The Representation of Precipitation Characteristics in High Resolution WRF Simulations over Western Canada

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[2]University of Northern British Columbia, Canada

June 12^{th}, 2019

Outline

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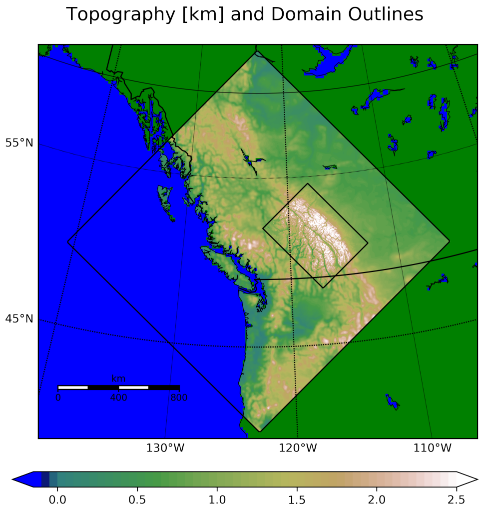
Overview

High-resolution WRF Simulations over Western Canada at 7 km and 1 km for 5 (water-)years

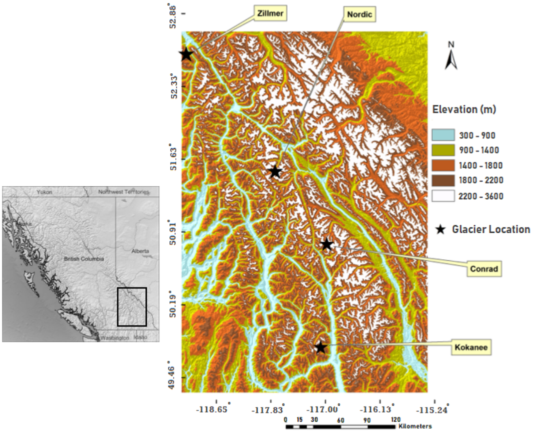
Simulated Years:

- 2010/11
- 2011/12
- 2012/13
- 2013/14
- 2014/15



Outer WRF domain at 7 km, and inner WRF domain at 1 km

Motivation: Glacier Mass Balance

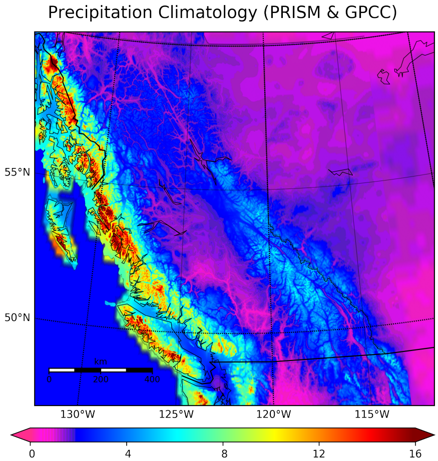


Brian Menounos' group at UNBC conducts fieldwork and mass balance modeling on glaciers in the Columbia mountains — we run WRF to drive mass-balance models

Field Work

Ben Pelto on Kokanee Glacier

Western Canada: Orographic Precipitation



Annual average precipitation over Western Canada (Merged Dataset)

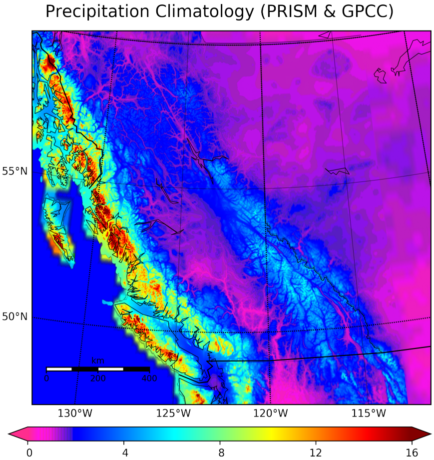
General precipitation pattern

Merged Observations

Combined data from PRISM (1 km) and GPCC (0.25°)

- Very high precipitation in the Coast Mountains
- Interior Plateau and the lee of the Rockies are very dry
- Precipitation gradient stronger in winter, weaker in summer

Western Canada: Orographic Precipitation



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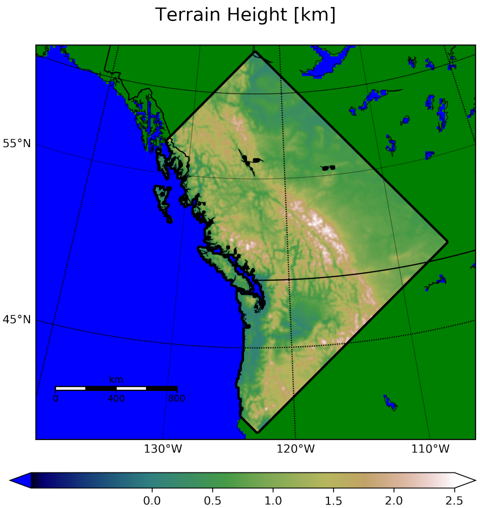
WRF Model and Domain Setup

WRF Domains

- 7 km Western Canada
- 1 km Columbia/Rocky Mountains

- WRF-ARW 3.6.1
- Noah-MP (CLASS snow), RRTMG radiation, Thompson MP, Grell-3 cumulus (at 7 km), MYNN3 PBL



