destructive interference inside the slab whose occurrence versus angle of incidence is dependent on thickness. Unfortunately, this feature cannot be use as a detector because it is not conserved when a statistical average is formed, as required in a realistic measurement.

C11A-0981 0830h POSTER

The Importance of Snow and Ice Surface Roughness in Ablation Processes

Ute C Herzfeld[1,2,3] (herzfeld@tryfan.colorado.edu); Jason E Box[1] (jbox@ice.colorado.edu); Konrad Steffen[1] (koni@seaice.colorado.edu); Helmut Mayer[2] (mayerh@tryfan.colorado.edu); Nel Caine[2]; Mark V Losleben[2]

[1]CIRES, University of Colorado, Boulder, CO 80309-0216, United States

[2]INSTAAR, University of Colorado, Boulder, CO 80309-0450, United States

[3]Geomathematik, Universitaet Trier, Trier 54286, Germany

The influence of surface roughness of snow and ice on melt energy has been greatly underestimated to date. Surface roughness has usually been included in climatological, meteorological, and snow-hydrological models as a one-dimensional parameter, roughness length, than has been estimated rather than measured. We define surface roughness as a spatial variable and measure it with the Glacier Roughness Sensor (GRS). GRS data from a part of the ablation area in the Greenland Ice Sheet (ice surfaces) and from a continental alpine environment (snow surfaces) are analyzed using geostatistical classification. A mathematical relationship between aerodynamic roughness length and spatial surface roughness is developed. Using this relationship, roughness length of a range of snow and ice surfaces is calculated from the GRS measurements, and the resultant values are input in energy balance calculations. As a result, melt energy varies by a factor of two or more dependent on surface roughness. Consequently, it is important to measure snow and ice surface roughness and include it more accurately in climatological, meteorological, and snow-hydrological models. Applications are the assessment of ablation and surface processes on glaciers and ice sheets in general, and in response to global warming in particular, resultant changes in sea level, study of changes in alpine glaciers and snowfields, and modeling of snow-hydrological processes.

C11A-0982 0830h POSTER

An Enhanced, Albedo Accounting Degree Day Melt Model for Distributed Application

Francesca Pellicciotti[1] (44-1-6332958; pellicciotti@ihw.baug.ethz.ch); Ulrich Strasser[2] (44-1-6332429; strasser@ihw.baug.ethz.ch); Ben Brock[4] (44-1382-345443; b.w.brock@dundee.ac.uk); Paolo Burlando[3] (41-1-6333812; paolo.burlando@ethz.ch); Martin Funk[5] (41-1-6324132; funk@vaw.baug.ethz.ch); Javier Corripio[6] (44-131-650-9170; jgc@geo.ed.ac.uk)

[1]Institute of Hydromechanics and Water Resources Management, IHW-HIL G28.2 ETH-Hnggerberg, Zurich CH-8093, Switzerland

[2]Institute of Hydromechanics and Water Resources Management, IHW-HIL G28.3 ETH-Hnggerberg, Zurich CH-8093, Switzerland

[3]Institute of Hydromechanics and Water Resources Management, IHW-HIL G33.1 ETH-Hnggerberg, Zurich CH-8093, Switzerland

[4]Department of Geography, University of Dundee, Dundee. DD1 4HN, Dundee DD1 4HN, United Kingdom

[5]VAW, ETH Zurich, Gloriastr. 37/39 CH-8092 Zrich, Zurich CH-8092, Switzerland

[6]Department of Geography, University of Edinburgh, Drummond St. Edinburgh EH8 9XP, Edinburgh EH8 9XP, United Kingdom

In this paper, an enhanced degree-day melt model for the point scale is presented, in which the classical dependency on temperature is extended by considering albedo and global radiation. The standard approach has been recently improved by addition of a potential direct radiation term. Here, this approach is taken a step further by the inclusion of albedo, which controls the amount of global radiation available for conversion to melt energy at the snow or ice surface. An additive form of the degree-day model is proposed, aiming at clearly separating the two important contributions to melt energy, namely the longwave radiation and turbulent fluxes in one term and shortwave radiation in the other.

The performance of the albedo enhanced degree-day model is tested against simulations obtained from a physically based energy-balance model. Hourly melt rates were calculated using the energy balance model at five sites on Haut Glacier d'Arolla, Switzerland, with data from a recent extensive field campaign.

