Global SCA mapping by active and passive microwave data

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Abstract.

Passive microwave data collected during the past 30 years supported the development of several algorithms for the retrieval of SWE and snow depth, which in turn can be used for mapping snow cover areas. Active microwave instruments recently launched provide unique opportunities for investigating the combination of active and passive microwave data to improve the retrieval of snow parameters with respect to techniques based solely on passive data. In this study, we report results concerning the mapping of snow cover area (SCA) derived from passive and active microwave data at large scale over the northern hemisphere between the years 2000 and 2004. In the case of passive data, for each day the difference between the 19 and 37 GHz brightness temperatures is used to map snow cover. In the case of active data, a reference value at the beginning of the snow season is selected and the snow cover is mapped by considering the difference between the recorded backscattering and the reference value. MODIS data are used as a reference to evaluate the SCA derived from the microwave sensors. Results show that, if considered separately, passive data can provide a better mapping of SCA than active data alone. However, the combination of the two data sets considerably improves the mapping of SCA with respect to the sole active or passive data showing that a multi-sensor approach for improving remote sensing of snow at global scale can provide significant benefits.

1. INTRODUCTION
Estimates of properties of snowpacks play an important role in weather and climate models, water resource applications and flood forecasting. For example, in California and Colorado snowmelt represents, respectively, 80% and 70% of all surface water (http://snobear.colorado.edu/Markw/SnowHydro/intro.html). Snow properties are also important in flood forecasting. In the USA, eight of the top 20 floods of the 20th century were related to snowmelt [1] with three of them causing over $1B each in damages (in 2002 dollars; [2]). Moreover, Earth’s radiation balance is influenced by snow and ice because of their high albedo relative to most other land and sea surfaces.

Remote sensing is a key tool for studying the state of the cryosphere at large scales, providing information in places where it would be difficult, if not impossible, to gather data in situ. Space-borne passive microwave instruments have been measuring the interaction of natural upwelling microwaves from the Earth for over 30 years and several algorithms for the retrieval of SWE or snow depth have been proposed in the literature (e.g. [3-8]). The snow cover area (SCA) can be, then, mapped by accounting for those areas where the values of snow depth (SD) or snow water equivalent (SWE) are greater than zero.

Concerning active microwave data, space-borne scatterometers have provided continuous coverage of the Earth for nearly a decade (NSCAT August 1996-June 1997 and Seawinds on QuikSCAT June 1999-today) and the sensitivity of space-borne scatterometer data to snow parameters has been investigated only recently in the literature (e.g. [9-11]). In this case it is possible to map the SCA by considering the difference between the recorded backscattering value and a reference value at the beginning of the season.

Recent studies have pointed out the benefits of combining active and passive data to improve the retrieval of geophysical parameters (e.g. AQUARIUS and HYDROS satellite missions). The NASA Cold Land Processes Working Group has identified in the combination of active and passive microwave data a high potential for improving the retrieval of snow parameters with respect to the use of solely passive data. Very few studies (e.g. [12]) exist in the literature reporting results about the combination of space-
borne active and passive microwave data for remote sensing of snow and, to our
knowledge, no study has been reported in the literature about their combination at global
scale (for snow applications). As suggested by Hallikainen et al. in [12], there are several
advantages in using active and passive data together for snow monitoring: (a) the
resolution is similar (~20-25km), (b) the incidence angle is constant and nearly the same
(QuikSCAT: 46º for H and 54º for V channel, SSM/I/AMSR-E: ~53º), (c) both sensors
have a wide swath (QuikSCAT 1800 km, e.g. SSM/I 1400 km) allowing data acquisition
for northern regions twice per day (QuikSCAT 6 am and 6 pm; e.g. SSM/I 7-9 am and 7-9
pm, depending on satellite).

