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Improved Processes & Parameterisation for Prediction in Cold Regions

2007 Progress Report

IP3: Improved Processes and Parameterisation for Prediction in Cold Regions

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1.0. Progress (from beginning of IP3 Network, July 2006, to September 2007)

IP3 has achieved its first year objectives and is making substantial headway on its second year objectives after 15 months of formal operation. All research basins are fully instrumented and producing a unique and valuable cold regions hydrometeorological dataset along transects from medium to high latitudes and low to high altitudes. Specific process investigations in these basins have already improved our understanding of snow, glacier, soil frost, and lake processes and have led to improved mathematical descriptions of these processes. Initial parameterisations of some of these processes have been developed and are being tested in the Cold Regions Hydrological Model (CRHM) on all of the basins. This is leading to improved landscape interactions in the Modélisation Environnementale Communautaire's (MEC) MESH (MEC - Surface and Hydrology) model. MEC and MESH models have been set up over the IP3 domains with component runs evaluated at many of the research sites. There are many areas of substantive advance in IP3, but three examples of special interest are below:
i) There is strong evidence for decadal-scale permafrost melting in the discontinuous zone of the southern Northwest Territories (NWT) with important implications for peat plateau extent, wetland water storage, and for reduced runoff generation in the summer period;
ii) It is anticipated that there will be substantively greater snowpack depth and faster melt rate with the destruction of pine canopies from the mountain pine beetle that is currently infesting the eastern slopes of the Rocky Mountains. These changes are due to snow accumulation and melt sensitivity to forest canopy leaf area; and
iii) Progress has been made in predicting the streamflow of small headwater cold regions basins using meteorological data, satellite-derived descriptions of basin attributes, and physically-based modelling techniques, with minimal calibration of parameters. Parameter transferability over hundreds of kilometers has been demonstrated. This will provide substantial assistance to estimation of streamflow in these relatively ungauged areas for resource development and conservation for federal, provincial, and local governments as well as industry. The use of these techniques in assessing mine rehabilitation efforts is already underway in the Yukon.

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.

Note: Milestones from both Years 1 and 2 are included below as many tasks from Year 2 have been addressed.

Theme 1 - Processes

The Process Theme has moved forward rapidly with the establishment of eight major research basins across latitudinal and elevational transects covering western and northern Canada. These basins are used to collect unique field observations to better describe and more fully understand cold regions hydrometeorological processes relating to snow, glaciers, frozen ground, and open water. Particular attention has been paid to the effect of sparse vegetation cover and complex terrain effects on the energetics and boundary layer interactions of all of these surfaces. Examination of the spatial variability of the fluxes and states has begun, with movement towards development of scaling relationships.

Year 1:

- **Install and upgrade hydrometeorological network in research basins and begin all field observations.**

Hydrometeorological networks have been established or upgraded in all research basins, providing a standardized suite of measurements for hydrological and land-surface modelling. In Wolf Creek (Yukon, sub-arctic cordillera), the three baseline meteorological stations have been upgraded with new weather sensors, including radiation components, and dataloggers and additional instrumentation have been installed to determine snowmelt infiltration and snowpack processes. Additionally, automated water samplers and high-frequency water quality sondes are now located at the outlets of sub-basins representing the major ecozones. The Lake O'Hara Research Basin (BC, Rockies) meteorological station has been fully upgraded and equipped with a satellite transmitter for remote data access, and two new sub-basins have been instrumented with streamflow gauges and automated water samplers. Havikpak Creek and Trail Valley Creek (NWT, taiga woodland and arctic tundra) meteorological stations have been upgraded with CNR1 radiometers. Scotty Creek and Baker Creek (NWT, shield wetlands and lakes) have a full suite of meteorological and hydrological instrumentation. At Marmot Creek (AB, Rockies), nine meteorological stations have been installed over a 1000 m elevation and ecozone transect. Sites include different forest stands (Lodgepole pine, Englemann spruce, Douglas fir) with different slope orientations, as well as alpine, clearcut, and meadow vegetation. At the Crean Lake (SK, boreal) open water site, flux stations were set up on an island and adjacent land to provide turbulent fluxes over water and the adjacent forest. Water temperature sensors and over-winter instrumentation were installed, with additional water temperature measurements at nearby lakes. For Peyto Glacier (AB, Rockies), four meteorological stations are operational, three on the glacier surface spanning 500 m in elevation and one on nearby rock surfaces.

