could be geocryological artefacts of surficial liquid water that percolated down through the regolith and froze in situ. The availability of liquid water is a requirement of pingo and ice-wedge genesis. Equally, the presence of ice-rich sediments would meet the ground impermeability requirement of pingo genesis. No less suggestive of periglacial processes are the hundreds of small pits and depressions that are ubiquitous in Utopia Planitia. The morphology of these pits and depressions is reminiscent of terrestrial thermokarst and differential frost heave. We argue that the disparate but interconnected strands of surficial and sub-surficial geomorphological data sustain the hypothesised presence of a crater-based and water-fed periglacial landscape in northwest Utopia Planitia.

C21C-0826 0830h POSTER

Potential Ground Ice and Small-Scale Polygons on Mars

Rachel Klima[1] (Rachel_Klima@brown.edu.)

Steven L. Forman[1] (312-413-9404; slf@uic.edu)

Peter Doran[1] (Pdoran@uic.edu)

Jeffrey S. Kargel[2] (jkargel@usgs.gov)

[1]Univ. of Illinois at Chicago, Dept. of Earth & Environmental Sciecnes 845 W. Taylor St., Chicago, IL 60607, United States

[2]U.S. Geological Survery, 2255 N. Gemini Dr., Flagstaff, AZ 86001, United States

Martian geomorphology reveals many Martian landforms suggesting the presence of ground ice-rich sediment. Fractured polygonal networks, which are similar in size and shape to polygons commonly found in Earth's permafrost and desiccated lake and stream beds, are observed in numerous localities at middle and high latitudes on Mars, but are rare at low latitudes. If polygons on Mars form similarly to those on Earth, they would provide information about the distribution and history of the Martian hydrosphere and especially the cryosphere. Although these and other features have been compared morphologically to those on Earth, there has previously been no way to independently determine whether the process which formed the polygons on Mars also involves ground ice or water. The Mars Odyssey mission, specifically the Gamma Ray Spectrometer (GRS), has provided unprecedented maps of subsurface hydrogen on Mars. Presented is the global polygon distribution in context with recent measurements of near-surface hydrogen abundance. Of roughly 34,000 narrow angle MOC images investigated, 730 sites containing polygons were identified. A cluster in Utopia Planitia (centered at 45°N, 90°E) accounts for about 15% of total sites. Excluding the polygons in Utopia Planitia, 99% of sites correspond with hydrogen levels measured by epithermal neutron flux that are equivalent to or >35% water ice by weight. MOC images from Utopia Planitia show the presence of beaded-drainage within polygonal permafrost-like features, and gravity- driven slumps indicating flowing liquids in Amazonian time.

C21C-0827 0830h POSTER

The Association of Liquid Water Springs With Permafrost Regions on Earth and Mars

Jennifer L. Heldmann[1] (jheldmann@mail.arc.nasa.gov)

Michael T. Mellon[2] (michael.mellon@colorado.edu)

Wayne H. Pollard[3] (pollard@felix.geog.mcgill.ca)

Dale T. Andersen[3] (dandersen@seti.org)

Christopher P. McKay[1] (cmckay@mail.arc.nasa.gov)

[1]NASA Ames Research Center , Mailstop 245-3, Moffett Field, CA 94035, United States

[2]University of Colorado , Laboratory for Atmospheric and Space Physics, UCB 392, Boulder, CO 80309, United States

[3]McGill University, Department of Geography , Montreal QC H3A 2K6, Canada

Recent space missions have confirmed the presence of ice-rich ground in the middle and high latitudes of Mars. Geologically recent gully features on Mars show a geographic distribution that is correlated with theoretical models of ground ice stability which is suggestive of a genetic relationship between ground ice and gully activity. Possible mechanisms of gully formation are thus examined. A liquid water aquifer on Mars activated by freezing cycles is the favored model of gully formation based on an analysis of Mars Global Surveyor spacecraft data. Additionally, liquid water spring activity occurs in regions of continuous permafrost on Earth. Spring systems in the Canadian High Arctic (Axel Heiberg Island) as well as the Norwegian Arctic (Spitsbergen) demonstrate different morphologies and mechanisms of formation for spring systems in polar desert environments. On both Earth and Mars, liquid water springs in permafrost regions provide a unique setting for the possible preservation of biological signatures.

