Ultra High Resolution Wind Retrieval for SeaWinds

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Abstract—**The SeaWinds series of scatterometer instruments were designed to measure vector winds over the ocean at a nominal resolution of 25 km. However, the radar backscatter measurements from which the wind is inferred are made at finer resolution than this. Further, the spatial sampling of the backscatter measurements can support reconstruction of finer scale backscatter values which can then be used to estimate the near-surface wind vector field at high resolution (pixel spacing of 2.5 km). At this resolution, the data can be used to study coastal and mesoscale wind features such as tropical cyclones and convective storms.**

In this paper we use simulation and actual data to validate the accuracy of the retrieved winds and analyze the effective resolution of the wind estimates. An empirical technique to compensate for the estimate bias is developed and applied and an improved method for ambiguity selection is developed. Comparison of the derived vector winds with a variety of other wind sensors is very encouraging.

I. Introduction

The first SeaWinds wind scatterometer was launched in 1999 on the QuikSCAT satellite. A second SeaWinds instrument was successfully launched in December 2002 aboard ADEOS-II. These Ku-band instruments are designed to make nominally 25 km resolution observations of near-surface vector winds over the ocean via mesurements of the normalized radar backscatter (σ°) of the surface. Over the ocean these measurements can be used to estimate the near-surface vector wind using a geophysical model function. SeaWinds wind observations are currently being operationally used at various weather forecasting facilities where it has improved forecasting skill.

The SeaWinds σ^o measurements have proven useful in a variety of land and ice applications. Applying reconstruction and resolution enhancement [1] can further improve the utility of the data for land and ice applications. For example, enhanced resolution backscatter images are being operationally used for sea ice monitoring and iceberg tracking.

Reconstruction of SeaWinds data can also be done over the ocean. This is facilitated by the dense SeaWinds sampling which enables single pass reconstruction. While the reconstruction performance with single pass data is not as good as with multiple passes, single pass reconstruction enables production of high resolution (2.5 km pixel resolution) backscatter imagery. This imagery is now being operationally used to improve hurricane and severe storm tracking [4].

The high resolution σ^o data can also be used in wind estimation, resulting in wind estimates posted at a very high resolution of 2.5 km. While the effective resolution is somewhat lower than this, the high resolution winds can provide significant insight into mesoscale phenomena. In this paper we describe some improvements to the high resolution wind processing and evaluate the accuracy of the resulting winds against aircraft and buoy observations. Some of the limitations of the approach are considered.

II. High Resolution σ^o

Using a dual scanning pencil-beam antenna system, SeaWinds makes σ^o measurements over a 1800 km wide swath at two nominal incidence angles, $46°$ (h-pol) and $54.1°$ (v-pol). Using range/Doppler filtering, the antenna beam limited footprint is resolved into 6×25 km elements termed 'slices' [2]. The summed slice measurements are known as 'egg' measurements which have an effective size of approximately 25×32 km. The standard JPL SeaWinds L2B wind product is produced at 25 km resolution using the egg measurements.

The slice measurements densely sample the surface and have significant measurement response overlap. This 'oversampling', along with the non-ideal roll-off of the spatial measurement response, enables the recontruction algorithm to enhance the effective resolution and produce enhanced resolution images of the surface σ^o [1], [4]. The resulting σ^o images have finer resolution than the 3 dB resolution of the individual slice measurements. The geometry of the rotating antennas and orientation of the slices measurement response results in variable effective resolution over the swath.

Resolution enhancement algorithms depend on the spatial sampling density of the surface, with finer (denser) sampling resulting in improved resolution. To achieve higher sampling density, multiple passes may be combined as done with previous sensors [3]. However, combining multiple passes degrades the temporal resolution and cannot, in general, be used over the ocean due to the rapid evolution of the wind-driven surface and thus cannot be used for wind retrieval. Wind retrieval requires azimuth diversity in the σ^o measurements in order to estimate the wind direction. As a result, the various azimuth look directions must be processed separately to preserve the azimuth diversity of the original measurements. Many land and ice applications have assumed an isotropic response by ignoring any azimuth dependence of the measurements which are combined to improve the sampling density [3].

