Environnement Canada Environment Canada

Canada

Land-Surface-Hydrological Models for Environmental Prediction

Dr. Alain Pietroniro P.Eng.
Director – Water Survey of Canada
Environment Canada

Dr. John Pomeroy
Centre for Hydrology
University of Saskatchewan

Dr. Pablo Dornes
Centre for Hydrology
University of Saskatchewan

Mr. Bruce Davison – HAL
Environment Canada

Mr. Matt Macdonal
Centre for Hydrology
University of Saskatchewan

Ms. Laura Comeau Centre for Hydrology
University of Saskatchewan

Ms. Brenda Toth – HAL
Environment Canada

Mr. Anthony Liu – HAL
Environment Canada

Objectives

- Highlight Environment Canada's Water Cycle Prediction Framework
- Operationalizing the system – Upper Lakes Study
  - Describe the system
  - Some results
- IP3 Contributions
- Future Considerations

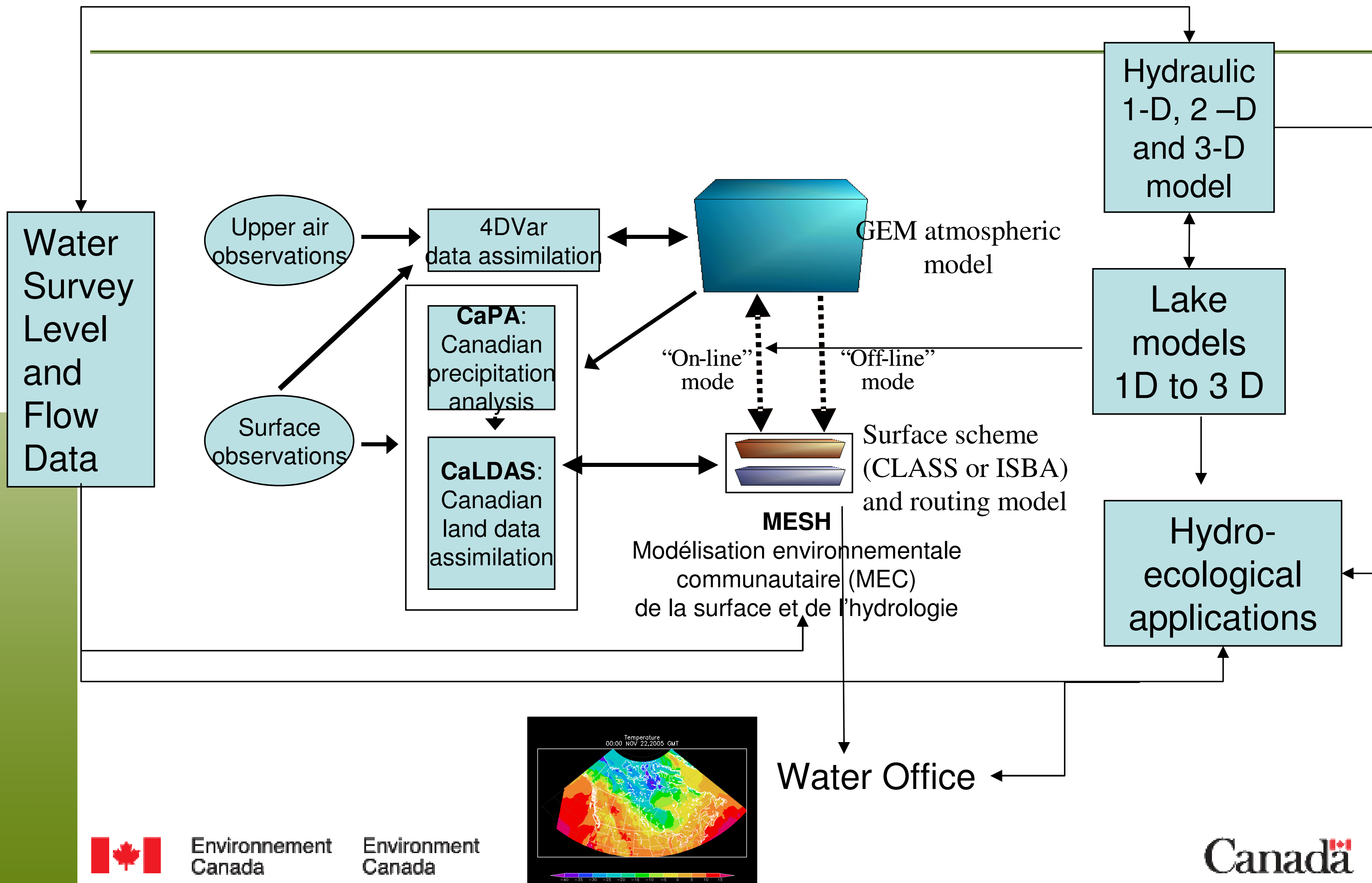
Water Cycle Prediction Science…

- Supports weather and environmental predictions and services, departmental decision making and policy development.
- By engaging a broad community of users and science providers (nationally and internationally)
- To deliver *credible, relevant, integrated and usable*
  - Environmental knowledge,
  - Advice
  - Decision making tools and
  - Information
- On existing and emerging issues in the discipline of Water Resources…

Water Cycle Program 2009-10

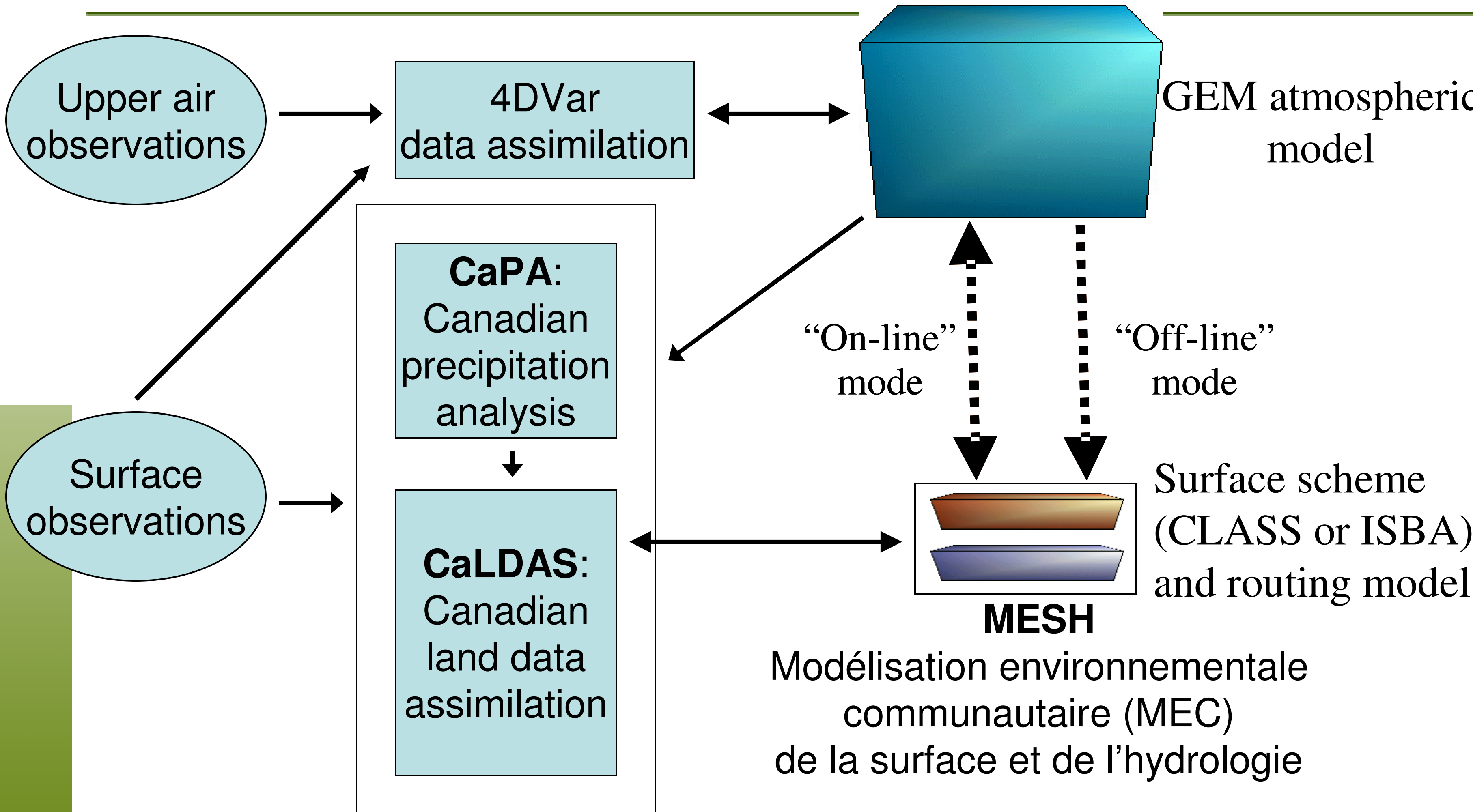
- ISO9001 certification in 2008-09
- Focal Points
  - Hydrometeorology
    - MESH development - Modeling and field work.
  - Eco-Hydraulic and Hydraulic
    - 2-D hydraulic model operationalizing linked with ecology
  - Hydro-climate
    - Hydro-climatic Analysis
- Services development
  - Applications and tools

Operational Prediction Framework for Water Services



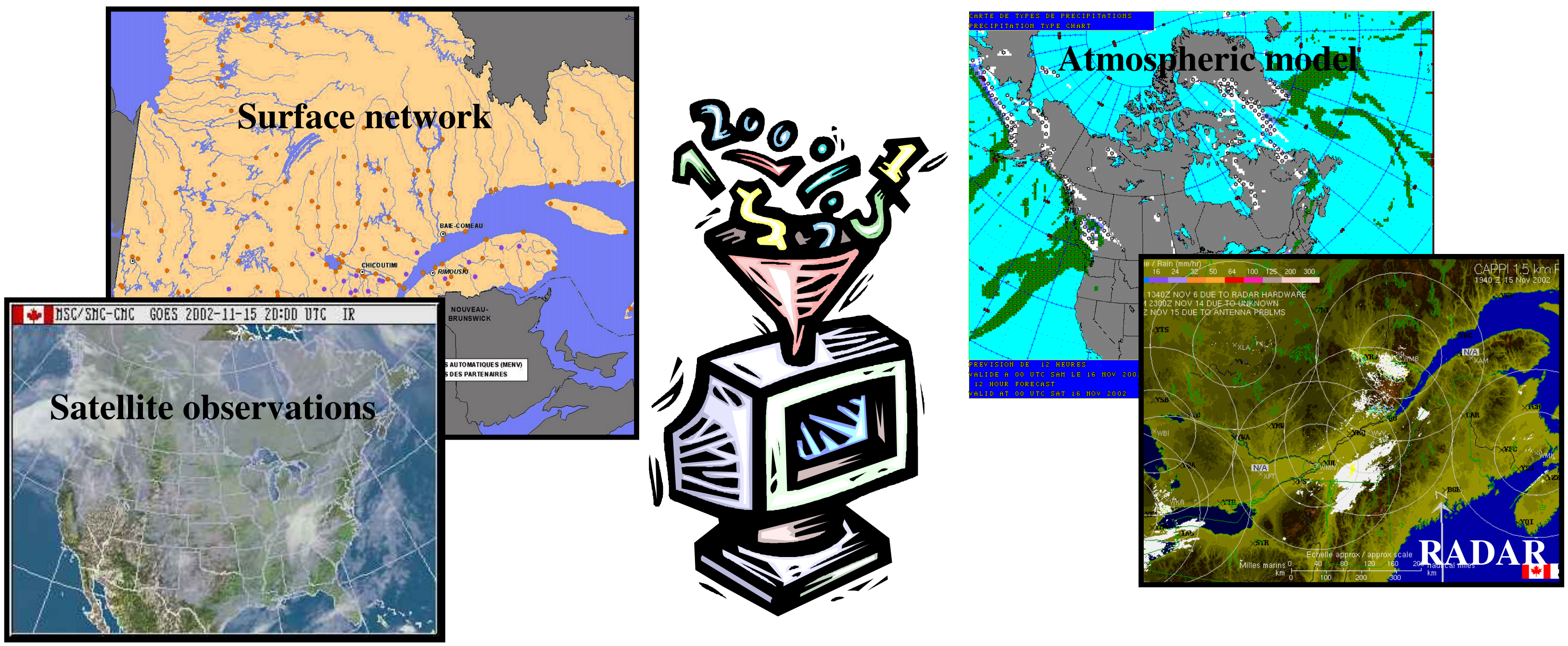
Temperature above 2 meters for Canada, November 22 2005, 00:00 (.gif image)

Environmental Prediction Framework



Canadian Precipitation Analysis (CaPA)

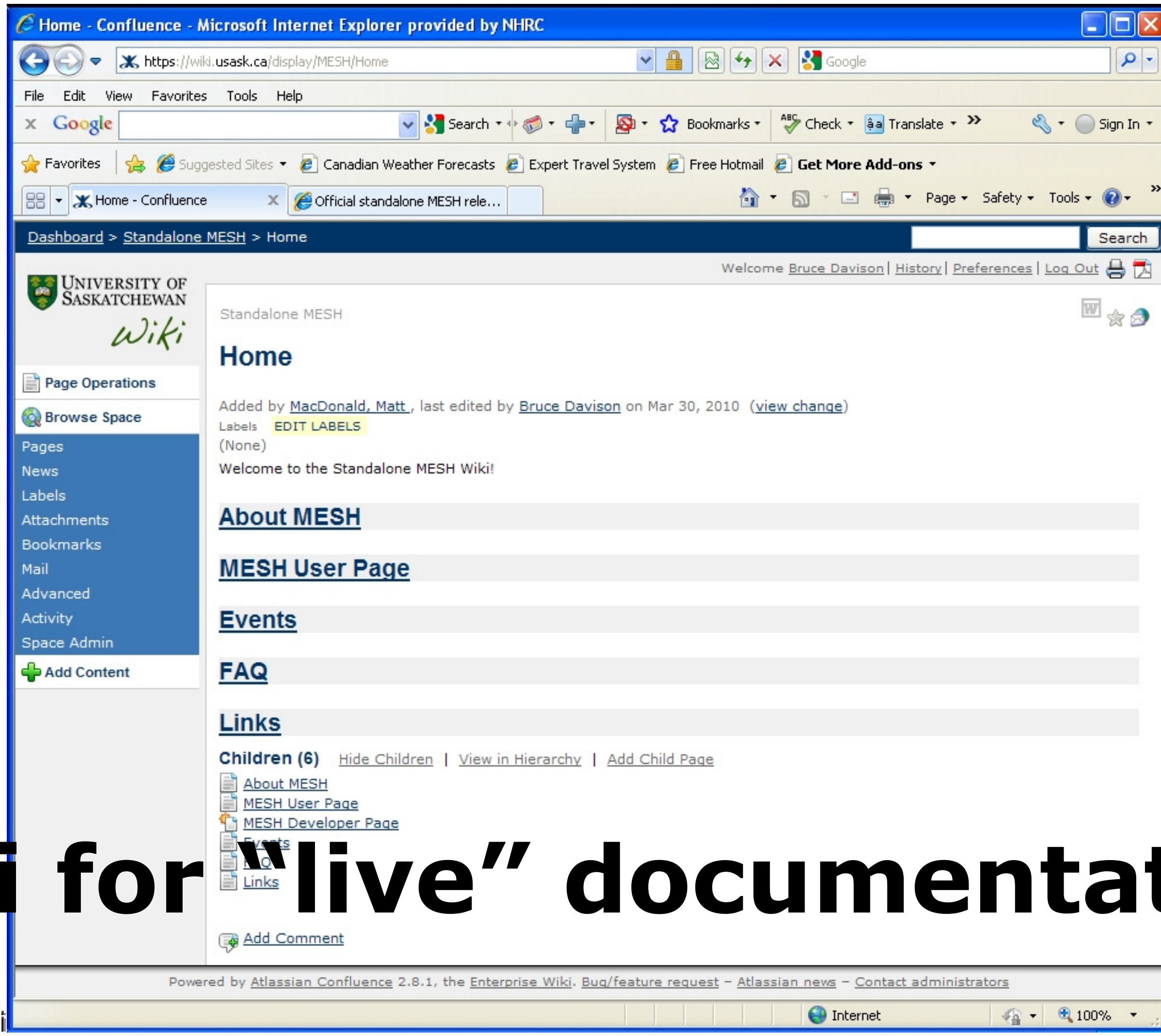
- Combines different sources of information on precipitation into a single, near real-time analysis using optimal interpolation
- Analysis is then used to improve environmental predictions and provide forcing for Canadian land-data assimilation system (CaLDAS)