C21C-0828 0830h POSTER

Understanding the Vertical Distribution and Exchange of H_2O in the Subsurface of Mars.

Norbert Schorghofer[1] ((626) 395 8860; norbert@gps.caltech.edu)

Oded Aharonson[1] (oa@caltech.edu)

[1]California Institute of Technology, MC 150-21, Pasadena, CA 91125, United States

Prompted by the recent discoveries of Mars Odyssey, we aim to better understand the exchange of water vapor between the atmosphere and the subsurface and the vertical distribution of water ice and adsorbate. We model vapor transport, adsorption, and sublimation of water ice in the regolith over diurnal, seasonal, and millennial time scales. We find that in long-term equilibrium the transition to the subsurface ice table is sudden, and, as expected, the depth to the ice table can be determined from the frost point at the surface. Accumulating subsurface ice reduces the vapor transport deep into the regolith, but, eventually, ice can amass through sublimation to great depths. Physical adsorption of water onto the regolith may deplete the water vapor substantially and can lead to considerable diurnal breathing, but it has little influence on the frost point. These are examples of dynamical effects not described by standard equilibrium models.

C21C-0829 0830h POSTER

Pingos in Solar System

Kenji Yoshikawa (ffky@uaf.edu)

Water and Environmental Reserach Center, University of Alaska Fairbanks, PO Box 755860, Fairbanks, AK 99775, United States

Periglacial geomorphology is one of the best ways to map permafrost distribution and to understand the sub-surface hydrologic conditions there. Polygons and thermokarst landscapes are indicative of permafrost terrain, but they may persist as relict features in ground that is now permafrost-free. However, pingos only exist in ground that is currently permafrost, since they are ice-cored, and thus are the most important indicators of active permafrost environments. Pingos are widely distributed in the terrestrial northern hemisphere of Earth. Because most of the outer solar system is in a cryophilic condition, I examined potential pingo growth environments on Mars, Io, and Titan as terrestrial analogues. At least two types of pingos are potentially in existence on other planetary bodies in our solar system: hydraulic and hydrostatic systems. Hydrostatic system pingos are most likely to be developed during climatic change, such as a cooling period in the Martian surface. Hydraulic system pingos are most likely in Martin brinish groundwater systems or Titan's methane or ammonia groundwater systems. I have examined these environments for pingos and will present characteristics of terrestrial pingos and a model of how pingos may develop in the rest of our solar system.

C21C-0830 0830h POSTER

Modeling the Deformation of Lobate Debris Aprons on Mars by Creep of Ice-rich Permafrost

Elizabeth P Turtle[1,2] (520-621-8284; turtle@lpl.arizona.edu); Asmin V Pathare[1]; David A Crown[1]; Frank C Chuang[1]; William K Hartmann[1]; Jane C Heinze[2]; Nievita F Bueno[2]

[1]Planetary Sci. Inst., 1700 E. Fort Lowell Suite 106, Tucson, AZ 85719-2395, United States

[2]Lunar and Planetary Lab. Univ. of Arizona, 1629 E. Univ. Blvd., Tucson, AZ 85721-0092, United States

Martian softened terrain and debris aprons have often been attributed to deformation of ground-ice within kilometer-thick layers of permafrost. We are using MGS MOC and MOLA data to document the structural and topographic characteristics of softened landforms and debris aprons in the Hellas and Noachis regions and comparing the observed landforms to the results of finite-element simulations of viscous creep to constrain the conditions necessary to allow such deformation on Mars. We have characterized debris aprons in a region east of the Hellas impact basin: 30° - 50° S, 240° - 280° W. No debris aprons are found around mountains at low elevation or west of 265° W, i.e., within Hellas. We are evaluating the characteristics of mountains with and without debris aprons outside of Hellas to look for other factors that may control ground ice distribution. The only attributes that show weak correlations to the existence of debris aprons were latitude (debris aprons are more abundant to the south of our study region) and slope. We have applied finite-element analysis to investigate the deformation of debris aprons by creep of an ice-rich surface layer. Our simulations demonstrate that the final morphology is very dependent on the initial distribution of the ice-rich material and on the conditions applied at the base of the ice-rich debris. Furthermore, even under present Martian conditions, viscous creep can occur quite rapidly; on timescales of 1-10 thousand years. We are investigating the extent to which blocks of intact rock distributed within the ice-rich regolith could serve to increase the deformation timescales.

