Advancing Modelling Strategies

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Sept 14, 2017

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Global Water Futures
GWF.USASK.CA

GWF Models for Water Resources

- Atmospheric Models or Forcing
  - GEM (Canadian NWP), WRF, CaPa
- Climate Models Outputs,
  - GCM, CRCM policy runs, Pseudo Global Warming with WRF (future weather)
- Coupled Atmospheric –Hydrological Systems
  - GEM Hydro, MESH, WRF Hydro
- Stand-alone Hydrology Models
  - Cold Regions Hydrology Model (CHRM)
  - MESH (includes a variant of ISBA, CLASS)
  - CHM-next generation
  - VIC
  - HYPE
- Decision Support and Water Management Models
- Non-point pollution models such as SPARROW
- Instream water quality models such as WASP

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Required Hydrological Predictions

Short Range – · – · – · – · – · – · – · – · – Long Range

hours --------> days --------> weeks --------> months -------> years

Flash Flood Warning

Flash Flood Guidance

Headwater Guidance

Flood Forecast Guidance

Reservoir Inflow and Snowpack Forecasts

Spring Snow Melt Forecasts

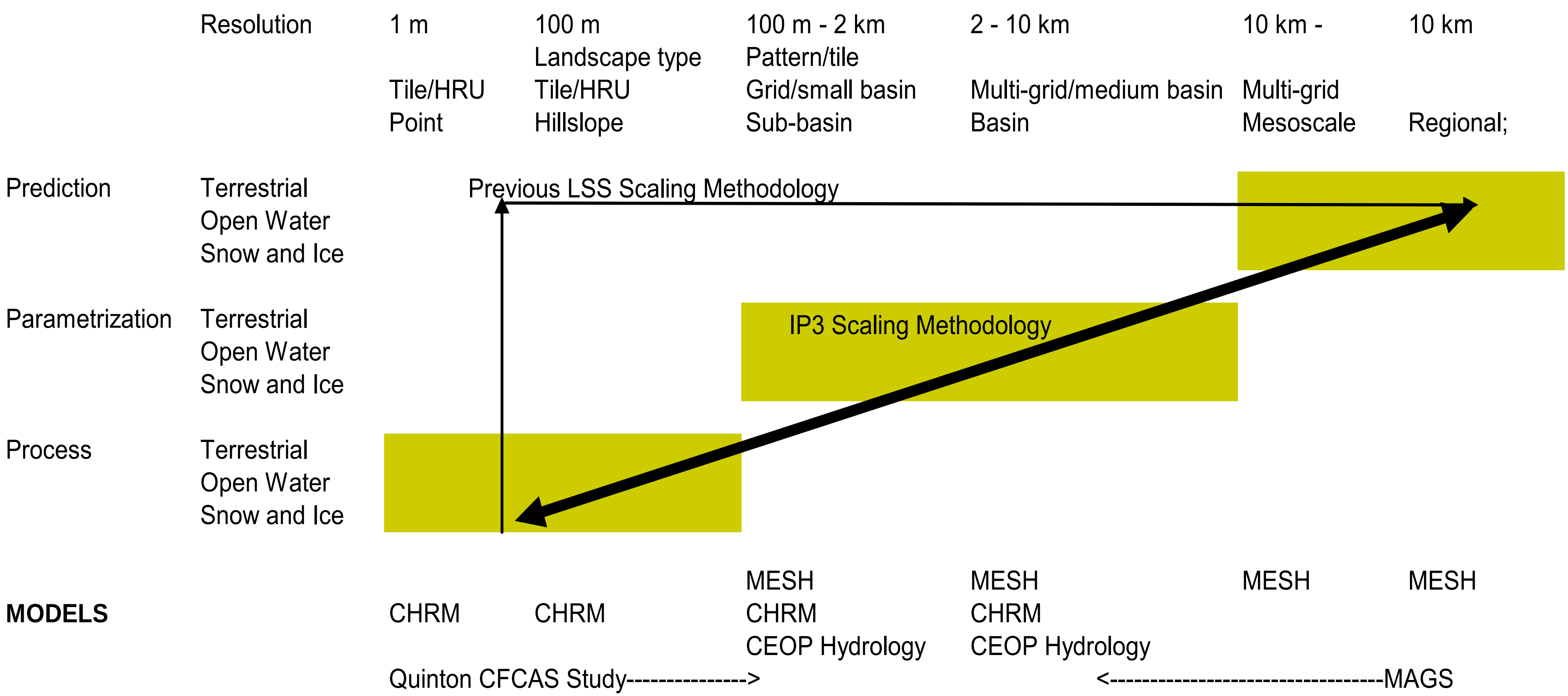
Water Supply Volume

←

Hindcast and Now-cast – Planning and design

Modified from Dr. Soroosh Sorooshian, University of California Irvine

An old model scaling idea that is still relevant….



Pietroniro and Pomeroy, (c) 2004

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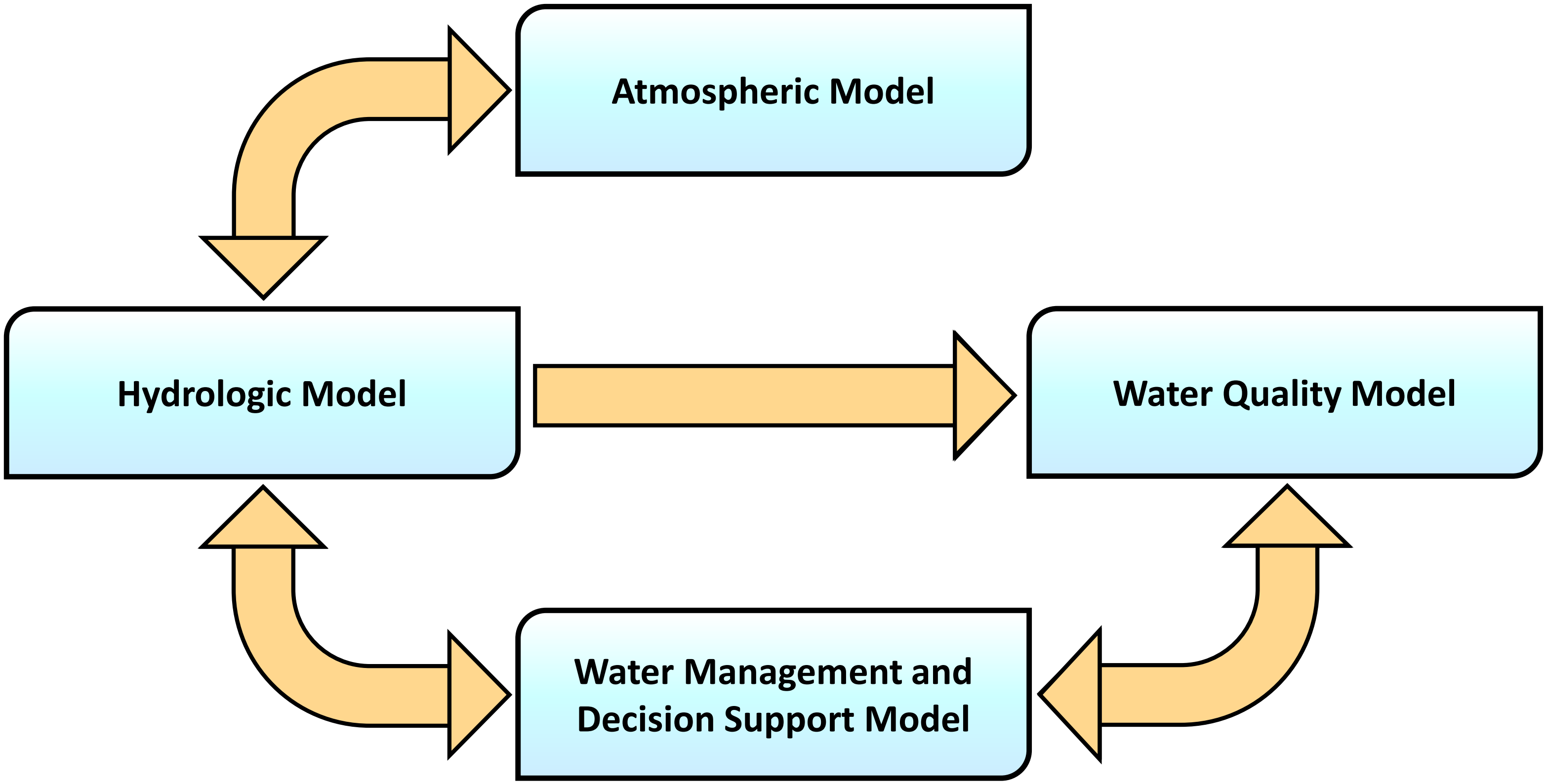
Model-Coupling Framework



Choosing a Model

- not straightforward and must consider;
  - choice of the appropriate model, parameterization and model setup;
  - reduction of problem dimensionality and choice of calibration parameters;
  - model calibration and model validation;
  - uncertainty assessment.
- Model identification involves the choice of the suitable model structure and degree of complexity
  - But better models are not necessarily the most complex –
- "fitness for purpose" should result from the application considering
  - the phenomena to simulate (not just streamflow)
  - the availability of data.

