4.2 COMPARISON OF RADARSAT SAR-DERIVED WINDS WITH BUOY AND QUIKSCAT MEASUREMENTS

F.M. Monaldo*, D. R. Thompson, and R. C. Beal
Johns Hopkins University Applied Physics Laboratory, Laurel, Maryland

1. INTRODUCTION

Spaceborne synthetic aperture radars (SARs) measure surface radar cross section (RCS) with ground resolutions from 25 to 100 m. In turn, the RCS of the ocean surface is a function of wind speed and direction. Over the past few years, we have been routinely using RCS measured by the RADARSAT SAR to compute high-resolution wind speed. We have converted over 3000 wide-swath SAR RCS images, provided by the Alaska SAR Facility (ASF), into high-resolution wind speeds. SAR images have covered both the East Coast of the United States and Gulf of Alaska and Bering Sea regions. To validate these SAR-derived wind speeds we have systematically compared them to model, buoy, and, most recently, QuikSCAT scatterometer wind speed measurements. Thus far, the standard deviations of SAR wind speeds with respect to buoy or QuikSCAT wind speeds are less than 2 m/s.

2. WIND SPEED ALGORITHM

RCS at HH-polarization is related to wind speed by

$$\sigma_0^{\mathrm{H}} = R(\theta,\alpha)F(U,\theta,\phi) \tag{1}$$

where $F(U,\theta,\phi)$ is the CMOD4 model function developed for the VV-polarization, C-band ERS-1 scatterometer and described by Stofflelen (1993). The variables U, θ, and ϕ represent wind speed, radar incident angle, and the angle between the wind direction and the radar look direction, respectively.

The RADARSAT SAR operates at HH-polarization and so we relate VV-polarization RCS to HH-polarization RCS using the ratio given by Thompson *et al.*, (1998) as

$$R(\theta,\alpha) = \frac{(1+\alpha\tan^2\theta)}{(1+2\tan^2\theta)} \tag{2}$$

where α is a scaling parameter. The value of α is a matter of some controversy. Some have suggested that $\alpha = 1$ where airborne measurements suggest that $\alpha = 0.6$. Thus far we have routinely used the 0.6 value (Unal *et al.*, 1991).

Since a SAR only measures RCS, we can only infer wind speed if we have an *a priori* estimate of wind direction. For this work, we obtained wind direction from the NOGAPS (Naval Operational Global Atmospheric Prediction) model. The two inputs to the SAR wind speed estimates were RADARSAT RCS (averaged over 1 km) and model wind directions.

3. MODEL COMPARISONS

Comparing model wind speeds to SAR wind speeds is limited by the lack of exact temporal coincidence and the relatively coarse 1°×1° longitude-latitude resolution of the model. Nonetheless, the large number of such comparison proved useful in looking for systematic differences. The most notable problem we found is the systematic underestimation of RCS and, hence, wind speed at near range (less than 25°) incident angles in RADARSAT wide-swath imagery. Thus, we have restricted SAR comparisons with buoy and QuikSCAT measurements to incident angles greater than 25°.

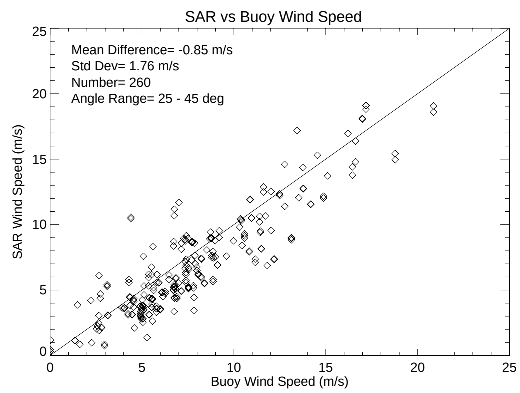

Figure 1: Scatter plot of SAR wind speed versus coincident buoy wind speeds.

4. BUOY COMPARISONS

The National Data Buoy Center operates a set of buoys off the East Coast of the United States. We accumulated 260 buoy-SAR wind speed comparison pairs at SAR incident angles greater than 25°. Figure 1 is a scatter plot of these comparisons. The standard deviation between the two is 1.76 m/s and the mean difference is –0.85 m/s. An α of 0.6 was used in this comparison. For α-values much less than 0.6, the standard deviation increases. For larger values of α, the

* *Corresponding author address:* F. M. Monaldo, The Johns Hopkins University Applied Physics Laboratory, Laurel MD 20723–6099; e-mail: f.monaldo@jhuapl.edu.

standard deviation does not increase much, but the mean difference grows.

