10^{-3} m) in ways strongly dependent upon deposition conditions and substrate micro- and meso-topography. Some "slow" processes, like snow settlement and kinetic growth due to temperature gradients, produce spatial variations that are predictable where the layer geometry is gently varying. Other "faster" processes, like the development of dunes during wind transport or melt water percolation, produce high lateral gradients in properties over short (10^{-1} m) distances that are currently beyond our ability to either measure (except with intense effort) or predict. A number of important snow processes (i.e., wind pumping, avalanche release, melt water routing) seem to be focused in or dominated by these sharp gradient zones and narrow facies boundaries. Future progress in modeling snow covers is going to require a better understanding of spatial variability of snow layers, as well as an improved identification of those problems requiring prediction of average vs. outlier properties. New approaches in modeling will also be needed. Fortunately, there are currently a number of new tools (micro-penetrometers, snow radars, mini-data loggers, digital imaging systems) that if we can figure out how to use in concert, should be able to generate the extensive data sets we will need in order to advance.

C72A-02 1350h INVITED

Sintering Concepts - Atomistic Mass Flow, Microstructure Evolution, and Macroscopic Property Changes

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Sintering is the process for bonding contacting particles by the application of thermal energy. At the atomistic level, mass flow is random, yet biased by subtle surface curvature gradients. During sintering microstructure changes become noticable and eventually bulk macroscopic property changes, such as strength increases and pore elimination, can be observed. Computer modeling of sintering has evolved to help understand and link the atomistic and macroscopic aspects. The recent emphasis in sintering models has forced theory to face up to some basic problems. From a perdictive view, the computer models are still behind observations, largely because of errors in our understanding of material property changes and the interactions between the evolving microstructure and kinetics of mass flow. New trends in sintering models will be introduced to show how accurate models require a firm grasp of these issues to predict bulk property changes. The identification of such problems sets in place an agenda for the sintering research community.

URL: http://www.cisp.psu.edu

C72A-03 1415h INVITED

Optical Properties of Snow for Solar and Infrared Radiation: Dependence on Grain Size, Grain Shape, Layering, and Microtopography

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The radiative properties of snow depend strongly on wavelength because the absorption coefficient of ice varies by eight orders of magnitude from the ultraviolet to the infrared. The reflectance, transmittance, absorptance, and emissivity of snow are determined by the distances that photons travel through ice between air-ice interfaces (i.e., between opportunities for scattering). Thus the grain size is the most important variable. To characterize the size of a nonspherical snow grain by a single number, the most relevant dimension is not the long dimension but rather the short dimension, which is proportional to the volume-to-area ratio. This effective optical grain size normally increases during destructive metamorphism, leading to increased path-lengths of photons through snow grains, more absorption and lower albedo. Alternatively, sorting of drift snow by wind can result in a concentration of the smallest grains at the top surface, raising the albedo.

The flux-penetration depth of radiation into snow can be several centimeters for visible light but less than a millimeter in the near-infrared, so the near-infrared reflectance is sensitive only to the surface grain size. A spectral signature thus results from layered snowpacks, which has been observed in measurements of spectral albedo on the Antarctic Plateau, where grain size increases with depth.

Snow cover on sea ice is often thin and vertically inhomogeneous, but very little snow is needed to effectively hide the underlying ice. Just 7 mm of snow can raise the albedo of thick ice from 0.5 to 0.8.

The angular distribution of the reflected radiation, knowledge of which is needed for remote sensing of snow in the solar spectrum, is affected not only by grain size but also by surface roughness, particularly sastrugi. However, the effects of sastrugi are mostly restricted to viewing-zenith angles greater than 50 degrees, so near-nadir viewing is recommended.

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C72A-04 1440h INVITED

Snow Microstructure and Hydrology

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The structure of naturally deposited snow on length scales from the grain scale to pit scale and above plays a very important role in the development of hydrological characteristics, both in seasonal snow packs where timing of water discharge and water chemistry may be of concern, and in the percolation zone of glaciers and ice sheets where routing of infiltrated water bears on the determination of glacier mass balance and the paleoclimatic interpretation of ice layers. The development of a predictive understanding of snow hydrology is complicated by the wide disparity between the length scales of the controlling processes and the much larger length scales at which the aggregate hydrological behavior is desired.

