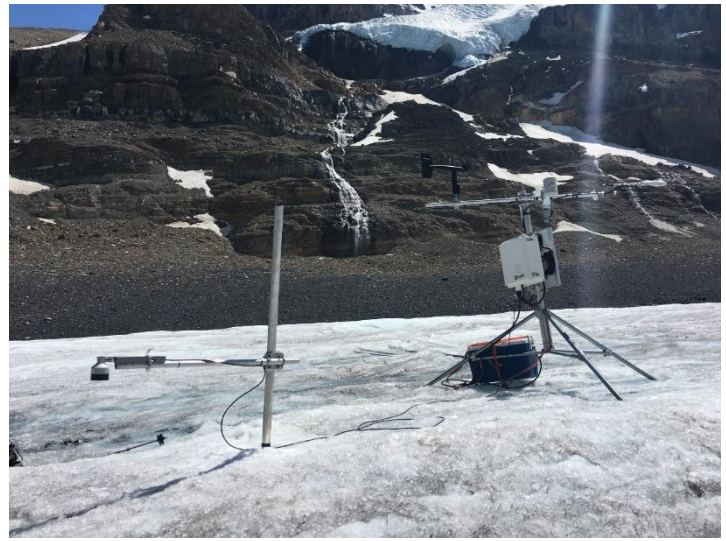
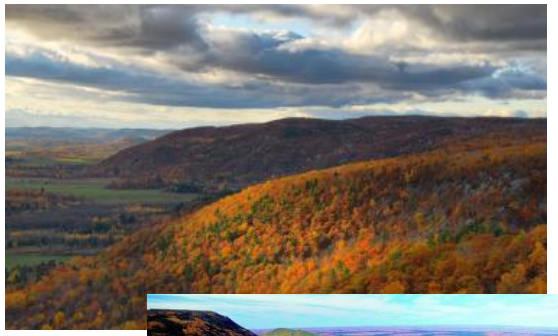
Advances in CRHM, CHM, MESH and application to diagnose changing hydrology from small to continental scales




John Pomeroy, Alain Pietroniro, Martyn Clark, Chris Marsh, Caroline Aubry-Wake, Vincent Vionnet, Zelalem Tesemma, Fuad Yassin, Mohamed Elshamy, Okan Aygun, Ala Bahrami, Wouter Knoben, Dan Princz

University of Saskatchewan, University of Calgary &
Environment and Climate Change Canada

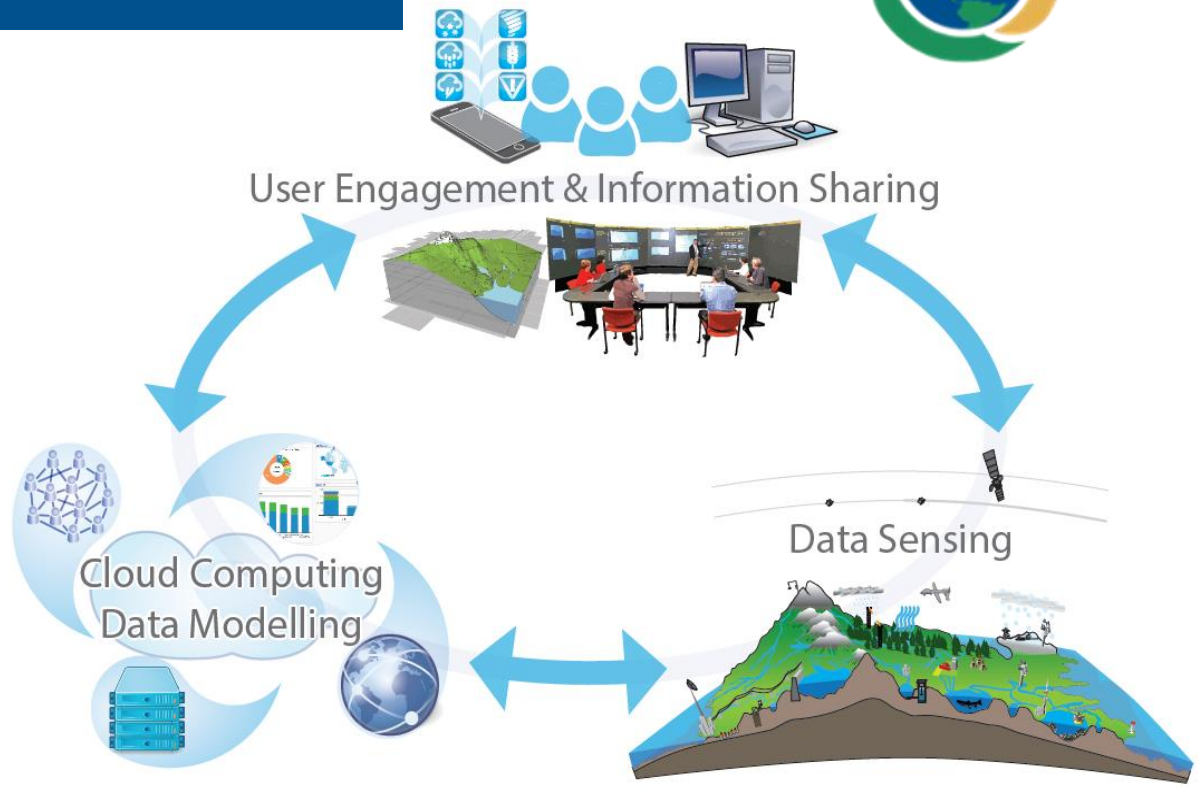
GLOBAL WATER FUTURES

SOLUTIONS TO WATER THREATS IN AN ERA OF GLOBAL CHANGE

Global Water Future's coupled water observation, data management, water prediction, and knowledge mobilization strategy

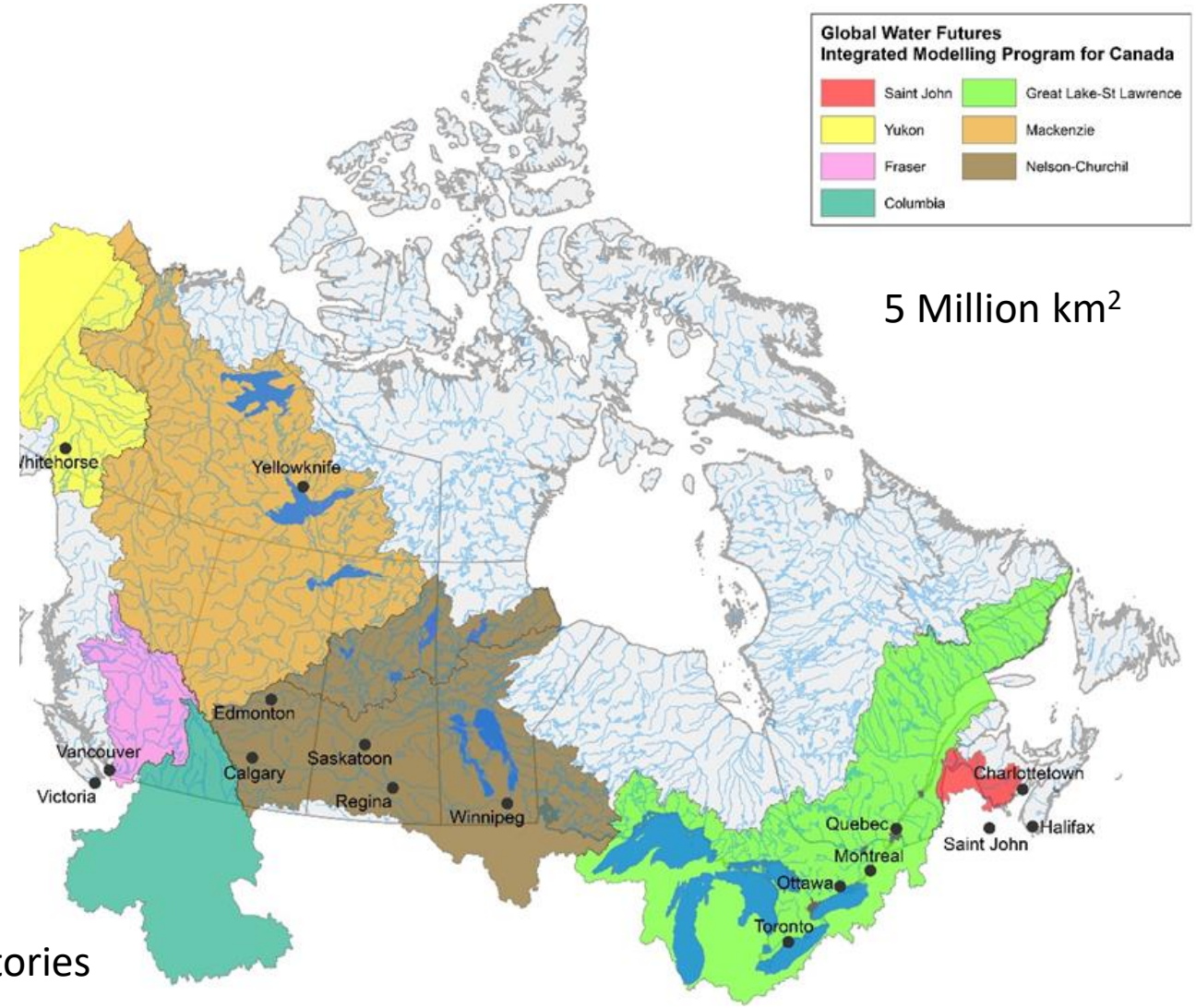
GLOBAL WATER FUTURES
RESEARCH IMPACT PROFILES

GWF Net



7 major river basins

76 water observatories
Global Water Futures Observatories

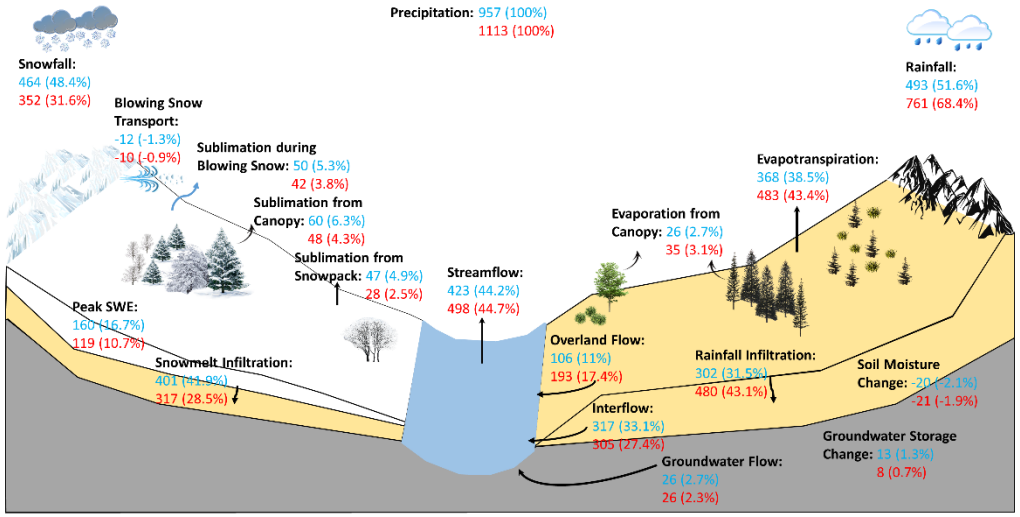


5 Million km^2

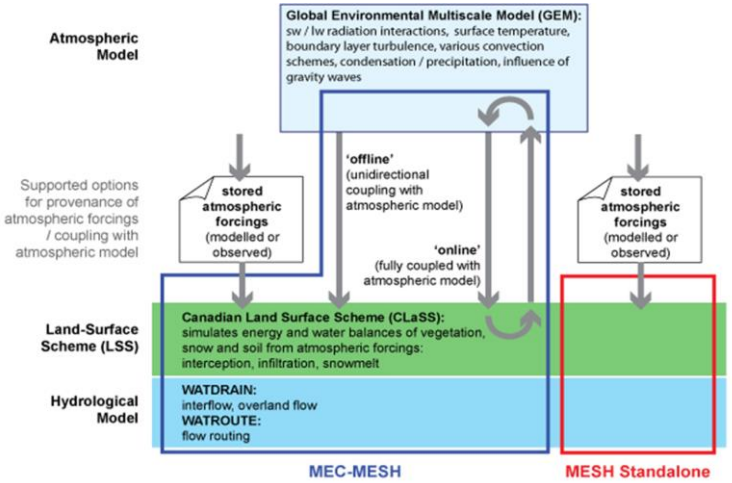
GWF Multi-modelling Strategy

Cold Regions Hydrological Modelling Platform (CRHM)

-modular, flexible, object-oriented process modelling
-users select modules to create a custom model
-spatial discretization based on hydrological response units
-catchment applications



*Pomeroy et al., 1998; 2007, 2016



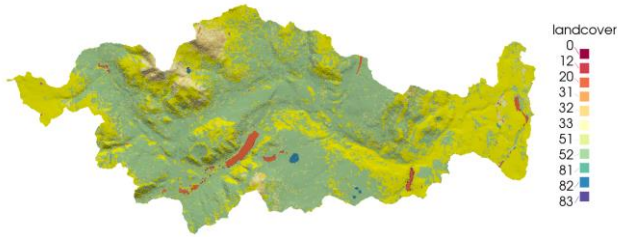
Pietroniro et al., 2007

Modélisation Environmentale Communautaire (MEC) – Surface and Hydrology (MESH)

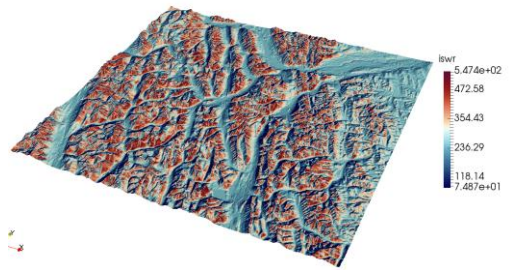
-Coupled land surface hydrological model
-Feedback with atmospheric and groundwater models
-Water management
-Cold regions
-Flexible
-Large river basins

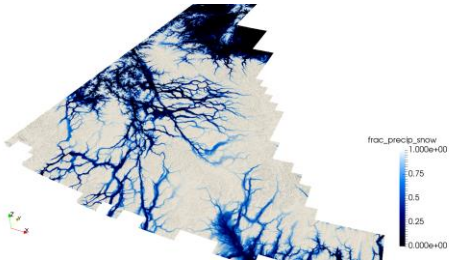
Canadian Hydrological Model (CHM)

Multi-scale, multi-physics, variable complexity and domain model
-Efficient TINS
-Assessment of model structural uncertainty



Marsh et al., 2018, 2020





Global Cryosphere and Water Prediction

Improved disaster warning from floods, droughts, and water quality degradation episodes

new code and computer technologies, for state-of-the-art prediction systems.

