SeaWinds views Greenland

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Abstract— Data from the Ku-band SeaWinds scatterometer is used to investigate the extent of the ice facies in Greenland. The duration of the summer melt over the Greenland ice sheet is calculated using the temporal signature of the SeaWinds data. Daily ascending and descending enhanced resolution radar backscatter images of Greenland are produced to investigate diurnal variations in backscatter measurements. These are compared with diurnal variations in the brightness temperature measured by SSM/I. Multi-annual changes in the Greenland ice sheet are studied by comparing 1999 SeaWinds data to 1996 NSCAT data.

INTRODUCTION

The location of key snow and ice zones, or facies, in Greenland is considered a sensitive indicator of global climate change. Microwave remote sensing satellites are excellent tools for analyzing changes in the Greenland ice sheet.

In June 1999, NASA launched a new Ku-band scatterometer, SeaWinds on QuikSCAT. SeaWinds, with its dense sampling and wide swath width, provides an unprecedented opportunity to investigate large scale changes in the Greenland ice sheet. SeaWinds is a pencil-beam Ku-band scatterometer which measures the normalized radar cross section with two antenna beams: the inner-beam is horizontally polarized (HH) with an incidence angle $\theta \approx 46.3°$, and the outer beam is vertically polarized (VV) with $\theta \approx 54.1°$.

SeaWinds data can be combined with other current data sets such as SSM/I radiometer data to obtain further information. Using resolution enhancement techniques, the spatial resolution of the raw SeaWinds measurements is increased from the native ~25 km resolution to a pixel resolution of 4.5 km to generate images for analysis. Fig. 1 shows enhanced resolution images of Greenland produced from SeaWinds and SSM/I data. The left images are during the summer melt, while the right images are after the summer melt has ended. The melted region is indicated by the dark areas in the SeaWinds image such as in the Southern portion of the ice sheet. During the winter, refrozen areas are very bright.

In contrast to the σ^o measurements, the emissivity (T_b) measurements increase when the snow surface partially melts as shown in the image on the bottom left. The liquid water content in the snow surface increases the emissivity causing the increase in T_b. As the liquid water freezes, the brightness temperature over previously melted area decreases reducing T_b.

GREENLAND ICE FACIES

The Greenland ice sheet can be divided into four different ice facies/zones (see Fig. 2). The dry snow zones are found in the highest portion of the Greenland ice sheet. There is no surface melt in these regions, and thus little temporal variation in σ^o.

The Percolation Zone is where the snow surface partially melts. The solid line in Fig. 3 shows a time series of σ^o in the Percolation Zone (point **A** in Fig. 2). As the snow melts and refreezes it forms ice structures referred to

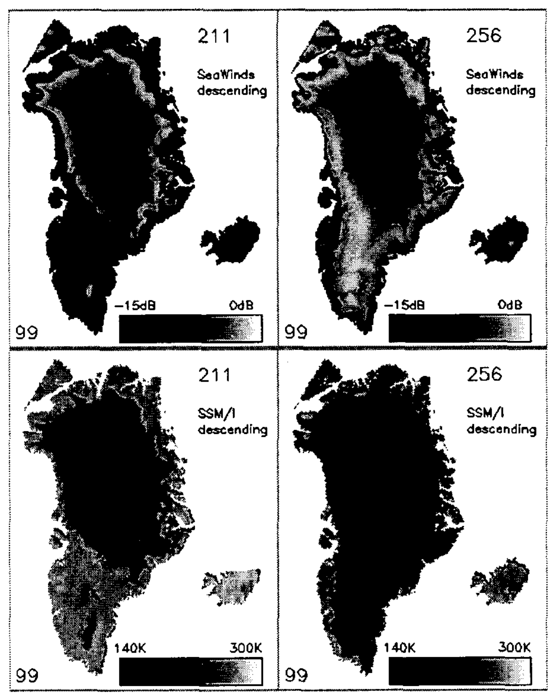

Figure 1: SeaWinds and SSM/I images during the peak melt (JD 211 or July 30) in 1999 compared to a measurements for a Greenland winter day (JD 256 or September 13). The SeaWinds images are for the h-pol inner beam, and the SSM/I images are for the 37 GHz channel.

