EnKF OSSE Experiments assessing the impact of HIRAD wind speed and HIWRAP radial velocity data on analysis of Hurricane Karl (2010)

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INTRODUCTION and METHODS

MOTIVATION

Previous studies (e.g., Zhang et al. 2009, Weng et al. 2011) have shown that radial velocity data from airborne and ground-based radars can be assimilated into ensemble Kalman filter (EnKF) systems to produce accurate analyses of tropical cyclone vortices, which can reduce forecast intensity error. Recently, wind speed data from SFMR technology has also been assimilated into the same types of systems and has been shown to improve the forecast intensity of mature tropical cyclones. Two instruments that measure these properties were present during the NASA Genesis and Rapid Intensification Processes (GRIP) field experiment in 2010 which sampled Hurricane Karl, and will next be co-located on the same aircraft for the subsequent NASA HS3 experiment. The High Altitude Wind and Rain Profiling Radar (HIWRAP) is a conically scanning Doppler radar mounted upon NASAs Global Hawk unmanned aerial vehicle, and the usefulness of its radial velocity data for assimilation has not been previously examined. Since the radar scans from above with a fairly large fixed elevation angle, it observes a large component of the vertical wind, which could degrade EnKF analyses compared to analyses with data taken from lesser elevation angles. The NASA Hurricane Imaging Radiometer (HIRAD) is a passive microwave radiometer similar to SFMR, and measures emissivity and retrieves hurricane surface wind speeds and rain rates over a much wider swath. Thus, this study examines the impact of assimilating simulated HIWRAP radial velocity data into an EnKF system, simulated HIRAD wind speed, and HIWRAP+HIRAD with the Weather Research and Forecasting (WRF) model and compares the results to no data assimilation and also to the Truth from which the data was simulated for both instruments.

WRF-ENKF SETUP

- The same WRF-EnKF system as in Zhang et al. (2009) is used

Assimilating model setup:
- 27/9/3 km WRF V3.1.1
- 35 vertical layers
- Model top at 10 hPa
- WSM-6 microphysics, and YSU the scheme for planetary boundary layer processes.

EnKF setup:
- Successive covariance localization:
  - 1215-km radius of influence (ROI) for 1/9 of obs. D1-3
  - 405-km ROI for another 2/9 on D2-3
  - 135 km for another 6/9 on D3
- Mixing with a = 0.8:

$$x^{a'}_{new} = (1-\alpha)x^{a'} + \alpha x^{f}$$

- Random, balanced, large-scale perturbations are added to the GFS analysis at 0000 UTC 16 August to create initial conditions for a 30-member ensemble forecast + an additional 'truth' member
- The pure ensemble is integrated forward until 0000 UTC 18 September (48 h), and the 'Truth' is selected as the member that best captures Karl's rapid intensification but also is reasonable with track error. The 'truth' member is then rerun with Goddard microphysics to represent model error.

TRUTH and PURE ENSEMBLE (No DA)