Canadian Land Data Assimilation System (CaLDAS)

- CaLDAS provides initial conditions (soil moisture, soil temperature) for both the atmospheric model (GEM) and the hydrological model (MESH)
- Using:
  - Forcings from GEM + CaPA precipitation analysis
- It finds:
  - Values of surface soil moisture and temperature which minimize the error in the diagnostics of 2m temperature and relative humidity made by the land surface model
- Work is in progress to include satellite observations of soil moisture

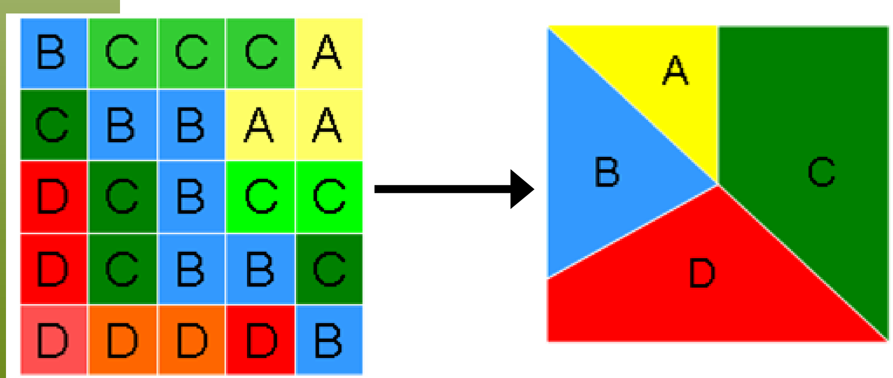
Community Model

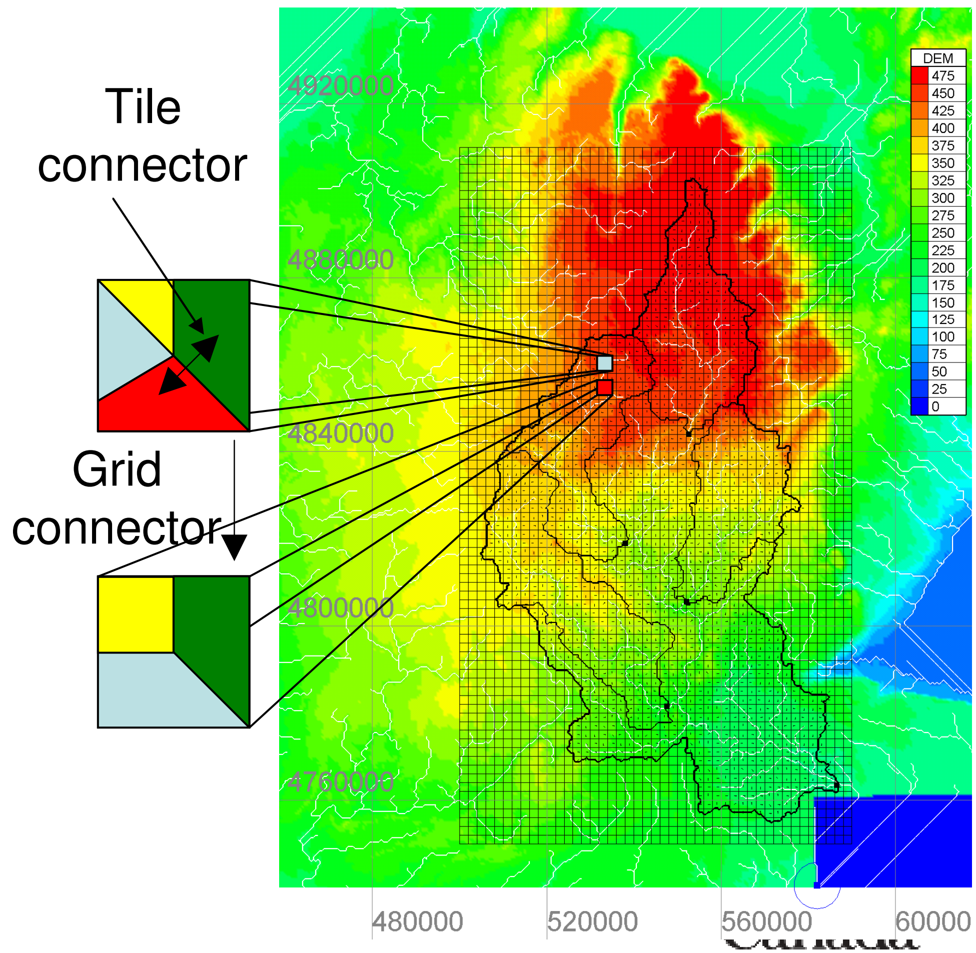


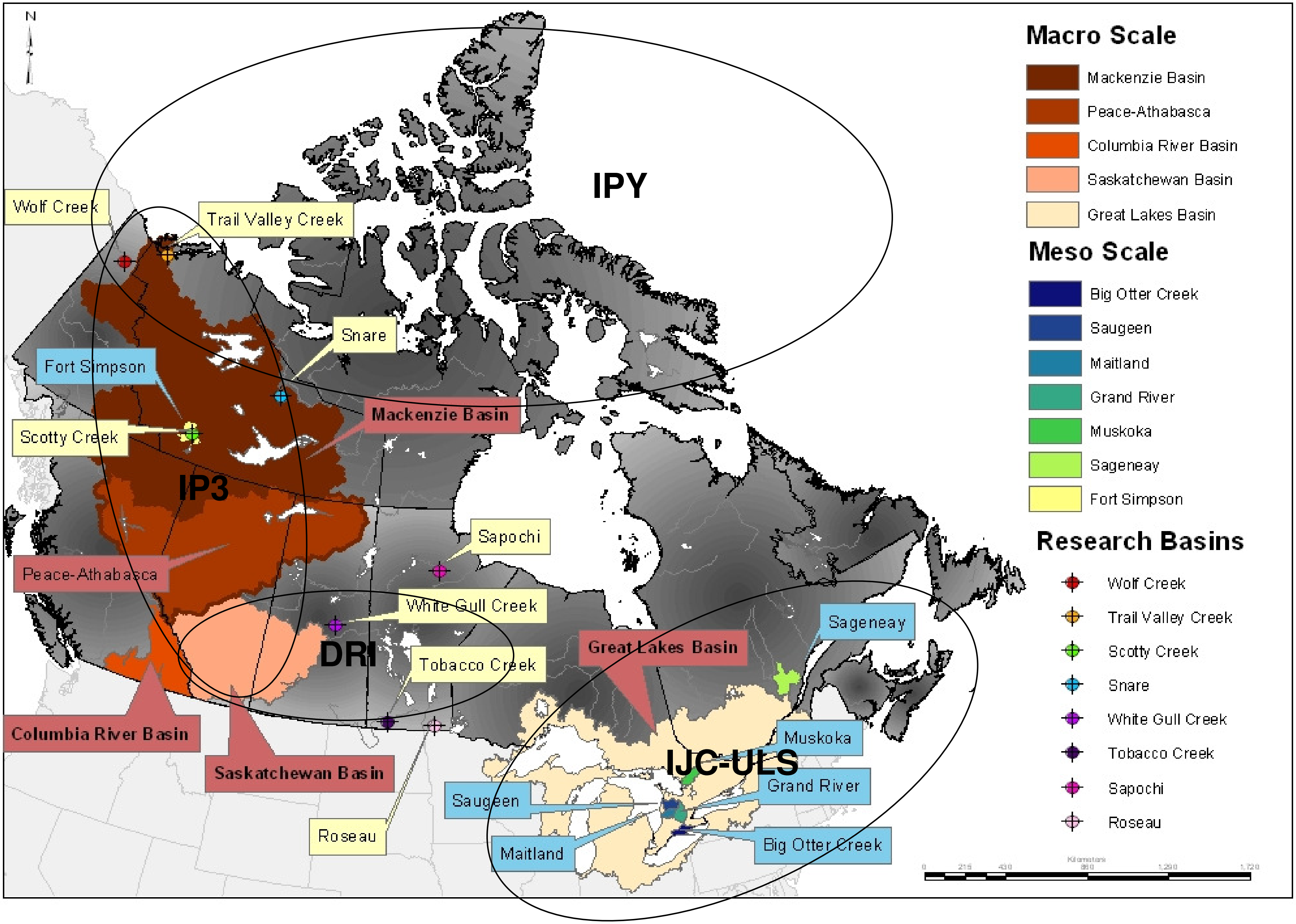
Wiki for "live" documentation

MESH: A MEC surface/hydrology configuration
BASIN SEGMENTATION ?

- The tile connector (1D, scalable) redistributes mass and energy between tiles in a grid cell
  - e.g. snow drift
- The grid connector (2D) is responsible for routing runoff
  - can still be parallelized by grouping grid cells by subwatershed



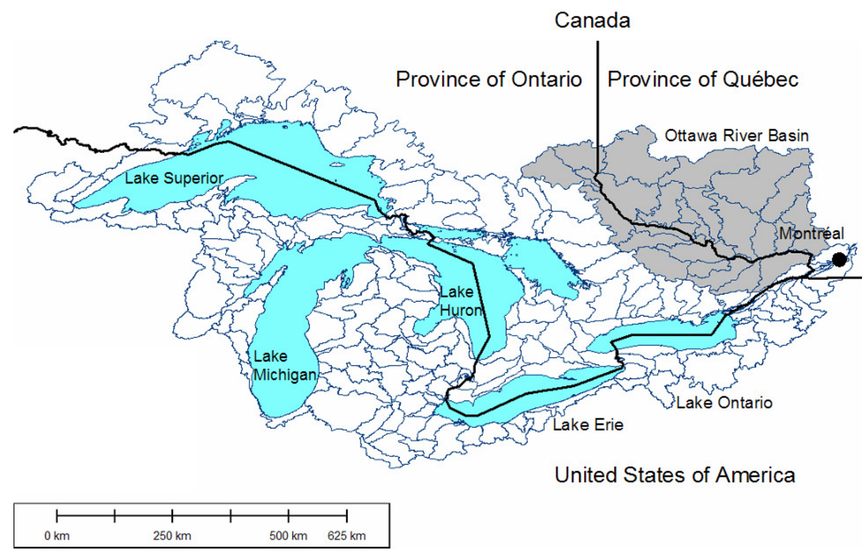



N
IPY
IP3
DRI
IJC-ULS
Wolf Creek
Trail Valley Creek
Snare
Fort Simpson
Scotty Creek
Mackenzie Basin
Peace-Athabasca
Sapochi
White Gull Creek
Tobacco Creek
Columbia River Basin
Saskatchewan Basin
Roseau
Great Lakes Basin
Sageneay
Muskoka
Grand River
Saugeen
Maitland
Big Otter Creek
Macro Scale
Mackenzie Basin
Peace-Athabasca
Columbia River Basin
Saskatchewan Basin
Great Lakes Basin
Meso Scale
Big Otter Creek
Saugeen
Maitland
Grand River
Muskoka
Sageneay
Fort Simpson
Research Basins
Wolf Creek
Trail Valley Creek
Scotty Creek
Snare
White Gull Creek
Tobacco Creek
Sapochi
Roseau

Applying EP framework
Great Lakes and St.Lawrence Testbed

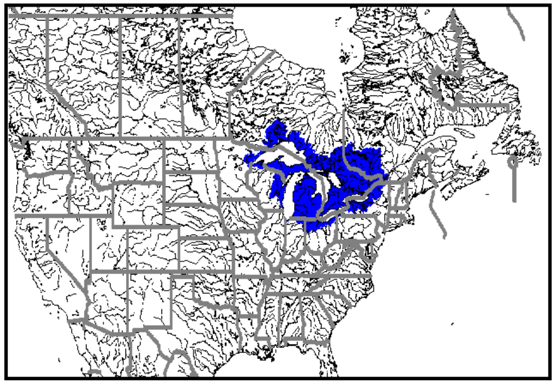
Largest lake group in the world:

- lake area: 250 000 km²
- watershed area: 1 000 000 km²
- population: 40 millions
  - 30% of Canada's population
  - 10% of US population



Regulated according to an international agreement between Canada and the US

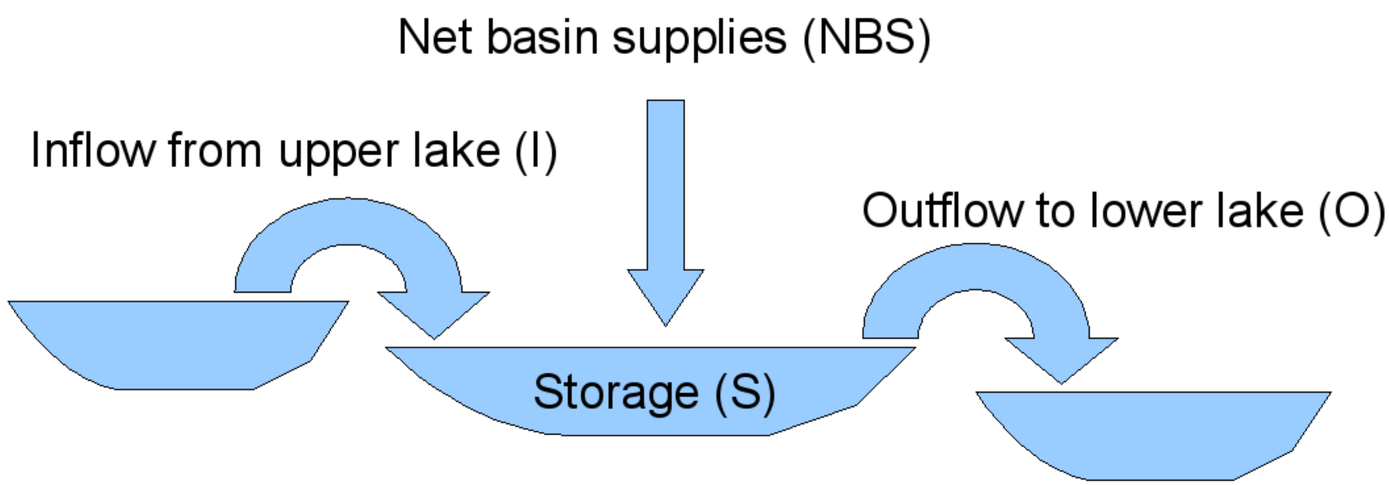
- implemented by the International Joint Commission



Making progress…..

