Validation of passive microwave snow algorithms

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Abstract Passive microwave satellite remote sensing can greatly enhance large-scale snow measurements based on visible satellite data alone because of the ability to acquire data through clouds or during darkness as well as to provide a measure of snow depth or water equivalent (SWE). This study develops a validation methodology and provides preliminary results from comparisons of several different passive microwave algorithms, including both mid- and high-frequency channels, vertical and horizontal polarizations and polarization difference approaches. Snow extent derived from passive microwave data is compared with the NOAA Northern Hemisphere snow charts. Results clearly indicate those time periods and geographical regions where the two techniques agree and where they tend to consistently disagree. Validation of SWE derived from passive microwave data is undertaken using measurements from snow course transects in the former Soviet Union. Preliminary results indicate a general tendency for nearly all of the algorithms to underestimate SWE.

Key words algorithms; climate change; global; passive microwave; remote sensing; satellite; satellite validation; snow

INTRODUCTION

Snow cover is an important variable for climate and hydrological models due to its effects on energy and moisture budgets. Seasonal snow, which can cover more than 50% of the Northern Hemisphere land surface during the winter (Frei & Robinson, 1999; Armstrong & Brodzik, 1999), is responsible for the largest annual and interannual differences in land surface albedo. Surface temperature is highly dependent on the presence or absence of snow cover and temperature trends have been shown to be related to changes in snow cover (Groisman et al., 1994). Realistic simulation of snow cover in climate models is essential for correct representation of the surface energy balance, as well as for understanding winter water storage and predicting year-round runoff. The lack of meteorological and snow-cover data to execute, calibrate and validate snow-cover models is a major obstacle to improved simulations (King et al., 1999).

When snow covers the ground, some of the microwave energy emitted by the underlying soil is scattered by the snow grains. Therefore, when moving from snow-free to snow-covered land surfaces, a sharp decrease in emissivity and associated brightness temperatures ($T_B$) provides a nearly unambiguous indicator of the presence of dry snow (Mätzler, 1994). In addition, theoretical and empirical studies have demonstrated that the amount of scattering can be correlated with snow mass and specific wavelength. From this basic relationship, regional algorithms have been developed which indicate the presence of snow and compute snow water equivalent ($SWE$).
BRIGHTNESS TEMPERATURE AND VALIDATION DATA

The NOAA/NASA Pathfinder Program was initiated in 1993 to facilitate the application of currently archived satellite data for global change research. With support from this program the National Snow and Ice Data Center (NSIDC) has produced a 22-year, consistently processed, time series of gridded passive microwave data in a common format called the Equal Area Scalable Earth-Grid (EASE-Grid). This dataset was developed using Scanning Multichannel Microwave Radiometer (SMMR) data for the period 1978–1987 and Special Sensor Microwave Imager (SSM/I) data for 1987–2000. These EASE-Grid $T_B$ values provide the standard input to all algorithms being evaluated in this study.

For the validation of snow-covered area, we compare microwave snow extent maps with the EASE-Grid version (Armstrong & Brodzik, 1998) of the NOAA Northern Hemisphere weekly snow charts (Robinson et al., 1993). The original NOAA charts were derived from the manual interpretation of Advanced Very High-Resolution Radiometer (AVHRR), Geostationary Operational Environmental Satellite (GOES) and other visible satellite data. With regard to SWE, this study focuses on the robust nature of the larger validation datasets, which can be expected to provide a full range of snow/climate conditions, rather than on smaller datasets, which may only represent a “snapshot” in time and space. Therefore the primary validation dataset in this phase of our study is the Former Soviet Union Hydrological Surveys (FSUHS)(Haggerty & Armstrong, 1996). These data represent a unique and invaluable source for algorithm validation as they include not only SWE values but additional information on snow structure, extent of snow cover within the surrounding terrain, and forest type and percent of forest cover, from a 50 km diameter area surrounding the station. These data are available during both the SMMR and SSM/I periods (through 1990) and comprise the average of measurements along transects of 1.0–2.0 km in length with measurements every 100–200 m. These surveys were undertaken on the 10th, 20th and last day of the month.