While the reconstruction provides improved spatial resolution, its high pass filter characteristics can also enhance the noise in the measurements. In conventional wind retrieval, the summed slices whose center falls within a 25 km grid element are average prior to wind retrieval. This decreases the noise, but also degrades the resolution, particularily since portions of the slice measurement responses lie outside of the grid element.

For resolution enhancement the AVE algorithm [3] is used to minimize computational requirements. The AVE algorithm has more limited enhancement capability than the scatterometer image reconstruction (SIR) algorithm, but also tends to be less noisy [3]. Four separate σ^o values are computed for each 2.5 km pixel using the individual slice measurement responses: 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.

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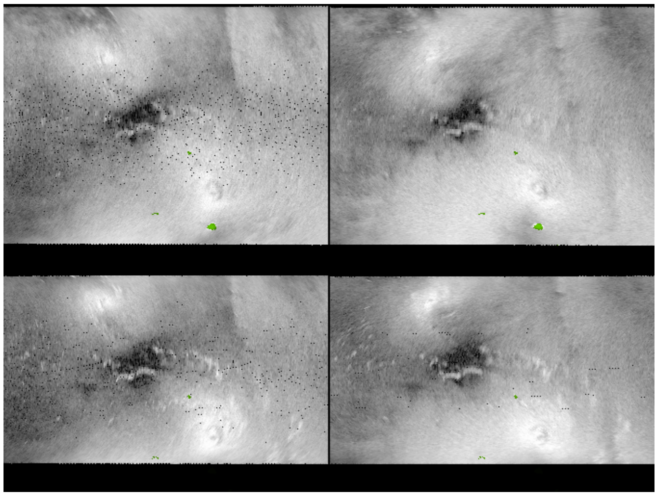

Fig. 1. AVE-derived 2.5 km pixel resolution σ^o (in dB) fields for SeaWinds derived from rev 19021 (14 Jan. 2003). (top, left) Forward-look, V-pol. (top, right) Aft-look, V-pol. (bottom, left) Forward-look, H-pol. (bottom, right) Aft-look, H-pol. Black dots in the lower image are pixels not covered in the sampling. Texture is due to mesoscale variability in the wind and σ^o measurement noise. Two cyclones are visible in the images at the upper left and lower right of center as bright areas corresponding to high wind speeds.

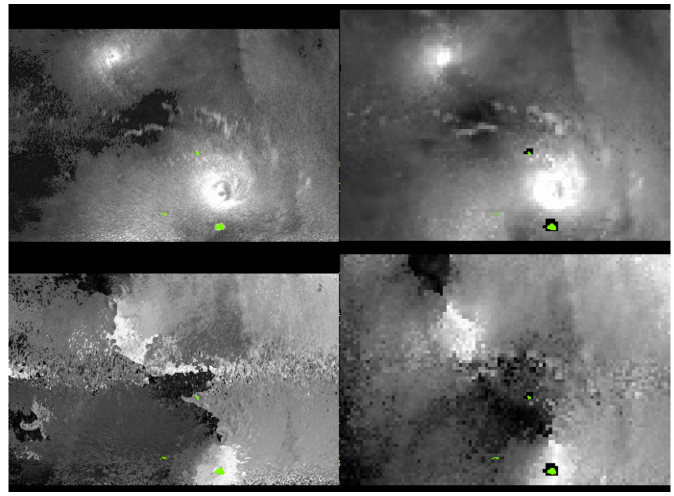

Fig. 2. Winds derived from QuikSCAT rev 19021 (14 Jan. 2003). (top, left) High resolution (2.5 km/pixel) wind speed. (top, right) Low resolution (25 km) wind speed. (bottom, left) High resolution wind direction. (bottom, right) Low resolution (25 km) wind direction. Wind speeds from 0 to 25 m/s correspond from black to white, while wind directions from 0 to 180 to 360 correspond to white to black to white. Two cyclones are visible in the images at the upper left and lower right of center. Note that the cyclone eyes are visible in the wind speed maps.

