Multi-Annual Changes in Microwave Backscatter over the Greenland Ice Sheet

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***Abstract* – Changes in the location of key ice facies/zones on the Greenland ice sheet are considered key indicators of global climate change. Microwave scatterometers are effective tools for monitoring these changes. Measurements for three Ku-band scatterometers, SASS (1978), NSCAT (1996), and SeaWinds (1999-present), span a 23 years period. While the ERS scatterometer (C-band) offers a continuous 9 year dataset (1992-present). Using the SIR algorithm to produce σ^o images, the measurements made by these sensors over Greenland are compared. We find an increase in σ^o along the southern border between the dry snow zone and percolation zone, and a decrease for C-band measurements along the northern portions of this boundary.**

I. Introduction

Lateral movement of the snow zone boundaries in Greenland is considered an important indicator of global climate change. Wind scatterometers are effective tools for monitoring the changes in the ice sheet because they provide frequent large scale coverage and are immune to atmospheric and solar effects. Also, microwave scatterometer measurements penetrate snow and ice, effectively "seeing" below the surface [1]. Scatterometers measure the normalized radar cross-section (σ^o) which is used to determine near surface vector wind speeds over the ocean. These σ^o measurements have also proven to be valuable in many land and ice studies.

The location of the Greenland ice facies have been successfully mapped using measurements made in 1978 by NASA's Seasat-A scatterometer [1]. Since that time two other Ku-band scatterometers have collected data: NSCAT (1996-97) and SeaWinds (1999-present). The ERS-1 and -2 scatterometers have collected C-band σ^o measurements from 1992-present. These four scatterometers cover a 23 year period providing an opportunity to look at changes in the ice sheet over nearly a quarter of a century. First, some background is given on how the σ^o images used for the comparisons, then the Ku-band comparisons are discussed with the C-band results following.

II. Background

The Scatterometer Image Reconstruction Algorithm (SIR) [2] is used to produce high resolution backscatter images of Greenland. The images have a pixel resolution of 4.5 km for the 3 Ku-band instruments and 9 km for ERS. Because of difference in design and/or frequency the images from different sensors are difficult to compare directly. For comparison purposes, SASS and NSCAT are similar. Both scatterometers operate at Ku-band (~14 GHz) and have a fan-beam design. For NSCAT, SASS, and ERS the SIR algorithm produces an A and a B image according to the model

$$\sigma^o(\theta) = A + B(\theta - 40)$$

where σ^o is measured in dB, $A \approx \sigma^o(40)$, and B is the slope of σ^o verses θ over $20^\circ < \theta < 60^\circ$. SeaWinds measurements are collected at only one incidence angle for each polarization (for h-pol $\theta \approx 46.3$ and for v-pol $\theta \approx 54.1$). Thus, for SeaWinds a single variate version of the SIR algorithm is used producing only an A image [3]. In order to properly compare NSCAT and SASS to SeaWinds, NSCAT and SASS σ^o images at the SeaWinds incidence angles are needed. For the comparisons in this paper such images are produced using NSCAT and SASS A and B images to evaluate model at the SeaWinds incidence angles.

III. Comparisons

A. Ku-band

Backscatter images for SASS, NSCAT, and SeaWinds are shown in Fig. 1. The SASS image was produced using 30 days of data (J.D. 249-278, 1978), the NSCAT image was produced from 6 days of data (J.D. 270-275, 1996), and the SeaWinds image was produced from 3 days of data (J.D. 271-273, 2000). All of the images are for v-pol. The h-pol images are not shown because for this study there is little difference between the v-pol and the h-pol results.

In the images in Fig. 1 the dry snow zone/percolation zone boundary (DPB) is easily visible as the inner light/dark boundary around the ice sheet. The dry snow zone is defined as the region where melt does not occur. The dry snow zone gives low backscatter measurements, showing up as the dark region in the interior of the ice sheet. In the percolation zone some melt occurs causing snow grains to grow together and forming subsurface ice structures. The increased snow grain size and subsurface ice structures contribute to higher backscatter measurements [1]. Therefore, the percolation zone shows up as

