IP42A-0706 1330h POSTER

Seasonal Transitions in High Latitudes : The Role of Land Surface Feedbacks

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An observational study has been initiated to examine the effects of land-surface processes on the seasonal transition from the cold season to warm season precipitation regime in the Ob River basin, Eurasian Arctic. Specifically, extreme anomalies in snow extent and mass during spring are examined in association with changes in convective available potential energy (CAPE), summertime precipitation, and the amount of precipitation recycled from local sources. The relative strengths of the positive and negative feedbacks associated with snow cover and surface hydrology is highlighted. The positive feedback, which involves a greater snow extent leading to higher albedo and a cooler land surface should result in a reduction of CAPE and convective precipitation, where as the negative feedback of greater snow mass leads to higher available soil moisture thus allowing for more local evaporation and precipitation. The hydrologic cycle in this region has implications for many processes ranging from the timing of the Asian monsoon to having impacts upon the extent of arctic sea ice.

IP42A-0707 1330h POSTER

An Evaluation of MODIS Snow Cover and Sea Ice Extent Products at the NSIDC DAAC

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With the launch of the MODIS instrument on NASA's Earth Observing System (EOS) Terra satellite a new era of cryospheric monitoring from space began. For the first time daily, global maps of snow cover and sea ice extent are being produced in a fully automated fashion from space-borne measurements in optical wavelengths.

The capabilities and limitations of the MODIS instrument for measuring snow cover and sea ice extent will be highlighted in several case studies in which the MODIS products are compared with other available operational analyses based on both optical and passive microwave measurements. The 1-km resolution MODIS sea ice product, as determined from both solar reflective and terrestrial emissive bands, will be compared to sea ice concentration based on passive microwave measurements. The 500-m MODIS snow cover product will be compared both to analyses based exclusively on passive microwave as well as to NOAA operational analyses based on multiple satellite sensors.

URL: http://nsidc.org/modis

IP42A-0708 1330h POSTER

NSIDC at the Millenium

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Over the past 25 years the National Snow and Ice Data Center (NSIDC) has played a pro-active role in cryospheric data management. Three themes illustrate the advances that have been made.

(1) Delivery of integrated data products: we have developed standalone, packaged integrative products, frequently published on CD-ROMs or on the Internet. Examples include: the first global assembly of data and information on frozen ground and permafrost; passive microwave gridded timeseries products from the ESMR, SMMR, SSMI sensors; collaborative development and distribution of the Environmental Atlases for arctic meteorology, oceanography, and sea ice. The Arctic System Science Data Coordination Center (ADCC), at NSIDC, archives and distributes via our website. These data sets are based on research under the Land Atmosphere Ice Interactions (LAII), Ocean Atmosphere Ice Interactions (OAII), including the Surface Heat Budget of the Arctic (SHEBA) program, and related reconnaissance satellite imagery; Paleoenvironmental Arctic Science (PARCS) data. R-ArcticNet: a Regional Hydrographic Data Network for the Pan-Arctic Region is available on CD-ROM. Data Sets to be added include the Rapid Integrated Monitoring System (RIMS), a collection of hydro-meteorological data for river systems that discharge into the Arctic Ocean.

(2) Leadership in data set archival and dissemination through active collaboration with scientific societies and organizations, Currently active affiliations include the International Permafrost Association, the World Glacier Monitoring Service for glacier inventory data, CONMAP SCAR for the US National Antarctic Data Center for Antarctic metadata, the Joint WMO-IOC Commission for Oceanography and Maritime Meteorology (JCOMM) for the Global Sea Ice Data Bank and the International Antarctic Buoy Program (IABP), as well as, for NSF in the form of the Arctic System Science Data Coordination Center, and the Antarctic Glaciological Data Center, as well as NOAA, and NASA.

(3) Delivery of large volume satellite data: In particular the NSIDC DAAC has begun delivery of snow and ice products derived from MODIS data on the TERRA satellite, and will deliver passive microwave data from the AMSR instrument on the upcoming AQUA satellite, and laser topography data from the ICESat. We expect an increasing emphasis on multi-sensor products and multi-disciplinary data sets.

IP42A-0709 1330h POSTER

The Advanced Microwave Scanning Radiometer-Earth Observing System Data Products from the Aqua Mission

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The Advanced Microwave Scanning Radiometer-Earth Observing System (AMSR-E) is scheduled to launch on NASA's Aqua Satellite in early 2002. The Aqua mission is an important part of the NASA Earth Science Enterprise (ESE). The Aqua mission provides a multi-disciplinary study of the Earth's atmospheric, oceanic, cryospheric, and land processes and their relationship to global change. With six instruments aboard, the Aqua Satellite will travel in a polar, sun-synchronous orbit.

The AMSR-E will measure passive microwave radiation, allowing for derivation of many geophysical parameters, including cloud properties, radiative energy flux, precipitation, land surface wetness, sea surface temperatures, sea ice, snow cover, and sea surface wind fields.

The AMSR-E has much greater spatial resolution than previous passive microwave radiometers: approximately double the spatial resolution of the Scanning Multichannel Microwave Radiometer (SMMR) and the Special Sensor Microwave/Imager (SSM/I). Further, the AMSR-E combines in one sensor all the channels that SMMR and SSM/I had individually. The AMSR-E has the following frequencies (in GHz): 6.9, 10.7, 18.7, 23.8, 36.5, and 89.

The level 1A data product will contain chronological antenna temperature count data. The level 2A data product will contain spatially-resampled brightness temperatures (in global swath format) at resolutions of 56, 38, 21, 12 and 5.4 km. Level 2B data will include ocean, soil moisture, and rain products. Level 3 data will include gridded ocean, soil moisture, and rain products; gridded snow water equivalent products; gridded brightness temperatures; and gridded sea ice concentration and snow depth products.

The National Space Agency of Japan (NASDA) will process level 0 data to level 1A data. The AMSR-E Science Investigator-led Processing System (SIPS) will process the level 1A data product to level 2 and 3 data products. The National Snow and Ice Data Center (NSIDC) will archive and distribute all AMSR-E products, including Levels 0, 1A, 2, and 3 data.

This presentation describes the AMSR-E data products and compares the AMSR-E sensor specifications with those of SMMR and SSM/I.

URL: http://nsidc.org

IP51A MC: Hall D Friday 0830h

Monitoring, Measuring, and Modeling Snow and Cold Land Processes *(joint with A, H)*

Presiding: **A Winstral,** USDA-ARS**; D Kline,** National Weather Service

IP51A-0709 0830h POSTER

Sublimation From the Forest Canopy at Different Elevations in the Fraser Experimental Forest, Fraser, CO

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Sublimation may return between 20 to 40% of annual snowfall to the atmosphere from dense conifer canopies in mid-latitude, continental climates. The local energy balance controls sublimation of snow intercepted by the forest canopy. The canopy energy balance is controlled by local climate, synoptic meteorological conditions and physical properties of both the canopy and forested slope. We quantified differences in snow sublimation from a canopy at different elevations as a function of net radiation, temperature, humidity and wind speed. Four trees (two live and two artificial) were suspended from load cells attached to towers located at two different elevations in Fraser Experimental Forest in central Colorado, U.S.A. The elevations of the lower and upper sites were 2,920 and 3,230 m a.s.l., respectively. Two anemometers were installed at each site to measure wind speed and direction at the height of the suspended trees and above the surrounding canopy. All other meteorological parameters were measured at the height of the suspended trees. Sublimation rates were monitored from January 1 to May 1, 2001. Analysis of 21 storms showed that maximum sublimation rates were similar between the sites, but the sublimation rates at the lower site showed a more rapid decline with time following the storm's cessation. Sustained higher sublimation rates at the upper site indicate that a greater total volume of water was sublimated from the trees when integrated over the sublimation period following each storm and, therefore, over the entire season.