Currently, high resolution σ^o fields are being operationally used to support hurricane monitoring. High resolution σ^o images are produced in near-real-time for each SeaWinds orbit. Even without wind retrieval, the enhanced resolution σ^o fields can be an important tool in severe storm forecasting. While specialized skill is required to interpret ocean surface σ^o fields, the symmetry and low wind speed central eye of hurricanes make such features easy to identify and track (see Fig. 1).

III. Wind Retrieval

Given the azimuth and incidence angles and the K_p coefficients at each pixel The wind retrieved using a standard SeaWinds wind retrieval algorithm. The result at each pixel is from one to four "ambiguities" having similar wind speeds, but with different directions. Associated with each ambiguity is a likelihood value. An initial selection is made by choosing the ambiguity closest (in the vector magnitude difference sense) to the selected L2B 25 km ambiguity. This ensures that that the mean flow exhibited in the high resolution wind field matches the flow in the 25 km L2B product. Then, a median-filter based ambiguity selection algorithm [5] with a window size of 17.5 km $\times$ 17.5 km is applied to select the final ambiguities. A variety of window sizes were evaluated, and this size was adopted as providing the best subjective tradeoff between computation and performance. An interesting example of the high resolution winds in the presence of multiple cyclones is provided in Fig. 2. We note that high resolution winds are retrieved right up to coastlines, unlike 25 km winds for which a near-to-land exclusion masked is applied (see Fig. 2) Caution must be exercised when using near-land high resolution winds to filter out estimates which may be land contaminated.

Since the high resolution σ^o values are noisier than the egg values normally used to retrieve the wind, the high resolution wind estimates tend to be significantly noisier than 25 km wind estimates, and exhibit direction and speed biases. To minimize the bias simulations are employed to estimate the bias as a function of wind direction and speed at each cross-track location. The resulting errors are binned by the estimated wind direction and speed and averaged. The average bias is then removed from the retrieved winds. Independent simulations show that corrected winds exhibit little bias. Not suprisingly, the estimated winds are noisier than conventional 25 km winds but with caution, the winds can be applied in mesoscale and near-coastal studies. We note that the estimated winds can be spatially averaged to reduce the error.

IV. Validation

For a further evaluation, Fig. 3 shows a comparison of QuikSCAT high-resolution wind vectors with data collected during ONR's Shoaling Waves Experiment (SHOWEX) in 1999. High-resolution QuikSCAT winds from a pass occurring near the time of aircraft flights on Nomvember 15, 1999 have been evaluated at the locations of the aircraft. The comparison data set consists of wind vectors from three fixed buoys and two aircraft. Buoy winds are from sonic anemometers on three Air-Sea Interaction Spar (ASIS) buoys (Yankee, Bravo, and Romeo) belonging to the University of Miami. Winds from the LongEZ aircraft are from a gust probe on the nose of the airplane. Winds from the Twin Otter aircraft were derived from a coherent, rotating, X-band radar via scatterometry. The map in the lower left corner of the figure shows the locations of data collection and QuikSCAT wind vector evaluation. The upper two plots in the figure show wind speeds and directions from the various sensors.

For offshore distances greater than about 10 km, wind directions from the various sensors agree with each other very well.

