

High-Resolution Snow Modeling for the Crown of the Continent

Theodore Barnhart¹, Erich Peitzsch², Zachary Miller², and Sheree Watson²

¹U.S. Geological Survey, Wyoming-Montana Water Science Center

²U.S. Geological Survey, Northern Rocky Mountain Science Center

Montana Chapter, American Water Resources Association Annual Meeting

October 12, 2023

This information is preliminary and is subject to revision. It is being provided to meet the need for timely best science. The information is provided on the condition that neither the U.S. Geological Survey nor the U.S. Government shall be held liable for any damages resulting from the authorized or unauthorized use of the information.



Presentation Outline

- Where is the Crown of the Continent
- Project Motivation
- Project Partners
- Approach
 - SnowModel
 - Simulation Domains
 - Topography and Land Cover Inputs
 - Driving Meteorology Data
- Evaluation
- Results: Example Analyses
- Data Access
- Conclusions

Where is the Crown of the Continent?

- Headwaters to three of North America's major river systems.
- High-elevation terrain that supplies snowmelt to downstream ecosystems.



Project Motivation

- Understand how changing snowpack processes impact water resources and infrastructure for downstream communities.
 - Snowmelt rate and timing.
 - Rain-on-snow events.
 - Avalanches.
 - Drought
- Contextualize point measurements in space and time.



Project Partners

Blackfeet Nation

Confederated Salish and Kootenai Tribes

Blackfeet Community College

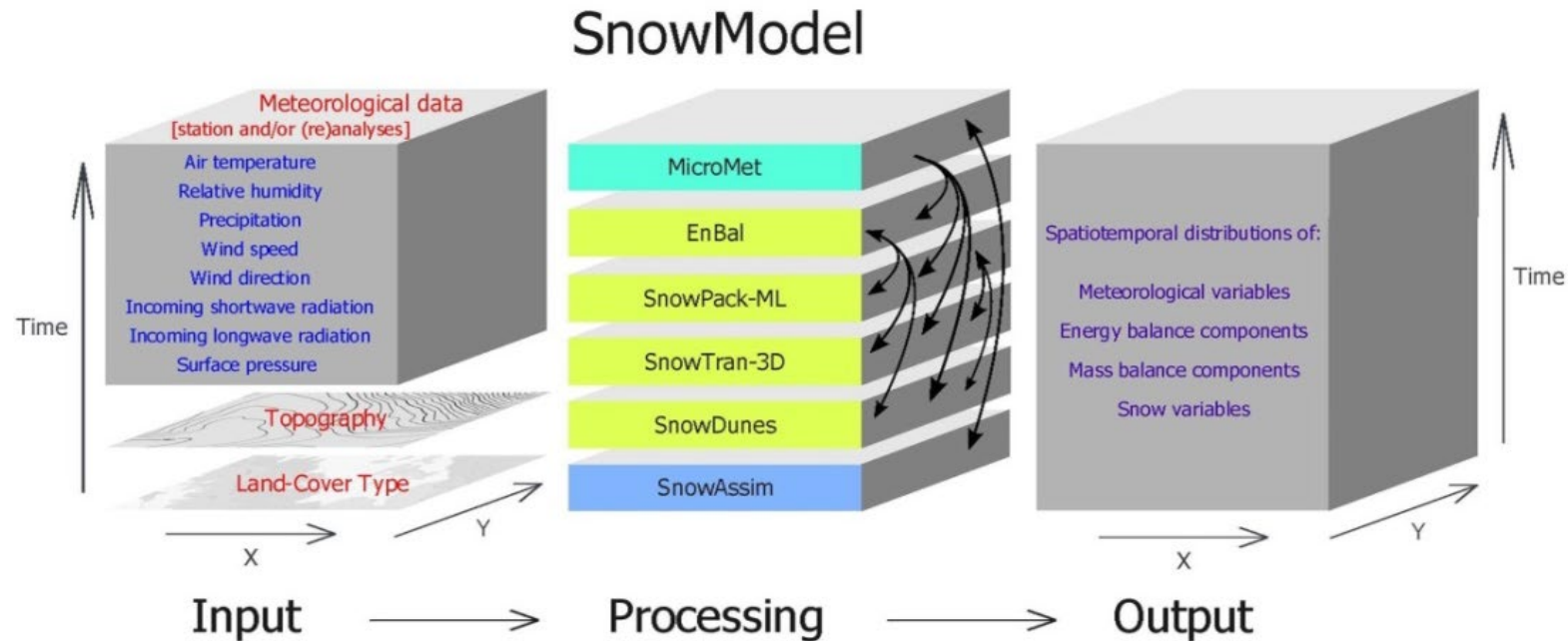
Salish Kootenai College

MT Department of Natural Resources &
Conservation

National Park Service (Glacier National Park)

