NEWSLETTER

Improved Processes and Parameterisation for Prediction in Cold Regions

JUNE 2010

Science Outreach

Bacon and Eggheads Breakfast

John Pomeroy was the invited speaker for the May 27th edition of the Bacon and Eggheads breakfast series organized by PAGSE (the Partnership Group for Science and Engineering) an umbrella group of more than twenty five science and engineering organizations cosponsored by NSERC (Natural Sciences and Engineering Council). Breakfasts are held once a month while Parliament is in session. The purpose is to provide a forum to showcase outstanding Canadian research accomplishments giving scientists the opportunity to share their research findings with an audience that includes influential decision makers. Over 175 government policy experts, scientists and Members of Parliament listened to Dr. Pomeroy's presentation "*Water prescriptions for a dry land—how the West can prepare for drought*". The presentation included many facets of IP3 water research, including climate change effects on Prairie streamflow and changes in mountain streamflow contributions to western watersheds. This particular breakfast topic was chosen to complement and lead into the two day Water Security Symposium held in Ottawa as well on May 27th and May 28th.

DeBeers

Water Security Symposium

A Water Security Symposium sponsored jointly by the Canadian Foundation for Climate and Atmospheric Sciences (CFCAS) and Environment Canada was held in Ottawa on May 27th and 28th. This two day event titled **Canadian Water Security—The Critical Role of Science,** attracted an audience of government and university scientists and policy experts with participants presenting on water science, water policy and other water resource issues. Several IP3 members contributed to the agenda. John Pomeroy presented *Where are the snows of yesteryear? The effect of climate on snow water supplies*, Sean Carey presented *Water in the Changing North*, and Phil Marsh presented *The Mackenzie Delta: Changing water supply in a sensitive arctic ecosystem*. Bob Sandford summarized each days' presentations and highlighted issues raised in a call to action in summarizing the two day event held at the Fairmont Chateau Laurier.

A set of rules for snow-canopy interaction derived from modelling an idealized mountain domain

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Introduction

Snow interception in a canopy has been identified as an important hydrological process with complex mass and energy exchanges with the ground snow cover. On the one hand, the meteorological conditions relevant for the energy transfer at the snow surface beneath the canopy are different from those in the open. On the other hand, a certain amount of precipitation is retained in the interception storage of stems, branches and needles. Snow that is intercepted in the canopy can melt, fall down, or sublimate into the air masses above the canopy (Figure 1). The latter process leads to a reduction of precipitation accumulated and stored in the ground snowpack. Pomeroy et al (1998) report that interception by forest canopies can store up to 60% of the cumulative snowfall resulting in a 30—40% annual loss of snow cover in many coniferous forest environments.

Figure 1: Inside-canopy snow interception on the branches of subalpine firs in the Bavarian Alps (Germany)

Generally the effect of snow losses due to interception and sublimation leads to declining accumulation of snow beneath the forest canopy with increasing canopy density and leaf area (Pomeroy et al 2002), whereas the changes in micrometeorological conditions in the forest canopy tend to delay the snowmelt in springtime mainly due to reduced incoming solar radiation. However, the interaction between these processes and their quantitative impact on the snow cover are still poorly understand. In high alpine regions with their complex terrain these processes overlap with effects of topography (e.g. aspect, slope, shading), making it even more challenging to understand and quantify the relevant interactions. We are not able to predict whether there will be more or less snow beneath the canopy than in the adjacent open at a certain point in time.

To enable an identification and analysis of the determining processes and effects we carried out a numerical experiment that allowed us to execute simulations under idealized laboratory conditions. The object was to create an idealized model domain with simplified terrain and vegetation cover, while driving the model with real measured meteorological forcing.

