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IMPROVED ANALYSIS OF THE TROPICAL CYCLONE OUTER WIND STRUCTURE USING IR SATELLITE WIND RETRIEVALS IN A GLOBAL NUMERICAL WEATHER PREDICTION MODEL

Christopher J. Slocum and Michael Fiorino*
NOAA Earth System Research Laboratory, Boulder, Colorado

1. INTRODUCTION

Tropical cyclones devastate islands and coastal regions around the globe and decision makers need accurate and precise information regarding tropical cyclone (TC) track and intensity for improving public response, saving lives, and protecting property. Improvements in the National Hurricane Center TC track forecasts can be attributed to the advances in numerical weather prediction (NWP), in particular on global scales (Rappaport et al. 2009).

Although medium-range TC track prediction (72 h) skill does not depend strongly on the analysis of the TC vortex (Fiorino and Elsberry 1989), in the short-range (24 h), track and intensity prediction does. To improve the analysis of the initial TC vortex, new satellite data sources and new means of assimilating 'TCVitals' (TCV) observations are assessed.

TCVs are operational assessments of 1st order TC properties, and because they are derived from measurements, are considered observations. The primary TCV observations include: 1) location, 2) motion, 3) intensity (maximum surface wind speed (V_{max}) and minimum central surface pressure (P_{min})), 4) surface wind structure defined by wind radii of 34, 50, and 64 kts, and 5) other miscellaneous data such as depth. Because TCVs are observations of 1st order TC structure, they must be assimilated in NWP models to analyze the initial TC vortex.

There are several methods for using the TCV data in the assimilation process. The National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL) model uses vortex replacement. Other NWP models, like the NOAA National Center for Environmental Prediction Global Forecast System (GFS) Gridpoint Statistical Interpolation (GSI) and Hurricane Weather Research and Forecast (HWRF) models, assimilate the TCV through background adjustment. Specifically, the GFS GSI takes the TCV into account when relocating the vortex using surgery. The HWRF does scaling and relocation of the 6-h model TC vortex. The Ensemble Kalman filter (EnKF) for the GFS and the WRF Advanced Research WRF (WRF-ARW) models either assimilate P_{min} or P_{min} and the location of the vortex from the TCV.

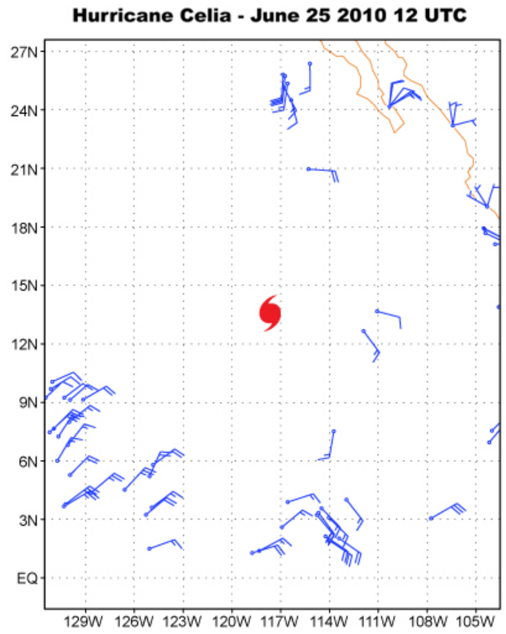

Figure 1. The plot shows wind barbs, in kts, for conventional and satellite observations for Hurricane Celia (red tropical cyclone symbol) on 20100625 at 12 UTC in the Eastern Pacific Ocean.

The first step in examining the effect of the TCV is to investigate the observations used in the assimilation process. No or few conventional observations (rawinsonde, radar wind retrievals, aircraft reconnaissance, buoy, etc.) and satellite wind observations (cloud drift, etc) are in the inner-core (radius = 0-100 km) and motion-critical annulus (radius = 300-600 km). This means that there are no observations to support the direct assimilation of P_{min} from the TCV. For TCs with poor data coverage in the motion-critical 300-600 km annulus (Fiorino and Elsberry 1989), the pressure observations alone cannot realistically constrain the TC vortex. The case shown in Fig. 1 is for Hurricane Celia (04E) on June 25 2010 at 12 UTC. According to the best track information from the National Hurricane Center, 04E had a maximum wind speed of 125 kts and a minimum surface pressure of 940 hPa.