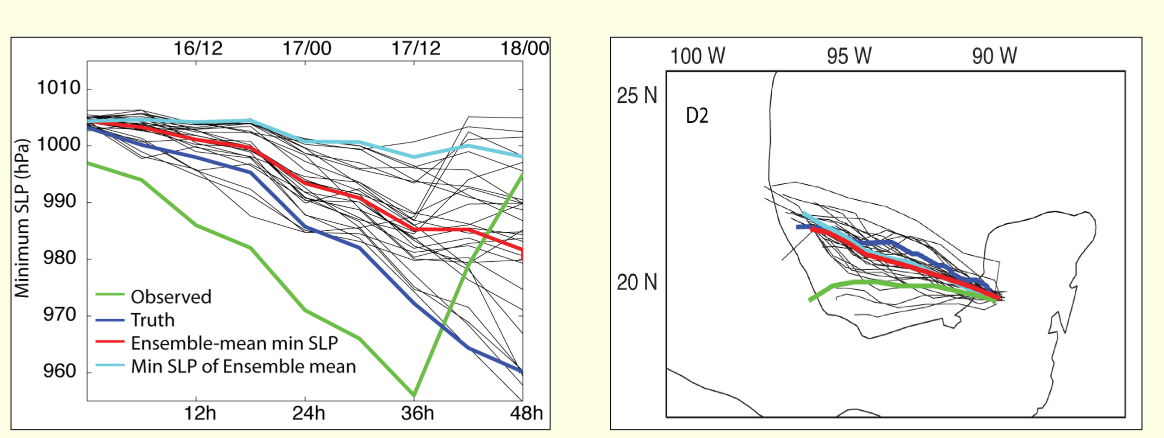


Fig. 1. Minimum sea-level pressure (SLP) evolution and track in domain 2

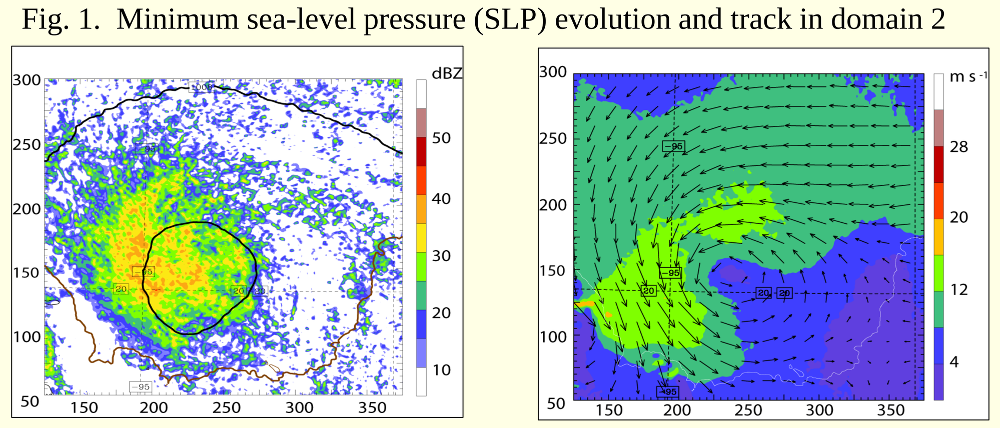


Fig. 2. No DA ensemble mean surface winds, pressure and reflectivity. Axis increments are grid points on D3.

