Perugia, Italy July 2-13, 2007

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EARTH: OUR CHANGING PLANET

IAHS

INTERNATIONAL ASSOCIATION OF HYDROLOGICAL SCIENCES

INTER-ASSOCIATION SYMPOSIA AND WORKSHOPS

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Abbreviations

IAG	International Association of Geodesy
IAGA	International Association of Geomagnetism and Aeronomy
IAHS	International Association of Hydrological Sciences
IAMAS	International Association of Meteorology and Atmospheric Sciences
IAPSO	International Association for the Physical Sciences of the Oceans
IASPEI	International Association of Seismology and Physics of the Earth's Interior
IAVCEI	International Association of Volcanology and Chemistry of the Earth's Interior
CliC	Climate and Cryosphere
Ev-K2-CNR	Everest-K2 CNR Committee
GEWEX	Global Energy and Water Experiment
HKH-FRIEND	Hindu Kush-Himalayan Flow Regimes from International Experimental and Network Data
IABO	International Association for Biological Oceanography
IACS	International Association of Cryospheric Sciences
ICACGP	International Commission on Atmospheric Chemistry and Global Pollution
ICASVR	International Commission on Atmosphere-Soil-Vegetation Relations
ICCE	International Commission on Continental Erosion
ICCL	International Commission on Climate
ICCLAS	International Commission on the Coupled Land-Atmosphere System
ICCP	International Commission on Clouds and Precipitation
ICDM	International Commission on Dynamic Meteorology
ICGW	International Commission on Groundwater
ICIMOD	International Center for Integrated Mountain Development
ICMA	International Commission on the Middle Atmosphere
ICRS	International Celestial Reference System
ICSIH	International Commission on Snow and Ice Hydrology
ICSW	International Commission on Surface Water
ICT	International Commission on Trac
ICWQ	International Commission on Water Quality
ICWRS	International Commission on Water Resources Systems
IGAC	International Global Atmospheric Chemistry
IGS	International Glaciological Society
ILP	International Lithosphere Program
INQUA	International Union for Quaternary Research
ION	International Ocean Network

IRC	International Radiation Commission
PUB	Prediction in Ungauged Basins
SCAR	Scientific Committee on Antartic Research
SEDI	Study of the Earth's Deep Interior
SPARC	Stratospheric Processes and their Role in Climate
UCCS	Union Commission for the Cryospheric Sciences
UNESCO	United Nation Educational, Scienti. c and Cultural Organization
UNITAR	United Nations Institute for Training and Research
WMO	World Meteorological Organization

Session code naming

The first letter of the session codes indicates whether the session is a Union, a Joint Interassociation or a single Association sponsored event, the second letter indicates the type of event: Symposium (S) or Workshop (W). For Joint events, the second letter indicates the Lead Association (with the abbreviations listed below) and the third indicates whether a session is a Symposium (S) or a Workshop (W). In some cases (namely IAGA, IAHS) Association session codes have an extra codi. cation referring to a speci. c Theme or Division.

U	UNION
J	JOINT
G	IAG
A	IAGA
H	IAHS
M	IAMAS
P	IAPSO
S	IASPEI
V	IAVCEI

Some examples:

US002

is a **U**nion **S**ymposium; **JGW**001 is a **J**oint IA**G** **W**orkshop with IAG as the Lead Association;

MS003

is an Association (IA**M**AS) **S**ymposium. **AS III** 020 is an Association (IAG**A**) **S**ymposium sponsored by its **III** Division.

JHS001 Symposium (627 - 633)

Convener : Prof. Michael Hambrey, Dr. Bryn Hubbard

Debris Transport in Glaciers (UCCS Symposium hosted by IAHS)

JHS002 Symposium (634 - 644)

Convener : Dr. Jean-Bruno Brzoska
Co-Convener : Prof. Edward E. Adams, Dr. Charles Fierz, Dr. Martin Schneebeli

Natural Ice Microstructures (UCCS Symposium hosted by IAHS)

JHW001 Workshop (645 - 677)

Convener : Dr. Richard Essery
Co-Convener : Dr. Takeshi Yamazaki

Interactions between snow, vegetation and the atmosphere (UCCS Symposium hosted by IAHS)

JHW002 Workshop (678 - 714)

Convener : Dr. Philip Marsh
Co-Convener : Dr. Oliver W. Frauenfeld

Climate-Permafrost-Hydrology Interactions: The Impact of Changing Climate on Cold Regions Hydrology (UCCS Symposium hosted by IAHS)

(H) - IAHS - *International Association of Hydrological Sciences*

JHS001 627 - 633

Symposium
Debris Transport in Glaciers (UCCS Symposium hosted by IAHS)

Convener : Prof. Michael Hambrey, Dr. Bryn Hubbard

The aim of this session are to apply a multidisciplinary approach to (i) enhance our understanding of debris entrainment and transfer in glaciers, and subsequent deposition at contemporary ice margins, and (ii) to use this knowledge to constrain numerical models of contemporary and former ice masses. The principal themes will be: the disposition of debris within glaciers (particularly in relation to structure), contemporary glacial depositional processes, and numerical modelling of glacial depositional systems.

(H) - IAHS - *International Association of Hydrological Sciences*

JHS001 Oral Presentation 627

Deglaciation and associated changes in landscape morphology as reflected by total suspended matter concentratio n at Gangotri Glacierised Region

Author : Dr. Shresth Tayal
None None IAHS

Co-Author: Prof. Syed I. Hasnain

The Himalayan Glaciers form a unique type of wetland, which supports mighty perennial rivers such as Indus, Ganga and Brahmaputra, which have been the cradles of human civilization and act as lifelines of millions of people residing in the north, northeast and northwestern parts of In dia. Today, however, the rapid pace of globalization, urbanization and mass tourism is threatening Himalayan mountain ecosystems, communities and resources. These factos leading to changes in climate and increase in level of pollution are posing a serious threat to the stability of glaciers by way of increasing glacier meltdown and corresponding shrinkage of glaciers. The same is reflected in the form of increased discharge and Suspended sediment concentration in meltwater. Among the three river systems, Meltwater of river Ganga transport maximum amount of sediments in proportion to the total runoff. River Bhagirathi, an important tributary of Ganga, or iginates from Gangotri glacier situated in Garhwal Himalaya. This region being situated in the transitional zone betw een temperate-western and tropical-eastern Himalaya and hence, is most affected by the vagaries of seasonal changes. Moreover, the region is highly affected with human interventions. As a result, climate change effects are prominently noticed in Garhwal Himalaya that are reflected in the enhanced rate of recession of glaciers i.e., upto 25-30 m/yr. In Gangotri glacier, excessive glacier erosive action as a result of enhaned rate of retreat of glacier snout is leading to changes in geomorphic landscape. The adjacent mountains are being eroded and huge amount of debris is being dumped on the supraglacial surface. Heavy monsoonal precipitation over the glacier surface during July and August transport this sediment to th e subglacial system through huge crevasse developed in the lower ablation zone of the glacier and comes out along with meltwater. About 64% of total discharge, 70% of total suspen ded sediment transport and 74% of rainfall take place during the months of July and August over the glaciers. The Gangotri headwater contains Total Suspended Matter ranging from 2-3 gm/L on an aver age. A total of 4.57 105 metric tons of sediment was transported in the month of July, 2003 and 2.40 105 metric tons in August, 2003. The associated physical denudation rate for July and August were 59 g m-3 day-1 and 31 g m-3 day-1 respectively. Heterogeneity of the curves between hourly va riation in discharge and suspended sediment concentration with respect to time indicates a comp lex interplay of Rainfall and Air temperature on glacier system, which get smoothen with progress of ablation season and attains a near uniformity by end monsoon season indicating a decrease in the impact of atmospheric variability on Glacier Hydrological Systems. The linear relationship between the suspended sediment concentration and discharge components as depicted by increasing r2 values, strengthens towards the close of monsoon season. Moreover, any intermittent heavy rainfall disr upts the linear pattern indicating strong influence of monsoon on supply of suspended matter into the hydrological system.

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JHS001 Oral Presentation 628

The state of glaciers of Tajikistan and adaptation of economic activiti es in conditions of global warming

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Co-Author: Georgy Petrov, Safarov M.T., Mahmadaliev B.U., Bekmurod Mahmadaliev, Mahmad Safar

North-West Pamir The main junction of glaciations of the Republic of Tajikistan is in mountains of Northwest Pamir which its the center of which is Fedchenko glacier - the largest mountain glacier in the world. The length of a glacier is 77 km, average wi dth is 2,5 km, the maximal width 5 km, thickness of ice reaches kilometer. From Fedchenko glacier begins Seldara - one of tributary of the Muksu river which, merging with Kizilsu gives rise Surkhob - to the right tributary of Vakhsh river. Thus, Fedchenko glacier can be found a source of Vakhsh river. By 1988 the glacier has receded more than on 500 m and has decreased on the area for four square kilometers. Average speed of step of Fedchenko glacier for the last century made 10-12 meters one year. Its lower part during nine kilometers settles was broken with numerous cracks. Thus Fedchenko glacier has lost almost all its right tributary- they became independent glaciers. Only for forty years from mountain ranges: Academy of Sciences, Zaallay and Kaindi have disappeared 14 not large glaciers with general area of 7,6 km2. Average speed of movement of glacier in connection with loss of weight has decreased with 72 up to 69 sm daily. In total for 20-th century the glacier has lo st about 12-15 km3 ice. Agency on hydrometeorology of the Republic of Tajikistan in September,2006 after a sixteen year has made survey of the Fedchenko glacier and a cross-section structure in area of Bivachni glacier. The glacier continues to recede with constant speed of 8-10 meters in one year, but irregularly. In the ei ghtieth years of the last century the glacier receded 20 m in year. On a cross-section structure in seven kilometers the glacier is higher than tongue settles 1,5 meters annually though twenty years ago intensity of subsidence made 2,0 - 2,5 m in year. For irrigation and water-power engineer ing regulation of river flow are in an antiphase. The irrigation interested in demands of water in winter and the use of it in summer on the contrary to the water-power engineering - accumulation of water in the summer. The cardinal decision of these contradictions between irrigations and water-power engineering is th e further development of the last by construction of many large Hydropower stations (HPS) with reservoirs. In this case th e reservoirs located in downstream of the rivers will work in a power mo de and reservoirs on the upstream rivers - in irrigational. Moreover, the possible changes of the river flow connected to change of the climate as show direct supervision, favorable to economic activities. The researches which have been carried out in Tajikistan have shown, that the end result of change of climate the order with change of volumes of a drain will be increase in quantity of an atmospheric precipitation.

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JHS001 Oral Presentation 629

Formation, evolution and failure of Himalayan moraine dams

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Moraine dams are unstable accumulations of unconsolidated sediment and relict glacier ice, original formed during the Little Ice Age. Dams are at increasing risk of failure as glaciers recede with climatic warming, since downwasting of the glacier surface results in the growth of lakes. Catastrophic failure of dams, commonly triggered by displacement waves from rock- and ice-avalanches, results in the release of millions of cubic meters of water in a few hours, known as glacial lake outburst floods or GLOFs. Thousands of people perished and infrastructure destroyed from GLOFs in the 20th century, particularly in the tropical Andes and the Himalaya, whilst the potential for further disasters is increasing as the number of lakes grows. Here we evaluate ground observations on the structure and composition of moraines, combined with an assessment of glacier dynamics from remote sensing techniques from several glaciers in the Mt Everest region of Nepal. The moraines grew from accretion of multiple sedimentary facies of basal glacial and supraglacial origin, and sometimes reworking of older lake sediments. Some moraines have a decaying ice core Folding and thrusting are believed to have been prime factors in moraine growth during the Little Ice Age phase of active flow. Using ASTER imagery, glacier surface gradients and velocities were quantified. The subsequent formation of moraine-impounded lakes is favoured by a debris-covered tongue, the coalescence of supraglacial lakes and negligible ice velocities. With the supply of ice to these flat glacier tongues essentially cut off, the number of potentially hazardous lakes will grow at an accelerating rate. The potential for dam failures will increase unless remediation measures are undertaken. Remoteness of many moraine dams means that the potential GLOFs may go undetected, necessitating a concerted effort to evaluate glacier hazards on a regional scale using remote sensing techniques in the first instance.

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JHS001 Oral Presentation 630

Quantifying sample bias in glacio logical clast fabric measurements

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Co-Author: David Chandler

The analysis of clast macro fabrics is one of the most commonly used sedimentological methods of reconstructing glacial debris transport processes and directions. However, sampling elongate clasts that protrude from a planar face for clast macro-fabric an alysis introduces a bias into reconstructed fabrics because clasts aligned perpendicular to the sampling face are over-represented relative to those aligned parallel to the face. Here, we develop a probability-ba sed mathematical analysis to quantify sample bias for a variety of clast shapes and population fabrics, including isotropic, clustered and girdled fabric styles. Bias is expressed in terms of sample eigenvalues and eigenvectors relative to those of the parent population. Results indicate that sampling always has the effect of artificially drawing fabrics towards perpendicularity to the sampling face relative to the populations from which they are drawn. This rotation generally has the effect of artificially stre ngthening population fabrics, by up to 30 % in the case of a very weakly clustered or girdled populations. However, fabric strengthening is by no means universal and sampling alters different parent popu lations in different, sometimes complex, ways: our analysis identifies situations where sampling can strengthen or weaken parent fabrics, it can rotate parent fabrics (by up to 90 in the case of a very we ak population fabric), and it can even change the style of a population fabric. For example, near-isotropic population fabrics can appear clustered, weakly clustered and weakly girdled population fabrics can appear isotropic, weakly clustered population fabrics can appear weakly girdled, and weakly girdled population fabrics can even appear clustered. Overall, our analysis indicates that weakly orientated population fabrics are most susceptible to bias. Thus, a weakly clustered population fabric aligned parallel to a sample face is particularly susceptible to major sample bias in both fabric strength (artificially overestimated) and orientation (artificially rotated perpendicular to the face).