- International Upper Great Lakes Study
  - Motivated by a recent drop in lake levels on the upper lakes
  - EC Hydrology contribution:
    - Explain through modelling variability in lake levels in the recent past
    - Predict long-term trend in lake levels using climate prediction models coupled to hydrology models
    - Contribute to adaptive management of the Great Lakes by designing an ensemble prediction system for water supplies

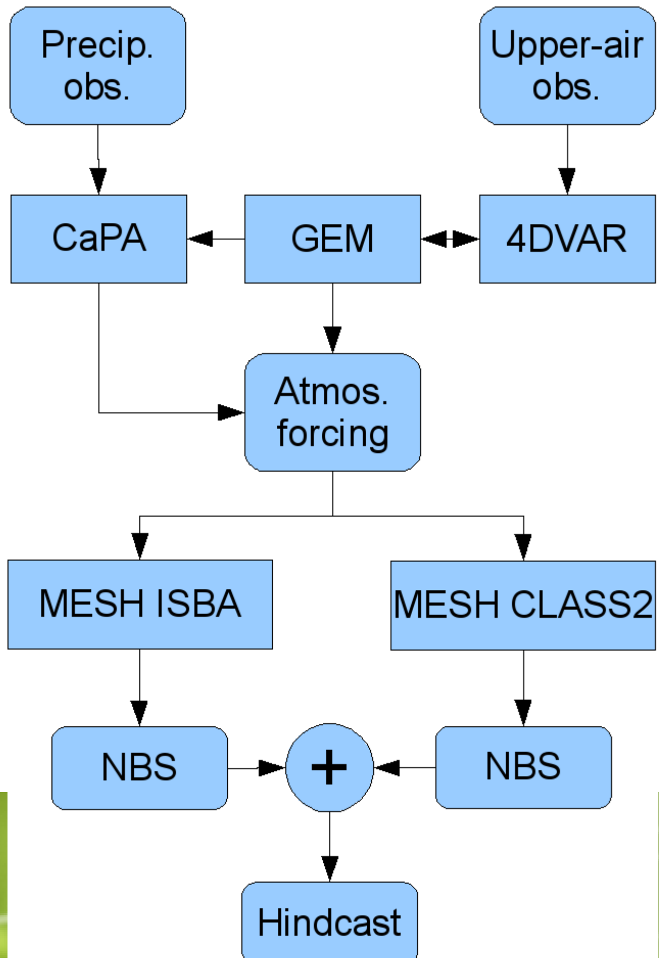
Performance of MESH in hindcast mode

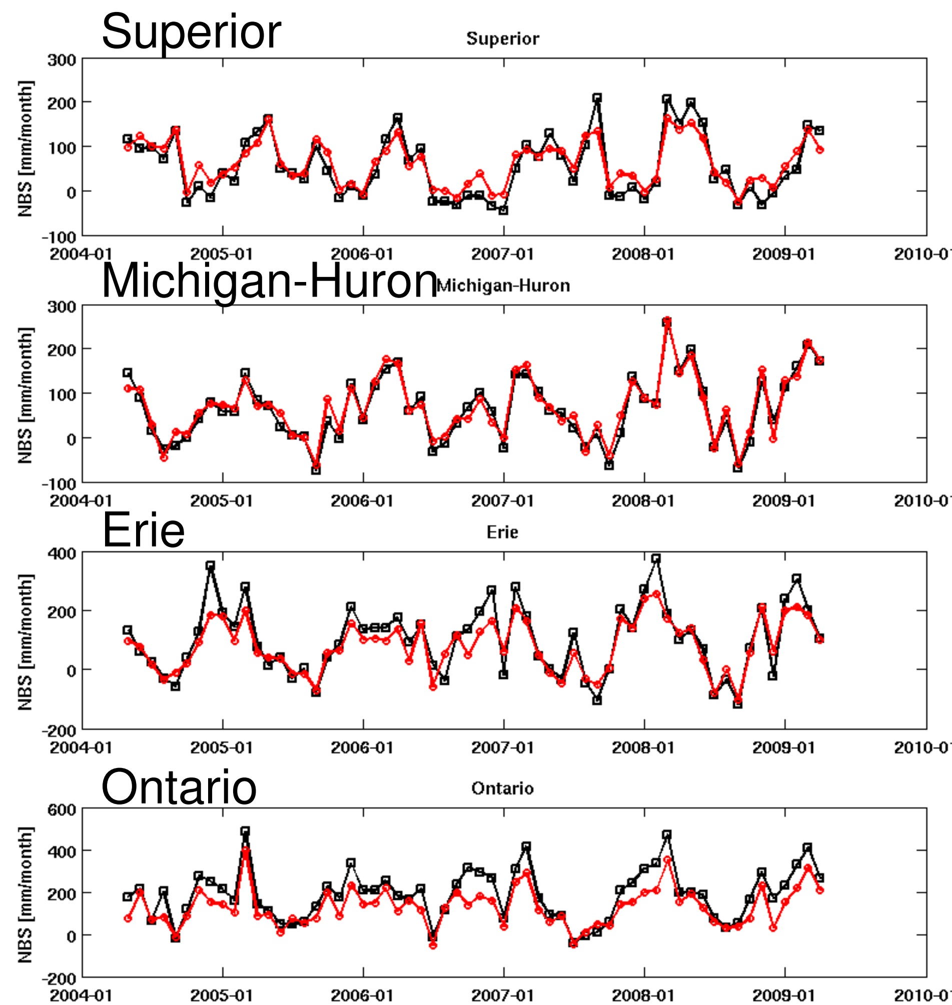


$$NBS = \Delta S + O - I$$

$$NBS = P_{Lake} - E_{Lake} + R_{Basin}$$

5-year hindcast with MESH in offline mode forced by GEM short-term forecasts + precip. analysis





Black: residual NBS

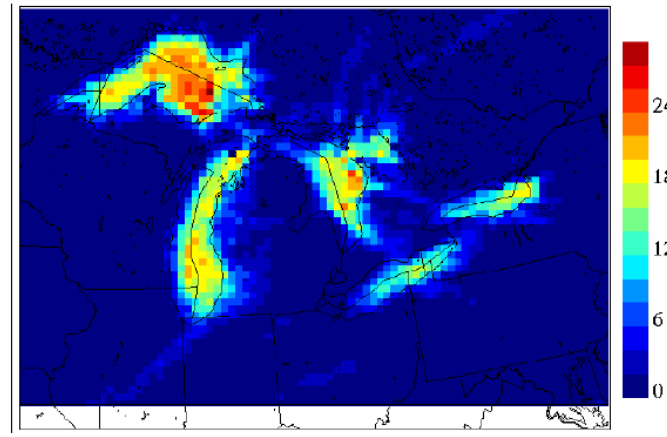
Red: component NBS

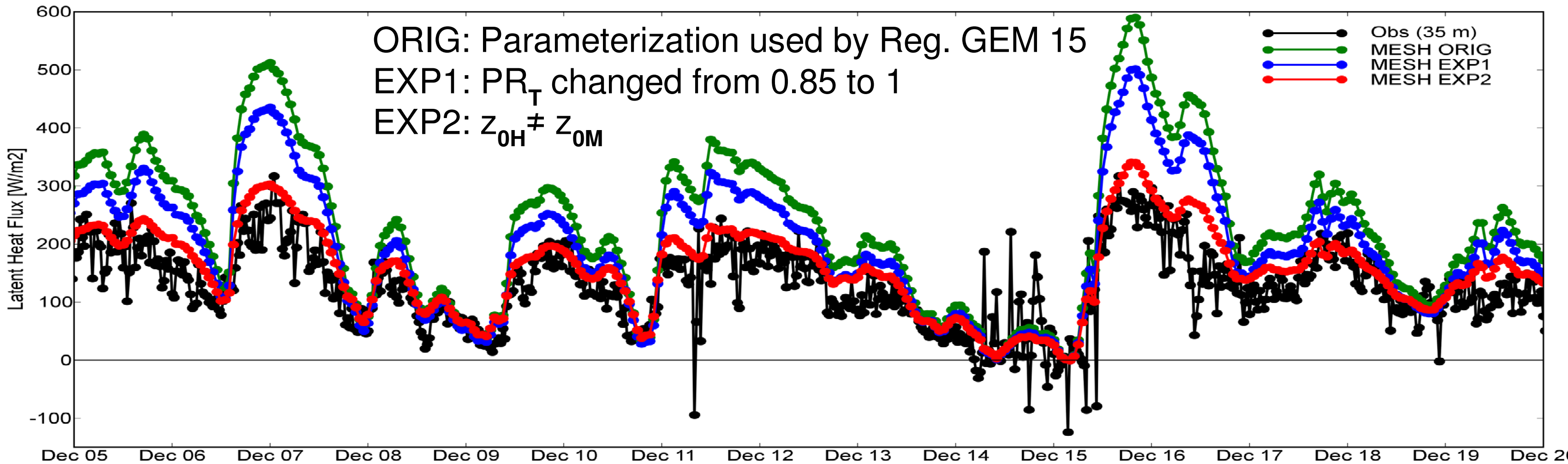
Environnement Canada Environment Canada

Canada

Getting NBS right required improvements to GEM evaporation parameterization over water

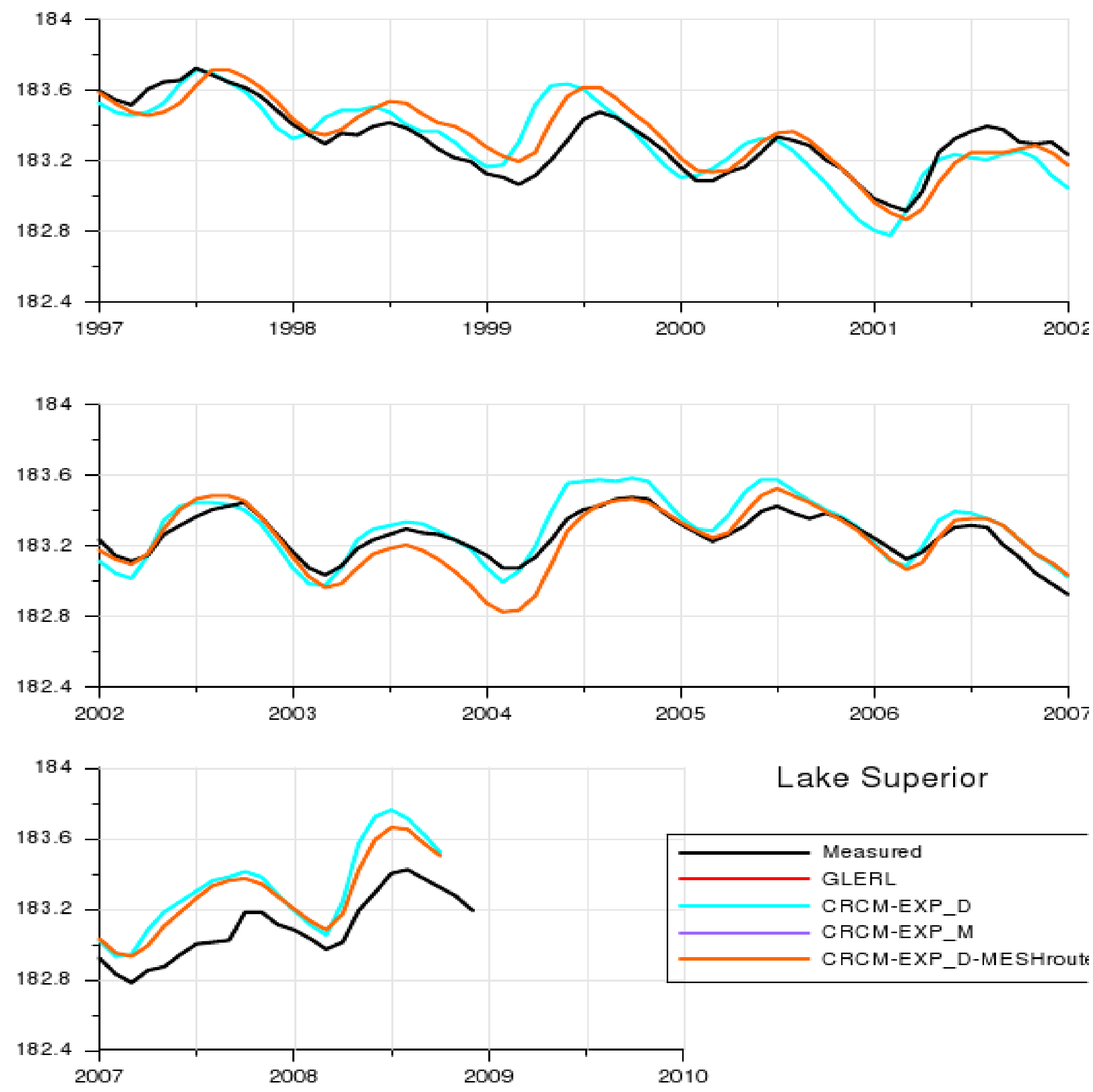
Impact of precipitation forecast (sum of 31 daily forecasts, Dec 09)





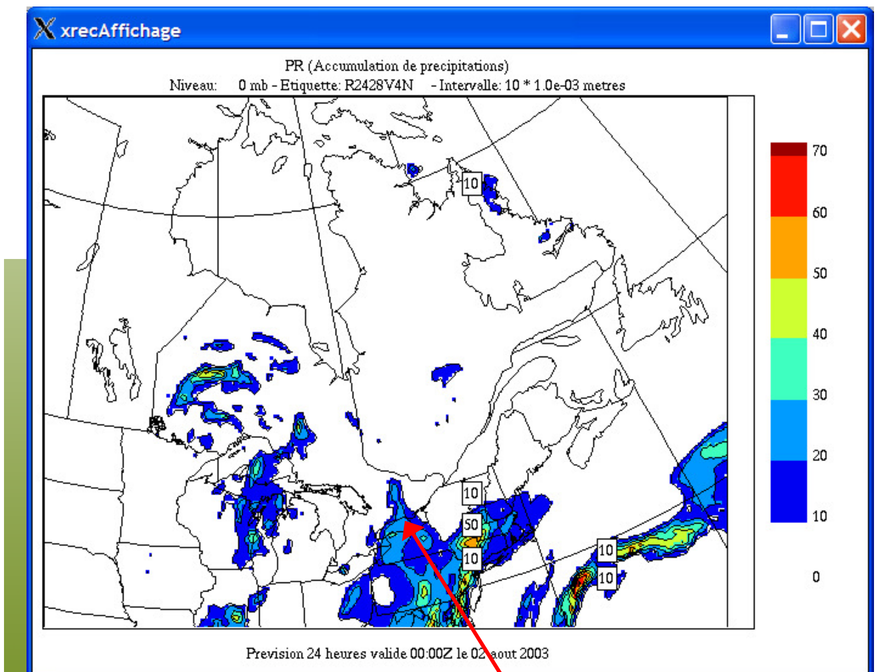
10-year hindcast, MESH two-way coupled to the Canadian RCM

