APPLICATION OF AN ARCTIC BLOWING SNOW MODEL

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INTRODUCTION

Wind transport and sublimation of blowing snow are anticipated to promote significant annual fluxes of water and energy in the Arctic. Improved estimates of winter precipitation are confirming results known for windswept temperate snow climates: snowfall is greater than was previously thought and significantly exceeds snow accumulation (Benson, 1982; Goodison, 1981, Tabler *et al.*, 1990; Woo *et al.*, 1983). The redistribution of snow by wind forms snowcovers of highly variable depth and density, whose variation governs surface energetics during melt (Shook and Gray, 1995). The spatial distribution of snow water equivalent is important to modelling the timing, amplitude and persistence of the snow melt freshet (Marsh and Pomeroy, 1995). For these reasons, physically-based, spatially-distributed process models of snow hydrology are required to calculate snow fluxes over a range of scales (Pomeroy and Gray, 1995; Marsh et al., 1995). However, the processes of winter mass exchange between the snowcover and the atmosphere have not been adequately investigated for the Arctic, nor have they been incorporated in any hydrological or atmospheric model.

ARCTIC BLOWING SNOW MODEL

The Prairie Blowing Snow Model or PBSM (Pomeroy et al., 1993) is a physically-based fine-scale model of blowing snow erosion, transport, sublimation and deposition over level landscapes of varied roughness and fetch. The data requirements and complexity of the PBSM presently restrict its application where data is limited and terrain is irregular, hence a simplified climatological version was derived from the output of the PBSM for 15 stations on the Prairies over 6 years of simulation (Pomeroy and Gray, 1994). The climatological blowing snow model calculates the monthly flux of snow removed and sublimated in transit (sublimation flux) and that removed and transported to the end of the fetch for potential deposition (transport flux). The climatological algorithms are the present "core" of the Arctic Blowing Snow Model, ABSM, which provides a practical, yet process-based tool to simulate snowcover development in open northern regions. The ABSM is distributed in that it divides a basin into "sources" and "sinks" of blowing snow and calculates the snow fluxes as a mass balance to control volumes over each terrain type whilst retaining a mass balance over the meso-scale (Fig. 1). Level tundra plains are considered sources; transport and sublimation fluxes for standard 1-km fetches of tundra are hence calculated. These fluxes are adjusted for the actual fetch measured in the basin and used to calculate:

1) sublimation and transport loss in mm snow water equivalent (SWE) over the tundra surface
2) the mass flux (kg/month) to sink areas of the basin.

Sink areas are defined as

1) Drifts - slopes greater than 9% and stream channels adjacent to tundra fetches
2) Shrub Tundra and Taiga - areas of tall shrubs and open transitional forest that buffer open tundra and forests.

