Joint Hurricane Testbed Final Report

Assimilating Moisture Information from Global Positioning System (GPS) Dropwindsondes into the NOAA Global Forecast System

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Accomplishments:
First year goals and accomplishments can be found in the first year report available at http://www.nhc.noaa.gov/jht/05-07_proj.shtml. Year-2 goals of this JHT project include:

1. Finish performing parallel Global Forecast System (GFS) runs that include dropwindsonde humidity and archive results.
2. Assess performance of 2005 GFS operational vs parallel track/intensity forecasts and any other fields required by EMC.
3. Assess how effectively the GFS operational analyses represent dry layers such as the Saharan Air Layer (SAL) through direct comparisons with dropwindsonde data.
4. Assess feasibility of performing targeted observations of humidity to improve GFS forecasts (Aug 2006-Mar 2007).

Goals 1 and 2

Goals 1 and 2 were completed using Gulfstream-IV (G-IV) dropwindsonde data during 2005 tropical cyclones (TCs) Arlene, Cindy, Dennis, Emily, Irene, Katrina, Rita, Wilma, and Gamma. Unfortunately, there were persistent failures in parallel GFS runs for a few of the 2005 TC cases (e.g. TCs Cindy, Dennis, and Gamma). These failures generally occurred during forecast days 4 or 5; all available forecasts were included in the assessments. NCEP did not have the resources to solve the problem in the low-resolution runs on their temporary Research and Development Computer (aqua), but the sample was large enough without these few cases to consider the results conclusive. The runs were also made difficult by the computer transitions from snow to aqua to haze. Based upon work from this JHT project, the NOAA/National Centers for Environmental Prediction approved the assimilation of dropwindsonde humidity data into the GFS model from all dropwindsondes launched from NOAA's G-IV jet beginning on 22 August 2006 as stated in the following 04 August JIFMEMO:

> *"995. DATACARDS - IBM Jobs GFS_PREP, GDAS_PREP. (Keyser, NP22). This program PREPOBS_PREPDATA prepares observational data for subsequent quality control programs and for subsequent analysis in all forecast networks, using data card switches in the input parm cards to control processing based on the forecast network. The input parm cards for the GFS and GDAS networks, prepobs_prepdata.gfs.parm and prepobs_prepdata.gdas.parm, respectively, are being modified to no longer flag Gulf Stream dropwindsonde moisture data. These data, on all levels, will now be assimilated by the Global SSI analysis. USAF dropwindsonde moisture will continue to be flagged and not assimilated in all networks, as will Gulf Stream dropwindsonde moisture in the NAM, NDAS and RUC networks."*

Goal 3

GFS moisture analyses have been compared with dropwindsonde humidity data from the NOAA/HRD 2005 and 2006 SAL Experiment (SALEX) missions. Two missions during 2005 examined the interaction between the SAL and Tropical Storm Irene (07 and 08 August) and pre-Tropical Depression 19 (27 and 28 August). During 2006, two missions were conducted around Tropical Storm Debby (25 and 26 August), and four missions were conducted in and around Hurricane Helene (15, 16, 18, 20 September). All dropwindsonde data were obtained by the NOAA G-IV, except during two missions in Helene which included coordination with a NOAA P-3. Total precipitable water (TPW) imagery derived from microwave satellite data was used to target dropwindsonde releases in dry SAL air mass, moist tropical non-SAL air mass, and along the boundary between the two air masses, around the storm. Table 1 shows the number of SAL and non-SAL drops identified during each set of missions.

System name	Number of SAL drops	Number of non-SAL drops
Irene	26	13
Pre-Tropical Depression 19	17	18
Debby	35	4
Helene	44	23

Table 1. Numbers of SAL and non-SAL drops obtained during each set of SALEX missions. Dropwindsondes from the final Helen missions have not been processed and are not included in the samples. A small number of dropwindsondes for each storm are not classified in either sample if they provided erroneous data or were dropped on the boundary between air masses.

Several interesting characteristics of the mean SAL and non-SAL profiles for the two sets of missions, and of the GFS analyses during these missions, were evident (Fig. 1):

During both 2005 and 2006, the SAL soundings showed a relative humidity (RH) minimum between 650 and 750 hPa. The 2006 SAL soundings were drier than those from 2005 in the SAL layer (~500 to 850 hPa) and above and also had a humidity minimum near 700 hPa. Since the 2006 data were obtained at higher latitudes and later in the season than the 2005 data, the deep, dry air may have its origins in mid-latitudes.

