Rocky Mountain Water Supply Resilience and Vulnerability Evaluation Project

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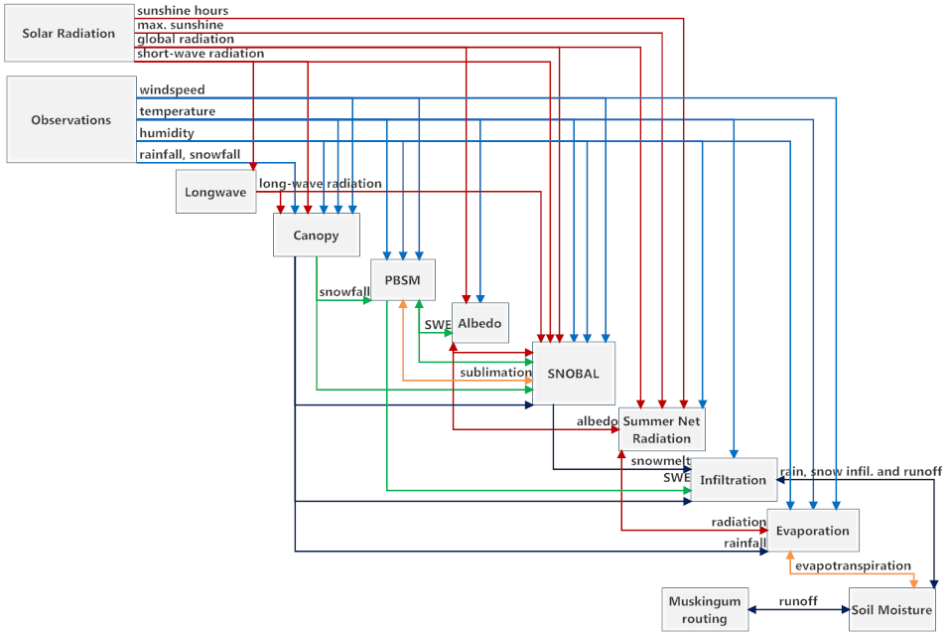
Cherie Westbrook, University of Saskatchewan



www.usask.ca/hydrology

Rationale

- IPCC (2014) WG II report – "***In many regions, changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality"***
- Mountain headwaters receive and produce a disproportionately large fraction of global precipitation and runoff including contributions to floods and water supply and drought protection for vast downstream areas.
- Snow, ice, and precipitation phase change dominate the behaviour of mountain hydrology – therefore especially sensitive to climate warming.

This Project:

Harnesses enhanced mountain observations, process hydrology advances and cold regions hydrological modelling to address water supply resiliency and vulnerability

- Forest cover and soil change
- Climate change
- Extreme hydrology – floods and droughts

The Partners

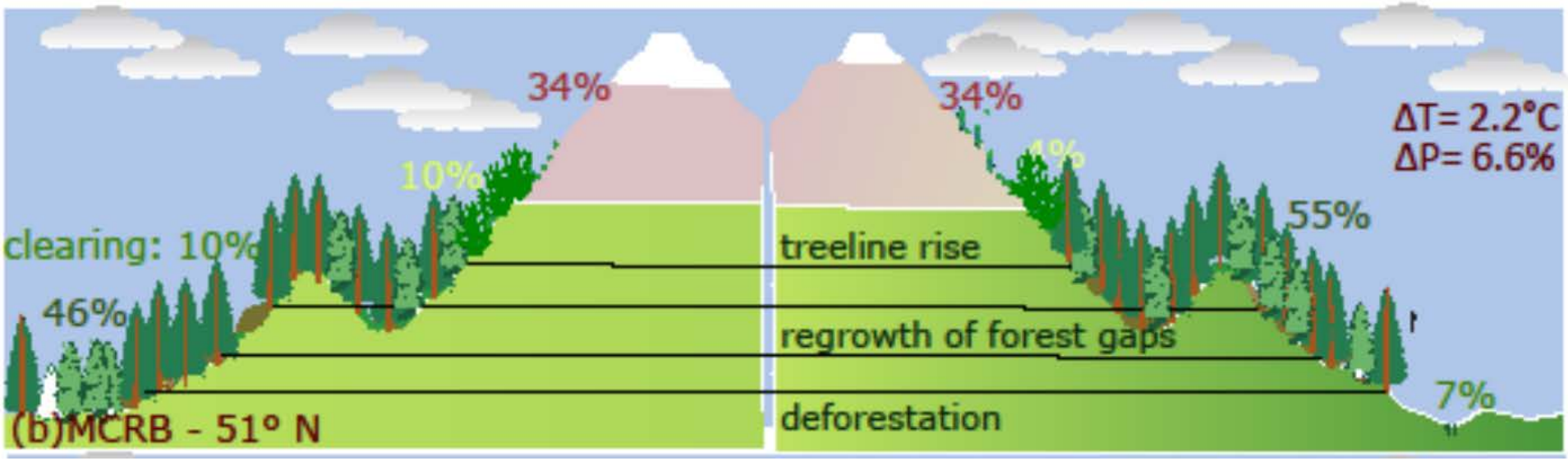
-Alberta Agriculture and Forestry (AAF)
-Alberta Environment and Parks (AEP)
-Parks Canada
-Environment and Climate Change Canada
-Natural Resources Canada
-City of Calgary
-Spray Lakes Sawmills
-Bow River Basin Council
-Fortress Mountain Resort
-Nakiska Ski Resort
-Brewster Travel Canada
-Global Water Futures Programme

SLS
Spray Lake Sawmills

Alberta Agriculture and Forestry

Science Questions

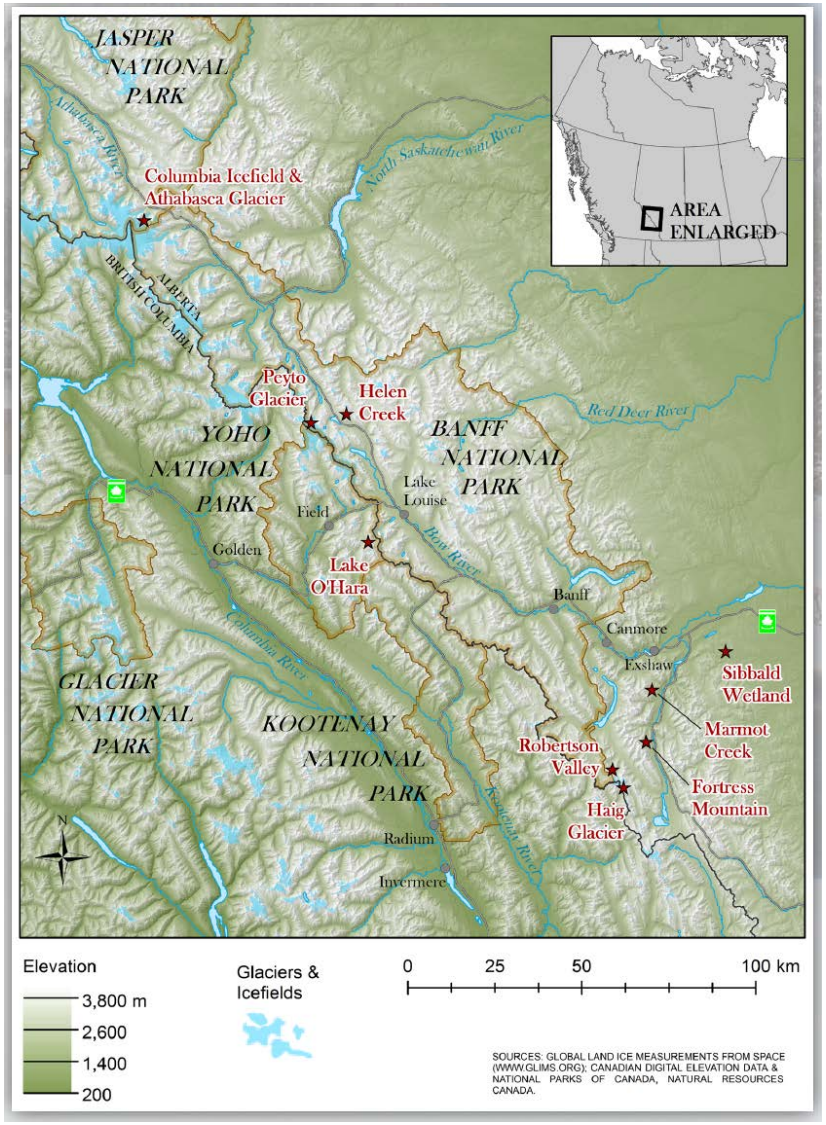
- How do the physical characteristics (forest cover, soil type, geology, etc.) of mountain headwater basins influence runoff generation? How does this vary across the region?
- Will the hydrological systems of the Rocky Mountains enhance or dampen the effects of climate change and extreme events on downstream streamflow and water resources?
- Can forest manipulations impact the hydrological resiliency of these systems?

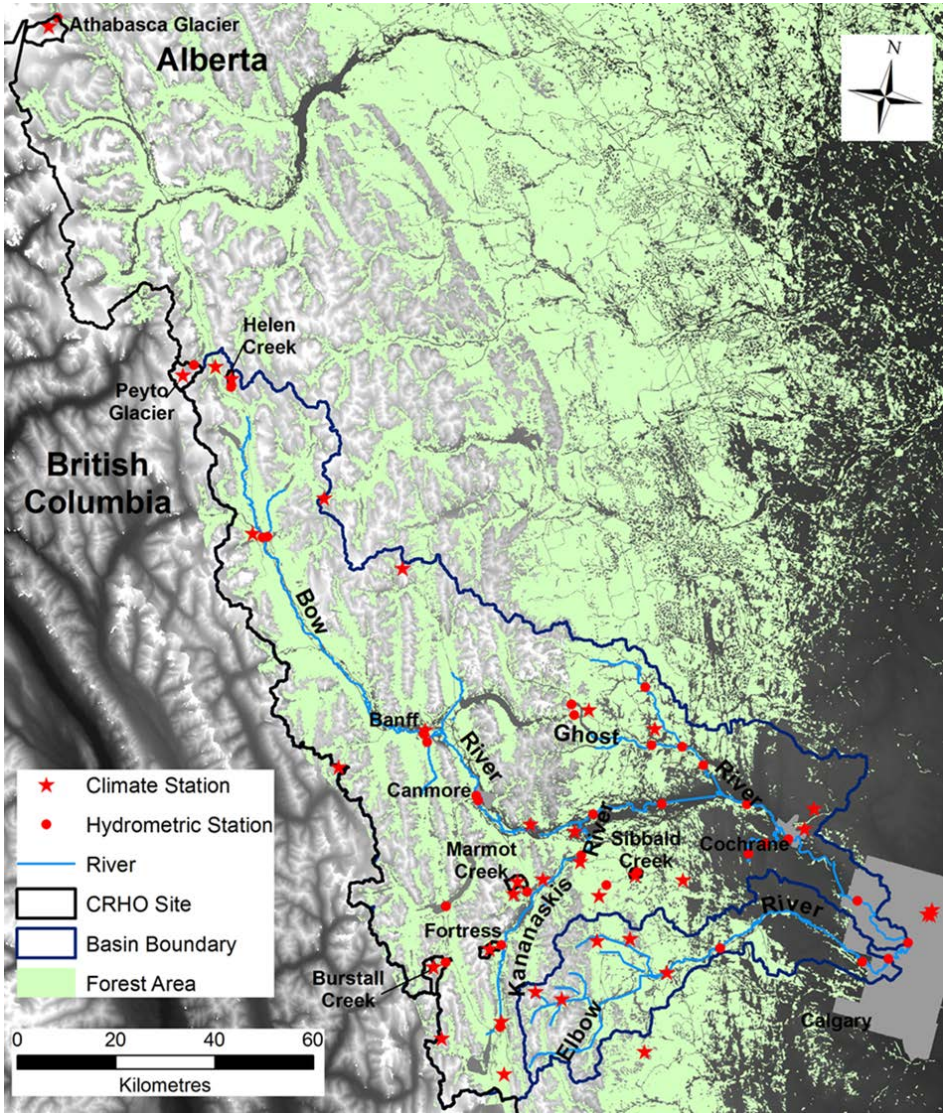


Approach

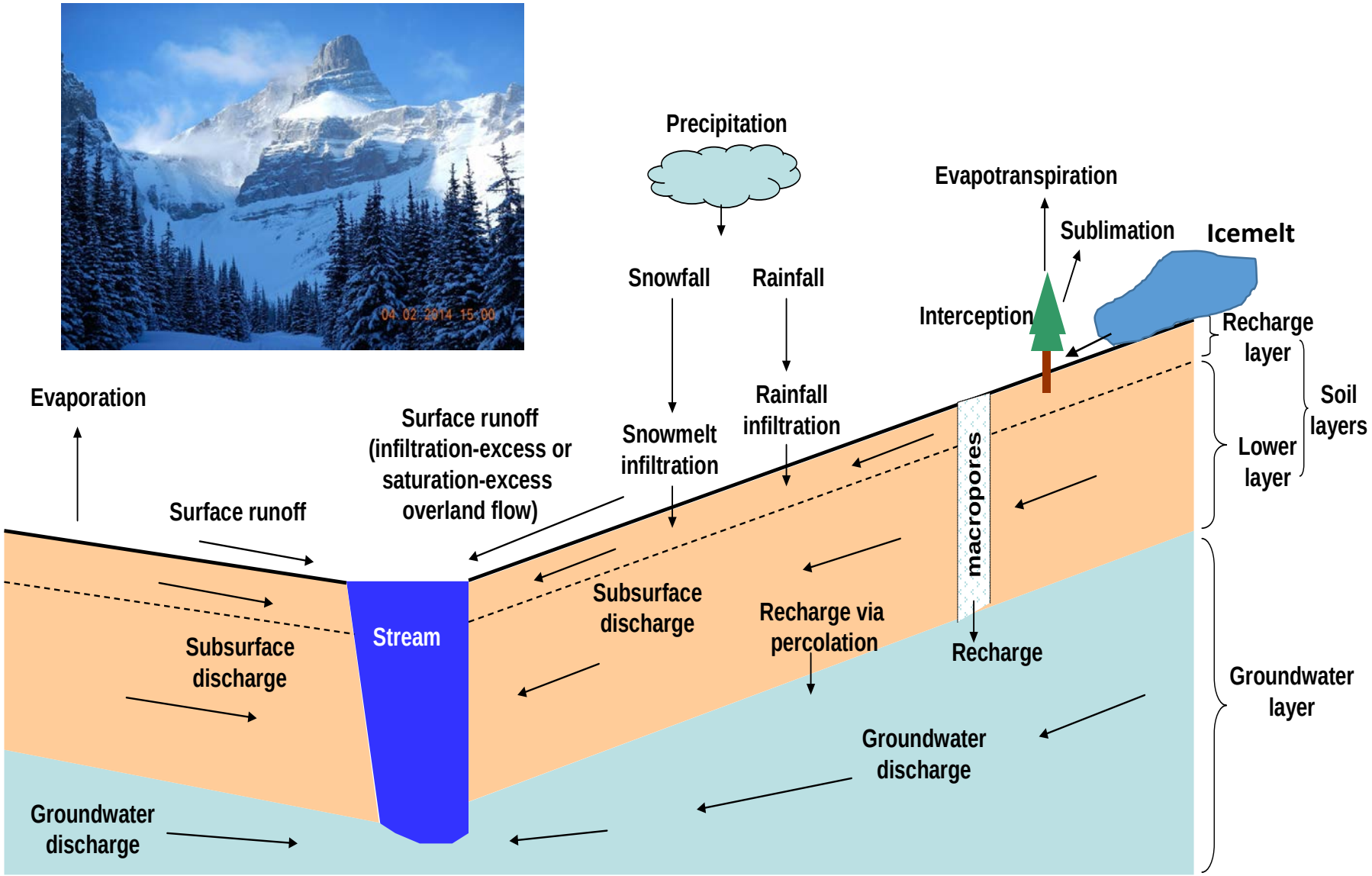
- Improve the understanding and description of hydrological processes governing mountain water supply,
- Demonstrate improved prediction of mountain streamflow using CRHM
- Assess historical and future mountain water resiliency in the Bow River Basin by:
  - Predicting water budgets and streamflow using CRHM, CRHO and downscaled atmospheric models,
  - Explaining how extreme events (e.g. 2015 drought, 2013 flood) have happened, and assess the vulnerability and resilience of the water supply system to extreme events.
  - Predicting concurrent impacts on water supply and hydrological extremes of:
    - Changing climate
    - Increasing weather extremes
    - Declining glacier volume
    - Managed or disturbed forest cover.

