Core Modelling Team

Core Modelling and Forecasting Team Advancmenets

Core Modelling Operations Meeting

Al Pietroniro , Martyn Clark, Shervan Gharari, and the Core Modelling Team

December 9, 2021

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE
UNIVERSITY OF SASKATCHEWAN
UNIVERSITY OF WATERLOO
McMaster University
LAURIER Inspiring Lives.
globalwaterfutures.ca

GWF Core Modelling

Global Water Futures | Core Modelling Team

- ***Co-leads***: Al Pietroniro and Martyn Clark
- ***Core modelling science-coordinator***: Shervan Gharari
- ***Core Modelling Coordination:*** *Joy Mitsogianni*
- Research themes:
  - Spatial meteorological data (Julie Theriault)
  - Geospatial intelligence (Martyn Clark)
  - Current generation hydrological modelling (Bruce Davison)
  - Next-generation hydrological modelling (John Pomeroy)
  - Water quality modelling (Philippe Van Cappellen)
  - Water resources modelling (Tricia Stadnyk)
  - Hydro-economics (Roy Brower)
  - Hydrological forecasting (Alain Pietroniro)
  - Human and Health Dimensions (new – Corinne Schuster-Wallace))
- Over 31 faculty, 33 research personnel (primarily postdocs), and 21 collaborators

Dr. Al Pietroniro
Co-Principal Investigator

Dr. Martyn Clark
Co-Principal Investigator

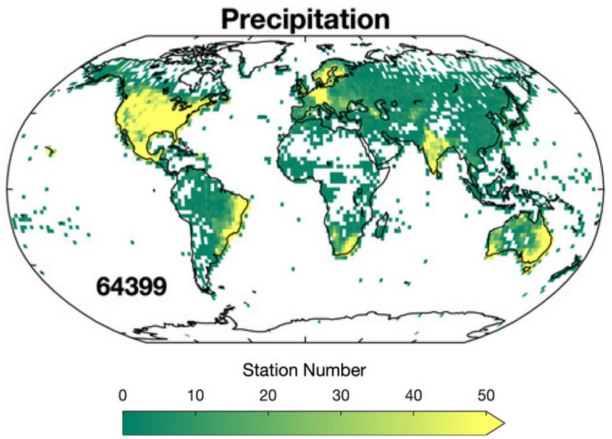
CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE
UNIVERSITY OF SASKATCHEWAN
UNIVERSITY OF WATERLOO
McMaster University
LAURIER Inspiring Lives.

Spatial Meteorological Forcing Data

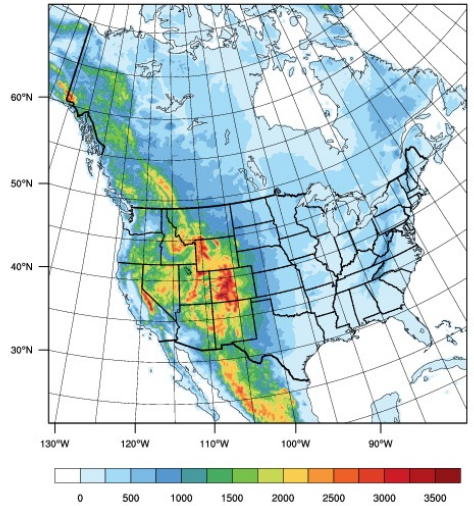
Global Water Futures | Core Modelling Team

- Meteorological measurement datasets developed:
  - Station (SCDNA) and ensemble (EMDNA) datasets over North American (1979-2020)
  - Global station-based serially complete (SC-Earth) and ensemble (EM-Earth) dataset (1950-2019)
  - Evaluation of satellite products for western Canada (on going)
- Climate simulations outputs (on going):
  - CONUS 2 simulations in collaboration with NCAR
    - Historical period (1995-2015) is completed and the future run should be ready early 2022
  - GEM simulations over western Canada
  - CMIP6 precipitation and temperature products for cities across Canada

FIG. 3.



Station density over a 2° x 2° grid-spacing



Domain of the CONUS 2 simulations

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

UNIVERSITY OF SASKATCHEWAN | UNIVERSITY OF WATERLOO | McMaster University | LAURIER Inspiring Lives.

globalwaterfutures.ca

EMDNA: Ensemble Meteorological Dataset for North America

Global Water Futures | Core Modelling Team

Precipitation and temperature estimates: 0.1°×0.1°; daily;100 members; 1979-2018.

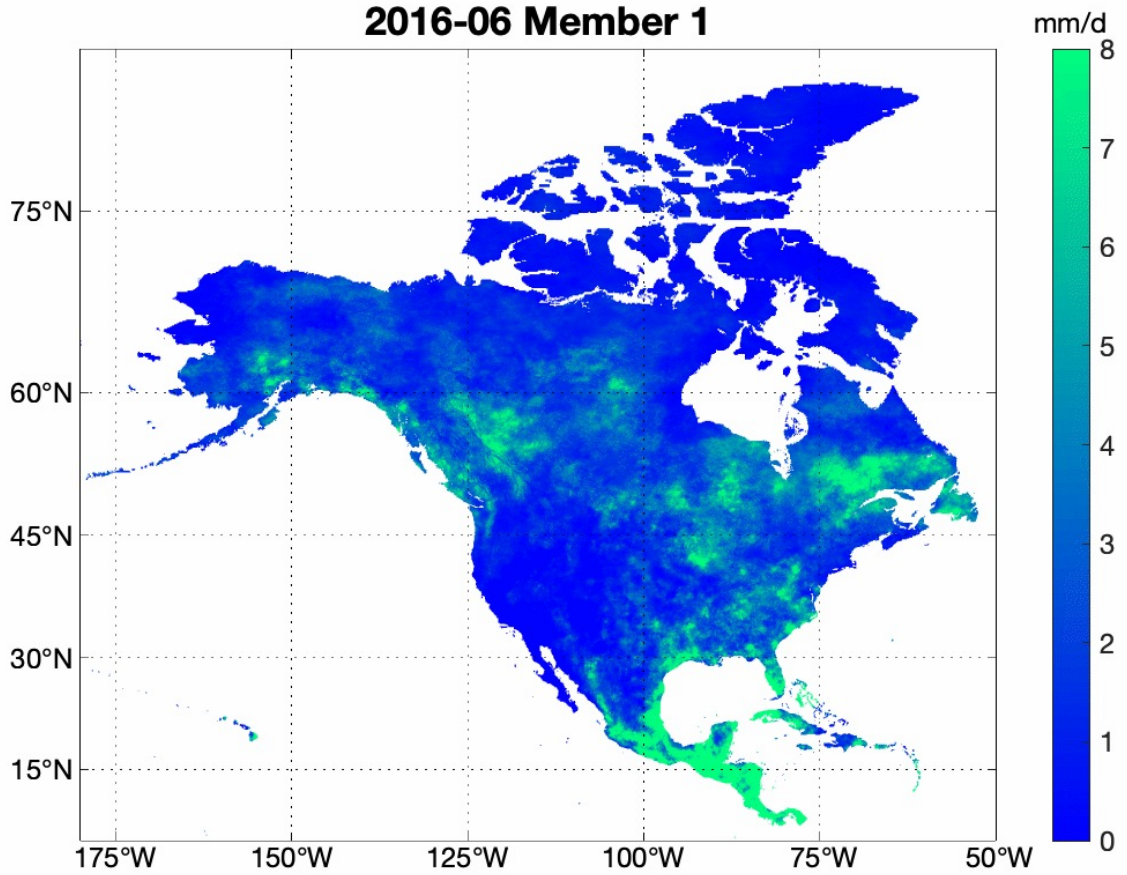
FRDR | Feedback | Log In | Help | About | EN

