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Snow level from post-processing of atmospheric model improves snowfall estimate and snowpack prediction in mountains

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Canada

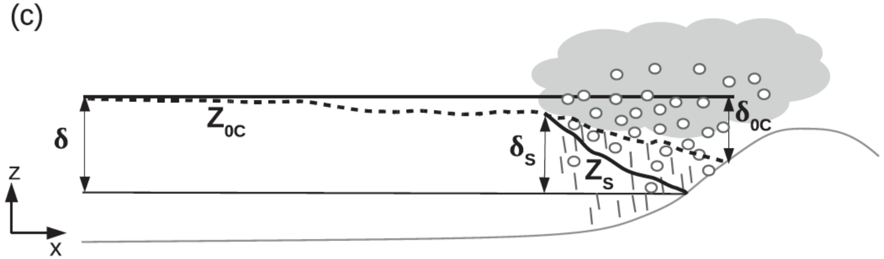
Precipitation phase and snowpack

- **Precipitation phase** influences **snow cover evolution** during the **accumulation** and **ablation** seasons.

- Snowpack schemes in hydrological models typically use **ground-based precipitation–partitioning methods** (PPMs) relying on **near-surface atmospheric variables** (temperature only or combined with humidity)

- **Atmospheric models** can be used to obtain information from **upper atmospheric layers** and obtain **atmospheric-based PPMs.**

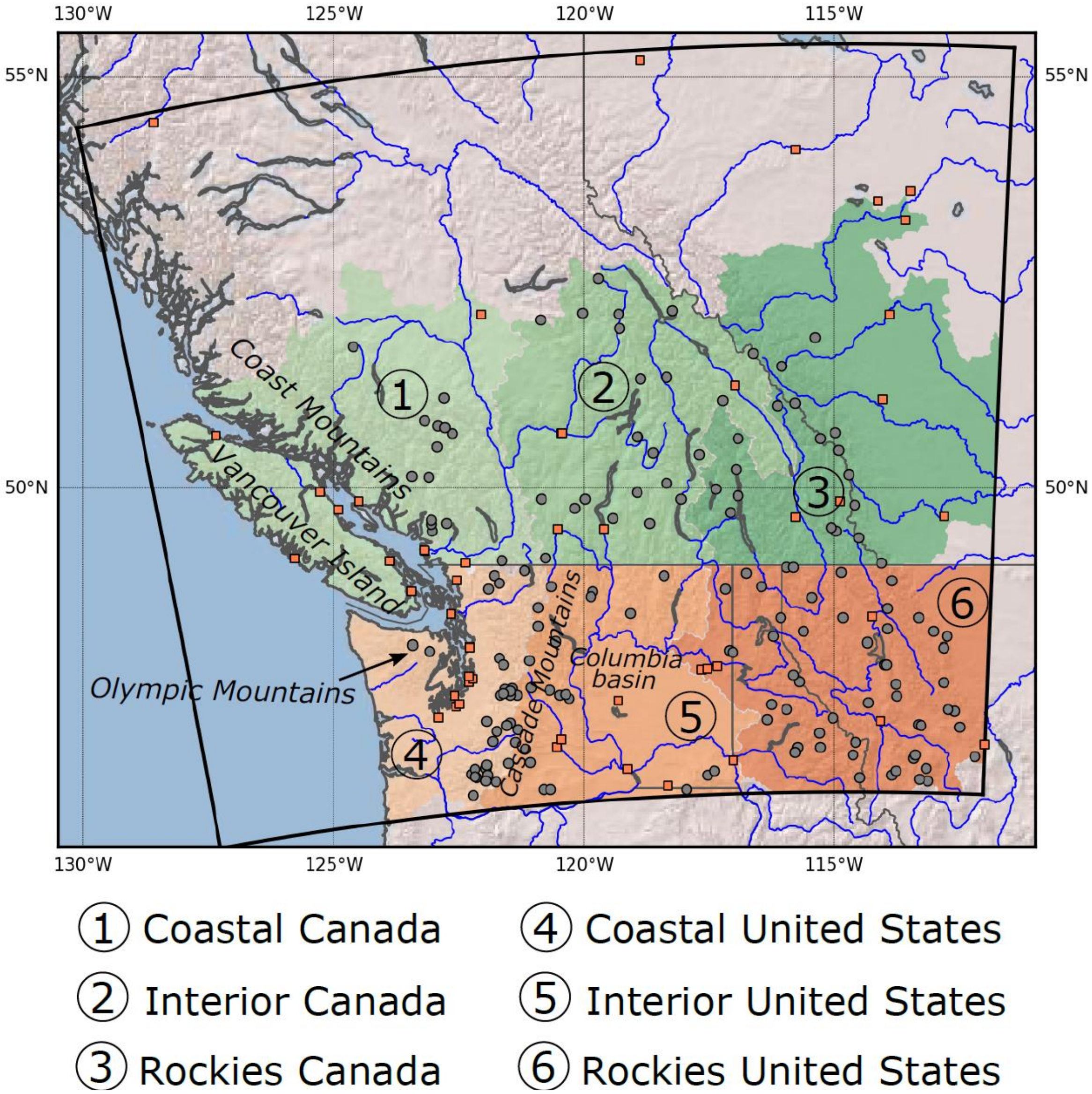
- **Questions:**
  - What is the possible added value of atmospheric based-PPMs relative to ground-based PPMs for snowpack modelling ?
  - Among the atmospheric-based PPMs, what is the benefit of using post-processed precipitation phase compared to raw phase discrimination from the microphysics scheme?