Approach: SnowModel

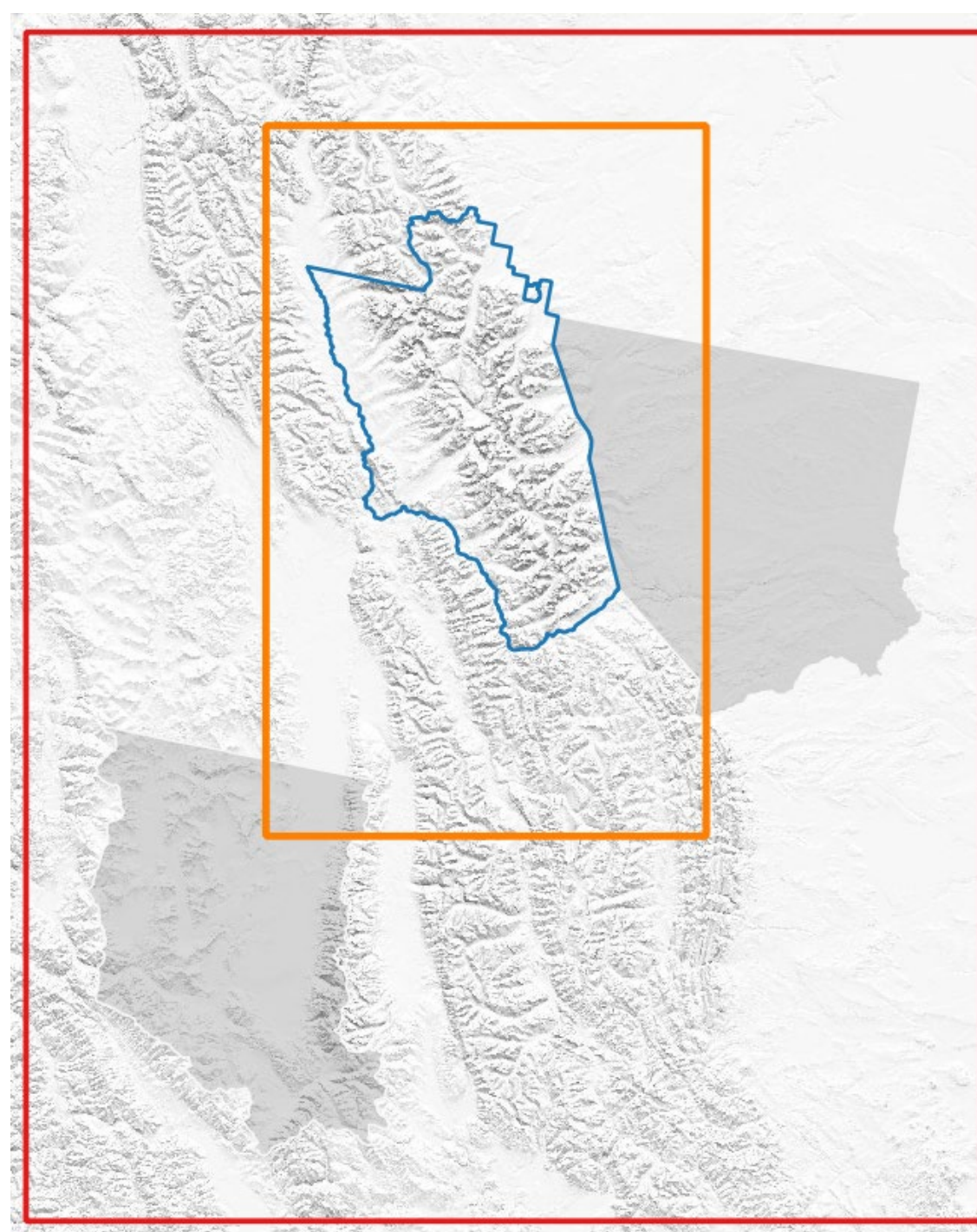
- Numerical snow simulation (Liston and Elder, 2006a).
- Estimates snow water equivalent over the landscape and through time.
- Relevant processes divided into four modules:
 - MicroMet: Distributes driving meteorology (Liston and Elder 2006b).
 - EnBal: Simulates the surface energy balance (Liston, 1995; Liston et al., 1999).
 - SnowPack: Simulates snow accumulation and melt (Liston and Hall, 1995).
 - SnowTran: Simulates blowing snow and sublimation (Liston et al., 2007).



SnowModel schematic showing model inputs, processing modules, and outputs. **Source: Glen Liston**

