Improved Real-Time Hurricane Ocean Vector Winds from QuikSCAT

Task-1 Deliverable: *Final Progress Report*

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Proposal Abstract

Satellite microwave scatterometer data, in particular, near-real time, ocean vector wind (OVW) measurements from the QuikSCAT were being used by the Tropical Prediction Center, (TPC), in the analysis of intensity and track of Atlantic and Caribbean hurricanes. Unfortunately, the quality of available OVW's from SeaWinds is severely compromised for extreme wind events because of both high wind speed saturation and associated precipitation contamination in tropical cyclones (TC's).

Under research sponsored by the NASA OVW science team, the Central Florida Remote Sensing Laboratory (CFRSL) has developed an innovative active/passive ocean vector wind retrieval algorithm *(Q-Winds)* that adjusts for rain effects and provides an improved geophysical model function (XW-GMF, based upon actual QuikSCAT hurricane observations with associated ground truth from aircraft underflights) to compensate for the effects of wind saturation. This proposal is to make this capability, to estimate wind vector in tropical cyclones from QuikSCAT measurements, available to improve hurricane guidance products produced at the Joint Center for Satellite Data Assimilation. Specifically, this proposal addresses the JHT program priority: "(TPC-12 (JTWC-12)) Improved utility of microwave satellite and radar data in tropical cyclone analysis" to aid hurricane forecasting and warnings produced at the TPC.

Under this JHT project, we propose to utilize the Ocean Surface Winds Team (OSWT) at the NESDIS Center for Satellite Applications and Research (STAR) office, who has developed a unique system for transitioning satellite OVW measurements from research to operations. Our team will provide a new QuikSCAT hurricane wind product for forecast guidance. It will use existing software utilities to transform the *Q-Winds* vector wind output to existing NRT QuikSCAT data products in the BUFR format, Merged Geophysical Data Record, the so called MGDR Lite, which is presently being used by forecasters at TPC/NHC and JTWC.

A 2-year development was proposed. In the first year, the operational software will be developed and ported to the NOAA computers for testing during the 2009 hurricane season. In the second year the *Q-Winds* hurricane product will be validated using the 2009 data and demonstrated as a prototype operational ocean vector wind product for the TPC/NHC and JTWC centers during the 2010 season. **Unfortunately the QuikSCAT instrument failed after approximately 5 months into year-1; therefore this project was not continued into year-2.**

Project Status/Summary

This project started in the middle of the 2009 Hurricane Season on August 1, 2009. Our first task was to contact our CoI Dr. Paul Chang at the NOAA NESDIS Ocean Surface Winds Team (OSWT) to make arrangements to receive the QuikSCAT near real-time (NRT) Merged Geophysical Data Record, MGDR Lite. Since CFRSL had no previous experience in processing these data, this was an important first step for this project.

The development of a suitable file reader in MatLab progressed reasonably well and after a few weeks of trails and errors, with the assistance of the OSWT, we were fully successful in understanding, opening the records, and extracting the required parameters. We used the MGDR files and the SeaWinds standard 12.5 km resolution level-2A (L2A-12) and level-2B (L2B-12) products to compare the radar backscatter (σ^0), QuikSCAT radiometer (QRad) brightness temperature (Tb), and OVW retrievals on a rev-by-rev basis to realize similarities and differences between these two data sets. Fortunately, there were no big surprises and as a result we were able to modify our *Q-Winds* MatLab codes to run the MGDR data. We performed numerous tests on our code under non-hurricane conditions and verified that the ocean vector retrieval comparisons between *Q-Winds*, QuikSCAT L2B and MGDR were all within acceptable levels of statistical uncertainty.

The first surprise came when we learned that the MGDR data were not archived for hurricane cases. We had assumed that QuikSCAT hurricane observations in 2009 or previous years, where there were Hurricane Research Division (HRD) aircraft underflights, could be used to validate our *Q-Winds* OVW retrievals. Since this was not the case, it was not possible to compare the differences between MGDR and Q-Winds with the surface truth provided by the HDR H*Wind hurricane surface wind field analysis. While this was disappointing, it was not crucial to our project success; and we implemented an archive of the NRT MGDR data for testing. We did capture passes over three hurricanes, and we have devoted significant effort in testing and analysis that will be described in greater details in this report.

