NOAA Joint Hurricane Testbed (JHT)
Progress Report, Year 2

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Project Title: *Development of a Real-Time Automated Tropical Cyclone Surface Wind Analysis*
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1. Long-Term Objectives and Specific Plans to Achieve Them

Although surface and near surface wind observations and flight-level winds and their proxies exist in sufficient quantity to create high quality tropical cyclone surface wind analyses (cf., H*Wind analyses; Powell et al. 1998), a real-time and fully automated surface wind analysis system is not available at the National Hurricane Center (NHC). Such analyses could however be invaluable; providing useful information for a variety of current and future operational products.

In this project we created a real-time and fully automated surface wind analysis system at CIRA by combining accepted operational wind reduction procedures and a comparably simple variational data analysis methodology (Knaff et al. 2011). Results were then made available to NHC in real-time and in formats they requested. Specifically, this project made use of the Franklin et al (2003) flight-level to surface wind reduction findings along with current operational procedures and incorporated the analysis and quality control (QC) procedures used in the multi-platform tropical cyclone surface wind analyses (MTCSWA; Knaff et al. 2011). The real-time operationally-available aircraft reconnaissance wind data (i.e. HDOBS), and the MTCSWA satellite-based MTCSWA were used as input data. The MTCSWA serves as a first guess field with very low weighting and the aircraft-based data will be composited over a finite period (maximum of 9 hours@ three hours after synoptic time) and analyzed. The analyses are performed on a polar grid at a common 700-hPa level and then adjusted to the surface level (i.e. 10-meter). The polar grid resolution and domain size was specified by the JHT and is consistent with the resolution of the aircraft reconnaissance data and the needs of the forecasters.

If acceptable to operations, the wind analysis would run at NHC and make use of the local data stream and JHT servers. The resulting two-dimensional wind analysis would then produce 1-min sustained winds valid for 10 meter (m) marine exposure with sufficient resolution to properly capture the radii of maximum winds.

2. Accomplishments

a. Software development

In August 2011 the project began with discussions with NHC about what data would be used to create surface wind analyses. The data used included the data available in the real-time HDOBS (flight-level winds, pressures, and SFMR surface wind speed estimates) and the operational satellite-based MTCSWA flight-level wind fields. Routines were developed to ingest the HDOBS and MTCSWA fields and store the information in a common data format. To provide estimates of real-time cyclone information, a track from a combination of operational best track positions, aircraft fixes and the OFCI forecast locations was created. In consultation with NHC hurricane specialists data weights for the flight-level and SFMR wind speed information that was a function of flight-level wind speed were implemented (Table 1). Another consideration requiring input from NHC was how the flight-level wind analysis would be reduced to the surface. Here we relied upon the information in Franklin et al. (2003) to provide the mean reduction factors (F_r) and other operational guidelines. Specifically we attempt to define a convective eyewall region and an outer region based on the radius of maximum wind (*RMW*) with azimuthal variation of 4% and 17%, respectively. Finally, the width of the eyewall region is at largest 20 nmi beyond the *RMW*. Examples of F_r are shown in Figure 1. The input and track information were then used to create a series of motion relative analyses and those results were presented at the IHC in 2012.

Table 1: A description of how the flight-level wind-speed-dependent data weights for the variational wind analysis are determined for the wind analysis.

Flight-Level Wind Speed (V[kt])	**Flight-Level Zonal Weight**	**Flight-Level Meridional Weight**	**SFMR Wind Speed Weight**
V ≥ 64	0.175	0.175	1.0
50 < V < 64	0.5–(V-50)(2.36E-2)	0.5–(V-50)(2.36E-2)	0.25+(V-50)(4.71E-2)
V ≤ 50	0.500	0.500	0.250

Near the end of the first year of this project scripts were written to generate analyses in a real-time manner using operationally available data within the CIRA computer infrastructure. Runs were scheduled at the synoptic time minus 30 minutes, plus 30 minutes and plus 90 minutes We also reran the analyses for the 2010 and 2011 hurricane season to better refine the algorithm. The output of the real-time 2012 and post 2010/11 analyses were made available via ftp to forecasters and NHC's JHT representatives. We also attempted to move the scripts and other software to NHC, but abandoned that effort after finding out that the JHT servers were outside the firewall.

It was also clear after the 2012 Hurricane season that some work was still needed on the existing scripts and software. We also were asked to improve methods of distribution of the analyses to better facilitate the use of these analyses in the NHC operational environment. Results were presented at the 2013 IHC. Since the IHC, several software features were corrected that were related to the errant negative weighting of the MTCSWA, too stringent gross error checking, and errors in the F_r estimation routine. Our script would also not run multiple aircraft cases at the same synoptic time.

During the 2013 Hurricane season real-time analyses were also created. Analyses were run one hour following the synoptic hour – a lesson learned from 2012. These analyses were then converted to GEMPAK format to better facilitate viewing by NHC forecasters (i.e. on N-AWIPS). The distribution was accomplished via ftp and naming conventions were coordinated with JHT operational representatives. Files were tested and they could be viewed in N-AWIPS, however the images were never imported in a real-time manner into NHC's operations. Thus, the operational utility of these analyses could not be evaluated.

