Potential for Monitoring Snow Cover in Boreal Forests by Combining MODIS Snow Cover and AMSR-E SWE Maps

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EXTENDED ABSTRACT

Keywords: Snow cover, MODIS, AMSR-E, SWE, Boreal forest.

INTRODUCTION

Monitoring of snow cover extent and snow water equivalent (SWE) in boreal forests is important for determining the amount of potential runoff and beginning date of snowmelt. The great expanse of the boreal forest necessitates the use of satellite measurements to monitor snow cover (Derksen, 2008). Snow cover in the boreal forest can be mapped with either the Moderate Resolution Imaging Spectroradiometer (MODIS) or the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) microwave instrument. The extent of snow cover is estimated from the MODIS data and SWE is estimated from the AMSR-E. Environmental limitations affect both sensors in different ways to limit their ability to detect snow in some situations. Forest density, snow wetness, and snow depth are factors that limit the effectiveness of both sensors for snow detection. Cloud cover is a significant hindrance to monitoring snow cover extent using MODIS but is not a hindrance to the use of the AMSR-E. These limitations could be mitigated by combining MODIS and AMSR-E data to allow for improved interpretation of snow cover extent and SWE on a daily basis and provide temporal continuity of snow mapping across the boreal forest regions in Canada. The purpose of this study is to investigate if temporal monitoring of snow cover using a combination of MODIS and AMSR-E data could yield a better interpretation of changing snow cover conditions.

The MODIS snow mapping algorithm is based on snow detection using the Normalized Difference Snow Index (NDSI) and the Normalized Difference Vegetation Index (NDVI) to enhance snow detection in dense vegetation (Riggs et al., 2006). (Other spectral threshold tests are also used to map snow using MODIS.) Snow cover under a forest canopy may have an effect on the NDVI thus we use the NDVI in snow detection (Klein et al., 1998). A MODIS snow fraction product is also generated but not used in this study. In this study the NDSI and NDVI components of the snow mapping algorithm were calculated and analyzed to determine how they changed through the seasons.

A blended snow product, the Air Force Weather Agency and NASA (ANSA) snow algorithm and product has recently been developed (Foster et al., in press). The ANSA algorithm blends the MODIS snow cover and AMSR-E SWE products into a single snow product that has been shown to improve the performance of snow cover mapping (Hall et al., 2007). In this study components

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of the ANSA snow algorithm are used along with additional MODIS data to monitor daily changes in snow cover over the period of 1 February to 30 June 2008.