In this presentation examples are given of how water and heat flow alter microstructure, both in subfreezing and isothermal conditions, and how in turn microstructure influences large-scale hydrological processes. Details of some of the transient processes which create the heterogeneous character of snow structure at the pit scale are presented, and the significant differences between snow hydrology and conventional porous media hydrology are outlined. The difficulties of applying microstructural characteristics to large-scale aggregate behavior are considered, and some analytical methods, including geostatistical analysis, are outlined. Finally, direct methods for observing microstructure are described, including existing methods (snow pit stratigraphy, lysimeter arrays, and temperature arrays) as well as promising new methods (FMCW, GPR, and GPR cross-hole tomography).

C72B MCC: 120 Sunday 1515h

Snow and Ice in the Earth System I

(joint with A, H, OS)

Presiding: **P Brooks,** University of Arizona**; Z Yang,** University of Texas

C72B-01 1520h

Spatial Relationships Between Snow Contaminant Content, Grain Size, and Surface Temperature in Multi-spectral Remote Sensing Data of Mt. Rainier, WA

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Relating cryosphere change to climate change requires estimation of radiative fluxes on snow-covered surfaces. The distribution of, and relationship between, snow-pack properties that affect radiative balance can be estimated with high-resolution remote-sensing data. MODIS/ASTER airborne simulator (MASTER) data were collected at Mt. Rainier to reveal spatial patterns of, and correlations between, snow contaminant content, grain size, and temperature. The visible and near-infrared (VNIR: 11 bands, 0.4-1.0 μm) and the short-wave infrared (SWIR: 14 bands, 1.6-2.4 μm) data are processed to bi-directional reflectance (BDR) and albedo, by removing atmospheric effects and by normalizing to Solar irradiance and incidence angle. VNIR BDR and albedo are used as a proxy for snow contaminant content. Physical and optical grain size are estimated by comparing SWIR BDR and albedo to modeled and measured spectra, and ground-truth measurements. The thermal infrared data (TIR: 10 bands, 8-13 μm) are processed to temperature by removing emissivity and atmospheric effects. In combination, the VNIR, SWIR, and TIR data reveal a distinct pattern of contaminants, grain size, and temperature related to a recent snowfall and the end-of-the-summer melting season. At lower elevations, the surface accumulation of dirty lag deposits resulted in snow with very low visible albedo (20-30 %), large physical and optical grain radii (500-1500 μm, 200 μm), and temperatures near the melting point. At higher elevations, the recent snowfall left snow with low contaminant content, and a higher visible albedo (60-90 %). However, a region near the summit with smaller physical and optical grain radii (400 μm, 100 μm), and temperatures below the melting point, is distinguished from a middle elevation region with grain sizes and temperatures similar to the lower region. Contaminants reduce VNIR albedo and significantly enhance absorption of incoming solar radiation. The spatial correlation between temperature and grain size supports the idea that rapid, destructive metamorphism occurs when snow temperatures are at the melting point.

C72B-02 1535h

Snow and Ice in the Earth System Viewed by Space Scatterometer Observatory

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Snow and ice have an important role in the Earth climate system due to their interactions with land, ocean, and atmosphere in complex feedback processes. This paper presents recent results from satellite scatterometer which serves as a space observatory to study the role of snow and ice from aggregation to hemispheric and global scales. Hemispheric snow cover is mapped on the daily basis by the QuikSCAT/SeaWinds scatterometer. The timing and duration of snowmelt process can be determined accurately to address snow impacts in both radiative and hydrologic balances. Extreme events such rapid snowmelt causing spring floods in cold land regions can be monitored leading to possible early detection or prediction of flooding conditions. Anomalous melt zones over the Greenland ice sheet and extreme warming events at McMurdo, Antarctica, have been detected and monitored with the space scatterometer observatory. Sea ice mapping by the scatterometer uncovers the mystery of the Svalbard sea-ice barrier, a rapid growth (1 day) of an elongated sea ice feature (100's km) that blocks off the sea route and traps fishing ship. Sea ice together with ocean wind mapping results show strong interactions among ice cover, atmosphere, and ocean currents which are related to ocean bottom bathymetry. In cold winter conditions, areas of seasonal and perennial sea ice are obtained to study the distribution and balance of new sea ice production and old sea ice export in different regions of the Arctic ocean. During seasonal transitions, the timing of sea ice surface albedo changes is determined. The albedo transition timing is important to accurately estimate solar radiation input into sea ice. In warm summer conditions, areas of positive and negative integrated energy absorption can be identified and mapped. Results present a clear impact of clouds as evident from cyclonic patterns of sea ice surface melt around an Arctic low pressure center. The space scatterometer observatory results affirm that snow and ice should be observed and studied together within the integral of the Earth system, and not as separated parts.