In late November, a hardware failure in the SeaWinds antenna spin motor terminated data collection on QuikSCAT. This unfortunate event is a fatal-blow to our JHT project, which will prevent the achievement our primary project objective to provide improved NRT hurricane observations from QuikSCAT. Nevertheless, we believe that the results achieved thus far and the future reanalysis of archived MGDR data can provide valuable benefit to planned follow-on NOAA/NASA scatterometer program.

Work Accomplished

The main objective of the first year of the project is to provide an improved near real-time (NRT) wind speed retrieval algorithm in extreme wind events. As described in the proposal abstract, most of this algorithm (*Q-Winds*) was developed previously under the NASA Ocean Vector Winds Science team funding. The *Q-Winds* algorithm was especially focused to improve the OVW retrievals in extreme tropical and extra-tropical cyclone wind events [1]. Moreover, NRT processing involves a significant analyst intervention in the form of automatically locating a given storm and its center of rotation; however, for non-real-time science applications, we used the NHC “best-track” analysis for this purpose.

1. X-Winds Algorithm

Several new algorithm modules were incorporated to Q-Winds to automatically search the QuikSCAT data for extreme wind events and to initiate data processing. This extended algorithm of Q-Winds, known as “X-Winds”, is presented by a top-level block diagram as shown in Fig. 1. The shaded blocks are the new modules specially developed to achieve NRT processing capability.

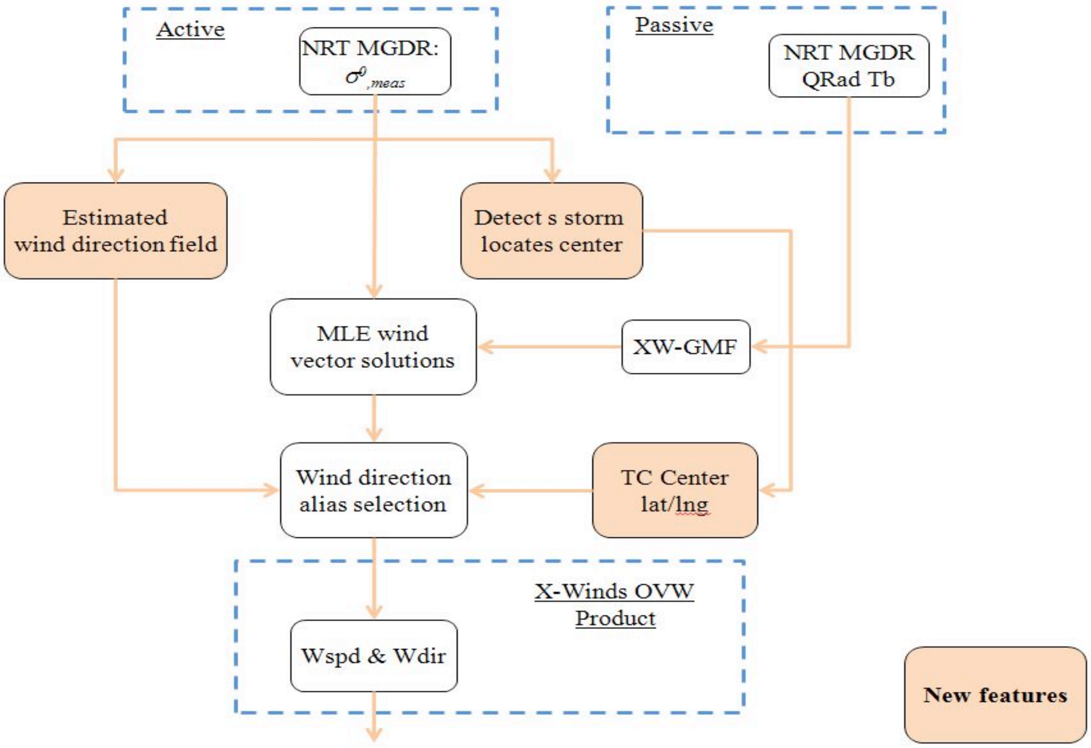


Fig. 1: X-Winds algorithm block diagram.

The new features added to the X-Winds algorithm are summarized in table 1:

Table-1 New Features for the X-Winds Algorithm

Feature	Description
• Storm Detection	- Detects storm(s) by locating cluster(s) of high σ^0
• Eye Location	- Locates centroid by σ^0 gradient differences
• Initial Wind Direction Field	- Initialization of wind direction
• Rain correction	- Compensation for rain effects

1.1 Storm Detection and Eye Location

The first module, Storm Detection/Center Location, identifies a TC by searching for a cluster of relatively high normalized radar backscatter measurements (σ^0) within ±45° latitude. A predetermined backscatter threshold was set to declare a "cluster of high backscatter" as a storm (-15 dB corresponding to ~20 m/s). This threshold was evaluated from L2A radar backscatters and H*Wind hurricane force-wind level from previous years.