Minder et al. (2011)

Region of interest

- Domain covering southwest Canada and northwest US: 1200 x 1050 km^2
- 6 regions selected for analysis from coastal to interior mountain ranges in Canada and the US
- Observations:
  - Square: Manual stations reporting precipitation type
  - Circle: automatic stations measuring precipitation, snow water equivalent and snow depth:
    - CanSWE in Canada (Vionnet et al., ESSD, 2021)
    - SNOTEL in the US



- NB: Only the stations with elevations within 200 m from the elevation of the 2.5 km grid are shown on this map and used in this study

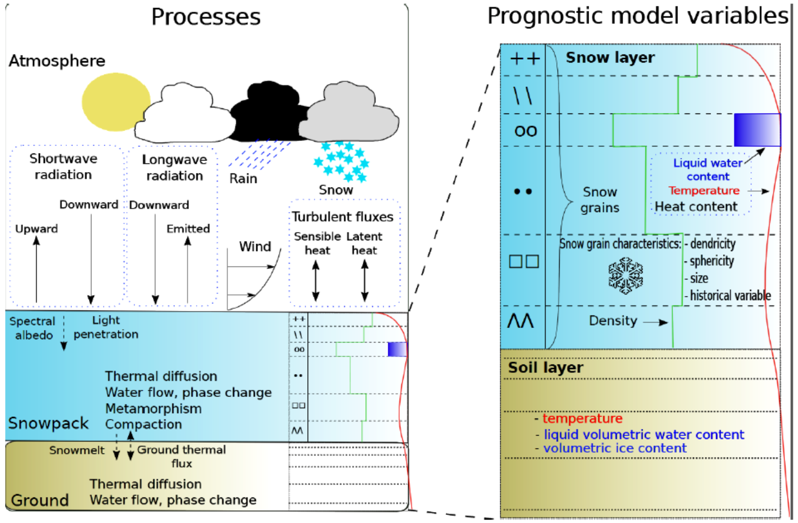
Offline model configuration

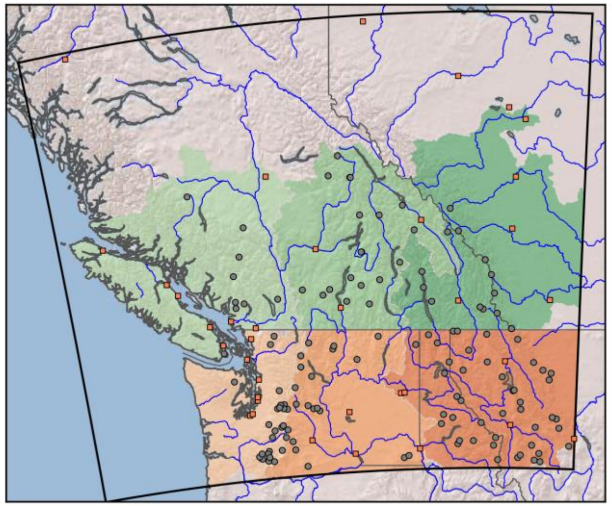
Atmospheric forcing

- T, Q, SW, LW, Wind, Pres.: short-term forecasts from the High-Resolution Deterministic Prediction System (HRDPS) at 2.5-km grid spacing *(Milbrandt et al., 2016)*

- Precipitation: 24-h analysis from CaPA (Canadian Precipitation Analysis)
  - hourly disaggregation using timing of HRDPS precip.
  - Phase estimation using 4 different PPMs

Snowpack simulations



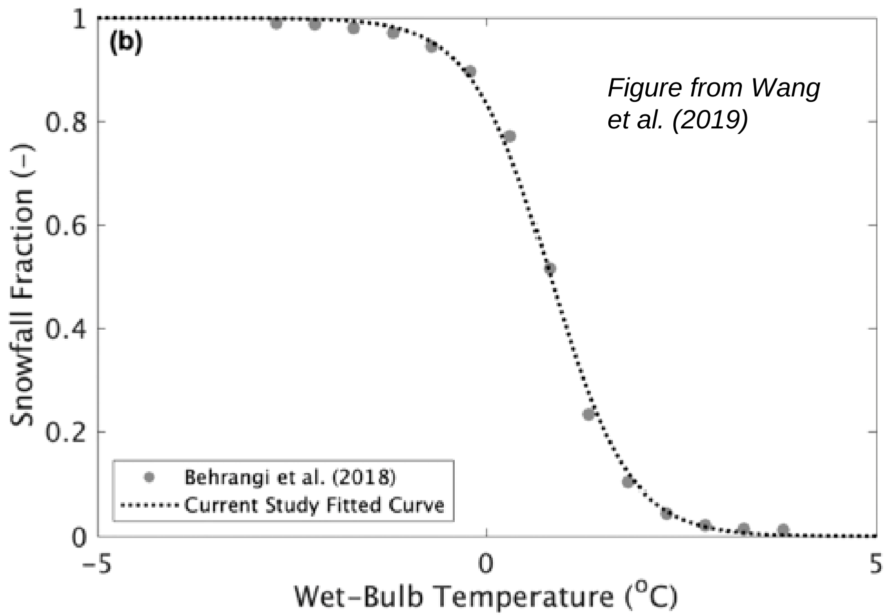


Vionnet et al. (2012)

