P5.22 DEVELOPMENT AND EVALUATION OF THE AMSU-BASED SNOW WATER EQUIVALENT RETRIEVAL ALGORITHM

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1. INTRODUCTION

The estimation of snow water equivalent (SWE) from passive microwave sensors remains a formidable challenge primarily due to the non-unique nature of the microwave scattering signatures over snow cover surfaces. Ideally, there is a straightforward relationship between the volume of snow crystals present in the snow pack, and hence, SWE or snow depth, and the degree of microwave scattering by ice grains, measured by the drop in the brightness temperature (TB) observed by the satellite at a specific microwave window frequency. The degree of scattering can also be measured by computing a Scattering Index (SI) as the positive difference in TB measured at two microwave frequencies, TBv1 – TBv2 where v indicates frequency and v2 > v1. This spectral scattering signature, e.g., the decrease in TB with increasing frequency is unique to snow-cover surfaces, and as such has been used successfully for the identification of global snow cover (Grody, 1991). Similar to snow cover identification, this scattering index approach is also used for the retrievals of SWE. (Chang et al., 1987; Goodison and Walker, 1994).

The interpretation of the relationship between SWE and the passive microwave measurements is complicated due to the large influence of other physical factors such as forest cover (Hall et al. 1982), snow wetness (Chang et al., 1985), grain size and density (Chang et al., 1987), and precipitation (Grody, 1991). Dense forest cover, melt-water and higher-density metamorphosed snow cover attenuate scattering signatures, and thus underestimate SWE, whereas coarse-grained snow cover (depth hoar) increase scattering, and thus overestimate SWE. Precipitation-sized ice crystals in the atmosphere also scatter microwave radiation, further complicating the interpretation of microwave scattering signatures due to snow cover. These factors vary to a large extent by geographical region, season and weather patterns. As a result, no single algorithm has been found sufficient for correctly modeling global distribution of SWE or snow depth (Chang et al. 1987; Hallikainen and Tiuri, 1984; Kunzi et al., 1982).

The objective of this paper is to describe a new algorithm for the instantaneous retrievals of SWE from the Advanced Microwave Sounding Unit (AMSU). These instantaneous retrievals are being evaluated for the development of a global SWE product generated within an operational framework called the Microwave Surface and Precipitation Products System (MSPPS), which is administered by NOAA/NESDIS (National Environmental Satellite, Data and Information Service/Office of Satellite Data Processing and Distribution) (Weng et al., 2003; Ferraro et al., 2002). The AMSU instrument offers a unique range of millimeter wavelength channels that are sensitive to both precipitation- and snow cover-sized particles. Another advantage of the AMSU sensor is its large swath width, which, when combined with other microwave sensors like SSM/I, offers more global coverage in time and space. Below we provide a brief description of the AMSU instrument and the suite of products generated at NOAA/NESDIS. Next, most recent AMSU observations over snow cover in the US are also presented. These observations led to the development of a new AMSU-based SWE retrieval algorithm, which is also described in this paper. This algorithm is unique in that it utilizes a combination of lower and higher window frequency channels. Algorithm description is followed by a validation example. A detailed validation plan is underway to improve SWE retrievals over the US, and to extend these retrievals globally.

2. DESCRIPTION OF THE AMSU INSTRUMENT

The AMSU instrument contains two modules: AMSU-A and AMSU-B. The A module has 15 channels in the 23-89 GHz frequency range. The B module has five channels n the 89-183 GHz frequency range. The AMSU-A has an instantaneous field of view (FOV) of 48 km at nadir for all frequency channels, and scans $\pm 48^0$ from nadir with a total of 30 measurements across the scan. For AMSU-B, 90 measurements are made across the scan with a nadir resolution of 16 km for all channels. The nadir resolution degrades at larger scan angles. The swath width of both AMSU-A and –B is 2343 km.

The AMSU is flown on board the NOAA 15, NOAA 16, and NOAA 17 satellites. This three-satellite suite offers a global sampling nearly every 4 hours. The products within the MSPPS are generated operationally for the three satellites on an orbit-by-orbit basis (Ferraro et al.,

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2002). The suite of operational MSPPS products includes rain rate, total precipitable water, cloud liquid water, ice water path, snow cover, sea ice concentration and land surface temperature. The variety of surface and atmospheric products is due to the unique combination of channels in the microwave window (23, 31, 89, 150 GHz), opaque water vapor (183±1, ±3, ±7 GHz) and oxygen absorption (50-60 GHz) regions.