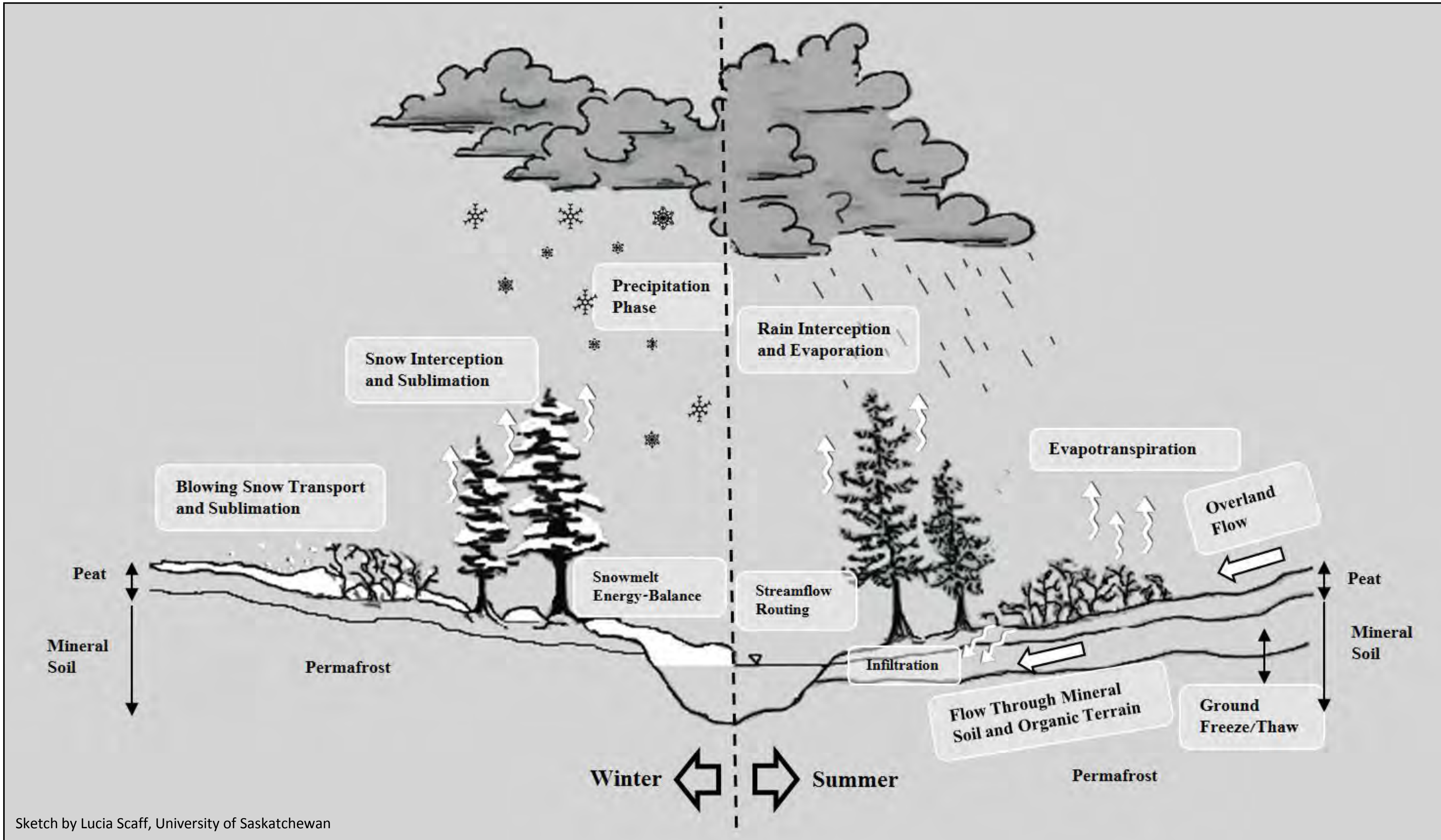
CRHM
Cold Regions Hydrological Modelling Platform:

- Modular, flexible, multiphysics – purpose built from C++ modules
- Parameters set by hydrological understandding rather than optimization
- Hydrological Response Unit (HRU) basis
  - landscape unit with characteristic hydrological processes/response
  - single parameter set
  - horizontal interaction along flow cascade matrix
  - Model tracks state variables and flows for HRU
- Coupled energy and mass balance, physically based algorithms applied to HRUs via module selection
- HRUs connected aerodynamically for blowing snow and via dynamic drainage networks for streamflow and via groundwater flowpaths for sub-surface
- Flexible - can be configured appropriately for prairie, agricultural, mountain, glacial, forest, arctic basins – new water quality modules
- Sub-basins connected via Muskingum routing
- Visualisation tools, GIS interface
- Model failure is embraced and instructive

Pomeroy et al., 2007 *Hydrol. Proc.*

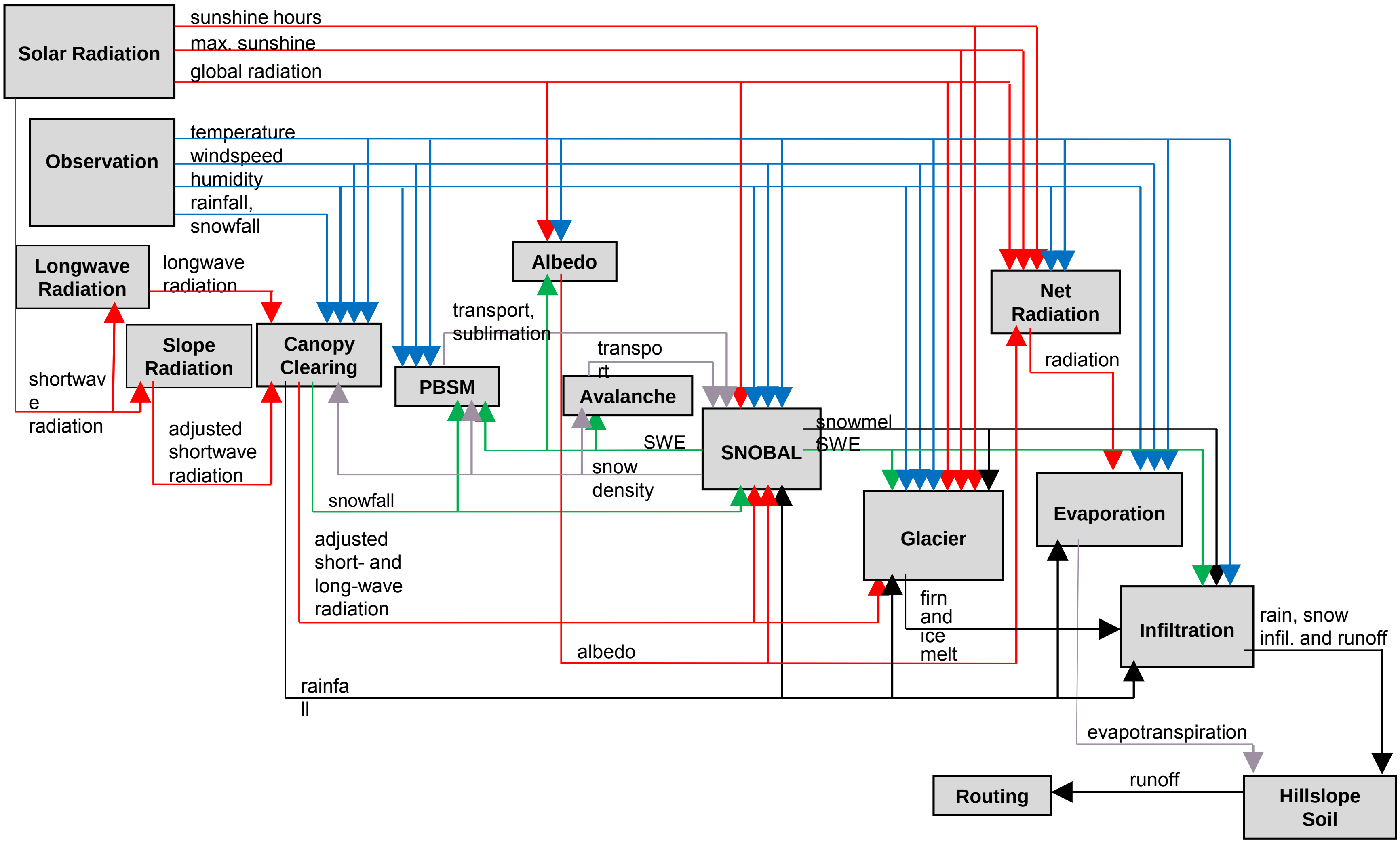
Tom Brown, CRHM Modeller

CRHM for Arctic



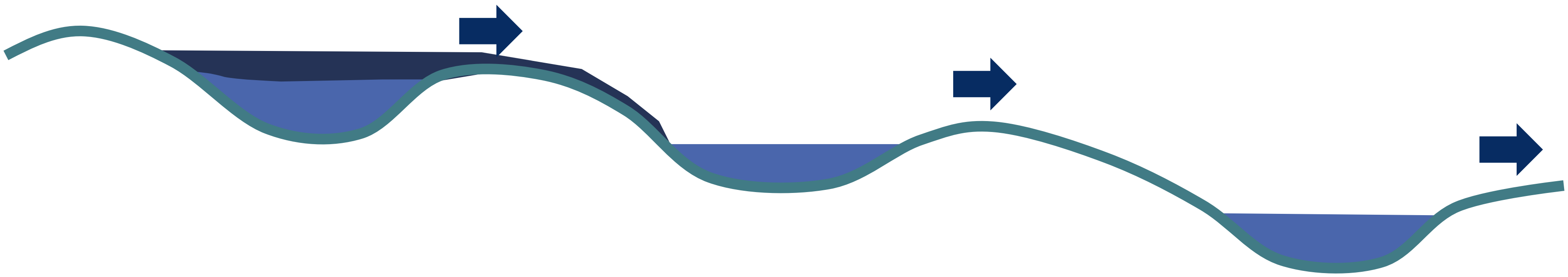
CRHM Arctic Model *Krogh, Pomeroy and Marsh, 2017. Journal of Hydrology, DOI: 10.1016/j.jhydrol.2017.05.042