STUDY AREA & DATA ANALYSIS

A region of the boreal forest across northern Manitoba and Saskatchewan, Canada, (www.mb.ec.gc.ca/nature/ecosystems/wbci-icbo/di00s03.en.html) was chosen for this study. The daily MODIS data products are mapped in Sinusoidal projection and stored in tiles that cover an approximately 10° x 10° area of the earth surface. A region of approximately 970 x 600 km (Figures 1-3) was chosen for study. This region is covered by the MODIS daily products stored in the tile h12v03 (horizontal and vertical tile indicies). MODIS snow cover and MODIS daily surface reflectance data products, and the AMSR-E daily SWE product were analyzed. The AMSR-E SWE daily product is global coverage in EASE-Grid projection; the study area was located by geographic coordinates in the products. The MODIS snow-covered area daily maps, MODIS surface reflectance products and AMSR-E SWE data product are available to monitor snow cover over the season but are used separately. The time period monitored for the study was from 1 February to 30 June 2008. The objective of the study was to determine if there are relationships among the snow products or spectral ratios of NDSI and NDVI that could be utilized to monitor snow cover, detect the beginning of snowmelt, and to interpret probable transient wet snow events that impact the quality of the SWE estimates.
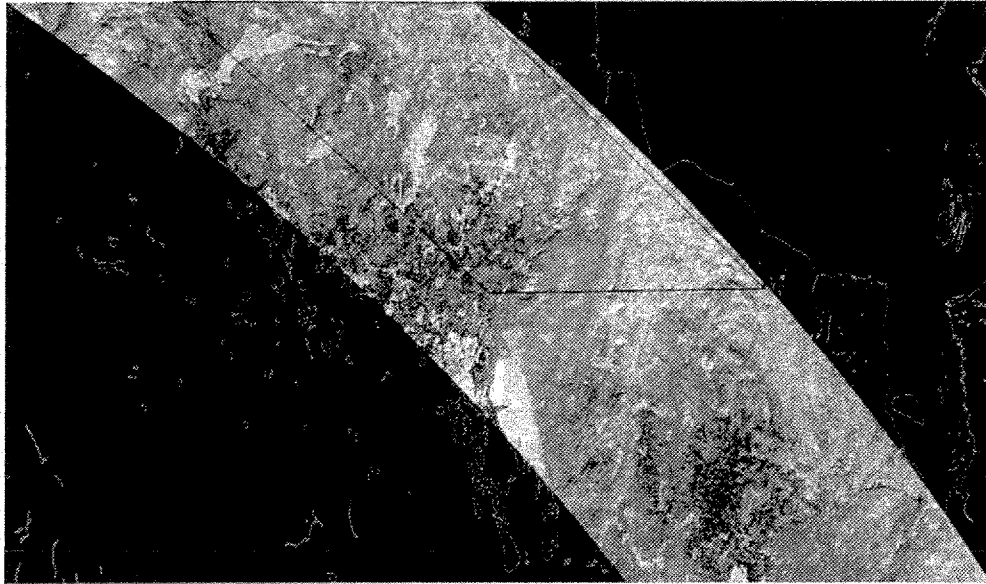

Figure 1. View of the boreal study area shown as MODIS bands 1, 4, 6 RGB image to highlight the presence of snow. Snow appears yellow in this band combination, pixels dominated by snow are brightest yellow; snow mixed with other surface features appears in decreasing shades of yellow. Clouds appear in white and light gray over some surface features. The study area is outlined (black polygon). Date of image is 10 April 2008; the daily surface reflectance product MOD09GA, tile h12v03, 500 m resolution, mapped in geographic projection. The star shows the approximate location of Thompson Zoo, Manitoba weather station.

MODIS data products used are the daily snow cover (MOD10A1), and the daily surface reflectance (MOD09GA) both at 500 m resolution. Daily data were extracted for the boreal forest region and processed for each day of the study. The NDSI = (MODIS band 6 – band 4 / band 6 + band 4); NDVI = (MODIS band 2 – band 1 / band 2 + band 1). (MODIS central wavelength

locations; band 1, 0.64 µm; band 2, 0.85µm; band 4, 0.55 µm; band 6, 1.6 µm.) MODIS reflectance data from the MOD09GA daily surface reflectance product, 500 m resolution were used to calculate these indices. For each day, MODIS observations that were not cloud obscured were used for analysis. The cloud mask from MOD10A1, carried through from the MODIS cloud mask product in processing, was applied as the cloud mask. The number of observations used varied depending on the extent of cloud cover each day. Daily SWE data were extracted for the study region from the AMSR-E SWE product at 25 km resolution.
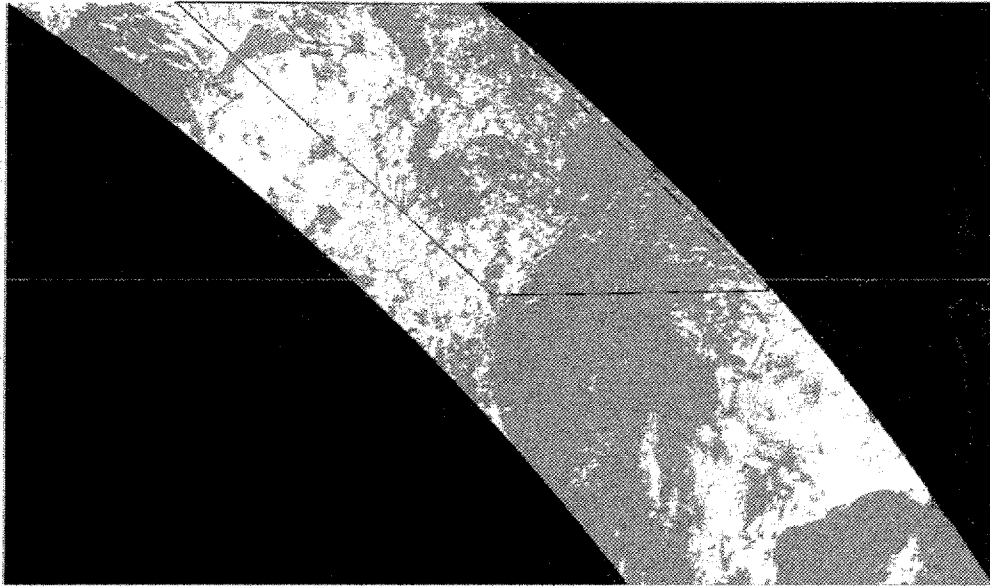

