Spatial Scale for Modelling Blowing Snow

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Background

❖ Blowing snow redistributes vast quantities of the seasonal snowfall to tall vegetation, streams and wetlands in the Canadian Prairies. Much blowing snow is sublimated whilst being transported by wind. Transport and sublimation result in significant ablation of the upland snowpack before spring melt occurs. These losses can exacerbate drought water shortages.

❖The winter redistribution of snow by wind is highly complex in this environment, and the resulting distributions of snow water equivalent strongly influence the magnitude, timing and duration of the snowmelt contribution to soil moisture, streamflow and wetlands.

❖ Both spatially aggregated and spatially distributed blowing snow models are now available, but the most effective resolution of model application for predicting the spring snow water equivalent for spring snowmelt infiltration and runoff calculations has not yet been determined.

Research Scope and Objectives

❖ This study examines how a spatially aggregated blowing snow model (Pomeroy and Li, 2000) might be applied to complex prairie parkland terrain and demonstrates the application of a spatially distributed blowing snow model (Essery et al., 1999).

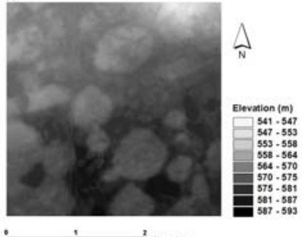
❖ The study then examines whether adequate information on spring SWE can be determined from the spatially aggregated approach, in comparison to the spatially distributed model result and to field observations.

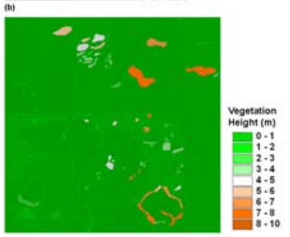
❖ Recommendations for model complexity are then made that are relevant to land surface schemes that would include blowing snow redistribution amongst landscape-based tiles.

Study Site

St Denis National Wildlife Area, Saskatchewan

LIDAR Based DEM





Aerial Photograph based land-cover

Observations

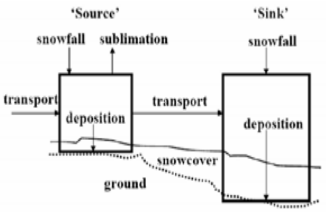
❖ Meteorological Data: Alter-shielded Geonor precipitation gauge, blowing snow particle detector (Brown & Pomeroy, 1989), anemometer, hygrothermometer

❖ Topography – DEM from LiDAR with ground verification. 0.5 m grid size

❖ Vegetation Cover – classification from aerial photographs with ground verification

❖ Four snow survey transects (total length 680 m) with 138 depth measurement and 28 density measurement points

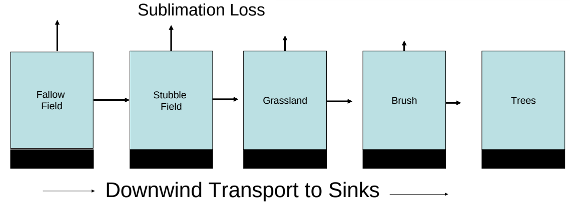
Aggregated Blowing Snow Modelling



❖ Landscape divided into source and sink landscape units. Source areas include upland fields, hilltops and sink areas include aspen bluffs, ravines, streams, ponds, & wetlands.

❖ Continuity applied to control volumes for each landscape unit – *Hydrological Response Unit (HRU)*

❖ Number of HRU guided by classifications of prairie snow accumulation from Steppuhn & Dyck (1974); Mackay and Gray (1981), Shook (1995); Pomeroy et al. (1998)



Sublimation Loss

Fallow Field → Stubble Field → Grassland → Brush → Trees

Downwind Transport to Sinks

❖ HRU for blowing snow do not necessarily have a geographical location but they do have an aerodynamic sequence and proximity to each other which can be characterised for an ecological region such as the Prairies. Characteristic sequence is from uplands of cultivated fields to steep hillsides of grass and brush to lowlands of grass, brush, trees and wetland ponds in depressions.

❖ Difficult to efficiently parameterise proximity and wind direction for snow transport when exact locations of fields and landcover units are not known.