CRHM Glacier



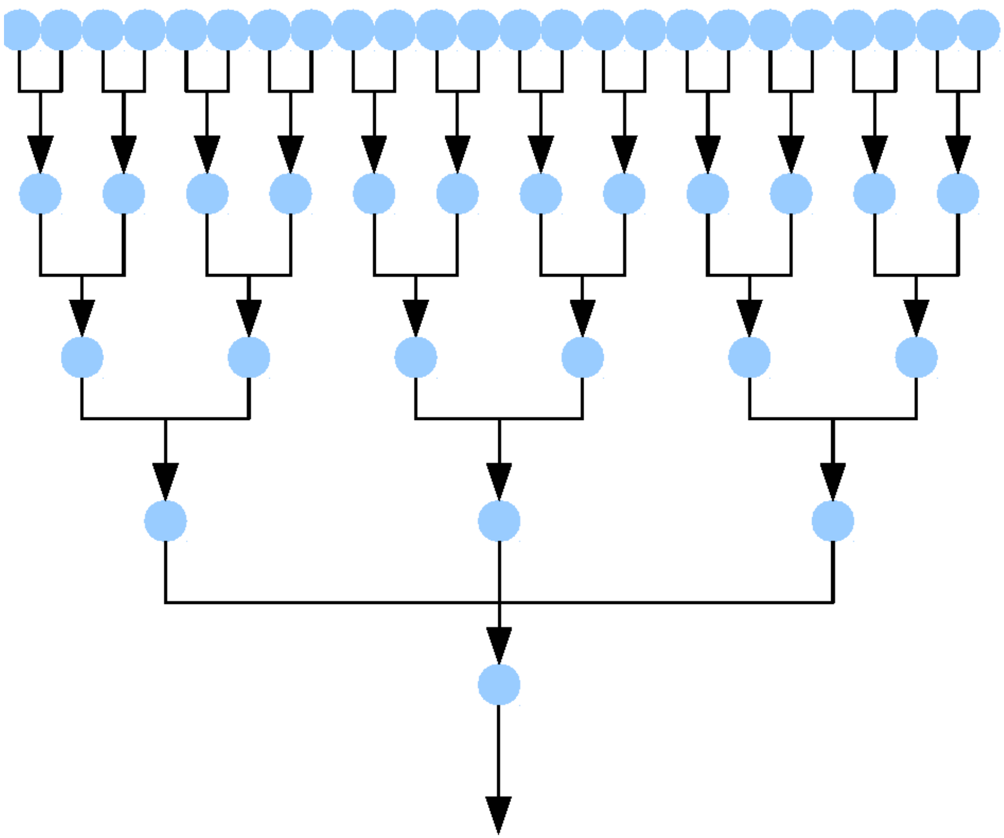
Prairie Hydrological Connectivity

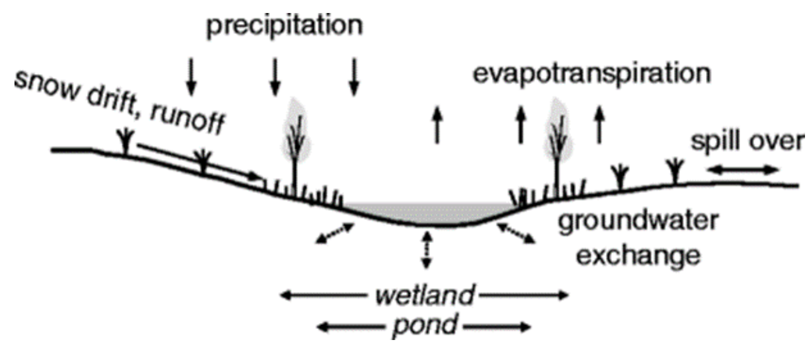
The 'fill and spill' hypothesis



Lack of groundwater connections in this landscape – heavy tills

Wetland Representation in CRHM



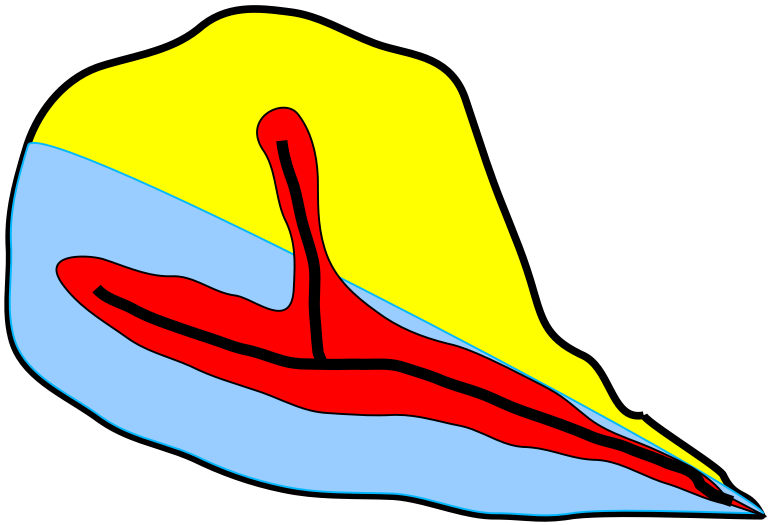


CRHM Surface Water Drought Modelling

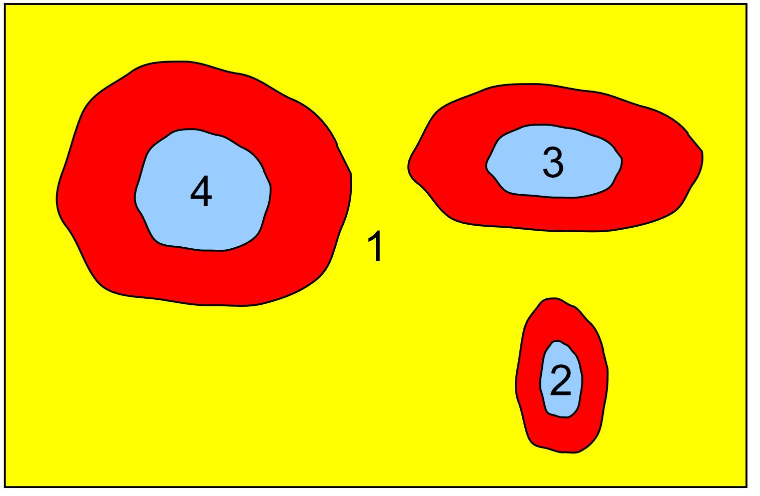
- CRHM was used to create “virtual” model of typical prairie upland basin
- Model was run over climate normal period (1961-1990)
- Output during drought period was compared to normal period and spatially interpolated

