Melting Snow from Passive Microwave Observations for a Microwave/Visible Blended Product: First Results

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ABSTRACT

Snow cover is a key component of the Earth's energy balance and a key storage mechanism for water. In many areas of the world, people rely on snowmelt runoff for their water resources. It is essential that the extent and water content of seasonal snow cover be determined to a degree of accuracy concomitant with the instrumentation available. The ability to characterize snow storage more accurately at the drainage basin scale is crucial for improved water resource management. Global patterns of snow storage are also key components to the understanding of global change.

A project aimed at providing snow cover fraction and area, snow water equivalent (SWE), snowmelt onset and snow albedo for the first time into a single, user-friendly product is currently being carried out by the Goddard Snow Team (GoST) at the Goddard Space Flight Center, in Greenbelt, MD, USA, and funded by the Air Force Weather Agency and NASA.

In this study, we show first results of an algorithm blending existing snow products to map snow extent and SWE, and using passive-microwave data to map areas of actively-melting snow as derived from the Advanced Microwave Scanning Radiometer (AMSR-E) brightness temperatures at 0.25 degree resolution. Melting snow is detected by means of threshold values on both brightness temperature values and relative differences between daytime and nighttime values (diurnal amplitude variations, DAV). Microwave and visible data are re-projected into the polar stereographic projection with a resolution of 0.25 degrees and co-registered for the generation of the blended product. First results obtained over a test area in the northern United States, and Canada are reported for the period February – April, 2003. We found that the number of melting days between February and April, 2003 ranged between 2 and 16 days. Also, we identified two distinct melting events on February 22 and February 26, 2003 over a test area located nearby the Great Lakes.

Keywords: Snow, Melting, Passive Microwave Remote Sensing

INTRODUCTION AND BACKGROUND

The following results are a consequence of an effort to support the development of a blended-snow product, called the AFWA-NASA, or ANSA (Air Force NASA Snow Algorithm) blended snow-cover product, jointly developed by the U.S. Air Force Weather Agency (AFWA) and the Hydrospheric and Biospheric Sciences Laboratory (HBSL) at NASA / Goddard Space Flight Center (Foster et al. and Hall et al.). The product uses the Moderate-Resolution Imaging

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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. In particular, in this study we focus on the detection of wet snow from AMSR-E brightness temperatures. The presence of wet snow, indeed, prevents the retrieval of SWE from space-borne data and, hence, also the snow cover mapping using AMSR-E product.

The detection of wet snow from space-borne microwave data is possible because a strong and sudden increase of the imaginary part of snow permittivity (and as a consequence of brightness temperature) occurs when liquid water particles appear within the snowpack (see Chang et al., 1976, 1982 and Tedesco et al., 2006), even in small amount. If snow is dry during the night (either frozen or refrozen) and it becomes wet during the day, then daytime brightness temperature will be higher than that acquired during nighttime. Also, if melting persists during the night then the brightness temperature will remain high. An increase in brightness temperature can be also caused by other factors such as the decrease of effective grain size due to new snow, or changes in snow temperature. However, these processes do not occur as fast as liquid water can appear in the snowpack in a diurnal cycle. Accounting, therefore, of the temporal dynamic of melting events is an important aspect that must be accounted for during the development of the algorithm.

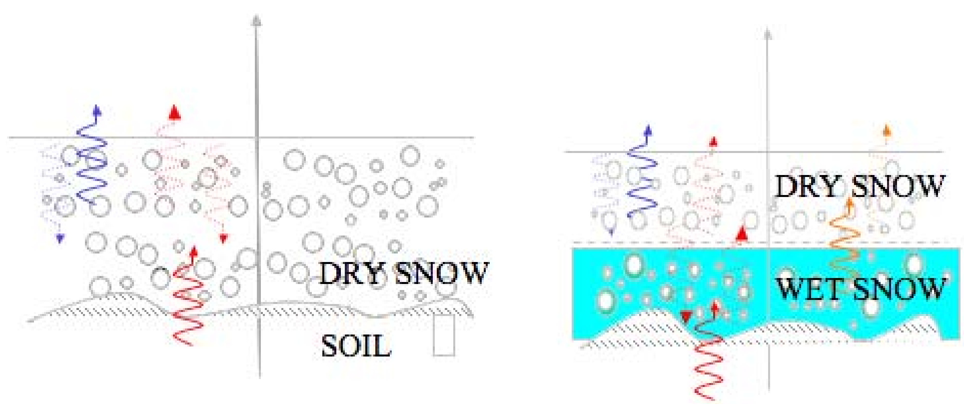

Figure 1. Cartoon of dry and wet snow contributions to brightness temperature. DRY SNOW: The main contribution to the microwave brightness temperature (Tb) is due to the soil for which signal is reduced by the volumetric scattering due to snow and to snow itself. WET SNOW: The main contribution to the Tb is due to the wet snow layer for which the signal is reduced by the volumetric scattering due to the upper layer of dry snow. The soil contribution is strongly reduced by the wet snow layer.

