ECCC's water cycle prediction program and Global Water Futures

Alain Pietroniro, Executive Director, National Hydrological Service, Meteorological Service of Canada and Lead - Global Water Futures Core Modelling Program

GLOBAL WATER FUTURES

SOLUTIONS TO WATER THREATS IN AN ERA OF GLOBAL CHANGE

Contributors

- Dr. John Pomeroy, University of Saskatchewan
- M. Michel Jean, Director General, MSC
- Dr. Vincent Fortin, Research Scientist, ECCC
- Dr. Bruce Davison, Research Scientist, ECCC
- Dr. Saman Razavi, Associate Professor, University of Saskatchewan
- Mr. Daniel Princz, Research Engineer, University of Saskatchewan
- Mr. Kevin Shook, Research Engineer, University of Saskatchewan
- All members of the core modelling team and many others

Outline

- Understanding the Federal context for hydrology
- Background on Numerical Weather Prediction in Canada
- ECCC and Environmental Prediction
- The importance of GWF to ECCC
- Review of Core modelling activity and modelling within GWF
- Selected updates on core modelling team efforts

ECCC Drivers for Change

The context of how we deliver our missions has changed significantly over the past 10 years by trends internal and external to department…

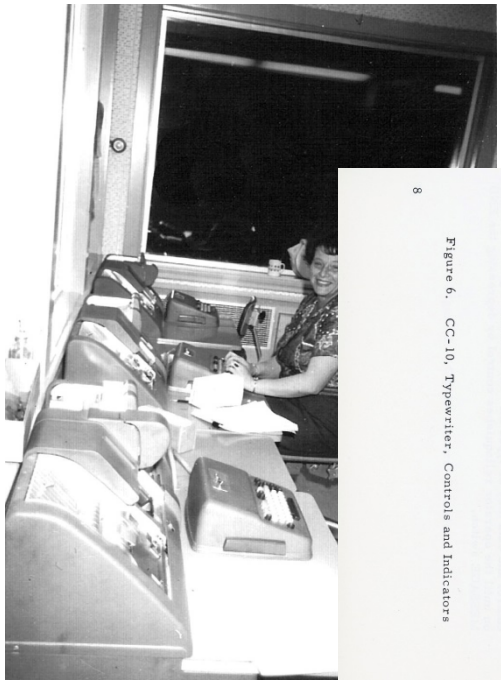
- *Climate Change and Resilience*
  - Demands for more reliable and accessible localized predictions and longer lead times of hydro-meteorological extremes are being accentuated by a changing climate.
- *Technology*
  - Today's technological environment is radically different than 10 years ago, providing tremendous potential for innovating and improving program delivery including new investments in technological developments such as upgraded supercomputing platform.
- *Digital Age*
  - As digital innovation permeates society to a greater and greater extent clients and stakeholders expectations' evolve accordingly.
  - New methods are arising to decipher through artificial intelligence, the relevant information in this big data environment with the potential for applications in a weather and climate forecasting.
- *Open Government*
  - Today's governments are placing a much stronger emphasis on being an open data and services as well as seeking to stimulate the Canadian economy through partnerships

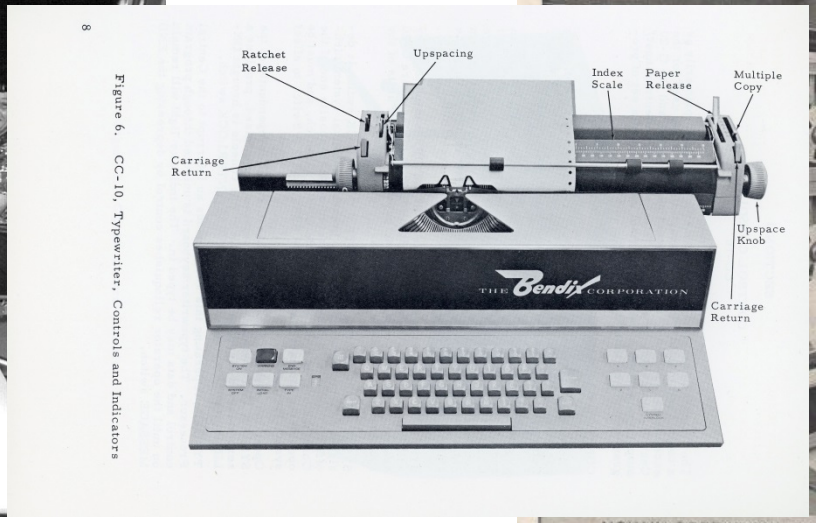
Context for Water Resources

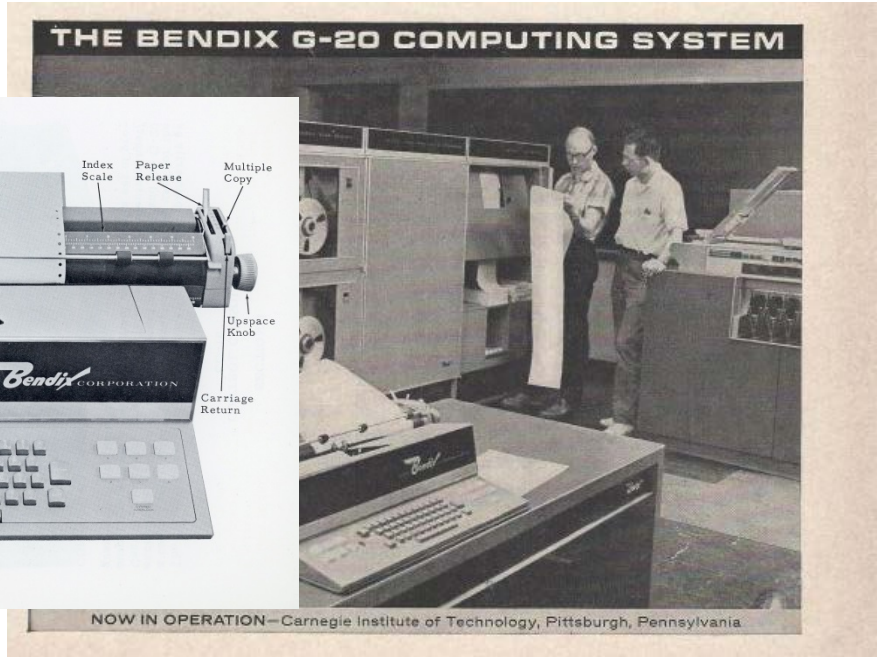
- ECCC has a series of mandated responsibilities for water resources and it management in Canada
- In 2013, MSC recognized the convergence of interest and capacity between MSCs national hydrometric program delivered through the Water Survey of Canada and its transboundary water management obligations.
- A National Hydrological Service was developed as a new forward-looking vision to optimize and consolidate existing MSC program elements.
- More recently the desire for a national framework for prediction in water resources is being discussed
  - Meet transboundary requirements
  - Work with Provinces and Territories for flow guidance systems tied to NWP

Some History :PRE-Canadian Meteorological Centre era

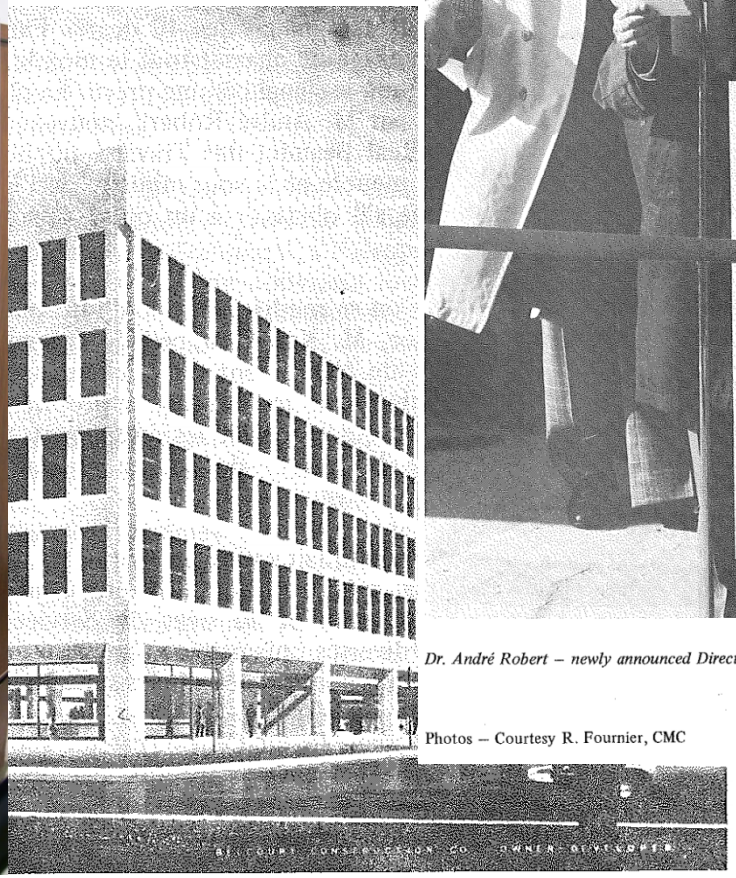
- 1963 Inauguration of the First Numerical Weather Prediction (NWP) Computer at the Central Analysis Office (CAO) Montreal - Bendix G20 (at YUL)