Canadian Rockies Hydrological Observatory and the Bow River Basin

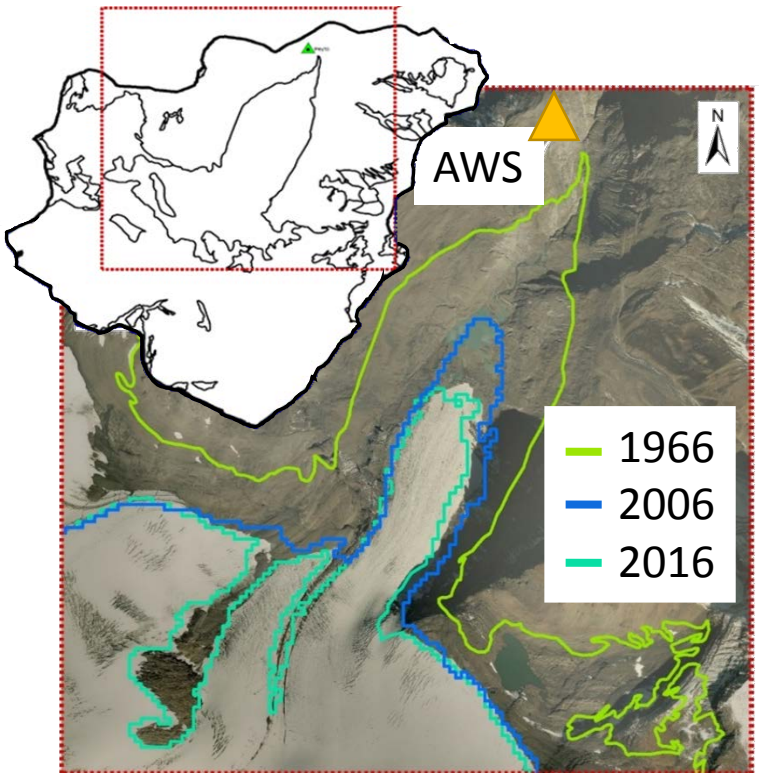




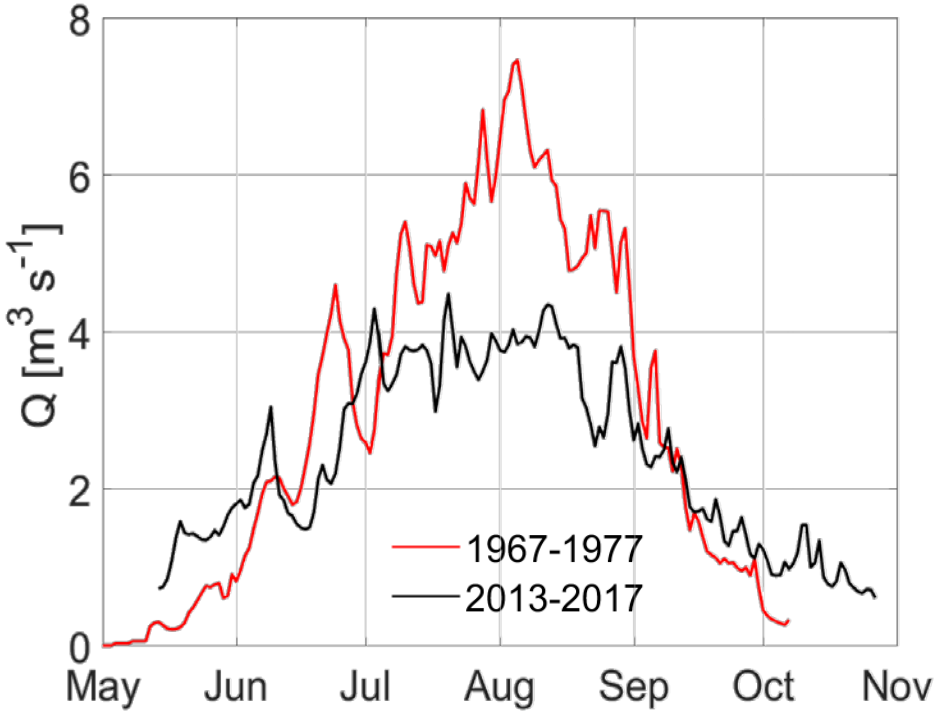
Cold Regions Hydrological Modelling Platform



Peyto Glacier Reconstruction of Historical Retreat and Streamflow Discharge Changes

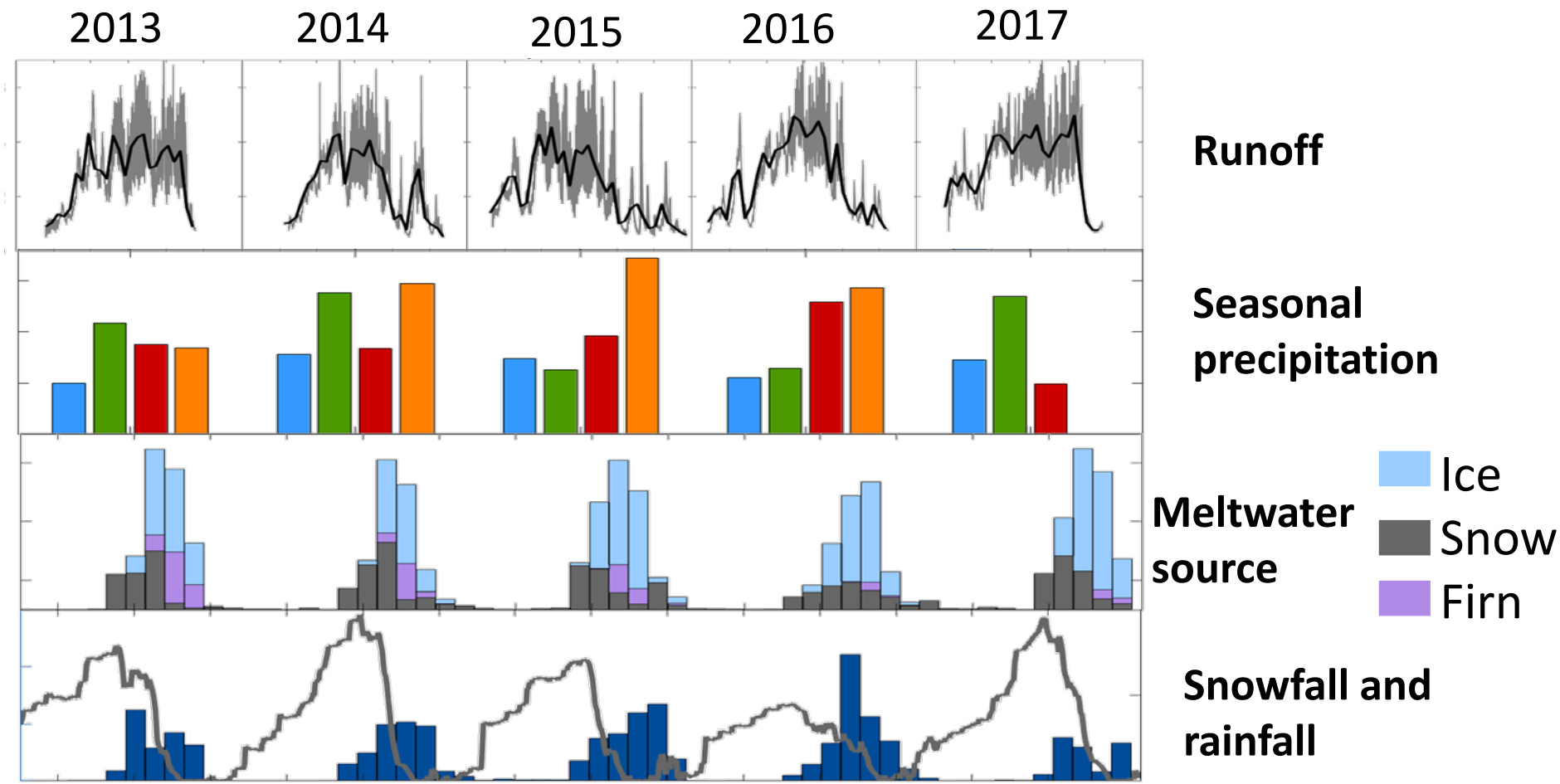


1966: 14.4 km^2
2016: 9.9 km^2



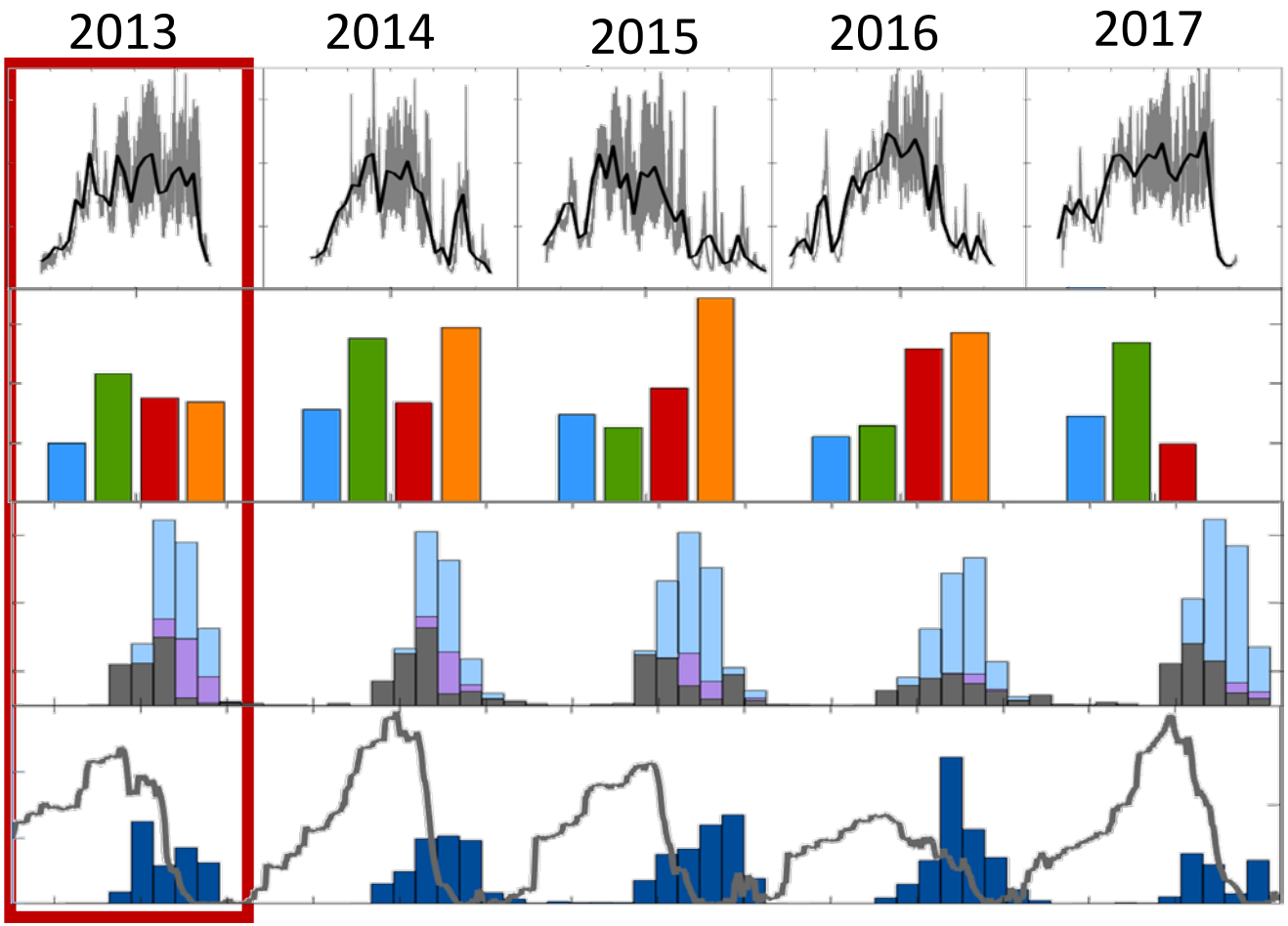
New salt dilution rating curve provides 21st c. streamflow measurements

Glacier Hydrology Resilience



Aubry-Wake and Pomeroy, in preparation

Glacier Hydrology Resilience



2013: Firn melt sustains late summer flow

2014: Nearly equal ice and snow contribution to melt

2015: Fall rain and snow sustain late summer flow

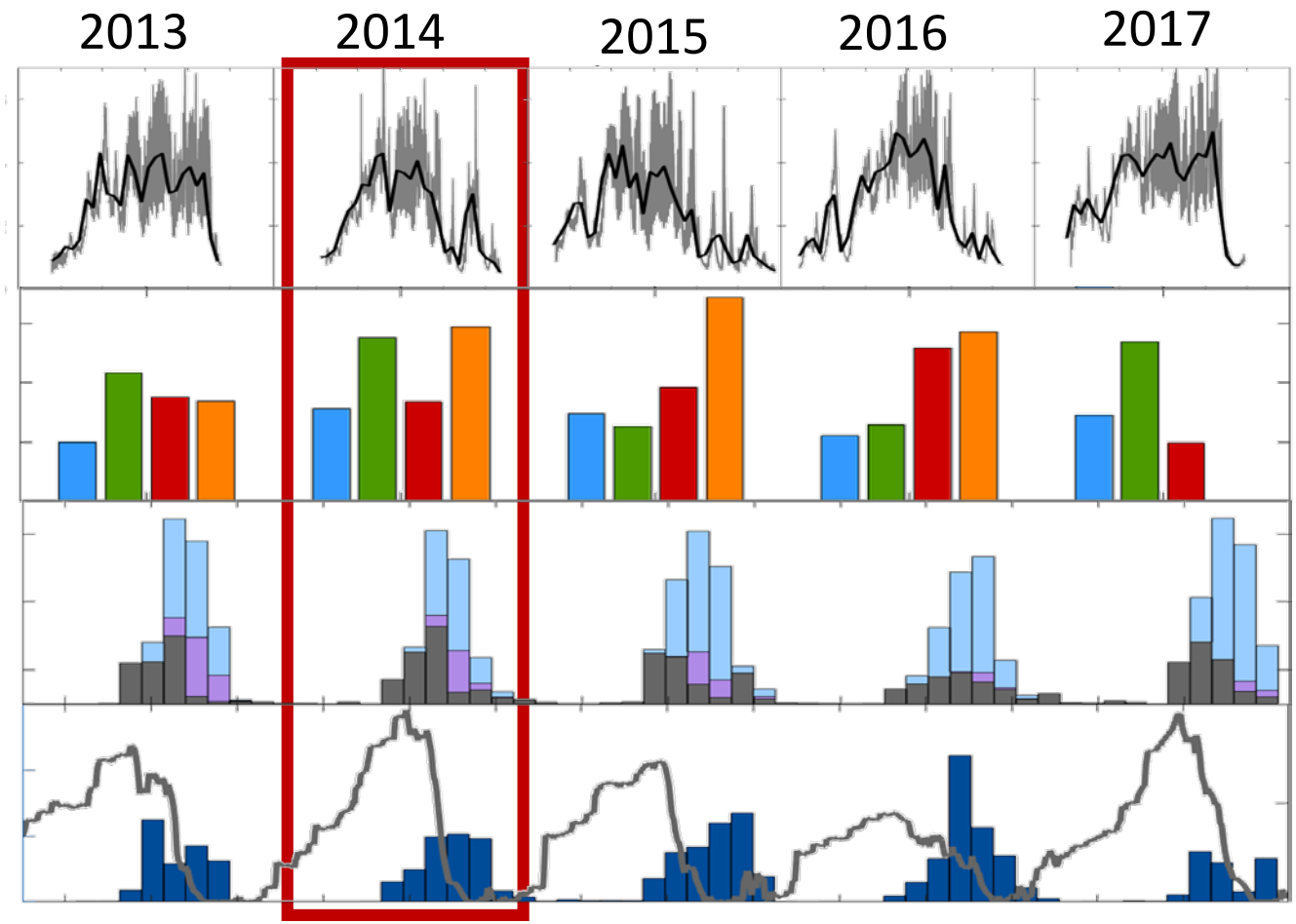
2016: High rain and melt compensates low snowpack

2017: Streamflow sustained by high snowmelt

Ice
Snow
Firn

Aubry-Wake and Pomeroy, in preparation

Glacier Hydrology Resilience



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Snow
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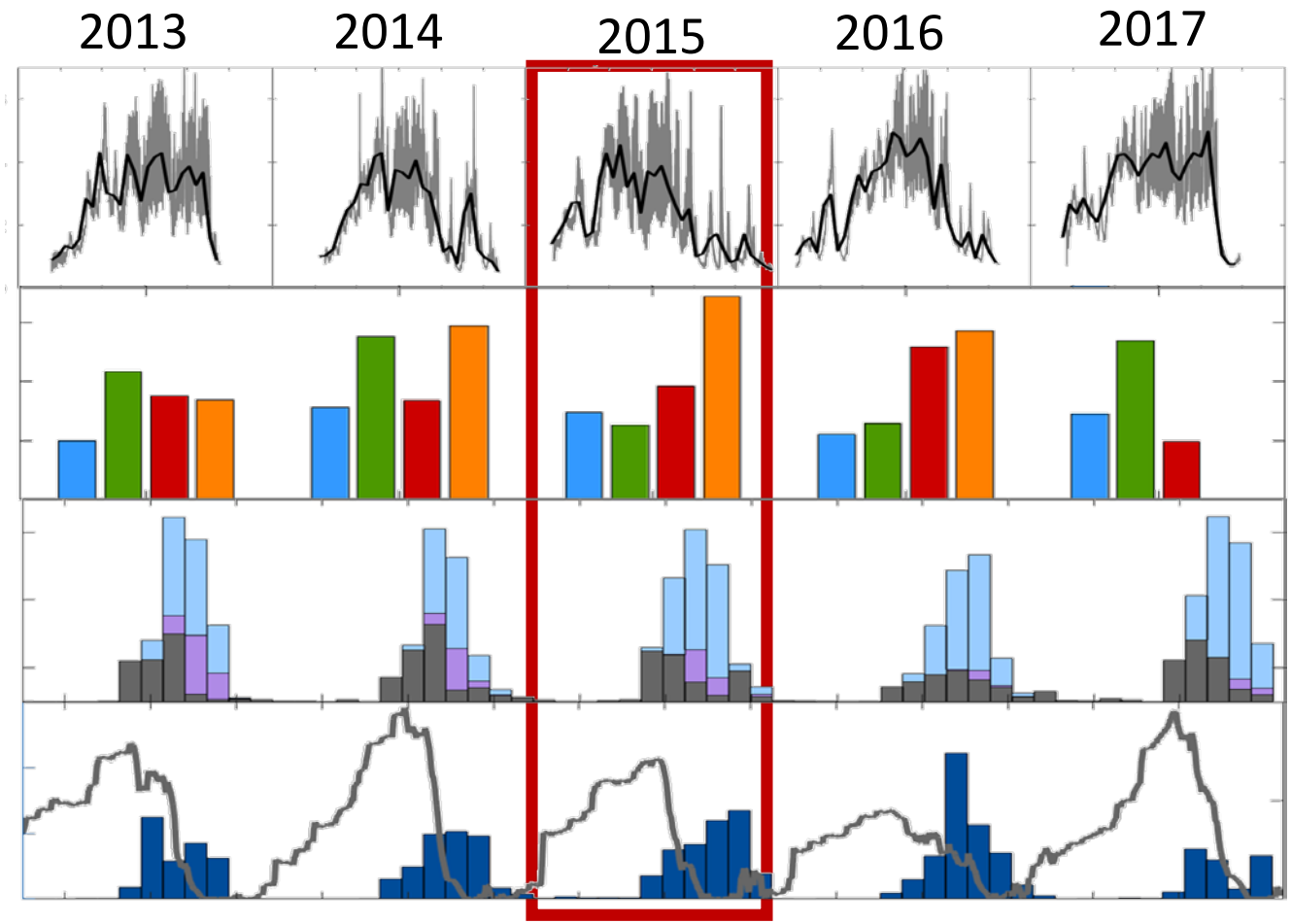

