Assessing Snow Water Equivalent Distribution Across the Canadian Northern Boreal Forest

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EXTENDED ABSTRACT

Developments in remote sensing technology have provided a range of satellite-derived data products for monitoring snow cover parameters. All-weather imaging capabilities, rapid scene revisit time, broad pixel dimensions, and the potential to retrieve snow water equivalent (SWE) make spaceborne passive microwave data ideal for regional scale climatological and hydrological studies. The Climate Research Branch of the Meteorological Service of Canada (MSC) has a long standing research program in the development of spaceborne passive microwave SWE datasets for specific landscape regions (Goodison and Walker, 1995; Goita et al., 2003) These regional algorithms are used to produce operational SWE maps distributed to various public and private sector users, and have allowed climatological analysis of SWE time series (1978–present) for central North America (Derksen et al., in press).

Composite patterns of monthly averaged passive microwave derived SWE characterize an interannually consistent and well-defined zone of high SWE retrievals (>100 mm), extending across the Canadian northern boreal forest (Fig. 1). A similar zone of high SWE values has also been characterized in both an observationally based SWE reanalysis dataset (Brown et al., 2003) and simulated SWE fields from the Canadian Regional Climate Model (MacKay et al., 2003).

Given an extremely sparse network of historical in-situ data across this region of interest, two dedicated snow survey field campaigns were conducted to identify the magnitude and distribution of SWE across northern Manitoba at a spatial scale commensurate with spaceborne passive microwave and regional climate modelling grids. Measurement transects were established in northern Manitoba, Canada: (1) between the communities of Thompson and Gillam, accessible on a winter-maintained gravel road, and (2) between Gillam and Churchill, accessible only by helicopter (Fig. 1). An additional measurement transect was examined during the second survey across another transitional boreal (high SWE) – tundra (low SWE) ecotone. Collectively, these transects cross the transition of consistently lower passive microwave SWE retrievals near Thompson, to ~50% higher retrievals near Gillam, through another transition to consistently lower SWE estimates over the open tundra south of Churchill.

At each site, 30 depth (ruler) measurements and five SWE (ESC-30 snow tube) measurements were acquired. Bulk snow density was determined from each snow core measurement, and a density profile was obtained from 10-cm-wedge samples extracted from the face of a snow pit. Snow stratigraphy information was obtained at each site through manual characterization of the snow pit profile. The in-situ data were subsequently compared to Special Sensor Microwave/Imager (SSM/I) SWE retrievals, derived using the MSC land cover sensitive suite of algorithms (see Derksen et al., 2003 for algorithm descriptions and evaluation).

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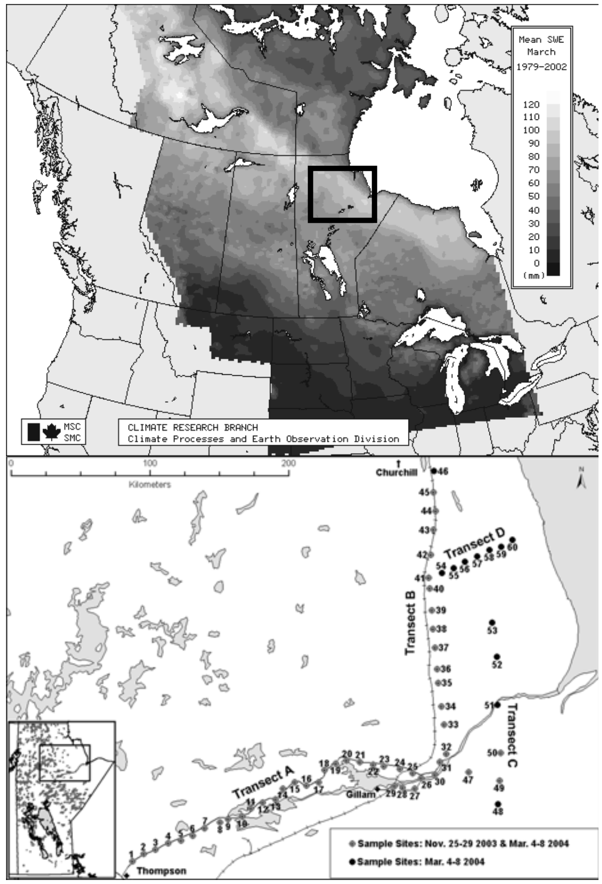