3. AMSU SCATTERING SIGNATURES OVER SNOW COVER

Recent studies with the AMSU instrument have shown that, similar to rain signatures, new snow cover surfaces scatter radiation in the 89-150 GHz region, displayed by stronger scattering at 150 GHz relative to that at 89 GHz. In contrast, scattering in the 20-30 GHz region for new snow cover is weak. Note that the current SWE algorithms utilize frequency channels below 40 GHz.

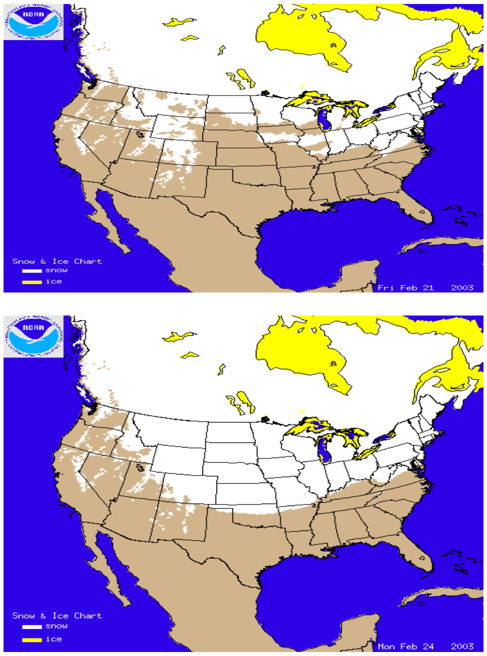

Figure1. Snow cover extent over US on February 21 (top) and February 24, 2003 (bottom).

Figure 1 displays snapshots of snow cover extent over the US (Ramsay, 1998) before (top panel) and after (bottom panel) an extensive snow storm that swept the US Great Plains. This snow storm deposited new snow as far south as northern Texas. The snow cover to the North (North Dakota and Northern Minnesota and Wisconsin) was older, resulting from previous snow accumulations as early as January 1, 2003. Figure 2 shows examples of AMSU measurements at 23, 31, 89 and 150 GHz window channels during the February 21-24, 2003 period. Note the flat microwave signature due to bare soil. In contrast, snow cover surfaces exhibit a decreasing brightness temperature gradient as the frequency increases. However, the spectral gradient exhibits some large differences as the snow becomes older. For freshly-fallen snow (6 hr old), the steepest gradient occurs in the 89-150 GHz region (about 25 K), due to strong scattering at 150 GHz by finer-grained snow cover. Note the flat response in the 20-30 GHz region, suggesting low microwave sensitivity in this low frequency range. As the snow becomes older and the grain size increases, sensitivity shifts to the 30-90 GHz region which attains the steepest gradient. Only for coarse-grained, metamorphosed snow cover, referred to in Figure 2 as “old snow” does the microwave sensitivity increase significantly at 23 and 31 GHz. Note also that for “old snow”, the spectral gradient in the 89-150 GHz reverses. This reversal is explained by grain size effects.

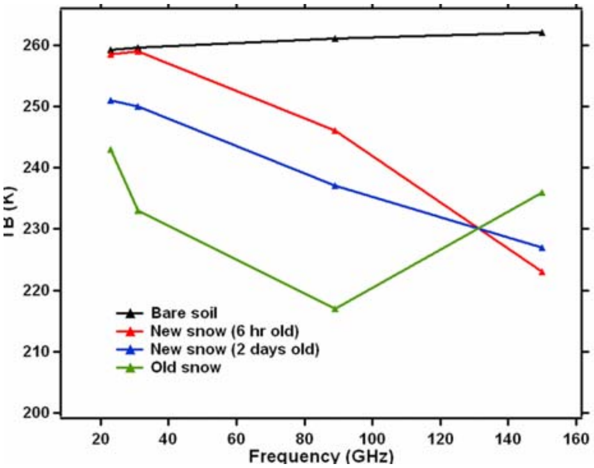

Figure 2. Examples of AMSU measurements over snow cover surfaces and bare soil.