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JHS001 Oral Presentation 631

Bryophyte Colonisation on a Temperate Glacier: Falljkull, Iceland.

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Co-Author: A. J. Evans, A. J. Hodson,A. T. Lowe, M. D. Crabtree

The ability of many moss species to tolerate harsh environments makes them potentially well suited to colonisation and growth in glacial environments. Although the presence of mosses in nival and glacial environments has been well documented, we are unaware of any study that has yet investigated moss growth within supraglacial ecosystems (which were hitherto assumed to be dominated largely by microbial consortia). We report results of investigations of globular moss growth on the surface of Falljkull, a temperate outlet glacier of the Vatnajku ll ice cap, Southern Iceland, and contend that the role of bryophytes within the supraglacial ecosystem might also require consideration. Supraglacial debris has provided a basis for moss colonisation and several large (>500m2) patches of moss growth (Racomitrium fasciculare (Hedw.) Brid and Racomitrium ericoides (Brid.) Brid.) are identified on the surface of Falljkull. Each area of moss-colonised supraglacial debris shows pronounced down-glacier elongation, with an increase in sphericity and moss cushion size and a decrease in percentage surface coverage of moss-colonised clasts evident in the down-glacier direction. We suggest that moss growth on supraglacial debris allows preferential down-glacier movement thro ugh an increase in both overall mass and sphericity associated with enlarging moss cushion growth. Thermal insulation by moss cushions protects the underlying ice surface from melt, and the resulting ice pedestals assist in down-glacier sliding and toppling of moss cushions. Moss cushions are known to accommodate nitrogen-fixing cyanobacteria in Arctic regions, and thereby contribute nitrogen to these ecosystems. In particular, the presence and dispersal of the moss also provides organic carbon for bacterial heterotrophy in supraglacial habitats such as cryoconite holes, as well as within the core of the moss cushions themselves. Moss growth therefore assists in the down-glacier movement of supraglacial debris and leads to the dispersal of organic and inorganic nutrients into the supraglacial ecosystem.

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JHS001 Poster presentation 632

Lift of debris across flow lines in basal shear flow in glaciers

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Co-Author: Alexei Lozinski, Jacques Rappaz, Heinz Blatter

Jansson and others (2000) report the existence of an englacial debris layer near the terminus of Storglaciren, northern Sweden. The position of entrainement of the debris is proposed to be near the basal thermal transition (BTT) between temperate and cold ice. Several mechanisms were proposed to explain the motion of the debris higher into the ic e to be transported along a flowline to the surface relatively high above the terminus. The proposed processes are basal freezingand accumulation of ice beneath the debris or thrusting at the BTT. A different rheological process is proposed that may contribute to the lift of debris across flow lines higher up into the ice. It is a known fact that solid particles carried along with a Poiseuille flow tend to move away from the wall of the tube. Similar effects are observed for a laminar shear flow across a plane, in which entrained particles move away form the plane. The effect seems to be related to th e vicinity of the plane and to a much lesser degree to a gradient in the shear rate.Numerical experiments for for a 2-dimensional circular rigid body entrained in a 2-dimensional shear flow field across a boundary show the same effect. The experiments were performed for realistic shear rates and viscosities for ice flow near a glacier bed. The flow field is computed for a Newtonian fluid in a regular finite difference grid with given boundary conditions for the shear rates. The solid body is considered by using the fictitious domain technique and a Lagrange multiplier to match the conditions at the interface between the fluid and the body. References: Jansson, P., J. Nslund, R. Pettersson, C. Richardson-Nslund, and P. Holmlund, 2000: Debris entrainment and polythermal structure in the terminus of Stoglaciren. IAHS-Publication 264, 143-151.

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JHS001 Poster presentation 633

Study into the englacial weathering of debris

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Little is known about the englacial weathering of de bris. A laboratory and fieldwork based investigation was used to investigate the extent and rate of the weathering of englacial debris. Samples of basal ice were recovered from Svinafellsjkull, Iceland,and were tested (either in situ or in the laboratory) for electrical conductivity, debris percentage volume, grain size and ionic composition. Laboratory investigations consisted of analogue englacial ice samples (composed of mixtures of descriptionised water ice and variations in debris). Debris-ice mixtures were prepared to recreate variations in physical parameters including grain size, lithology and debris volume over a set time span. A setof standardised debris-ice samples were also made where only temporal variationwas applied(measurements were taken between 2 to 120 days). Results indicate that ions (as indicated by EC) from the debris are present in all melted samples of ice (both in the field and laboratory samples). These measurements range form 1 uS cm-1 to 36 uS cm-1. Ion concentration from the standardised ice samples did not increase significantly over the time period tested. Variations in EC were seen in the melted ice samples between variables within each debris basedphysical parameter. The EC measurements for each sample did not alter significantly over a set time period, re gardless of the variables testedwithineach physical parameter.

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JHS002 634 - 644

Symposium
Natural Ice Microstructures (UCCS Symposium hosted by IAHS)

Convener : Dr. Jean-Bruno Brzoska
Co-Convener : Prof. Edward E. Adams, Dr. Charles Fierz, Dr. Martin Schneebeli

Similar phenomena happen at a given physical scale in any of the various environments addressed in the research fields of cryospheric sciences. This is specially the case of the so-called capillary scale (typically from micron to millimetre) that governs th e behaviour of precipitation elements in clouds such as graupel, snow cover, ice fabric in ground or marine ice as well as icing patterns on mobile or immobile substrates. Applications of these studies are numerous in snow science and glaciology, particularly for snow model parameterisations and ice core measurement interpretation. All these ice microstructures are fully tri-dimensional assemblies of grains and bonds with extremely complex interface shapes. They require specific techniques of investigation that ra nge from 3D imaging and modelling to stereology (to bridge 2D to 3D properti es) and statistical approaches to reach the scalar and continuous parameterisations required by current cryosphere models. Furthermore, snow parameters relating the laboratory capillary scale to the much simpler and coarser field observation method are needed, such as described in the Intern ational Classification of Seasonal Snow on the Ground. The objective of this symposium/workshop is to develop a discussion and understanding of natural ice microstructures, with emphasis on the current state of the art in the field and promoting exchange of knowledge. Synergies are expected between the fields of glaciolo gy, snow science, cloud meteorology, image processing and scientific instruments. Contributions on the interdisciplinary exchange with marine, aircraft or po wer engineering would be welcome.

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JHS002 Oral Presentation 634

Observation and Simulation of an Ice Layer in Snow Subjected to a Temperature Gradient

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Co-Author: Martin Schneebeli, Thomas U. Kaempfer, Kelly Elder

Ice crusts are important stratigraphic, hydraulic, and mechanical features in snowpacks. In the laboratory, we applied a temperature gradient to natural snow samples containing an artificial ice layer (4 mm). We observed microstructural changes in the snow samples with serial sections and time-lapse X-ray microtomography. The density above and below the ice layer remained constant within the precision of our measurements (5%), but we observed dramatic changes in the specific surface area and shape of the ice structure. There was no clear signal from the ice layer in the temperature profile of the samples (1 cm resolution). However, numerical simulation of the experiments shows a large temperature gradient both above and below the ice layer. The ice layer created a strong signal in the microstructure as numerous bonds formed below the ice layer and very few formed on its eroding upper surface. The time-lapse microtomography showed a large redistribution of ice mass due to vapor diffusion. These observations indicate that our current understanding of sublimation and deposition in porous snow around large density changes is limited. These results have implications for avalanche research, hydrology and interpretation of polar snow covers.

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JHS002 Oral Presentation 635

Effect of microstructure on effe ctive heat conductivity of snow

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Co-Author: Martin Schneebeli

One of the main effects of snow cover on climate system is related to thermoinsula tion of soils. Physical parameter describing this effect is named effective heat conductivity of snow cover and, when incorporated to climate models of various scales, is normally expressed as dependence on snow density. In addition to previously noted high variability in effective heat conductivities of snow with similar snow density, our laboratory experiments on heat and ma ss transfer in snow showed significant temporal change of the effective heat conductivity of snow with snow density remaining constant. This could be explained by observed by computed microtomography change in snow microstructure during the experiments. Relation between several characteristics of snow microstructure provided by computed microtomography and effective heat conductivity of sn ow is presented. The effective heat conductivity is, on one hand, expressed as a combination of the conduction in ice matrix/pore space and alternating latent heat release/gain at the ice matrix surface; on the other hand a map of the microstructure relative to simple cases, such as parallel plates and disconnected spherical particles, where modeled effective heat conductivity of media has solid physical background is constructed. Distribution of the microstructural parameters over the map determines distribution of the effective heat conductivity, allowing predicting its value when micr ostructural characteristics are known.

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JHS002 Oral Presentation 636

Microstructural Modeling of Snow Metamorphism Using a Phase Field Method

Author : Dr. Thomas Kaempfer

Co-Author: Mathis Plapp

Snow is a highly porous medium consisting of an ice matrix and porous space containing water vapor. Moreover, snow undergoes metamorphism as heat flow and interface effects induce mass flow and thus profoundly change the microstructure, i.e., the distribu tion of ice and pores. Reciprocally, this evolution influences the thermophysical, chemical, and mechanical properties of snow. In particular, the microstructure of snow influences the heat conductivity as heat transport consists in (i) heat conduction in the ice and pores, (ii) heat transport related to wa ter vapor diffusion in the po res, and (iii) latent heat release and gain due to phase changes at the ice-pore interfaces. Recently, detailed image series of metamorphing snow using X-ray micro-tomography became available and models for heat conduction through a steady state ice and pore network emerge d. We present a phase-field model to solve the coupled heat and mass transport problem including phase-change processes in an evolving ice-pore network. The model considers mass fluxes that are induced by temperature gradients in the snow as well as by curvature effects. We applied the model to simple ice lattices and tomographic data to study the relative importance of the different heat transp ort components in snow and to examine the interplay between heat flow and mass transport. The results underline the link between microstructure and heat conductivity of snow and indicate that reliable heat conduction models for snow have to consider the complex microstructure of snow rather than only bulk properties such as the density.

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JHS002 Oral Presentation 637

Investigating the metamorphism of snow and firn with micro-computer-tomography microstructure and air transport properties of Hercules dome, Antarctica

Author : Mrs. Maria Hrhold

Co-Author: Mary R. Albert, Johannes Freitag

The origin and metamorphism of polar snow and firn microstructure is strongly governed by climatic conditions such as temperature and accumulation rate. The transport properties of the firn are affected by and do affect the microstructure and do have an impact on the climatic signal stored in the ice. In this study micro Computer Tomography is used to investigate the firn microstructure of a 15 meter deep firn core retrieved at Hercules Dome, Antarctica and its relation to the measured air permeability. The anisotropic behavior of snow grain and pore properties due to metamorphic processes at the surface becomes visible. Microstructural parameters like the specific surface or geometrical properties such as tortuosity and the connectivity of the pore space can be linked to airpermeability. The influence of the accumulation rate on the coarsening of the firn and the development of pore connectivity could be involved in the approach of modeling air transport properties and in firnification studies.

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JHS002 Oral Presentation 638

Isothermal metamorphism of snow at different temperatures

Author : Dr. Martin Schneebeli
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Co-Author: Thomas U Kaempfer

Isothermal metamorphism is based on the fundamental process of snow sintering. However, the physical processes responsible for sintering are still debated. Probable processes are grain-boundary diffusion or sublimation-condensation, but no conclu-sive experiments were conducted until now which support unequivocally one or the other theory. We observed the changes in porosity, shape factor, specific surface area, and trabecular number during one year at intervals of 1 months at temperatures of -3, -10, -20 and -50? C of undisturbed metamorp hing snow samples using x-ray micro- tomography. The results showed a first phase of very rapid initial change in porosity and specific surface area during the first month and rapid change of trabecular number and shape factor and a second phase where trabecular number and shape were con-stant but a decrease in porosity and specific surface area following a power law was observed. Our measurements and observations indicate that grain-boundary diffusion is the dominating process during isothermal metamorphism. At -50? C the changes in porosity were slow, and specific surface area changed by only 10% from the inital value after 1 year. The initial phase of snow metamorphism from new snow to a mo re rounded shape require data at higher temporal resolution than available.

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JHS002 Oral Presentation 639

Explicit iterative computation of diffusive vapor field in the 3D snow matrix: some preliminary result s for low flux metamorphism

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snow physics Meteo-FranceGAME-CNRM IAHS

Co-Author: Frdric Flin, Jean Barckicke

The metamorphism of superficial layers of seasonal snow is classically considered as limited by vapor diffusion in the pore phase. Accounting for the p oor present knowledge of the ice/vapor reaction coefficient near 0 C, the opposite assumption of a reaction-limited metamorphism was tested in 3D simulations at low and very low temperature gradients; however, the validity of such results is hard to check experimentally. By a reasoned use of traditional iterative schemes, vapor diffusion is simulated in 3D on tomographic snow data, mapping the gradient of vapor pressure near the grains. Repeating this process allows to simulate the isothermal metamorphism without grain packing at a reasonable expense of computation time. These preliminary results are then compared with existing simulations made within the "reaction-limited" hypothesis.

