Preliminary Evaluation of the AFWA-NASA (ANSA) Blended Snow-Cover Product over the Lower Great Lakes Region

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ABSTRACT

The Air Force Weather Agency (AFWA) – NASA (ANSA) blended-snow product utilizes EOS standard snow products from the Moderate-Resolution Imaging Spectroradiometer (MODIS) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) to map daily snow cover and snow-water equivalent (SWE) globally. We have compared ANSA-derived SWE with SWE values calculated from snow depths reported at ~1500 National Climatic Data Center (NCDC) co-op stations in the Lower Great Lakes basin. Our preliminary results show that conversion of snow depth to SWE is very sensitive to the choice of snow density (we used either 0.2 or 0.3 as conversion factors). We found overall better agreement between the ANSA-derived SWE and the co-op station data when we use a snow density of 0.3 to convert the snow depths to SWE. In addition, we show that the ANSA underestimates SWE in densely-forested areas, using January and February 2008 ANSA and co-op data. Furthermore, apparent large SWE changes from one day to the next may be caused by thaw-re-freeze events, and do not always represent a real change in SWE. In the near future we will continue the analysis in the 2006-07 and 2007-08 snow seasons.

INTRODUCTION

A blended-snow product (Fig. 1) has been developed jointly by the U.S. Air Force Weather Agency (AFWA) and the Hydrospheric and Biospheric Sciences Laboratory at NASA / Goddard Space Flight Center. A detailed description of the product, called the AFWA – NASA (ANSA) blended-snow product, may be found in Foster et al. (in press). The product utilizes the Moderate-Resolution Imaging Spectroradiometer (MODIS) standard snow-cover product (Hall and Riggs, 2007) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) standard snow-water equivalent (SWE) product (Kelly et al., 2004) to map daily snow cover and SWE globally. The objective of this work is to study the capability of the ANSA product to map SWE in the Lower Great Lakes region for the 2007-08 winter.

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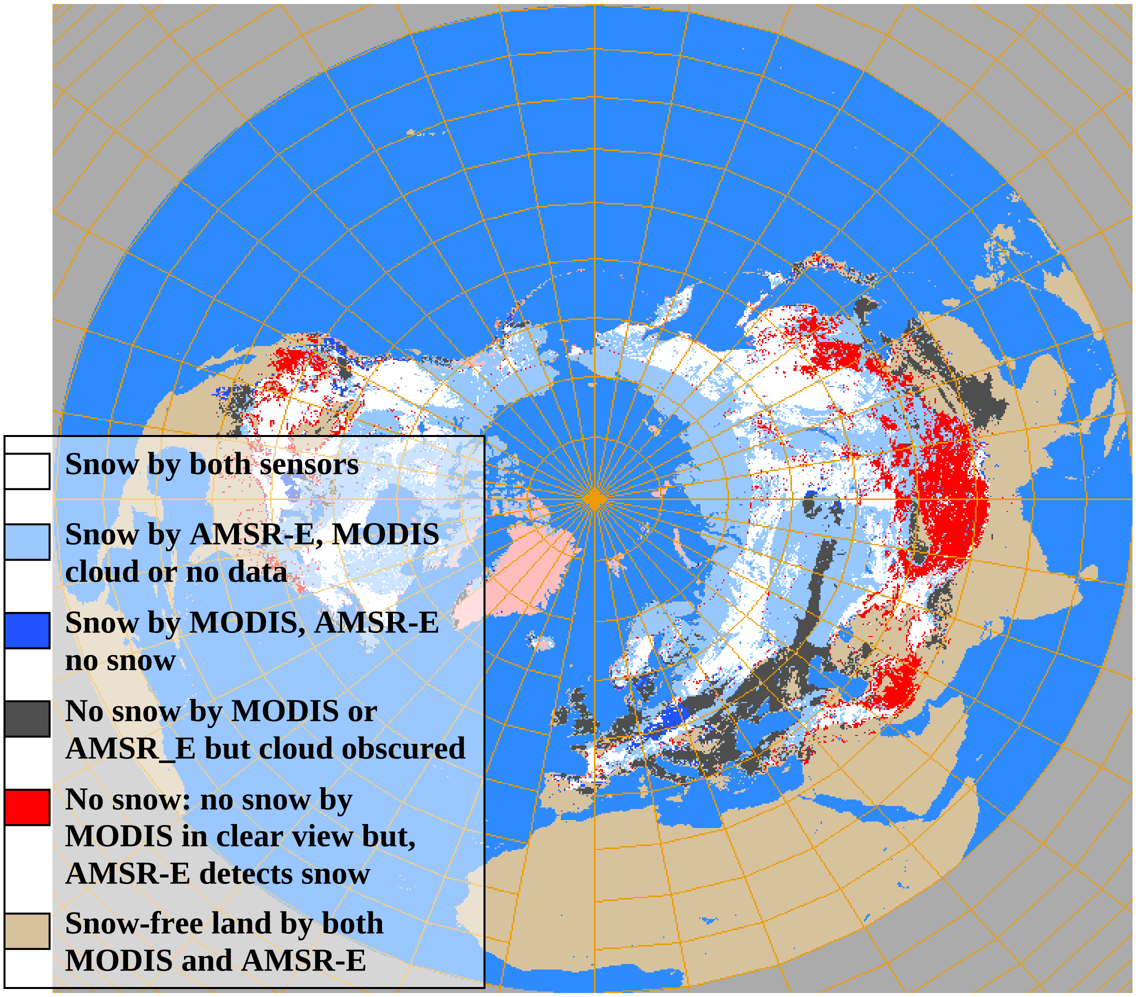