- **Explore alternative methods to LiDAR for obtaining high-resolution DEMs (Digital Elevation Models) for research basins.**

LiDAR-based DEMs were obtained using external partners and funding sources for Lake O'Hara, Trail Valley Creek, Havikpak Creek, and Peyto Glacier. It was determined that a common LiDAR mission was the most efficient way of obtaining high-resolution DEMs for the remaining basins (Marmot Creek, Wolf Creek, Baker Creek, and Scotty Creek), so the C-CLEAR consortium was contracted to fly a mission in August 2007 in collaboration with the Western Canadian Cryospheric Network (WC2N) and Natural Resources Canada (NRCan). The mission was heavily subsidized by NRCan.

- **Collate historical process data collected in MAGS and the Quinton-CFCAS project.**

Historical MAGS (Mackenzie GEWEX) and Quinton-CFCAS data from Wolf Creek, Havikpak Creek, Trail Valley Creek, and Scotty Creek have been reviewed and archived. Data have undergone QA/QC to be used for the first model runs and diagnostic tests of CRHM, MESH, and CLASS (Canadian LAnd Surface Scheme).

- **Begin analysis of MAGS historical turbulent and radiative transfer data applicable to IP3 project.**

Preliminary analyses have been completed of aircraft sensible and latent heat flux and radiation observations from Trail Valley and Havikpak Creeks to compare the aircraft measurements to tower flux observations and to determine areal average fluxes and snow covered area. This will provide the basic data to compare modelled fluxes to observations of both point (from tower) and basin scale (basin average from aircraft) fluxes. To create a gridded data set of fluxes from the aircraft data for comparison to gridded model outputs, collaborations are being investigated with researchers at the National Research Council and Agriculture Canada with expertise in analyzing aircraft flux data.

- **Begin boundary layer growth experiment.**

A boundary layer growth experiment was carried out over Crean Lake (SK). Two tethered balloons carrying temperature and humidity sensors provided upwind (land) and downwind (lake) profiles, allowing for calculation of average open-water evaporation using a boundary layer integration technique.

<u>Year 2:</u>

- **Have all field sites fully operational with personnel on site for intensive data collection.**

This objective has been achieved. For Wolf Creek, a hydrometeorological network of four baseline meteorological stations, four hydrometric stations, and one deep groundwater monitoring well has been maintained and operated continuously. Snow surveys and station maintenance were carried out monthly during the winter season, and hydrometric surveys were carried out monthly throughout the year and more frequently during the freshet. For Baker Creek, field studies of ground frost/runoff processes are well underway using hydrometric, hydrochemical, and remote sensing techniques. At Lake O'Hara, snow surveys were conducted in April 2006 and April 2007 to characterize snow depth and density distribution. A geophysical survey using electrical resistivity imaging and ground penetrating radar was conducted in August 2006 to delineate potential pathways of groundwater in the moraine field. Intense hydrometeorological monitoring was conducted during April-October of 2006 and 2007, including weekly manual gauging of streams, water sampling, and snowmelt monitoring covering a large elevation range. For Havikpak Creek and Trail Valley Creek, field observations were conducted during spring/summer 2006 and 2007. This included end-of-winter snow cover distribution, standard micro-meteorological observations, discharge measurements, and eddy flux measurements at towers over shrub, tundra, and lakes. Marmot Creek has been the subject of intense field campaigns to study micrometeorology over snow and forests, interception/ unloading, snowmelt, meltwater, streamflow, and flowpath chemistry, with personnel on site much of the year. At Scotty Creek, personnel were on site for the snowmelt, early summer, and late summer. Field observations were conducted on Peyto Glacier during spring and late summer 2007.

