JHT Mid-term Report

(September 1, 2012 – February 28, 2013)

Improved Automation and Performance of VORTRAC Intensity Guidance

31 March 2013

Principal Investigators: Wen-Chau Lee, Earth Observing Laboratory, UCAR,
Paul Harasti, Marine Meteorology Division, NRL
Michael Bell, Department of Meteorology, UHM

Introduction:

This document gives the second year mid-term progress report on the "improved automation and performance of Vortex Objective Radar Tracking and Circulation (VORTRAC) intensity guidance" for the JHT. VORTRAC uses a series of algorithms to deduce the central pressure and radius of maximum wind (RMW) of a landfalling TC in near real time from WSR-88D Level II radar data and environmental reference pressure data from nearby coastal weather stations. VORTRAC version 1 (hereafter, it is referred as VORTRAC 1.0) was officially accepted for operation at the National Hurricane Center (NHC) in 2008 (Fig. 1). In its previous operational form, VORTRAC 1.0 required external scripts to fetch input data and user input of an initial TC position, RMW estimate, and radar selection. These additional steps made the software vulnerable to failures and inefficient operation.

The purpose of this project is to improve the real-time operational capability of VORTRAC 1.0 to automatically diagnose central surface pressure and its tendency from radar-derived wind fields at NHC as additional guidance for TC intensity change near landfall when a TC center is within the Doppler range of a coastal WSR-88D. Most aspects of the VORTRAC 1.0 operation have now been automated, and take advantage of operational data streams to form the basis of VORTRAC 2.0 software (Fig. 2). Improved VORTRAC 2.0 software performance was seen in the 2012 hurricane season, and the PIs have continued to improve several aspects of VORTRAC 2.0 in the first half of year two, which are summarized below.

Accomplishments:

The progress so far in year two can be broadly divided into two categories: 1) Continue to improve the automation and robustness of the core software and 2) continue to identify and correct points of failure through analysis of historical landfalling datasets. Wallace Hogsett, one of our previous POCs, left NHC just prior to the 2012 hurricane season. However, Jose Salazar was able to run VORTRAC 2.0 in real-time continuously during two hurricane landfalls for Isaac and Sandy. The newly upgraded automatic operation worked well, and there were no software failures during both events. A snapshot of the VORTRAC 2.0 products is shown in Fig. 3. The large, asymmetric, and baroclinic nature of Sandy precluded a good pressure retrieval, but the event was a good test of the software and automatic fetching of operational data streams. Progress results on the project were presented at the Tropical Cyclone Research Forum in March 2013.

After the 2012 season, a new operational mode was added to the VORTRAC 2.0 software. In its original form, VORTRAC 1.0 required interactive operation via a graphical user interface (GUI). With the addition of many improvements related to automatic operation, a "server" mode was implemented that allows the software to run without the GUI. This new mode paves the way for complete automation as a background application on the JHT server, and distributed display of the VORTRAC products via a web server. The new server mode also has allowed for more efficient testing of the software by running batch processing over the 12 landfall test cases.

Batch processing of historical landfalling datasets through VORTRAC 2.0 package has allowed continued analysis of possible points of failure in operations. A review of the 12 US landfalling hurricanes between 2005 and 2011 that were selected as the test cases (See Table 1) and their tracks are illustrated in Fig. 4. The examination of these VORTRAC 1.0 runs of the 12 hurricanes provided useful insights on several areas that could be improved in the VORTRAC 2.0 logic. Key improvements to the software are listed below.

1) **Improved software robustness.**

Considerable testing has led to many "under the hood" improvements that will allow VORTRAC to operate under a wider variety of conditions and radar data quality. Continued testing to identify more exceptions, such as missing or incorrect data feeds, missing or bad radar data, and different storm types has been conducted in year two.

Given the wide variety of storm shapes and sizes, VORTRAC must be able to run and handle many different types of tropical cyclones, even if an analysis is not possible. In some cases, VORTRAC 1.0 returns unreasonable and/or inconsistent results. One of the more challenging and important aspects of VORTRAC 2.0 is to objectively determine the analysis quality and provide the user with confidence intervals on the intensity guidance. Results from two case studies that illustrate progress in this area are described below.