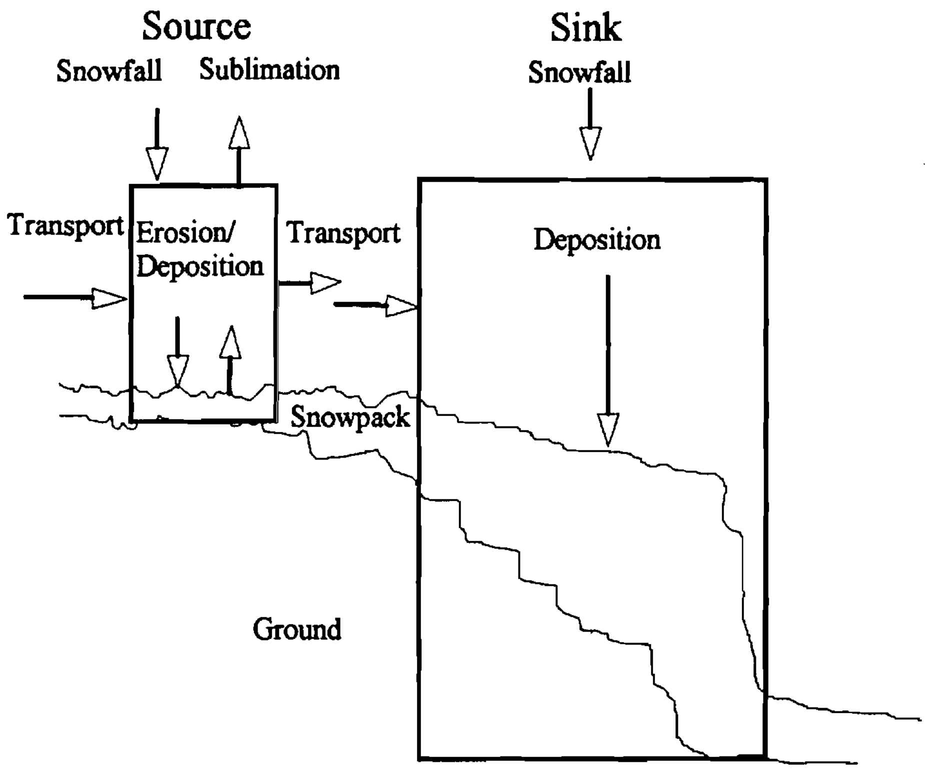

Figure 1. Arctic Blowing Snow Model. Schematic showing fluxes and mass balance over an irregular landscape.

The geometry and extent of tundra, drifts, taiga, shrubs and forest are determined using a digital elevation model (DEM) and a classification of a Landsat thematic mapper image for the basin. The mass flux to a sink area divided by its fetch determines the accumulation in mm SWE. Climatological data required are the major annual snow transport directions, mean monthly wind speed, monthly mean of the daily maximum air temperature and relative humidity and corrected monthly snowfall.

ABSM APPLICATION

The ABSM was applied to Trail Valley Creek basin, a 68 km^2 NHRI-GEWEX research basin located just north of the treeline near Inuvik, NWT. The basin has an arctic-subarctic transitional vegetation pattern of 75% short-bush tundra, 16% shrub tundra, 0.14% open forest (taiga) and 0.54% closed canopy forest. The valley is incised in a tundra plateau and runs east-west forming an effective snow trap for the NW-SE primary snow transport directions; 7.8% of the basin is adjacent to tundra and has slopes of greater than 9% grade, forming regular, annual snow drifts. Fetches range from 1450 m for tundra to 80 m for shrub tundra and 40 m for drifts. The simulation ran from October 1992 through May 1993. Over this time the mean monthly wind speed ranged from 3.3 to 5.9 m/s, mean monthly daily maximum temperature from -20.3^{o} to 1.9^{o} C, mean monthly daily maximum relative humidity from 85% to 94% and monthly snowfall from 8 to 39 mm SWE. Total snowfall was estimated from surface measurements in a small glade surrounded by trees as 190 mm SWE.

SIMULATION RESULTS

Monthly fluxes are shown for two example landscape types that represent the range of simulated blowing snow climatology; tundra and drift (Fig. 2a, b). Both show a predominance of blowing snow fluxes in the mid-winter months when cold, dry snowcovers