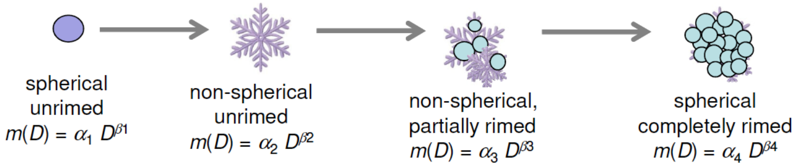
- **GEM-Hydro** modelling platform with an updated version of the SVS land surface scheme (Soil Vegetation and Snow) including the detailed **snowpack model Crocus**
- Area: sub-grid of the HRDPS domain at 2.5-km grid spacing (same orography)
- Simulation from September 1st 2019 to June 30th 2020

PPMs in GEM-Hydro

- **Ground-based PPMs:**
  - ***Lower benchmark: GrdT0***: constant near-surface **air temperature** threshold at 0°C
  - ***Upper benchmark: GrdTW***: snowfall fraction depending on near-surface **wet bulb temperature** (includes humidity effect on precip. phase) *(Wang et al., 2019)*



- **Atmospheric-based PPMs**:
  - ***AtmMP***: precipitation phase taken directly from the P3 **cloud microphysical scheme** implemented in HRDPS *(Morrison and Milbrandt, 2015)*
  - ***AtmSL***: computation of the **snow level** (see next slide) with the Latent Heat Method

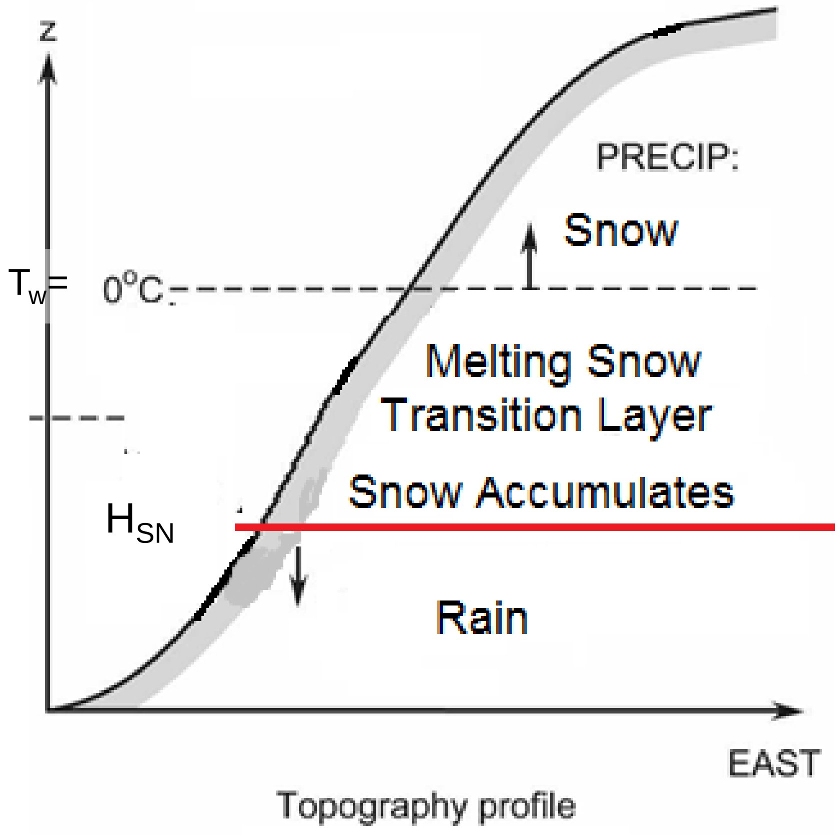


Evolution of ice crystals in the P3 microphysical scheme

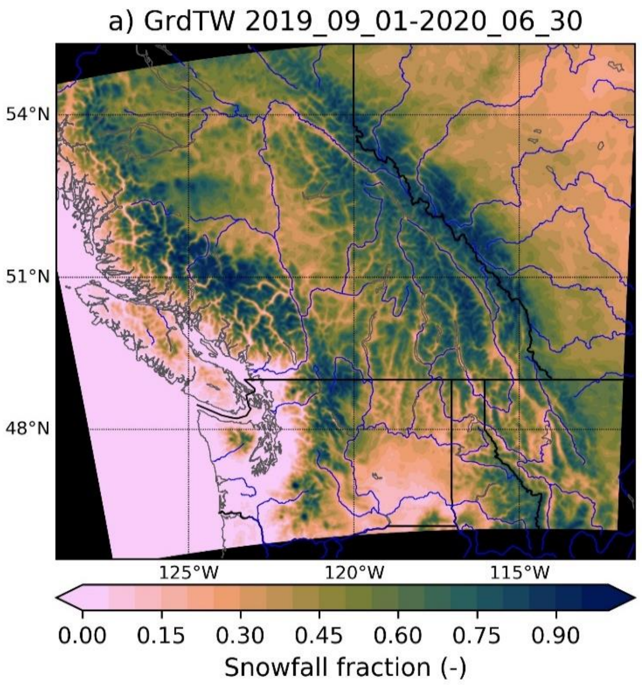
Latent Heat Method (LHM)

