Million km² large-extent snowdrift-permitting snowpack predictions

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Animation + Poster

Background

- Need to improve the predictions of mountain snowpacks to aid in water supply forecasts for local and downstream populations, ecosystems, floods, hydroelectricity, and irrigated agriculture
- Remote-sensed observations of snowpack limitations:
  - Airborne lidar has limited spatial extent, measures only depth, and is challenged under dense forest canopies.
  - Satellite-derived snow depth (e.g., Pleiades) has large errors in steep terrain
  - Microwave unsuitable for deep snow, sub-canopy snow, wet snow, ice layers
- A solution is to use multiscale land surface models to simulate winter processes

Science Objectives

1. Can a deterministic, non-calibrated, snowdrift-permitting model be applied to a spatial extent ≥ 1M km²?
2. Are late-lying snowpacks well captured by these models?
3. What are the implications of neglecting redistribution processes in hydrological predictions?

Methodology

- Simulate snowpacks via Canadian Hydrological Model (CHM) including avalanching, blowing snow redistribution, canopy interception and shading for 1.3M km² at a snowdrift-permitting resolution
- Falsification with and without snow redistribution (avalanche + blowing snow)
- Multi-scale evaluation using: Landsat8 and Sentinel2 Snow Covered Area (SCA), lidar observed snow depths, and point observations of snow water equivalent (SWE)
- Evaluate falsification at regional scale by aggregating gridded SWE to MERIT basins in each region (Fig1). Basins were then binned for outlet elevation and then aggregated for regions shown in Figure 1

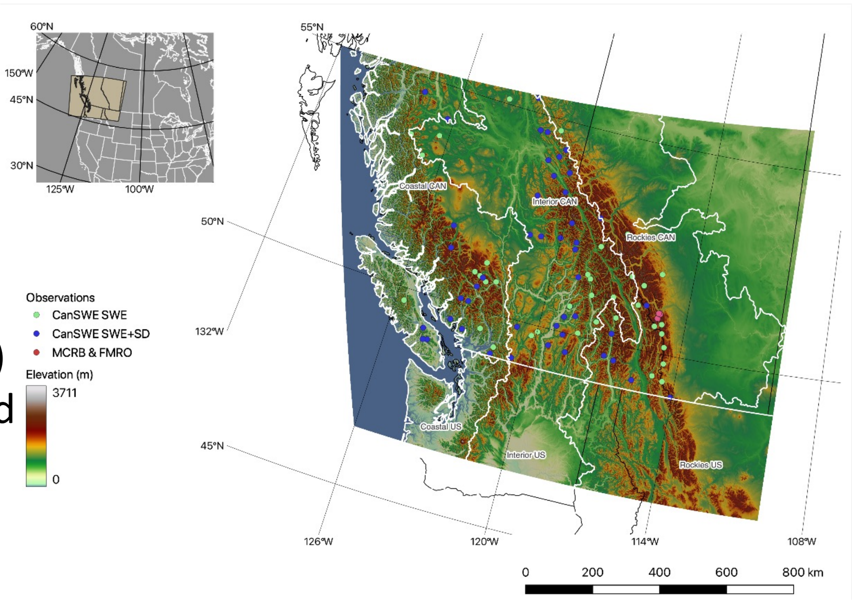

Figure 1: Simulation domain, broad regions shown in white. Locations of point observations shown as dots. Lidar obtained at Fortress Mountain (FMRO)

High Performance Computing (HPC) Advances in CHM

- Massively parallel code via Message Passing Interface (MPI)
- Inclusion of new parallel linear algebra solver Trilinos allows for a global solution to blowing snow
- The SnowSlide avalanche scheme was improved to be MPI aware
- Model outputs are now regridded using the MPI Earth System Modelling Framework (ESMF)
- Domain partitioning uses METIS to minimize MPI communication