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JHS002 Oral Presentation 640

A bonding process between grains in mechanically disaggregated snow

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Co-Author: Steven M. Jepsen, Bryan Close

Microstructure and inter-granular bonding between snow grains is of importance to avalanche stability, over-snow mobility, conductivity and other thermo-mechanical properties. A strong macro-structure is often observed to rapidly develop in snow that has been mechanically worked by mechanisms such as wind, avalanches, snowplows, etc. Causal processes that have been attributed to this include, mechanical heat dissipation, which causes slight melt followed by refreeze between grains and particle sintering."Equi-temperature" snow metamorphism, which yields sintering between ice grains, has typically been considered using a two-spherical-particle model in which the two particles are in contact at the neck or bond. The model considers transport mechanisms that may supply material to the neck. In an endeavor to observe the sintering process, samples of older rounded grained snow were disaggregated by sifting through a 0.991 mm sieve into a 16 mm diameter crucible. This snow was then positioned within a Linkam BCS196 cold stage, which provides a very stable, accurate temperature platform. Time-lapse images were recorded using a Nikon Eclipse 80i microscope. The viewing area was focused to examine grain-to-grain and grain-to-pore interaction. In addition to necks that appeared to sinter in a manner congruent with the two-particle model, there also appeared unanticipated first order dendritic growth on some grains into the pore. These slender branches developed preferentially only on part of individual grains. Branches developed in different directions on individual grains and often grew to join with another grain in close proximity, whose surface did not show any similar growth. The random growth orientation is in contrast to other tests in which a similar sample preparation was used, but a temperature gradient was imposed, using a Linkam GS120 temperature gradient stage. In the presence of this imposed temperature gradient, faceted, kinetic growth crystals developed that aligned with the gradient. As expected, a source-to-sink directionality across the pore was apparent in which kinetic the growth crystal grew at the expense of the neighboring source grain. The process of mechanically disaggregating the ice grains produces numerous broken shards and sharp edged fracture surfaces. We hypothesize that it is the sublimation of these high surface energy regions that provide the excess vapor to facilitate the dendritic growth observed in the "equitemperature", mechanically processed snow. This vapor source will be available until these high energy regions are depleted. The dendritic crystal growth will occur on either the prism or basal face, depending on temperature, which explains the random orientation. Although additional verification is required, if the experimental protocol adequately represents field scale metamorphism, the additional bond connections that develop as the result of the dendritic crystal growth may help to explain the strengthening of processed snow and the irregular microstructural morphology.

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JHS002 Oral Presentation 641

Assessment of techniques for analysing snow crystals in 2-dimensions

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At present there are several comprehensive and advanced 3-dimensional methods for the characterisation of snow. Whilst providing thorough physical information about snow microstructure, these methods require somewhat elaborate equipment. On the other hand, numerical models presently used for avalanche forecasting such as SNOWPACK still rely on parametrisations based on 2-dimensional grain analysis. A link from 3 to 2-dimensional analysis would be welcome, as 2-dimensional snow grain analysis remains an effective and useful technique. There are several well-developed shape descriptors already used for snow grain classification. The ratio of the perimeter of a grain to its area (dendricity), e.g., is used to indicate the complexity of the grain outline. The complexity of the outline then allows distinguishing between new and old snow. Curvature is also a very useful shape descriptor that can be used to distinguish between faceted and rounded grains. However, results obtained from segmented 2-dimensional images of disaggregated snow grains depend on both resolution and methods chosen to extract grain outlines. In this contribution we present a detailed assessment of various methods and shape descriptors. To avoid the inherently unknowns of closed-source, commercial software, we developed a self-contained software that encompasses both image processing and post-analysis in one package. Accordingly, we can readily use either the parabola-fitting method currently used or a new method using a cubic smoothing spline to calculate curvature. To perform a systematic assessment of both methods, they were applied to several parametrically generated shapes with increasing degree of complexity. Descriptor values obtained from either method could then be compared with their analytical counterparts. After determining the best fitting parameters, it was found that the spline method could measure a greater range of curvatures to a reasonable degree of accuracy than the parabola method. Nevertheless, relative errors can still be as high as 30% for given descriptors. Finally, the methods are used to analyse samples of disaggregated snow grains. Beside assessing the classification potential of 2-dimensonial analysis, emphasis is put on the search for descriptors capable of better discerning between different stages of decomposing and fragmented particles, a still not satisfactorily solved problem.

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JHS002 Oral Presentation 642

Numerical heat diffusion model ling of snow microstructure

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Snow is a highly porous medium consisting of an ice matrix and pore space containing water vapor. Its microstructure influences the heat conductivity as heat transport consists in (i) heat conduction in the ice and pores, (ii) heat transport related to water vapor diffusion in the pores, and (iii) latent heat release and gain due to phase changes at the ice-pore interfaces. In the field, heat conductivity measurements of snow are often performed using a needle-probe. Considerable discrepancies for snow of similar density and grain sizes and forms must be expected. Recently, heat flux measurements and simultaneous X-ray micro-tomography images of the snow microstructure were performed with the goal to elucidate such discrepancies. However, no direct comparisons of field measurements and the heat flow through the complex snow microstructures were available. We applied a numerical heat diffusion model to the snow microstructure as obtained by X-ray micro-tomography images from several snow samples collected during a field campaign in Antarctica. Beforehand, the heat conductivity of these snow samples was measured in the field using a needle-probe. Comparison of the experimental and numerical conductivities gave new insight into how the snow microstructure relates to the needle-probe conductivity measurements and to heat flow through snow in general.

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JHS002 Oral Presentation 643

Lattice Boltzmann modelling of polar firn

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To study the flow of air in snow we have developed a Lattice-Boltzmann (LB) model that operates on a microstructural representation of snow. The model provides an accurate estimate of the permeability of the snow sample and detailed information about the velocity field within the snow sample. The LB model provides a physical, microstructural basis for describing the air flow through snow. The three-dimensional snow microstructural input is provided by a three-dimensional reconstruction from computed X-ray micro-tomography (-CT) imaging of firn core samples obtained from a megadunes region. Megadunes are low amplitude, long wavelength surface features which cover extensive areas of East Antarctica. In megadunes regions, snow accumulates on the windward face of the dunes while the leeward faces of the dunes experiences little to no snow accumulation. Samples from various depths and locations along a dune profile were used in LB modeling and compared to laboratory measurements of permeability. Both the modeling and laboratory measurements of permeability show variation due to microstructure, which in turn is affected by the variation of accumulation rate across the dune profile.

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JHS002 Oral Presentation 644

Sea ice brine inclusions: new insights from X-ray CT and connectivity analysis

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Sea ice is now widely appreciated as both an agent and indicator of climate variations. It is a composite material with temperature- and salinity- dependent volume fractions of primarily ice, brine and air. In congelation ice the bulk of brine resides not in grain boundaries but in intra-crystalline brine layers separating ice lamellae within each crystal. Our focus is the microstructural control of the fluid permeability which affects the melt-season albedo (shortwave reflectance) by controlling the drainage of surface meltwater, and is relevant for other processes including nutrient delivery to microorganisms colonizing lower layers of the ice. At low temperatures, the relative brine volume is small, the inclusions are disconnected, and the permeability is small. The relative brine volume increases with temperature, and the permeability increases strongly above a porosity of ~5%. To examine directly the temperature-dependent morphology and connectivity of the brine layers, we have imaged the pore space of natural and laboratory-grown sea ice with X-ray micro-computed tomography (CT) over a temperature range typical of that in the Arctic (- 25C to -3C) and which spans order-of-magnitude changes in the permeability. We have examined the brine volume connectivity from the segmented CT data using a medial axis analysis and a new tight dual model' approach to identify pore bodies, throats and critical pathways. We find the first direct, quantitative evidence of a connectivity threshold at this scale: The vertical connectivity displays threshold-like behavior with an onset in connectivity at a lower brine volume than in bulk samples. 3D visualizations illustrate important deviations from the classic sea-ice microstructural model.

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JHW001 645 - 677

Workshop
Interactions between snow, vegetation and the atmosphere (UCCS Symposium hosted by IAHS)

Convener : Dr. Richard Essery
Co-Convener : Dr. Takeshi Yamazaki

Vegetation influences snow distribution by trapping falling and wind-blown snow, and exposed vegetation canopies alter the radiative and turbulent energy fluxes to underlying snow and the atmosphere. Snow insulates the ground and releases water and nutrients on melt, in turn influencing distributions of vegetation. Snow and vegetation distributions both respond to and feedback on changing climates. For this workshop, submissions are invited on observational and modelling studies of ecological, hydrological, meteorological and interdisciplinary aspects of interactions between snow, vegetation and the atmosphere.

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JHW001 Oral Presentation 645

Distributed modelling of snow processes in mountain canopies (Berchtesgaden National Park, Germany)

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In the Berchtesgaden National Park an automatic network of meteorological stations belonging to the Bavarian avalanche warning service and other institutions has been assembled. From these stations, continuous records of 10 minute to half-hourly measurements are collected via wireless GSM transmission and stored in a central database, starting in August 1998. The spatial arrangement of the stations, their range in altitude between 617 and 2520 m a.s.l. and the temporal duration of the measurements generated a unique data set enabling a continuous, distributed and physically based modelling of a wide range of environmental processes. This paper describes the application of a spatially distributed sow processes model which includes (a) spatial interpolation of the meteorological variables considering topography, (b) a sophisticated scheme to compute short- and longwave radiative fluxes and shadows, (c) derivation of cloudiness from records of global radiation, (d) parameterization of snow albedo based on its age and temperature and (e) simulation of the snow surface energy balance by iteratively adopting its temperature. Finally, snow interception, sublimation and melt unload in forest canopies are simulated with a physically based scheme considering effective leaf area index and tree height. These data are available from an extensive forest inventory survey for the prevailing mixed forest, larche, spruce and mountain pine stands in the National Park area. Results for the forest snow processes simulations, their temporal and spatial variability and their effects on the water balance of the region are discussed. The simulation results for the ground snow cover are compared to point measurements. This modelling system represents a basis for the concept of eco-systemic environmental monitoring in the National Park, and thus for in cluding further distributed eco-physical models.

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JHW001 Oral Presentation 646

Sub-canopy radiant energy during snowmelt in uniform and non-uniform forests spanning a latitudinal transect

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Co-Author: Richard Essery, Danny Marks, John Pomeroy, Janet P. Hardy, Michele L. Reba, Jean Emmanuel Sicart

In mountainous, forested environments, snowcover dynamics exert a strong control on hydrologic and atmospheric processes. Snowcover ablation patterns in forests are controlled by a complex combination of depositional patterns coupled with radiative and turbulent heat flux patterns related to topographic and canopy cover variations. Quantification of small-scale variations of radiant energy in forested environments is necessary to understand how canopy structure affects snowcover energetics to improve the representation of snowmelt processes in spatially-explicit physically-based snowmelt models. Incoming solar and thermal radiation were measured during the melt season within continuous and discontinuous forest stands, and at the interface between forest patches and small clearings along a transect spanning the North American Cordillera. Results indicate that reductions in solar radiation at the snow surface are partially balanced by increased thermal radiation from the forest canopy, relative to open locations. The differences between the transfer processes for solar and thermal radiation can produce two net incoming and net snowcover radiation paradoxes in heterogeneous environments. In discontinuous canopies, net radiation in forested areas may exceed radiation in open sites, whereas in other situations, net radiation may be less than net radiation in closed canopy forests. The empirical results coupled with theoretical modeling indicates that the effects of forest canopies on the radiative regimes at the snow surface are controlled by complex interactions of slope, aspect, gap sizes, canopy height, canopy density, canopy temperature, snow surface temperature and snowcover albedo. In higher latitude, closed canopy forests, radiative regimes may be characterized by relatively simple geometric optical radiation transfer methods, whereas at lower latitude and more non-uniform forests, other processes such as canopy and stem heating must be considered. These net radiation differences coupled with decreased turbulent fluxes due to lower wind velocities and reduced snow water equivalent values due to canopy interception losses help to explain small-scale patterns of snowmelt in non-uniform forested areas. Future investigations will use physically based models coupled with LiDAR derived topographic and vegetation data to assess how these small-scale processes integrate in both space and time to control the timing and rates of snowcover ablation in complex vegetated terrain.

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JHW001 Oral Presentation 647

The effect of forest to sublimation from snow cover in Northern Eurasia

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Through intensive observations of micro-lysimeter, eddy covariance and meteorological elements, cold season processes at the snow-atmosphere interface were clarified at sites representing a variety of geographic and vegetative cover conditions both in Mountain taiga of eastern Siberia and in southern periphery region of Eurasia cryosphere in Mongolia Sublimation from snow cover was investigated by latent heat fluxes calculation using the mean-profile method and verified by eddy covariance and pan observation. Data were collected in the winter from 2002 to 2006, and analyzed from three sites located at various geographic and vegetation condition. During observation period, significant snow sublimation was observed episodically in beginning and end of snow cover, which was caused by strong wind and ensuing light snowmelt. Intense sublimation events, defined by daily sublimation levels of more than 0.4 mm, were predominant in their effect on the temporal variability of sublimation. The dominant meteorological elements affecting sublimation were wind speed and air temperature, with the latter affecting sublimation indirectly through the vapor deficit. The forest reduced 48% of snow sublimation comparing to open field. As atmospheric stability decrease, the effect of forest cover on snow sublimation was clear, with a significant difference between forested areas and open fields. Later in the spring, increased net all-wave radiation did not lead to an increase in sublimation but was consumed in meltwater production. Seasonal and interannual variations in sublimation were investigated using long-interval estimations for 19 years at a mountainous-area meteorological station and for 24 years at a flat-plain meteorological station. The general seasonal pattern indicated higher rates of sublimation in October and November, when the wind speed and vapor deficit were higher, followed by declining sublimation rates throughout mid-winter. Near the end of the snow-cover period, sublimation became highest when the vapor deficit and wind speed reached their peaks. Annual sublimation averaged 11.7 mm at the flat-plain meteorological station, or 20.3% of the annual snowfall, and 15.7 mm at the site in the mountains, or 21.6% of snowfall. The sum of snow sublimation and snowmelt evaporation represented 17 to 20% of annual evapotranspiration.

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JHW001 Oral Presentation 648

Modelling Canopy-Snow Interaction in the Canadian Boreal Forest Using CLASS

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The Canadian Land Surface Scheme (CLASS) was designed to represent surface processes in Environment Canada's global and regional climate models. CLASS contains a single layer vegetation canopy with explicit interception and unloading/drip of snow/rain, over a multi-layer soil model. The snowpack is a single layer of variable depth and coverage, with changes in albedo and density (ageing) modelled as functions of time, temperature, and in the case of density, also depth. Experiments aimed at assessing and enhancing the representation of snow processes in CLASS are presented. Snow interception and unloading are important processes in boreal forests, and their representation in CLASS has evolved in recent years. Data from the BERMS (Boreal Ecosystem Research and Monitoring Sites) forests in Central Saskatchewan have been used to derive new snow unloading algorithms for use in CLASS; changes in observed albedo have been used to derive new unloading time constants and digital photographs of canopies have been examined to derive relationships between the rate of unloading and meteorological conditions. Model runs of CLASS 3.3 are presented to illustrate the effect of these changes on modelled snow and related properties.