Figure 1. (top) Passive microwave derived average SWE, March, 1979–2002. SWE domain includes only those land cover regions for which MSC algorithm development and evaluation efforts have occurred or are ongoing. Box outlines region of focus for the ground surveying campaigns. (bottom) Snow survey locations

An intercomparison of the in-situ and SSM/I-derived SWE datasets is shown in Fig. 2. For both survey dates, the lowest ground measured SWE along transect A was near Thompson, with a general increase in SWE measured along the transect east towards Gillam—a gradient that agrees closely with the SSM/I retrievals. The highest ground measured SWE values were co-located with the zone of high SSM/I SWE retrievals to the north of Gillam along transects B and C, again showing good agreement between the two datasets. In open tundra environments, however, the ground measurements and SSM/I retrievals diverge: the passive microwave estimates decrease dramatically, while the in-situ measurements indicate an increase in SWE. This is evident along the northern portion of transect B during both surveys, and also along the length of transect D in March.

A quantitative comparison of mean in-situ SWE and the passive microwave retrievals for the EASE-Grid cell within which each site was located is shown in Fig. 3. During survey 1, all forested sites except for one agree within ±15 mm, the level of uncertainty in SSM/I retrievals found in a previous evaluation of the MSC algorithm suite (Derksen et al., 2003). Across transect A during survey 1, the direction of dataset disagreement is varied, although there is a tendency towards slight passive microwave overestimation along the forested sites of transect B. The four open tundra sites, however, are all characterized by passive microwave SWE underestimation which approaches 25 mm (>50%). During survey 2, the two datasets are strongly correlated (r=0.88), but passive microwave underestimation is a consistent issue along all of transect A with SSM/I derived retrievals exceeding the *in situ* measurements at only 4 sites. The direction of bias is mixed along transect B, with a higher magnitude of dataset disagreement compared to survey 1. Results for transect D (results not shown) confirm that the gradient towards lower SWE over the open tundra is not reflected in the in-situ measurements.

A potential physical explanation for these results can be hypothesized: snow interception is maximized in the dense southern forest canopy, with interception loss via sublimation estimated as high as 30 to 40% during winter (Pomeroy et al., 1998). This loss is reduced over the northern boreal forest due to the sparse and patchy forest mosaic which actually maximizes snow catchment and retention at the surface, with reduced interception loss. Wind redistribution and sublimation loss is prevalent across the unsheltered tundra (Pomeroy and Li, 2000) with high amounts of water stored in spatially constrained drifts. The spatial distribution of tundra SWE, in combination with the microwave properties of small but numerous tundra ponds and lakes, leads to systematic SWE underestimation. Further analysis of the 2003/04 snow survey dataset, regional climate model simulations, and ongoing tundra SWE retrieval algorithm development efforts will be applied to this issue.