C72B-03 1550h

Parameterization of the Sublimation of Blowing Snow in a Macroscale Hydrology Model

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Blowing snow events involve erosion, horizontal transport and in-transit sublimation of snow and hence play an important role in the spatial and temporal distribution of water and energy fluxes in high-latitude regions. Sublimation of eroded blowing snow is episodic and can result in high winter evaporation rates, which, over the season, can ablate a significant portion of seasonal snowfall in cold arid environments. Nonetheless, blowing snow sublimation has not been well quantified at regional scales, and in general is not represented in the current generation of land surface schemes. An algorithm to represent the topographically induced subgrid variability in wind speed and blowing snow sublimation was designed for use within the Variable Infiltration Capacity (VIC) macroscale hydrology model. The sub-grid distribution of wind speed is calculated based on the distribution of terrain gradients, and is assumed to follow a Laplace probability distribution. The strategy is extended to large spatial domains where only course resolution digital terrain information is available by utilizing the fractal scaling properties of the terrain gradients. The total downwind transport of blowing snow depends on the length of downwind development of the boundary layer, or fetch. This limitation is represented in VIC by integrating over the transport profile. The integration distance, or grid cell average fetch, is calculated using digital terrain and vegetation data. Annual average sublimation from blowing snow predicted by the VIC algorithm for a region on the Alaskan north slope is approximately 50 mm both in the foothills of the Brooks Range and on the Arctic coastal plain. The total blowing snow sublimation is generally limited by fetch in the foothills and by vapor pressure on the coastal plain.

C72B-04 1605h INVITED

Sublimation From Snow in Northern Environments

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Sublimation from snow is an often neglected component of water and energy balances. Research under the Mackenzie GEWEX Study has attempted to understand the snow and atmospheric processes controlling sublimation and to estimate the magnitude of sublimation in high latitude catchments. Eddy correlation units were used to measure vertical water vapour fluxes from a high latitude boreal forest, snow-covered tundra and shrub-covered tundra in Wolf Creek Research Basin, near Whitehorse Yukon, Territory Canada. Over Jan-Apr. water vapour fluxes from the forest canopy amounted to 18.3 mm, a significant loss from winter snowfall of 54 mm. Most of this loss occurred when the canopy was snow-covered. The weight of snow measured on a suspended, weighed tree indicates that this flux is dominated by sublimation of intercepted snow. In the melt period (April), water vapour fluxes were uniformly small ranging from 0.21 mm/day on the tundra slope, 0.23 mm/day for the forest and 0.27 mm/day for the shrub-tundra. During the melt period the forest and shrub canopies was snow-free and roots were frozen, so the primary source of water vapour from all sites was the surface snow.

C72B-05 1630h

Simulating Snow Over Sea Ice in Climate Models

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We have evaluated two methods of simulating the seasonal cycle of snow over sea ice in and around the Arctic: The NCAR global climate model CCM3, with its standard snow hydrology, and the snow pack model SNTHERM, forced with hourly atmospheric output from CCM3. A new dataset providing dates for the onset of snow melt over Arctic sea ice provides a means for assessing basin-wide how well the models simulate melt onset, but contains no information on how long it then takes for all the snow to melt. Use of data from the SHEBA site provides very detailed information on the behavior of the snow before and during the melt season, but only for a very limited area. Russian drift data provide climatological data on the seasonal cycle of snow water equivalent and snow density, over multi-year sea ice in the central Arctic basin. These datasets are used to compare the two modeling methods, and to see if use of the more physically-realistic SNTHERM provides any significant improvements. Conclusions obtained so far include: 1. Both CCM3 and CCM3/SNTHERM do a good job overall of matching the onset of snow melt dataset; although CCM3/SNTHERM consistently tends to underestimate the date and CCM3 to overestimate it. 2. SHEBA and ice drift data for the Arctic show that CCM3/ SNTHERM does a better job than CCM3 at simulating the total melt period. 3. Ice drift snow density and accumulation data suggest that while providing superior results, CCM3/SNTHERM may still suffer from overly vigorous melting. 4. Both the large-scale atmospheric forcing and snow pack physical processes are important in proper simulation of the snow seasonal cycle. Ongoing work includes further diagnosis of CCM3/SNTHERM, use of more observational datasets, especially from marginal seas in the pan-Arctic, and full coupling of SNTHERM into CCM3 (work to date has all been off-line simulations).

C72B-06 1645h

How Much Does Surface Albedo Feedback Contribute to Climate Variability and Global Climate Change?

