Global Water Futures Core Modelling Update

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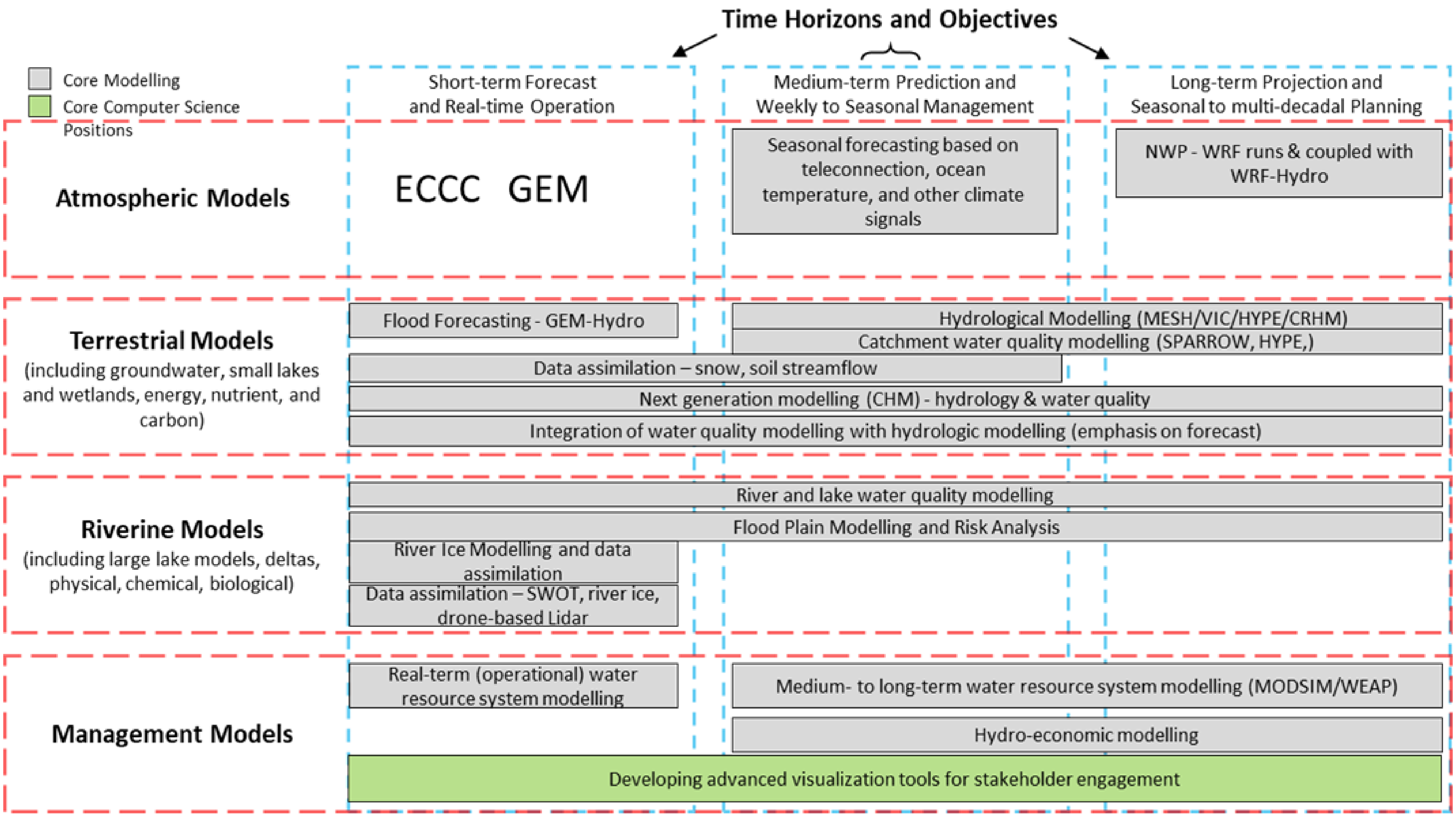
SOLUTIONS TO WATER THREATS IN AN ERA OF GLOBAL CHANGE