Hurricane Dennis (2005) was observed by two WSR-88D's during landfall, which allows for a unique comparison of the pressure retrieval from two single Doppler analyses. Results from the automatic analysis in server mode are shown in Fig. 5. The top panel shows the retrieved pressure from Eglin AFB, FL (KEVX) and Mobile, AL (KMOB) compared to the NHC best track. The pressure traces compare well with the best track in the latter period of the analysis, with higher temporal variability than the 6-hourly best track but on a similar weakening trend. The Radius of Maximum Wind (RMW) shown in panel (b) also compares well throughout the analysis period.

However, the pressure traces show a clear deficiency in the early period as Dennis approaches both radars. The distance of the retrieved TC center to each radar is shown in panel (c), which indicates that a significant pressure drop occurs once the center passes 150 km Doppler range. The pressure retrieved near the edge of Doppler range meets the quality control flags in the VORTRAC 1.0 software, but is clearly too high. The discrepancy is due to the fact that although the radar is observing the broader wind field, it is not capturing the strongest winds and the corresponding pressure gradient. This example illustrates that additional diagnostics are required to ensure that the RMW is in Doppler range, not just the broader wind field. These diagnostics are being added to

VORTRAC 2.0 for the 2013 hurricane season. After Dennis' center entered the Doppler range for both radars after 18:00, the center pressure derived from both KEVX and KMOB are consistent.

Another example requiring additional diagnostics is shown in Fig. 6 from the automatic analysis of Hurricane Ophelia (2005). VORTRAC requires an initial rough estimate of the RMW in order to perform the wind retrieval. A test of the sensitivity to the initial RMW estimate is shown in Fig. 6, with the red and blue curves indicating VORTRAC 1.0 analyses using initial RMW estimates of 25 and 83 km, respectively. The 25 km estimate does not perform well, with a failure of the center finding and a high-biased pressure estimate. When using a larger RMW estimate that is more consistent with the increased size of Ophelia at landfall the pressure trace and center finding improve considerably.

If the initial RMW is reasonably close to the actual RMW then the radar algorithms can refine the estimate, but analysis errors can arise if the initial estimate is significantly off. In VORTRAC 1.0, the mechanism for providing the RMW range was through the GUI, with the user expected to input updated operational RMW estimates as they became available. VORTRAC 1.0 can key in on small-scale vortices that are not representative of the system-scale vortex when the actual RMW is too large, or potentially broad-scale wind features when the actual RMW is too small. In VORTRAC 2.0, the RMW estimate is obtained automatically from the ATCF database as part of the "tcvitals" file. While it is recognized that the operational RMW estimates can have errors, VORTRAC only requires a reasonable range for which to search for the RMW using the Doppler data. Testing has indicated that improved automatic constraints on the initial RMW estimate should help the operational intensity guidance.

While the large RMW estimate improves Ophelia's pressure retrieval and the intensity trend, the trace still contains a slight high bias. We believe this is due to the relatively close approach of the RMW to the radar. Panel (c) indicates that the center distance is near 100 km for much of the period, such that the RMW is only ~15 km away from the radar. Geometric aliasing introduces errors in the wind retrieval as the analysis radii begin to approach the radar and the axisymmetric tangential wind cannot be fully resolved. Additional diagnostics to alert the user to this possibility for large storms are being implemented.

2) **Improved radar algorithms.**

(a) The principle component analysis (PCA) method was completely automated in year 2. The method estimates the circulation center and RMW from an analysis of range- and azimuth-referenced eigenvectors derived from a PCA of the Doppler velocity data. The former semi-automated version of PCA used with Level III data at NHC in 2000-01 involved an analysis of the range eigenvector by hand while the azimuth eigenvector was analyzed automatically. It is expected that the PCA estimates of the circulation center and RMW will help VORTRAC 2.0 constrain these parameters for more robust results, particularly when the TC is near the fringe of Doppler velocity range. Tests to confirm this utility, and methods to synergistically combine PCA estimates with other estimates available to VORTRAC 2.0, are currently underway.

(b) The tropical cyclone eye tracking (TCET) algorithm has been tested to improve the overall TC center identification. TCET is a reflectivity based TC center finding algorithm and it is particularly powerful for TCs with a closed eyewall. It is anticipated that TCET will improve and stabilize the center estimates when a TC begins to enter the effective Doppler range before the Doppler velocity based TC center finding algorithms are effective. TCET has been tested on Hurricane Dolly that had an open eyewall for most of the time and posed challenges to the TCET indicated by the high frequency fluctuations in the track (red line in Fig. 7). Nevertheless, TCET shows encouraging results in providing consistent TC centers as initial guesses during her landfall.