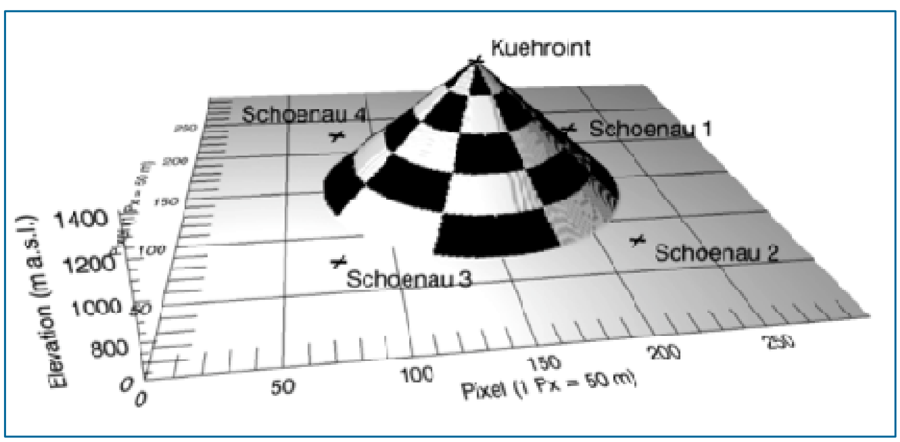

Figure 2: Setup of the numerical experiment: The modelling domain and the idealized mountain with the meteorological stations located on top of it, and around it. Dark areas indicate forest standings.

Methods

To test-drive our physically based snow-canopy model, we constructed an idealized, cone-shaped mountain covered with a geometrically regular pattern of coniferous forest stands and clearings (Figure 2). The lack of surrounding terrain, the regularly shaped topography of the mountain, and the known distribution of forests and clearings eliminates many unknown, influencing factors and simplifies analyzing the complex process structures. The meteorological data are recorded datasets from two station in the Bavarian Alps, Kuehroint (1407m a.s.l.) and Schoenau

(617m a.s.l.) for which both the real horizontal and vertical distances are preserved in the simulation domain, thus ensuring physical plausibility of the produced meteorological fields. The model is then applied for three winter seasons with different snowfall intensities and distributions. Results show the effects of the above mentioned processes on the pattern of the ground snow cover, its duration, and the amount of melt water release.

Model

The model applied in this study, the **A**lpine **MU**ltiscale **N**umerical **D**istributed **S**imulation **EN**gine (AMUNDSEN) (Strasser et al 2004, 2008) is a simulation framework for continuous, distributed modelling of snow processes in high mountain areas. In the current version, the functionality of AMUNDSEN includes (a) rapid computation of topographic parameters from a digital elevation model (DEM); (b) several interpolation routines for scattered meteorological measurements (Strasser et al 2004); (c) simulation of short wave and long wave radiative fluxes including consideration of shadows and cloudiness (Corripio 2003, Greuell et al 1997); (d) parameterization of snow albedo (U.S. Army Corps of Engineers 1956, Rohrer 1992); (e) modelling of snowmelt with either an energy balance model (Strasser et al 2008) or an enhanced temperature index model considering radiation and albedo (Pellicciotti et al 2005); (f) modelling of forest snow processes (Liston and Elder 2006); as well as (g) simulation of snow slides from steep mountain slopes along couloir courses which are derived from the DEM (Gruber 2007). The latter is required to remove snow from areas where it would otherwise infinitely accumulate in long-term simulations.

Beneath canopy climate

In AMUNDSEN, the inside-canopy modification of the micrometeorological conditions over the ground snow surface is modelled explicitly; short wave radiation, precipitation and wind speed are reduced, whereas long wave radiation and humidity are increased and the course of temperature is attenuated (Strasser and Etchevers 2005, Tribbeck et al 2004, Link and Marks 1999a, b). The only stand characteristic required for the modelling is the effective leaf area index LAI_{eff} including the leaves or needles, the branches and the stem.