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JHW001 Oral Presentation 649

Results from a simple parameterization of the snow-vegetation interaction in energy-budget and temperature index models

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The Office of Hydrologic development (OHD) within the National Oceanic and Atmospheric Administrations (NOAA) National Weather Service (NWS) is investigating advanced snow models in order to improve river and water resources forecasts. One area of needed research is improvement of the modeling of snow accumulation and melt in forested areas. The forest canopy can significantly affect the energy transfer to and from the snow surface, complicating the development of snow accumulation and ablation models. Moreover, the lack of meteorological and snow cover measurements in forested areas exacerbates this problem. To address these issues, Phase 2 of the Snow Model Intercomparison Project (SnowMIP 2), initiated by the Commission for the Cryospheric Sciences, was specifically designed to allow scientists to test their snow models with high quality data from five paired forested/open sites in different climatological regions. The OHD is participating in SnowMIP 2 with two operational snow models: an energy budget model (the Noah land surface model) and a temperature-index model (SNOW-17). The Noah land surface model is a component of the NWS numerical weather prediction models. The snow component of the Noah model is based on the energy and mass balance of a one layer snow pack overlaying a multi-layer soil column. Vegetation is defined as a single combined snow-ground-vegetation layer. Therefore, the Noah model cannot account for redistribution of energy and mass between the forest canopy and the snow-soil surface. This restriction leads to biased simulations of snow cover under a dense forest canopy. To reduce these under-canopy snow mass biases, a snowfall reduction factor similar to the SNOW-17 snow correction parameter was introduced for the SnowMIP 2 tests. No changes were made to the heat transfer components. SNOW-17 is a conceptual model that uses air temperature as an index to approximate snow cover energy exchange. Snowmelt is calculated using seasonally varying melt factors. SNOW-17 is run at NWS River forecast centers to compute melt used in rainfall-runoff models. Both models were applied in accordance with SnowMIP 2 guidelines at all SnowMIP 2 sites using data from two snow accumulation and melt seasons. Parameter calibration was only allowed using data from the first season. Only the snowfall reduction parameter of both models was adjusted at each site to achieve the best fit of simulated and observed snow water equivalent (SWE) under the forest canopy. All other parameters were defined using vegetation and soil data, or were derived from recommended values for SNOW-17. Test results suggest that for the calibration period, reasonable agreement between simulated and observed SWE of calibration data sets can be achieved for all sites from both models. However, significant differences in SWE between these two models were noted for the second simulation period. This means that a simple snowfall reduction factor cannot consistently reproduce snow-canopy interactions, implying that more complex approaches are needed. It appears that differences in snowfall accumulation rates need to be considered. This presentation will first provide a brief overview of the two NWS models used in SnowMIP 2. The snowfall reduction factors will be discussed as will the simulation results of SWE at the four SnowMIP 2 sites.

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JHW001 Oral Presentation 650

Comparison of forest-snow process models (SnowMIP2): uncertainty in estimates of snow water equivalent under forest canopies

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Complex processes control energy and mass exchanges between the atmosphere, forest canopies and sub-canopy snowpacks; representations of these processes are required in many applications for hydrological and atmospheric forecasting and remote sensing, but they are considered to be poorly represented in current land surface models. Consequently, the second phase of the Snow Model Intercomparison Project (SnowMIP2) was designed to evaluate uncertainties in estimates of snowpack properties by current land surface models and suggest areas in which to focus further model development. The first results of this evaluation, comparison of modelled estimates and measurements of snow water equivalent (SWE), are presented. More than thirty different models participated in SnowMIP2, ranging in complexity, purpose and spatial scale of operation. Each model was provided with meteorological driving data and site-specific initialization data from five locations, providing a range of snowpack types. Each location consisted of two sites, a forested site and an adjacent non-forested (open) site which acted as a control. At four of the five sites (Alptal, BERMS, Fraser, Hyytil) two years of driving data were provided. SWE observations were provided for the first year at each of these sites to allow calibration of model parameters but withheld for the second year to allow independent evaluation of each model. At the site with only one year of driving data (Hitsujigaoka), no calibration data were provided. Firstly, an overview is presented of the ability of all models to estimate SWE at all sites and for all years. A root mean squared error (RMSE) is calculated for each model in forested and open sites using independent in-situ SWE observations. When collated, the distribution of RMSEs for all models provides the overall mean error and variance. Secondly, this analytical technique is replicated for temporal, spatial and categorical subdivisions of the total population of model RMSEs (e.g. accumulation versus ablation, inter-site, calibration year versus non-calibration year, complex versus simple models). Differences between the means and variances of subsets of the total population using Z and F-tests are also presented.

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JHW001 Oral Presentation 651

Simulations of snow process sensitivities to atmospheric conditions at forest and open sites

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A multi-layer Snow-Atmosphere-Soil-Transfer scheme (SAST) and a land surface model (BATS) were employed to investigate how the atmospheric conditions (radiation, temperature, wind speed, relative humidity) influence snow accumulation and ablation under canopy and at open areas. Sensitivities of snow processes to different schemes calculating surface snow cover fraction (SCF) and to vegetation parameters like Leaf Area Index (LAI) are also studied. The results indicate that snow processes under canopy and at open areas are quite different, mostly due to the attenuation of radiation and interception of precipitation by canopy. Snow under canopy is sensitive to snow-holding capacity of the canopy, especially for those cases of moderate but frequent snowfall. Open site snow processes are very sensitive to SCF due to positive feedback between surface albedo and SCF, usually at the beginning of snow accumulation period and near the end of snow season, whereas snow under canopy is much less sensitive to SCF. Higher LAI increases the interception of snowfall, leads to less snow accumulation under canopy at the beginning of the snow season, but less solar radiation transmitted through denser canopy to the ground results in retardation of snow melting. Generally speaking, less incident thermal or solar radiation, lower atmospheric temperature, drier atmosphere and smaller wind speed are favorable for more snow accumulation in winter and therefore longer snow season for both forest and open sites, and vice versa. Slight differences in sensitivities to various factors exist between snow under canopy and that at open areas. Downward thermal radiation is the most important energy source for snow melting in winter, especially for snow under canopy.

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JHW001 Oral Presentation 652

Finding the Rain/Snow Transition Elevation During Storm Events in Mountain Basins

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In mountainous, forested environments, the interact ion between vegetation and precipitation during winter storms is strongly dependant on whether th e precipitation falls as snow or rain. In remote mountain regions, the elevation of rain/snow transiti on is very transient, and difficult to determine without onsite observation. In mid-la titude locations, at elevations wi thin the rain/snow transition zone (1000-2000m), snow commonly falls when air temperatur es are above C. In general hydrologists and watershed modelers use a calibrated air temperature relationship to determine precipitation phase, though such relationships are site specific, and highly variable, depending on season and storm track. Further, as the climate continues to warm, these relati onships will need to be re-calibrated each year. In an effort to develop a more stable indicator of pr ecipitation phase in mountain basins, we present data from a transect of 8 sites at 50m elevation interval s in a small mountain catchment in the northwestern US. The 1.8 km2 catchment in the Owhyee Mountains of Idaho, USA, ranges in elevation from 1488-1868m. In this region, it is typical for precipitation ev ents to occur as rain in the lower and snow in the upper elevations. Air temperature, humidity and snow depth are measured at all eight transect sites, while full meteorology and precipitation are measured at three of the eight sites. Two years of data from the transect show a weak and highly vari able relationship between air temperature and precipitation phase, while dew point temperature shows a strong, nearly 1:1 relationship to precipitation phase. When the dew point temperature is C or less, precipitation is snow; if the dew point temperature is above C, it is raining. The method was also satisfactorily tested over a mid-sized basin in Idaho (~240 km2), and a large river basin in southern Oregon (~5,000 km2). In all cases the elevation of the rain/snow transition was very dynamic, changing rapidly and continuously during the storm event. Because dew point temperature during a storm is a pr operty of the air mass, it is less likely to be influenced by site or local conditions, and will be a more stable predictor of precipitation phase for modeling snow properties and processes in mountain basins.

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JHW001 Oral Presentation 653

Modelling interaction between snow and vegetation within a coniferous forest stand

Author : Dr. Sirpa Rasmus
- - IAHS

Modelling of snow cover in a forest setting is a complicated task because of several interdependencies between forest microclimate, canopy, ground vegetation, snow and soil in the forest system. SNOWPACK is a sophisticated snow cover structure model developed at the Swiss Federal Institute for Snow and Avalanche Research (SLF). One of the most recent modifications of the model is the inclusion of the forest layer in the atmosphere/snow/soil system modeled. The model is one-dimensional, but progress has also been made in modelling the areal snow amount on the watershed scale using SNOWPACK. Local variation within a stand has not been considered. Modelling at a sub-stand level poses problems with the resolution of the input data, especially canopy closure and spatiality, which will need to be solved. In order to facilitate modelling of snow cover at the sub-stand level, we did observations of snow depth and WE (density) regularly with a good spatial resolution in a pine forest stand in Southern Finland during winter 2005/2006. The locations of trees, canopy closure and ground vegetation patterns of the stand have also been observed with good spatial resolution. Continuous air, ground and snow temperature measurements are available from the site, and other climate data from the synoptic meteorological network. There was considerable spatial variation in the snow conditions observed despite the open structure of the forest and the even forest floor. The aim of the study is to model the amount of snow in the forest with better spatial resolution than before. Possibilities to also model snow pack structure variation in the forest will also be discussed and knowledge gaps identified. Variation in ground vegetation (type, height, density) is expected to have an effect on the variation of the snow pack structure in the forest. On the other hand, for example lingonberry (Vaccinium vitis-idaea) has been observed to be able to photosynthesize under the snow cover in suitable conditions. In this study we will work together with SLF to give first ideas how to include simple ground vegetation modeling in snow pack structure modeling.

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JHW001 Oral Presentation 654

A modelling study of snow-vegetation interaction in a forested watershed

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The paper presents a modeling approach to the investigation of snow-vegetation interaction in a forested watershed. The influence of wooden cover on precipitation and snow in particular is extensively studied and reported in the literature. A convention al approach requires a thorough measurement and comparison of the water balance items obtained on the paired watersheds with and without forest vegetation. However, data for such a comparative study are not always available to the researchers. In such a case, the only alternative would be to model individual hydrological processes of moisture transformation and runoff formation with a subseque nt comparison of the water budget in a computer simulation experiment. The paper discusses the simulation model Forest hydrology (SMFH) which models hydrological processes in the boreal forested watersheds including snow transformation by forest vegetation. One of the main ideas in the development of the SMFH was to get a reliable computation of the water balance components based on observed values of meteorological data and a limited set of parameters with a clear physical or biological meaning. The SMFH takes as its inputs parameters and initial values, such as forest type and age, percent forested area, meteorological data, soil type and physical properties, as well as projected management activity. Based on this input information, it simulates the whole chain of moisture transformations in the boreal forested watershed by the processes of forest hydrology and particularly calculates crown interception, evaporation from snow and water, snowmelt, water release from snow, freezing and thawing, infiltration, formation of all kinds of runoff, and transpiration. These processes are modelled at three levels: tree crown, forest floor, and a specified soil layer. The model produces as its outputs the values of the water balance components and provides a quantitative assessment of the hydrological service of forest. Computer simulations have been conducted with a modeled watershed representing a boreal forest ecosystem in the Northeastern part of Europe. In general, the ca lculated results are qualitatively and quantitatively consistent with the data on forest hydrology in the literature and those of em pirical observations. Thus, the model simulations confirmed the theoretical concept of higher evaporation from a forested area compared to forestless territories. They demonstrated a better snow accumulation in forest than in open. This, in turn, explains why the soil under the forest froze much less than the soil in open. The SMFH has also shown the water-regulating function of a forest during the melting season due to delayed and prolonged snowmelt and substantially reduced peak flow of the spring flood.

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JHW001 Oral Presentation 655

Changes in radiation to snow from forest-cover reduction in the rocky mountains

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In North America snowmelt runoff from the Rocky Mount ains provides the majority of the river flows to the western portion of the continen t. Much of the Rocky Mountains are covered by needle-leaf forest-cover, where turbulent energy-exchanges are largely suppressed and snowmelt is driven primarily by radiation energy. Decreasing forest-cover increases shortwave radiation and decreases longwave radiation. In mountain regions, radiation to sn ow-cover is further complicated by topography, influencing both shortwave and longwave components. As a result, it is unclear which parts of mountain catchments are likely to exhibit the greatest sensitiv ity to reductions in forest-cover brought about by about causes such as fire, clear-cutting or disease. To investigate, simulations of shortwave and longwave radiation energy were made for forests of va rying (i) slope and aspect (ii) forest-cover density and (iii) longwave radiation contributions from su rrounding terrain. Simulations were conducted over numerous years using meteorological observations of above-canopy down-welling shortwave and longwave radiation as well as air temperature collected at various sites within Rocky Mountains of Canada and the . Preliminary results show that slope and aspect exert strong controls on the rate of change in net radiation with decreasing forest-cover. Overall, reductions in forest-cover caused the greatest change in net radiation under level and south- facing slope forests. By contrast, little change in net radiation with forest cover reduction was found for north-facing slope fore sts, where increases in shortwave radiation were largely compensated for by reductions in longwave radiation.