The results show that the enhanced degree-day model delivers significant improvements over other versions of the degree-day model, accounting for about 90% of the surface melt rate variation. In particular, including albedo enables the model to capture the major increases in the surface melt rate caused by metamorphism of new snow and the transition from a snow to an ice surface. Through a more physically-based representation of the surface melt process, the enhanced degree-day model offers a higher transferability than the simpler formulations. The potential for a distributed application of the enhanced degree-day model to Haut Glacier d'Arolla is discussed.

C11A-0983 0830h POSTER

Radiation Index Melt Modelling and Implications for the North American Deglaciation

Faron S Anslow[1] ((403) 220-8031; fsanslow@ucalgary.ca)

Shawn J Marshall[1] ((403) 220-4884; smarshall@ucalgary.ca)

[1]University of Calgary, Department of Geography ES 356 2500 University Drive NW., Calgary, AB T3B 2B6, Canada

A proper energy balance calculation of snow and ice melt is difficult to carry out in ice sheet models due to the need for detailed meteorological data (i.e. wind conditions, cloud cover, etc.) that are unavailable for the past and too complex and spatially variable to be extracted from climate models. Ice sheet models therefore resort to more simple positive degree day (PDD) melt relationships to parameterize snow and ice melt from air temperature inputs for mass balance calculations. However, the PDD parameters that have been developed for use in ice sheet models are based on studies done in Greenland and the Canadian Arctic where temperatures are relatively low and radiation regimes different than those at lower latitudes. This becomes a problem in applications to the former Laurentide ice sheet, which was in radiation and temperature conditions possibly much different than those in which present relationships were established.

The work presented here seeks to remedy the above problem by introducing new surface melt parameters for an alpine glacier based on both temperature and radiation. This study focuses on a mid-latitude alpine glacier in the Canadian Rockies as a potential analogue to the southern margin of the former Laurentide ice sheet after the last glacial maximum. Meteorological and ablation measurements were made over two summer seasons in 2001 and 2002 and have been used to compute radiation- and temperature- melt parameters. It is believed that the inclusion of these two variables in melt simulations will allow extension of the model to geographical and climate regimes other than the alpine setting in which they were derived. We apply the new melt model to simulations of the former Laurentide Ice Sheet during the period from the last glacial maximum to the present to provide insights into the pattern and timing of ice sheet collapse.

C11A-0984 0830h POSTER

AWS Measurements of Surface Ablation on the Petermann Gletscher, Greenland

Russell Huff[1] (303 492 6881; russell.huff@colorado.edu)

Nicolas J. Cullen[1] (303 492 6881; cullenn@cires.colorado.edu)

Konrad Steffen[1] (303 492 4524; koni@seaice.colorado.edu)

[1]University of Colorado CIRES, CB 216, Boulder, CO 80302, United States

Most Greenland glaciers are tidewater glaciers flowing directly into the ocean with little or no floating section, but slowly moving glaciers in the north flow into ice shelves. The largest of these is the Petermann Gletscher, which has a 70 km long floating tongue and is 20 km wide at the grounding line. Remote sensing has shown that 95% of the ice that crosses the grounding line melts before it reaches the calving front, with peak values exceeding 20 m a^{-1} near the hinge line. The dominant form of this mass loss (55%) has been attributed to basal melting of the ice tongue, with the never measured surface ablation thought to account for about 2-3 m a^{-1}. However, the installation of a transmitting automatic weather station on the Petermann Gletscher, prior to the onset of melt, during an extensive field campaign during 2002 allows surface ablation to be described for the first time. Measurements from sonic ranging instruments show a surface lowering of only 1.4 m during the melt period, which occurred between early June and mid August. This melt is compared to predicted melt rates using an ablation model. Although surface melting does not dominate the mass budget of the Petermann Gletscher, field observations lend support to the notion that it may be relevant towards weakening and fracturing the floating tongue.