EMDNA: Ensemble Meteorological Dataset for North America

Contact Dataset Administrator

Description:	The Ensemble Meteorological Dataset for North America (EMDNA) contains daily precipitation, mean daily temperature, and daily temperature range at the 0.1-degree resolution from 1979 to 2018. Minimum and maximum temperature can be calculated from mean temperature and temperature range. EMDNA merges station observations and reanalysis model outputs to improve the quality of estimates. The dataset is expected to be useful for hydrological and meteorological applications in North America. Two types of datasets are provided by EMDNA, including the probabilistic dataset and the deterministic dataset. The probabilistic dataset has 100 equally plausible ensemble members, which can be used to evaluate the impact of the uncertainties in a myriad of applications. The deterministic dataset is generated during the production of ensemble members and can be applied in studies that do not need uncertainty estimation.
Authors:	Tang, Guoqiang; University of Saskatchewan; https://orcid.org/0000-0002-0923-583 Clark, Martyn P.; University of Saskatchewan Papalexiou, Simon Michael; University of Saskatchewan Newman, Andrew J.; National Center for Atmospheric Research Wood, Andrew W.; National Center for Atmospheric Research Brunet, Dominique; Environment and Climate Change Canada Whitfield, Paul H.; University of Saskatchewan
Keywords:	Precipitation Temperature Ensemble North America
Date:	8-Oct-2020
Publisher:	Federated Research Data Repository / dépôt fédéré de données de recherche
URI:	https://doi.org/10.20383/101.0275
Appears in Collections:	Global Water Futures

Precipitation from 100 members



Tang and Clark et al. (2021), ESSD

Dataset link: https://doi.org/10.20383/101.0275

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE | UNIVERSITY OF SASKATCHEWAN | UNIVERSITY OF WATERLOO | McMaster University | LAURIER Inspiring Lives.

globalwaterfutures.ca

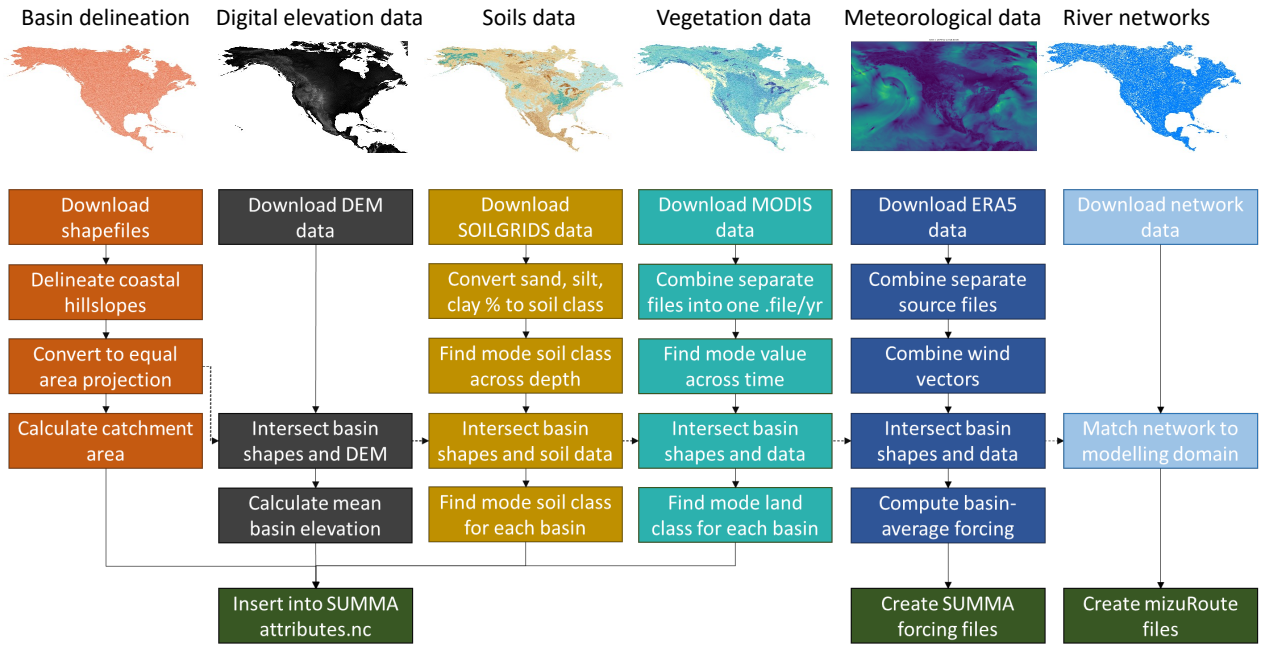
Geospatial Intelligence

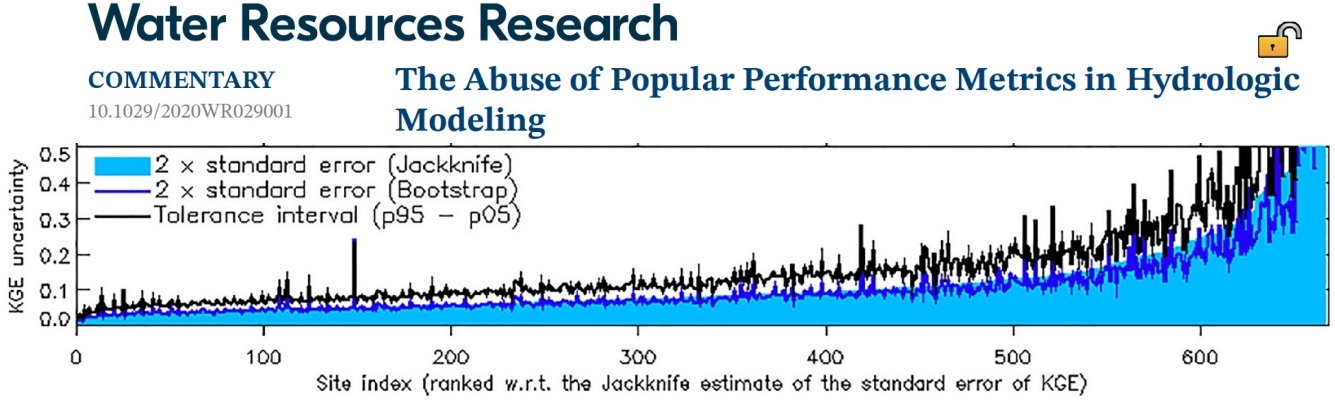
Global Water Futures | Core Modelling Team