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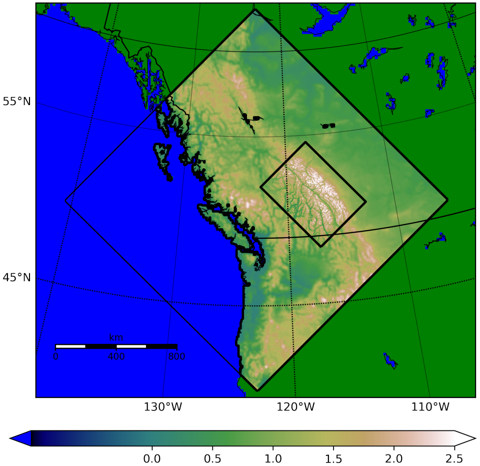
Terrain Height [km]



Outer WRF domain at 7 km and Inner domain at 1 km

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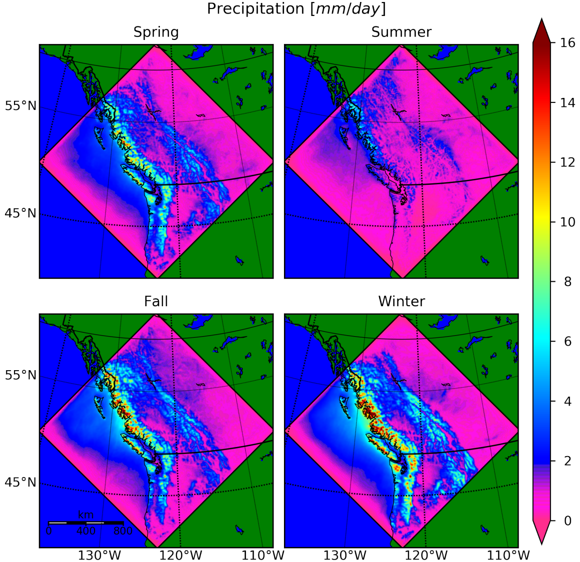
Seasonal Precipitation Pattern at 7 km



Outer Domain Precipitation Pattern

- Very high precip at Coast Mountains
- and drier downwind of mountains
- But orographic precip is too low and rain shadow too weak
- Summer precip is far too low

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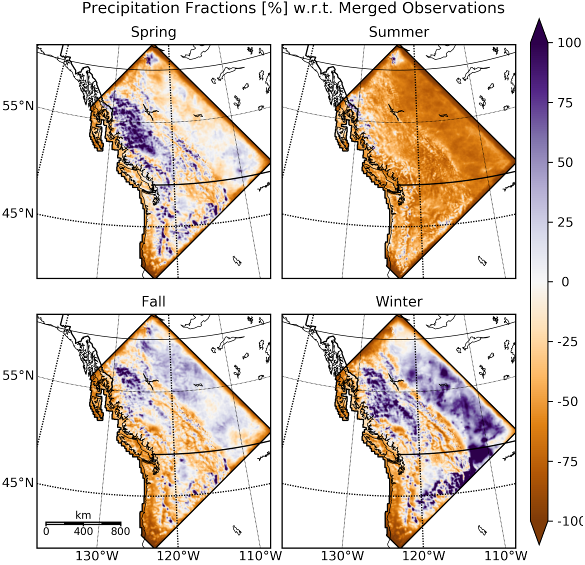

Outer Domain Precipitation Bias

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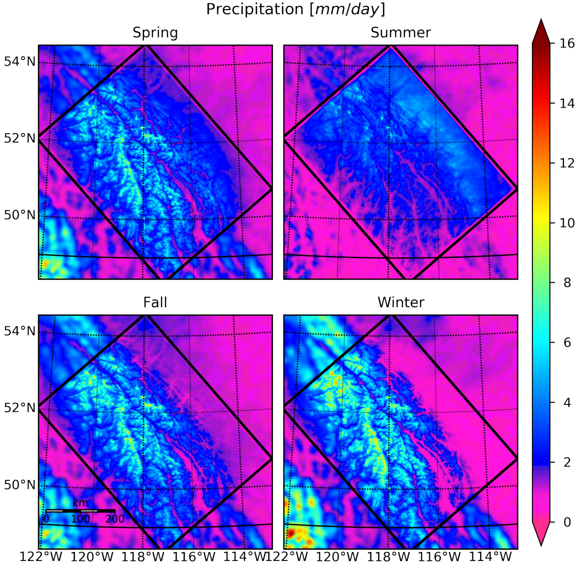
Seasonal Precipitation Patterns at 1 km

Inner Domain Precipitation Pattern

- Summer is too dry, Spring too wet
- Winter shows pronounced N-S dipole

Observations

Reference period is 1970-2000, which may influence spatial patterns due to PDO, NPO, etc.