- Method to derive the **snow level** H_{SN} (height where the snow has completely melted) using HRDPS **vertical profiles** of **wet-bulb temperature** T_w. Used in operations at ECCC

- **Top to bottom** approach to determine where snow starts to melt (T_w>0)
- Accounts for **latent heat exchanges** in the **transition layer** (cooling due to melt and warming due to condensation; *Kain et al., 2000*)
- H_{SN} depend on precip rate**: large precip. rates** can lead to local **lowering of H_{SN}**



Snowfall fraction



- Variability of snowfall fraction between the coastal and interior

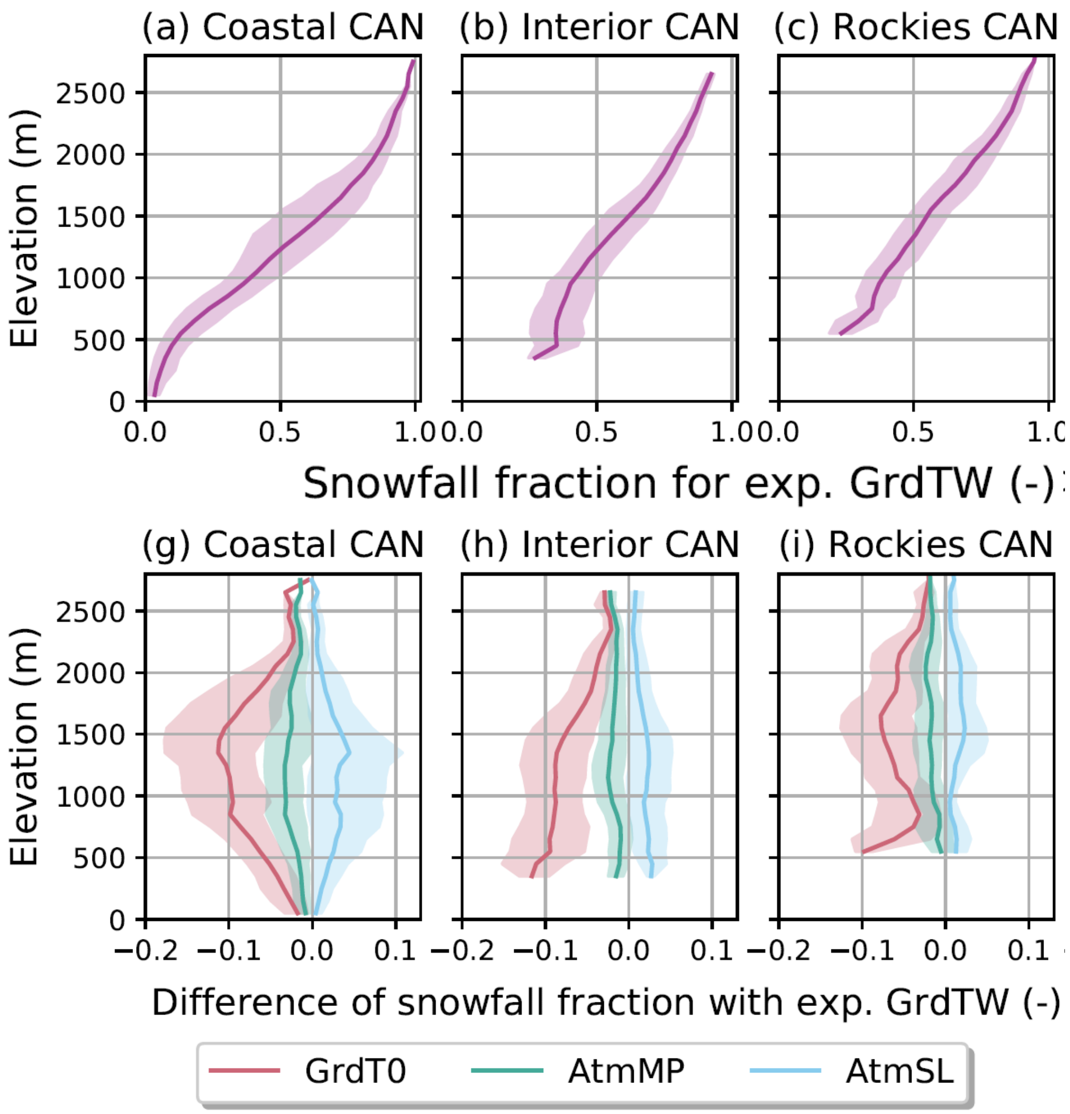
- *GrdT0* provides systematically lower snowfall fraction than *GrdTW* .

