Canadian Foundation for Climate and Atmospheric Sciences (CFCAS)
Fondation canadienne pour les sciences du climat et de l'atmosphère (FCSCA)

Improved Processes & Parameterisation for Prediction in Cold Regions

2008 Progress Report

IP3: Improved Processes and Paramaterisation for Prediction in Cold Regions

Project Leader: John Pomeroy, University of Saskatchewan

1.0. Progress (from September 2007 to August 2008)

We are currently at the mid point of Year 3 of the IP3 Network. Student recruitment and data collection necessary for process understanding, and improved parameterisation have been completed and work is underway to further improve and apply models to the research basin domains.

1.1. Describe progress towards meeting the project objectives. How are the original milestones being met? List the key objectives and results achieved to date as well as any relevant application(s) of the results.

Theme 1 – Processes

Due to the staggered nature of the IP3 funding and research cycle, Theme 1 has currently completed Year 2 and is moving towards Year 3 milestones. As such, progress against the Year 2 Milestones and Deliverables will be assessed at this time with the recognition that Year 3 activities are ongoing.

Year 2 Milestones and Deliverables

- *All field sites fully operational with personnel on-site for intensive data collection*

All field sites are operational and have had at least two years of intensive field campaigns.
i) Wolf Creek Research Basin (WCRB) has been fully instrumented since 2007 and has had the three long-term baseline meteorological stations (forest, buckbrush, and alpine) upgraded. Researchers were on-site for most of the year to examine all major hydrometeorological processes, including studies of shrub burial under snow. New experiments involving time-lapsed cameras, heat-pulse probes, TDR networks, and other instrumentation continue to add to the considerable infrastructure.

ii) Lake O'Hara Research Basin underwent intense monitoring during April-October of 2007 and 2008. Detailed snow and geophysical (seismic refraction, GPR, resistivity) surveys were conducted in 2008.
iii) Baker Creek Research Basin is fully instrumented and studies of ground frost/runoff are continuing with intensive studies from May through September of 2007 and 2008.
iv) Instrumented lake evaporation sites (island, water temperature profile, and adjacent forest) were maintained at Crean Lake in Prince Albert National Park for process studies to better understand and describe open water evaporation. Complete observations occurred in 2007 and 2008. A new site was established at Landing Lake, NWT to further the open water evaporation objectives.
v) Trail Valley and Havikpak Creek Research Basin observations were obtained through August 2008 including basic hydrometeorological parameters over the winter, snow surveys, eddy flux measurements at three sites, and discharge. Researchers were on-site for approximately 8 weeks.
vi) Scotty Creek Research Basin had personnel on site from mid-March to mid-June and late August. Additional sensors were added (Geonor precipitation, CNR1, sonic anemometers) to the existing network.
vii) Marmot Creek Research Basin was intensively studied in 2008 with bi-weekly visits and essentially continuous occupation during snowmelt. Particular attention was paid to snow accumulation in forested versus non-forested terrain, wind redistribution of snow in alpine areas, interception and unloading of snow throughout the winter season, snow ablation energetics under forest canopies on slopes, and snow cover depletion. An acoustic snow sensor was tested. The infrastructure continues to be upgraded with telemetry added to 6 stations for real-time downloads and improve data quality.
viii) Peyto Glacier Research Basin continues operation with two eddy correlation systems and other new instrumentation being deployed on the three weather stations on and near the glacier to measure bulk transfer from the glacier surface in the summer ablation period.
ix) Reynolds Creek Research Basin was adopted as an IP3 basin and continues to have standard meteorological measurements at 36 stations and streamflow and soil moisture measurements at many other stations. Snow surveys and solid precipitation are measured at several sites in this basin.