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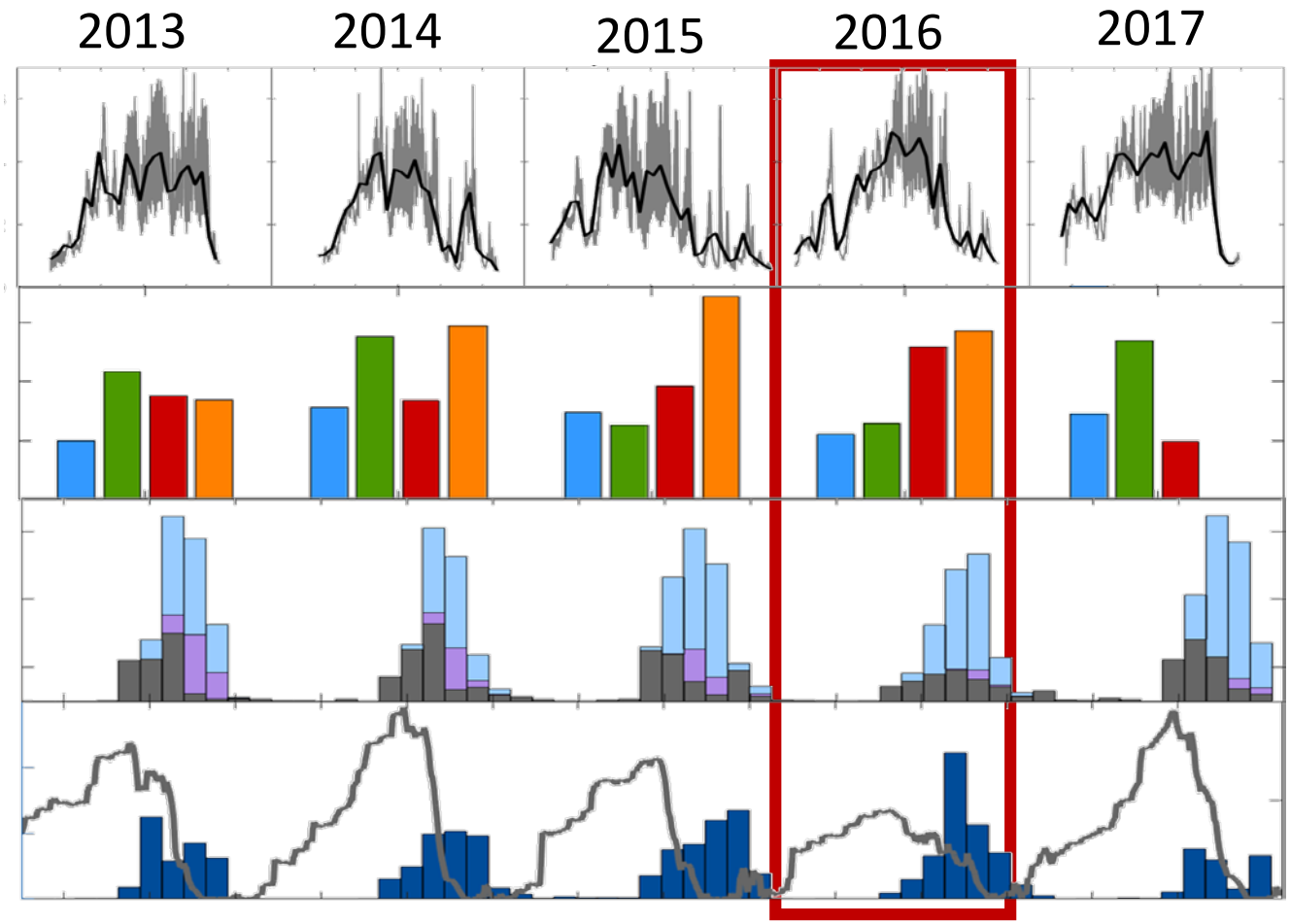

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Snow
Firn

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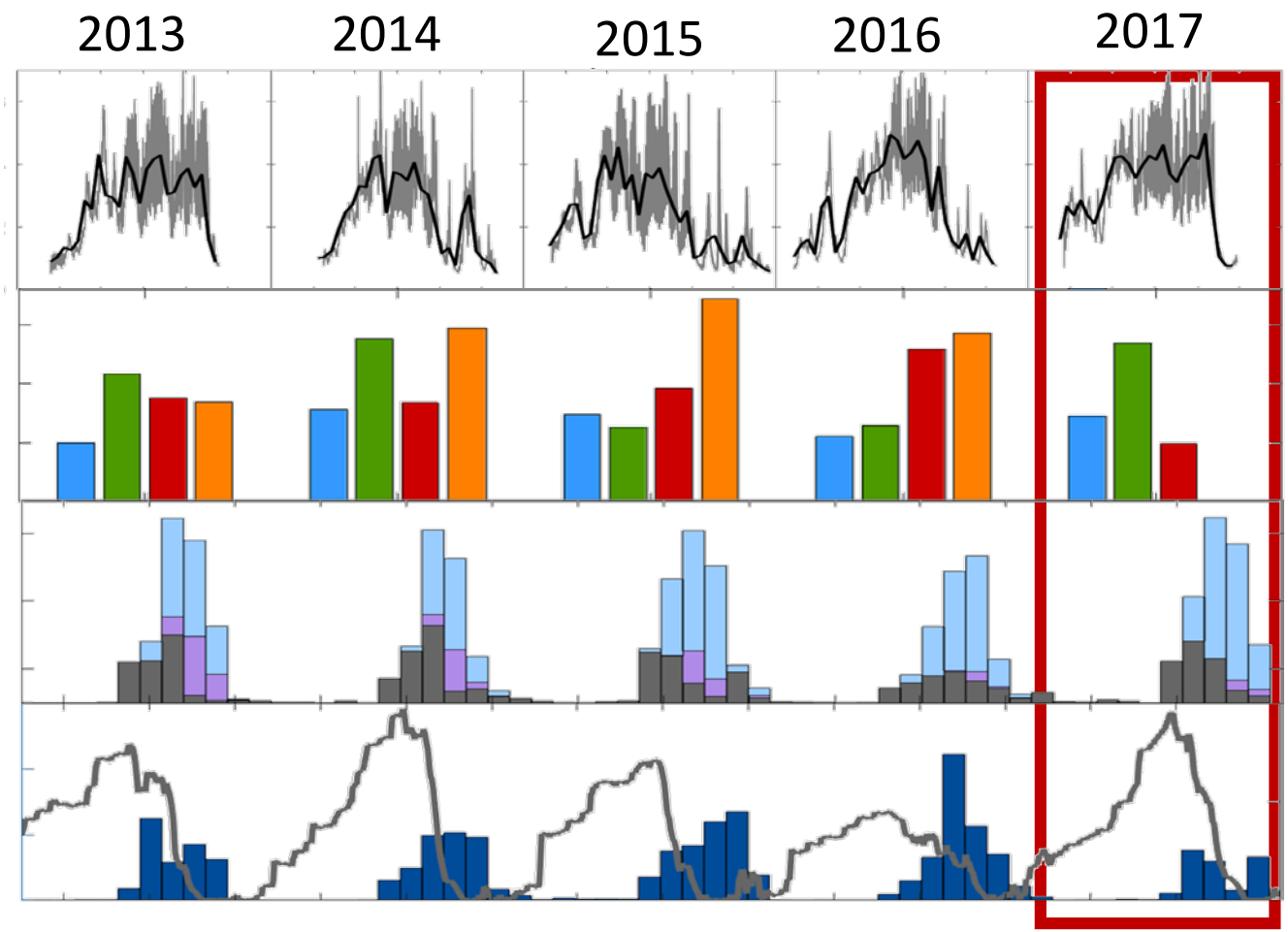

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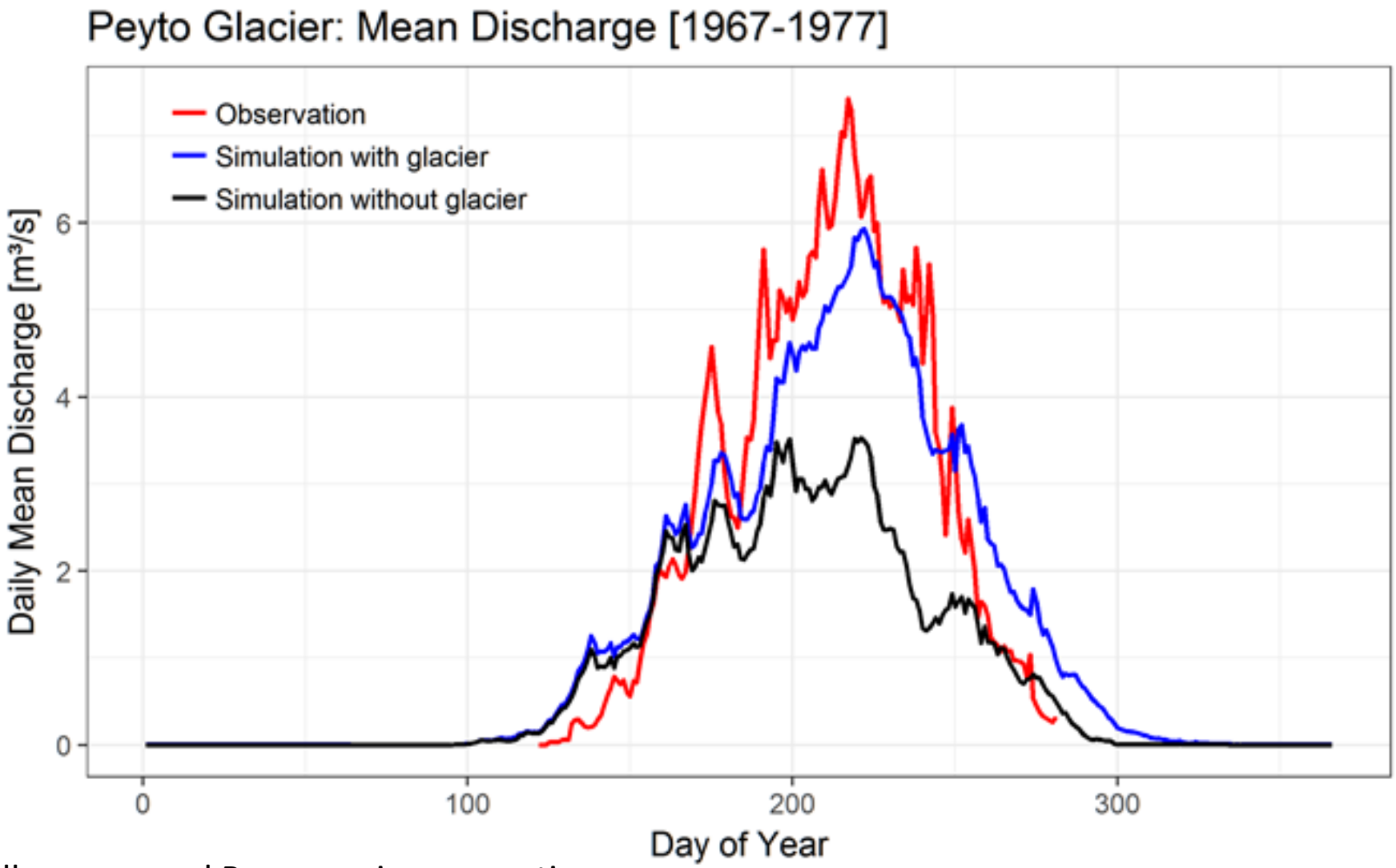
2017: Streamflow sustained by high snowmelt

Ice
Snow
Firn

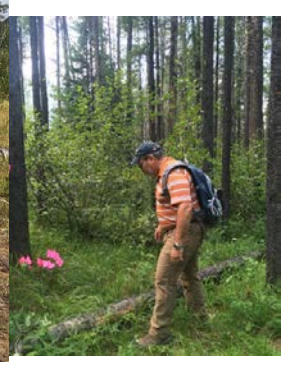
Aubry-Wake and Pomeroy, in preparation

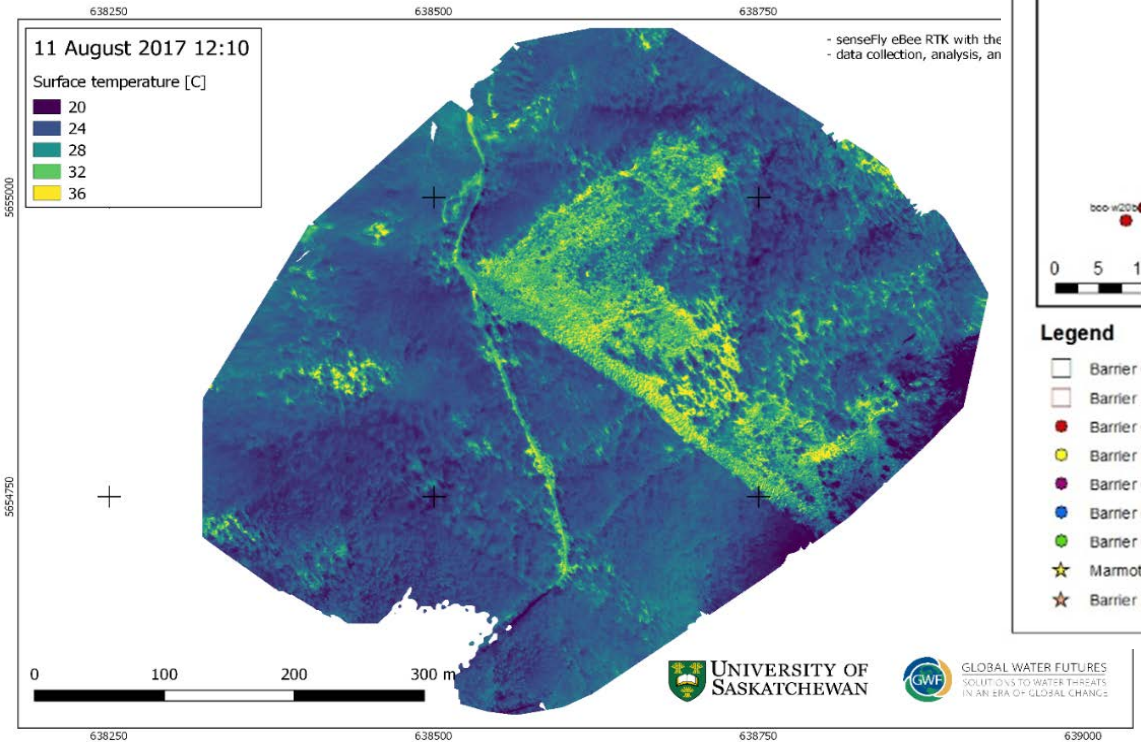
Streamflow Regime – with and without glaciers