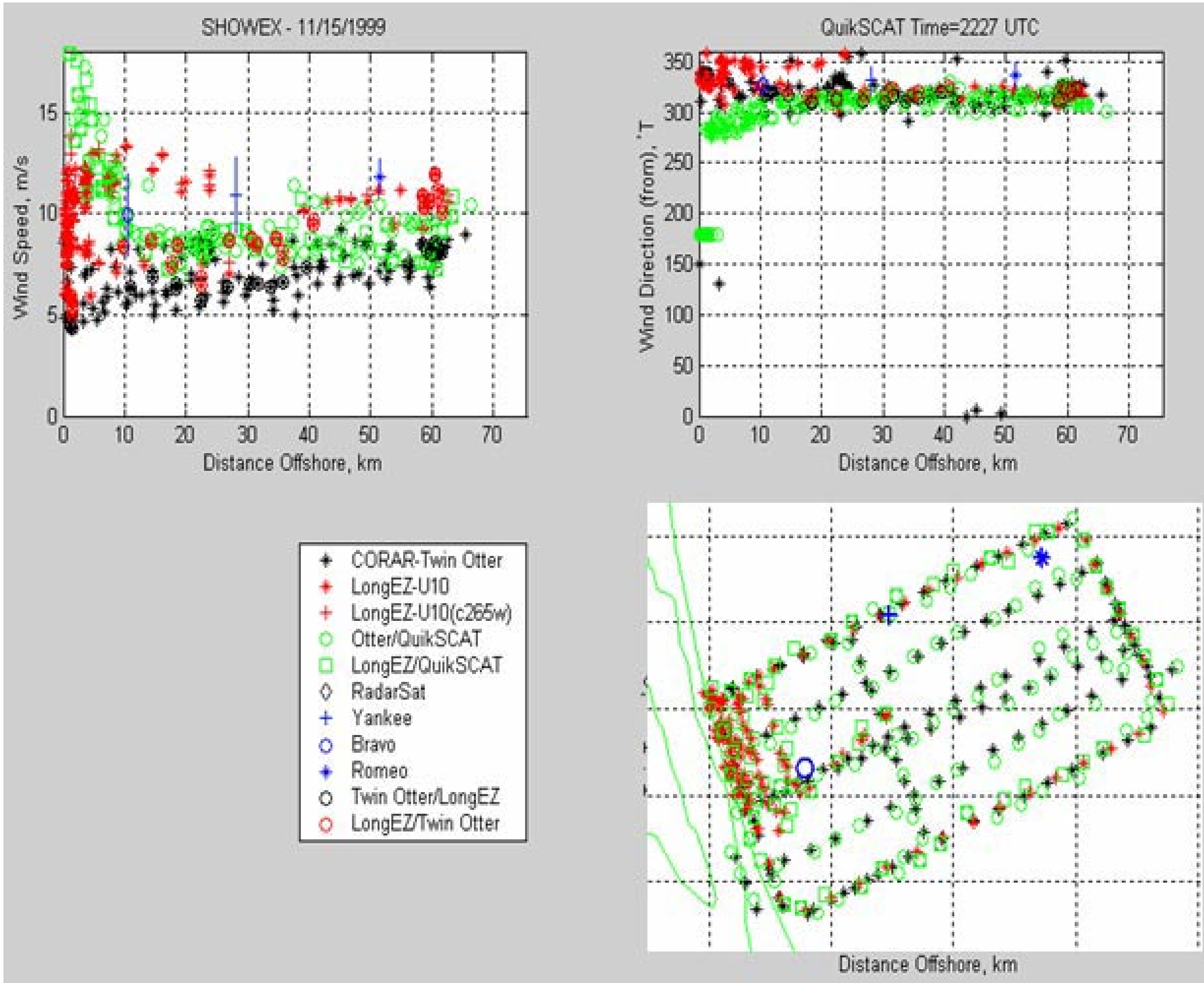

Fig. 3. Comparison of colocated QuikSCAT high resolution winds with other sensors during SHOWEX. (top, left) Wind speed comparison. (top, right) Wind direction comparison. (bottom, right) Location of observations. The shore line, indicated with green lines, is at the left.

Wind speeds are more scattered but agree on the general increase in wind speed with distance offshore. The disagreement of the QuikSCAT winds with the other measurements within 10 km of shore is to be expected due to the contamination of the original QuikSCAT measurements by land. While the estimated wind speed fields always appear consistent, missing σ^o measurements and poor azimuth geometry combine to occasionally produce poor wind direction estimates at certain cross-track bands.

CONCLUSION

Though originally designed to measure vector winds over the ocean at 25 km resolution, SeaWinds can retrieve vector winds at higher resolution, albeit with reduced accuracy. The high resolution winds are not suitable for all applications due to the high noise level but may have application in the study of near-coastal and mesoscale winds. A bias correction step and improved ambiguity selection increases the wind accuracy. Validation of the high resolution wind estimates is continuing and comparison against SAR images and other wind senors is encouraging.

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