Hydrological models have common requirements for DEM analysis, parameter inference, etc., but different models use different tools

Research focus:

- New datasets and model workflows
  - *Model-agnostic geospatial intelligence*
  - *Share pre-processing using jupyter notebooks*
  - ***Developing publishable general tools***
- Process-based parameter inference across large regions
  - *Evaluate alternative parameter estimation strategies (e.g., landscape calibration, etc.)*
  - *Multiple datasets/signatures (e.g., snow, permafrost, streamflow, etc.)*
  - *Multi-objective / multi-response parameter estimation strategies*
- Formal benchmarking system
  - *Multi-scale process-based model evaluation*
  - *Catalog of past modeling efforts*
  - *Data integration/synthesis*





CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

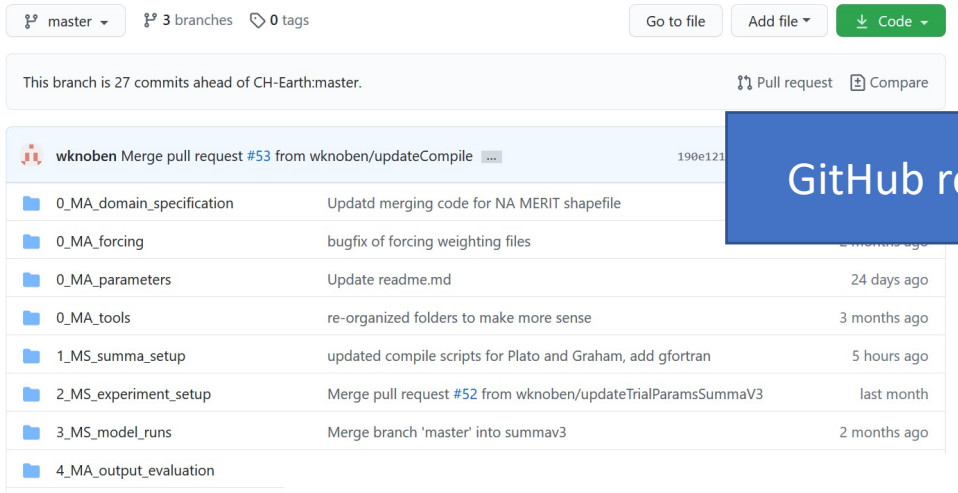
UNIVERSITY OF SASKATCHEWAN | UNIVERSITY OF WATERLOO | McMaster University | LAURIER Inspiring Lives.

globalwaterfutures.ca

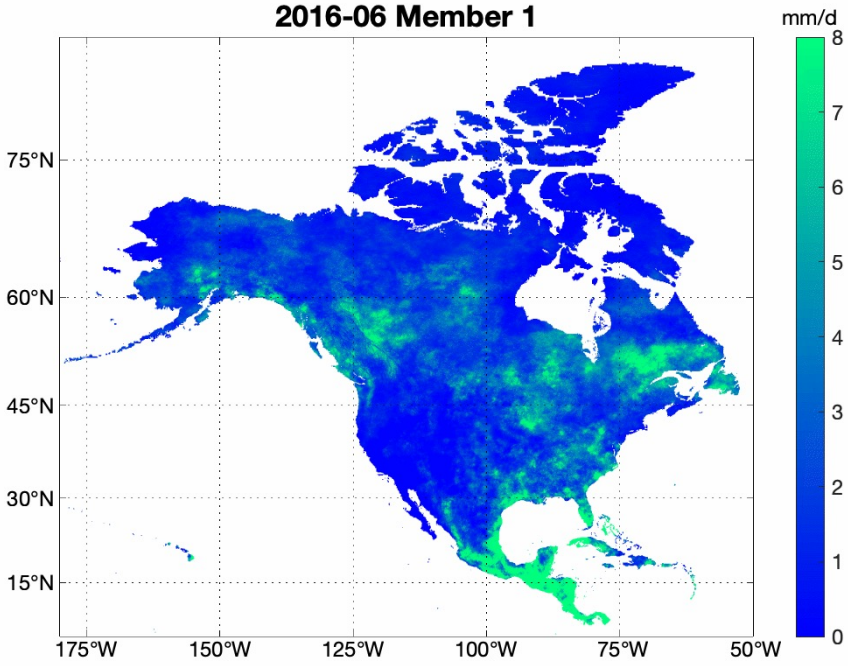
Developing model-agnostic workflows

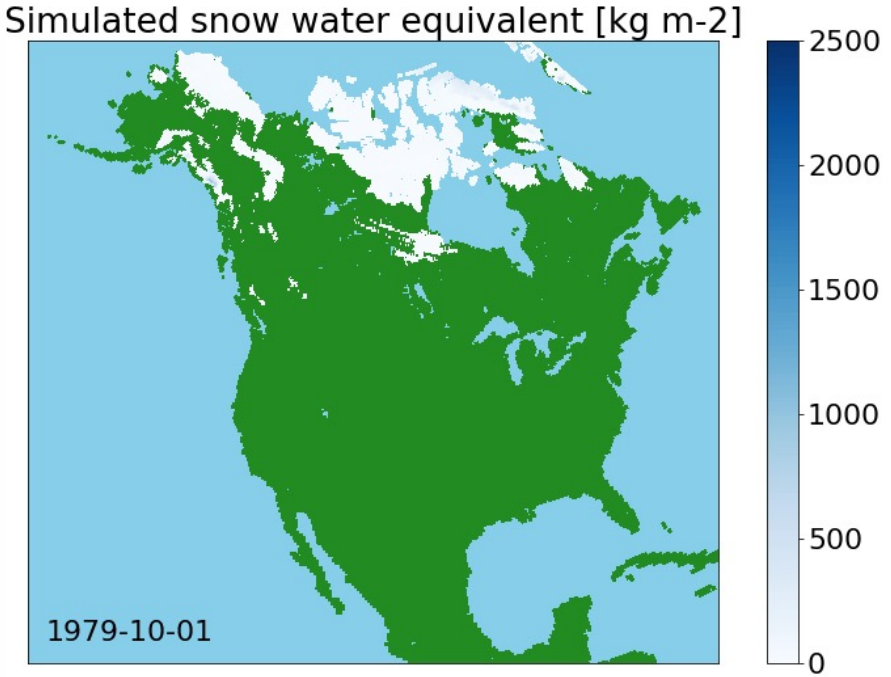
Global Water Futures | Core Modelling Team

- Goal: Improve the efficiency of continental-domain model implementation tasks
- Easier to collaborate; easier to keep track of work for reporting and paper reviews
- Increase transparency, reproducibility, and code re-use
- Advance ***community hydrological modelling***, rather than a *community hydrological model*



GitHub repository





Streamflow and lake level

Current Generation Hydrologic Modelling

Global Water Futures | Core Modelling Team

- ❑ First production runs complete for the St. John River Basin, publication submitted
- ❑ Model benchmarking runs well underway for the Mackenzie, Saskatchewan, Yukon and Fraser basins
- ❑ Model benchmarking runs underway for the Great Lakes basin
- ❑ Improvements to glacier representation
- ❑ Improvements to water management and irrigation algorithms
- ❑ Vector-based land surface and routing workflow completed and documented
- ❑ Modelling International basins (Ganga, Darya)