3) **Improved HVVP environmental winds for GBVTD**

The original HVVP algorithm used by VORTRAC has been improved in a number or ways: (i) The HVVP elevation angle and range limits have been increased to increase the dispersion in the basis functions which has significantly improved the goodness of fit.

(ii) A new, organically-estimated Xt makes HVVP less dependent on empirical relations, although a new way to test the representativeness of those relations has also been developed for their inclusion in an average Xt estimate. (iii) New wind asymmetry measurement parameters have been formulated and bias-calibrated to flag HVVP results as questionable when excessive asymmetric winds occur. (iv) A new outlier reduction technique has been developed to improve robustness.

Summary and Future Work:

The project is progressing well and on schedule. Several improvements were made in year one, and a new VORTRAC 2.0 was installed at NHC. Tests of the upgraded software during Hurricane Isaac’s landfalls at Key West and New Orleans and Hurricane Sandy’s landfall in the northeast showed significant improvement over the VORTRAC 1.0 software. We completed the automatic VORTRAC 1.0 analysis for 12 historical hurricanes, and an examination of the 12 cases revealed several challenging characteristics and exceptions that caused VORTRAC 1.0 failures. Further improvements to the software in the remainder of the project will focus on analysis diagnostics, and improvements to the center tracking that take advantage of multiple radar algorithms. The VORTRAC PIs plan to visit NHC in May 2013 to discuss the progress of VORTRAC software improvements and obtain feedback from NHC POCs on their experiences in running VORTRAC 2.0 during the 2012 season. Modifications based on feedback from the NHC POCs will also be incorporated, and updated documentation will be completed. VORTRAC 2.1 will be installed at NHC before the 2013 hurricane season and the PIs will remotely monitor VORTRAC 2.1 operation during US landfalls. PIs will also visit NHC to work with POCs on one US hurricane landfall if the opportunity arises before the end of the project.

Table 1. The list of 12 hurricanes used in this study.

Year	Max. Intensity (Kts)	Hurricane
2005	110	Katrina
2005	105	Dennis
2005	105	Wilma
2005	100	Rita
2005	65	Cindy
2005	65	Ophelia
2007	80	Humberto
2008	75	Dolly
2008	90	Gustav
2008	95	Ike
2009	60	Ida
2011	75	Irene