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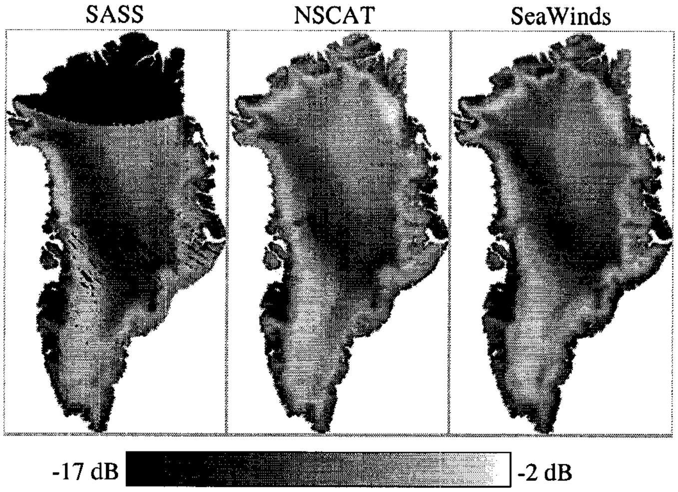

Fig. 1. Images used for measuring backscatter changes. Each image shows $\sigma_v^o(54.1°)$. The SASS image is from 1978, NSCAT 1996, and SeaWinds 2000.

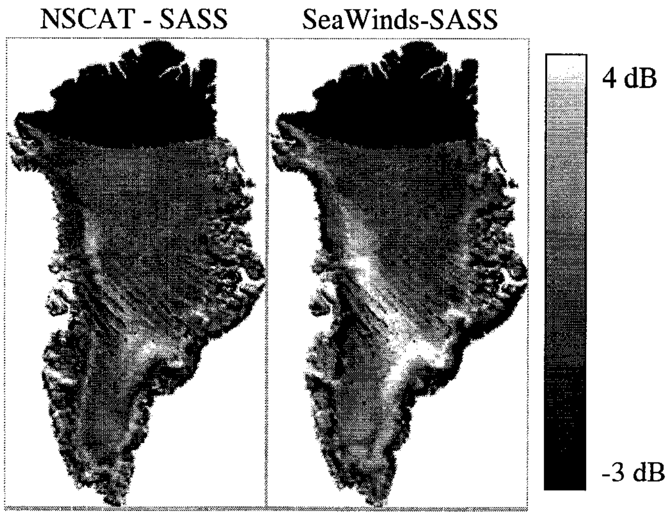

Fig. 2. Difference images showing changes in $\sigma_v^o(54.1°)$ from 1978 to 1996 (NSCAT - SASS) and from 1978 to 2000 (SeaWinds - SASS).

the bright area outside of the dry snow zone.

The difference between NSCAT and SASS and the difference between SeaWinds and SASS is shown in Fig. 2. Between 1978 (SASS) and 1996 (NSCAT) there was an increase in σ^o of about 4 dB along portions of the DPB. By 2000, the area of the increased σ^o values had grown substantially. It is important to note that this is a comparison between sensors and some design/calibration differences could impact the difference. It is unlikely, however, that instrument difference alone could account for the large increase in backscatter observed.

Shorter term changes are shown in Fig. 3. The image on the left shows the difference between the SeaWinds (2000) and NSCAT (1996). As with the previous comparisons,

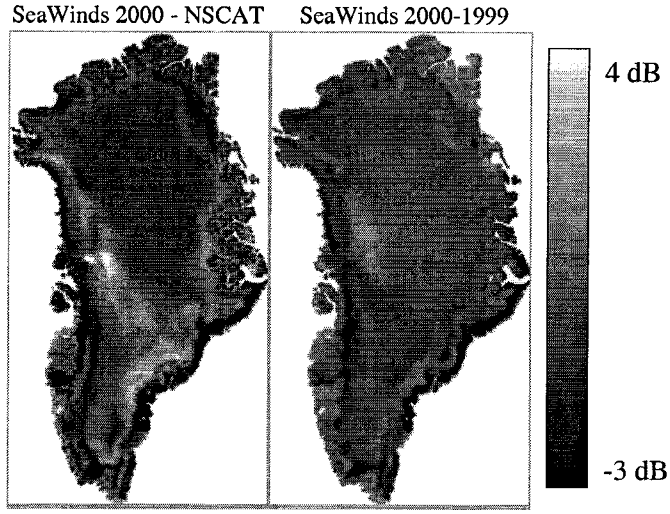

Fig. 3. Difference images showing changes in $\sigma_v^o(54.1°)$ from 1996 to 2000 (SeaWinds 2000 - NSCAT) and from 1999 to 2000 (SeaWinds 2000-1999).

there are significant increases in σ^o on the south-west portion of the DPB. The image on the right shows a single year change; the difference between the SeaWinds image in Fig. 1 and a SeaWinds image generated from the same time period in 1999. This one year trend shows a continued increase in backscatter on the western edge of the dry snow zone, but a σ^o decrease in the southern and western portions of the DPB.