Time Horizons and Objectives
Core Modelling
Core Computer Science Positions
Short-term Forecast and Real-time Operation
Medium-term Prediction and Weekly to Seasonal Management
Long-term Projection and Seasonal to multi-decadal Planning
Atmospheric Models
ECCC GEM
Seasonal forecasting based on teleconnection, ocean temperature, and other climate signals
NWP - WRF runs & coupled with WRF-Hydro
Terrestrial Models
(including groundwater, small lakes and wetlands, energy, nutrient, and carbon)
Flood Forecasting - GEM-Hydro
Hydrological Modelling (MESH/VIC/HYPE/CRHM)
Catchment water quality modelling (SPARROW, HYPE,)
Data assimilation – snow, soil streamflow
Next generation modelling (CHM) - hydrology & water quality
Integration of water quality modelling with hydrologic modelling (emphasis on forecast)
Riverine Models
(including large lake models, deltas, physical, chemical, biological)
River and lake water quality modelling
Flood Plain Modelling and Risk Analysis
River Ice Modelling and data assimilation
Data assimilation – SWOT, river ice, drone-based Lidar
Management Models
Real-term (operational) water resource system modelling
Medium- to long-term water resource system modelling (MODSIM/WEAP)
Hydro-economic modelling
Developing advanced visualization tools for stakeholder engagement