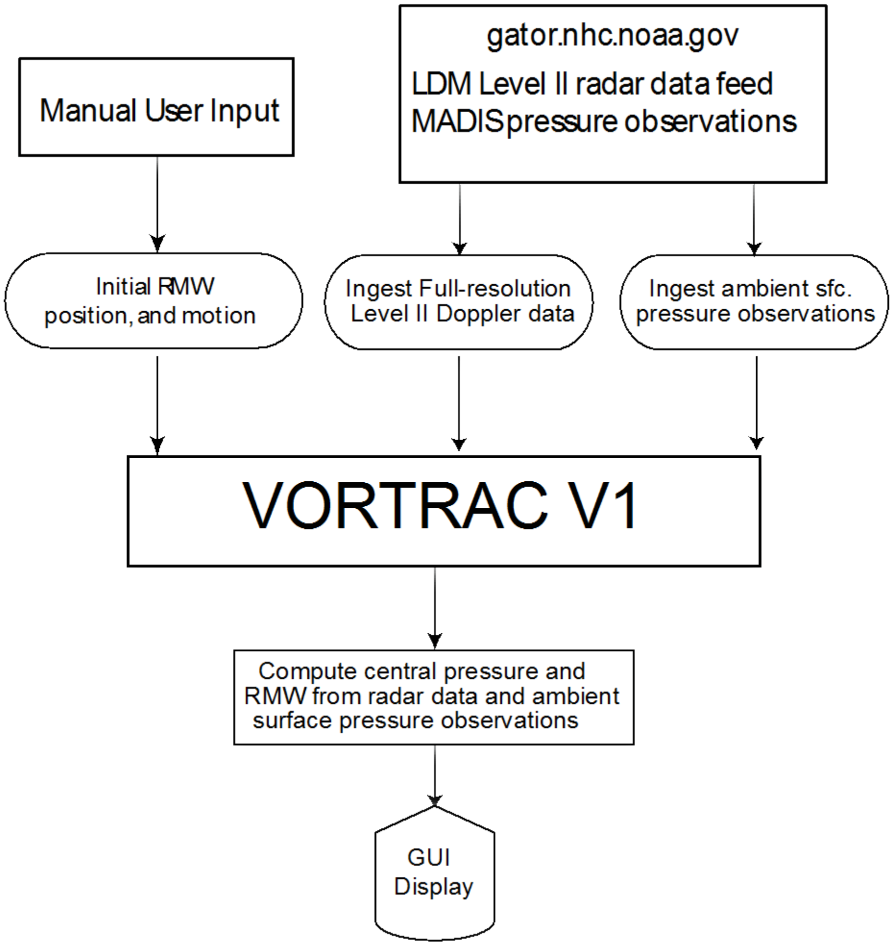

Figure 1. Software flowchart of VORTRAC version 1 installed for operational use at NHC in 2008.

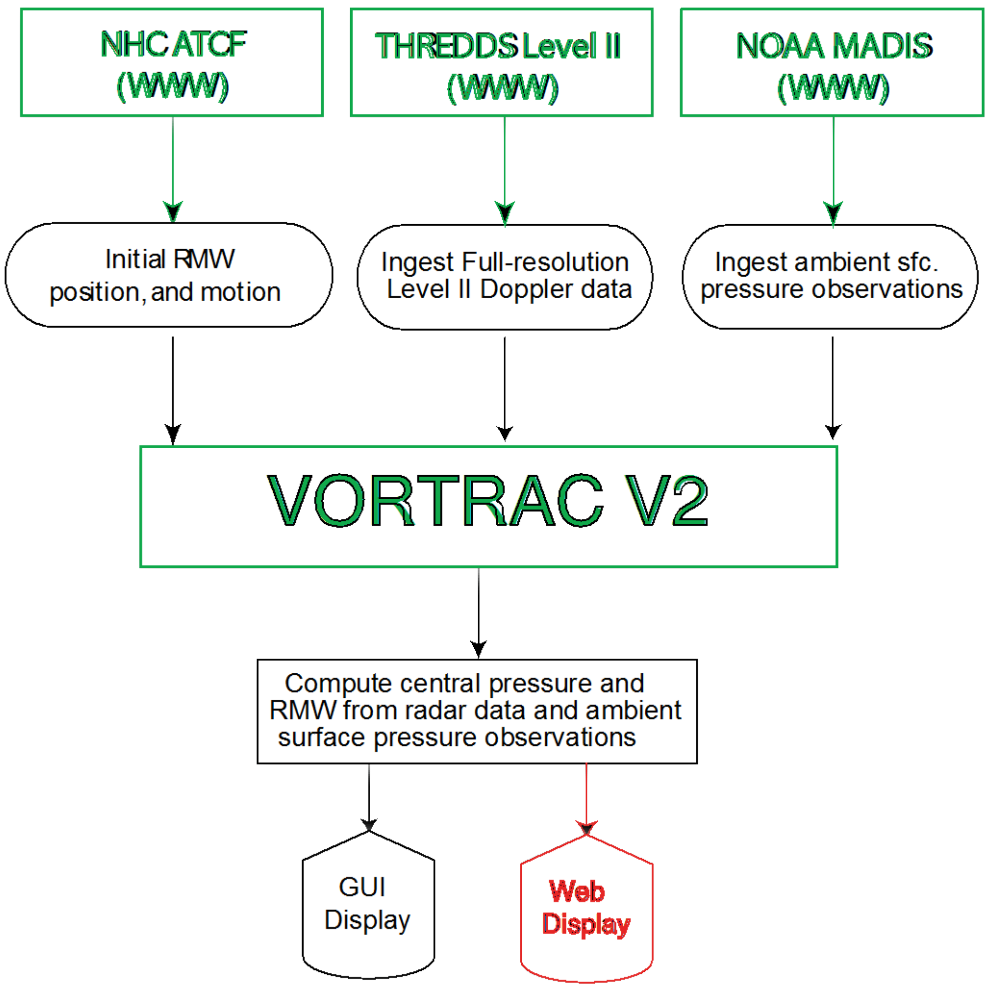

Figure 2. Software flowchart of VORTRAC version 2 installed for testing at NHC in 2012. Green items indicate working functionality, and red items indicate planned, but not fully implemented functionality.