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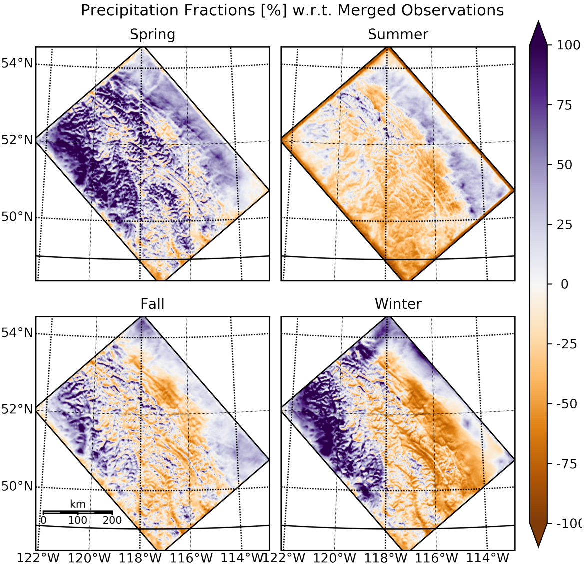

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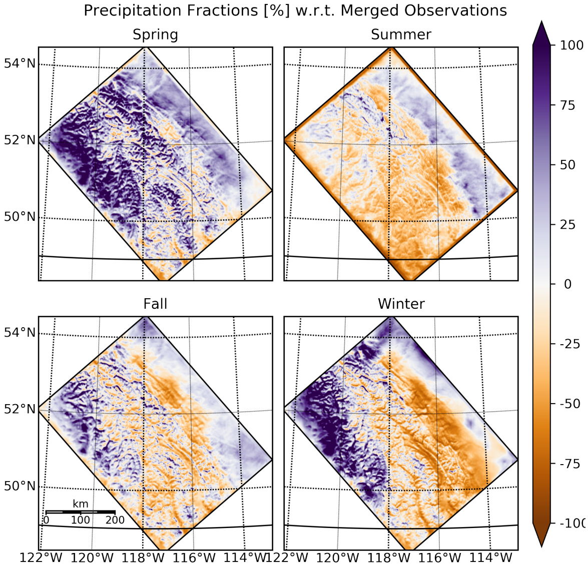
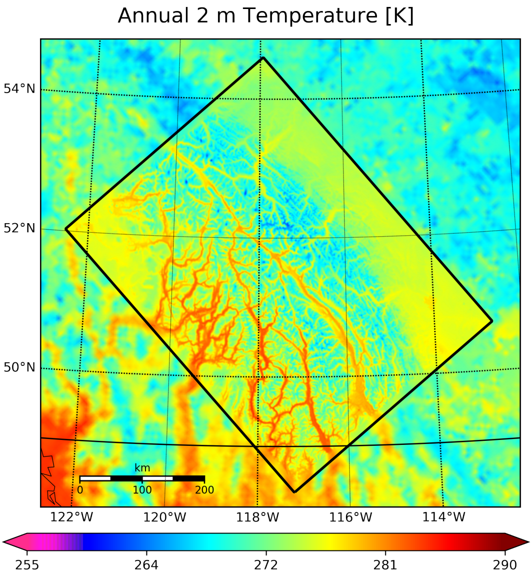


Temperature Bias (at 1 km; annual average)



Outer Domain Precipitation Pattern

- N-S gradient, but dominated by elevation
- Biases strongly associated with valleys and peaks

Inversions?

Potentially missing inversions and PBL processes at higher peaks — or Observations?

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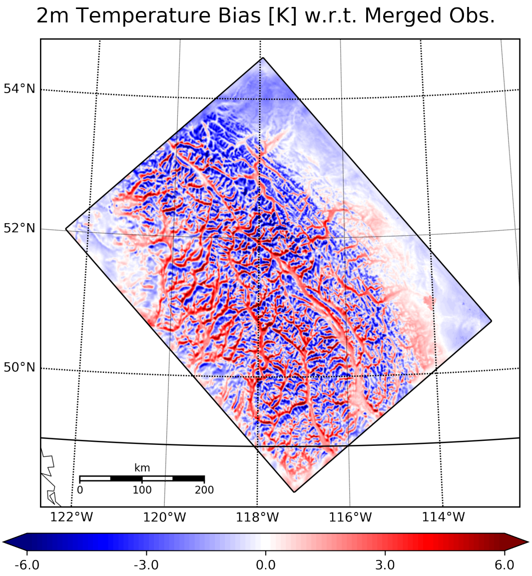

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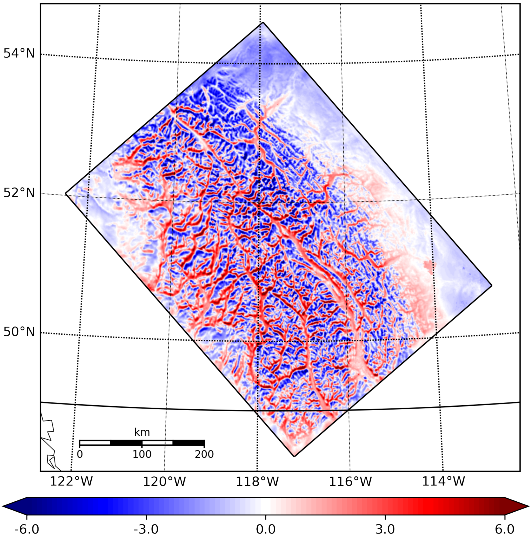
2m Temperature Bias [K] w.r.t. Merged Obs.