The non-SAL soundings were markedly moister during 2006 than 2005. The reason for this is unclear.

During 2005, when dropwindsonde humidity data were not assimilated into the operational GFS, the model initial conditions at the dropwindsonde locations were up to 20% RH too moist through the SAL layer, and nearly 15% RH too dry below. Therefore, the GFS had about 75% too much moisture throughout the SAL layer. During 2006, when the humidity data were assimilated operationally, the GFS was closer to the observations at nearly all levels than during 2005, except in the core of the SAL (near 700 hPa). The dry bias near the surface was eliminated during 2006.

The differences between the GFS and the dropwindsonde data were smaller in the non-SAL sample than in the SAL sample below about 400 hPa.

During both years the operational GFS was too moist above 400 hPa compared to both the SAL and non-SAL soundings. During 2005, the GFS had about three times too much moisture; during 2006, the GFS was four to five times too moist there. This is similar to findings presented by Dunion et al. 2004 and suggests that the upper-level moisture in the TC environment appears to be consistently overestimated by the GFS. The causes and implications of these large differences are currently unknown.

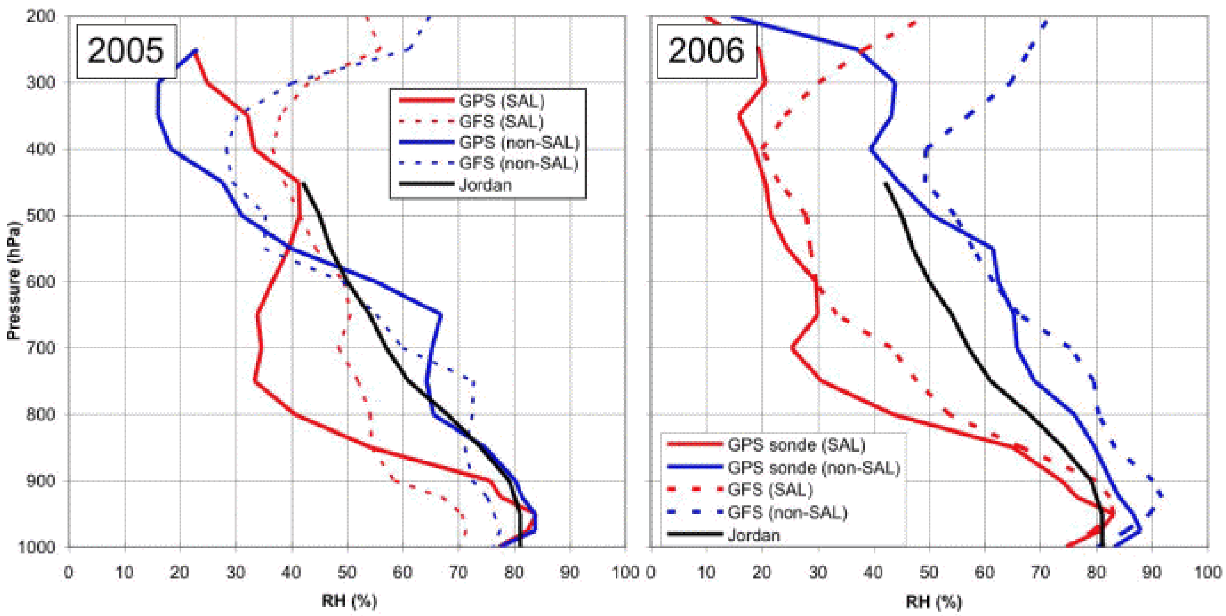

Figure 1. Mean co-located dropwindsonde and GFS analysis humidity profiles during (left) 2005 and (right) 2006. The numbers of soundings in each mean are given in Table 1. The mean Jordan sounding is shown for comparison.

The results associated with Goal 3 suggest that the GFS moisture analyses of the SAL and near-surface regions have improved with the assimilation of dropwindsonde humidity data. However, a marked moist bias remains near the core of the SAL. The GFS also greatly overestimates the upper-level moisture in the TC environment, and this has not improved with the assimilation of the dropwindsonde humidity data.