Once a storm is detected, the "Eye Location" algorithm is initiated to compute an optimized weighted centroid that minimizes the sum of the distances between each cluster point and the storm center through an iterative procedure.

This processing module has been tested with reasonable success, and in Fig. 2 an example of the estimated storm center and NHC hurricane "best-track" for Super Typhoon Melor is shown. Note that since NHC best-tracks are available for every six hours, the location error may be magnified due to time differences between the QuikSCAT pass and the best-track fix.

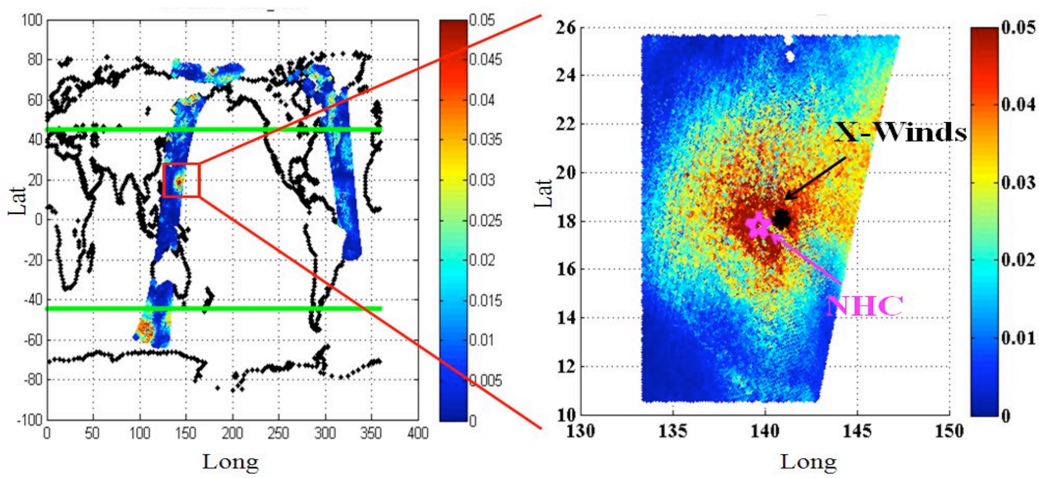


Fig. 2: Storm detection & center location.

1.2 Nudging Wind Direction

After the storm center is identified, an initial wind direction field is estimated in a two-step procedure. First, we locate the near-zero, minima, and maxima regions of the contrast (difference between forward and aft looks) of the backscatter field as shown in Fig.3, where the color denotes the magnitude of the backscatter difference. Near-zero difference (white) regions are produced by the relative wind direction (χ) of 45°, 135°, 225°, or 315°; maxima (dark red) are from χ of 0° or 180°; and minima (dark blue) are from χ of 90° or 270°.

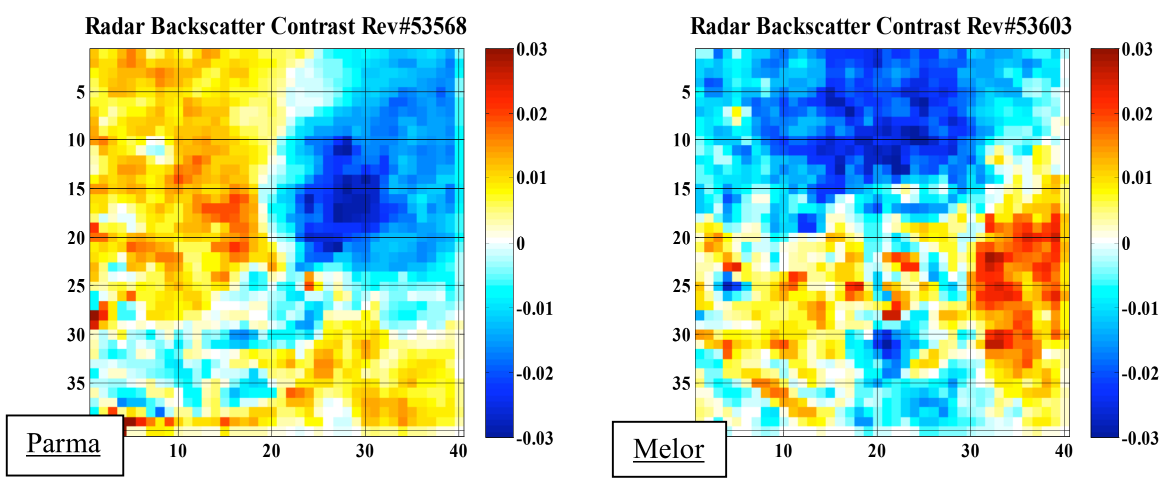


Fig. 3: Radar backscatter contrast.