C21C-0831 0830h POSTER

Searching for Ground Ice at the Martian Equator

David A. Paige[1] (dap@mars.ucla.edu)

Andrew N. Hock[1] (ahock@ucla.edu)

Joshua M. Scherbenski[1] (josh@mars.ucla.edu)

Jean-Pierre Williams[1] (jpierre@mars.ucla.edu)

[1]UCLA, Dept. of Earth and Space Sciences, Los Angeles, CA 90095, United States

C

The Mars Global Surveyor and Mars Odyssey results suggest that the present distribution of High-Latitude ground ice on Mars is spatially continuous from the poles to 60N and 60S. However, Mars Odyssey results show large regions at mid and equatorial latitudes with 5 to 10% equivalent water content. We are exploring the hypothesis that the mid and low latitude water observed by Odyssey is due to the presence of discontinuous, thermally stable, near-surface ground ice in localized cold niches formed by topographic relief. We use the Mars Global Surveyor Thermal Emission Spectrometer and Mars Orbiter Laser Altimeter data to map the global distribution of cold niches at high spatial resolution and compare the results with low spatial resolution maps of the global distribution of near-surface water derived from the Mars Odyssey Neutron Spectrometers.

C21D MCC: 3010 Tuesday 1020h

Glaciers and Ice Sheets II *(joint with G, H, OS, PP)*

Presiding: **J Weertman,** Northwestern University**; W Pfeffer,** Institute of Arctic and Alpine Research, University of Colorado

C21D-01 1020h INVITED

US International Trans Antarctic Scientific Expedition Overview

Paul Andrew Mayewski (207-581-3019; paul.mayewski@maine.edu)

Climate Change Institute, Universtiy of Maine 303 Bryand Global Sciences Ctr, Orono, ME 04469-5790, United States

Antarctica plays a pivotal role in Earth's complex climate system. It is: encircled by the world's most biologically productive oceans, the largest reservoir of fresh water on the planet, a major site for the production of the cold deep water that drives global ocean circulation, a significant influence (through albedo effects) on Earth's energy budget, and a crucial driving component for Southern Hemisphere atmospheric circulation. Yet despite its importance, instrumented records of climate change over this vast continent are extremely sparse spatially and temporally. Fortunately, through the recovery of ice cores in combination with glacier geophysics, surface glaciology, and atmospheric chemistry programs, Antarctica has the potential to be the best understood region on Earth climatically. On 2 January 2003 the United States component of the International Trans Antarctic Scientific Expedition (US ITASE) arrived at South Pole having completed, over the period 1999-2003, >5000 km of over snow traverses that included much of West Antarctica and a portion of East Antarctica. During the traverses US ITASE focused on the collection of data that will allow the reconstruction of sub-annual scale climate variability and change in the chemistry of the atmosphere for the last 200+ years. In the process US ITASE collected an integrated, multi-disciplinary assemblage of data extending from the bed of the ice sheet (>3000 m) to >20 km in the atmosphere. Results from US ITASE offer new insights into the understanding of Southern Hemisphere climate variability (eg., temperature, accumulation rate, atmospheric circulation, atmospheric chemistry, climate forcing), with particular emphasis on the

documentation of atmospheric teleconnections between the Pacific Ocean and West Antarctica.

C21D-02 1035h INVITED

Interactions Between Large Bedrock Features and Ice Sheet Dynamics Interpreted From Deep-Penetrating Radar Along the US-ITASE Traverse Routes

Brian C Welch[1] (welchb@stolaf.edu)

Robert W Jacobel[1] (jacobel@stolaf.edu)

Knut Christianson[1]

Kieran Cofell-Dwyer[1]

