# NOAA Joint Hurricane Testbed (JHT): TARGETING STRATEGIES TO IMPROVE HURRICANE TRACK FORECASTS

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## 1. Purpose of Work

Each time a tropical cyclone (TC) is deemed as a potential threat to land, the NOAA Gulfstream-IV (G-IV) aircraft is deployed to release "targeted" GPS dropwindsondes in the TC environment to improve operational track forecasts. Presently, the target locations for the dropwindsondes are chosen subjectively, based on a combination of uniform sampling around the storm, and the 'spread' of NCEP Global Forecast System (GFS) ensemble forecasts of 850-200 hPa deep-layer-mean winds (Aberson 2003). This JHT project focuses on the development and testing of a new targeted observing strategy, the Ensemble Transform Kalman Filter (ETKF) (Bishop *et al.* 2001, Majumdar *et al.* 2002). The aims of the new strategy include (i) to expedite flight planning, (ii) to *objectively* use numerical model output, (iii) to account for specific TC forecasts, and (iv) to reduce the likelihood of choosing irrelevant target regions.

## 2. Achievements since May 2004

The objectives outlined in the Annual Report (May 15, 2004) were met. The ETKF code was prepared on NCEP's IBM SP supercomputer for use with tropical cyclones before the 2004 Atlantic Hurricane season. Further details are given in the Annual Report. During the active 2004 season, the code was run for almost every case in which synoptic surveillance missions were being considered (Majumdar and Etherton). ETKF maps for the 2004 season are archived on the website

http://orca.rsmas.miami.edu/~majumdar/tc/

A 40-member 1° resolution NCEP GFS ensemble, initialized 48-72 h prior to mission nominal time, was used in all the calculations. Since the 2004 season, the ETKF has also been extended to run for a 50-member 1° resolution ECMWF ensemble. The recent availability of these high-resolution ensembles has likely improved targeting guidance considerably, compared with the old 2.5° resolution ensembles.

The ETKF predicts a quantity entitled ‘signal variance’, which gives the expected reduction of forecast error variance in a given verification ‘norm’ (e.g. wind speed) due to any particular set of targeted observations. An ETKF summary map shows the predicted signal variance for a specific TC forecast of interest, as a function of the observing location. Hence, the locations in which signal variance is highest represent areas in which the ETKF suggests that targeted observations would be most useful for reducing TC forecast errors with respect to the given verification norm.

The NCEP ensemble spread of 250, 500 and 850hPa wind components for a 40-member NCEP GFS ensemble was also computed in real-time. These maps were presented alongside the ETKF for comparison during the 2004 hurricane season; note that this is different from the deep layer mean wind spread produced regularly at HRD.

A flight track “planner” code, developed under funding from a prior JHT project, was tested in summer 2004 (Aberson and Leighton). It was coupled to the ETKF and ensemble spread outputs, to produce synoptic surveillance tracks that accounted for the targeting guidance and also several parameters such as flight departure and return points, the routine rawinsonde network, no-fly zones and others.

An example of the flight planning guidance is given in Figure 1, with the aim being to improve a 2-day forecast of Hurricane Jeanne. The regions of blue shading in the ETKF map (Fig.1a) indicate that observations to the north and east of the predicted storm location are expected to benefit the forecast. These regions coincide with the deep-layer easterlies that are acting to steer the hurricane. Based on the ETKF map, the automated flight planner code draws a track with dropwindsonde locations shown by the black dots. A data file with dropwindsonde coordinate locations is produced for easy dissemination.

