Land and Ice Applications of SeaWinds Data

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Abstract–While originally designed for wind vector measurements over the ocean, past and present scatterometers have been demonstrated to be effective for large scale monitoring of the Earth's land and ice surfaces. SeaWinds is the next generation of Ku-band scatterometers. The wide swath of SeaWinds enables much more frequent coverage of the Earth's surface than has previously been possible. SeaWinds is already finding new practical land and ice applications. In this paper some sample land and ice results from SeaWinds on QuikScat are presented. These are based on applying the Scatterometer Image Reconstruction (SIR) algorithm to produce enhanced resolution σ^o images. Backscatter images with effective resolutions as fine as 4 km are possible using SeaWinds data. Images can be produced on much shorter time scales (1 day in the polar regions) than previously possible.

INTRODUCTION

Scatterometers offer wide-area, frequent coverage of the Earth's surface. Though designed for wind observation, scatterometer data is increasingly being used in land and ice applications. The latest Ku-band scatterometer, SeaWinds on QuikScat, provides data of unprecedented coverage, resolution, and quality which can be used in studies of land and ice. Coupled with the Scatterometer Image Reconstruction (SIR) algorithm, images of σ^o at resolutions approaching 4 km can be made with SeaWinds data. Such images are useful in a variety of land and ice applications. A global view of the Earth from SeaWinds data is shown in Fig. 1.

In this paper resolution enhancement of SeaWinds is briefly discussed followed by a brief presentation of several on-going applications of SeaWinds data for ice monitoring. Some of these applications are discussed in more detail in other papers at this conference.

SCATTEROMETER IMAGING

SeaWinds is a dual scanning pencil-beam scatterometer. It makes σ^o measurements at two nominal incidence angles, 46° and 54.1°, corresponding to the inner and outer beams. The inner beam is h-polarization while the outer beam is v-polarization.

SeaWinds σ^o measurements are reported in two forms: termed 'eggs' and 'slices'. These differ in their spatial sizes and shapes. The nominal instantaneous SeaWinds antenna footprint is an ellipse. However, by using on-board range-doppler processing, the measurement resolution can be improved. Using the filtering, twelve individual σ^o measurements are obtained for each footprint, though only 8 are reported in the data products. These individual measurements are termed 'slices'. The slices are typically 4-6 km long (depending on the instrument mode and antenna beam) by 20 km wide. The summed slice measurements are known as 'egg' measurements and are reported as a standard product. The effective resolution and shape of the egg measurement nearly matches the elliptical 3 dB antenna footprint at approximately 15 km by 25 km depending on the antenna beam and instrument mode. Although lower resolution, the egg measurements have smaller K_p and are less sensitive to calibration errors.

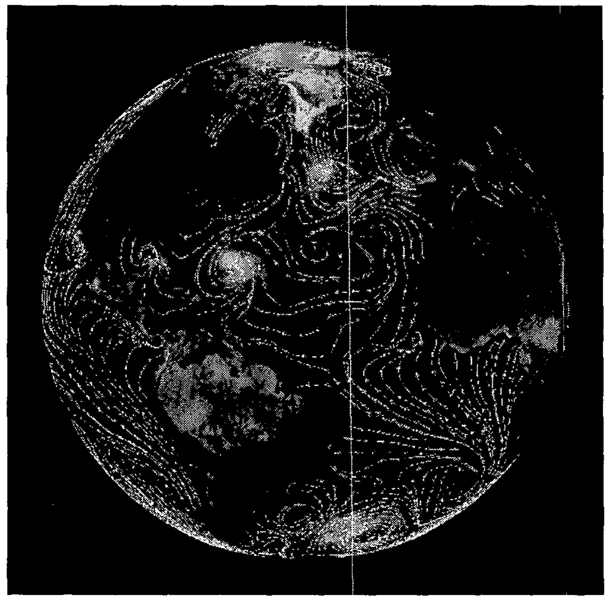

Figure 1: A global view from SeaWinds. SeaWinds-derived wind fields are shown over the ocean while V-pol Ku-band σ^o values are shown over land and ice regions in false color.

Resolution enhancement requires a tradeoff between resolution and the noise level [1, 2]. Multiple passes over the target can be used to improve the measurement overlap required by the algorithm; however, for SeaWinds resolution enhancement algorithms can be effectively applied for even single pass data, though the resolution enhancement is not as great. The resolution enhancement depends on the number of measurements with greater numbers contributing to reduced noise and improved resolution. However, during the "imaging time interval" the radar characteristics must remain constant between

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passes. Due to temporal change some tradeoff must therefore be made between the imaging time interval and the resolution. Previous scatterometers required several days of data to obtain enough measurements to produce high quality, enhanced resolution images. However, SeaWinds collects spatially very dense measurements over a wider swath than previous scatterometers. As a result, very high quality enhanced resolution images can be made over the polar regions with only a single day of data. For equatorial regions, several days are still required to obtain full coverage.