- **Ongoing: Analyze HRU (Hydrological Response Unit) runoff sources, pathways, residence times, and intra-basin hydrological interaction.**

This objective is ongoing in all research basins. Additional chemical and isotope data have been collected at most sites, and geophysical methods have been used at Lake O'Hara to discern subsurface flow pathways.

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

An exhaustive survey of numerical techniques used to predict frost depth and ground temperature has been completed (Zhang *et al.*, submitted). Organic soil hydrological models are being assessed, and HYDRUS-1D (a finite-element infiltration model) is being modified to allow application in organic soils with a freezing routine.

- **Ongoing: Analyze radiative and turbulent transfer data from lake and snow experiments.**

Preliminary analysis of flux data from snow-covered sites in Trail Valley Creek and Wolf Creek (both tundra and shrub) has been completed, and the fluxes have been compared to those estimated from CLASS and other models. A new shortwave radiation algorithm that deals explicitly with patchy shrub cover has been developed and verified (Bewley *et al.*, 2007). The lake flux data are currently being quality-controlled and will soon be available for detailed analysis. Analysis for spatial and temporal variance of sub-canopy longwave radiation to snow has been completed with Marmot Creek radiometer array, hemispherical photography, and meteorological data (Ellis and Pomeroy, 2007). Turbulent transfer experiments were conducted at rough open sites in the Rockies and Yukon and contrasted to an open level site outside of Saskatoon (analog for level tundra environment) (Helgason and Pomeroy, 2007). Raw turbulence data were analysed for the various sites to better characterize turbulent transfer relationships over snow and ice surfaces. The purpose of the experiments was to rigorously determine the applicability of current 'state of the art' flux gradient theory including stability corrections in these environments. For open environments, despite the relatively simple terrain, application of the flux-gradient estimation technique was not generally successful. For the majority of the measurement period, low to moderate wind speeds prevailed which resulted in "non-ideal" conditions such as intermittent turbulence and significant non-stationarity of the turbulent fluxes. Only during strong winds (which typically occurred immediately prior to blowing snow storms) were the theoretical conditions fulfilled and the flux-gradient techniques performed as they were intended. In level forest openings in mountainous terrain, the heat and mass transfer rates were strongly affected by non-local processes resulting from wind-flow perturbations caused by the surrounding complex terrain. This greatly compromised the ability to estimate fluxes using flux-gradient theory such that its use in these environments is not advised.

- **Determine frequency distributions for spatial representation of soil parameters.**

The spatial distributions of soil moisture, porosity, organic layer storage, and snow water equivalent have been determined from measurements taken during MAGS in Wolf Creek (Janowicz *et al.*, 2002). The spatial covariance of these distributions has been analyzed to determine runoff production zones. Other efforts to describe this are underway for Wolf and Scotty Creeks.

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

Seven numerical routines for ground thaw have been developed and tested against data from Wolf Creek and Scotty Creek. These will be integrated into CRHM for future modelling.

- **Obtain DEMs for each basin.**

Existing LiDAR and DEM data are available for Lake O'Hara, Peyto Glacier, Trail Valley, and Havikpak Creek. The C-CLEAR LiDAR mission was completed in August 2007 for Wolf Creek, Marmot Creek, Scotty Creek, and Baker Creek, and high-resolution DEMs will soon be available for all eight research basins.

Theme 2 - Parameterisation

The Parameterisation Theme has proceeded with development of the Cold Regions Hydrological Model as a flexible tool for incorporating numerical parameterisations of cold regions hydrological processes. CRHM has been set up in arctic, alpine, wetland, and shield locations and has had many new process algorithms added to it. It has new features that permit parameterisation intercomparison within the model and new algorithms dealing with blowing snow, forest effects on water and energy balance, sub-surface flow, and the fill-and-spill runoff mechanism. Spatially variable datasets for testing upscaled parameterisations have been collected and are being readied for evaluation. New tile parametersations have been developed for wetlands and alpine terrain and are being added to MESH.