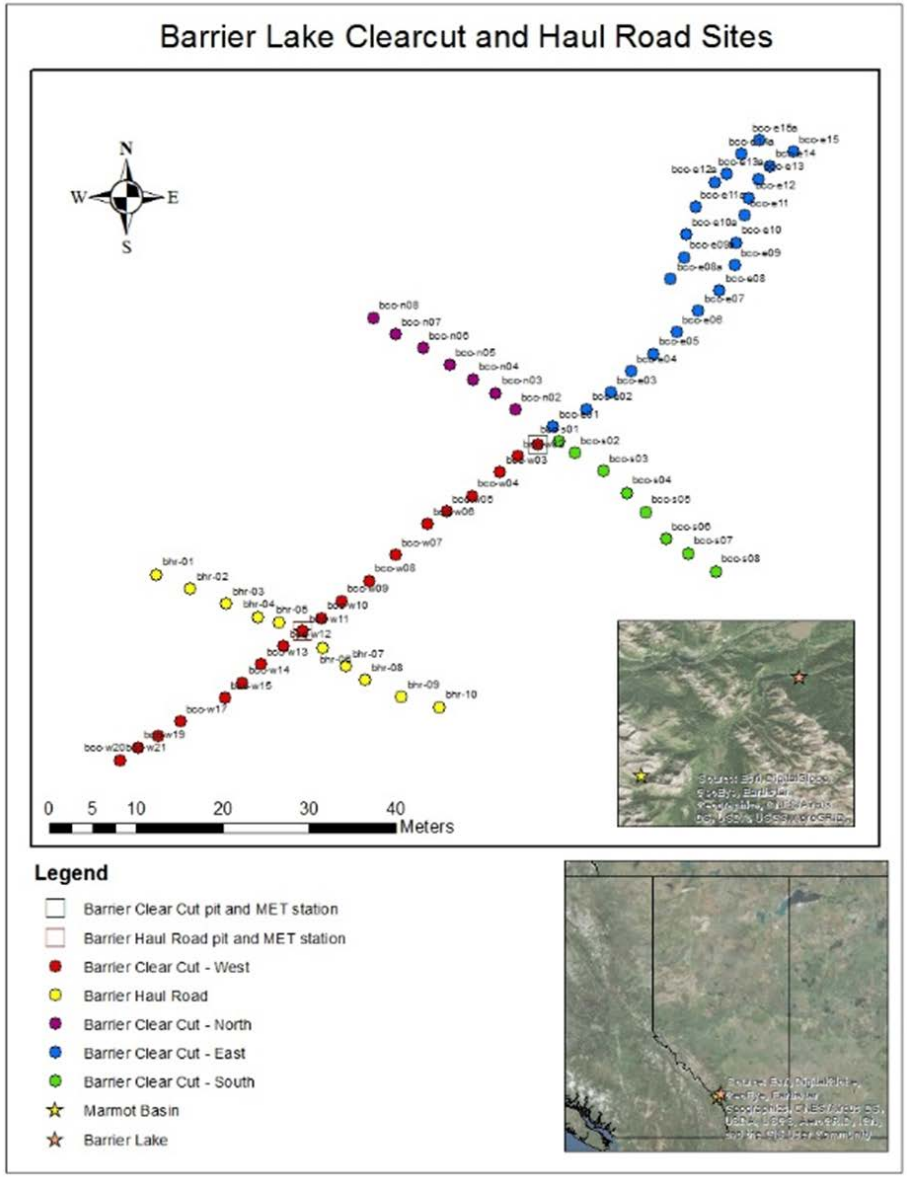


Pradhananga and Pomeroy, in preparation

Forest Hydrology







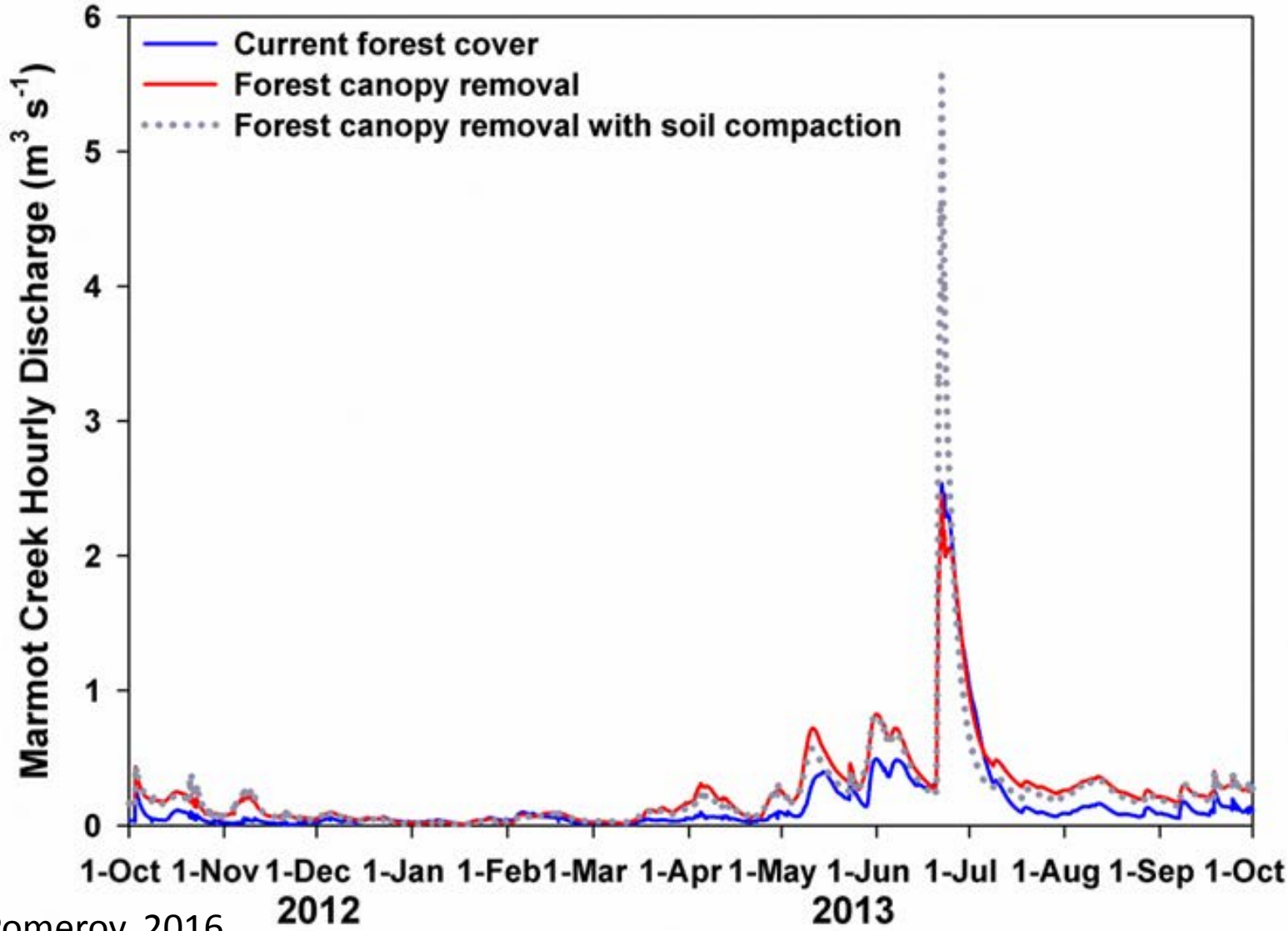
Forest and DisturbedSoils

Barrier Forest Soil

Barrier Clearcut Soil

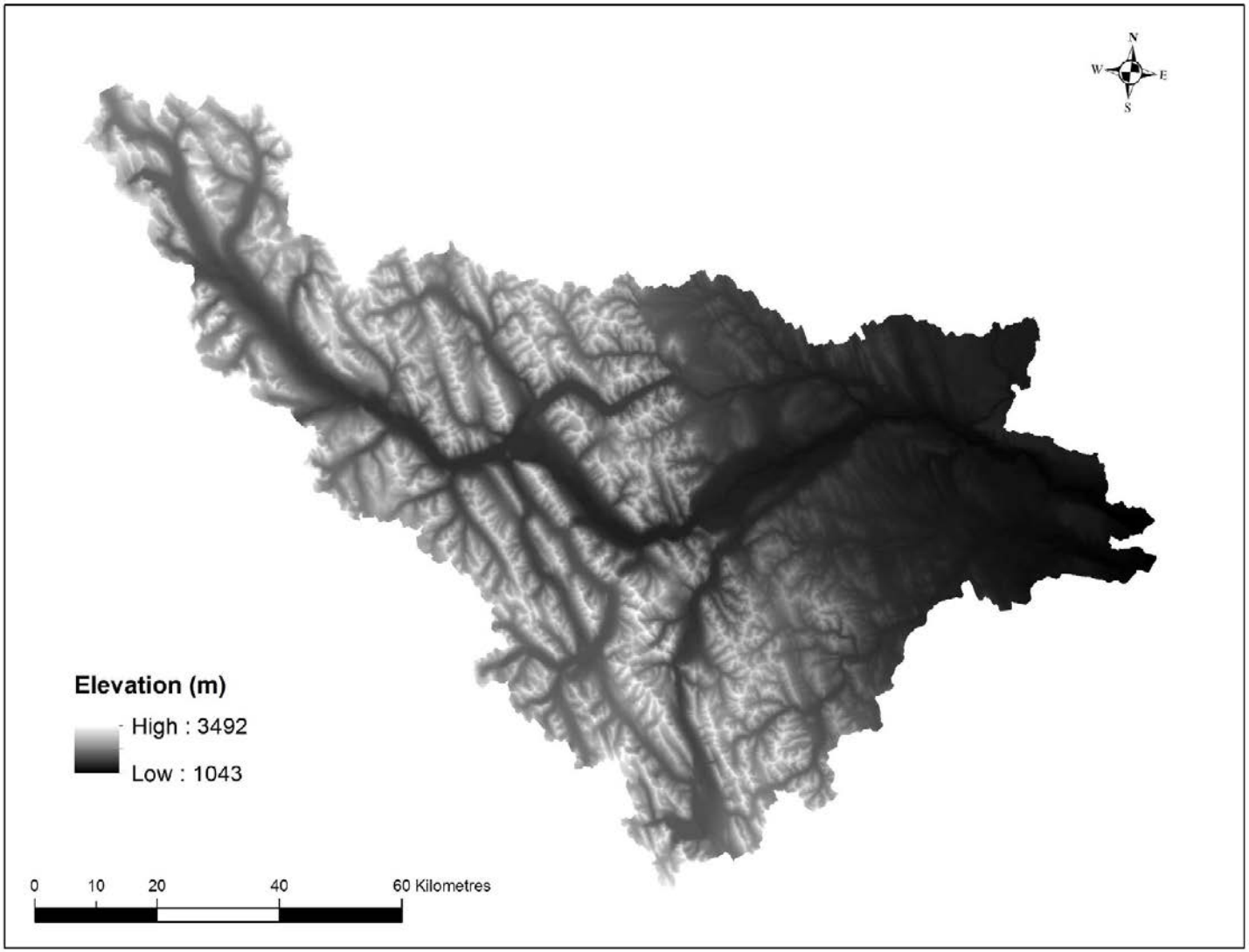
Barrier Haul Road Soil

Flood Simulation with Sequential Forest Canopy Removal and Soil Compaction – Marmot Creek



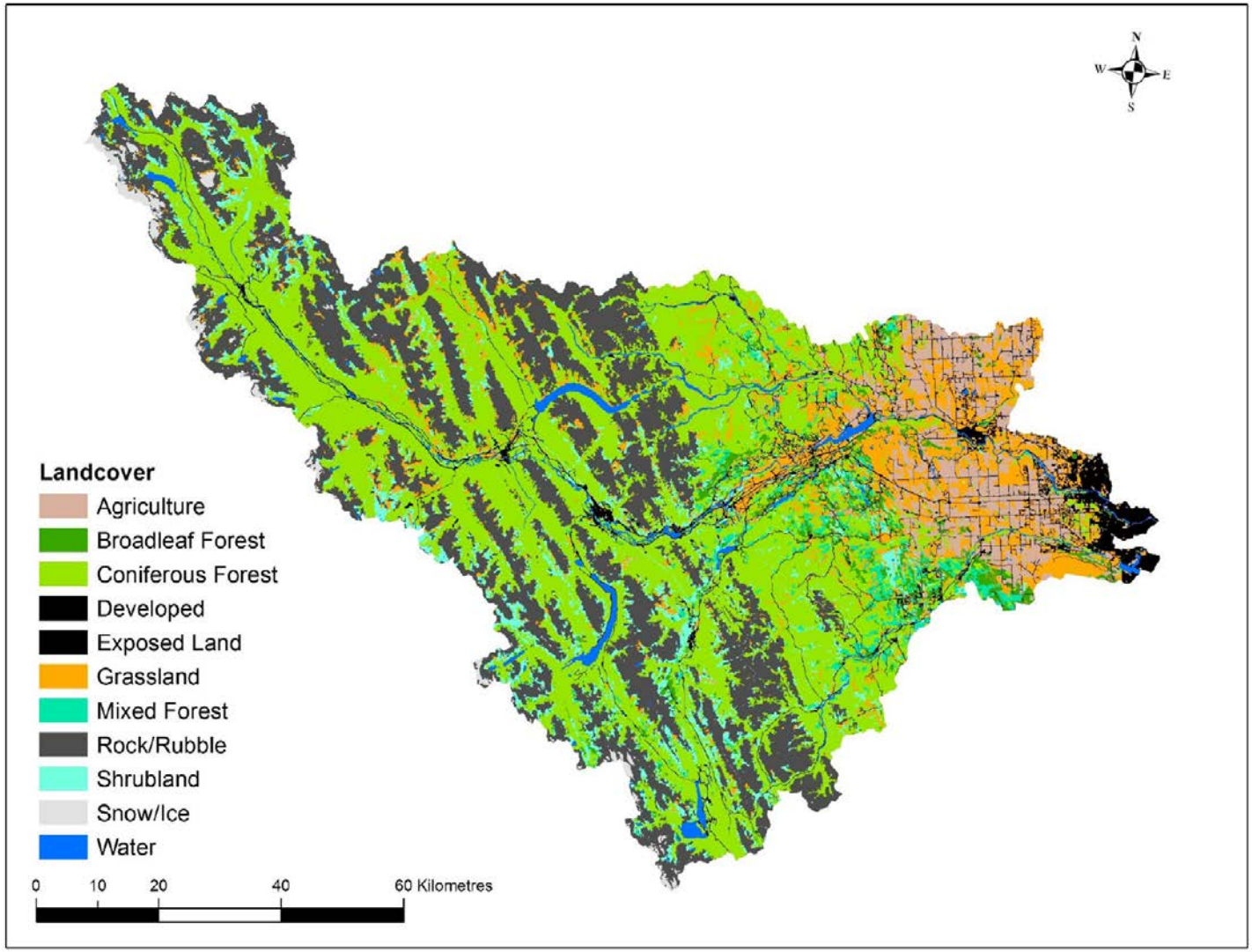
Fang and Pomeroy, 2016

Modelling the Bow & Elbow at Calgary with CRHM



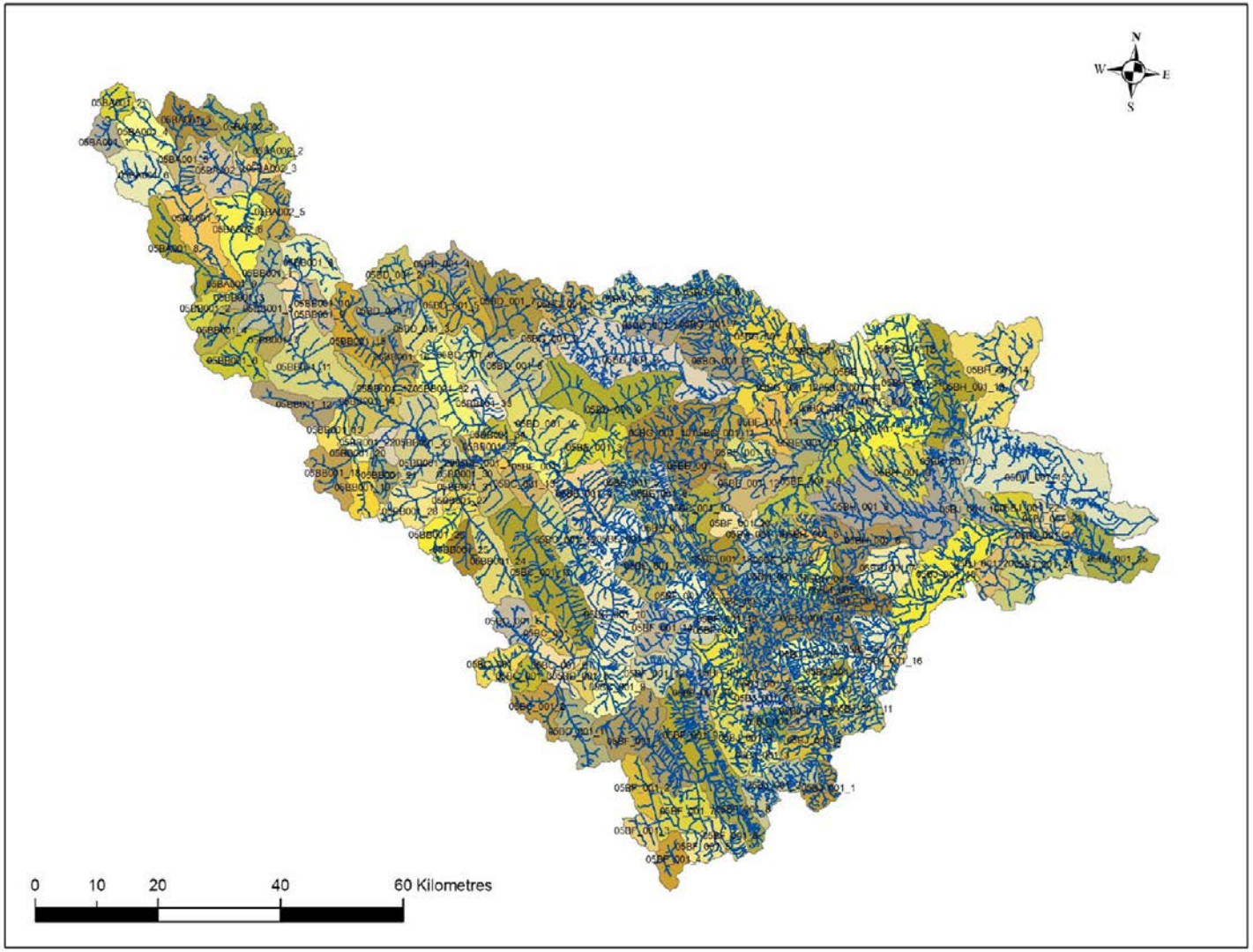
- 2450 m of relief
- Basin area 7823.6 km^2

Modelling the Bow & Elbow at Calgary with CRHM



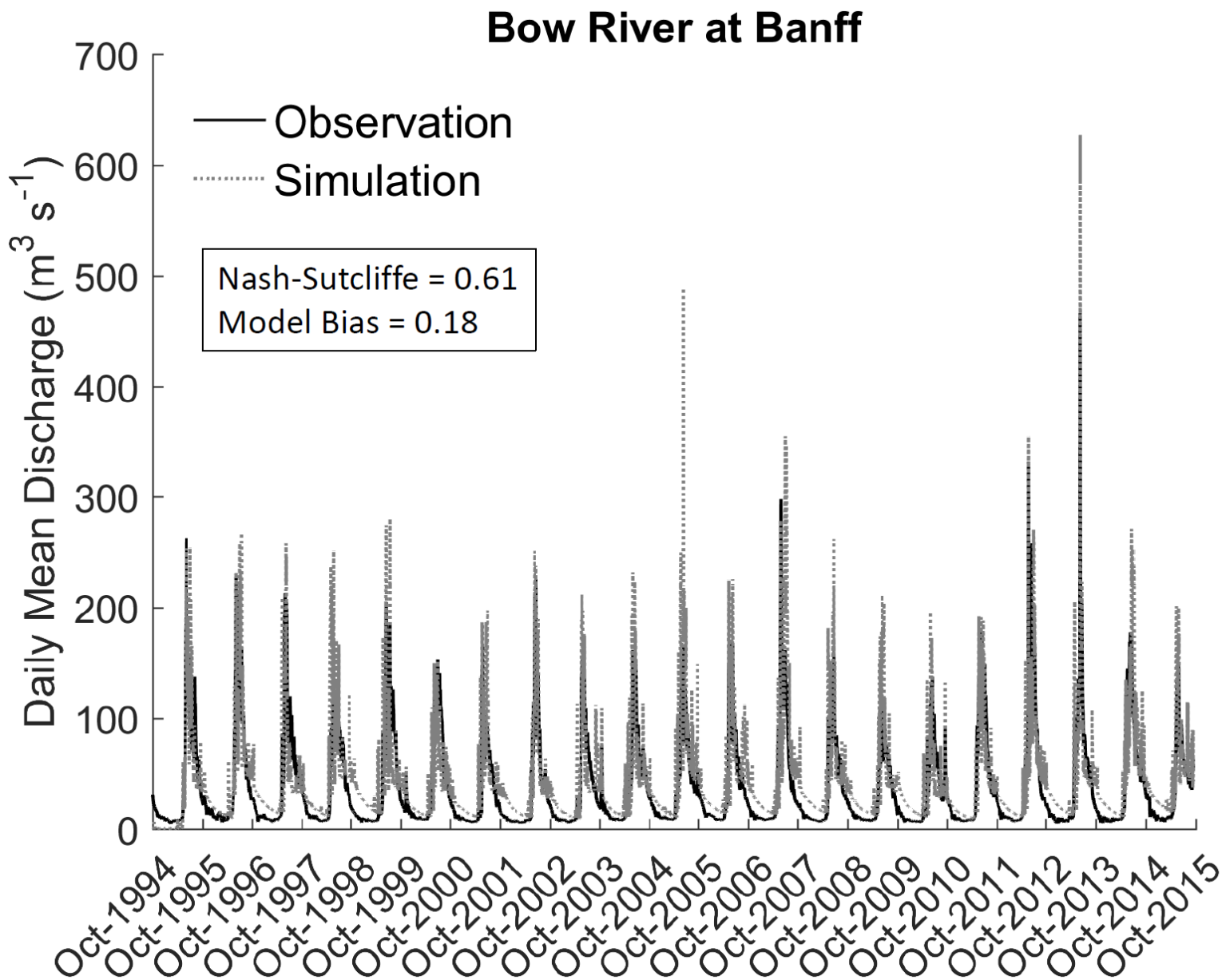
- 2518 hydrological response units based on vegetation, soils, slope, aspect, elevation, drainage, glacier cover, water bodies