A single-variate form of the Scatterometer Image Reconstruction (SIR) algorithm, similar to the form developed for radiometer applications [1], is used to generate enhanced resolution images of σ^o (which are termed $\mathcal{A}_V$ and $\mathcal{A}_H$) at each of the two polarizations and nominal incidence angles of the antenna beams. The SIR algorithm is based on a multivariate form of block multiplicative algebraic reconstruction. Combining multiple overlapping passes results in robust performance in the presence of noise and provides improved resolution enhancement of the surface response characteristics. To improve the noise performance, slice processing additionally incorporates a modified median filter [2] which is not used with egg data.

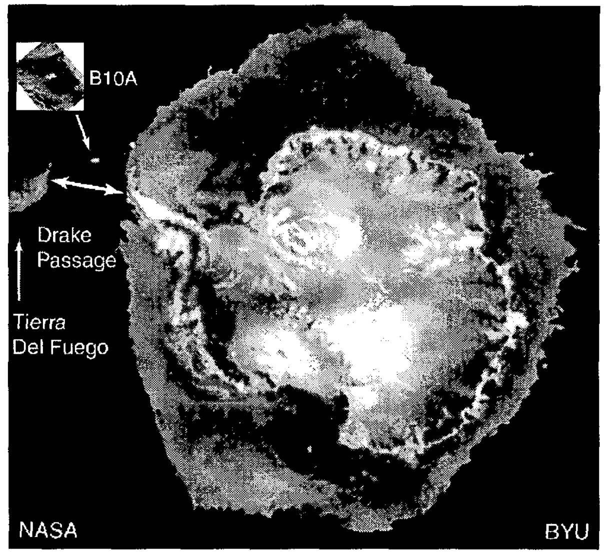

Figure 2: An enhanced resolution SeaWinds on QuikScat image of Antarctica showing the observed location of iceberg B10A and generated from one day of SeaWinds v-pol data.

SAMPLE APPLICATION: ICEBERG TRACKING

One of the primary non-wind applications of SeaWinds data is polar ice observation and mapping. SeaWinds data is being operationally processed to map the extent of polar sea ice using enhanced resolution imagery. A serendipitous new application for SeaWinds is tracking large icebergs. In the first enhanced resolution SeaWinds on QuikScat image made from data collected in June 1999, a large iceberg was observed in the Drake Passage. Figure 2 illustrates an image formed from SeaWinds measurements and demonstrates the wealth of information contained in the scatterometer data. This enhanced resolution image shows Antarctica and the surrounding sea ice constructed from a single day of SeaWinds data. Volume and surface scattering combine to produce a very bright radar return from glacial snow and ice covering Antarctica. The relative brightness is related to the wind-induced surface roughness and the annual snowfall. The variations in sea ice backscatter reveal circulation patterns in the sea ice and are due to snow cover, ice thickness, and history of the ice since formation. Ice-free ocean has been masked off using a SeaWinds-only ice edge mapping algorithm [6]. Iceberg B10A is located in the Drake passage and is approximately 21x42 NM. Other large icebergs are also visible in the image as bright spots in the sea ice. B10A was created when a large (33x64NM) iceberg broke off of the end of the Thwaites glacier which flows into the sea from Western Antarctica. It has been drifting in the ocean since 1995, driven by ocean currents and winds.

Large icebergs are regularly tracked by the Naval Ice Center using ship reports, optical images from satellites, and microwave sensor data. However, darkness during the Antarctic winter, obscuring cloud cover, and rapid iceberg motion can result in "losing track" of an iceberg. This happened in mid-1999 and the exact whereabouts of B10A were unknown. However, B10A was spotted again in the first overpass of SeaWinds on QuikScat, demonstrating the all-weather, day/night capabilities of radar to observe both oceans and ice. With the updated location of B10A, the National Ice Center issued an iceberg navigation hazard warning.