Hydrological Processes

TOWARDS MORE CREDIBLE MODELS IN CATCHMENT HYDROLOGY TO ENHANCE HYDROLOGICAL PROCESS UNDERSTANDING | Open Access

Advances in modelling large river basins in cold regions with Modélisation Environmentale Communautaire—Surface and Hydrology (MESH), the Canadian hydrological land surface scheme

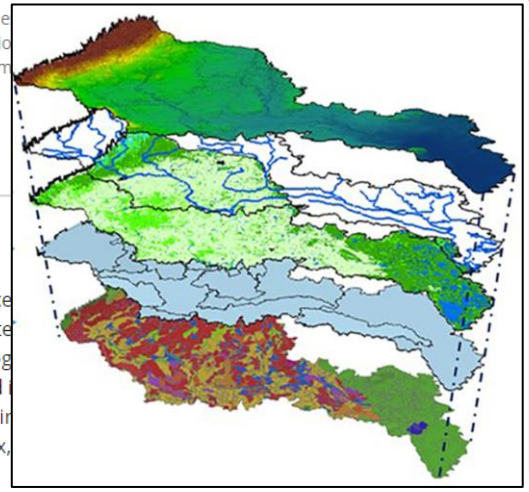
Howard S. Wheater, John W. Pomeroy, Alain Pietroniro, Bruce Davison, Mohamed Elshamy, Fuad Yassin, Prabin Rokaya, Abbas Fayad, Zelalem Tesemma, Daniel Princz, Youssef Loukili ... See all authors

First published: 22 March 2022 | https://doi.org/10.1002/hyp.14557 | Citations: 1

Find It

Funding information: Canada Excellence Re
Research Excellence Fund; Canada Foundatio
Atmospheric Sciences; Environment and Clim
Research Council of Canada

SECTIONS



Abstract

Cold regions provide water resource
change. Their hydrology is dominate
is having profound effects. Hydrolog
water resources but are challenged
meteorological forcing and constrair
hydrological processes are complex,

https://doi.org/10.1002/hyp.14557

JOURNAL OF FLOOD RISK MANAGEMENT | CIWEM | Open Access

SPECIAL ISSUE | Open Access

Physically based cold regions river flood prediction in data-sparse regions: The Yukon River Basin flow forecasting system

Mohamed Elshamy, Youssef Loukili, John W. Pomeroy, Alain Pietroniro, Dominique Richard, Daniel Princz

First published: 19 July 2022 | https://doi.org/10.1111/jfr3.12835

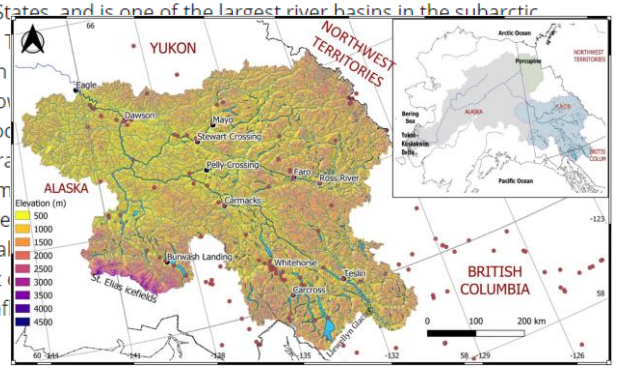
Find It

Funding information: Global Water Futures; Yukon Environment

SECTIONS PDF TOOLS SHARE

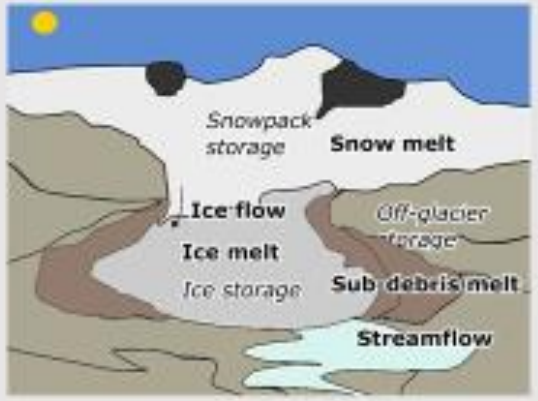
Abstract

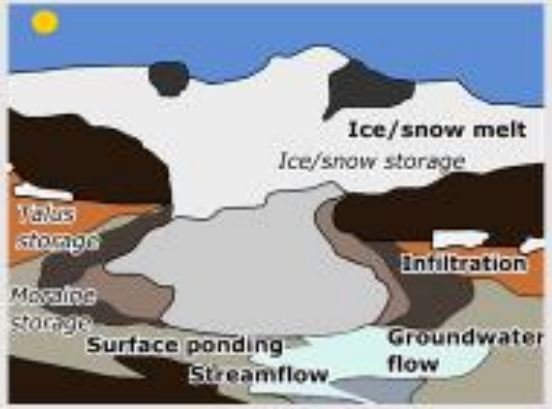
The Yukon River Basin (YRB) is one of the most important river networks shared between Canada and The United States, and is one of the largest river basins in the subarctic region of North America. T
partly glaciated mountain
glaciers and seasonal sno
freezing–thawing soil proc
runoff and evapotranspira
generation in the basin, m
region. Due to the remote
of observational data, mal
infeasible. At the request
operationalized a streamf

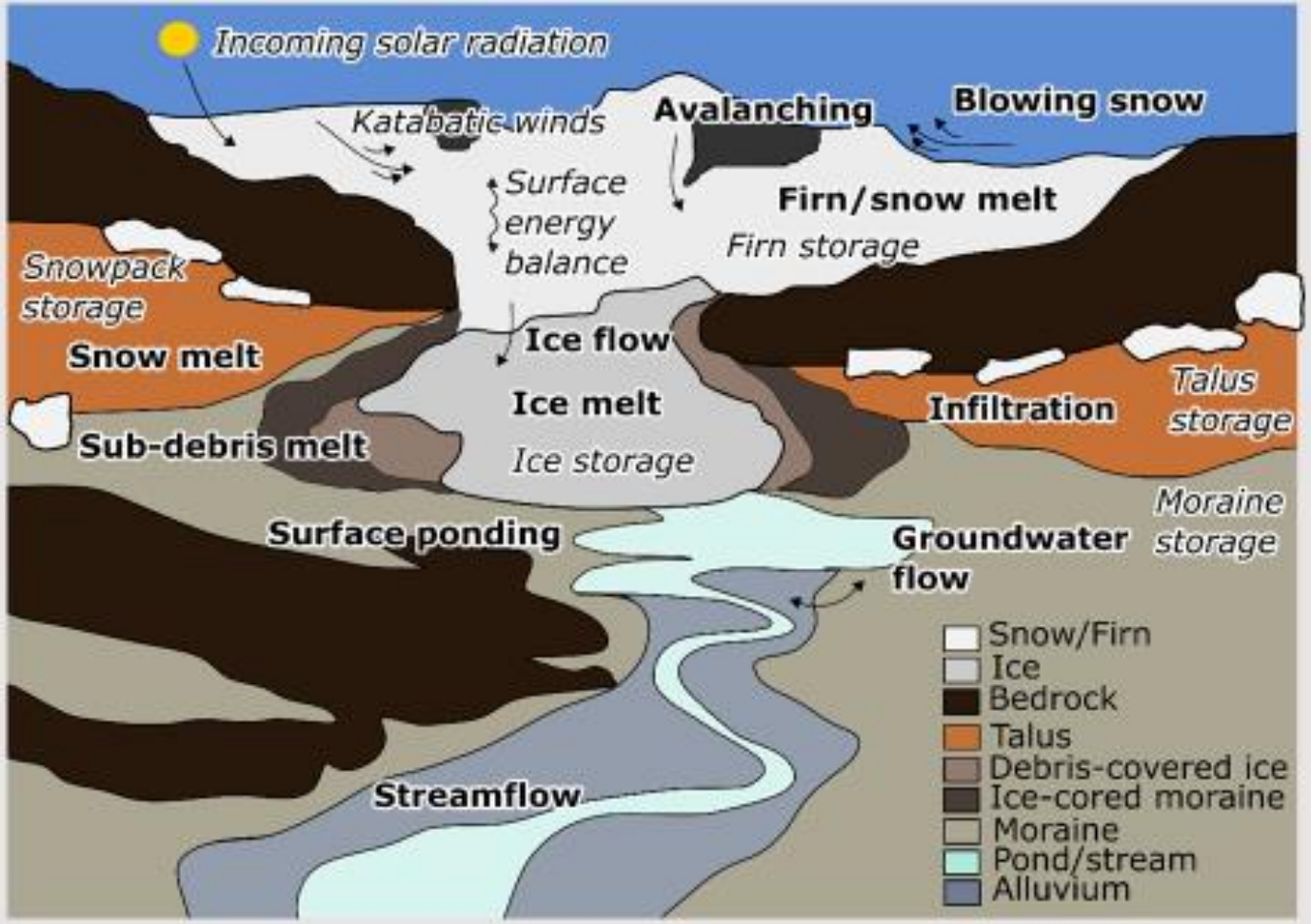


https://doi.org/10.1111/jfr3.12835

Cold Regions Hydrological Modelling Platform (CRHM)



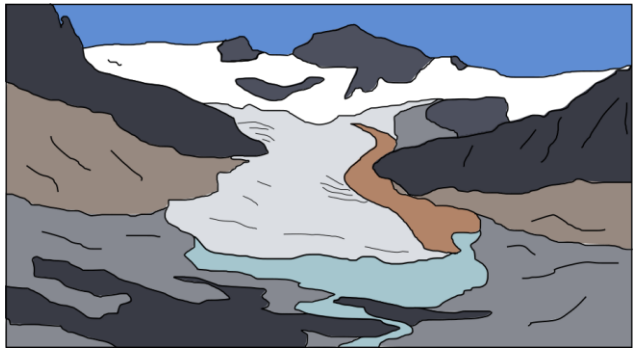




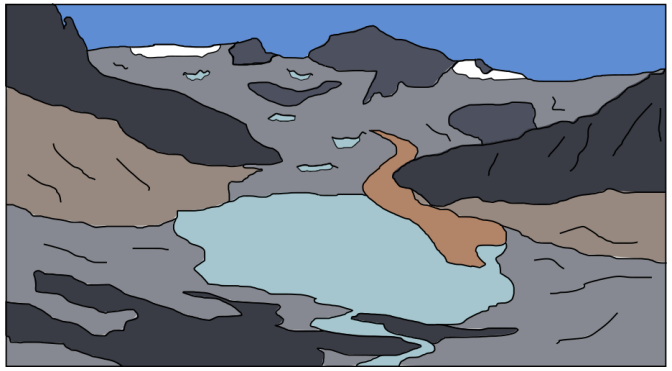
Created 1998. Pomeroy et al., 2007; 2013; 2016; Pradhananga & Pomeroy, 2022, Aubry-Wake & Pomeroy, 2022, 2023. http://www.usask.ca/hydrology