Modelling the Bow & Elbow at Calgary with CRHM

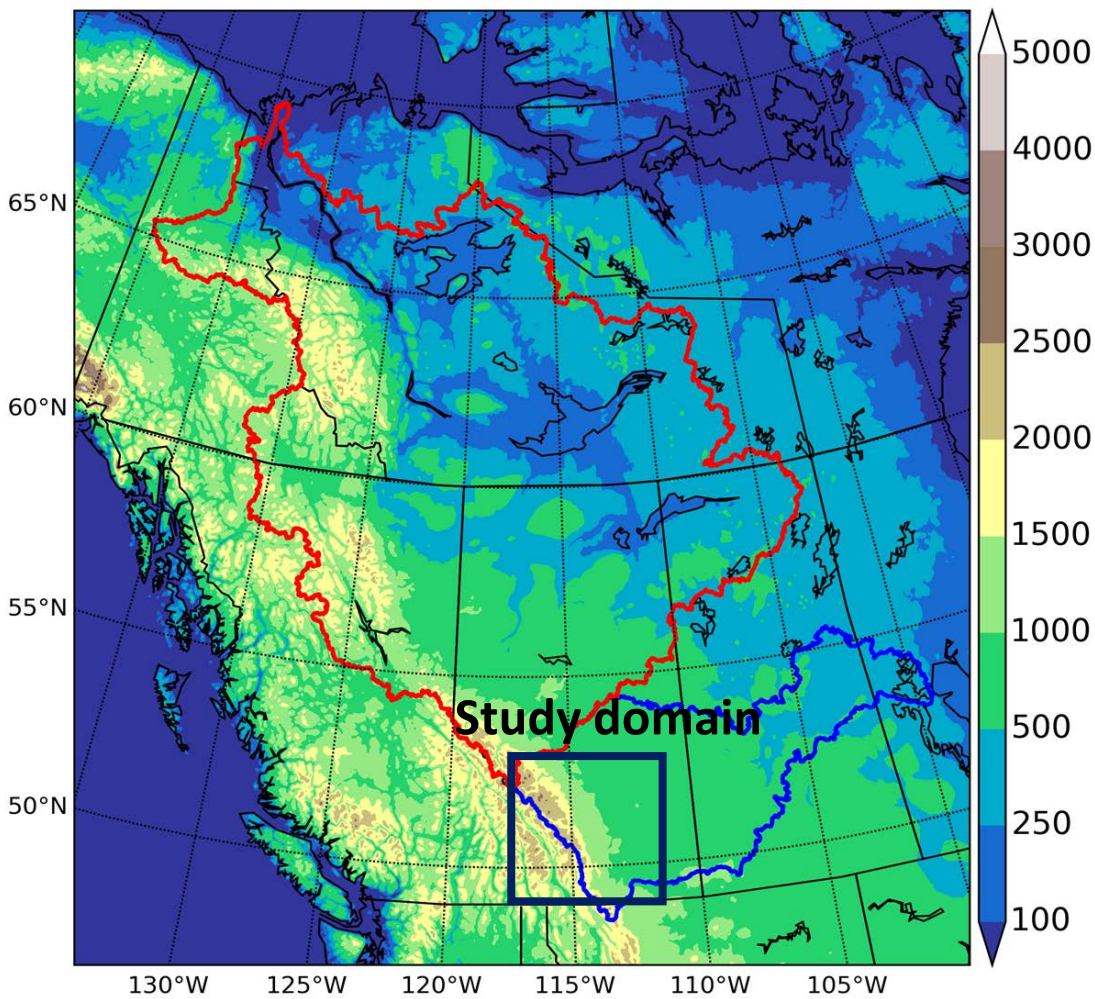


- 142 sub-basins, of which 41 have glaciers

Model test – no calibration, local meteorological data



Weather Research and Forecasting (WRF) Model, 4 km domain over Western Canada



WRF Model
Version 3.4.1

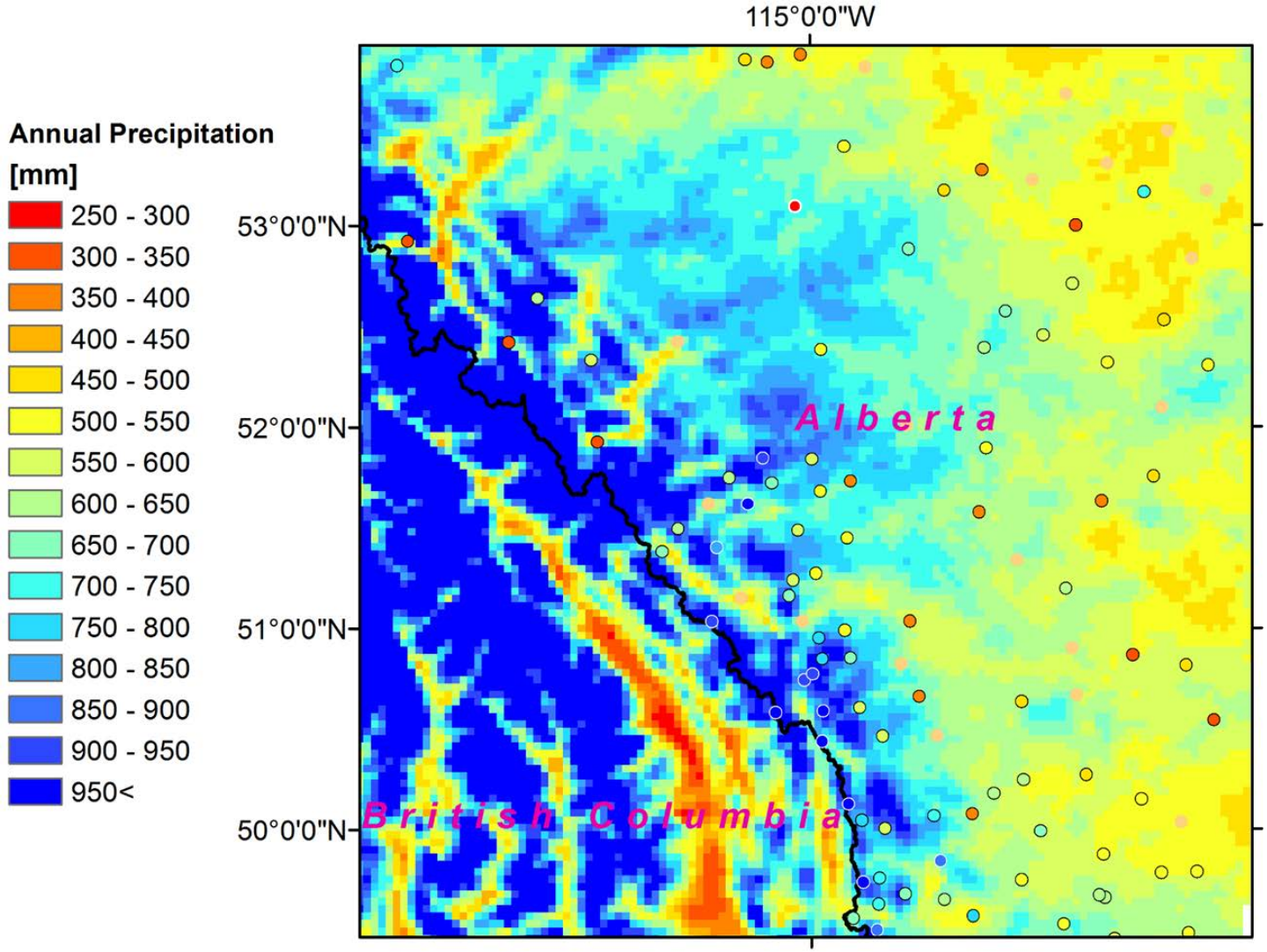
domain
2560 x 2800 km^2
4 km grid spacing
37 levels

Microphysics Scheme
New Thompson et al.

No Cumulus parameterization

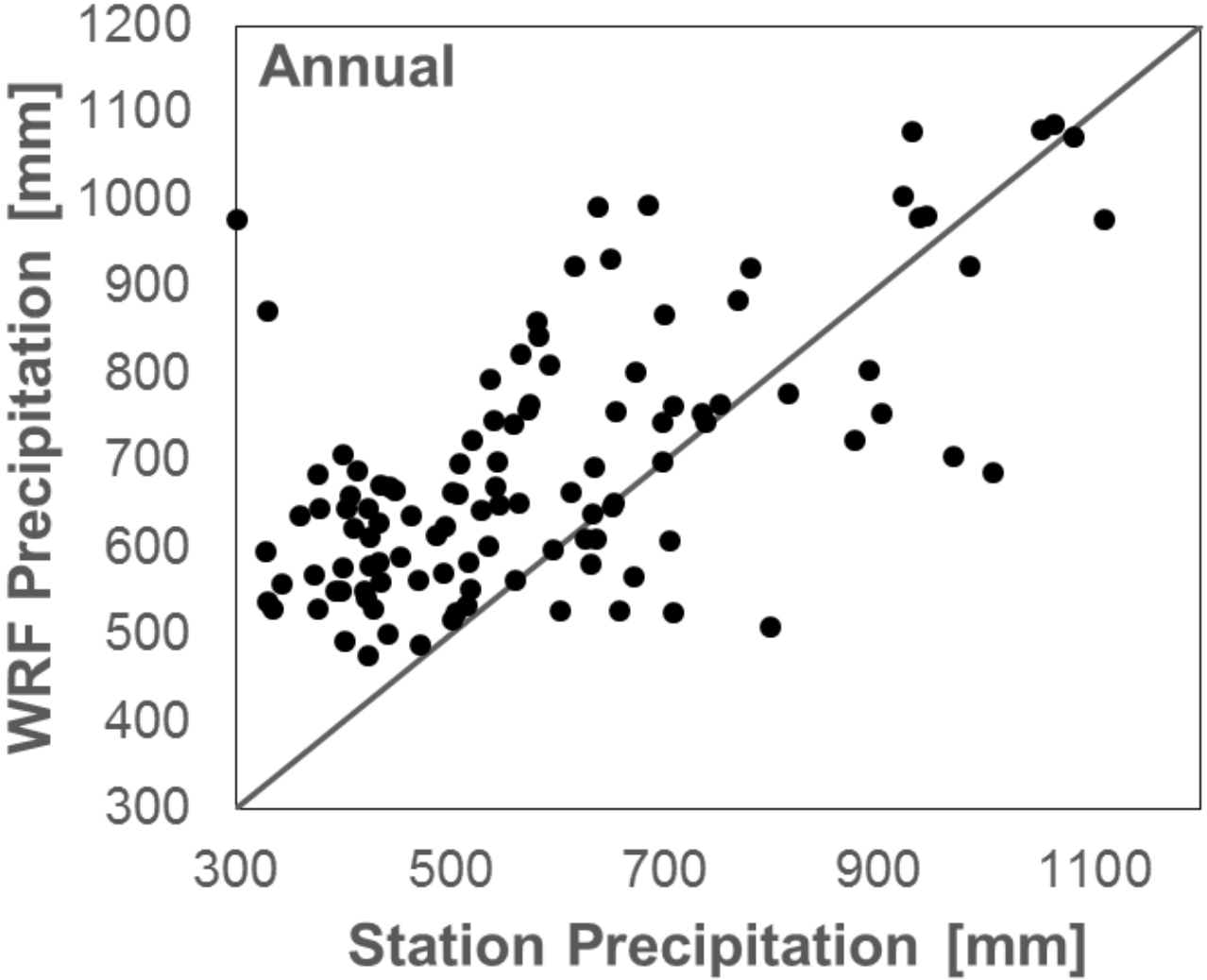
Planetary Boundary Layer scheme: Yonsei University (YSU)
Long-wave and Short-wave scheme: Rapid Radiative Transfer Model relevant for GCMs (RRTMG)
Forcing Data: 6-hourly, 0.703° x 0.703° resolution ERA-Interim

WRF Comparison to Station Data in the Rockies



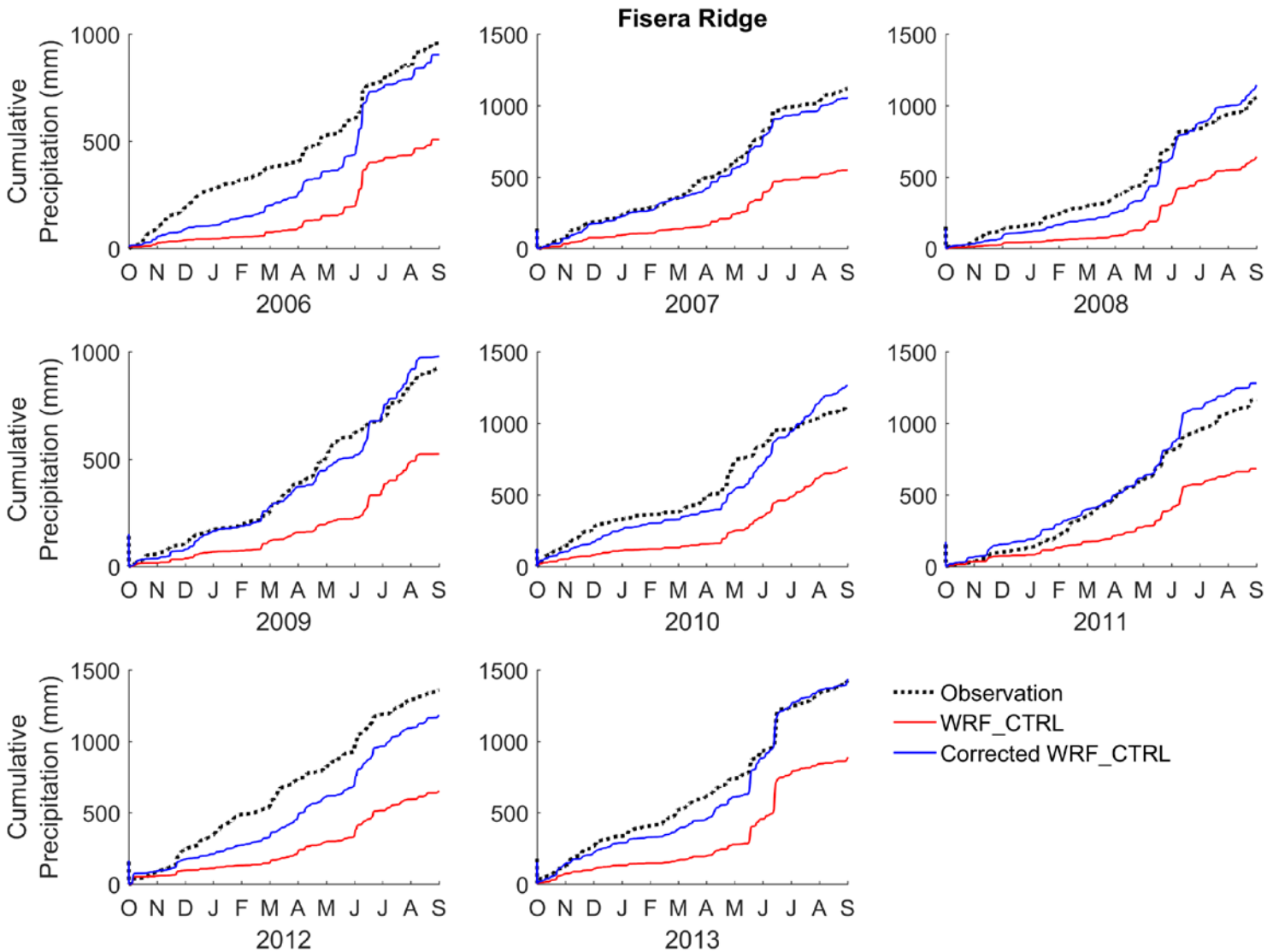
Rasouli et al., in preparation

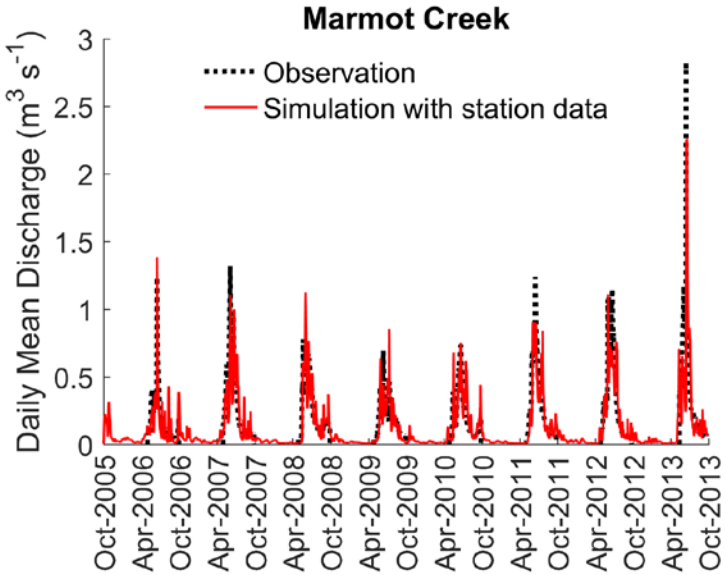
WRF Comparison to Station Data in the Rockies