SAMPLE APPLICATION: GREENLAND

Long-term changes in the patterns and extent of melting on the large ice sheets reflect the effects of climate variability. The thickness of the snow layers reveal details about the past global climate. Comparing snow accumulation and snow melting over time can provide insight into climate change and global warming. For example, the extent of summer melting of snow in Greenland is considered a sensitive indicator of global change. Previous scatterometer data (NSCAT and ERS-1/2) suggests that Greenland has experienced significantly more melting in recent years than in previous years [3]. The frequent coverage afforded by SeaWinds provide unprecedented capability to monitor diurnal and seasonal changes in the key melt zones of Greenland where it possible to create twice-daily enhanced resolution images. Figure 3 shows the temporal variations observed in the radar backscatter over 15 days during July in Greenland. The changing dark areas around the central light area consitute the main melt zones and have lower radar backscatter due to changes in the surface reflectivity due to meltwater. As the days warm up, the melt extent dramatically increases. Comparing this data with computer models and past scatterometer data will enable evaluation of the inter-annual variability of the melting as a step toward understanding potential climate change.

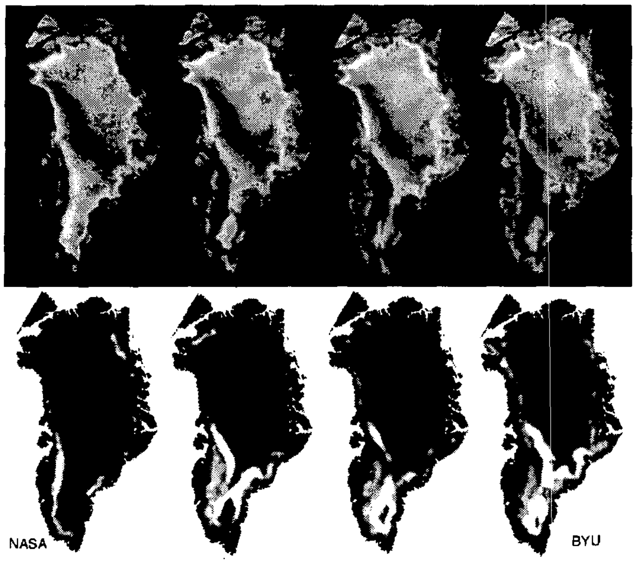

Figure 3: Time series of V-pol SeaWinds on QuikScat image of Greenland. (top row) single day images for for (a) day 203, (b) 208, (c) 213, and (d) 218 in 1999. (bottom row) corresponding standard deviation images created by computing the standard deviation of all the measurements covering each pixel during a single day.

SEAWINDS IMAGE PRODUCTS

Because of the utility of the SeaWinds enhanced resolution images, a standard set of enhanced resolution and non-enhanced images is being produced. The products will be distributed through the JPL PO.DAAC.

Two main types of SeaWinds data products are produced depending on the σ^o measurement source: 1) slices and 2) eggs. SIR-resolution enhanced and non-enhanced (gridded) images are produced for each. The nominal pixel resolution of the slice-based SIR images is 2.225 km with an estimated effective resolution of $\sim$ 4 km. Egg-based SIR-enhanced images have a nominal pixel resolution of 4.45 km with an estimated effective resolution of 10 km. A set of low-resolution (4 pixels/deg) global browse products are also produced. Gridded image products are not resolution enhanced and are produced at pixel resolution of 5 times the nominal SIRF resolution (11.125 km and 22.25 km for slices and eggs respectively). Gridded images are created by accumulating all of the measurements whose center falls with a given grid element and averaging. For a given grid element $\mathcal{A}_V$and $\mathcal{A}_H$ images are generated. Thus in effect, the $\mathcal{A}$ values are temporal averages over the imaging time interval. Sea-ice extent maps are made using an extension [5, 6] of the NSCAT ice edge algorithm [4]. ASCII file and ice masked $\mathcal{A}$ polar images are distributed as separate products.

CONCLUSION

Though originally designed to measure vector winds over the ocean, SeaWinds can be effectively used to study polar ice and land regions. Using the Scatterometer Image Reconstruction (SIR) algorithm, SeaWinds data is processed to generate enhanced resolution images. In the polar regions the resulting daily images can be used to track large icebergs and map the extent of sea ice cover. A time series of such images reveals the dynamics of iceberg motions and the sea-ice edge.

An advantage of the SeaWinds instrument over NSCAT is the increased coverage of the earth's surface. SeaWinds has a wider swath than NSCAT and has no nadir gap allowing SeaWinds polar images to be produced using only 1-2 days of data rather than the 6 days required for NSCAT. As a result, daily ice extent maps can be produced. Tropical images require a minimum of two days to achieve maximum overlap and coverage. A standard set of enhanced resolution polar (including sea-ice extent maps and ice-edge ASCII file) products as well as non-polar image products are being produced by the Brigham Young University Microwave Earth Remote Sensing Laboratory. The data will be distributed by the JPL PO.DAAC.

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