Figure 1. ANSA blended-snow product for 26 January 2007 in Lambert Azimuthal polar projection.

BACKGROUND

MODIS standard snow maps (MOD10C1) provide high-quality snow maps under clear-sky conditions, and represent the default for mapping snow cover in the ANSA algorithm. AMSR-E data can map snow through clouds and darkness and provide accurate measurement of SWE in some land-cover types. The SWE in the ANSA map is derived solely from the AMSR-E. An updated description of the AMSR-E algorithm may be found in Kelly (2009).

Previous work (Fig. 2) showed that use of the ANSA product enables improved mapping of snow-cover extent in the Lower Great Lakes region relative to using either MODIS or AMSR-E maps alone (Hall et al., 2007; Akyurek et al., submitted).

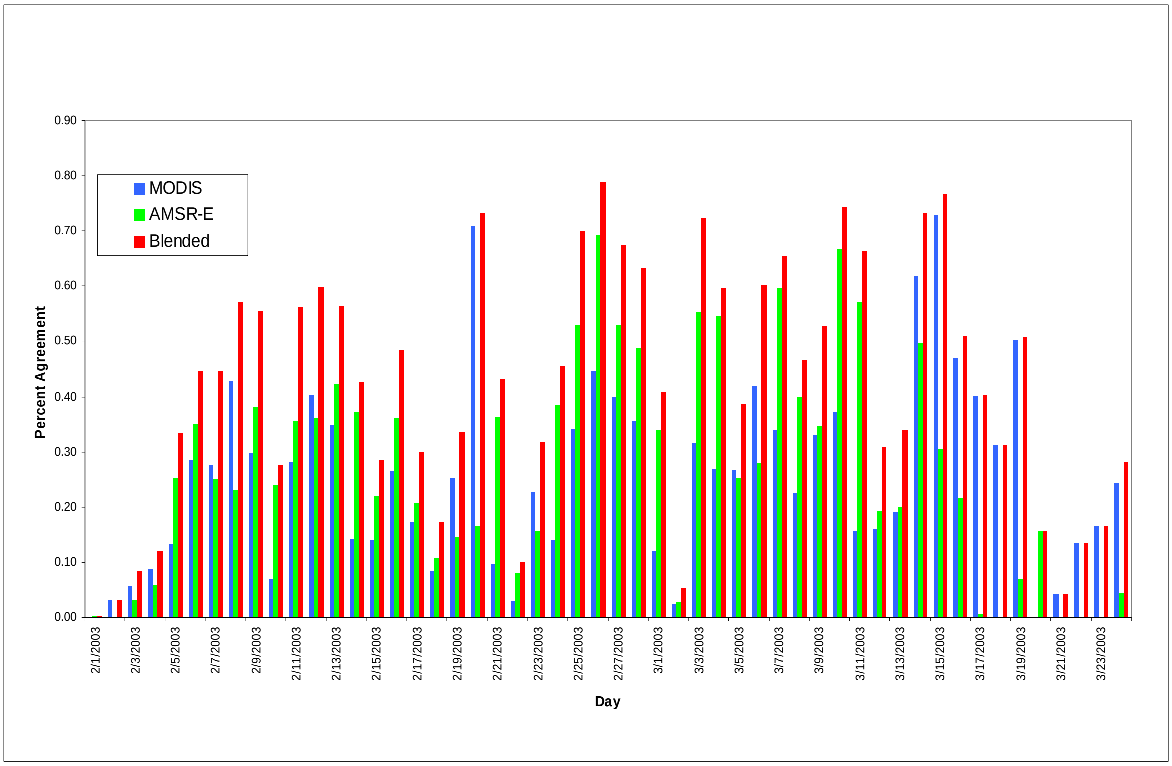

Figure 2. Relationship of the Percent of Agreement of the ANSA product, and the MODIS and AMSR-E input products, alone, as compared to ground truth for the lower Great Lakes region for mapping snow-cover extent in 2003. The AMSR-E contribution (green) becomes more