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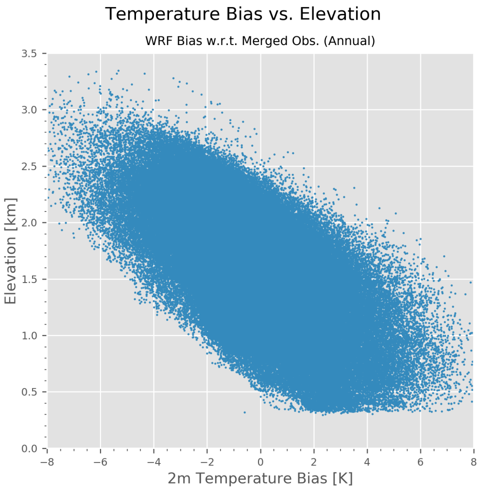
Temperature Bias vs. Elevation



Temperature bias vs. elevation
(WRF inner domain vs. Merged Obs.)

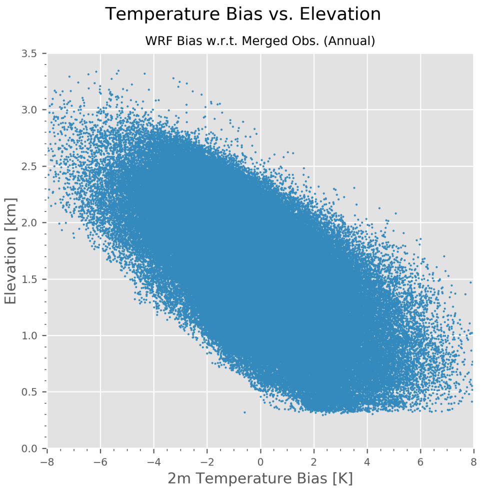
Lapse-rate Bias

- Valleys are too warm, peaks too cold
- Pattern is similar in winter and summer
- But much less pronounced in outer domain

Linear Bias

Linear bias-correction by elevation may work very well: $\sim 4.5\,\mathrm{K/km}$

Temperature Bias vs. Elevation



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Summer Precipitation (Inner Domain)

Inner Domain Summer Precip.

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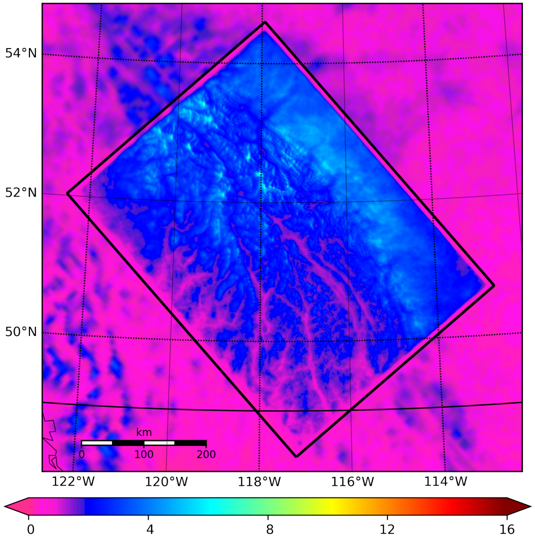
- ... but outer domain (7 km) is even drier
- Something is missing here...

Convection?

Could this be missing convection? (We have a convection scheme...)

Summer Precipitation [*mm/day*]



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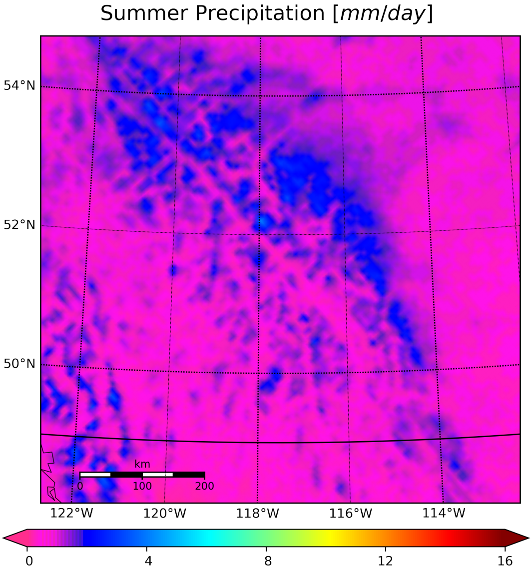

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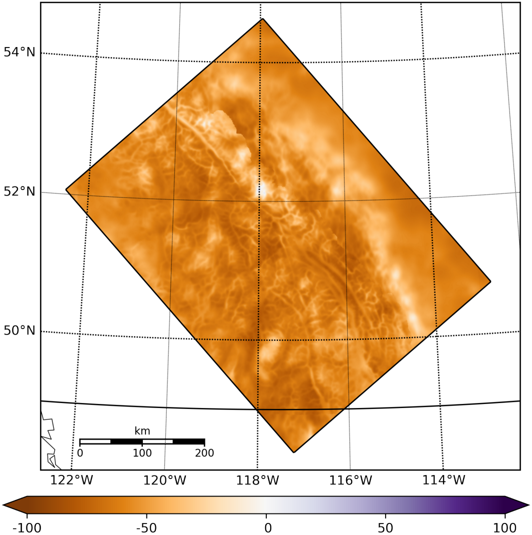
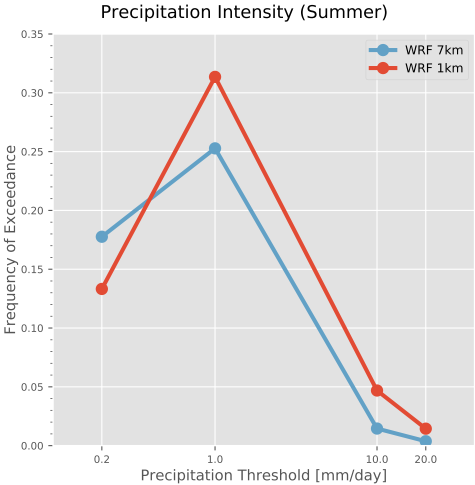
Summer Precipitation Fractions [%] w.r.t. Merged Obs.