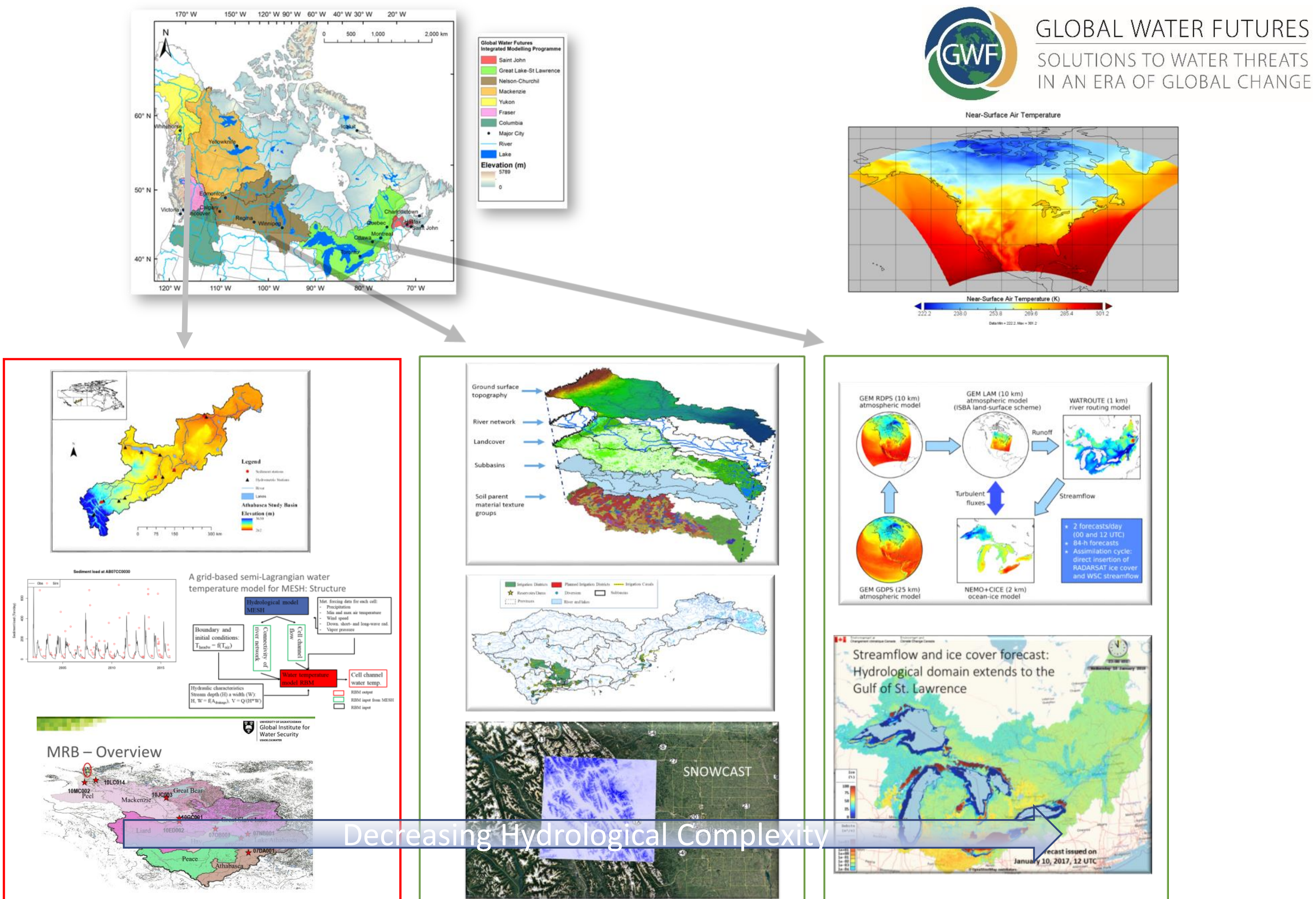
Some GWF Models

- Atmospheric Models or Forcing
  - GEM (Canadian NWP), WRF, CaPa
- Climate Models Outputs,
  - GCM, CRCM policy runs, Pseudo-Global Warming with WRF
- Coupled Atmospheric –Hydrology Systems
  - GEM Hydro, MESH, WRF Hydro
- Non-point pollution models such as Sparrow, MAGIC, HYPE
- Instream water quality models such as WASP
- Transport Models
  - PorousMediaLab, MatSedLab
- Stand-alone Hydrology Models
  - Cold Regions Hydrological Model (CHRM), MESH (includes a variant of ISBA, CLASS) , Canadian Hydrological Model-next generation, VIC, HYPE, SUMMA/mizuRoute
- Decision Support and Water Management Models such as MODSIM and WEAP
- Lake Models
  - MyLake model suite, ELCOM-CAEDYM, Nemo

GWF Model Principles

- Open-Source models if possible
- Consistent meta-data approaches to model runs
- Strong version control
- "Digestible " by user community
- Linking and coupling of various modelling systems
  - Common formats between models if possible
  - Shared tools / geospatial intelligence

- *Core modelling team starting to work closely with Core computing team*



MRB Model 19,598 grid cells, 11/12 GRUs, 1.755 M Km²

a) MESH development on Athabasca (T, Sed, Ice) b) Scenario runs for CC includes glaciers and permafrost

a) MESH Model Setup for the Saskatchewan River Basin; b) Incorporating reservoirs and water management in MESH; c) New model developments (TIN based) for snow forecasting in the Rocky Mountain Head-waterrs using CHM (Canadian Hydrological Model)

GEM-Hydro and NEMO operational system for Environment and Climate Change Canada's Great lakes Prediction System

Examples of key accomplishments

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- Developed prototype forecasting streamflow forecasting systems for key mountain river basins (e.g., the Bow River)
- Produced pan-Canadian WRF simulations for current and future climate
- Applied large-domain hydrologic models in major Canadian basins (e.g., Mackenzie, Great Lakes, Saskatchewan)
- Applied process-models in a range of headwater research basins (e.g., Marmot Creek, Whitegull Creek)
- Advanced next-generation modeling capabilities (e.g., initial development of the Canadian Hydrologic model, improved representations of dynamic contributing areas in the prairies).
- Developed process-based models of water quality (e.g., FLUXOS).
- Evaluated and applied water management models in highly managed river systems.
- Coupled hydrological-water temperature-sediment models.