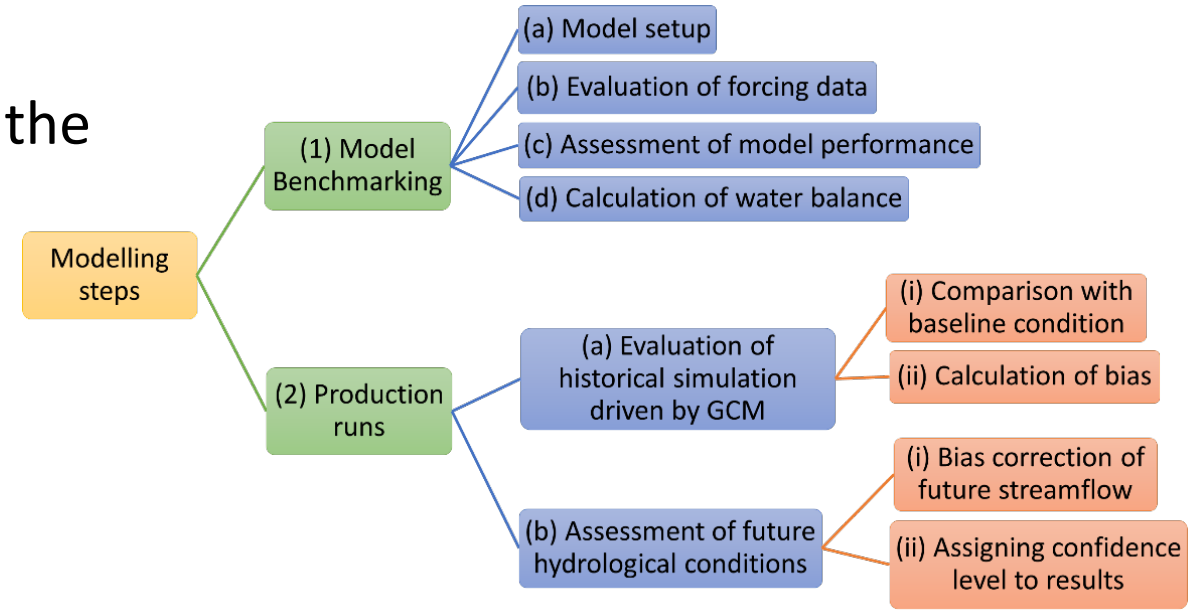
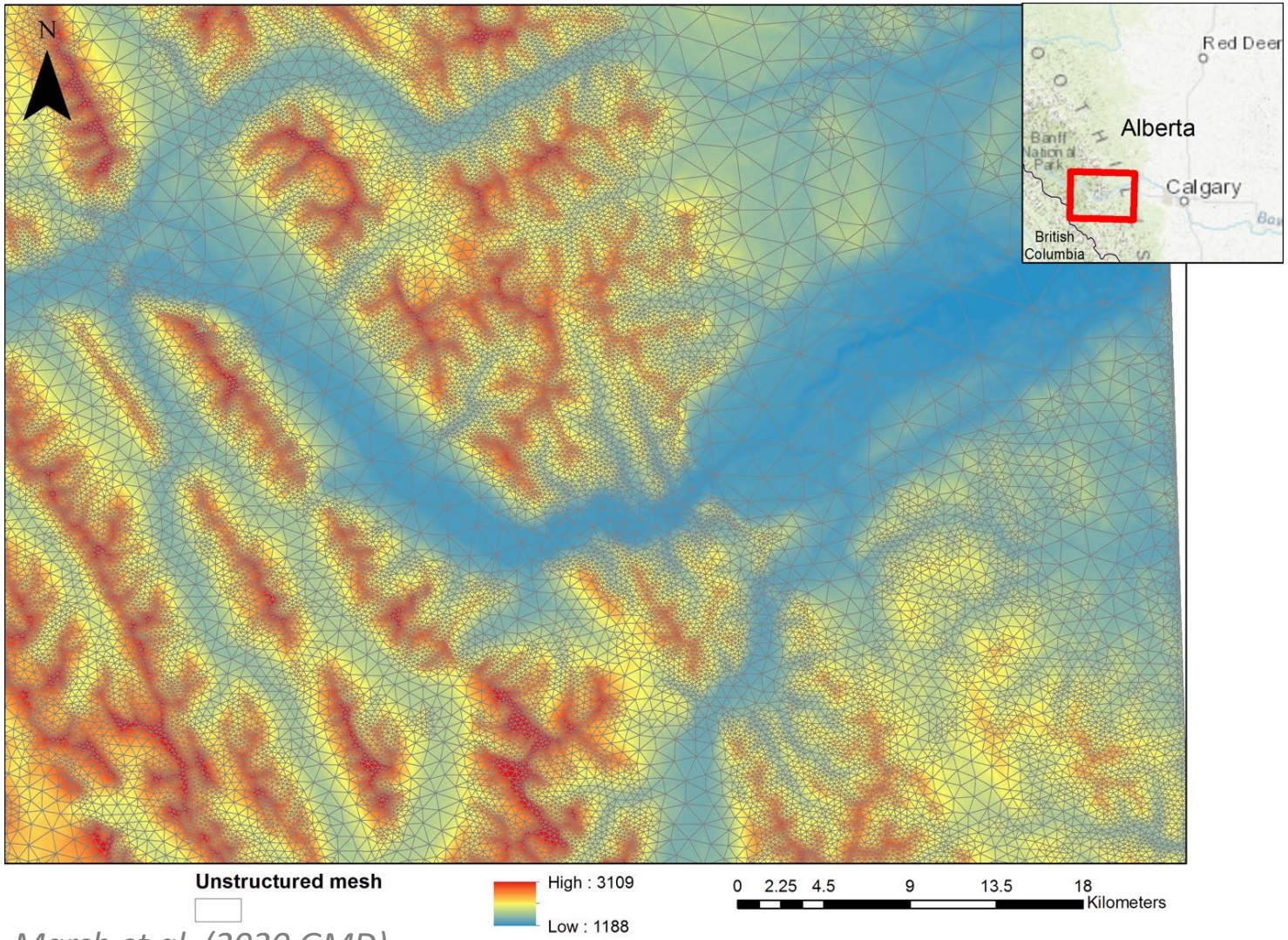


Fig: Workflow for Production Runs completed (Fig. by Prabin Rokaya)

Next-generation hydrological modeling

Global Water Futures | Core Modelling Team

- **Unstructured triangular mesh** depending on topography and vegetation complexity
- Flexible structure to test multiple hypothesis, assessment of uncertainty
- Incorporation of existing code
- Algorithms for downscaling meteorological data (e.g., from NWP)
- **Modular and physical equation structure**
- **Hierarchical coupler**



Marsh et al. (2020 GMD)