Keywords: passive microwave, snow water equivalent, SSM/I, boreal forest

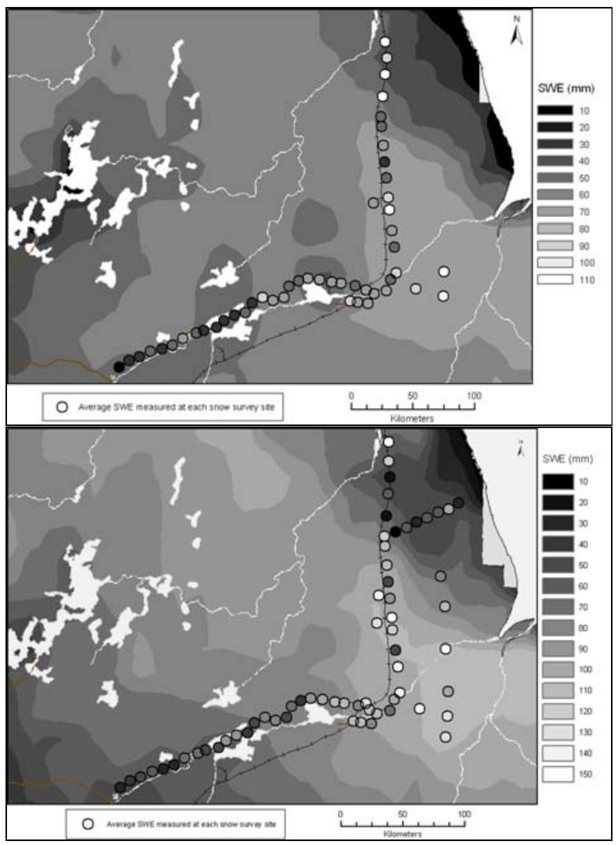

Figure 2. Comparison of in-situ (circles) and SSM/I (background) derived SWE datasets. SSM/I data are from 27 November 2003 for survey 1 (top), and from 6 March 2004 for survey 2 (bottom)

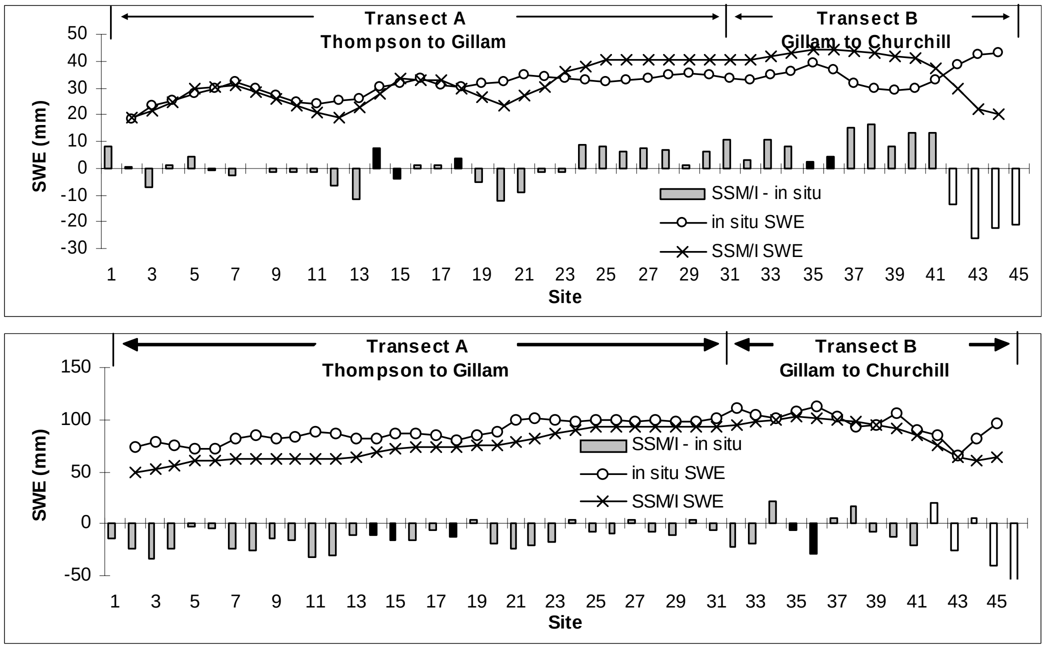

Figure 3. Agreement between SSM/I derived and in-situ SWE for the November 2003 (top) and March 2004 (bottom) surveys. Gray represents forested sites, black represents burn sites, and white represents open tundra sites.

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