A Comparison of Hurricane Eye Determination Using Standard and Ultra-High Resolution QuikSCAT Winds

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Abstract— **Space-borne scatterometers are instruments designed to measure the radar backscatter of the earth's surface at a variety of azimuth angles from orbiting satellites. Empirical model functions relate these backscatter measurements to geophysical parameters such as wind speed and direction. For SeaWinds on QuikSCAT, standard wind retrieval is performed on wind vector cells of 25 x 25 kilometers in size. Because of the inherent spatial over-sampling, image reconstruction techniques may be applied to enhance the resolution of the backscatter images. Using such methods, higher resolution winds are possible. This paper compares the use of standard resolution QuikSCAT wind information with ultra-high resolution QuikSCAT data for the observation of hurricanes.**

I. Introduction

Space-borne scatterometers such as SeaWinds on QuikSCAT are instruments designed to measure the radar backscatter of the earth's surface at a variety of azimuth angles from orbiting satellites. A geophysical model function relating backscatter to wind is then, under standard QuikSCAT processing, inverted on 25×25 km resolution elements—termed wind vector cells—to obtain near-surface ocean wind speed and direction. Recently, algorithms have been developed to exploit QuikSCAT's inherent spatial oversampling and improve the backscatter resolution. Using image reconstruction techniques, posted resolution of winds at 2.5 km is possible, though the effective resolution of the retrieved winds is somewhat lower [1].

Scatterometer data find many applications of significant utility. Among these is the observation and tracking of tropical cyclones including hurricanes. Several features of interest to forecasters including the structure and size of the inner core, the magnitude of the surface winds in the eyewall, and presence of double eyewalls are generally unresolvable at low resolution [2]. For this reason, ultra-high (2.5 km posting) resolution QuikSCAT data is proving valuable in the study of tropical cyclones. Wind fields obtained at ultra-high resolution are somewhat noisier than the 25 km product—especially with regard to wind direction. However, there is important storm characterization detail available in the 2.5 km wind *speed* field that is not present in 25 km speed fields.

This paper compares the use of standard (25 km) resolution QuikSCAT wind information with resolution enhanced (2.5 km) data for the observation of hurricanes. First, the data set of storm observations used herein is described. Next, we explore two case study examples of circulation center location using both standard and ultra-high resolution QuikSCAT derived winds. The best visual estimates of circulation centers are determined using standard resolution and compared with estimates of hurricane eye centers in ultra-high resolution wind speed images. The performance of storm center location using each resolution is then described and error statistics presented. National Hurricane Center (NHC) "best-track" storm paths for the hurricanes of interest are employed as a reference. Discrepancies in perceived storm locations are noted. Finally, conclusions are provided.

II. Circulation Center Comparison

A. Data Set

This comparison utilizes QuikSCAT passes observing selected storms for all hurricane seasons over the life of the mission—1999 through 2005. In total, 19 storms are compared ranging from Category 1 through Category 5 on the Saffir-Simpson Hurricane Scale. The chosen storms are summarized in Table I. *Cat* refers to the maximum Saffir-Simpson category attained by the storm. *Pass* dates and totals refer to observations by QuikSCAT. A total of 285 QuikSCAT observations are used, although not all provide a discernible circulation center because of occlusion by land, an insufficiently developed storm, or poor QuikSCAT coverage.

Truth data for circulation centers are derived from the NHC's "best track" positions. These subjectively smoothed representations of tropical cyclones' locations and intensities are produced in six hour intervals. They are based on post storm analysis of all available data. For more useful comparison, we interpolate the six hour "best track" positions using a parametric spline method to QuikSCAT observation times.

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TABLE I

QUIKSCAT OBSERVED STORM SUMMARIES.