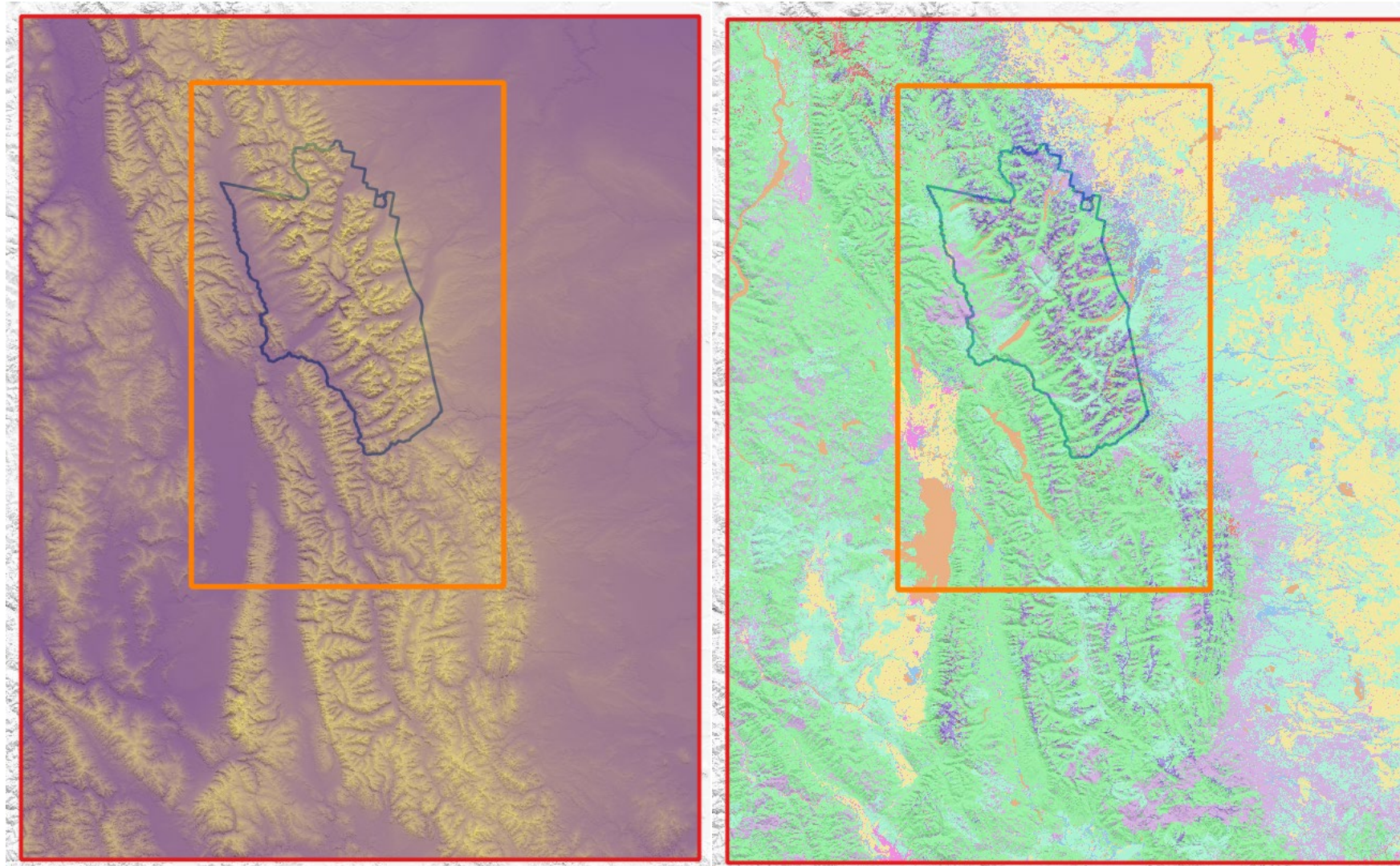
SnowModel: Simulation Domains

- Two simulation domains.
 - Large: 90 m horizontal resolution
 - Small: 30 m horizontal resolution
- Large domain:
 - Upper Flathead River
 - Confederated Salish and Kootenai Reservation
 - Blackfeet Reservation
- Small domain:
 - Focused on Glacier National Park and surrounding watersheds



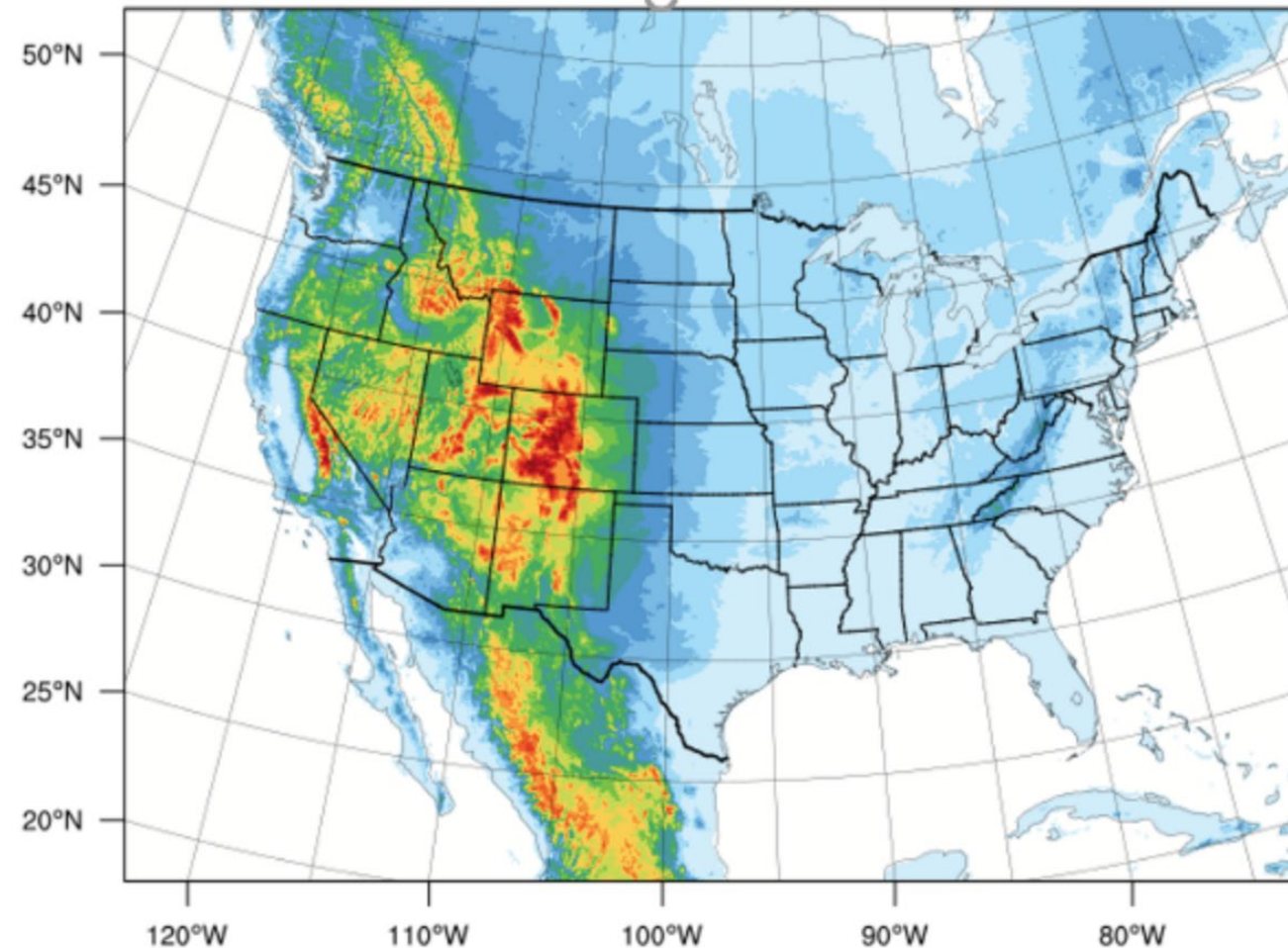
SnowModel: Topography and Land Cover Inputs

- Topography data from USGS (Gesch et al., 2018).
 - 30 m data resampled to 90 m for the larger domain.
- Land cover from the 2010 North America Land Change Monitoring Service (CEC, 2020).
 - Resampled and recoded to SnowModel land cover types.