SIMULATED OBSERVATIONS

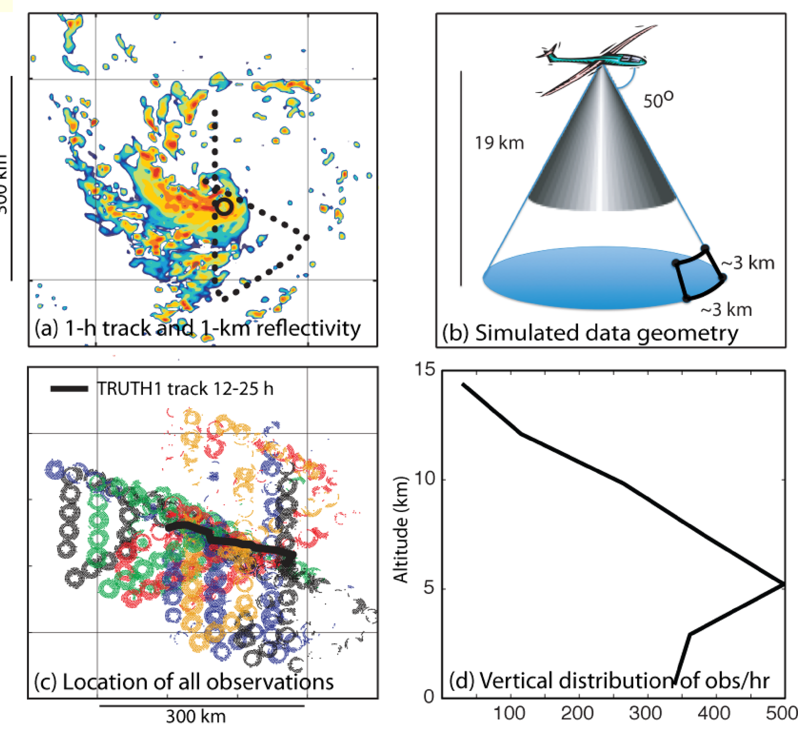


Fig. 3. Schematics showing the method for gathering data and data distribution. (a)A sample 1-h flight track at 19 h superposed upon 1-km reflectivity. (b)Schematic illustrating the three-dimensional distribution of a single simulated scan. (c) The track of the cyclone from 12-24 h superposed upon the location of all data points. (d)The average vertical distribution of observations.

HIWRAP

- Instantaneous simulated radar scans are performed every ~28 km along the flight path within the truth simulation with Goddard microphysics. The scans are then divided into 1-h segments whose lengths are consistent with the Global Hawk air speed of 330 kt. For example, observations representing the time from 1130 to 1230 UTC are extracted from the 1200 UTC model output file and assimilated at 1200 UTC. This combination yields 22 radar scan locations per hour.
- Observations collected every ~3 km radially and azimuthally, and observation error is assumed to be Gaussian with a standard deviation of 3 m/s for HIWRAP.
- No data collected when attenuated dBZ < 10
- Attenuation relationship (dBZ/km): $k = \alpha Z^{\beta}$

HIRAD

- The simulated HIRAD data is taken by imposing the lat and lon positions of real HIRAD observations of Karl from GRIP onto the model domain of the Truth, and simulating the wind speeds that it would observe at locations following the storm every hour. The nature of the HIRAD data is spacially and temporally very dense, so the observation locations were thinned such that the EnKF system would accept a large and yet still somewhat representative wind field of data points given limitations to the covariance based on the number of ensemble members for assimilation. Random error is estimated and included for all wind speeds assimilated.

ASSIMILATION CYCLES

- Thirteen assimilation cycles are completed for HIWRAP. Also, thirteen assimilation cycles are completed for HIRAD. For the HIWRAP + HIRAD experiment, one cycle of HIRAD data is assimilated into the 13th HIWRAP-only analysis (effectively, 12 cycles of HIWRAP only + 1 cycle of HIWRAP/HIRAD), and the impact of the HIRAD observations is assessed.