- *Ongoing analysis of HRU runoff sources, pathways, residence times, and intra-basin hydrological interaction*

This work continues at all terrestrial basins. The role of channel snow and aufeis is being explored in Wolf Creek using geochemical, hydrometric, and geophysical techniques, and mean residence times are being assessed via convolution methodologies. Lake connectivity and threshold relations continue to be studied in Baker Creek. Groundwater flow has been the focus of research in Lake O'Hara. In alpine tundra, results at the HRU scale indicate that accurate simulation of runoff at the hillslope scale during melt requires consideration of patterns of both melt and thaw depth. Remote sensing and thermal models developed in this study were combined to assess the spatial nature of melt and thaw and the implications of this on drainage. The relation between hillslope thaw and hydrological connectivity during the melt period was determined.

- *Evaluate and upscale existing numerical process descriptions for frozen and organic soils*

Peat hydraulic conductivity profiles were examined at three sites in north-western Canada. Multiple independent measures showed similar values of saturated hydraulic conductivity and their transition to lower values with depth. Digital image analysis showed that hydraulic conductivity is controlled by pore radius, which is strongly related to the degree of decomposition and is largely independent of location. Depth-conductivity associations have been established. Zhang *et al.* (2008) describe the parameterisation of frozen soils for IP3 research basins. In addition, a comprehensive review of methods to simulate infiltration into frozen soils has been completed with model simulations occurring at a number of basins to assess the efficacy of different process descriptions and parameterization techniques.

- *Ongoing analysis of radiative and turbulent transfer data*

Eddy correlation observations of sensible and latent heat flux from shallow lakes (TUP Lake and Denis Lagoon near Trail Valley Creek) and adjacent land sites are being analysed to determine the effects of wind speed, fetch, and stability on the hourly fluxes of water vapour over the lakes. In collaboration with scientists at Agriculture Canada, preliminary analysis has occurred of the NRCC Twin Otter aircraft flux data collected during the Mackenzie GEWEX Study (MAGS), and maps showing the magnitude of sensible and latent heat flux for 3x3 km grids over the Trail Valley domain have been produced. Preliminary analyses of flux data from snow covered sites (both tundra and shrub) have been compared to those estimated from CLASS.

Turbulent transfer studies at Scotty Creek are focusing on the snow-free period in bogs, the only areas of suitable fetch. Radiation studies there are focused on the differences of net all-wave radiation at the ground of the major HRUs for the purpose of understanding and then numerically describing the rate of soil thaw of each HRU. For the peat plateau HRU, the spatial variation of net-all wave radiation at the ground is relatively high, due to variations in canopy factors. This affects drainage patterns due to variations in soil thaw depth (i.e. depth to the impermeable frost table).

- *Turbulent Transfer Processes and Parameterization for Snowmelt*

Mountain flux measurements in 2007 showed fundamental theoretical problems with Monin-Obukov stability relationships applied to snow sensible and latent heat fluxes in complex terrain. To assess the relationship between snow surface fluxes and internal energy changes at an ideal simple cold regions site, detailed energy balance measurements were made in a 50 cm deep snowpack on a flat homogeneous agricultural field 5 km east of Saskatoon, SK. The internal energy status of the snowpack was calculated using finely spaced internal temperature measurements made during cold mid-winter periods when the liquid content was negligible and internal energy status was dominated by the heat capacity of the ice and air constituents. Results indicate that changes in the internal energy status were not matched by the net surface and ground heat flux suggesting that these fluxes were under-measured. The surface energy balance was dominated by long-wave radiation losses, typical of mid-winter periods, whereas the net positive contribution of the turbulent heat fluxes was generally very small (< 30 W m^{-2}). The lack of closure in the energy balance is attributed to energy transferred by a non-turbulent convective exchange of air with the porous snowpack that is not measured by eddy covariance measurements. The energy balance discrepancy was most prominent during warming trends when warm air was advected over the cold snowpack causing a large increase in snow pack temperatures (to a depth of 20 cm), even though the net surface energy balance was negative. The non-turbulent convective exchange can be parameterized by setting the aerodynamic surface roughness to an effective value that is substantially higher than that measured.

A parameterization for the simultaneous calculation of turbulent fluxes over snow and exposed shrub vegetation in complex terrain has been developed, and datasets have been prepared for further evaluation of this scheme.