IP51A-0710 0830h POSTER

Multi-Year Assessment of Seasonal Freeze-Thaw Dynamics in Boreal Landscapes With Spaceborne Ku-Band Scatterometers

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Seasonal transitions of the landscape between predominantly frozen and non-frozen (i.e., thawed) conditions occur each year over roughly 50 million square kilometers of Earths Northern Hemisphere, affecting surface meteorological conditions, ecological trace gas dynamics, and hydrologic activity profoundly. The timing of spring thaw in particular, can influence boreal carbon uptake dramatically, accumulating 1% of the annual total each day and leading to interannual variability on the order of 30%. The ability to quantifiably apply multi-year observations of landscape freeze-thaw status of 1- to 2-day temporal fidelity to ecosystem process studies in high-latitude regions will allow improved assessment of modeled processes for long-term monitoring. The capability for multi-year monitoring of high-latitude seasonal dynamics with near-daily temporal accuracy from spaceborne Ku-band scatterometers was initiated with the NASA Scatterometer (NSCAT) which flew on board ADOES from September 1996 to June 1997. This was followed by the SeaWinds scatterometer, launched in June 1999 on board Quikscat, which continues to operate. This capability will continue with the launch of SeaWinds on ADEOS II, currently scheduled in 2002. Throughout the duration of these data series, we have maintained a series of biophysical monitoring stations at various locations in Alaska. Utilized for ground validation purposes, these stations allow assessment of the backscatter response to soil temperature, vegetation tissue temperature, micrometeorological parameters, and xylem sap flux. We apply data from these stations to quantify the scatterometers sensitivity to surface freeze-thaw state transitions and associated vegetation biophysical processes under a variety of terrain and landcover conditions. We develop a time series of landscape freeze-thaw products at regional and pan-boreal scales across multiple years. These time series products demonstrate the highly complex spatial and temporal nature associated with these critical processes. The continued capability for monitoring seasonal freeze-thaw cycles across the pan-boreal region will provide a means for assessing interannual variability and, eventually, longer-term trends in ecosystem function.

This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, and at the University of Montana under contract to the National Aeronautics and Space Administration.

IP51A-0711 0830h POSTER

A Satellite Radar Remote Sensing Measure of High Latitude Growing Seasons for Improved Regional Carbon Cycle Monitoring

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Seasonal cycles of evergreen forests at high latitudes and elevations are characterized by alternating periods of active growth and winter dormancy, with growing seasons strongly limited by sub-freezing temperatures for much of the year. The growing season defines the period of active growth and associated net assimilation of atmospheric CO_2 by vegetation and is thus an important control on regional productivity and net carbon exchange. We conduct a temporal analysis of satellite daily radar backscatter measurements from the Seawinds Ku-band scatterometer onboard Quikscat to quantify the geographic pattern and seasonal dynamics of the circumpolar high latitude non-frozen period. Satellite measurements of the timing of seasonal freeze and thaw cycles are found to effectively bound the growing seasons of evergreen boreal and sub-alpine forests as indicated by sap-flow and CO_2 eddy-flux network measurements. Spatial patterns of radar defined growing seasons, latitudinal and elevational tree line for evergreen forests are also compared. Remote sensing based freeze-thaw information is incorporated within an ecosystem process model as a seasonal control on canopy conductance for improved simulations of seasonal phenology and associated carbon exchange dynamics. These results are particularly relevant at high latitudes where regional monitoring and assessment of vegetation dynamics and associated ecosystem processes are problematic because of relatively sparse surface measurement networks, and cloud cover and solar illumination problems affecting optical-IR remote sensing. This work is being conducted at the University of Montana and Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.

IP51A-0712 0830h POSTER

Comparison of Spaceborne Synthetic Aperture Radar Backscatter to SNTHERM-Modeled Snow Properties in a Boreal Landscape

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By altering the transfer of energy from above the canopy to the forest floor, forest canopies affect both the rate of supply of melt water to the soil system and the remote sensing signature. The state transition of the boreal forest between frozen and thawed conditions affects a number of terrestrial processes that cycle between wintertime dormancy and summertime active states. Accurate assessment of snow condition and forest energy state will detect long-term changes to the boreal forest and provide input for modeling both the biophysics and landscape hydrological processes. In this investigation, we examine the relationship between time series ERS-1 C-band Synthetic Aperture Radar (SAR) backscatter measurements and spring snow cover dynamics within a 3500 km2 portion of the BOREAS Southern Study Area (SSA) of central Saskatchewan, Canada. We apply SNTHERM, a one-dimensional mass and energy balance model, to calculate surface energy exchange and associated snow cover dynamics at selected sites within the study region. SNTHERM calculates, at a stand scale, such snow properties as density, grain size, liquid water content and temperature for discrete layers within the snow pack. Previous work integrated SNTHERM with a forest canopy model to account for stand-level effects on snow pack properties. Building on this work, we spatially distributed SNTHERM results across the BOREAS SSA modeling region, providing regional-scale multi-temporal maps of snow pack properties. Multi-temporal C-band imagery from the ERS-1 SAR are compared with these spatially distributed snow property maps. Using point-scale in situ meteorological and biophysical data for validation, we assess the temporal response of the radar backscatter to the landscape thaw transition across the BOREAS SSA modeling region. We assess the sensitivity of ERS SAR backscatter to the SNTHERM-based snowpack properties for a variety of landscape cover classes, and demonstrate the utility of combining the modeled parameters with the radar data for improving the interpretation of radar-based springtime thaw assessments for boreal landscapes.

IP51A-0713 0830h POSTER

Variability and Trends in the Annual Snow Cover Cycle in Northern Hemisphere Land Areas, 1972-2000

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This study investigated variability and trends in the annual snow cover cycle in regions covering high latitude and high elevation land areas in the Northern Hemisphere. The annual snow cover cycle was examined with respect to the week of the last observed snow cover in spring (WLS), the week of the first observed snow cover autumn (WFS), and the duration of the snow-free period (DSF). The analysis employed a corrected version of a 29-year time-series (1972-2000) of weekly, visible-band satellite observations of Northern Hemisphere snow cover from NOAA. Substantial interannual variability was observed in WLS, WFS, and DSF (standard deviations of 0.8-1.1, 0.7-0.9, and 1.0-1.4 weeks, respectively), which is directly related to interannual variability in snow cover area in the regions and periods of snow cover transition. Over the nearly 3-decade study period, WLS in all study regions shifted earlier by 3-5 days/decade as determined by linear regression analysis. DSF increased by about 5-6 days/decade, primarily as a result of earlier snow cover disappearance in spring. No strong evidence of any systematic trend in WFS was observed. In addition to altering the surface energy balance through the snow-albedo feedback effect, the observed variability and trends in the annual snow cover cycle are potentially significant factors for terrestrial ecosystem functioning, including annual primary production and net ecosystem carbon dioxide fluxes.

IP51A-0714 0830h POSTER

Accounting for wind-induced spatial heterogeneities in snow accumulation and melt using terrain analysis

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In mountainous headwater basins, local topography and canopy cover strongly affect snow distribution, snowpack energy fluxes, and resultant melt rates. Wind has often been cited as the dominant control on snow accumulation in these alpine regions. Snow accumulation in the Reynolds Mountain East research area, a 0.36 km^2 headwater basin in southwestern Idaho, is typical of such regions; a wind-exposed ridgeline accumulates very little snow throughout the winter while hydrologically significant drifts develop on lee slopes persisting well into the spring. In this study we established an efficient means of accounting for the spatially variable wind effects upon snow accumulation and melt in this basin. Wind speeds and effective precipitation rates were distributed based on upwind topography adjusted for vegetative cover and applied as input to ISNOBAL, a spatially distributed energy balance snowmelt model. Simulations of the accumulation and melt of the snowcover were performed for three winter seasons. In all three seasons, modeled snow distribution closely matched a time-series of snow-cover-classified aerial photographs taken during each melt season. The timing and magnitude of modeled surface water inputs also exhibited a strong correspondence to the basin hydrograph.

