High Resolution Wind Retrieval from SeaWinds

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***Abstract*–SeaWinds is a Ku-band pencil-beam scatterometer launched in 1999 on the QuikSCAT mission. It is designed to make nominally 25 km resolution observations of vector winds over the ocean. However, by taking advantage of resolution enhancement and its dense sampling characteristics, the wind can be retrieved at much higher resolution, albeit with greater noise. Winds with resolutions as fine as 2.5-5 km can be retrieved. Such wind data can support a variety of applications including hurricane monitoring and studying submesoscale wind phenomenology. While validation of this high resolution wind measurement capability is in progress, initial results are very encouraging.**

INTRODUCTION

The SeaWinds scatterometer on QuikSCAT has been successfully operating since mid-1999. While originally designed for measuring vector winds over the ocean, SeaWinds data is also used in land and ice studies. These applications have been furthered by the application of resolution enhancement algorithms. The measurement sampling and geometry of SeaWinds is particularly well suited for applying resolution enhancement algorithms for such studies [1].

Previous scatterometers have required multiple overlapping orbits in order to effectively apply the resolution enhancement techniques. This precludes the use of the enhanced data for wind retrieval. However, the SeaWinds sampling geometry enables the use of resolution enhancement even for single-passes, albeit with degraded performance. This suggests that it may be possible to apply resolution enhancement techniques to the scatterometer backscatter measurements to enable retrieval at higher effective resolution than otherwise possible. In this paper a technique for retrieving enhanced resolution winds at high resolution (2.5 km sample spacing) is developed for SeaWinds data. The limitations of the approach are considered. The application of high resolution wind fields in hurricane and storm monitoring is illustrated.

SCATTEROMETER IMAGING AND WIND RETRIEVAL

Though designed for wind observation, scatterometer data is increasingly being used in land and ice applications. A scanning pencil-beam scatterometer, SeaWinds provides data of unprecedented coverage, resolution, and quality. SeaWinds makes σ^o measurements at two nominal incidence angles, $46°$ (h-pol) and $54.1°$ (v-pol), corresponding to the inner and outer beams.

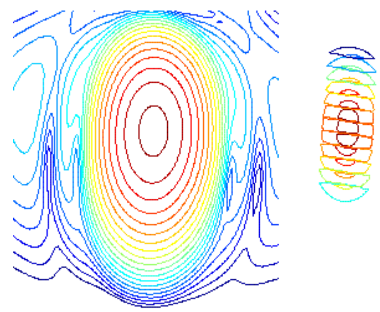

Fig. 1: Illustration of the spatial σ^o measurement response for (left) eggs and (right) slices. Contour interval is 3 dB. Only the inner 8 slices are reported.

SeaWinds σ^o measurements are reported in two forms: ‘eggs’ and ‘slices’ [2]. These differ in their spatial sizes and shapes (Fig. 1). The nominal instantaneous SeaWinds antenna footprint is an ellipse. Using onboard filtering, twelve individual σ^o measurements (termed ‘slices’) are also obtained for each footprint, though only 8 are reported in the data products. The slices are approximately 6×25 km. The summed slice measurements are known as ‘egg’ measurements which have an effective size of approximately 20×30 km. Egg measurements are used in 25 km resolution wind retrieval.

The SeaWinds pulse timing and rotation rate result in a dense sampling of the surface with significant along-scan and along-track overlap in the spatial response functions of the measurements, particularly for slices (see Fig. 2). This dense ’oversampling’ over the surface can be exploited by reconstruction and resolution enhancement algorithms to produce enhanced resolution images of the surface σ^o. By exploiting the non-ideal roll-off characteristics of the spatial response function such algorithms can produce images with finer resolution than the instrument’s intrinsic resolution [1].