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The presence of snow and ice at earth's high latitudes is generally thought to provide a positive feedback to earth's climate: if a warm anomaly occurs, snow and ice retreat, decreasing surface albedo, increasing net incoming solar radiation, and increasing the magnitude of the original temperature anomaly. (Opposite reasoning applies for cold anomalies.) In this study, this idea is tested by comparing a coupled ocean-atmosphere model simulation where surface albedo feedback (SAF) is artificially suppressed by prescribing surface albedo to one where snow and ice anomalies are allowed to affect surface albedo, as the model was originally designed.

One goal is to see whether SAF truly is positive in the context of the model's internally-generated temperature variability. Surprisingly, in the northern hemisphere (NH), SAF hardly amplifies internal variability, except during springtime, when there is about 20% more variability in mid to high latitudes when surface albedo feedback is present. This is because NH albedo anomalies are mainly generated by anomalies in snow cover. During winter and fall, snow cover is controlled by accumulation, a process associated with the warm temperatures of the precipitating sector of synoptic-scale waves. This results in a positive correlation between snow accumulation and local temperature, effectively disrupting the positive SAF loop. In spring, melting controls the snow budget. Since melting is highly correlated with warm temperatures, this sets up perfect conditions for a large positive feedback. Like snowmelt, the growth and decay of sea ice are directly associated with coldness and warmth, respectively, so that SAF is also strongly positive in regions where sea ice generates most surface albedo variability. For example, in the mid to high latitudes of the southern hemisphere (SH), there is 50-80% more variability in the simulation with SAF during all seasons.

Another goal is to see how much SAF controls the geographical distribution of the warming when greenhouse gases increase. To examine this issue, canonical CO_2-doubling experiments where performed with both models and the resulting equilibrium climates were compared. Though there is about twice as much warming at mid to high latitudes of both hemispheres when SAF is present, there is also a surprisingly large degree of polar amplification in the experiment without SAF, with the poles warming approximately twice as much as the tropics. This occurs because of a significant increase in sensible heat flux from the warm ocean to the cold atmosphere when sea ice thickness and extent are reduced in the warmer climate. Another surprise from these experiments is the effect of SAF on the warming in the tropics. In this region, there is approximately 20% more warming when SAF is present, in spite of the absence of any local change in simulated surface albedo. This occurs because of the larger decrease in the equator-to-pole temperature gradient in the experiment with SAF. Since the poleward heat transport is sensitive this gradient, a larger reduction in the poleward heat transport occurs when CO_2 is doubled in the presence of SAF, resulting in more tropical warming when SAF is present.

URL: http://www.atmos.ucla.edu/csrl

C11A MCC: Hall C Monday 0830h

Snow and Ice in the Earth System II Posters *(joint with A, H, OS)*

Presiding: **M Williams,** University of Colorado**; Z Yang,** University of Texas

C11A-0968 0830h POSTER

Recent Variations in Great Lakes Ice Cover and Relationships to Antecedent Atmospheric Conditions

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Skillful 30-day forecasts of winter ice conditions on the Great Lakes could be valuable to a wide variety of regional socio-economic activities, particularly merchant shipping which is largely restricted by the presence of ice. Recent analyses suggest interannual variations in ice conditions are strongly related to coincident atmospheric conditions, including low-frequency annular modes, yet little is known about the relationship between ice conditions and antecedent atmospheric conditions. Utilizing monthly accumulations of freezing degree days (FDD) as a proxy for ice conditions, interannual variations in atmospheric conditions are compared with accumulated FDDs from 1950 through 1999. Results suggest variations in antecedent Pacific-North American (PNA), Southern Oscillation Index (SOI), and North Atlantic Oscillation (NAO) indices, in combination with preceding FDD accumulations, show promise for increasing the skill of 30-day forecasts of Great Lakes ice conditions.

C

C11A-0969 0830h POSTER

Spaceborne Active Microwave Observation of Snowmelt Progression in Northern Alaska

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The transition from frozen to thawed conditions for the Arctic land surface is the most significant event of the Arctic annual cycle. Acquisitions from active satellite microwave sensors such as scatterometers can be used to observe the spatial and temporal characteristics of the Arctic freeze/thaw episodes. NASA Scatterometer (NSCAT) data during the 1997 melt season along with meteorological data are used to map the progression of snowmelt across the North Slope of Alaska. Refreezing episodes after initial melt are also identifiable from temporally averaged NSCAT data. A classification of snowpack melt progression is presented based on the backscatter and the standard deviation of the temporal averaged backscatter. Classification results correspond with NCEP/NCAR reanalysis air temperature data.

C11A-0970 0830h POSTER

Characterizing the Pan-Arctic Hydrologic Cycle with Arctic-RIMS

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