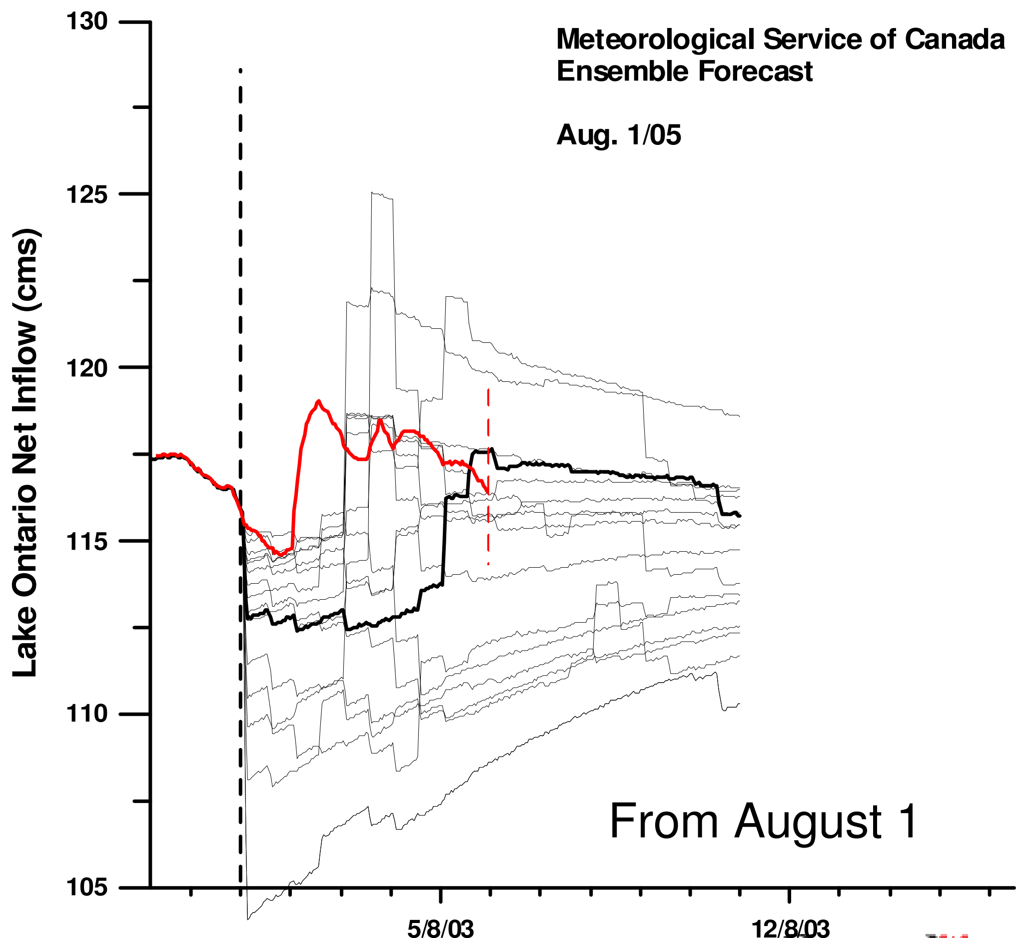
- Predicting the level of Lake Superior:
  - Black: observed
  - Blue: levels obtained from P–E predicted by RCM, no hydrology
  - Orange: levels predicted by MESH



Environnement Canada Environment Canada

Ensemble forecast of inflows into Lake Ontario, August 2003

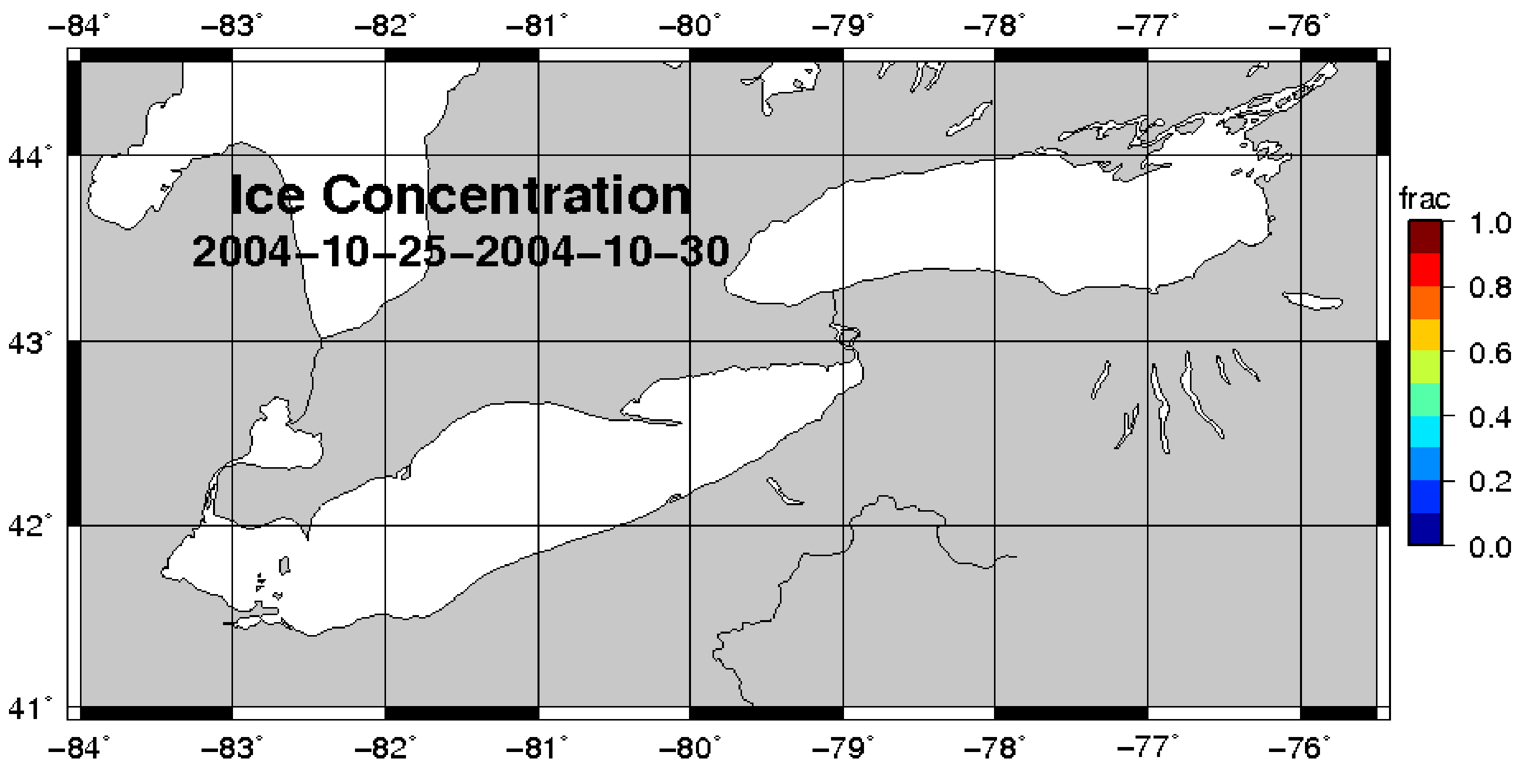




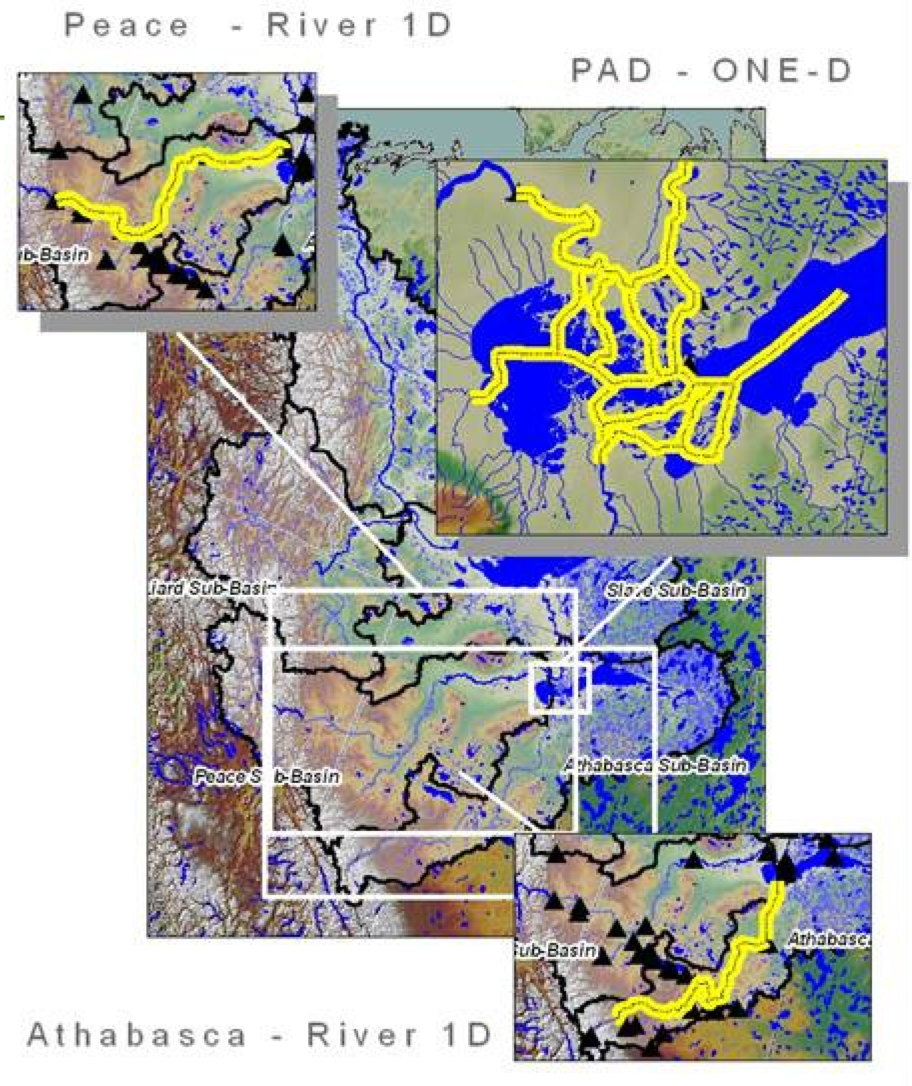
Lake Ontario

3D hydrodynamic modelling of the Great Lakes with NEMO

- Realistic ice cover simulations obtained (currently being verified)



Model Domain



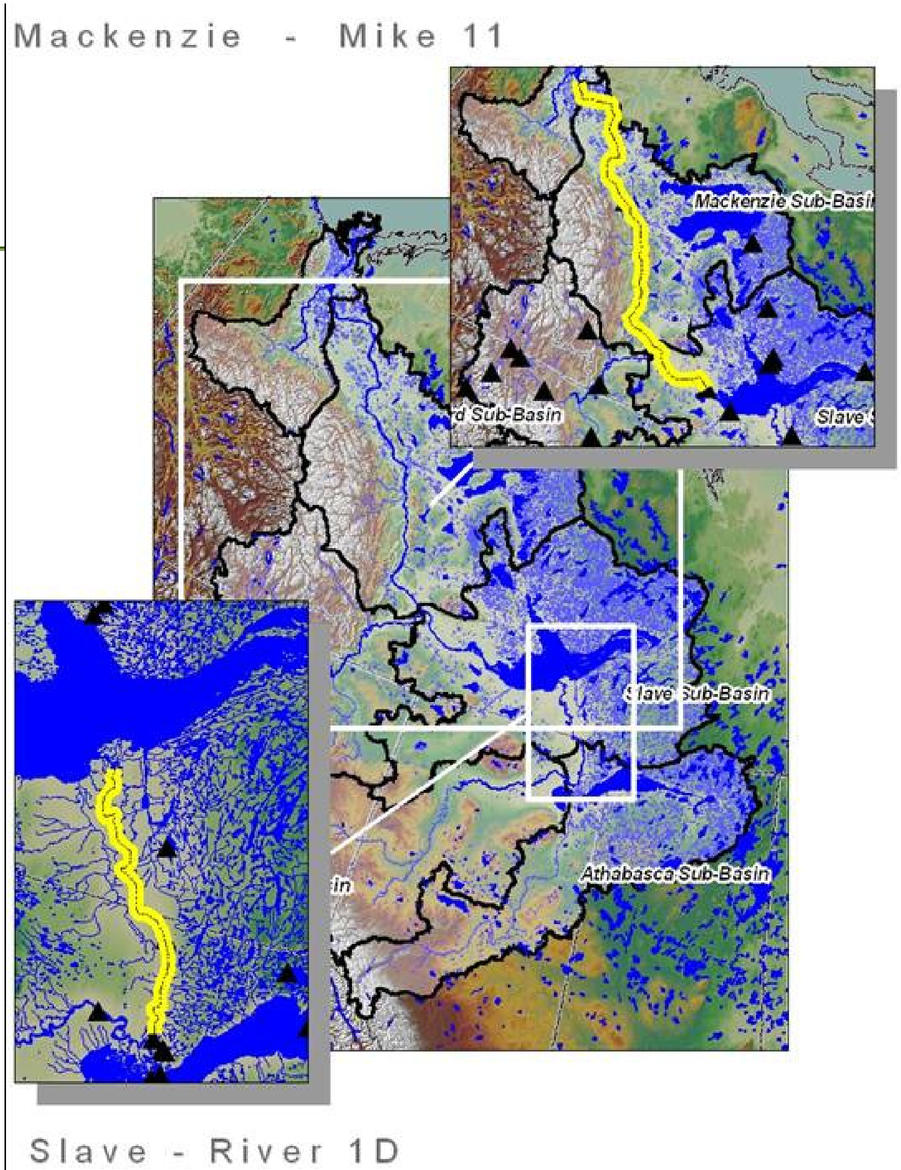
Approximate locations of the hydraulic modeling domains for both the Environment Canada ONE-D model and the River1D model.

Note the black triangles indicate current WSC streamflow and /or level gauges.

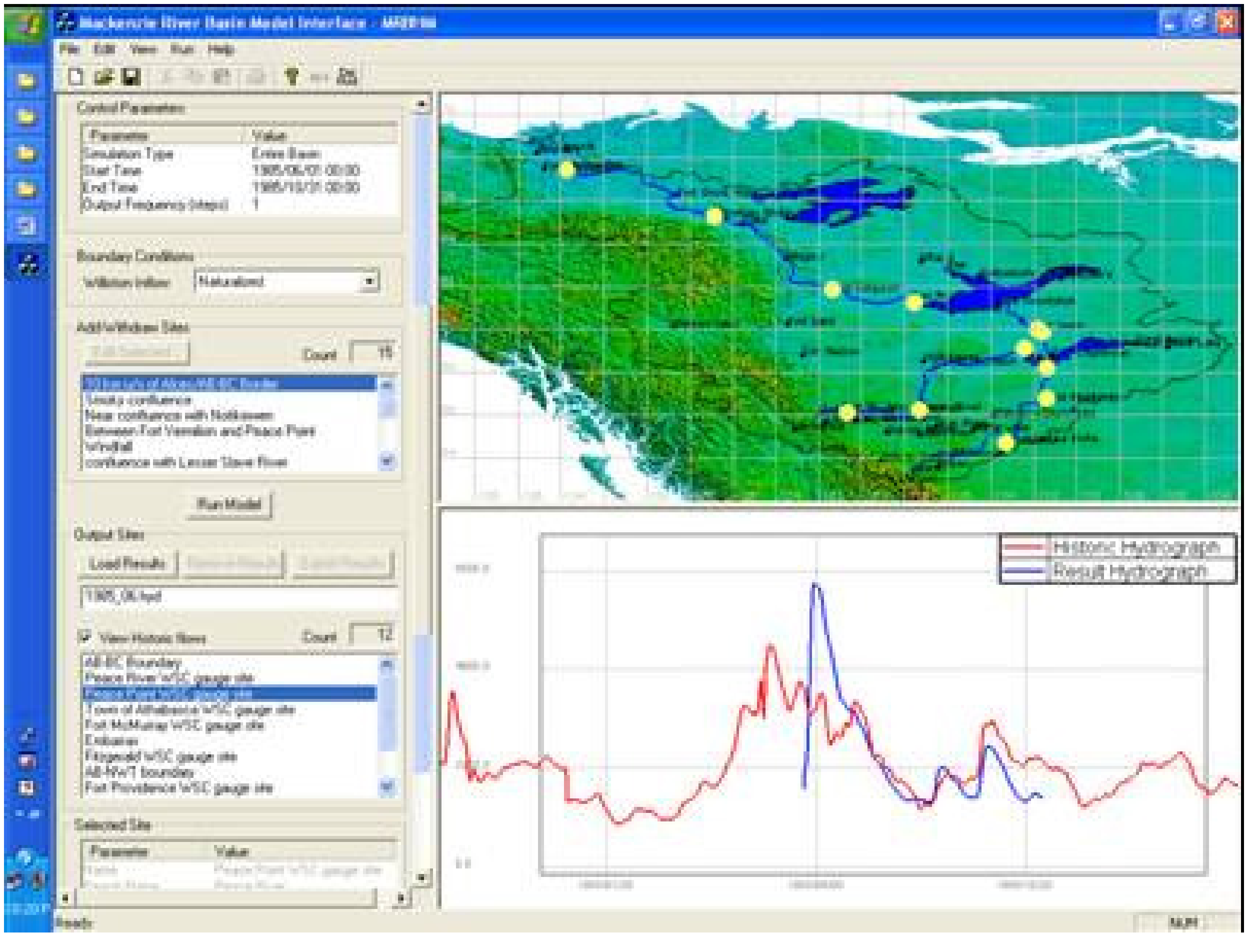
Model Domain

Approximate locations of the hydraulic modelling domains for both the MIKE-11 model and the River1D model.