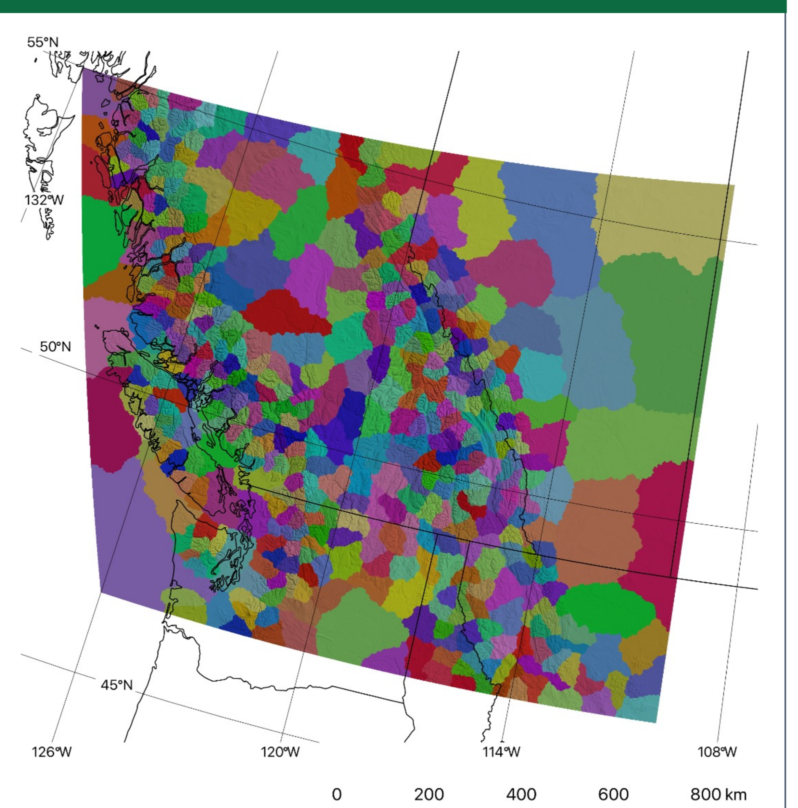

Figure 2: MPI domain decomposition. Domains minimize MPI communication

Conclusions

Including redistribution had the largest impact on late spring and summer seasons because it captured late-lying drifts and avalanche deposits

Including redistribution was shown to be important at a large-extent, regional scale

In some regions, neglecting snow redistribution resulted in errors in SWE of 100% for multiple months