Readers of the report will recognize that the 2012 milestones related to running this analysis at NHC were not met due to more pressing priorities at NHC, changes in network security and the reliance on external (to operations) JHT servers. As are result the code was never moved to the JHT servers and real-time testing was conducted solely at CIRA. Near the end of the 2013 hurricane season all of the cases 2010-2013 were rerun using the final software and script versions. In 2013 we were also able to process all of the aircraft cases in real-time. Issues with the creation of GEMPAK grids were rectified. Some of those results are now presented.

It is quite difficult to summarize how well an analysis system performs when ground truth data is based on subjective analysis of the same information. In addition automating the input data preparation and analysis presents a number of issues. Quality controls can be too stringent; removing important data or too lacks allowing errant points into the analysis. In addition the data weights in the variation analysis are based on observed generalizations and may not always be appropriate or representative of how a human analyst would weigh the data. Finally, HDOBS are undoubtedly undersampling the wind field, which will result in our analyses often having lower maximum wind speeds than the corresponding best track verification time. Nonetheless, we feel we have developed a method that can provide real-time objective analyses of aircraft-based observations (i.e. HDOBS). Furthermore, because these analyses are performed on a polar grid, do not suffer from square grid aliasing. The resulting wind fields when differentiated to estimate vorticity and convergence fields do not exhibit any features that result from the analysis grid. In the following discussion we examine some of these analyses and present some of the potential operational enhancements these analyses could offer NHC operations.

b. Example cases

To examine some of these issues we present analyses associated with two 2011 hurricane cases, namely Hurricane Jova, 10 October 18 UTC and Hurricane Irene, 25 August 00 UTC. In the cases 2 and 61 input data were removed by the quality control, as part of the Jova and Irene analyses. Irene had several SFMR wind estimates that were in excess of 105 kt that were removed by the gross quality control operations – noting that the best track intensity estimate was 95 kt. Both cases also had a complete alpha flight pattern and thus similar amounts of flight-level observations.

Case 1: Hurricane Jova (2011), 10 October 18 UTC:

Best Track Intensity: 110 kt
Best Track R34: 90, 90, 60, 60
Best Track R50: 35, 40, 30, 30
Best Track R64: 25, 20, 20, 15

Some details of the automated analysis of Hurricane Jova are shown in Figure 2. The larger domain shows that region of analyzed gale-force winds is quite a bit larger than the best tracked R34 values. In addition the asymmetries appear shifted 90 degrees in the analysis with the strongest winds occurring in the SE and SW quadrants of the storm. R50 and R64 have similar values as the best track, but again the asymmetries seem rotated to the southern quadrants in the analysis. The maximum wind was estimated at 95 knots based on a maximum analyzed flight-level wind as 109 knots. The lower right panel of Figure 2 shows the flight-level wind speeds and SFMR equivalent flight-level wind speed inputs following quality control plotted as a function of latitude, along with a horizontal line representing the maximum wind found in the analysis at flight level (112 kt). It is clear that the analysis is under estimating the maximum found in the SFMR observations. However the analyzed maximum flight-level wind speed is slightly nudged toward those SFMR observations (i.e., the analyzed flight-level wind is larger than the observed maximum flight-level winds (109 kt) based on several SFMR observations that indicate higher surface winds than the flight-level winds would indicate). We note here that the 140 kt SFMR flight-level equivalent wind speeds that pass QC would supported by a 109 kt SFMR observation. The analysis on the other hand, produced a 95 kt maximum surface wind based on 112 kt at flight-level (F_r=.85). For the analysis as a whole, the fit to the wind speed data at flight level produced biases of -3.3 kt, mean absolute errors of 7.5 kt, and RMSE or 10.4 kt (n=1013). Tangential and radial wind RMSE's were 4.8 kt and 4.4 kt, respectively (n=455).

Case 2: Hurricane Irene (2011), 25 August 00 UTC:

Best Track Intensity: 95 kt
Best Track R34: 220, 180, 100, 150
Best Track R50: 100, 90, 50, 80
Best Track R64: 60, 60, 25, 50

Irene represented different challenges as it had a broad horizontal wind profile and the analysis produced poorer results in terms of maximum winds. The wind field in the NE quadrant was rather strong and constant. However, the azimuthally averaged radius of maximum wind was 18 nmi and the storm was moving to the northwest. The analyzed flight-level maximum wind was 101 kt and this was a little lower than the observations would suggest. The strongest flight-level winds were not close to the azimuthal mean radius of maximum wind so the estimated F_r for that point was ~ 0.7 (cf. Figure 1). As a result the maximum surface wind for Irene was estimated at 71 kt, which represents an underestimate of 25%. For the analysis as a whole, the fit to the wind speed data at flight level produced biases of -4.8 kt, mean absolute errors of 6.7 kt, and RMSE or 9.9 kt (n=1196). Tangential and radial wind RMSE's were 5.1 kt and 4.9 kt, respectively (n=557). The analysis based wind radii were also generally smaller than the best track values, especially the northeast quadrant, where the MTCSWA flight-level winds reduced to the surface were not indicating gale-force winds beyond 120 nmi, but F_r was order 0.63, which might be too small.

