Improved Real-Time Hurricane Ocean Vector Winds from QuikSCAT

Task-1 Deliverable: *Semi-Annual Progress Report*

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Proposal Abstract

Currently, satellite microwave scatterometer data, in particular, near-real time, ocean vector wind (OVW) measurements from the QuikSCAT are 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 Lab (CFRSL) has developed an innovative active/passive ocean vector wind retrieval algorithm that adjusts for rain effects and provides an improved geophysical model function (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 directly addresses the JHT program priority: "(TPC-12 (JTWC-12)) Improved utility of microwave satellite and radar data in tropical cyclone analysis" to aid hurricane warning and forecasting products 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. We will process, in near real-time, all QuikSCAT hurricane passes routinely captured by NOAA/NESDIS/ORA in Suitland, MD using the improved *Q-Winds* algorithm. 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 is 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 an prototype operational ocean vector wind product for the TPC/NHC and JTWC centers during the 2010 season.

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), QRad brightness temperature (Tb) and OWV 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. Never-the-less, 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.

The following sections of this report will provide details of the progress to date and a plan for future work to complete this grant.

Developed Algorithm description (X-Winds)

The main objective of this phase 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. Moreover, this approach involved significant analyst intervention in the form of locating a given storm and its center of rotation. For non-real-time science applications, we used the NHC "best-track" analysis for this purpose; however for NRT storm processing, our objective was to automate this process.

Therefore, several new algorithm modules were required to automatically search the QuikSCAT data for extreme wind events and to initiate data processing. This extended algorithm known as "X-Winds" is best presented in Fig. 1, which is a top-level block diagram. The shaded blocks are the new functions specially developed to achieve NRT processing capability.
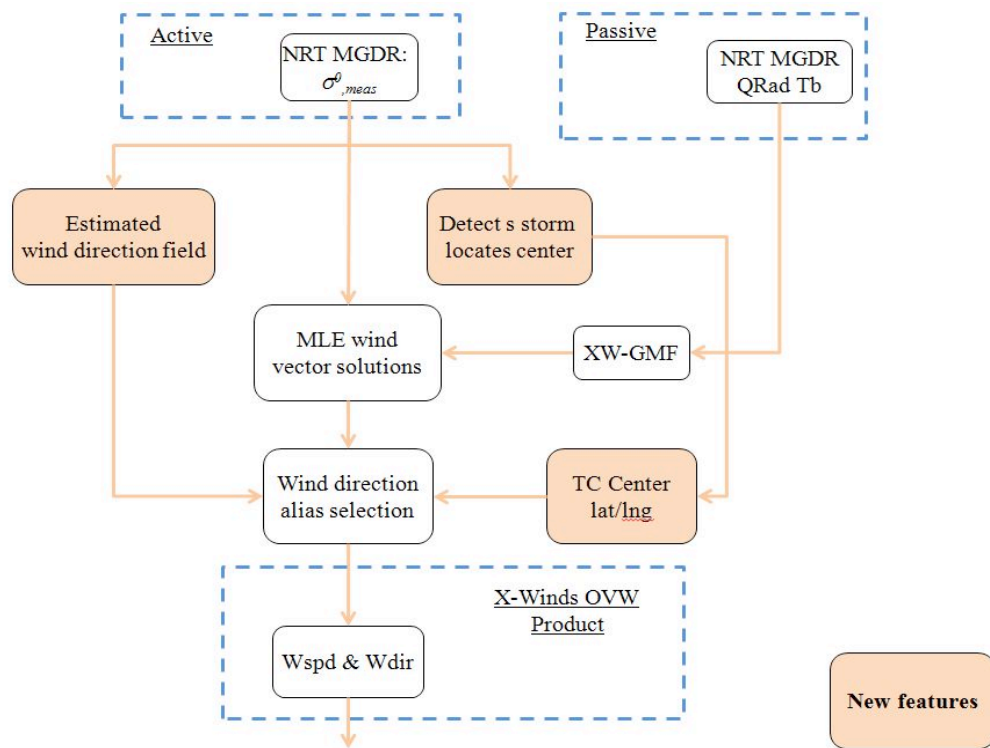

Fig. 1: X-Winds algorithm block diagram.

The new features incorporated into the "X-Winds" algorithm are summarized in table 1:

Table-1 New Features for the X-Winds Algorithm

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

Storm Detection and Storm Center Locating

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

Once a storm is detected, the "Center 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.
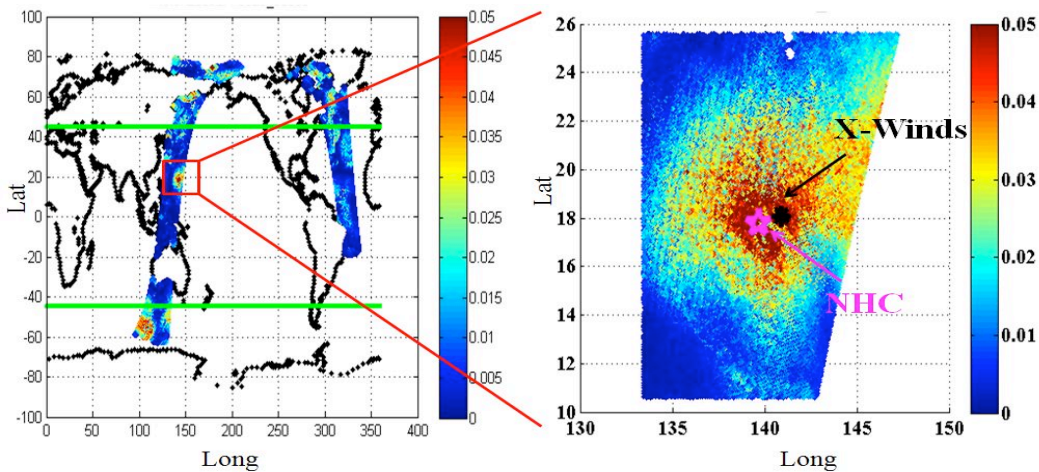

Fig. 2: Storm detection & center location.

Initial Wind Direction Estimation

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 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°.
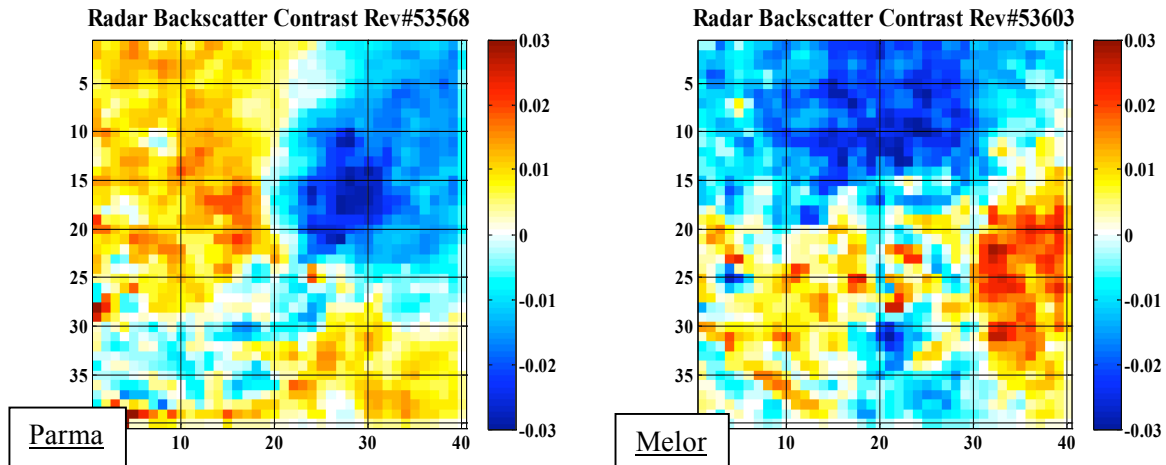

Fig. 3: Radar backscatter contrast.

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 aliases selection.
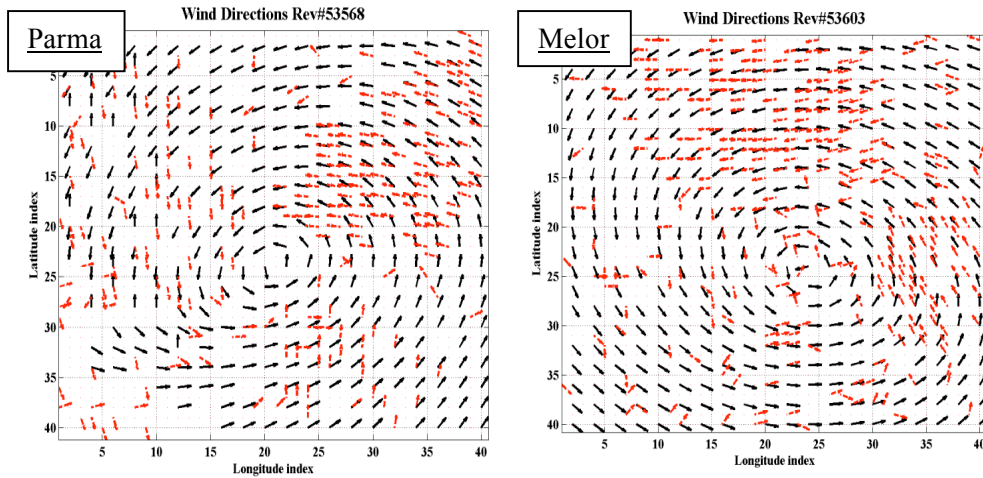
Fig. 4: Initial and retrieved wind directions comparisons.

Algorithm for Rain Correction

The present QuikSCAT NRT MGDR uses the SeaWinds wind vector retrieval algorithm that ignores the presence of rain and 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, the *Q-Winds* (X-Winds) incorporates rain correction through an additional measured parameter (QRad brightness temperature). This Tb parameter is incorporated into a new geophysical model function (known as "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.