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

UNIVERSITY OF SASKATCHEWAN | UNIVERSITY OF WATERLOO | McMaster University | LAURIER Inspiring Lives.

globalwaterfutures.ca

CHM with blowing snow (PBSM3D)

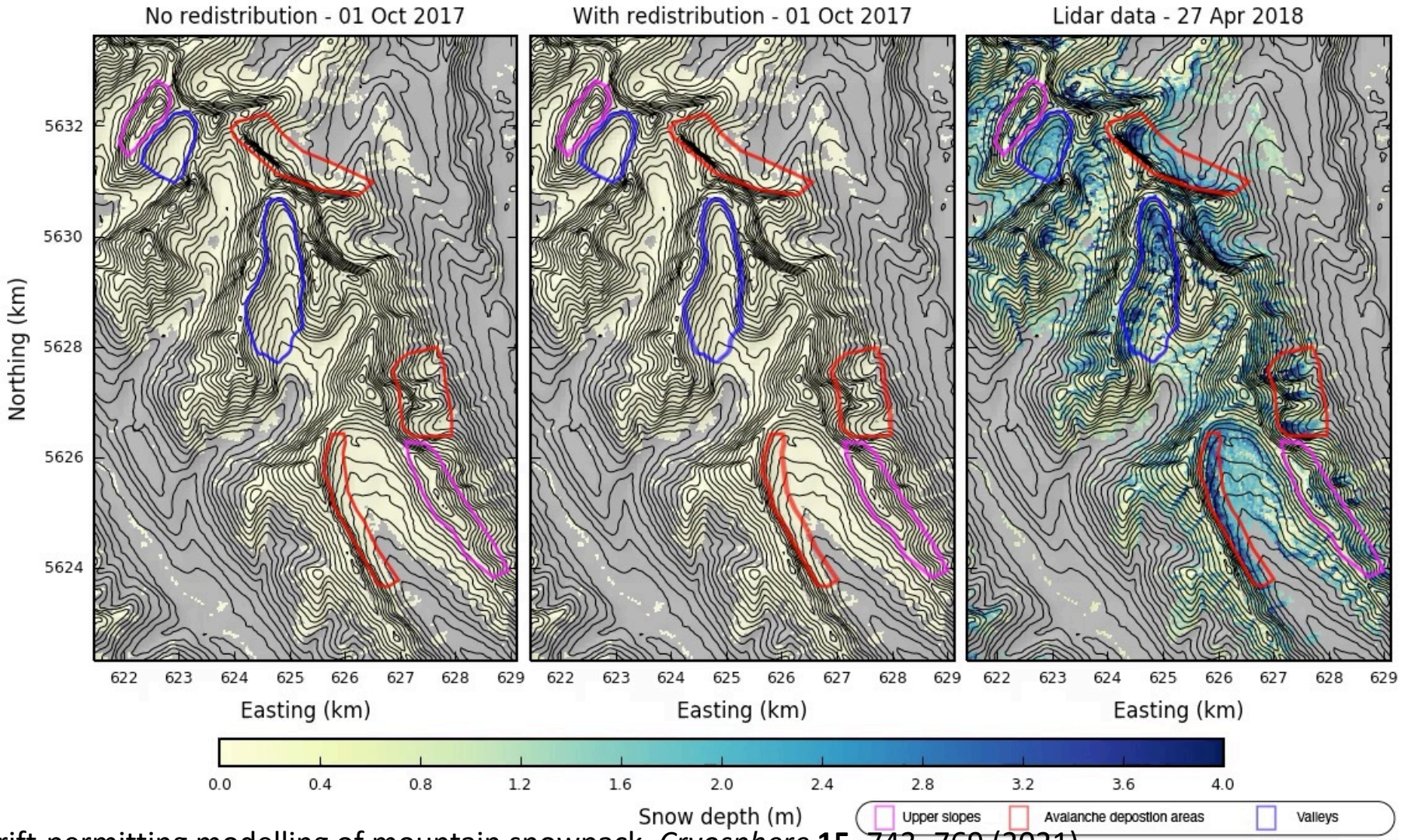
Global Water Futures | Core Modelling Team

- Kananaskis valley (~1000 km^2)
- Snow drift permitting resolution (~50 m)

- Snowdepth compared with
  - Aerial lidar observations
  - Satellite derived snow index

- Simulation without lateral snow redistribution cannot capture the spatial variability

- Over-estimates high elevation snowpack
- Under-estimates low elevation snowpack



Vionnet, V. *et al.* Multi-scale snowdrift-permitting modelling of mountain snowpack. *Cryosphere* **15**, 743–769 (2021).

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE
UNIVERSITY OF SASKATCHEWAN | UNIVERSITY OF WATERLOO | McMaster University | LAURIER Inspiring Lives.
globalwaterfutures.ca

Water Quality Modelling

Global Water Futures | Core Modelling Team

Thematic areas:

- ❑ Soil and snowpack processes
- ❑ Stream temperature modeling
- ❑ Sediment transport modeling
- ❑ Coupled hydrology-biogeochemistry
- ❑ Dams and reservoirs
- ❑ Urban hydrology and water quality
- ❑ Nutrient legacies
- ❑ Watershed-lake continuum
- ❑ Algal blooms: controls and prediction

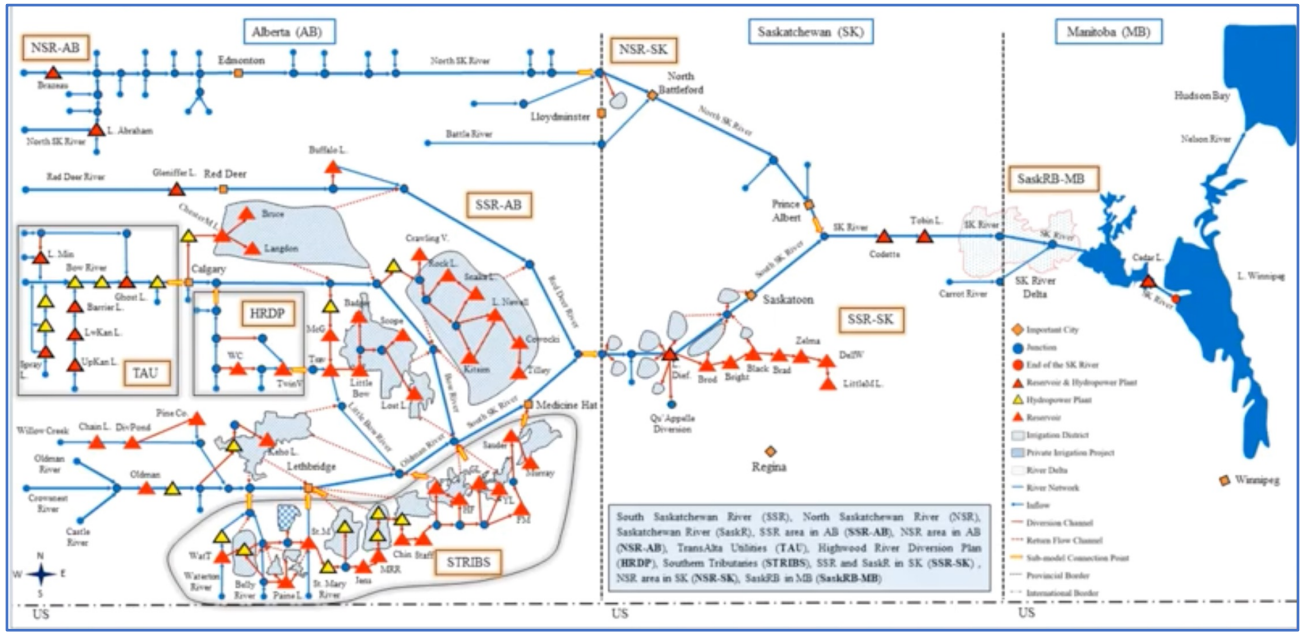
Examples of major outcomes:

- ❑ **A focus on soil winter processes**
  - ➢ Snowmelt chemistry and chemical fluxes
  - ➢ Soil respiration during the non-growing season: temperature and moisture controls
  - ➢ Freeze-thaw cycles: impact on fertilizer leaching
- ❑ **Model functionalities and performance: coupling and upgrades**
  - ➢ MESH-SED, MESH-WASP, WASP-CE-QUAL-2, SWMM-EFDC, CRHM-WQ, FLUXOS, RAVEN-Urban
- ❑ **Comparative assessment of water quality models**
  - ➢ HYPE, HSPF, INCA, SWAT AnnAGNPS
- ❑ **Catchment sediment and contaminant loads**
  - ➢ Sediment transport: Athabasca River, South Saskatchewan River
  - ➢ Metal pollution: Don River, Toronto
  - ➢ Urban stormwater nutrient export: Western Lake Ontario
- ❑ **Dams and reservoirs: water supply and nutrient cycling**
  - ➢ Lake Diefenbaker and Buffalo Pound Lake: operation and water quality
  - ➢ Great Lakes Basin: nutrient retention by dam reservoirs
- ❑ **Nutrient legacies: implications for nutrient management**
  - ➢ Agricultural N and P legacies: accumulation and release dynamics
  - ➢ Internal P loading: response to external load reduction and climate change
- ❑ **Cold regions lakes: understanding eutrophication**
  - ➢ Large lakes: role of littoral processes and nearshore-offshore exchanges
  - ➢ Algal growth windows and rates: a new open access data base
  - ➢ Nutrient enrichment versus climate change: Machine Learning analysis

Water Resources Management Modelling

Global Water Futures | Core Modelling Team

- **Main objectives:**
  - (i) Apply and integrate existing water management modeling frameworks.
  - (ii) Create platforms for integration of human impact, such as reservoir operation in land surface and hydrological models under climate change scenarios.
- **Recent advances and ongoing developments:**
  - (i) Inclusion of various lake/reservoir models in mizuRoute (Döll, Hanasaki and HYPE).
  - (ii) mizuRoute is included in Earth System Community Modeling Portal, https://github.com/ESCOMP/mizuRoute
  - (iii) New lake model for large scale application in HYPE mdoel with emphasis on the arctic region.
  - (iv) Review of practices and visions from various communities, water management experts, decision makers and earth system modelers in including and coupling human impact.
  - (v) Climate change impact assessment on water resources management (such as allocation).
  - (vi) Climate change impact on ice covered rivers and reservoirs operation.



Credit: Ali shah et al., 2020

Publications:

Mizukami, Clark, Gharari, Kluzek, Pan, Lin, Beck, Yamazaki: A Vector-Based River Routing Model for Earth System Models: Parallelization and Global Applications, Journal of Advances in Modeling Earth Systems, doi: https://doi.org/10.1029/2020MS002434

Tefs, Stadnyk, Koenig, Déry, MacDonald, Slota, Crawford, Hamilton: Simulating river regulation and reservoir performance in a continental-scale hydrologic model, Environmental Modelling & Software, doi: https://doi.org/10.1016/j.envsoft.2021.105025

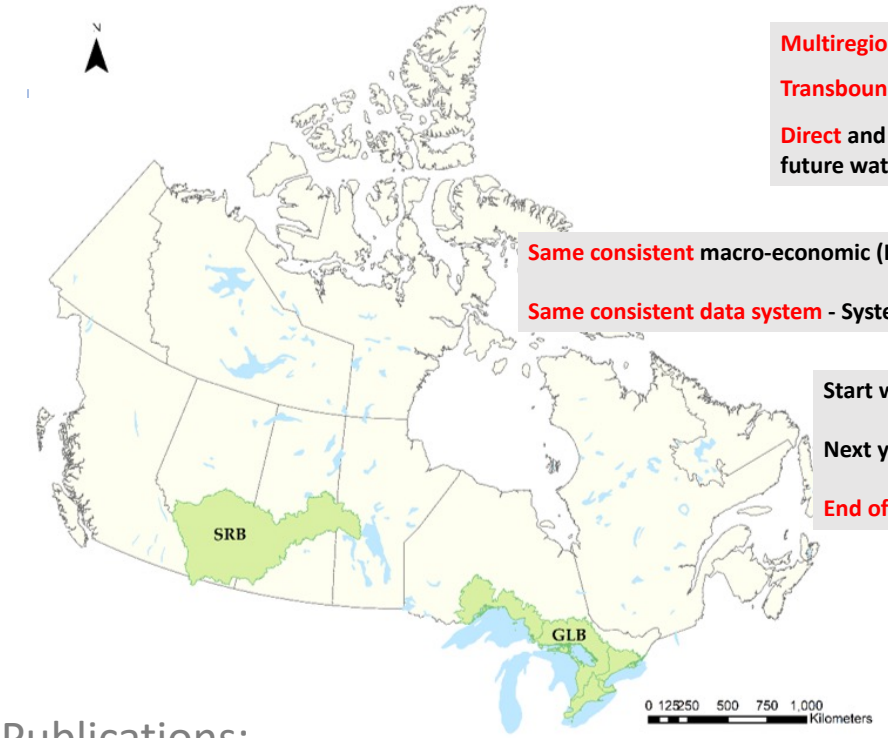
T. Stadnyk, tricia.stadnyk@ucalgary.ca

globalwaterfutures.ca

Hydro-Economics

Global Water Futures | Core Modelling Team

- Main objective: development of integrated hydro-economic modeling tools to assess the broader direct and indirect economic impacts of water policy under climate change
- Development of a consistent economic water **data and modelling framework** at relevant scales respecting hydrological boundaries
- New multi-regional input-output models for Great Lakes and Saskatchewan River Basin, including water use and pollution, to inform policy and decision-making under climate change
- New economic optimization procedures based on IO-modelling
- Development of a water quality valuation model to assess the non-market values of water quality improvements



Multiregional multi-sector input-output modelling

Transboundary basin scale

Direct and indirect economic impacts of potential future water supply disruptions under climate change

Same consistent macro-economic (I-O) modelling framework

Same consistent data system - System of National Accounts / Statistics Canada

Start with GLB and SRB (phase 1)

Next years (phase 2): inclusion other river basins

End of GWF (year 7): pan-Canadian

Publications:

Garcia-Hernandez, J.A. and Brouwer, R. (2021). A multiregional input-output optimization model to assess the economic impacts of water supply disruptions in the Great Lakes Basin. Economic Systems Research, https://doi.org/10.1080/09535314.2020.1805414.

