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. Ensemble Transform Kalman Filter (ETKF)

The objectives of the Proposal and first Annual Report have been met. The ETKF code for tropical cyclones was prepared at NCEP EMC and run for almost every case during the active 2004 Atlantic hurricane season in which synoptic surveillance missions were being considered (*Majumdar, Etherton*). A 40-member 1° resolution NCEP GFS ensemble, initialized 48-72h prior to mission nominal time, was used in all calculations. ETKF maps for 2004 are archived on http://orca.rsmas.miami.edu/~majumdar/tc/. A flight track "planner" code, developed under funding by a prior JHT project, was coupled to the ETKF and ensemble spread outputs, to produce synoptic surveillance tracks that accounted for the targeting guidance and also parameters such as flight departure and return points, the routine rawinsonde network, no-fly zones etc (*Aberson, Leighton*).

For the 2005 Atlantic hurricane season, the ETKF has been automated at NCEP EMC (*Etherton*). Guidance has been provided for the early storms threatening landfall (Cindy, Dennis and Emily: Fig. 1). Wherever possible, the surveillance aircraft sample areas deemed sensitive by both the ensemble spread and ETKF, while still sampling in every quadrant around the storm.

To run the ETKF, the desired lead time of a specific TC forecast is first chosen. If the TC is expected to remain over water 72h after the nominal surveillance time, a 72h lead time is chosen. If the TC is expected to make landfall between 24-72h, the landfall time and location predicted by NHC are chosen as the verification time and region center. The ETKF predicts the horizontal wind 'signal variance' of the selected forecast due to any hypothetical deployment of wind and temperature observations at the nominal time. The signal variance is equal to the expected reduction of forecast error variance of the wind field within the verification region. This verification region is chosen to enclose the spread of TC forecasts at the verification time. The ETKF summary map in Fig. 1a shows the predicted 3-day forecast signal variance associated with Hurricane Emily, as a function of the observing location. The locations in which signal variance is highest depict 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. These areas deemed sensitive by the ETKF often coincide with locations of large ensemble spread.

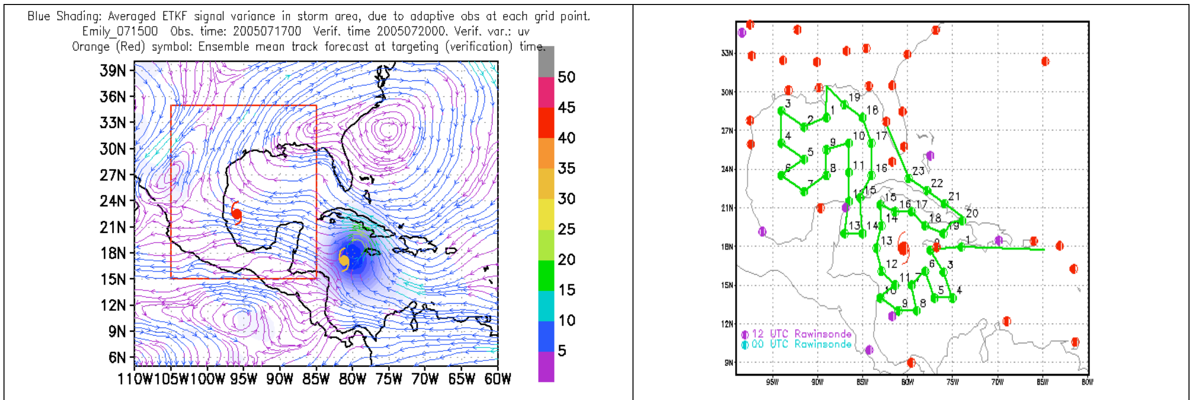

FIGURE 1. (a) ETKF summary map of 850-250hPa wind signal variance (shaded), for a 3-day forecast of Hurricane Emily.

(b) 2 concurrent Synoptic Surveillance flight tracks for Hurricane Emily, centered on 00 UTC 17 July 2005.

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

The PIs have also been advising personnel in Taiwan on this year's DOTSTAR typhoon surveillance missions using ensemble spread and ETKF guidance.

3. Evaluation of data impact in target regions

All 31 cases from 2004 have been examined to compare sampling strategies. Two cases were presented in the midyear summary, and will not be reiterated here. In each case, the operational cycle with all dropwindsonde data (GFSO), and three additional runs were completed: (1) no dropwindsonde data are assimilated (GFSN), (2) only those dropwindsonde data that meet the targeting requirements specified in Aberson (2003) are assimilated (GFTG), and (3) those dropwindsondes that meet the sampling strategy specified in Aberson (2003) but with targets defined by the ETKF are assimilated (GFET). Tests of the various strategies were conducted only if at least one-third of all the dropwindsonde data were not within the respective target region. Of the 31 cases, 14 had GFET runs, 16 had GFTG runs, and ten had both GFET and GFTG runs.

The results are as follows:

AVG. TRACK ERRORS (KM) FOR HOMOGENEOUS SAMPLE

FCST TIME	12h	24h	36h	48h	60h	72h	84h	96h	108h	120h
GFSN	51.1	62.6	100.0	142.1	184.1	264.1	207.7	261.0	303.1	334.0
GFSO	33.1	54.0	93.2	116.9	164.2	237.8	264.5	330.3	382.7	392.4
GFET	34.5	57.1	88.6	113.7	167.0	236.0	238.3	312.9	368.5	388.7
#CASES	14	14	14	14	14	14	13	13	13	12

The 84-h forecasts with ETKF targeting are statistically significantly better than those from the standard sampling at the 90% level.