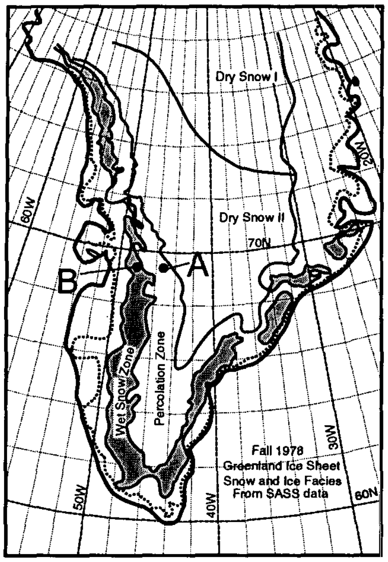

Figure 2: Facies map of the Greenland Ice Sheet derived from Seasat-A scatterometer data [1].

as pipes and lenses. A liquid water content of 0.5% can increase the imaginary part of the permitivity by more than order of magnitude when compared to dry snow. This corresponds to a decrease in the penetration depth by the same ratio which causes more surface scattering and less volume scattering. For SeaWinds incidence angles, this corresponds to a large drop in σ^o such as those shown in Fig. 3. Once the liquid water has frozen, the newly formed ice structures substantially increase σ^o.

The Wet Snow Zone is defined as the region where the entire annual accumulation of snow is subject to melt and refreeze. Melt events cause a drop in σ^o, just as in the percolation zone. The dashed line in Fig. 3 shows a time series of σ^o over the Wet Snow Zone (point **B** in Fig. 2). A sharp

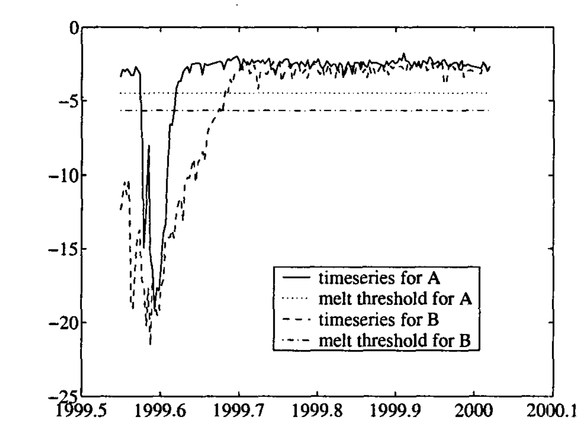

Figure 3: Time-series plots of SeaWinds σ^o measurements from points **A** and **B** in Fig. 2.

drop in σ^0 is shown from the middle of July through the middle of August 1999. This corresponds to a relatively long melt event.

MELT DAYS

One way to differentiate between the percolation and wet snow zones is to find a correlation between the depth and the duration of the melt. Fig. 3 shows that a melt event causes a sharp drop in σ^o. By determining how long σ^o remains below a threshold value (σ^o_{melt}) the duration of the summer melt can be calculated. For purposes of automation, $\sigma^o_{melt} = \mu_{winter} - 8\sigma_{winter}$ was defined where μ_{winter} and σ_{winter} are the mean and standard deviation respectively of σ^o during the mid-winter period (the last 10% and first 10% of the year according to the Julian calendar). This definition for σ^o_{melt} was chosen because it gives consistent results throughout the Greenland ice sheet. The results are only mildly sensitive to the threshold used. The values of σ^o_{melt} are shown as the horizontal lines in Fig. 3.

Fig. 4 shows the calculated duration of the melt over Greenland for the summer of 1999. The time period actually begins on Julian Day (JD) 201, the first day for which SeaWinds data is available. This is actually a little after the beginning of the Greenland summer melt. The duration of the melt over most of the Wet Snow Zone is approximately 40 days. There is a gradual decrease in the duration of the melt moving upslope from the Wet Snow Zone through the Percolation Zone to the Dry Snow Zone.

DIURNAL VARIATIONS

SeaWinds provides an unprecedented opportunity to investigate diurnal variations in σ^o over the Greenland ice sheet. By dividing the SeaWinds measurements into as-

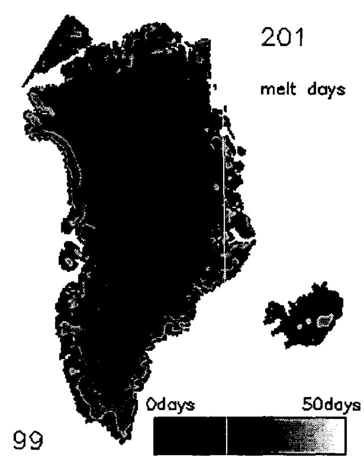

Figure 4: Duration of the melt over Greenland during the summer of 1999 as calculated from SeaWinds data.

cending and descending passes, two images can be produced for each day. The ascending passes occur during the Greenland morning, and the descending passes occur during the evening.

