shows the utility of the technique. The radar surveys together with the borehole experiments suggest a new model for englacial drainage, wherein crevasse-like features are the main conveyors of water and form a fracture-like network consisting of numerous pathways rather than the traditional view of a few melt-enlarged conduits in ice.

C62A-0903 1330h POSTER

Visualizing glacial sediment inclusions using 3-D ground-penetrating radar

Tavi Murray[1] (+44 113 343 6753; t.murray@geog.leeds.ac.uk); Lee E. Clarke[2]; Graham W. Stuart[2]; John Woodward[3]; Hamish D. Pritchard[1]; Paul Miller[1]

[1]School of Geography, University of Leeds, Leeds LS2 9JT, United Kingdom

[2]School of Earth Sciences, University of Leeds, Leeds LS2 9JT, United Kingdom

[3]Physical Sciences Division, British Antarctic Survey High Cross Madingley Road, Cambridge CB3 OET, United Kingdom

Retreat since the 1940s surge of Kongsvegen, Svalbard has exposed sediment structures on the glacier surface and along a 1 km long, 5–20 m high, grounded cliff section near the terminus. Glacier ice provides an almost ideal target for ground-penetrating radar (GPR) because low attenuation means that penetration up to 100s metres can be achieved. Reflections result from changes in the dielectric properties of the ice, typically due to changes in sediment or water content of the ice. Coincident GPR and real-time kinematic GPS data were collected on Kongsvegen by towing the instruments behind a moving snowscooter. Grids (∼ 100 m x 50 m) of closely spaced common offset GPR lines (∼ 0.25 m in line and 1 m between line spacing) were imaged over prominent englacial sediment features. The data were tied through a time stamp at each radar trace. The data have been 2-D interpolated at each time interval onto a regular grid to allow visualization. Prior to interpolation each line was de-spiked, and filtered to remove low frequency noise and horizontal banding resulting from ringing in the antennae. After interpolation the data were topographically corrected and migrated before visualization. The grids imaged two sub-horizontal reflectors. The upper reflector is strong and continuous, dips gently upglacier, and is interpreted to be the base of the glacier or the top of a basal ice layer. The lower reflector is discontinuous and is interpreted either as a thermal boundary (between frozen and unfrozen sediments) or as a décollement layer within the sedimentary bed material. Above the basal reflector a series of strong upglacier dipping faults were imaged, which do not cross the basal reflector. Weaker features occur between the basal reflector and the lower reflector. We interpret these structures in terms of the surge history of the Kongsvegen glacier complex.

C62A-0904 1330h POSTER

Ground Penetrating Radar Imaging of Glaciotectonic Sediment Deformation in an Ice-Cored Moraine Generated by Movement of the Buried Ice During a Re-advance of the Active Ice, Matanuska Glacier, Alaska

Kendra Pyke[1]; Gregory S Baker[1] (716-645-6800 x2252; gbaker@geology.buffalo.edu); Edward Evenson[3] (ebe0@lehigh.edu); Nelson Ham[4] (nelson.ham@snc.edu); Grahame Larson[5] (larsong@pilot.msu.edu); Staci Ensminger[2] (SLE@mail.nwmissouri.edu); Daniel Lawson[6] (dlawson@crrel.usace.army.mil)

[1]University at Buffalo, Dept. of Geology 876 Natural Sciences Complex, Buffalo, NY 14260, United States