- Atmospheric-based PPMs are closer to *GrdTW* than *GrdT*0

- *AtmSL* simulates larger snowfall fraction than *GrdTW* except in the Columbia basin

Snowfall fraction (Tot. Snowfall / Tot. Precip) for GrdTW and differences with othe
PPMs from 1 Sep. 2019 to 30 June 2020

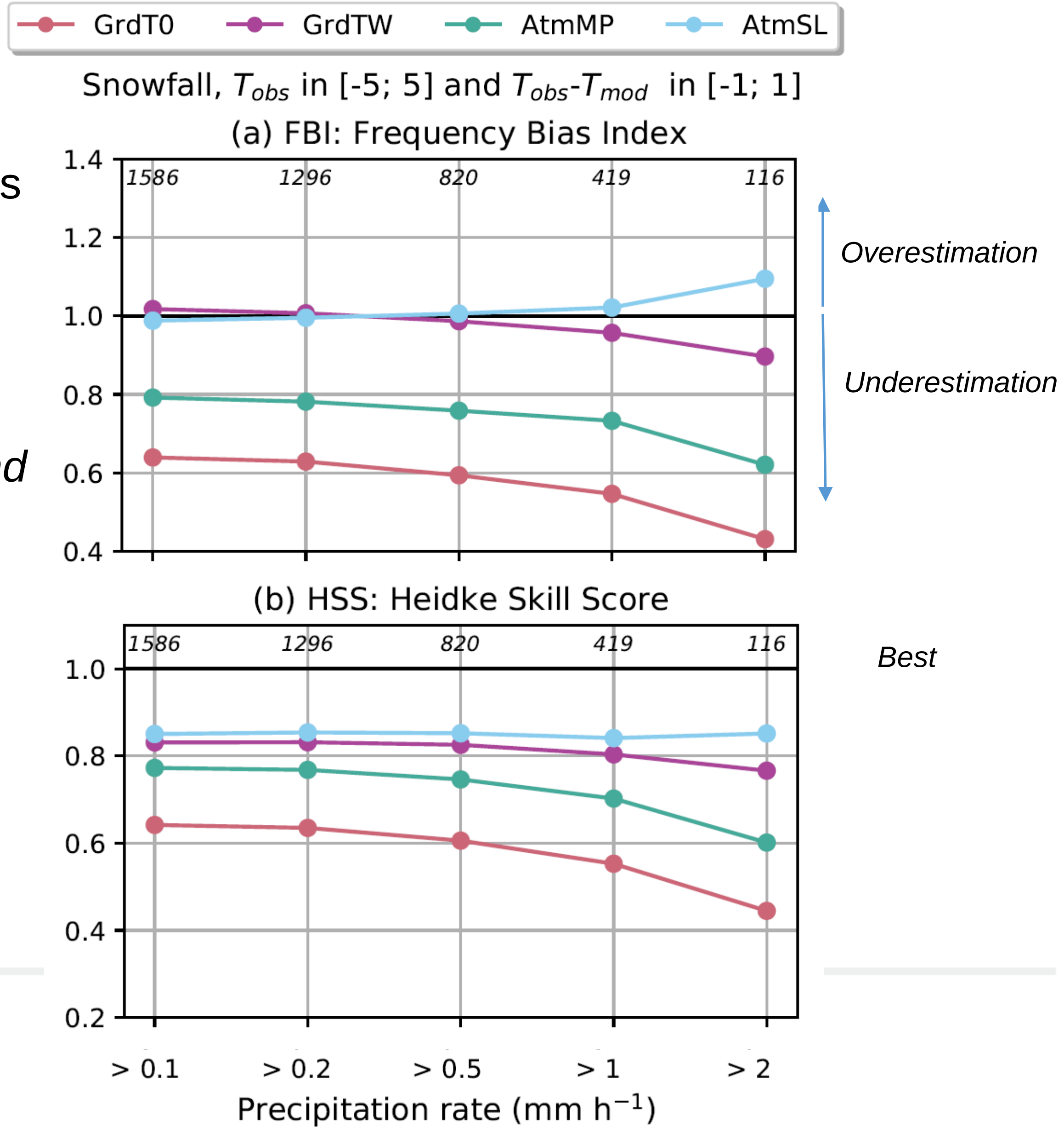
Snowfall fraction



- **Elevation dependency**:
  - Largest differences found between 500 m and 2000 m a.s.l. in most of the regions
  - Above 2000 m: small differences: most of the precipitation is falling as snow.
- Same behavior for the US subregions

Evaluation of precip. phase

- Hourly observations from manual METAR stations compared with simulated precip. phase for different PPMs
- Contingency tables derived for different precipitation thresholds
- **Underestimation** of **snowfall** occurrence with ***GrdT0*** *and* the microphysics scheme (***AtmMP)***
- **Decrease** in **performances** (-12 % in mean HSS) with ***AtmMP*** compared to the upper benchmark ***GrdTW***
- **Increase** in **performances** (+5 % in mean HSS) with the **snow-level** method (*AtmSL)* compared to the upper benchmark ***GrdTW***