In the microwave region, dry snow can be represented as ice particles embedded in an air background (see Figure 1). Volumetric scattering due to the ice particles attenuates the signal emitted by the soil, decreasing measured brightness temperatures with respect to those measured in the case of bare soil. In the case of wet snow, snow can be considered as a mixture of ice, liquid water and air. As the liquid water content (LWC) increases, and so does brightness temperature (as a consequence of the reduced volumetric scattering and increased absorption) until when a further increase on the LWC is not followed by an increase in the brightness temperature. When snow refreezes, brightness temperatures decrease, mainly as a consequence of the decrease of both LWC and snow temperature.

The algorithm used here is based on the Diurnal Amplitude Variation (DAV), originally proposed by Ramage and Isacks (2002), Ramage (2001) and Ramage and Isacks (2003). The DAV approach has been also used recently by Tedesco (2007) to derive surface snowmelt over the Greenland ice sheet. In the algorithm, wet snow is detected when 1) the brightness temperature and 2) the difference between brightness temperatures collected during daytime and nighttime exceeds fixed threshold values *A* and *B* (see Figure 2). In order to account for melting that eventually might persist during the night, we use the rule that snow is melting when both ascending and descending brightness temperatures are greater than the threshold value, *A*. The main hypothesis is that histograms of brightness temperatures measured during both dry and wet snow conditions can be modeled by means of a bimodal distribution, with the left-normal distribution (LND) being representative of dry snow conditions and the right-normal distribution (RND) representative of wet snow conditions.

T_{b37v} > 242 K AMSR-E	T_{b19H} > 243 K AMSR-E
DAV = abs($T_{basc.}$-$T_{bdesc.}$) 10 K	DAV = abs($T_{basc.}$-$T_{bdesc.}$) 24 K

Figure 2. Threshold values used within the DAV algorithm for different frequencies.

Hence, wet snow can be detected according to the condition that measured brightness temperature belongs to the RND and that the difference between nighttime and daytime measurements is greater than a threshold value. This last condition assures us that the change in brightness temperatures is related to the appearance of liquid water (because of the abrupt and sudden change in brightness temperature) instead of other factors.

In order, to consider only those areas covered by snow, microwave and visible data are re-projected into the polar stereographic projection with a resolution of 0.25 deg and co-registered (Figure 3). First results obtained over a test area in the northern United States and Canada are reported for the period February – April, 2003.

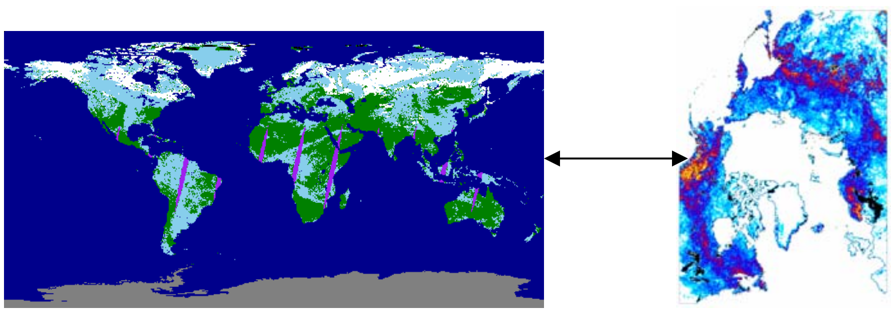

Figure 3. Blending product concept.

RESULTS AND DISCUSSION

Figure 4 shows the number of melting days observed in (a) February – April, (b) March and (c) February 2003 for different periods derived from 36.5 GHz AMSR-E brightness temperatures using the approach described in the previous section. Only those areas classified as snow by MODIS are used to produce the maps shown in Figure 4. From Figure 4 (a) we see that the cumulative number of melting days between February and April 2003 ranges from 2 to 16 days. The area showing the highest number of melting days is located in north-west Canada. It is also possible to see that, as expected, the number of days when melting occurs is increasing from northern to southern locations. Figure 4 (c) shows that melting occurred during February 2003 in Alaska, Russia and along the Great Lakes area. The Lower Great Lakes study area is also used as a validation area for the blended product (see Hall et al., this issue). The land cover is varied, consisting of farming land and predominantly mixed tree cover, with generally less than ~30% forest-cover density.