1973
The first days of CMC



West Isle Office Tower

Dr. André Robert – newly announced Director of CMC

M. André Robert – nouveau Directeur du Centre

Photos – Courtesy R. Fournier, CMC

Photographies – Courtoisie de R. Fournier, CMC

Model calculations – HPC power – Fore

Forecast qu

30
20
10
0

CDC
Cray
NEC
IBM

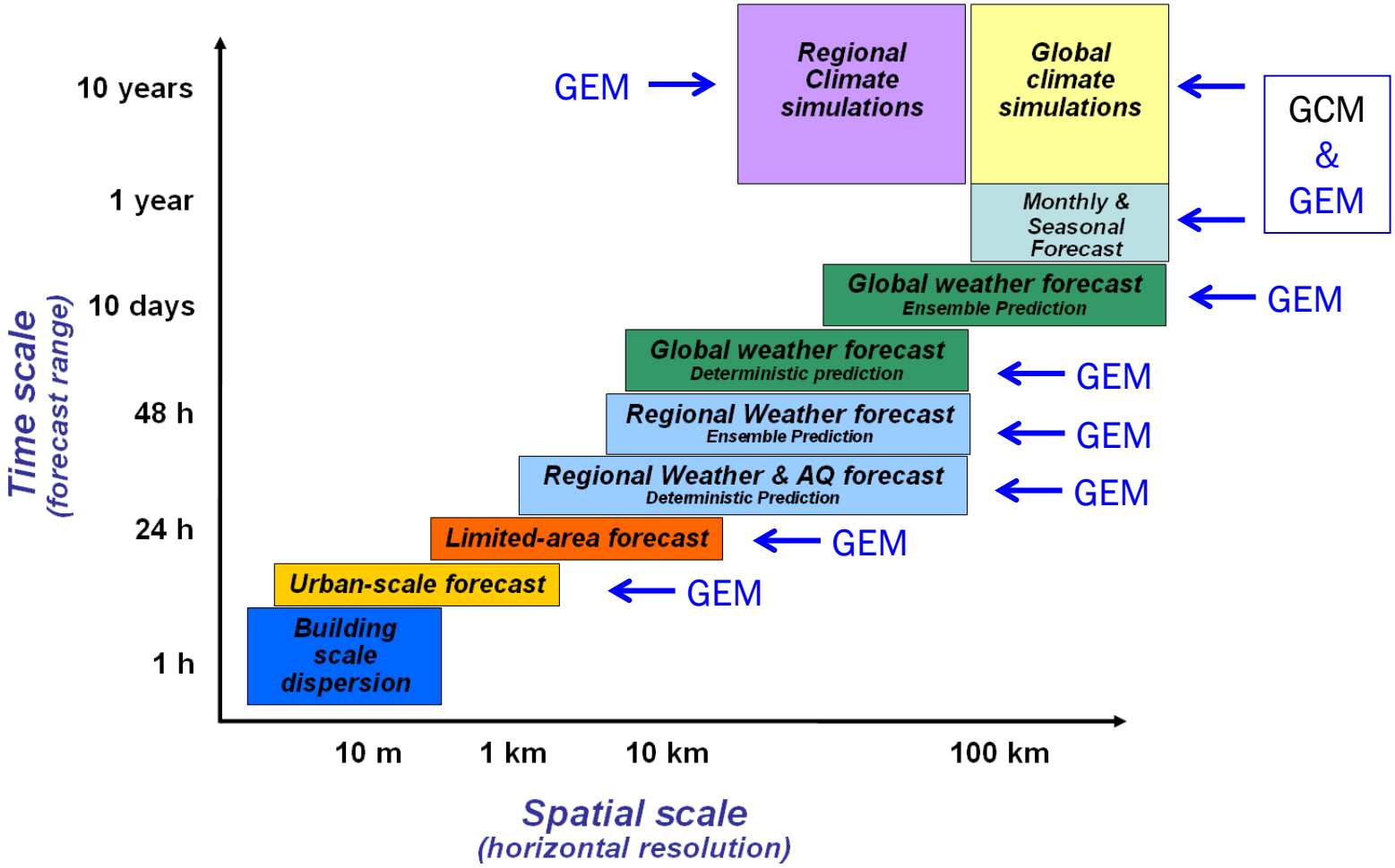
1.0E+01
1.0E+00
1.0E-01
1.0E-02

Mflo

Model calculatio

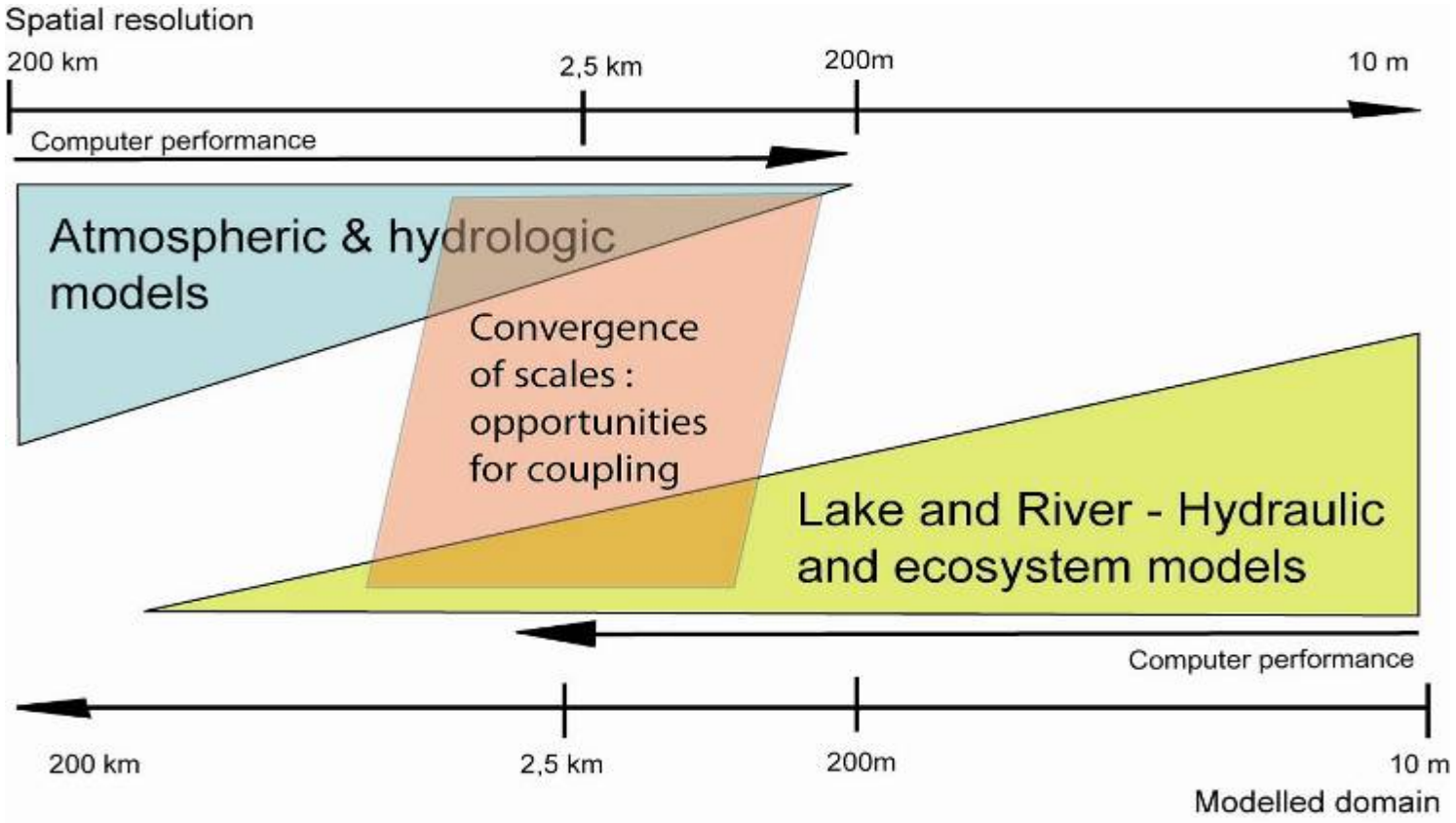
1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016

Modeling systems running on ECCC supercomputer



Why hydrologic, lake, river and ecosystem model applications are emerging?

- Established models exist for most components
- Modeling scales are converging

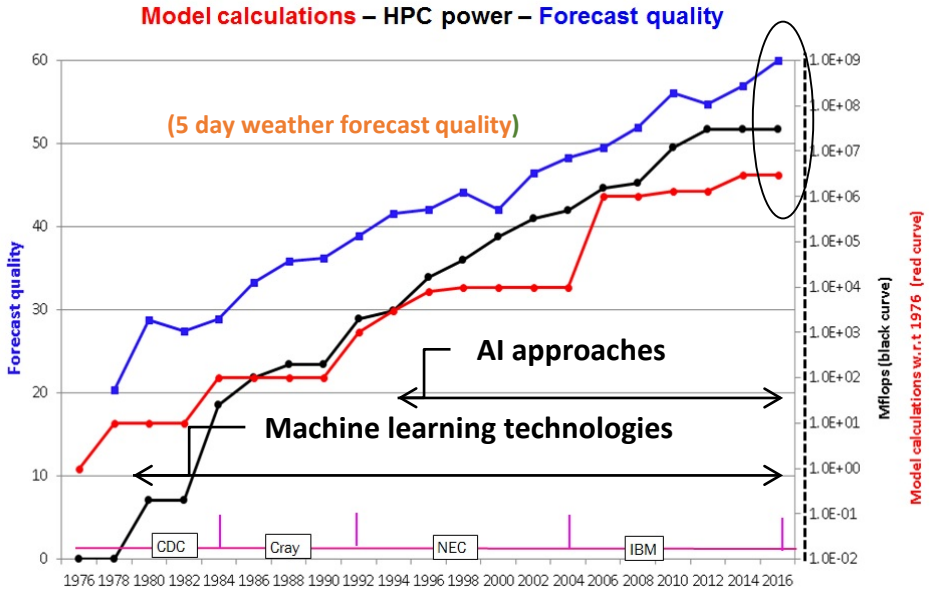


Supercomputing capacity (biggest ever inCanada) has allowed for great improvements in our ability to predict changes in the environment…

- Our ability to predict changes in the environment has improved substantially over the past 20 years driven by science and computing capacity

"On the global scale, we can today predict out to six days ahead as accurately as we could do for four days 20 years ago. This means society has much more advance warning of weather hazards".

WMO, 2015, Seamless prediction of the Earth system: from minutes to months

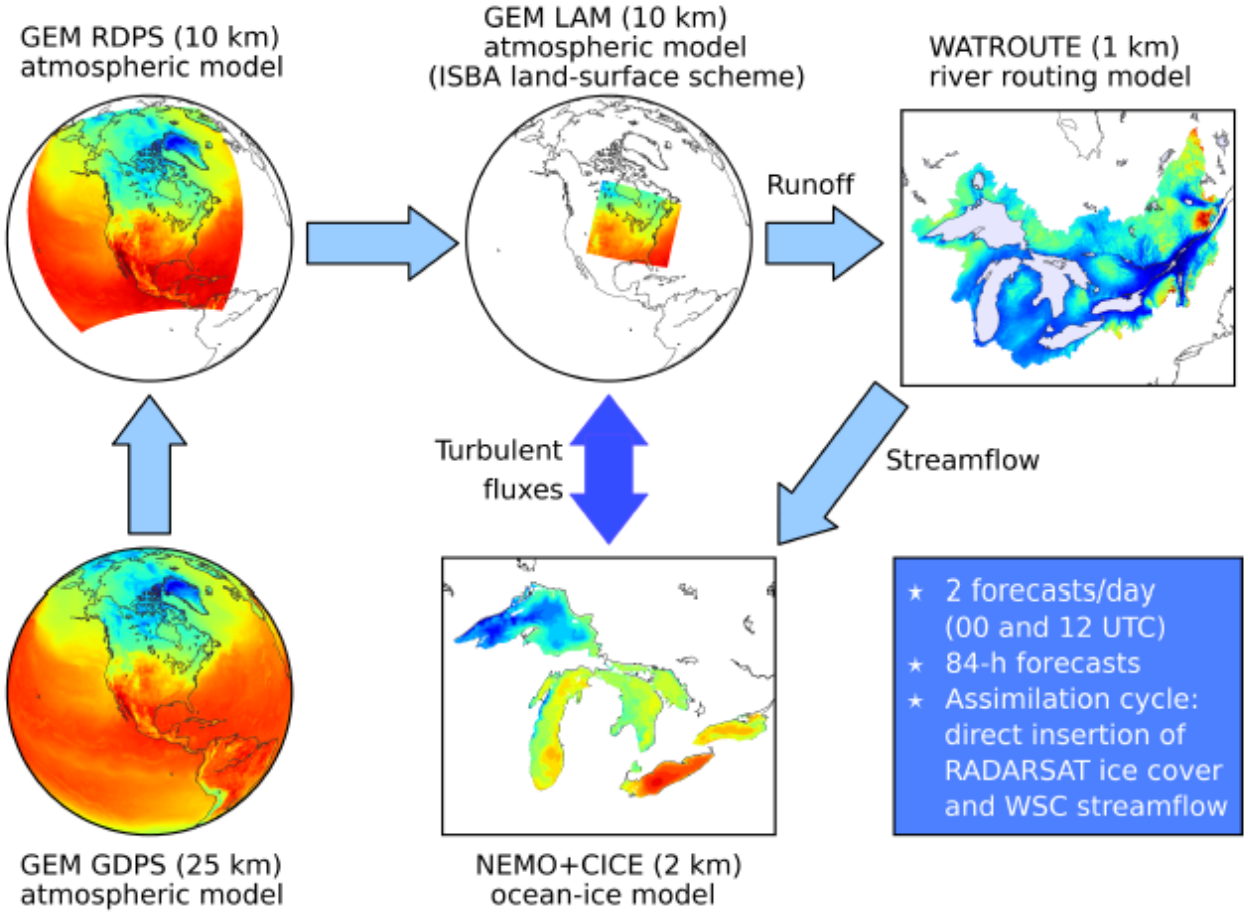


- Increased computing capacity allows for
  - Run more complex models (simulating more nat
  - Integrate larger and more observation data sets, including satellites and crowd-sourced information
  - Produce more prediction information and services to support immediate and longer-term problems such as climate change (service delivery platform)

Benefits are significant to further policy objectives….