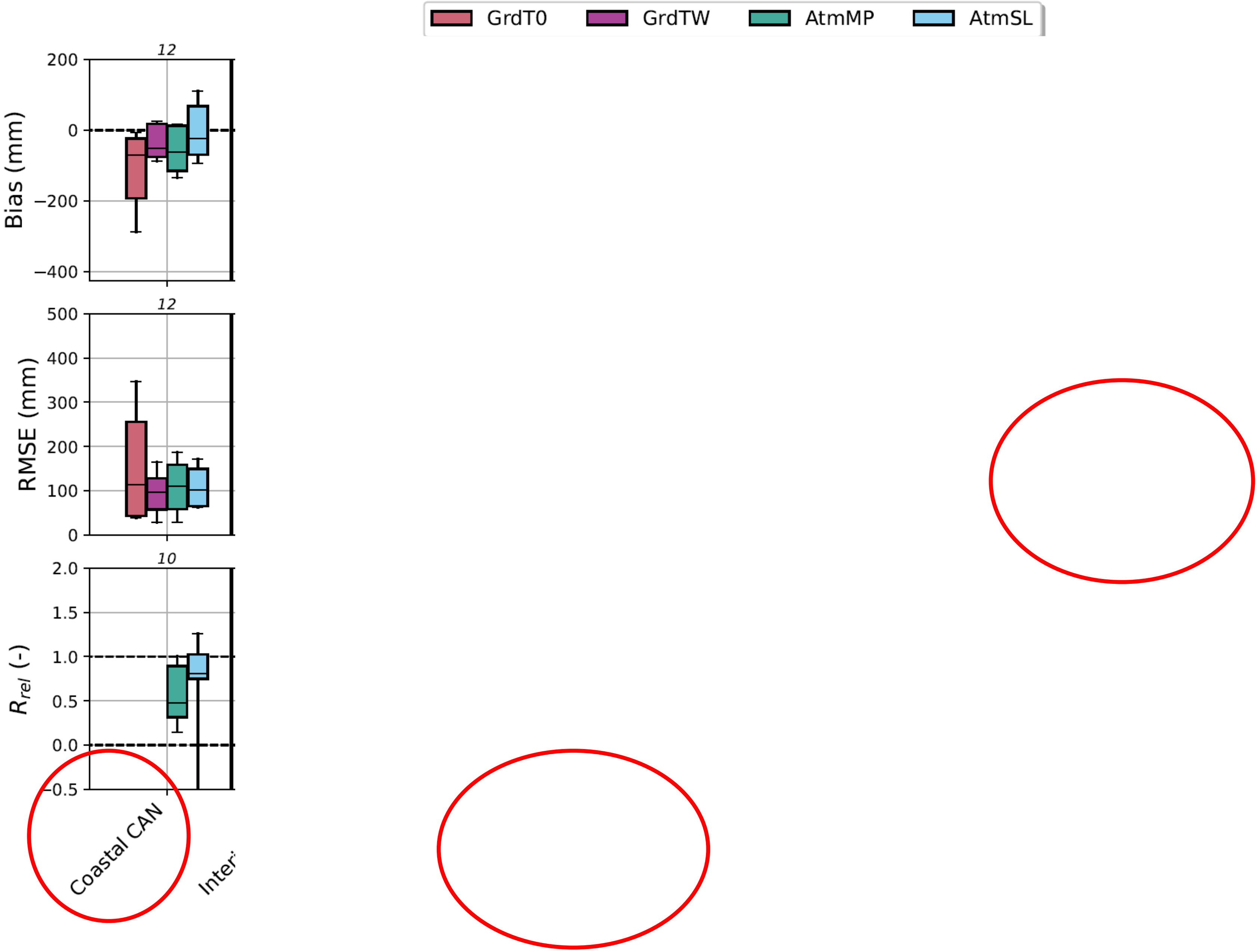
Impact on SWE simulations

Snow accumulation season

- Account for error in precipitation forcing in US regions
- Largest sensitivity in the coastal regions
- **Microphysics scheme** *(AtmMP):* intermediate performances between the two benchmarks
- **Snow-level method** *(AtmSL):* performances similar to the upper benchmark

$$R_{rel} = \frac{RMSE_{GrdT0} - RMSE_{Atm*}}{RMSE_{GrdT0} - RMSE_{GrdTW}}$$

Seibert et al. (2018)



