Joint Hurricane Tesbed First Year Accomplishments and Second Year Proposal

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

Principle Investigator: Sim D. Aberson
NOAA/AOML/Hurricane Research Division

Co-Investigator: Jason P. Dunion
University of Miami/RSMAS/CIMAS

1. Introduction

Since 1997, NOAA has conducted operational synoptic surveillance missions in and around tropical cyclones (TCs) to improve track forecasts during the watch and warning forecast periods (24-48 h). Using targeted observations and improved sampling strategies, the missions have provided large improvements in track forecasts. However, changes to intensity forecasts have been shown to be minimal. Temperature, wind, height, and pressure measurements from Global Positioning System (GPS) dropwindsondes launched during these operational missions are assimilated into the National Centers for Environmental Prediction (NCEP) Global Forecasting System (GFS). However, because of a dry bias in the early model dropwindsondes, moisture measurements have not been assimilated. By 2003, the dry bias was corrected.

Dunion and Velden (2004) found that low humidity air from the Saharan Air Layer (SAL) might be an important factor in TC intensity change in the North Atlantic and Caribbean Sea. This suggests that accurate initial conditions of moisture are necessary for accurate intensity forecasts. Subsequent studies by Dunion et al. (2004) have shown that the GFS may be significantly overestimating the moisture in the SAL, suggesting the need for assimilation of high quality moisture data. The goal of the current study is to conduct a parallel run of the GFS to test the impact of dropwindsonde moisture data during the 2005 hurricane season. A record 42 synoptic surveillance missions were conducted in ten storms. A further set of missions conducted during the NOAA Saharan Air Layer Experiment (SALEX) are also available for testing. The following provides preliminary results of the parallel runs.

2. Year-1 Project Goals (June 1, 2003 – April 3, 2006)

This project includes the following commitments in year-1:

- June-Dec 2005: Perform parallel runs of the GFS that include dropwindsonde humidity and archive results
- Jan-May 2006Assess performance of 2005 GFS operational versus parallel track/intensity forecasts and any other fields required by EMC.
- Jan-June 2006: Assess how effectively the 2005 GFS operational versus parallel fields represent dry layers such as the Saharan Air Layer (SAL) through direct comparisons with dropwindsonde data.

3. Year-1 Project Accomplishments (June 1, 2003 – April 3, 2006)

a. Perform parallel runs of the GFS that include dropwindsonde humidity and archive results

The 2005 Atlantic hurricane season was a record-breaking year for tropical cyclone (TC) activity and also a record-breaking year for the NOAA G-IV jet. The G-IV flew over 40 operational synoptic surveillance missions into 10 separate TCs. Parallel runs of the GFS model that include dropwindsonde humidity are being run for all of these 2005 cases under this JHT project. Table 1 lists the current status of this parallel run effort, which includes 45 G-IV operational missions around 10 TCs and four G-IV research missions around two TCs. Parallel runs have been made for eight storms as of the date of this report. Of these eight parallel runs, five storms have been successfully completed (Arlene, Emily, Irene, Katrina, and Rita) and three storms have had recurring GFS run failures. The PI and Co-I are currently working with scientists at NCEP/EMC to resolve these failures. All parallel runs are currently being saved on the NCEP supercomputer in Washington, D.C.

Storm	G-IV Missions	Parallel Run Status
Arlene	2	Completed
Cindy	1	Run failed
Dennis	4	Run failed
Emily	4	Completed
SALEX (Irene)	2	Completed
Irene	2	Completed
Katrina	6	Completed
Ophelia	9	Not Completed
Rita	8	Completed
SALEX (pre-TD19)	2	Not Completed
Wilma	9	Not Completed
Gamma	1	Run failed

Table 1: Storms being investigated (parallel GFS runs) under this project and the current run status for each storm. Parallel Run Status indicates if the research runs have been successfully completed (Completed), have yet not been completed (Not Completed), or have had recurring GFS run failures (Run Failed).

b. *Assess performance of 2005 GFS operational versus parallel track/intensity forecasts and any other fields required by EMC*