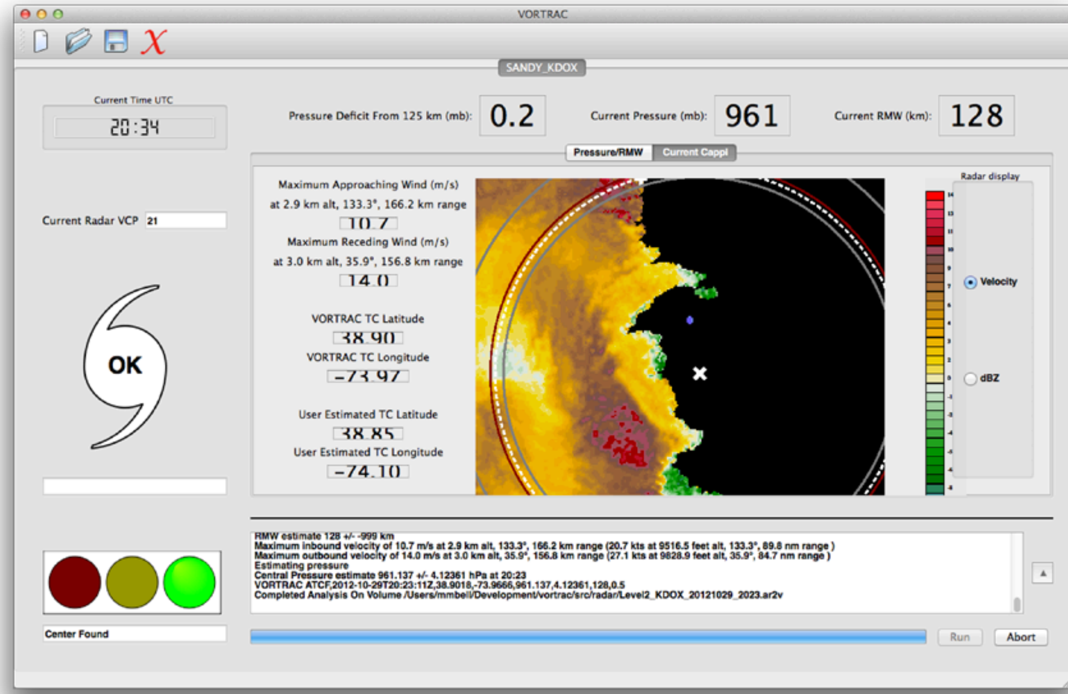

Figure 3. Screenshot from real time VORTRAC analysis of Hurricane Sandy. The precipitation field was strongly asymmetric and not conducive to pressure retrieval.

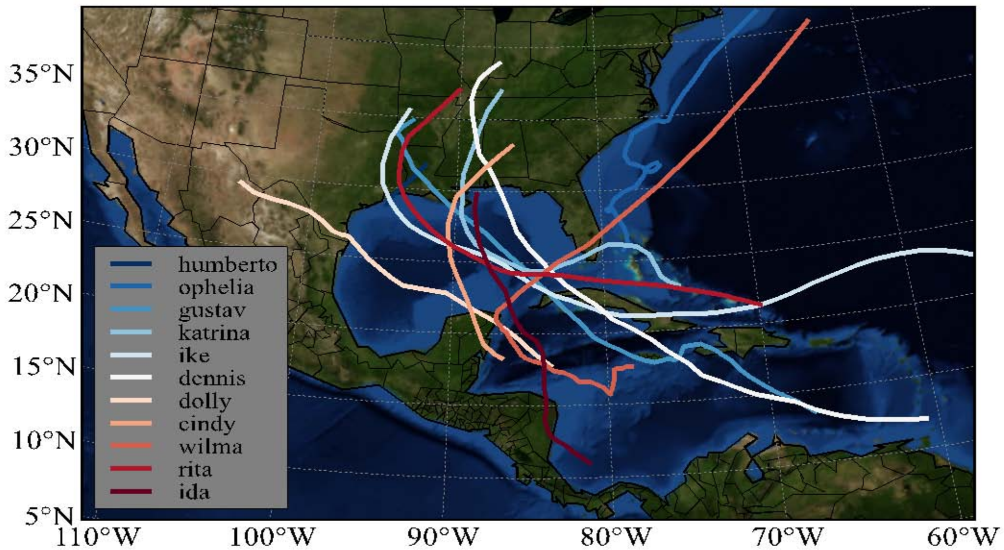

Figure 4. The best tracks of 12 hurricanes selected in this study.