These advances provide a strong foundation to develop the computational infrastructure necessary for hydrological research and applications in Canada.

Core modeling plans (focus areas)

- Spatial meteorological forcing data (CPPA, WRF, GEM)
- Geospatial intelligence to support large-domain hydrological modeling (topography, vegetation, soils, etc.)
- Current-generation hydrological modeling
- Next-generation hydrological modeling
- Model calibration, sensitivity analysis, and benchmarking
- Water resources modeling
- Hydrological forecasting
- Water quality

Spatial meteorological forcing data

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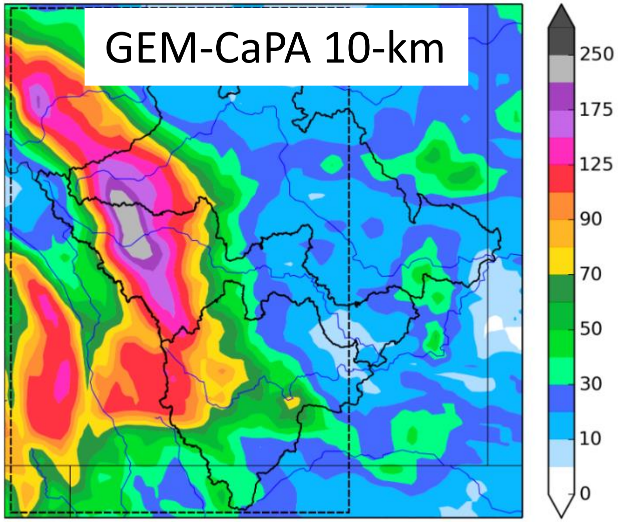
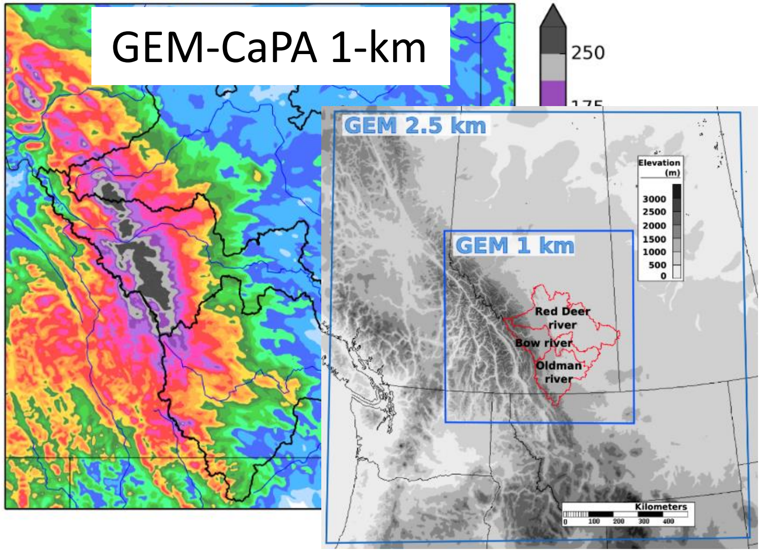
Spatial meteorological forcing datasets are used to correct biases in atmospheric models and to drive hydrological models

<u>Opportunities for improvement:</u>

- New datasets from ECCC
  - ➢ *New CAPA reanalysis (15-km grid, 1980-now).*
  - ➢ *New CPPA ensemble (only run in real time).*
- New regional climate model simulations, e.g., alternative configurations of GEM:
  - ➢ *Small-domain high-resolution instantiations over critical areas*
  - ➢ *Periodic re-initialization using atmospheric reanalyses*
  - ➢ *Nudge simulations within the model domain*
- New meteorological forcing datasets
  - ➢ *Use new regional climate model simulations*
  - ➢ *Use additional information sources (provincial climate networks, satellite information, etc.)*
  - ➢ *Use alternative spatial interpolation schemes*
  - ➢ *Quantify uncertainty.*





From Vincent Vionnet: *1-km GEM-CPPA improves simulations of the 2013 Canmore-Calgary flood*