AVG. TRACK ERRORS (KM) FOR HOMOGENEOUS SAMPLE

FCST TIME	12h	24h	36h	48h	60h	72h	84h	96h	108h	120h
GFSN	61.0	84.2	126.7	188.4	253.7	338.6	343.9	366.6	467.2	404.3
GFSO	41.6	62.9	103.0	146.8	208.9	281.7	354.1	422.7	535.4	533.0
GFTG	40.8	62.9	98.5	138.8	208.2	276.4	325.4	384.3	494.6	517.6
#CASES	16	16	16	16	16	16	15	12	12	10

The 84-, 96-, and 108-h forecasts with ensemble spread targeting are statistically significantly better than those from the standard sampling at the 90% level.

AVG. TRACK ERRORS (KM) FOR HOMOGENEOUS SAMPLE

FCST TIME	12h	24h	36h	48h	60h	72h	84h	96h	108h	120h
GFSN	56.1	73.7	121.7	178.4	232.3	324.8	248.9	305.3	357.4	382.0
GFSO	38.1	61.0	102.9	137.9	195.5	278.9	311.9	395.8	464.1	503.5
GFET	43.2	61.6	98.9	140.7	205.5	284.0	286.5	371.8	447.8	501.3
GFTG	42.1	57.6	95.2	132.0	203.5	277.5	279.2	367.7	439.1	492.1
#CASES	10	10	10	10	10	10	9	9	9	8

The ensemble spread targeting is statistically significantly better than the ETKF targeting at the 90% level at 24 and 48 h, though the size of the error differences is very small in this relatively small sample.

The results of these cases continue to suggest that both the targeting and sampling strategy described in Aberson (2003) and from the ETKF are appropriate for the design of flight tracks for the improvement of tropical cyclone track forecast. Both techniques provide forecasts statistically significantly better those with no sampling during the first three days of the forecast. The sample sizes are as large as those in the original HRD synoptic flow paper, and are therefore expected to be robust.

Results from individual cases are at http://www.aoml.noaa.gov/hrd/data_sub/assessment.html. Tests of cases from the 2005 season are ongoing.

Inner core dropwindsondes

Intensive study of the Hurricane Ivan missions during 2004 was conducted to deduce the reason for the degradation of track forecasts in the GFS due to the synoptic surveillance missions. It was concluded that the cause of the degradation was the assimilation of eyewall dropwindsondes from both NOAA and Air Force aircraft. Tests (GFIC) of Hurricane Ivan, in which the surveillance missions showed large degradations, and of Hurricane Charley, in which the surveillance missions showed large improvement, conclusively showed that the Ivan degradations were eliminated, and the Charley cases were even further improved by the elimination of all dropwindsonde data within 111 km of the operational tropical cyclone center.

AVG. TRACK ERRORS (KM) FOR HOMOGENEOUS SAMPLE (CHARLEY AND IVAN)

FCST TIME	12h	24h	36h	48h	60h	72h	84h	96h	108h	120h
GFSN	49.9	67.6	97.5	139.6	201.8	274.9	318.8	400.9	494.5	585.2
GFSO	51.7	83.2	122.8	164.4	224.9	291.6	360.2	461.6	569.0	657.7
GFIC	43.6	64.4	97.5	133.7	196.0	250.0	323.4	413.4	522.2	601.0
#CASES	45	44	44	44	44	42	40	38	36	35

FORECAST ERRORS (KM) FOR CHARLEY

FCST TIME	12h	24h	36h	48h	60h	72h	84h	96h
GFSN	107.9	131.7	207.5	330.5	461.0	610.9	245.0	408.9
GFSO	74.4	103.0	179.0	279.2	382.3	392.7	254.4	366.3
GFIC	77.0	96.1	139.4	224.4	328.6	309.0	295.3	337.4
#CASES	7	6	6	6	6	4	2	1

FORECAST ERRORS (KM) FOR IVAN

FCST TIME	12h	24h	36h	48h	60h	72h	84h	96h	108h	120h
GFSN	39.3	57.5	80.1	109.5	160.8	239.5	322.6	400.6	494.5	585.2
GFSO	47.6	80.0	113.9	146.2	200.1	281.0	365.8	464.2	569.0	657.7
GFIC	37.5	59.4	90.9	119.4	175.0	243.8	324.9	415.5	522.2	601.0
#CASES	38	38	38	38	38	38	38	37	36	35

As a result, the elimination of all dropwindsonde data from within 111 km of the operational storm center was implemented operationally at the beginning of the 2005 hurricane season.

Outstanding issues:

1. The automated flight track drawing software is nearly complete. It works for all prospective missions except those in which it must fly around Cuba. The issue of flying around Cuba has been much more difficult than expected, and further coding and testing are necessary before the software can be used operationally.

2. The current 2005 version of the GFS has been extremely difficult to implement on the computer system available for testbed work. As of writing, tests are ongoing to see if running the current operational version is possible.

3. Mirroring of data from the operational to the testbed computers has been spotty at times during the first two months of the 2005 hurricane season. This has greatly limited the opportunities to further test both the ensemble spread and ETKF targeting strategies during this time.

REFERENCES

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