Year 1:

- **Set up CRHM at selected test basins representing each of the 4 regions (i.e. arctic, alpine, wetland, shield) in HRU and then GRU (Grouped Response Unit) mode.**

CRHM has been set up for all sites. At Wolf and Scotty Creeks, CRHM has been used to evaluate surface-atmospheric fluxes of mass and energy and a coupled heat-mass transfer algorithm used to simulate subsurface drainage to channels. At Trail Valley and Baker Creeks, the performance of CRHM is being compared with water and energy balance calculations. CHRM accumulation and melt algorithms have been tested in open and forested environments in Marmot Creek (DeBeer and Pomeroy, 2007).

- **Implement new and developing numerical process algorithms into CRHM.**

The following process modules have been added to or modified in CRHM this year (Pomeroy *et al.*, 2007; Ellis *et al.*, 2007):
1) Complex terrain windflow: Numerically-efficient algorithms developed by Salmon *et al.* (1989) for changes to horizontal wind speed over simple topographic features.
2) Shortwave extinction in conifer forest canopies: Algorithms developed by Pomeroy and Dion (1996).
3) Longwave radiation: a) Algorithms devised by Sicart *et al.* (2004) for longwave emission from canopies as a function of sky view factor, b) Algorithms devised by Sicart *et al.* (2006) for estimating longwave emission from clear and cloudy skies during the snow-covered period, and c) Algorithms proposed by Pomeroy and Essery (in preparation) for longwave emission from snow surfaces.
4) Interception of rain and snow: a) Algorithms for calculating interception, throughfall and drip of rainfall were devised from the work of Rutter (1972) and Liu (1997), b) Algorithms for calculation of snowfall interception, sublimation and unloading were devised from Hedstrom and Pomeroy (1998) and Gelfan *et al.* (2004), c) Evaporation algorithms (Granger and Pomeroy, 1997; Penman-Monteith, Bulk Transfer) were linked to the rainfall interception module, and d) Sublimation algorithms (Pomeroy *et al.*, 1998; Parviainen and Pomeroy, 2000) were linked to the snowfall interception algorithms.
5) Snowmelt: a) Sub-canopy wind flow routines modified from those of Parviainen and Pomeroy (2000) were devised, b) The layered snow energy balance model 'Snobal' (Marks *et al.*, 1999) was linked with the blowing snow model as PBS-Snobal.
6) Depressional storage and ponds: Soil and routing modules were modified to account for i) sub-HRU (hydrological response unit) depressional storage and ii) land covered with water (ponds).
7) Hillslope flow: Water flowing as sub-surface runoff can now be routed directly from one HRU to either the surface or the recharge zone of a downslope HRU.

- **Test parameterizations against archives of mass and energy balances over complex terrain.**

Current parameterisations for snow accumulation and ablation in CRHM were tested against independent observations in the SnowMIP2 model intercomparison and results presented in the SnowMIP2 workshop at the IUGG (Ellis *et al.*, 2007). Blind runs of CRHM were made for forested and open sites in Switzerland, Finland, Colorado, Saskatchewan, and Japan. CRHM generally did quite well in simulating snow-water equivalent (SWE) during accumulation and melt phases at all sites and in diagnostic variables such as snow surface temperature and upwelling radiation. Compared to the 35 other models involved in the intercomparison, CRHM showed that it is one of the most accurate snow accumulation and ablation models available.

- **Assess existing parameterizations and develop (initial) improved parameterizations.**