Simulating Water Supply from "Virtual" Prairie Drainage Basins over 46 years

Upland Drainage Basin

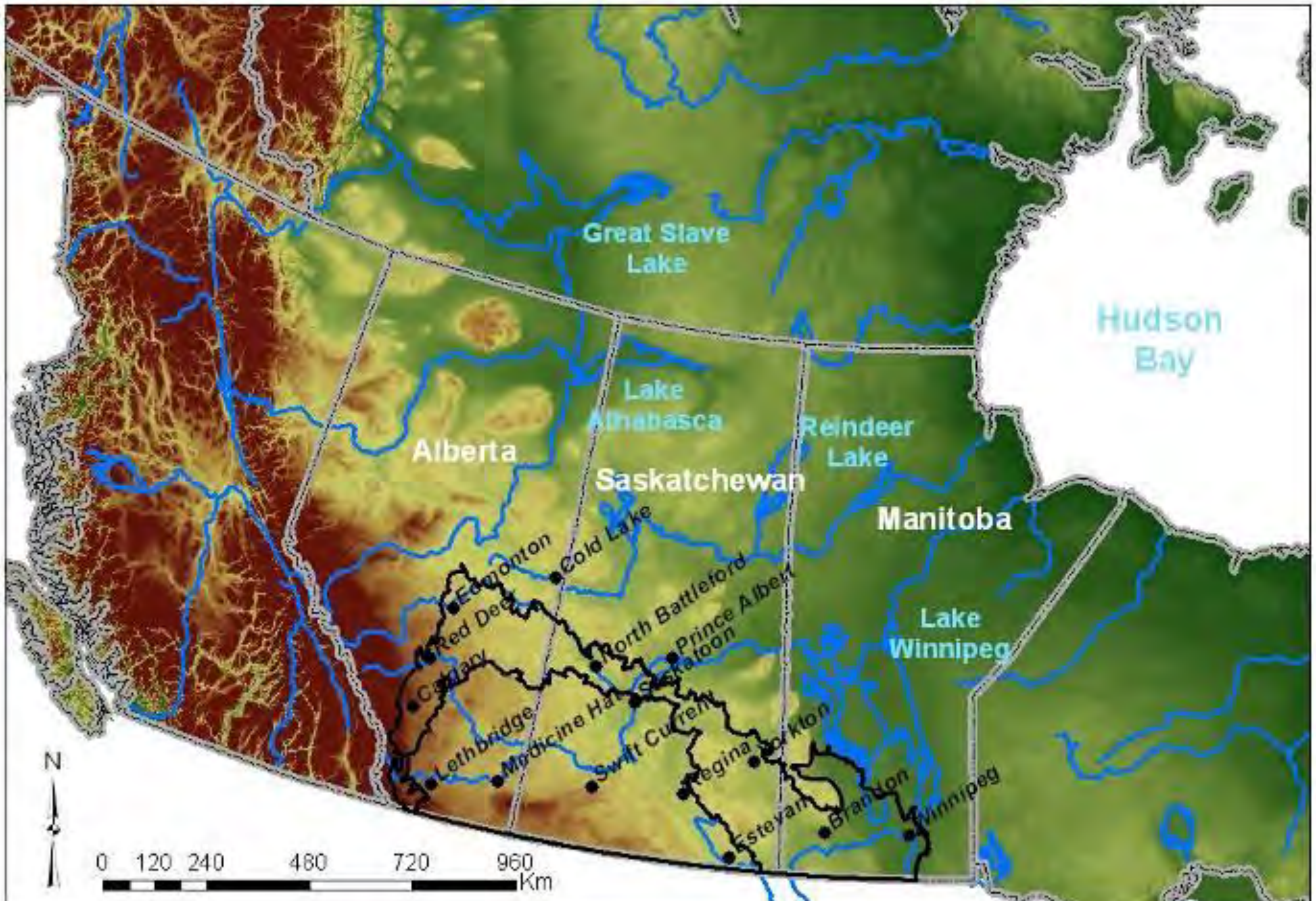


Wetland Drainage Basin



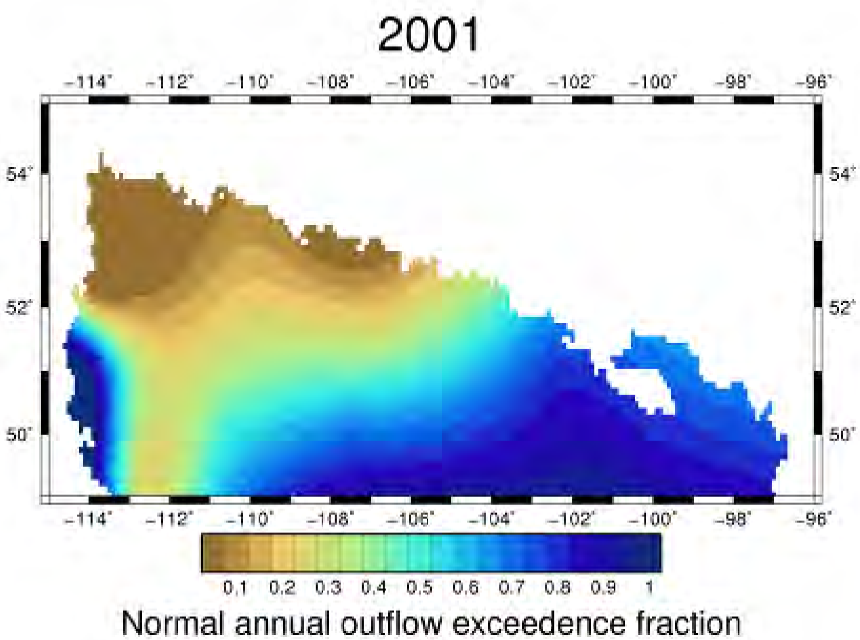
Drought Hydrology Simulations

Station locations, Prairie ecozone and Palliser Triangle boundaries

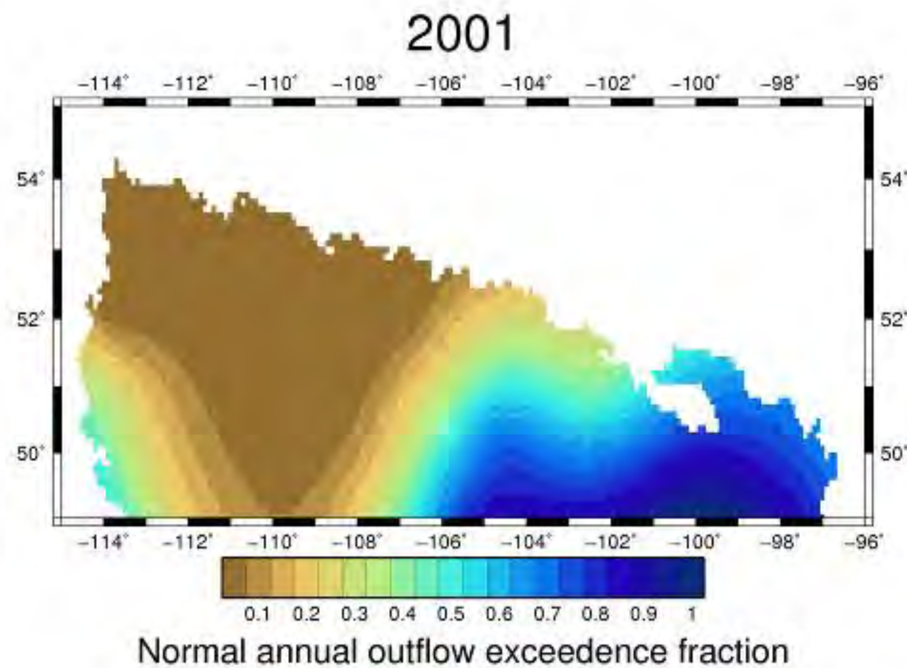


Prairie Spring Discharge Early Drought

Wetlands



Uplands

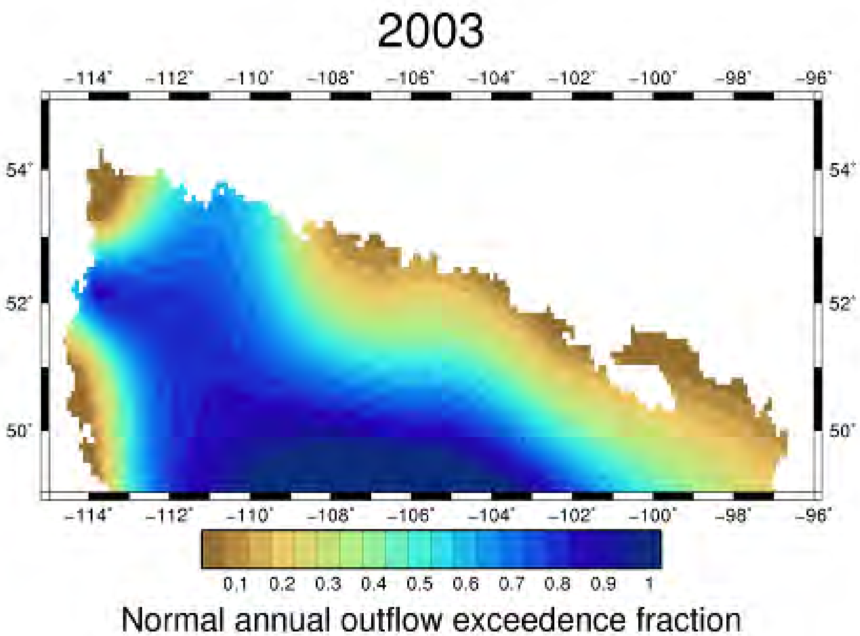


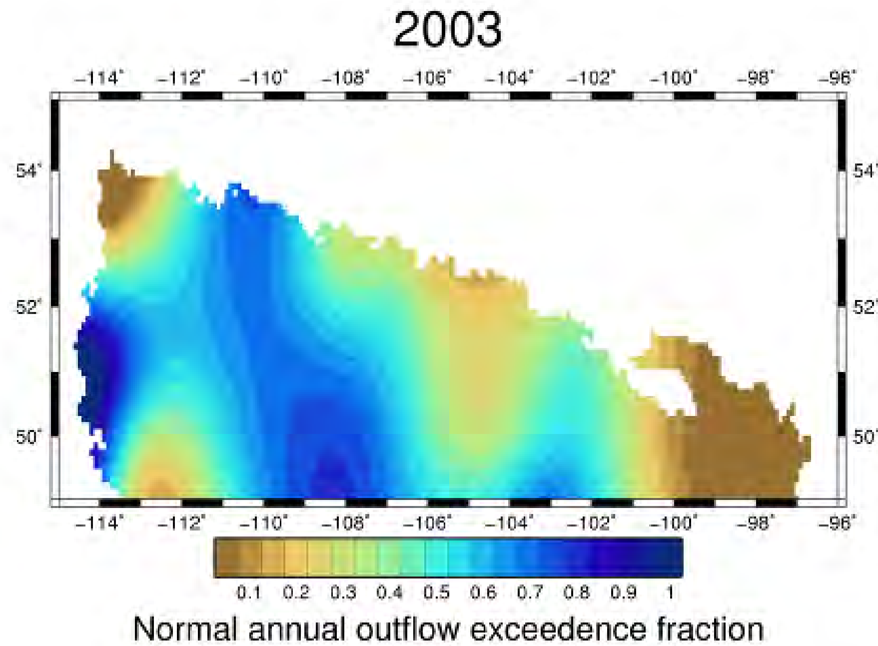
Kevin Shook, research

Prairie Spring Discharge Late Drought

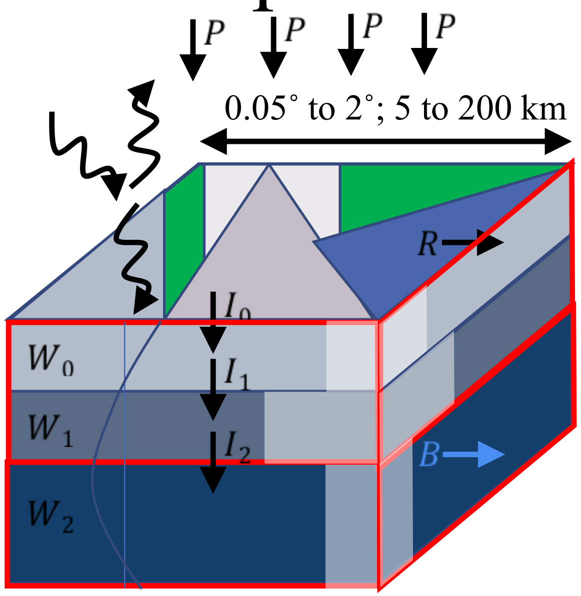
Wetlands

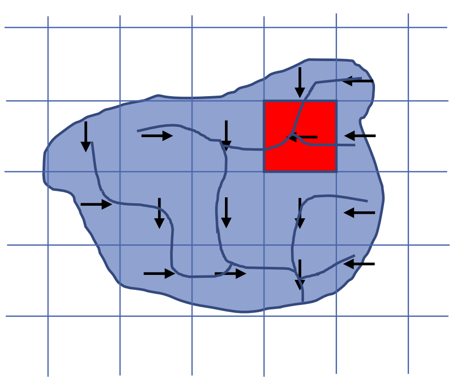
Uplands





The VIC Variable Infiltration Capacity LSS developed as a simple land surface et al.,1994).