Large-extent Results

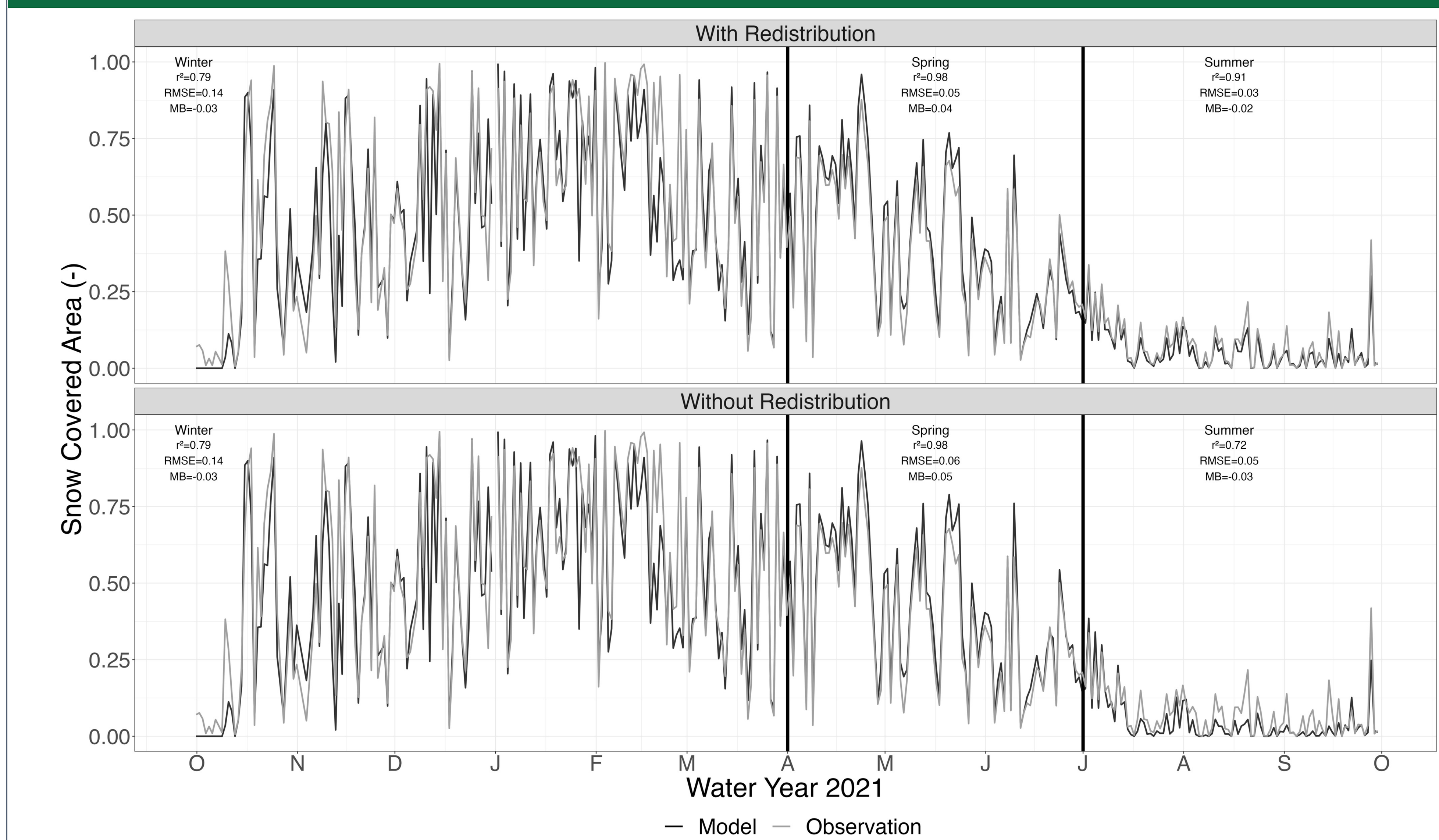

Figure 3: Daily SCA observations (L8+S2) versus SCA derived from CHM. Largest differences in the summer season