❖ Parameterisation of snow transport (Q_T) was accomplished using a simple distribution function. For instance, consider 4 HRU each with progressively taller vegetation, A, B, C & D where no transport can leave the last HRU, D and no transport enters the first HRU, A. Each HRU has a distribution parameter, a, b, c or d. Each HRU has Q_T in and out (except for A which has only out and D which has only in). For the first HRU downwind of A, *B* the transport in will be:

$$Q_T(in, B) = \frac{b\,Q_T(out, A)}{b + c + d}$$

for the next HRU downwind of B, *C*, the transport in will be:

$$Q_T(in, C) = \frac{c\,Q_T(out, A)}{b + c + d} + \frac{c\,Q_T(out, B)}{c + d}$$

and for the last HRU, which is the next downwind of C, *D*, the transport in will be

$$Q_T(in, D) = \frac{d\,Q_T(out, A)}{b + c + d} + \frac{d\,Q_T(out, B)}{c + d} + \frac{d\,Q_T(out, C)}{d}$$

This series can be expanded to include a large number of HRUs (500 tested so far).

Acknowledgements

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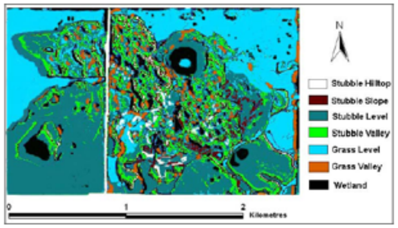
Aggregated Model Implementation



HRU Name	Area (km^2)	Vegetation Height (m)	Blowing Snow Fetch Distance (m)
Stubble Hilltop	0.5	0.05	300
Stubble Slope	0.4	0.12	300
Stubble Level	1	0.15	300
Stubble Valley	0.5	0.2	300
Grass Level	1	0.5	300
Grass Valley	0.3	0.5	300
Wetland	0.15	5	300

❖ Prairie Blowing Snow Model (PBSM) from Pomeroy and Li (2000) was driven with point meteorology and wind flow distributed over complex topography and vegetation using a parametric version (Walmsley et al., 1989) of the Mason & Sykes boundary layer model.

❖ Models implemented in the Cold Regions Hydrological Model (CRHM) platform (Pomeroy et al., 2007).

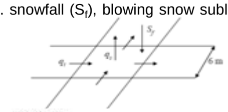
❖19 initial HRU based upon combinations of topographic exposure, and vegetation simplified to 7 HRU based upon distinct snow accumulation and transport characteristics.

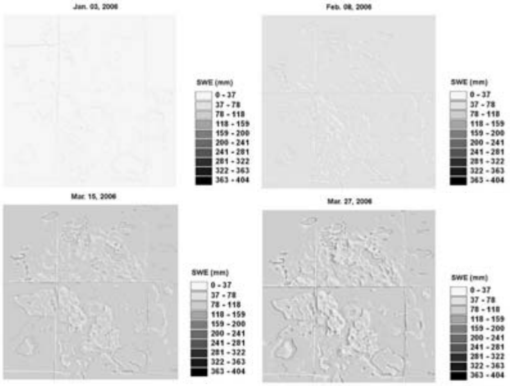
❖ Wetlands are ponds surrounded by tall grass, brush and trees (depressions).

Distributed Modelling

❖ Implementation of Essery et al. (1999) distributed blowing snow model – physics based on PBSM with actual Mason and Sykes boundary layer windflow model applied over a 6-m grid of 262,144 grid cells . Similar to the aggregated approach, the mass balance for snow water equivalent (SWE) is based on continuity w.r.t. snowfall (S_f), blowing snow sublimation Q_S and divergence of transport Q_T:

$$\frac{dSWE}{dt} = S_f - Q_s - \nabla \cdot Q_T$$





- Distributed model SWE output (over 3.1 x 3.1 km domain) from early winter to late winter.
- Predicted SWE corresponds well to observations at fine scale.
- Variance of SWE increases with time.
- Deep drifts develop in tall vegetation and depressions (including roadside ditches) as transport to sink areas accumulates over the winter.
- Wetlands receive most blowing snow.

Conclusions

❖ Spatially aggregated and distributed blowing snow models both provided adequate prediction of SWE on landscape units that corresponded to areas of distinct snow accumulation.

❖ It is appropriate to calculate Prairie blowing snow transport and sublimation using just a few landscape classes based on common vegetation-topography groups.

❖ Land surface schemes and large scale hydrological models can implement such a strategy by transporting blowing snow between tiles defined on snow retention characteristics.