Snow interception and unloading algorithms were tested at a forested site in Marmot Creek in which sub-canopy hanging "bucket" lysimeters were used to measure the timing and amount of snow unloading from the canopy. Initial results show greater snow interception losses in mountain forests than from previous boreal forest experiments suggesting that new parameterisations will be needed. The extent to which averages and variances of sub-canopy longwave radiation in coniferous stands of varying density/canopy gaps can be parameterized using measured air temperature as a proxy for canopy temperature was investigated. Collaboration was undertaken in work on improving parameterization when direct measurements of canopy temperatures are available. From runoff studies, it was found that geometric properties of area and perimeter of runoff-producing landscape patches (i.e. peat plateaus) could be used to derive representative hydraulic lengths (L_h) in permafrost/wetland areas. This will enable simulation of cumulative hillslope runoff to channels. The simultaneous processes of snow-cover removal and active layer thaw were examined over 100 m x 100 m hillslope sections at Wolf Creek. From this, analytical tools are being developed to predict subsurface drainage using remotely-sensed images. Small-scale studies on the parameterisation of peat properties have shown that the porosity of peat can be treated as a single, large, inter-connected pore (single pore hypothesis) and that the hydraulic properties of the inter-particle flowpath network can be directly measured using x-ray tomography. Parameterisation of soil thaw has been advanced with extensive inter-comparison of thaw models for a range of cold-regions conditions.

- **Propose simple snow redistribution algorithm and evaluate in CRHM.**

A linear windflow model proposed by Mason and Sykes was incorporated in a portable version of the Distributed Blowing Snow Model. Simulations of both wind and snow distributions were compared with observations from Granger Basin. It was found that snow drifting is strongly controlled by slope artefacts in the existing DEM. It is hoped that the August 2007 LiDAR survey will provide an improved DEM and much improved vegetation mapping for input to the model. The model is documented and ready for testing at other locations. Initial model testing at a simpler prairie site shows excellent performance in estimating seasonal SWE over a fine (6 m) grid spacing where LiDAR DEMs are available. The model was used to inform the development of an HRU-based snow redistribution algorithm for CRHM. The CRHM algorithm uses a simple wind speed adjustment routine for complex terrain, and the simple blowing snow model algorithm forms the core of the distributed model. Initial tests in rolling prairie terrain show very similar results between this CRHM routine and the fully distributed blowing snow model.

- **Develop (initial) improved parameterizations including advection of heat and mass between tiles.**

The major TILES (Tilted Landscape Elements) have been identified for wetland, discontinuous permafrost terrain. Mass transport among bog, fen, and peat plateau TILES has been simulated for Scotty Creek for different landscape arrangements of TILES.

- **Coordinate with WC2N (CFCAS Network) to acquire a data set for testing mass and energy balance models over glaciated terrain.**

WC2N was assisted with the installation of an energy-balance system on the Opabin Glacier as part of a coordinated effort to understand energy and mass balance processes over partially-glaciated terrain. The energy-balance system was operated from June to September 2007. A project on Landsat determination of glacier albedo fields was reactivated in July 2006 and is now near completion. A final question being addressed is whether an ice/snow albedo designation is sufficient for modelling purposes or whether the glacier ice cover should be further subdivided. Radiation modelling is well in hand, and the transfers of sensible heat and water vapour will be explored further.

- **Assess MAGS aircraft data for use in determining regionally averaged fluxes.**

We have begun assessing the MAGS aircraft estimates of regionally averaged fluxes of sensible and latent heat over Trail Valley and Havikpak Creek basins (average flux over an area of approximately 100 km^2).

Year 2:

- **Evaluate performance of CRHM in both GRU and HRU routing/aggregation modes against field and distributed modelling data.**

CRHM was set up at Wolf Creek in Granger sub-basin and for Marmot Creek for the purposes of testing snowmelt, infiltration, runoff, and streamflow generation routines in open environments (Granger) and snow accumulation and ablation in forested environments (Marmot). CRHM was able to produce reasonable snow ablation and spring streamflow discharge at Granger basin when run in a semi-distributed mode that accounted for snow redistribution and variable melt energy due to slope, aspect, and elevation. It could not reproduce snow-covered area and streamflow when run in aggregated mode with one tundra GRU (Dornes *et al.*, 2007). At Marmot, CRHM produced good snow accumulation and ablation estimates in forest and open environments except for one year when it grossly underestimated interception and sublimation losses from an upper elevation forest. The reasons for this are currently the subject of the intercepted snow unloading study being conducted at Marmot (see Theme 2, Year 1 above).