Garcia, J., Brouwer, R., Pinto, R. (2020). Estimating the total direct and indirect costs to the Canadian economy of Phosphorus emission reduction policies in the Great Lakes Basin using a multi-regional input-output model. Under review.

Eamen, L., Brouwer, R. and Razavi, S. (2020). The economic impacts of water supply restrictions due to climate and policy change: a transboundary river basin supply-side input-output analysis. Ecological Economics, 172: 106532. https://doi.org/10.1016/j.ecolecon.2019.106532.

Eamen, L., Brouwer, R., Razavi, S. (2021). Integrated modelling to assess the impacts of water stress in a transboundary river basin: Bridging local-scale water resource operations to a river basin economy. Science of the Total Environment, 800: 149543. https://doi.org/10.1016/j.scitotenv.2021.149543.

Eamen, L., Brouwer, R., Razavi, S. (2021). Comparing the applicability of hydro-economic modelling approaches for large-scale decision-making in multi-sectoral and multi-regional river basins. Environmental Modelling & Software. Under revision.

Brouwer, R and Pinto, R. (2021). How much are Canadians willing to pay for clean surface and ground water? A meta-analysis of the Canadian non-market valuation literature. Canadian Water Resources Journal, http://dx.doi.org/10.1080/07011784.2021.1973568.

Canada First Research Excellence Fund | Apogée Canada | University of Saskatchewan | University of Waterloo | McMaster University | Laurier

globalwaterfutures.ca

Hydrological forecasting

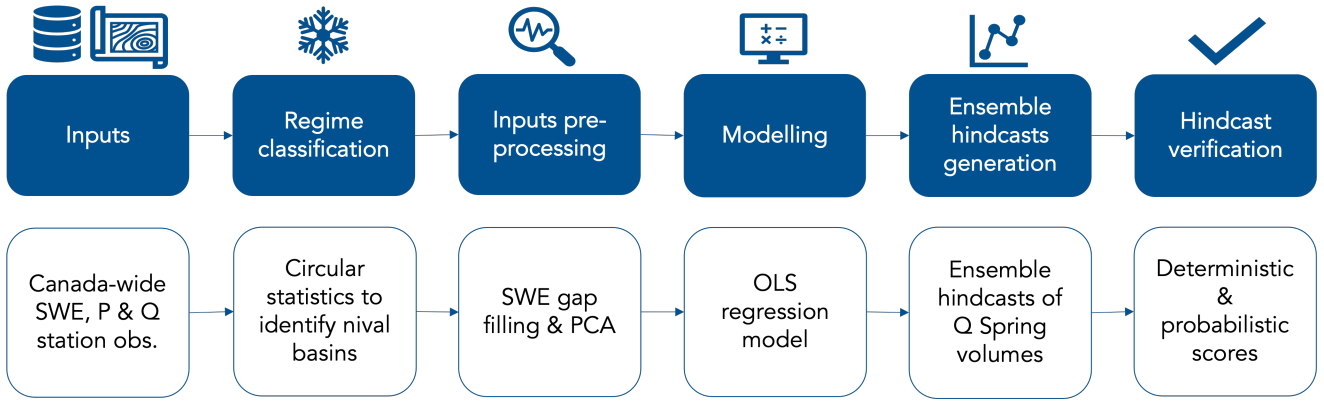
Global Water Futures | Core Modelling Team

Comprehensive evaluation/advances in operational hydrologic forecasting

Research focus:

- System development for Flow Guidance
  - ➢ *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.).*
- Hydrological Forecasting development
  - ➢ *Focused development on critical topics in hydrologic forecasting, especially downscaling, data assimilation, and post-processing*
- Hydrologic prediction testbeds
  - ➢ *Implement test-beds for specific basins to enable rapid prototyping of new prediction methods*

This work is evolving in close collaboration with the ECCC hydrologic prediction effort



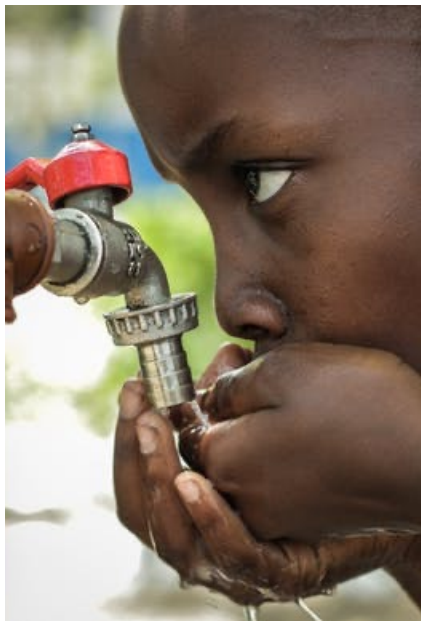
Outcomes:

- *Cloud-based Quasi-Operational flow forecasting system prototype operating for over a year for the Yukon River Basin using MESH*
- *Implementation of the SHARP system for Canadian basins*
- *Development and operationalization of River-ice modules for MESH*
- *Data dashboards for testbed development*
- *Advances in understanding the importance of initial conditions and meteorological forcing for seasonal forecasting skill and prediction sensitivities*
- *GWF Co-hosted the 2nd Canadian Flood Forecasting Symposium*

Canada First Research Excellence Fund | Apogée Canada | University of Saskatchewan | University of Waterloo | McMaster University | Laurier

globalwaterfutures.ca

Human and Health Dimensions



Thematic Priorities:

- Societies and people are impacted directly and indirectly by water in many inter-related ways. Climate change is affecting the incidence and distribution of these impacts.
- Water is a direct disease vector, transmitting waterborne diseases from human and animal-sourced pathogens including E. coli and Giardia lamblia.
- Water provides the breeding habitat for vectorborne diseases, such as West Nile virus and malaria. Water resources are a key driver of food security and green water is a mechanism through which water can be redistributed.
- Floods and droughts (leading to wildfires and crop shortage) have direct and indirect impacts on people, communities, and health and wellbeing, such as disrupting access to healthcare services, injury, malnutrition, property damage and loss, and subsequent financial and psychological trauma. Compromised ecosystem services further contribute to negative societal impacts through loss of habitat and food supplies as well as water stress.

Workplan

Infectious disease

- Adapting and developing extensions to current GWF models to improve future assessments of waterborne diseases towards a comprehensive assessment of future water-related disease burden in Canada and exploration of mediating strategies.

Vectorborne disease

- Adapting and developing extensions to current GWF models to improve future assessments of mosquito- and aquatic vector-borne diseases towards a comprehensive assessment of future water-related disease burden in Canada and exploration of mediating strategies.

Flood and Drought Resilience

- Assessing social dimensions of vulnerability and resilience to flood and drought events to inform development of current and future scenario hydrological model outputs in forms that are more practical for local decision-makers.