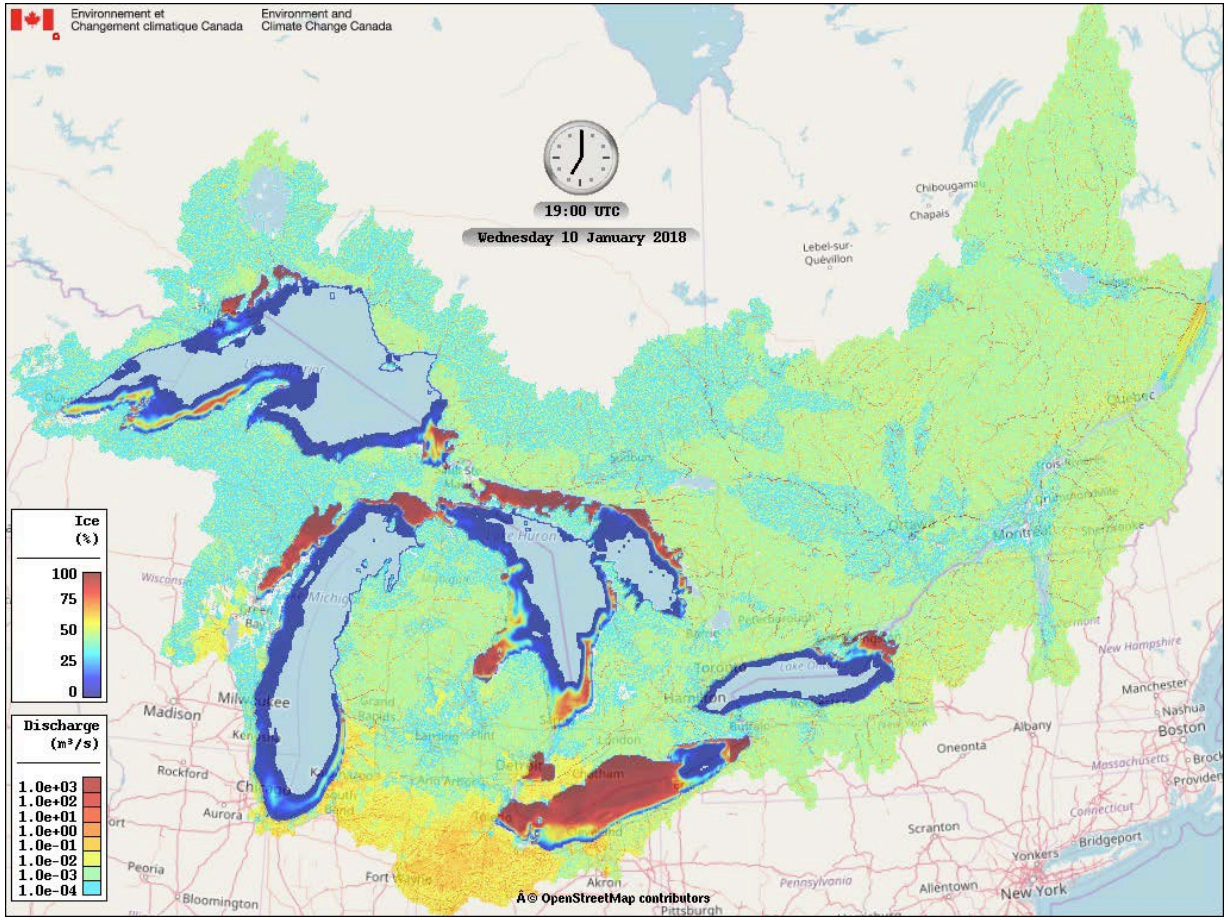
- **Essential services for health, safety and security of Canadians**
  - **Safe transportation** (ex. forthcoming opening of the Northwest Passage, autonomous vehicles…)
  - **Health and environmental protection** (ex. climate change adaptation measure scenarios…)
- **Clean economic growth and climate change**
  - **Clean Energy** (ex. power grid control of sources between wind, hydro and solar…)
  - **Cities** (ex. Smart Cities…)
  - **Infrastructures** (ex. supporting *Investing in Canada Plan…*)
- **Policy and regulation development (carbon, etc) and enforcement**
- **Positive national environmental outcomes**
  - **Water management** (soil & land surface information for flood control…)
  - **Landscape evolution, SARA and EA considerations**
- **Collaborative government science objectives**

A Water Cycle Prediction System for the Great Lakes

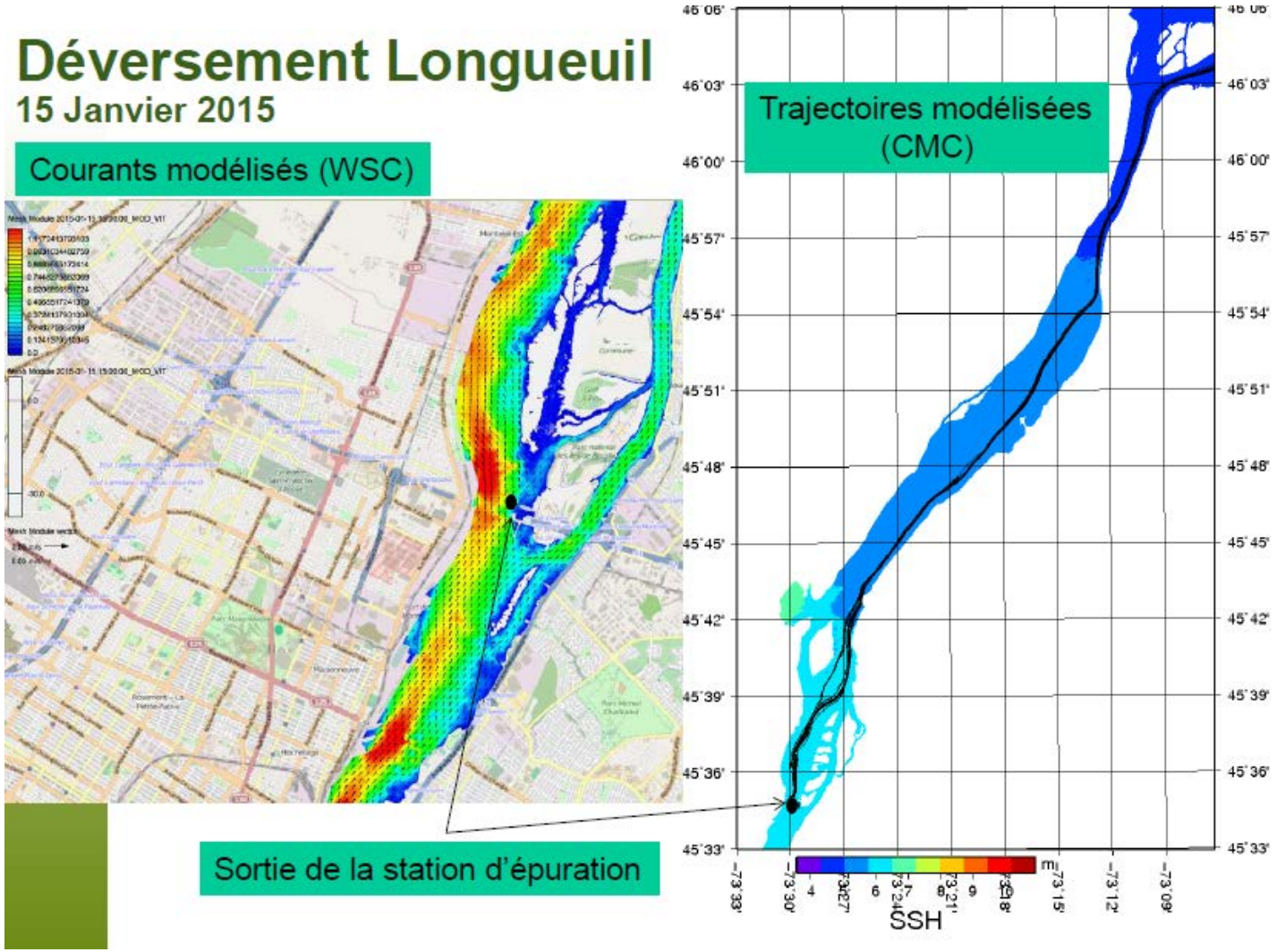


System described in the Bulletin of the American Meteorological Society, March 2018

Streamflow and ice cover forecast: Hydrological domain extends to the Gulf of St. Lawrence



Operational 2D hydraulic and dispersions model for the St. Laurent



Modernizing ECCC's Water Cycle Prediction Programme

GEM-Hydro

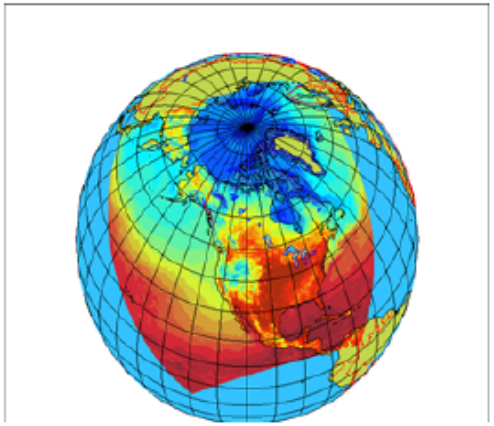
- Integrated into MSC's operational forecasting infrastructure
  - **SVS land-surface scheme**
  - CaLDAS data assimilation
  - GEM atmospheric model
  - Two-way coupling with GEM
- Designed for regional-scale, high resolution forecasting
  - short simulation periods
  - 2.5 km resolution or better

MESH

- Initially designed for R&D activities and hydroclimatic applications
  - **CLASS land-surface scheme**
- Stand-alone platform
- Community model
- Efficient system for:
  - long simulations periods
  - model calibration

GEM Hydro – Gaborit, 2017

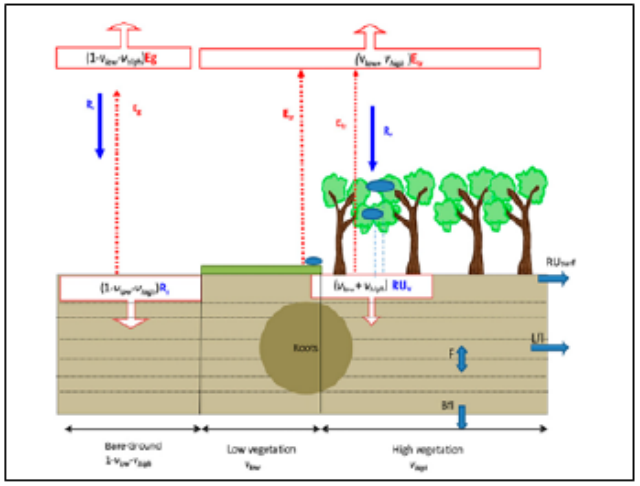
Atmospheric forcing



- Init. cond.: CaLDAS
- Forecasts from the GEM model
- Canadian Precipitation Analysis (CaPA)

Land Surface Scheme
SVS (Soil Vegetation and Snow)

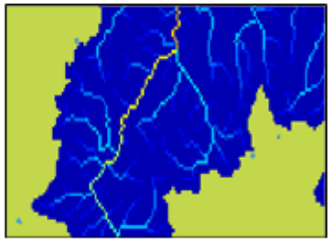
Alavi et al. (2016) Husain et al. (2016)

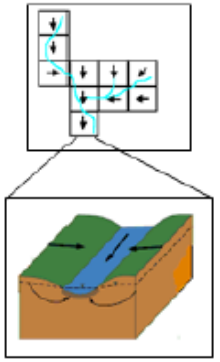


- Multiple energy budgets for bare ground, low and high vegetation
- Single layer snowpack scheme

Routing
WATROUTE

Kouwen (2010)

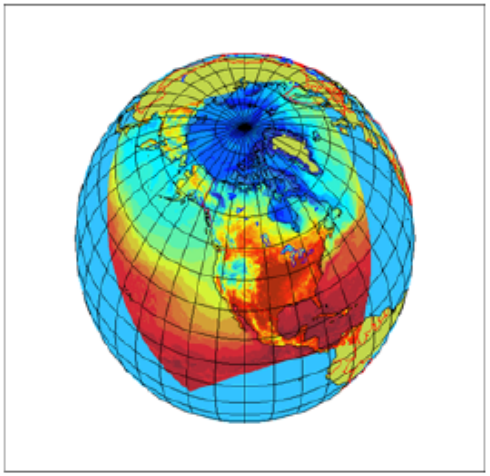




WATFLOOD
Routing scheme

MESH (Pietroniro *et al.*, 2006)

Atmospheric forcing

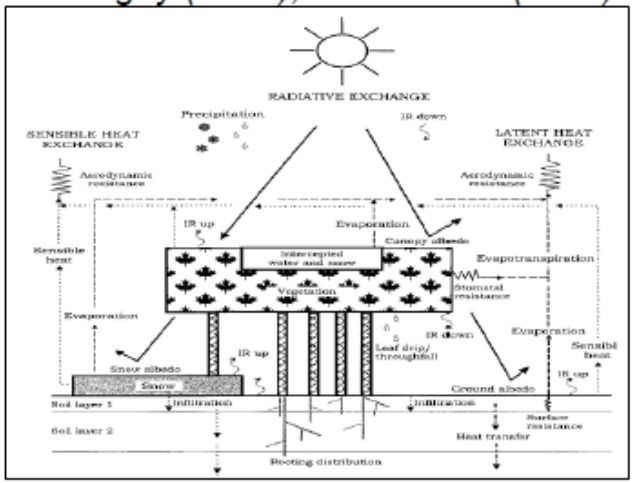


- Gridded hourly met. forcing data
- In practice, GEM and CaPA are often used

Land Surface Scheme

CLASS + WATROF/PDMROF

Verseghy (1991), Soulis et al. (2011)



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Routing

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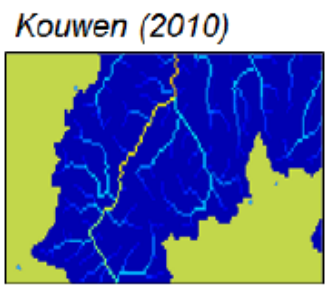
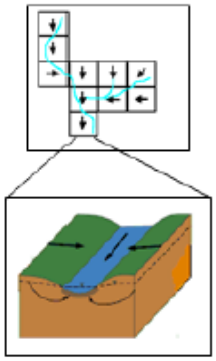




WATFLOOD
Routing scheme

Designed for open-loop simulations – testing and evaluating – limited assimilation capacity