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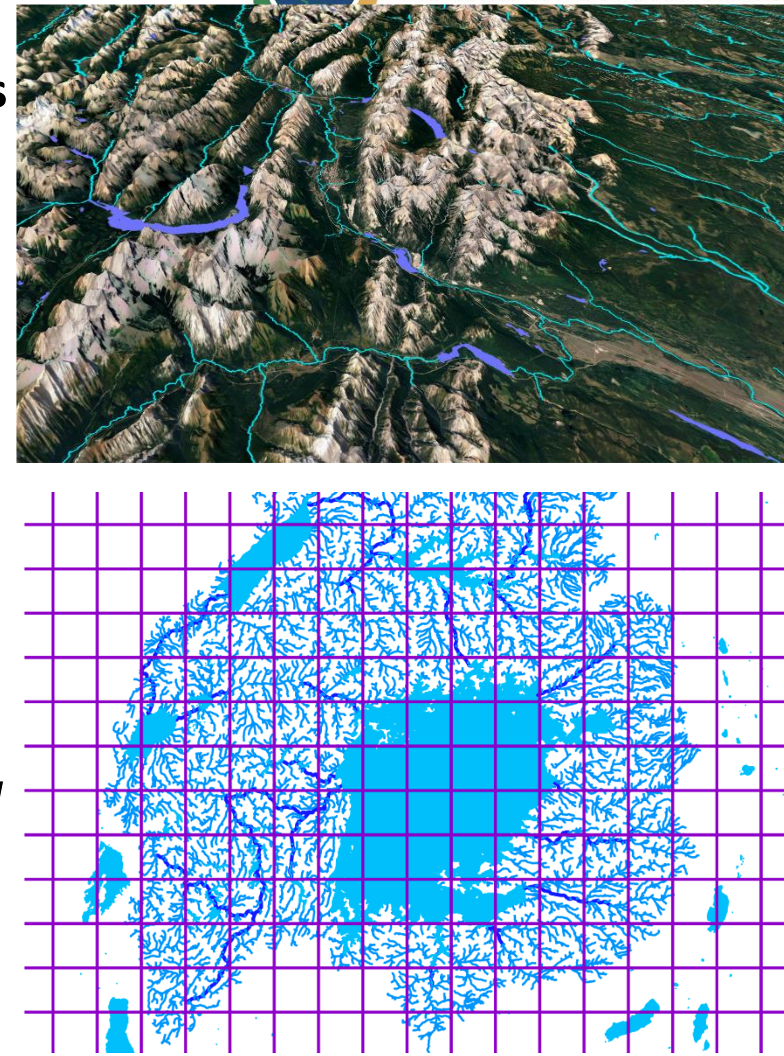
Geospatial intelligence

Hydrological models have common requirements for DEM analysis, vegetation and soils data, etc.; different models use different geospatial tools

<u>Opportunities for improvement:</u>

- Generalized methods for terrain analysis
  - *Open-source tools to delineate catchments and rivers, hillslopes and riparian areas, intersect rivers/lakes, etc.*
- Improve geophysical information
  - *New estimates of bedrock depth/permeability, river width, etc.*
  - *New transfer functions to relate geophysical data to model parameters*
- New datasets and model workflows
  - *Model-agnostic geospatial intelligence*
  - *Share pre-processing using jupyter notebooks*
  - ***Focus more on developing publishable general tools** to reduce workload for specific model implementations (advance PDF careers…)*