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JHW001 Oral Presentation 656

Hot Trees: Influence on Incoming Longwave Radiation to Snow

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Snowmelt under coniferous forest canopies is primarily driven by radiation of which longwave radiation constitutes a major portion. Incoming longwave radi ation is complicated by the presence of forest canopy; most calculations assume that the canopy temperature is equal to some reference air temperature and that the emissivity of canopy is ~0.98. The first assumption was tested using pyrgeometer arrays at Fraser Experimental Forest and Marmot Creek Research Basin in the Rocky Mountains of Colorado and Alberta respectively. The results show that there is no uniform reference air temperature to which canopy temperature can be derive d from and that there is considerable variability in canopy temperature. Normal temperature inversions led to air at the bottom of the canopy being 1o (day) to 3o C (night) cooler than air temperatures at a reference height above the canopy. Canopy temperatures could be distinguished into two grou ps: needles (including small branches) and tree trunks. Trunks were warmer than needles by 12o to 35o C during clear days and at night and on cloudy days were up to 3o C warmer than needles the effect was most pronounced in discontinuous stands. The sub-canopy air temperatures matched needle temperature well at night and on cloudy days and all of the time in continuous stands. However, in a di scontinuous stand needle temperatures exceeded air temperatures by up to 5o C on clear days. The differe nces in longwave irradiance due to distance from trunks was an important component of the variability of net radiation und er the canopy on a daily basis. An attempt to model the sub-canopy longwave i rradiance using sky view, measuring sky longwave exitance and sub-canopy air temperature (substitut e for canopy temperature) was satisfactory on cloudy days but underestimated irradiance by up to 30 W m-2 during clear days. Using above canopy air temperatures overestimated longwave at most time s but underestimated during clear days. The model was substantially improved by including a trunk fraction in the canopy view (0.3 of canopy fraction for most forests). The most accurate simulations of sub-canopy irradiance used measured trunk temperatures for the trunk fraction and either measur ed needled or sub-canopy air temperatures for the non-trunk canopy fraction. The results suggest that the longwave exitance from sunlit trunks is a substantial component of longwave irradiance to snow in sunny climates.

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JHW001 Oral Presentation 657

Snow simulation on and under canopy using a land-surface model

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A land-surface model (2LM) has been applied to various forest sites to simulate snow on and under the canopy. The land surface model includes three submodels; vegetation, snow cover, and soil (Yamazaki et. al., 2004). It can calculate water and energy fluxes above and within forest, if meteorological data over the forest are given as input. The model has been connected with an interception model that considers both liquid and solid water on forest, melting and freezing, changing transfer coefficient of sensible and latent heat fluxes, and albedo changing (Yamazaki et. al., 2007). The applied sites are SnowMIP2 (Snow Model Intercomparison Project for forest snow processes, including five sites: Alptal, BERMS, Fraser, Hitsujigaoka and Hyytil), Moshiri (Japan) and Yakutsk (Siberia). Data of one through five winters are available in these sites. The situation of snow is very complex, it depends on forest type, forest density, precipitation pattern and climate conditions (air temperature and wind speed). Simulated snow on the canopy is continuous and always near maximum value in midwinter in Yakutsk . Yatktks is severely cold, the air temperature becomes lower than -40C in midwinter. The snow on the canopy disappears because of sublimation in Yakutsk . On the other hand, simulated snow on the canopy continuous but with increase and decrease in Histujigaoka and Moshiri, and intermittent in Alptal and Fraser; BERMS is intermediate. The maximum snowwater equivalent (SWE) on the canopy is 3.5 (BERMS) through 8 (Hitsujigaoka) according to effective plant area density (from 1.66 to 3.0). For Alptal site, SWE is much at open site in 2003-2004 than in 2002-2003 but SWE in forest is much in 2002-2003. This opposite tendency could not be simulated with our model, 2LM. It seems that also most of models could not simulate reasonably.

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JHW001 Oral Presentation 658

Parameterisation of patchy snow cover in a surface exchange model

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Seasonal snow covers demonstrate small-scale heterogeneity associated with complex topography and vegetation patchiness. Most surface exchange models assume uniform snow covers over large-scales. The small-scale patchiness of snow exerts a strong influence on the energetics and surface hydrology within seasonally snow-covered environments. We present the results of field observations from the Snow in Tundra Environments: Patterns, Processes and Scaling project (STEPPS - http://www.dur.ac.uk/stepps.project) and model analyses with the Joint UK Land Environment Simulator (JULES - http://www.jchmr.org/jules/). We demonstrate the link between patchy snow cover, surface energetics and hydrology, and suggest appropriate parameterisations for use in large-scale surface exchange models.

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JHW001 Oral Presentation 659

Dynamics of the radiation balance in a snow-covered sub-alpine forest and its link to snow properties

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Short-wave radiation inside forests is highly variable in space and time due to the heterogeneity of the canopy. In winter the interception of snow in trees and a non-uniform accumulation of snow on the ground lead to an even more complex radiation dynamics. Therefore, representative measurements of net radiation, albedo and transmissivity inside a snow-covered forest require an elaborate set-up. In this study we present observational data of the radiation balance inside a coniferous sub-alpine forest covering three winter seasons using a novel measuring set-up. Therefore, a four-component net-radiometer was mounted on a carriage and constantly moved back and forth on a 10-m rail. This device enabled recording the natural variability of the net-radiation balance and of the ground snowpack albedo, respectively. A second net-radiometer mounted on a tower 10 m above the canopy at the same site allowed additionally calculating the transmissivity of the canopy for short-wave radiation. Here, we focus our analysis on the response of canopy transmissivity and snowpack albedo to snow properties. Contrary to our initial expectations, we found higher transmissivity values after snowfall events and with increased amounts of intercepted snow. Moreover, we come up with the formulation of a new and easy-to-use albedo model for snow-covered sub-alpine forests, which only requires the input of five simple snow meteorological properties, such as snow depth and time since last snowfall. The results contribute to enhancing the representation of forest snow processes in our snowpack and runoff models.

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JHW001 Oral Presentation 660

Impact of snow interception on water and energy balance of a forest stand in northern Sweden - combining measurements with impulse radar and eddy-correlation with numerical modelling

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Snow interception evaporation and the influence of forest canopy on snow cover melt are important for land surface water and heat balance. The exchange of heat and water between snow cover, canopy, and atmosphere involves many processes that can be difficult to observe at the relevant scales. Particularly, the snow interception storage is difficult to observe on a forest stand level, as compared to snow cover development and forest evaporation. In this study we investigate the impact of snow interception evaporation on snow cover distribution and wintertime water and energy balance in a boreal forest stand in northern . Measurements of turbulent heat fluxes above the forest canopy and distributed snow cover observations are combined with small scale observations of the snow interception storage. A new application of impulse radar to measure the total amount and vertical distribution of the snow interception storage is presented. The mass of snow stored in the tree canopies were measured in two ways: firstly by the weight of a single tree scaled to a forest stand average, and secondly using impulse radar measurements through a small section of the forest. The propagation velocity of radar waves is dependent on the dielectric properties of the travelling media, and can be determined by measuring the travel time along a known distance. A transmitting and a receiving antenna were placed in two small towers, separated horizontally by about 15 m. Vertical profiles of the one-way travel time were conducted over the entire height of the canopy, and integrated to a forest stand average. A simplified model for the snow interception storage was derived, based on the difference in one-way travel times between snow-free and snow-covered conditions. Laboratory tests and comparison with observations using the single tree scale showed that impulse radar is a promising method to study snow interception. However, systematic differences were observed between the radar measurements and the reference data, most likely due to a poor model for the dielectric constant of the snow covered canopy. The data is further used to analyse the relation between the dynamics of the snow interception storage and the measured heat fluxes, as well as to evaluate the representation of forest snow processes in a distributed forest snow processes model (Alpine3D). Results showed that evaporation of intercepted snow is important both during events of rapidly decreasing snow interception storage (unloading or melting snow) and in situations with slowly decreasing interception storage and air temperatures well below zero (evaporation).

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JHW001 Oral Presentation 661

A multi-sensor synergistic approach to improving fractional snow cover mapping in forested areas

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Current satellite-derived snow covered area products do not adequately characterize vegetation effects on snow cover retrievals. Although the MODIS binary snow product incorporates a correction for vegetation canopy over snow it remains limited for hydrologic purposes because it assigns values of either 0% or 100% snow cover to pixels. An alternative product, the MODIS Snow Covered Area and Grain size (MODSCAG) product, provides the fraction of snow cover in a pixel thereby providing the higher precision needed for hydrologic applications. However, daily retrievals from MODSCAG produce only the projected area of snow cover and do not incorporate any vegetation correction making it less accurate in areas with forest canopy especially when viewing at off-nadir. In this work, we present a vegetation correction that uses satellite-based retrievals of vegetation gap fraction information from the Multi-angle Imaging SpectroRadiometer (MISR). The viewable fraction of the ground (FGROUND) is computed as 1-BHRPAR-FPAR where FPAR is the fraction of photosynthetically active radiation and BHRPAR is the PAR-integrated bihemispherical reflectance integrated. Both BHRPAR and FPAR are MISR standard products. This study focuses on the region covered in the Cold Land Processes Experiment (CLPX). We assume that changes in measured snow fraction that are detected with MODSCAG are a function of the true snow cover fraction reduced by 1-FGROUND. For validation of the retrievals, we use data collected from the two winters of CLPX field campaigns. These data include measurements of snow covered area and canopy properties such as density, height, viewable gap fraction and forest cover type. In addition to improving snow cover estimates, this approach is also aimed at improving estimates of canopy density and height in regions where vegetation cover is changing and affecting snowpack dynamics, such as the Arctic .

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JHW001 Poster presentation 662

Application Of Remote Sensing And GIS In Snow Hydrology

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Most of watersheds with considerable annually yield are located in mountains. Much of precipitation in these watersheds is snow. Estimation of snowmelt runoff in different se asons is very important in water resources management. Snowmelt Runoff Model (SRM)with was developed applied to Alpine mountain watersheds by Martinec in 1975 nowadays is used as an operational model in more than twenty-five countries. Kamehwatershed located on the North-East of Torbat Heydarieh has been selected as a reference watershed and all of the hydro meteorological (hydrological data) of this watershed has been recorded for several years. In this work images taken by NOAA satellite in AVHRR format has been analyzed with making use of Remote Sensing (RS) soft wares and snow covered area witch is one of the most important input parameters of SRM model, has been determined. Then hypsometric map of watershed has been reproduced by making use of Geographical Information System (GIS) soft wares such as Arc View. Next, hydrological and hydro meteorological data such as precipitation and temperature and physiographic parameters of watershed have been transferred to SRM model and snowmelt runoff which is simulated by SRM model has been compared with actual snowmelt runoff recorded at hydrometric station. Finally, SRM model has been calibrated for Kameh watershed, and has been shown that SRM can be used as an operational model in similar watersheds for prediction of snowmelt runoff in the case of temperature increase due to global change.

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JHW001 Poster presentation 663

Modelling Studies of Snow Runoff between Snow, Vegetation

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There is a strong global research effort in coupling snow, the atmosphere and vegetation in hydrology models. The hydrology models is developed for on observational and modelling studies of ecological, hydrological, meteorological and interdisciplinary aspects of interactions between snow, vegetation and the atmosphere. The LL-V distributed hydrology model using GIS, landuse and soil type is applied to Tangnaihai basin in Yellow riverhead of China. The LL distributed hydrology model produced by Lan Li in Wuhan university in 1997. Snow runoff is main water resource Tangnaihai catchment. The basin hydrology station is a importance observation station for factor of hydrology and weather in Yellow riverhead. The catchmeng area is over 120000 sq. The LL-V modelling studies of interactions between snow, vegetation and the atmosphere. When air temperature is higher that snow temperature will exceed some value, snow water equivalent is calculated when snow will is thawed. Next calculate vegetation canopies water circle,and the radiative and turbulent energy fluxes to underlying snow and the atmosphere. These studies will include those that snow- vegetation and the atmosphere interaction process in various biomes, frozen soil depth and role of vegetation cover form , NDVI and soil type, dynamics on snow and hydrology process. The examples are chosen to illustrate the LL-V distributed hydrology model utility by 20 years data when applied in the study of snow- vegetation ecosystems and water resource forecast.

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JHW001 Poster presentation 664

Climate-related vegetation characteri stics derived from GIMMS NDVI in China during 1982-2003

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Since vegetation typically shows seasonal as well asannual dynamics, it constitutes the natural interface among air, water and soil. Vegetation is a mediator in climate and climate change as well. Hence, monitoring vegetation change is an important method to study the impacts of global climate change.. The daily temporal resolution and global coverage of some satellite sensors (NOAA-AVHRR, SPOT-VEGETATION and Terra/Aqua-MODIS) make it possibleto monitor vegetation at globally, at different spatial and temporal scales. Quite some research and development effort is based on the NDVI=[NIR-R]/[NIR+R], the most widely used vegetation index in the analysis of data from remote sensing sensors. Previous studies indicate that there is a positive relationship between the NDVI derived from the AVHRR and the green leaf area index (LAI), vegetation cover, and the fraction of photosynthetically active radiation absorbed by vegetation (fAPAR). It is also suggested, that precipitation and temperature are the main driving forces for vegetation cover change. A global data set at 8-km resolution (square pixels) developed by the Global Inventory Monitoring and Modeling Studies (GIMMS) group was used in this study. The dynamic monitoring results indicate that obvious increasing trend occur in the north and northwest of China. On the contrary, there is decreasing tend in south, east, and northeast of China. Some climatic factors, annual total precipitation, annual average temperature, annual total sunshine hours, were selected to analyze the climatic effect ion on the vegetation changes based on the empirical mode decomposition (EMD) method. This method could decompose any time-varying data into a finite set of functions called intrinsic mode functions (IMFs). The EMD analysis successively extracts the IMFs with the highest local temporal frequencies in a recursive way (Khademul et al., 2006). It can be indicated that the temperature and sunshine conditions are the most important driving factors in south, east, and northeast of China, and precipitation is the most important driving factor in north and northwest of China.