Convection? Analysis of Precipitation Intensity



Frequency of threshold exceedance for inner and outer domain

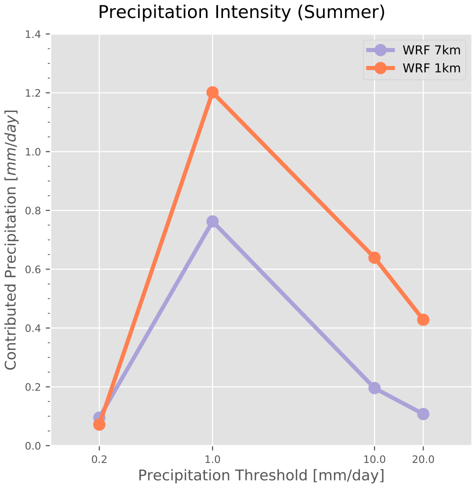
Frequency of heavy precip. (Summer)

- Heavy precip events much more frequent in inner domain (x4)
- ... and they do count!
- Likely not due to grid-scale precip

Convection?

Could be convection, but why are extremes in winter higher?

Convection? Analysis of Precipitation Intensity



Contribution of precipitation exceeding the given threshold

Contribution of heavy precip. (Summer)

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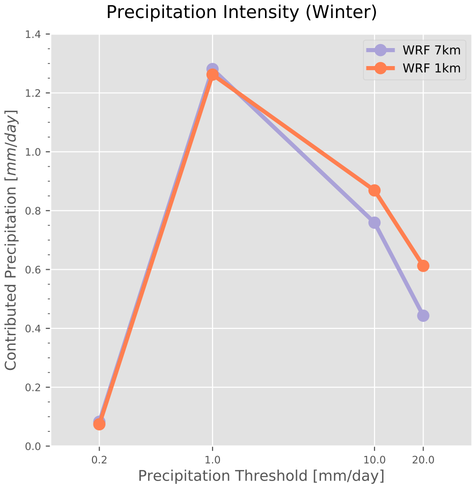

Contribution of threshold exceedance in winter

Contribution of heavy precip. (**Winter**)

- Heavy precip events much more frequent in inner domain (x4)
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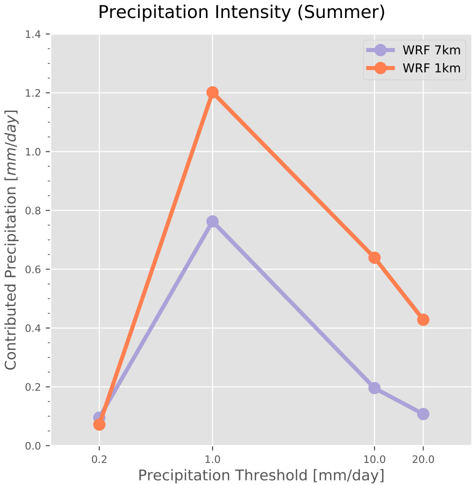
Convection? Analysis of Precipitation Intensity



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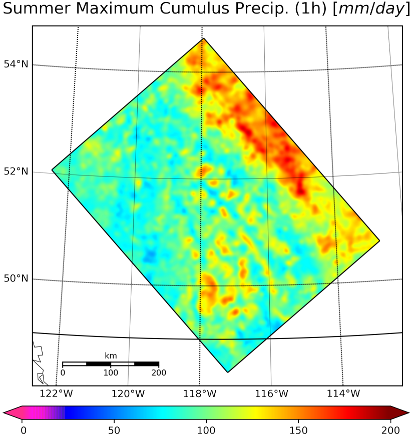

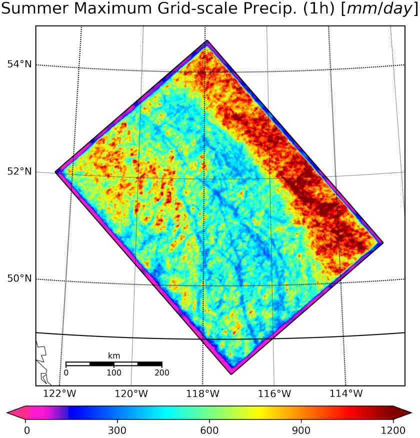

Maximum hourly accumulation per month: convective precip for outer domain (left) and grid-scale for inner domain (right).
Note different scales — inner domain is 6x higher!