important in late February during periods of cloudiness when MODIS cannot map the snow. When the sky is clear, MODIS (red) is the primary instrument to map snow cover in the ANSA algorithm (after Hall et al., 2007).

METHODOLOGY

For the present work we used National Climatic Data Center (NCDC) co-op station data from the winter of 2007 – 2008 in the Lower Great Lakes region, to compare with ANSA-derived SWE (Fig. 3). Co-op snow depth data were interpolated to develop a daily map (see sample map in Fig. 4) and then converted to SWE using two different conversion factors: 0.2 and 0.3 (representing snow density estimates of 0.2 and 0.3 g / cm^3, respectively). (Since the exact snow density was unknown, we converted snow depth to SWE using two different snow densities which are reasonable for the conditions and time of year.) Difference maps were then constructed to permit evaluation of the differences in SWE derived from ANSA vs. station data.

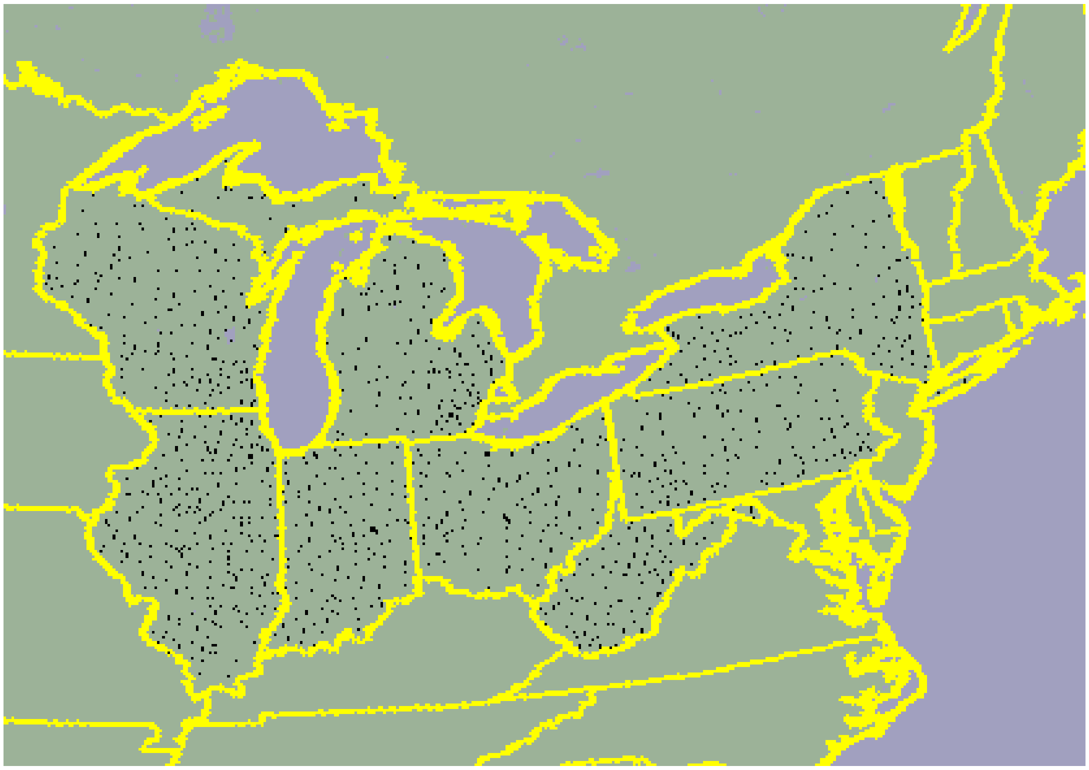

Figure 3. Dots represent locations of NCDC co-op stations in eight states.