Previous scatterometers have *required* multiple passes over the target area to obtain sampling sufficiently dense to benefit significantly from resolution enhancement. (Resolution enhancement algorithms depend on the number of measurements and their spatial sampling of the surface with greater numbers contributing to reduced noise and improved resolution, thereby trading temporal resolution for spatial resolution [3].) While multiple passes are still desired for optimal application to SeaWinds, the dense SeaWinds sampling permits resolution enhancement for even single pass data, though the resolution enhancement capability is more limited and noisy.

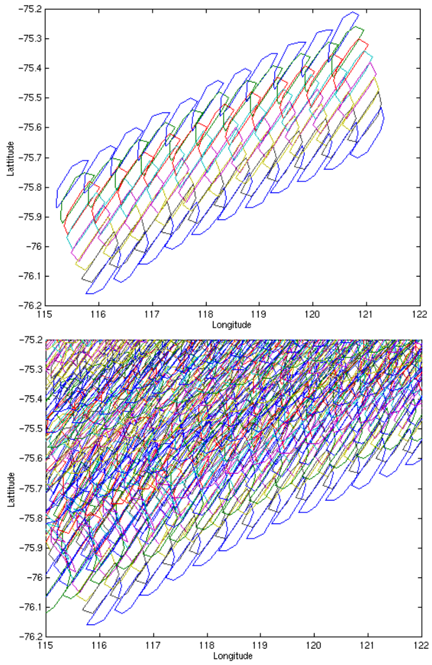

Fig. 2: Illustration showing the relative locations of multiple slice measurements. Individual slices are approximately 6×25 km. (top) Ten consecutive pulses. (bottom) Multiple pulses and antenna rotations.

In past applications, scatterometer resolution enhancement algorithms have, in effect, assumed an isotropic response by ignoring any azimuth dependence of the measurements. However, wind retrieval requires azimuth diversity in the σ^o measurements. Further, multiple passes preclude wind retrieval due to the temporal variability of ocean winds. By eliminating the need for multiple passes and by separately processing the various azimuth look directions and incidence angle/polarization combinations of the SeaWinds data, single-pass enhanced resolution σ^o images can be created which preserve the azimuth diversity of the original measurements. The resulting σ^o images can then support high resolution wind retrieval.

For resolution enhancement the Scatterometer Image Reconstruction (SIR) algorithm [1, 3] can be successfully used, as can the AVE algorithm [3]. Because of reduced computational requirements the AVE algorithm has been used in this paper. We note that the AVE algorithm has more limited enhancement capability compared to SIR, but also tends to be less noisy. Over most of the swath four separate σ^o values can be computed: h-pol fore and aft azimuth looks and v-pol fore and aft azimuth looks. Over the outer edges of the swath only v-pol measurements are available. σ^o fields for each case are separately computed from the raw σ^o measurements using the individually varying spatial responses of the measurements and the AVE algorithm. A sample σ^o field is shown in Fig. 3. At each resolution element (pixel) the azimuth and incidence angle is computed as the average of the σ^o measurements combined in

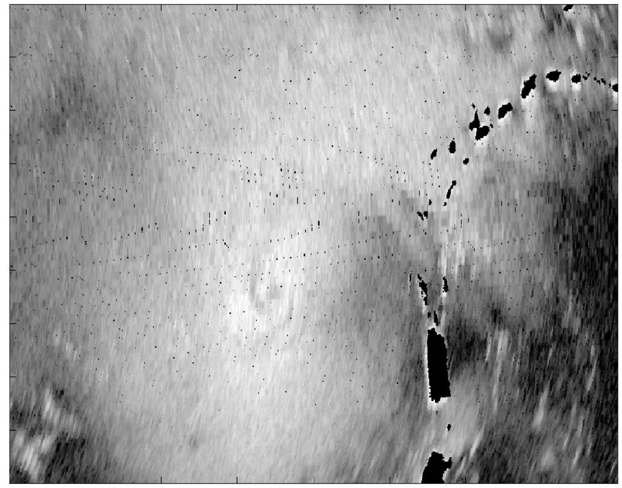

Fig. 3: AVE-enhanced 2.5 km pixel resolution σ^o field for SeaWinds v-polarization, fore-look over Hurricane Floyd. The vertical direction corresponds to cross-track ($\sim$ 1000 km) while horizontal corresponds to along-track ($\sim$ 2400 km) which is approximately north-south. The largest island is Haiti.