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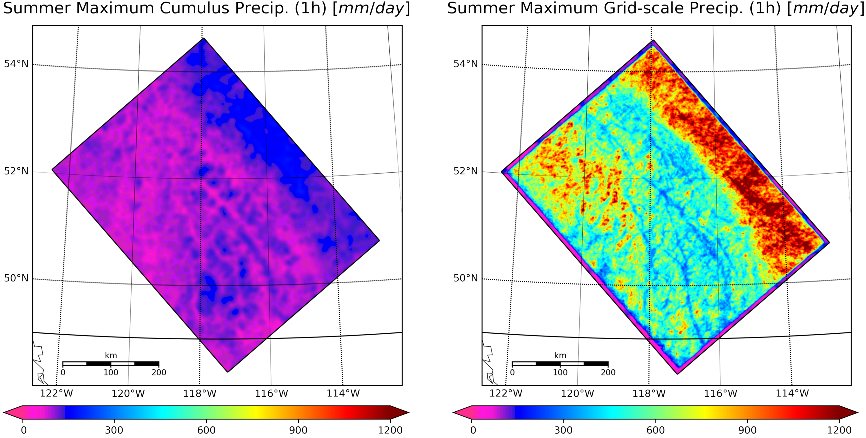

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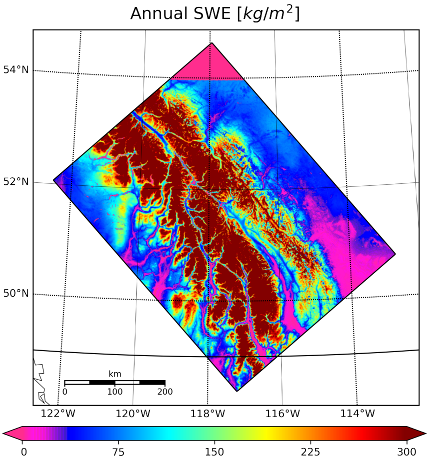
SnoDAS — Snow Data Assimilation System



Annual average snow (SWE) over the Columbia Mountains

Annual average distribution of Snow Water Equivalent

SnoDAS

Snow Data Assimilation System at 1 km and daily; assimilates SNOTEL observations

- Clear increase with elevation
- Lower SWE in Prairies
- In western Canada since 2010, only up to 54°N

Snow/SWE Representation in 1 km WRF Simulations

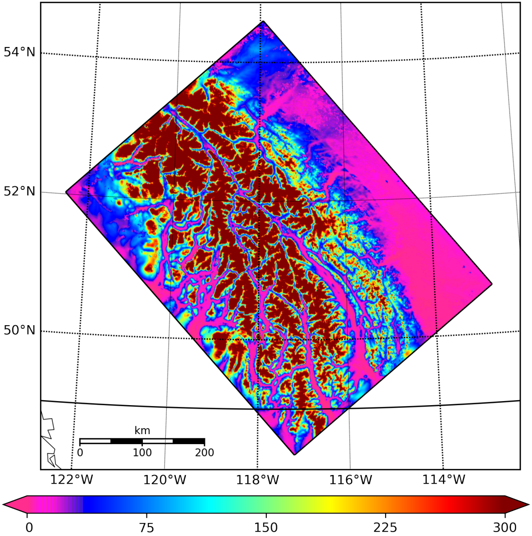
Inner Domain Average SWE

- More structure in 1 km WRF
- Biases correlate with elevation
- Biases in outer domain smoother

Assimilation

Assimilation may be smoothing snow field in SnoDAS, reducing vertical gradients

Annual SWE [kg/m^2]



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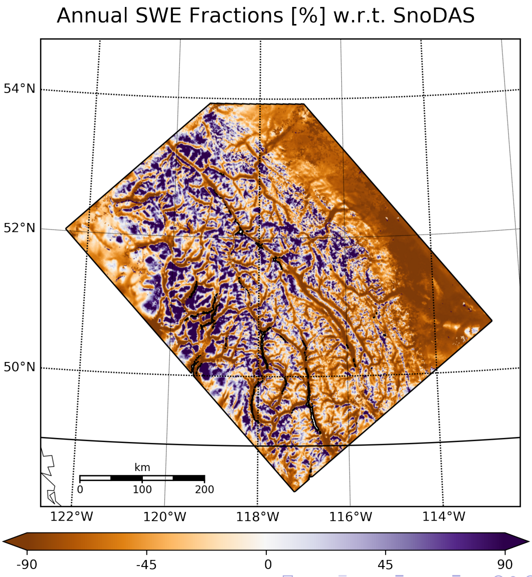

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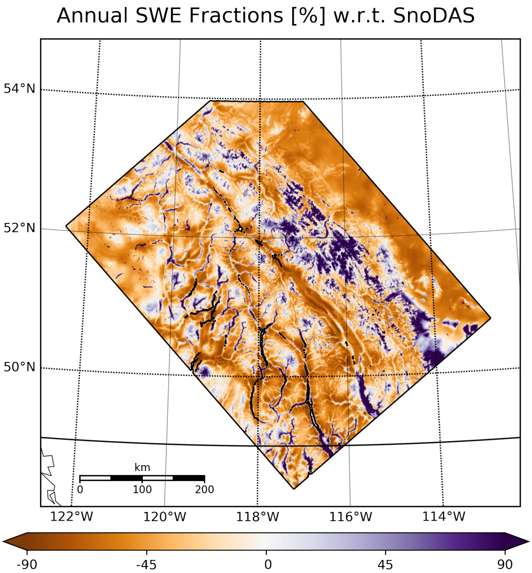
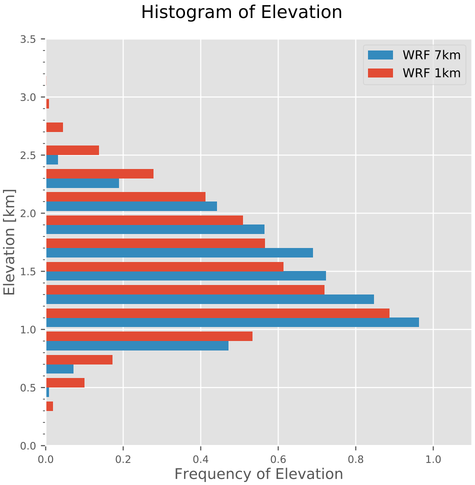