While there seems to be a general low bias associated with the maximum surface wind estimates, these analyses do provide detailed information concerning both the 64- and 50-kt wind radii. In addition objective estimates of the radius of maximum wind and location are also provided. Objective guidance for these quantities does not currently exist. Furthermore, since the wind field is output other information could be ascertained from the digital wind field if that is desired in operations.

c. Estimation of maximum winds

We examined a few cases when several days of consecutive aircraft sorties and analyses were performed to estimate the maximum wind speed estimates. Figure 4 shows three cases. Generally these are lower than the best track estimates. However, the analysis of flight-level maximum winds agrees quite well with the flight-level observations data as shown in Figures 2 and 3 and is true for most other cases. The mean F_r that would remove much of the bias in the maximum surface wind estimates is around 0.95. At this time it is unclear if there are problems with the F_r being used or if the underestimates are caused by undersampling the wind field (cf, Ehlhorn and Nolan 2012). As a result it is not clear how to rectify this shortcoming. However, both applying a bias correction to account for under sampling and modifying the F_r rules are relatively easy to implement within the software.

d. Wind structure

One of the potentially useful capabilities of these analyses is the monitoring of the wind structure over time. Figure 5 shows the azimuthally averaged profiles of wind speed, radial wind and tangential wind for Hurricane Earl. Analyses are separated by approximately one day. The evolution of the radius of maximum wind, radial convergence and steepness of the tangential wind can be compared between different analyses. These analyses could be particularly useful for detection of secondary wind maximum development, and initial eye formation. However, display methods would need to be developed to make such information easily accessible in operations.

3. Operational Transition Considerations

If the NHC desires to make this an operational capability there are a number of factors that need to be considered.

a. Software

The current software requires a FORTRAN 90 compiler, Python 6.4 or higher, Bash shell script, Gempak, and GrADS. The GrADS options can be easily removed from the scripts, but GrADS-based graphics may be useful for quick looks after the season.

A master script runs at 1 hour after synoptic time. It creates a production location and copies all the information and data it needs to that directory, and runs the executables in the proper order. Active storms are identified, and short-term tracks of each active storm are created that include the aircraft fix locations when available. HDOBs for the last couple of days are then copied to the processing location. Python code then reformats the aircraft information into a simple ASCII input file. The short-term tracks and reformatted HDOBS are then used as input the analysis executable. Each analysis takes less than 3 minutes on a five-year-old Linux workstation running RH5 32bit.

Scripts will likely have to be rewritten to operational standards, but the FORTRAN code follows NESDIS operational standards. Developers are willing to assist in any revisions.

b. Input data

Input data comes from three sources. The operational locations and aircraft fix information comes from the databases of the ATCF. In the CIRA implementation we have a mirror of NHCs a, b, f, and e decks in one directory location. When the analysis is run we copy a, b and f decks to a production area for each run. HDOBS are also mirrored at CIRA in one location from their locations on the NHC web server (http://www.nhc.noaa.gov/archive/recon/2013/AHONT1/ and http://www.nhc.noaa.gov/archive/recon/2013/AHOPN1/). Data from the last couple of days is typically used as input the analysis executable after being reformatted by a python routine. The final input are the flight-level MTCSWA files (*.WIN). The MTCSWA is also mirrored at CIRA from it location at the National Satellite Operations Facility (ftp://satepsanone.nesdis.noaa.gov/MTCSWA). The master script figures out what MTCSWA to use as a first guess/environmental field. The mirroring of HDOBS and MTCSWA is accomplished using wget (a gnu tool) scripts.

c. Output files

A number of files are archived from the surface wind analysis software A list of files and a brief description of each is provided below. The master script can be modified to save fewer files if that is desired.

2011082500_2011al09_L_TCWA.AAV	Ascii, azimuthal mean radial profiles
2011082500_2011al09_L_TCWA.AIRC	Ascii, flight-level wind, location, weights
2011082500_2011al09_l_tcwa_airc.dat	Ascii, GEMPAK input flight-level wind
2011082500_2011al09_l_tcwa_airc.sfc	Binary, Gempak SFMR at flight-level
2011082500_2011al09_l_tcwa_airc.tbl	Ascii, Gempak locations for surface data
2011082500_2011al09_L_TCWA.bin	Binary, Grads binary grid
2011082500_2011al09_L_TCWA.ctl	Ascii, Grads control file