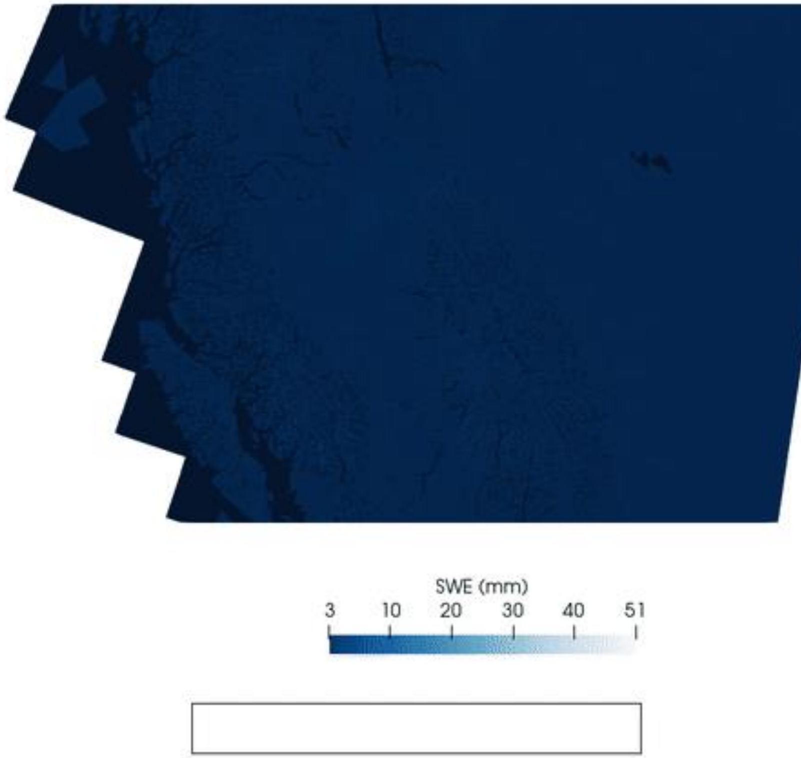
Hydrography datasets from globally-available elevation and lakes data. The figure shows Canadian Rockies (top) and the Nile headwaters (bottom).

Next-generation modeling

Canada has extensive expertise in cold-region hydrologic modeling.

Opportunities for improvement:

- Improve process representation
  - ➢ ***Glaciers*** *(the dynamics of glacier flow dynamics)*
  - ➢ ***Snow*** *(blowing snow, forest snow, dust loading)*
  - ➢ ***Vadose zone*** *(partially frozen soil, macropores)*
  - ➢ ***Potholes*** *and changes in contributing areas*
  - ➢ ***Groundwater*** *(shallow and deeper aquifers; characterizing hydrogeology; karst landscapes)*
  - ➢ ***Lakes and wetlands*** *(small, large, managed; fens and bogs)*
- Hierarchal coupling/workflow infrastructure
  - ➢ ***Inter-component coupling*** *(e.g., adding new capabilities to an existing model)*
  - ➢ ***Intra-component coupling*** *(e.g., managing exchange of information and time stepping for different model components)*
  - ➢ ***Multi-model coupling*** *(e.g., a chain of discrete models with one-way flow of information)*
  - ➢ ***Workflow management*** *(e.g., managing flow of information in a complex forecasting system).*



From Chris Marsh: *Example CHM simulations for a 96-hour storm in western Canada*

Parameter sensitivity/estimation

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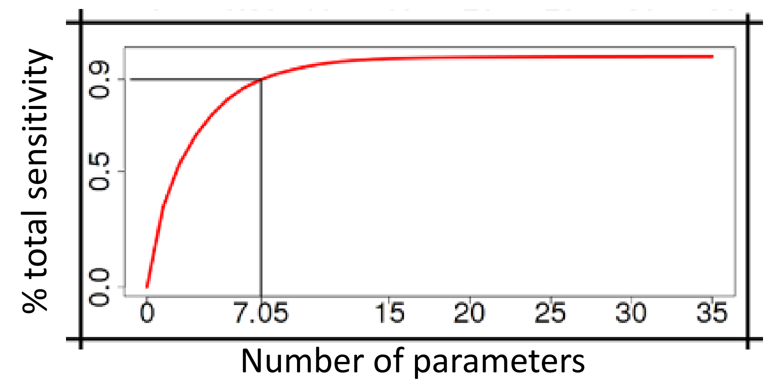
Extend model calibration and sensitivity analysis methods to pan-Canadian simulations.