Name	Cat	First Pass (Julian Day)	Last Pass (Julian Day)	Total Passes
Bret	4	8/8/99 (230)	8/22/99 (234)	8
Dennis	2	8/26/99 (236)	9/4/99 (247)	23
Floyd	4	9/7/99 (250)	9/16/99 (259)	16
Gert	4	9/9/99 (255)	9/22/99 (265)	15
Isaac	4	9/22/00 (266)	9/30/00 (274)	16
Michelle	4	10/29/01 (302)	11/6/01 (310)	13
Lili	4	9/20/02 (263)	10/3/02 (276)	17
Fabian	4	8/26/03 (238)	9/7/03 (250)	19
Isabel	5	9/5/03 (248)	9/18/03 (261)	23
Juan	2	9/24/03 (267)	9/29/03 (272)	11
Frances	4	8/25/04 (238)	9/5/04 (249)	16
Ivan	5	9/1/04 (245)	9/15/04 (259)	18
Jeanne	3	9/14/04 (258)	9/26/04 (270)	19
Dennis	4	7/4/05 (185)	7/10/05 (191)	8
Emily	4	7/11/05 (192)	7/20/05 (201)	11
Katrina	5	8/24/05 (236)	8/29/05 (241)	9
Ophelia	1	9/6/05 (249)	9/17/05 (260)	19
Rita	5	9/18/05 (261)	9/24/05 (267)	10
Wilma	5	10/15/05 (288)	10/24/05 (297)	14

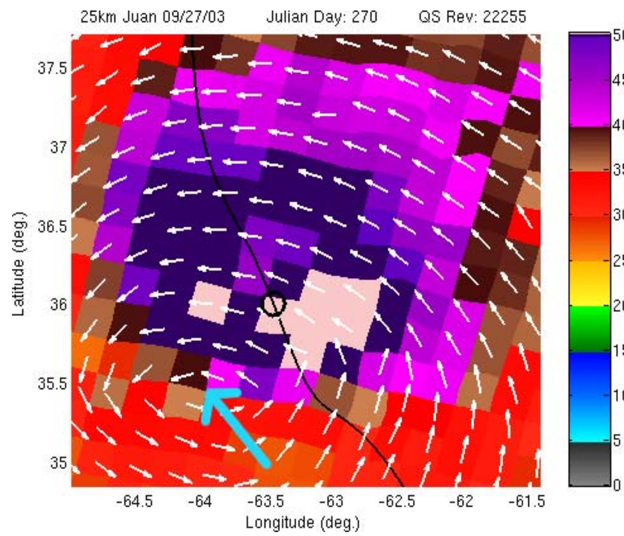

Fig. 1. QuikSCAT standard resolution observation of Hurricane Juan on September 27, 2003. Background color indicates wind speed in knots. Small white arrows indicate wind direction. Black curve running through the image shows NHC "best track". Black circle on curve indicates interpolated "best track" location at QuikSCAT observation time. Large blue arrow indicates selected circulation center location. Difference in selected circulation center and "best-track" location is 84.8 km.

B. Location Method

Determination of circulation center positions from QuikSCAT winds is done subjectively by observation of the wind speed field at each resolution with the standard-product (L2B) wind direction field overlaid. Resolution enhanced wind directions are noisier than standard resolution wind directions. For this reason, we overlay standard resolution direction vectors onto both the 25 km and the 2.5 km wind speed field.

The relative degrees to which the speed and direction fields are utilized in center determination for this comparison vary. At 25 km, we primarily utilize the direction field to locate the circulation center directly. This is complicated, however, because QuikSCAT's sensitivity to rain frequently causes a characteristic pinning of the wind direction field toward the cross-track for severe storms. In such cases, we derive the circulation center from the speed field alone. The additional detail evident in the ultra-high resolution speed field warrants its increased emphasis in storm center determination for 2.5 km images. To determine the circulation center using ultra-high resolution images, we identify the wind speed contrast between the high wind speed eyewall and the relatively calm center.