A study of the spatial scaling of topographic characteristics controlling accumulation and melt was conducted, comparing topographic statistics for Wolf Creek with Reynolds Creek.

- *Implementation of new and developing numerical process descriptions into CRHM*

CRHM has had substantial development of its core code over the last year. Improvements to blowing snow modules, snowmelt, evaporation, and radiation transfer in forests have been completed, and a new "fill and spill" scheme has been incorporated. The USDA SNOBAL model has been added as a snowmelt module and coupled to a blowing snow model. Other key developments to CRHM this year have been the documentation of 'groups' and 'structures.' The 'groups' feature permits CRHM to characterize changes in land use such as from forested to non-forested in a basin. The group can be an area of a basin which can change for assessment of land use change impacts. The structures feature permits CRHM to be applied to complex mesoscale basins (10-1000 km^2) with a variety of major sub-basins. Representative basins are given a structure which is then repeated to simulate the complexity required for physically based modelling, without increasing parameter requirements for the model beyond that which available data can provide. A dynamic linked library (DLL) feature had been added that permits any user to link new modules using commercially available C++ compilers.

- *Frequency distributions for spatial representation of soil parameters determined*

Log-normal frequency distributions of thaw depths have been demonstrated at WCRB and Scotty Creek. As time progresses through melt, the variation of thaw depth decreases.

- *New numerical routines to accurately estimate ground thaw and how it relates to surface and vegetation properties*

The simulation of ground thaw has been comprehensively explored by Zhang *et al*. (2008) with respect to the methods of simulation and the parameterization of frozen and organic soils. In addition to complex numerical routines, a simple heat conduction model was proposed that calculates the daily rate of thawing from ground surface temperature and bulk thermal conductivity, where the latter is essentially determined by soil water content.

- *DEMs obtained for research basins*

This milestone has been achieved with the LiDAR campaign in fall 2007 and subsequent processing of the resulting data into high-resolution DEMs for each basin. These DEMs are being used to determine basin physiographic parameters and relate these to runoff and other hydrological processes. In addition, the LiDAR data are being used for extraction of vegetation and other HRU parameters.

Theme 2 – Parameterisation

This year is the 'year of parameterisation' for IP3. The major focus of the network in 2007-2008 has been improving parameterisations based on the developments in process understanding. The purpose of improving the parameterisation is to improve models so that the predictive theme of the network can take advantage of these advances next year. In support of parameterisation IP3 had a focussed Parameterisation Workshop in Waterloo in June and two CRHM courses, in Calgary and Waterloo to train the network, collaborators and users on CRHM as a parameterisation and prediction tool for physically cold regions basin hydrology.

Year 2 Milestones and Deliverables

- *Performance evaluation of CRHM in both GRU and HRU routing/aggregation modes against field and distributed modelling data*

As it evolves, CRHM is being evaluated against existing data sets from all basins. In particular, the USDA SNOBAL model, coupled to a blowing snow model, has been evaluated in alpine terrain, and the new "fill and spill" algorithm is undergoing field validation. Additionally, CRHM has been tested with respect to runoff in Scotty Creek over the period 2001-2008. The values compared closely with detailed water balance calculations of runoff for the same periods, and correlated well with the timing and magnitude of basin hydrographs measured by the WSC.

Tests of blowing snow redistribution and sublimation by wind were performed over Granger Basin (in WCRB) and Trail Valley Creek using a physically-based blowing snow model in CRHM. At Trail Valley Creek, a sequence of flow from smooth to rough surfaces and drifts was employed with perturbation of wind flow using a parametric version of the Walmsley-Taylor-Salmon wind flow model. At Wolf Creek, snow transport fluxes were distributed over multiple hydrological response units (HRUs) using an inter-HRU snow redistribution allocation factor (S_R) which requires only wind direction and speed data, HRU slope and aspect, and the spatial arrangement of the HRUs in the catchment. Model results show that end-of-winter snow accumulation can be accurately simulated using a physically-based blowing snow model with the spatially- and meteorologically-defined inter-HRU S_R. Since snow transport scales with the fourth power of wind speed (u^4), S_R can vary year-to-year according to the predominant u^4 direction and magnitude. The viability of applying an identical S_R scheme year-to-year depends on the application scale. The independent effects of topography and vegetation were examined to assess their importance on snow redistribution modelling over mountainous terrain. Snow accumulation was best simulated when including explicit representations of both landscape vegetation and topography. Vegetation was shown to have the strongest control on snow redistribution; therefore, it is necessary to include an explicit representation of vegetation. Snow redistribution caused substantial variation in end of winter SWE for sub-basins of Trail Valley Creek.