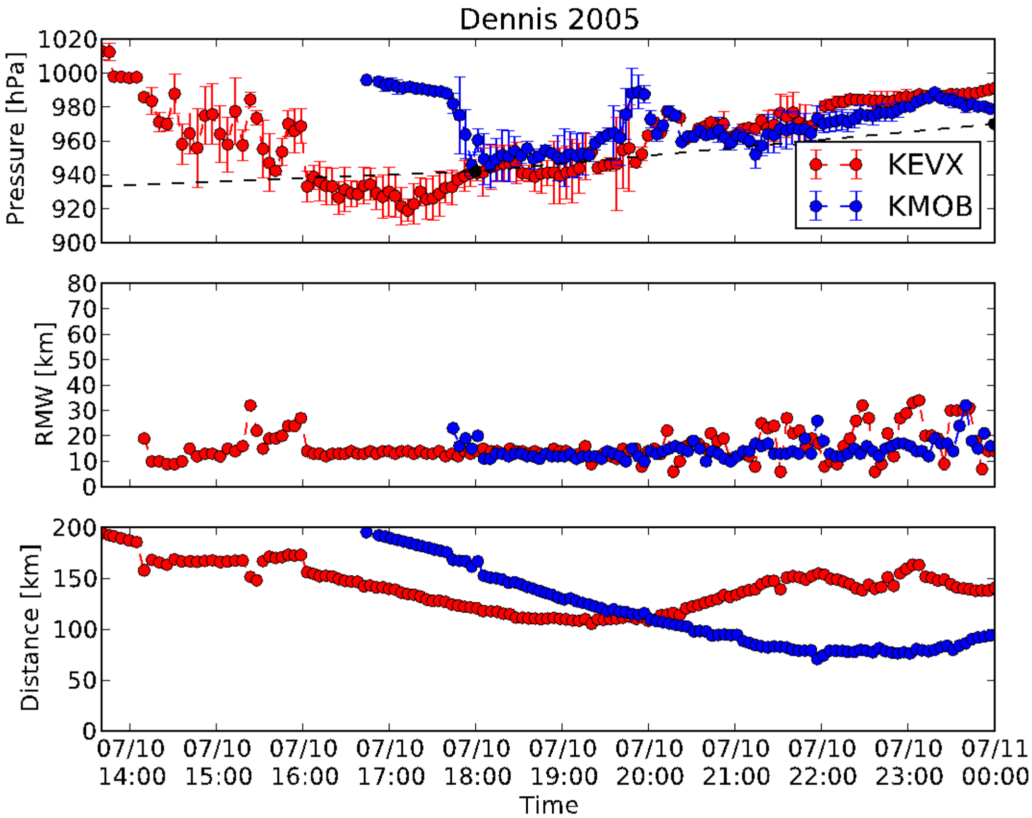

Figure 5. Automatic VORTRAC analysis of Hurricane Dennis (2005) from KEVX and KMOB radars. Panels show (a) retrieved pressure, (b), retrieved radius of maximum wind, and (c) distance of the retrieved TC center from the radar.