the AVE estimate. Given these values, the wind is retrieved at each pixel location using a standard SeaWinds wind retrieval algorithm. The result at each pixel is from one to four "ambiguities" having similar wind speeds, but differing directions. For these initial experiments ambiguity selection is based on choosing the ambiguity closest (in the vector magnitude difference sense) to the closest standard L2B selected wind vector.

To evaluate the accuracy of the wind retrieval, Monte Carlo simulations are used. Using a synthetic wind field with a k^{-2} spectrum, simulated σ^o measurements are generated using the measurement geometry and spatial responses from actual SeaWinds data. Retrieved winds are then compared with the synthetic winds. As expected, the rms error in the retrieved wind is much larger than for the conventional 25 km resolution product. The rms wind speed error varies from 3 to 6 m/s, depending on the true wind speed, while the wind direction error exhibits significant directional biases related to the true wind direction. Nevertheless, the results are encouraging. Further research to validate the high resolution winds is underway.

APPLICATIONS: HURRICANE MONITORING

One of the primary potential applications of both high resolution σ^o and high resolution winds is hurricane monitoring. Even without wind retrieval, enhanced resolution σ^o fields can be an important tool in operational storm forecasting. The fundamental principle on which scatterometry is based is the measurement of σ^o of the wind-roughened surface. While it can be very difficult to directly interpret ocean surface σ^o fields, the symmetry and low wind speed central eye of hurricanes significantly simplify σ^o field interpretation. Thus, high resolution σ^o fields can be of value in accurately locating the hurricane eye at the surface as the reduced σ^o center of the storm (see

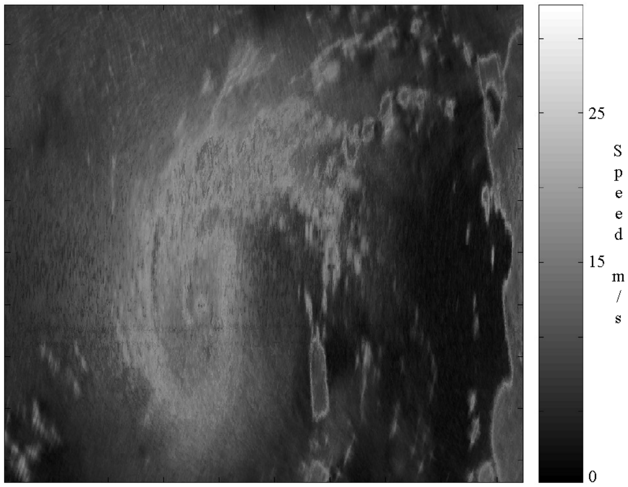

Fig. 4: Enhanced resolution SeaWinds 2.5 km pixel resolution wind speed estimates derived from enhanced resolution σ^o fields (compare Fig. 3).

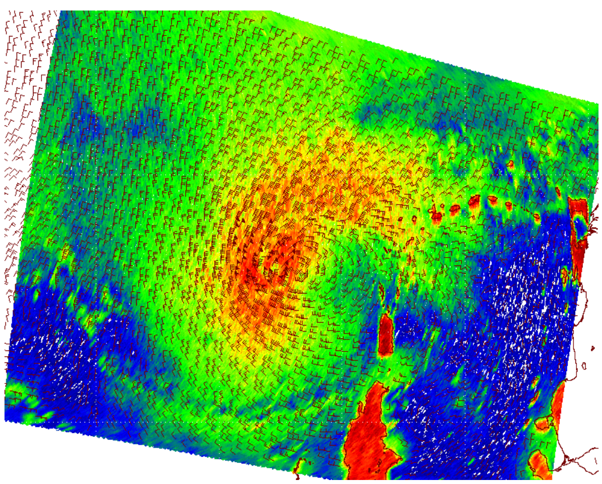

Fig. 5: SeaWinds views Hurricane Floyd. Wind barbs indicate the locations, directions, and speeds of conventional 25 km resolution SeaWinds wind estimates. Color background field shows 2.5 km pixel resolution wind speed estimates derived from AVE-enhanced σ^o fields. This image reveals the tilt of the swath with respect to true north which is to the left.