Figure 2. MODIS snow map, 500 m resolution, of the boreal study area on 10 April 2008, tile h12v03 with the study area outlined (black polygon). Snow is white, snow and ice covered lakes are blue-green, clouds are pink. The image shown is mapped in geographic projection. The star shows the approximate location of Thompson Zoo, Manitoba weather station.

DISCUSSION & RESULT

Snow cover extent and SWE appear to remain relatively constant through the winter except for an event 8-15 April. After that snowmelt occurs over the period of about 20 April through early May as indicted by declining snow-covered area and SWE (Figure 3). Snow-covered area is 100% through the winter though there is day to day variation in the NDSI and NDVI. The SWE amount is relatively constant through the winter though there are day to day variations. The day to day variations in snow-covered area and SWE are interpreted as normal and attributable to day to day changes in environment and observing conditions. Drastic changes over a few days are of interest as that signals a significant change in snow pack conditions or the start of snowmelt.
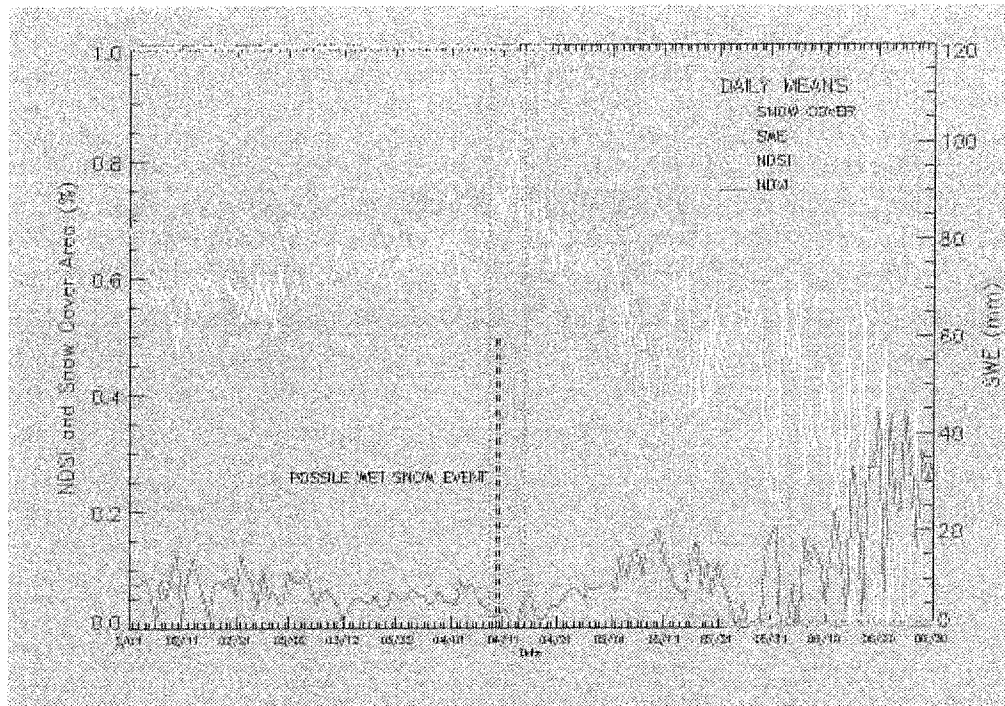
Figure 3. Average daily values for MODIS snow-covered area, NDSI, NDVI and AMSR-E SWE in the boreal forest study region. Averages for the MODIS data were derived using only cloud free pixel observations of land surface. A possible wet snow event occurred between the dotted vertical lines. Figures 1, 2, 3B and 4 are from 10 April, noted as the dash-dot line on plot, a relatively cloudless day over the region.