Challenges with Gem-Hydro

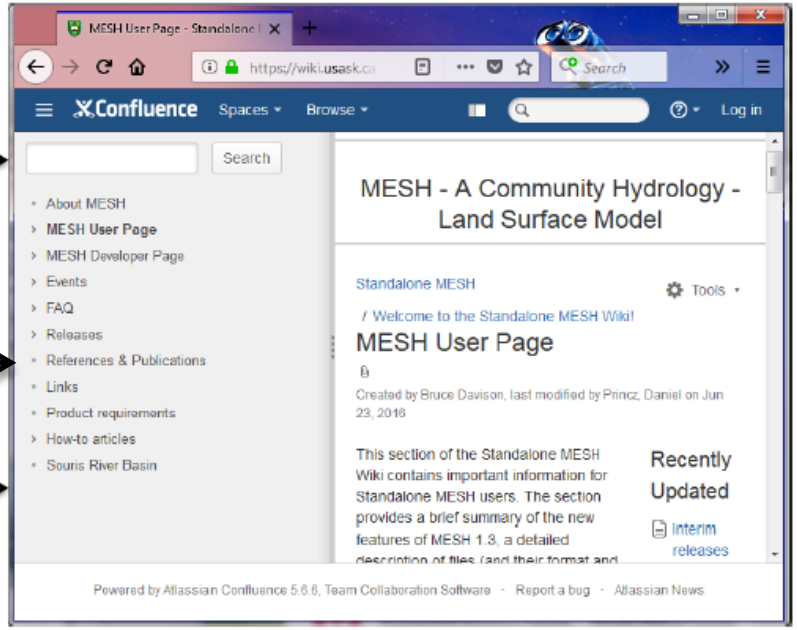
- Challenging to set up and configure
- Dependent on ECCC's HPC software solution
- Needs to be tuned to ECCC's HPC hardware solution
- Incomplete documentation
- Limited support for external users

Why 2 land-Surface hydrology Schemes

- CLASS (in MESH) closes the energy balance and represents more physical processes than SVS
  - Recommended for hydro-climate prediction
  - Also used by ECCC's GCMs
- SVS (in GEM-Hydro) is coupled to a land-data assimilation system (CaLDAS) that assimilates in-situ and satellite data on precipitation, soil moisture and surface temperature
  - Recommended for hydro-meteorological forecasting
  - Available for use in ECCC's NWP model GEM

See talk by Bruce Davison on description of MESH

Advantages of MESH and future plans



- Integrate SVS into MESH as new land-surface scheme option
- Promote the evaluation and improvement of SVS by the academic community
- Within ECCC
  - Test the impact of proposed improvements to the SVS model and its parameters in GEM-Hydro (for both coupled and uncoupled runs)
  - Use MESH coupled to automated calibration tools (such as DDS) to optimize the configuration of GEM-Hydro

Why GWF and ECCC and Why Now ?

- Hydrology still not completely defined, particularly Cold Regions
  - Dealing with spares data systems, incorporating cold regions processes, basin segmentations and physics, data assimilations ….
- No systematic water quality models have been implemented
  - No In-stream quality systems e.g. (WASP)
  - No non-point pollutions models operational
  - No lake quality modelling systems
- Hydraulic models currently limited in ECCC systems
- No DSS implemented
- No water management

At ECCC we recognize Current Hydrological Approaches are Limited

- Hydro-mythology : *Concepts that have been dismissed by scientific investigation but persist in hydrological model (*Pomeroy)
- Examples:
  - Radiation is difficult to estimate with normal meteorological data
    - Evapotranspiration can be estimated by temperature and wind functions
    - Temperature index melt of snow and soil thaw
  - Snowfall determines snow available for melt
    - Sublimation = 0
    - Snowfall gauge correction = snow redistribution loss
  - Soils can be represented as uniform porous media and subjected to clever mathematical manipulations
    - Macropores = 0
    - Green-Ampt or Richard's Eq. can work "as is" or are still physically based when heavily calibrated from streamflow
  - All land surfaces drain freely to streams with quick flow at overland flow velocities
    - Hortonian overland flow
    - Contributing area = 100%
  - Frozen soils behave like unfrozen soils
    - Calibration of unfrozen soil infiltration for frozen conditions

GWF National Water Observation and Prediction Strategy

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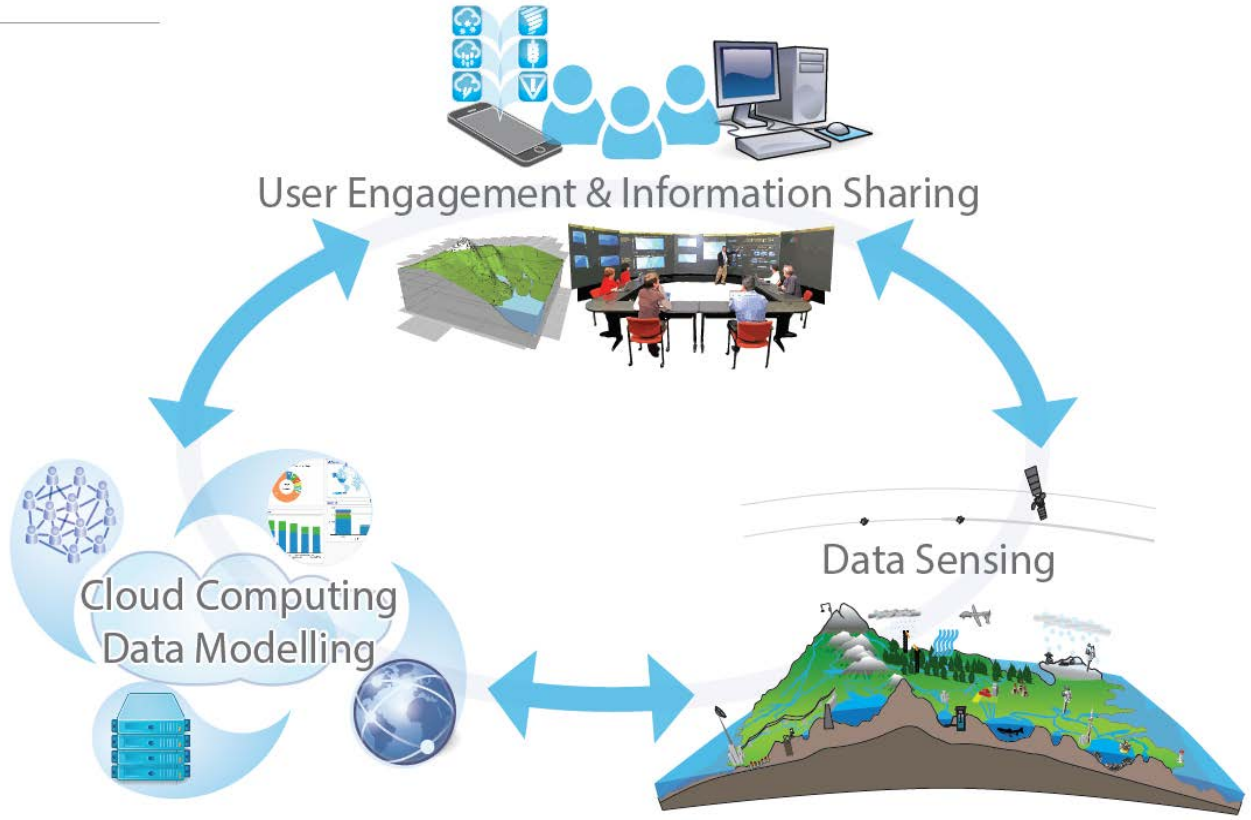
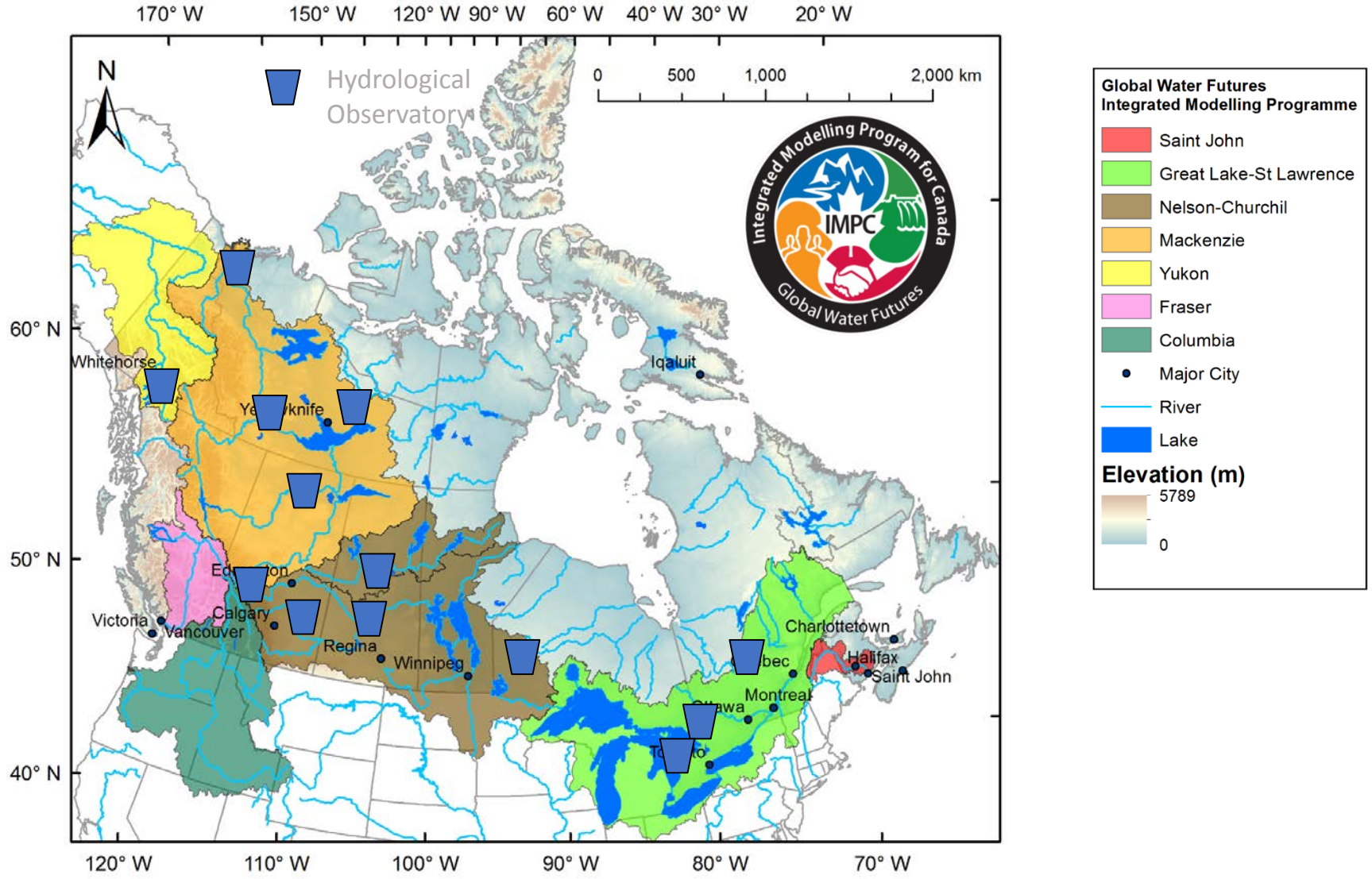
- **Core support teams to deliver national modelling capability, advanced computer science, new observational science and knowledge mobilization**
- **User-question led project-focussed funding**

- **Technical Team (20)**: Observatories & Observations
- **Data Management (4)**
- **Computer Science (7)** – Human Computer Interface, Data & Re-engineering Codes
- **Modelling Core Team (36)**
  - Hydrological & Water Quality Forecasting
  - Climate Change, Diagnostic Hydrological & Water Quality Modeling
  - Water Resources Modelling
- **Knowledge Mobilization (4)**
- **Communications (9)**



ECCC and GWF National Water Prediction Strategy



Integrated Modelling for Prediction and Management of Change in Canada's Major River Basins

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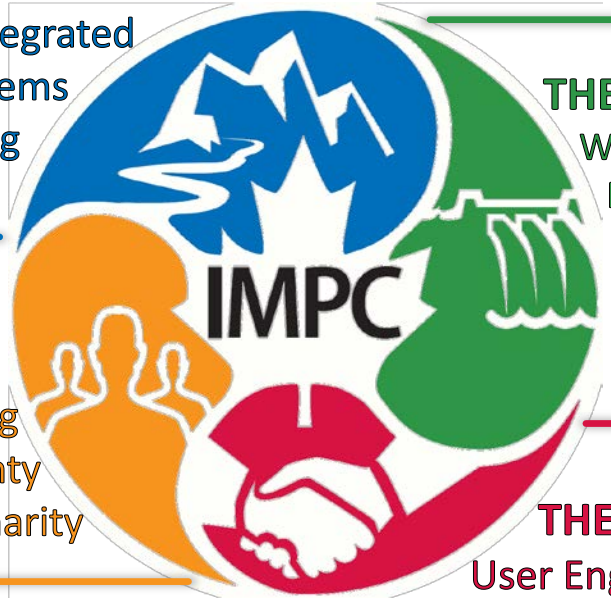
THEME A: Integrated Earth Systems Modelling