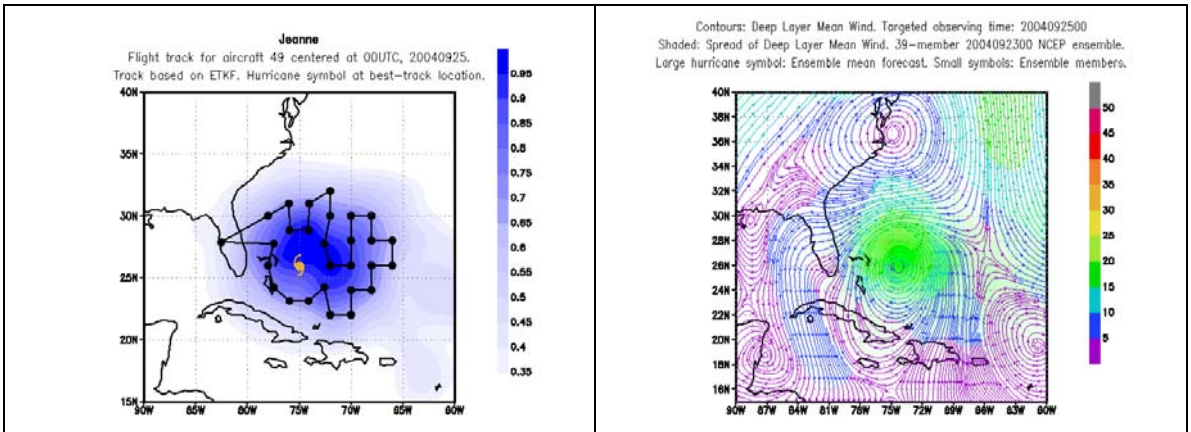


FIGURE 1. (a) ETKF summary map of 850-250hPa wind signal variance (shaded), for a 48-h forecast of Hurricane Jeanne. The automated flight track coordinates at 00UTC 25 Sep 2004 are based on the ETKF map.

(b) Ensemble spread (green shading) at the observing time (00UTC 25 Sep 2004). Contours show the deep layer mean wind forecast valid at the same time.

## 3. Evaluation of data impact in target regions

Two cases in which the three sampling strategies are compared have been completed: Hurricane Charley initialized 1200 UTC 12 August 2004 Hurricane Frances initialized 0000 UTC 30 August 2004. In each case, the operational cycle with all dropwindsonde data (AVNO), and three additional runs were completed: (1) no dropwindsonde data are assimilated (AVNN), (2) only those dropwindsonde data that meet the targeting requirements specified in Aberson (2003) are assimilated (AVTG), and (3) those dropwindsondes that meet the sampling strategy specified in Aberson (2003) but with targets defined by the ETKF are assimilated (AVET).

In the Charley case (Fig. 2), for the AVTG run, the six dropwindsondes extending from the eastern tip of Cuba to southwest of Jamaica, the two northernmost dropwindsondes to the east of Florida, the dropwindsonde near Cozumel, Mexico, and the eight dropwindsondes extending from the northern tip of the Yucatan peninsula to Tampa (except the one dropwindsonde closes to Key West), were removed from the data assimilation cycle. For the AVET run, the dropwindsonde at the easternmost tip of Cuba, the two northernmost dropwindsondes east of Florida, the dropwindsonde near Cozumel, Mexico, and the eight dropwindsondes extending from the northern tip of the Yucatan peninsula to Tampa were removed from the data assimilation cycle. Figure 3 shows the track forecasts for the four runs, and the errors are shown in Table 1. All three runs with dropwindsonde data provided better forecasts than the run with no dropwindsonde data, and only small differences between the forecasts with various combinations of the dropwindsonde data are evident.

In the Frances case (Fig. 4), for the AVTG run, all dropwindsonde data from the round-robin flight from Keesler Air Force base and the three northeasternmost dropwindsondes were removed from the data assimilation cycle. For the AVET run, all dropwindsonde data from the round-robin flight from Keesler Air Force base and the two northernmost dropwindsondes northeast of Hurricane Frances were removed from the data assimilation cycle. Figure 5 shows the track forecasts for the four runs, and the errors are shown in Table 2. The errors for all four runs are much smaller than those of the Charley case, and only small differences between all the forecasts are evident.

The results of these two cases, in addition to similar AVTG tests completed for the 2003 hurricane season, continue to suggest that the targeting and sampling strategy described in Aberson (2003) is appropriate for the design of flight tracks for the improvement of tropical cyclone track forecast. In both of these cases, the removal of between one-third and one-half of the dropwindsonde data from the data assimilation did not appreciably change the errors of the forecasts. The results of these two cases for the AVET version is only preliminary, and no conclusions can yet be drawn.

Testing with the remainder of the 31 cases from the 2004 season is proceeding.