SnowModel: Driving Meteorology

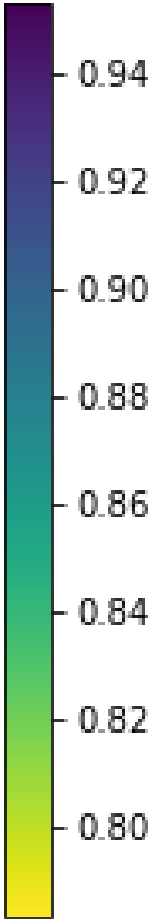
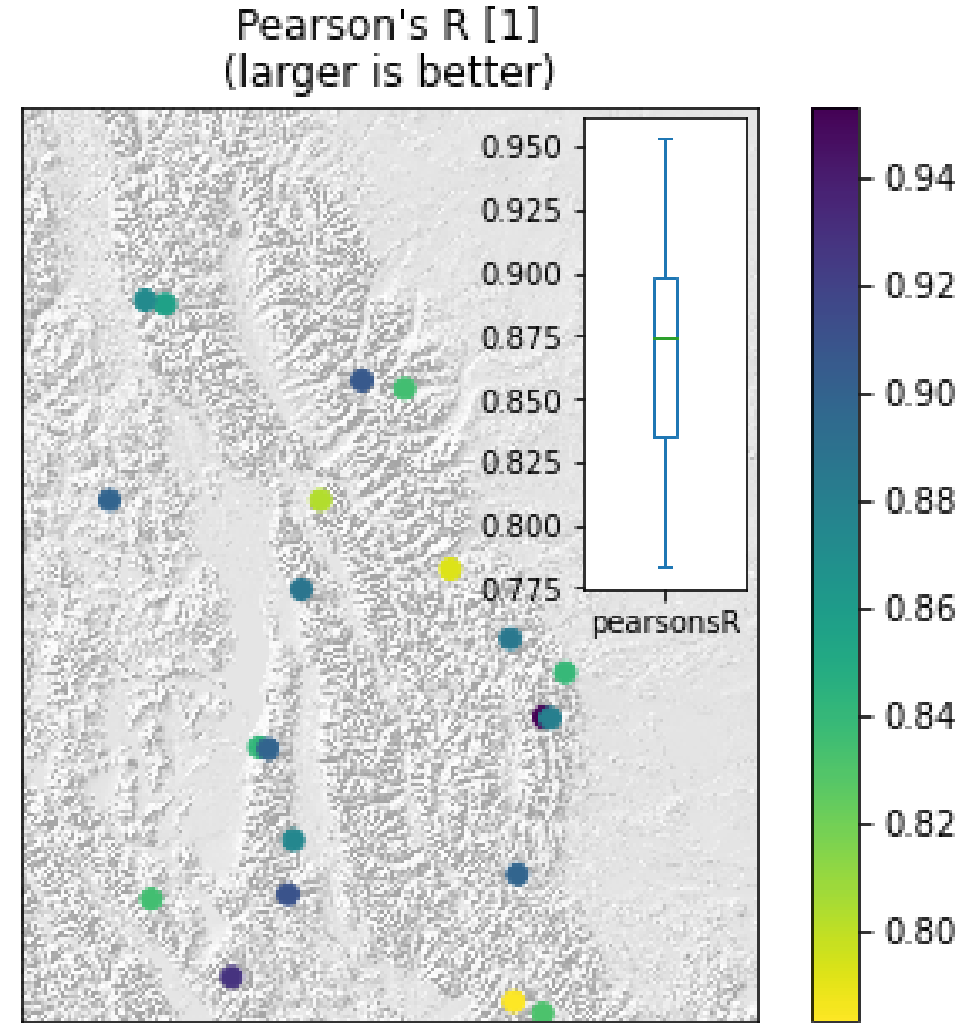
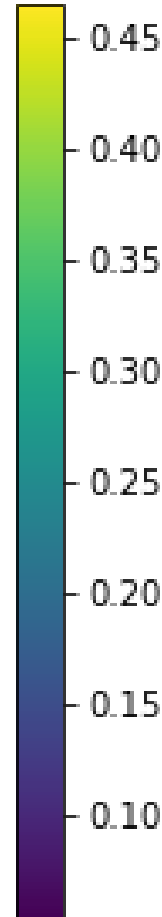
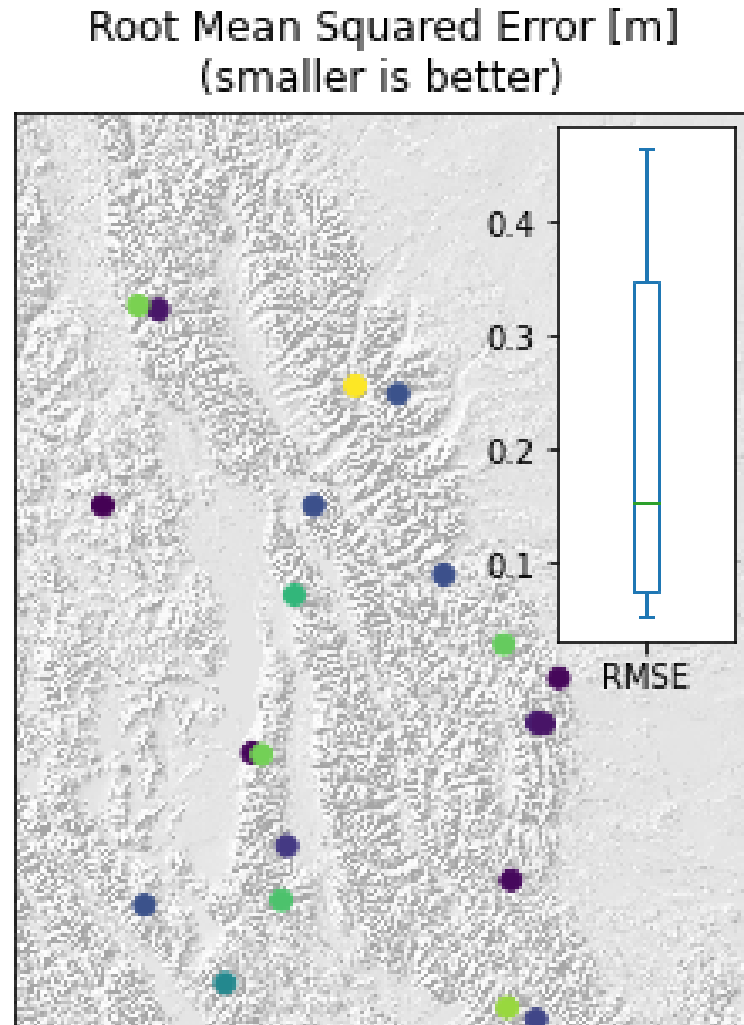
- CONUS 404 Reanalysis Dataset (Rasmussen et al., 2023).
- 4 km hourly meteorology for the contiguous United States and vicinity:
- 3-hourly variables used:
 - Air temperature
 - Precipitation
 - Relative humidity
 - Wind speed
 - Wind direction