IP51A-0715 0830h INVITED POSTER

Continental-scale Assimilation of Remotely Sensed Snow Observations

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Snow plays an important role in governing both the global energy and water budgets, as a result of its high albedo, thermal properties, and being a medium-term water store. However, the problem of accurately forecasting snow in regional and global atmospheric and hydrologic models is difficult, as a result of snow related features that display variability at scales below those resolved by the models and errors in model forcing data. Hence, any Land Surface Model (LSM) snow initialization based on model spin-up will be affected by these errors. By assimilating snow observation products into the LSM the effects of these errors may be offset, but special care must be taken to avoid erroneous systematic influences on the water budget as a result of the assimilation. We have developed Kalman Filter based methods for the assimilation of relevant microwave (SSM/I) and visible (MODIS) remotely sensed snow observation products into the catchment-based LSM that is being used by the NASA Seasonal-to-Interannual Prediction Project (NSIPP). This work is focused on a retrospective study of North America, using the uncoupled NSIPP LSM, with a perspective of eventual coupled global implementation.

URL: http://ldas.gsfc.nasa.gov

IP51A-0716 0830h POSTER

The use of a Winter Precipitation Index to Assess Snowpack Changes in the Colorado Rockies and Oregeon Cascades

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Freezing levels are rising in many areas of the world according to work by others. The potential impact of such change is enormous in regions such as the western United States, that rely heavily on snowpack as a water source. As freezing levels rise, more of the winter precipitation will be in the form of rain, or rain-on-snow events. Changes in snowpack will be observed first in sensitive areas and during sensitive months, defined as wherever and whenever the mean temperature is close to freezing. Thus, a month such as May, can be a sensitive month indicator in colder areas.

This study analyses the state of winter precipitation for shifts that increase or decrease snowpack in the Colorado Rockies and the Oregon Cascades. Snowpack and total winter precipitation data for the past two decades are compared to the long term mean (about 1937-2000), on the basis of the winter as a whole, the first of each month, January 1 to May 1, and by El Nino-Southern Oscillation (ENSO) phase.

A snowpack index which normalizes for changes in winter and monthly precipitation amounts, is used for this analysis. This index is the ratio of the percent of snowpack snow water equivalent (SWE) to the percent of cumulative total winter precipitation. Thus, a value of one indicates no change in the snowpack regime, a value of less than one indicates less of the winter precipitation is in the form of snowpack, and a value of greater than one indicates more winter precipitation is snowpack. This integrative index reflects changes in climatic factors such as temperature, wind, atmospheric moisture, and insolation. Thus, an index value of less than one, or a negative temporal trend, roughly suggests warming conditions, whereas a value greater than one, or a positive trend, suggests cooling during the 1981-2000 compared to the longer record.

The northern and southern Colorado Rockies, and the Oregon Cascades are analyzed on the basis of slope (east versus west), and ENSO phases of warm (El Nino), cold (La Nina), and neutral. Preliminary results for northern Colorado show index values of less than one (warming) for the east and greater than one (cooling) on the west slope for the 1981-2000 winter seasons, and on the first of each month. These slope differences are significant seasonally (3.9% level), and monthly (0.00Trend analysis shows the May 1 snowpack index slightly increasing (cooler) on both slopes (east: 0.015/year, sig. at 6.6Trends for the other months are not significant.

Results for Oregon show the east and west to be more similar to each other, and ENSO phase differences to be more variable, compared to northern Colorado. The mean data also suggests that more of the winter precipitation is in the snowpack on May 1, particularly during La Nina (both east and west), on the west slope in neutral years, and on the east slope during El Nino. This is consistent with the positive trend in ratio values for N. Colorado.

IP51A-0717 0830h INVITED POSTER

Modeling the Interaction of Radiation Between Vegetation and the Seasonal Snowcover

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Prediction of meltwater runoff is crucial to communities where the seasonal snowpack is the major water supply. Water is itself a vital resource and it carries nutrients both in solution and in suspension. Simulation of snowpack depletion at a point in open areas has previously been shown to produce accurate results using physically based models such as SNTHERM. However, the radiation balance is more complex under a forest canopy as radiation is scattered and absorbed by canopy elements. This can alter the timing and magnitude of snowpack runoff substantially.

The interaction of radiation between a forest canopy and its underlying snowcover is modeled by the coupling of a physically based snow model and an optical and thermal radiation canopy model. The snow model, which is based on SNTHERM (Jordan, 1991), is a discrete, multi-layer, one-dimensional mass and energy budget model for snow and is formulated with an adaptive grid system that compresses with the compacting snowpack and allows retention of snowpack stratigraphy. The vegetation canopy model approximates the canopy as a series of discrete, randomly orientated elements that scatter and absorb optical and thermal radiation. Multiple scattering of radiation between canopy and snow surface is modeled to conserve energy.

The coupled model SNOWCAN differs from other vegetation-snow models such as GORT or SNOBAL as it models the albedo feedback mechanism. This is important as the albedo both affects and is affected by (through grain growth) the radiation balance. SNOWCAN is driven by standard atmospheric variables (including incident solar and thermal radiation) measured outside of the canopy and simulates snowpack properties such as temperature and density profiles as well as the sub-canopy radiation balance.

The coupled snow and vegetation energy budget model was used to simulate snow depth at an old jack pine site during the 1994 BOREAS campaign. Measured and simulated snow depth showed good agreement throughout the accumulation and ablation periods, yielding an r^2 correlation coefficient of 0.94. The snowpack development was also simulated at a point site within a fir stand in Reynolds Creek Experimental Watershed, Idaho, USA for the water year 2000-2001. A sensitivity analysis was carried out and comparisons were made with field observations of snowpack properties and sub-canopy radiation data for model validation.

URL: http://www.nerc-essc.ac.uk/~mjt/agu2001

IP51A-0718 0830h POSTER

The Soddie Dataset A Multi-year Dataset of Spatially-Distributed Snowmelt Measurements

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One of the least understand aspects of snow hydrology is meltwater flow through snow. In an effort to improve our standing of the spatial distribution of snowmelt, we have constructed a large lysimeter array to measure the snowmelt discharge near the ground surface. The array is located at Niwot Ridge, Colorado, at 3250 m in an open meadow below treeline. The array was constructed in 1997 and contained 36 lysimeters on a two-meter grid. The grid was expanded to 105 lysimeters in 1998. Each lysimeter collects snowmelt near the base of the snowpack over a 0.2 m^2 area. Discharge from each lysimeter is routed through dedicated tipping buckets and is recorded on a 10-minute interval throughout the melt season.

Data will be used to evaluate the spatial variability of snowmelt over a multi-year period. Preliminary results show a decrease in snowmelt variability over the melt period, with a dramatic decrease as the snow becomes isothermal. We will evaluate the following null hypotheses:

1) the spatial variability of meltwater discharge does not increase with scale;

2) the range of correlation is reached at 5 to 10 meters separation;

3) the semivariance of discharge does not change over time.

IP51A-0719 0830h POSTER

Influence of snow surface sublimation on stable isotope and chemical records and on surface energy balance over a Bolivian glacier, Illimani.