Canopy snow processes

Various modelling approaches have been developed to simulate snow-vegetation interaction (see Hedstrom and Pomeroy 1998, Pomeroy et al 1998, Hardy et al 1997 and Pomeroy and Gray 1995 for reviews). In AMUNDSEN the processes of interception, sublimation, as well as unloading by melt and fall down, are calculated depending on LAI_{eff}, using the well documented parameterizations from the literature. The snow interception and sublimation model applies the physical understanding of snow interception from the branch scale to the canopy and scales the corresponding understanding of snow sublimation of a single snow crystal to the intercepted snow in the canopy. When canopy air temperatures are above freezing, intercepted snow is melted and transferred to the ground storage.

Apart from sublimation, snow can also be removed from the interception storage by melt unload. The snow masses are hereby assumed to fall down to the ground after a partial melt at the surface. Melt unload L_m (kgm^{-2}) is estimated for temperatures above freezing, using the temperature index melt model of Pellicciotti et al (2005). By means of this snow-canopy interaction model, the processes of interception, snow sublimation, and melt unload are simulated. In a period of heavy snowfall, the interception storage can be filled up to its maximum. From the interception storage, snow is removed by sublimation and melt unload induced by a period of positive temperatures.

Both the simulated rates of sublimation and the combined effect of melt and fall down of intercepted snow strongly depend on effective LAI which represents canopy characteristics in the described model: it modifies canopy transmissivity for solar radiation, wind speed, canopy density, and the maximum interception storage capacity.

The snow interception model has been validated by Montesi et al (2004) using observations from a continental climate site located within the U.S. Department of Agriculture (USDA) Fraser Experimental Forest (39°53'N, 105°54'W) near Fraser, Colorado, U.S.A. Integrated in AMUNDSEN, the scheme has been compared to a variety of other paramerizations for snow-canopy interaction in the framework of the SnowMIP2 program (Rutter et al 2009).

Data

The input data required for the distributed modelling of snow processes consists of a digital elevation model (DEM, resolution 50m), the sky view factor (SVF, portion of the hemisphere which is visible at each location), maps of canopy LAI and height, as well as hourly meteorological recordings of precipitation, global radiation, temperature, humidity and wind speed. We used station meteorological forcing data from the three seasons 2005/2006, 2006/2007 and 2007/2008, each from August to July the following year. Two of the sets represent conditions typical for the region, while the meteorological situation of the winter 2006/2007 results in atypical small amounts of snow.

Results

The model results vary in space due to altitude and aspect and, dependant on both, radiative fluxes, as well as due to the interpolated meteorological variables (Figure 3). Both the rates and the seasonal total of sublimation of previously intercepted snow in a canopy are much higher than respective sublimation losses from the compact snow surface at the ground. This leads to significantly reduced accumulation of snow at the ground beneath a canopy. However, shadowing and reduced radiative input under the trees leads to a process of protection and due to reduced melt and sublimation the inside—canopy snow cover duration is extended compared to the open. The effect of reduced accumulation is dominant during winter, whereas the shadowing effect with reduced ablation prevails during spring. In addition the specific

