Distributed modelling of the Canadian Prairie snowpack: model evaluation and demonstration

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Animation + Poster

Background

- Canadian Prairie snowmelt generates most annual runoff to creeks and wetlands and infiltrates to replenish the soil water reserves necessary for crop growth
- Snowmelt volume is governed by over-winter snow accumulation, wind redistribution, and sublimation by blowing snow
- Blowing snow redistribution is strongly affected by vegetation and topography
- There is a large gap in the capacity to remotely sense or model the snow processes on the prairies at snow-drift permitting scales for large spatial scales

Objectives

- Evaluate the ability to model the spatial variability of snow accumulation, redistribution, and ablation on the Canadian Prairies at a high spatial resolution
- Identify and inform the model development needs to support near real-time prairie-wide prediction of snowpack at sub-field scale

Methodology

- 100 ha study site at the Clavet Livestock and Forage Centre for Excellence near Saskatoon — part of Global Water Futures Observatories
- Simulated snow accumulation, redistribution, and ablation processes at a 3 m resolution with the Canadian Hydrological Model (CHM)
  - Blowing snow redistribution simulated with PBSM3D, snow energetics with Factorial Snow Model (FSM), and small-scale windfields with Windmapper
  - Topography resolved from UAV-lidar digital elevation model
  - Constant 0.3 m vegetation height
  - Driven by both local meteorological observations and ECCC's High Resolution Deterministic Prediction System (HRDPS) data from Nov 1, 2022 to April 24, 2023

Spatial Validation Data

- Model evaluated with a 1 m resolution snow water equivalent (SWE) dataset
- UAV-lidar snow depth map combined with manually surveyed snow densities
- Riegl miniVUX-2UAV lidar on a FreeFly AltaX UAV platform surveyed bare surface on April 19, 2019 and snow-covered surface on Mar 24, 2023

Figure 1: Riegl miniVUX-2UAV FreeFly AltaX UAV-lidar system

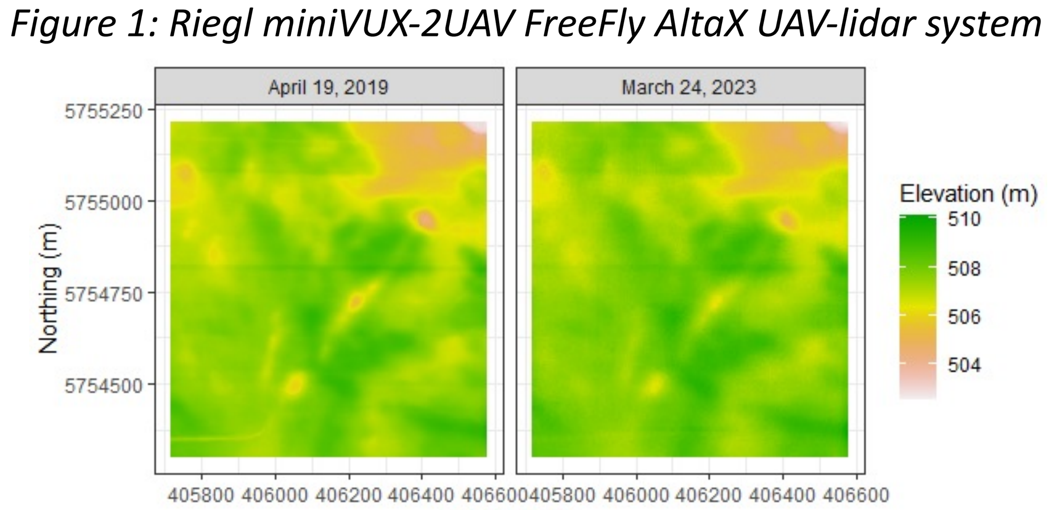

Figure 2: Study area snow-free and snow-covered 1m DEM

Conclusions

The first high-resolution application of PBSM3D in Canadian Prairies simulated key topographic aspects of snow redistribution to depressions