To address situations of poor data coverage in the motion-critical annulus, we propose to use observations that represent the outer wind structure; specifically, geostationary satellite infrared (IR) wind retrievals (IRWD) in the motion-critical outer wind structure of the TC. 'Superobs' are generated from the high-density IRWD retrievals by calculating the mean values at the spatial scales appropriate for the model and data

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* *Corresponding author address*:
Dr. Mike Fiorino, Earth System Research Laboratory, NOAA, e-mail: Michael.Fiorino@noaa.gov

assimilation system. The IRWD superobs were first tested for Hurricane Celia (04E) and Hurricane Darby (05E) in the eastern North Pacific, two TCs that formed in late June 2010, because the GFS GSI failed to assimilate the central surface pressure and to accurately forecast the 24-h TC intensity. The expectation is that assimilating data into the motion-critical annulus should increase TC forecast skill through an improved initial analysis of the TC vortex.

2. METHODS

2.1 *INFRARED WIND RETRIEVAL DATA*

The IRWD retrievals used in the assimilation system come from the NOAA Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (Mueller et al. 2006). The IRWD retrievals are based on a statistical relationship between patterns in IR imagery and wind observations from aircraft reconnaissance. The IRWD retrievals are generated through three algorithms that seek to identify symmetry, to generate regressions of the critical wind radii of 34, 50, and 64 kts even with the opacity of cirrus clouds, and two-dimensional wind fields. The product generates the IRWD retrievals for the lower troposphere (850 and 700 hPa) with a pattern that forms a symmetric component of the vortex and a wave number one asymmetry from the motion (Fig. 2) for TCs in all basins at 00, 06, 12 and 18 UTC by using globally available geostationary IR. For further details on the IRWD retrieval product, see Kossin et al. (2007).

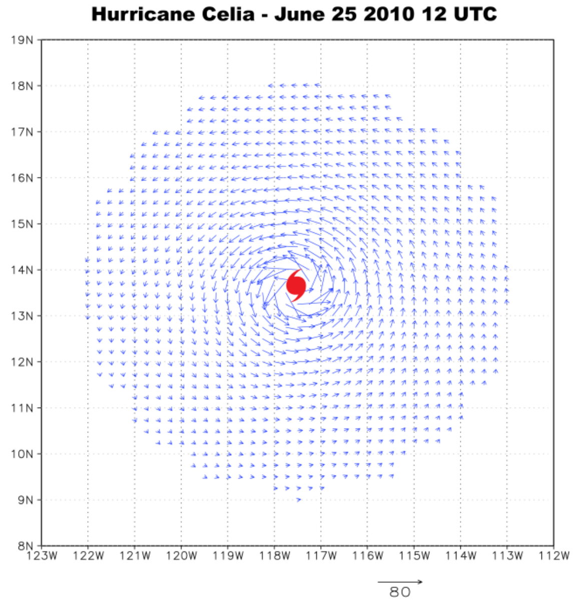

Figure 2. The plot is a wind vector representation of the CIRA IRWD retrievals for 04E at 2010062512 with units in kts.

2.2 *SUPEROBS*

To reduce 'representativeness' errors in the analysis, the observations should be subsampled to the spatial scales of the model, in our study the GFS at T254 or dx~60 km. We take the high-density CIRA IRWD retrievals and 'superob' (subsample) within the motion critical annulus to the spatial scales representative of the model grid. This allows the data assimilation to adjust the background with the TCV P_{min} as the primary observation constraining the inner core.

One of three superobing schemes - weak, small, and medium/large - are set by using the TCV V_{max} to determine strength and the critical radii of 34-kt (R34) winds for the TC size. The weak superob scheme is used when a TC has a V_{max} less than 35 kts. Any V_{max} greater than or equal to 35 kts is defined as a small TC if the R34 is less than 60 nm and is defined as a medium/large TC if the R34 is greater than or equal to 60 nm.