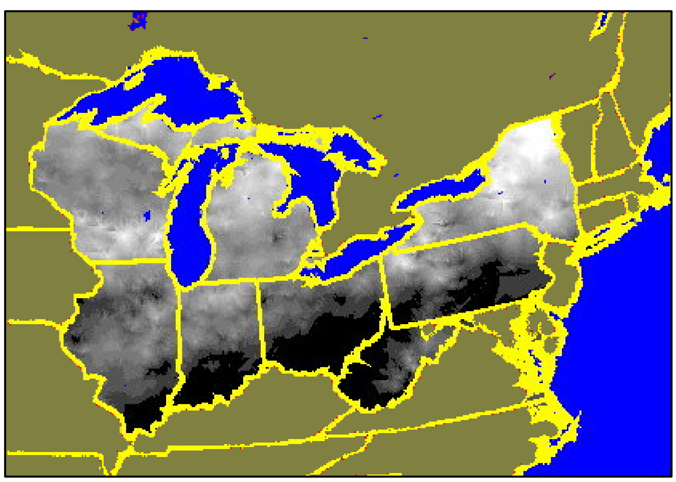

Figure 4. 1 Dec. 2007 snow depth map interpolated from co-op station measurements. Snow depths are shown in various shades of B&W (lighter grey indicates deeper snow).

We also constructed daily difference maps after removing the mean monthly bias. Mean monthly bias was calculated by calculating the mean of the daily bias measurements for each cell (the difference between the co-op-derived SWE and the AMSR-E SWE).

RESULTS & DISCUSSION

Maps in Figs. 5a & 5b show the difference between the interpolated co-op data compared to the ANSA SWE on a cell-by-cell basis. The blue colors indicate that the ANSA underestimates SWE as compared to station data, and the pink colors indicate that ANSA overestimates SWE. The areas of best agreement are shown in neutral colors.

