Preliminary Evaluation of the AFWA-NASA Blended Snow-Cover Product over the Lower Great Lakes region

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ABSTRACT

A new snow product created using the standard Moderate-Resolution Imaging Spectroradiometer (MODIS) and Advanced Microwave Scanning Radiometer for EOS (AMSR-E) snow cover and snow-water equivalent products has been evaluated for the Lower Great Lakes region during the winter of 2002-03. National Weather Service Co-Operative Observing Network stations and student-acquired snow data were used as ground truth. An interpolation scheme was used to map snow cover on the ground from the station measurements for each day of the study period. It is concluded that this technique does not represent the actual ground conditions adequately to permit evaluation of the new snow product in an absolute sense. However, use of the new product was found to improve the mapping of snow cover as compared to using either the MODIS or AMSR-E product, alone. Plans for further analysis are discussed.

Keywords: snow-cover map, MODIS, passive microwave, AMSR-E, Great Lakes region

INTRODUCTION

A preliminary blended-snow product has been developed jointly by the U.S. Air Force Weather Agency (AFWA) and the Hydrospheric and Biospheric Sciences Laboratory (HBSL) at NASA / Goddard Space Flight Center. A description of the preliminary product, called the AFWA – NASA or ANSA blended snow-cover product, may be found in Foster et al. (this volume). The product utilizes the Moderate-Resolution Imaging Spectroradiometer (MODIS) standard daily global (5-km resolution) snow-cover product (Hall and Riggs, 2007) and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) standard daily global (25 km resolution) snow-water equivalent (SWE) product (Kelly et al., 2003) to map snow cover and SWE. Future enhancements will include the use of scatterometry data (see Nghiem and Tsai, 2001). We have undertaken an analysis of the ability of the ANSA blended product to map snow-cover extent in the Lower Great Lakes region for the winter of 2002 – 2003. Some of the benefits and challenges of validating this new product for mapping snow cover as compared to using the MODIS or AMSR-E products alone, are discussed.

BACKGROUND

In previous work, the MODIS snow-cover and cloud-masking products were validated in the Lower Great Lakes region using student-acquired data from the Global Learning and Observations to Benefit the Environment (GLOBE) and Students and Teachers Evaluating Local Landscapes to Interpret The Earth from Space (SATELLITES) (a K-12 program developed at the University of Toledo), or GLOBE-SAT, and National Weather Service (NWS) Co-Operative Observing Network observations (Ault et al., 2006). Quantitative analysis of the Version 4 MODIS snow algorithm produced an accuracy of 94% when compared to student observations, the largest errors being associated with partly cloudy conditions during the winters of 2001-2002 and 2002-2003 (Ault et al., 2006).

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Other work reports on the accuracy of the MODIS snow-cover products (Hall and Riggs, 2007). Various researchers (e.g., Bussières et al., 2002; Klein and Barnett, 2003; Simic et al., 2004; Zhou et al., 2005) have studied the accuracy of the products under a variety of snow- and land-cover conditions. Most studies show an overall accuracy of ~94% compared with ground measurements, but lower accuracies are reported in the fall and spring, and under thin-snow conditions and in dense forests. Omission errors (misclassifying snow as non-snow-covered land) tend to be low. A significant source of error in the MODIS snow products is due to the overly conservative nature of the cloud-masking algorithm (Ackerman et al., 1998), used as an input to the snow algorithm, which may result in more cloud obscuration than is actually present.

Currently, the SWE of a dry snowpack can be estimated with passive-microwave sensors such as the Special Sensor Microwave/Imager (SSM/I) (Chang et al., 1987), and the Advanced Microwave Scanning Radiometer for EOS (AMSR-E) (Kelly et al., 2003), which was launched on the Aqua satellite in May of 2002. In Canada, SSM/I data have been used to provide operational SWE map products (Derksen et al., 2002) for the Canadian prairie region. Forest cover can adversely affect the SWE retrieval accuracy by reducing the characteristic scattering response from snow. Foster et al. (2005) showed that dense vegetation is the major source of systematic error in passive microwave algorithms, and in static algorithms, the assumption of a constant snow grain size also contributes significant errors. Kelly et al. (2003) developed a methodology to estimate snow grain size and density as they evolve through the season using SSM/I and simple statistical growth models. The current version of the algorithm estimates snow depth first and then calculates SWE from climatology data from Brown and Braaten (1998) and Krenke (1998). The approach uses the scattering signal determined by the difference in brightness temperature between 10 and 36 GHz at vertical and horizontal polarizations (Tb10V-Tb36V and Tb10H-Tb36H). A variable parameter (*a*) is calculated from the polarization difference at 36 GHz brightness temperatures which is used to multiply the brightness temperature differences (Tb10V-Tb36V and Tb10H-Tb36H). The overall approach is split into two parts with one part retrieving snow depth for the fraction of a footprint that is forest covered and the other retrieving the fraction that is forest-free.