The result from the first step provides a set of possible wind direction candidates. The second step is to remove the ambiguous wind directions by comparing their locations to the counter-clockwise rotation about the previous estimated storm center; this wind direction field becomes the "initial direction field" and later serves as a powerful tool in ambiguity selection algorithm. Note that these wind directions can be estimated without performing the conventional MLE retrieval. On average, approximately 30% of the wind directions could be estimated in this process.

Figure 4 shows initial wind directions (red arrows) compared to the final decimated (plot once for every two pixels) retrieved wind directions (black arrows) for two TC's. The initial wind directions can provide a reasonable guidance in the final wind direction alias selection.

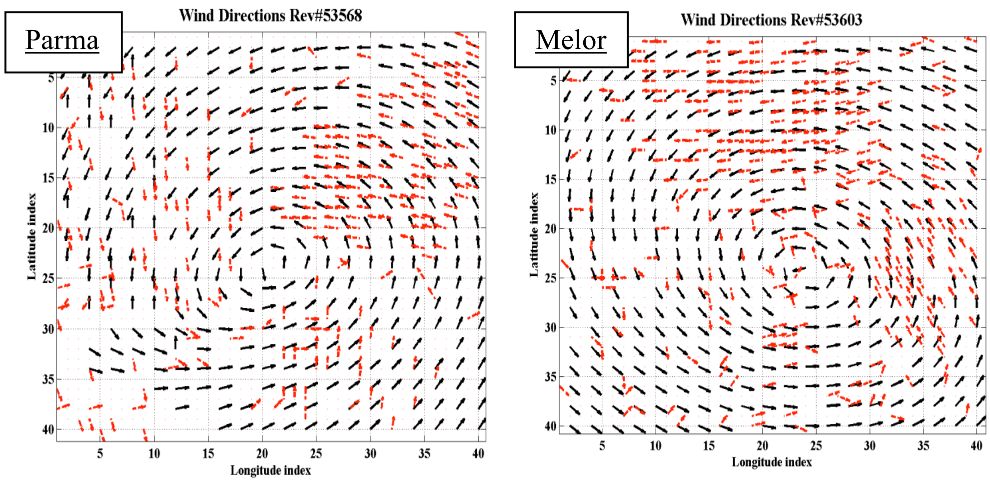
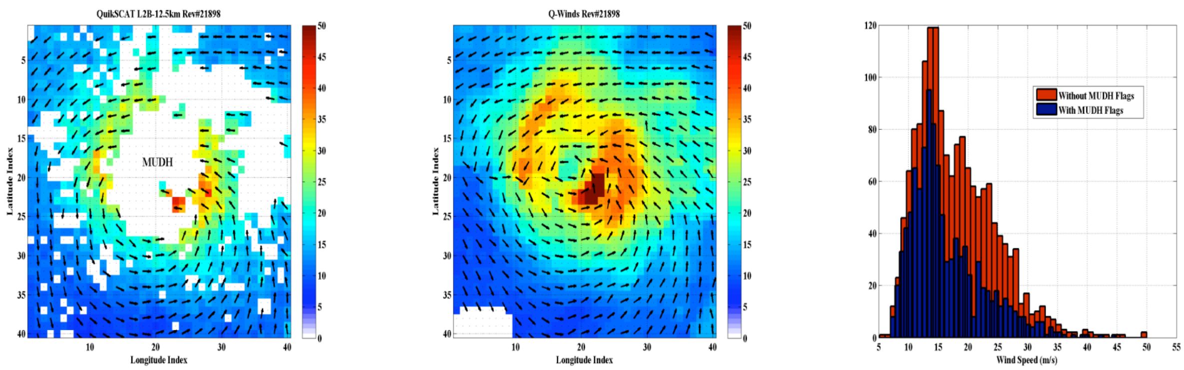


Fig. 4: Initial and retrieved wind directions comparisons.