C11B MCC: Hall C Monday 0830h

The Role of Microstructure and Layering in the Physical Properties, Metamorphism, and Deformation of Snow Covers II Posters *(joint with A, H)*

Presiding: **M Schneebeli,** Swiss Federal Institute for Snow and Avalanche Research**; J Johnson,** U.S. Army Engineer Research and Development Center

C11B-0985 0830h POSTER

A Discrete Element Model of the Micromechanical Processes that Control Snow Deformation

Jerome B. Johnson[1] (907-353-5179; jjohnson@crrel.usace.army.mil)

Mark A. Hopkins[2] (603-646-4249; Mark.A.Hopkins@erdc.usace.army.mil)

John W. Weatherly[2] (603-646-4741; John.W.Weatherly@erdc.usace.army.mil)

[1]USA CRREL, P. O. Box 35170, Ft. Wainwright, AK 99703, United States

[2]USA CRREL, 72 Lyme Rd., Hanover, NH 03755, United States

Snow deformation affects many geophysical processes. It is important to the stability of snow-covered slopes and causes an evolution of snow structure that determines hydrologic, electromagnetic, and thermal properties. Self-weight densification influences how atmospheric gases are trapped in ice; an important consideration for climate studies using recovered ice cores. Snow is a relatively porous, highly structured material that exists near its melting temperature resulting in complex deformation processes controlled at the microscale. Unbonded snow grains are transformed into a matrix of bonded particles by sintering. Deformation occurs at grain contact points through grain boundary sliding and rolling, power law creep, elastic compression and tension, and the rupture and resintering of particles. These processes are influenced by temperature, time, and deformation rate. We use a morphological discrete element method (DEM) to simulate the structure of a three-dimensional snow sample composed of realistically shaped ice grains bonded together by frozen joints whose strength varies with time and temperature. The DEM explicitly models the dynamics of assemblies of individual particles modeled as a mixture of axisymmetric shapes. Snow grain contact models allow bonds to grow through diffusion and power law creep. The contact models support elastic torque, tension, compression and tangent forces. Grain contacts undergo tangential creep in response to tangential forces that replicates grain boundary creep for ice and is described by a temperature dependent linear viscosity. The temperature dependent tensile strength of ice and the radius of the bonds determine failure of grain bonds. Tensile failure of a bond occurs when the tensile stress acting on a particle contact equals the ice tensile strength. Bond failure due to torque loading occurs when the bending stress at the outer edge of a bond equals the ice tensile strength. By incorporating algorithms for grain bond sintering and micromechanical processes we can explicitly model the temperature and time dependent microscale processes that control large-scale discontinuous deformations of snow.

C11B-0986 0830h POSTER

A One-Dimensional Model for the Annual Snow-Firn Layer Structure

Olga Sergienko[1] (olga@uchicago.edu)

Oleg V. Nagornov[2] (nagornov@dpt39.mephi.ru)

[1]The University of Chicago, 5734 S. Ellis Ave, Chicago, Il 60637, United States

[2]Moscow Engineering Physics Institute, 31 Kashirskoe sh, Moscow 115409, Russian Federation

The annual layers at all depth horizons are found in ice cores from different glaciers. The formation of such layers starts at the upper part of glaciers where snow interacts with atmosphere. Here we present a one-dimensional model that describes the annual layer formation. In our model firn is performed as an ice skeleton with pore spaces. The sceleton is constructed from cubic packed spherical ice grains. The fresh snow layers are compressed under the weight of upper layers and due to metamorphism. Melted in warm seasons water permeates to the deeper cold horizons and re-freezes on the ice grains. All these processes lead to the pore space vanishing and ice layer formation. Short wave radiation penetrates to the snow depth and initiates internal melting. The top and bottom melting fronts spread up and down. Melted water decreases the snow albedo and intensifies melting. The interaction with atmosphere is taken into account through the surface heat budget. The snow surface temperature depends on atmosphere parameters such as wind speed, specific humidity, atmosphere pressure and temperature. The 15 year integration forced by climate fields from station #42020 World Meteorological Organization of year 1994 results in snow firn layers with well distinct annual structure characterized by different melt feature index. These results allow establishing a connection between the mean annual air temperature and the melt feature index.