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JHW001 Poster presentation 665

Study on Vegetation Cover Change and Its Relationship with Climate in Chinese Arid and Cold Regions by Using GIMMS AVHRR NDVI Data

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Chinese arid and cold regions play an important role in the whole China. The importance of the study on Chinese arid and cold regions has become increasingly recognized in both scientific literature and popular media especially in the last few years. And the research on vegetation cover change and its relationship to climate in these areas have become a focus in the Chinese geographic world. Especially, a strong signal of climatic shift from Warm-Dry to warm-humid pattern has been appearing in the last few years. By now, few academicians did a systemic research on this area. Thus, the study on vegetation cover change and its response to climate in Chinese arid and cold regions become more and more indispensable. To define Chinese arid and coldregions respectively, temperature and precipitation data sets provided by National Meteorological Information Centre ware employed. Following 3 conditions of temperature ware used as the sign to identify the cold regions: 1. the average temperature of the coldest month should less than -3.0 ; 2. the number of month whose monthly average temperature exceeds 10.0 should not more th an 5; 3. the yearly average temperature should be under 5.0 . And other two conditions of precipitation was employed to classify the moist status: 1. regions in which yearly average precipitation is low than 250mm are recognized as arid regions; 2. regions in which yearly average precipitation is between 250mm to 500mm are considered as semiarid regions. The final study area includes Greater Khingan Range, Lesser Khingan Range, Changbai Mountains, Mongolian Plateau, Yinshan Mountains, Kansu Corridor, Qilian mountain, Qinling Mountains, Tianshan Mountains, Taihang Mountains, Heng-tuan Mountains, Taklamakan Desert, Badain Jaran Desert, Tengger Desert, Qinghai province and the most area of Tibet. The GIMMS AVHRR NDVI (Normalized Difference Vegetation Index) data sets, a global data set with 8-km resolution (square pixels) developed by the Global Inventory Monitoring and Modeling Studies (GIMMS) group was used in this study. The time-series starts form 1982 to 2003. In order to get the pattern of vegetation cover change, we make use of SINDVI (Seasonally Integrated Normalized Difference Vegetation Index), linear regression, anomaly analysis, and persistence index (P) whose availabilities have already been proved. And to study the relationship between them, we em ploy SINDVI and yearly average temperature and precipitation data sets. Preliminary results suggest that vegetation in more than ha lf part of Chinese arid and cold regions have obviously increase trend, such as Tianshan Mountains, Himalayas, Qilian Mountains, Yinshan Mountains, Mongolian Plateau, and Northeast Plain. We hypothesize that the vegetation cover change in Chinese arid and cold regions has a positive relativity with yearly average temperature and precipitation.

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JHW001 Poster presentation 666

Topographic, meteorologic, and canopy controls on the scaling characteristics of the spatial distribution of snow depth fields

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In this study, LIDAR snow depths, bare ground elevations (topography), and elevations filtered to the top of vegetation (topography + vegetation) in five 1-km2 areas are used to determine whether the spatial distribution of snow depth exhibits scale invariance, and the control that vegetation, topography and winds exert on such behavior. The one-dimensional and mean two-dimensional power spectra of snow depth exhibit power law behavior in two frequency intervals separated by a scale break located between 7 m and 45 m. The spectral exponents for the low frequency range vary between 0.1 and 1.2 for the one-dimensional spectra, and between 1.3 and 2.2 for the mean two-dimensional power spectra. The spectral exponents for the high frequency range vary between 3.3 and 3.6 for the one-dimensional spectra, and between 4.0 and 4.5 for the mean two-dimensional spectra. Such spectral exponents indicate the existence of two distinct scaling regimes, with significantly larger variations occurring in the larger scales regime. Similar bilinear power law spectra were obtained for the fields of vegetation height, with crossover wavelengths between 7 m and 14 m. Further analysis of the snow depth and vegetation fields, together with wind data support the conclusion that the break in the scaling behavior of snow depth is controlled by the scaling characteristics of the spatial distribution of vegetation height when snow redistribution by wind is minimal and canopy interception is dominant, and by the interaction of winds with features such as surface concavities and vegetation when snow redistribution by wind is dominant. Implications of such results for hydrologic modeling purposes and measurement of snow depth are discussed.

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JHW001 Poster presentation 667

Modeling vegetation dynamics due to climate change and its hydrologic impacts in the Hanjiang River basin, China

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Climate characteristic is one of most important factors in determining the vegetation types and its distribution pattern in global and regional scales. Therefore, human-induced long-term climate change tends to influence vegetation dynamics intensively. In this study, the LPJ (Lund-Postdam-Jena) dynamic global vegetation model was used to assess the possble vegetation responses to climate change in the Hanjiang River basin, one of the main tributaries of the Yangtze River in China, in the years 1961-2100. First of all, three simulation schemes as follows were set up: i) Scheme C tests the vegetation responses in the Hanjiang River basin due to the increase in CO2 concentration while atmospheric forcings (air temperature and precipitation) do not change; ii) Scheme T investigates how the changes in air temperature and precipitation influence vegetation dy namics in the study region with CO2 concentration being at a lower level (317.2 ppm); and (iii) Scheme CT assesses the vegetation responses induced by the variations in atmospheric forcings (air temper ature and precipitation) and the increase in CO2 concentration. Secondly, numerical simulations over the Hanjiang River basin with those above schemes were performed through the LPJ model. Results show that remarkable vegetation changes occur in terms of net primary productivity (NPP), leaf area in dex (LAI), vegetation comp osition and distribution. Scheme C indicates that compared with the years 1961- 1990, the fertilization effect of atmospheric CO2 may result in a notable enhancement in NPP, a small increase in the ratio of forest cover and a remarkable rise of LAI in the Hanjiang River basin in the years 1991-2100. Scheme T demonstrates that though the CO2 concentration remains the same, the increase of air temperature would lead to severe degradation of forest cover, subsequent succession of herbaceous vegetation and a sharp reduction in LAI in the Hanjiang River basin. Numerical simulation of Scheme CT shows that the increases in air temperature and CO2 concentration tends to augment NPP in the Hanjiang River basin. Since the increase in CO2 concentration could improve the water use efficiency of vegetation effectively, the forest cover in the Hanjiang River basin degrades unremarkably. Finally, the Xinanjiang vegetation-hydrology model coupled with the LPJ model was applied to hydrologic simulation with the consideration of vegetation variations caused by climate change. The conclusion here is drawn that vegetation dynamics should be taken into consideration in streamflow simulation over long-term scale.

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JHW001 Poster presentation 668

Snow changes in forests with different LAI

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Snow deposit and melting models are developed considering energy budget and interception, which are influenced by leaf area index (LAI). The snow deposit model is composed of snow interception process and dumping process. Maximum interception amount is expressed by LAI and the excess snowfall amount of the maximum interception reaches ground surface. Snowmelt is calculated from the energy balance consisting of net radiation, sensible heat, latent heat at each layer. Radiation is estimated from LAI dominating radiation decay. Sensible and latent heats are mainly calculated by wind profile. LAI decides wind profile. Snow depth model is also used to compare with observed data. This model is composed of self-consolidation and melting which are influenced by snow density. We selected LAI values from typical surface conditions, grassland (no interception), evergreen forest (LAI=2.0 and 5.0), and deciduous forest (LAI=0.3) in Japan. LAI decides some parameters of the model, which are wind roughness, albedo, interception capacity, and radiation decay. The simulated and observed snow depth are compared in the Zao Mountain in Japan in winter of 2005 and are agreed well. In the case of 2005, deciduous forest had double maximum snow and melted 20days earlier depth to evergreen forest. Grassland had almost same change to the deciduous forest. Using this model, numerical experiments are carried out to evaluate LAI effects in snow change. As the results, remaining duration of snow in evergreen forest is longer than others in any condition because of radiation screening. This means that higher LAI delays snow disappearing date.

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JHW001 Poster presentation 669

Systematic Errors in the Daily mean He at Flux due to the Errors of Diurnal Variation of Solar Radiation in a Canopy Model

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Prediction of diurnal variation of solar radiation by GCMs is not well correspond to that of observation. These errors may potentially influence long time energy budget. In this study, we did numerical experiment in order to examine the influence of diur nal variation of shortwave radiation on the energy flux from land and vegetation. We use the multilay er canopy model driven with two atmospheric data set: one is the averaged three typical sunny days in August 1987 at the middle of Japan (case 1), and the other is the average of the data in case 1 (case 2) . In the case 1, the variables in the data set have a diurnal variation, whereas they are constant in time in case 2. The integrated shortwave radiation in two cases is the same. The integration time in both cases is 7 days. In case 1, the 7-days averaged sensible heat flux is larger than that in case 2. The increase of turbulent viscosity in case 1 owing to the imbalance in daytime causes large sensible heat flux As a result, the total ener gy flux from the canopy top in case 1 is 5 to 6 W m-2 larger than that in ca se 2. Considering that the radiation forcing by CO2 is estimated as only 1 to 2 W m-2, our result suggest s that the diurnal variation of solar radiation may produce the remarkable error of energy flux from canopy model.

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JHW001 Poster presentation 670

Modeling snow accumulation and melt under parametric uncertainty - SnowMIP2 experience

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A physically based model was applied to simulate snow accumulation and melt for open and forested sites of SnowMIP2 (Snow Model Intercomparison Project). The model describes energy and multiphase mass balance of snow cover, snow interception, redistribution and sublimation of intercepted snow, canopy effect on reducing radiation and turbulent fluxes at the surface of sub-canopy snow cover. The model was used to make an uncalibrated simulation of surface snow water equivalent (SWE) for SnowMIP2-sites on the basis of the provided meteorological data. The model parameters were either specified a priori or derived from the empirical dependences (based on the results of snow process experiments in Russia and Canada) on the measured site characteristics. In the absence of data for calibration of the model, both the specified values of the parameters and ones derived from the empirical dependences contain considerable proportion of uncertainty. Sensitivity analyses were carried out to investigate the effect of variation in the model parameters on snow dynamics. The analysis indicates that modelled peak pre-melt SWE and melt duration are mostly sensitive to 3 parameters controlling albedo, sublimation and interception rates. Uncertainty of simulation results caused by the uncertainty of the parameters was investigated; mean values and standard deviations of the modelled SWE were estimated by Rosenblueths method both for forest and open sites. It was shown that in the absence of data measurements for the model calibration, uncertainty interval for the modelled SWE can be rather wide, differ from site to site and depend on specific meteorological conditions.

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JHW001 Poster presentation 671

Snow cover-relief-climate-vegetation interaction an example from Tatra MTS. (Poland)

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The interactions between snow cover, micro-climate, relief and spatial differentiation of high mountain vegetation (altitudinal zonality, habitat zonation) were studied. The research were carried out in the Tatra Mts. on the slope with NE exposure, covered with grassland vegetation, natural for the alpine belt, and anthropogenic (post-grazing) vegetation within the subalpine belt. Maps of relief, exposure, potential radiation and vegetation of the study area were elaborated. The ground adjacent air temperature was measured inside and outside a nival gully. The snow cover-climate-relief-vegetation interdependence was demonstrated on the local scale. The temperature gradient is accompanied by the gradual passage of the zonal vegetation proper for the subalpine and alpine belts. Differentiation of vegetation depending upon snow cover and exposure is also visible. Distribution of abiotic factors finds its reflection in the distribution of altitude-related plant species, their numbers and abundance of appearance. Close relationships between micro-relief, snow cover, air temperature and vegetation were found. Plant cover in the studied area was determined by thermal conditions existing inside nival gully, in which a snow patch persists for a long time, and outside of it.

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JHW001 Poster presentation 672

Simulation of snow accumulation and melt under needle-leaf forests using the cold regions hydrological model

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Drawing upon numerous field observations and modelling exercises of forest-climate-snow interactions in cold-regions, the Cold Regions Hydrological Model (CRHM) was developed to simulate the four-season hydrological cycle in cold regions and contains modules dealing with most components of catchment hydrology. CRHM provides a particularly detailed physical representation of energy and mass transfer processes to snow in forests, with modules describing the transmission and reflection of shortwave radiation, exchange of sub-canopy longwave radiation, canopy interception and sublimation of snowfall, canopy interception and evaporation of rainfall, and snowmelt. Due to the physical basis and rigorous testing of each of these modules there is high confidence in their appropriateness for snow accumulation and ablation simulations and thus a reduced need for model calibration. Parameterization requirements of the model are modest, requiring latitude, elevation, slope gradient and aspect of the site, with forest-cover defined by species, winter leaf-area index and stand height. Forcing data requirements of the model are that of standard meteorological observations, including precipitation, incoming shortwave radiation or cloudiness, air temperature, windspeed, and relative humidity. CRHM was used to simulate sub-canopy snow accumulation and melt for forests located within the sub-Arctic and boreal regions of , as well as locations within the . Results show CRHM effectively estimated both the magnitude and timing of snow accumulation and melt at all sites; thus providing an effective tool for hydrological prediction in ungauged forested basins.

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JHW001 Poster presentation 673

Can we detect snow-temperature feed backs fom long term observations?

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Snow influences surface temperatures through its effect on the albedo and on the surface hydrology of the land surface. Surface temperature patterns in turn affect the distribution and persistence of snow cover, suggesting a feedback loop in seasonally snow-covered regions. The strength of this feedback is likely ot be modified by the structure of vegetation and topography. we present the results of analyses of long-term observations (25 years) of northern hemisphere snow cover, snow water equivalent and surface temperature to identify regional fee dback "hotspots" where snow cover and surface temperature are most strongly coupled. Patterns of coupling strength are considered in relation to the distribution of vegetation and topography.

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JHW001 Poster presentation 674

Impact of forest canopy on snow-to-air mercury fluxes

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Mercury dynamics in snow packs under forested canopy is currently unknown, even though these snow packs may represent important Hg pools eventually released towards lakes at snowmelt. We followed Hg distribution and partitioning in snowpacks under different temperate canopy types over space and time, and conducted short-term experiments on Hg redox behaviour in these snow packs. Hg concentrations were ca. 2 times higher in snow deposited under coniferous than deciduous canopies; the lowest concentrations were observed in snow over a frozen lake in the same watershed. In snow on the ground, up to 80% of the Hg was bound to particles between 10 and 70 Ëm. Incubations of snow in situ showed that i) Hg photoreduction and evasion was significant in open areas (lake surface) but was greatly hampered by light attenuation under winter canopies and ii) oxidation of newly produced Hg(0) was a significant process in boreal snow, affecting Hg evasion to the atmosphere. We used a mass balance approach to compare Hg pools in snow packs with wet deposition measured by precipitation collectors. A net gain of Hg was observed in snow under mixed canopies whereas, under a deciduous canopy, the pool of Hg stored at the end of the wint er was comparable to that of wet deposition. Snow over lake acted as a winter source of Hg. Whereas most Hg deposited by snow on lakes is lost before snowmelt, Hg deposited on the forested watershed is largely retained in snowpacks, presenting a threat to systems receiving meltwaters.