Further refinement of vegetation-wind interactions and the effect of ice layers on transport thresholds will improve estimates of snow erodibility

HRDPS had a low wind speed bias that restricted redistribution

Spatial Variability of Snow Water Equivalent

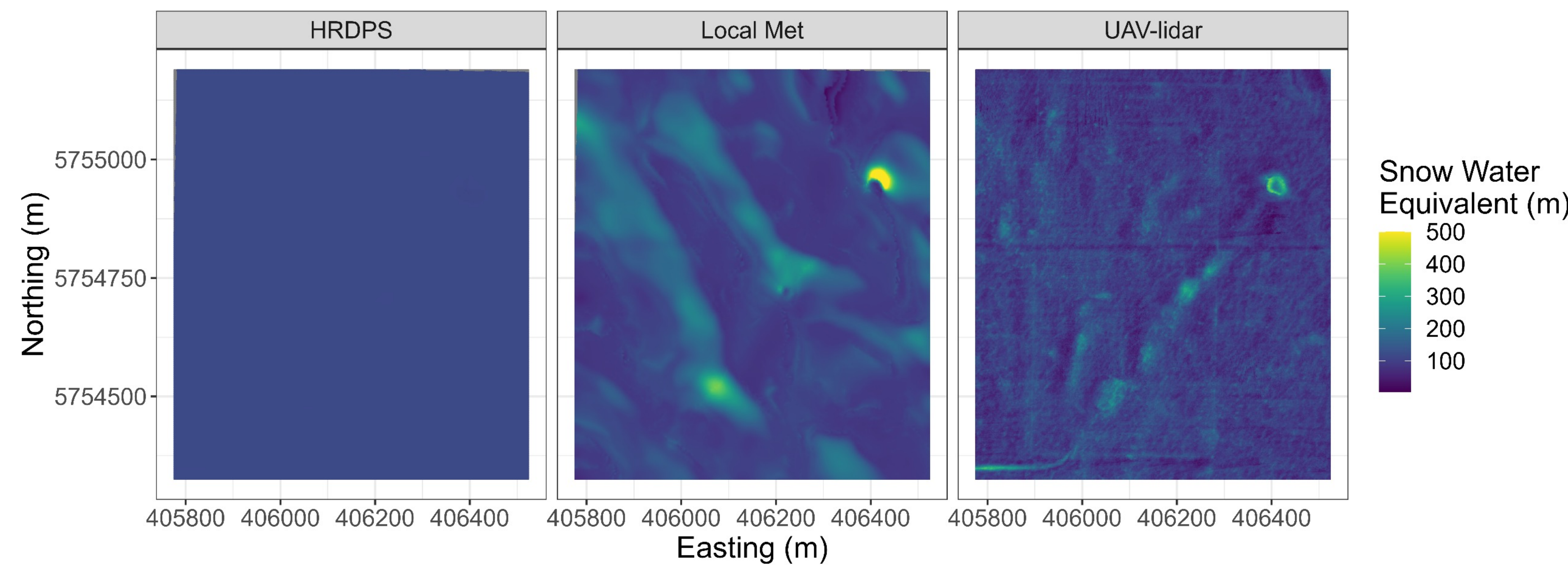

Figure 3: Snow water equivalent (mm) on Mar 24, 2023 as modelled by CHM driven by HRDPS (left), local meteorology (centre), and as observed by the UAV-lidar (right)

- Simulated redistribution patterns represented topographic impacts but smaller scale (<10 m) snow dune dynamics were missed
- Windmapper with the Winstral Sx leeside parameterization, developed for mountain environments, successfully captured spatial pattern of wind speed acceleration and deceleration in this low relief area
- HRDPS wind speeds were too low to permit snow transport and redistribution

Table 1: Field average SWE metrics for Mar 24, 2023 for simulations and observed lidar.