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

Ice-penetrating radar studies depicting the structure of internal stratigraphy in ice sheets can be used to infer information about past ice dynamics and changes in ice flow over time. To date, most radar studies in the interior of major ice sheets have shown internal layers draped smoothly over bed topography with decreasing relief toward the surface. This result is one consequence of ice frozen to the bed and accumulation patterns that do not vary substantially in space or time. In contrast, areas that show significant deformation of internal layers are typically found in ice streams, where sliding can cause large strains. Deep-penetrating radar profiles from the 2001 and 2002 US-ITASE traverses show several areas in the interior of West Antarctica and the transition region between the East and West Antarctic Ice Sheets where internal stratigraphy is disrupted and discontinuous in the vicinity of large topographic bed features with relief >50% of regional ice thickness. Ice in these areas is presumably frozen to the bed. In some locations these disruptions in internal layers appear to result from surface wind scouring and redeposition. The influence of bed features on surface topography evidently causes local changes in snow accumulation and the interactions between wind and snow surface may facilitate the development of wind ablation regions. In another area near Byrd Surface Camp a significant bed feature, "Mt. Resnik," appears to be causing breaks in internal stratigraphy imaged in a grid of 4 radar profiles oriented across the flow direction and several kilometers downstream. We hypothesize that there is a ratio of mountain height to regional ice thickness where the ice above the mountain will effectively decouple from the surrounding ice flow and crevasses will develop. Such a scenario would cause a seam to form and disruption of internal layers that is similar to what we have observed. The fact that deeper layers in the same region are continuous implies that conditions producing the disruption may be transient, perhaps due to lowering of the ice surface. Modeling of the ice flow around this feature may provide estimates of the post-LGM thinning rates in central West Antarctica.

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

C21D-03 1050h INVITED

Tracking Isochronal Radar Reflections Across West Antarctica

Vandy Blue Spikes[1] (207-581-2112; vandy.spikes@maine.edu)

Steven A Arcone[2] (603-646-4368; steven.a.arcone@erdc.usace.army.mil)

Gordon S Hamilton[1] (207-581-3446; gordon.hamilton@maine.edu)

[1] Climate Change Institute, University of Maine, 5790 BGSC, Room 303, Orono, ME 04469-5790, United States

[2] USACE Engineer Research and Development Center , Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755-1290, United States

We used a 400 MHz radar profiling system to resolve and track individual horizons within firn along the 1999 to 2002 International Trans Antarctic Scientific Expedition (ITASE - U.S.A. component) traverses across West Antarctica. Nearly 5000 km of radar data ranging in depth from 56 m to 135 m were collected while traveling between ice core sites. Throughout the dataset we observe continuous reflections that are caused by density variations related to summer melt layers and wind crusts. By tracking such horizons between dated ice cores we demonstrate that the isochronal accuracy of each continuous reflection is less than 1 year. This result highlights the vertical resolution of our radar system which is about 30 times greater than that provided by standard radio echo sounders. This result also justifies the use of these horizons for determining historical snow accumulation rates along survey lines. The benefits of using this continuous measurement approach are that it reveals the spatial and temporal patterns of snow accumulation over large regions and it produces an accurate spatial mean. These data are currently being used to update continental-scale datasets of Antarctic surface mass balance and to improve mass balance estimates of the West Antarctic Ice Sheet.

URL: http://www.geology.um.maine.edu/user/blue_spikes/research.htm

C21D-04 1105h

Siple Dome: a Case Study of Flow Near an Ice Divide

Erin C Pettit[1] (206-543-0162; epettit@ess.washington.edu); Edwin D Waddington[1] (edw@ess.washington.edu); H Paul Jacobson[1] (paul@ess.washington.edu); Mark A Zumberge[2] (zumberge@ucsd.edu); Eric Husmann[2]; William D Harrison[3] (harrison@gi.alaska.edu); Dan H Elsberg[3] (ftdhe@uaf.edu); John L Morack[3] (ffjlm@aurora.alaska.edu); Throstur Thorsteinsson[4] (throsturt@raunvis.hi.is); Gregg Lamorey[5] (gregg.lamorey@dri.edu)

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

[2] Scripts Institute of Oceanography, University of California, San Diego, La Jolla, CA 92093, United States

[3] Geophysical Institute, University of Alaska, Fairbanks, Fairbanks, AK 99775-7320, United States

[4] Science Institute University of Iceland, Hofsvallagotu 53, Haga, Reykjavik 107, Iceland

[5] Desert Research Institute, 2215 Raggio Parkway, Reno, NV 89512, United States