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JHW001 Poster presentation 675

Snow accumulation along the Chinese ITASE traverse line from Antarctic coast to Dome A: measurements from stakes and automatic weather stations

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Surface snow accumulation along the Chinese ITASE traverse line was measured using bamboo stakes. Stakes along the initial (coastal) 1097 km). Snow accumulation measurements were also made with ultrasonic sensors mounted on automatic weather stations (AWSs) installed at LGB69, Eagle (DT364) and Dome A. More than four-years of surface snow height (SSH) data are available for LGB69, and more than one-year for Eagle and Dome A. The AWS data provide not only net accumulation at the sites, but also information on accumulation events and the processes of densification and wind-redistribution of snow. The stake results show a high accumulation rate in the coastal 15 cm/a), followed by a decrease as both altitude and distance from the coast increase. The stake array at LGB69 had a mean annual snow accumulation between 1999 and 2001 of 6.3cm at DT401. The SSH data at LGB69 show snow accumulation of approximately 28 cm. However, longer SSH observations are needed at Dome A and Eagle to determine more precise accumulation rate there.

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JHW001 Poster presentation 676

Unexpected vegetation changes in High Mountain Environment in response to recent Climate Change

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During the 20th century the warming of air temperature was 0.6±0.2 C at a global scale. Ample evidences indicate that a broad range of organisms were affected by this recent climatic change, with greater amplitude expected at high latitudes and altitudes. The biotic impacts of climate change were mainly assessed at the species level,while only major climatic changes are expected to affect ecological levels higher than species. Here we show that the vegetation communities of a high altitude site of the European Alps experienced spatial changes between 1953 and 2003 as a result of climate change. Between 2500 and 2800 m there are contrasting patterns of change, while above 2800 m, vegetation coverage and succession exhibited unexpected patterns of regression. These results are unexpected because former evidence at the species level indicated an upward migration of alpine and nival species, quantified at a rate of 8-10 m per decade in the Austrian Alps on the mountain summits. As these changes follow the sudden warming of summer and annual temperatures after 1980, it is suggested that alpine and nival vegetation respond in a faster and more flexible way than previously hypothesized. Increased summer precipitation and early snow melt may result in greater hydrological disturbance, leading, in turn, to both the rejuvenation of vegetation and the increase of bare ground, while the degradation of the permafrost may also trigger disturbance in the form of debris flow and landslides. In contrast with most studies on alpine and nival species, our data suggest that even 1-2C warming of air temperature may produce significant changes in vegetation community dynamics and that the observed unexpected effects may also have unpredictable consequences on biodiversity. Increased surface instability and disturbance - which caused the unexpected regressions - may create a migration barrier that restricts the colonisation of higher altitudes to disturbance-adapted species, allowing the upward migration of single species while limiting the vegetation communities.

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JHW001 Poster presentation 677

Impact of increased shrub density on snow accumulation and melt in the Arctic tundra.

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Co-Author: Stefan Pohl, Glen E. Liston

Studies have shown there has been a substantial increase in shrub and low cover vegetation densities within the Arctic. This trend is forecast to continue and intensify over the coming decades. The increase has the potential to have many profound effects on hydrologic processes in this geographic region, including spring runoff, snow water equivalent at th e end-of winter, snow melt energy balance, and the soil nutrient balance. Using observed data, including satellite images and air photos, the SnowModel snow-evolution modeling system was validated at a tundra site north of Inuvik, NWT in north-western . Multiple model runs were utilized to assess the effects of this shrub and low cover vegetation increase on hydrological processes. Although an increase in vegetation has been documented, the effects, if any, have been undetermined. Hypotheses that we consider include changes in snow accumulation (less blowing snow and therefore less sublimation leading to an increased end-of winter snow pack) and changes in snowpack melt rates resulting from th e increased shrub canopy density. After SnowModel validation using observed data from the Trail Valley Creek research basin, the model was run with different shrub covers to examine the effect on snow accumulation and melt. This study is the first step in a series of studies using SnowModel as input for other hydrological models, such as TopoFlow, in an effort to develop an improved coupled model for arctic regions, and as the basis for additional experimental model simulations. Furthermore, the results of this study can be used by other researchers to explore other aspects such as large scale climatic implications.

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JHW002 678 - 714

Workshop
Climate-Permafrost-Hydrology Interactions: The Impact of Changing Climate on Cold Regions Hydrology (UCCS Symposium hosted by IAHS)

Convener : Dr. Philip Marsh
Co-Convener : Dr. Oliver W. Frauenfeld

In the cold regions, the surface condition is strongly controlled by complex interactions between the climate, permafrost and hydrology. These interactions are a subject of study by the 2007 International Polar Year. Interactions include those between climate, snow cover, soil moisture, soil heat conduction, evaporation, and vegetation. In order to consider future changes in hydrology due to anthropogenic climate change it is necessary to understand these interactions. However, the nature of these interactions, and our ability to model them, are currently very limited. It is expected that both natural climate variability and anthropogenic climate change will result in significant changes to both the permafrost and local hydrological processes. However, due to the complex interactions involved, it is difficult to quantify changes in active layer depth, soil temperature and permafrost depth in areas near the current zero-degree isotherm. Factors of interest include: vegetation, snow accumulation and melt, snow free period, sub-surface flow patterns as related to active layer depth and runoff. This workshop will address these issues by bringing together experts in the field of climate change, permafrost, and cold regions hydrology in order to discuss important issues and advances in both our understanding of the interactions between climate, permafrost and hydrology, and to consider future advances in this field. Contributions are solicited on, but not limited to, the following: 1. Interactions between climate, permafrost, and hydrology; 2. Documented past changes in climate, permafrost and hydrology; 3. Potential impacts of future climate variability and change on permafrost and hydrology; 4. The ability of existing hydrologic and land-surface models to consider the complex interactions between climate, permafrost and hydrology, and the ability of these models to consider the impact of climate change on the hydrologic system in permafrost dominated regions.

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JHW002 Oral Presentation 678

A Distributed Hydrologic Model for Simulating Snow-cover Variation in the Head Region of Yellow River, China

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HW1002 None IAHS

Co-Author: Xi Chen

Global average temperature has increased by 0.6}0.2 since beginning of available meteorological record in 1860. The temperature increase of the Northern Hemisphere in the 20th century is considered to be the largest in the past 1,000 years. Climate changes of the 21th century from the IPCC publication showed that the global average temperature would keep the increase tendency, ranging from 1.4 to 5.8. The increase in the high altitude mountain regions would be larger than that in the low altitude regions due to the global warming. Moreover, snow, glacier and frozen soil in the high mountain regions are more sensitive to the temperature change. The head region of the Yellow River is located in the northeast of the Qinghai-Tibet plateau area. The watershed average altitude is about 4,000 m. Its surrounding mountains high over 5,000 m are mostly covered by perennial frozen soil. The head region has a contributing area of 121,000 km2, approximately 15% of the Yellow River basin area. It provides 38% of annual runoff for the Yellow River basin. The temperature in the study region is lower than the average during 1960s and 1970s, and higher during 1980s and 1990s. The temperature in the latter period was increased by 1.0. In this study, a distributed hydrologic model was established to simulate runoff generation, evaportranspiration, streamflow, and snow and frozen ice melting. The model describes influences of watershed slope and aspect on radiation which are important for simulation of spatial variations in snow-melting and evaportranspiration. Available data included daily precipitation, pan evaporation, temperature, humidity, sunlight etc. from the 18 observation stations during 1961-2000, daily streamflow records of four hydrological stations, and measured snow depth during 1978-2000 with a grid resolution of 25km. The model is calibrated and validated against the observation data from 1961 to 1990 and from 1991 to 2000, respectively. Study results demonstrated that the model successfully simulated hydrological processes including snow and frozen soil melting in the head region. The efficiency coefficients of streamflow simulation in the four sub-catchments are larger than 0.85 and 0.80 in the calibration and validation periods, respectively. Moreover, spatial distribution of snow covers during winter and spring of 1980, 1990 and 2000 are simulated, and changes of the snow cover areas related with the temperature increase during 1980s and 1990s are further investigated. This study is very useful for environmental protection and water resources planning of the Yellow River, and even for western-line water transfer project from south to north of China.

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JHW002 Oral Presentation 679

Thermal regime of the crust near hydrotechnical objects: permafrost-hydrology interactions (Western Yakutia)

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Hydraulic engineering objects in permafrost area represent the open systems which are taking place in unstable quasi-equilibrium condition at temperature near to a melting point of ice. Stability of dams adjoining to frozen coastal massifs is defined, first of all, by thermal processes in conditions of possible development of under seepage resulting in creating talik zones and sharp change of properties of breeds, including their load-carrying ability. During the annual and long-term periods the temperature of grounds, composing hydro constructions are undergone with spatial-temporal changes in rather wide ranges. It causes respective alterations of ground properties. Original combinations of man-caused grounds and natural grounds, a variety temperature- moister state, strongly complicate carrying out researches for estimation and forecasting the state of coastal flank of hydraulic engineering objects. Regular water and energy supply in permafrost areas are vitally important conditions for inhabitants of the large North territories of Russia, Canada, US and Alpine areas of China. Dam and flank shore stability is the key point for safety of reservoir (power pool, water supply, tailing pit, etc.). In permafrost areas stability of many engineering structures, including hydraulic work, associated with thawing-freezing process. As a result of it we can have the loss of mechanical properties causing destructive of the unit. Emergency situation of the unit we have when seepage occurs in originated permeable talik zone adjoining to reservoir.We present original results of long-term geophysical study on hydro technical objects of Western Yakutia analyzing problems associated with use of geophysical methods for the study of rocks and soils in permafrost area. The hydro technical engineering objects which are carried up in permafrost zone like Western Yakutia, are exposed to action of a different sort of the negative factors step-by-step resulting some of them in a labile state, down to catastrophic. Owing to these circumstances for last 5 to 10 years on a number of hydro technical objects of Western Yakutia are observed thawing-filtration processes, are found out local filtration zones posing under threat their secure exploitation. The primal problems of studies were focused to I)eliciting and checking of a position of talik zones and places of filtering of water in a body of foundation and coastal contiguity of Sytikan dam and Vilui HPS (constructing and operating reservoirs) dams; II)estimation of dynamics of progressing of filtration processes for a development of a complex of measures, directional on exception of losses of water from reservoir and supply of stability of a body of a dam. Due to a difficult and hardly predictable geocryological situation in this area, the geophysical methods were included into the system of local monitoring. From ground-level methods of studies in composition of operations were included high frequency electric profiling, electric profiling on a method of a natural field, georadar, seismic profiling and seismic sounding. Down-hole observations on dams included long-term regime temperature measurements and complex of logging studies (resistance, flow meter survey, gamma logging, neutron gamma logging, caliper measurement, radio wave cross-borehole testing). On the ground of geophysical studies the detailed geological section was studied and the binding of filtering spacing to definite lithologic horizons was established. The purpose of geophysical investigations was, first, to control the thawing of frozen rock (talik) within the coastal zone of the reservoir and to assess the dynamics of the process, and second, to identify and to locate places of the most intensive thawing and filtration of water from the reservoir. On the base of surface and borehole observations in Western Yakutia the numerical model of the part of right-bank contiguity was done. The model shows temperature evolution of thawing zone as a function of air and water temperature, lithology, thermal

properties of the section. Observed geophysical data compared with numerical modeling. We analyzed conditions causing origin and development of talik near reservoir constructed in permafrost conditions. The results of 2D heat-mass transfer modeling indicate that the development of talik formation depends on the specific thermal and hydraulic material parameters, thickness of the layer covering talik and winter snow blanket insulating ground rocks, seasonal temperature trend as well as of presence of fractures in frozen rocks

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JHW002 Oral Presentation 680

Recent Changes In Hydrologic Response Observed In Permafrost Regions Of Northwestern North America

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Temperature and precipitation trends have been observed to change over the last several decades in northwestern North America. Within Yukon Territory summer and winter temperatures have increased in most regions except southeastern Yukon. Summer precipitation has been observed to increase in all regions, while winter precipitation has decreased in all regions with the exception of western Yukon. The greatest changes have occurred in western, mountainous regions where both summer and winter temperatures and winter precipitation increased significantly. Hydrologic response was generally found to be characterized with higher year round flows. Mountainous streams were found to have the timing of the freshet advanced. Significant changes were observed in the mean annual flood (MAF) over the last 20 years, with a progressive decrease in this parameter moving from south to north. The greatest increases in MAF were observed to occur within the sporadic permafrost zone, from predominantly glacierized systems in western Yukon. Winter baseflow conditions, as represented by the mean 7 day low flow, have likewise experienced apparent changes over the last two decades. As with peak flows, the greatest changes are observed in glacial systems, where winter baseflows have increased significantly. The glacial basins are exclusively located within the sporadic permafrost zone, but because of relatively high elevations, alpine permafrost is extensive. Winter baseflow in most other unglacierized systems within the sporadic permafrost zone remains unchanged or has decreased. Winter baseflow conditions within the discontinuous permafrost zone are variable. Baseflow within large basins (> 50,000 km2) draining eastern Yukon remains unchanged, while baseflow from smaller basins has increased. Winter baseflow from basins within the continuous permafrost zone (drainage areas range from 14,000 to 60,000 km2) are observed to have increased.