Preliminary Information-Subject to
Revision. Not for Citation or Distribution.

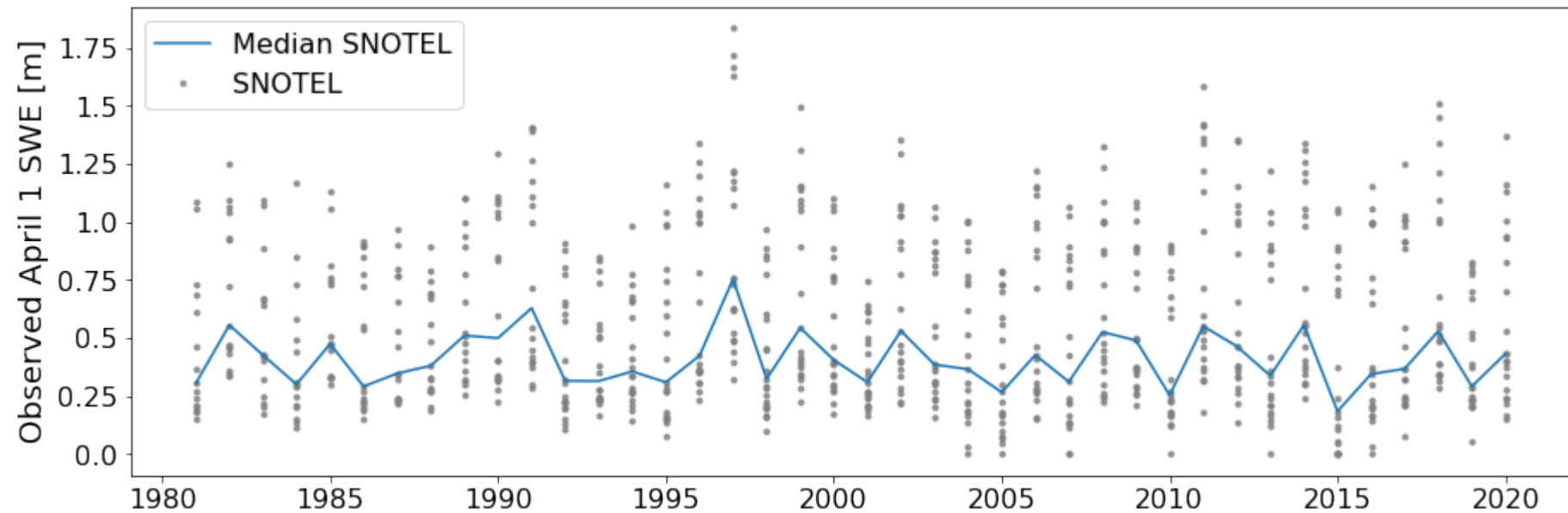
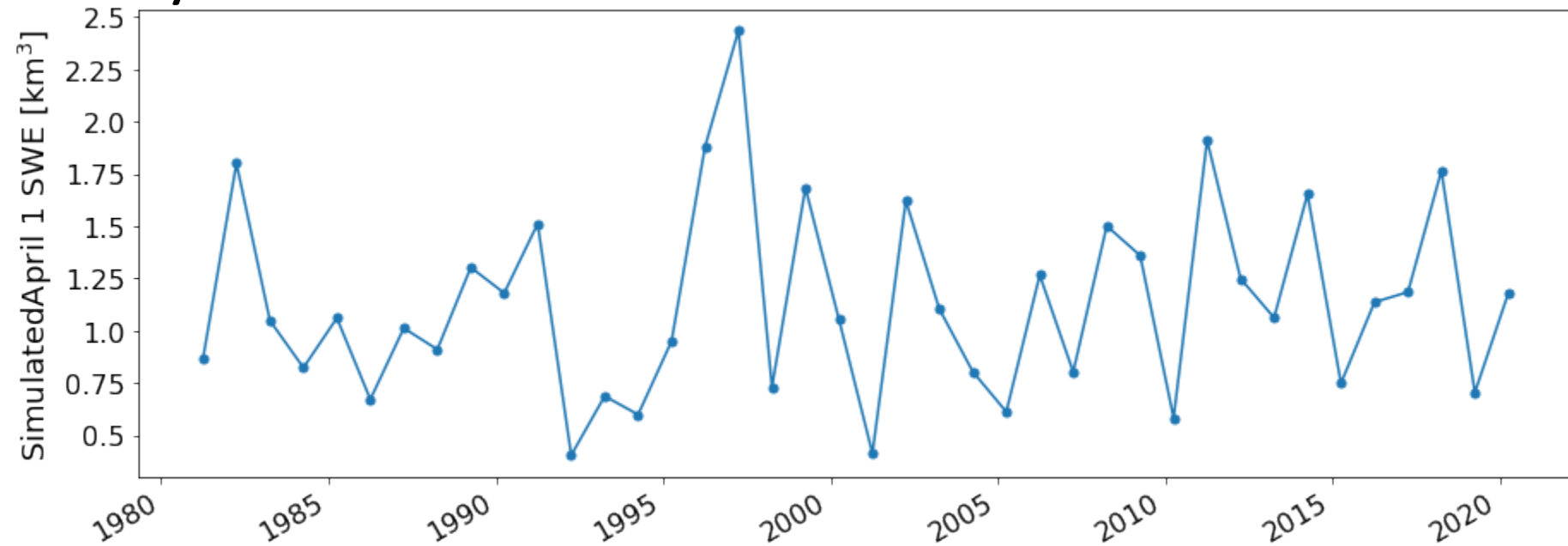
Evaluation: SNOTEL Stations