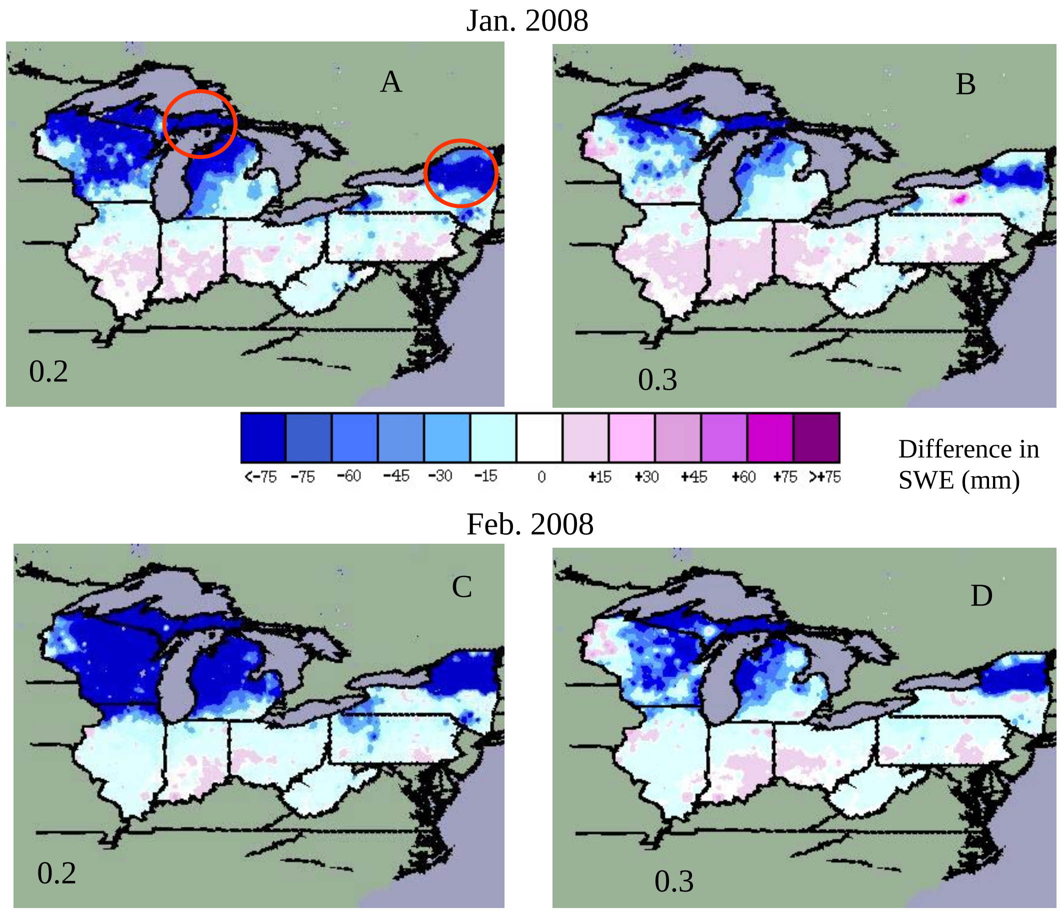

Figure 5. Mean difference between AMSR-E and station-derived SWE for January (A & B) and February 2008 (C & D) using 0.2-conversion factor (A & C), and 0.3-conversion factor (B & D). Conversion factors are used to convert co-op station snow-depths to SWE and are based on snow density. If snow density is not known, it must be assumed. This demonstrates the importance of knowing the snow density, for the calculation of SWE.

Snow density -- conversion of density to SWE. In January and February of 2008, ANSA underestimates SWE in densely-forested areas such as in the Upper Peninsula of Michigan and in the Adirondacks in New York State by up to ~75 mm (see red circles in Fig. 5a). Even when using its forest-fraction adjustments, passive-microwave algorithms may still underestimate SWE in dense forests.

In this work, we addressed the question, “What snow density should be used to convert the co-op snow depths to SWE?” In both the January and February 2008 average SWE difference maps (Figs. 5a & 5b), there is overall better agreement when we use a snow density of 0.3 to convert the snow depths to SWE (Figs. 5c & 5d). Note the substantial differences when different conversion factors are used. This demonstrates the need to improve density estimates, especially in areas where snow conditions change rapidly. Models that improve the evolution of snowpack parameters, including grain size, and use of dynamic algorithms that better account for changes in snow density, should be the focus of future work.

Over Wisconsin (see red arrow in Fig. 6a), for example, between 9 and 10 January 2008, the AMSR-E SWE ranged from ~4-30 mm (on 9 January), and jumped to ~54-100 mm (on 10 January). Figures 6a and b show difference maps that illustrate the change in SWE. This kind of rapid change in SWE might indicate that there was a snowfall event between the two image dates. MODIS snow maps show cloud cover on both dates, and NOAA IMS snow maps show nearly complete snow cover in Wisconsin on both dates. But the station data in Wisconsin do not support the contention that there was a substantial snowfall event. Instead, we think that decreasing air temperatures between 8 and 10 January may have caused a surface layer of refrozen snow to form which may have increased the microwave scattering, thus lowering the T_B and causing the AMSR-E SWE algorithm to erroneously calculate an increase in snow depth and SWE.

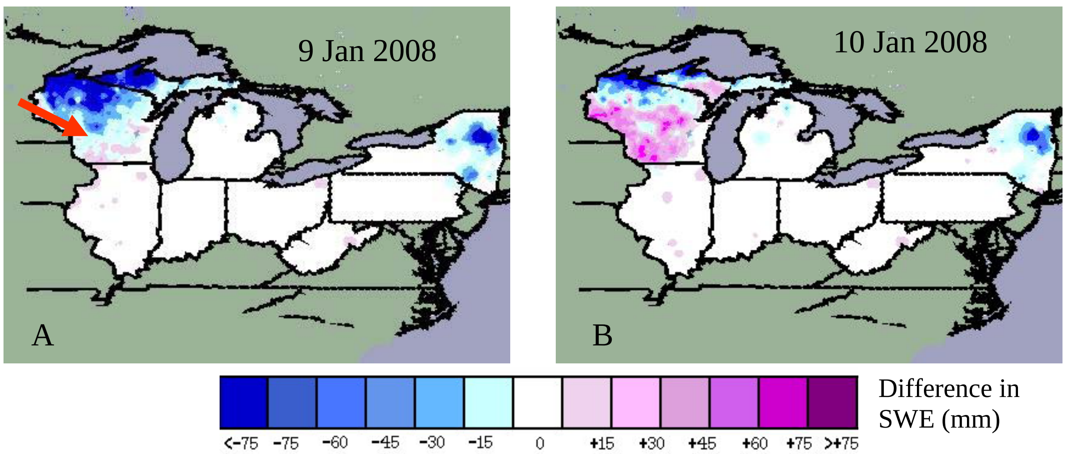

Figure 6. Note change in SWE from one day to the next in Wisconsin (snow depth to SWE conversion factor for co-op data used = 0.3).