Goal 4

Ensemble Transform Kalman Filter targeted observation guidance during the 2006 SALEX missions were made thanks to Dr. Sharanya Majumdar (UM/RSMAS). (Daily guidance during August and September of 2006 using TPW water as the norm are available at < http://orca.rsmas.miami.edu/~majumdar/amma/ >.) In the special guidance, a 144-member combination European Centre for Medium-Range Weather Forecasting/Canadian Meteorological Centre/National Centers for Environmental Prediction global ensemble is used. Four norms (deep-layer mean wind and temperature, 700 hPa wind, 850 hPa temperature, and 850 - 500 hPa RH) are used, with the goal of improving the 700 hPa wind forecast in a box 20 degrees on each side centered on the forecast location of the TC at the observing time. An example of such guidance is shown in Fig. 2 for Tropical Storm Debby.

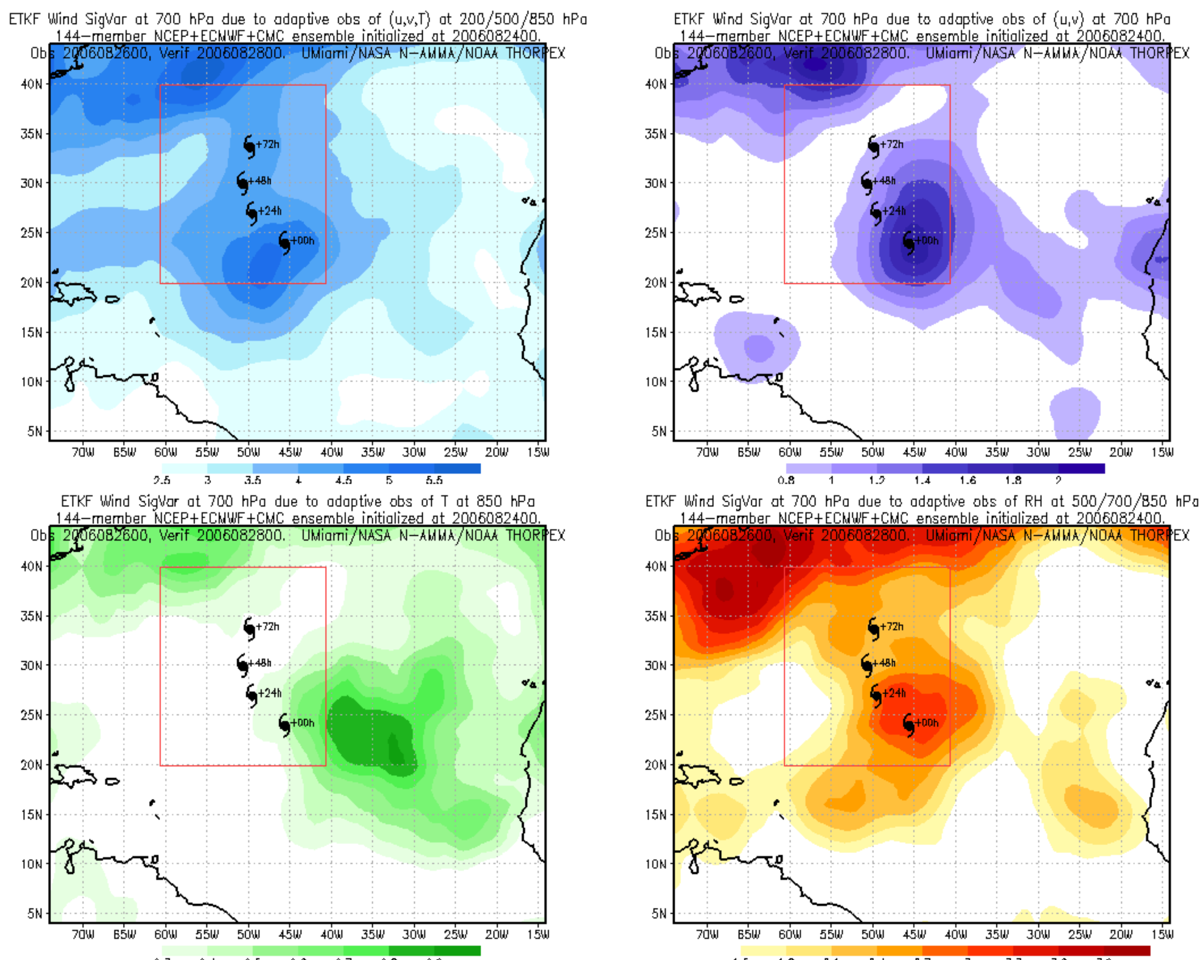

Figure 2. ETKF guidance for Tropical Storm Debby for observations taken 0000 UTC 26 August 2006 to improve the subsequent 48-h forecast of 700 hPa wind within the verification region (red square), for (upper left) deep-layer-mean wind, (upper-right) 700 hPa wind, (lower-left) 850 hPa temperature, and (lower-right) 850-500 hPa RH. Past and forecast locations of Debby are also shown.