2011082500_2011al09_L_TCWA.DIA	Ascii, Diagnostic file
2011082500_2011al09_L_TCWA.fgue	Ascii, first guess from MTCSWA
2011082500_2011al09_L_TCWA.FIX	Ascii, ATCF fix
2011082500_2011al09_L_TCWA.gif	Binary, large-scale surface wind plot
2011082500_2011al09_L_TCWA.grd	Binary, Gempak gridded analysis
2011082500_2011al09_L_TCWA.gs	ASCII, grads script that makes the plot
2011082500_2011al09_L_TCWA_hr.gif	Binary, small-scal surface wind plot
2011082500_2011al09_L_TCWA.hrgs	Ascii, grads script that make the hr plot
2011082500_2011al09_L_TCWA_hr.ps	Postscript file of small-scale plot
2011082500_2011al09_L_TCWA.inp	Ascii, Short-term track file
2011082500_2011al09_L_TCWA.log	Ascii, production log
2011082500_2011al09_L_TCWA.obs	Ascii, formatted HDOBS
2011082500_2011al09_L_TCWA.ps	Postscript file of large-scale plot
2011082500_2011al09_L_TCWA_RECO.fld	Ascii, all recon obs, locations, weights
2011082500_2011al09_L_TCWA_RECO.gif	Plot of motion relative recon obs
2011082500_2011al09_L_TCWA_RECO.ksh	Script that make the above plot
2011082500_2011al09_L_TCWA_s.fil	Ascii, Gempak input to grid wind speed
2011082500_2011al09_L_TCWA.SSFM	Ascii, SFMR @ fl, locations and weights
2011082500_2011al09_l_tcwa_ssfm.dat	Ascii, Gempak input to make SFMR@fl
2011082500_2011al09_l_tcwa_ssfm.sfc	Binary, Gempak file SFMR@ fl
2011082500_2011al09_l_tcwa_ssfm.tbl	Ascii, Gempak locations for SFMR
2011082500_2011al09_L_TCWA_u.fil	Ascii, Gempak input to grid u wind
2011082500_2011al09_L_TCWA_v.fil	Ascii, Gempak input to grid v wind

4. Summary

This project strived to create an automated tropical cyclone surface wind analysis that effectively analyzed the real-time data from aircraft reconnaissance using a satellite-based surface wind product as a first guess. The project was successful in this endeavor, but the work was never transitioned to pre-operations at NHC. The output analyses (see locations below) also tend to be low biased with respect to the maximum wind reported in the best track record. It is unclear if this low bias is due to the assumptions made to reduce the flight-level wind analysis to the surface or due to undersampling the wind field. Regardless of the exact cause, the method developed here could be easily modified to account for undersampling (bias correction) and/or modification of F_r. So with a little effort these methods could be tuned to alleviate many of the shortcomings of the current surface wind estimates. Furthermore, the application could easily be installed in NHCs operations (details in Section 3) and would provide an enhancement to operations by improved utilization of aircraft reconnaissance data. We summarize what worked and what did not in bullets following the details on the output locations.

Output (gif image, by atcf number) 2010-2013 available at
ftp://rammftp.cira.colostate.edu/Knaff/JHT_TCSWA/
N-AWIPS files

ftp://rammftp.cira.colostate.edu/Knaff/JHT_TCSWA/nawips/
ATCF Fixes
ftp://rammftp.cira.colostate.edu/Knaff/JHT_TCSWA/atcf/

What worked?

- Software to grab the available HDOBS and analyse these data in a motion-relative composite manner
- Estimate wind structure from the analyses (R34, R50, R64, RMW)
- Create ATCF formatted fixes
- Create graphics and GEMPAK-formatted binaries
- Make real-time analysis information and binaries available via ftp

What did not work?

- We were unable to install any of the software in NHCs operational environment
- GEMPAK-formatted binaries were never imported into NHC's N-AWIPS
- Output was never viewed by specialists during their operational duties.
- Estimating Maximum winds from these analyses
- ATCF fixes were never imported to the operational ATCF.