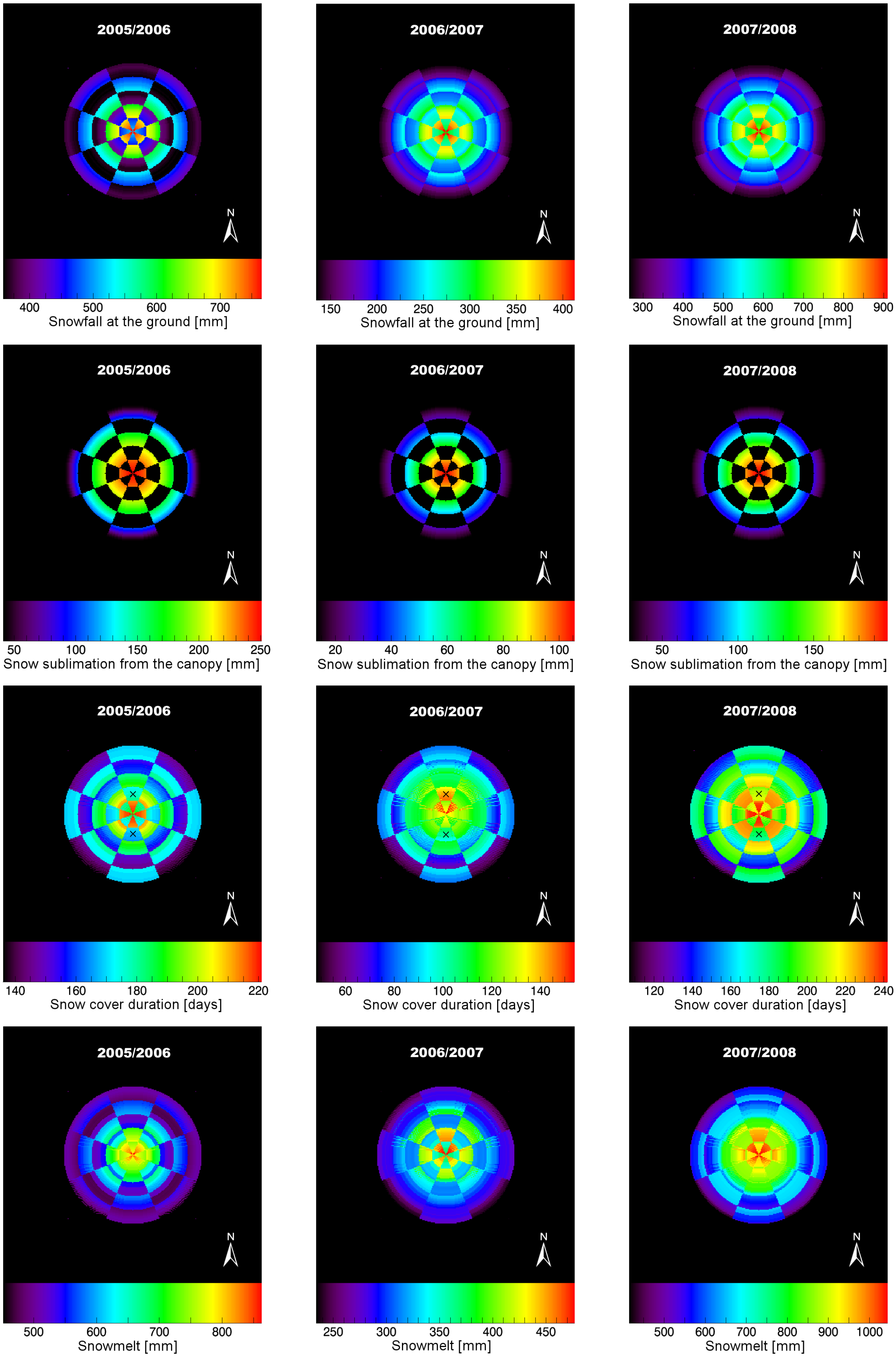

Figure 3: Snowfall at the ground (top row), snow sublimation from the canopy (second row), snow cover duration (third row) and snowmelt (bottom row) for the three winter seasons 2005/2006 (left), 2006/20007 (centre) and 2007/2008 (right).

meteorological conditions and the general evolution of a winter season play an important role, as shown by the occurrences in winter 2006/2007 when only a shallow and short lasting snow cover developed; the canopy prolongs the ground snow cover compared to the open only from a minimum amount of snow. If only little snow is existent, the effect of reduced radiation at the forest ground alone cannot outbalance the reduced accumulation, and the snow cover then disappears earlier than in the open.

Furthermore, the experiment shows that the snow hydrological processes inside a canopy depend little on aspect. In the open, the respective snow processes show effects which vary more, depending on which side of the mountain the slope is situated.