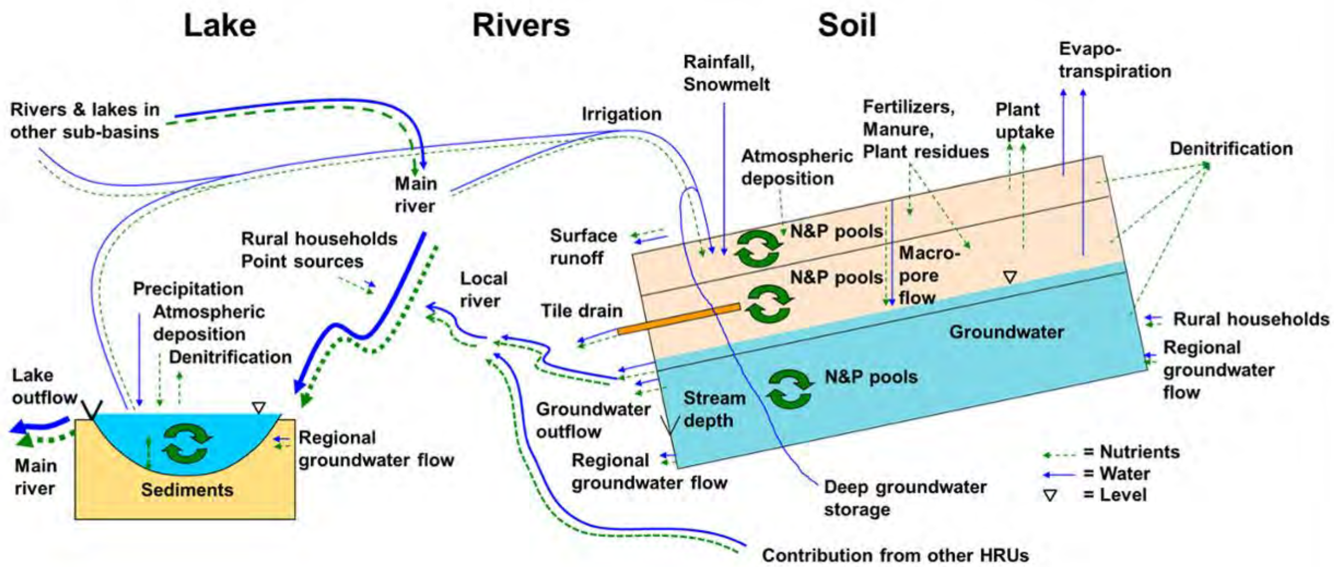




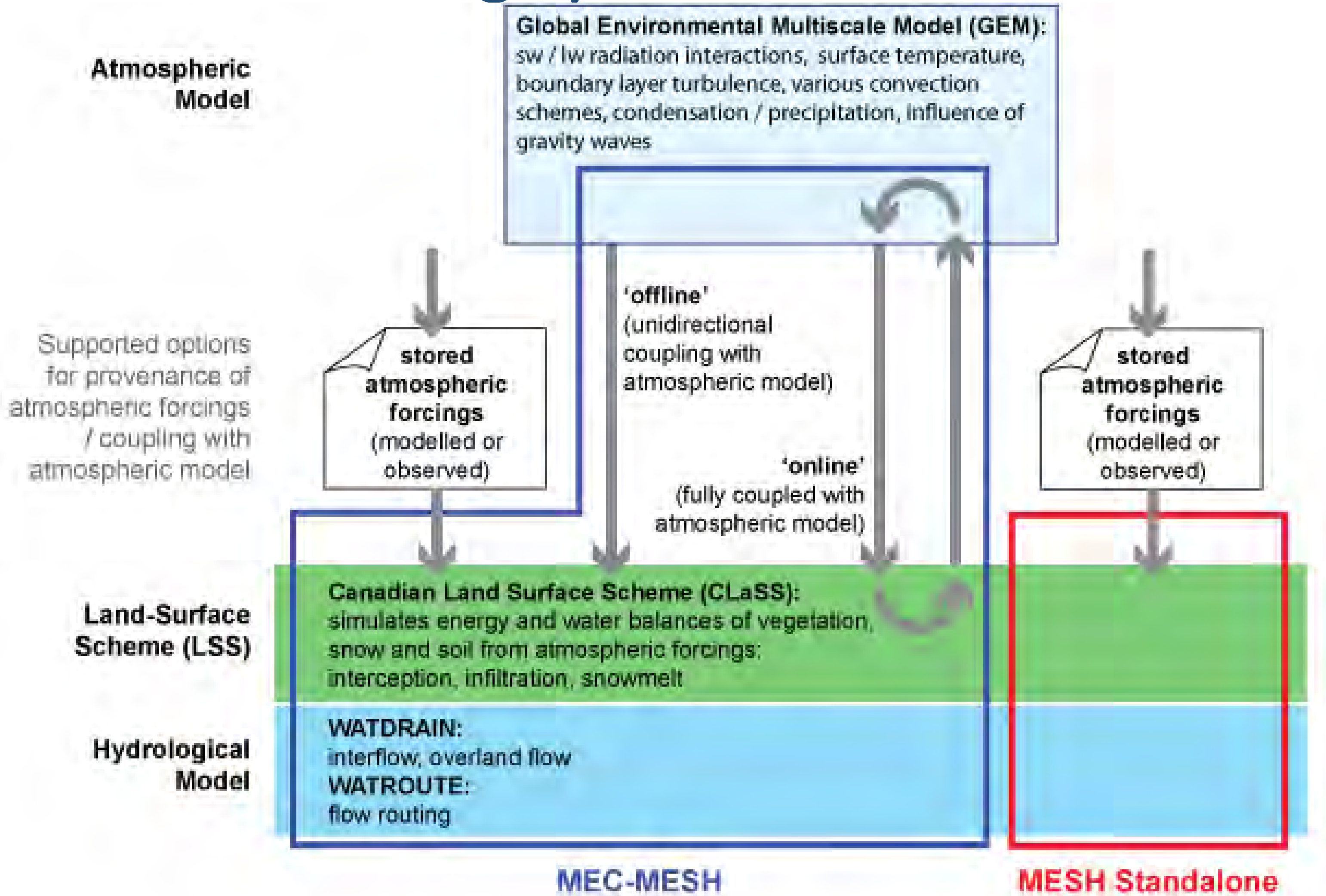
- VIC is a meso- to large- scale model at grid scale.
- VIC accounts for various land covers and lakes within a grid.
- Infiltration capacity varies based on a distribution of saturated areas define by *b* as infiltration shape parameter.
- $I_0 = f\,(W_0 + W_1);\ R = P - I;$
- Base flow is calculated based on storage of the lowest soil layer as a nonlinear reservoir.
- $\mathrm{B} = f\,(W_2)$
- Water flow between the layers are calculated by an approximation of Richards equation.
- VIC is able to calculate energy fluxes for soil profile, atmosphere and lake (1-D lake model).
- VIC is able to account for frozen soil and its impact on infiltration and transpiration.
- The routing model is consist of a unit hydrograph at a grid scale and linearized Saint-Venant equation based on velocity and diffusivity.

HYPE - SMHI

- The hydrological catchment model HYPE simulates water flow and substances on their way from precipitation through soil, river and lakes to the river outlet (Arheimer et al., 2008; Lindström et al., 2009).
- The catchment is divided into subbasins which in turn are divided into classes (calculation units) depending on land use, soil type and elevation (Figure 1).
- The classes can not be coupled to a geographic location within the subbasin but are given as part of its area. Typical land uses are forest, lake, open land, but also different crops, e.g. cereal and potatoes, are common. Elevation can be used to get temperature variations within a subbasin to influence the snow conditions.

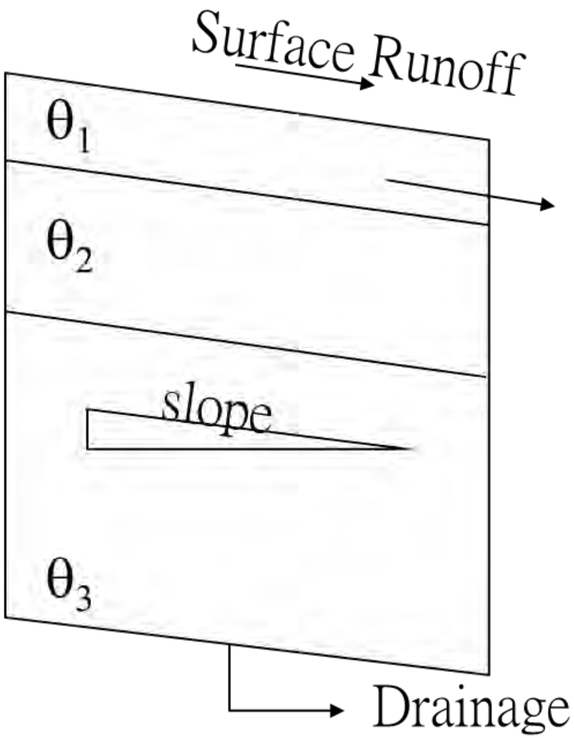


MESH modelling system

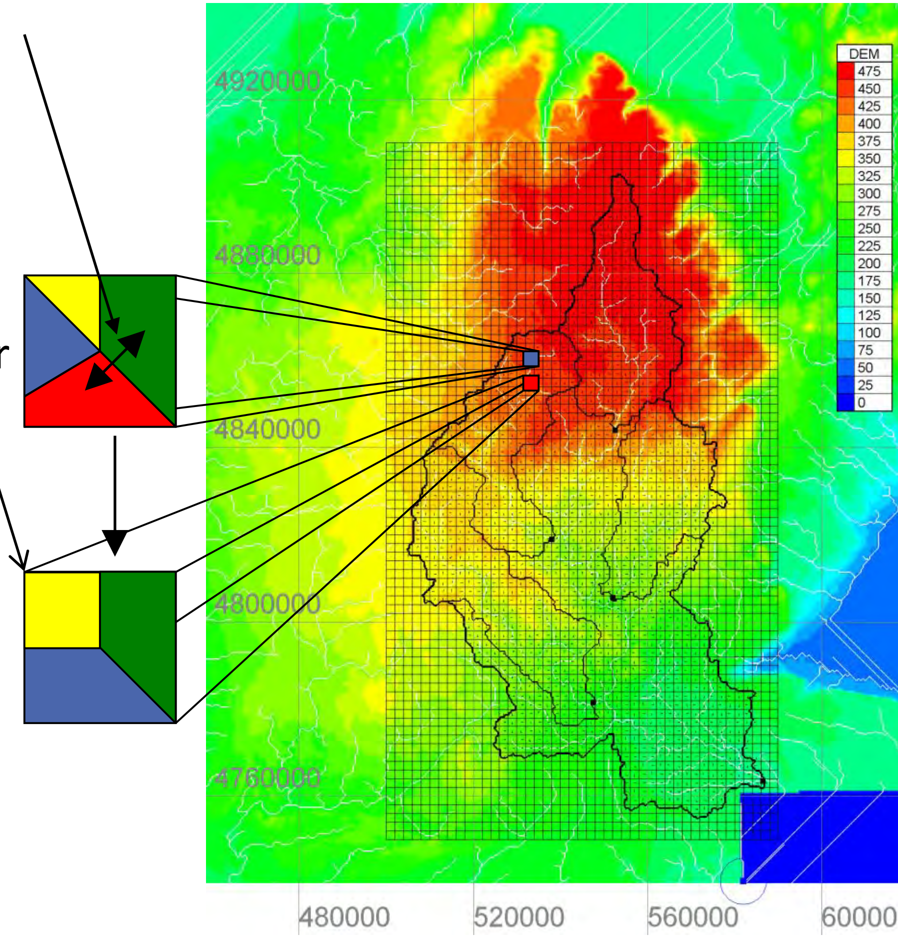


Pietroniro A., Fortin V., Kouwen N., Neal C., Turcotte R., Davison B., Verseghy D., Soulis E. D., Caldwell R., Evora N., and Pellerin P. (2007). Development of the MESH modelling system for hydrological ensemble forecasting of the Laurentian Great Lakes at the regional scale. *Hydrol. Earth Syst. Sci.*, 11: pp 1279-1294.