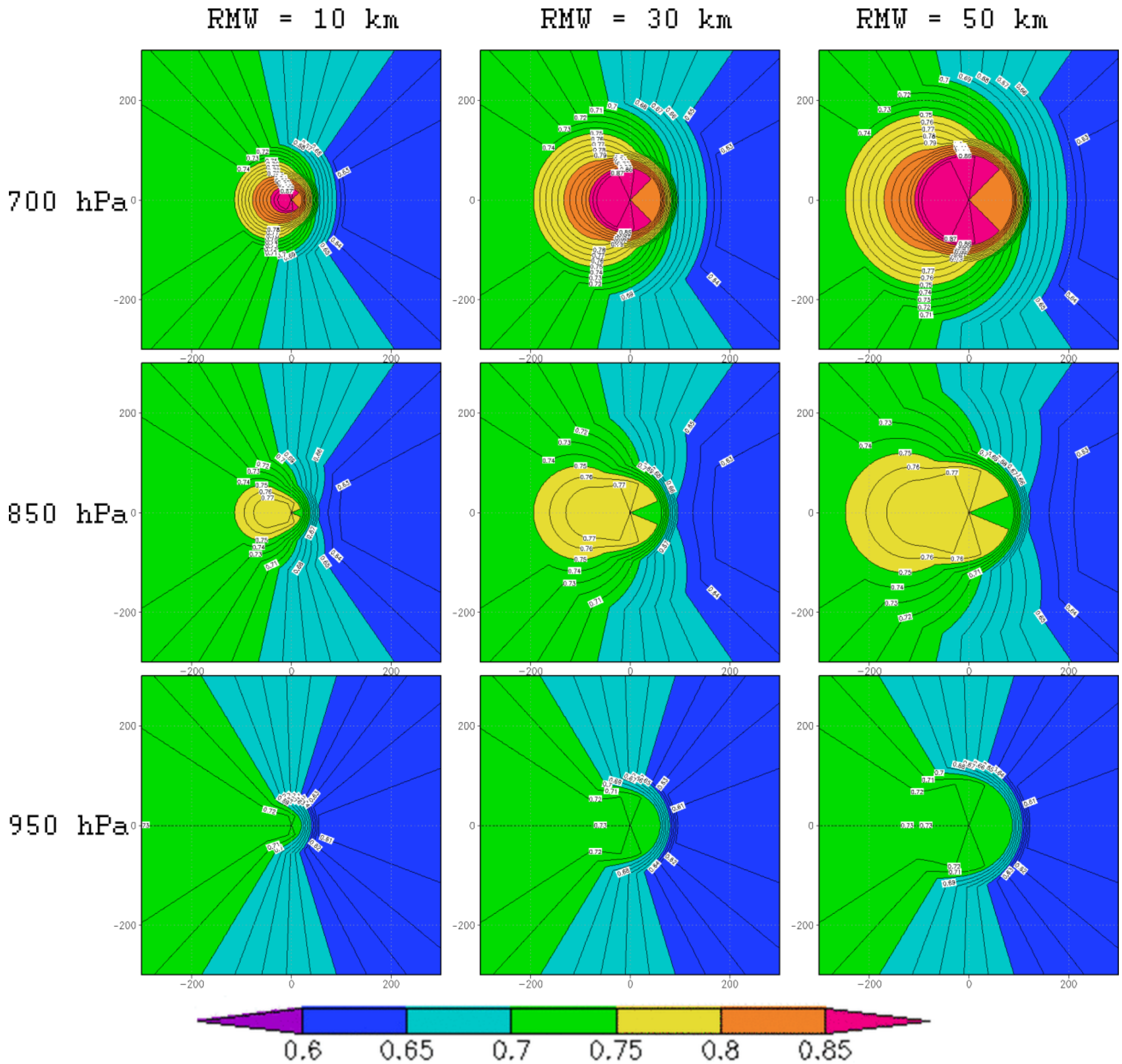

Figure 1: Examples of the flight-level to surface wind reduction factors (F_r) used for this application. These examples show the F_r values for a storm moving toward the top of the page for three values of RMW and three typical flight-level pressures.