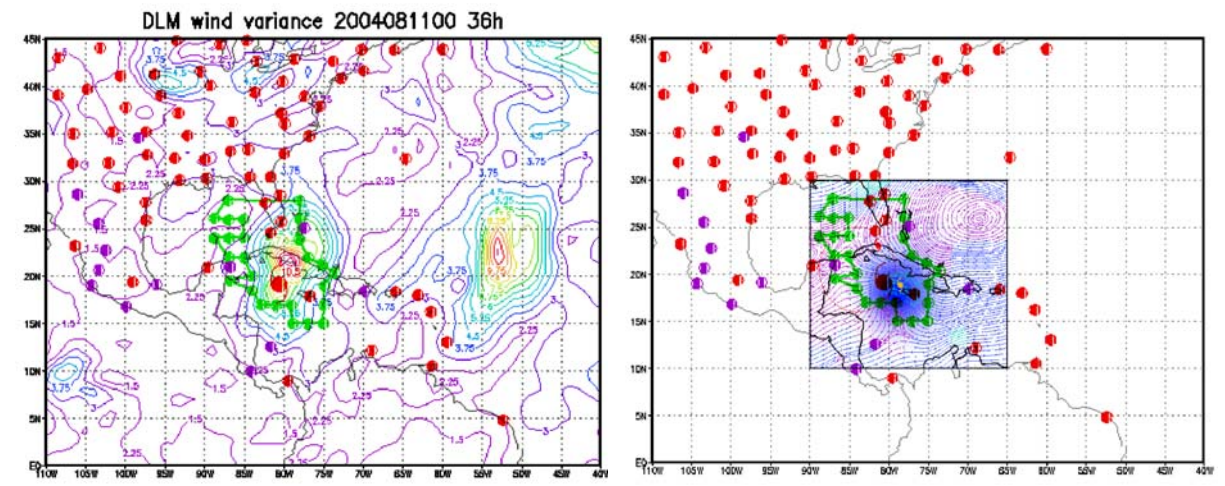


FIGURE 2. (a) Ensemble perturbation variance at the nominal sampling time 12 August 2004 1200 UTC from the previous day NCEP ensemble forecast, and (b) Variance explained within the verification region (large red circle) for observations taken at the sampling time 12 August 2004 1200 UTC from the Ensemble Transform Kalman Filter run from the previous day NCEP ensemble forecast. The green circles represent the dropwindsonde locations. Red and purple dots represent locations of regular and 1200 UTC rawinsonde locations.

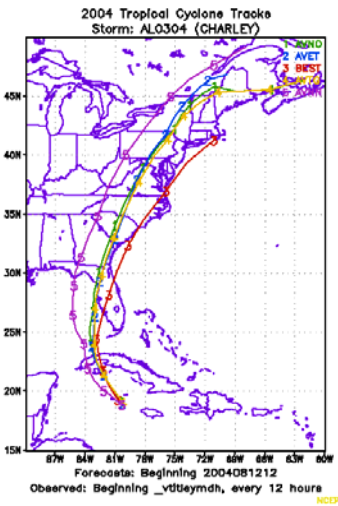


FIGURE 3. Best track and GFS forecast tracks for the four data assimilation cycles discussed in the test, for Hurricane Charley initialized on 12 August 2004 1200 UTC.

| TIME | 12h | 24h | 36h | 48h | 60h | 72h |
|---|---|---|---|---|---|---|
| AVNN | 89. | 289. | 519. | 844. | 1234. | 1620. |
| AVNO | 46. | 67. | 214. | 368. | 562. | 655. |
| AVET | 46. | 78. | 243. | 427. | 642. | 754. |
| AVTG | 46. | 59. | 184. | 372. | 641. | 751. |

Table 1: Track forecast errors (km) for the four runs of the Global Forecasting System initialized 1200 UTC 12 August 2004 for Hurricane Charley.

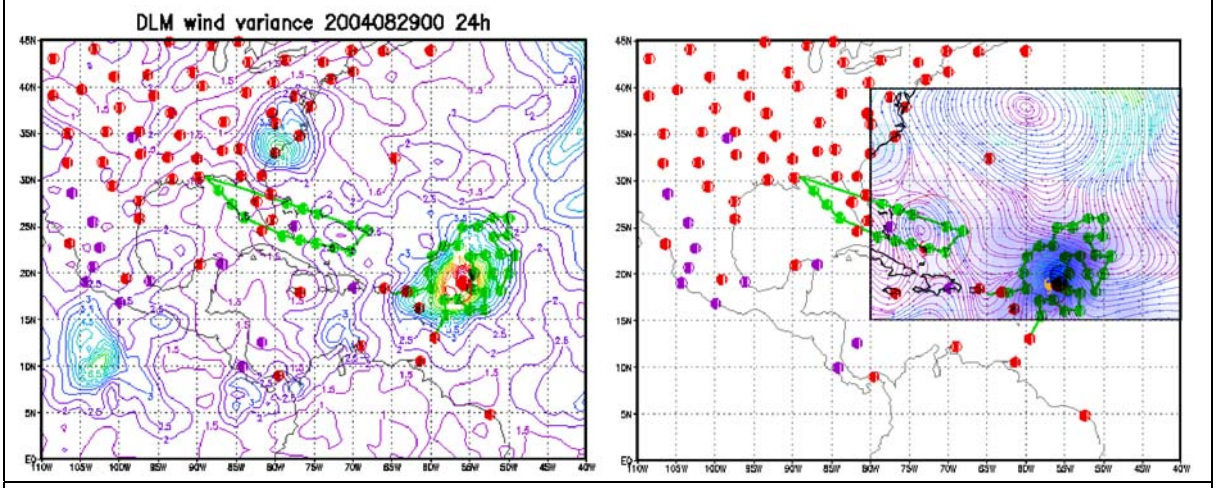


FIGURE 4. As in Fig. 2, except for 30 August 2004 0000 UTC.