C11B-0987 0830h POSTER

Measurements of the Microstructure and Hardness of a Buried Surface Hoar Layer Using the SnowMicroPen

Karl Birkeland[1] (406-587-6954; kbirkeland@fs.fed.us)

Martin Schneebeli[2] (schneebeli@slf.ch)

Christine Pielmeier[2] (pielmeier@slf.ch)

[1]U.S. Forest Service National Avalanche Center, P.O. Box 130, Bozeman, MT 59771, United States

[2]WSL Swiss Federal Institute for Snow and Avalanche Research, Fluelastrasse 11, Davos Dorf 7260, Switzerland

Surface hoar is the most dominant persistent weak layer for avalanche formation in many geographic locations. Insights into the microstructure and hardness of buried surface hoar, and how they change through time and space, improves our understanding of the role of these weak layers in avalanche formation. We investigated the microstructure of a buried surface hoar layer in southwest Montana, U.S.A. using the SnowMicroPen (SMP), an instrument designed to measure extremely detailed snowpack profiles. We collected two sets of microstructure data from two adjacent parts of a slope six days apart. In addition, one manual snowpack profile was sampled each day, as well as 50 shear strength measurements using the Quantified Loaded Column Test. For the SMP data, a 900 m2 area was sampled on both days in an approximate 3 by 3 m grid, with some subareas of more closely spaced measurements. We collected 85 SMP profiles on the first day and 130 SMP profiles on the second day. The buried surface hoar layer, which had relatively low-density snow both above (180 kg m-3) and below (220 kg m-3) it, was readily identifiable in the SMP profiles. In our analyses, we manually located layer boundaries and calculated statistics for the force signal through both the surface hoar layer and the overlying slab. This allowed: 1) a comparison of the SnowMicroPen data to manual snowpack profiles on each day, 2) a comparison of the temporal changes between the two sampling days, and 3) a comparison of the spatial variations present on each day. Though the median thickness of the layer measured by the SMP was similar between the two days, changes in microstructure and hardness may help to explain the observed increase in shear strength between the days.

C11B-0988 0830h INVITED POSTER

Relation between grain size and correlation length of snow

Christian Matzler (matzler@iap.unibe.ch)

Institute of Applied Physics University of Bern, Sidlerstrasse 5, Bern 3012, Switzerland

It has often been difficult to compare results of different types of snow-structural information. Grain-size and correlation length are such parameters of granular media, and there exist different definitions and different methods for both of them. The relation between these parameters is analyzed from theoretical and from experimental points of view, considering optical and microwave properties. For spherical ice grains the connecting formulas are simple, but for other shapes the two parameters are not directly related. Care must be taken in the measurement procedure. Especially if grain size is regarded as the maximum extent of connected ice particles, the results are likeley to lead to extreme overestimates. Therefore it is concluded that grain size should be complemented by an additional size parameter, namely the surface-to-volume ration of equivalent spheres, i.e. a measure of the correlation length. Methods to determine this quantity in the laboratory have been known for a long time. Methods to do such measurements in the field are described here.

C11B-0989 0830h POSTER

The Snow Guillotine a New Instrument for Identifying Meltwater Pathways in a Draining Snowpack

Tyler A Erickson[1] (tyler.erickson@colorado.edu)

Mark W Williams[1] (markw@snobear.colorado.edu)

[1]Institute of Arctic and Alpine Research, 1560 30th Street; UCB 450, Boulder, CO 80309, United States

The transport of meltwater through a wet and draining snowpack is a poorly understood aspect of snow hydrology, even though the meltwater process is an important component of water resource forecasting and contaminant transport modeling. Numerous field experiments have shown that a draining snowpack does not behave as a homogeneous porous medium, but rather routes significant quantities of meltwater through vertical preferential pathways and horizontally along stratigraphic interfaces.

Dye tracer experiments are often used to identify preferential flowpaths within a snowpack. In these experiments, a colored dye is applied to a melting snow surface, and the dye is carried along into the snowpack with the meltwater. In order to take quantitative measurements of the occurrence of meltwater pathways, an instrument (the snow guillotine) was designed to shave thin vertical layers off the side of the snowpit wall, exposing preferential pathways. A sequence of vertical sections is then imaged with a digital camera to create a 3-D data set of preferential pathways. Vertical sections were located 1-cm apart and images of the vertical sections were resampled to a 1-cm square pixel size, resulting in a 3-D dataset of approximately 1 million voxels (volume elements). The 3-D datasets were analyzed using connectivity statistics, which provide a quantitative method of comparing different preferential pathway networks.