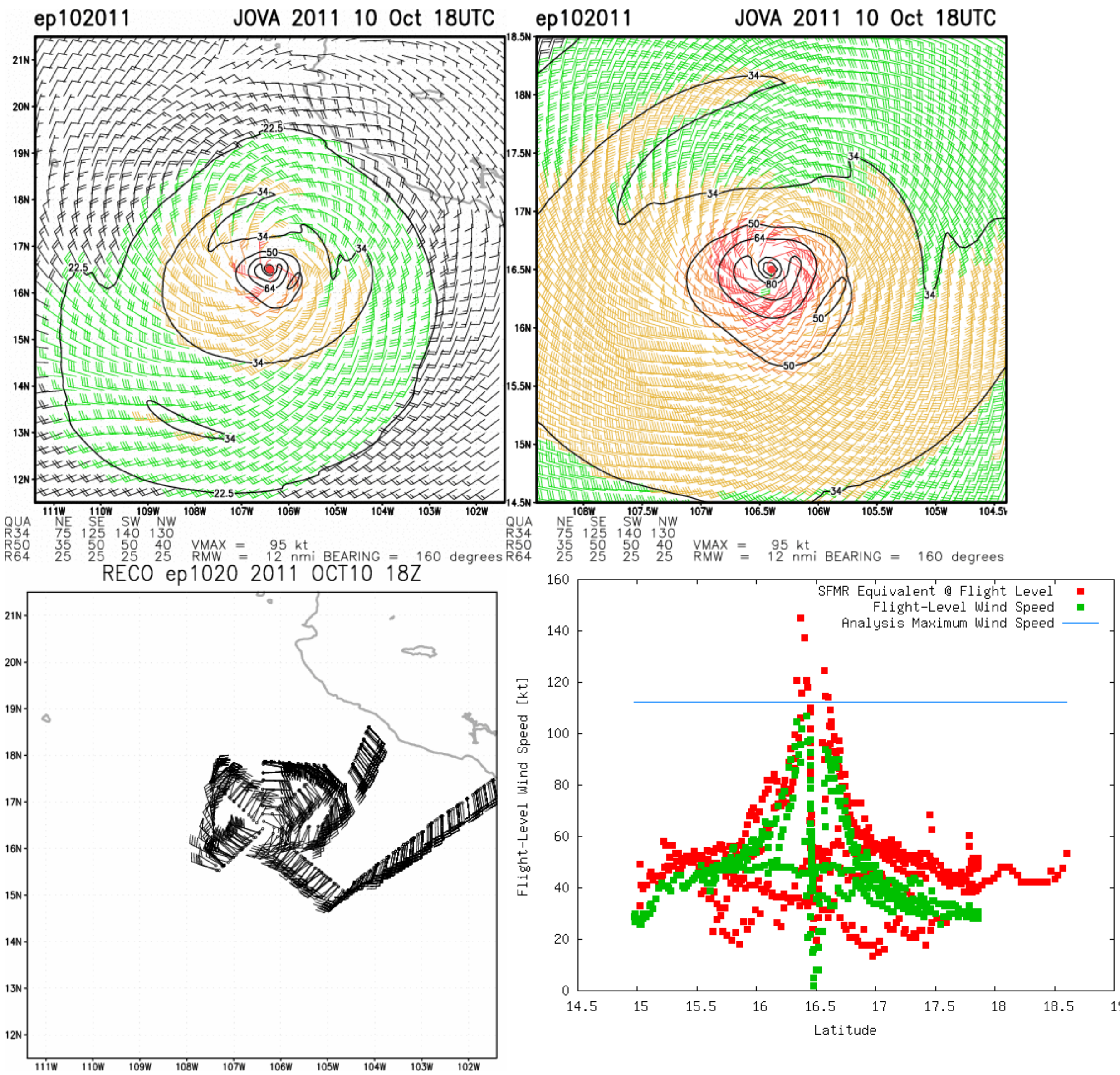

Figure 2: Some details of the surface and flight-level wind analysis associated with Hurricane Jova (2009) October 10 18UTC. (Top left) Large scale analysis showing the effective combination of MTCSWA and HDOBS data, (top right) small-scale view of the wind analysis showing the details of the wind asymmetries and inner core winds, (bottom left) a schematic showing the storm-motion-relative aircraft flight paths for this analysis, and (bottom left) plot of winds speeds as a function of latitude that have been standardized to a 700-hPa flight-level and the maximum analyzed flight-level wind is indicated by the horizontal line.