SSM/I radiometer data can also produce daily ascending and descending T_b images. Fig. 5 shows the diurnal variations for JD 209 as observed by both SeaWinds and SSM/I (37 GHz channel). For the SSM/I images the 37 GHz channel is shown. The extremely bright areas in the difference images correspond to the areas where the snow is frozen in the morning and partially melted by evening.

In a comparison between the two difference images in Fig. 5 it is clear that there is a significant correlation between T_b and σ^o. Both show large differences throughout the Percolation Zone, and small differences elsewhere. However, the two variables are sensitive to slightly different mechanisms in the melt process. The SSM/I measurements indicate that the daytime melt occurred a little further upslope than indicated by SeaWinds data. The SeaWinds image also shows the daytime melt occurs over a larger region. These differences may be due, in part, to the difference in local time of the overpasses.

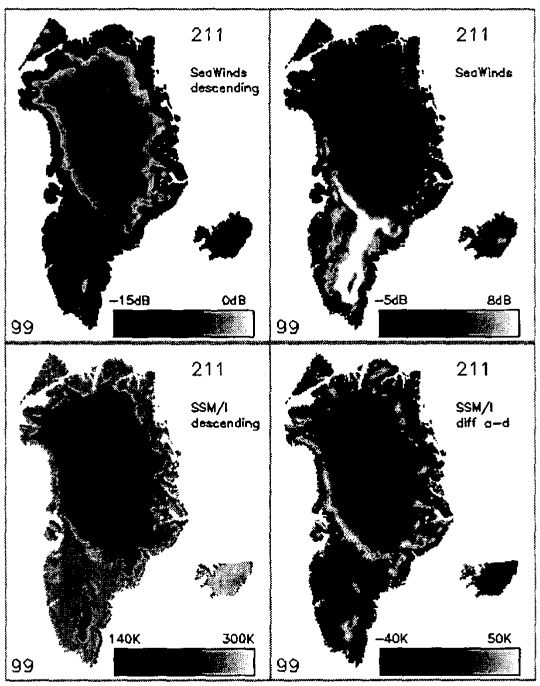

Figure 5: Diurnal variations in σ^o and T_b during the peak melt period. The images on the top and bottom left are composed of SeaWinds and SSM/I measurements from descending passes on JD 209, or July 28, 1999. The images on the right show the difference between the ascending and descending images (ascending-descending).

MULTI-ANNUAL CHANGES

The November and December 1999 SeaWinds data is compared with measurements made by the NASA Scatterometer (NSCAT) during the same months of 1996. While SeaWinds collects measurements at only two incidence angles, NSCAT collects measurements over a range of incidence angles. In order to adjust the NSCAT measurements to the SeaWinds incidence angles, σ^o is assumed to be linear function of incidence angle in dB space. A linear fit to the NSCAT measurements is used, which was then evaluated at the SeaWinds incidence angles.

The comparison between the SeaWinds and NSCAT measurements (SeaWinds - NSCAT) is shown in Fig. 6. The differences are fairly constant over the two month period, and there is little difference between the results for the H-V polarizations. A small part of the difference is likely due to modeling errors in the linear incidence angle model. However, there are significant patterns throughout the difference image signifying that some changes have occurred in the transition regions between the different snow zones. For example, the light area in the difference image at the Southern end of the dry snow zone may suggest increased melt.

REFERENCES

[1] D.G. Long and M.R. Drinkwater, "Greenland ice-sheet surface properties observed by the Seasat-A scatterometer at enhancee resolution," Journal of Glaciology, vol. 4, num. 135 pp. 213-229, 1994.

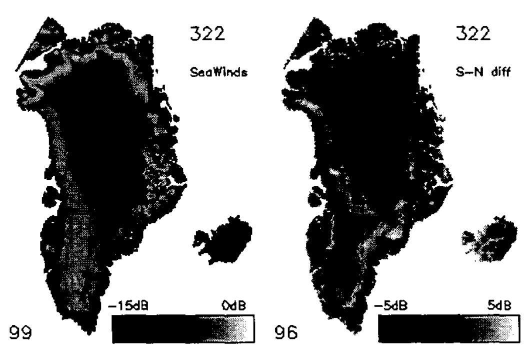

Figure 6: Difference in σ^o during the winter months between 1999 and 1996. The image on the left is from SeaWinds, created using three days of data (JD 322-324, 1999). The images on the right is the difference between the SeaWinds image, and an image created from six days (JD 319-324, 1996) of NSCAT data (SeaWinds - NSCAT). During this time of year there is little temporal variation in σ^o over Greenland.