The conducted study allows the derivation of the following set of simple rules for how a mountain canopy modifies the evolution of the seasonal snow cover:

- A forest canopy represents an interception storage for snowfall and the amount of snow that sublimates does not reach the ground. This results in reduced snow accumulation in the canopy.
- A forest canopy produces a shadowing effect beneath the trees, leading to reduced radiative energy reaching the ground.
- Effects of aspect on the snow cover and its evolution are significant in the open, but small in the canopy and become visible only at low effective LAI's.
- The difference in snow cover duration between a forest snow cover and an open snow cover are therefore more significant in the south aspect.
- In snow rich winters, the shadowing effect is dominant and the snow lasts longer inside the forest than in the open.
- In winters with only little snow, snow sublimation losses are dominant and consequently the snow lasts longer in the open than inside the forest, mainly in the north aspect.
- In early and high winter, the radiation protection effect of shadowing by the canopy is still small. If only little snow is available, an intermittent melt out of the snow cover inside the forest can occur. In late winter and spring, the shadowing effect becomes more efficient and the canopy develops its protective value.

In conclusion, during the high winter season the snow water equivalent (SWE) is generally reduced inside a mountain canopy compared to the open, but in the course of spring, SWE in the open decreases faster, first in the southern exposure and later also in the north.

A complete description of the model setup and a detailed discussion of these and other results is currently in preparation to be published in an American Meteorological Society journal article.

Acknowledgments

We are thankful to all who provided their help and assistance for this work, in particular Helmut Franz and Michael Vogel from the National Park Administration (Berchtesgaden) for data processing and subsidizing our activities. The meteorological data were generously supplied y the Administration Union of the Berchtesgaden-Koenigssee region (Schoenau) and the Bavarian Avalanche Warning Center of the State Office for Environment in Munich (Kuehroint).

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Network News

IP3 Secretariat Changes

The IP3 community would like to wish Julie Friddell, IP3's founding Network Manager all the best in her new position with the University of Waterloo. Julie has accepted a permanent position as Information Services and Science Manager for the Canadian Cryospheric Information Network (CCIN)/Polar Data Catalogue at the University of Waterloo effective May 17th, 2010.

In order to facilitate an easier secretariat transition, the IP3 Network Manager's position has been divided between three individuals who already have great familiarity with IP3 and its work. Joni Onclin, Research Assistant for the Centre for Hydrology at the University of Saskatchewan takes over all network financial functions and becomes the IP3 Financial Manager; Michael Allchin, IP3 Data Manager, adds IP3 Webmaster to his responsibilities; while Nadine Kapphahn, IP3 Outreach Coordinator, takes on the report writing and coordinating responsibilities for the IP3 Network Managers' position. If you have any questions regarding any aspect of IP3, please contact:

Nadine Kapphahn	nadine.kapphahn@usask.ca	250-960-5898
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Michael Allchin	michael.allchin@usask.ca	

IP3 Photo Contest





In celebration of four years of IP3 research, IP3 is running a photo contest open to all IP3 participants. Participants are invited to submit their original images in any or all of the following three categories:

Fieldwork North of 60

Fieldwork South of 60

Labs, workshops and conferences (or any other IP3 activity)

Cash prizes are to be awarded in each category for 1st, 2nd and 3rd, at $100, $50, and $25.

Multiple entries may be submitted, however each photo must be sent in a separate email to:

ip3.wc2n@mapmatics.com with "**IP3 photos**" in the subject line.

Submission emails must include: your name, institution, role related to IP3 (eg, student, collaborator, workshop participant, etc), phone number, and brief description of photo setting (where, when, type of activity, etc). Photos will be judged by a panel formed from the IP3 Scientific Committee with winners to be announced in September and published in the October newsletter. Photos may be used on the IP3 website or in any IP3 publication. Detailed contest rules can be found on the IP3 website.