- **A1:** Atmospheric Modelling
- **A2:** Hydrologic Modelling
- **A3:** Water Quality Modelling
- **A4:** River Ice Modelling
- **A5:** Model Intercomparison
- **A6:** Floodplain Mapping
- **A7:** Uncertainty Characterization

THEME B: Water Management Modelling, Coupling Human-driven and Natural Systems

- **B1:** Basin-wide Water Resource Modelling
- **B2:** Environmental Demands
- **B3:** Hydro-economic Modelling



THEME C: Decision Making under Uncertainty and Non-stationarity

- **C1:** Future Scenario Generation
- **C2:** Optimization and Multi-Criteria Decision Analysis

THEME D: User Engagement and Knowledge Mobilization

- **D1:** Outreach and User Engagement
- **D2:** Decision Support Systems

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
- Decision Support and Water Management Models such as MODSIM and WEAP
- Lake Models
  - MyLake model suite, ELCOM-CAEDYM,Nemo

CORE OUTCOMES

- The modelling core project will focus on creating a common platform for scientists from various disciplines and different universities/institutes to work together. The focus on the first 3 years will
  - Develop and apply new coupled modeling systems that integrate regional climate, land management, hydrology and water management over climate change sensitive regions.
  - Improve models with the capability to explore and assess how changes in population, economic development, and land use will impact water resource management and water quality, in addition to climate change.
  - Determine how state-of-the-art model scenarios and predictions can be best framed to inform decision making, policy and adaptive governance for the management of risks from hydrological change to water resources.

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Core Team – Modelling & Forecasting

- Hydrological and Water Quality Forecasting
  - **Flood Forecasting**
  - **Seasonal and Drought Forecasting**
  - **Floodplains**
  - **Data Assimilation**
  - **River Ice Modelling**
  - **Water Quality**
- Climate and Diagnostic Hydrology and Water Quality Modelling
  - **Climate - high resolution pan-Canadian**
  - **Hydrological Modelling**
  - **Next Generation Water Modelling**
  - **Catchment, River and Lake Water Quality**
- Water Resources Systems

ECCC Grant

- Dan Princz – MESH community model development
- Nassim Hosseini – SWOT and Hydraulic model development

Center for Hydrology

-Tom Brown – CRHM development

- Dominique Richard – MESH forecasting and testing – Yukon and Bow

ECCC modelling Team

- Fortin, Gaborit, Dunford, others GEM Hydro development
- Bruce Davison/Anthony Liu /Frank Seglenieks– MESH development

University Teams

- Saman Razavi – VIC/MESH development and IMPC
- Bryan Tolson – IMPC inter-comparison
- Trish Stadnyk – IMPC, HYPE, Isotopes

GWF Model Principles

- Open-Source models if possible
- Consistent meta-data approaches to model runs
- Strong version control
- “Digestible “ by use community
- Linking and coupling of various modelling sytems
  - Common formats between models if possible
  - Shared tools

- Core modelling team starting to work closely with Core computing team
  - Visualization
  - Model efficiency
  - Sophisticated data handling tools
  - Basin processing software

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Dealing with Forecasting and Forcings

FloodNet NSERC

CaSPAr
Canadian Surface Prediction Archive

Juliane Mai, **Kurt Kornelsen**, David Schäfer,
Bryan Tolson, Paulin Coulibaly, François Anctil,
Vincent Fortin, Michael Leahy, Brent Hall

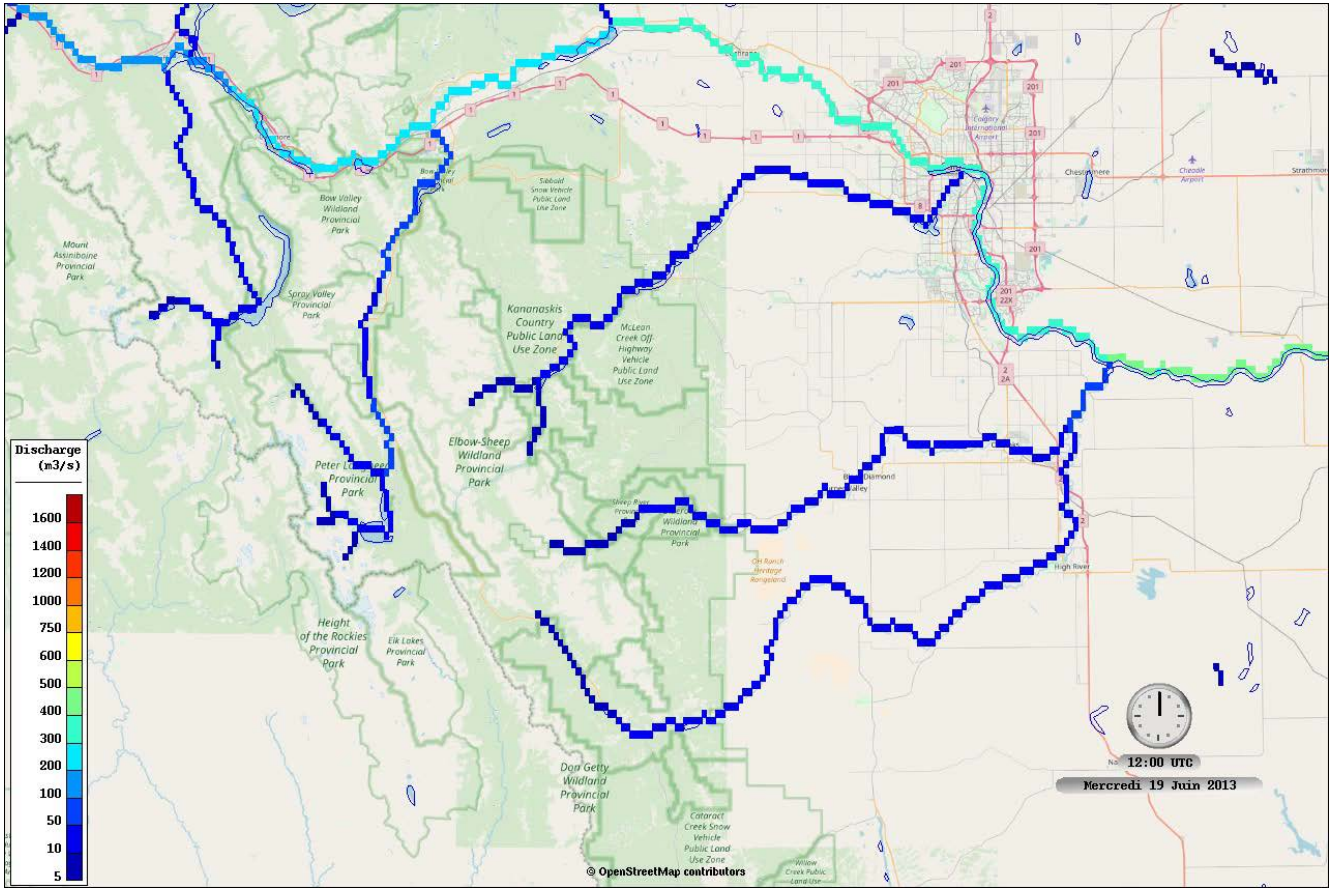
University of Waterloo
McMaster University
Université Laval
compute canada
Environment and Climate Change Canada
Environnement et Changement climatique Canada
Helmholtz Centre for Environmental Research – UFZ
esri
NSERC CRSNG

CaSPAr Status Report ECCC-CMC
October 24, 2017

Core modelling results

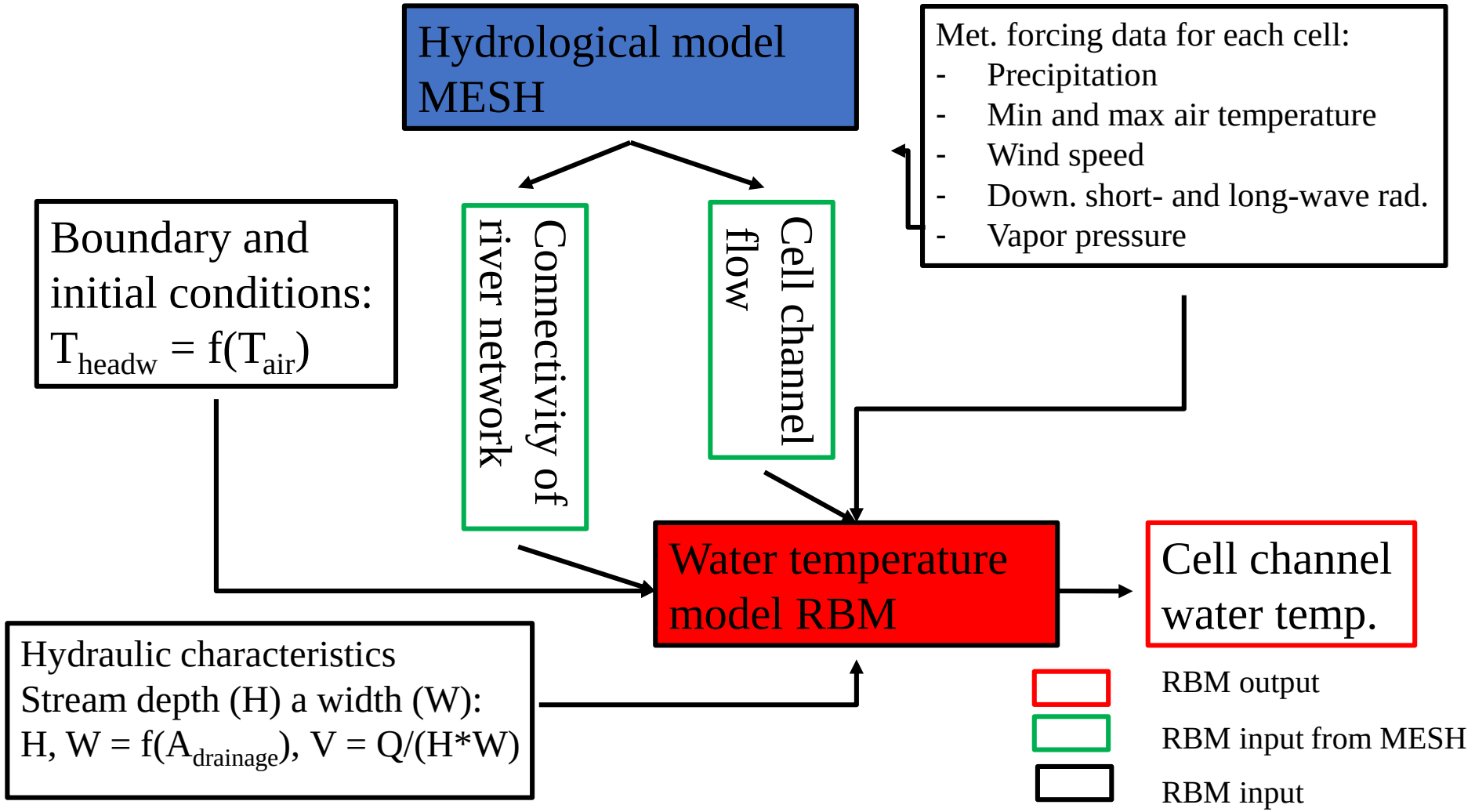
- Please look at the program – many interesting talks and posters from the core team