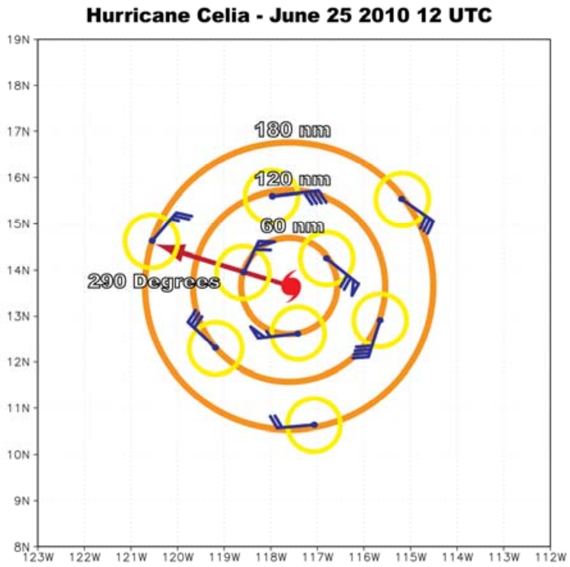

Figure 3. The figure shows the superob pattern for Hurricane Celia (04E) on June 25 2010 at 12 UTC. The red symbol indicates the location of 04E. The arrow shows the TC motion. The orange rings show the space of obs in the motion critical annulus. The yellow circles show the IRWD retrievals averaged to the blue wind barbs.

Once the size and strength of the TC has been determined, the location of the superobs within the motion critical annulus must be defined before calculating the superobs themselves. For weak storms, the superobs are located 45 nm from the storm's current position. The first superob is placed in the direction of the TC motion with the next two superobs within ± 120 degrees of the TC bearing. For the small TC storm scheme, the superobs are located on two rings: one with a radius of 45 nm and the other with a radius of 90 nm. The location of the superobs on the outer most ring (90 nm) is identical to weak storms and the superobs on the inner ring are offset by 60 degrees. The medium/large TC scheme contains three rings at 60 nm, 120 nm, and 180 nm. The position of the superobs on inner (60 nm) and outer most (180 nm) rings is configured like the weak storm and the middle ring (180 nm) is offset by 60 degrees.

The individual superobs are then calculated by taking the mean of the CIRA IRWD retrievals in a circle with a diameter equivalent to the distance between the rings in the scheme (45 nm in the case of a weak storm) (Fig. 3). In the case of 04E on 25 June 2010 at 12 UTC, the storm had a V_{max} of 133 kts, a R34 of 101 nm, and a bearing of 290 degrees according to the TCV. The superobs are then used in the GFS/EnKF.

2.3 *FORECAST MODEL AND DATA ASSIMILATION*

This study uses T254L64 of the GFS, which has an approximate horizontal resolution of 60 km and uses the physics package implemented in July 2010. The GFS is initialized with an eighty member EnKF. The GFS/EnKF assimilates conventional observations normally used in the National Center for Environmental Prediction operational Gridpoint Statistical Interpolation (GSI), the TCVs, and superobs. For further information on the GFS/EnKF, refer to Hamill et al. (2011).

Three assimilation experiments are conducted: 1) the addition of the P_{min}-only, 2) P_{min} and the TC location, and 3) P_{min}-only with the IRWD superobs. We tested the P_{min} with the IRWD superobs for 04E (Hurricane Celia, the 4th numbered storm in the eastern North Pacific) and 05E (Hurricane Darby) during the period 00 UTC 20 June 2010 – 00z 28 June 2010, but we examined in detail 04E on June 25 2010 at 12 UTC.

2.4 *METRICS*

Standard TC metrics include calculating ‘intensity error’ (model–observed V_{max} and P_{min}) as well as the track error or great-circle distance between model position and the verifying best track location.

Several metrics are used to evaluate the performance of the data assimilation process: 1) the *innovation* or difference between the observation and the background, 2) the *increment* or the difference between the analysis and the background, and 3) the *increment persistence* or the degree to which the new information is carried forward into the model forecast that becomes the background for the subsequent analysis.

3. DISCUSSION

First, consider the operationally most important TC skill metric: track. Errors less than 100 nm at day 5 or 120 h are well below typical model and/or official errors. Thus, even though P_{min}-only runs have lower forecast errors, differences are not statistically significant and both assimilation runs are extremely low at 72 h (~80 nm) (Fig. 4c).