<u>Opportunities for improvement:</u>

- Sensitivity analysis methods to understand model behavior across large domains.
- Process-based parameter inference across large regions (inter-comparison project)
  - ➢ ***Evaluate alternative parameter estimation strategies*** *(e.g., parameter multipliers applied to a-priori fields; landscape calibration, etc.)*
  - ➢ ***Multiple datasets/signatures*** *(e.g., snow extent, permafrost extent, streamflow, etc.)*
  - ➢ ***Multi-objective / multi-response parameter estimation strategies*** *(e.g., ABC).*
- Formal benchmarking system
  - ➢ ***Multi-scale*** *(data from research catchments to evaluate each process individually as well as large-scale model benchmarks)*
  - ➢ ***Catalog of past modeling efforts***
  - ➢ ***Data integration/synthesis***

Number of parameters that control infiltration



Example large-domain parameter sensitivity analysis in the USA
(Markstrom et al., HESS 2017)

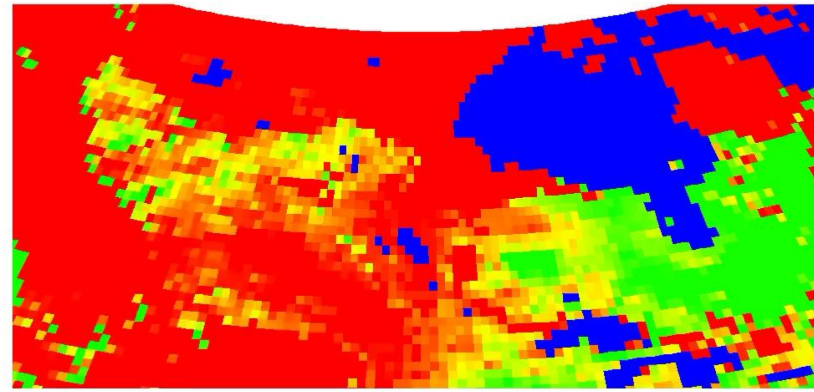
Water resources modeling

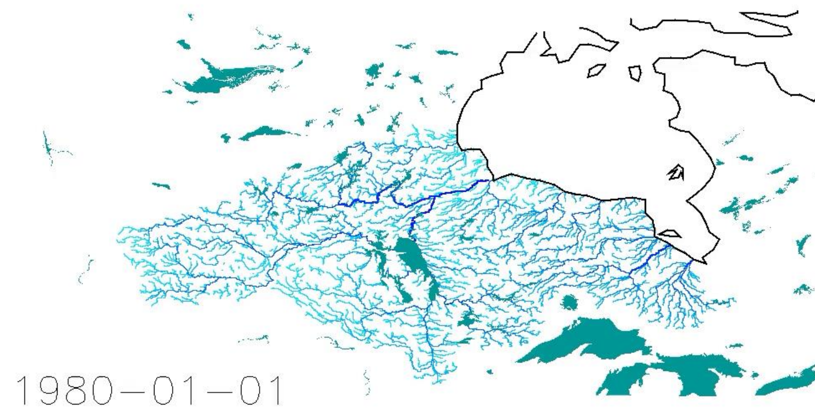
Much more work is needed to represent the human impacts on the terrestrial water cycle across Canada.

Opportunities for improvement:

- Develop water management benchmarks
  - *Apply existing water management models (e.g., WEAP) to provide a benchmark for the representation of water management in ESMs.*
  - *Detailed comparison between land models and water management models is necessary to identify key development needs.*

- Advance water management in ESMs
  - ***Small lakes** (i.e., sub-grid lakes that are not represented as objects on the river network)*
  - ***Large lakes** (i.e., the lakes that are represented as objects on the river network)*
  - ***Managed lakes** (i.e., representation of reservoir management)*
  - ***Water diversions and irrigation**.*
  - *A key issue is the coupling of the lake water balance and the lake energy balance.*