Snow Accumulation (SWE) vs. Elevation



Distribution of grid points by elevation for inner and outer WRF domain

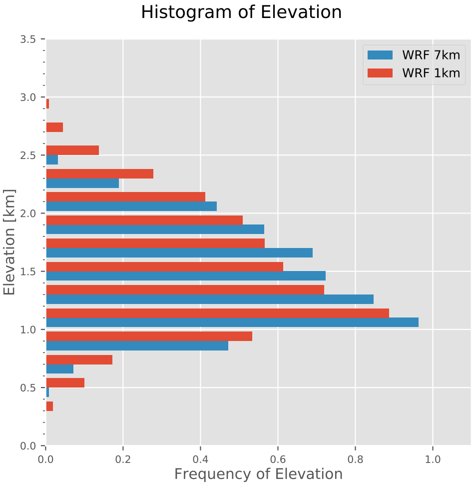
Elevation Distribution at 1 km & 7 km

- Outer domain concentrates around 1,000 - 2,000 m
- Tops out at 2,600 m

? How does this affect snow accumulation and snow melt?

All datasets were interpolated to inner WRF domain grid and then aggregated by elevation.

Snow Accumulation (SWE) vs. Elevation



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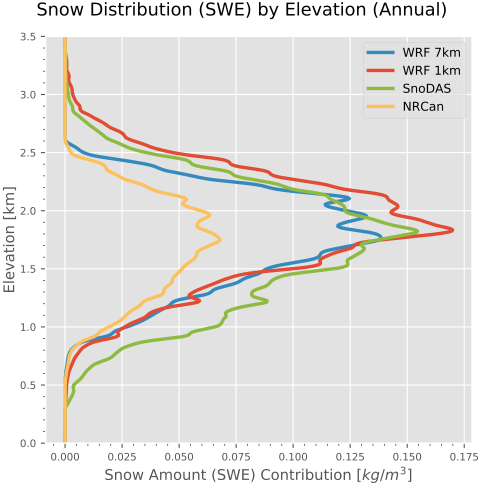

Annual average SWE distribution by elevation for WRF, SnoDAS & NRCan

SWE vs. Elevation (Columbia Mountains)

- Outer domain and NRCan dataset have no snow above 2,600 m
- SnoDAS has higher SWE at low elevation
- WRF at 1 km is quite close to SnoDAS, ...
- ... but places more snow at high elevation

$\Longrightarrow$ Temperature Bias?

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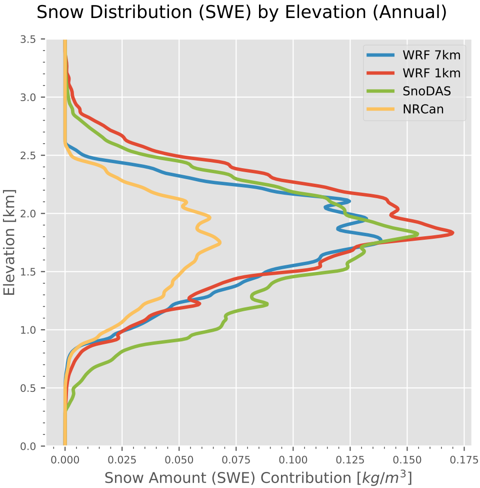

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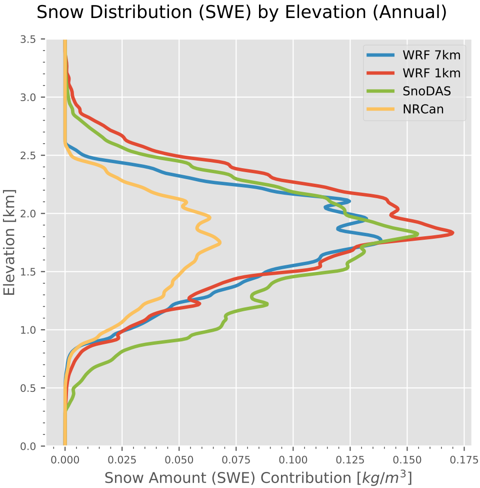