Improvement of ANSA SWE calculation using monthly bias information. Finally, we experimented with the monthly bias information to produce "corrected" SWE maps as shown in Fig 7.We also changed the algorithm so that only areas that are currently snow covered are displayed on the maps, and other areas are shown in green (or non-snow-covered terrain). Thus the maps in Fig. 7 represent our current "best effort" in determining SWE from AMSR-E for our study area and time period.

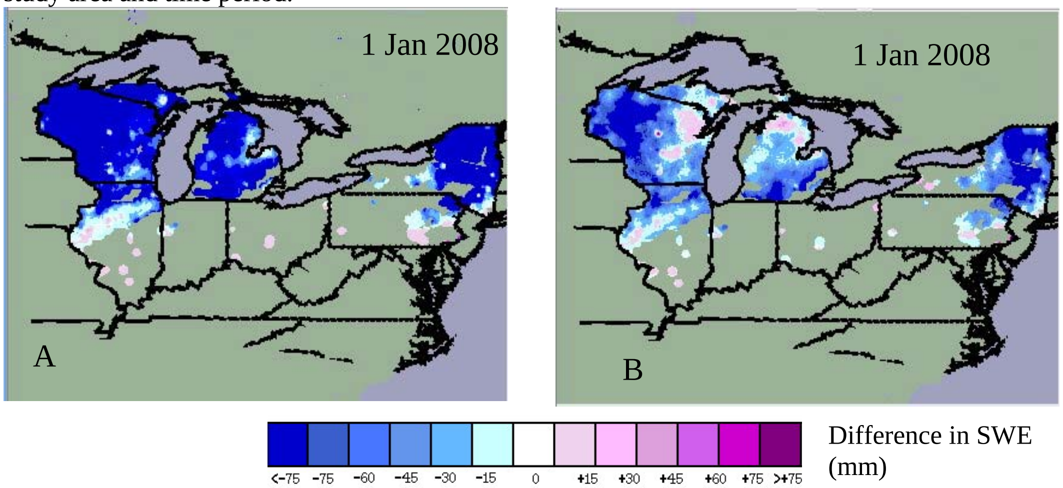

Figure 7. Mean difference between AMSR-E and station-derived SWE for 1 January 2008, using a conversion factor of 0.2 (A). In (B), the mean monthly bias is subtracted from each cell in the difference map, and is shown in (A). In these images, the non-snow-covered areas are shown in green.

Figure 7 shows the mean difference between AMSR-E and station-derived SWE for 1 January 2008 using a conversion factor of 0.2 (Fig 7A). Conversion factors are used to convert co-op station snow depths to SWE and are based on snow density. In Fig. 7B, the mean monthly bias, calculated from the daily differences between the ANSA-derived and co-op-derived SWE, is removed from each cell of the difference map shown in Fig. 7A.

CONCLUSIONS AND FUTURE WORK

We have examined the ability of the preliminary ANSA blended-snow product to measure SWE in the Lower Great Lakes region of the U.S. Results demonstrate that the ANSA underestimates SWE in dense forests, a known limitation of passive-microwave SWE algorithms.

Estimation of snow density is needed to convert the co-op station data to SWE values, so that ANSA SWE can be compared with "ground truth." For our study area, use of a conversion factor of 0.3 (corresponding to a snow density = 0.3 g / cm^3) provides overall better agreement between ANSA and co-op SWE for both January and February 2008. This illustrates that a dynamic method of calculating snow density in a passive-microwave SWE algorithm would likely result in improved SWE estimates from microwave sensors.

Rapid changes in ANSA-derived SWE can occur such as are seen in Wisconsin between 9 and 10 January 2008. A change in snow conditions due to a thaw-re-freeze event may have caused erroneous AMSR-E SWE determination on 10 January 2008. We conclude this because the co-op data do not show an obvious increase in snow depth and SWE between these two days, but they do show air temperatures that support a thaw-refreeze event.

We calculated the average monthly bias (difference between co-op-derived SWE and AMSR-E SWE) from the daily maps from 1 – 31 January 2008. Those values, on a cell-by-cell basis, were subtracted from the AMSR-E SWE values for each day of January 2008. Results show an improvement in agreement between the co-op station-derived and AMSR-E SWE after the monthly bias was removed.

This analysis will eventually include the entire 2007-08 snow season for the Lower Great Lakes region. In addition, we are in the process of quantifying the improvement in the “corrected” maps. Additional study areas having varied snow- and land-cover conditions will also be studied in future work.

ACKNOWLEDGEMENTS

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