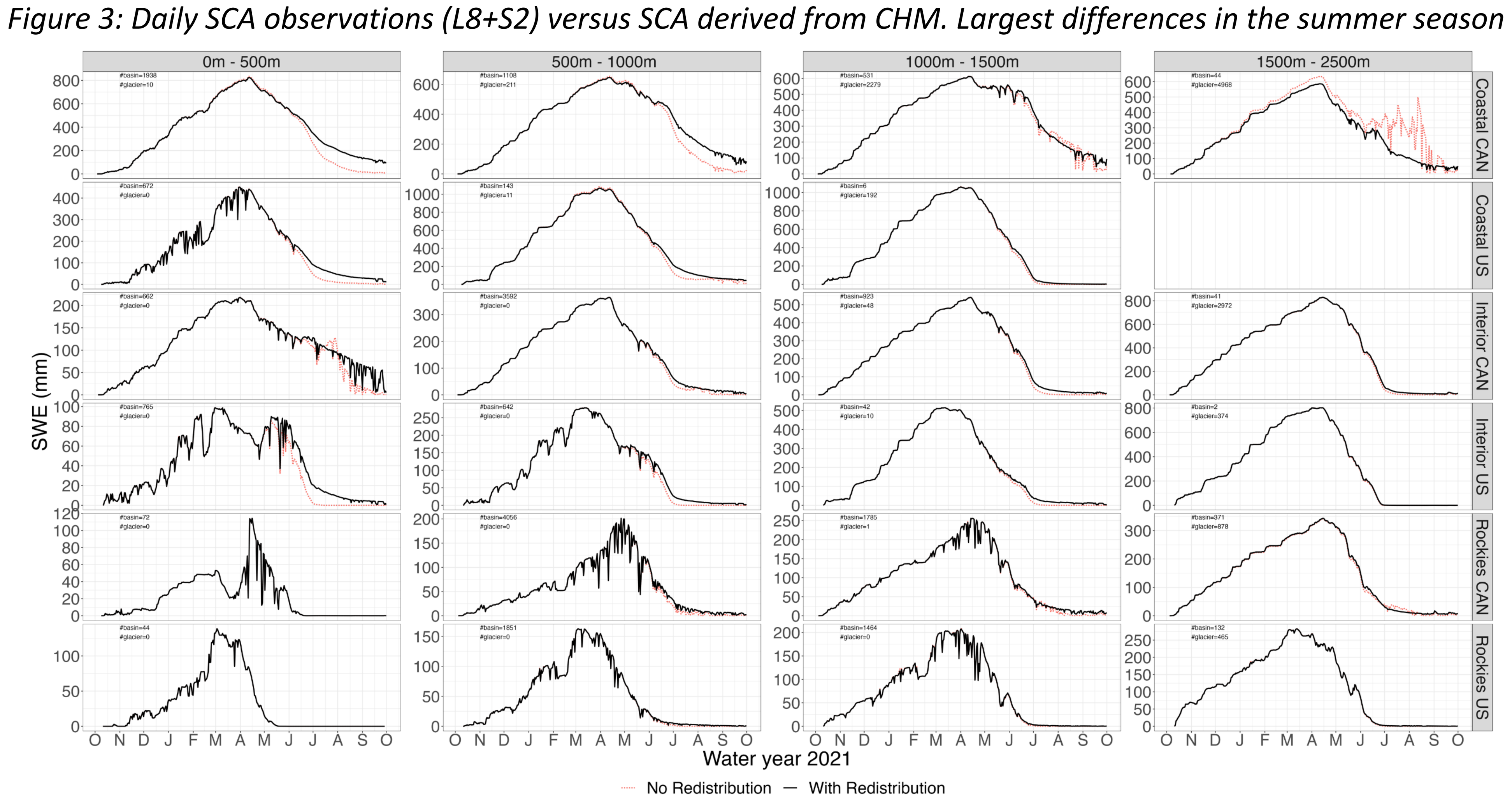

Figure 4: Simulated SWE aggregated to MERIT basins, grouped for outlet elevation, and aggregated to region scale shows that predictions neglecting redistribution impact spring ablation, but there is a regional dependence

Discussion

- Evaluation via SCA is difficult due to the snapshot in space and time of observations (Fig 5)
- Evaluating small scale processes like ridgeline redistribution with SCA observations is difficult due the mismatch in spatial resolution
- Mid-winter SCA observations were dominated by regions where snow redistribution did not occur
- Snow redistribution impacts on spring and summer periods were well captured