5. QUIKSCAT COMPARISONS

QuikSCAT is a satellite designed to measure wind speed over the ocean (reference). Although it operates at Ku-band rather than C-band, the relationship between RCS and wind speed and direction is much the same as given in Equation 1. The QuikSCAT scatterometer, however, measures surface RCS with two-pencil beam, rotating antennas. As a consequence, a particular spot on the surface is measured multiple times from different aspect angles. With multiple measurements it is possible to infer both wind speed and direction. However, conventional scatterometers have 25-km spatial resolution and difficulty with contamination from land returns in coastal areas. The 1-km resolution SAR wind speeds become a perfect complement for scatterometer wind speeds in coastal areas.

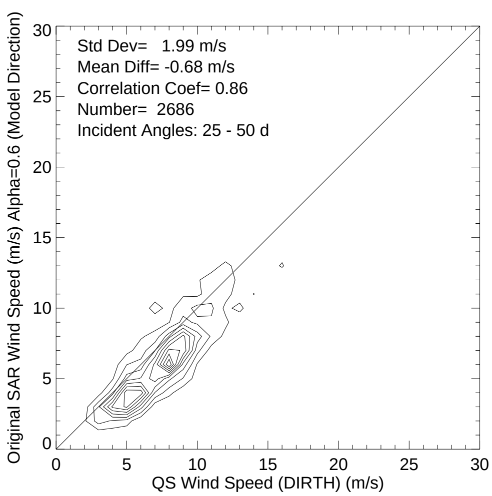

Figure 2: SAR wind speed versus QuikSCAT wind speed. SAR wind speeds were computed using model wind directions.

How well do the SAR and scatterometer wind speeds compare? Using the SAR imagery data set and constraining QuikSCAT and SAR comparisons to be between 15 minutes of each other, we have accumulated 2686 individual comparisons. To make the SAR measurements more comparable, we averaged SAR wind speed estimates over areas 25 km in diameter.

Since there are so many QuikSCAT-SAR comparisons, a scatter plot comparing the two would be cluttered. We, therefore, present the comparison as a contour plot in Figure 2. Note that the standard deviation between the two is 1.99 m/s with a mean difference of -0.68 m/s. Comparisons at other α-values do not significantly reduce the standard deviation.

One source of error in SAR wind speed retrieval is the *a piori* wind direction. We re-computed the SAR wind speeds using the wind directions from the QuikSCAT scatterometer. After doing so, the comparisons dramatically improve. The standard deviation

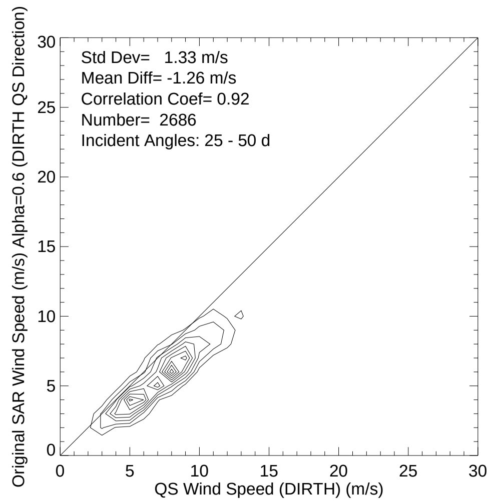

Figure 3: SAR wind speed versus QuikSCAT wind speed. SAR wind speeds were computed using QuikSCAT directions.

drops to 1.33 m/s. Figure 3 is a contour plot of the SAR-QuikSCAT comparison.

6. CONCLUSIONS

Spaceborne SARs offer the unique opportunity to measure wind speeds at 1-km resolution over a 500-km swath. Point-by-point comparisons with independent buoy and QuikSCAT measurements show a standard deviation of less than 2 m/s. When QuikSCAT wind directions are used in the SAR retrievals, the standard deviation between SAR and QuikSCAT wind speeds drops to 1.33 m/s.

SAR imagery has demonstrated the potential of making high-resolution wind speed measurements. These recent results demonstrate that if QuikSCAT and SAR measurements are combined an even better high-resolution wind speed measurement is possible.

7. REFERENCES

Spencer, M. W., C. Wu, and D. G. Long, 2000: Improved resolution backscatter measurements with the SeaWinds pencil-beam scatterometer, *IEEE Trans. Geosci. and Remote Sensing,* **38**, 89–104.

Stoffelen, A. and D. L. T. Anderson, 1993: Wind retrieval and ERS-1 scatterometer radar backscatter measurements, *Adv. Space Res.,* **13***,* 53–60.

Thompson, D. R., T. M. Elfouhaily, and B. Chapron, 1998: Polarization ratio for microwave backscattering from the ocean surface at low to moderate incidence angles, *Proc. 1998 International Symposium on Geoscience and Remote Sensing,* Seattle Washington.

Unal, C. M. H., P. Snooji, and P. J. F. Swart, 1991: The polarization-dependent relation between radar backscatter from the ocean surface and wind vectors at frequencies from 1 to 18 GHz, *IEEE Trans. Geosci. and Remote Sensing*, **29**, 621–626.