MESH: A MEC surface/hydrology configuration designed for regional hydrological modeling

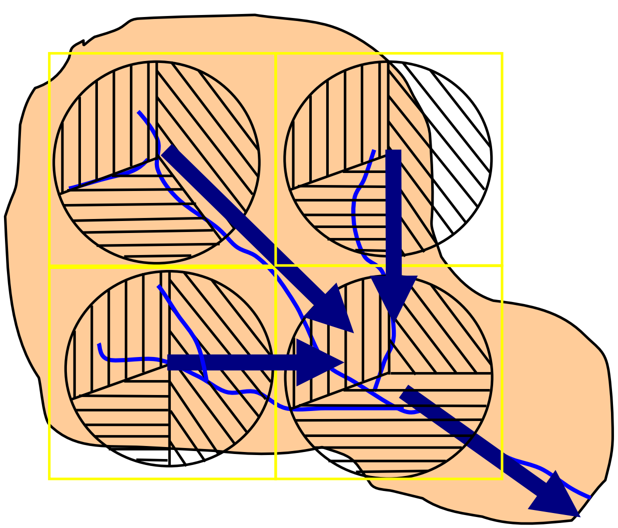


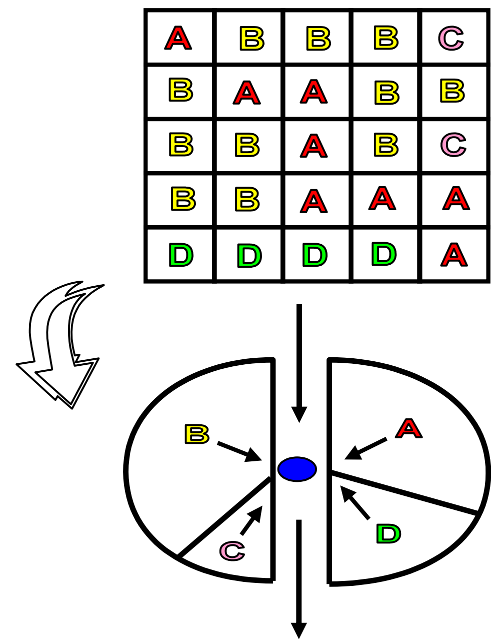
- The tile connector (1D, scalable) redistributes mass and energy between tiles in a grid cell
  - e.g. snow drift
- The grid connector (2D) is responsible for routing runoff
  - can still be parallelized by grouping grid cells by subwatershed



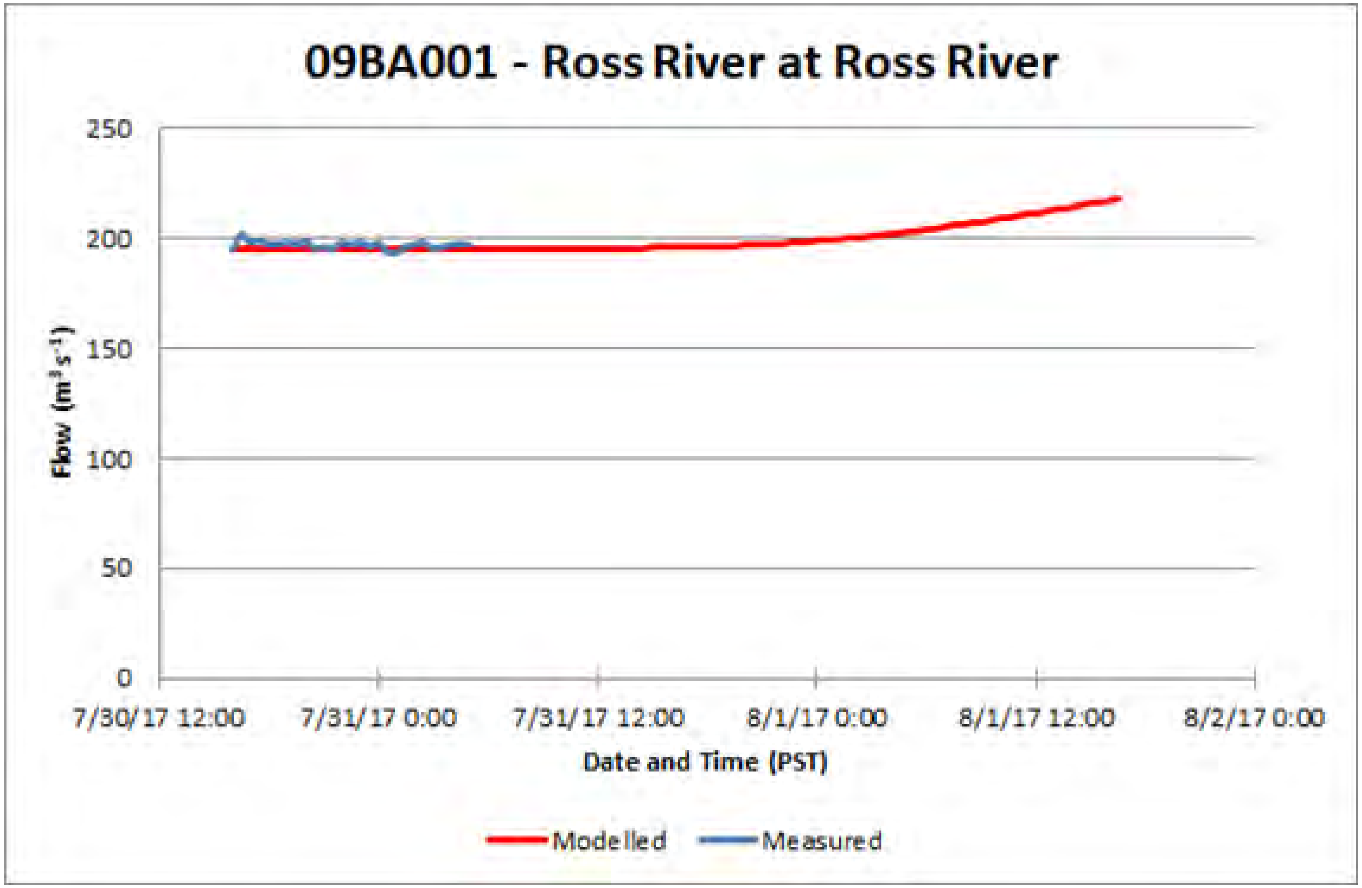
Basin Segmentation using the GRU

- The WATFLOOD model divides a watershed into a number of units known as Grouped Response Units and discritizes the basins into a series of a square grids.
- GRU is consistent in approach to many LSS used in atmospheric models
- The objective in using the GRU is to model hydrologically-consistent subareas of the watershed, each with known properties.
- Optimization of parameters on a landscape basis is possible
- Reduced the degrees of freedom and calibrate landcsape componenets to the observed hydrograph





GEM-MESH Operational Forecasts

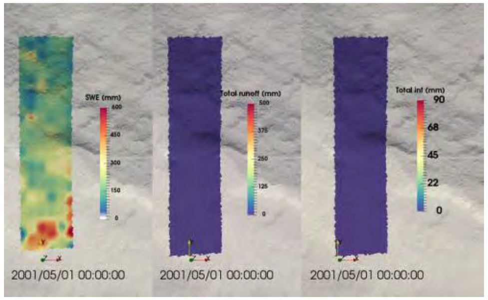


Canadian Hydrological Model (CHM)

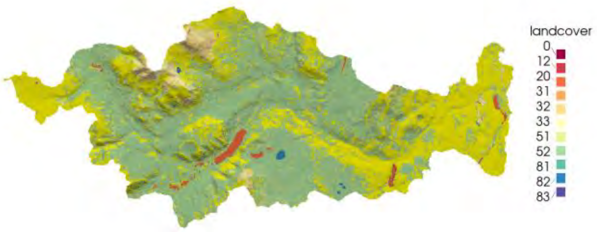
- Need to understand complex hydrological changes in cold regions
- Traditional modelling approaches are less viable under anthropogenic changes
- Next generation forecast and diagnosis hydrological model

Example model outputs

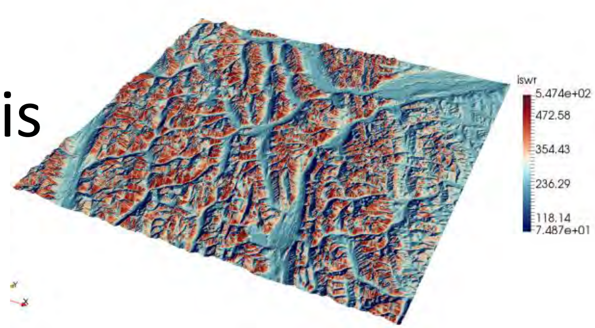
Hillslope (1 km^2)



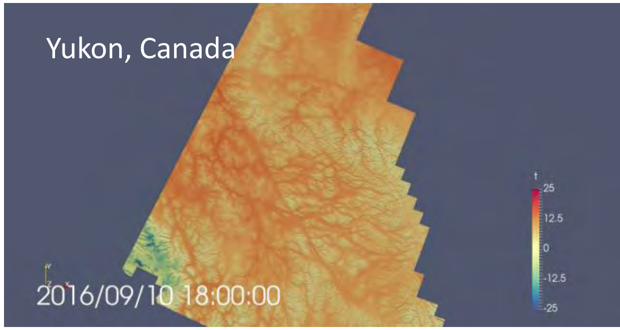
Basin (100 km^2)