For large grain sizes, the geometric optics limit is reached at 150 GHz, after which TB150 stays fairly constant, whereas TB31 and TB89 decrease due to scattering at 31 and 90 GHz. Figure 2 also shows that over all, the most sensitive microwave region for snow cover detection is 30-90 GHz due to strong scattering at 89 GHz by a broad range of snow ice grains. Grody (2004) interpreted AMSU observations over snow cover using a snow emissivity model, and found that the grain size parameter explained most of the variability in microwave response, particularly at frequencies 89 GHz and above. New snow cover with grain radii less than 0.4 mm exhibited scattering only at 89 and 150 GHz. In contrast, scattering at 23 and 31 GHz was significant only when the radii were greater than the 0.4 mm. These measurements suggest that the AMSU has the potential to capture a broad range of snow cover surfaces. In addition, these examples show that the 20-30 GHz region is sensitive only to older snow cover.

Therefore, current algorithms that utilize this low frequency range have limited applicability.

4. DESCRIPTION OF THE SWE RETRIEVAL ALGORITHM

The current AMSU-based SWE retrieval algorithm was developed from case studies over the US Great Plains areas (Kongoli et al., 2004). The current formulation is based on three microwave window channels: 23, 31 and 89 GHz. From TB measurements at these window frequencies, the following indices are computed:

$$SI31 = TB23 - TB31 \text{ and, } \quad (1)$$
$$SI89 = TB31 - TB89$$

For new snow cover surfaces, SI89 is used to estimate SWE based on the following empirical relationship:

$$SWE = 0.08 * SI89 + 1.15 \quad (2)$$

Where SWE is in cm.
For older snow cover, SI31 is used instead:

$$SWE = 0.60 * SI31 + 1.71 \quad (3)$$

The switch from SI89 (Equation 2) to SI31 (Equation 3) occurs when the ratio between SI89 and SI31 computed from Equation 1 is less than an established threshold, corresponding to large SI31 values (above 5 K). Low ratios between SI89 and SI31 indicated a larger sensitivity to SWE in the 20-30 GHz region, which is indicative of older snow cover. On the other hand, large ratios indicated stronger scattering and sensitivity to SWE in the 30-90 GHz region, a characteristic of new snow cover (see also Figure 2). Figure 3 is a scatter plot of SWE versus SI31 and SI89 (Kongoli et al., 2004). AMSU measurements were made over the US Great Plains during December 2000-March 2001. Coincident SWE was estimated using a snow hydrology model. As shown, SI89 is a better predictor of SWE for low SI31 values. Correlation (r) and estimated error improved, and this improvement was statistically significant ($p < 0.05$).

5. VALIDATION EXAMPLES

The AMSU-based SWE algorithm is being implemented at NOAA/NESDIS in experimental mode over the US, North America and globally. Below we provide a validation example over the US. Validation data sources include ground-based observations, gamma ray measurements and other ancillary SWE products.

Figure 4 depicts snapshots of the retrievals of SWE over the US on January 24, 27 and 31, 2004, based on the AMSU NOAA-16 satellite measurements at about 2:00 US central time (descending pass). Note the retrievals of small SWE values due to new snow cover deposited over South Dakota and Nebraska on January 27, 2004 (Figure 4, middle panel). This new, low-density snow was the result of a snowfall event at very low air temperatures, so the new snow cover had small amounts of water equivalent. These small SWE values were captured due to the utilization of 89 GHz frequency channel (Equation 2). The snow cover in North Dakota and western US had higher amounts of SWE resulting from previous accumulations, captured by the lower-frequency channel measurements at 23 and 31 GHz (Equation 3). Snowfall continued after January 27, 2004. Note the increase in SWE over South Dakota and Nebraska from January 27 (Figure 4, middle panel) to January 31 (Figure 4, bottom panel), 2004.