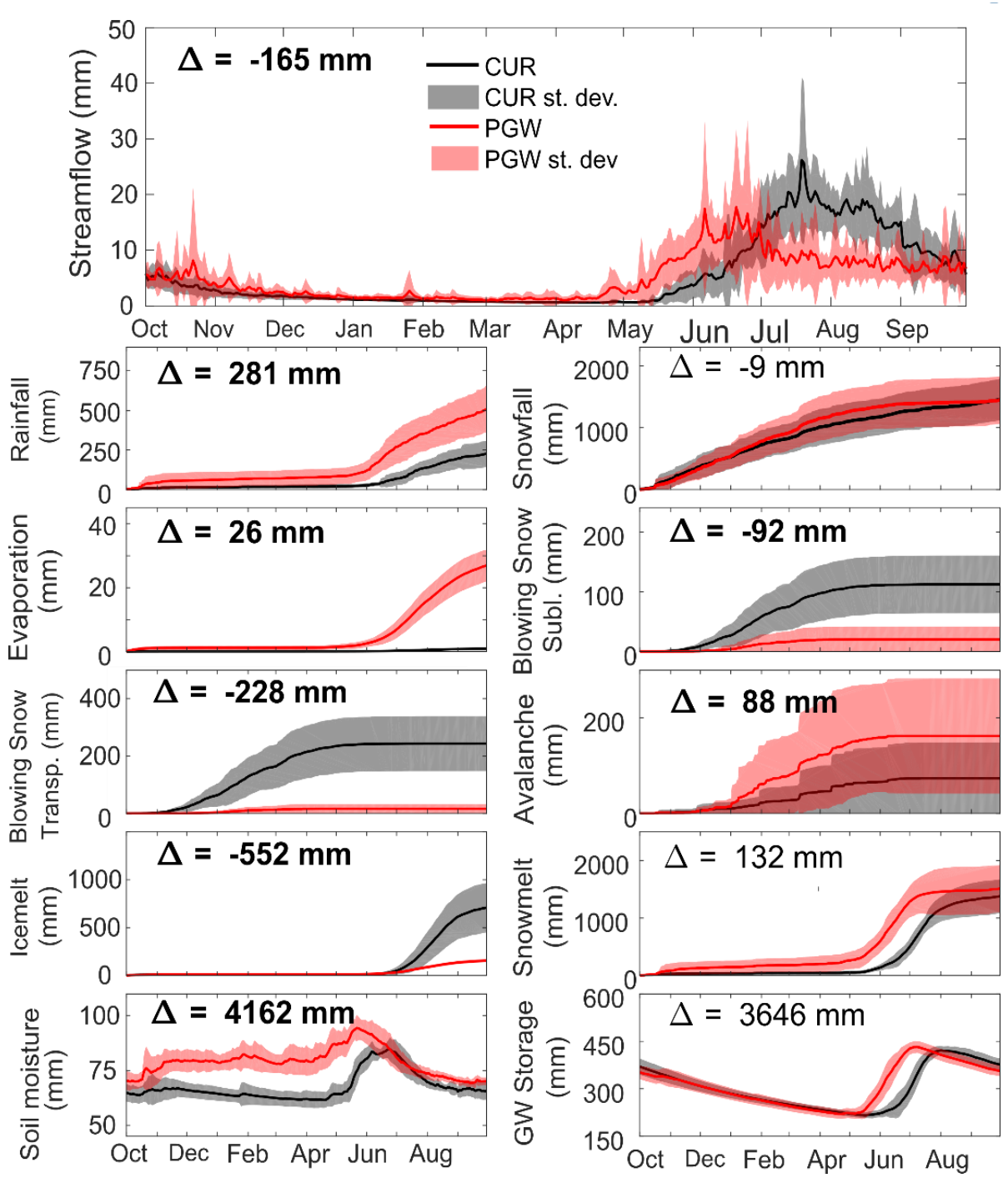
Dramatic changes in both streamflow and hydrological processes are predicted to occur in Peyto Glacier Basin with deglaciation and climate change

Current (2000-2015)



Pseudo-Global warming, RCP 8.5 (~2085-2100)





Canadian Hydrological Model

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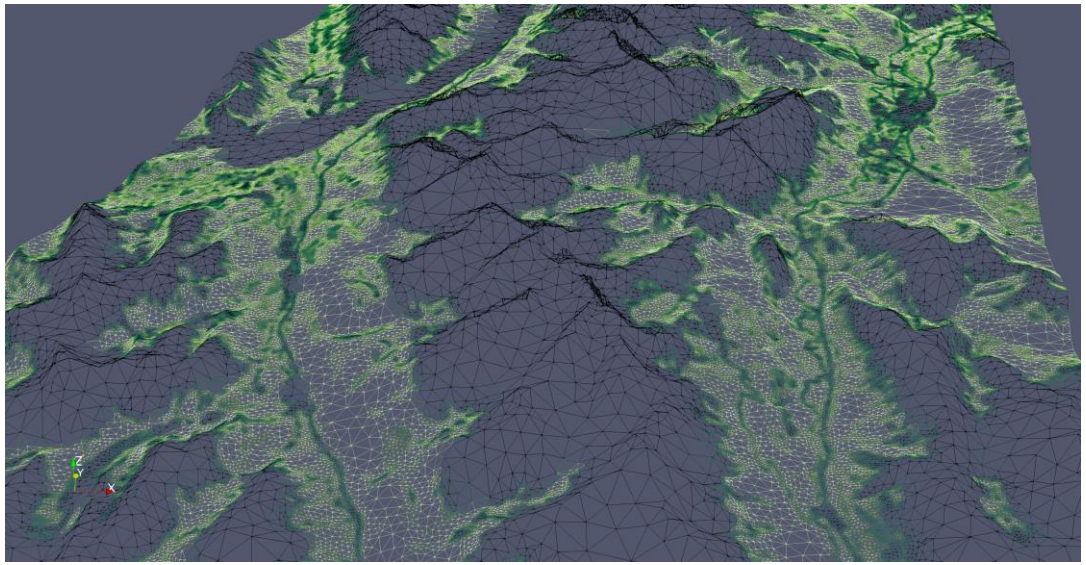
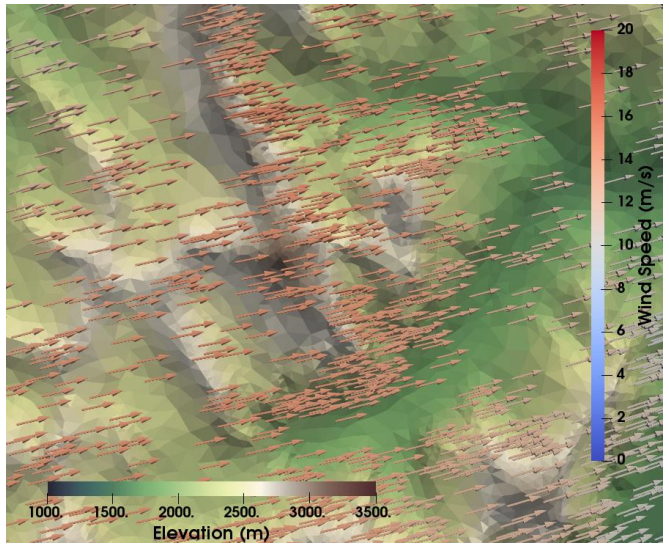
Global Water Futures
GWF.USASK.CA

- Modular multiphysics, scalable HPC model
- Spatially explicit
- Variable resolution triangular mesh
- Downscale radiation to slopes including shading, complex terrain windflow, T, q, P
- Energy balance snowpack, blowing snow, avalanching, canopy interception

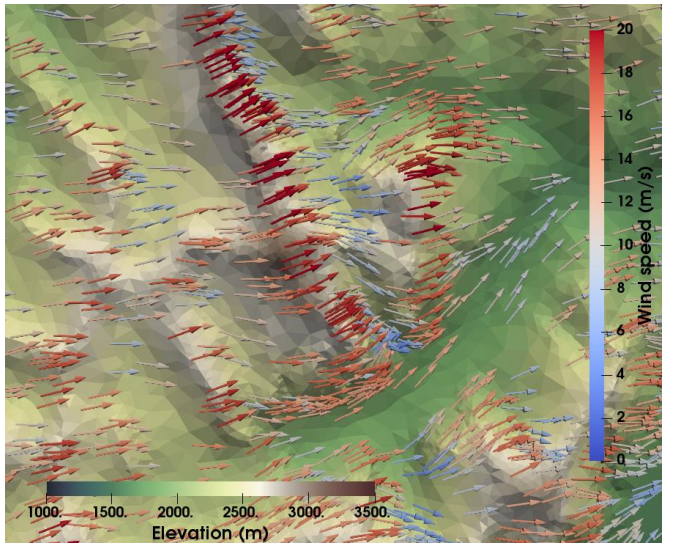


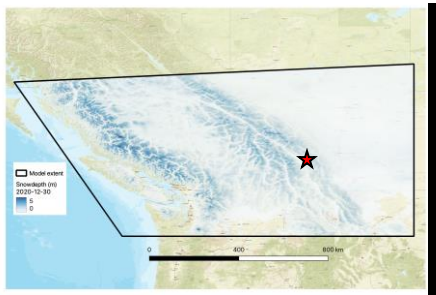
- SNOBAL (2-layers), FSM 2.0 (3-layers)
- PBSM3D (blowing snow), Snowslide (avalanche)
- 1.3M km^2 (1.3x the area of Germany + France + Switzerland + Austria)
- Forcing: downscaled 2.5km Canadian NWP output
- Snowdrift-permitting resolution = 50 m
- 3B raster cells reduced to 34M triangles