C. Standard Resolution Examples

In order to determine the circulation center of tropical cyclones using 25 km winds, we plot the standard product (L2B) direction field (small white arrows) overlaid onto the standard resolution speed field as in Figure 1. This figure additionally shows a spline interpolation of the NHC "best track" (black curve) and the "best track" position interpolated to QuikSCAT observation time (black circle). When estimating circulation centers, the "best-track" information is not included. It is plotted here for illustrative purposes. The circulation center location according to the QuikSCAT direction vectors (large blue arrow) is delineated. Represented in Figure 1 is a view from the QuikSCAT standard L2B product of the circulation center of Hurricane Juan, a Category 2 (maximum) hurricane, on September 27, 2003. In this case, a circulation center is clearly evident within the QuikSCAT wind *direction* vectors. The error between the selected circulation center and the interpolated "best-track" position is approximately 84.8 km.

QuikSCAT is known to be sensitive to rain. Frequently, rain within the measurement swath causes a characteristic bias of the derived wind directions toward the cross-track. As illustrated in Figure 2, a rain-caused cross-track pinning of wind direction combined with the lower resolution speed field leads to difficulty in confidently locating the circulation center of a rain affected storm. This figure shows the standard resolution QuikSCAT observation of Hurricane Michelle, a Category 4 (maximum) storm, on November 2, 2001. The selected storm center location is again denoted with a large blue arrow. Because of the absence of a discernible vortex in the QuikSCAT direction vectors, the location of this storm center is obtained by roughly identifying the middle of the high wind speed region. There is subjectively greater uncertainty in estimating the circulation center via the standard resolution speed

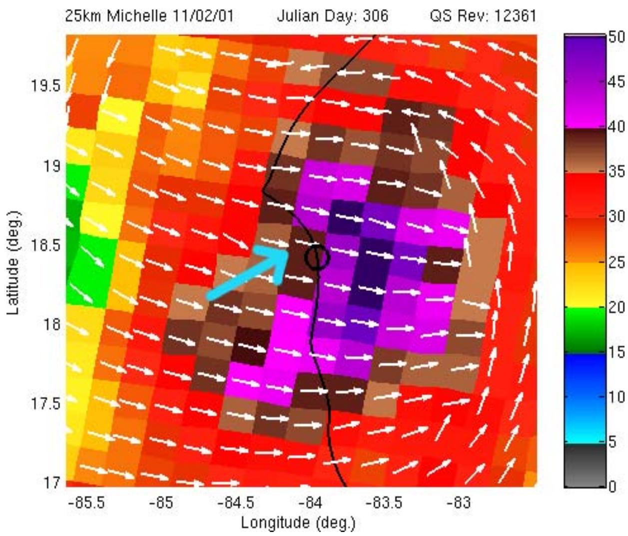

Fig. 2. QuikSCAT standard resolution observation of Hurricane Michelle on November 2, 2001. Plotted as in Figure 1. Difference in selected storm center and "best-track" positions is 21.4 km.

field alone, and the distance to "best-track" error in this case is 21.4 km.

D. Ultra-High Resolution Examples

This section observes the same cases as above, but uses the resolution enhanced wind speed field. To determine the circulation center of tropical cyclones using ultra-high resolution data, we follow a similar procedure to the standard resolution cases substituting the 2.5 km speed field for the 25 km speed field. For reference, we plot standard product direction vectors. Figure 3 shows the same QuikSCAT observation as in Figure 1, but viewed with the resolution-enhanced wind speed field.

Additional storm structure is immediately apparent in this figure. Outer rain bands are clearer, and there is greater wind speed contrast in the eye wall region. The lower wind speed eye is evident. In this case, the circulation center location is estimated to be the center of the low wind speed area (large blue arrow). This selection nearly co-locates with the interpolated "best-track" location (black circle). The error between the storm center selection and "best-track" is 2.1 km.