Note the black triangles indicate current WSC streamflow and /or level gauges.



MRB Hydraulic Model



Environnement Canada Environment Canada

Canada

So what about IP3… ?

Modelling methodology

Inductive Approach → ← **Deductive Approach**

basin segmentation

Landscape based
Topography – vegetation

- Snow accumulation regimes
- Blowing snow transport
- Snowmelt energectics
- Snow interception
- Runoff generation/response

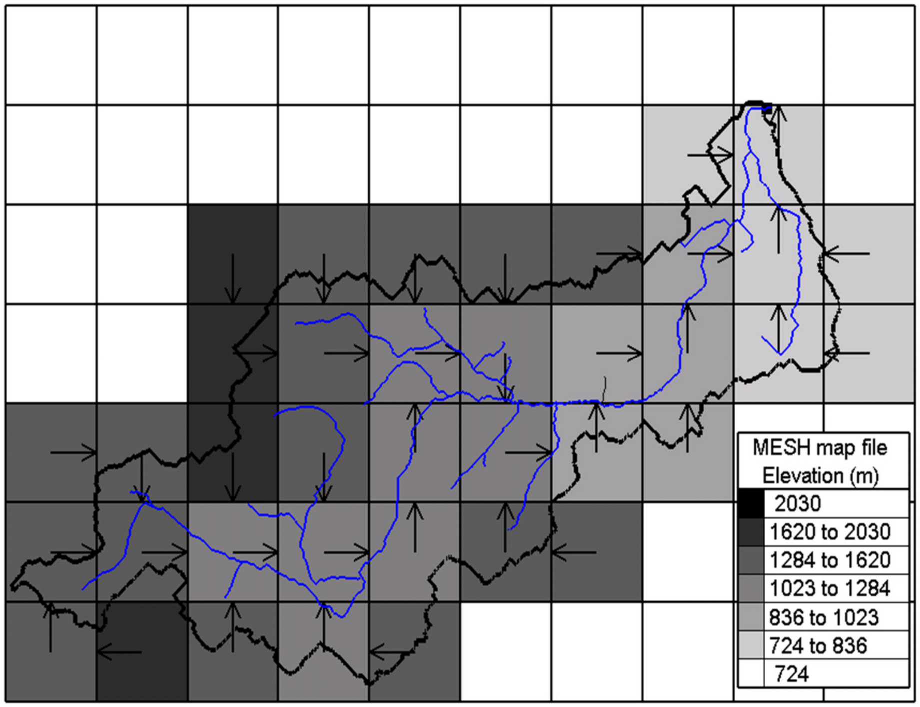
process descriptions

Detail process understanding
In cold regions research
basins
(e.g. WC, TVC, prairies)

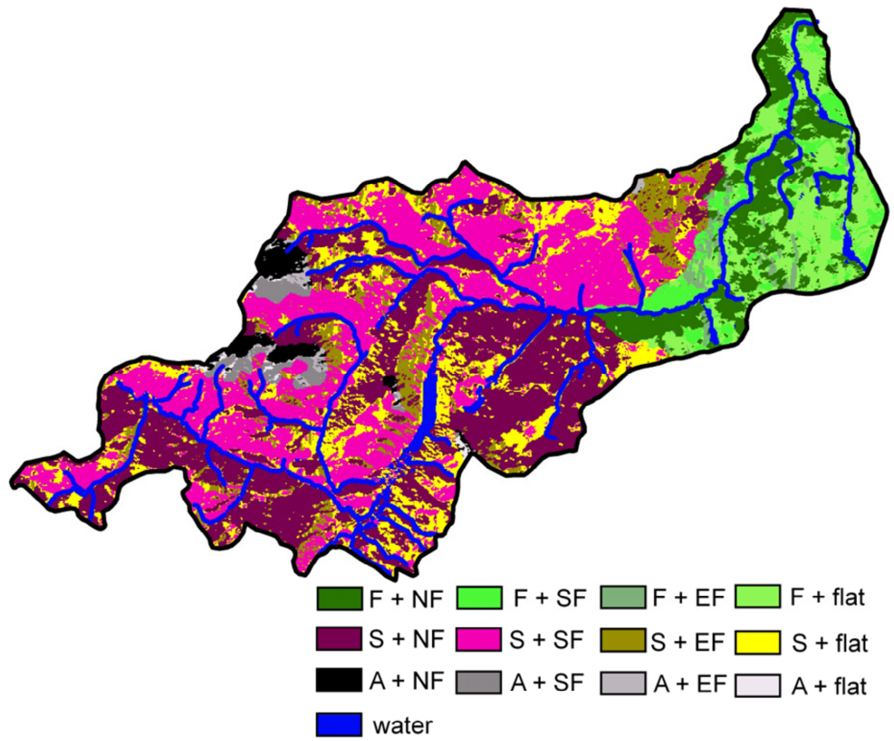
HAL/U of S Research

- Dornes (Ph.D- Complete) - Pomeroy
  - Successfully modeled stream flow and SWE during melt period
  - Successful transfer of parameterization
- Comeau (MASc – Complete)
  - Large scale modelling of NSRB and SSRB using WATFLOOD
  - Estimates of Glacier contribution to flow
  - Preparation fro MESH testing in glaciated basins
- MacDonald (MASc – in progress) - Pomeroy
  - PBSN coded into CLASS/MESH
  - Testing and evaluation in WOllf and Marmot Creek
- Marsh (MASc – in progress) – Pomeroy, Spitteri

MESH – Model Testing

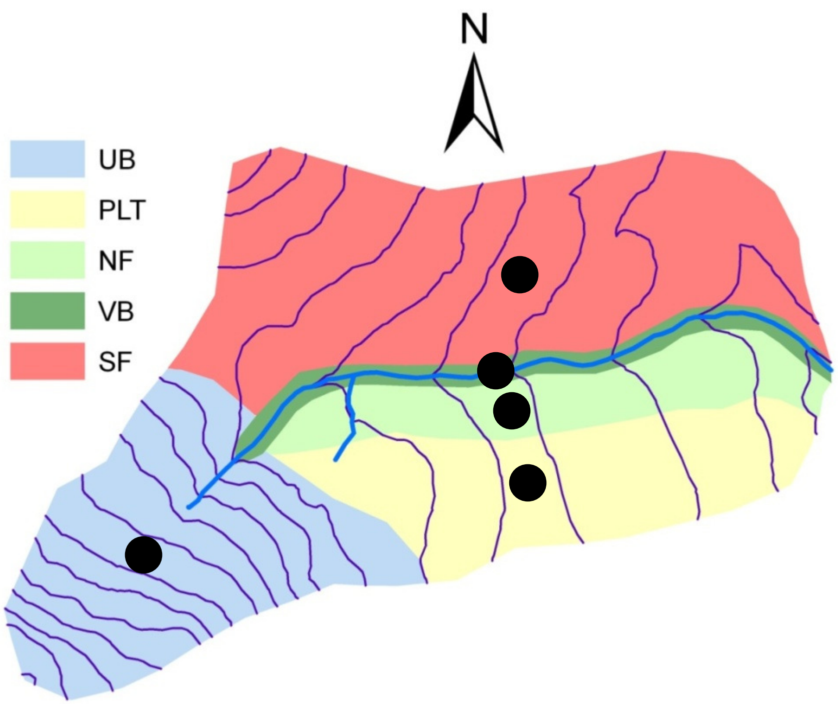


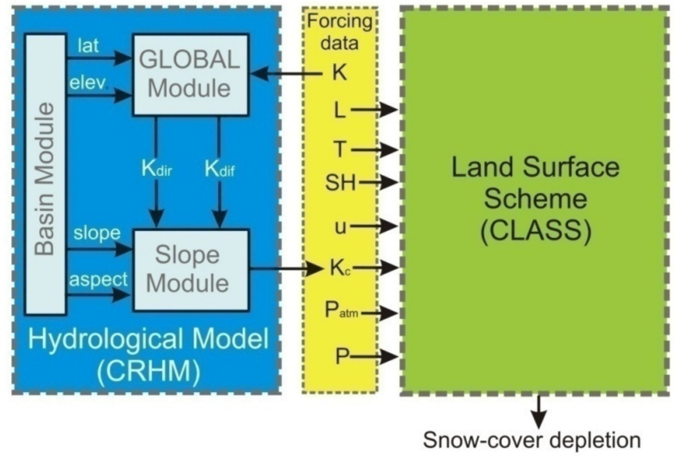
Grid model
spatial discretisation
3 km x 3 km