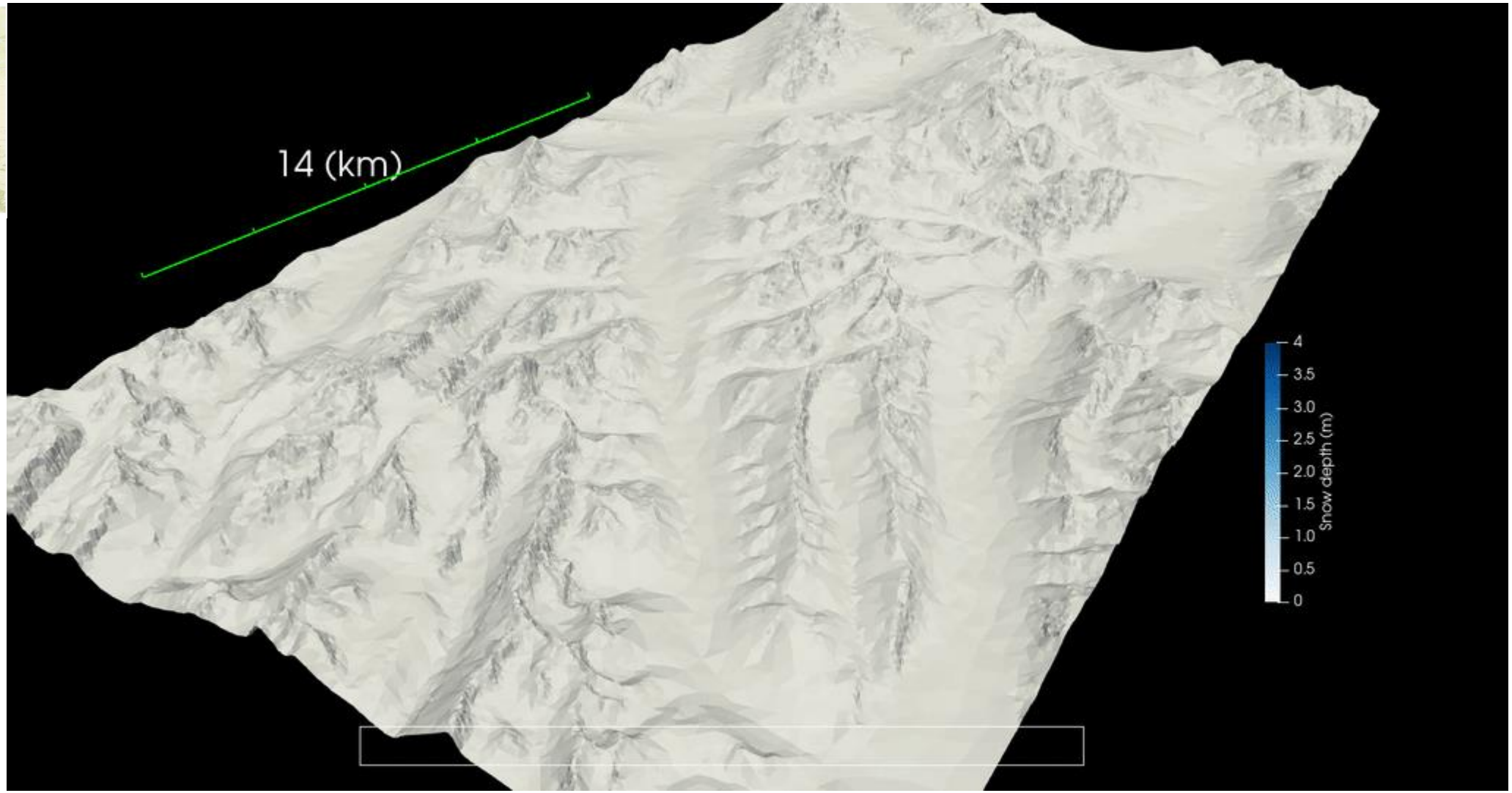
Input wind field



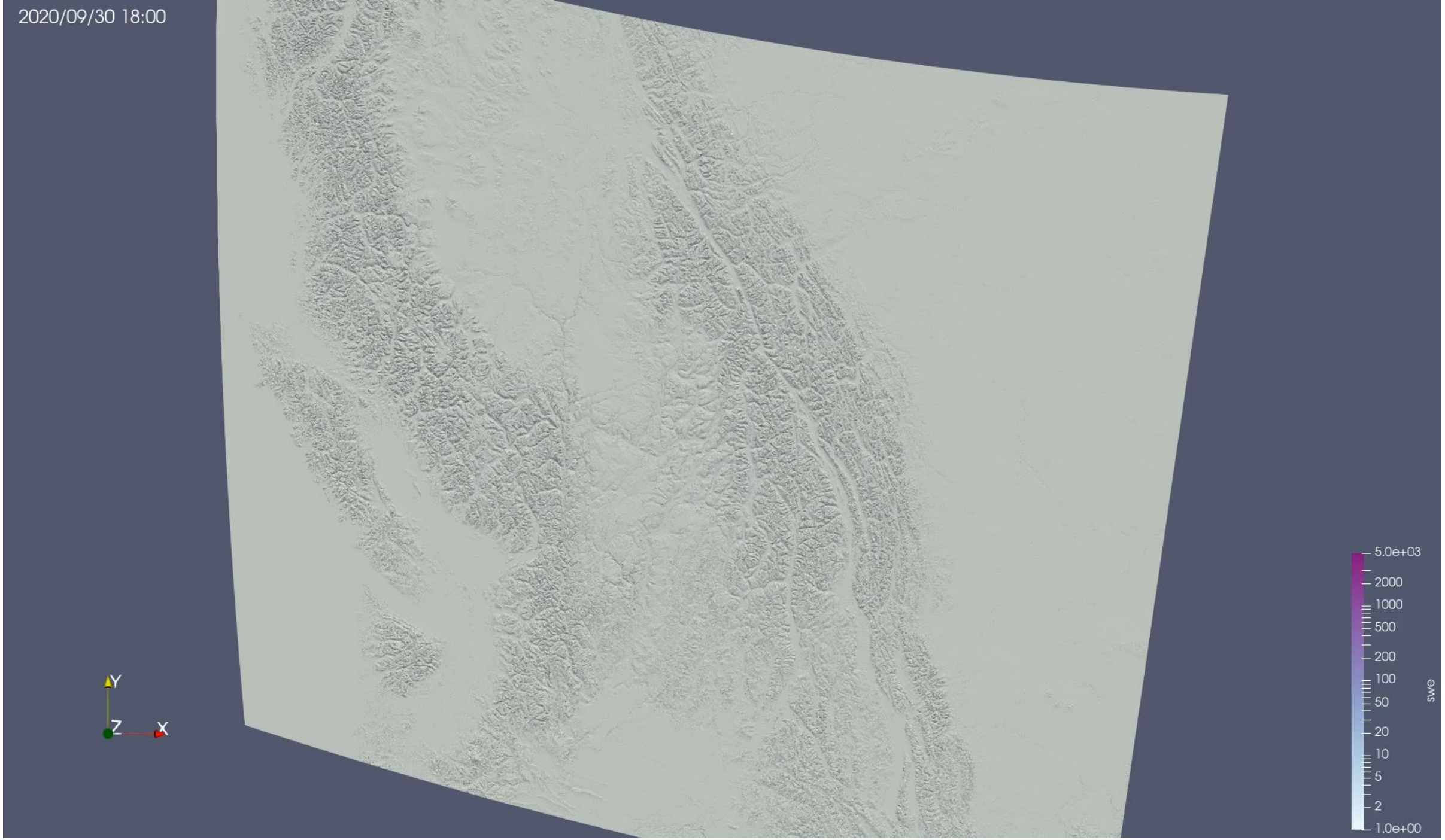
Downscaled with WM





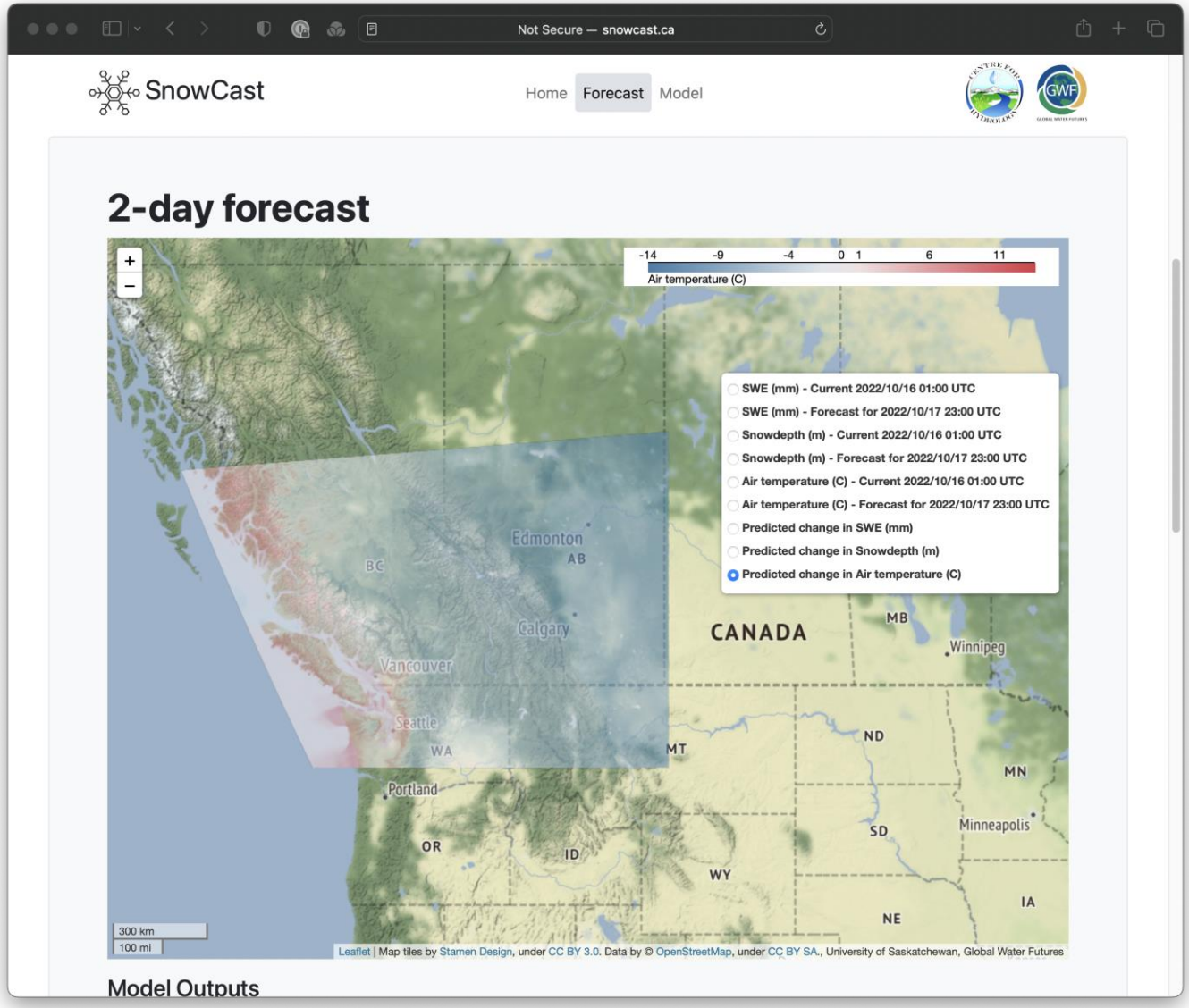


- Zoom in of the star region in the above plot
- This is the resolution the full domain is run at


2020/09/30 18:00
Y
Z
X
5.0e+03
2000
1000
500
200
100
50
20
10
5
2
1.0e+00
swe

SnowCast

- Nightly runs of CHM
- CHM forced with 2-day, 2.5 km meteorological forecasts
  - Environment and Climate Change Canada (ECCC) High Resolution Deterministic Prediction System (HRDPS)
- Zoomable Leaflet-based webUI
- www.snowcast.ca



MESH – the Canadian Hydrological Land Surface Scheme

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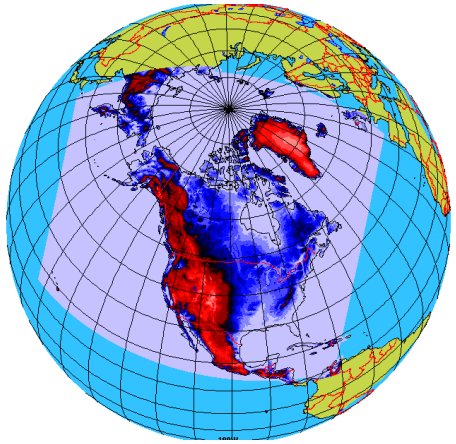
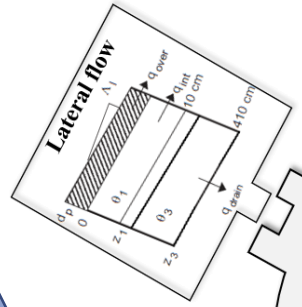
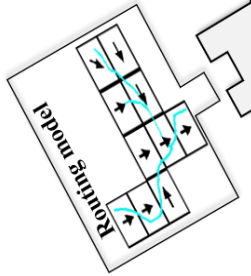
Model Simulations

Atmospheric model



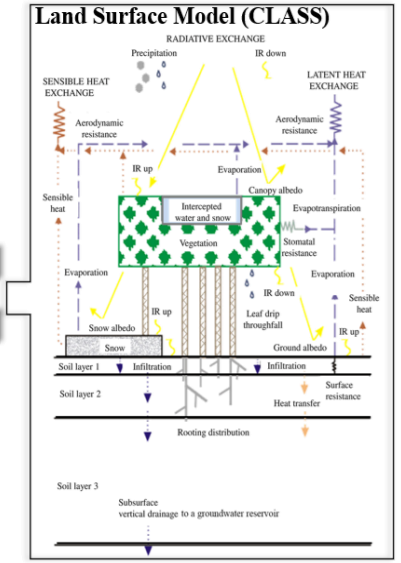
Process Sub-Models and Modules

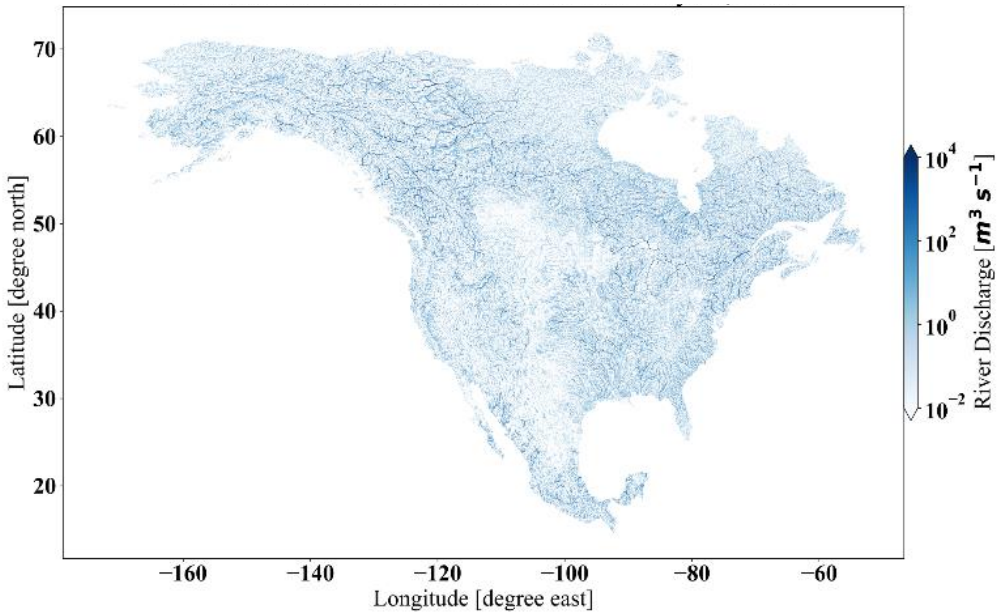


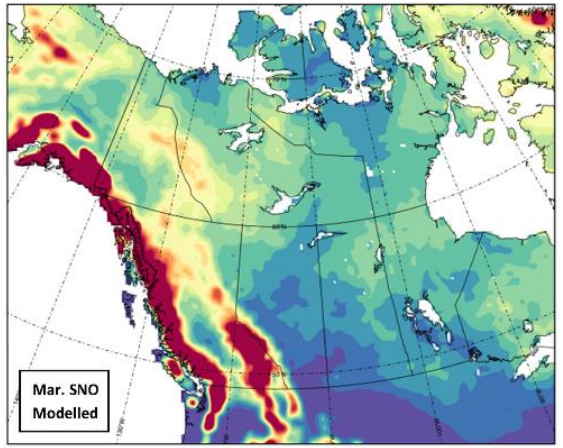


MESH CORE

- Vertical exchange of fluxes
- Lateral water movement
- Horizontal water transfer







Hydrology-Land-Surface Scheme

Benefits and advantages of the MESH model

- Based on decades of cutting edge hydrological and atmospheric science and water resources engineering
- Rigorously tested in GWFO and major river basins.
- Ties directly into a series of science projects and programs in Canada – it links to ECCC, provinces, universities – and internationally
- Uses multiple process-based features (blowing snow, permafrost dynamics, reservoir and irrigation, glacier processes, etc.)
- An 'open-source' community model
- Integrated in the operational forecasting system
- Data processors have been developed (Data assimilation, Mountain MESH)