For the purpose of monitoring the snow cover detecting the start date of snowmelt is important as the hydrologically significant SWE is determined at that time. The start of snowmelt appears to be detected by the MODIS snow-covered area, NDSI, and NDVI showing a rapid decreasing trend in snow-covered area beginning about 20 April (Fig. 3). Decreases in the snow-covered area and NDSI with corresponding increase in NDVI signal the beginning of snowmelt on about 20 April (Fig. 3). Those indicators presage a rapid decreases in SWE beginning about 1 May (Fig. 3). The SWE also begins a decreasing trend a few days after the MODIS snow cover indicators began decreasing. However, a very rapid decrease in SWE followed by a rapid steep rise in SWE occurred several weeks before seasonal melt of the snow cover began. That anomaly in SWE trend was likely caused by a wet snow event. It is possible that the wet snow event could have been misinterpreted as the start of snowmelt if SWE monitoring alone was used.

Rapid changes in the wetness of a snow pack can cause the snow pack to 'disappear' to the AMSR-E because wet snow has a negligible scattering signal (Kelly et al., 2003) but if the snow refreezes the scattering signal returns causing the snow to re-appear. A wet snow event appears to have occurred between 8-15 April, as seen by the dotted vertical lines on Fig. 3. Evidence for a possible wet snow event is the sudden rapid drop in derived SWE (increases in Tb) with a sudden sharp rise in SWE after a few days to SWE values in the range prior to the drop. SWE maps over the period 6-19 April (Fig. 4) chronicle the areal extent of the decline and rise in SWE. Meteorological data from the Thompson Zoo, Manitoba station listed in Fig. 5 indicate a warm period with continuous snow cover over that period. The MODIS snow-covered area, NDSI and NDVI remained relatively consistent over that period (Fig. 3) indicating continuous snow cover, though NDSI did spike during the period. Conditions observed on 10 April, early in the warm period, by MODIS, AMSR-E and ANSA are shown in Figs. 1, 2, 4B and 6. Though some of the snow cover may have melted and depth decreased (Fig. 5), the snow cover did not almost

disappear as the SWE maps show on 14 April. The MODIS snow cover map, NDSI, NDVI, and the ANSA map all show a continuous snow cover over the wet snow period. In the ANSA the snow cover is continuous and some amount of SWE (Fig. 6) is shown in the region. In the classification scheme used in the ANSA, SWE is not broken into ranges for combination with MODIS snow cover area. There was no reported snowfall (Fig. 5) that would subsequently cause the SWE to return to the range shown for about 6 April on 19 April. The rapid divergence of SWE compared to the MODIS snow cover indicators suggest that SWE estimates were affected by a transient wet snow event, which caused SWE estimates to fall to less than 50% of pre-event values then suddenly rebound.

Figure 4. Sequence of AMSR-E SWE maps, 25 km resolution, of the boreal forest study area (black polygon) over the time of the probable wet snow event. (From left to right, A,B,C,D.) Dates shown are A) April 6, B) April 10, C) April 14, D) 19 April 2008, mapped in geographic projection. The star shows approximate location of Thompson Zoo, Manitoba weather station.

Figure 5. Daily data report April 2008, Thompson Zoo, Manitoba.

