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Comparison of SSM/I SWE with Modelled Snowpack for Mattagami Watershed

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ABSTRACT

Microwave-frequency data acquired from the Special Sensor Microwave Imager (SSM/I) has been interpreted as snow-water equivalent (SWE) for the snowpack on the upper Mattagami river watershed for the winter of 1998–1999. The Mattagami watershed is in a forested region of Ontario, Canada. Less than 10% of the area is lake or unforested wetland. The algorithm applied to the SSM/I data uses the difference in brightness temperatures registered on the 19 and 37 GHz frequencies as an indicator of the solid (ice-crystal) content of the snowpack. The algorithm was developed for dry snowpack and is invalid for snow with liquid water present. The snowpack water equivalence has been modelled using daily precipitation and air temperature data collected at three different weather stations and an ASAAM algorithm. The snowpack SWE derived from the SSM/I data shows an accumulation and ablation pattern similar to that obtained from the model results and from the limited snowcourse data available. The SSM/I readings appear to be interpreted best under cold conditions (<–10ºC) while factors such as snowfall and cloud cover do not appear to have a great effect on the accuracy of the SSM/I interpretation.

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

INTRODUCTION

Passive microwave radiometry has the ability to monitor conditions of the earth's atmosphere and surface, including snowpack properties. This sensing system is robust and provides data during cloudy conditions and during the night. Another advantage of the Special Sensor Microwave Imager (SSM/I) on US Defence Meteorological Satellite Program (DMSP) series of satellites is the daily frequency of the satellite coverage for most areas, which is an important feature for snowpack monitoring.

The algorithms used to interpret SWE from SSM/I brightness temperatures are subject to land cover type (DeSeve et al, 1999). SSM/I brightness temperature gradients are being used operationally in the Canadian Prairies to derive SWE estimates (Goodison and Walker, 1994). Smyth and Goita (1999) in forested sites in New Brunswick and Eastern Quebec found that there was almost no relationship between the brightness temperature gradient and snow depth or SWE. Rather, in their study they found that the microwave emission from the forest canopy dominated the overall brightness temperature. These contrasting results demonstrate the need to adapt algorithms to different environments.

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STUDY AREA

This study was carried out for the Mattagami River Watershed (47º 30' N and 81º 30' W) near Timmins, Ontario, Canada. The watershed studied has an area of 11,560 km^2 of which over 90% is forested with less than 10% of the watershed as lake or unforested wetland. The land has been classified as 25% evergreen needle forest and 65% mixed forest according to the 1995 AVHRR landcover map (Cihlar and Beaubien, 1998). The annual precipitation in the area is 880 mm here one third is from snow with a snowpack accumulation period generally from November to April (Atmospheric Environment Service, 1993).

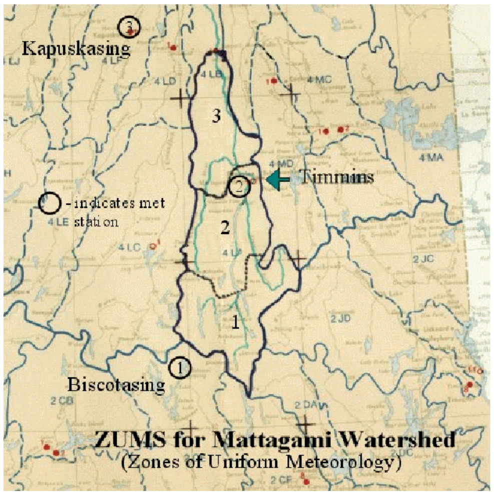

Figure 1. Map of Mattagami river watershed

MODELLING OF SNOWPACK

ASAAM, an Areal Snow Accumulation and Ablation Model (Schroeter and Whiteley, 1987), has been applied to the calculation of SWE for the Mattagami river watershed. The model uses daily rain, snowfall, and air temperature data to calculate the accumulation and ablation of the snowpack.

The ASAAM model has the capability to allow for snow transfer between landscape blocks due to wind but in this application to forested blocks no allowances for wind transfer was needed.

Figure 1 shows the map of the Mattagami River Watershed as well as the boundaries of the three zones of uniform meteorology, ZUMs, used in the modelling of the snowpack. Each ZUM is an aggregation of subwatersheds; the meteorological data for each ZUM is applied to all the included subwatersheds in the hydrological model for the watershed. The meteorological data for ZUMs 1, 2 and 3 were obtained from the Biscotasing, Timmins and Kapuskasing climate stations respectively. Their locations are shown in Figure 1. There were no temperature readings available for the Biscotasing site; thus, the daily temperature data from Timmins was adapted for ZUM 1 by increasing the maximum daily temperature by 2ºC and the minimum daily temperature by 1.5ºC as a latitude-based adjustment.