C11B-0990 0830h POSTER

Light Transmission Through Snow

Donald K Perovich[1] (603-646-4255; perovich@crrel.usace.army.mil)

Bruce Elder (belder@crrel.usace.army.mil)

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

An understanding of light transmission by snow is important for snow thermodynamics, hydrology, ecology, and remote sensing. Snow has an intricate microstructure replete with snow-ice interfaces that scatter light. Spectral observations of light transmission, from 400-1000 nm, were made within and through temperate and polar snowpacks, under cold conditions and under melting conditions. The optical observations were made using a dual-detector spectroradiometer. One detector was placed above the snow surface to monitor the incident and reflected solar irradiance. The second detector was placed either at the base of snowcover to measure downwelling irradiance, or was lowered through the snow to measure profiles of upwelling irradiance. The optical measurements were supplemented by a physical characterization of the snow including depth, density, and an estimate of grain size. In general, transmitted light levels were low, and showed a strong spectral dependence with maximum values between 450 nm and 550 nm. For example, a 10-cm-thick snow layer reduced visible transmission (500 nm) to about 5% of the incident irradiance and infrared transmission (800 nm) to less than 1%. Extinction coefficients were in the 3 to 30 per meter range, and tended to increase with increasing grain size and snow density.

C11B-0991 0830h POSTER

Stress distribution in the microstructure of snow

Martin Schneebeli (schneebeli@slf.ch)

Swiss Federal Institute for Snow and Avalanche Research SLF, Fluelastrasse 11, Davos Dorf 7260, Switzerland

The arrangement of crystals in sintered snow determines the mechanical properties. The microstructure of snow is measured using optical or x-ray tomography. A voxel-based finite element model to calculate the stress distribution is used to determine the elastic properties of snow samples. Snow samples of different texture are reconstructed in 3D by optical tomography. Out of the reconstructed cubes of 30 mm width, smaller cubes of 5 mm are used for the numerical simulation. A small elastic deformation was then simulated and the average elastic moduli of these samples determined. Locations of stress concentrations can be extracted and compared to the microstructural location of bonds. By this method we are able to determine mechanical properties of thin or extremely brittle snow layers which are difficult or impossible to measure otherwise.

C11B-0992 0830h POSTER

Stratigraphy of snow profiles using near-infrared photography

Margret Matzl[1,2] (margret.matzl@gmx.net)

Martin Schneebeli[2] (schneebeli@slf.ch)

[1]Humboldt University, Geographical Institute, Berlin 10099, Germany

[2]Swiss Federal Institute for Snow and Avalanche Research SLF, Fluelastrasse 11, Davos Dorf 7260, Switzerland

The detailed representation of the layers in snow profiles is extremly time consuming. Translucent profiles are used to reveal layer boundaries, however no method is known to relate the transmitted light intensity to morphologic parameters. We use digital near-infrared photography (NIP), centered at a wavelength of 890 nm, to determine optical grainsize on snow profiles. The reflectivity was calibrated with snow samples of different grain size and shape. The digital image of a snow profile is optically and geometrically corrected and the intensities are then converted to optical grain-size. The measured snow profiles on different slopes are compared to planar sections and classical snow profiles. In several cases the NIP image revealed thin layers, layer transitions and disturbances which are also visible in the planar section, but were not recorded in the snow profile. NIP profiles could be as large as 1 m high and 3 m long at very high spatial resolution by assembling several images. NIP of snow profiles is well suited to document and analyse snow stratigraphy and to determine optical diameter .

C11B-0993 0830h POSTER

Numerical Model of Multiple Scattering and Emission from Layering Snowpack for Microwave Remote Sensing

Ya-Qiu Jin[1] (0086-21-65643902; yqjin@fudan.ac.cn)

Zhichang Liang[1] (0086-21-65643902; yqjin@fudan.ac.cn)

[1]Fudan University, Center for Wave Scattering and Remote Sensing, Shanghai 200433, China