In this study we address two main questions: which of the two techniques based on active
or passive microwave data is able to provide a better mapping of the SCA? and is the
combination of the active and passive data able to provide improved maps with respect to
the sole active or passive data? In order to answer these questions we derive daily maps
of SCA from both SSM/I 19 and 37 GHz brightness temperatures (vertical polarization)
and QuikSCAT backscattering coefficients (vertical polarization as well) for latitudes
above 50 degrees North in the period 2000-2004. We compare the maps of SCA derived
from the two different microwave data and validate the results by means of a recently
released MODIS product providing maps of SCA at 0.25 degree resolution. The SCA
derived from the combined active and passive microwave data is also compared with that
derived by using solely active or passive data.
2. DESCRIPTION OF SATELLITE DATA

In the following we report a brief summary of the satellite data used in the study.
We make use of three different datasets: 1) brightness temperatures, 2) backscattering coefficients, and 3) MODIS snow cover area. Brightness temperatures were collected by the Special Sensor Microwave Imager (SSM/I) radiometer, flying on board of the DMSP (Defense Meteorological Satellite Program) series satellites at 19- and 37-GHz. More specifically, the data used in this study consist of Level 3 EASE-Grid brightness temperatures over the northern hemisphere with a resolution of 25 km [13], and were obtained from the National Snow and Ice Data Center (NSIDC). Further information can be found at the website http://nsidc.org. Active data consist of NASA's Quick Scatterometer (QuikSCAT) backscattering coefficients sigma-0s at 13.4 GHz at vertical polarization with an incidence angle of 54°. The data used in this study were obtained from the website http://podaac.jpl.nasa.gov/ and consist of one-day temporal averages of all the sigma-0 (normalized radar cross section) measurements whose centers fall within each image pixel area [14]. The standard deviation and counts for each pixel are also available to perform a statistical analysis of the data used. The scatterometer data are re-projected to the Equal-Area Scalable Earth-Grid (EASE-Grid) with a resolution of 25 km (from the original resolution of 22.5 km per pixel at the equator) with a software developed for this purpose by the authors. The software determines the latitude and longitude of the QuikSCAT pixel and finds the closest EASE-grid pixel as determined by that latitude and longitude.

In order, to validate the SCA retrieved by the microwave data we use the recently released MODIS/Terra Snow Cover Daily Global 0.25 Deg Geographic CMG product. It consists of a daily climate-modeling grid (CMG) snow cover map at 0.25° resolution from February 24, 2000 to the present. Also in this case the data are re-projected to the EASE-Grid projection for the comparison with microwave data by means of an ad-hoc software developed for this purpose. Further information about the MODIS product here used can be found at the website http://modis-snow-ice.gsfc.nasa.gov/new_snow_CMG.html.
3. DERIVING SNOW COVER MAPS FROM MICROWAVE DATA

In this section we briefly describe the approaches adopted to derive SCA maps from the microwave data.

The SCA from microwave passive data is derived from those pixels where the difference between the brightness temperatures at 19 and 37 GHz is greater than zero. Indeed, it is known that this difference increases as snow SWE/SD increases because of the volumetric scattering induced by the ice particles. (e.g. [3-5]). Hence, the SCA can be mapped from those areas where the values of SWE/SD are greater than zero. The technique is therefore based on a *spectral gradient* between two quantities acquired **concurrently**.

Active data are collected at one single frequency (13.4 GHz) and it is not possible to make use of the same approach used in the passive case. In this case SCA is derived by considering the difference $\Delta \sigma$ between the recorded backscattering value collected on the day of interest and a reference value collected at the beginning of the snow season. If $\Delta \sigma > 0$ then the area is classified as covered by snow. Instead of using a fixed day for each snow season, we select the reference value as the minimum value within a period between mid October and the beginning of November of each year. This choice is related to the fact that the backscattering decreases as the soil freezes before the snow falls reaching a minimum and then increases again as snow accumulates (e.g. [10,11]).
4. RESULTS AND DISCUSSION

In this section we report and discuss the obtained results.
Figures from 1 to 3 show the maps of SCA derived from both passive (top) and active (bottom) microwave data matching the MODIS SCA averaged over a three month period. Each pixel represents the number of days (expressed in terms of percentage over the number of days when MODIS was detecting snow) where the microwave data match the visible data. The white color corresponds to the minimum (0 %) where the black color to the maximum (100 %). In example, if a pixel value in the passive and active cases are, respectively, 60 % and 30 % then this means that the passive technique was able to match MODIS observations for 54 days while the active technique reported 27 days. The three figures show the results concerning three different periods of the year. Figure 1 shows the results for the period going from November through January for the years 2000 through 2004. Figures 2 and 3 show the same as Figure 1 but for the periods from February through April (Figure 2) and from May through June (Figure 3). We decided to use a three month period because with this value we can divide the snow seasons in periods showing different characteristics such as new accumulating snow at the beginning of the snow season with low/medium snow depth (November through January), compacted and metamorphosed snow with medium/high values of snow depth and melted/refrozen snow (February through April) and of melting and high latitudes/perennial snow (May through June). Also, the three month period displays good visible information in terms of details where the choice of a longer period would reduce the ability to show the small differences.