	Mean (mm)	CV (-)	RMSE (mm)	MB (mm)	Variogram Range (m)
Lidar	101	0.28			50
Local Met	122	0.38	52.2	21.6	118
HRDPS	116	0	31.6	14.8	68

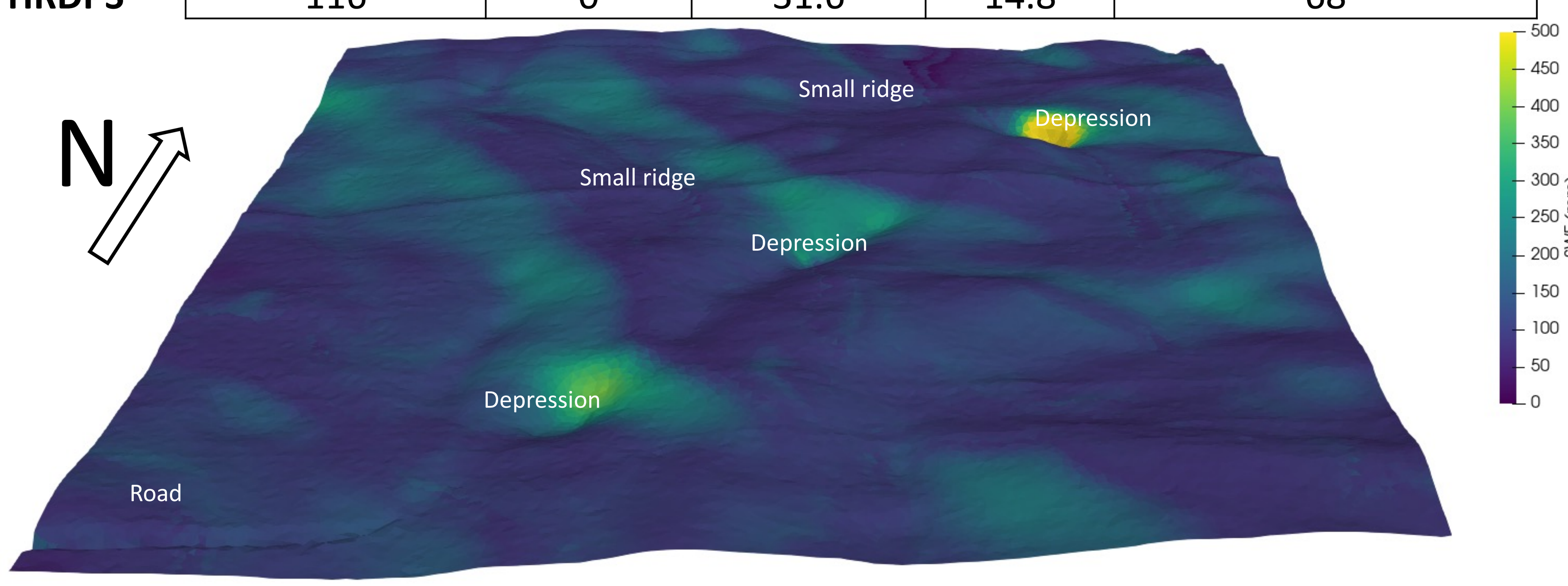

Figure 4: Simulated SWE for Mar 24, 2023 driven with local meteorology. Topography is 10x exaggerated.