- SnowModel evaluated against 21 SNOTEL sites.
- Median SWE RMSE was 15 cm.
- Median SWE Pearson's R was 0.87.
- There is quite a lot of spatial variability in RMSE and Pearson's R.

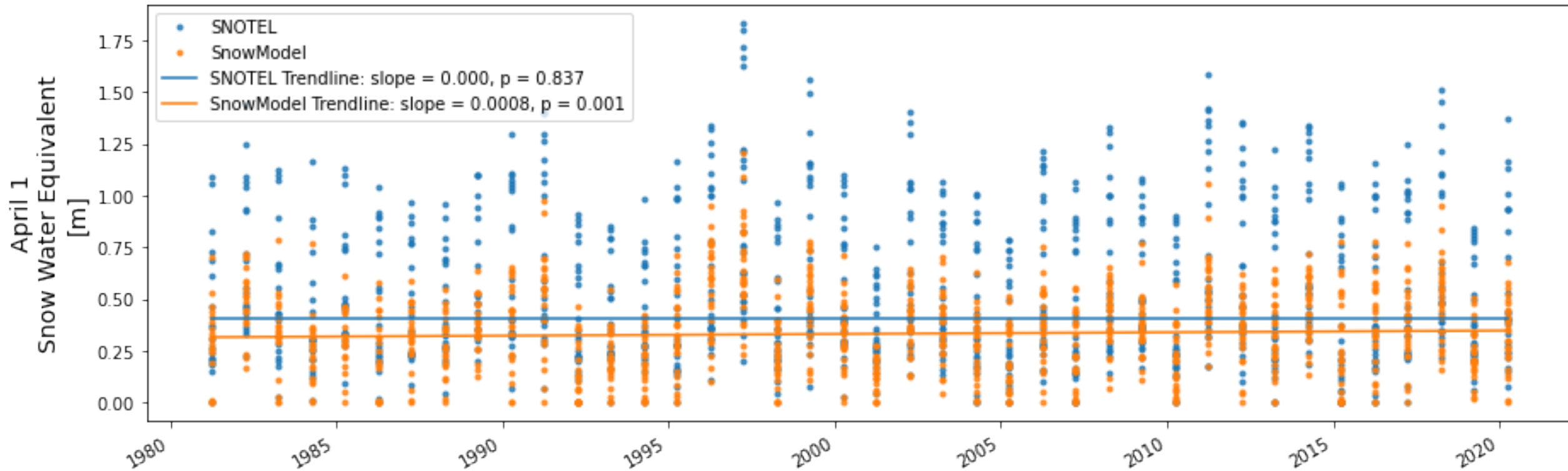


Results: Variability across the domain

- Patterns between cumulative April 1 SWE resources and SNOTEL match.
- SnowModel captures the whole domain while SNOTEL are point samples over the domain.