ASAAM utilizes equivalent accumulation blocks (EAB) where all areas with homogeneous land cover types are categorised into one block. Each ZUM was modelled as an EAB with 100% forest cover and no redistribution of the snow by wind.

SSM/I DATA AND ALGORITHM

The data used for this project is the Special Sensor Microwave Imager (SSM/I) on US Defence Meteorological Satellite Program (DMSP) and was downloaded from the National Oceanic and Atmospheric Administration (NOAA) satellite active archives site. The daily SSM/I brightness temperatures for the winter of 1998–1999 have been interpreted as ground-surface snow cover index (SCI) at a resolution of 25 km x 25 km using the following algorithm.

$$SnowCover\,Index = 2.7 \times \left[\frac{0.085 - \frac{(Tb_{37V} - Tb_{19V})}{18}}{0.036} \right] [mm]$$

where Tb_{19V} = brightness temperature vertical polarization, 19 GHz
Tb_{37V} = brightness temperature vertical polarization, 37 GHz

The data generated for the 1998–1999 winter season consisted of nearly 250 days of readings. The presence of a snow pack, indicated by a positive SCI value, was present for just over 100 days, from the end of December to mid-April.

COMPARISON OF SSM/I AND ASAAM

The temporal pattern of variation of the SCI, while displaying considerable scatter in individual values, had a general trend that was similar to the SWE pattern obtained from the ASAAM model (Figure 2). The appreciable short-period temporal variation (noise) in the satellite-based data requires interpretation and explanation. The influence of landcover, cloud cover, precipitation events, variations in air temperature and episodic presence of liquid water in the snowpack are being examined as possible causes of this variability.

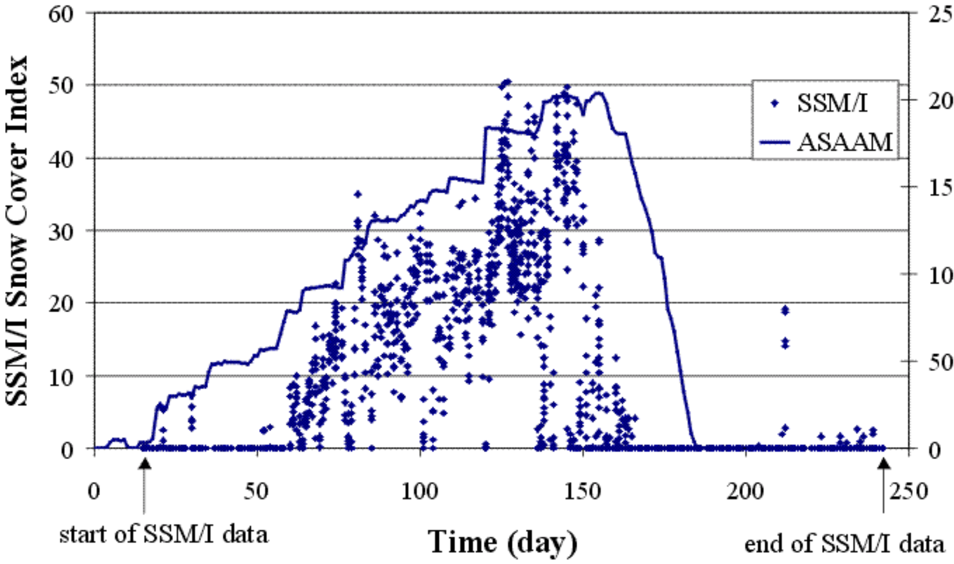

Figure 2 2. SSM/I Snow cover index time series and ASAAM model for ZUM 1.

As seen in Figure 2, the SSM/I derived SCI is about 4 times lower than the modelled SWE. Positive values of SCI, indicating the presence of a snowpack, appear later and disappear earlier in the season than the modelled SWE. This could suggest that the SSM/I signals are not capable of detecting shallow snow packs and are not applicable to SWE determinations of a wet snowpack.

The initial investigation of factors affecting the variation SSM/I readings included maximum and minimum daily air temperatures, 24-hour range in temperature, precipitation events and cloud cover. It was found that using data from passes for which the daily minimum air temperature was less than –10ºC gave an improved correlation between ASAAM SWE and SSM/I SCI values. There was no improvement in the correlation with any of the other factors.