MESH Continental Water Simulations

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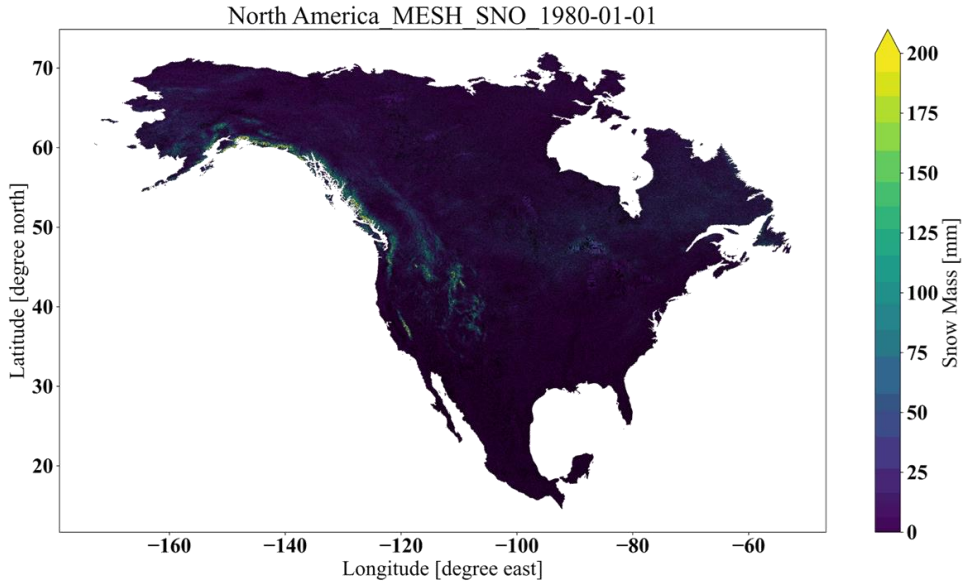
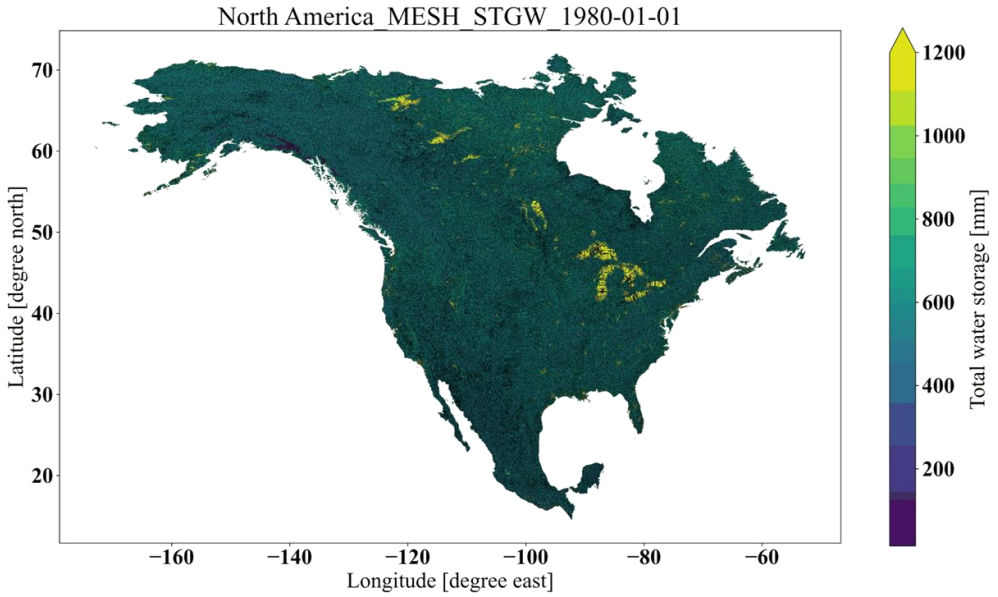
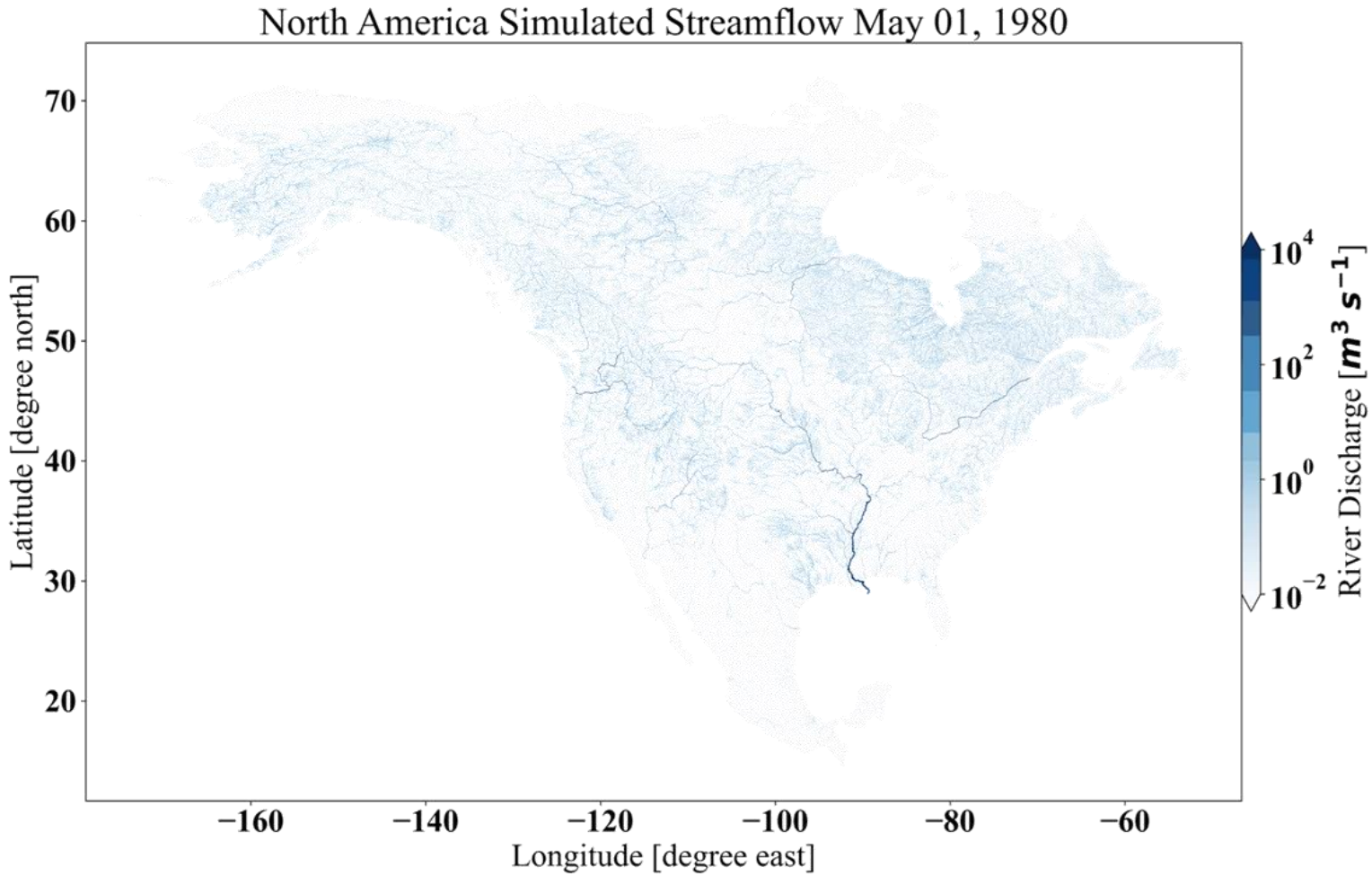
~0.5M basins

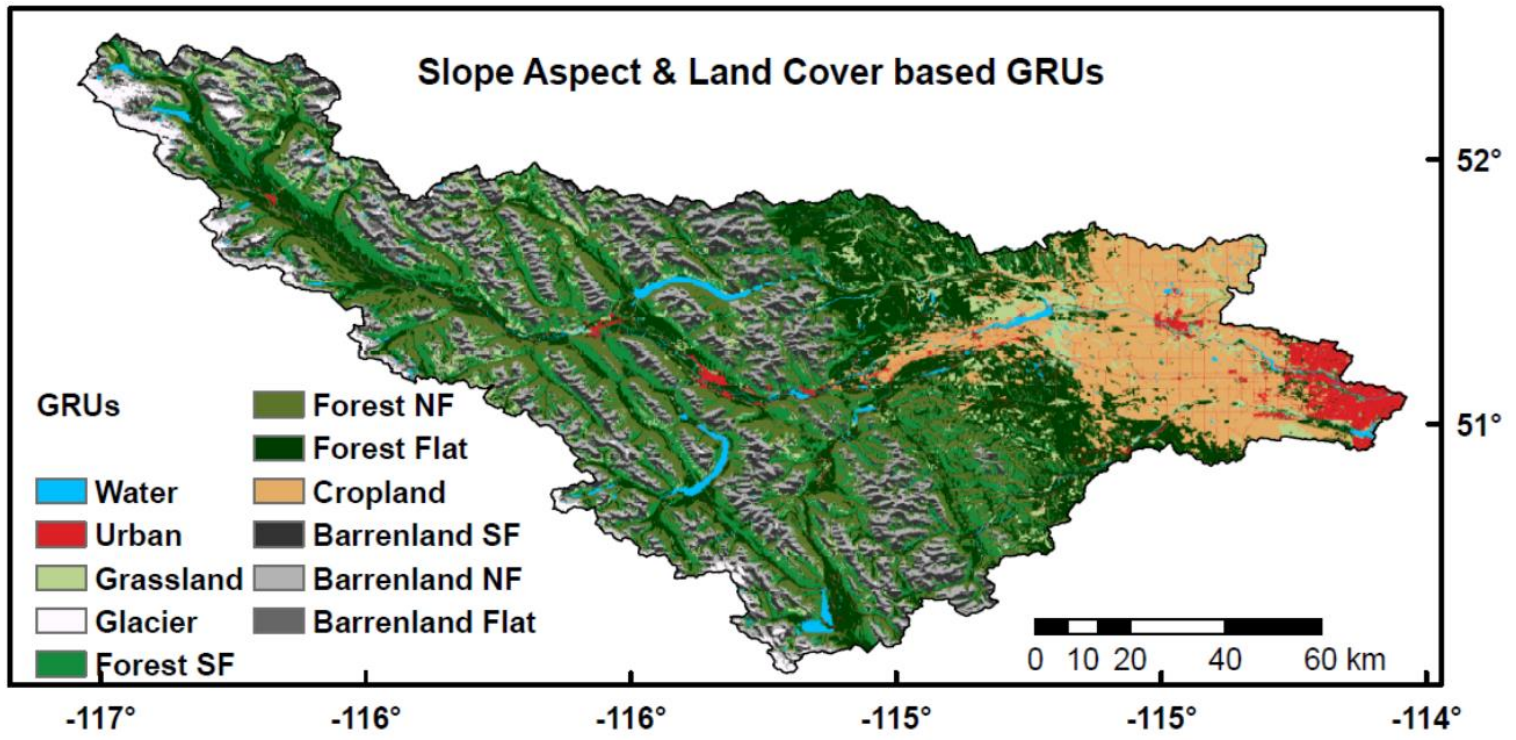


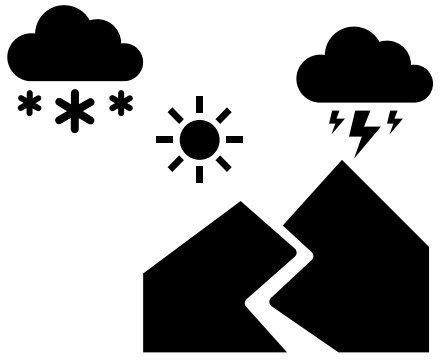




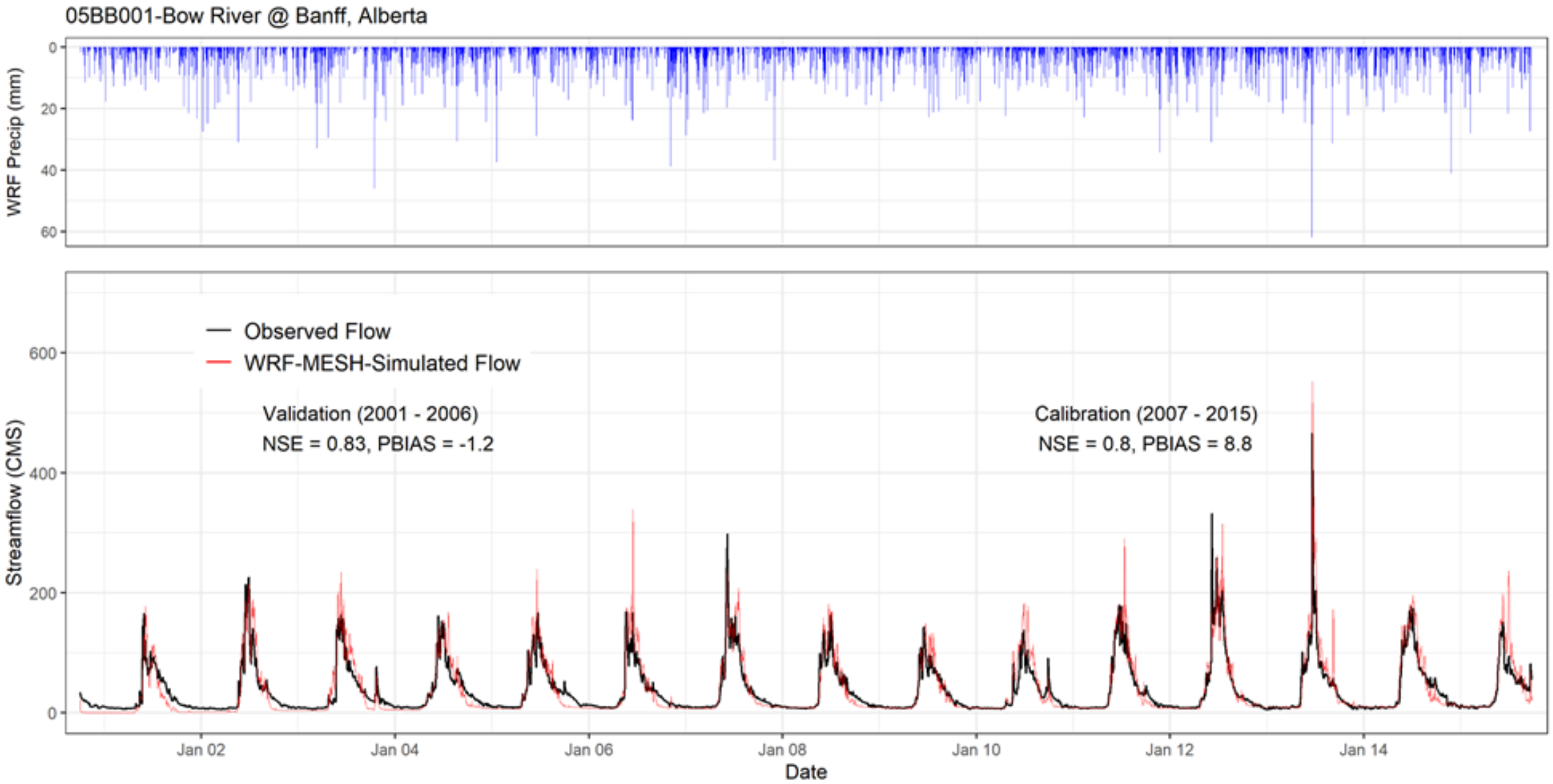
MESH model setup for Bow River at Calgary