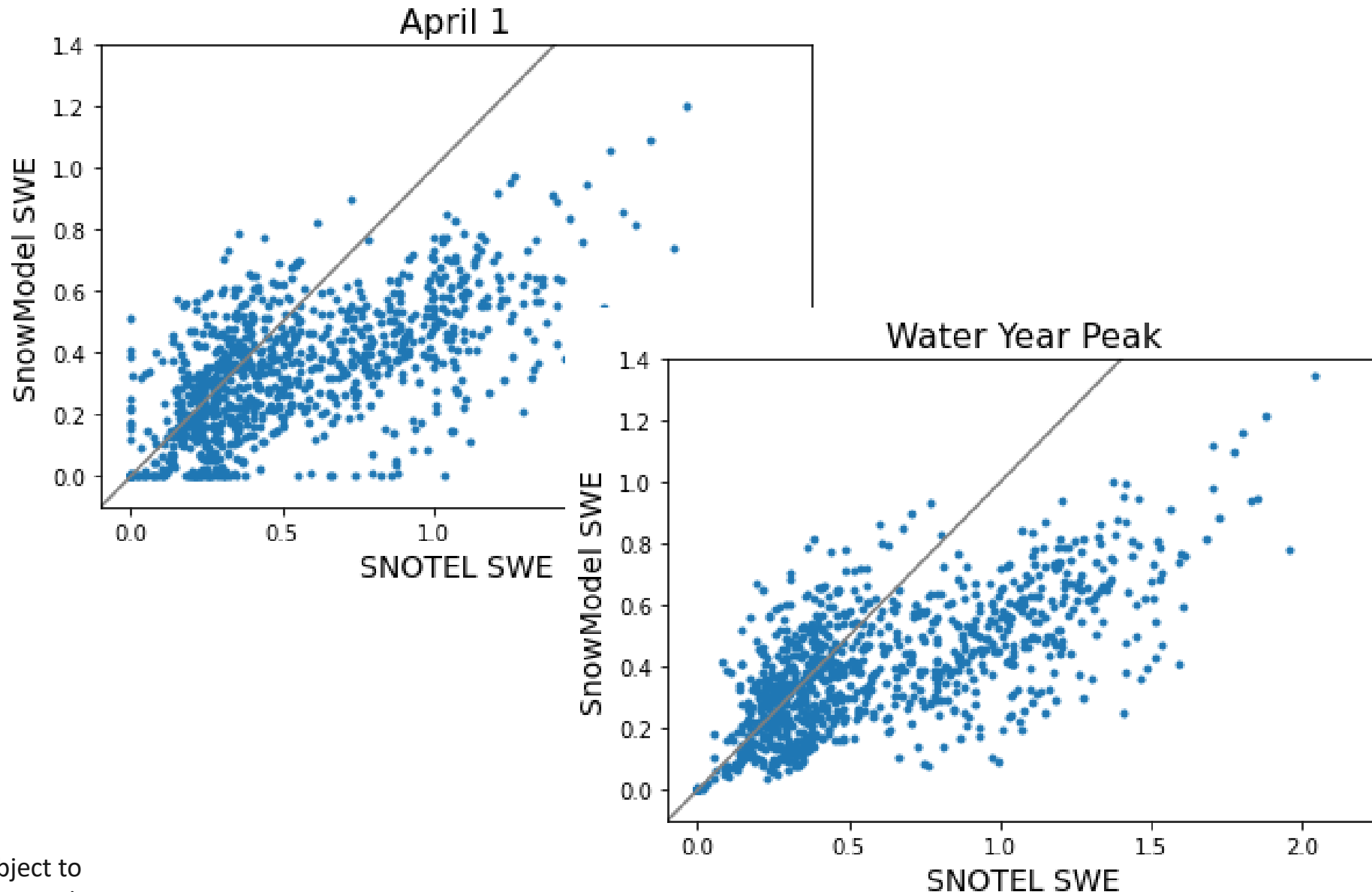
Results: SNOTEL Sites Trends



- Mann-Kendal Regional Trend Test shows no trend in April 1 SWE observations and simulated values at SNOTEL sites.
- SnowModel values are uniformly less than SNOTEL sites.

Results: SnowModel vs SNOTEL Sites

- There is a persistent low-bias in the simulated April 1 SWE and peak SWE.
- High correlation and negative bias suggest temporal pattern matches observations, but simulated values need bias correction.