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Post deposition processes like sublimation of surface snow are on primary importance in cold high latitude glaciers in the tropical Andes. Such a process modifies surface energy balance, isotopic and chemical composition of deposited snow. This is a real problem for interpretation of isotopic and chemical profiles from tropical ice cores. A sublimation experiment has been carried out during May 2001 where a 137 m ice core has been drilled down to the bedrock in June 1999 (Illimani, 17°S, 68°W, 6340 m). Variations of surface snow composition (both water stable isotopes and chemistry) have been monitoring over one week, twice a day while measurements of surface enegy balance were made with an automatic weather station. We present here the combination of these results. Main result from energy balance surface study is that sublimation rate is very hight. Chemical and isotopic compositions of surface snow, show also that sublimation probably affects climate signal recorded in the ice. Thus, interpretation of stable isotopes and chemical records from ice cores have to be carefully done under a certain temporal resolution.

IP51A-0720 0830h POSTER

Improving Models of Snow Over Arctic Sea Ice

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The extent and duration of snow cover plays an important role in mid to high latitude climates. Our work to date has focused on improving the modeling of snow cover in climate models. One key element in the proper modeling of snow cover is the simulation of the snow temperature profile. This feature is especially important to accurately simulate the onset of melt for the snow pack. We have assessed the ability of the SNTHERM snow pack model to improve the performance of current global and regional climate models, particularly in the area of the thermal profile of snow. We did this by forcing SNTHERM with output from the NCAR CCM3 global model and then compared the resulting snow cover with that simulated by CCM3. Over both land and sea ice, the SNTHERM/CCM3 combination provided a better simulation of the seasonal cycle of snow cover than did CCM3 alone. This improvement was especially obvious over sea ice, where the climate models by themselves did very poorly but SNTHERM gave results in broad agreement with existing satellite and surface observations. The research presented here will focus on the results of these simulations for snow cover over sea ice in the Arctic. Comparison of four years of SNTHERM/CCM3 simulations to CCM3 climatology and observations show a marked improvement in modeling the onset of snow melt over Arctic sea ice.

IP51A-0721 0830h POSTER

Integrating Satellite-Derived Snow Covered Area Information with a Hydrologic Forecast Model

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A NASA sponsored Regional Earth Science Application Center (RESAC) has been established to develop hydrologic modeling and analysis tools for operational management of water resources in the southwestern United States. An important component of the RESAC is development of methods to integrate satellite derived information about snow covered area (SCA) and station measurements of snow water equivalent with hydrologic models to improve forecasts of the amount and timing of runoff from mountain drainage basins. Images from satellite borne sensors with moderate spatial resolution and short revisit times can be used to produce frequent maps of snow cover. This satellite-derived information can be used to calibrate and validate model snow routines, and to initialize and update SCA during model runs.

We have developed procedures to assimilate satellite-derived maps of SCA into a distributed hydrologic model. The Precipitation Runoff Modeling System, developed by the U.S. Geological Survey is used as the hydrologic model. Snowmaps produced by National Operational Hydrologic Remote Sensing Center of the National Weather Service at a resolution of 1km and temporal resolution of about a week are used to update initial model estimates of SCA. Basin runoff is then simulated based on these updated initial conditions. Runoff has been simulated for two high elevation, gauged headwater basins of the Gunnison River, a tributary of the Upper Colorado River, U.S.A. These basins present a challenge to modeling and snow mapping because a much of the basins areas are forested. Simulations of basin daily total runoff using model estimates of SCA and model estimates of SCA updated with satellite maps are compared with observed runoff.

IP51A-0722 0830h POSTER

Accessing and Utilizing the MODIS Snow and Ice Products at the NSIDC DAAC for Cryospheric Research

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The Moderate Resolution Imaging Spectroradiometer (MODIS) is the key instrument for snow and ice studies supported by the Terra satellite. The spectral and spatial resolutions of MODIS represent a considerable improvement in capability for global cryospheric monitoring over comparable existing systems. The MODIS snow and ice products augment the existing record of satellite-derived snow cover and sea ice products that began about 30 years ago.

The MODIS snow products are archived and distributed by the National Snow and Ice Data Center (NSIDC) as part of its NASA Earth Observing System Distributed Active Archive Center (DAAC). Level 2 swath format and level 3 gridded snow extent data, collected since September 2000, are available through the EOS Data Gateway (EDG).

This poster describes and illustrates the steps involved in accessing the MODIS snow products via the EDG, displaying them with NSIDC-provided MODIS tools, and includes some simple image analysis and scientific interpretation.

URL: http://nsidc.org/modis

IP51A-0723 0830h POSTER

Validation of a Spatially Distributed Energy Balance Snow Simulation Model

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A spatially distributed snow simulation model (ISNOBAL) is used to simulate the development and ablation of the seasonal snowpack for the 1998 water year over the Boise River basin, a large mountainous basin in Idaho. The model accounts for topographic effects on the snowpack energy balance, corrects for forest canopy effects on solar and thermal radiation, and uses spatially distributed precipitation, temperature, and other meteorological inputs. While snow water equivalent measurements at several sites within the basin show good agreement with simulation results, verification in the spatial domain is more difficult. A series of AVHRR-derived snow covered area (SCA) images, corrected for forest canopy effects, are used to show that the simulated SCA over the basin closely matches that derived from the satellite data. Simulated runoff from snowmelt and rain from ISNOBAL are used to drive a spatially distributed watershed hydrology model, the Bochum Water Balance Model developed at the Ruhr University in Germany. Measured streamflow from the basin closely matches simulated streamflow, showing that both the simulated distribution and volume of snowmelt runoff must approximate reality. This effort will help scientists and hydrologists develop water management models that more effectively address the diverse natural resource management issues in mountainous regions.

IP51A-0724 0830h POSTER

Spatial Variation of, and Correlations Among, Snow Surface Albedo and Physical Parameters of Summer Snow Cover on Sea Ice in the Ross Sea, Antarctica

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All-wave albedo and spectral albedo of snow on sea ice were measured in the Ross Sea during a cruise in January-February, 1999. Concurrent measurements of physical parameters of the snow cover such as composite snow grain size, single snow grain size, snow mass density, snow surface temperature, and snow stratification were carried out. Snow particles in each 3 cm deep sample (volume 100 cm^{-3}) were described in terms of shape and general appearance using standardized terms, i.e., facets, striates, meltclusters, chains of grains, etc., and the relative proportion of each particle type with average radius <r> were determined. Most of the snow samples had undergone some metamorphosis. As a consequence, the particles were divided into two categories: the overall centimeter-order size of the larger, composite grains such as meltclusters, and the millimeter-order size of the grains (single grains) that made up the meltclusters. Based on these in situ measurements, three statistically average grain size models (equal grain number model, size distribution integrated average model and effective radius model) are used for the relation analyses between albedo and snow grain size for the two categories (composite grain and single grain).

Correlations between albedo and snow physical parameters show that summer snow albedo is more sensitive to the snow cluster grain size than the single snow grain size for the top 9 cm of the snow cover. The strongest correlation is observed for the top 3 cm of snow. Coefficients and significance of correlation between albedo and composite grain size decrease with snow depth. Correlation analyses between albedo and composite grain number density show that in the top 9 cm of the snow cover, albedo is strongly correlated with the composite grain number density: the larger the number density of composite grains of the snow surface layer, the higher the albedo. This correlation decreases with depth. The same analyses for the single grain size and single grain number density show that there is no significant correlation between albedo and single grain size or between albedo and single grain number density. From the correlation analyses between albedo, snow surface temperature and composite grain size, it is found that the lower the surface temperature and the smaller the surface composite grain size, the higher the albedo.

Spatial variation analyses of snow albedo and physical parameters show that in the Ross Sea pack ice there are notable latitudinal variations in albedo and physical snow parameters. As the ship moved southward through the pack ice: the snow surface temperature decreased; albedo was higher; the snow mass density was higher; the snow composite grain size decreased; and the number density of composite grains increased. All-wave albedo in visible and near infrared were lower at ice edges than at central pack ice due to larger grain size and lower number density.