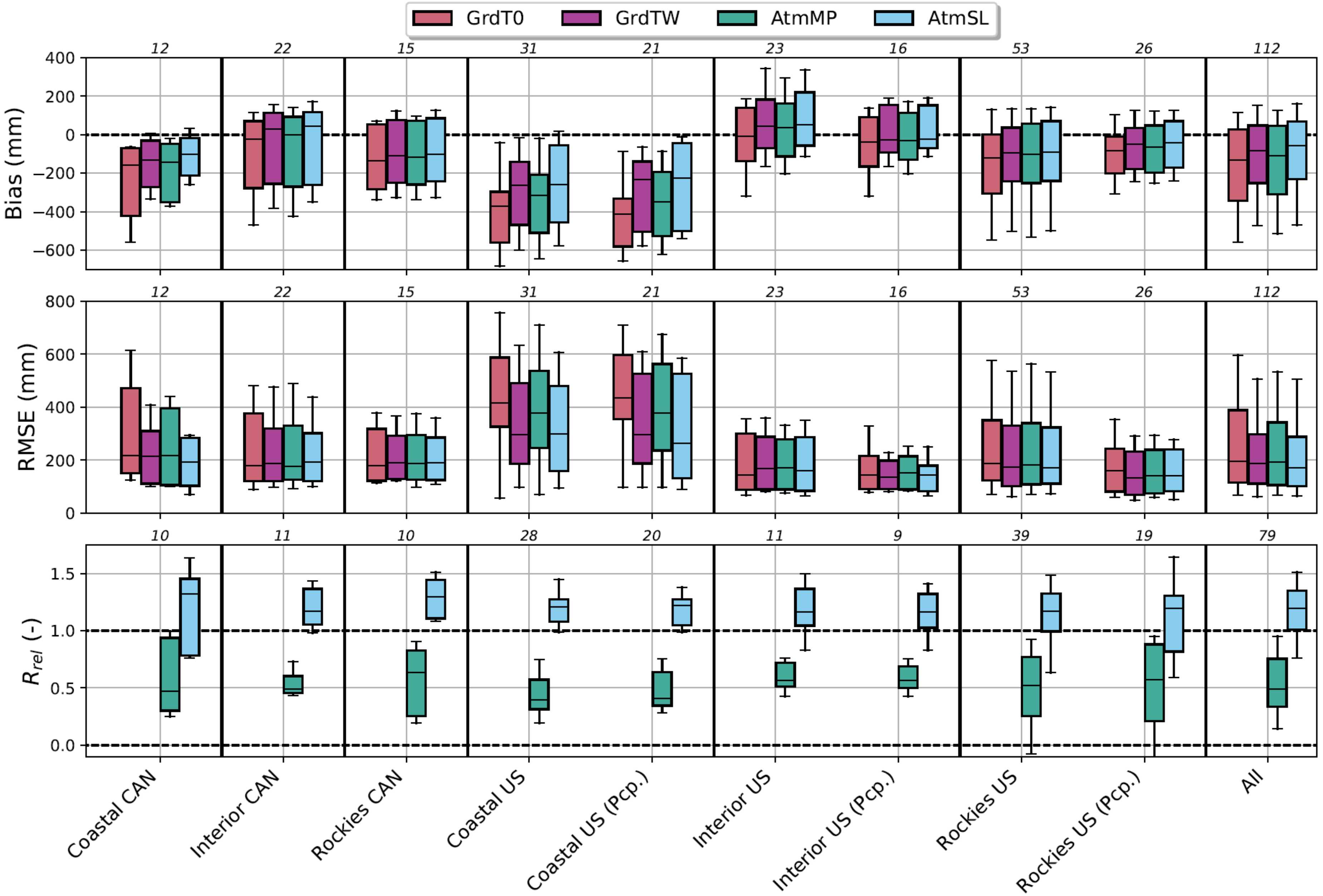
Snow melting season

Impact on SWE simulations

- **Microphysics scheme** (*AtmMP*): intermediate performances between the two benchmarks

- **Snow-level method** *(AtmSL):* improvement compared to the upper benchmark (-9% in median RMSE)

$$R_{rel} = \frac{RMSE_{GrdT0} - RMSE_{Atm*}}{RMSE_{GrdT0} - RMSE_{GrdTW}}$$



Conclusions and perspectives

- Phase from **microphysics scheme** (*AtmMP*)
  - **Intermediate performances** between the **two benchmarks** for phase prediction and snowpack simulations
  - **Missing** representation of the **liquid fraction** on **mixed-phase particle** in P3 may explain this result (on-going work to improve it)
  - **Need** for the hydrology community to **systematically evaluate precipitation phase** from microphysics schemes.

- Snow-level from post-processing (*AtmSL*):
  - **Improvements** in phase prediction and snowpack simulations compared to the **upper benchmark**
  - **Potential** for **mountain snow** hydrology of the **snow-level approach** including upper-air information

- **Future work**:
  - Evaluation during extreme events (e.g. BC flood in November 2021)
  - Downscaling and adaptation required for snowpack simulations at slope scale (e.g. Snowcast)

Vionnet, V., Verville, M., Fortin, V., Brugman, M., Abrahamowicz, M., Lemay, F., Thériault, J.M., Lafaysse M., and Milbrandt, J.A. : Snow level from post-processing of atmospheric model improves snowfall estimates and snowpack predictions in mountains, *Water Resources Research, In revision (minor)*