- Model was set up at 4 km resolution consistent with WRF forcing data
- Model was parameterised from
  - DEM 90 m for slope, aspect and drainage
  - Land cover 30 m
  - Soils - ECCC
  - Streams from ECCC
- Managed Basin setup
  - with dams and reservoirs
- “Mountain Mesh”
  - Downscale shortwave irradiance to slope/aspects
  - Downscale wind speed, air pressure, temperature, humidity, precipitation, precipitation phase to elevation
  - Improved glacier model in MESH, snow redistribution used





MESH Bow River at Banff: calibration and validation with historical WRF - 4km data



Future Streamflow Calgary

WRF 4 km Forcing with Pseudo-Global Warming (PGW) based on CMIP5 RCP8.5

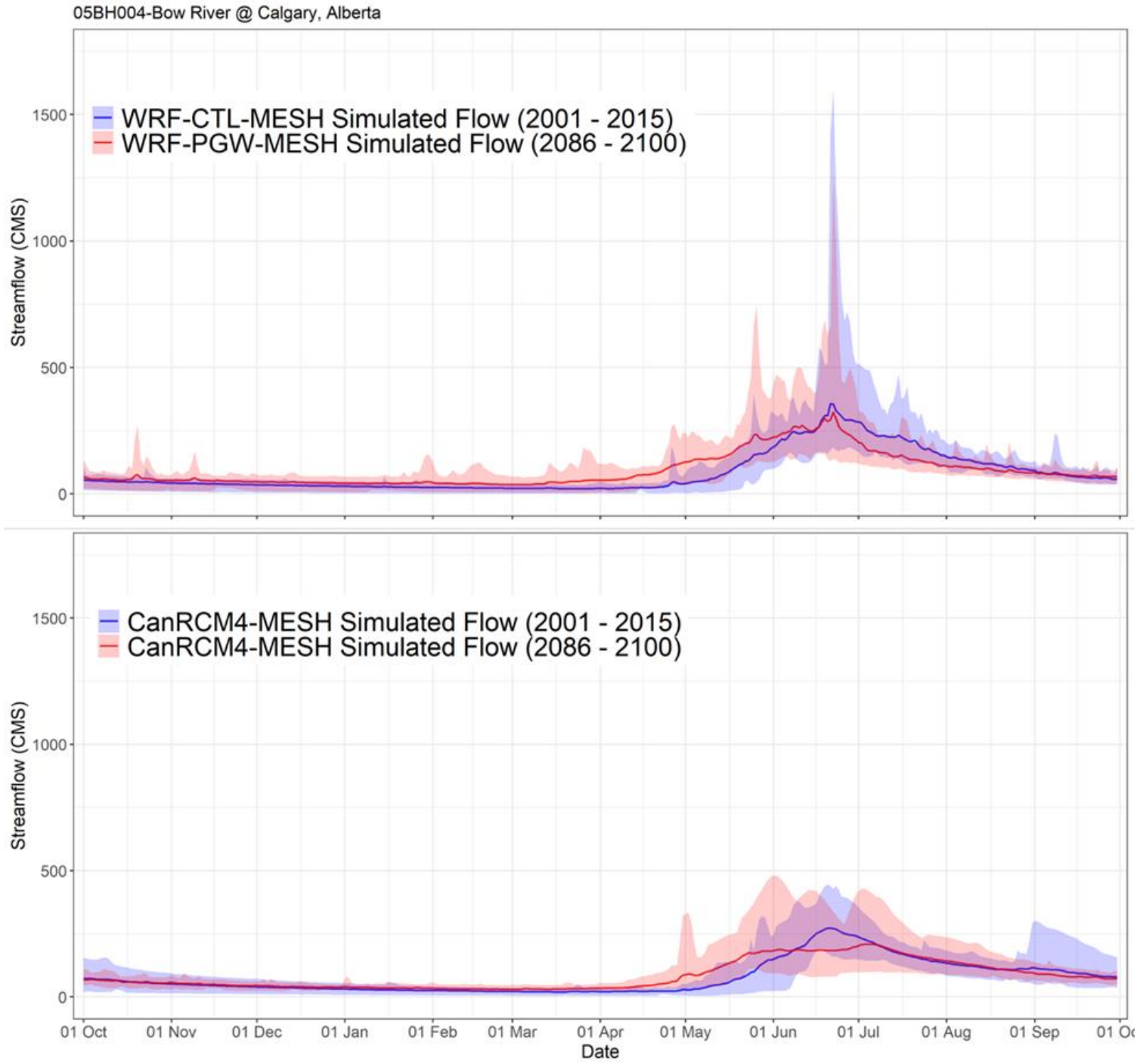
-captures mountain storms, melt

-higher spring & lower summer flows

CanRCM4 10 km downscaled forcing