Siple Dome, West Antarctica, is the site of a recent deep ice core. Its dynamic behavior has been inferred through surface strain networks, ice-penetrating radar, and *in situ* strain gauge arrays. In this case study, we explore the combined effects of crystal anisotropy, temperature, and rheology on the unique dynamic behavior of steady-state ice divides. The low-stress regime near ice divides causes a flow anomaly due to the nonlinearity of ice flow. This phenomenon is observable as an arch in the internal layer structure (imaged by radar). The pattern of divide flow can be inverted for flow law parameters. Specifically, at low stresses, the dominant micro-scale flow mechanism shifts to one that is more linear. This shift is expressed as a change in the flow-law exponent; therefore its effect is distinguishable from that of anisotropy or temperature. We have developed a 2D plane-strain finite-element flow model with a two-term flow law modified for anisotropic flow. With this model and available measurements, we use Siple Dome as a case study to assess the relative importance of linear-viscous behavior compared to anisotropic behavior and discuss the implications for other ice divides.

C21D-05 1120h

Channel-Like Bottom Features and High Bottom Melt Rates of Petermann Gletscher's Floating Tongue in Northwestern Greenland

Konrad Steffen[1] (303 492 4524; konrad.steffen@colorado.edu); Russell D Huff[1] (303 492 6881; rhuff@cires.colorado.edu); Nicolas Cullen[1] (303 492 6881; cullenn@cires.colorado.edu); Eric Rignot[2] (818 354-1640; eric@adelie.jpl.nasa.gov); Craig Stewart[3] (44-1223-221493; 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 CB 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. We finished a second field season in spring 2003 collecting in situ data on local climate, ice velocity, strain rates, ice thickness profiles and bottom melt rates of the floating ice tongue. Last years findings have been confirmed that large channels of several hundred meters in depth at the underside of the floating ice tongue are running roughly parallel to the flow direction. We mapped these channels using ground penetrating radar at 25 MHz frequency and multi-phase radar in profiling mode over half of the glacier's width. In addition, NASA airborne laser altimeter data was collected along and cross-glacier for accurate assessment of surface topography. We will present a 3-D model of the floating ice tongue and provide hypothesis of the origin and mechanism that caused these large ice channels at the bottom of the floating ice tongue. Multi-phase radar point measurements revealed interesting results of bottom melt rates, which exceed all previous estimates. It is worth mentioned that the largest bottom melt rates were not found at the grounding line, which is common on ice shelves in the Antarctica. In addition, GPS tidal motion has been measured over one lunar cycle at the flex zone and on the free floating ice tongue and the result will be compared to historic measurements made at the beginning of last century. The surface climate has been recorded by two automatic weather stations over a 12 month period, and the local climate of this remote region will be presented.

C21D-06 1135h

Recent Increase in Flow Rates of the the Jakobshavn Isbrae, Greenland

Waleed Abdalati[1] (202-358-0746; wabdalat@hq.nasa.gov); Serdar Manizade[2] (manizade@osb1.wff.nasa.gov); Jim Golder[3] (golder@pop500.gsfc.nasa.gov); Robert H. Thomas[2] (robert_thomas@hotmail.com); William Krabill[4] (krabill@osb1.wff.nasa.gov); Bea Csatho[5] (csatho.1@osu.edu)

[1] NASA Headquarters, Office of Earth Science 300 E Street SW, Washington, DC 20546, United States

[2] EG&G, Code 972 NASA Wallops Flight Facility, Wallops Island, VA 23336, United States

[3] Raytheon ITSS, Code 971 Goddard Space Flight Center, Greenbelt, MD 20771, United States

[4] NASA WFF, Code 972 Wallops Flight Facility, Wallops Island, VA 23336, United States

[5] Byrd Polar Research Center, 171 Scott Hall 1090 Carmack Road The Ohio State University, Columbus, OH 43210, United States

Greenland's Jakobshavn Isbrae is one of the world's fastest-moving ice streams and accounts for approximately fifteen percent of the ice sheet's total annual discharge. During the early and mid 1990's, while many of Greenland's outlet glaciers and near-coastal areas were thinning, the Jakobshavn drainage basin remained relatively unchanged. Since 1997, however, the ice stream has been thinning at rates that far exceed those that could be attributed to increased ablation or reduced accumulation, even after taking into account the recent high melt-rates observed on the ice sheet. Analyses of feature movement in various Landsat image pairs from 2001 and 2002 reveal that coincident with that thinning there has been an increase in ice stream surface velocity to levels that are much greater than the historically observed 7 km/yr. These velocity increases coincide with recent warm temperatures of the last several years and, unlike previous observations, the flow rates appear to be greater in summer than in spring. Although this seasonal velocity increase suggests an association with enhanced basal lubrication as increased surface melt water drains to the glacier bed, the larger overall velocity increase most probably results from very rapid thinning and breakup of the glacier's floating ice tongue that began in 1997. Both of these processes indicate a significant link between glacier flow rates and recent climate characteristics in the region, and represent glacier dynamic responses that are not included in current assessments of sea-level change in a warming climate.