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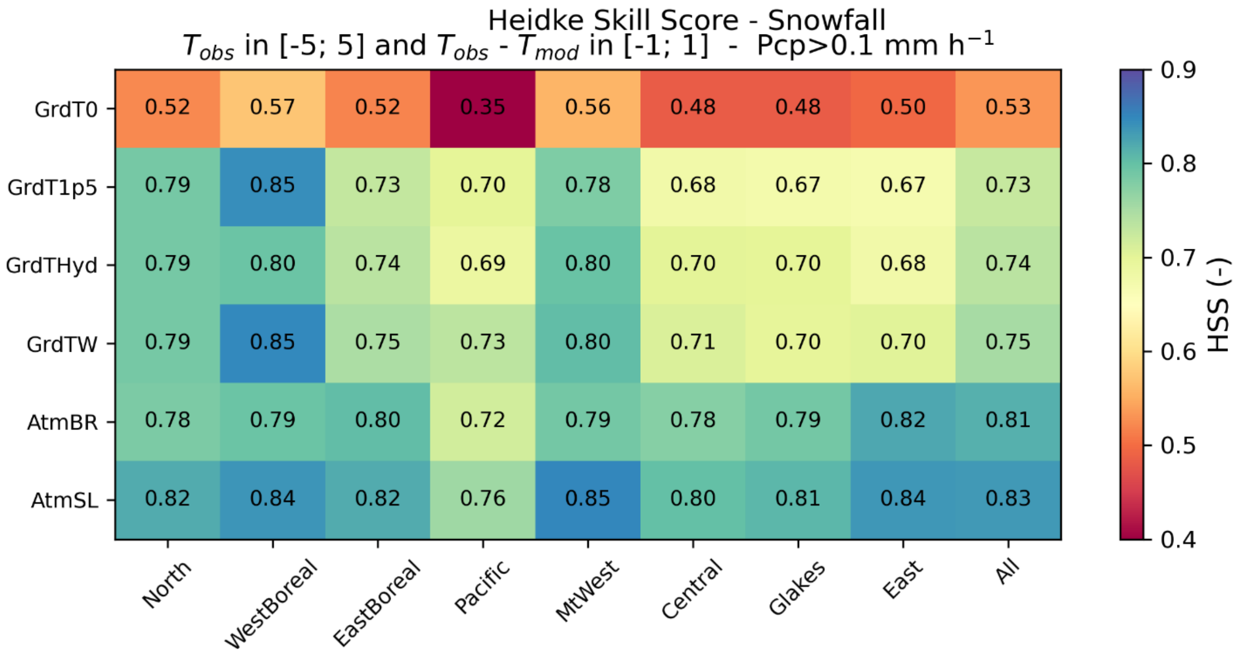
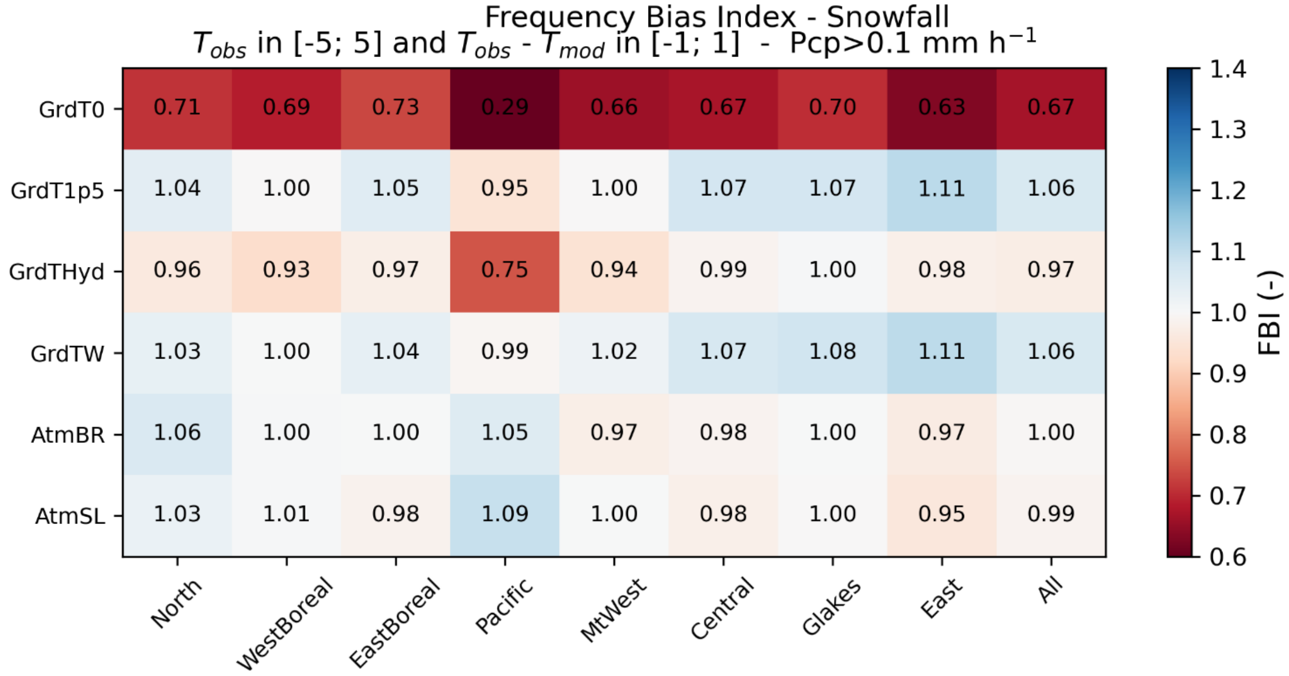
Evaluation across Canada





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