There have been numerous studies undertaken to combine or blend datasets or data products to map various snow-cover parameters. For example, Kongoli et al. (2006) blended Advanced Microwave Sounding Unit (AMSU) and Interactive Multi-Sensor Snow and Ice Mapping System (IMS) (Ramsay, 1998) data to map snow cover and extent. The blended product was found to retrieve large-scale SWE quite well over Slovakia in the winter of 2005-06 (e.g., it showed the increase in SWE toward the northeast), but did not capture SWE well at the small scale. The accuracy of the SWE retrieval was found to be influenced by elevation and land-surface temperature. Azar et al. (2006) blended active- and passive-microwave data to map SWE and found that the addition of the active-microwave data to the passive-microwave data permitted improved SWE retrieval, but the use of active-microwave data, alone, did not produce satisfactory results. Many other blended products are available and others are under development.

STUDY AREA AND VALIDATION DATA

The Lower Great Lakes study area is located roughly between the Canadian border to the north to approximately 38°N to the south, and 92° and 73° W, including the following states: Illinois, Indiana, Michigan, New York, Ohio, Pennsylvania, West Virginia and Wisconsin (Figure 1). The land cover is varied, consisting of farming land and predominantly mixed tree cover, with generally less than ~30% forest-cover density. Approximately 1293 NCDC data points from the NWS cooperative observing network are located throughout the 8 states in the study area. In addition to the NWS Co-op station data, up to139 GLOBE-SAT data points are available (Ault et al., 2006) from the 2002-03 winter.

The study area includes the lake-effect snowbelt areas to the east of Lake Michigan and Lake Erie. Deep snow cover forms sometimes in small bands when eastward-moving cold-air masses, originating from the continental polar regions of Canada, flow over the Great Lakes and pick up additional energy and moisture. The air mass must be cooler than the lake surface to instigate lake-effect snowfall. If the air mass at the at the 850 mb level is at least 13°C colder than the lake surface, heavy lake-effect snow can occur. Snowfall rates are often quite intense (>2.5 cm/hour) and resulting snow depths can exceed 0.5 m or more during a

24-hour period. The deepest snow occurs on the lee side of the lakes and in higher-elevation areas due to orographic uplifting which enhances the cooling of the air mass. Once ice forms on the Great Lakes, it effectively cuts off the formation of lake-effect snow.

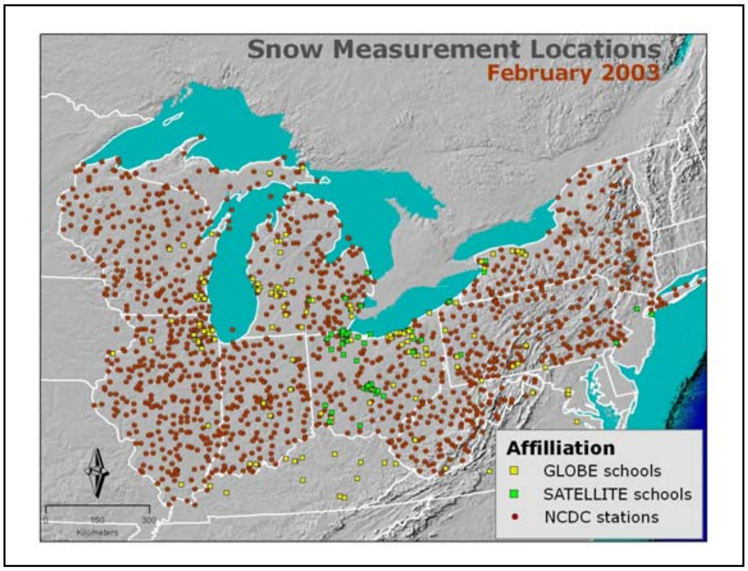

Figure 1. Locations of 1293 NWS Co-op stations and 139 GLOBE-SAT stations in the study area.

RESULTS AND DISCUSSION

The ANSA blended-snow map represents improved detection of snow-cover extent as compared to using either MODIS or AMSR-E data alone. Figure 2 shows the percentage of snow mapped using MODIS and AMSR-E data alone, and using the ANSA product for each day during the 2002-03 winter from 1 November 2002 through 31 March 2003, in comparison with a snow-cover map developed using kriging to interpolate the station data. Note in Figure 2 that the contribution to the ANSA blended product is predominantly from MODIS in the early part of the snow season, while the contribution from the AMSR-E becomes greater after mid-January. As the snow deepens during the winter, snow grain size increases and the temperatures become consistently colder, the ability of the passive-microwave sensors to map snow increases, and the agreement between the visible and passive-microwave maps improves (Basist et al., 1996; Armstrong and Brodzik, 2001). MODIS snow maps were compared with SSM/I-derived snow maps over the prairie and boreal forest region in western Canada by Bussières et al. (2002); generally good correspondence was found in the taiga region in eastern Canada, however, the SSM/I maps were not as accurate as were the MODIS maps in the fall and spring. This is because the passive-microwave sensors are not able to map wet snow cover effectively since the penetration of the microwave signal when the snow is wet is extremely low.