The vector radiative transfer (VRT) equation is an integral-deferential equation to describe multiple scattering, absorption and transmission of four Stokes parameters in random scatter media. From the integral formal solution of VRT equation, the lower order solutions, such as the first-order scattering for a layer medium or the second order scattering for a half space, can be obtained. The lower order solutions are usually good at low frequency when high-order scattering is negligible. It won't be feasible to continue iteration for obtaining high order scattering solution because too many folds integration would be involved. In the space-borne microwave remote sensing, for example, the DMSP (Defense Meterological Satellite Program) SSM/I (Special Sensor Microwave/Imager) employed seven channels of 19, 22, 37 and 85GHz. Multiple scattering from the terrain surfaces such as snowpack cannot be neglected at these channels. The discrete ordinate and eigen-analysis method has been studied to take into account for multiple scattering and applied to remote sensing of atmospheric precipitation, snowpack etc. Snowpack was modeled as a layer of dense spherical particles, and the VRT for a layer of uniformly dense spherical particles has been numerically studied by the discrete ordinate method. However, due to surface melting and refrozen crusts, the snowpack undergoes stratifying to form inhomogeneous profiles of the ice grain size, fractional volume and physical temperature etc. It becomes necessary to study multiple scattering and emission from stratified snowpack of dense ice grains. But, the discrete ordinate and eigen-analysis method cannot be simply applied to multi-layers model, because numerically solving a set of multi-equations of VRT is difficult. Stratifying the inhomogeneous media into multi-slabs and employing the first order Mueller matrix of each thin slab, this paper developed an iterative method to derive high orders scattering solutions of whole scatter media. High order scattering and emission from inhomogeneous stratifying media of dense spherical particles are numerically obtained. The brightness temperature at low frequency such as 5.3 GHz without high order scattering and at SSM/I channels with high order scattering are obtained. This approach is also compared with the conventional discrete ordinate method for an uniform layer model. Numerical simulation for inhomogeneous snowpack is also compared with the measurements of microwave remote sensing.

C

C11B-0994 0830h POSTER

3D modeling of curvature-driven snow metamorphism: first results and comparison with experimental tomographic data

Frédéric Flin[1] ((33) 4 76 63 37 60; frederic.flin@meteo.fr)

Jean-Bruno Brzoska[1] ((33) 4 76 63 79 25; jean-bruno.brzoska@meteo.fr)

Bernard Lesaffre[1] ((33) 4 76 63 79 10; bernard.lesaffre@meteo.fr)

Cécile Coléou[1] ((33) 4 76 63 79 12; cecile.coleou@meteo.fr)

Romeu André Pieritz[1] ((33) 4 76 63 37 63; romeu.pieritz@meteo.fr)

[1]Meteo-France, Centre d'Etude de la Neige, 1441 rue de la Piscine, St Martin d'Heres F38400, France

Snow, from its fall until its full melting, undergoes a structure metamorphism governed by local temperature and humidity fields. Among the many possible mechanisms that contribute to snow metamorphism, those that depend only on curvature are the most accessible to modeling. The isothermal metamorphism of a dry snow sample near 0°C is addressed in this work. Near 0°C, the vapor pressure of water is high: the metamorphism can be considered,*in first approximation*, as fully curvature-driven. This corresponds to neglect crystallographic orientation and diffusion-limited effects.

A law for the growth of the ice phase can be analytically obtained from Kelvin and Langmuir-Knudsen equations. In this law, the local volume fraction variation is proportional to the difference between average and local mean curvatures. A simple iterative model inspired by the work of J. W. Bullard [1] was implemented in three dimensions and applied on real tomographic images. First, the mean curvature map [2] of the binary image is computed from the normal vector field [3]. Then the new surface of the image is obtained by applying the growth law to each point of the surface. Such an approach allows model solution by increments of matter (image voxels) instead of time, reducing the required number of time-consuming curvature evaluations.

First results will be presented on geometrical shapes and subsamples (200^3 voxel) of 3D images of natural snow obtained at the ESRF by X-ray microtomography [4, 5]. An experiment of isothermal metamorphism in cold room at -2°C followed by tomography at the ESRF was held this spring. The evolution of curvature distributions will be compared between natural and simulated metamorphisms.

References [1] - J. W. Bullard, *J. Appl. Phys.* vol 81(1), 159-68 (1997) [2] - J.B. Brzoska et. al., *Eur. Phys. J. AP.* vol 7, 45-57 (1999) [3] - F. Flin et. al., *Image Anal. Stereol.* vol 20, 187-191 (2001) [4] - J.B. Brzoska et. al., *ESRF Newsletter* vol 32, 22-23 (1999) [5] - C. Coléou et. al., *Ann. Glaciol.* vol 32, 75-81 (2001)

C11B-0995 0830h POSTER

Characterization of the Microstructure of Snow with TDR

Richard Fortin[1] ((613) 990-6118; richard.fortin@nrc.ca)

Nirmal K. Sinha[2] ((613) 990-0650; nirmal.sinha@nrc.ca)