C21D-07 1150h

Two Decades of Gravity Variations at a Site on the South-central Greenland Ice Sheet

Kenneth Jezek[1] (614 292 7973; jezek.1@osu.edu)

Francois Baumgartner[2] (frb@byg.dtu.dk)

William Krabill[3] (804 824 1417; william.b.krabill@nasa.gov)

John Sonntag[3] (sonntag@osb1.wff.nasa.gov)

[1] Byrd Polar Research Center, 1090 Carmack Road, Columbus, OH 43210, United States

[2] Arctic Technology Center, Technical University of Denmark, Lyngby DK-2800, Denmark

[3] Laboratory for Hydrospheric Processes, Wallops Flight Facility, Wallops Island, VA 23337, United States

At the 2002 AGU Fall Meeting, we reported on changes in gravity and surface elevation measured at a site on the South-Central Greenland Ice Sheet. Our goal was, and remains, to understand relationships between changing ice sheet elevation and ice sheet mass.

We discussed gravity data collected in 1981, 1993 and 1995 and found a favorable comparison between decreasing trends in the gravity data and the increasing trends in more densely sampled observations of changing elevation. However, our analysis of those data also suggested that while the elevation of the ice sheet was increasing, the magnitude of the change in gravity did not support concluding that there was a comparable increase in mass. This year we report on the analysis of an additional set of gravity and surface elevation measurements collected at the same locations. During June 2003, we measured surface gravity and geodetic positions at six locations separated by about 20 km at a site located on the South-central Greenland Ice Sheet. We used two gravimeters and each was tied to the International Gravity Station Network before and after each set of field observations. A GPS unit operated at each field site and a base station unit recorded data for differential post-processing of the GPS data. The same measurement sites were occupied in 1981 and all were part of a hexagonal network of geodetic and glaciological measurements established by The Ohio State University in 1980. Additional gravity observations were acquired at three of the sites in 1993 and 1995. Gravity data were collected in conjunction with Doppler satellite measurements of position and elevation in 1981 and global positioning system measurements subsequently. The use of satellite navigation techniques permitted reoccupation of the same sites in each year to within a few 10's of meters or better. After detrending the gravity data, making adjustments for tides and removing the residual effects of local spatial gradients in gravity, we observe an average secular decrease in gravity of about 0.01 milligal/year, but with tenths of milligal variations about the mean trend. The trend is consistent with a nearly linear increase in surface elevation of between 7 to 10 cm/yr (depending on location) as measured by repeated airborne laser altimeter, surface Doppler satellite and GPS elevation measurements. We go on to discuss differences between the residual gravity anomalies after free air correction in terms of local mass changes.

C22A MCC: 3010 Tuesday 1340h

Glaciers and Ice Sheets III *(joint with G, H, OS, PP)*

Presiding: **J Harper,** University of Wyoming**; D G Vaughn,** British Antarctic Survey

C22A-01 1340h INVITED

A Macroscopic Approach to the Response of Glaciers to Climate

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

Geophysical Institute, University of Alaska, Fairbanks, AK 99775-7320, United States

We explore a drastic simplification of the theory of glacier response to small climate changes, a "macroscopic" one in which the distribution of thickness change is replaced by its integrated value, the total volume change. We also deal with change of area near the terminus rather than change in length. In the resulting area-volume relationship there are three parameters: an "area" time scale characterizing the time for area to respond to changes in volume, a thickness scale, and area characterizing the condition of the initial state. The first two characterize the dynamics of the glacier, and are 8 years and 123 meters for South Cascade Glacier as obtained by a fit of cumulative balance and area data from 1977 to 1997. Combining the area-volume relationship with a version of mass continuity expressed in terms of these same variables produces a theory of response of area and volume to climate in which a second time scale appears, the "volume" time scale. It is about 48 m for South Cascade Glacier, and differs from the usual estimate in that it includes the effect of both glacier length and surface elevation. The macroscopic theory characterizes a glacier as a damped oscillator forced by climate. For climate driving frequencies that are not too high, it reproduces the response of South Cascade Glacier predicted by the more complicated traditional theory of Nye; the analogous oscillator is critically damped. The response can be expressed in terms of a single "reaction" time scale, the geometric mean of the area and volume time scales.