From Figure 1 we observe that the passive data generally show better mapping of SCA with respect to the active data (e.g. more dark pixels). In Eurasia, the technique based on passive data shows best results where in the case of the North America slight differences between the East and the West coast exist. The active data work better in the Aleutian Islands (Bering Sea), on Greenland and in the south of the Scandinavian Peninsula where the passive data seem not to be able to retrieve SCA. However, as we move from North to South the performance of the active-based technique is reduced. We can assume that
passive data provide better estimation because at the beginning of the season, when snow is shallow, the sensitivity to the SD/SWE of the active data is smaller than that of the passive data at 37 GHz. In Figure 2, we see that for the period February – April the passive technique shows a high number of days matching the MODIS data, with an improved performance compared to the previous trimester (Figure 1). The performance of the active technique also improved, especially in eastern North America and southern Europe. This might be due to the fact that snow depth increased during this trimester. In Figure 3, a clear trend is observed in the passive case. Here, the snow cover on the U.S. West coast and Canada is well mapped but it does not happen the same for the snow on the East coast. On the other hand, the active technique shows a less homogenous SCA in the Eurasia but it is able to well map the snow in those areas where the passive data cannot, as, in example, on the East coast of the United States.

Figure 4 shows the daily values of MODIS snow cover area (expressed in millions of km²) together with the percentage of snow MODIS pixels detected by the only passive (light grey line), by the only active (dark grey line) and by both (black line). The light gray rectangles indicate the periods between November 1st and May 31st of each year and are used to provide a temporal reference to the reader. We see that, in general, the technique based on the sole passive data shows higher percentage values than the technique based on the sole active data. This answers the first of the two questions that we posed in the Introduction. More in detail, the results using only passive data show a minimum percentage value around 60% and an average value around 75% where the use of the only active data to provides a minimum percentage value around 40% and average percentage value around 60%. Both passive and active techniques give comparable results for the data between November and March, when the matching between the microwave and optical techniques is maximum. Figure 4 also provides an answer to the second questions that we want to answer, showing that the combination of the two data sets considerably improves the mapping of the SCA. Indeed, the combined use of active and passive data shows a minimum percentage value of 75% and an average percentage value around 90%.
5. CONCLUSIONS

We derived daily maps of SCA from both SSM/I (19 and 37 GHz brightness temperatures at vertical polarization) and QuikSCAT backscattering coefficients for latitudes above 50 degrees North in the period 2000-2004. We examined which of the two different data sets was able to better match SCA provided by MODIS and also investigated whether the combination of the two data sets was able to provide improved maps with respect to the sole active or passive data.

Our results show that either passive or active microwave retrievals of SCA do not completely report the SCA values when MODIS SCA is used as validation. The technique based on the passive data generally provides better results than the one using the only active data. We also observed that there are geographical and temporal variations that the combined technique is able to resolve. For the five northern hemisphere winter periods reported in Figure 4, the combined technique increases the minimum match with MODIS to values above 75% (being around 40% and 60%, respectively, in the active and passive case) and the average matching percentage value to around 90% (being around 65% and 75%, respectively, in the active and passive case). Hence, results show that the combination of active and passive microwave spaceborne data is an important factor for improving remote sensing of snow at global scale.

After studying the improvement of SCA retrieval, an undergoing study is focusing on the potentiality of the combined data set for improving the retrieval of snow depth and snow water equivalent.

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References:


FIGURES AND TABLES

Passive

Active


Figure 1 Maps of SCA derived from both passive (top) and active (bottom) microwave data matching the MODIS SCA averaged between November through January for the years 2000 through 2004. Each pixel represents the number of days (expressed in terms of percentage over the number of days when MODIS was detecting snow) where the microwave data match the visible data. The white color corresponds to the minimum (0 %) where the black color to the maximum (100 %).
Figure 2 The same as Fig. 1 but for the period February – April.
Figure 3 The same as Fig. 1 but for the period May – July.
Figure 4

Daily values of MODIS snow cover area (in millions of $\text{Km}^2$) and percentage of snow MODIS pixels detected by the passive only (light grey line), the only active (dark grey line) and both (black line). The light rectangles indicates the periods between November 1$^{st}$ and May 31$^{st}$ of each year.