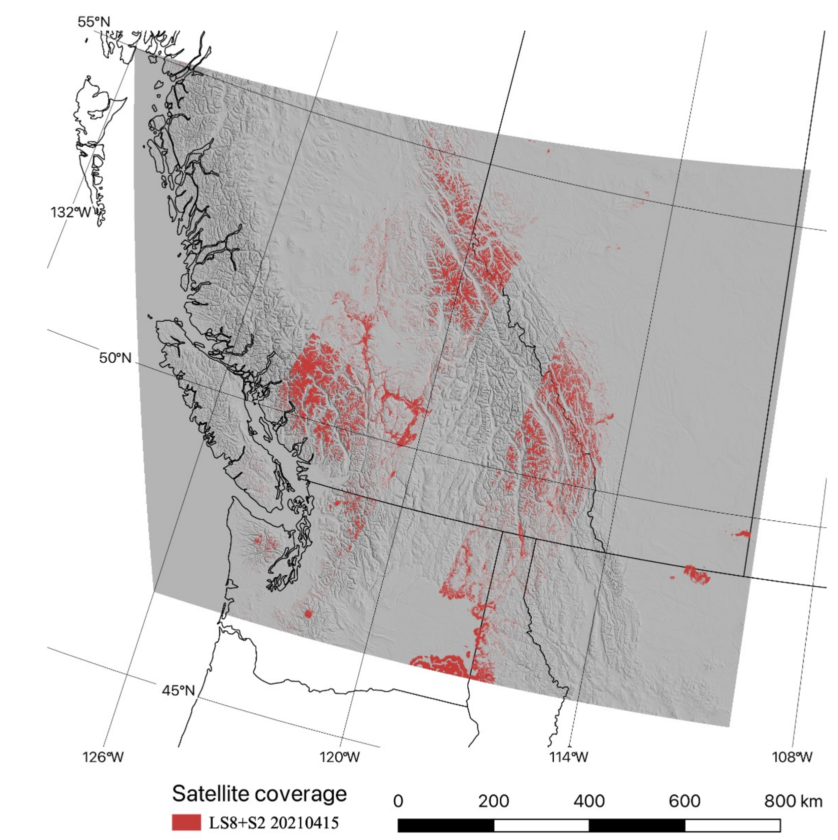

Figure 5: Satellite coverage (red) for a single day

- UAV-lidar provides the only high-resolution sub-canopy spatial comparison of snow depth
- The sub-canopy results suggests a HRDPS precipitation low bias in this region as preferential deposition from the headwall was not captured (Fig 6)
- Inclusion of snow redistribution is apparent with avalanche deposits at the headwall (Fig 6, left)
- The complex wind patterns observed at Fortress were not well captured by CHM and require a more accurate wind model

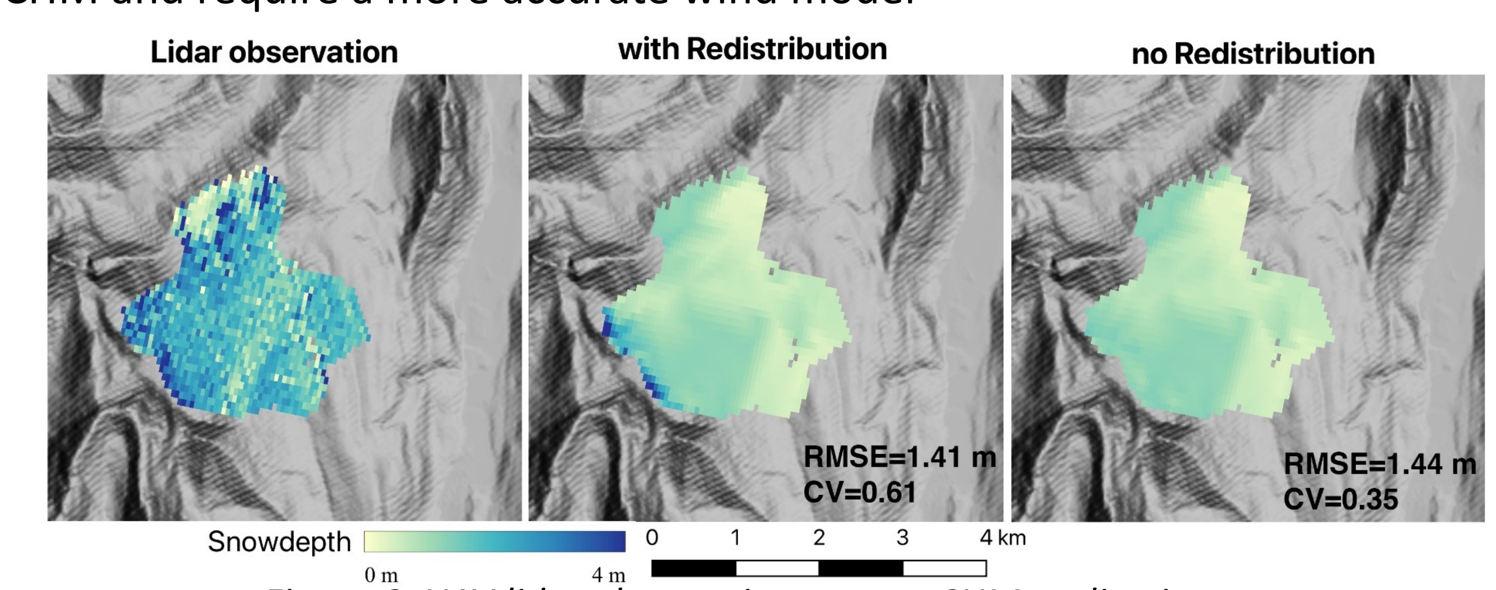

Figure 6: UAV-lidar observations versus CHM realizations.

Future Research Directions

- These simulations were only possible through HPC innovations
  - Continuing to advance these capabilities is required for global application
- Obtaining Pleiades and airborne lidar observations will further quantify model capabilities and limitations
- The impact of late-lying summer snowpack deposits on hydrology and sensitivity to climate change will be examined
- Apply these methods to GWF Planetary Water Prediction Initiative partners in the Andes and Pyrenees

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