C22A-02 1355h

Why Do Ice Streams Have Fast Velocities in Transtion Region of Low Surface Slope?

Johannes Weertman (847-491-3197; j-weertman2@nwu.edu)

Northwestern University, Materials Science & Engineering Dept. and Geologicla Sciences Dept., Evanston, IL 60208, United States

It seems generally accepted that when water at the base of a glacier flows mainly through channels (cut into the basal ice) the basal water itself has little influence on the sliding speed of the glacier. On the other hand, sliding speed can be increased if channel water flow is disrupted and water is forced to flow in some kind of broad distributed pattern. (If basal till underlies the ice mass these statements still may hold if flowing basal water is largely confined between ice and till.) In an early paper (Weertman, *Rev. Geophys. Space Phys.* (1972), **10**, 287-333) we analyzed the basal pressure gradient in the direction normal to a channel axis and showed that the presence of the basal shear stress can change the sign of the pressure gradient. The distance from the channel at which the sign reversal first occurs is smaller the larger is the shear stress and the greater is the water pressure within the channel. Water is driven away from a channel in the region of sign reversal. This effect makes it more difficult for water flow to occur primarily through channels and more likely that basal water will cause increased sliding velocity. In this presentation it is pointed out that the same sign reversal effect occurs if a longitudinal (with respect to the channel axis direction) deviatoric stress exits within the basal ice. A pressure gradient sign reversal around water channels arising from a longitudinal deviatoric stress that lead to speed up of sliding could be important in two physical situations. (1) In the transition zone where an ice stream of an ice sheet becomes part of an ice shelf. In this region the basal shear stress is greatly reduced (because the upper ice surface becomes almost horizontal). However, the longitudinal deviatoric stress is increased to almost the level of that of an ice shelf. (2) In a surging glacier. A surging glacier elongates by a significant fraction of its length in a relatively short period of time. As a consequence, a large longitudinal deviatoric stress must exist during a surge. In each of these situations the presence of a large longitudinal deviatoric stress will help disrupt water flow through channels and lead to increased speed of sliding. This mechanism may be the solution to the existing vexing problem: Why do ice streams have fast velocities in the transition region of low surface slope?

C22A-03 1410h

Load Sensitivity of a Surge-Type Glacier

Garry K 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

During the winter season Trapridge Glacier, Yukon, Canada, is subject to puzzling short-lived mechanical events. Such events are characterized by a pronounced increase in icequake activity, abrupt changes in the internal ice strain, and rapid local adjustments of the mechanical interaction between the glacier and its bed. Although the events are closely monitored by a network of englacial and subglacial instruments (including geophones and sensors to measure vertical strain, subglacial water pressure, basal sliding, and sediment strength) it has been unclear, until recently, whether the events are internally or externally triggered. Observations during the winters of 1999–2000 and 2002–2003 indicate that the events are externally triggered and that the forcing mechanism is rapid barometric and/or precipitation loading of the glacier surface. Such sensitivity to small changes in loading is unexpected and suggests that some fraction of the sediment substrate of Trapridge Glacier is near the threshold for mechanical failure. Winter triggering of glacier surges might be explained by fast surface loading.

C22A-04 1425h

Glacier-Scale Variability of the Subglacial Drainage System: Year-Long Records from Boreholes at Sites Along the Length of a Glacier

Joel T Harper[1] (307-766-6752; joelh@uwyo.edu)

Neil F Humphrey[1] (307-766-2728; neil@uwyo.edu)

W. Tad Pfeffer[2] (303-492-3480; pfeffer@tintin.colorado.edu)

[1]Department of Geology and Geophysics, University of Wyoming, Box 3006, Laramie, WY 82071, United States

[2]Institute of Arctic and Alpine Research and Dept. of Civil, Environmental, and Architectural Engineering, University of Colorado, Boulder, CO 80309, United States