Deadline for photos is **12 noon Wednesday 1st September 2010**

Public Presentations

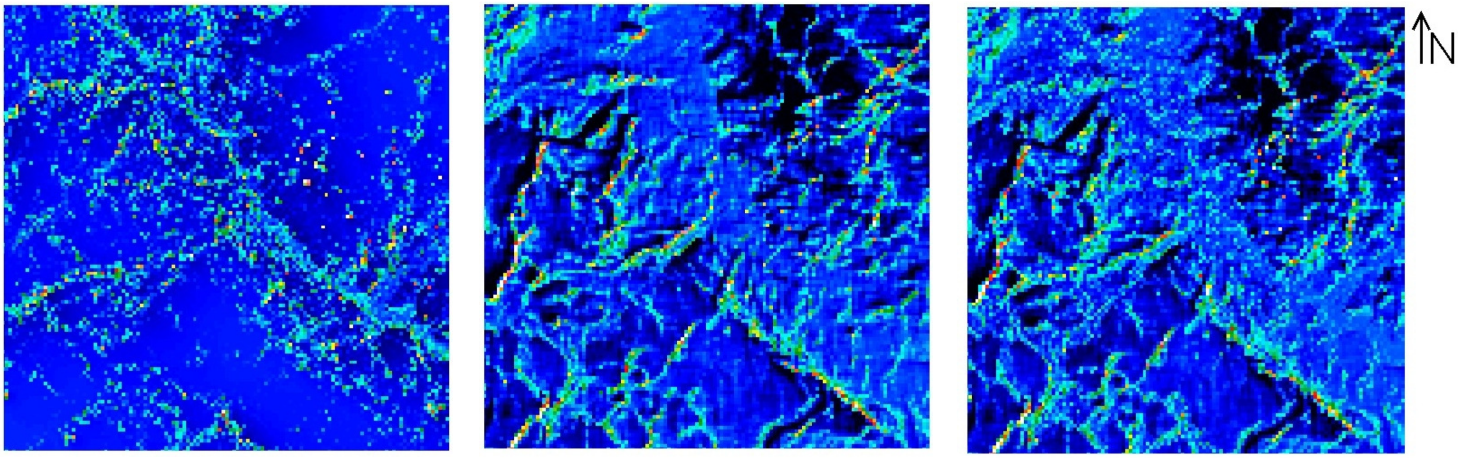
- The very popular Canadian Rockies Snow and Ice Speaker Series wrapped up its final presentation of the season with a presentation by Shawn Marshall in Canmore on May 19, 2010. The Canada Research Chair in Climate Change at the University of Calgary gave a lecture titled *Glacier fluctuations: what glaciers tell us about climate change.* Video for all the speaker series presentations can be accessed from the IP3 Outreach & Education page at: http://www.usask.ca/ip3/outrch.php .
- Masaki Hayashi, IP3 research scientist and Canada Research Chair in Physical Hydrology at the University of Calgary presented the outcomes of a multiyear study of groundwater in the Lake O'Hara basin (Yoho National Park) at a Parks Canada Research Update event at the Whyte Museum in Banff on May 20, 2010. A podcast of the presentation *Groundwater—the natural water reservoir: finding of Lake O'Hara study* can be accessed from Banff Park Radio at: http://www.friendsofbanff.com/park-radio/podcast/masaki-hyashi-groundwater-the-natural-water-reservoir-finding-of-lake-ohara/

IP3 will be offering a training session on the Cold Regions Hydrological Model (CRHM), in Yellowknife in September 2010. If you are interested in attending—please contact Nadine at nadine.kapphahn@usask

Ongoing Research

Granger Basin Research shows impact of vegetation cover on snowmelt and runoff processes

Cécile Ménard, who is finishing her PhD at the University of Edinburgh (UoE), has been investigating the effects of shrub-tundra on snow and runoff processes under the supervision of Richard Essery (UoE) and Douglas Clark (Centre for Ecology and Hydrology, UK). Observational and modelling studies show that Arctic warming is leading to shrub expansion. This shift in vegetation cover is expected to significantly alter the distribution of snow and land surface-atmospheric interactions. Shrubs capture windblown snow, increasing snow depth and decreasing winter water loss through sublimation. Shrubs also bend beneath the weight of snow, getting buried during winter and "springing up" rapidly during the spring snowmelt, suddenly changing the albedo. Cécile and her supervisors developed a shrub bending model (SBM) which calculates the exposed faction of the shrubs (*Fv*) during a snow season