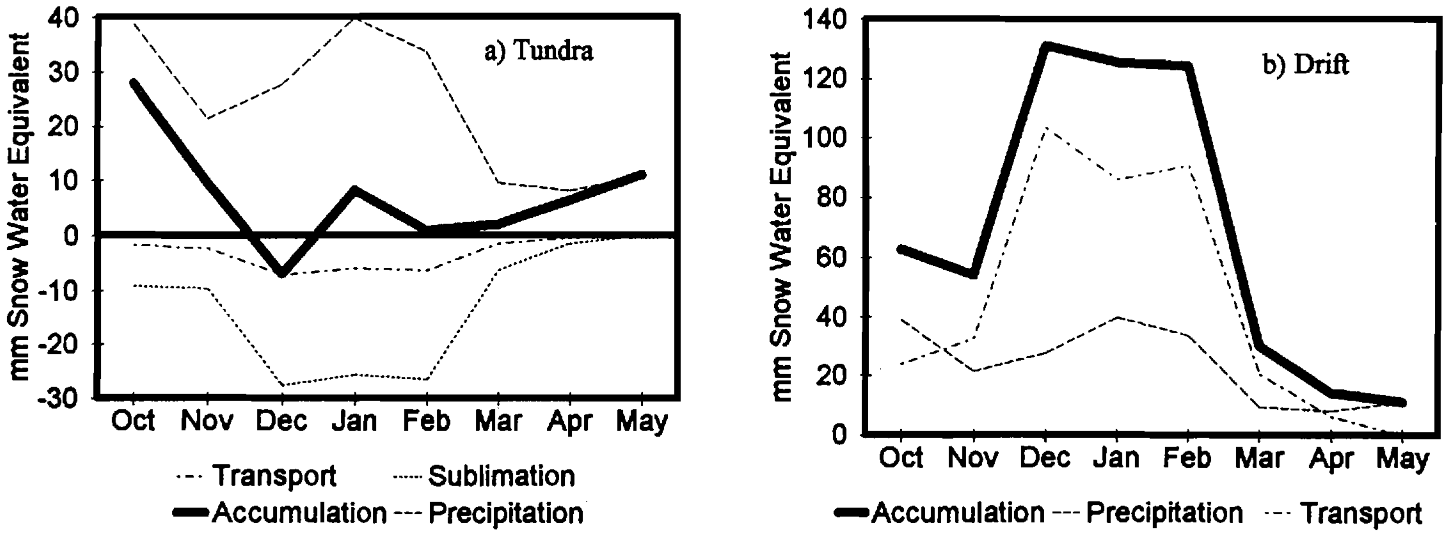

Figure 2. Monthly snow fluxes on surfaces of Tundra (a) and Drift (b) at Trail Valley Creek, NWT for 1992-93 as predicted by the ABSM.

and high wind speeds promote relocation. The spring and fall months have wet or icy snowcovers that are rarely eroded and only by the highest wind speeds. The tundra simulation shows accumulation somewhat matching precipitation in the fall and spring but largely decoupled from precipitation in December through February. Mid-winter losses to transport and sublimation are similar in magnitude to the snowfall flux, with December's negative accumulation reflecting erosion of previously deposited snow. The drift simulation (Fig. 2b) shows accumulation is highly uncoupled from precipitation, rather matching the incoming transport flux of blowing snow. For December through February the incoming blowing snow transport is 4 to 5 times greater than snowfall. Snowfall fluxes only dominate accumulation in October, April and May.

The ABSM shows that for tundra in Trail Valley Creek, 56% of annual snowfall was sublimated, 13% transported to drifts or shrubs and 31% remained to accumulate as the annual snowcover. Annual drift accumulation was roughly 2.8 times snowfall. Over the basin the spatially-weighted averages for snow fluxes are shown in Table 1. Two-thirds of the snowfall accumulates in the basin, the 42% loss to sublimation compensated by a net transport flux into the basin. These results are specific to Trail Valley Creek, its size, vegetation cover and topography; using the ABSM, Marsh et al. (1995) show that for nearby and more extensively shrub-covered and incised Siksik Creek (0.83 km^2) the sublimation loss was 18% of snowfall with a gain from net transport of 27%. The winter water balance of the two basins is substantially different from each other and from snowfall.

Table 1. Annual snow fluxes in Trail Valley Creek as predicted by the ABSM, 1992-93.

Snow Flux	% of Snowfall	Snow Water Equivalent (mm)
Sublimation	42	-80
Transport	9	17
Accumulation	67	127

VERIFICATION OF RESULTS

Extensive snow surveys were used to test the model results for accumulation, transport to drifts and sublimation loss. In May, 1993, landscape-stratified surveys involving 25 depth and 5 density measurements over a 125 m transect in each landscape type, coupled with auxiliary depth measurements were made. The Landsat and DEM classification of basin landscapes were used to distribute average SWE from these measurements over the basin. The basin average SWE is modelled as 127 mm by the ABSM and estimated as 142 mm by the snow surveys, an underestimation by the model of 10% and well within the expected measurement errors for this type of verification. Both are well below the snowfall of 190 mm. Greater detail is provided in Fig. 3 which shows the modelled and measured SWE for each landscape type and indicates that the pattern of accumulation is described correctly, if often underestimated. The ABSM underestimated snow accumulation on the tundra by 9 mm SWE (15%), on the shrub tundra by 17 mm (7%), on the taiga by 9 mm (4%) and for drifts by 60 mm (12%). The ABSM includes no formal forest snow routine and overestimated forest snow by 34 mm (18%).