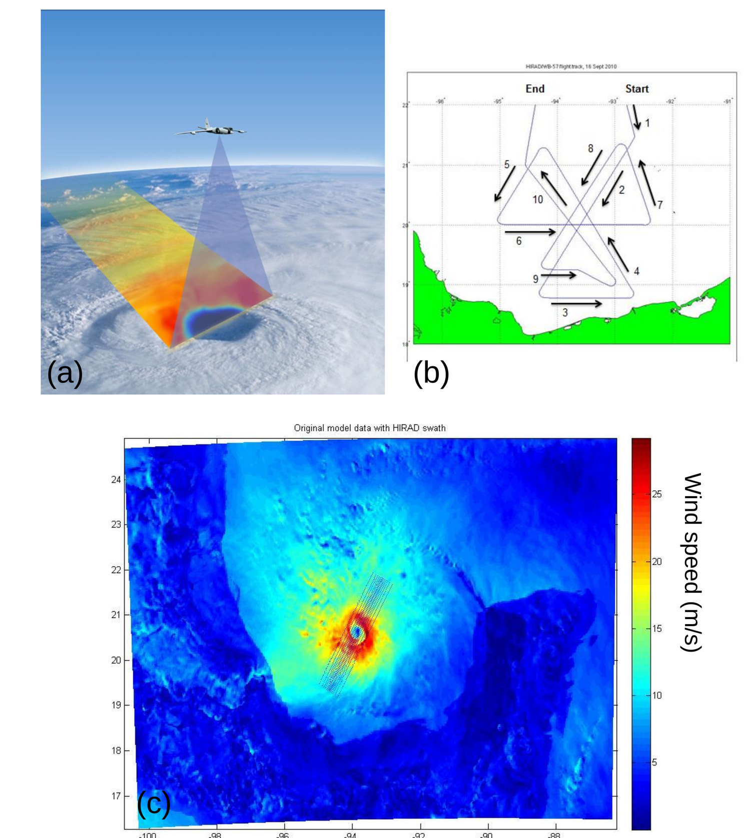
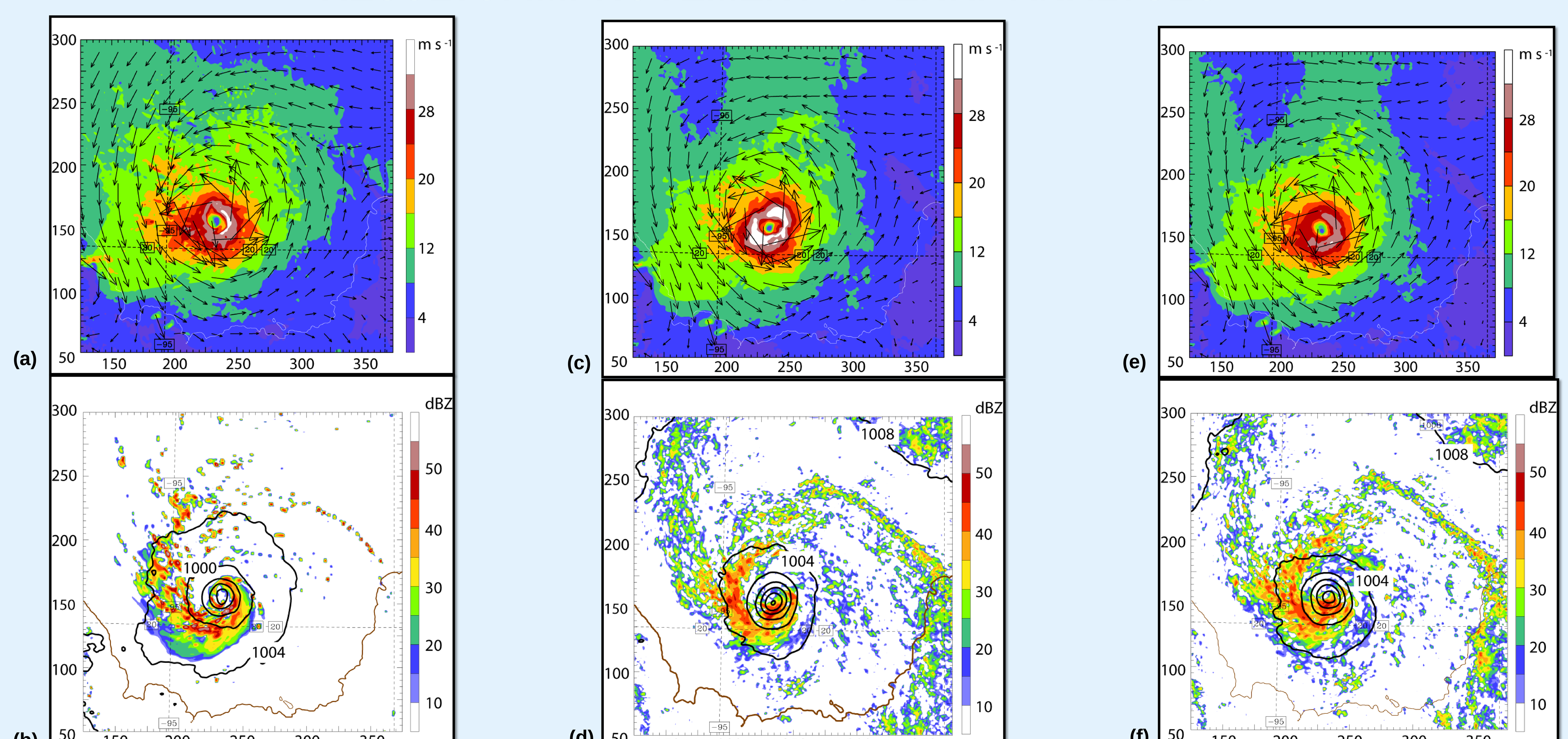