METHODS AND RESULTS

Digital image comparison techniques are being applied to a multi-year, time series analysis of several different algorithms (Chang et al., 1987; Goodison, 1989; Grody & Basist, 1996; Hiltbrunner, 1996; Nagler, 1991; Tait, 1998; Walker & Goodison, 1993). The ultimate goal of this study is to determine whether the differences between the algorithm output and the validation data are random or systematic. In the case of systematic differences, the patterns are being correlated with the specific effects of land-cover type, atmospheric conditions and snow structure. Because we compare algorithm output with continuous records of station data, we will be able to identify any seasonal or interannual patterns in the accuracy of the algorithms.

Snow-covered area

This phase of the study evaluates the overall capability of the passive microwave data to map snow-covered area through comparison with the EASE-Grid version of the
NOAA Northern Hemisphere snow extent data. For the period 1978–1999, both passive microwave and visible datasets show a similar pattern of interannual variability and both indicate maximum extents consistently exceeding 40 million km$^2$ (Fig. 1). The visible data typically show greater variability in the departures from the monthly
means while the long-term trends based on the departures are similar with each dataset indicating a decrease in Northern Hemisphere snow extent of approximately 0.3% per year. (Figs 2 and 3). In Figs 1-3, the Chang et al. (1987) algorithm has been used to compute snow-covered area for the SMMR period and a modified version of this same algorithm (NSIDC1) has been used during the SSM/I period. In this example, and throughout this study, only $T_b$ from “cold period” orbits are used.

The monthly climatologies produced by the two data sources are compared using the same algorithms as used in Figs 1-3. During the early winter season (October–December) the passive microwave algorithms generally indicate less snow-covered area than is indicated by the visible data (Fig. 4). This same pattern was also observed in a similar study by Basist et al. (1996). The difference is greatest in the region of the southernmost snow extent, for example at the lower elevations across both North America and Eurasia where the snow cover is more likely to be shallow (less than about 5.0 cm) and may often exist at the melting temperature. In both of these situations (shallow and/or wet snow) the microwave algorithms tested thus far are often unable to detect the presence of snow. Preliminary results indicate that the inclusion of the 85 GHz channel, with the associated enhanced scattering response, improves the accuracy of mapping shallow snow.

As the snowpack continues to build during January–March, agreement between the two datasets improves (Fig. 4). However, in this example, the microwave data indicate less snow-covered area than the visible data throughout the year with a mean difference for the monthly climatologies of $3.5 \times 10^6$ km$^2$, ranging from $8.9 \times 10^6$ km$^2$ in November to $0.5 \times 10^6$ km$^2$ in August.

![Fig. 4 Northern Hemisphere mean monthly snow-covered area ($\times 10^6$ km$^2$) derived from visible (NOAA) and passive microwave (SMMR and SSM/I) and the difference between the two (visible minus passive microwave), 1978–1999.](image)

Snow water equivalent ($SWE$)

In this phase, a topographically consistent subset of the FSUHS data was selected for the validation. This subset ($45$–$60^\circ$N, $25$–$45^\circ$E) has the highest station density (approximately one transect per 100 km grid cell) and is primarily composed of non-complex terrain (grassland steppe) with maximum elevation differences of less than 500 m.
We have developed a specific processing environment and output format to compare the various algorithms with the station SWE data. For each station file this involves the combination of the daily $T_b$ files for the observation date and for the previous two days to provide complete spatial coverage. Values of SWE for all pixels containing at least one transect measurement are compared with the output from the respective algorithms. Figure 5 shows a time series comparison of station data with a single algorithm (19H – 37H) averaged over the total study area for a 12-year period. Figure 6 shows a single year comparison of three different algorithms. (During 1989, 85V data were not available after 31 January.)

Results indicate a general tendency for the algorithms tested thus far to underestimate SWE. Unlike snow extent, differences between the validation data and the microwave algorithms appear to be generally consistent throughout the winter season. Underestimates of SWE increase significantly as the forest-cover density begins to exceed 30–40%. Because of the detailed land-cover data available for this validation study area, we will apply algorithm adjustments as a function of fractional forest cover based on earlier work by Chang et al. (1996).

In addition to the time series comparisons shown in Figs 5 and 6, our analysis includes image-subtraction time series comparisons, which allow evaluation of both temporal and spatial differences. Coupled with additional data on topography, vegetation cover, surface air temperature and snow structure, these spatial comparisons (not included here) viewed throughout the winter season will provide valuable insight.
into the actual causes of the observed differences. Future analysis will continue the comprehensive multi-year comparison of at least these seven algorithms with the FSUHS data and other surface station measurements.

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REFERENCES