IP51A-0725 0830h POSTER

Spatially Distributed Snowmelt Modeling with the Utah Energy Balance Snowmelt Model

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This paper describes some improvements that have been made to the Utah Energy Balance Snowmelt model in the way that snow surface temperature is modeled. The Utah Energy Balance snowmelt model is a single layer snowmelt model designed to be parsimonious for spatially distributed grid applications. In the model snowmelt is driven by surface energy fluxes that depend strongly on surface temperature. Recognizing that surface temperature is different from an average or representative single layer snow temperature the model has to date used an equilibrium gradient approach to parameterize surface temperature. Comparisons against measurements of internal snow temperature revealed that this scheme led to deficiencies in the modeling of snowpack internal energy. This paper describes new components added to the model to address these deficiencies. We have changed the parameterization of surface temperature from an equilibrium gradient approach to a modified force restore approach. We have also added a simplified representation of the advance of a refreezing front during periods of heat loss following melt. These parameterizations retain the simple one layer property of the model, important for parsimony, but improve the comparisons between measured and modeled internal energy, snow surface temperature, melt outflow and snow water equivalent. This model has been applied to the simulation of snowpack on a spatially distributed grid over the Green Lakes Valley watershed in Colorado as part of an effort to understand the spatial distribution of snow and parameterize the subgrid variability of snow processes for application with larger model elements.

URL: http://www.engineering.usu.edu/dtarb

IP51A-0726 0830h POSTER

The Effect of Anisotropic Bi-directional Reflectance on Imaging Spectroscopy Models for Retrieving Snow Physical Properties

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This work describes a sensitivity study to determine the effect of snow bi-directional reflectance on models for mapping snow spatial and physical properties from imaging spectrometer data. The study applies two spectroscopy models to synthetic imaging spectrometer reflectance images with prescribed snow-covered area and snow grain size. The first model (MEMSCAG) performs multiple endmember spectral mixture analysis to determine sub-pixel snow-covered area and the grain size of the fractional snow cover. The second model (Nolin/Dozier) analyzes the ice absorption feature at wavelength 1.03 micrometers for an estimate of snow grain size under the assumption of complete snow cover. The synthetic bi-directional reflectance factor scenes span a range of grain sizes, fractional snow covers, view geometries , and solar zenith angles. The study indicates similar strong sensitivity to bidirectional reflectance between the two spectroscopy models. Sensitivity to bi-directional reflectance changed with solar geometry and with particle size.

IP51A-0727 0830h POSTER

The Relationship Between Real-time Snow Water Equivalent Pressure Sensor Measurements and Snow/soil Mechanical, Thermal, and Hydrologic Processes

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Most water in the western states originates from melted snow. Estimating water stored as snow, predicting water flow, and developing snowmelt runoff models needed for water resource management requires accurate real-time snow water equivalent (SWE) measurements. These measurements are made primarily with SWE pressure sensors. It is, therefore, important to understand the factors controlling SWE pressure sensor performance to minimize errors and design improved sensors. Our work indicates that SWE sensor performance is caused by a complex interaction between the sensor, snow, and soil. In early winter, stored heat in the sensor may melt snow that would otherwise remain frozen. Winter SWE measurements may exhibit errors when the snow/soil interface is at the melting temperature. During the winter/spring transition anomalous SWE measurements are often observed. In the spring, the variation of water flow magnitude may cause errors. The controlling factors that determine the SWE pressure sensor response depend on the sensor design and the environmental conditions. Important design factors include sensor surface area, aspect ratio, elastic modulus, heat capacity, thermal conductivity, and permeability. Important environmental factors include the thermal conductivity of the soil, the freezing or thawing condition at the snow/soil interface, snow temperature, snow elastic modulus and viscosity, snow permeability and snow melt water flow.

Over the last four years we modified a SWE pressure sensor with a load sensitive area of less than 0.2 m^2 by identifying the important sensor design and environmental factors. As a result, SWE measurement errors were reduced from over 200% during the first winter to about 6% during this past winter. These improvements allow for more flexible sensor designs with lower installation and maintenance effort than using traditional SWE pressure sensors.

IP51A-0728 0830h POSTER

Regional Characteristics of Snowmelt Across the North American Arctic

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In the springs of 1999, 2000 and 2001 we conducted a simple regional-scale experiment in arctic hydrology and climatology. The ”experiment” consisted of obtaining detailed ground-based observations of snow conditions and meteorology during the melt from a wide variety of locations and types of snow cover. The project was possible because there were already a number of groups who were monitoring snow melt in eleven sites across Alaska and Northern Canada. Snowmelt in the Arctic is hydrologically important and a dramatic time of year; the land surface can change from fully snow-covered to snow-free in one week, and in some catchments, as much as 80 percent of the annual run-off is generated. Temporal and spatial patterns developed during the snowmelt are determined by the weather and the stratigraphic character of the snow. Different climate classes of snow, such as taiga and tundra snow, melt differently because both snow pack structures and climatic patterns differ in the two zones. The purpose of this project is to begin the work of extrapolation of our knowledge of hydrologic processes across broad areas of the Arctic.

This snowmelt consisted of data collection from eleven key sites in Alaska and Canada. The regional vegetation usually consisted of polar desert (barren gravel with mosses, sedges and lichen in wetter areas) in the Canadian High Arctic, tussock tundra (primarily tussock sedges and mosses) in the northern sites and boreal forest (spruce, aspen and birch trees with shrubs or sphagnum, tussock tundra in the valley bottoms) in the more southerly sites. Snow usually begins to accumulate in the middle of September when the days are getting short and the nights longer and colder. Arctic and Subarctic Alaska and Canada usually do not experience substantial mid-winter melt events but continue to accumulate snow until spring, about nine months after the first snowfall. Melt across the northern North America typically begins in April in the interior Subarctic and extends into late June or July in the High Arctic. The snowpack characteristics and the melt processes vary significantly being primarily controlled by regional climate.

URL: http://www.uaf.edu/water/projects/Snowmelt2000/CD/CDBrowser.htm

IP51A-0729 0830h POSTER

Solid Precipitation Measurement Intercomparison in Barrow Alaska, 2000-2001

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It has been recognized that systematic errors of gauge precipitation measurements are mainly caused by wind-induced undercatch, wetting and evaporation losses and that the error of snowfall observation in high wind speeds is very large. When the hydrological cycle of the high latitude regions is discussed, the errors of the precipitation cannot be overlooked any more at present. Frontier Observational Research System for Global Change (FORSGC) and the Water and Environmental Research Center, University of Alaska Fairbanks (UAF) have collaboratively undertaken an intercomparison of precipitation gauges in high latitude regions of high winds. This presentation will report the progress of this research.

We set up an AWS in the Arctic, in winter of 2001, at Barrow, Alaska and have observed the weather and snow since then. A Wyoming snow gauge system has been set up for measuring true snowfall amount. National standard precipitation gauges commonly used in the Arctic regions were also set up for test. A snow particle counter system with a laser diode was introduced, and the number flux of snow particles at different particle diameters was measured vertically for investigating the structure of blowing/drifting snow within 2.5m above the ground. Preliminary data collection shows that blowing/drifting snow often occurred in Barrow, thus studies of gauge measurement errors in high latitude regions of high winds must take not only wind-induced undercatch, wetting and evaporation losses but the influence of blowing/drifting snow on gauge performance. More precipitation data will be collected in the coming winters and they will enable us to carry out further analysis.