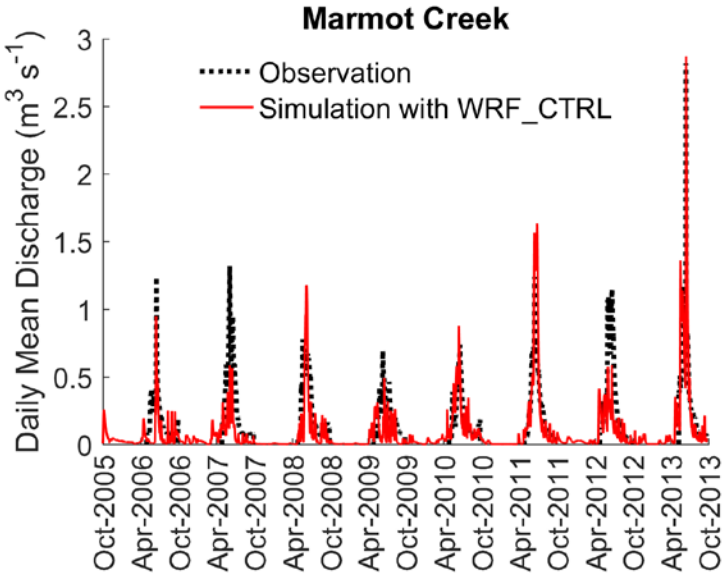


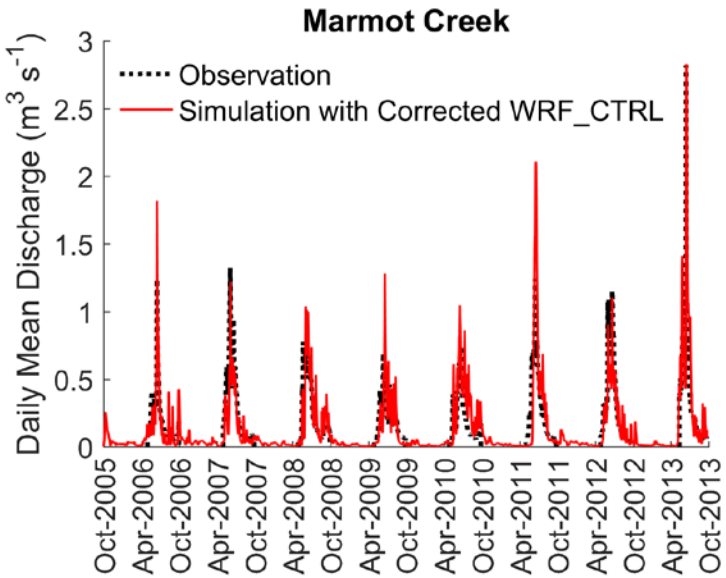
Rasouli et al., in preparation

Using Station Data to Correct WRF









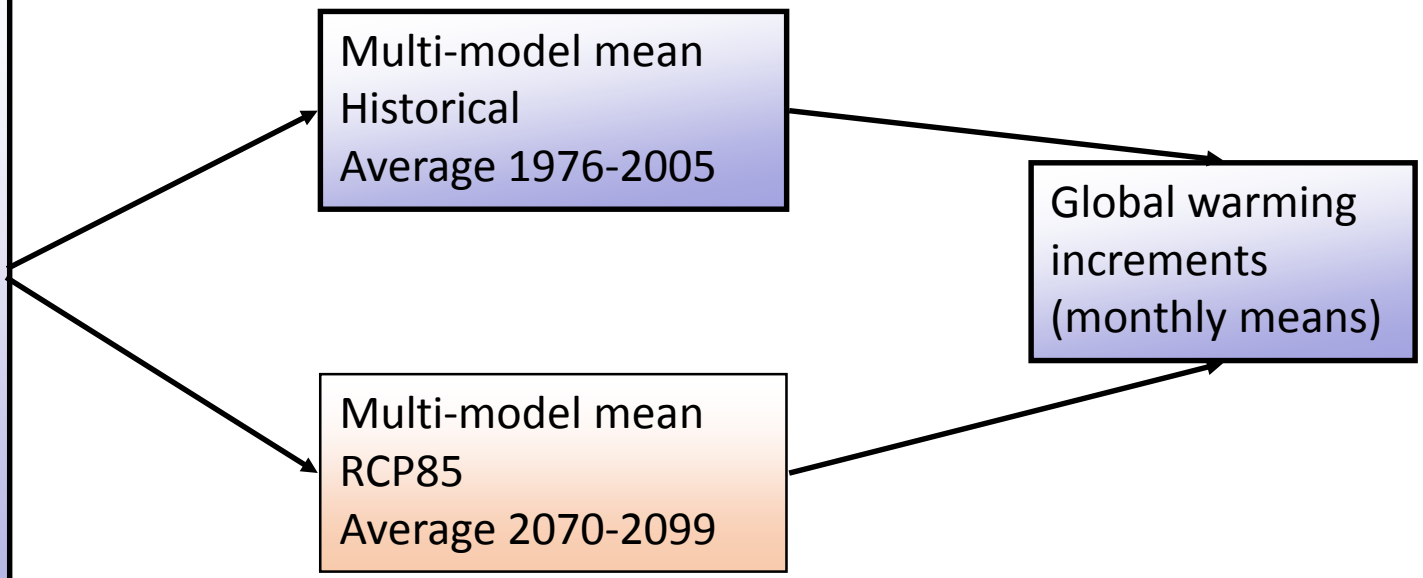
	Obs	WRF	WRF-corrected
NSE	0.57	0.22	0.36
MB	-0.03	-0.29	0.08

Pseudo-Global-Warming 2070-2099

CMIP5 models

- ACCESS1-3
- CanESM2
- CCSM4
- CESM1-CAM5
- CMCC-CM
- CNRM-CM5
- CSIRO-Mk3-6-0
- GFDL-CM3
- GFDL-ESM2M
- GISS-E2-H
- HadGEM2-CC
- HadGEM2-ES
- Inmcm4
- IPSL-CM5A-MR
- MIROC5
- MIROC-ESM
- MPI-ESM-LR
- MPI-ESM-MR
- MRI-CGCM3

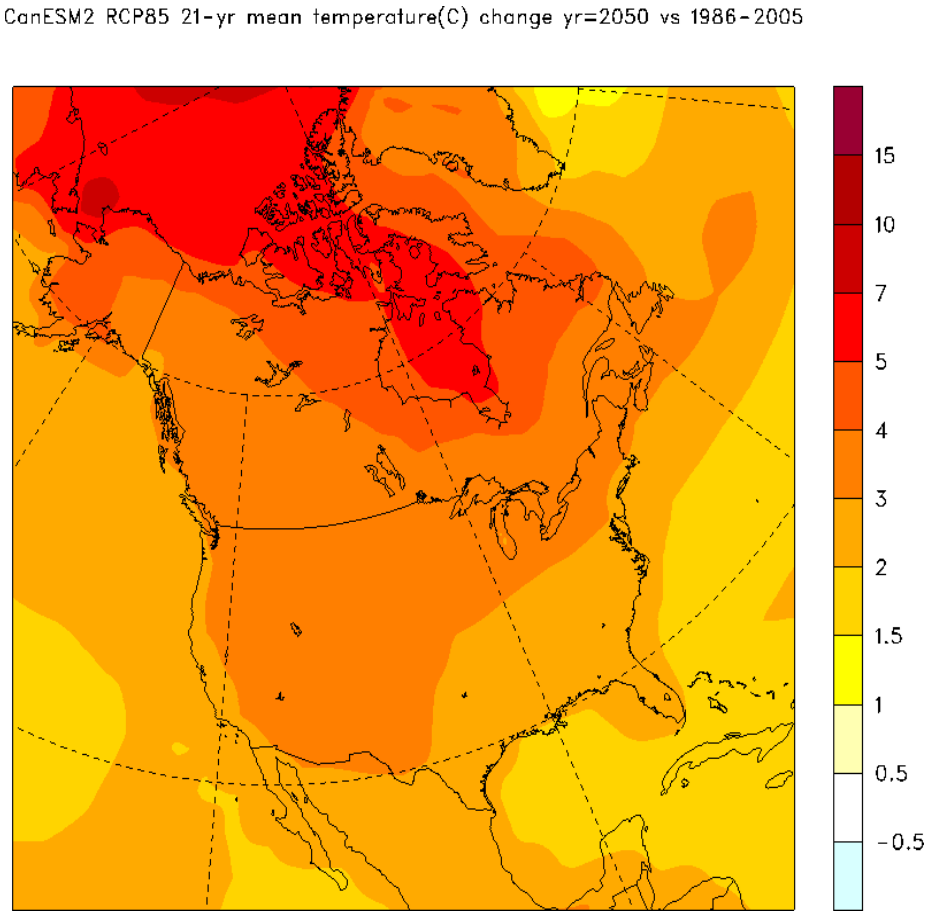
1. Calculate 30-year monthly mean values of U, V, T, Qv, PSFC, Tsoil and SST of current and future climate periods from multi CMIP5 model ensemble (1976-2005 historical and 2070-2099, RCP8.5)



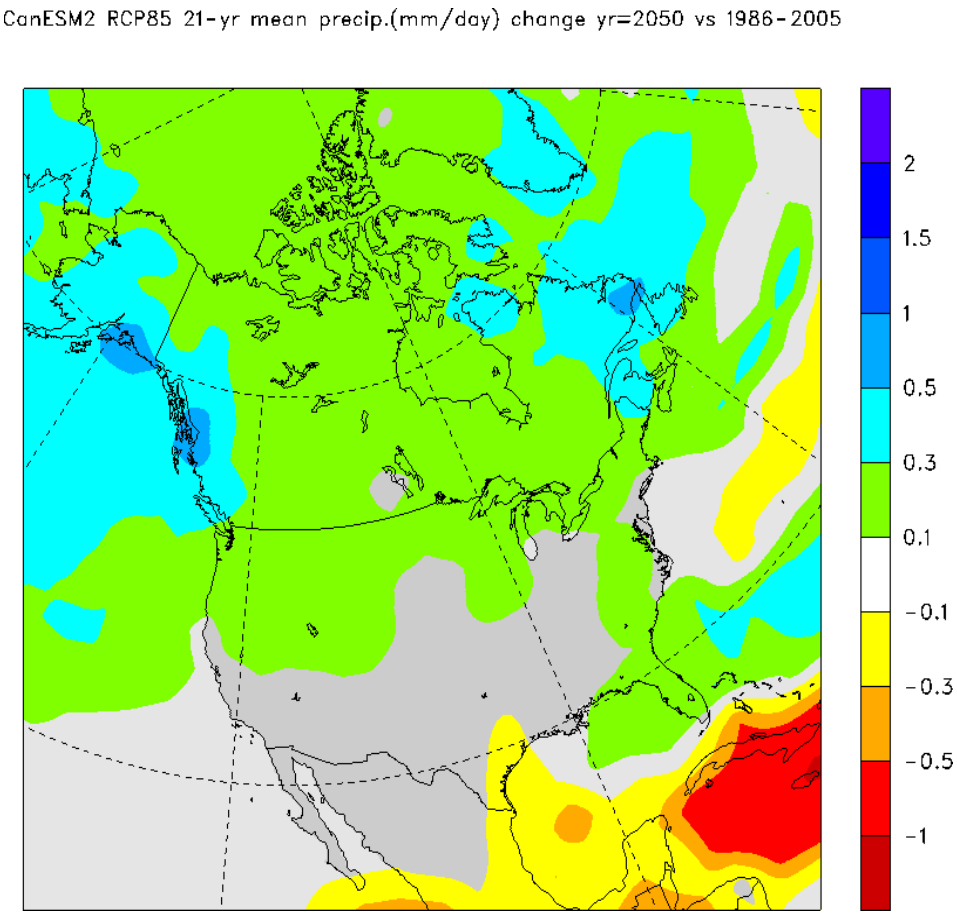
2. Subtract current from future to get monthly climate perturbations
3. Add time-interpolated perturbation to current reanalysis (ERA-Interim, 6-hourly) to give new WRF model initial and lateral boundary conditions

Future Change in the 21st Century

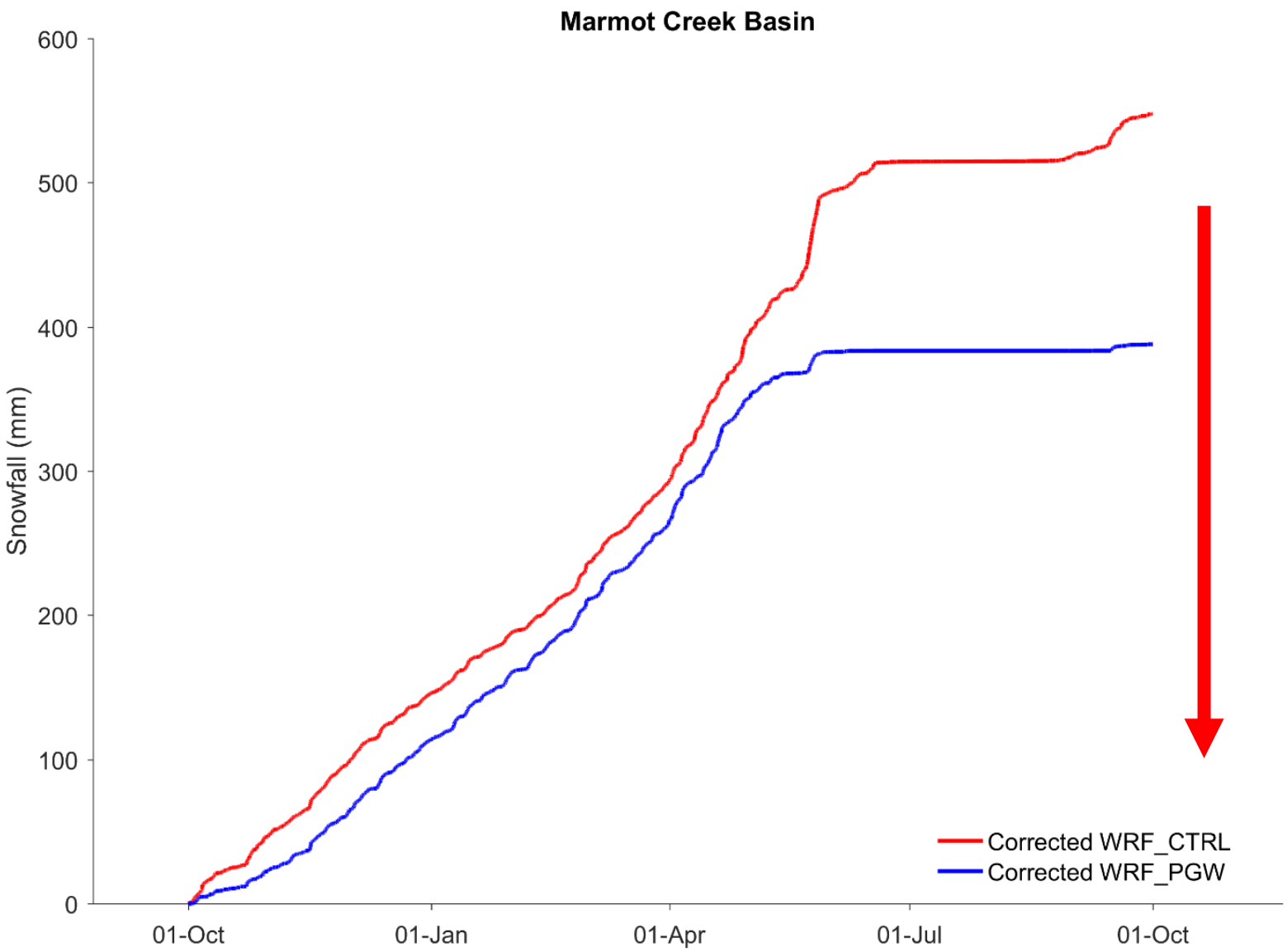
Canadian model projected conditions RCP8.5 '2050' – (1986-2005)