Governance Metrics

- Developing a benchmarking system based on core governance and social learning indicators in order to assess current status and evaluate future policy interventions to inform and be informed by current and future scenario hydrological model outputs.

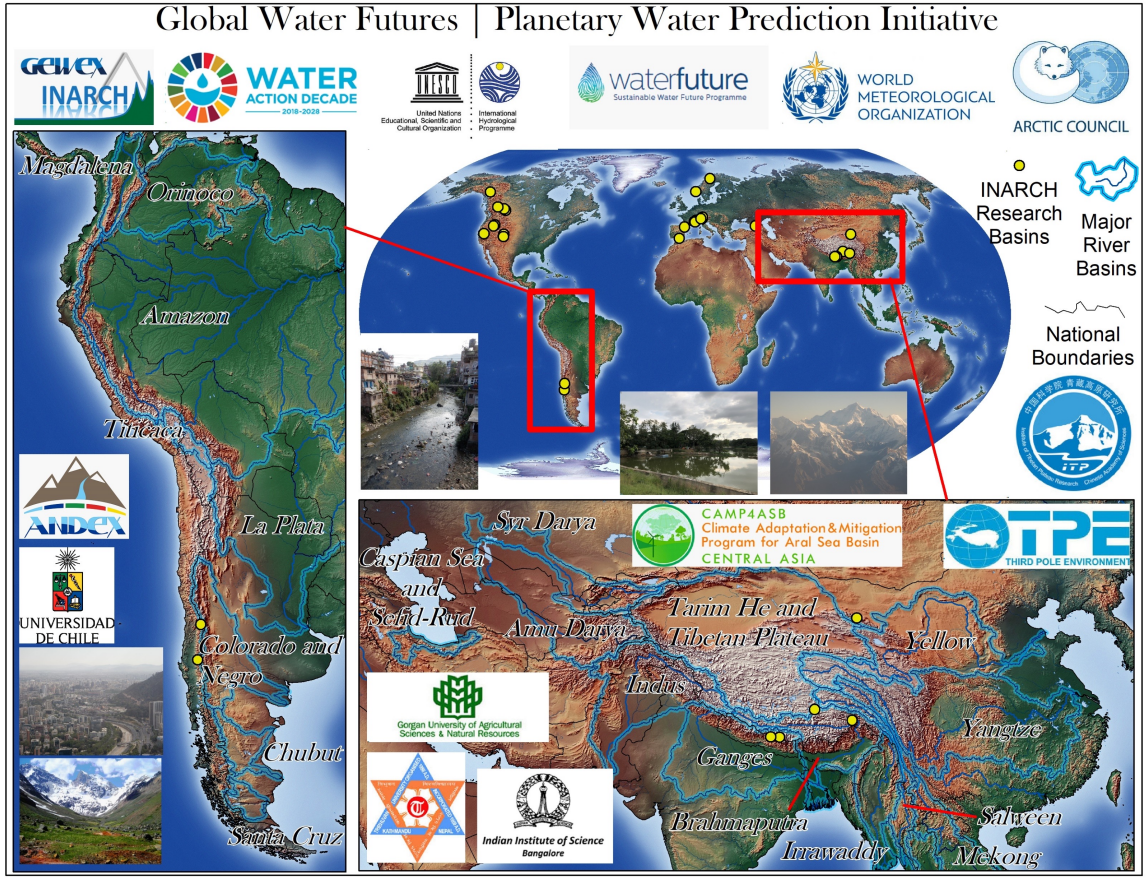
GWF Planetary Water Prediction Initiative

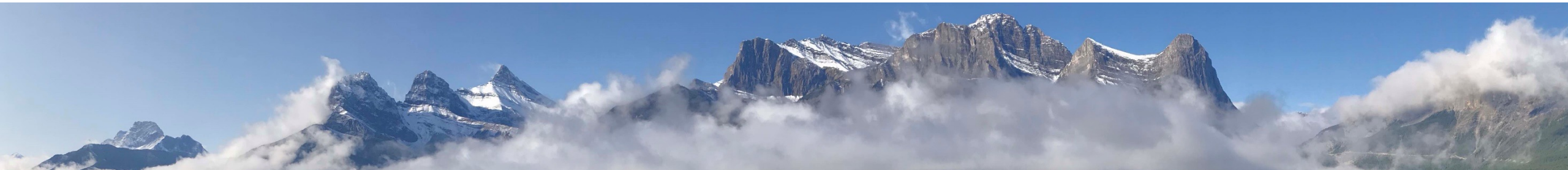
Global Water Futures | Core Modelling Team

- Exploit GWF science advances to improve our understanding and predictions of the global hydrological cycle

- Build computational infrastructure (models, data) to enable state-of-the-art hydrological simulations anywhere on the planet.
  - ➢ *Improve global datasets on climate forcing, DEMs, veg, soil etc.*
  - ➢ *Use these datasets to configure hydrological models for the global domain.*
  - ➢ *Address challenging questions of global hydrological change*

- Develop regional models in key areas where GWF has strong collaborations (Arctic, Himalaya, Andes, central Asia) to address pressing societal needs.
  - ➢ *The regional models will be constructed as cut-outs from the global-scale fabric*
  - ➢ *Address challenging questions of regional change*

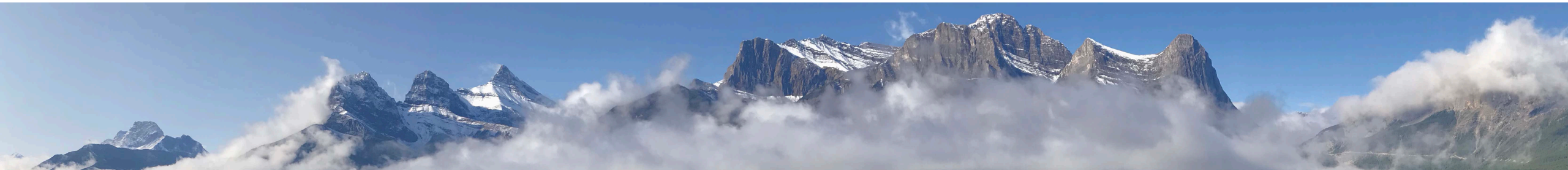




Summary and outlook

Global Water Futures | Core Modelling Team

- Computational infrastructure to enable large-domain hydrological modelling
  - Deterministic and probabilistic forecasting capabilities
- Model agnostic philosophy
  - Focus on *community hydrological modelling* rather than developing a community hydrological model
  - Advance a community of practice to more effectively share code and concepts across different model development groups
- Developing state-of-the-art capabilities in predicting terrestrial water, energy, and biogeochemical cycles



Thank you for your time!

Global Water Futures | Core Modelling Team

Questions?

CANADA FIRST RESEARCH EXCELLENCE FUND | APOGÉE CANADA FONDS D'EXCELLENCE EN RECHERCHE

University of Saskatchewan | University of Waterloo | McMaster University | Laurier – Inspiring Lives.

globalwaterfutures.ca