- *Evaluate MESH performance with reference to measured mass and energy balances, CRHM, and distributed modelling data*

Over the last year, field data were used to evaluate storage and flow parameters of talus slopes at Lake O'Hara using analytical techniques including water balance, tracer-based hydrograph separation, recession analysis, and time-series analysis. These parameters will be used in the MESH model. The MESH model was run in a single column mode to identify the algorithms requiring significant modification. Preliminary results suggest that modification will be required to the snowmelt and subsurface flow algorithms. MESH runs are in preparation at most other IP3 sites.

- *Characterize surface parameter distributions*

LiDAR-based measurements at all study sites in 2007 and 2008, in some cases accompanied with high-resolution aerial photography, has provided the data required to evaluate surface parameter distributions and delineate HRUs with increased confidence.

Spatial and temporal distributions of areal snowcover depletion (SCD) were studied over a small (i.e. <0.6 km^2) alpine cirque in Marmot Creek Research Basin using a combined approach of daily acquisition of remotely sensed imagery, together with meteorological observations and snowmelt modelling. Digital terrestrial photographs were georeferenced using a novel software tool together with a high resolution digital elevation model, and used to derive measurements of fractional snowcovered area (SCA) over the cirque. Manual snow surveys carried out in the pre-melt period were used to describe the initial frequency distribution of snow water equivalent (SWE) values over the cirque, and indicated a log-normal distribution of SWE when surveys were stratified by terrain features. Rates of snowmelt were simulated using a physically based snowmelt energy balance model, SNOBAL, driven by observed meteorological conditions at a nearby station, which were adjusted for slope orientation and exposure by making corrections to observed incoming short- and longwave radiation components in CRHM. Simulated melt rates were then applied to the approximated SWE distributions to model the decline in SCA over the spring. The model performed well for the simulation of snowmelt based on point observations of SWE at the meteorological station, and produced a close correspondence between simulated and observed SCD curves representing two opposing slopes within the cirque. The results show that both the pre-melt distributions of SWE and the spring melt rates exhibit considerable spatial variability between distinct slope units within the cirque, and that this variability has a significant impact on simulated SCD. Assuming a unimodal pre-melt frequency distribution and conditions of spatially uniform snowmelt over complex terrain such as this can lead to large errors in the simulation results. It is suggested that modelling applications intended to represent snowmelt dynamics and areal SCD in similar alpine environments consider the effects of spatial variation in SWE distribution and melt energetics between slopes.

A similar study was conducted on a north-facing slope at Granger Basin (WCRB) where the spatial and temporal pattern of snow-cover depletion on a north-facing slope was used to drive the pattern of soil thaw initiation, assuming that soil thaw is initiated once the snow-cover of grid-cell has ablated. In this study, the TONE model was used to map the distribution of soil thaw over the north-facing slope (~25,000 m^2), and using a recently derived depth association of hydraulic conductivity (K), the latter were used to derive maps of K over the same hillslope for various stages of the thaw period.

IP3 researchers proposed a new energy-based framework for delineating runoff contributing areas in organic-covered permafrost terrain. Aerodynamic energy and roughness height control the end-of-winter snow water equivalent, which varies several orders of magnitude across the landscape. Radiant energy in turn controls snowmelt and ground thaw rates. The combined spatial pattern of aerodynamic and radiant energy control flow pathways and the runoff contributing areas of the catchment, which are persistent on a year-to-year basis. While ground surface topography obviously plays an important role in the assessment of contributing areas, the close coupling of energy to the hydrological cycles in arctic and alpine tundra environments dictates a new paradigm.