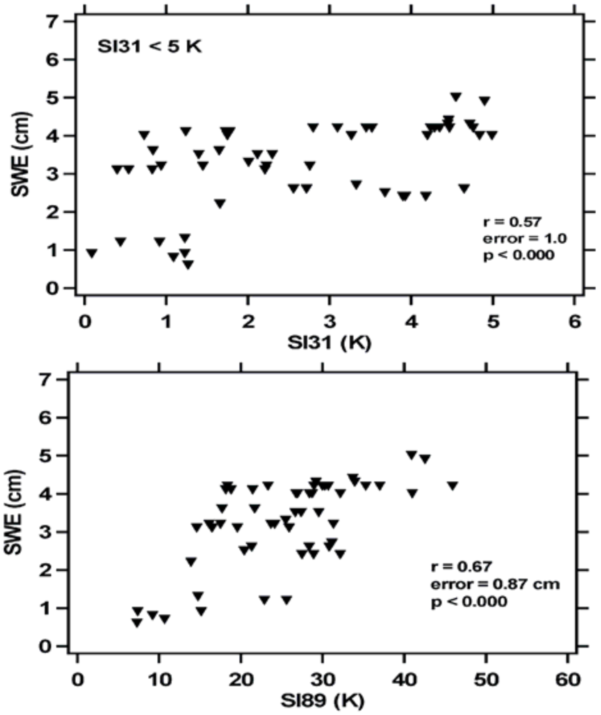

Figure 3. Scatter plot of SWE versus SI31 and versus SI89 as predictors

Figure 5 depicts near coincident snapshots of SWE estimated from a product developed at the National Operational Hydrologic Remote Sensing Center (NOHRS) at NOAA. This product estimates snow cover parameters through the assimilation of ground-based, airborne and satellite measurements, and other weather data sources into a snow hydrology model. Note the striking similarity in the spatial patterns of SWE, e.g., for old snow cover in Western US and North Dakota, and for recently deposited snow in South Dakota and Nebraska on January 25, 27, and 31, 2004. It appears that the AMSU-based SWE product may underestimate SWE in Western US due to the predominance of high elevation terrain. High elevation biases are expected because the current formulations were derived over relatively flat terrain.

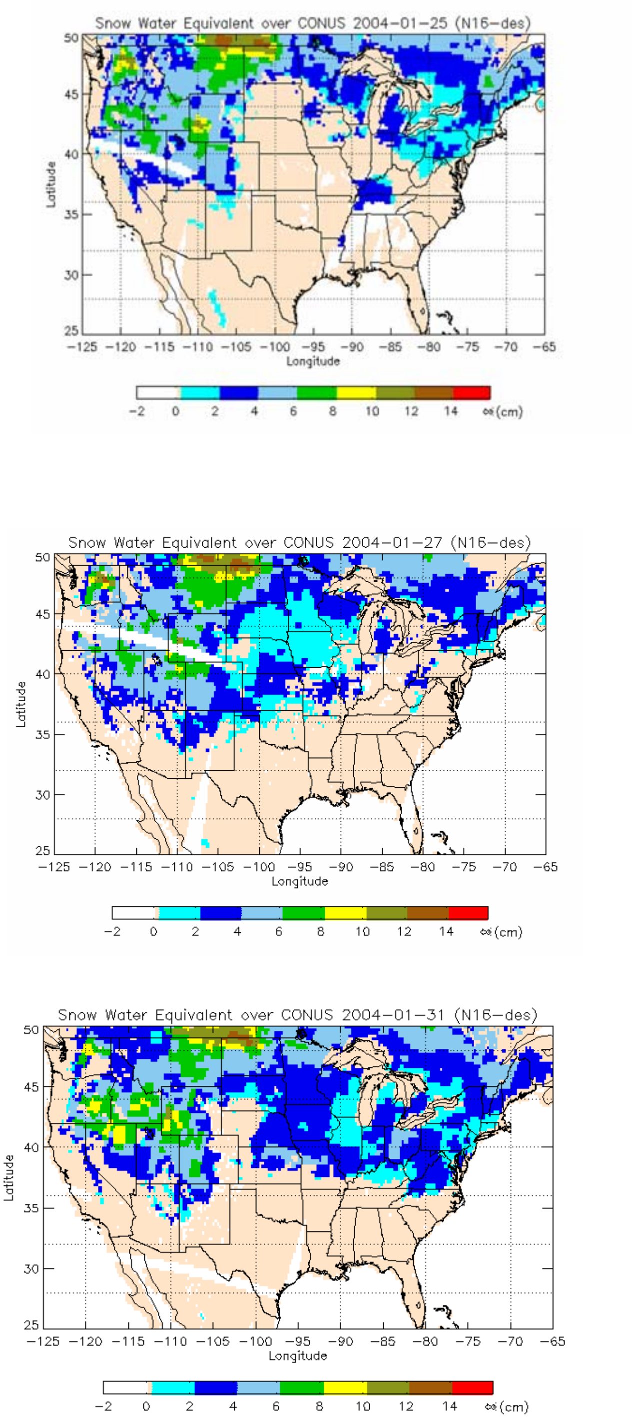

Figure 4. AMSU-based SWE retrievals on January 25 (top), 27 (middle) and 31 (bottom), 2004.