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JHW002 Oral Presentation 681

Relating hillslope runoff to basin discharge in a wetland dominated zone of discontinuous permafrost

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Co-Author: M. Hayashi, N. Wright, E.D. Soulis

Field studies were initiated in 1999 at Scotty Creek, Northwest Territories, Canada, in order to improve the understanding and model-representation of the major water flux and storage processes within the wetland-dominated region of discontinuous permafrost. From these studies, there has emerged a conceptual model of runoff generation that recognises distinct hydrological roles among the major peatland types peat plateau, flat bog and channel fen. The hydrological function of the peat plateaus is mainly one of runoff generation, owing to their relatively high topographic position, relatively deep snowpack, and limited capacity to store meltwater due to the presence of permafrost. For 5 consecutive annual freshets (2002 2006), snowmelt runoff from an instrumented peat plateau was computed from the water balance and from the Cold Regions Hydrological Model (CRHM). It is demonstrated that the magnitude and timing of basin discharge during the spring freshet is largely controlled by the runoff regime of the peat plateaus, and that the latter was strongly controlled by the soil thaw regime. Field measurements combined with image analysis methods were used to derive a composite hydrograph for the overall cover of peat plateaus at Scotty Creek. Physically-based methods of routing this composite hydrograph to the basin outlet were also discussed.

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JHW002 Oral Presentation 682

Development of a simplified frozen soil model

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Co-Author: Chu Yao

In this report, the procedure to simplify complete but complicated frozen soil model with ten equations to simple one with 5 equations is described. Numerical results show that the simplified frozen soil model has same accuracy as the complete model does. Since there is a term of water-ice phase change rate explicitly shown in the governing equations of the currently used frozen soil models which will give trouble to numerical iteration for solution obtaining, a new version of simplified frozen soil model is developed through the variables transformation. The new version uses two new predictive variables of volumetric enthalpy and total water mass to replace two predictive variables of temperature and volumetric moisture used currently. Associated with the new version of model, an efficient numerical scheme for the new version model is designed. Using two observation data, the numerical results from the model show reasonably good agreement with the two data.

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JHW002 Oral Presentation 683

Climate, Permafrost, and Hydrological interactions: Implications to Rapid lake drainage in the Western Canadian Arctic

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Co-Author: M. Russell, C. Onclin, S. Pohl, H. Haywood

Previous studies have considered lake formation and drainage in the continuous permafrost areas of the Western Canadian Arctic, and disappearing arctic lakes in Siberia . Given the vast number of permafrost controlled lakes in many Arctic regions, there is a concern that climate change will have significant impacts on these lakes, with many lakes disappearing from the landscape, and with significant implications to arctic hydrology and ecology. This paper will discuss changes in both the area and number of permafrost dominated lakes in the Mackenzie Delta region of the Canadian Western Arctic. Like many arctic regions, the Western Canadian Arctic has a vast number of lakes and ponds. These permafrost dominated lakes developed due to a complex interaction of climate, permafrost, and hydrology. Although it is well known that climate warming may (a) increase the size, and number, of lakes due to thermokarst processes, as well as (b) decrease the number of lakes due to lake drainage, the relative importance of each process is not well known and therefore the impact of climate change on permafrost dominated lakes is unknown. The sensitivity of these processes, and complex interactions between climate, permafrost and hydrology is not well understood. Rapid lake drainage is common in the Mackenzie Delta region, and occurs when lakes enlarge or create new drainage channels through ice rich permafrost, resulting in the complete, or partial, drainage of the lake in a few hours. The effect of climate change on rapid lake drainage is controlled by a number of processes, with each having a different response to changes in climate. For example: (i) warmer and snowier winters typically result in decreased ice wedge cracking and therefore decreased rapid drainage through ice wedge cracks, (ii) warmer summer temperatures often result in increased bank slumping and therefore increased number of drainage events as lake water flows over the exposed low drainage divides, and (iii) wetter summers will result in higher lake levels, and at times result in the overtopping of low drainage divides and subsequent lake drainage through melting of the underlying permafrost. As a first step in improving our understanding of the relationship between climate and permafrost controlled lakes, we have used a combination of field observations, hydrologic modeling, and analysis of airphotos and satellite images to consider past changes to permafrost controlled lakes in the Canadian Western Arctic. Analysis shows that the rate of lake drainage has decreased in the northern portions of the study area over the last 50 years, and increased in the southern portions of the study area. Factors controlling these changes will be discussed.

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JHW002 Oral Presentation 684

Plausible impact of climate change on water resources in cold headwater catchment of the Yellow River Basin

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Co-Author: Fangfang Zhao, Jingyu Li

The cold upstream of the Yellow River from headwater to Lanzhou is called the water tower of the river, from which more than sixty percentage of the runoff is generated. However, the streamflow in this area decreased very much and some small tributaries dried up during the past decades. Did this result from climate change or anthropogenic impacts? Understandng of the mechanism for the declining of runoff in the cold upstream becomes a great challenge for the sustainable water resources management in the Yellow River basin. On the basis of the mean air temperature, precipitation, and evaporation from 23 meteorological stations in the upper Yellow River basin from 1960 to 2001, the long-term trend for major climatic variables has been investigated in this paper. The possible trends of annual and monthly climatic time series are detected by using nonparametric Mann-Kendall method. The results showed that the annual mean temperature increased by 0.8 in the upper Yellow River basin during the last 42 years. The warmest center was located in the northern part of the basin. The nonlinear tendency for annual precipitation was negative during the same period. The declining center in annual precipitation was located in the eastern part and the center of the basin. The variation of annual precipitation in the upper Yellow River basin during the last 42 years exhibited an increasing period from 1972 to 1989 and a decreasing period from 1990 to 2001. The evaporation decreased during the past 40 years as well. Especially the evaporation in spring and summer decreased significantly. Although the results obtained in this study are preliminary, it is undoubted that climate change has indeed occurred in the study area during the past four decades. This may result in variation of available water resources in the Yellow River basin.

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JHW002 Oral Presentation 685

Arctic subsurface hydroclimate simulated by a high-resolution global climate

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Co-Author: Masahide Kimoto, Tingjun Zhang, Kumiko Takata, Seita Emori

The land cryosphere, mostly underlain by permanently or seasonally frozen ground, may experience large changes under global warming, which can exert a large impact on the local and regional socioeconomy and ecoclimate system, as well as remote influences on climate in other areas. Physiochemical (e.g. albedo, freshwater discharge to the Arctic) and/or biological (e.g. vegetation changes, anaerobic decomposition of tundra) feedbacks and interactions are probable linkages between cryospheric land and global climate. Global Climate models (GCMs) can be an effective tool to investigate the impacts of cold region changes on global hydroclimate, however the reproducibility of the current states, and the feasibility of future change projection need to be examined adequately with comparison to the observations. An Atmosphere-Ocean-Land coupled global climate model (CCSR/NIES/FRCGC CGCM) at high horizontal resolution (ca. 0.5 land-mesh) with a 5-layer, 4.0m-deep soil was evaluated as a tool to simulate changes in the distribution of frozen ground and subsurface hydro-thermal regimes under global warming scenario (IPCC AR4 SRES A1B). The land scheme (MATSIRO) explicitly treats soil freezing/thawing processes, surface energy exchange, and water fluxes, including snow cover effects. Modeled soil temperature showed large cold biases in the cold seasons, especially in high latitudes, which likely resulted from shallow and simplified soil column with zero heat flux condition at the bottom, and insufficient snow representation. Two types of frozen ground were classified according to monthly soil temperatures: permafrost for regions with the maximum active layer thickness less than 4 m, and seasonally-frozen ground. Simulated present-day (1980-1999) distribution is in good agreement with observational estimates for both. Under climatic warming forcing, projected change in land and subterranean hydro-thermal regimes shows amplification in higher latitudes. Approximately 60% of the present-day permafrost regions would degrade into seasonally-frozen ground by 2100. In the circum-Arctic basins, increased precipitation would lead to 13.7% increase in freshwater discharge into the Arctic Ocean. The reliability of these results, however, may be conditioned by the limitations of the current model configuration. A medium-resolution (ca. 2.8 mesh) ensemble produces qualitatively similar results for the hydro-thermal regimes in the cold regions, although some local features were inevitably smoothed out, giving different quantitative estimates. Sensitivity of the subsurface hydro-thermal regimes to the land surface specifications was also investigated to identify sources of the large systematic errors. Examined are the prescribed soil and snow properties (e.g. thermal conductivity and heat capacity), resolved depth and thickness of soil layers, thermal parameterization, and initial conditions. The results indicate that assignment of appropriate physical values is as important as improvement of parameterization and soil column configurations.

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JHW002 Oral Presentation 686

Importance of point and spatial processes to runoff generation in northern latitudes.

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IAHS

Co-Author: Richard Harding

Using data from a hillslope in Northern Sweden collected during the STEPPS programme ,the land surface model JULES is constrained to reproduce thepoint and hill-slope scale water balance. Important aspects of the landscape which impact on the runoff generation are the hydraulic properties of the soil, the snow melt, the soil freezing and the patchy nature of the landscape. All of these processes are studied in the field and with the model. This work is beingextended in the ABACUS project with a semi-distributed version of the JULES model. In addition, fully distributed model simulations acrossNorthern Europewere carried out during the EU-funded BALANCE project to assess the runoff generation in northern latitudes and the impact of climate change on the runoff.

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JHW002 Oral Presentation 687

How well do the IPCC AR4 models represent permafrost regions? A comparison between the observed and modeled freezing/thawing index for the 20th century

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Co-Author: Tingjun Zhang, Andrew J. Etringer, Haiyan Teng

Surface and subsurface hydrology, the surface energy and moisture balance, carbon exchange, and ecosystem diversity and productivity in high-latitude cold regions depend largely on variations in the ground thermal regime. However, our ability to assess these variations, particularly in light of reported widespread atmospheric and terrestrial changes over recent decades, remains limited due to the sparse observing networks in high latitudes. The annual freezing/thawing (F/T) index can be used to predict and map permafrost and seasonally frozen ground distribution, active layer and seasonal freeze depths, and has important engineering applications, thereby providing important information on climate variability in cold regions. Reliable long-term measurements of the F/T index are thus important variables for understanding and predicting high-latitude climate processes. The F/T index is defined as the cumulative number of degree-days below/above 0C for a given time period. However, in recent work we have established that long-term monthly air temperature measurements can be used very reliably to approximate the annual F/T index. This has enabled us to produce a 25-km gridded Northern Hemisphere annual F/T index data set for 19012002 (see http://nsidc.org/data/ggd649.html). An important next step will be to determine the potential future changes in the F/T index. For this, we plan to model projections of surface air temperatures from the Intergovernmental Panel on Climate Change (IPPC) Fourth Assessment Report (AR4) to provide anestimate of 21st century F/T index changes. We will make use of runs for four emission storylines ("commit," "SRES-A2," "SRES-A1B," and "SRES-B1") and calculate the 21st century F/T index for these scenarios. However, before employing model projections for the 21st century we have to establish the ability of these models to reproduce observed 20th century variability. In this current effort, we therefore use the IPCC AR4 models "20th Century Climate in Coupled Models" (20C3M) output and perform a comparison for the overlapping period of 19012000 with our existing historical database of F/T. Using statistical approaches, this comparison is performed for various Northern Hemisphere permafrost and seasonally frozen ground regions for both the warm (thawing index) and cold (freezing index) season. We find varying levels of correspondence, and some seasonal biases and trend discrepancies are evident in the IPCC AR4 models.

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JHW002 Oral Presentation 688

Hydrology of a Small Upland Tundra Lake: Implications for Rapid Lake Drainage

Author : Dr. Stefan Pohl
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Co-Author: Philip Marsh

The phenomenon of rapid lake drainage of permafrost lakes in circumpolar regions has been well documented. This rapid drainage occurs when drainage channels are either expanded or created through ice rich permafrost, resulting in the complete, or partial, drainage of the lake in a few hours. It is unclear how future climate change may impact the vast number of permafrost controlled lakes in many Arctic regions, and whether the rate of rapid lake drainage would increase or decrease. The occurrence of high lake levels is a key factor that leads to rapid lake drainage. In order to consider the impact of high lake levels on this phenomenon, this study will examine the hydrology and water balance of a small upland tundra lake located in the Mackenzie delta region of north-western . The water balance of the lake was computed from modelled inflow and observed precipitation, evaporation, and lake outflow and validated against observed lake levels. Subsequently, lake levels for an extended time series were calculated using archived climate data. The computed lake levels were then related to known instances of rapid lake drainage in nearby areas. In conjunction with the analysis of other factors such as average air temperature, this should provide important insights to understand the complex interaction of climate, permafrost conditions, and hydrology for the rapid drainage of Arctic lakes.

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JHW002 Oral Presentation 689

Hydrologic changes in large siberian watersheds

Author : Dr. Daqing Yang
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Observational records show significant climate change in the high latitude regions over the past several decades. Hydrologic response of the large northern watersheds to climate change and variation is one of the key issues in understanding atmosphere-land interactions in the northern regions. Examination and documentation of changes in the major northern rivers are also important to studies of global change, regional water resources, and distribution of ecosystems. This presentation will provide a review of arctic hydrologic system changes with emphasizes on regional/basin-scale hydro-climatic characteristics and differences. In order to define the hydrologic regime, and to document its changes induced by human activities (particularly large reservoirs) and by climate variations/changes, we have analyzed long-term records of streamflow, river ice thickness, water temperature, and sediment records over the past 40-50 years for the largest northern watersheds, such as the Lena, Yenisei, Ob rivers. Our results demonstrate remarkable changes in northern hydrology system. These include changes in streamflow seasonal cycle (such as shifts of snowmelt timing and peak flow, decreases in summer discharge, and increases of winter discharge in the Siberian watersheds), thinning of river ice thickness, and warming of stream water temperatures over eastern Siberia. These changes identified indicate a hydrologic regime shift due to recent climate warming, changes in permafrost conditions, and influence of human activities over the northern regions. Our efforts continue to identify changes in the arctic hydrologic system, and to examine hydrologic responses to climatic change and human impact in the arctic regions as whole.

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