The ground measurements derived from the NWS Co-op station data does not characterize the actual snow cover over the larger study area accurately over much of the 2002-03 winter. In addition, the density of the station data may not be adequate to conduct a validation study using ground measurements in a 25 km^2 cell. Chang et al. (2005) report that a density of 10 ground measurements in a 25 km^2 SSM/I or AMSR-E pixel is necessary in order to produce a sampling error of 5 cm or better. That ground-truth or station density has not been achieved in this work. Yet there are some interesting things to be gained from the analysis comparing the MODIS and AMSR-E maps.

The benefit of the ANSA blended-snow map is maximized when AMSR-E contributes where there is cloud cover and MODIS data are available to map snow at the edges of snow-covered areas. MODIS provides snow data under clear skies, and where there is shallow or wet snow – these types of snow cover may not be mapped using AMSR-E alone.

The primary limitation of the MODIS snow-cover maps is the inability of the MODIS to map snow through cloudcover. This study area is also very challenging for mapping snow cover using passive-microwave sensors due to the varied land cover and the frequency of lake-effect snows (deep and wet snowfalls). Especially in Wisconsin, the large number of small lakes further complicates the determination of SWE. The relatively coarse resolution of the AMSR-E product (25 km^2) is problematic, due to mixed-pixel effects, for mapping snow near the coasts of the Great Lakes where much of the lake-effect snow accumulates.

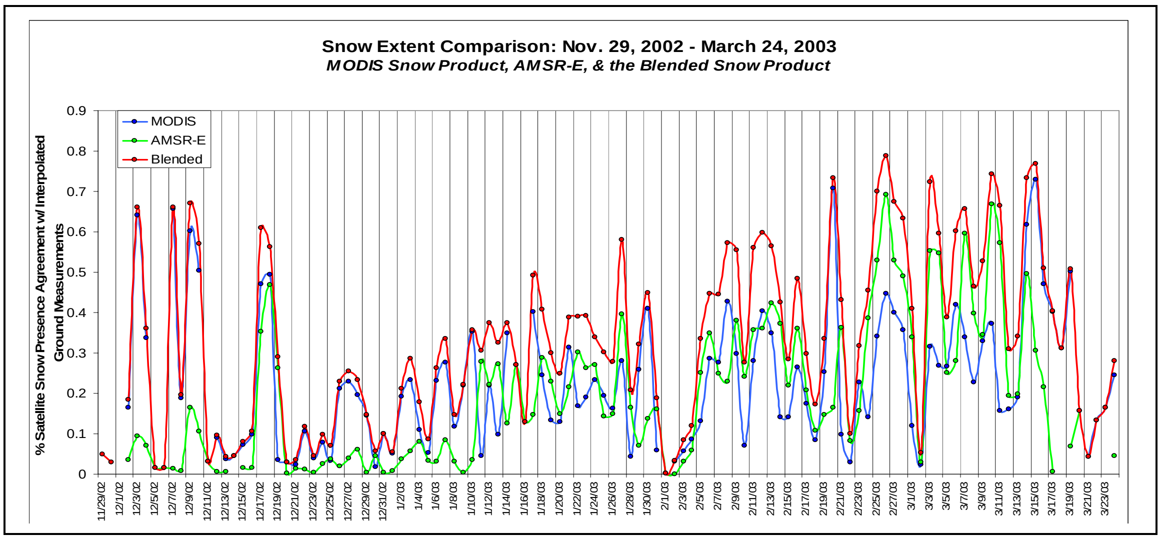

Figure 2. Graph showing the relationship of the Percent of Agreement of the ANSA blended product, and the MODIS and AMSR-E input products, alone, as compared to the interpolated snow map, for the winter of 2002 – 03. Note that in the beginning of the snow season, snow extent from the blended product is determined mostly from MODIS, and that the AMSR-E contribution becomes important in mid-January.

In short, several issues have been identified in this analysis that warrant further work. The density of the ground measurements may not be adequate to provide accurate snow-cover information to permit the interpolation technique to adequately represent the snow cover in the area. Furthermore, the selection of the method of interpolation will also affect the accuracy of the "ground truth" map; for example, Fassnacht et al. (2003) discussed methods of interpolation to validate SWE measurements using snow telemetry (SNOTEL) data. Also, at the 25-km spatial resolution of the ANSA blended product, there may be little actual correspondence between the point measurements (station data) and the 25 km^2 cell of the ANSA map.

CONCLUSIONS

For the Lower Great Lakes region, our results show an improvement in monitoring snow cover using the ANSA product for the winter of 2002-03, relative to using either MODIS or AMSR-E snow maps alone. But the results demonstrate that the utilization of interpolated NWS Co-op station data, at least in this challenging study area, do not provide adequate "truth" to which the ANSA, or any other snow cover product, can be compared for absolute validation for the relatively-large cell size (25 km^2) of the ANSA product.

ACKNOWLEDGMENTS

Funding for this project was provided by the Air Force Weather Agency (AFWA) and NASA. The authors thank John Eylander / AFWA for his many ideas relating to the development and validation of the blended-snow algorithm.

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