B. C-band

A nine year time-series of the changes observed by ERS is shown in Fig. 4. To produce these images, 30 days of data (J.D. 331-360) for each year were used. The 1992 image is shown in the upper left corner of the figure. The rest of Fig. 4 is difference images showing the cumulative changes occurring since 1992.

During this nine year period there is a significant amount of fluctuation both increasing and decreasing σ^o along the DPB. The largest decrease occurred in 1994. By 2000, the cumulative result is a significant increase in σ^o along the southern portions of the DPB, and a small decrease in σ^o along the northern portion.

IV. Summary

In comparing σ^o images in the period 1978 to 2000, the largest change occurs along the boundary of the dry snow zone and percolation zone. The overall trend is an increase in σ^o along the southern portion of this boundary, although some years are exceptions. A trend is also seen in the C-band measurements of a decrease in σ^o along the norther portion of this border. Because data is lacking for the 1980's it is not known what kind of changes occurred in this period. However, the Ku-band observed changes

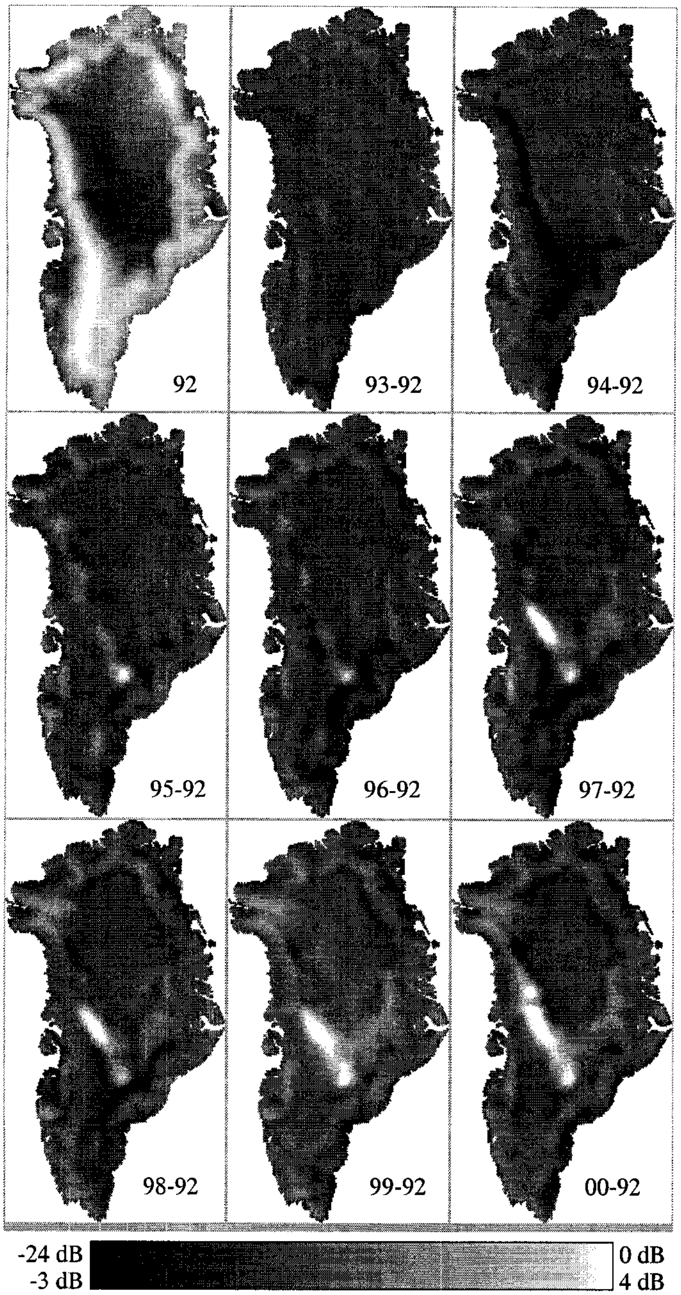

Fig. 4. Change in $\sigma_v^o(54.1°)$ observed by ERS. The upper left image is from 1992. The other images show change from 1992 to the specified year. The top limits on the color bar are for the original image and the bottom limits are for the difference images.

since 1978 closely parallel the C-band changes since 1992. Overall, significant changes have occurred on the ice sheet in the past few years, and scatterometers are proving to be an effective tool for monitoring these changes.

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