On 26 August, Debby was surrounded by a large region of dry air of Saharan origin (Fig. 3). The ETKF in both Debby cases suggests that the 700 hPa wind forecast would be improved by sampling the moisture in the dry region around Debby, especially in its extension to the southwest of the storm, in the dry, continental air behind the cold front off the east coast of the United States, and in the next SAL outbreak currently located near the Cape Verde Islands. The first region would impact the short-term forecast and follow the storm; the second and third regions would impinge upon Debby during the forecast and influence the future track and intensity. On the other hand, for Tropical Storm Helene (not shown), a large region of moist air surrounds the storm, and the ETKF suggests sampling this region. No major mid-latitude troughs nor SAL outbreaks further to the east are in evidence.

Unresolved issues:

Dropwindsonde humidity data from the NOAA G-IV are currently assimilated into the GFS. Dropwindsonde humidity data from other NOAA aircraft and aircraft from other agencies (e.g. Air Force C-130s) are not assimilated into the GFS.

References:

Dunion, J.P., C.S. Velden, J.D. Hawkins, and J.R. Parrish, 2004: The Saharan Air Layer- Insights from the 2002 and 2003 Atlantic hurricane seasons. *AMS 26th Conference on Hurricanes and Tropical Meteorology*, Miami, FL, American Meteorological Society, 495-496.

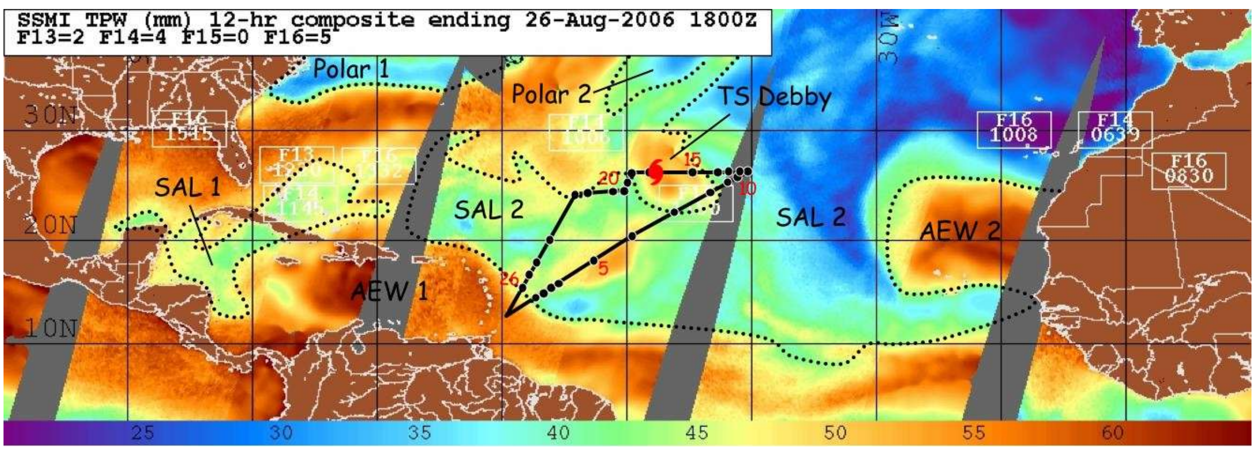

Figure 3. Twelve hour composite (ending 1800 UTC 26 August) of satellite-derived TPW data across the north Atlantic with major features labeled. Black dots represent dropwindsonde locations.