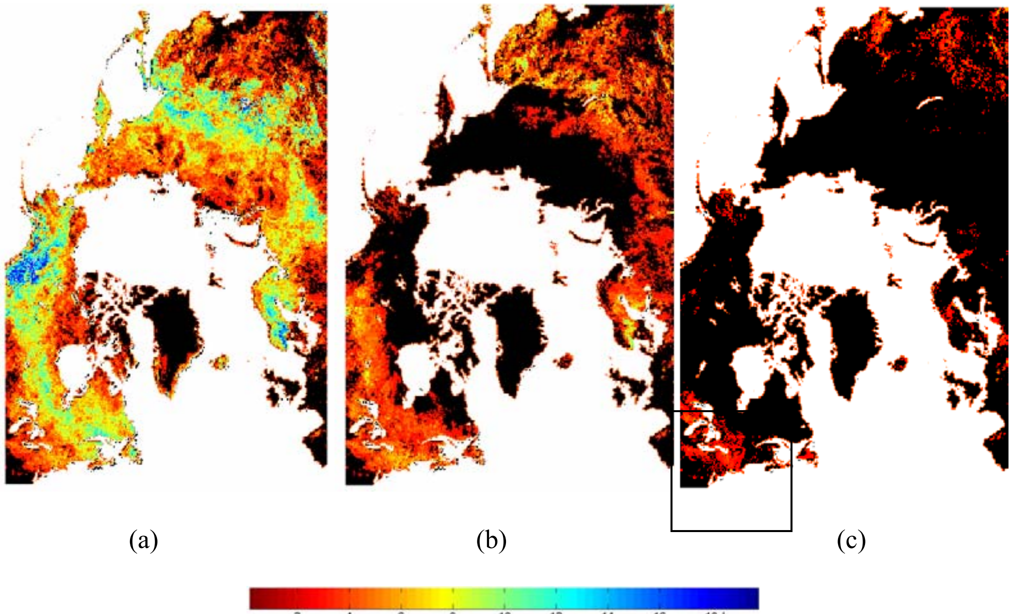

Figure 4. Number of melting days observed in (a) February – April, (b) March and (c) February 2003 for different periods: note that only areas classified as snow by MODIS are reported here.

Figure 5 shows the temporal trend of the melting area derived from the blended product for February 2003 for the validation area (rectangle in Figure 4 (c)). Two distinct peaks can be identified, the first one occurring on February 22, 2003, when the melting area reached an extension of approximately 0.35 million km^2 and a second one, occurring on February 28, 2003 with a melting area of approximately 0.2 million km^2. Before February 22, 2003 sporadic melting occurred, never exceeding 0.05 million km^2.

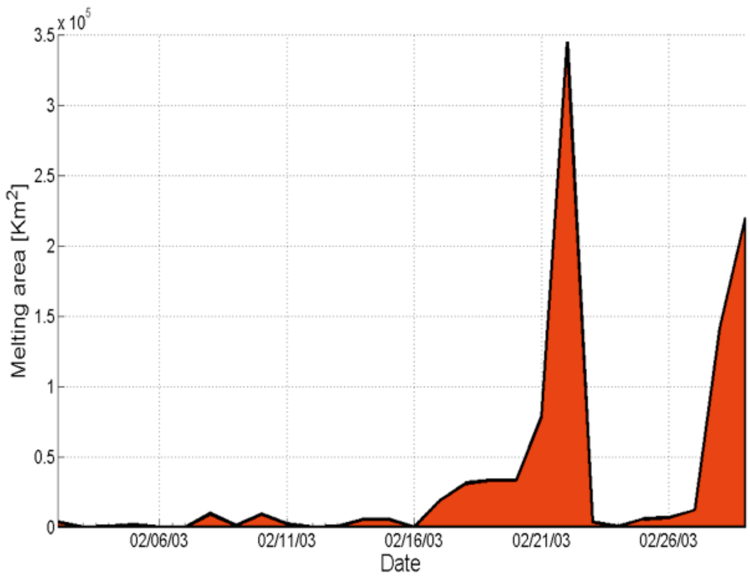

Figure 5. Melting area derived from the blended product for February 2003 for the validation area (rectangle in Figure 4 (c)).

CONCLUSION AND FUTURE WORK

We showed preliminary results of an algorithm blending melting snow as derived from AMSR-E brightness temperatures with MODIS snow cover. The algorithm is part of a project aimed at providing snow cover fraction and area, snow water equivalent (SWE) and snowmelt onset and into a single, user-friendly product developed at the Goddard Space Flight Center, in Greenbelt, MD, USA, and funded by AFWA. Melting snow is detected utilizing a threshold algorithm using both brightness temperature values and relative differences between daytime and nighttime brightness temperature values (diurnal amplitude variations, DAV). Microwave and visible data were re-projected into a polar stereographic projection with a resolution of 0.25 deg and co-registered to generate the blended product. In particular, we report results in the Northern Hemisphere between February and April, 2003. We showed preliminary results obtained over a validation area, located within the Great Lakes area regarding both spatial and temporal trends of melt extent. The cumulative number of melting days between February and April 2003 ranges from 2 to 16 days. Also, we identified two distinct melting events on February 22 and February 26, 2003 over a test area located nearby the Great Lakes. These results will be validated by means of ground-based measurements and compared with results obtained from space-borne microwave active data (e.g., QuikSCAT). For future work, we intend to refine the melting snow algorithm by using dynamic threshold values, both in space and time.

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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