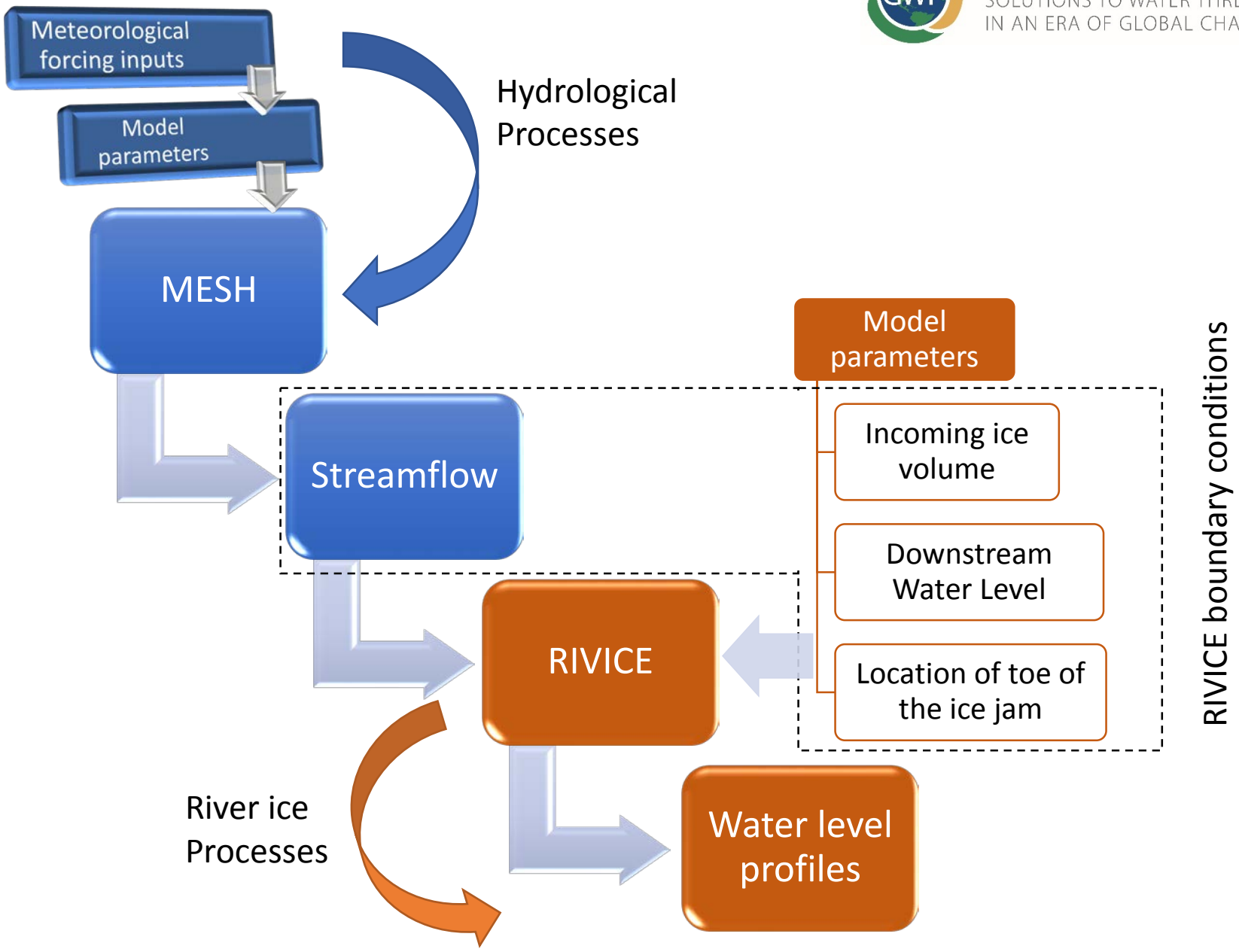
- Applied GEM – WRF to Calgary 2013 flood driven by Capa at 1 km resolution – presentation Vionnet



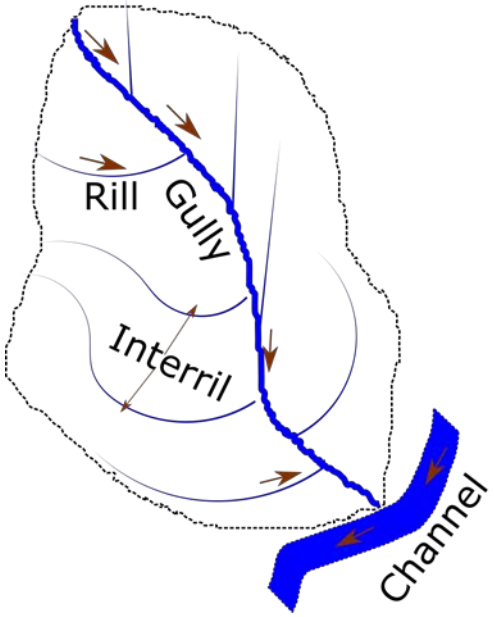
A grid-based semi-Lagrangian water temperature model for MESH: Structure

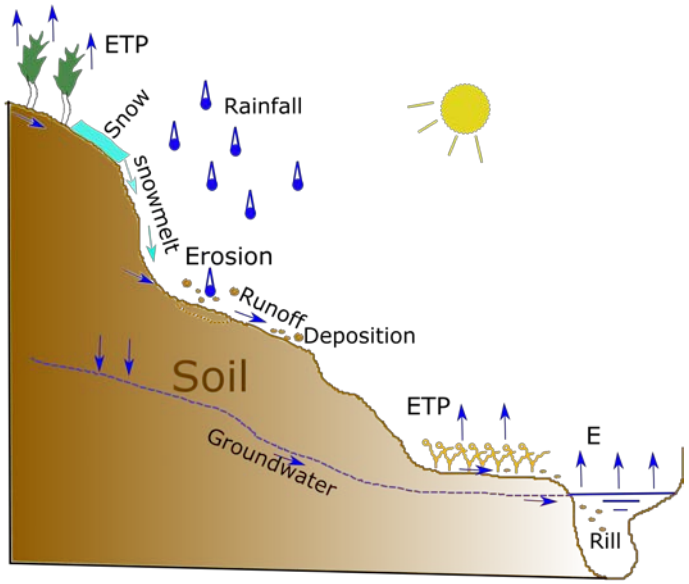
Team Lindenschmidt

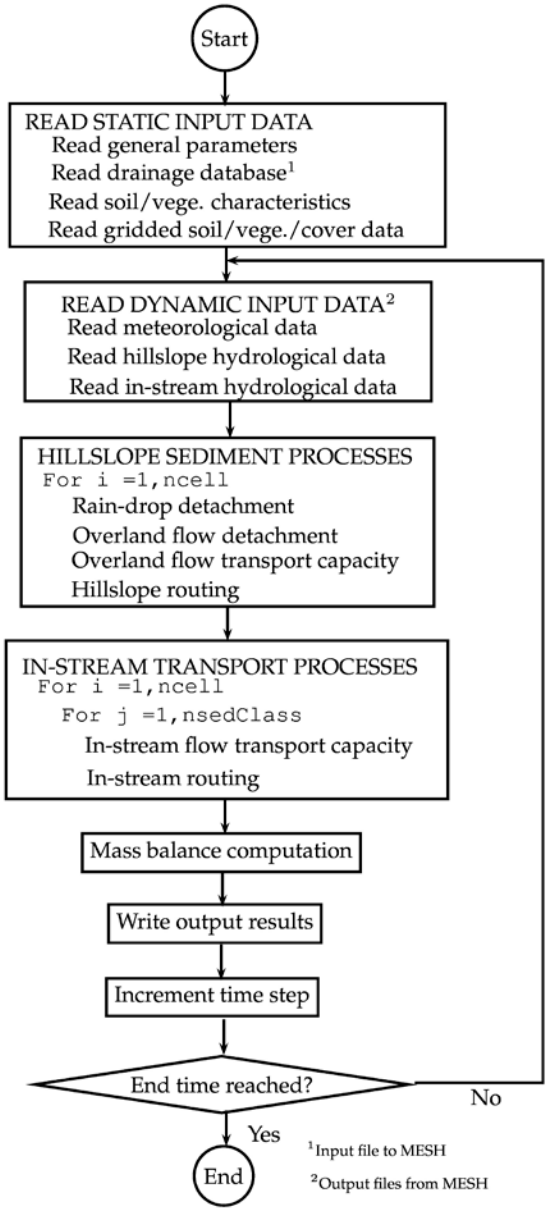



Meteorological forcing inputs
Model parameters
MESH
Hydrological Processes
Streamflow
Model parameters
Incoming ice volume
Downstream Water Level
Location of toe of the ice jam
RIVICE boundary conditions
RIVICE
River ice Processes
Water level profiles

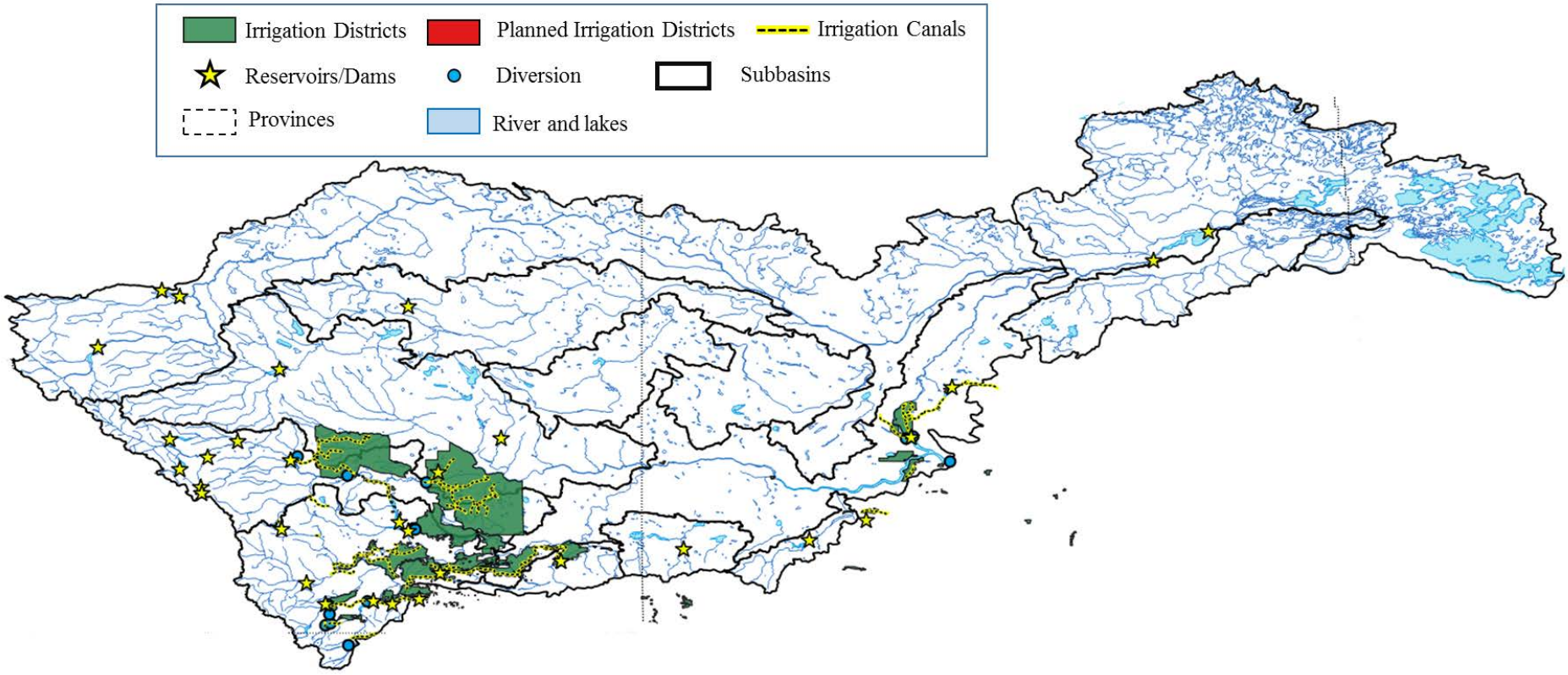
MESH-SED conceptualization and software flow diagram







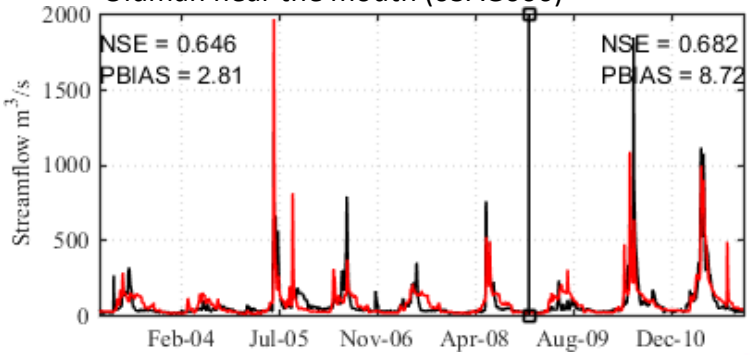
Fuad Yassin
Reservoirs, Irrigation and Diversion in SRB -



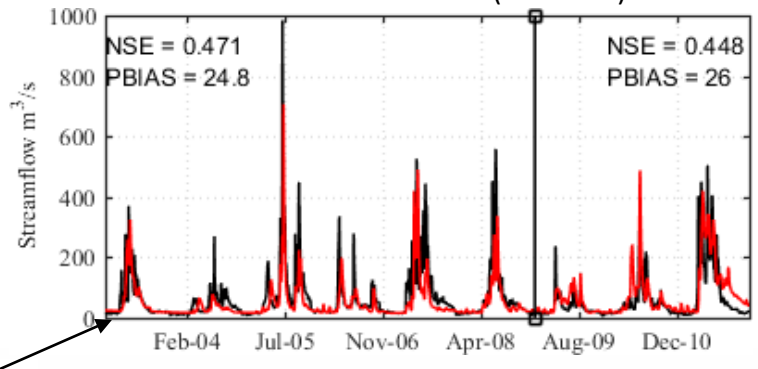
- In Southern Alberta, there are 13 irrigation districts providing water to 1,412,836 acres of farmland
- In Saskatchewan Lake Diefenbaker supplies water to 11 irrigation districts with total area of some 80,000acres