Franois Anctil[1] ((418) 656-3653; francois.anctil@gci.ulaval.ca)

[1]Dpartement de Gnie Civil Universit Laval, Qubec, Canada, Qubec, Qc G1K 7P4, Canada

[2]Institute for Aerospace Research National Research Council of Canada , 1200 Montreal Road, Ottawa, on K1A OR6, Canada

Snow microstructure is a significant element in the description of snow physical properties. However, microstructure characterization remains a complex and challenging task. The dielectric permittivity is an electromagnetic parameter of snow that is determined by composition and structure. Permittivity therefore, appears as a promising basis for an objective and quantitative characterization of snow microstructure. Many dielectric measurement instruments that are appropriate for field operation and telemonitoring have been designed. Among them, the time-domain reflectometry (TDR) technique is well documented following years of application in physical chemistry, earth sciences, engineering,and agriculture, and has showed some success for the characterization of snow. A few of the advantages of TDR over other instruments are that it is highly sensitive, it allows probe geometry optimization, and it is a broadband system yielding a full waveform response.

Experimental evidences have shown that density is the main determinant of snow permittivity, while dielectric models indicate an additionnal textural effect. However, density and microstructure of snow are to some extent coupled parameters. The objective of this study was to evaluate the relation between TDR response and structural parameters of snow. A database was established from over 35 measurements obtained in natural seasonal snowpack at 5 different locations. Pointers describing the snows complex permittivity were extracted from the time-domain TDR signal while a quantitative analysis of snow microstructure was performed from image analysis of snow thin sections and photographs of individual ice grains. Temperature, density, and chemical profiles of the snow samples were also obtained in the field in addition to descriptive observations on snowpack layering. Meteorological records and occasionnal visits over the season to the various locations yielded a dynamic picture of the snow cover corresponding to each measurements. Results show that different ice grain type exhibit different trends on the TDR response. Moreover, it appear possible to establish a classification of snow based on TDR-measured permittivity, where new snow, rounded grains, refrozen snow and metamorphic forms could be discriminated. Under certain circumstances, solid faceted grains and depth hoar grains can also be differentiated.

C11B-0996 0830h POSTER

Modeling the interface between two layers of snow using finite elements

Hans-Peter Marshall (303-735-8167; marshalh@colorado.edu)

University of Colorado at Boulder, Institute of Arctic and Alpine Research 1560 30th St Campus Box 450, Boulder, CO 80309, United States

Although dry slab avalanches in maritime climates can occur due to failure within a layer, avalanches in more continental climates are often caused by a weak bond between layers, usually as a result of the presence of surface and/or depth hoar. This can make modeling such a situation complex, as the quantitative material properties of the strength between two layers are difficult to measure and poorly understood. In addition, it is well known that the strength of snow shows a large degree of spatial variability. Measurements indicate local areas of the snowpack can have a strength which is less than the overburden stress, while the slope remains intact. The stress due the weight of snow above these areas is redistributed to areas of greater strength, a phenomenon which has been termed "bridging". Interface elements for use in finite element analysis have been developed in structural mechanics, which simulate the interface between two different materials (i.e. layers) and allow modeling of discontinuities within in a continuous system, as well as allowing the traditional elements within the model to slip relative to one another. The interface elements exhibit non-linear strain softening behavior after failure is initiated. Preliminary finite element modeling with these interface elements in the context of snow slope stability indicate that they may provide a useful tool for modeling the transfer of stress from weak to strong areas within the snowpack, as well as fracture propigation of dry slab avalanches.

C11B-0997 0830h INVITED POSTER

Microstructural Studies on Bonds and Crystal Growth in a Snowpack

Edward E. Adams (1-406-994-6122; eda@ce.montana.edu)

Civil Engineering Dept, Montana State University, Bozeman, MT 59717, United States

The role of microstructure in a snowpack influences virtually all of its thermo-mechanical properties. Density, grain size and importantly the structure of the bonds between grains have a very significant influence. We have focused on the microstructure of snow in a number of studies. Among these, the restructuring of a processed snowpack subjected to a persistent temperature gradient resulted in a microstructure, which metamorphosed from an essentially isotropic configuration into what appears to be transversely isotropic. Considering the geometric relationship of the bond to grain to be the significant microstructural consideration, a fabric tensor for snow has recently been developed and demonstrated by application to the evolving microstructure of the processed snow. Although the specific form of the tensor is not unique, it demonstrates promise for using a fabric tensor as a means to quantify the microstructural configuration of a snow pack.