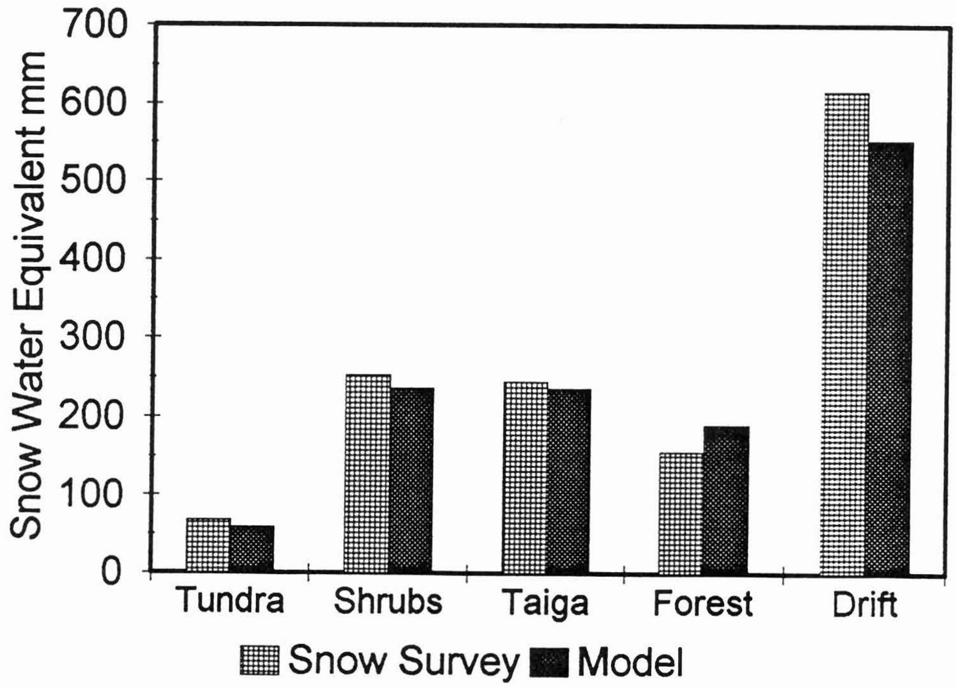

Figure 3. Snow accumulation modelled by the ABSM compared to the results of extensive snow surveys, Trail Valley Creek, NWT, May 1993.

CONCLUSIONS

An application of the Arctic Blowing Snow Model to a dissected low arctic basin has shown:

1) Blowing snow fluxes are large in the Arctic and exceed snowfall fluxes for mid-winter months; for a tundra fetch 56% of snowfall sublimated and 13% was relocated to shrubs and drifts.
2) Incised catchments can gain wind-transported snow from adjacent tundra plains; Trail Valley Creek gained 17 mm of equivalent precipitation from areas outside of its drainage area. The magnitude of such gains will depend on the scale of comparison.
3) Sublimation losses are notable on a catchment-scale; 42% of snowfall sublimated during blowing snow at Trail Valley Creek over the winter, an important latent heat flux, loss of surface water supply and source of atmospheric water vapour that has not been considered in hydrological or meteorological models.
4) The formation of snowcovers in the Arctic cannot be adequately described without reference to relocation of snow by the wind. Blowing snow processes govern the snow water supply available for melt, infiltration and stream discharge, the distribution of snow and therefore the surface energetics at the time of melt.

These results should not be extrapolated without reference to local climate and terrain.

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