- *Develop improved snow, melt, subsurface flow, radiation and turbulent flux parameterizations*

Granger Basin LiDAR and ground data have been used to investigate methods of extracting canopy parameters for shrub vegetation. Simulations of windflow over complex landscapes using simple physically-based and empirical parameterisations have been evaluated. Distributed simulations of snow redistribution have been conducted using newly-available LiDAR data for surface characterisation. Numerical parameterisations for ground thaw at Granger and Scotty have been completed. Parameterization of infiltration into frozen soil is an ongoing task. At Scotty Creek, parameterisations are also focussed on hydrological interactions amongst major peatland types. This is linked to the runoff from the peat plateaux, based on the depth – conductivity parameterisation defined using multiple IP3 study sites.

To better parameterise the role of longwave radiation from forest canopies on snowmelt, measurements were taken in coniferous forests of differing density, insolation, and latitude to test whether air temperatures are suitable surrogates for canopy temperature in estimating sub-canopy longwave irradiance to snow. Under conditions of low insolation, air temperature generally was a good representation of canopy radiative temperature. However during high insolation, needle and branch temperatures were well estimated by air temperature only in relatively dense canopies; in more open canopies needle and branch temperatures exceeded air temperatures during strong insolation. Tree trunks exceeded air temperatures in all canopies during high insolation, with the relatively warmer trunks associated with a sparse canopy cover, dead trees, and interception of direct beam solar radiation. The exitance of longwave radiation from these relatively warm canopies exceeded that calculated using the common assumption that canopy temperature equals the air temperature. This enhancement of longwave exitance was strongly related to the extinction of solar radiation by the canopy. Estimates of sub-canopy longwave irradiance using either two-energy source or two thermal regime approaches to evaluate the contribution of canopy longwave exitance performed better than did estimates that used only air temperature and sky view. However, there was little evidence that such corrections are necessary under cloudy or low solar insolation conditions. The longwave enhancement effect due to shortwave extinction was important to sub-canopy longwave irradiance to snow during clear, sunlit conditions. Longwave enhancement increased with increasing solar elevation angle and decreasing air temperature. Its relative importance to longwave irradiance to snow was insensitive to canopy density. As errors from ignoring enhanced longwave contributions from the canopy accumulate over the winter season, it is important for snow energy balance computations to include the enhancement to better calculate snow internal energy and therefore the timing and magnitude of snowmelt and sublimation.

Measurements of incoming shortwave and longwave irradiance to sites of varying forest cover and slope/aspect in Marmot Creek Research Basin were used to develop new and evaluate existing topographic and forest cover irradiance correction algorithms for the purpose of snowmelt modelling under forested mountain slopes. Due to the non-uniform distribution of forest-cover typical of pine stands, transmission of shortwave irradiance was determined through calculation of the geometric fractions of non-transmitting trunk, partially transmitting needle-leaf foliage, and fully-transmitting gaps apparent to beam and diffuse components of incoming shortwave irradiance. Sub-canopy longwave irradiance was determined by atmospheric and forest longwave contributions weighted by the sky view fraction of the celestial hemisphere, with account made for longwave emissions from heated trunks and foliage exposed to shortwave irradiance. To resolve net radiation to snow, reflected shortwave radiation was determined by a forest snow albedo decay model and longwave exitance from snow via a recently developed and validated psychrometric-longwave exchange model. To describe forest cover density by a single parameter, the dimensions of trunk, needle-leaf foliage and gap fractions collected from forest surveys were related to an effective leaf area index as determined from analysis of digital hemispheric photographs. Simulations of net radiation with respect to varying forest cover density and topography were performed using meteorological forcing data collected from two sub-alpine sites of differing elevation over three years. In general, results show that reductions in forest cover density on south-facing slopes and level sites are met with accelerated snowmelt, but with decreased or no change in snowmelt rates on north-facing forests. Consequently, the effects of changes in forest cover on snowmelt for Rocky Mountain basins will be strongly influenced by the topographic exposure of the stand.