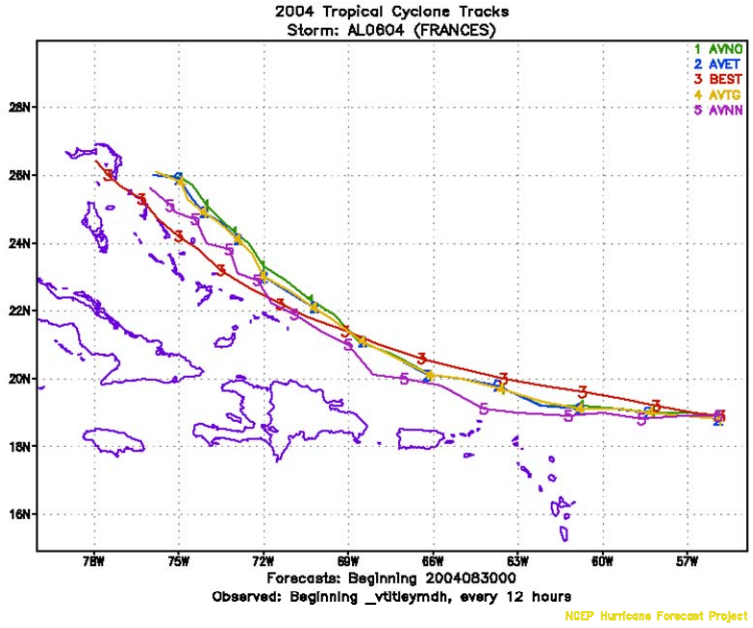


FIGURE 5. As in Fig. 3, except for Hurricane Frances initialized on 30 August 2004 0000 UTC.

Table 2: Track forecast errors (km) for the four runs of the Global Forecasting System initialized at 0000 UTC 30 August 2004 for Hurricane Frances.

| TIME | 12 h | 24 h | 36 h | 48 h | 60 h | 72 h | 84 h | 96 h | 108 h | 120 h |
|---|---|---|---|---|---|---|---|---|---|---|
| AVNN | 69. | 94. | 124. | 91. | 46. | 61. | 137. | 188. | 202. | 242. |
| AVNO | 25. | 44. | 33. | 64. | 62. | 114. | 153. | 203. | 232. | 260. |
| AVET | 39. | 56. | 30. | 59. | 70. | 124. | 155. | 213. | 226. | 250. |
| AVTG | 31. | 56. | 35. | 64. | 70. | 124. | 155. | 213. | 226. | 261. |

## 3. Work plan for remainder of JHT project

The bulk of the remainder of the JHT project will be spent evaluating the performance of the operational NCEP GFS model, initialized using observation locations predicted to be important by the different targeting strategies (Aberson, Etherton, with advice from TPC personnel).

Synoptic and dynamical insights into the targets selected by the respective techniques for 2004 are ongoing (Aberson, Etherton, Majumdar).

The ability of the ETKF to predict reduction in forecast error variance for the 2004 tropical cyclones will be evaluated (Etherton, Majumdar)

Much of the ETKF, ensemble spread and flight planner code at NCEP/EMC is automated. However, it still needs human input on the key parameters, and file transfer to be displayed on the website. Some minor modifications to the shell scripts will be required to automate the code fully.

The PIs have also been advising personnel in Taiwan (Dr Chun-Chieh Wu) on this year's DOTSTAR typhoon surveillance missions using ensemble spread and ETKF maps.

# REFERENCES

Aberson, S. D., 2003: Targeted observations to improve tropical cyclone track forecast guidance. *Mon. Wea. Rev*., **131**, 1613-1628.

Bishop, C. H., B. J. Etherton and S. J. Majumdar, 2001: Adaptive Sampling with the Ensemble Transform Kalman Filter. Part I: Theoretical Aspects. *Mon. Wea. Rev*., **129**, 420-436.

Majumdar, S. J., C. H. Bishop, B. J. Etherton and Z. Toth, 2002: Adaptive Sampling with the Ensemble Transform Kalman Filter. Part II: Field Program Implementation. *Mon. Wea. Rev*., **130**, 1356-1369.