1.3 Rain Contamination Correction

The present QuikSCAT NRT MGDR uses the SeaWinds wind vector retrieval algorithm that uses the multi-dimensional histogram (MUDH) rain flags to identify vectors with probable rain contamination. Unfortunately, for hurricanes, this results in the majority of high wind speeds being flagged (see Fig. 5a). To mitigate this problem, *Q-Winds* (X-Winds) incorporates rain correction through an additional measured parameter (QRad brightness temperature). This Tb parameter is incorporated into a new XW-GMF that is tuned for extreme wind events and rain. The use of XW-GMF in the *Q-Winds* retrieval algorithm significantly compensates for rain effects and results in higher wind speed retrievals. For comparison, the SeaWinds L2B-12 and *Q-Winds* wind fields for Hurricane Fabian in 2003 are shown in Figs. 5a & b, respectively, where colors indicates wind speeds in m/s. The *Q-Winds* results in significantly improved retrievals as indicated quantitatively in the wind speeds distributions for these two products (Q-Winds in red and L2B-12 in blue) as shown in Fig. 5c.



a) b) c)

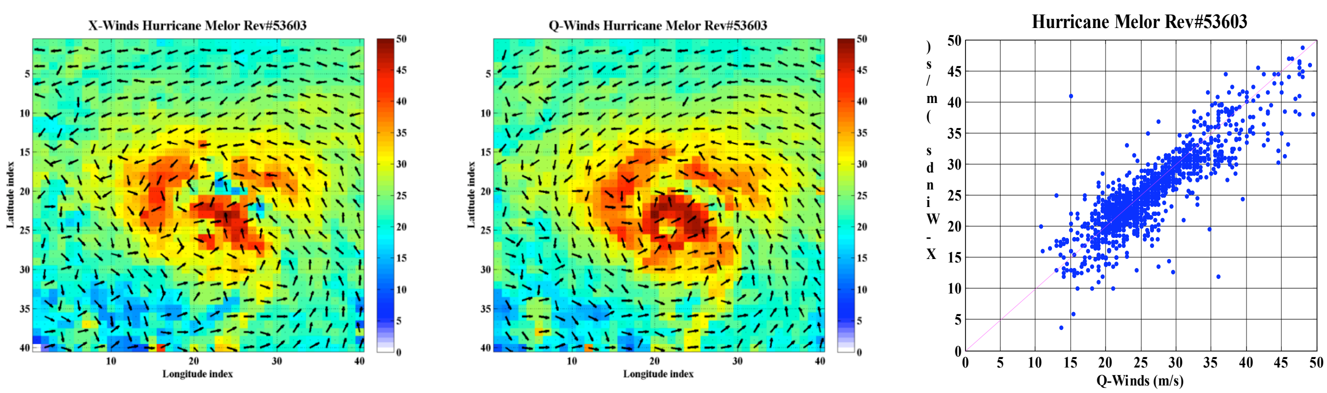
Fig. 5: Rain flags comparison: a) L2B-12 & MUDH, b) Q-Winds, c) Wind Speed Distribution.

2. Results

2.1 X-Winds Validation

To validate the performance of X-Winds, the retrieved wind speeds are compared with the Q-Winds as the assumed surface truth. An example of the decimated (plotted once every two pixels) wind field of Hurricane Melor is presented in Fig. 6 for the QuikSCAT Rev#53603. Each panel represents a hurricane image in a 5° x 5° analysis window with the hurricane eye (based upon the NHC best track location) centered at coordinates (20, 20).

Figure 6 (a, b) shows wind speeds presented in the same color scale that ranges from 0 to 50 m/s, the arrows are the decimated flow directions. Both wind fields are highly correlated, although X-Winds is less spatially homogenous than Q-Winds. The scatter plot (in panel c) demonstrates the agreement between the X-Winds and Q-Winds retrieved wind speeds in all wind speed ranges along the perfect agreement line. This validation was necessary to us to make sure that the developed X-Winds algorithm for NRT applications is comparable to the assumed surface truth.