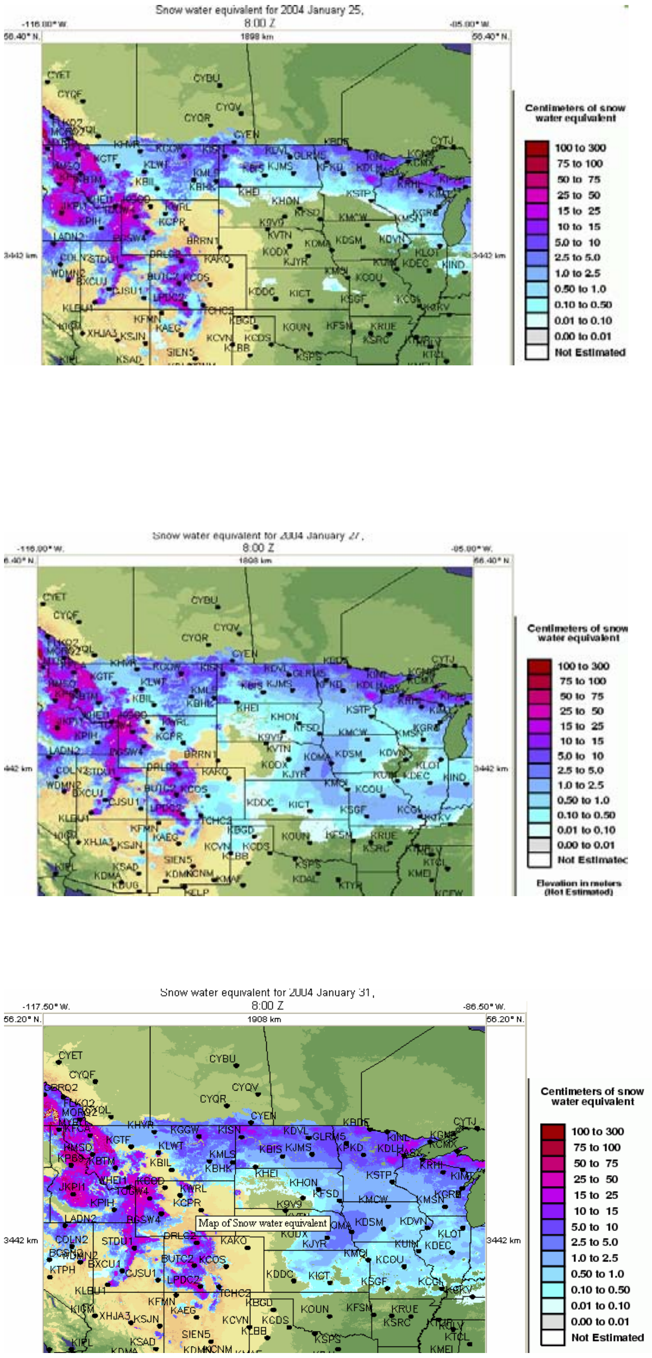

Figure 5. SWE retrievals from the NOHRS product on January 25 (top), January 27 (middle), and January 31 (bottom), 2004.

6. CONCLUSIONS AND FUTURE WORK

Estimation of SWE from microwave sensors remains a major challenge due to the non-straightforward relationship between SWE and microwave scattering signatures over snow cover. There is now wide recognition of the strong influence of snow metamorphism, and especially grain size, on the microwave measurements. The AMSU instrument has shown potential to capture these metamorphic changes by instantaneous measurements in a wide window frequency region, e.g., 23, 31, 89 and 150 GHz. The objective of this paper was to present most recent AMSU observations over snow-cover as well as to describe a new SWE retrieval algorithm. This SWE algorithm is being evaluated within an operational framework called the Microwave Surface and Precipitation Products System (MSPPS) at NOAA/NESDIS. The algorithm is unique in that it utilizes a combination of low and high window frequency channels, sensitive to SWE for a broader range of snow-cover sized particles. Note that the current SWE algorithms utilize only low frequency channels. A retrieval and validation example was also shown over the US. The new algorithm showed robustness in capturing SWE spatial patterns due to fresh and older snow-cover, as well as temporal changes in SWE. A detailed validation plan is being implemented to improve the algorithm by maximizing the utility of AMSU measurements. In addition, algorithm improvements will include adjustments for high elevation and dense forest terrain.

The views, opinions, and findings contained in this report are those of the author(s) and should not be construed as an official National Oceanic and Atmospheric Administration or U.S. Government position, policy, or decision.

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