IP51A-0730 0830h POSTER

Simulation of Soil Freezing and Thawing: direct and inverse problems

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We developed a numerical simulation model based on a finite difference method in order to clarify the combined effect of snow cover and unfrozen water in soils on the ground thermal regime. A two-dimensional computer modeling was carried out for the West Dock site in Prudhoe Bay region, Alaska, where we have a complete set of input data for 1998-1999 and where the active layer and upper permafrost temperatures were measured continuously since 1986. These calculations were made to evaluate the new model performance and to study the spatial and temporal variability of temperatures and unfrozen water contents in the active layer and permafrost for this particular site. The comparison between measured and calculated ground temperatures shows good agreement. The modeling results also show that there is a significant lateral variability in soil temperatures on a one-meter special scale. This variability is caused mostly by the spatial changes in the snow thickness and micro topography. However, this lateral inhomogeneity in the permafrost temperatures rapidly decreases with depth.

In the present study we propose methods for reconstruction of the snow cover thermal properties and the unfrozen water content curves based on precise high-frequency temperature measurements in shallow boreholes using a solution of improperly posed problems for the one-dimensional quasi-linear Heat Equation. The temperature data measured at several depths in the active layer and near-surface permafrost from the Alaskan sites (Barrow, Franklin Bluffs) and from Yakutsk (Chabody) were used as an overdetermined data for the Heat Equation.

IP51A-0731 0830h POSTER

Impact of Soil Freezing on Climate Change in Northern Latitudes

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Soil freezing has several direct and indirect impacts on climate. Particularly, it is expected to play an important role in the climate's sensitivity in northern latitudes. Indeed, it directly influences high latitudes temperatures through large storage and release heat at the interseasons, delaying cooling in autumn and warming in spring. Freezing also modifies the thermal and hydrological soil properties, leading to waterlogged soil and (seasonal) wetlands in high latitudes.

Here, we focus on the direct thermal effect of soil freezing on climate change with the analysis of four GCM simulations, performed with the french model LMDz3.3. The simulations were run with and without the process of freezing. Two simulations correspond to the present-day climate and two others represent the end of the 21st century.

The simulated present-day extent of permafrost well reproduces the observations in Siberia, North America and above the Tibetan plateau. The comparisons between Present-Day and Future runs display some changes aspects of the surface temperature, precipitation and pressure when taking into account for soil freezing. We will specifically discuss how freezing in a GCM can modify the simulated response of the model to anthropogenic climate forcing.

IP51A-0732 0830h POSTER

Interpretation of RADARSAT SAR interferograms of Sagwon, Alaska, to establish temporal and physical permafrost parameters

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A series of Synthetic Aperture Radar (SAR) interferograms formed from orbits with a 24-day repeat, produced by the RADARSAT Satellite over the Sagwon region of Alaska, allow us to describe the area in the microwave spectra. Using scenes of a single beam mode acquired primarily from early August to late November 2000, we selected pairs of images that were suitable for analysis. When a scene pair is processed, the strong dependence of the quality of the resulting interferogram on the soil moisture status in the surface layer is apparent; interferogram from a pair with similar moisture parameters can indicate the distribution of acidic tundra (high interferometric coherence) and non-acidic tundra (low coherence). The results we obtain agree with previous field investigations of the area. The double-difference method uses a pair of interferograms of the same beam mode, which are processed together by establishing their difference in phase; one interferogram is rewrapped to the baseline of the second and then the phase of the second interferogram is subtracted. This technique allows small expression of surface deformation to be seen. The method is dependant on the interferometric coherence and consequently the quality of the unwrapping and re-wrapping of the first interferogram, so a scene pair of high coherence and low noise levels dictates which beam modes and date pairs are suitable for us to analyze with this technique. The double-difference images reveal areas of different characteristics in active layer frost heaving, and show their progressive development through the time period. Although we cannot attribute the spatial difference seen in the interferograms to a single process, we are able to establish basic temporal and physical permafrost parameters using the concurrent frost heaving measurements obtained at several field sites within the time span of our SAR scenes as main constraints in our analysis.

IP51A-0733 0830h POSTER

Moisture source controls on fresh snow deuterium excess values in the Andes

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Water isotope (d18O and dD) data from fresh snow samples collected on Ecuadorian glaciers during January 2001 (EC01) are used to investigate high-altitude precipitation processes in the northern Andes. To examine source, location, and/or elevation effects on precipitation isotopic composition, snow samples were collected along altitudinal transects on three peaks: Cayambe, Cotopaxi, and Chimborazo. Average isotopic values at the three sites are consistent with data from regional sites in the Global Network of Isotopes in Precipitation (GNIP). The local mean water line (LMWL) extrapolated from January data of the fourteen GNIP sites (slope 7.2) is similar to the LMWL from Cayambe (8.7), Cotopaxi (9.1), and Chimborazo (8.4). However, the difference in LMWL may reflect variability in hydrological processes, particularly at high elevation. There is a correlation between increased elevation and decreased d18O values when the GNIP and EC01 date are compared together. However, data from individual EC01 sites display a weaker trend with respect to elevation and d18O, suggesting that over a limited elevation range temperature-driven equilibrium fractionation is not significant. Deuterium excess (d) values from both GNIP and EC01 sites vary with both elevation and location, and particularly with longitude; sites within the Andes have d values that are 5-10 higher than Pacific coastal sites. The difference in d values may reflect moisture transport to the high elevation sites from the Atlantic basin. Moreover, d values at the three high elevation sites are significantly different, with Cotopaxi having d values 4 higher than Cayambe. We suggest that the complex topography of the Andes affects the relative inputs of Pacific and Atlantic moisture, and attempt simple isotope mixing and moisture advection models to explain the observed differences in d values.

IP51A-0734 0830h POSTER

The Frozen Ground Data Center: A Continuing Task for the International Permafrost Community

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Permafrost and seasonally frozen ground underlie about 24% and 60% of the surface of the Northern Hemisphere respectively. Data and information on frozen ground collected over many decades and in the future are critical for fundamental process understanding, environmental change detection, impact assessment, model validation, and engineering applications. However, many of these data sets and information remain widely dispersed and relatively unavailable to the science and engineering community, and some are in danger of being lost permanently.

The International Permafrost Association (IPA) has long recognized the inherent and lasting value of data and information, and has developed a strategy for data and information management to meet the requirements of the cold regions science, engineering, and modeling community. NSIDC has played an active role in implementing this strategy by developing and distributing the first Circumpolar Active-Layer Permafrost System (CAPS) CD-ROM including the Global Geocryological Database (GGD). Now, NSIDC, in collaboration with the International Arctic Research Center (IARC), seeks to expand the CAPS data holdings, update the GGD, and improve frozen ground data access and utility through a new web-based "Frozen Ground Data Center."

NSIDC plans to reformat several existing data sets and create value-added products such as gridded fields for model validation and analysis. We also plan to acquire and distribute certain key data sets, including data from: (1) the Global Terrestrial Network for Permafrost (GTN-P) and its Borehole and updated Circumpolar Active Layer Monitoring (CALM) components (Burgess et al 2000), (2) the Arctic Coastal Dynamics project, (3) the Cryosol database and maps, and (4) various permafrost maps and soil temperature time series for Russia and China.

NSIDC seeks the help of the frozen ground research community through data contributions and suggestions on data acquisition, management and distribution. The IPA Standing Committee on Data, Information and Communication will continue to coordinate the GGD and CAPS activities.

IP51A-0735 0830h POSTER

Estimates of Snow Fall on Antarctic Sea Ice

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Accurate precipitation rates (mostly as snow) in the Southern ocean are highly needed for the verification of precipitation trends as predicted in climate models and are also critically needed in coupled ice-ocean models. Because of the general weak oceanic stratification in the Southern Ocean small variations in fresh water balance can significantly alter Antarctic water mass modification. The absence of spatially and temporally continuous measurements of snow fall over Antarctic sea ice is a major limitation in the accuracy of model results.