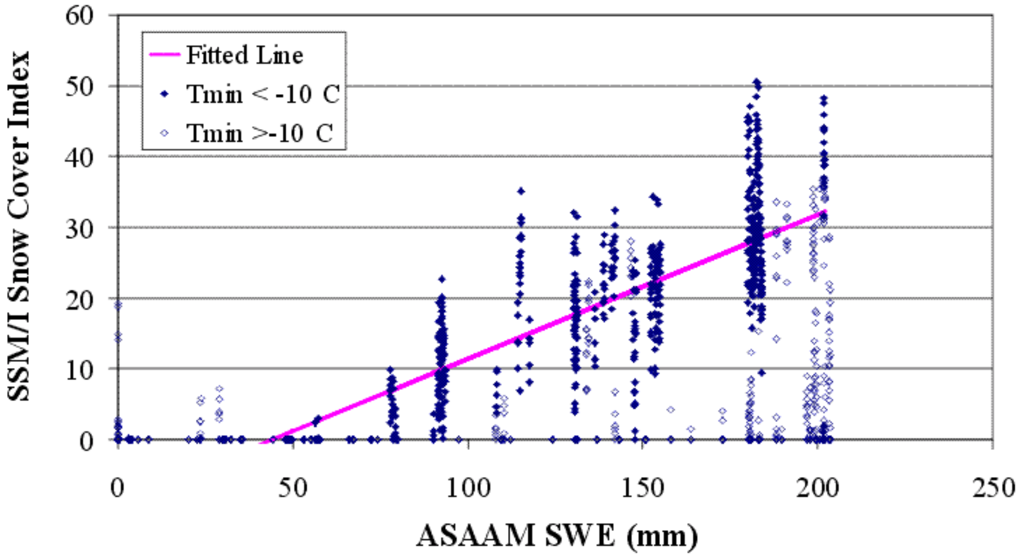

Figure 3. SSM/I snow cover index vs. ASAAM snow water equivalent for ZUM 1.

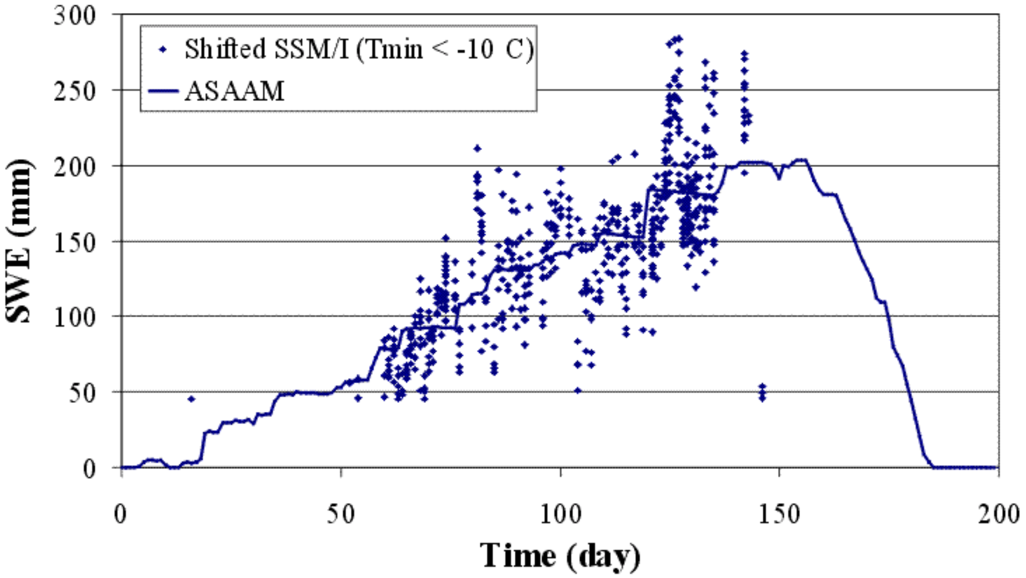

Figure 4. Rescaled SSM/I time series for minimum daily air temperatures less than –10ºC for ZUM 1.

Figure 3 shows a data set for ZUM 1 during the snow accumulation period for winter 1998–1999. The line was fitted by linear regression using only the SSM/I points occurring on days with daily minimum air temperatures less than –10ºC. This fitted line was used to rescale the SSM/I data as shown in Figure 4.

This screening and rescaling procedure improves the relationship between SSM/I derived data and modelled SWE, but eliminates all the SSM/I readings for the melt period, which is an unfortunate outcome. The shifting required in the other two ZUMs was not consistent with the first, indicating that there are other factors that must be considered in the algorithm.

CONCLUSIONS

The SSM/I can be used to predict SWE but there is considerable temporal variability in the prediction. The SSM/I readings appear to be interpreted best under cold conditions (<–10ºC) while factors such as precipitation events and cloud cover do not appear to have a great effect on the accuracy of the SSM/I interpretation. Further investigation, which will include applying the relationships found between the SSM/I snow cover index and the modelled snow-water equivalent to further data sets, is underway.

The result of filtering out the SSM/I readings where the daily minimum air temperature is less than –10ºC should be compared with other methods of screening data, such as eliminating readings where the Tb_{19V} is above a threshold value. Additional research in this area is required in order to establish the feasibility of use and range applicability of SSM/I data for SWE in forested watersheds.

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