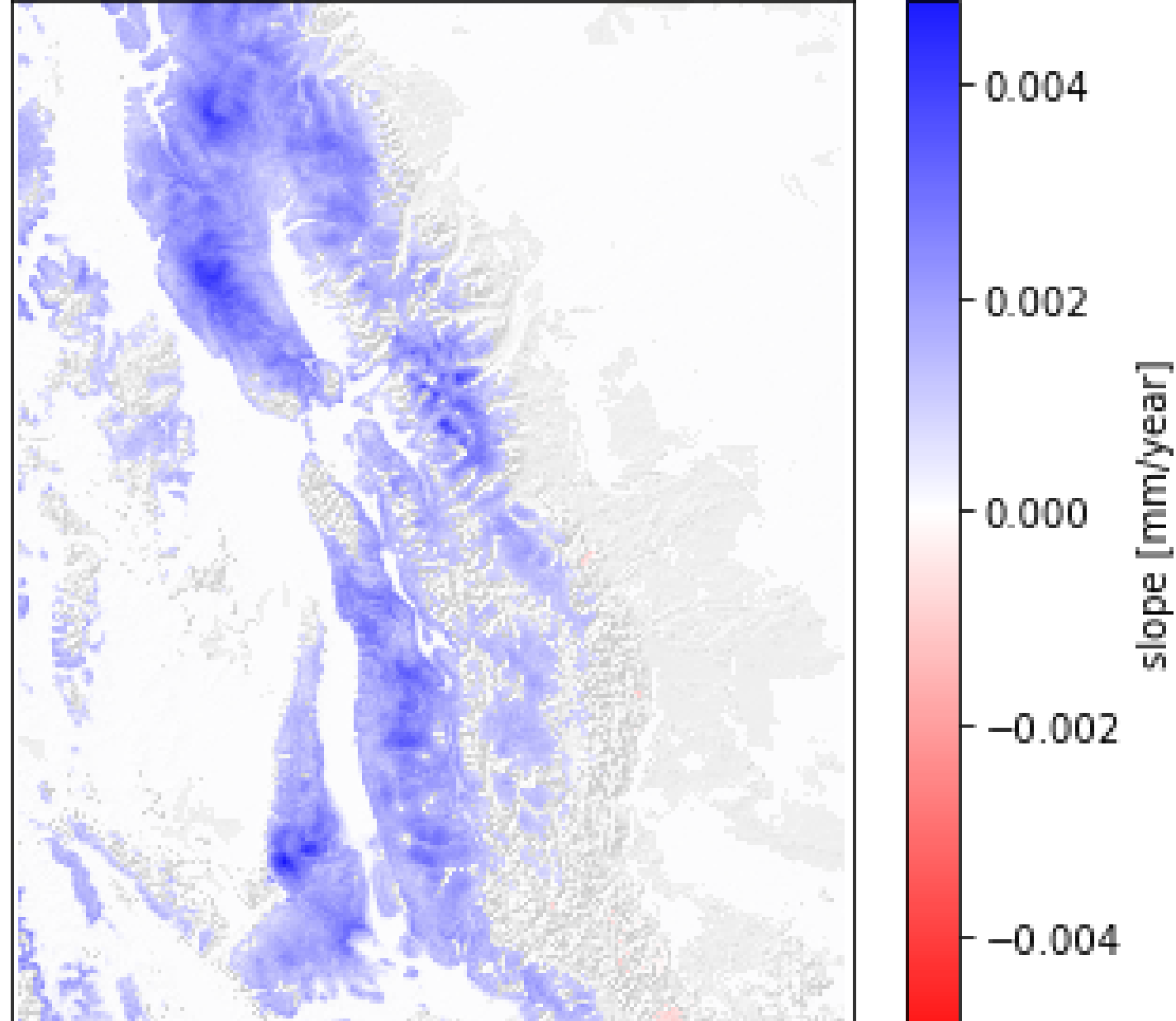


April 1 SWE 4x4 MK Regional Trend Test
 $p < 0.05$

Results: SnowModel

April 1 Trend

- MK regional trend test conducted on 4x4 windows of simulated April 1 SWE.
- Similar to simulated April 1 values at SNOTEL sites there appears to be a very modest positive trend, particularly in the high-elevation portions of the domain.



Data Access:



A screenshot of the USGS ScienceBase Catalog website. The top navigation bar includes the USGS logo, "ScienceBase-Catalog", "Communities", and "Help". Below the navigation bar is a breadcrumb trail: "ScienceBase Catalog → Northern Rock... → Northern Rock... → Historical simul...". The main content area displays the title: "Historical simulated snowpack and other hydrometeorology data at 90 m for the Crown of the Continent and vicinity, United States and Canada, water years 1981-2020".

- 90 m USGS Data Release: <https://doi.org/10.5066/P9TB1F2M> [just released!]
- 30 m USGS Data Release: <https://doi.org/10.5066/P9N5LP2H> [in review]
- Collections of netCDF files:
 - Daily data for 15 SnowModel variables
 - Monthly summaries [90 m data only]
 - Annual peak SWE summary [90 m data only]
- Shapefiles:
 - HUC12 monthly watershed summaries [90 m data only]
- ~1.7 TB dataset in total.

Preliminary Information-Subject to
Revision. Not for Citation or Distribution.

Conclusions

- 30 m and 90 m snow climatology data generated for the Crown of the Continent.
- There was good temporal correspondence between SnowModel and SNOTEL (median $R = 0.87$).
 - RMSE was spatially variable (0.06 cm – 0.46 cm; median = 15 cm)
- There appears to be a dry bias in simulated SWE compared to SNOTEL observations.
- Lack of strong temporal trends matches between SNOTEL observations and SnowModel.
- Spatially, positive temporal trends are slightly stronger in high-elevation portions of the domain.
- These data have been used for a MS project at Salish Kootenai College.
- Glacier National Park is interested in the data for ecology studies and road maintenance.



Questions?

References

- Canada Centre for Remote Sensing. (2020). Canada Centre for Mapping and Earth Observation, Natural Resources Canada, Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, Comisión Nacional Forestal, Instituto Nacional de Estadística y Geografía, U.S. Geological Survey, 2020: 2010 Land Cover of North America at 30 meters. Version 2.0. Retrieved from <http://www.cec.org/north-american-environmental-atlas/land-cover-2010-landsat-30m/>
- Gesch, D. B., Evans, G. A., Oimoen, M. J., & Arundel, S. (2018). The National Elevation Dataset (pp. 83–110). American Society for Photogrammetry and Remote Sensing. Retrieved from <http://pubs.er.usgs.gov/publication/70201572>
- Liston, G. E. (1995). Local Advection of Momentum, Heat, and Moisture during the Melt of Patchy Snow Covers. *Journal of Applied Meteorology*, 34(7), 1705–1715. <https://doi.org/10.1175/1520-0450-34.7.1705>
- Liston, G. E., & Elder, K. (2006a). A Distributed Snow-Evolution Modeling System (SnowModel). *Journal of Hydrometeorology*, 7(6), 1259–1276. <https://doi.org/10.1175/JHM548.1>
- Liston, G. E., & Elder, K. (2006b). A Meteorological Distribution System for High-Resolution Terrestrial Modeling (MicroMet). *Journal of Hydrometeorology*, 7(2), 217–234. <https://doi.org/10.1175/JHM486.1>
- Liston, G. E., & Hall, D. K. (1995). An energy-balance model of lake-ice evolution. *Journal of Glaciology*, 41(138), 373–382. <https://doi.org/10.3189/S0022143000016245>
- Liston, G. E., Winther, J.-G., Bruland, O., Elvehøy, H., & Sand, K. (1999). Below-surface ice melt on the coastal Antarctic ice sheet. *Journal of Glaciology*, 45(150), 273–285. <https://doi.org/10.3189/002214399793377130>
- Liston, G. E., Haehnel, R. B., Sturm, M., Hiemstra, C. A., Berezovskaya, S., & Tabler, R. D. (2007). Simulating complex snow distributions in windy environments using SnowTran-3D. *Journal of Glaciology*, 53(181), 241–256. <https://doi.org/10.3189/172756507782202865>
- Rasmussen, R.M., Chen, F., Liu, C. H., Ikeda, K., Prein, A., Kim, J., et al. (2023). CONUS404: The NCAR-USGS 4-km long-term regional hydroclimate reanalysis over the CONUS. *Bulletin of the American Meteorological Society*. <https://doi.org/10.1175/BAMS-D-21-0326.1>
- Rasmussen, Roy M., Liu, C., Ikeda, K., Chen, F., Kim, J.-H., Schneider, T., et al. (2023). Four-kilometer long-term regional hydroclimate reanalysis over the conterminous United States (CONUS), 1979-2020 [Other]. U.S. Geological Survey. <https://doi.org/10.5066/P9PHPK4F>