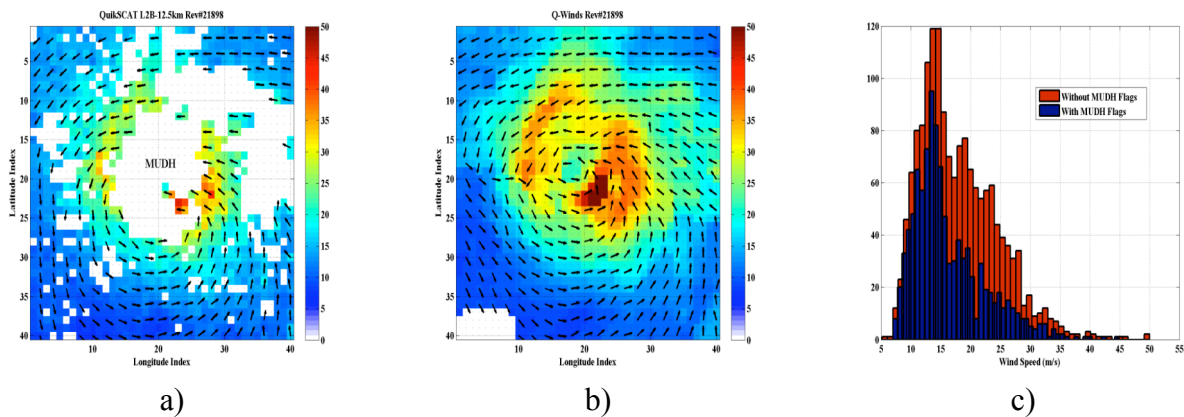a)   b)   c)

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

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* Retrieve higher wind speeds than L2B-12 OVW, which saturates at ~30 - 35 m/s. Similar results are expected when comparing X-Winds with MGDR.

2009 Hurricane Season Preliminary Results

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 Figs. 6a & b that shows the MGDR and X-Winds retrieved wind fields respectively, where colors indicates wind speeds in m/s. Fig. 6 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.
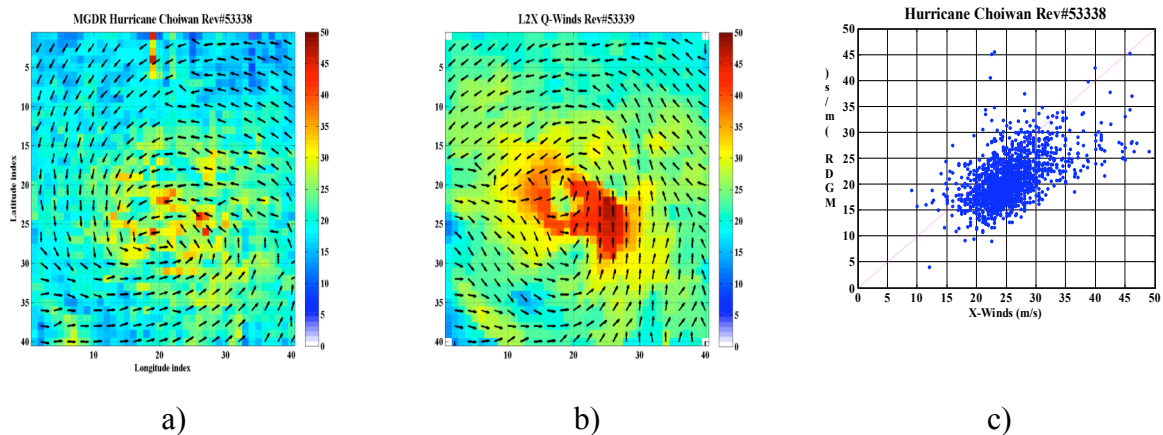

a)   b)   c)

Fig. 6: Super Typhoon Choi Wan: a) MGDR, b) X-Winds, c) wind speed scatter plot.

Future Work for Year-1

The loss of QuikSCAT prevent us from pursing the designated project objectives:
- Implementing the algorithm at the NESDIS center for Satellite Applications and Research (STAR) processing system, and
- Delivering a NRT OVW product in the 2010 hurricane season to the NHC for test and evaluation.

However, the X-Winds algorithm will be validated and compared with the MGDR for QuikSCAT hurricane observations with aircraft underflights and the corresponding HRD's H*Wind analysis. Because this requires MGDR data for the 2003 and 2004 hurricane seasons, which have not been archived, we have requested that JPL regenerate certain MGDR records. Once available, we will run the MGDR retrievals and X-Winds retrievals and perform the H*Wind evaluation.

A paper describing the new X-Winds algorithm will be presented at 64th Interdepartmental Hurricane Conference (IHC) 2010 in Savannah, Georgia, and a final project report will be provided for the documentation of this project.

References

Laupattarakasem, P., Jones W. L., Hennon, C. C. and Black, P., "Improved Hurricane Ocean Vector Winds using SeaWinds Active/Passive Retrievals", accepted for pub IEEE Trans. Geosci. Rem. Sens. 2010.