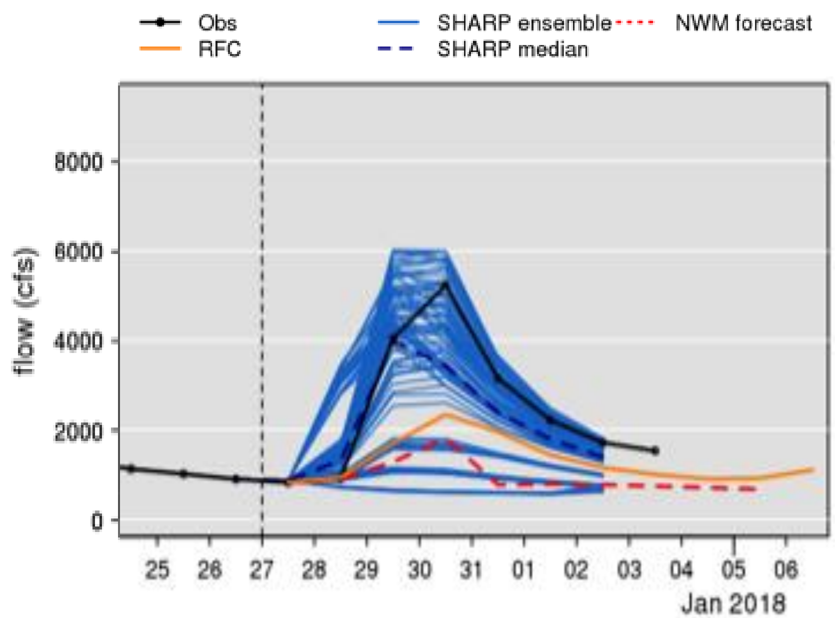
Human impacts on the terrestrial water cycle are ubiquitous and must be an essential component of ESMs

Hydrological forecasting

Need for comprehensive evaluation/advances in operational hydrologic forecasting

Opportunities for improvement:

- System development
  - *Develop a system to couple and schedule forecasting components (model spin up, data assimilation, downscaling numerical weather prediction model output, forecast runs, post-processing, visualization, etc.).*
- Hydrologic prediction research
  - *Focused research on critical topics in hydrolog forecasting, especially downscaling, data assimilation, and forecast post-processing*
- Hydrologic prediction testbeds
  - *Implement test-beds for specific basins (e.g., the Bow and the Grand) to enable rapid prototyping of new prediction methods*



Example streamflow forecasts for the test-bed in Howard Hanson Dam, USA

This work will evolve in close collaboration with the Treasury hydrologic prediction effort

Onward: Proposed tiger teams

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- **Spatial meteorological data**
  - *Julie Theriault, Yanping Li, Vincent Vionnet, Elvis Asong, Simon Papalexiou*
- **Geospatial intelligence**
  - *Mohammed Elshamy, Dan Princz, Shervan Gharari, Julienne Mai, Bryan Tolson*
- **Next-generation hydrological modeling**
  - *Chris Marsh, Vincent Vionnet, Dave Rudolph, Ray Spiteri, Kevin Schneider, Kevin Shook, Dan Princz, Zelalem Tessmma, Xing Fang*
- **Model evaluation, parameter estimation, and sensitivity analysis**
  - *Saman Ravazi, Bryan Tolson, Julienne Mai, Mohammed Elshamy, Dan Princz, Markus Schnorbus, Shervan Gharari*
- **Water management**
  - *Saman Ravazi, Fuad Yassin, Nhu Do, Andrew Saughter, Hongxiu Li*
- **Hydrological forecasting**
  - *Vincent Vionnet, Youssef Loukili, Zhenhua Li, Zelalem Tessmma,Nasim Hosseini, Siva Prasad, Parbin Rokaya*
- **Water quality**
  - *Phillippe van Cappellen, Helen Baulch, Diogo Costa, …*

Global Water Futures

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