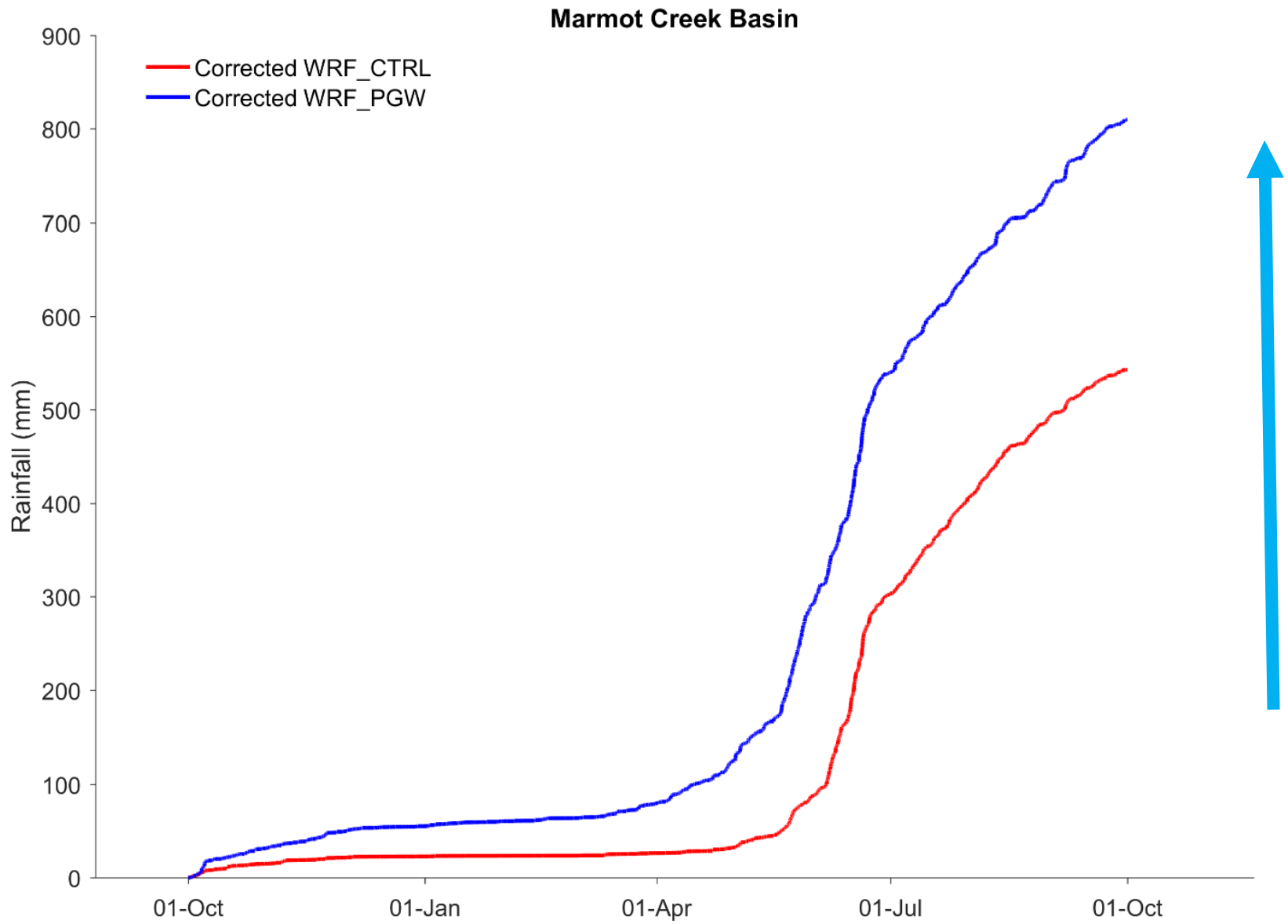


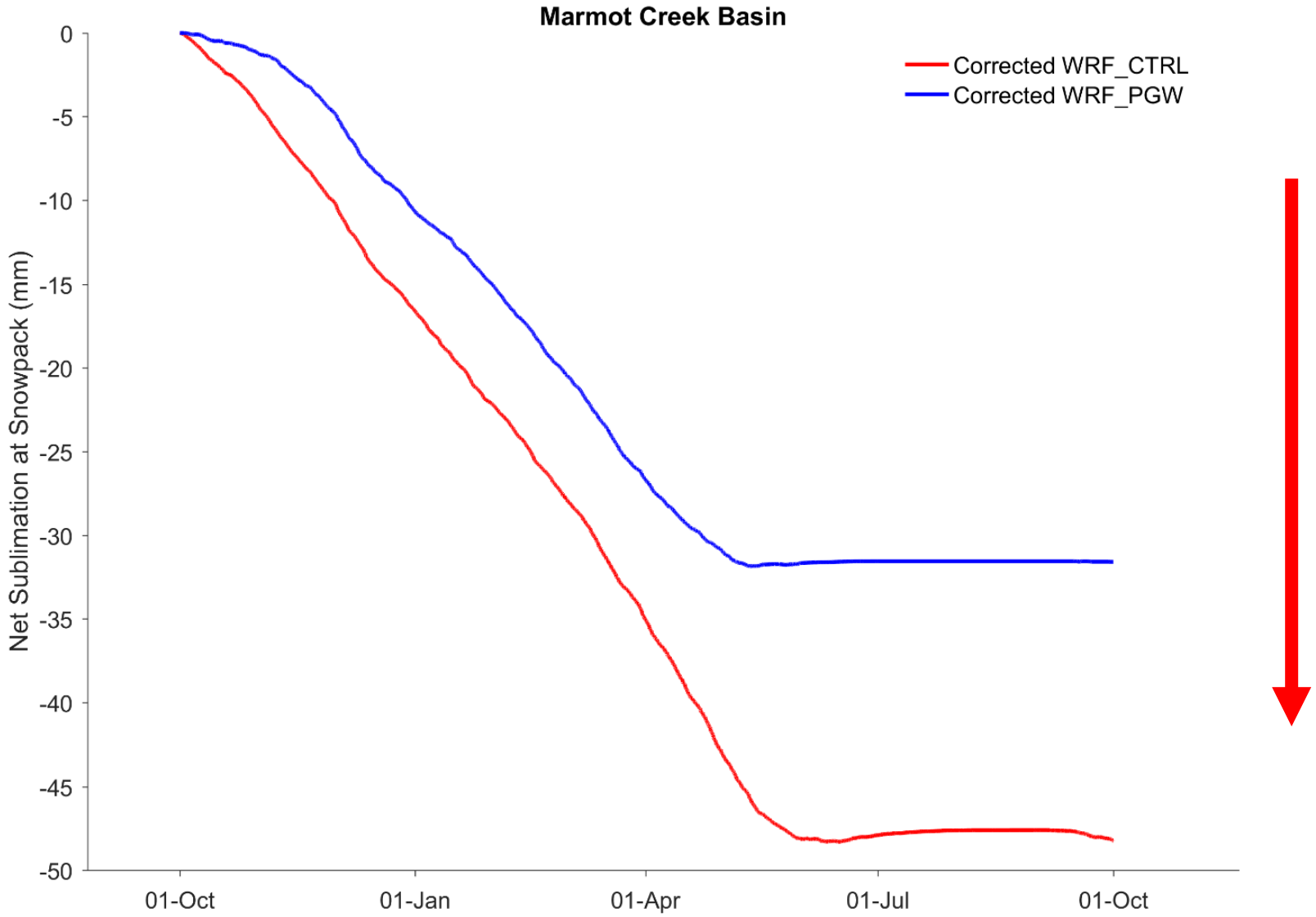
Temperature

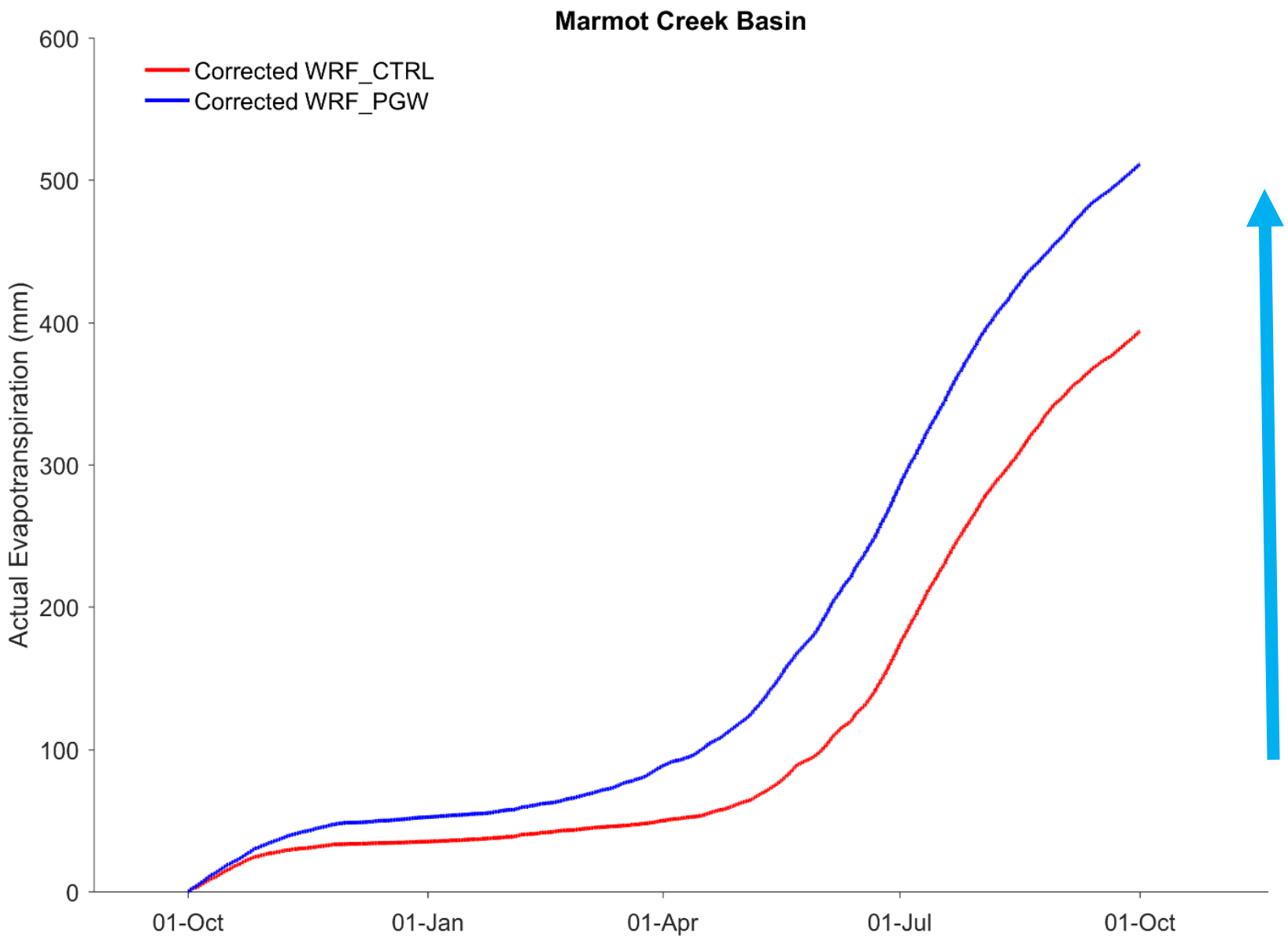


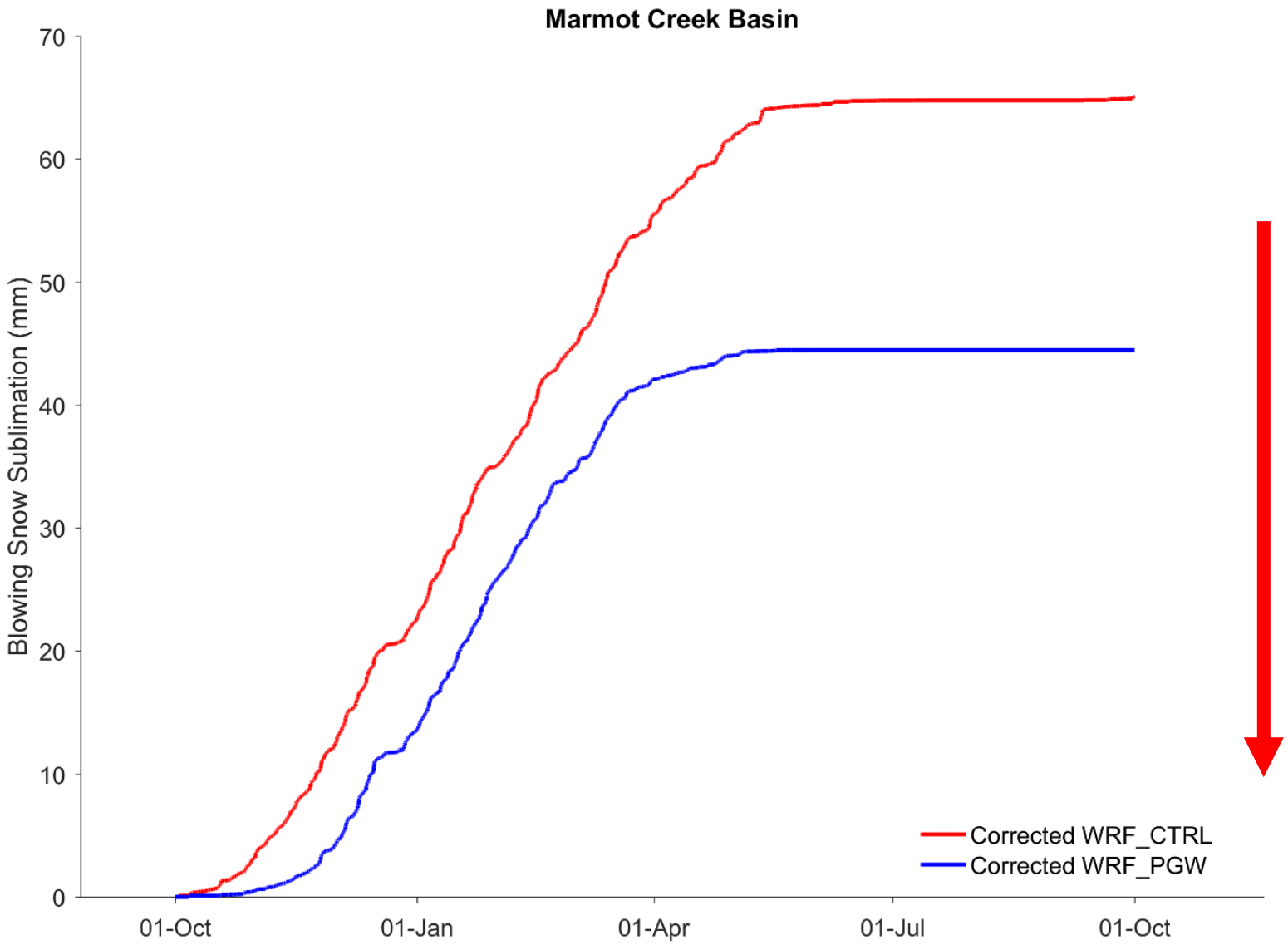
Precipitation

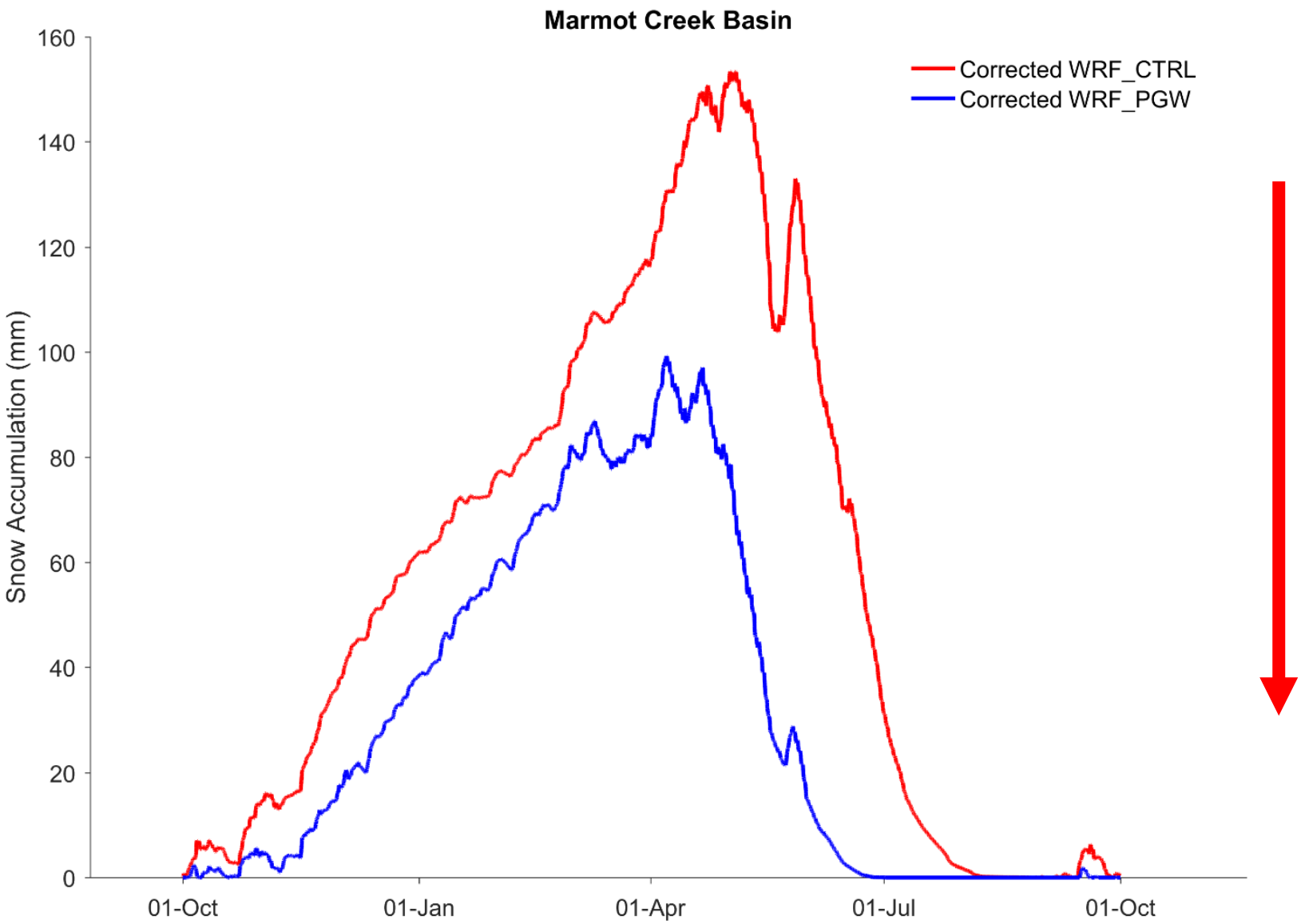

Marmot Creek Basin
Snowfall (mm)
600
500
400
300
200
100
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct
Corrected WRF_CTRL
Corrected WRF_PGW