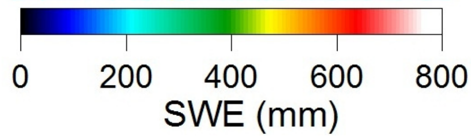


Figure 1 (above): Initial SWE in the Granger Basin for the run without topography (left), without vegetation (middle) and for the control run i.e. with the current shrub distribution and topography from DEM (right).

cycle. The parameterisation was then included in a distributed three-source (snow-shrub-ground) model (D3SM), which was developed to investigate the effects of shrub expansion on high latitude basins. D3SM, was evaluated against snow and energy flux measurements from Granger Basin, Yukon Territory and was found to perform well. Model investigations into the current snow distribution in the basin showed that topography exerts a stronger control on the spatial variability of snow than shrub distribution (Figure 1). Shrub cover and canopy height were increased to assess the effect of shrub expansion on snowmelt energetics. While topography was still found to have a large influence, increasing shrub cover reduced the spatial variability of snow depth and increased the snow cover fraction. D3SM also found that increasing shrub cover changed the direction of sensible heat fluxes during snowmelt, which were now predominantly from the surface to the atmosphere (3 Wm^{-2} against –4 Wm^{-2} currently) (Figure 2). Shrub expansion is therefore expected to contribute to the positive feedback whereby warming temperatures enhance shrub growth which stimulates further warming. Cécile will continue to investigate snow-shrub interactions working in a National Environmental Research Council (NERC) funded project on the response of Arctic regions to changing climate at the University of Edinburgh.

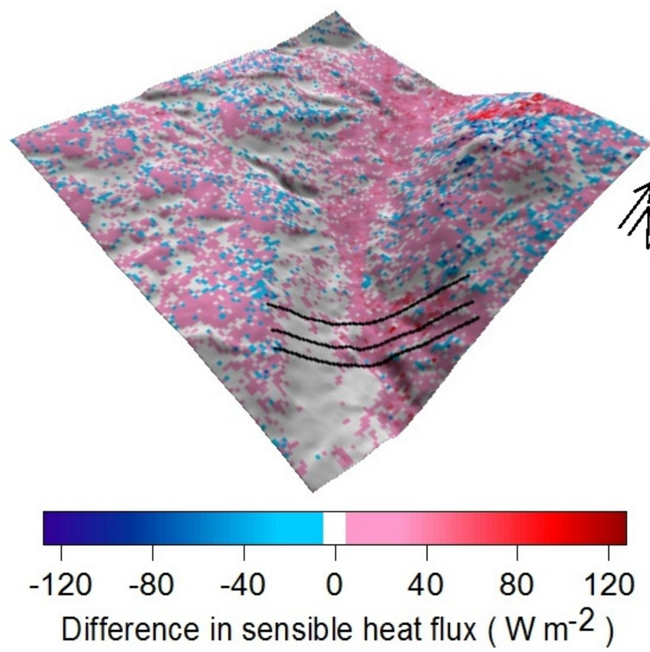


Figure 2 (above): Difference in sensible heat fluxes (H) between the control run and the increased vegetation run. Positive values mean that H is greater with the increased vegetation run.

IP3

Improved Processes & Parameterisation for Prediction in Cold Regions

IP3 Outreach is available for setting up cold regions model training sessions or meetings between scientists and users for sharing of information. Informational brochures are available for public distribution, including brochures on IP3 research focused in the north, IP3 research in the mountain watersheds, and an overview of the Cold Regions Hydrological Model (CHRM) and its structure and specifications.

Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)

Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

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