Because of the primary reliance on wind speed, hurricane circulation center location in rain contaminated cases using resolution enhanced winds does not suffer to the same degree from rain-induced wind direction as do standard resolution wind images. As illustrated in Figure 4, the additional storm structure provided by ultra-high resolution wind data enables accurate location of the circulation center even in the absence of meaningful direction data. This image corresponds to the standard resolution observation in Figure 2. The distance from

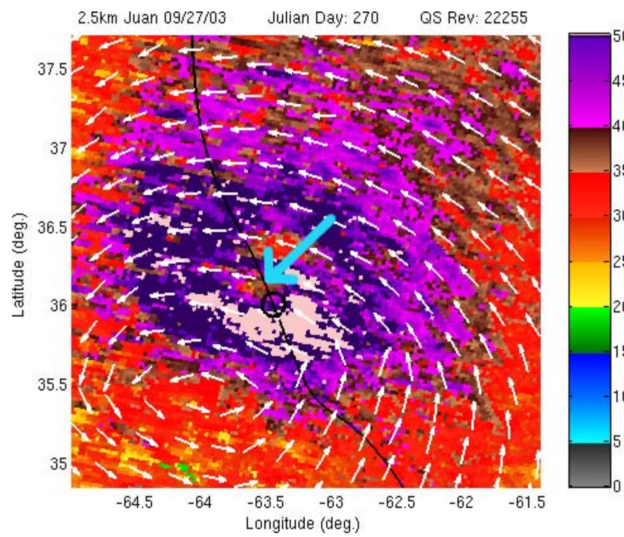

Fig. 3. QuikSCAT ultra-high resolution observation of Hurricane Juan on September 27, 2003. Background color indicates resolution enhanced wind speed in knots. Small white arrows indicate wind direction. Black curve running through the image shows NHC "best track". Black circle on curve indicates interpolated "best track" location at QuikSCAT observation time. Large blue arrow indicates selected circulation center location. Difference in selected circulation center and "best-track" location is 2.1 km.

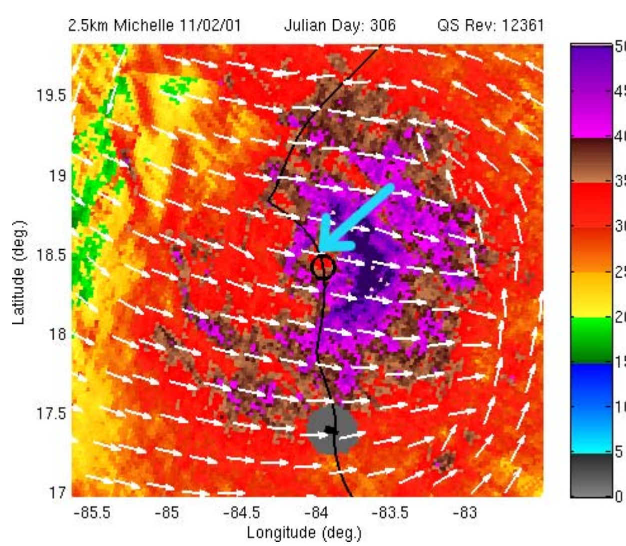

Fig. 4. QuikSCAT ultra-high resolution observation of Hurricane Michelle on November 2, 2001. Plotted as in Figure 3. Difference in selected storm center and "best-track" positions is 6.2 km.

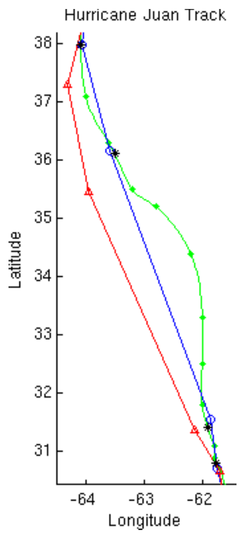

Fig. 5. Plot of partial track in latitude and longitude for Hurricane Juan in 2003. Red triangles indicate circulation center determined using standard resolution wind images. Blue circles indicate circulation center locations using resolution enhanced wind images. Green curve is spline interpolated "best-track". Black asterisks indicate "best-track" interpolated to QuikSCAT observation times.

estimated circulation center to interpolated "best-track" position is 6.2 km.