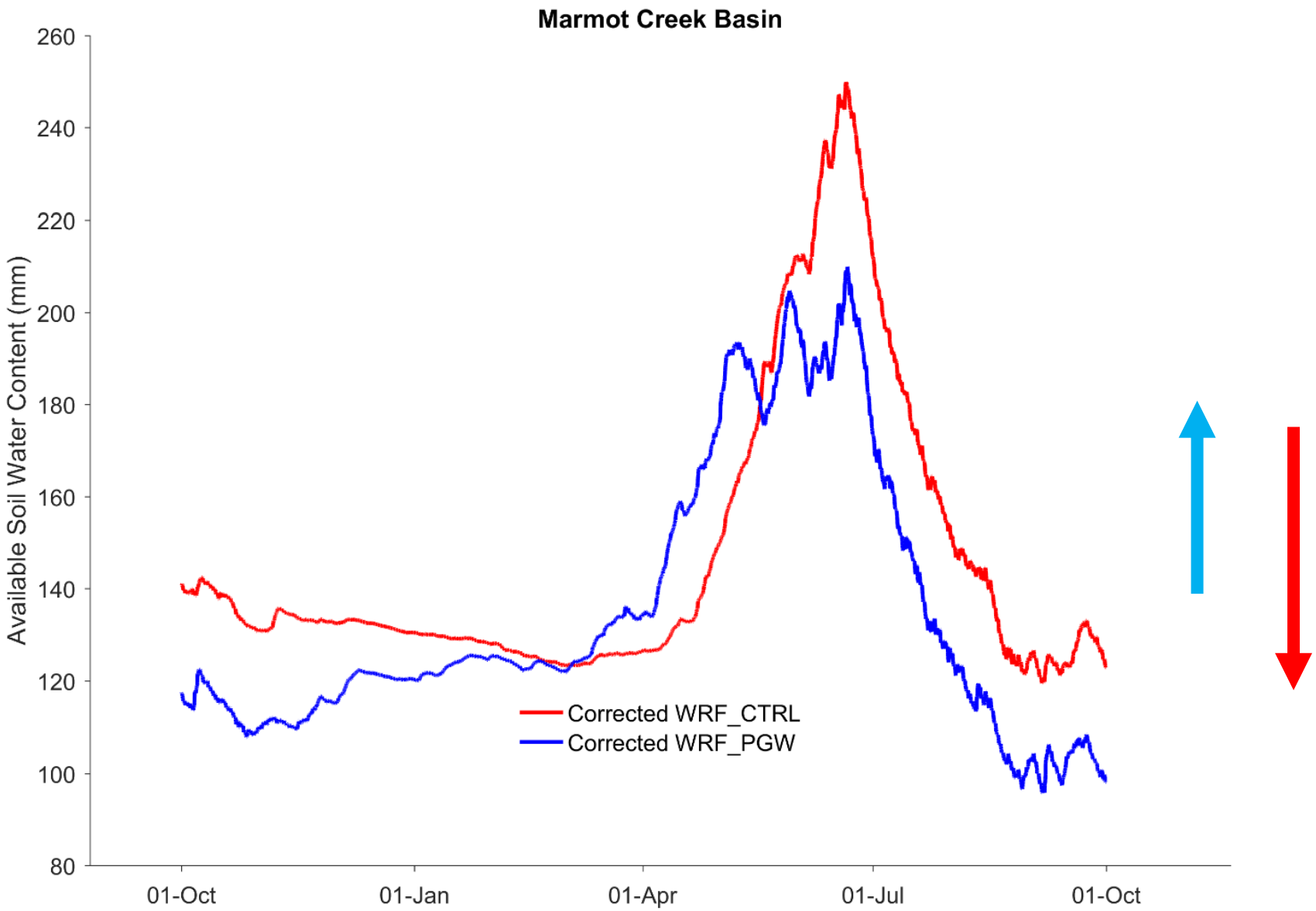

Marmot Creek Basin
Corrected WRF_CTRL
Corrected WRF_PGW
Rainfall (mm)
900
800
700
600
500
400
300
200
100
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct

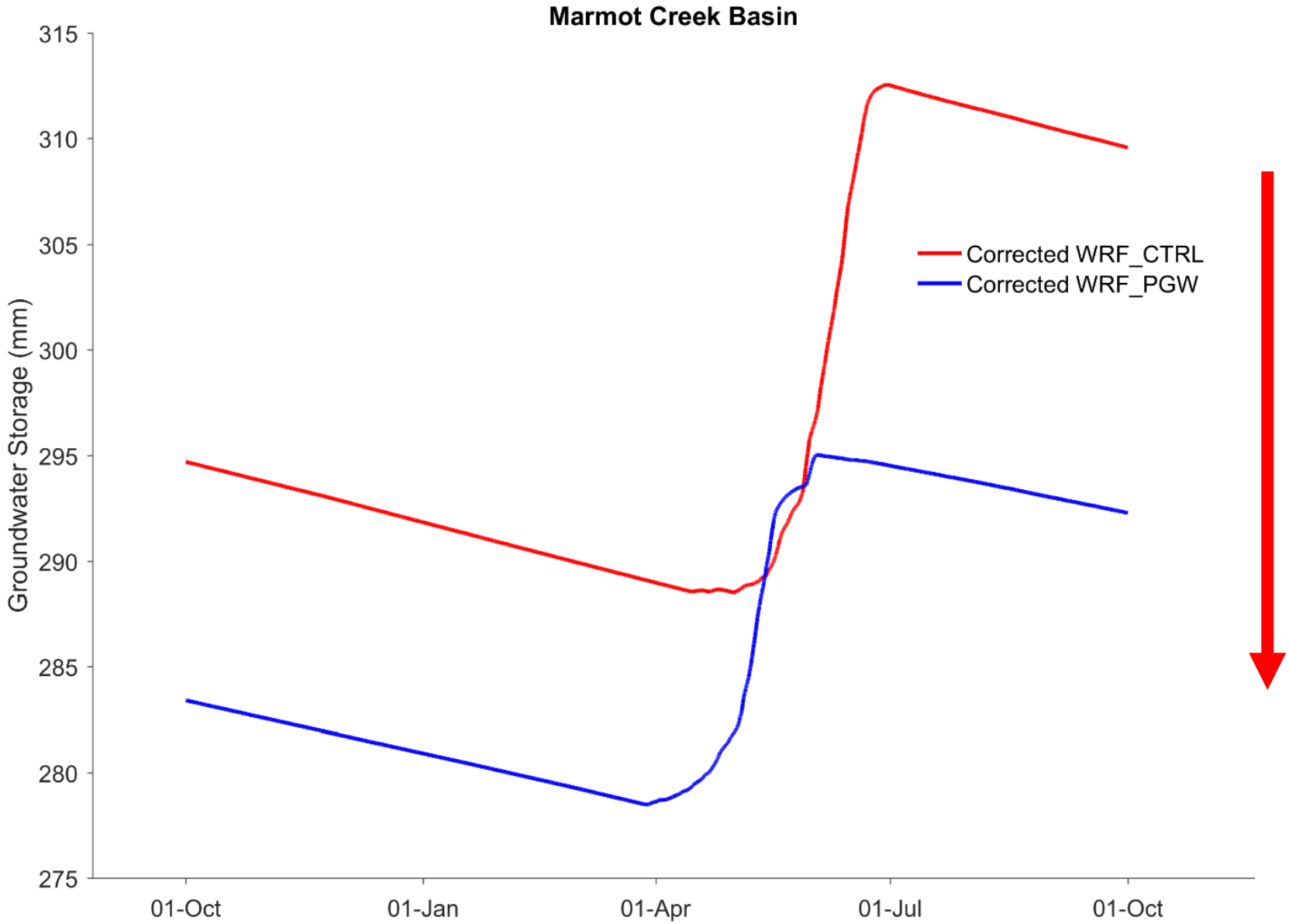

Marmot Creek Basin
Corrected WRF_CTRL
Corrected WRF_PGW
Net Sublimation at Snowpack (mm)
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct

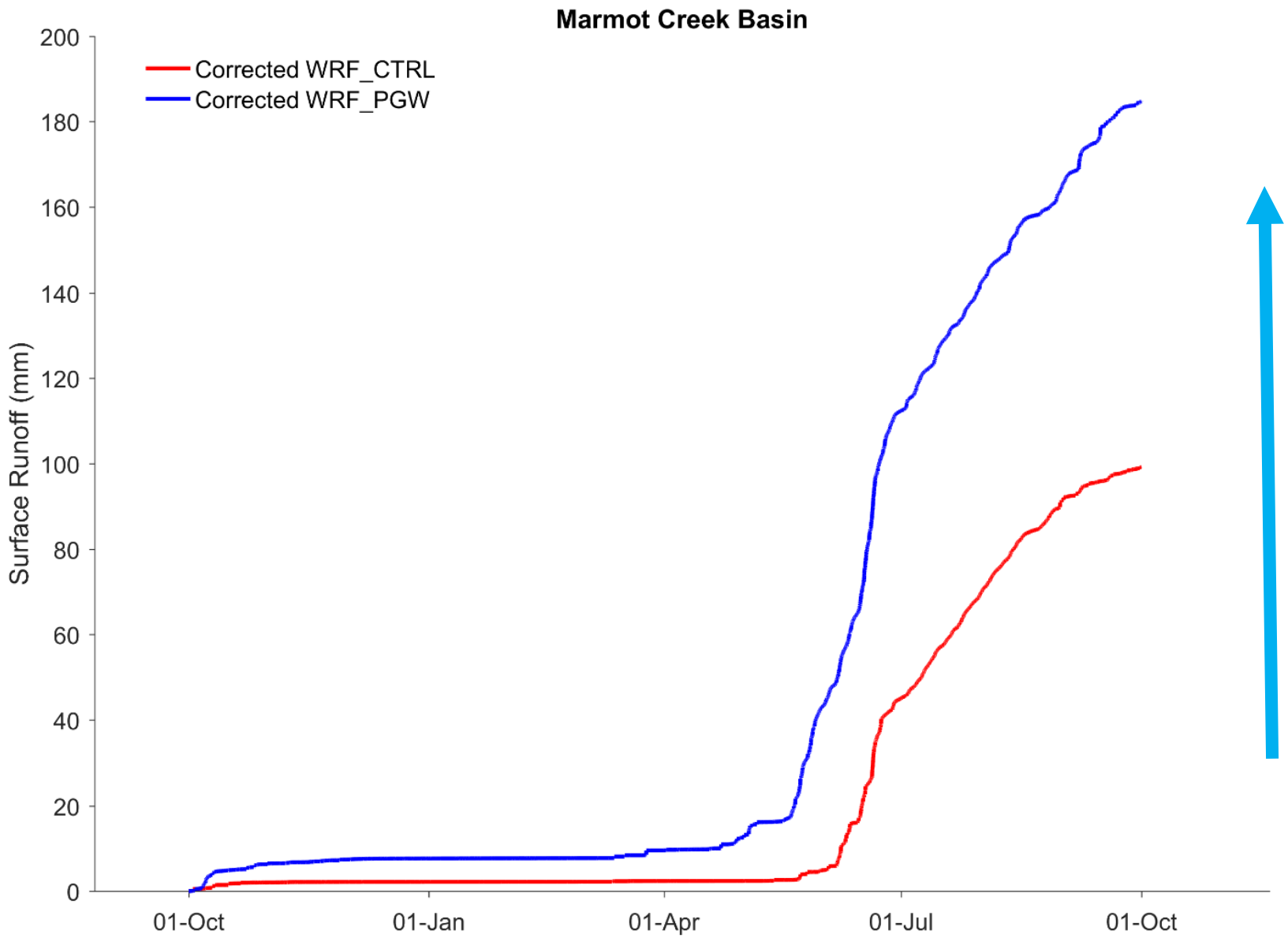

Marmot Creek Basin
Corrected WRF_CTRL
Corrected WRF_PGW
Actual Evapotranspiration (mm)
600
500
400
300
200
100
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct

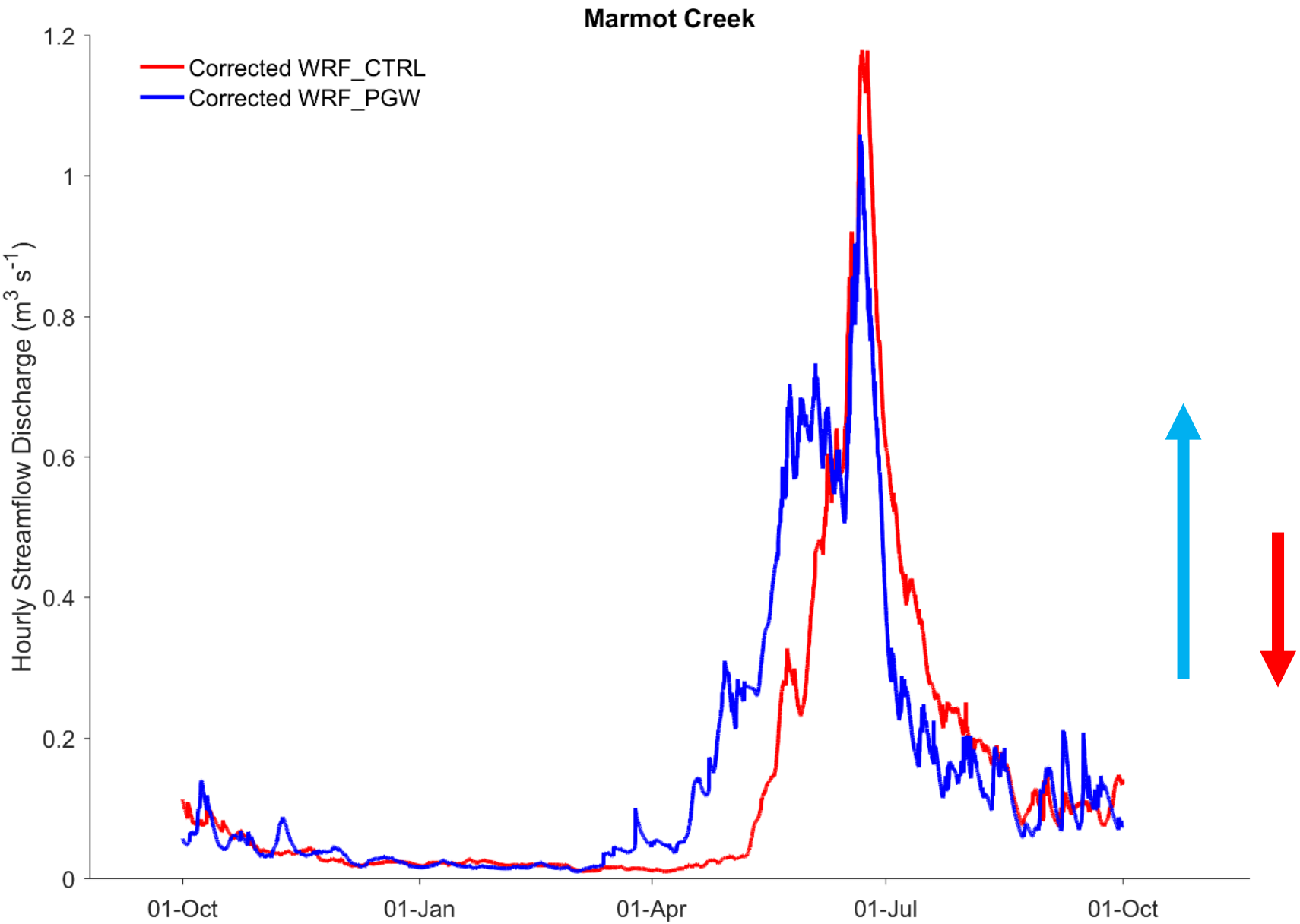

Marmot Creek Basin
Blowing Snow Sublimation (mm)
70
60
50
40
30
20
10
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct
Corrected WRF_CTRL
Corrected WRF_PGW


Marmot Creek Basin
Corrected WRF_CTRL
Corrected WRF_PGW
Snow Accumulation (mm)
160
140
120
100
80
60
40
20
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct


Marmot Creek Basin
Available Soil Water Content (mm)
260
240
220
200
180
160
140
120
100
80
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct
Corrected WRF_CTRL
Corrected WRF_PGW


Marmot Creek Basin
Groundwater Storage (mm)
315
310
305
300
295
290
285
280
275
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct
Corrected WRF_CTRL
Corrected WRF_PGW


Marmot Creek Basin
Corrected WRF_CTRL
Corrected WRF_PGW
Surface Runoff (mm)
200
180
160
140
120
100
80
60
40
20
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct


Marmot Creek
Corrected WRF_CTRL
Corrected WRF_PGW
Hourly Streamflow Discharge (m3 s-1)
1.2
1
0.8
0.6
0.4
0.2
0
01-Oct
01-Jan
01-Apr
01-Jul
01-Oct

Deliverables

- Assess the uncertainty, resilience and vulnerability of mountain water supplies in the Bow River Basin.
- Develop an integrated hydrological simulation system for the mountain headwaters of the Bow River.
- Predict climate and forest cover tipping points for hydrology,
  - explore forest management options,
  - develop future water supply scenarios and
  - estimate the risk of future extreme hydrological events.

Conclusions

- Glaciers, avalanches, discontinuous forest energetics, forest evapotranspiration, wetlands, groundwater and complex terrain snow redistribution and ablation processes are better understood and are now better represented in CRHM models.
- Observations to date and historical diagnostic modelling shows remarkable resilience in Canadian Rockies hydrology for both glacierized and alpine-forested basins, despite substantial warming in winter.
- Future hydrological change has been predicted using dynamically downscaled high resolution climate model driving a physically based process hydrological model.
  - At Marmot Creek and Peyto Glacier there is loss of resiliency: more rainfall, less snowmelt, less glacier melt, less sublimation, greater evapotranspiration, drier soils, lower groundwater, earlier streamflow, more overland flow, lower low flows, greater discharge volumes

Publications

- Marsh C*, Spiteri R, **Pomeroy J,** Wheater H, (Submitted Revision Requested). Multi-objective unstructured triangular mesh generation for use in hydrological models, *Computer and Geosciences,* accepted
- Marsh CB*, **Pomeroy JW,** Wheater HS, (Submitted Revision Requested). Sensitivity of snowpack energy balance models to input and parameter uncertainty in a mountain basin, *Water Resources Research*, in review
- Wayand NE*, Marsh CB*, Shea JM*, **Pomeroy JW,** (Submitted Revision Requested). Snow Redistribution and Ablation Impacts on Remotely Sensed Alpine Snowcovered Area, *Remote Sensing of Environment,* accepted
- Leroux N*, **Pomeroy JW,** (Submitted). Simulation of Capillary Overshoot in Snow Combining Trapping of the Wetting Phase with a Non-Equilibirum Richards Equation Model, *Water Resources Research,* in review
- Aksamit NO*, **Pomeroy JW,** (2018). Scale Interactions in Turbulence for Mountain Blowing Snow, *Journal of Hydrometeorology, 19*(-): 305 - 320. DOI: 10.1175/JHM-D-17-0179.1
- **Pomeroy J,** (Feb 15, 2018). As a water crisis looms in Cape Town, could it happen in Canada? In *The Conversation and Maclean's*
- MacDonald M, **Pomeroy J,** Essery R, (2018). Water and energy fluxes over northern prairies as affected by chinook winds and winter precipitation, *Agricultural and Forest Meteorology, 248*(-): 372 - 385. DOI: 10.1016/j.agrformet.2017.10.025
- Aksamit NO*, **Pomeroy JW,** (2017). The Effect of Coherent Structures in the Atmospheric Surface Layer on Blowing-Snow Transport, *Boundary-Layer Meteorology, 167* (2): 211 - 233.DOI: 10.1007/s10546-017-0318-2
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- Mercer J.*, **Westbrook CJ**. 2016. Ultrahigh resolution mapping of peatland microform with ground-based structure from motion with multi-view stereo. *Journal of Geophysical Research – Biogeosciences* 121: 2901-2916.