Bias corrected CanRCM4 using WFDEI-GEM-CaPA	**1950 - 2100**

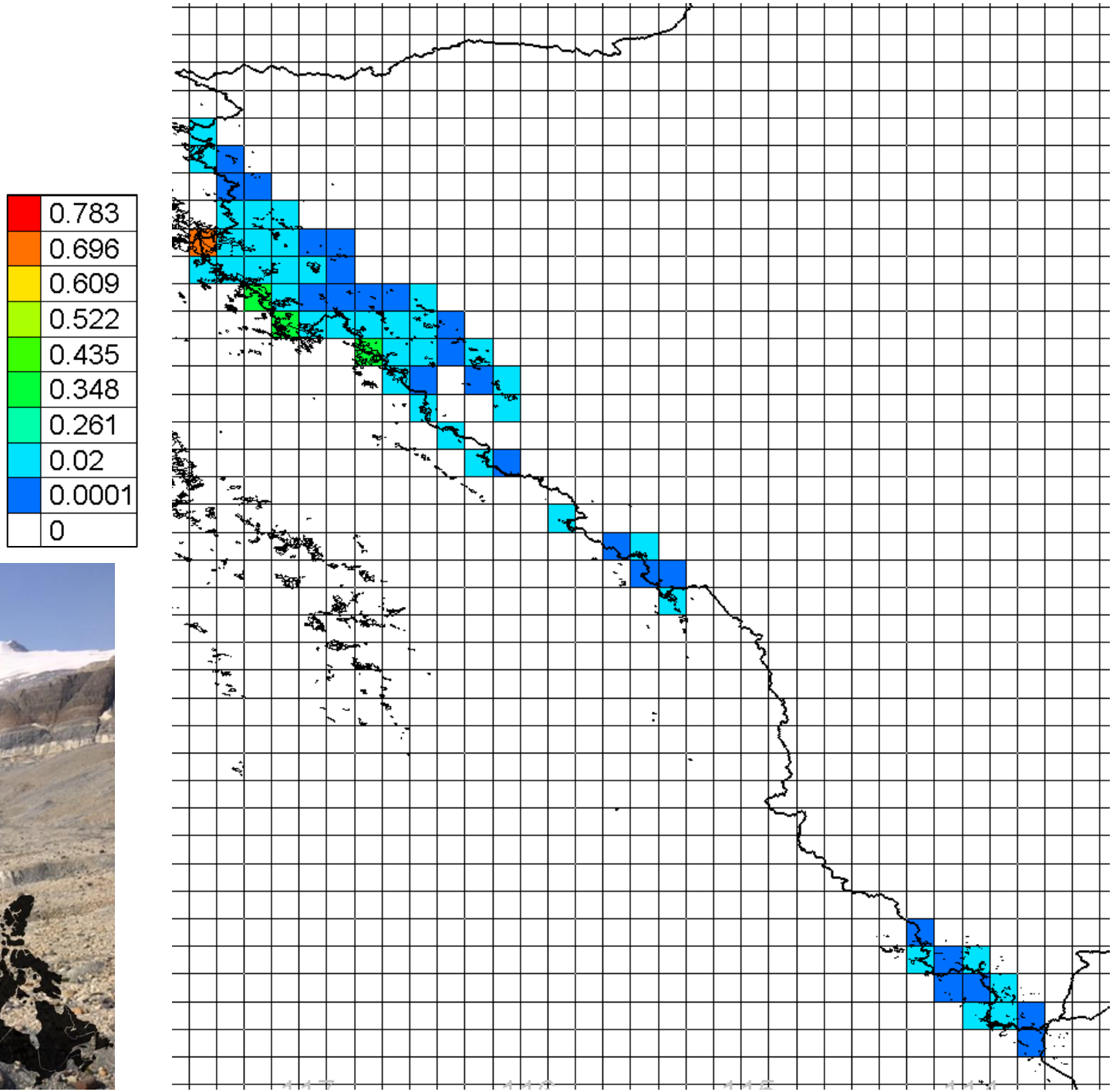
Poor dynamics, earlier flows



Glacierised fraction

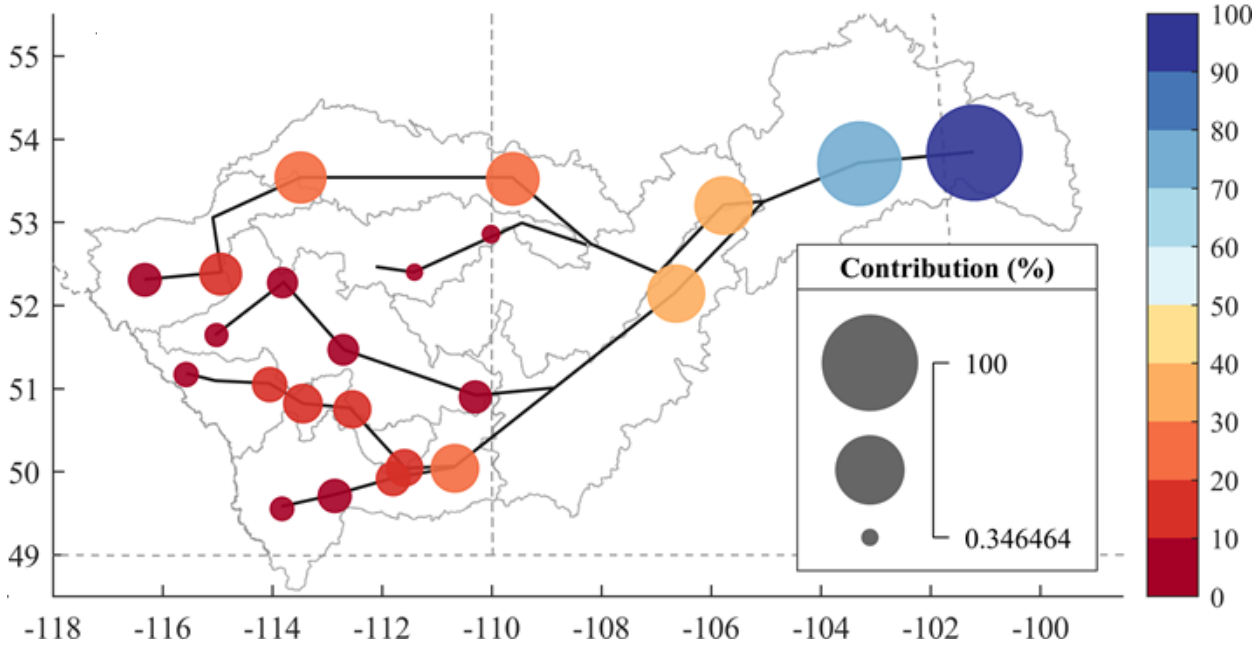
Canadian Rockies

Total glacierised area 338.8 Km^2

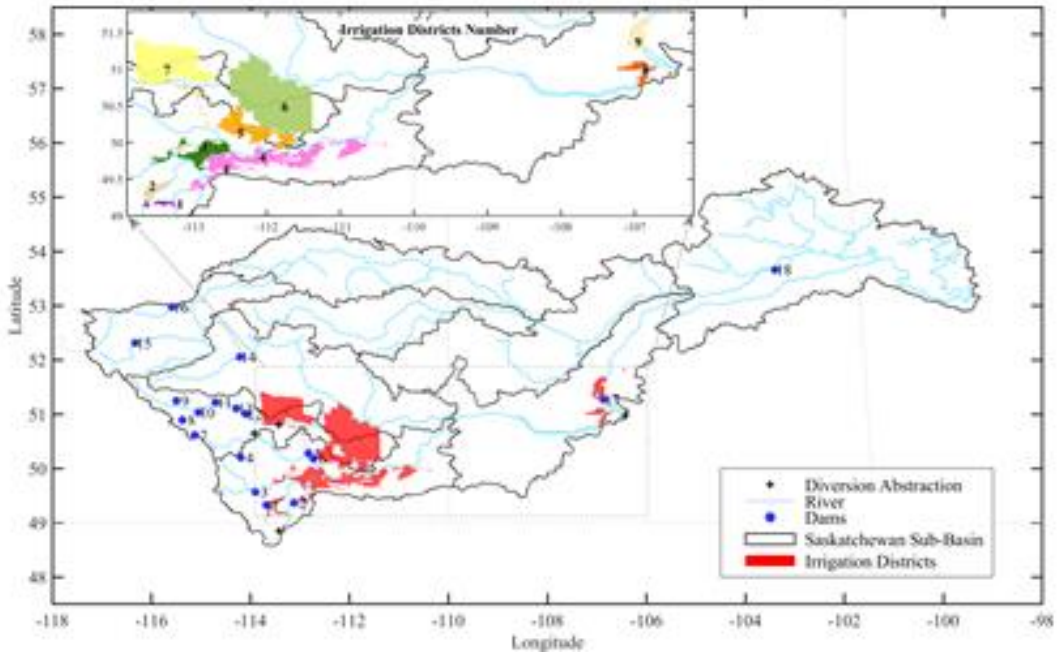


Saskatchewan River Basin Prediction - MESH

Cumulative Streamflow Volume and River Network

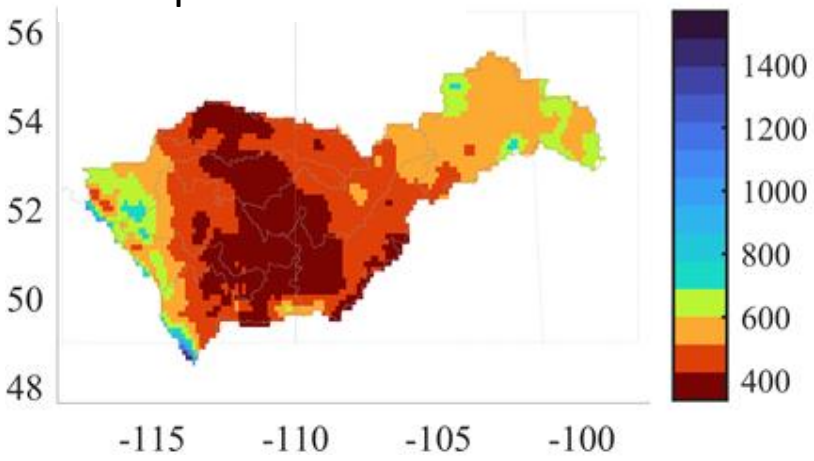


Irrigation Districts and Area Modelled

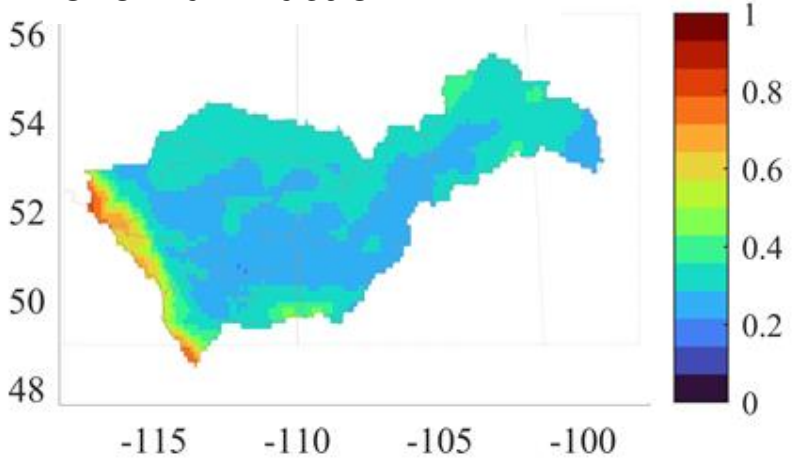


Saskatchewan River Basin Current Water Balance

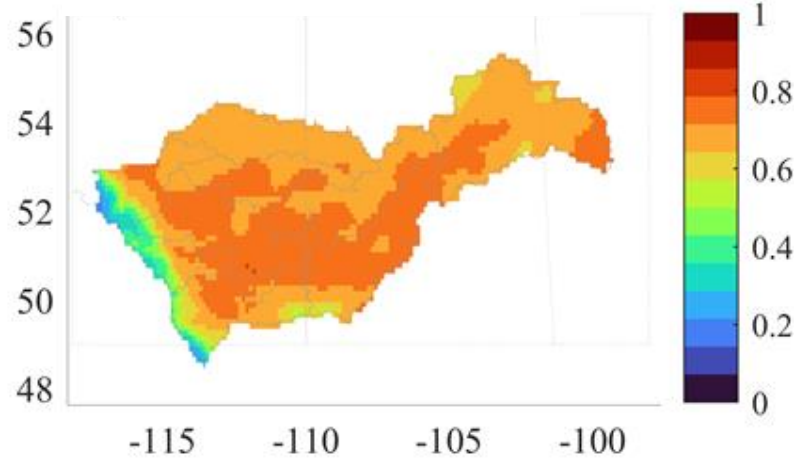
Precipitation mm



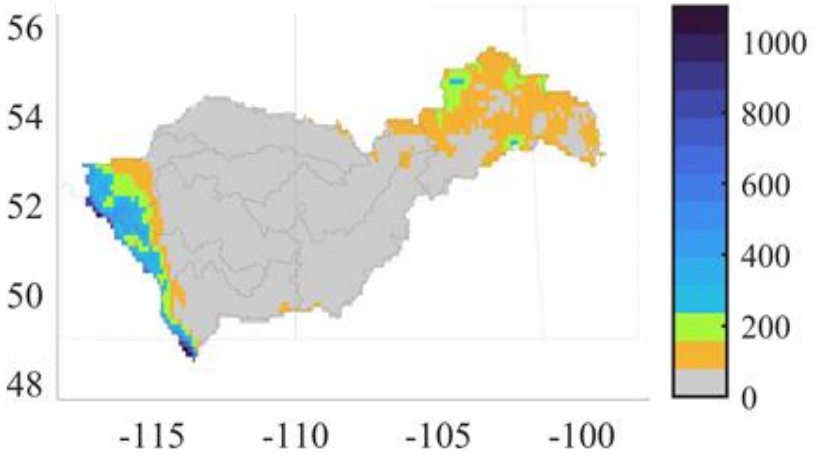
Snowfall Fraction



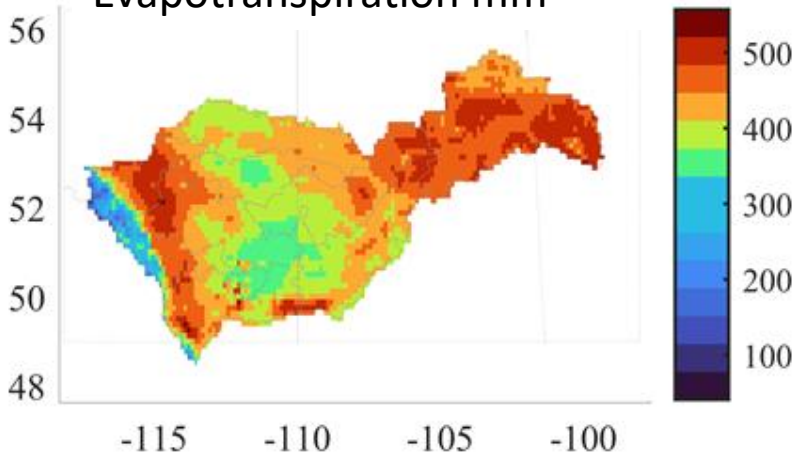
Rainfall Fraction



Runoff mm



Evapotranspiration mm



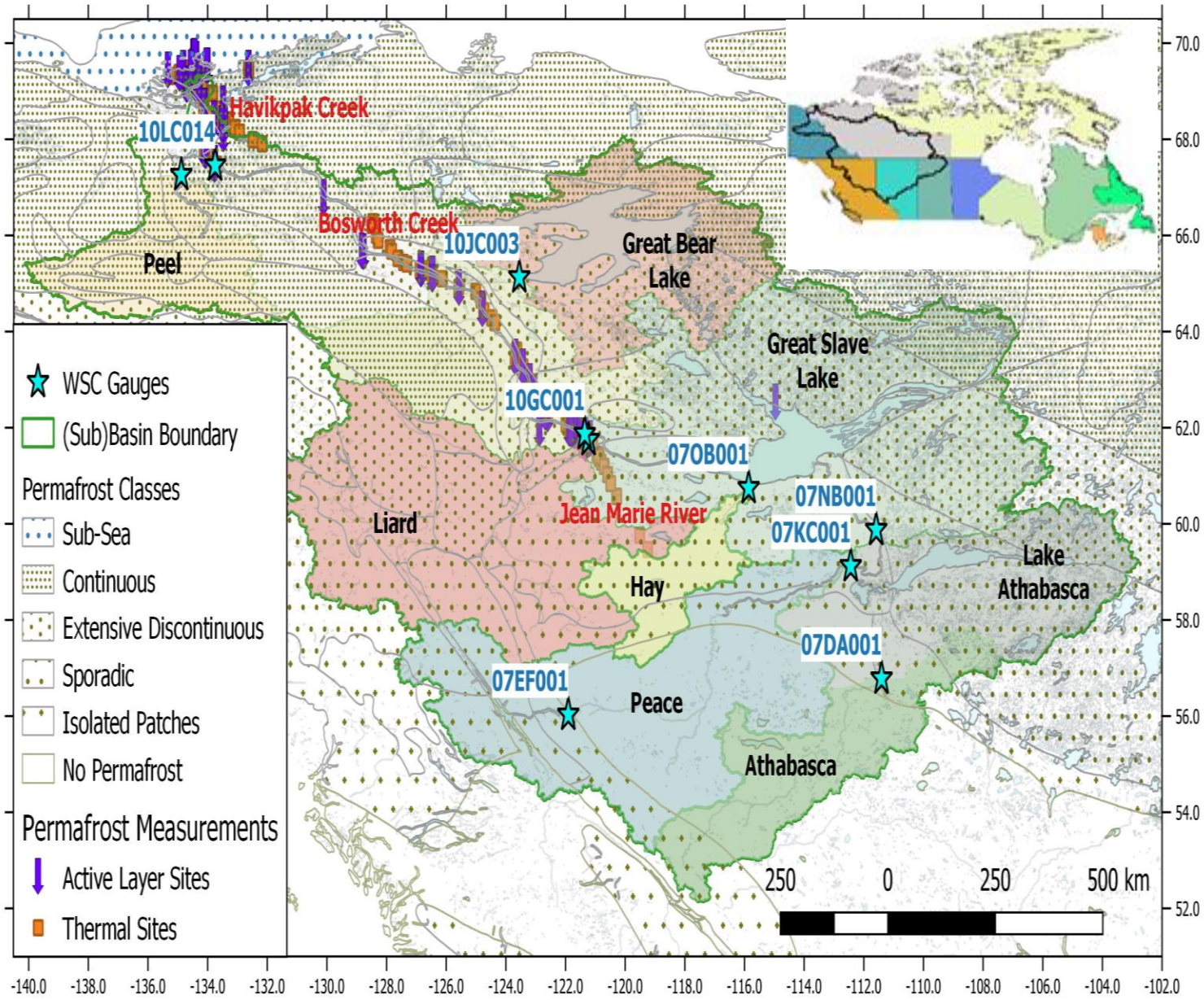
2006-2016 model diagnostic runs (MESH) Fuad Yassin