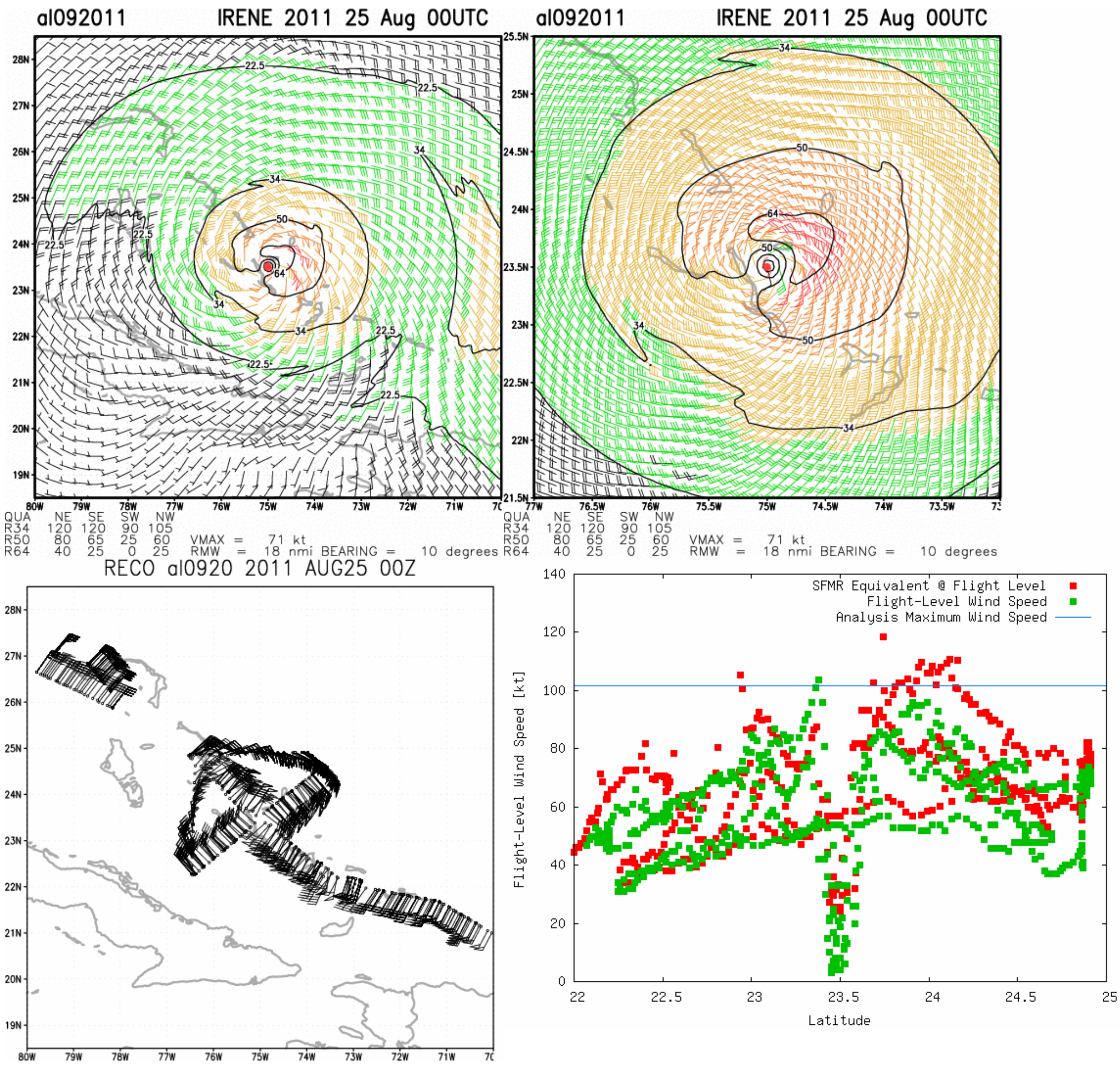

Figure 3: Same as Figure 2, except for Hurricane Irene (2011) on 25 August at 00 UTC.

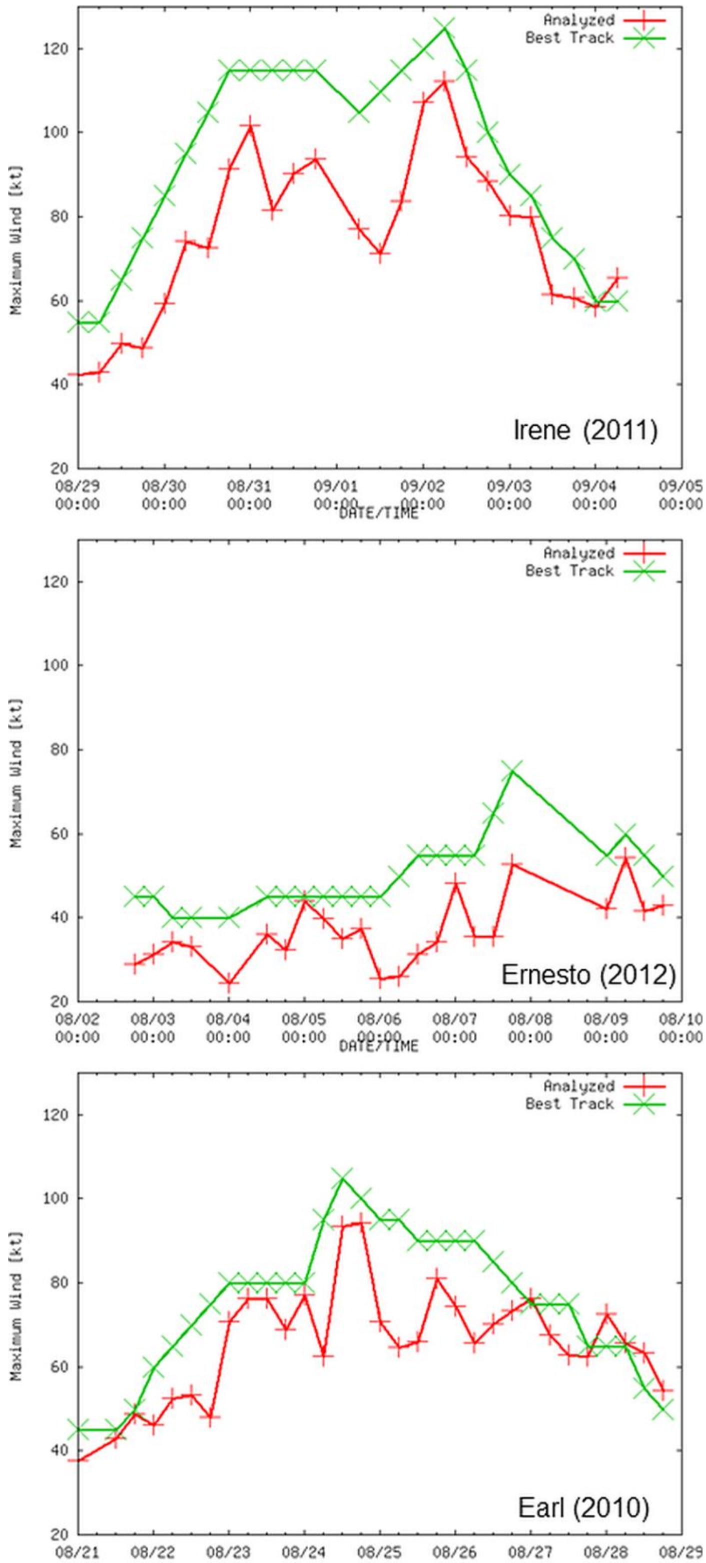

Figure 4: Time series comparison of analyzed maximum winds and best track maximum wind estimates for three hurricane cases.