Regional (8000 km^2)

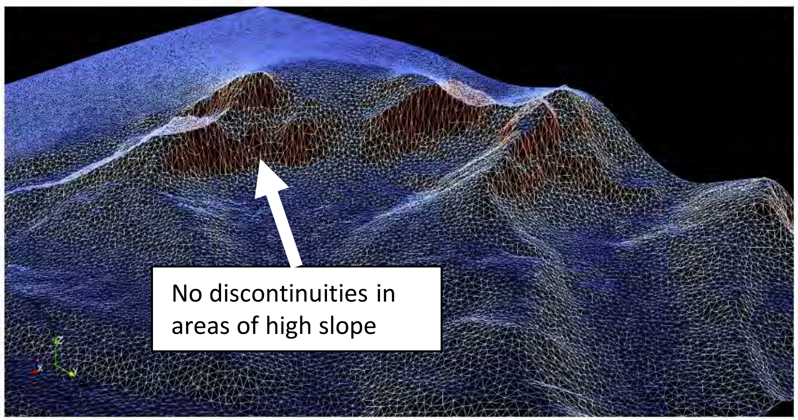


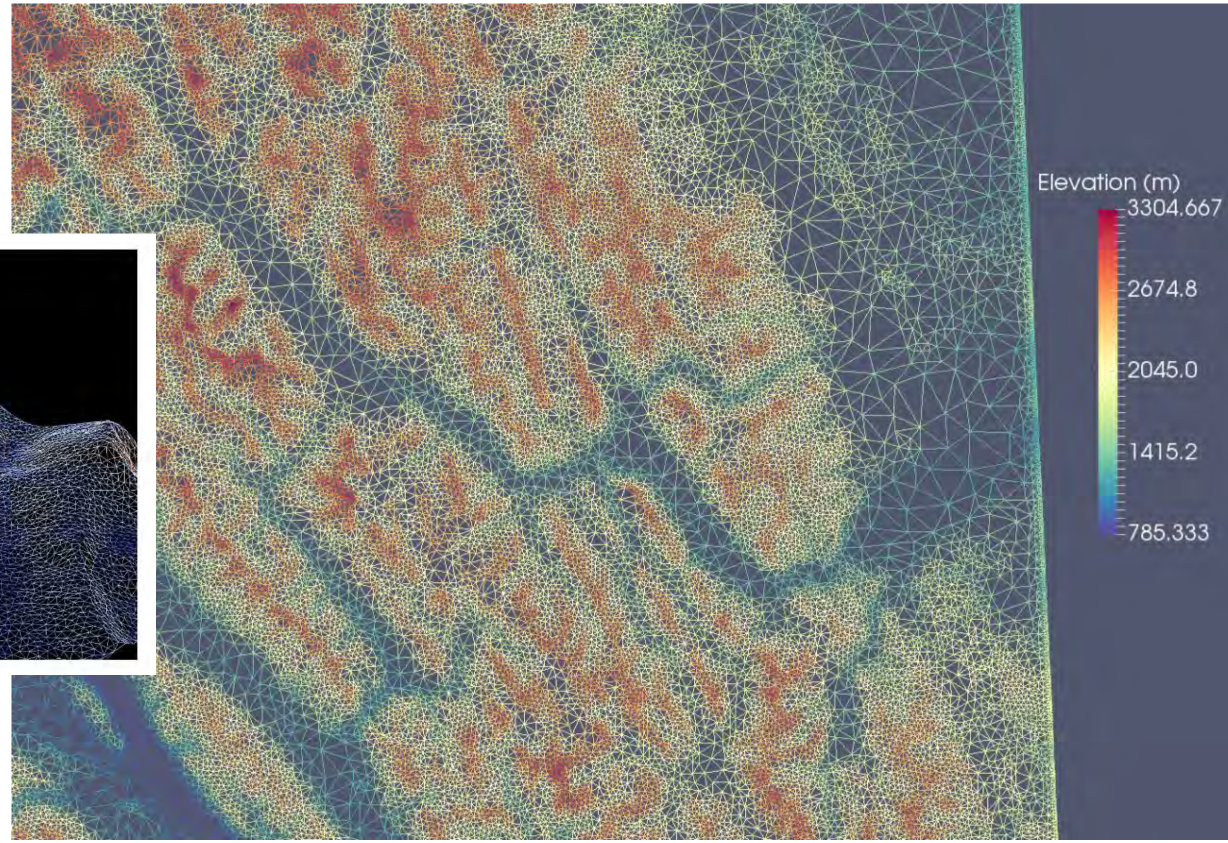
Provincial (500 000 km^2)



Unstructured triangular mesh

- Appropriate basin discretization
- Reduced number of elements
- Variable resolution

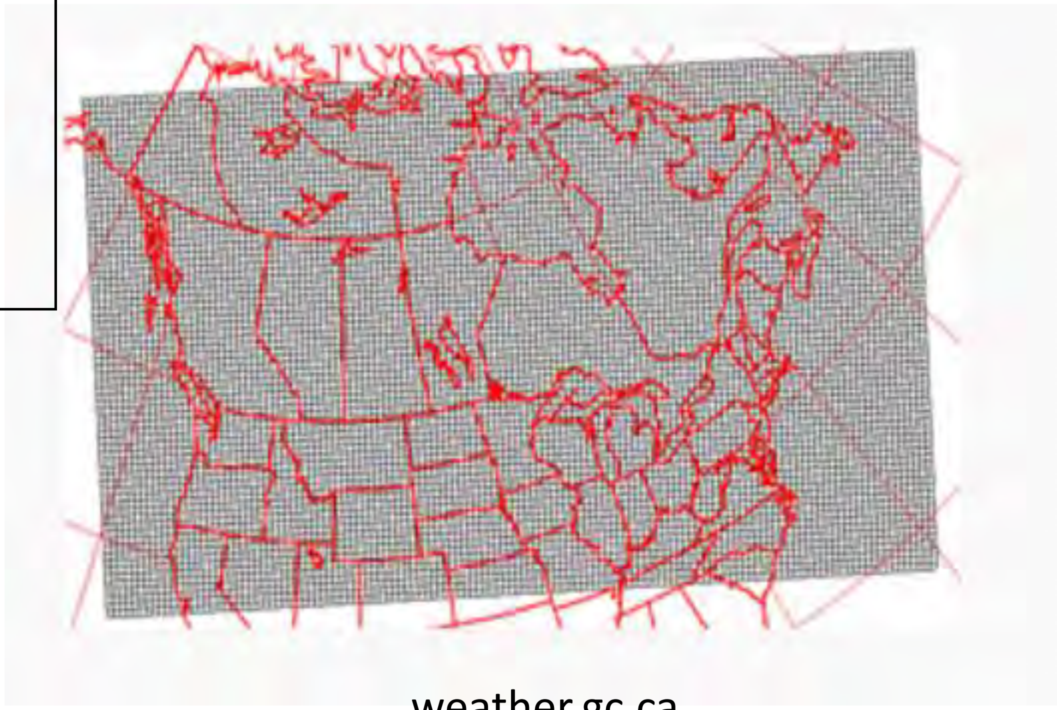




Global Environmental Multiscale (GEM) model

- 2.5 km resolution
- 48 Hour forecasts 4 times daily (00,06,12,18 UTC)
- Archived output (2014-Present)

Continental GEM domain



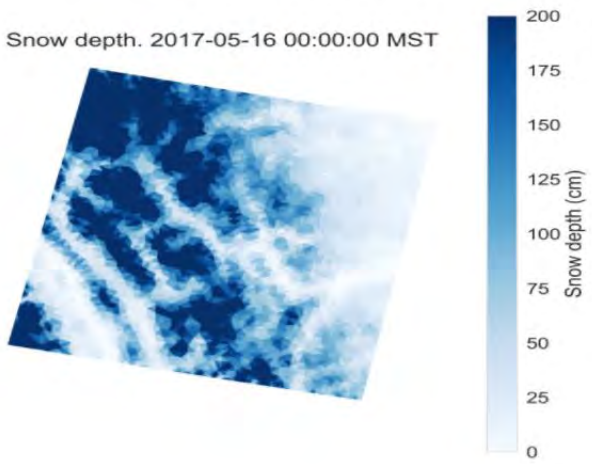
weather.gc.ca

1. What surface forecast variables are well predicted?
2. Can downscaling techniques compensate for persistent GEM issues?
3. Are higher GEM resolutions needed?

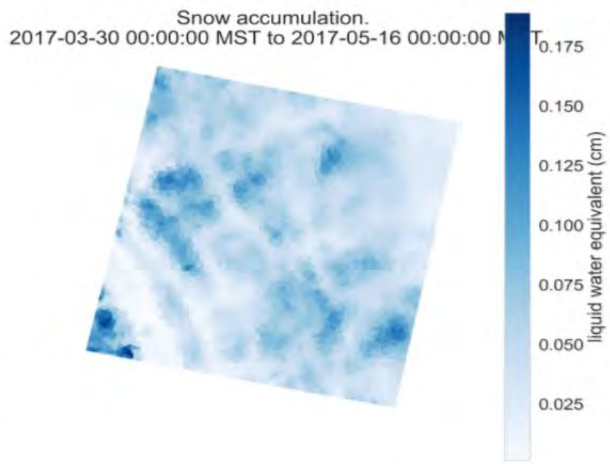
Experimental GEM-CHM Forecasts

- Running daily
- Evaluate historical forecasts and snow predictions

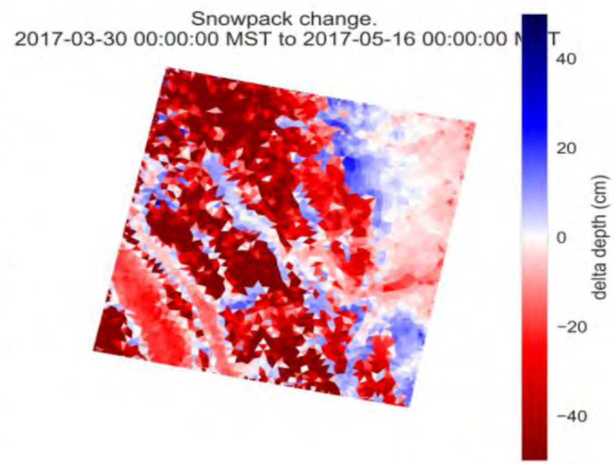
Snow Depth 2017-05-15



Snow accumulation (past 48 hours)