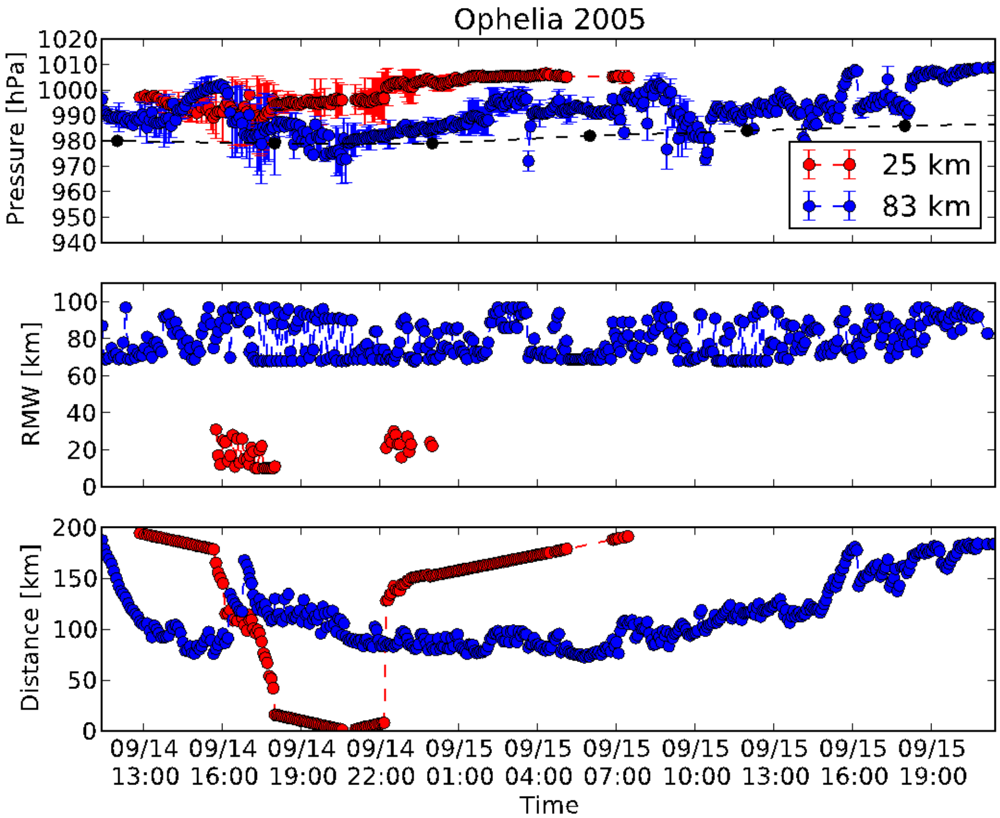

Figure 6. Automatic VORTRAC analysis of Hurricane Ophelia (2005) from KHMX radar using initial RMW estimates of 25 and 83 km. Panels show (a) retrieved pressure, (b), retrieved radius of maximum wind, and (c) distance of the retrieved TC center from the radar.

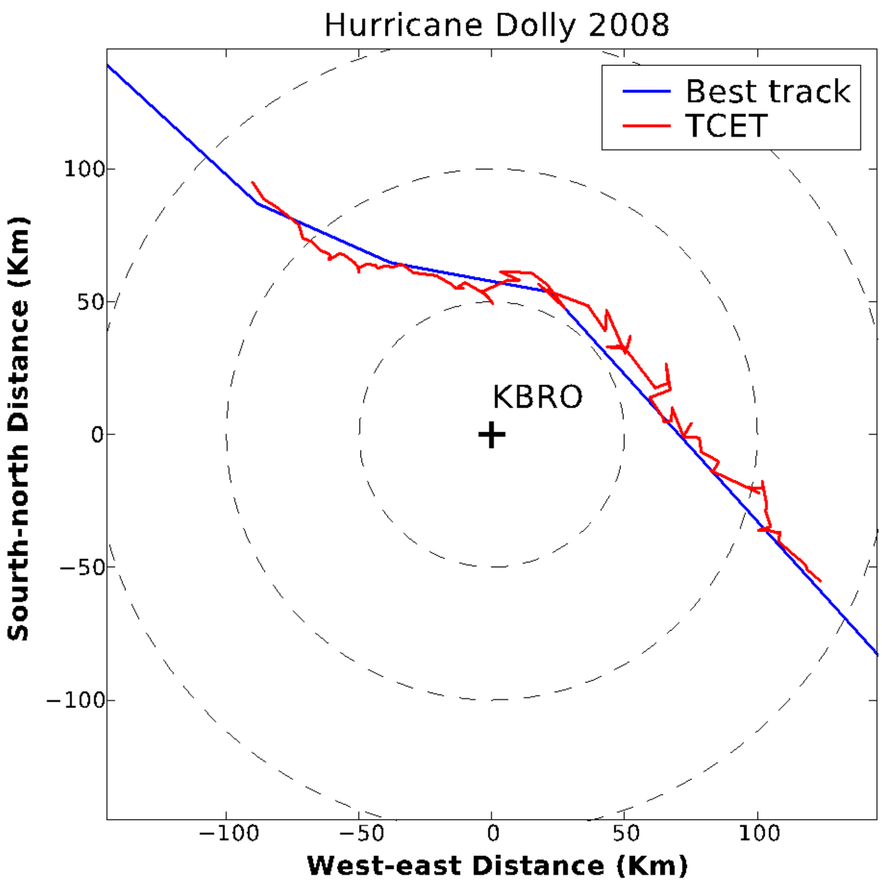

Figure 7. The tracks of Hurricane Dolly obtained from TCET (every six minutes) in red and from the best track (every six hours) in blue.