Mackenzie River Basin Glacier, Hydrology and Permafrost Modelling

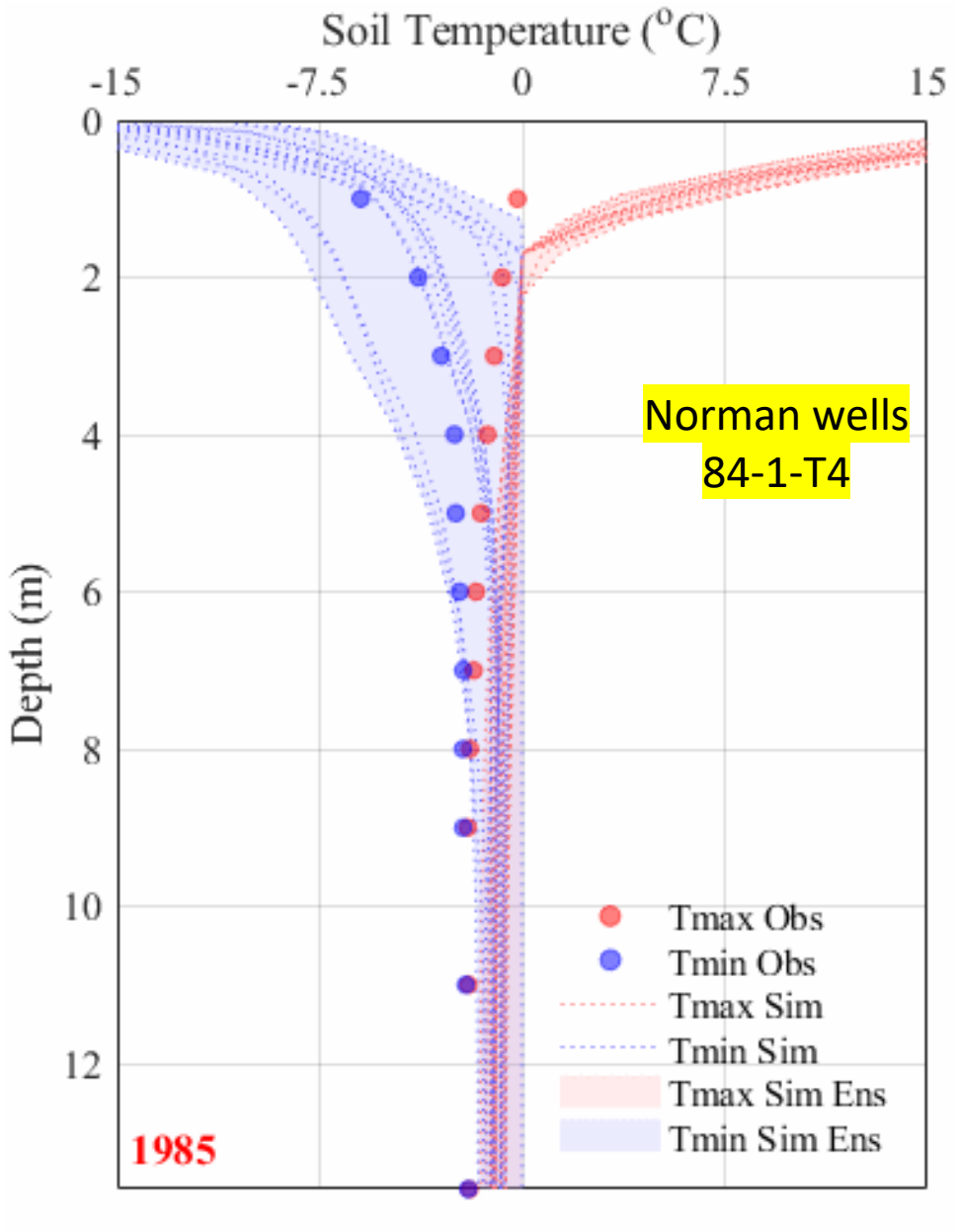
The MRB is the largest in Canada (1.8×10^6 km^2),

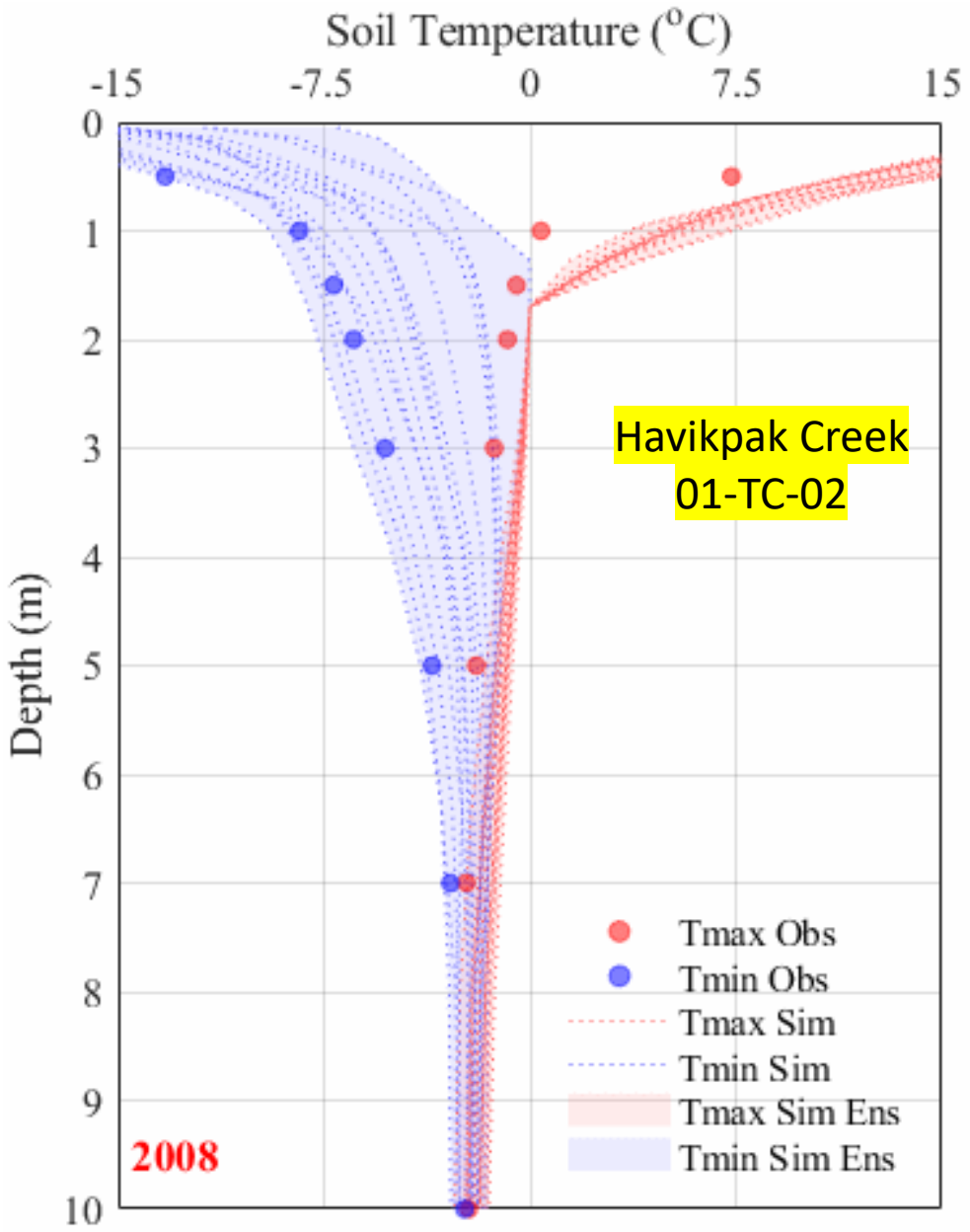
Headwaters in the Columbia Icefields

Lower basin is continuous permafrost

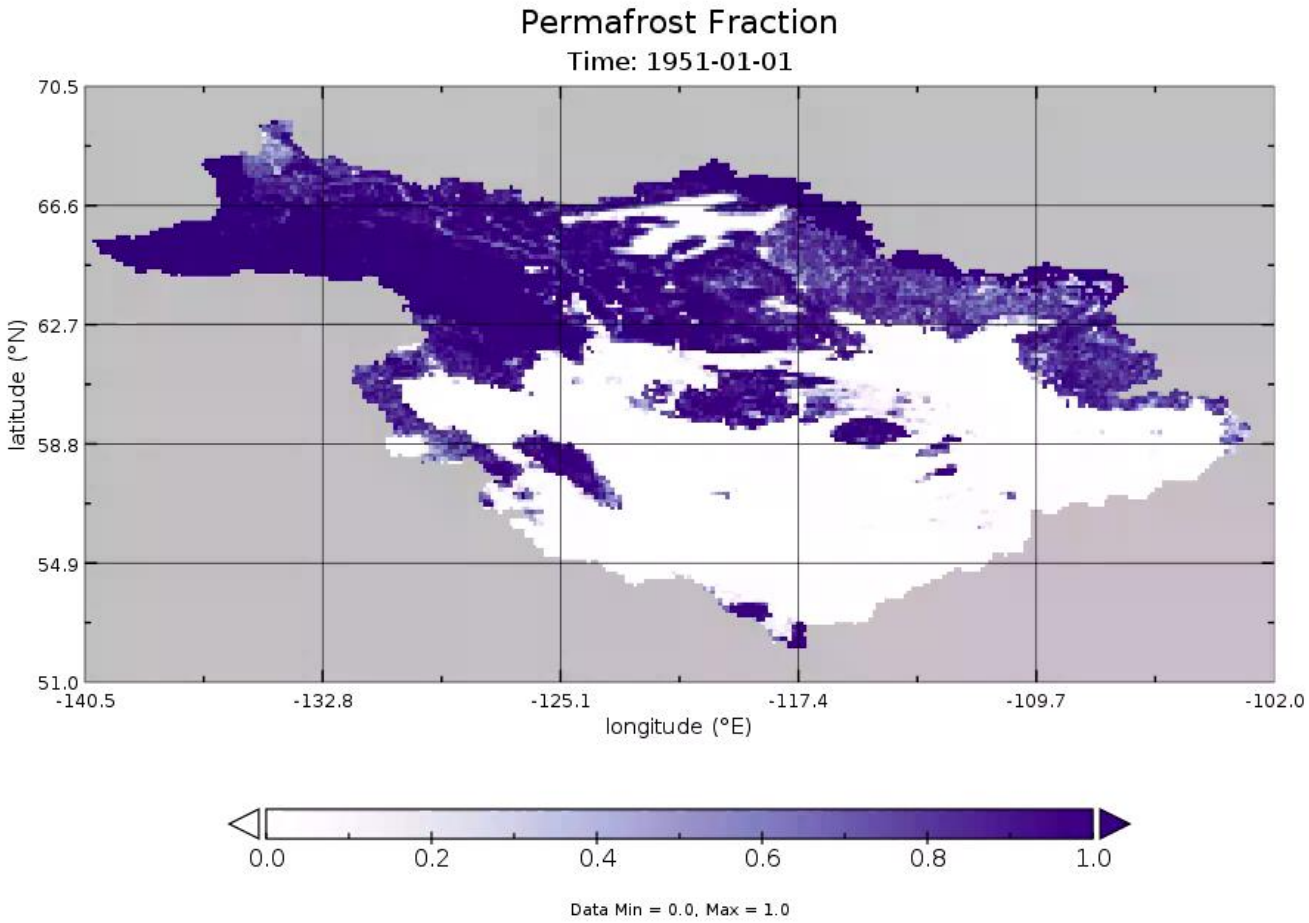


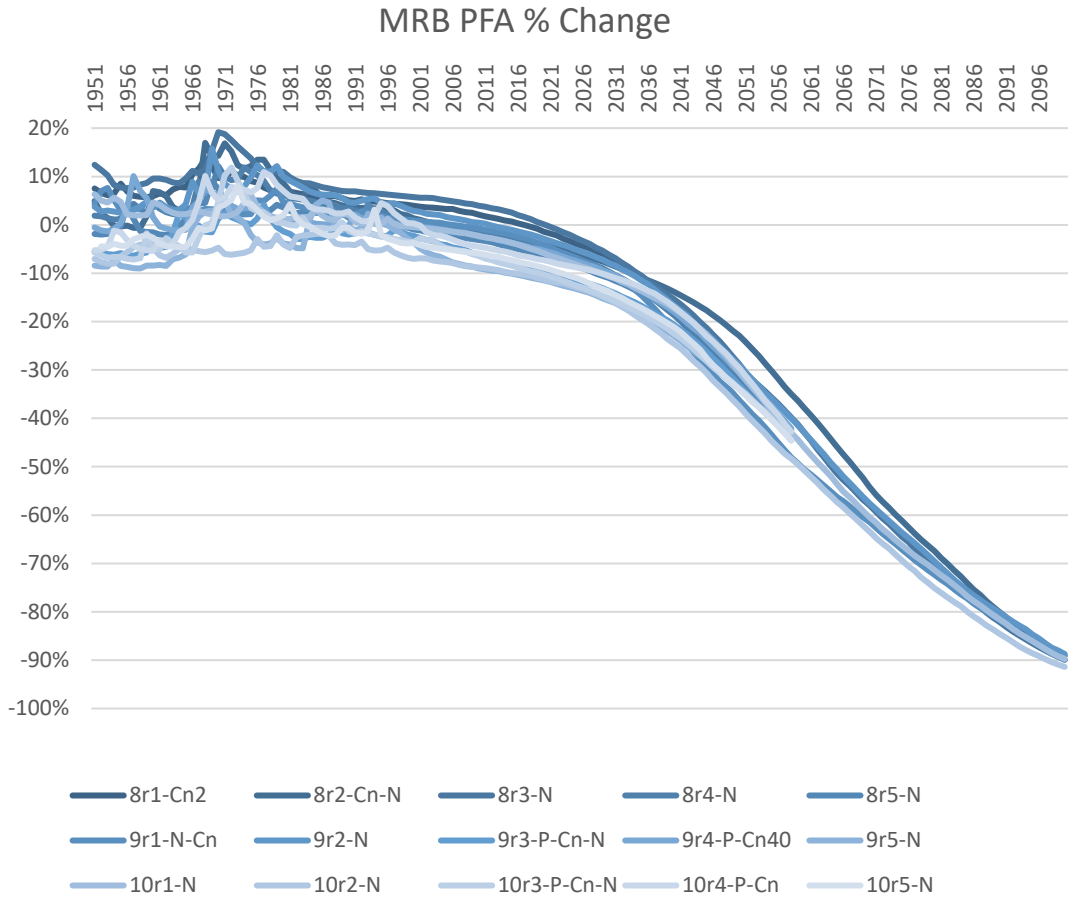
Comparison of Thermal Envelopes





Future Permafrost Area Projections - MRB





Conclusions

- Glaciers, snow redistribution, and frozen ground have been incorporated into multiple hydrological land surface models for different applications – physics developed from and tested at instrumented INARCH basins.
- Snow redistribution by wind, gravity and vegetation is needed to calculation winter sublimation and areal snowcover depletion during melt
- Glaciers hydrology impacts decline with increasing basin size – most important in dry years and seasons
- Frozen ground dynamics controls basin connectivity, storage, runoff efficiency and baseflow
- Climate warming threatens the persistence of continental glaciers and permafrost and dramatically changes snow dynamics.