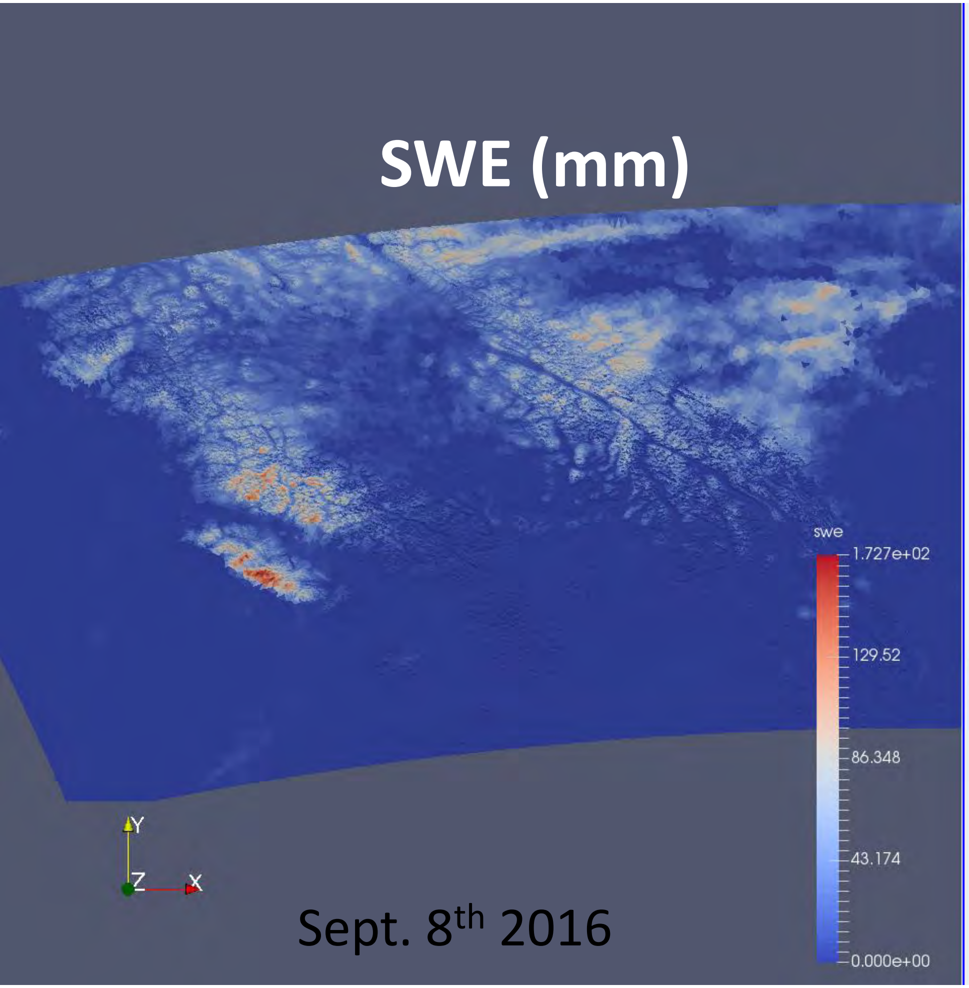


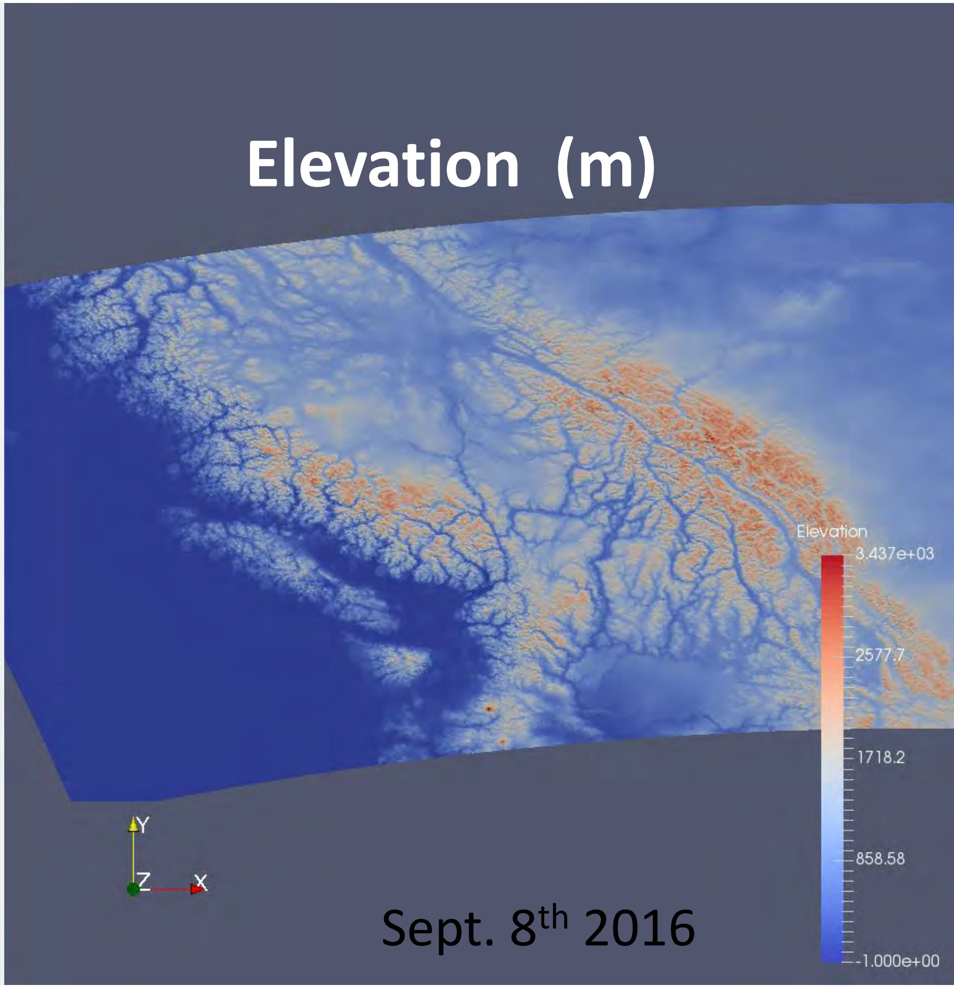
Snow Depth change (past 48 hours)



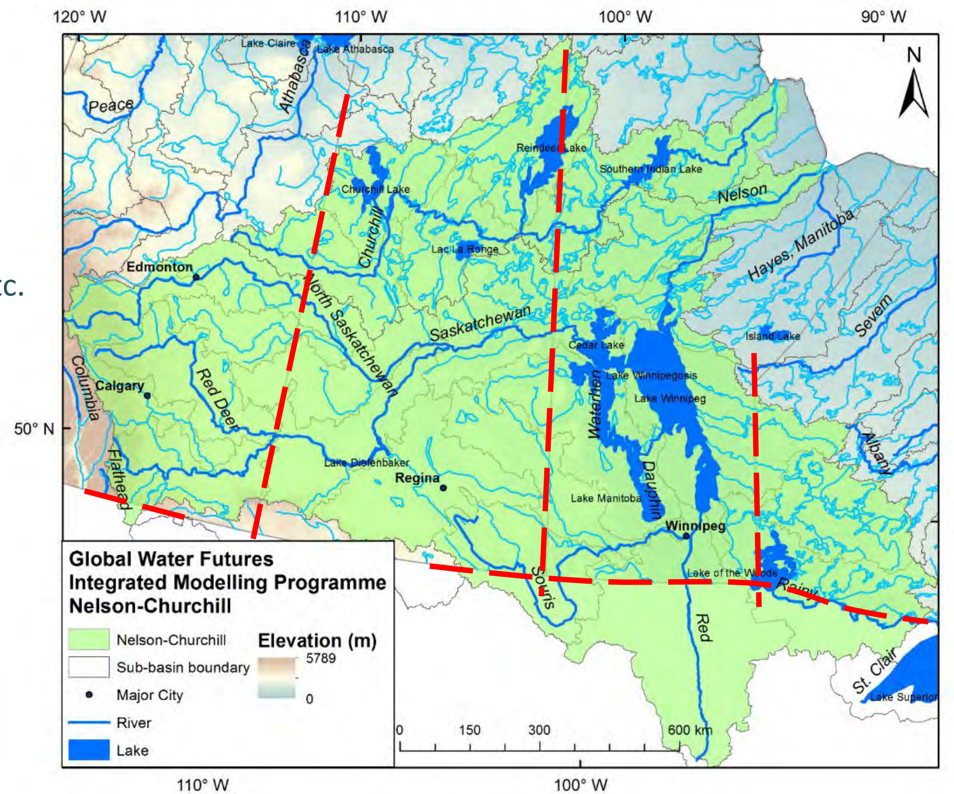
Upper Bow River domain

CHM modeled Snow Water Equivalent using GEM forecast forcing data





Nelson-Churchill River Basin: A Test Bed



Hydrologic Prediction Issues:

- Complex hydrology (Rockies, prairies, boreal forest),
- Floods and drought,
- River ice,
- Lakes and wetlands,
- Heavily regulated catchments,
- Land cover change and atmospheric feedback loops, etc.

Water Quality Issues:

- Eutrophication and nutrient transport,
- Algal blooms,
- Manure and fertilizer application,
- Contamination due to oil and gas extraction, etc.

Water Management Issues:

- Transboundary water issues,
- "Localized" approach to water management,
- Indigenous water needs,
- Over-allocation and competing demands,
- Environmental flows, etc.

And there are plans for new agricultural and industrial developments ?

What will a changing climate bring ?   How can we adapt ?