Theme 3 – Prediction

Prediction methods are under rapid development in IP3 with major advances in the full documentation and distribution of CLASS 3.4, the development, documentation and release of MESH 1.1 and the release of CRHM with training provided to the user community. The current focus has been on both small and group collaborations between modellers and process and field scientists using both models and basins as focal points for collaboration. This provides a robust foundation for the next year's work for which IP3 focusses on prediction as its major network activity.

Year 2 Milestones and Deliverables

- ***Incorporate new process and possible parameterizations into the MESH system***

Scotty Creek
MESH has been set up on Scotty Creek by Soulis. To examine the model in peatlands there has been an assessment of field data and initial selection of parameter values by Soulis.

Wolf Creek
MESH has been set up on Wolf Creek by Pietroniro. CLASS was set up and tested at Granger sub-basin, by coupling to CRHM which distributed inputs of radiation and air temperature to CLASS and by forcing initial snow conditions with snow redistribution from snow surveys. By distributing the CLASS tiles by slope, aspect, and elevation, to account for differing energetics and snow accumulation, accurate representation of snowmelt can be achieved. MESH-CRHM was run over all of Wolf Creek with the information learned from CLASS-CRHM runs in Granger Creek. Reasonably successful simulations at the Wolf Creek scale confirm the general applicability of MESH in sub-arctic mountains with additional provisions for energy balance and snow redistribution on mountain slopes.

Trail Valley Creek
The MESH modelling domain has been established in the TVC region with assistance from Bruce Davison of the HAL lab. MESH was calibrated at TVC using the SCA method established by Tolson (collaborator at U of Waterloo). TVC was successfully modelled using parameters calibrated using observations from Wolf Creek. This was a significant advancement in establishing parameterizations within the MESH model framework that are transferable by landscape within a large region.

Baker Creek
MESH has been established by Soulis but no analysis or validation has been done to date.

Marmot Creek
The MESH modelling domain is being established on this basin by Pietroniro. Given the important role that groundwater storage of snowmelt water has on streamflow response, strategies to enhance MESH by dealing with the dynamics of the groundwater system have been explored by Snelgrove. The general approach for this revolves around the redistribution of moisture within a landscape unit. Relationships between landscape position (elevation, aspect) / land cover / topographic index are being explored to aid in the discovery of new measures of hydrologic similarity that combine features of both land cover and topography. Most modern hydrologic models identify similar hydrologic units based on either land cover or topographic index. It is anticipated that by combining these measures of similarity that a mechanism of moisture transfer between adjacent tiles can be developed.

TOPMODEL simulations were undertaken over the Marmot Creek basin in an attempt to simulate the observed streamflow at the basin outlet and suggest new developments of drainage functions for MESH. TOPMODEL was found to be unable to account for inputs due to variable snowmelt or spatial variability in precipitation and evaporation and is therefore ill conditioned to function in the Marmot Creek basin. This was surprising as Marmot Creek is a mountainous basin and the closest to meeting TOPMODEL assumptions of hillslope drainage. The modelling exercise yielded a number of positive outcomes and insights for development of MESH:

- Spatial distributions of modeled soil moisture over the basin.
- Organized datasets of topography, land cover, and meteorology that will be utilized in subsequent modelling.
- A CLASS based tool to generate aerodynamic resistance time series from meteorological data.

Lake O'Hara

The MESH domain has been established by Soulis and further verification is anticipated this year.

- ***Establish and evaluate water and cycle predictions derived from the MESH modelling domains using primarily the CLASS land surface model and existing routing models***

Work on the WATFLOOD model in the North and South Saskatchewan River basin (which incorporates Marmot Creek) has been completed. This domain will also be used for MESH evaluation in the region which is expected to be completed by the end of April. The primary purpose of this domain is to focus on glacier and snowmelt for water supply issues within the region.