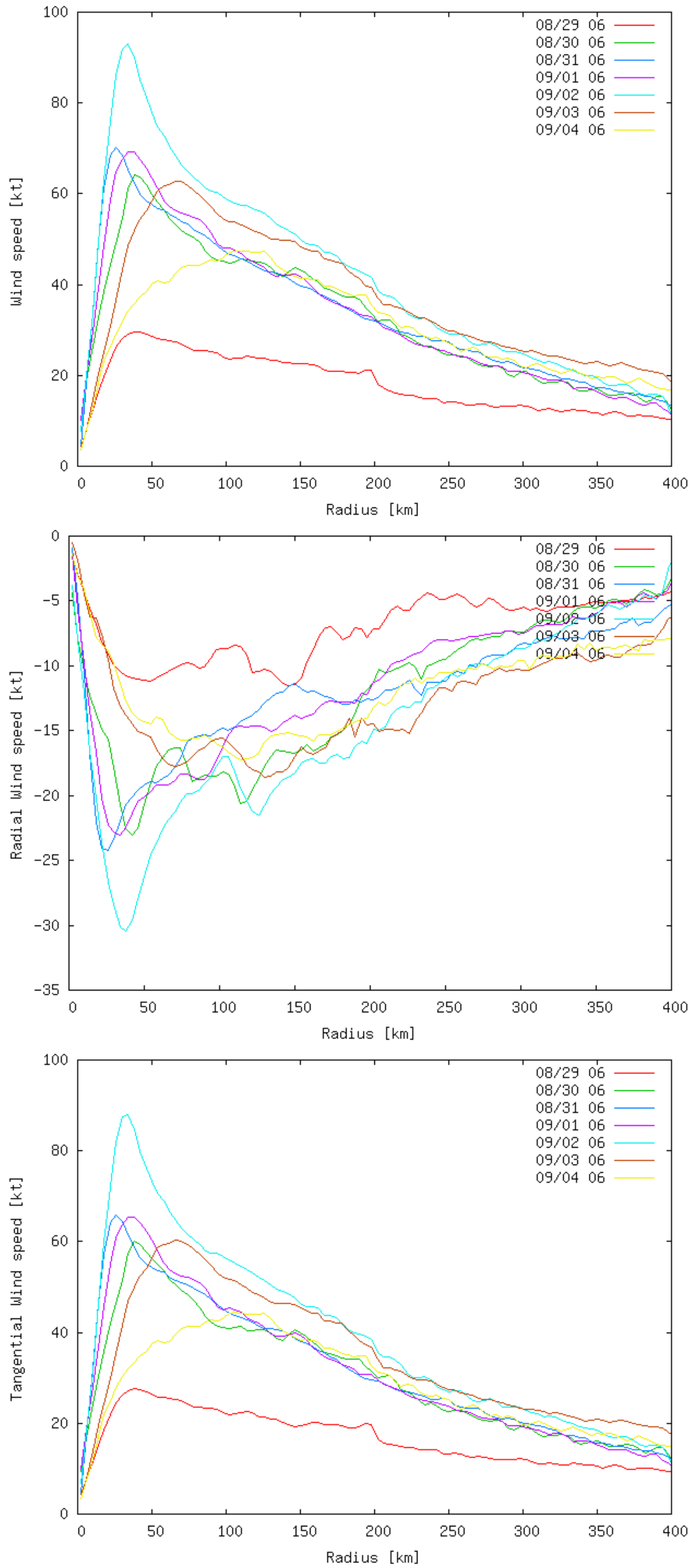

Figure 5: Azimuthally averaged radial wind profiles from each day there were analyses

for Hurricane Earl (2010). The total wind speed is shown at the top, radial wind in the middle and tangential winds in the bottom panels.

Appendix A: Original Milestones.

Year 1
Aug 2011 – Project begins
Aug 2011 – Discussions with NHC to determine desired analysis properties
Aug 2011 – Begin the development of local data ingest design
Aug 2011 – Develop routines to ingest aircraft flight-level, SFMR, and GPS sonde data
Sep 2011 – Develop scripts to combine aircraft center fixes, operational best tracks and OFCI
Nov 2011 – Combine the TC track and the analysis (CIRA and CIMAS)
Dec 2011 – Develop methods to standardize the data types based on NHC's preferences
Feb 2012 – Meet with NHC specialists to discuss options for data weights and smoothing constraints.
Mar 2012 – Present progress at the IHC (ALL)
Mar 2012 – Begin Development scripts to automate the local (CIRA) data ingest, quality control and analysis on a JHT workstation
Apr 2012 – Work with NHC to develop text and graphical output.
May 2012 – Begin testing of the automated analysis routines on past events (CIRA, FSU)
May 2012 – Evaluation of past events and their sensitivity to weight and smoothing, confer with NHC.
May 2012 – Start to test the automated routines in real-time at CIRA
July 2012 – Respond to feedback from NHC (ALL)

Year 2
Aug 2012 – Real-time testing continues
Dec 1012 – Evaluation of the analyses, gather feedback from NHC
Jan 2013 – Modify analysis parameters based on feedback and evaluation results
Feb 2013 – Rerun cases, if necessary
Mar 2013 – Present results at the IHC
May 2013 – Prepare the analysis for a full season of real time testing
July 2013 – Gather feedback and make appropriate changes to the analysis system
July 2013 – Project ends

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