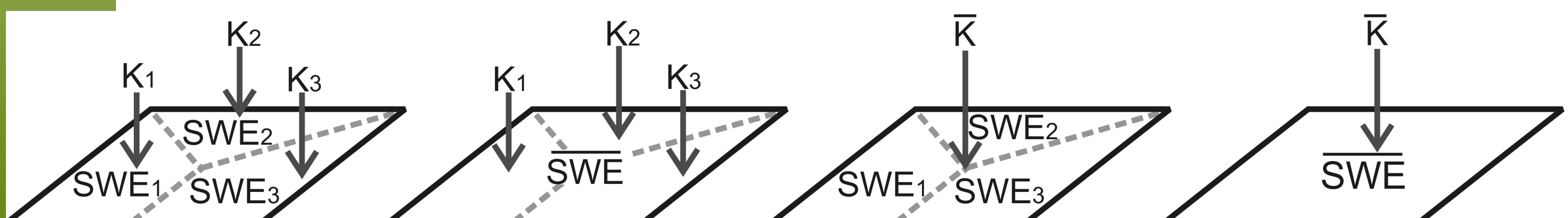


Landscape
representation
topography + land-
cover

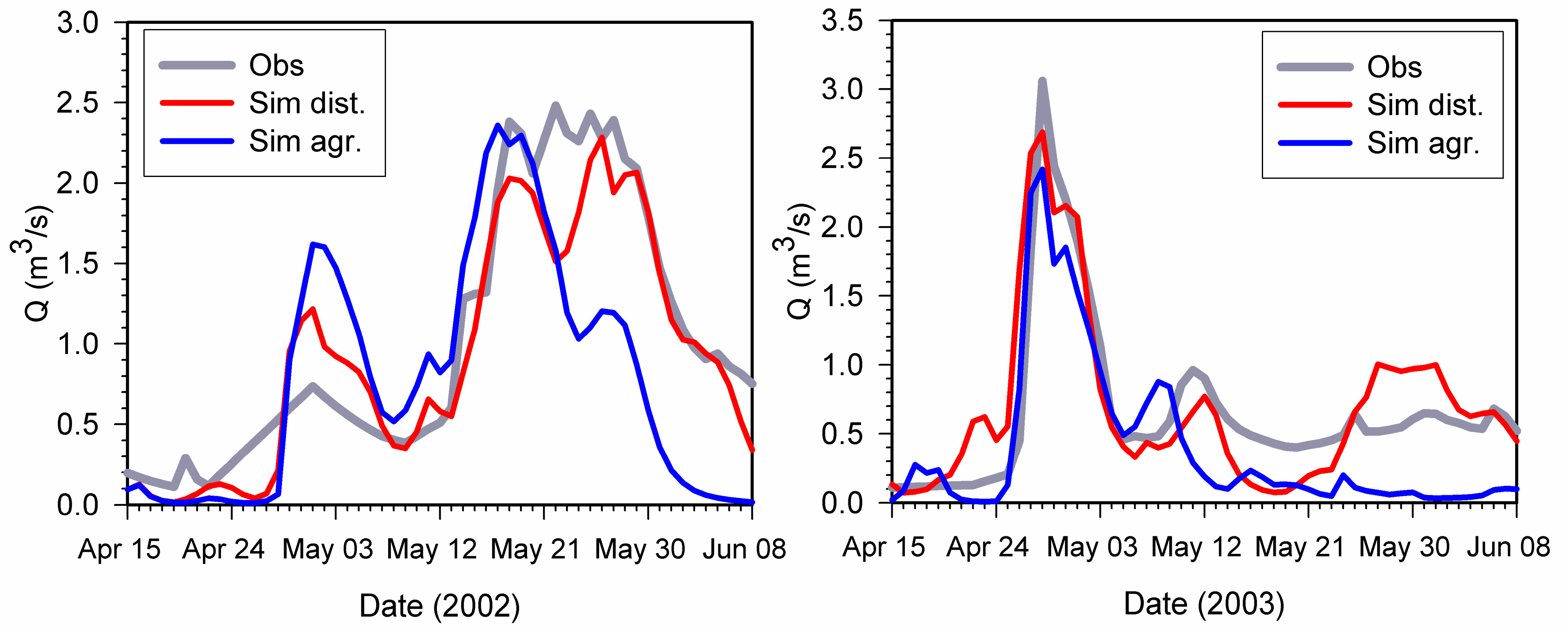
Snow-cover ablation – CLASS - Dornes



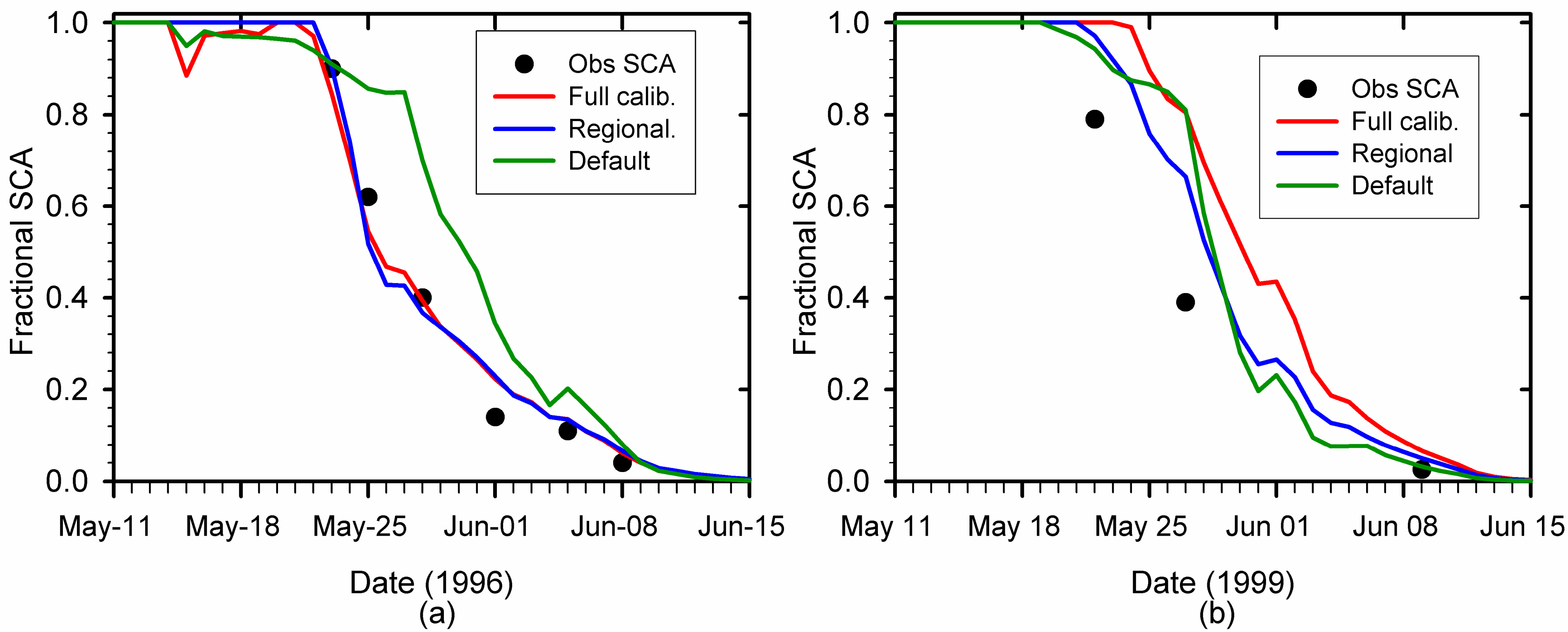




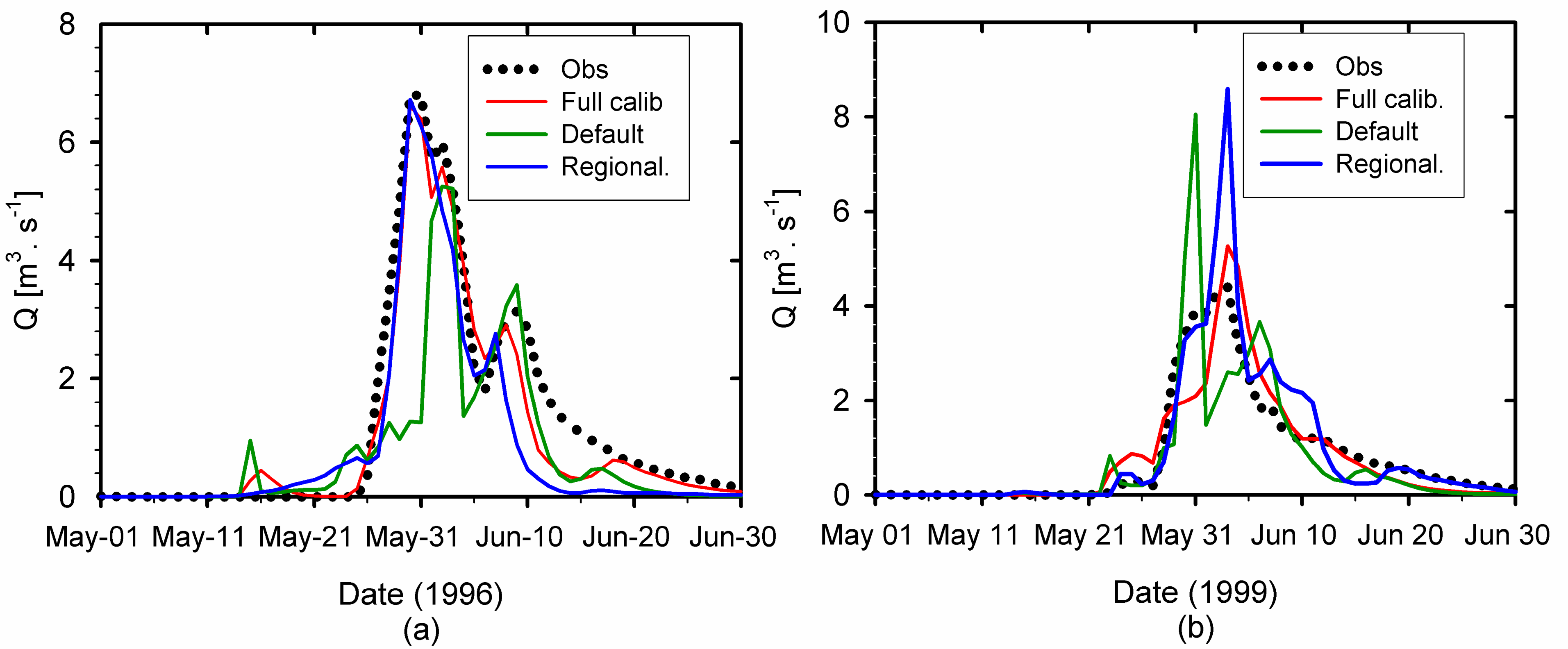
Wolf Creek- discharges (calib.)



Model Regionalisation TVC - SCA



Model Regionalisation TVC - streamflow



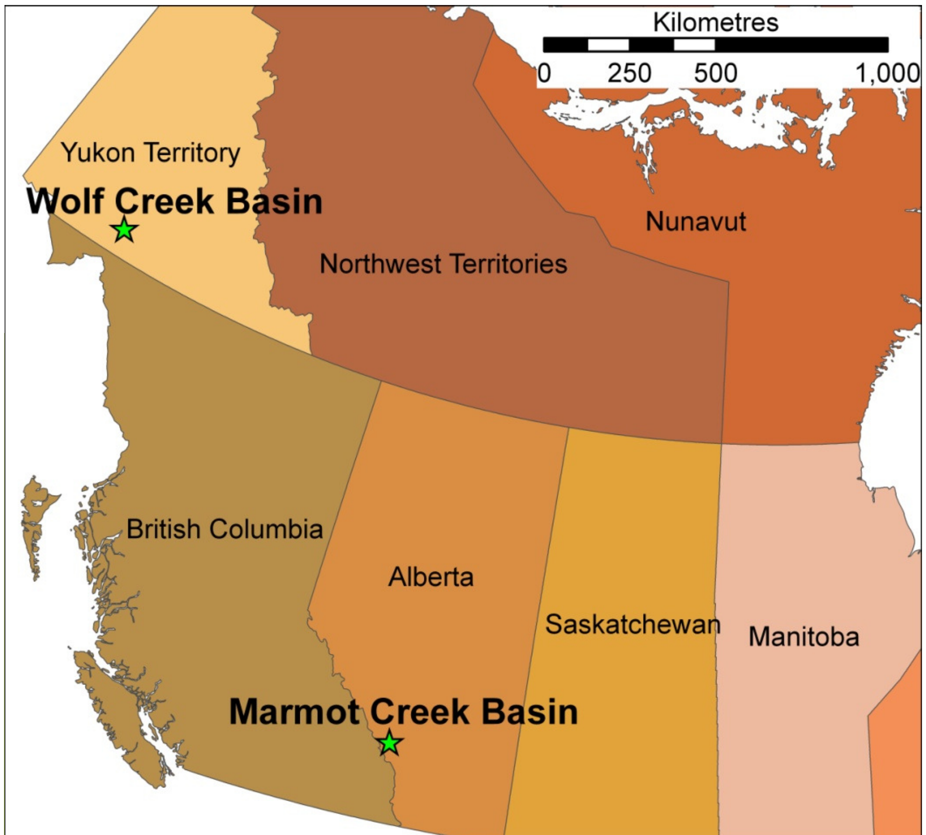
HRU-Based Blowing Snow Model (MacDonald)

- Snow accumulation regimes over mountainous terrain are highly variable due to blowing snow redistribution
  - Topography
  - Vegetation
- Seasonal snow accumulation governs
  - Snowmelt
  - Runoff
  - Infiltration
- Snow redistribution by wind has largely been neglected in large-scale hydrological models

Objectives

1) Evaluate the ability of a prairie-derived blowing snow model to estimate snow transport and sublimation in mountains
2) Develop and test an approach to derive hydrological response unit scale wind speed forcing over alpine topography
3) Identify stable hydrological response unit parameterizations that are suitable for modelling snow accumulation and redistribution
4) Simulate snow transport, sublimation and accumulation using a physically based hydrological model and a hydrological land-surface model.