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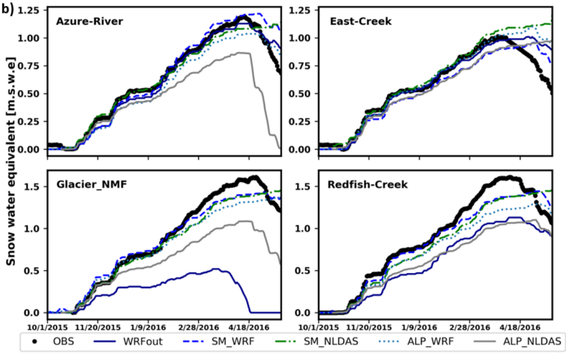
1. Downscaling WRF (1 km) and NLDAS to 30 m over four BC glaciers
2. Simulating accumulation and melt using two snow models (2010 - 2016)
3. Climate change impact simulations based on existing 10 km WRF projections are planned (Erler & Peltier 2017)



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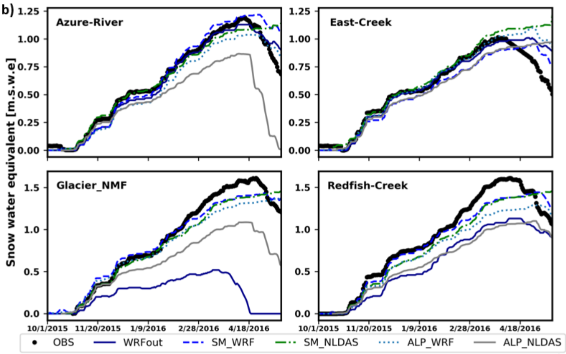

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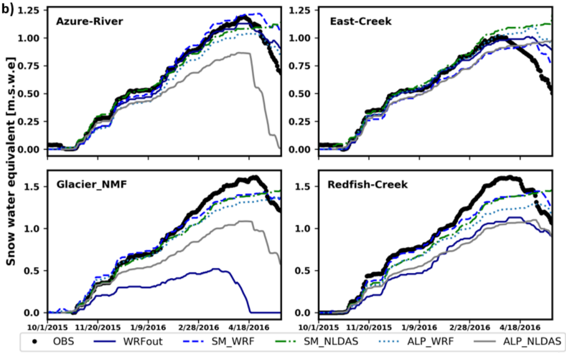

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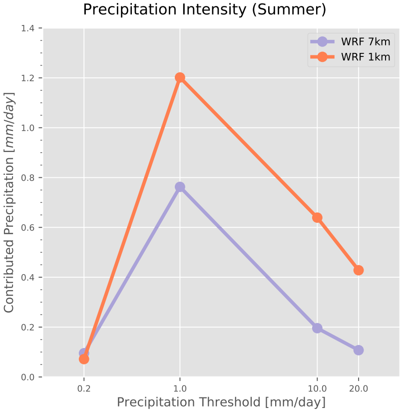
Summary of Results

- 5-year, 1 km WRF simulations over Western Canada / Rockies
- Precipitation at first rain barrier is consistently underestimated
- Temperature / Lapse-rate bias

The Added Value of High Resolution

- Summer-time (orographic) convection is **much** better captured (not perfect, though)
- Snow accumulation at elevation is quite well captured (similar but a bit higher than SnoDAS)



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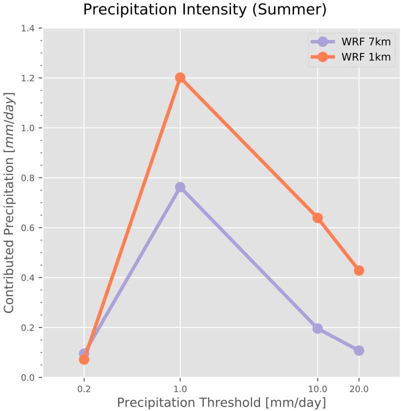

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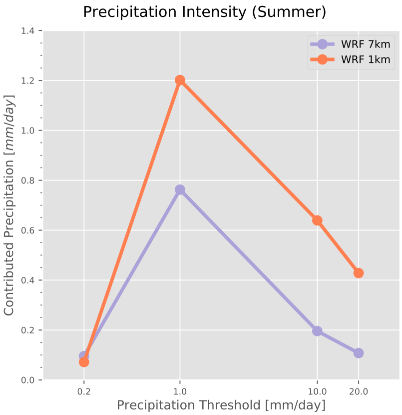

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Aquanty Inc. Team

List of Relevant Publications

- **Erler, Andre R.** and W. Richard Peltier, 2017, "Projected Hydro-climatic Changes in Two Major River Basins at the Canadian West Coast Based on High-resolution Regional Climate Simulations", *Journal of Climate*.
- **Erler, Andre R.** and W. Richard Peltier, 2016, "Projected Changes in Precipitation Extremes for Western Canada based on High-resolution Regional Climate Simulations", *Journal of Climate*.
- **Erler, Andre R.**, W. Richard Peltier and Marc d'Orgeville, 2015, "Dynamically Downscaled High Resolution Hydro-Climate Projections for Western Canada", *Journal of Climate*.
- Peltier, W. Richard, Marc d'Orgeville, **Andre R. Erler** and Fengyi Xie, 2018, "Uncertainty in Future Summer Precipitation in the Laurentian Great Lakes Basin: Dynamical Downscaling and the Influence of Continental Scale Processes on Regional Climate Change", *Journal of Climate*.
- Marc d'Orgeville, W. Richard Peltier and **Andre R. Erler**, Jonathan Gula, 2014, "Climate change impacts on Great Lakes Basin precipitation extremes", *Journal of Geophysical Research*.