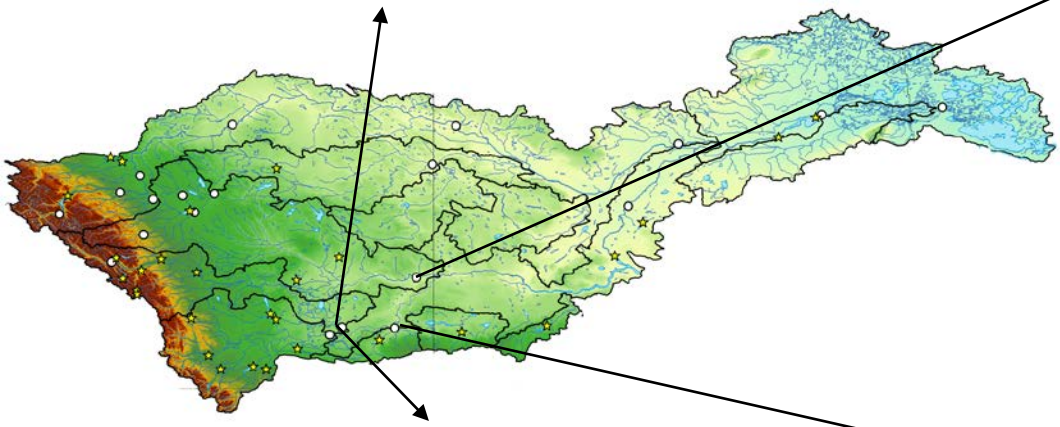
Yassin - Model Calibration and Validation

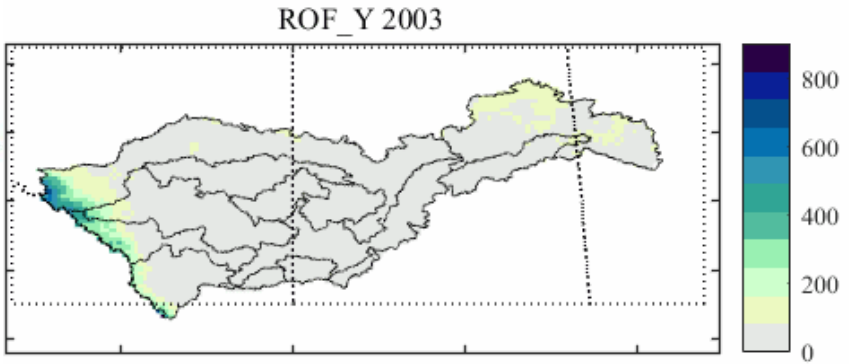
Oldman near the mouth (05AG006)



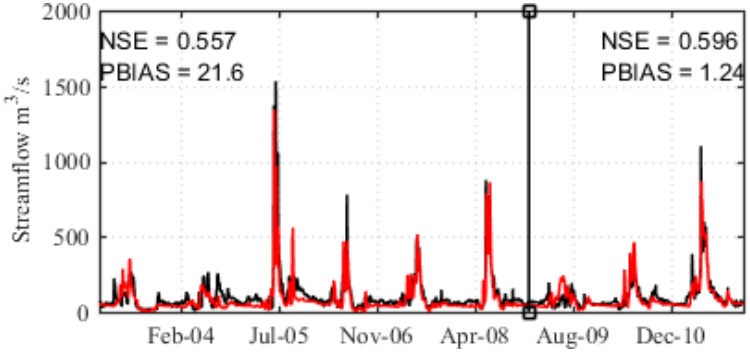
Red Deer near Bindloss (05CK004)



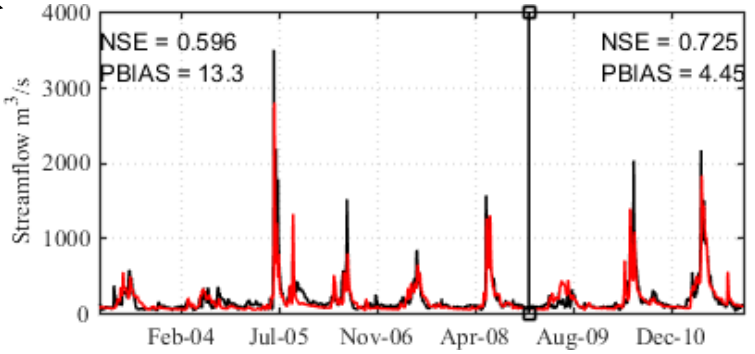




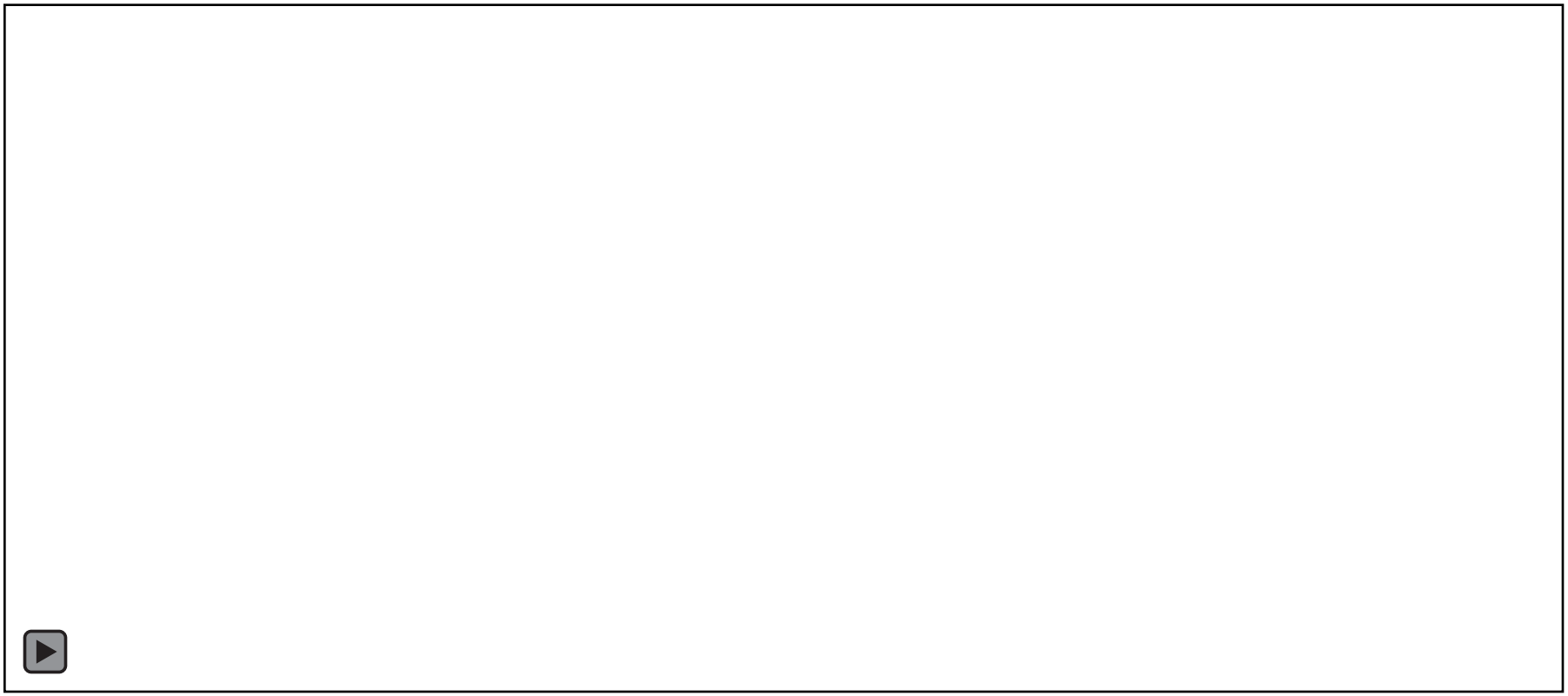
Bow near the mouth (05BN012)



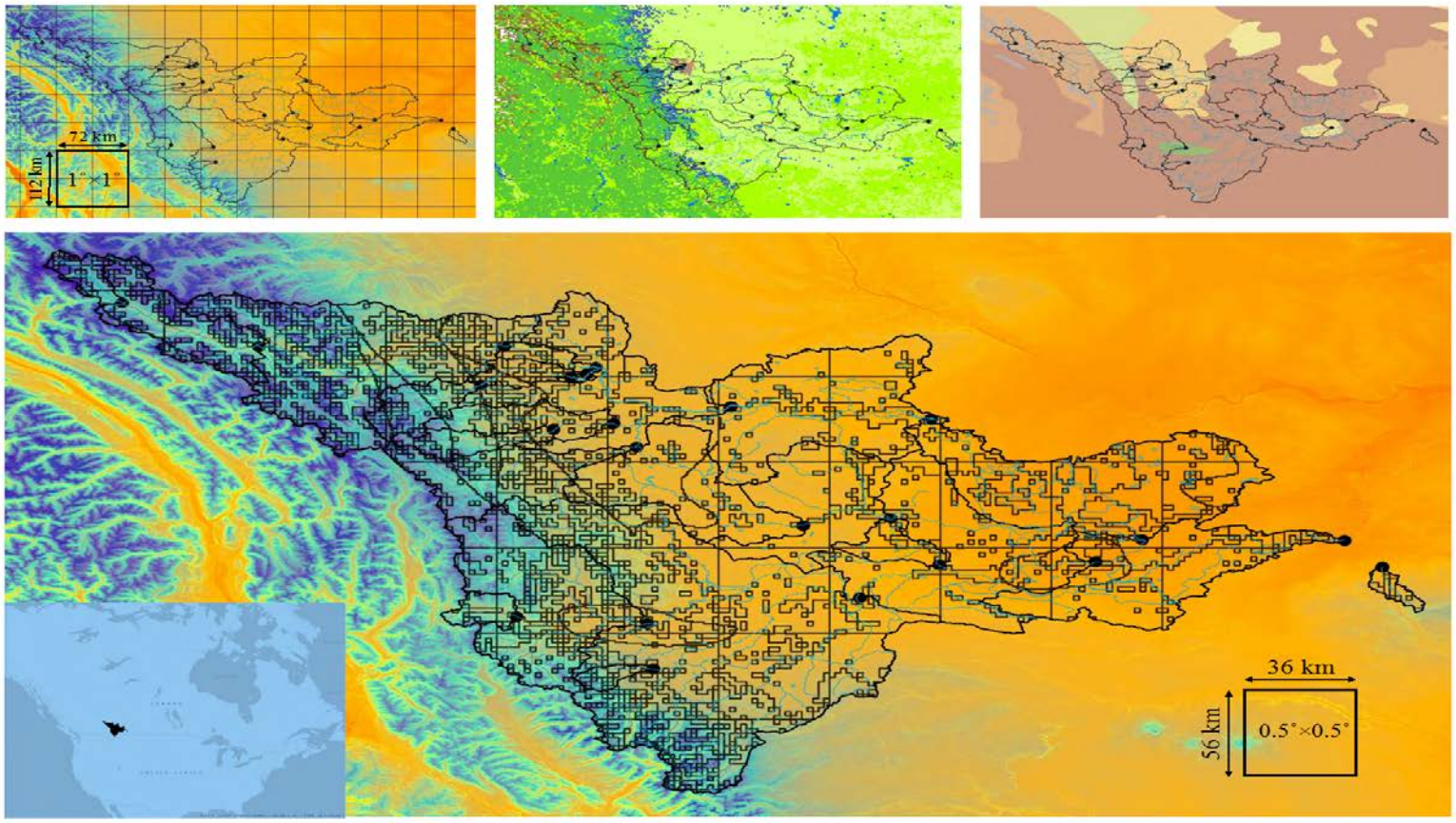
South Saskatchewan @ Medicine Hat(05AJ001)