Fig. 4. Simulated HIRAD observations. a) HIRAD observes in a push-broom fashion, as depicted here. Typical swath geometry with Global Hawk configuration would be a width of ~80km with a resolution of 1-5 km, and would observe wind speeds in the range of 10-85m/s. b) The actual track of the HIRAD instrument aboard the WB-57during the GRIP field campaign. Legs 2 and 4 have been used in the simulation of HIRAD for this experiment. c) A typical swath of HIRAD observations taken from the Truth across the center of the storm (blue dots) based on the instrument information in a). The data has been thinned for the EnKF analysis to handle due to restrictions imposed by the number of members on the development of proper covariance.

RESULTS: IMPROVEMENT OF ENKF ANALYSES



Truth HIWRAP –Only HIWRAP + HIRAD

Fig. 5. Truth, HIWRAP-Only EnKF analysis, and HIWRAP+HIRAD EnKF analysis, respecitively, of (a, c, e) reflectivity and surface pressure, and (b, d, f) surface wind speed and vectors at 0000 UTC 17 September, after 13 analysis cycles. Axis increments are in model grid points on D3.

COMPARING HIWRAP-ALONE AND HIRAD-ALONE OSSE ANALYSES TO CONTROL & TRUTH

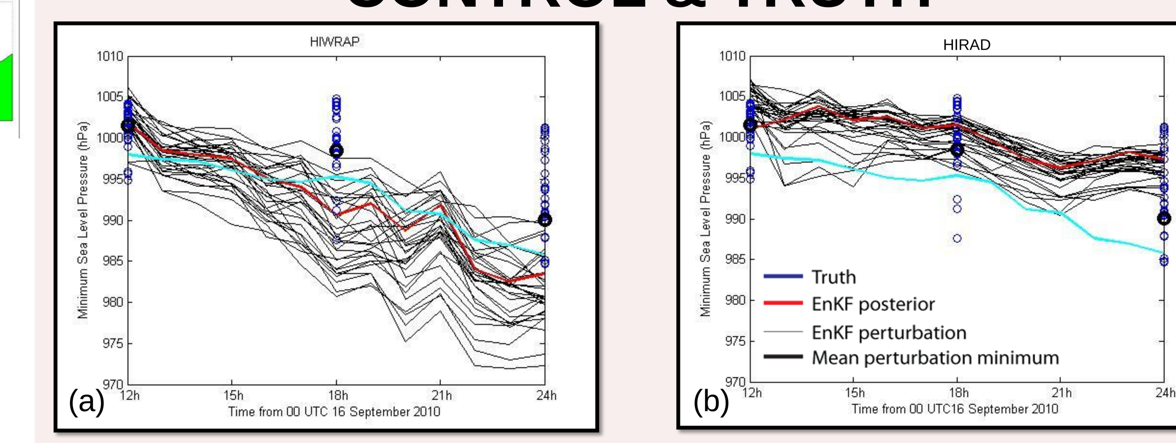


Fig. 6. a) Comparison of minimum SLP (hPa) evolution in EnKF analyses and no DA ensemble from 12 to 24 h for HIWRAP only. b) for HIRAD only.