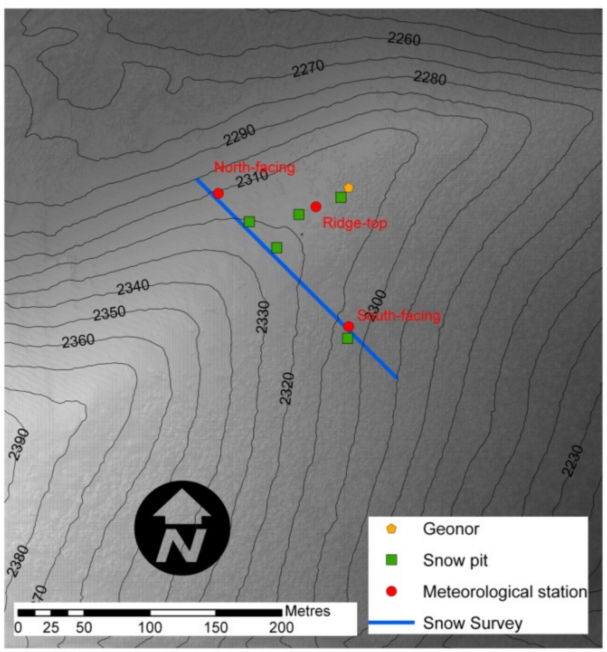
Study SItes

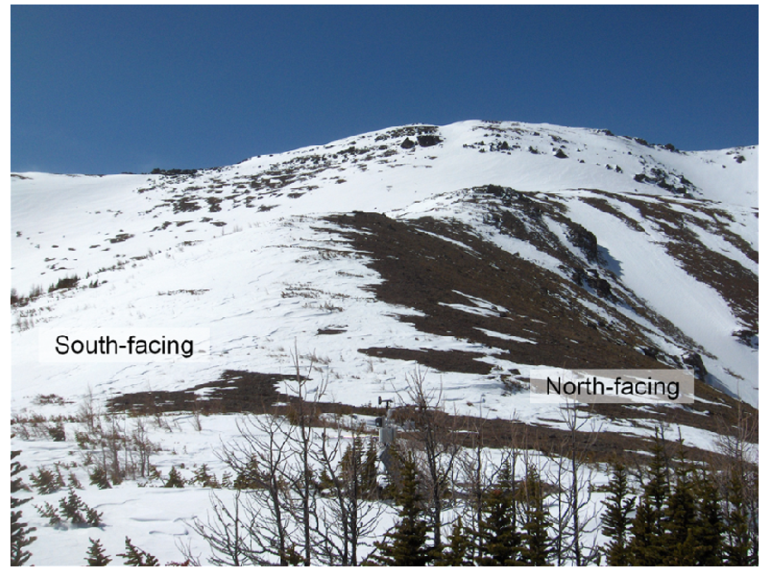


- Marmot Creek Basin
  - Fisera Ridge
- Wolf Creek Basin

Fisera Ridge

- Rocky Mountains
  - Kananaskis Country
- 2310 m ASL

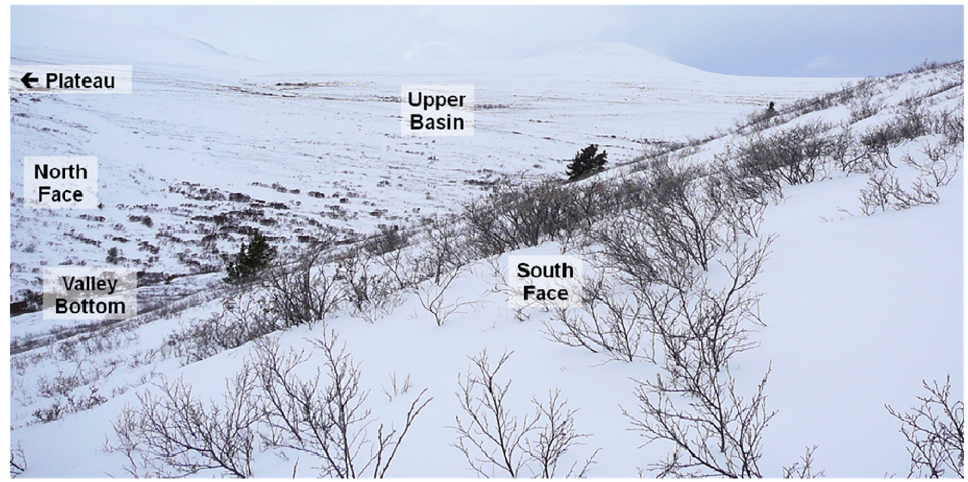


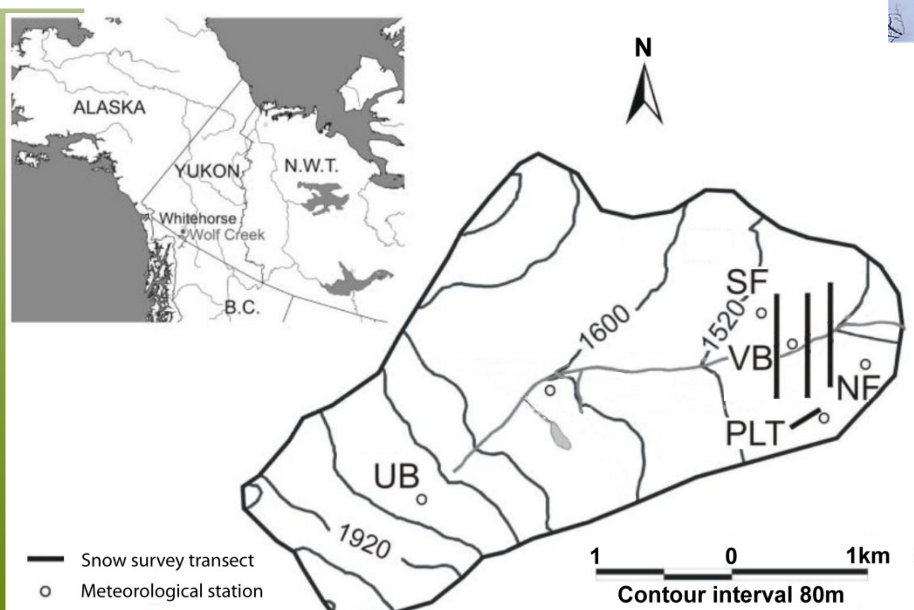


Canada Canada

Granger Basin

- 15 km South of Whitehorse
- 1310-2100 m ASL
- 8 km^2





- Subartic tundra cordillera
- 5 meteorological stations

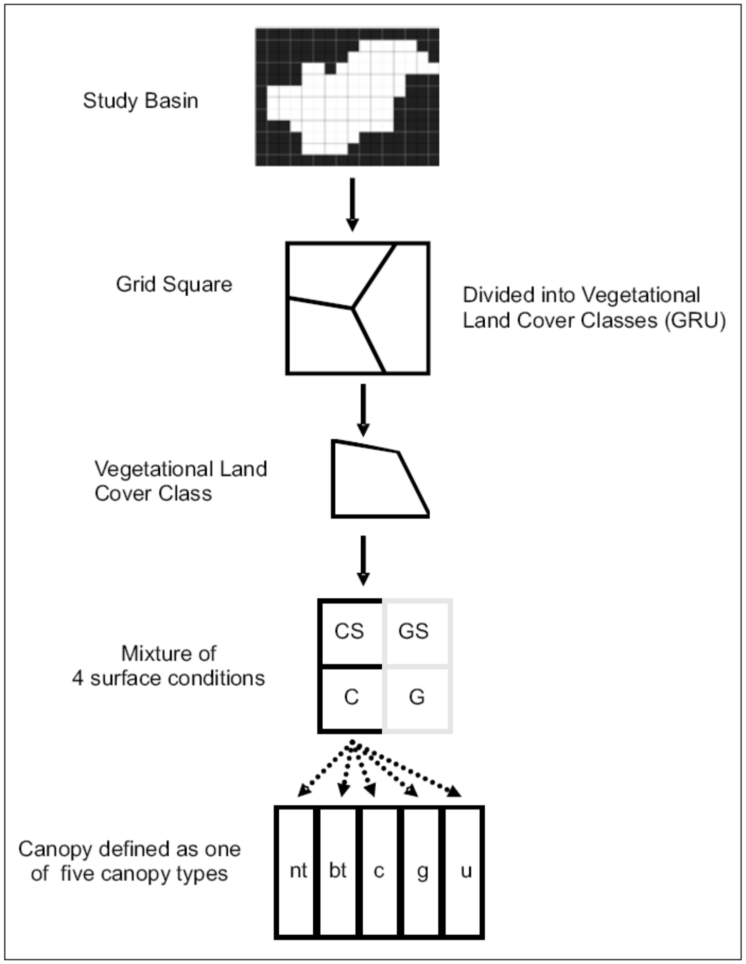
Canadä

Models Used and Developed

- Cold Regions Hydrological Model (CRHM; Pomeroy et al., 2007)
  - Prairie Blowing Snow Model (PBSM; Pomeroy & Li, 2000)
    - Blowing snow transport
      - Saltation + suspension
    - Blowing snow sublimation
      - f(particle size, radiation, turbulent & latent heat exchange, vapour density)
    - Vegetation partitions wind shear stress on snow surface
      - f(stalk characteristics, drag coefficients)
  - Snobal (Marks et al., 1998, 1999)
    - Snow melt and sublimation/condensation
    - Two layers
  - Canopy module (Ellis et al., 2010)
    - Canopy radiation adjustment (Pomeroy et al., 2009)
    - Snow interception, unloading, throughfall (Hedstrom & Pomeroy, 1998)
    - Intercepted snow sublimation (Pomeroy et al., 1998)
    - Enhanced longwave irradiance to surface from the canopy

Large Scale Models Testing

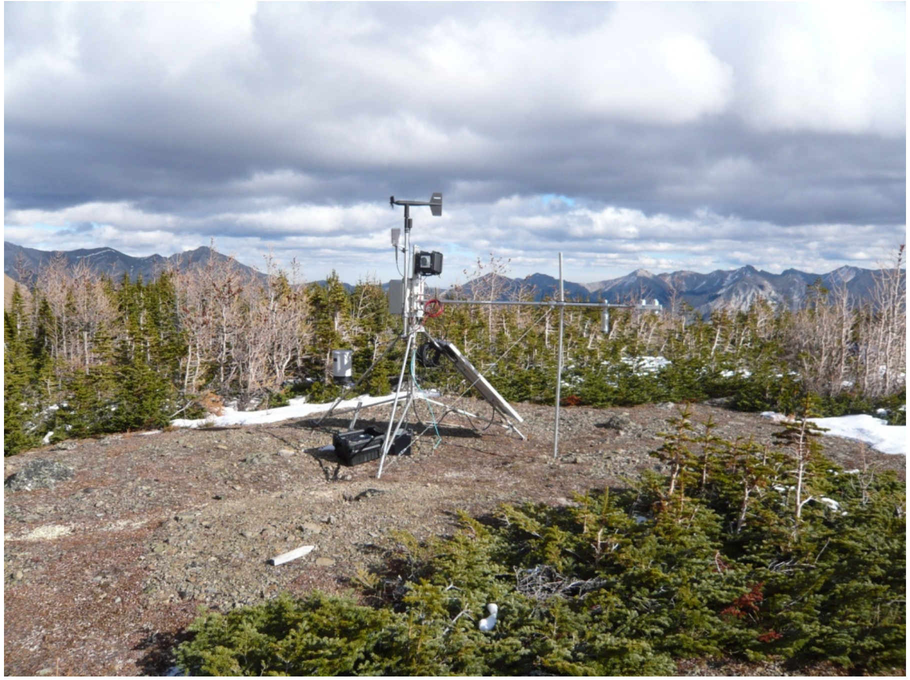
- Modélisation Environmentale Communautaire – Surface & Hydrologogy (MESH; Pietroniro et al., 2007)
  - WATROUTE (Kouwen, 1988, 2000)
    - Grid-to-grid surface water routing
  - Canadian Land Surface Scheme (CLASS; Verseghy et al., 1991, 1993)
    - Vertical energy and water balance
    - Landcover types: needleleaf, broadleaf, grass, crops, bare ground
    - Single snow layer



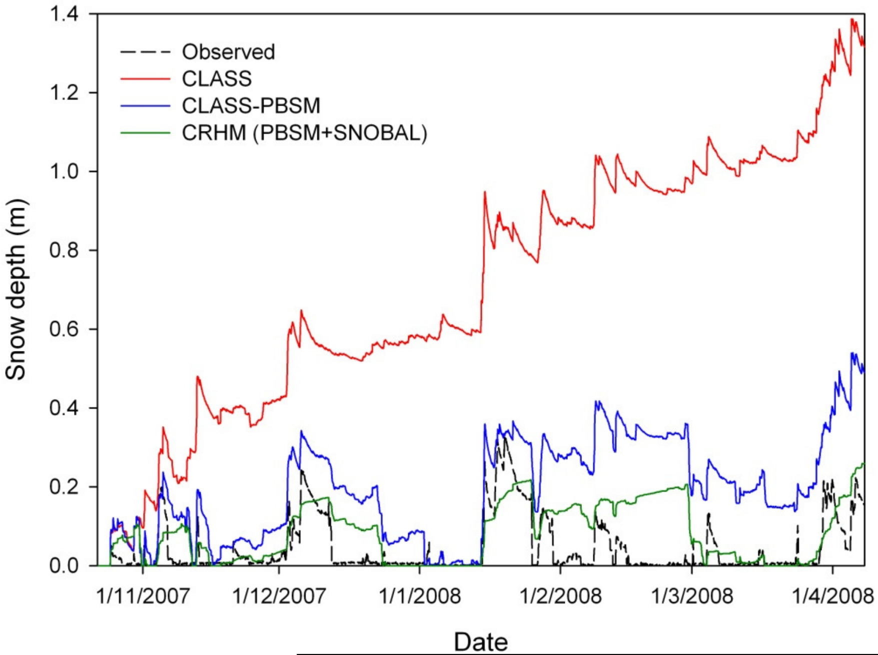
PBSM/CLASS Development

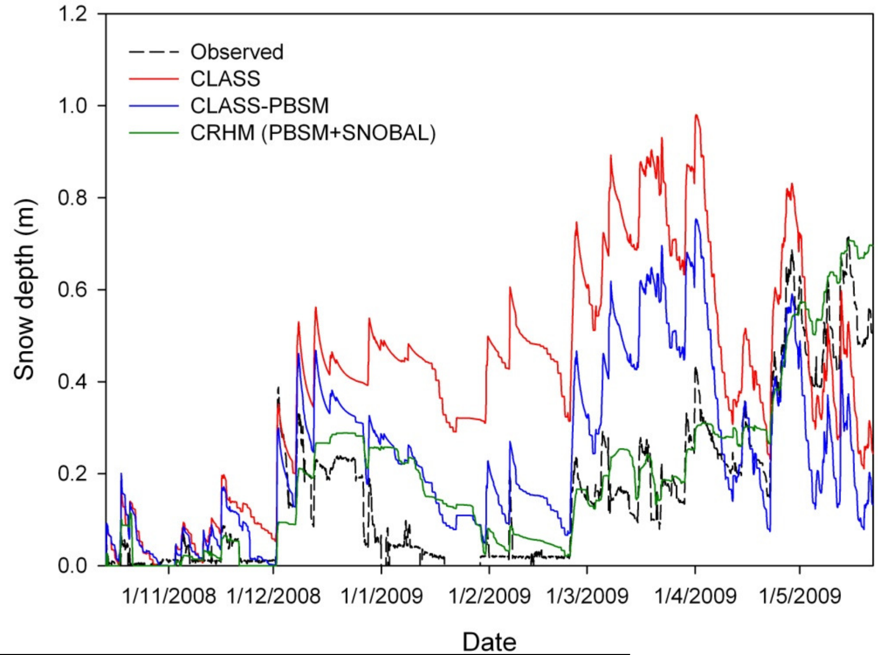
- PBSM coded into MESH
  - inter-GRU snow redistribution

- Single column tests
- Fisera Ridge
  - Windswept
  - Winters 2007/2008 & 2008/2009



Single Column Evaluation

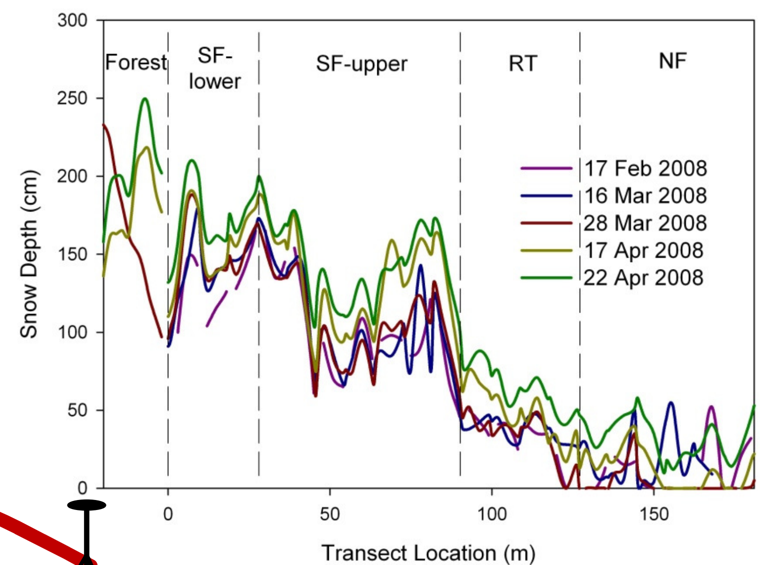


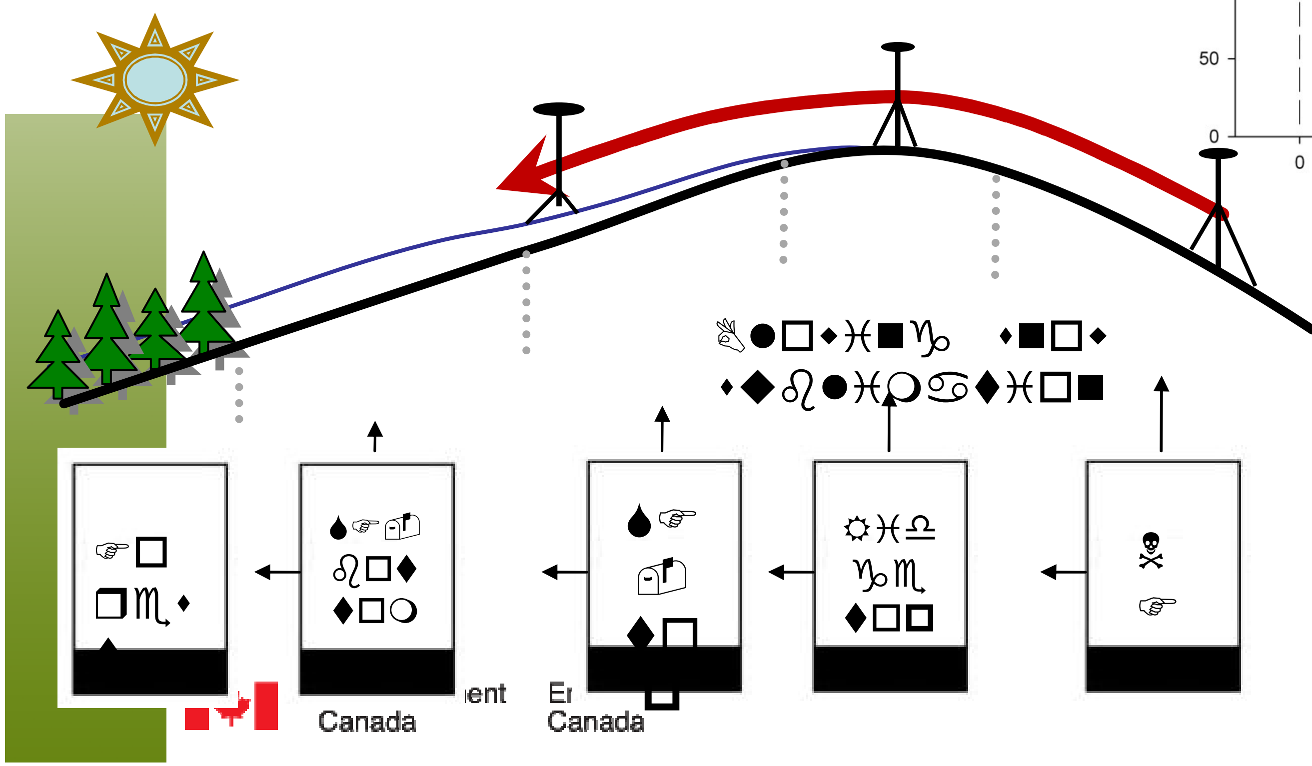


Year	RMSE (cm)			MB		
	CRHM	CLASS	CLASS-PBSM	CRHM	CLASS	CLASS-PBSM
2007/2008	7.2	73.9	18.4	0.07	15.2	3.42
2008/2009	8.5	33.7	19.0	0.20	1.57	0.52