Recently, a method has been developed to retrieve snow depth on sea ice from satellite passive microwave data. These data have now been used for estimating snow fall. The basic idea is that observed positive changes in snow depth can result from either ice drift or snow fall. In this new technique, ice advection is accounted for through the utilization of ice motion vectors which are also derived from passive microwave data (developed by C. Fowler, Univ. of Colorado) so that snow fall rates can be estimated.

This technique is applied to the period of 1988-1998. The results are compared to recent climatological studies of Antarctic precipitation and in-situ precipitation measurements. Trends and anomalies in the data are explored. The results suggest a decrease in Antarctic snowfall over sea ice in the winter season of about 0.02 cm/day per year.

IP51A-0736 0830h POSTER

Drought and Water Resources Assessment in the Western United States Using Data and Analyses From the USDA Natural Resources Conservation Service

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Recent extremes in western snowpacks, from record maximums to record minimums, have raised the awareness of climate variability and its effect on water resources. Water availability from melting snowpacks plays a key role in assessing water supplies and drought and their effects on agriculture, municipalities, hydropower, application of endangered species legislation, and forest management. The Natural Resources Conservation Service of the U.S. Department of Agriculture has a 60 year history of measuring western snowpacks and producing water supply forecast products. With the installation of the SNOTEL (SNOwpack TELemetry) network in the early 1980s and wide availability of the Internet, many thousands of users have access to real-time climate information collected by the 660 SNOTEL sites throughout the West. These data are not only used directly by users but also are fundamental to a number of analyses and products, including water supply forecasts, a surface water supply index, and a drought map. This information is critical to managing water resources in the West, especially during drought years.

IP51A-0737 0830h POSTER

Assessing the Heterogeneity of Snow-Water Equivalent During the Snowmelt Season: Spatial Variability and its Controlling Factors in an Alpine Setting

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A distributed energy-balance model was developed for simulating the seasonal snowmelt at a grid scale of 30 meters in rugged alpine terrain and applied to a 45 km2 headwater catchment in the Tobacco Root Mountains, Montana. Micrometeoroligical data that were collected over the 1997-1998 snow-accumulation and snowmelt seasons were used as boundary conditions for estimating initial snow distributions, as well as calculating the timing and distribution of snowmelt from 47,000 individual cells in the basin. Heterogeneity of energy distribution was accomplished by coupling the general radiation algorithm of Olyphant (1986) with detailed topographic analysis and remotely sensed ground-cover classifications. Heterogeneity of the initial snow distribution was calculated using SnowTran-3D (Liston and Sturm, 1998). Simulated snowmelt volumes compare favorably with measured outflow from a stream gage located just downstream of the study area. Although the primary control on snowmelt patterns was net radiation in the early snowmelt season, the later season patterns and melt rates were more closely related to the initial distribution of snow-water equivalent. This is demonstrated by a decline in the standard deviation of radiation received by remnant snowcover from 2.80 $\mathrm{MJ/m^2d^{-1}}$ to 0.88 $\mathrm{MJ/m^2d^{-1}}$. Also by the end of the simulation, virtually no snow remained on west-facing (windward) slopes, whereas east-facing (leeward) slopes had the highest remaining number of snow-covered cells. Such results emphasize the critical importance of establishing an accurate initial snow-water equivalent distribution in addition to representing the evolving distribution of energy income. This modeling approach may lead to a more complete understanding of the impact of heterogeneity on the evolution of an alpine snowpack.

IP51A-0738 0830h POSTER

Pathways to the Gauge: the Diurnal Streamflow Cycle as an Indicator of Snowmelt Rates and Transport

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Snow water storage and the average rates and paths of meltwater transport within a basin are difficult to monitor directly because snow occurs in patches of nonuniform depth and density and because it melts at varying rates, particularly in mountainous regions. However, another source of information is the daily variability in the discharge in snowfed streams, which provides a unique, indirect measure of these factors. During snowmelt-dominated seasons, the relative amplitude of the diurnal fluctuations, measured as half the difference between the daily peak and subsequent daily minimum, divided by the average discharge during that period is largest when most meltwater reaches the gauge within one day of melting and is smallest when most meltwater arrives as part of the recession curve several days after melting. The timing of the maximum discharge each day also relates to basin drainage rates. The days peak flow follows the peak radiative forcing most closely when meltwater transport is most rapid. The lag time between melt forcing and discharge increases with longer travel times. Because snowmelt input ceases at night in many rivers, leaving only water contained in storage to drain, the falling limb of the daily hydrograph can be modeled with a recession curve, where flow is approximated as $\mathrm{Q(t)=Q_0e}^{-kt}$, where Q is discharge, $\mathrm{Q_0}$ is discharge at time zero, k is a recession coefficient, and t is time. Larger values of the recession coefficient, k, correspond to rapid meltwater drainage through the snowpack and basin, while smaller values indicate longer meltwater storage in snow, subsurface, and groundwater reservoirs. Rates of transport are greatest when basin storage is small and the magnitude of discharge is large. Because the snowpack is a dominant water storage compartment in many alpine basins, its depth and extent greatly affect meltwater travel times. Hence, diurnal flow characteristics can indicate the relative size of the snow reservoir over the melt season. These relationships are illustrated in several basins in the Sierra Nevada and Rocky Mountains of the Western United States.

IP51A-0739 0830h POSTER

Comparison of Spatial Prediction Methods for Estimating Snow Distribution in the Colorado Rocky Mountains

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Seasonally snow covered areas account for a significant percentage of the land surface of the earth. Seasonal snow cover is important due to its contribution to annual runoff and due to its role in defining the global energy balance. Our understanding of snow distribution in the mountains is limited as a result of the extreme spatial variability snow exhibits. More accurate representations of snow distribution are greatly needed for improvements to hydrological forecasts, climate models, and for the future testing and validation of remote-sensing retrieval algorithms. In this study, the relative performances of four spatial prediction methods were evaluated to estimate snow water equivalent (SWE) for three 1 km^2 study sites in the Colorado Rocky Mountains. Each study site is representative of different topographic and vegetative characteristics. From 1-11 April 2001, 550 snow depth measurements and approximately 16 snow density profiles were obtained within each study site. The analytical methods used to estimate snow depth over the 1 km^2 areas were 1) inverse distance weighting, 2) ordinary kriging, 3) modified residual kriging and cokriging, and 4) a combined method using binary regression trees and cokriging. The independent variables used were elevation, slope, aspect, net solar radiation, and vegetation. Using cross validation procedures, each method was assessed for accuracy. Snow density was modeled over the 1 km^2 area using a linear regression technique. Snow depth estimates from the "best" or most accurate method were combined with modeled snow depth to produce SWE estimates for each of the study sites.

IP51A-0740 0830h POSTER

Snow Stratigraphy in an Alpine Environment: Spatial Variability and a Comparison of Measurement Methods

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Instrumentation and methods for measuring snow properties are compared in an investigation of mm to m scale variability of snow at Pika Glacier, Alaska Range, central Alaska. Field measurements were conducted within a 20x20x2 m plot in an area near the glacier centerline with no slope or topography. Snow within the plot was characterized by 600+ point measurements of snow density, 400+ measurements of snow temperature, stratigraphic mapping in 19 snow-pits, and along 20 profiles with a pulse radar system. Density was measured manually by weighing methods, and was calculated from electric permittivity. The snow's permittivity of was measured with a hand-held probe and by radar velocity analysis. Manual measurements of density and stratigraphic mapping in snow-pits suggested a relatively homogeneous snowpack, yet image analysis of a back lighted snow column revealed extremely complex stratigraphy at the mm scale. Both the permittivity probe measurements and the radar profiles are effective at revealing the stratigraphy at the scale of cm. Additionally, independent density calculations from the two methods are in good agreement with each other and with the manual measurements. While snow properties were found to vary vertically at the mm scale, major features in the density and temperature profiles were laterally continuous over 10s of m.