- ***Perform sensitivity analysis of atmospheric fluxes and prognostic predictions, as well as through comparison with observed hydrographs. Where possible, the model predictions will be compared with key variables such as discharge, surface water storage, water balance, snowcover, soil moisture, soil frost, soil heat flux, and evaporation***

This work has begun in TVC and Wolf Creek. Hydrograph and SWE comparison from the CRHM-MESH and CRHM model were made with historic and recent observations. These data were also used in CRHM-CLASS model calibrations. CRHM is used to parameterise MESH or CLASS for cold regions processes that are not yet incorporated into these models. The IP3 GEM Modeller (Herrera) is examining Canadian Global Environmental Mutiscale (GEM) in limited area mode (LAM) where the horizontal resolution typical for the mesoscale is applied to a small region of interest within the IP3 domain. The importance of using the GEM-LAM model on IP3 basins is to fill in the temporal or spatial coverage of field observations, particularly wind and precipitation fields.

The GEM-LAM domains for IP3 are nested from 15 km resolution to high resolution runs centred on each basin. The first focus is on Marmot, Reynolds, and Wolf Creeks at 2.5 km resolution. Fine resolution runs at 500 m resolution have also been set up. Extremely fine resolutions runs at 100 m resolution have been set up for comparison to field data sets for short time periods. These are initially to be coupled to blowing snow models to provide improved initial conditions for melt simulations using MESH.

Year 3 Milestones and Deliverables

- ***On-going improvements of MESH with new algorithms on each research basin, and evaluate model performance with reference to measured mass and energy balances***

Verseghy completed and distributed the next official frozen version of CLASS, version 3.4, together with the full suite of documentation, and assisted students with the implementation of version 3.4 implementation in their projects. A new developmental lake model has been incorporated into the CLASS mosaic structure, and the CLASS offline driver has been re-tooled to run the model in regional applications and over basins, rather than single field sites, in preparation for running over the IP3 research basins.

This year's focus for Soulis was the design of an interface between the atmospheric and hydrological models, which involves a revisit of the coupling system design. The fundamental end member of the modelling system is hillslope hydrology yet its treatment is primitive. The two leading models, TOPMODEL and VIC, use simple partitions of saturated area vs. unsaturated area. The consequence is an oversimplification of infiltration, evaporation, and recharge, with severe limits to applicability in the complex terrain associated with the IP3 basins.

The new approach to near surface flow includes a solution to Richard's Equation for unsaturated conditions, and a definition of field capacity based on soil properties and topography. This is showing promise of leading to a general solution for near surface flow that will combine the variable infiltration capacity approach with the variable saturated area approach used with the leading models, TOPMODEL, and VIC2L. This will consolidate the two approaches for drainage and provide a distribution of soil moisture at the near-surface, with the resulting improvement in evaporation and infiltration.

The approach builds on the MESH drainage algorithm, which was designed for soils that are near saturation, which were typical to MAGS. However, because suction is ignored, it does not perform well in long dry periods. The theoretical framework has been extended from near saturation to field capacity. The analytical expressions have been established and tested for bulk soil moisture vs. flow for saturation ranging from half the available water to complete saturation. The remaining range is still under investigation. A by-product of this work is a new version of field capacity that reflects both soil properties and topography.

- ***Re-evaluate regional hydrological response based on improved parameterization from research basins and IP3 field studies***

Parameterisations for Wolf Creek and TVC are largely complete and Marmot and Scotty Creek parameterisations are underway. Multi-objective optimization in combination based on the work by Tolson (collaborator) and inductive and deductive approaches to obtaining these parameters are now complete. The proof-of-concept for this approach has now been shown to work reasonably well. This initial success needs to be evaluated on the other research basins. We expect that a strategy for doing this will be finalized at the November 2008 IP3 Workshop in Whitehorse.