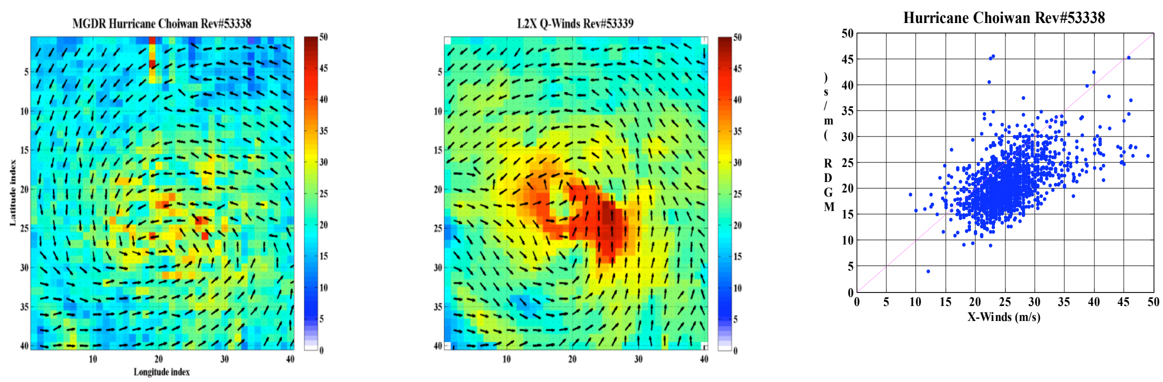
a) b) c)

Fig. 6: Hurricane Melor comparisons. a) X-Winds, b) Q-Winds, c) wind speeds scatter plot.

2.2 X-Winds versus MGDR

The *Q-Winds* and SeaWinds L2B-12 OVW products has been evaluated in hurricanes by comparison with HRD H*Wind surface wind analyses derived from near simultaneous aircraft surveillance flights [1]. Both wind speeds agree well up to ~20 m/s, however, *Q-Winds* retrieves higher wind speeds than L2B-12 OVW, which saturates at ~30 - 35 m/s. Similar results are expected when comparing X-Winds with MGDR.

Three tropical cyclones in 2009 were used to compare X-Winds performance with NRT MGDR: Super Typhoon Choi Wan, Super Typhoon Melor, and Typhoon Parma. An example for Super Typhoon Choi Wan is given in Fig. 7 (a, and b) that shows the MGDR and X-Winds retrieved wind fields respectively, where colors indicates wind speeds in m/s up to 50 m/s (dark red). Fig. 7 (panel c) shows the wind speed scatter plot with MGDR wind speeds on the y-axis and X-Winds wind speeds on the x-axis. These comparisons illustrate that X-Winds retrieves higher wind speeds than the standard MGDR product, but unfortunately there are no independent surface truth available.



a) b) c)

Fig. 7: Super Typhoon Choi Wan: a) MGDR, b) X-Winds, c) wind speed scatter plot.

Summary

The main goal for the first year proposal was to develop and validate an algorithm for an improved NRT OVW retrievals based on MGDR data, especially for extreme weather events. QuikSCAT NRT & non-NRT OVW retrievals significantly underestimate hurricane peak winds due to rain contamination and backscatter saturation effects by incorporating passive QRad measurements.

The results demonstrated in this report (also presented in the IHC 2010 conference) show the work accomplished by the CFRSL to achieve the first year goal. A new NRT OVW retrieval algorithm with several *ad-hoc* modules were developed for this purpose. The results of the X-Winds retrieval algorithm are encouraging with respect to the conventional QuikSCAT OVW product. X-Winds is able to retrieve higher peak wind speeds (~10-15 m/s) than the conventional QuikSCAT MGDR wind product. CFRSL active/passive algorithm is candidate for future NOAA/NASA dual frequency scatterometry missions.

Even with the loss of QuikSCAT, we believe that there is merit in proceeding with the planned validation of the Q-Winds hurricane product for use in future NOAA/NASA scatterometer systems. However, we must shift our emphasis from near-real time QuikSCAT data processing during the next hurricane season (2010) to reanalysis of QuikSCAT hurricane observations in the 2009 and earlier seasons.

Thus, a year-2 proposal was initiated by the CFRSL to continue the work done with the following intentions:

1. *X-Winds* ocean vector wind products for QuikSCAT hurricane overpasses for the 2009 hurricane season.
2. Validation report for 2003/2004 hurricane seasons
    a. Comparisons with existing QuikSCAT L2B OVW products
    b. Comparisons with aircraft surface wind analyses (H*Wind).
3. Documented source codes for *Q-Winds* processing
4. Semi-annual progress reports for 2010
5. Presentation at IHC for 2011
6. Project final report

References

[1] P. Laupattarakasem, W. L. Jones, C. C. Hennon, J. R. Allard, A. R. Harless, and P. G. Black, "Improved hurricane ocean vector winds using SeaWinds active/passive retrievals," *IEEE Trans. Geosci. Remote Sens.*, vol. 48, pp. 2909-2923, Jul. 2010.