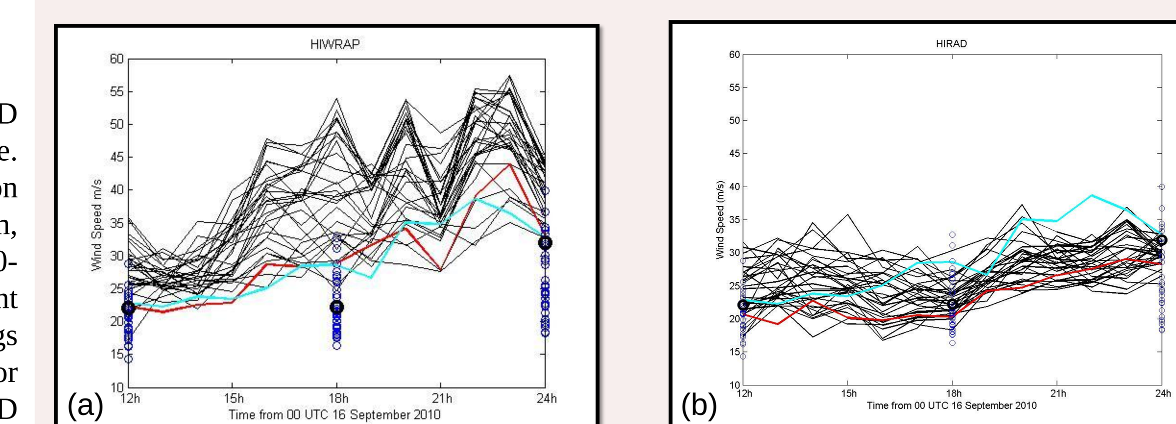


Fig. 7. a) Comparison of maximum wind speed (m/s) evolution in EnKF analyses and no DA ensemble from 12 to 24 h for HIWRAP only. b) for HIRAD only.

Analysis of Figures 6. and 7. shows that although the HIWRAP-Only observations drop the minimum central pressure fastest, it also tends to overestimate the intensity by the end of the assimilation period. On the contrary, HIRAD tends to drop the minimum slp more slowly and not as dramatically, but it still underestimates the intensity. With regard to winds however, the spread in the ensemble members for the HIRAD-only analyses more accurately predict the maximum wind speed compared to the HIWRAP-only analyses. Combining these two sets of simulated observations will produce the most optimal forecast of the intensity, as shown in the preliminary results in Figure 5.

SUMMARY

Preliminary results show that radial velocity data from the HIWRAP radar can be useful for assimilating into a WRF-EnKF system. This is also true for wind speed data from HIRAD. In the vicinity of the hurricane, the error of the EnKF posterior analyses is significantly less than that in an ensemble with no data assimilation (Figs. 5-8). This reduction in error is due to corrections in both the storm position and intensity. Though the simulated HIWRAP-only EnKF analyses eventually have too strong of a cyclone, the addition of simulated HIRAD observations for even just one assimilation cycle to the end of the HIWRAP-only 13-cycle assimilation improves the intensity estimation to nearly perfect in terms of several factors: First, the wind speeds near the eyewall are improved. Second, the over-estimation of HIWRAP-only is improved so that the minimum sea level pressure is identical to the Truth and the wavenumber of the hurricane center is corrected. The error is diminished compared no data assimilation (Fig. 5) for every experiment.

The quality of the analysis with simulated HIWRAP+HIRAD data shows improvement over HIWRAP-only or HIRAD-only. Several experiments were performed assimilating HIWRAP data, but this is just the first preliminary result of assimilating HIRAD data, and certainly adding HIRAD to HIWRAP. The results are encouraging, nonetheless, and evidences the promising contribution that both of these observing systems will have on intensity modeling, especially when combined. This is yet another reason why colocating these two instruments during HS3 will prove especially beneficial for the hurricane modeling community.

REFERENCES

Zhang, F., Y. Weng, J. A. Sippel, Z. Meng, and C. H. Bishop, 2009. *Mon. Wea. Rev.*, **137,** 2105-2125.

Weng, Y. and F. Zhang, 2012. *Mon. Wea. Rev.*, **140**, 841-859.