Munro has been developing a spatially distributed modelling framework for the Peyto Glacier basin, such that it is feasible to model the daily mass balance distribution. This requires a realistic mapping of glacier albedo, so to this end a project on Landsat determination of glacier albedo fields was reactivated. The results of the work suggest that an ice/snow albedo designation of glacier surface cover is sufficient for modelling purposes. Thus, radiation modelling is well in hand, leaving only the transfers of sensible heat and water vapour to explore further.

- ***The prediction team will work closely with the research teams in themes 1 and 2 to evaluate the relative importance, sensitivity and cumulative effect of introducing algorithms, parameterizations and new landscape segmentations derived through field and basin experiments***

Pomeroy and Pietroniro have worked extensively on testing and evaluating MESH in an offline model for both Wolf Creek and Trail Valley Creek. Testing and parameterization are now complete. Parameters for the CLASS model in Wolf Creek have successfully been transferred to TVC, and final testing and evaluation is at hand. We consider this work complete with the exception of minor refinements. Other basins as listed above are in various stages of completion as outlined in the Theme 1 and Theme 2 reports.

As noted in the 2007 progress report, the focal point for the research program is on testing and evaluating results from the process based experiment and the watershed scale. The focus is on scaling, segmentation and parameterization of hydrological land surface models for application in the regimes being considered by IP3. The platform for model evaluation is the Hydrology Land Surface Schemes H-LSS (MESH) hydrological system that is part of the MEC modelling platform. A close partnership between this activity and scientists supported by the first two themes of this program are essential to the success.

The objectives of this prediction research are 3-fold:

i) The first objective, optimization, is to examine the potential of multi-objective optimization for model parameterization at the basin scale. This avoids equifinality by incorporating both snow and streamflow objectives in optimization procedures There has been significant advancement in this area through the work of Pablo Dornes (PhD- student). Using field estimates of SWE and streamflow hydrographs, both inductive and deductive approaches to hydrological simulations were used. In the inductive approach, optimisation using a muti-objective approach for both snow covered area and streamflow was required. Both MESH and CHRM models were used and optimized using the methods developed by Brian Tolson to better fit observations..

ii) The second objective, basin segmentation, is to examine different combinations of tile and tile connectors that can best represent the spatial variations in the cold regions hydrological cycle. Segmentation within MESH is based on the GRU approach which focuses on land-cover as the method for segmentation. Forcing is consistent with the model grid. Although this is a well-established protocol, it is based on the assumption that variability (both atmospheric forcing and hydrological response) are consistent with land-cover. There is still much research in assessing the appropriate level and type of segmentation required in order to capture the sub-grid variability of the energetics and hydrology of the basin. In this part of the study, the importance of representing topographic variability within a model grid was examined. It was well understood that variations in forcing data (e.g.solar radiation, air temperature) and initial conditions for snowmelt (redistributed snow water equivalent, soil moisture) required a further level of landscape segmentation in the GRU approach. A methodological approach based on inductive reasoning, and small scale modelling with CHRM, has provided a framework and systematic process for establishing the appropriate level of basin segmentation necessary for larger scale models. The current operational framework for atmospheric forcing in MESH does not take this into account, and advances made in this research will need to be operationalized into the EC environmental prediction system. Moreover, snow accumulation is not only a unique function of land-use, but also a function of regional topographic effects due to redistribution by blowing snow. The MEC-MESH framework is designed to allow for various combinations of grouped units to be established. Optimum and appropriate basin segmentation schemes for various cold-region domains have been proposed and will be evaluated at the GEM-LAM scale.

iii) In order to achieve these objectives, it is critical to ensure that all collaborators and PI's involved in Theme 3 have access to the MESH modelling system. This third objective, MESH development, has largely been achieved through the assistance of Bruce Davison, an IP3 collaborator. On this objective, there was significant progress made. Close collaboration with E.D. Soulis (U of Wateroo), Diana Verseghy and others has allowed for a software development and version control group to be developed. A stand-alone version of the MESH modelling system is available to all IP3 investigators, and is supported largely through in-kind EC contributions, but also through efforts of this study. A "user group" MESH workshop was held this past year.