The TC intensity metrics show that the assimilation with IRWD winds (P_{min}-only) have little bias and lower V_{max} and P_{min} (t=0 h in Fig. 4a,b) intensity errors. It might be concluded that the no-IWRD analysis is ‘better.’ However, a 60 km global model numerically should not represent/analyze a 130-kt TC at 130 kts. Thus, the standard TC intensity metrics are not consistent with the modeling and the meteorology.

Increment persistence is shown in Fig. 5 for the three assimilation tests[1]. In the P_{min}-only case, the model loses the strong winds in 6 h (Fig. 5a,b) or the high winds in the analysis did not persist or were not consistent with the scales representative of the model grid. In the P_{min} and TC location assimilation, the analysis shows a much weaker storm that is more likely representative of the model grid and these weaker winds were maintained during the 6-h forecast used for the background of the next assimilation cycle (Fig. 5c vs. 5d). However, the winds in the analysis for the P_{min} with the IRWD superobs are much closer to the observed TC and more interestingly the strong winds are maintained by the 60-km model in the 6-h forecast (Fig. 5e vs. 5f). This persistence of the increment in the IRWD assimilations implies that IRWD superobs are supporting the assimilation of TCV P_{min} so as to produce an initial TC vortex consistent with both the model resolution and the inner-core TCV observation.

4. CONCLUSIONS

Several preliminary conclusions can be made from the results of assimilating the IRWD data. In the case of P_{min} only, the data assimilation process drew too close to the P_{min} value. The P_{min} with the IRWD counteracted the issues caused by the P_{min} only. This allowed for a more realistic TC vortex structure. From the P_{min} with the IRWD case, it appears that the 60-km global model maintained the strong winds. Further analysis of this surprising increment persistence is needed to confirm the benefit of the IRWD superobs

In the future, the IRWD retrievals will be assimilated with the P_{min} and TC location. Also, the cases will be rerun with other storms and basins during the 2010 Northern Hemisphere season.

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[1] Forecasts were not made with the P_{min} and TC location assimilation