Using a scanning electron microscope (SEM) to examine the bonds between grains of well-sintered snow, a raised feature that encircled the contact between grains, which we termed a grain boundary ridge, was revealed. The ridge has implications to grain boundary diffusion as a sintering mechanism and may be influenced by contamination concentrated at the grain boundary. Focusing the SEM on the attachment or bond area of very well developed depth hoar crystals revealed a complex microstructure, (of much smaller scale than the crystal itself) which merge into the large striated crystal. The many vacancies and sharp corners in this region should lead to stress concentrations, however, the mechanism of formation and a definitive notion on the role of these microstructural features on strength, beyond mere speculation, is unknown. In another study relevant to depth hoar crystal development, a substrate of large crystals of known crystallographic orientation where placed in a supersaturated vapor environment. The numerous hopper crystals that developed adopted the same crystal orientation as the substrate. Crystal habit is a function of the environment under which it is grown, based predominantly on temperature and supersaturation. This led to the hypothesis of a dominant grain growth theory whereby nucleation onto existing crystals optimally oriented for given conditions would dominate resulting in crystallographically oriented regions within a snowpack.

C12A MCC: Hall C Monday 1330h

Glaciers and Ice Sheets IV Posters

(joint with A, H, GC, PP)

Presiding: **S Marshall,** University of Calgary**; H A Fricker,** Scripps Institution of Oceanography

C12A-0998 1330h POSTER

Spatial Accumulation-Rate Pattern Inferred from Radar Internal Layers and Point Measurements of Velocity and Accumulation near Taylor Mouth, Victoria Land

Edwin D Waddington[1] (206-543-4585; edw@ess.washington.edu)

Thomas A Neumann[1] (taneuman@ess.washington.edu)

David L Morse[2] (morse@utig.ig.utexas.edu)

Hans-Peter Marshall[3] (marshalh@colorado.edu)

[1]Earth and Space Sciences, University of Washington, Box 351310, Seattle, WA 98195-1310, United States

[2]Institute for Geophysics, University of Texas at Austin, Austin, TX 78712, United States

[3]INSTAAR, University of Colorado, Campus Box 450, Boulder, CO 80309, United States

Internal layers in ice sheets, as measured by ice-penetrating radar, are most likely isochrones. The depth to a shallow internal layer is proportional to the local accumulation rate. However, low-frequency radars often do not record very shallow layers. High-frequency radars (GPR) record shallow layers, but cannot detect the deeper layers that reflect longer-term patterns of climate. Older, deeper layers are also influenced to an increasing degree by accumulated strain due to ice flow, and by the upstream accumulation rate. For this Geophysical Inverse Problem, our Forward Model is a steady-state ice-flow model with measured ice-sheet surface topography, ice thickness, and flowband width, which tracks particles to create modelled internal layers. Ice motion is driven by the input flux into the upper end of the flowband, and by the accumulation pattern along the flowband. To solve the Inverse Problem, our observations comprise depth of an internal layer, and point measurements of accumulation rate and surface velocity. Associated uncertainties are also required. We use Least-Squares or Singular-Value Decomposition to solve for model parameters (input ice flux, piece-wise linear accumulation-rate profile, and layer age) that minimize the mismatch between the data and the model estimates of the data. If the layer age and its uncertainty are known independently, they can also be used. Variable weights can be assigned to each type of data. The data-resolution matrix shows that, for shallow layers, we can resolve high-wavenumber variations in accumulation rate. For deeper layers, we resolve spatial averages of accumulation rates.

We apply the model to a flowband at Taylor Mouth between Taylor Dome and Taylor Glacier. The model finds more variation in the inferred accumulation-rate profile than in the depth-profile of an internal layer. The new accumulation-rate profile produces an improved chronology for an ice core collected along the flowline.

C12A-0999 1330h POSTER

Investigation of the Glacial History of the Siple Coast Using Radar-Detected Internal Layers and the Ice Core from Siple Dome

Dale P. Winebrenner[1] (206-543-1393; dpw@apl.washington.edu)

Howard Conway[2] (206-685-8085; conway@ess.washington.edu)