Borehole measurements are used to examine the long time/space evolution of the subglacial drainage system. Over the course of two field seasons more than 50 boreholes were drilled to the bed of Bench Glacier, a temperate valley glacier in Alaska. The holes are located at 15 sites that span the 8 km from the headwall to the terminus of the glacier. Each site has at least two boreholes and one site has a grid of 16 boreholes spaced 20 x 20 m. The ice depth at the sites ranges from 70 to 190 m. Each borehole was fitted with instrumentation for measuring borehole water level and water flow velocity, and some boreholes were also fitted with conductivity and turbidity probes. Data have been collected at 15 minute intervals for a period in excess of one year. The boreholes were also imaged by video camera and used for slug/pump experiments, and high time/space resolution measurements of surface velocity were collected in the vicinity of the borehole grid. Observations reveal important details about the evolution of the subglacial drainage system over the length of the glacier, and over the course of the year: 1) the onset of summer diurnal variations in water pressure does not undergo an up-glacier spatial progression as is commonly assumed; 2) the termination of summer diurnal variations in water pressure is simultaneous along the length of the glacier; 3) the accumulation and ablation areas of the glacier have actively changing, but differing pressure fields; 4) short-lived subglacial events impact all sites along the length of the glacier, including those in the accumulation and ablation areas and those above and below an ice fall. These findings have diverse implications for the processes dictating the time/space evolution of the subglacial drainage system and the link between hydrology and glacier sliding.

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

C22A-05 1440h

C

Subglacial Bed Topography and Ice Sheet Surges

Christian G Schoof (604-822-3063; cschoof@eos.ubc.ca)

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

Bed topography at the scale of the ice thickness can lead to multiple flow states for an ice sheet. By analogy with classical hard-bed sliding, ice flow over this type of bed obstacle, which occurs commonly in the form of drumlins and similar bedforms, leads to the generation of drag on the ice, particularly when ice flow is rapid. In this presentation, we investigate the effect of this drag on the bulk dynamics of the overlying ice sheet. A crucial difference with classical sliding is that the upper, free surface of the ice has a significant effect on the sliding process through the formation of a standing wave. The shape of this wave not only depends on bed topography and sliding velocity, but also affects the stress field in the ice and hence the sliding velocity. The consequent nonlinearity in the sliding process leads to the possibility of multiple flow states, that is, of multiple surface wave configurations corresponding to different possible sliding velocities for the same large-scale ice sheet geometry. Using a theoretical model, we demonstrate that such multiple flow states are indeed possible, and that they lead to oscillatory behaviour in the ice sheet which can be interpreted as ice sheet surges.

C22A-06 1455h

Outburst Flooding and Surge Initiation

Richard B. Alley[1] (1-814-863-1700; ralley@essc.psu.edu); Todd K. Dupont[1] (dupont@essc.psu.edu); Byron R. Parizek[1] (parizek@essc.psu.edu); Sridhar Anandakrishnan[1] (sak@essc.psu.edu); Daniel E. Lawson[2] (dlawson@crrel.usace.army.mil); Grahame J. Larson[3] (larsong@pilot.msu.edu); Edward B. Evenson[4] (ebe0@lehigh.edu)

[1]Department of Geosciences and EMS Environment Institute, Pennsylvania State University, Deike Building, University Park, PA 16802, United States

[2]Cold Regions Research and Engineering Laboratory, 72 Lyme Road, Hanover, NH 03755, United States

[3]Department of Geological Sciences, Michigan State University, Geological Sciences Building, East Lansing, MI 48824, United States

[4]Department of Earth and Environmental Sciences, Lehigh University, 31 Williams, Bethlehem, PA 18015, United States

Antarctic subglacial lakes are well-known, and published geomorphic evidence from Pine Island Bay and from the Transantarctic Mountains suggests outburst flooding from subglacial lakes at different times in the past. Sedimentary evidence also indicates that abundant meltwater was involved in Heinrich events from Hudson Strait despite cold conditions, suggesting outburst flooding. Trapping of subglacial water is favored by development of a locally reversed ice-air surface slope, and by freeze-on; either may be sufficient singly, and both together should be sufficient. A cycle of ice-shelf grounding, freeze-on and development of slope reversal, thickening, thawing, and outburst flooding explains many observations, and is consistent with new modeling and with a range of observations from ice streams and ice shelves, although the ice-shelf step is not a necessary prerequisite.