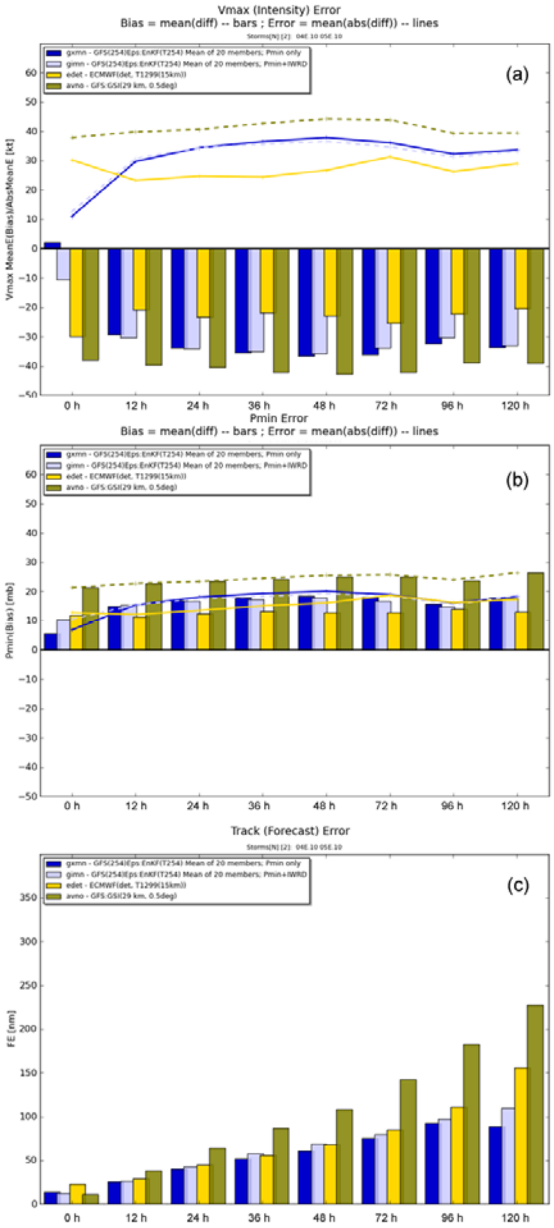

Figure 4. Plots of standard TC forecast metrics. GFS/EnKF P_{min}-only is dark blue. GFS/EnKF P_{min}-only and IRWD is light blue. ECMWF is gold. GFS/GSI is olive. The bars in panels a) and b) are the bias and the lines the absolute mean error. (a) V_{max} (intensity) absolute mean error. (b) P_{min} (intensity) absolute mean error and (c) Track (forecast) mean error.

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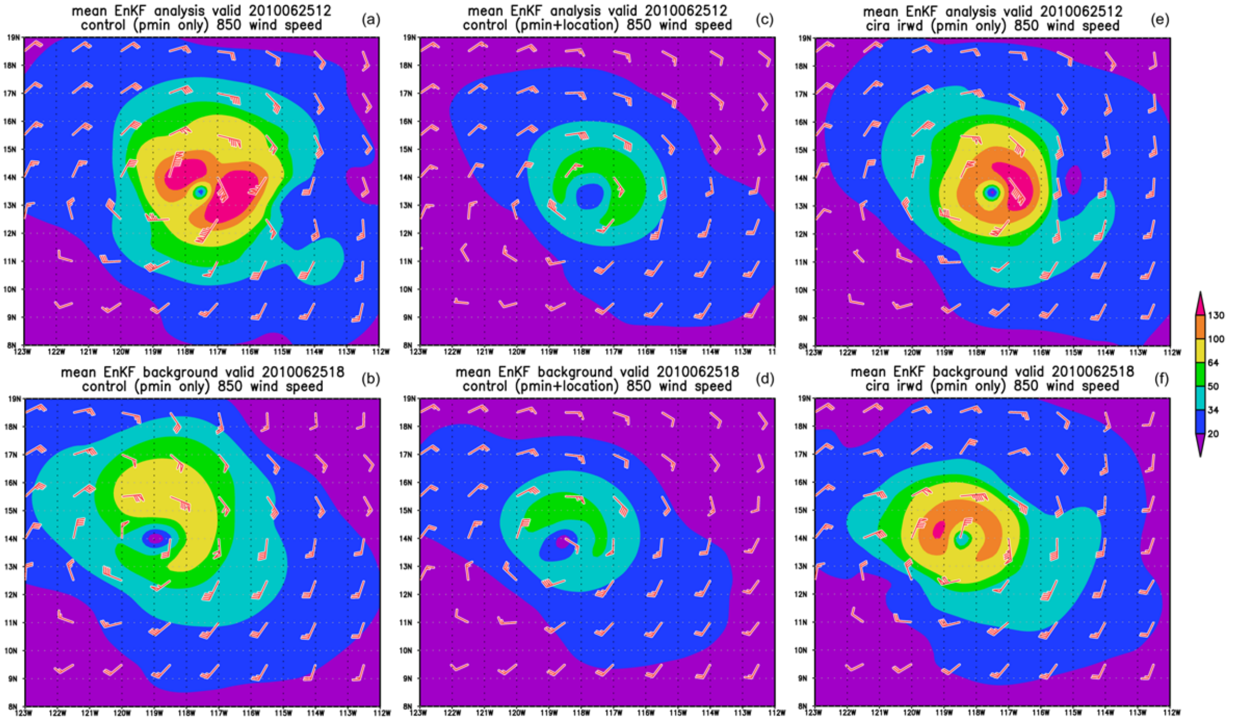

Figure 5. Mean EnKF analysis (June 25 2010 at 12 UTC) and subsequent background (6-h forecast valid June 25 2010 at 18 UTC) plots showing the 850 hPa wind. Contours represent the wind speed in kts. Wind barbs are overlaid to show specific values. Panels: (a) Analysis for P_{min}-only. (b) Background for P_{min}-only. (c) Analysis for P_{min} and TC location. (d) Background for P_{min} and TC location. (e) Analysis for P_{min} with IRWD superobs. (f) Background for P_{min} with IRWD superobs.