Discussion

- Winter 2023 was unique in that 90% of snowfall occurred prior to January and subsequent melt/rain refreezes resulted in a relatively static snowpack
  - the snow aging controls on snow erodibility in PBSM were not sufficient for this and need to be expanded to include ice layers
- Further refinement of snow-vegetation interactions
  - spatially variable stubble heights and shear stress interactions
  - inclusion of small trees/shrubs around depressions and impact on fetch
- Model control volume representation at ≈15 m² did not capture all small-scale variability associated with snow dunes and small drifts

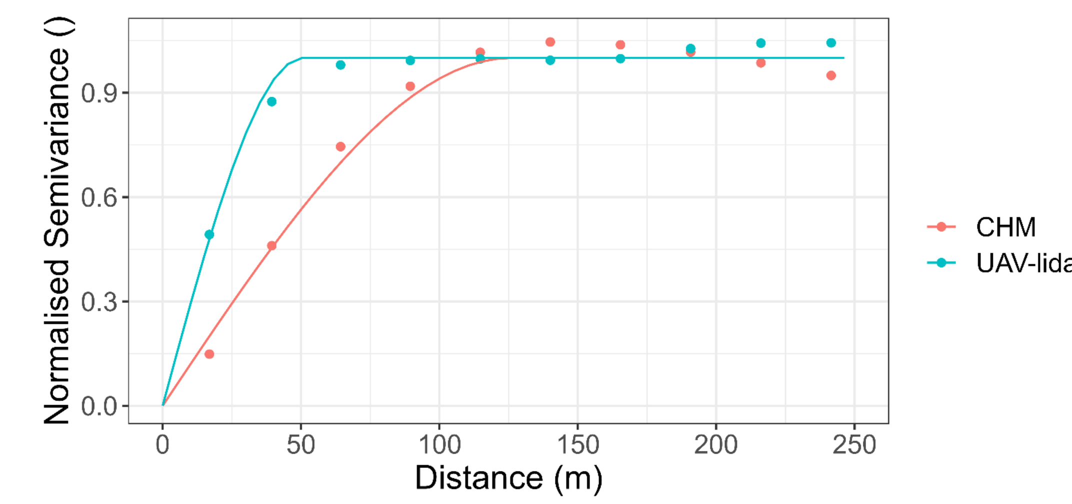

Figure 5: Normalised variograms for CHM and UAV-lidar observations

- Need to bias correct HRDPS wind field before large scale modelling can progress
  - HRDPS missed all >10 m/s wind speeds which dominate blowing snow transport

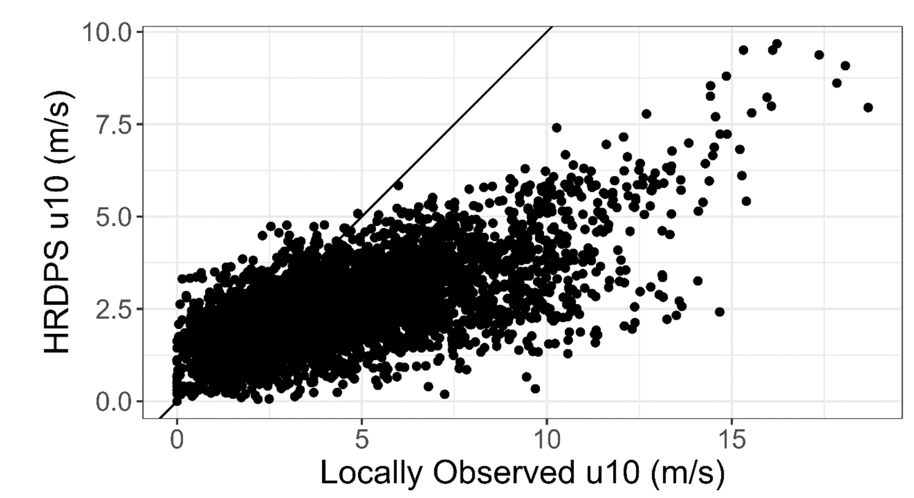

Figure 6: Hourly HRDPS and locally observed windspeeds adjusted to 10 m height

Research Implications

- The current gap in field-scale snow information can be addressed by high resolution snow modelling across the Canadian Prairies
- Given the importance of snow water to prairie hydrology, wetlands and agriculture, improved of snow prediction informs water management
- Sub-field scale snow redistribution modelling can support precision agriculture and risk management

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