E. Performance and Conclusions

This section compares the performance of circulation center locations using standard and resolution enhanced QuikSCAT wind images. Center location using ultra-high resolution wind images is generally more accurate and is achieved with subjectively higher confidence. Figure 5 shows a sample track in latitude and longitude for Hurricane Juan in 2003. The center positions of the ultra-high resolution derived track (blue circles) are much closer to the NHC "best-track" (green curve and black asterisks) than the standard resolution derived curve (red triangles). This is, in general, true for other storms as well.

Histograms of the distance to "best-track" (error) for standard resolution and ultra-high resolution derived circulation center locations of storms listed in Table I are shown in Figures 6 and 7 respectively. Within this comparison, there are 153 standard resolution QuikSCAT observations in which the circulation center is discernible. The center is discernible in 182 resolution enhanced images. The ultra-high resolution derived center locations exhibit lower median, mean and standard deviation of error. These statistics for each resolution are given in Table edII.

Positions obtained with ultra-high resolution images are significantly closer to the best-track locations than those obtained with standard 25 km winds. The 2.5 km storm images also reveal, to a greater extent, storm characterization details and features of interest, and do so for a greater number of observations. Resolution enhanced QuikSCAT wind data are thus a useful tool for tropical cyclone observation.

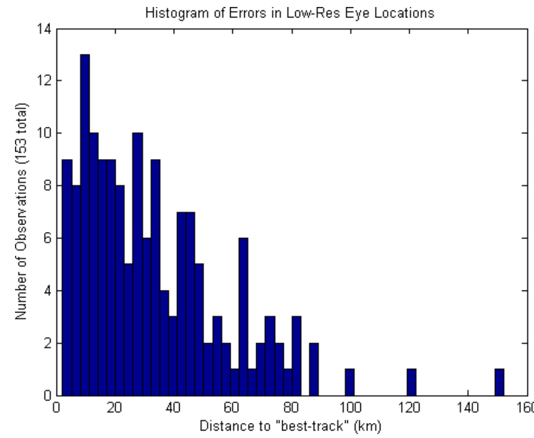

Fig. 6. Histogram of distance to "best-track" (error) for standard resolution derived circulation center locations.

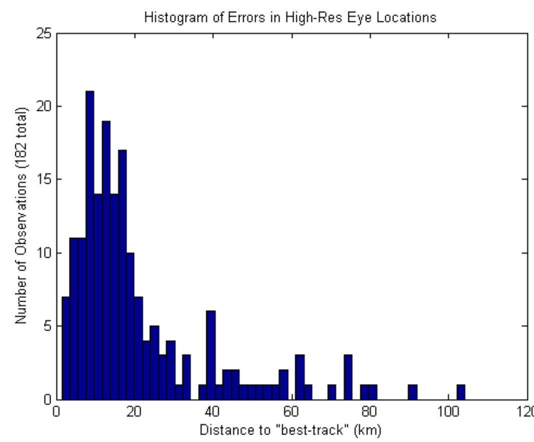

Fig. 7. Histogram of distance to "best-track" (error) for ultra-high resolution derived circulation center locations.

REFERENCES

[1] D.G. Long, "High Resolution Wind Retrieval from SeaWinds," *Proceedings of the International Geoscience and Remote Sensing Symposium*, pp. 2187-2189, Sydney, Australia, 9-13 July 2001.

[2] K.B. Katsaros, P.W. Vachon, W.T. Lio, and P.G. Black, "Microwave remote sensing of tropical cyclones from space," *J. of Oceanography*, vol. 58, pp. 137–151, 2002.

TABLE II

DISTANCE TO "BEST-TRACK" STATISTICS

Resolution	Standard	Ultra-high
Mean Error	33.3 km	21.2 km
Median Error	28.5 km	15.0 km
Error Standard Deviation	25.3 km	18.9 km