IP51A-0741 0830h POSTER

Semi-distributed, Physically Based, Snowmelt Modeling using Semi-distributed, Physically-based, Snowmelt modeling using Remotely Sensed data

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A semi-distributed snowmelt model (SDSM) is developed to take advantage of the remotely sense data. It models basin scale snow accumulation and ablation processes on a sub-basin basis. SDSM handle snowmelt processes using either the modified temperature index method or the energy balance method. The latter includes: (a) vertical energy exchange processes in open and forested area, considering liquid and ice phases, canopy interception, fresh snow density, sublimation, refreezing, snow compaction etc.; and (b) snow surface temperature simulated by the force restore method. This SDSM is coupled to the DPHM-RS (semi-distributed, physically based, hydrologic model using remotely sensed data) that simulates basin hydrology. Input data includes meteorological data, DEM, and spatial information retrieved from NOAA-AVHRR data. SDSM is calibrated 1999 winter data and validated with 1998 and 2000 winter data for the Paddle River Basin (about 265 Km^2) of central Alberta. We obtained good agreements between the simulated and the observed runoff at the basin outlet, between the simulated and observed snow depth and the snow water equivalent, and between simulated snow surface temperature and that retrieved from NOAA-AVHRR data in different land use.

IP51A-0742 0830h POSTER

A Comparison of Spatial Statistical Techniques for the Development of a Validation Data set for Mesoscale Modeling of Snow Water Equivalence

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Mesoscale estimates (>1km2) of distributed snow water equivalence (SWE) are seldom validated with ground truth data beyond observations made by the Natural Resource Conservation Service (NRCS) Snow Telemetry (SNOTEL) network. SNOTEL data may be insufficient to validate pixel values of SWE at the low spatial resolutions (>1km) used in mesoscale modeling. In order to validate mesoscale estimates of SWE at 1km resolution, we sampled snow depth and snow density at 250m intervals over 4km2 areas at three different sites in the San Juan Mountains of Colorado during water year 2001. We also conducted our analysis on data collected during water year 1997 in the 19.1 km2, Tokopah Basin of the Sierra Nevada, California. We compared the robustness of the following four statistical techniques: kriging, co-kriging, inverse distance weighting, and neural networks. We found that average SWE over the Tokopah basin during the April, May and June snow surveys was 995mm, 701mm and 283mm respectively and SWE at the Colorado sites during water year 2001 decreased from 269mm to 104mm, 452mm to 261mm, and 845mm to 447mm to 219mm for the three sites respectively.

IP51B MC: 124 Friday 0830h

Glacial Sediment Systems From Source to Sink I *(joint with H, T, DI)*

Presiding: **S Anderson,** CSIDE; **D Lawson,** CRREL-Anchorage

IP51B-01 0835h INVITED

Sediment Production and Storage Through a Glacial-Interglacial Cycle on a Cool-Temperate Glaciated Margin

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The southern Alaska margin has high coastal mountains, which coupled with temperate glaciation, result in extremely high modern erosion rates (e.g. Jaeger et al., 2001), possibly exceeding rates of orogenic uplift (Meigs and Sauber, 2000). Where measured, modern sediment yields are among the highest of any basin worldwide (Hallet et al., 1996; Elverhoi et al., 1998; Jaeger et al., 1998). In Muir Inlet, Glacier Bay, sediment yields from slowly retreating glaciers decrease logarithmically with decreasing drainage basin area (Powell, 1991), a trend also reflected in regional data synthesized in Hallet et al. (1996). Alley (1997) then hypothesized that if erosion increases with basin area then where two tributaries join, deeper erosion would ensue, which is consistent with linear erosional troughs and hanging valleys. The idea is also consistent with the general downglacier increase in water flux at the glacier bed. However over longer periods, data from seismic profiles of the Gulf of Alaska shelf, show sediment yields are nearly the same through a glacial-interglacial cycle; regional data from other glaciated basins appear to confirm that trend (Elverhoi et al., 1998). If yields are continuously high from bedrock erosion, then why are mountains not eroded to base level because erosion rates are higher than isostatic uplift? Why are trends in yields apparently different during recent retreats with decreasing basin sizes than during longer term glacial cycles? Answers to these questions may be numerous and compound; however, one possibility will be evaluated.

We know there is significant modern bedrock erosion occurring during glacial retreat and that also appears to have been the case during advance. Native stories describing the last (Little Ice Age) advance in Glacier Bay describe a large amount of sediment being produced (Powell et al., 1995) indicating that significant erosion was occurring. Fjord-wall stratigraphy shows that sediment had infilled much of the Bay up to ca. 200 m above modern sea level (Goldthwait,1986) prior to the LIA. During that advance, all sediments were then eroded down to bedrock, locally up to 400-500 m below sea level (Powell and Molnia, 1989), and then dumped at the Bay entrance, the site of maximum advance Powell et al., 1995). By inference, because most sediment packages on the shelf are deposited during glacially advanced phases, they probably mostly include sediment redistributed from fjords and inner shelf with a minor component from freshly eroded mountain bedrock. The ELA, under which most erosion may occur (Meigs and Sauber, 2000), lies over fjords during glacial maxima where the glacier is probably thickest with pressure melting and melting/freezing occurring at the bed. Erosion of sediment deposited there during a retreat phase may be enhanced, as may fjord over-deepening, whereas, thinner ice over mountains is likely to be cold at the bed, limiting erosion. As the glacier retreats the ELA moves toward the mountains as may the center of erosion, which then occurs mainly on bedrock. Mountain uplift may be enhanced during interglacials when glacio-isostatic rebound occurs and increased erosion adds to the isostatic effect. Therefore, during glacial-interglacial cycles average sediment yields from a glacier may not vary significantly, but the main centers of erosion change through time as does the eroding substrate and locations of depocenters.

IP51B-02 0850h

The Importance of Sediment Gravity Flows and Submarine Slope Failures in the Creation of Glacimarine Strata in Southern Alaska

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The redistribution of sediment by sediment gravity flows and mass movements may play a fundamental role in creating strata on glacimarine continental margins. Previous USGS work in the Gulf of Alaska region related numerous submarine failure deposits to the low cohesiveness of the glacially derived sediments and the high frequency of triggering mechanisms (i.e., earthquakes). Underconsolidation of sediment due to high sedimentation rates was not thought to have contributed to the failure, although numerous studies have documented very high sedimentation rates elsewhere on the shelf. Recently we have observed more gravity flow and mass movement activity than previously described by the USGS. Combining MMS seismic reflection data with high-resolution Huntec DTS and airgun profiles and sedimentary data collected in 1994-95, we find highly episodic sediment input and correspondingly high deposition rates related to glacial processes, such as meltwater events from the Malaspina, Bering and Columbia glaciers and catastrophic floods of the Alsek River (i.e., Jokulhlaups). Downslope movement has various signatures in seismic profiles: wave-like slumping offshore of the Malaspina Glacier; rotational slumping that produced a 30-km-long debris flow runout off the Bering Glacier; uneven surface slumps off the Copper River and in Prince William Sound. Cores contain a spectrum of gravity flow/slope failure deposition from normally graded beds to highly chaotic debris flow deposits. Stratigraphic and radioisotopic data collected in cores demonstrate that sedimentary strata caused by gravity flow/slope failure may represent 30-50 percent of total core length. Seismic reflection data reveal that the incidence of gravity flow/slope failure sedimentation has increased over the late Holocene whereas the probability of earthquakes likely has not changed. Stratigraphic and radioisotopic data also indicate high activities of these processes over the complete length of cores collected (Little Ice Age time scales). We suggest that gravity flow/slope failure has increased due to renewed glacial activity during the late Holocene Neoglacial, and that the sedimentary record created by these flow/slump deposits are a proxy record for Holocene climate change in this region.