- **Synthesize surface and atmospheric observations for up-scaled flux and discharge calculations.**

Methods of deriving the spatial distribution of soil thaw from spatial distributions of canopy density, surface albedo, and soil moisture are being developed and will draw from the new LiDAR data set for Scotty Creek. This research will incorporate algorithms for radiation flux through forest canopies.

- **Develop (preliminary) subsurface flow module for CRHM.**

Over-winter cycling of moisture and energy is not well represented in the CRHM runoff module. In August, 2007, four 200 kg peat samples were taken from Scotty Creek and have been installed into the BIOTRON (a climate simulator) at the University of Western Ontario. Laboratory studies into the parameterisation of organic soil processes, including infiltration, over-winter moisture redistribution, and active layer development will commence this fall. In addition, HYDRUS-1D, a finite element infiltration model based on Richard's equation, is being modified for frozen soils and incorporation into CRHM.

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

For Scotty Creek, subsurface drainage to channels was computed for 5 consecutive years and compared with water balance calculations based on measurements at instrumented soil pits. A strong correlation was found between slope runoff (CRHM) and observed peak discharge from the basin outlet. Evaluation of MESH is in progress.

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

A computer model called SFASH (Simple Fill and Spill Hydrology) was created to simulate how variations in frost table elevation may affect lateral drainage and hillslope connectivity. A numerical model to calculate direct and diffuse radiation beneath coniferous forests on slopes was devised and tested at Marmot Creek (Ellis and Pomeroy, 2007). The model accounts for both canopy density and slope/aspect effects on irradiance for the first time in a radiative transfer scheme. The variability of energy available for snowmelt controls the snow cover depletion curve but is currently not represented in snow models. The model is being tested using observations from forest stands of varying density in Colorado and Marmot Creek. Seven models were modified/developed to simulate soil freezing processes with standard parameterizations.

Theme 3 - Prediction

The Prediction Theme has made significant progress by completing the operational version of the MESH model. MESH is an innovative combination of the CLASS land surface scheme with tile- and grid-based hydrological routing of water that is driven either by itself as a hydrological model or within Environment Canada's Global Environmental Multi-scale model (GEM) system as part of the Numerical Weather Prediction (NWP) model. MESH provides a multi-scale calculation procedure for cold regions hydrometeorology. MESH has been set up for the eight research basins and its structure over a much larger and more complex domain (Saskatchewan River Basin) has started. Parameter transfer for MESH from the mountain alpine tundra to lowland Arctic tundra has been demonstrated and routing parameter estimation using topographic indices has begun. The GEM-LAM (GEM - Limited Area Mode) has been set up for some of the research basins and is undergoing initial evaluation.

Year 1:

- **Establish operational version of existing MESH model for all research basin and NWP domains. This includes:**
  - **Reviewing current modeling and data status in meso-scale and regional research basins.**
  - **Establishing GEM-LAM domains for each of the research domains that incorporate the MESH system for hydrological routing and basin segmentation (tiles, tile connectors, and grid connectors).**
  - **Basing the simulations on existing Water Survey of Canada climate and synoptic station gauge locations within the domain.**

This project has the primary task of supporting the field component of IP3 with meso-scale modelling. This involves interacting with field researchers to help develop the model and its parameters and to implement the MESH model in all the research basins. Operational code developed at Environment Canada's Hydrometeorology and Arctic Laboratory (HAL) must be made available to all Theme 3 researchers on a consistent and timely basis. Significant progress has been made in developing and using software engineering processes to improve our ability to collaborate including implementation of an accessible software configuration management (SCM) system for effectively working with code developers and modellers across the country. The system revolves around a central repository in Saskatoon of model code, documentation, and run files that can be downloaded by any authorized IP3 participant. The repository has three main directories: a trunk directory for the latest version of the model, a tag directory for tagged releases of the model, and a branch directory containing sub-directories for each developer or model user to do his or her work. The trunk and tag directories can only be altered by a very limited number of people. To date, successful training, implementation, and use of the SCM system has been completed with numerous researchers. Other advances in the implementation of software engineering include improved documentation and the beginning of regular code reviews of MESH subroutines. We have also begun to organize monthly conference calls for model developers and users.