Fig. 3). Fig. 4 shows an image of the wind speed retrieved at each pixel from the enhanced resolution σ^o fields. Though part of the variability is due to the noisy measurements, the image clearly reveals mesoscale features in the wind field. For comparison Fig. 5 shows a view of the high resolution wind field with conventional 25 km winds overlaid as wind barbs.

As an additional illustration of the application of enhanced resolution wind fields in studying mesoscale and sub-mesoscale phenomenology consider Fig. 6. Significant small-scale wind features are evident. These cannot be resolved by conventional processing.

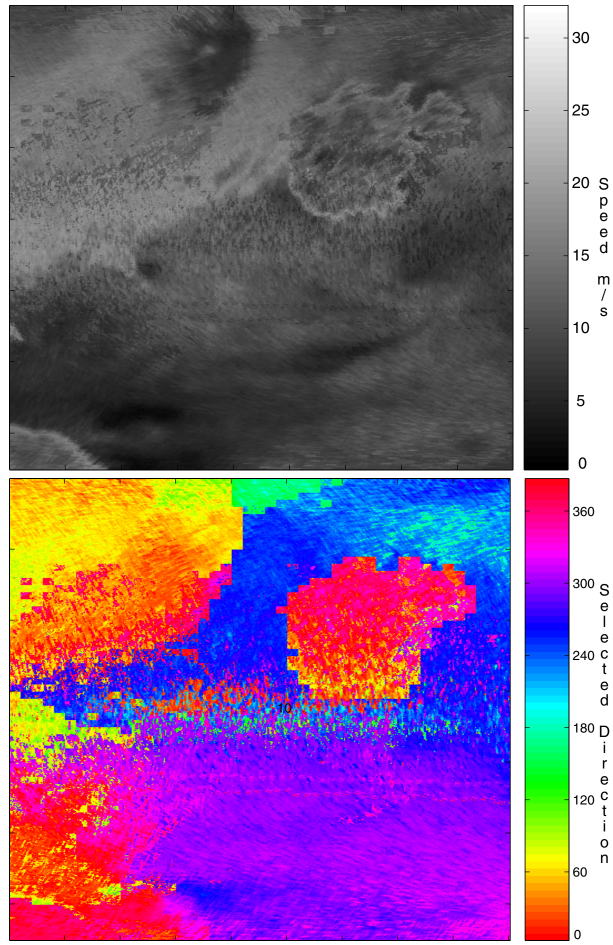

Fig. 6: Images of estimated (top) wind speed and (bottom) wind direction for cyclonic storm near Iceland. Iceland is visible as a white outlined patch in the upper-right quadrant. The storm center is located in the upper center. The storm front and various mesoscale features are evident in the wind speed and wind direction images.

References

[1] D.S. Early and D.G. Long, "Image Reconstruction and Enhanced Resolution Imaging from Irregular Samples," *IEEE Trans. Geosci. Remote Sens.*, vol. 39, no. 2, pp. 291-302, 2001.

[2] M.W. Spencer, C. Wu, and D.G. Long, "Improved Resolution Backscatter Measurements with the SeaWinds Pencil-Beam Scatterometer," *IEEE Trans. Geosci. Remote Sens.*, vol. 38, no. 1, pp. 89-104, 2000.

[3] D.G. Long, P.J. Hardin, and P.T. Whiting, "Resolution Enhancement of Spaceborne Scatterometer Data," *IEEE Trans. Geosci. Remote Sens.*, vol. 31, no. 3, pp. 700-715, 1993.