Blended Snow Grid Values

(575) MODIS snow 80-100% and SWE 2-480 mm
(550) MODIS snow 21-79% and SWE 2-480 mm
(450) MODIS snow 1-20% and SWE 2-480 mm
(390) MODIS snow 80-100% and SWE 0 mm
(370) MODIS snow 21-79% and SWE 0 mm
(360) MODIS snow 1-20% and SWE 0 mm
(375) MODIS snow 1- 100% and SWE water mask
(355) MODIS snow 0% and SWE 2-480 mm
(350) MODIS cloud and SWE 2-480 mm
(330) MODIS cloud and SWE 0 mm
(300) MODIS cloud in AMSR-E swath gap
(345) MODIS snow1-100% in AMSR-E swath gap
(305, 290) MODIS no data SWE 2-480 mm
(295) MODIS in darkness and SWE 2-480mm
(250) MODIS in darkness and SWE 0 mm
(253) AMSR-E Permanent Snow/Ice
(201) MODIS snow 1-100% and SWE land not processed
(200) MODIS snow 1-100% and SWE no data
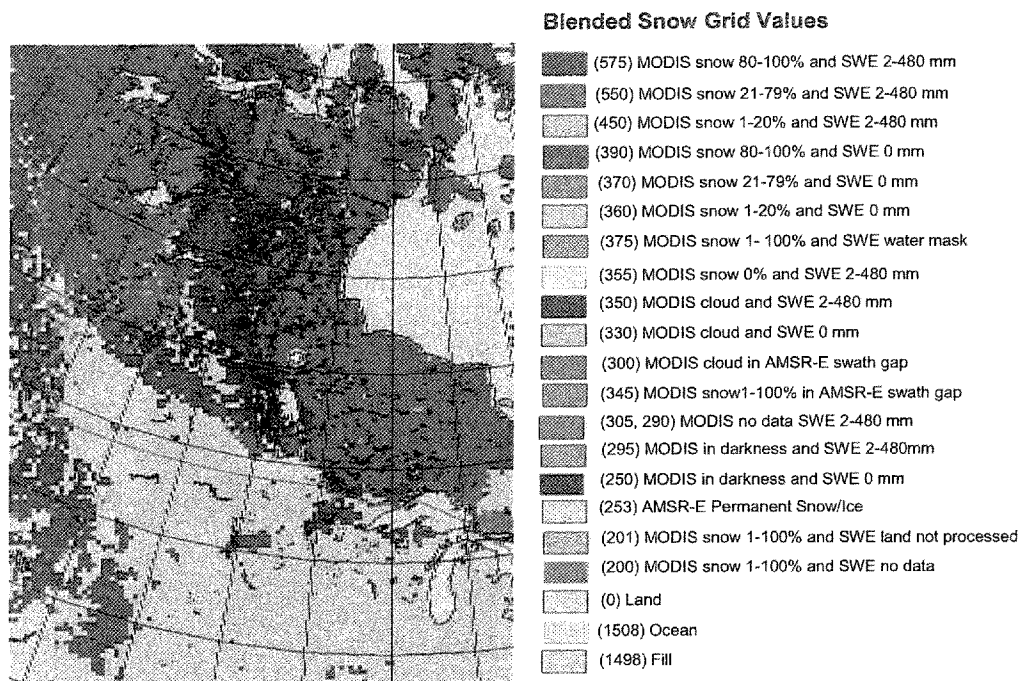(0) Land
(1508) Ocean
(1498) Fill

Figure 6. ANSA snow map, 25 km resolution, of the boreal forest study area on 10 April 2008, shown mapped in Lambert Azimuthal projection. The star shows approximate location of the Thompson Zoo Manitoba, station.

The suggestion emerging from this study is that monitoring and analysis of trends in snow-covered area and other indicators of snow cover observed concurrently with MODIS and AMSR-E could be utilized to interpret transient wet snow events that affect SWE estimates. In addition, trends of these snow cover indicators could be used to determine when seasonal snowmelt begins. An anticipated benefit would be improved estimates of the extent, volume and timing of snowmelt.

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