Impacts on Permafrost – Mid 21st Century
Mohammed Elshamy

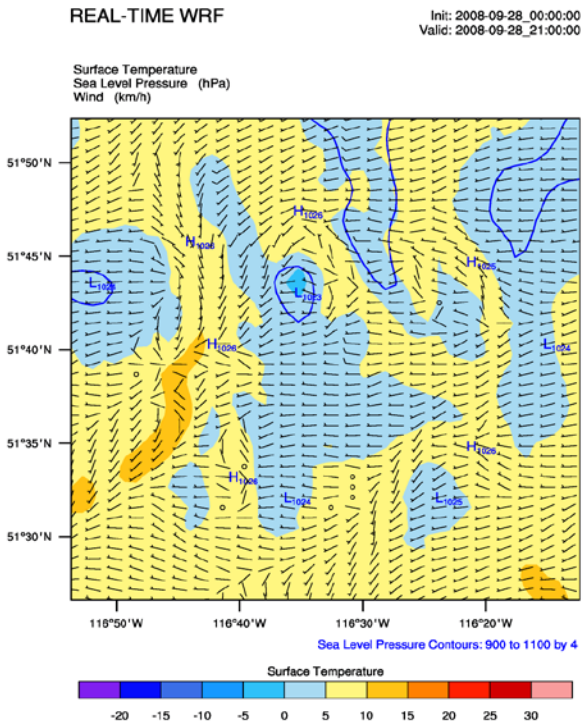


Shervan Gharari –VIC implementation using GRUs on the Saskatchewan



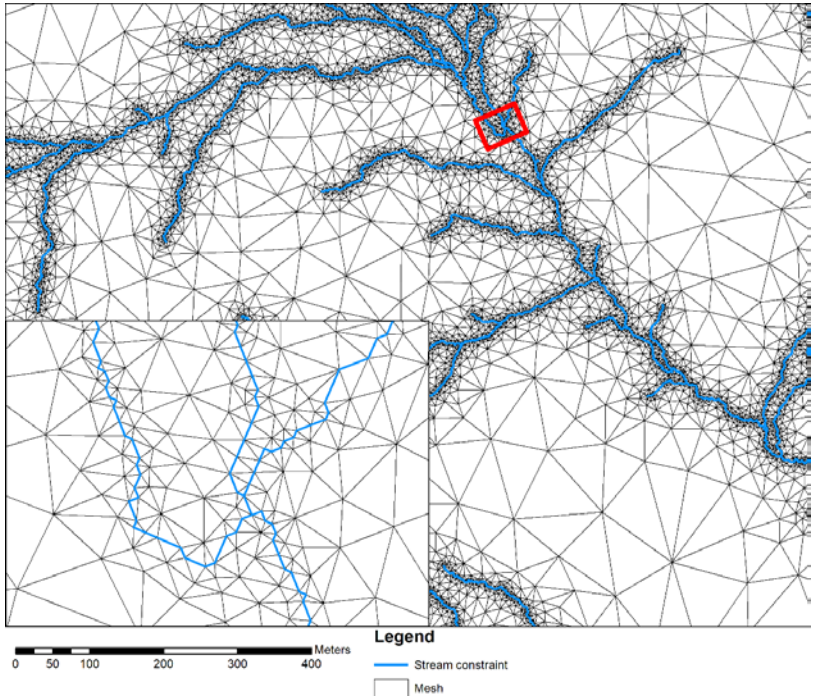
New High Resolution Modelling Approaches

High Resolution Atmospheric Models



Conway, Helgason, Pomeroy, 2018

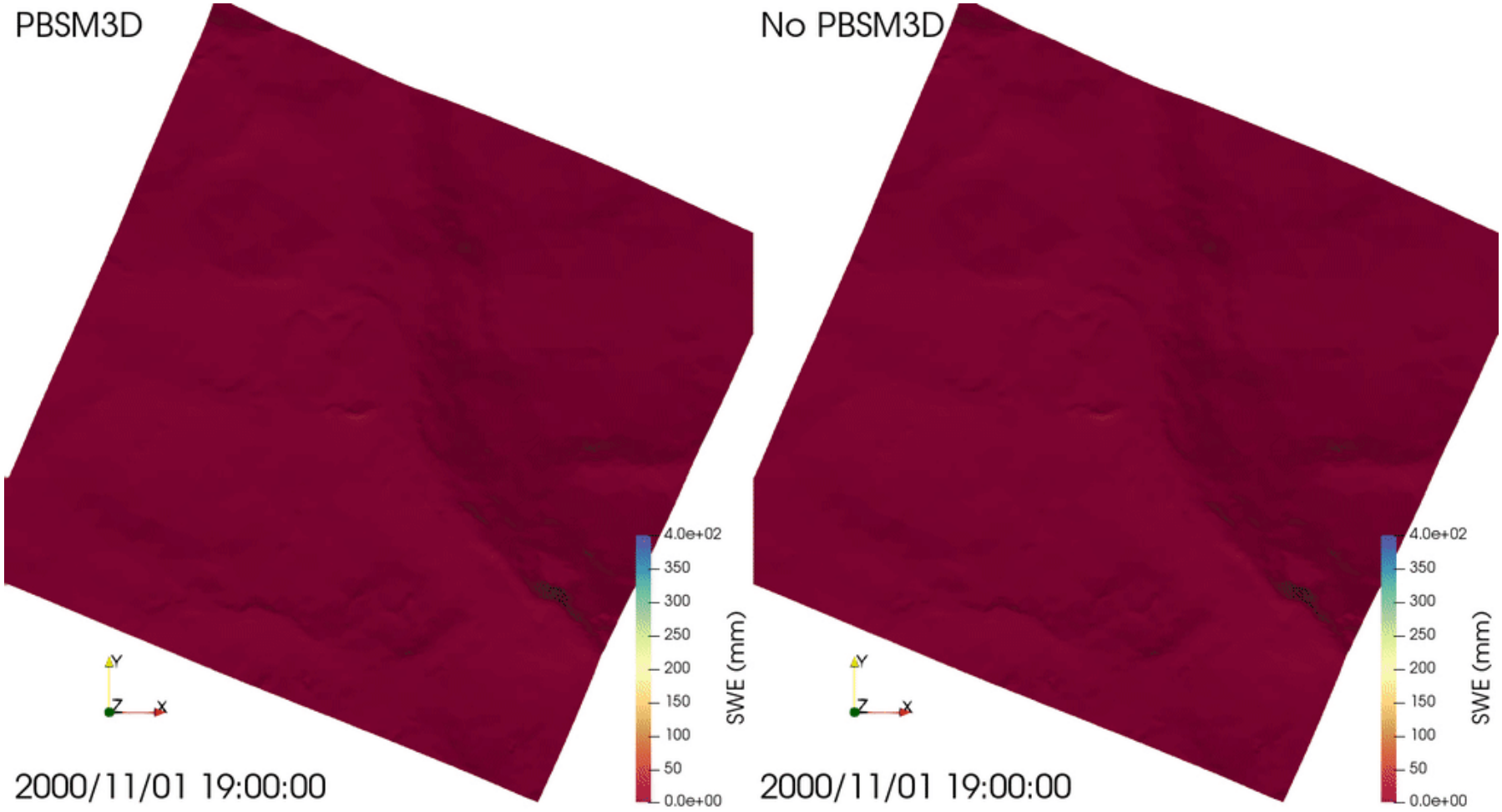
Variable Mesh, Physically Based, Multi-physics Hydrological Models



Coupling at hillslope-snowdrift scale

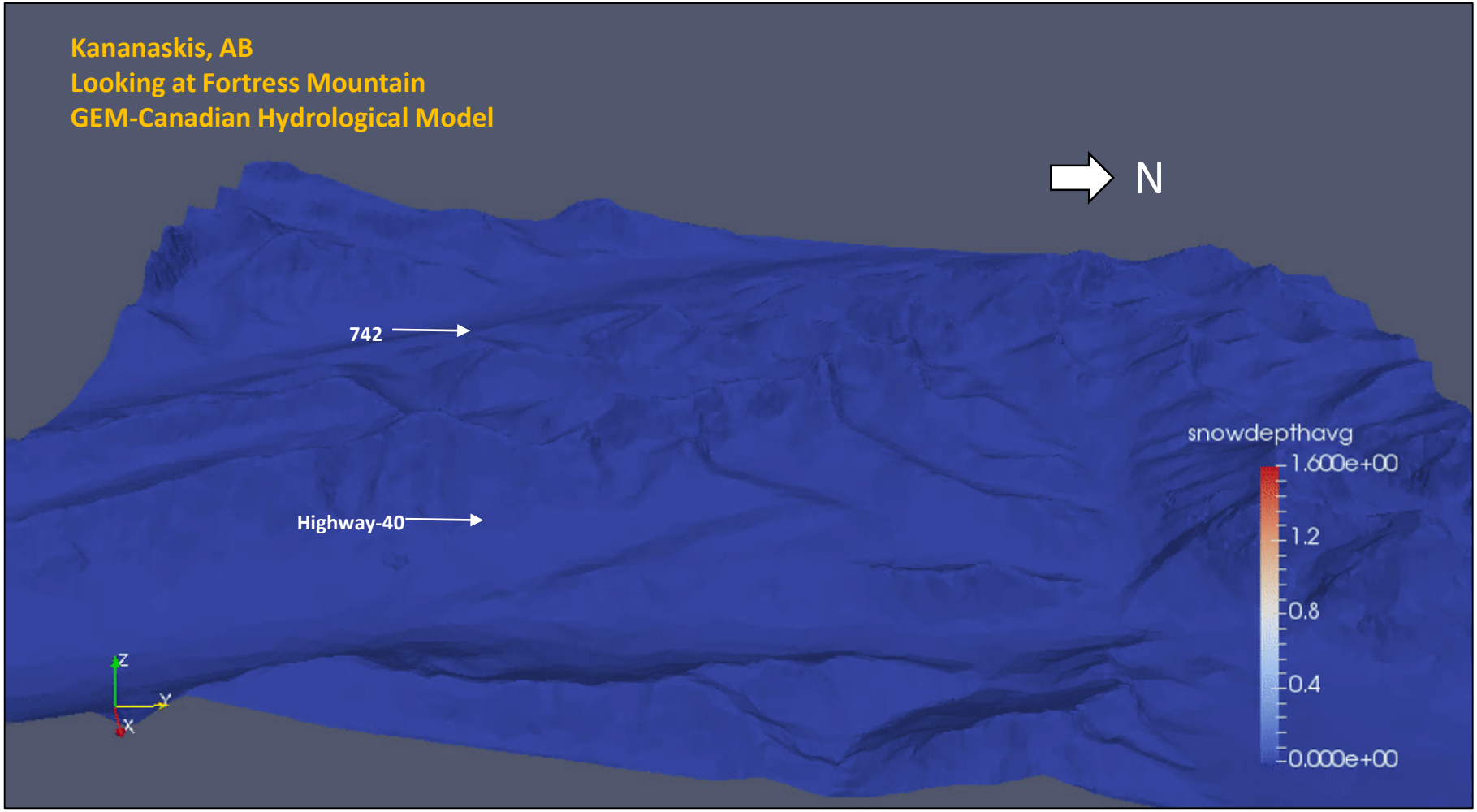
Marsh, Spiteri, Pomeroy, Wheater, 2018

Hydrology is Governed by Spatial Variability



Marsh, Pomeroy, Wheater, 2018

New Coupled Multiphysics, Multiscale Models



Some Others

- Youssef Loukii – Applied MESH-CLASS to entire Yukon Basin
- Dominique Richard – MESH application for real-time forecasting on selected Yukon Rivers on the Amazon Cloud
- Zelalem Tessma : Dealing with Sub-Grid variability in High Relief Regions with MESH applied for the Bow River at Calgary

Affiliated GWF projects

- Bruce Davison - Souris River Basin Study, MESH application for climate change and reservoir plan formulations, IJC study
- Vincent Fortin – SVS application for Richelieu Forecast system development, IJC Study
- International
  - Abdolreza Bahrmand – MESH Model Development for Iran
  - Amir Givati – Mesh Model testing in Israel
  - Laurent Pfister, Luxembourg Institute of Science and Technology , MESH Model evaluation on Mosel River

Summary

- Given the size, data realities and complex hydrology conditions in Canada, a very systematic and detailed modelling framework was developed at ECCC in collaboration with university to deal with those realities.
- A precipitation assimilation system was developed and operationalized in ECCC to deal with the sparse nature of the atmospheric observations.
- A community H-LSS framework that could be tested offline for improved physics, parametrization, segmentation, optimization and sensitivity analysis was needed.
- Offline MESH-Model (using CLASS) shows promise in hindcast mode where many other models have failed.
  - Systematic inclusion of non-contributing areas, glaciers, water management were necessary to make the model work.
- GEM-Hydro (using a modified version of ISBA), along with NEMO for the Great Lakes basin show much promise for short term forecasting. We expect better results, particularly in complex terrain and cold regions with SVS.
- Because of the community-based approach, recent funding of GWF and a federal need to develop a national water modelling platform, MESH and GWF models will provide the necessary community platform for model integration and systematic testing and evaluation moving towards eventually operationalizing the system.
- GWF will be pivotal in moving our ECCC hydrology, water quality, Large Lake and Water Management modelling foreword
- We look forward to the continued collaboration.

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