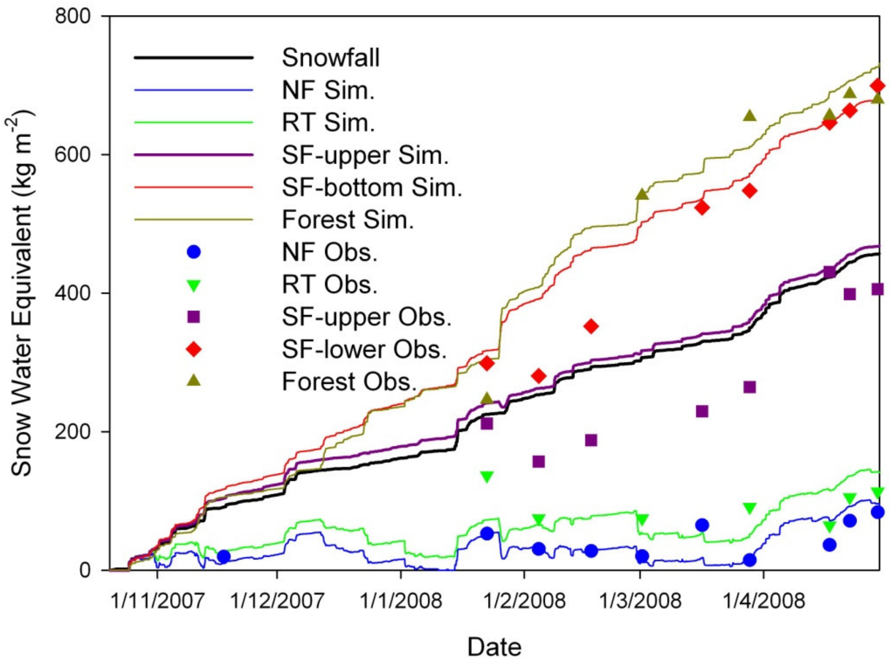
Distributed Approach – Fisera Ridge

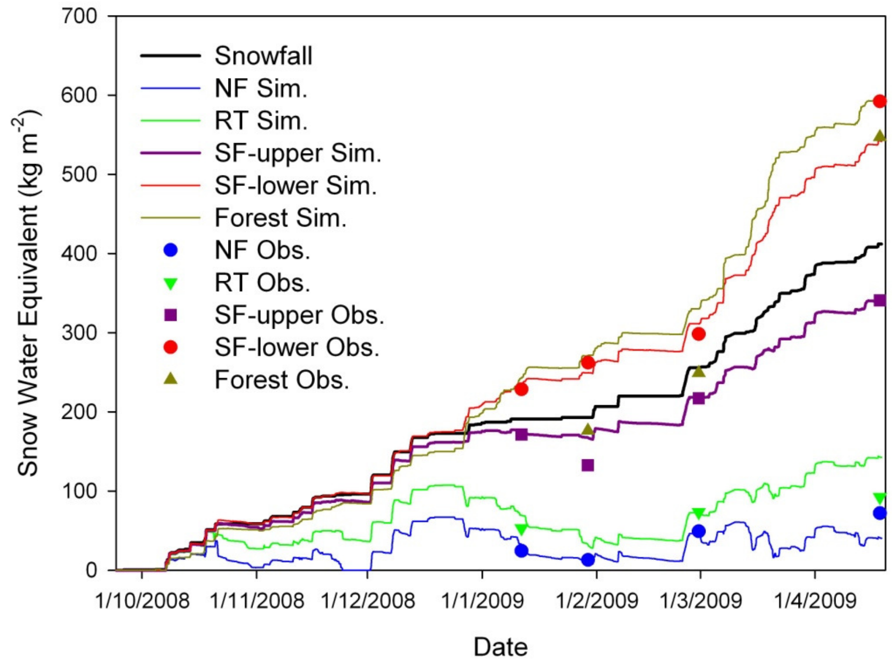
- Flow over ridgetop and into forest





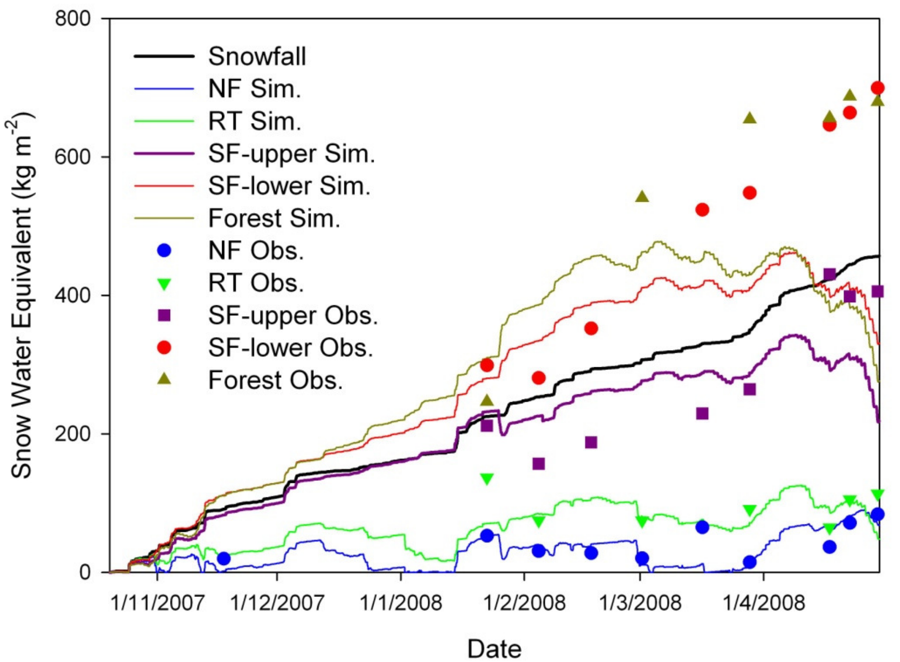
Results using CHRM(Fisera Ridge) (PBSM including SNOBAL)

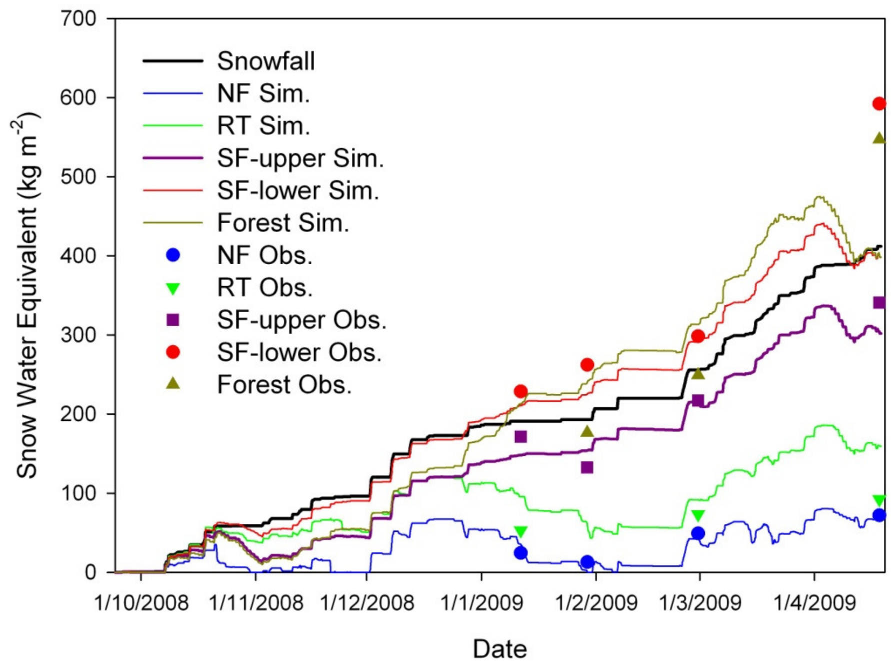




	CRHM (PBSM + Snobal)		
Year	***RMSE***	***MB***	R^2
2007/2008	13.2	0.13	0.87
2008/2009	5.1	0.05	0.97

Results (Fisera Ridge) – MESH with PBSM





	MESH-PBSM		
Year	***RMSE***	***MB***	***R^2***
2007/2008	20.6	-0.18	0.68
2008/2009	8.9	-0.05	0.90

✍👌💧💣 ◆□❒&◆ 💣♏●◆ □❖♏❒♏⬧◆♓❍♋◆ ♏♎✎

Environnement Canada Environment Canada

Canada

Summary Fisera Ridge

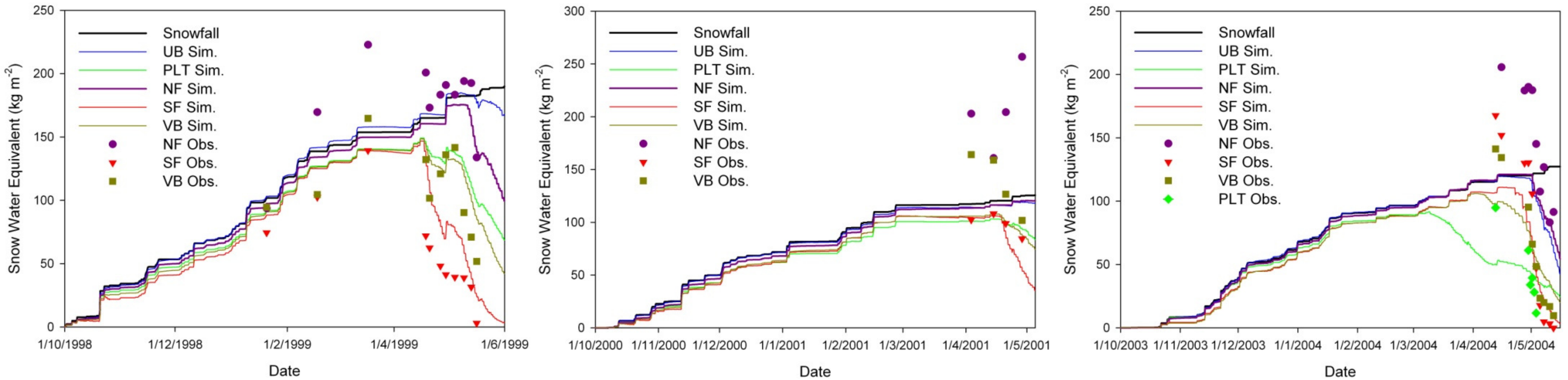
- Snow transport from windward slopes and ridgetops reduces snow accumulation to 10-34% of snowfall (NF and Ridge-top)
- Snow transport to lee slopes and treelines increases snow accumulation by 33-61% of snowfall (SF-bottom and Forest)
- Alpine blowing snow sublimation losses substantial (17-19%) and most prevalent on windward slopes and ridgetops
- MESH (CLASS) overestimated snowmelt in this environment

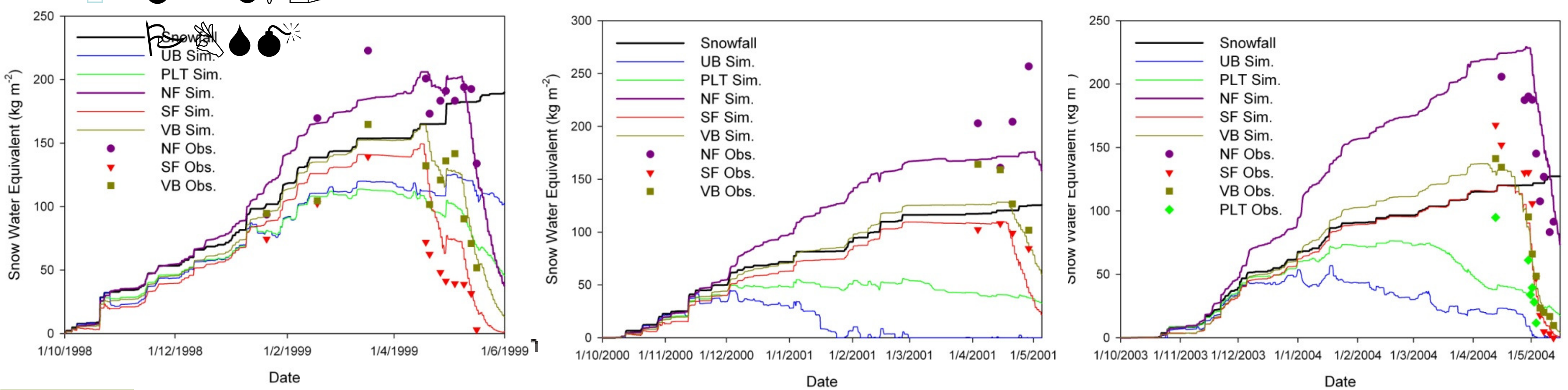
Distributed Model – Granger Basin in Wolf Creek

- Establish how snow drift is distributed across HRUs
  - Drift allowed to enter GB from 'outside' basin
  - Drift allowed to exit GB
  - Distribution across HRUs according to pre-established S_R allocation factors
- Three S_R schemes tested
  1. All HRUs receive same fraction of drift

		S_R			
Gain	PLT	NF	SF	VB	Loss
0.5	0.20	0.20	0.20	0.20	0.20

Results – MESH and MESH(PBSM)





Results for Granger

Year	MESH RMSE	MESH MB	MESH R^2	MESH-PBSM RMSE	MESH-PBSM MB	MESH-PBSM R^2
1998/1999	18.4	0.24	0.28	17.3	0.27	0.55
2000/2001	23.3	-0.23	-0.49	19.9	-0.18	0.39
2003/2004	18.4	-0.84	-0.09	15.1	-0.82	0.64

- Evaluation statistics do not reflect decreased snow accumulation on UB and PLT (1998/1999 and 2000/2001)
  - No snow surveys

- Granger Basin blowing snow sublimation
  - 10-37% of snowfall (CRHM)
  - 12-36% of snowfall (MESH-PBSM)

Summary

- A physically based blowing snow model developed in the prairies (PBSM) was linked to
  - A snowmelt model (Snobal; within CRHM)
  - A hydrological-land surface model (MESH)
- Models adequately simulated snow accumulation regimes in mountainous terrain
  - Careful definition of landscape units is required
  - MESH (CLASS) overestimated snowmelt for long-term simulation
  - MESH (CLASS) able to simulate melt period when initialized at MAX snow amount (work by Dornes)
  - Issue with persistence in internal energetics needs to be resolved.
- Empirical windflow model is not adequate for simulating snow redistribution in alpine terrain
- Seasonal blowing snow sublimation losses considerable in mountainous environments
  - 10-37% of cumulative snowfall

Future Requirements

- HRUs/GRUs discretized rather subjectively
  - Future work to generalize based on terrain characteristics
- Must improve CLASS snowmelt simulations
- Test/develop other windflow models in/for mountainous terrain

Publications

- Comeau, L., A. Pietroniro, M. Demuth, “Glacier Contribution to the North and South Saskatchewan Rivers”, Hydrological Processes, CGU Special Edition
- Dornes, P.F., J.W. Pomeroy, A. Pietroniro, S.K. Carey and W.L. Quinton, 2008. “Influence of Landscape Aggregation in Modelling Snow-cover Ablation and Snowmelt Runoff in a Subarctic Mountainous Environment”, Hydrological Science Journal
- Dornes, P.F., J.W. Pomeroy, A. Pietroniro, and D.L. Verseghy, 2008. “Effects of Spatial Aggregation of Initial Conditions and Forcing Data on Modelling Snowmelt Using a Land Surface Scheme”, Journal of Hydrometeorology
- Demuth, M.N., V. Pinard, A. Pietroniro, B.H. Luckman, C. Hopkinson, P. Dornes and L. Comeau, 2008. “Recent and Past-century Variations in the Glacier Resources of the Canadian Rocky Mountains – Nelson River System. Terra Glacialis, Vol 11, No 248, 27-52.
- Dornes, P.F., B. Tolson, B. Davison, A. Pietroniro and J.W. Pomeroy, 2008. “Regionalisation of Land Surface Hydrological Model Parameters in Subarctic and Arctic Environments”, Physics and Chemistry of the Earth. Special Issue: From Measurement and Calibration to Understanding and Predictions in Hydrological Modelling, doi:10.1016/j.pce.2008.07.007.

- ……………..

Acknowledgments

- Funding for the work provided by IP3 and IPY
- In-kind support – HAL lab – Environment Canada
- Data provided through many collaborative studies over the years
  - Specific thanks to Rick Janowicz for providing advice and data for this work.
  - Diana Verseghy and Paul Bartlet for advice on CLASS
  - Bryan Tolson for assistance with DDS
  - Nick Kouwen for WATFLOOD help
  - many other ……………………