Development of MESH revolves around 5 components. 1) CLASS code is developed and controlled by Environment Canada's (EC) Climate Research Directorate (CRD) with input from the University of Waterloo, HAL, and Recherche Prévision Numérique (RPN). 2) The routing component and other sub-grid water flow processes have been developed at the University of Waterloo. The remaining 3 components are different versions of the model driver, which control all of the input, initialization, and output processes surrounding the model physics execution. Currently, 3) CLASS has its own standalone driver, 4) standalone MESH has its own driver based on the University of Waterloo's WATCLASS, and 5) MEC-MESH has its own driver based on the GEM NWP model. Work is ongoing to merge these three drivers as much as possible to simplify future use and development of MESH.

One of the key accomplishments has been setting up all of the research basins using the MESH model. This involved a base-case MESH dataset, supplied by the co-investigators from each basin, where each of the basins is represented by a single grid square and a single land cover. This base-case will serve as a starting point for comparisons of future model runs. This has allowed for the testing and verification of the input data. To increase interaction with the co-investigators, a form-based parameter entry system called PARAMESH has been developed.

<u>Year 2:</u>

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

A preliminary assessment of field data from Scotty Creek has been performed, and appropriate parameter values are being evaluated based on field experience. This includes the distribution of peat plateau parameters and different ways to characterize the diversion of flow throughout the system. Current work is focussed on a multi-objective calibration involving soil moisture and temperature along with streamflow. CLASS was set up and tested at Granger basin (in Wolf Creek) by coupling to CRHM which distributed inputs of radiation and air temperature to CLASS. It was shown that by distributing the CLASS tiles by slope, aspect, and elevation, accurate representation of snowmelt could be achieved. Further research (Dornes *et al.,* submitted) compares modelling results obtained at Trail Valley Creek and Wolf Creek. Landscape-based parameters for shrub-tundra were shown to be transferable between these two very different hydrological regimes (arctic tundra and tundra cordillera). There were difficulties, however, in measuring or transferring the parameters for snow-covered area (SCA) depletion. For Trail Valley Creek, MESH modelling has evolved from earlier work into calibration of the model using the SCA-depletion method established at the University of Waterloo (Donald *et al.*, 1995). Field studies of ground frost/runoff processes have begun at Baker Creek using hydrometric, hydrochemical, and remote sensing techniques. Model tests have begun using CRHM, with encouraging results. At Marmot Creek, modelling using topographically-based indices has proceeded. This should help inform some of the lateral transfer (overland runoff) issues in the basin.

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

The grid-based hydrological routing aspects of MESH have been completed for the North and South Saskatchewan basins, which incorporate Marmot Creek and Peyto Glacier. Water routing tests, provisionally driven by WATFLOOD point hydrology, are being run to evaluate the completeness of this routing framework. The full MESH model has not yet been run over this domain but will be run as parameter sets are developed. 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 through comparison with observed hydrographs. Model predictions will be compared, where possible, 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 Trail Valley and Wolf Creeks. Comparisons of hydrograph and SWE from the MESH model were made with historic and recent observations. These data were also used in CLASS/MESH model calibration. CLASS/GEM interactions are being explored, with the Canadian GEM operating 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 objective of using the GEM-LAM model is to develop high-resolution simulations to improve our understanding of local conditions (e.g. orography or vegetation), physical processes (e.g. cloud microphysics or radiation), and dynamical atmospheric organization (e.g. multiscale weather systems). The importance of using the GEM-LAM on IP3 basins is to address temporally or spatially incomplete databases. Phenomena of special interest include cloud/radiation interaction, ice phase microphysics, and turbulence parameterization (of the boundary layer). Thus, it is possible to reproduce the regional detail in surface climate as forced by topography, lakes, coastlines, and variations in land surface type. The GEM-LAM model has been installed on the Saskatoon HAL lab cluster and has been made available to IP3 researchers for running the nested version of GEM-LAM on the IP3 domain.