The performance of the GFS in forecasting track has been assessed for the storms that have been completed as of the date of this report (Arlene, Emily, Irene, Katrina, and Rita). NOAA/NCEP/EMC requested that the parallel GFS runs be run at a lower resolution (T254) in order to limit the EMC resources that would be required. Therefore, the GFS parallel runs from this project were compared with lower resolution (T254) GFS operational runs, in order to normalize the comparisons. Figure 1 shows the performance of these runs and indicates that the parallel runs performed similarly to the operational runs, and tended to slightly outperform the operational model at the later time periods (~84-120 hr). The probabilities for model track differences (T254 operational versus parallel runs) range from 52% at T=24 hr to 89% at T=60 hr (adjusted for 24 hr serial correlation). These values are expected to stabilize as additional 2005 storms are added to the dataset. These preliminary results suggest that the addition of the GPS dropwindsonde humidity data to the GFS will not adversely affect track forecast performance.

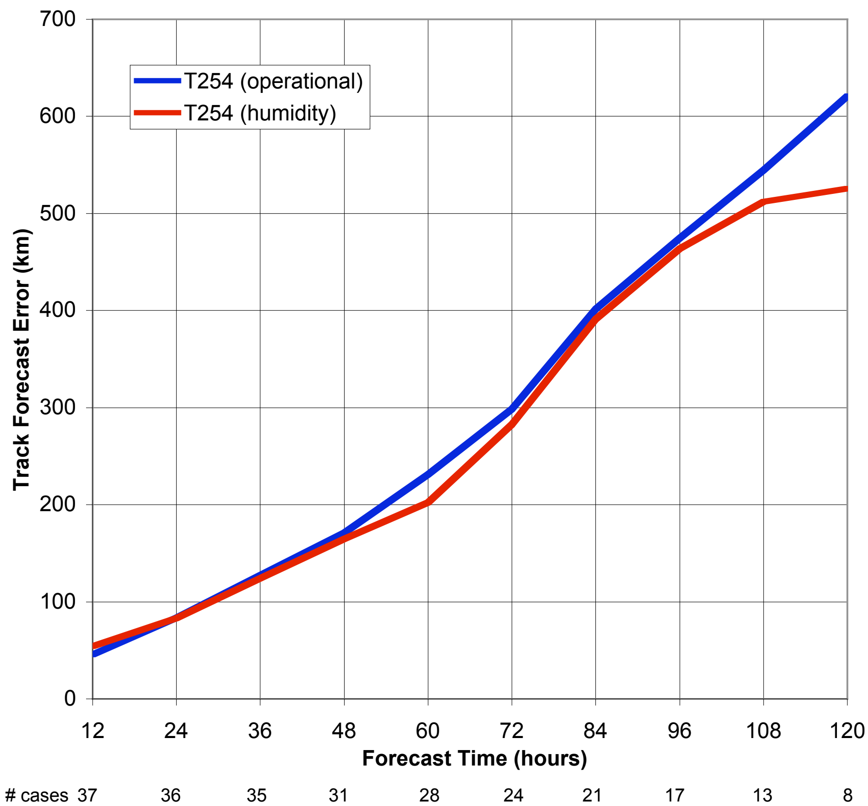

Figure 1: Plots of GFS T254 parallel (red curve) versus operational (blue curve) track forecast errors for the TCs that have been completed as of the time of this report (Arlene, Emily, Irene, Katrina, and Rita). The performance of both runs is quite similar, with the parallel runs slightly outperforming the operational runs in the later forecast periods (~84-120 hr). The number of cases that contributed to each forecast time is indicated below the x-axis for this homogeneous sample.

Since the database of parallel runs associated with this project are still being compiled, individual cases of track performance were also made. Figure 2 shows a sample of the T254 parallel versus operational GFS track forecasts for 2005 Hurricane Katrina. Although both forecasts had an eastward track bias, the GFS parallel run forecast consistently outperformed the operational forecast relative to the best track. This plot indicates that by merely adding the GPS dropwindsonde humidity information to the GFS assimilation process, the track forecasts for Katrina were significantly impacted. In other cases (e.g. Emily), the results were mixed and neither model run consistently outperformed the other.

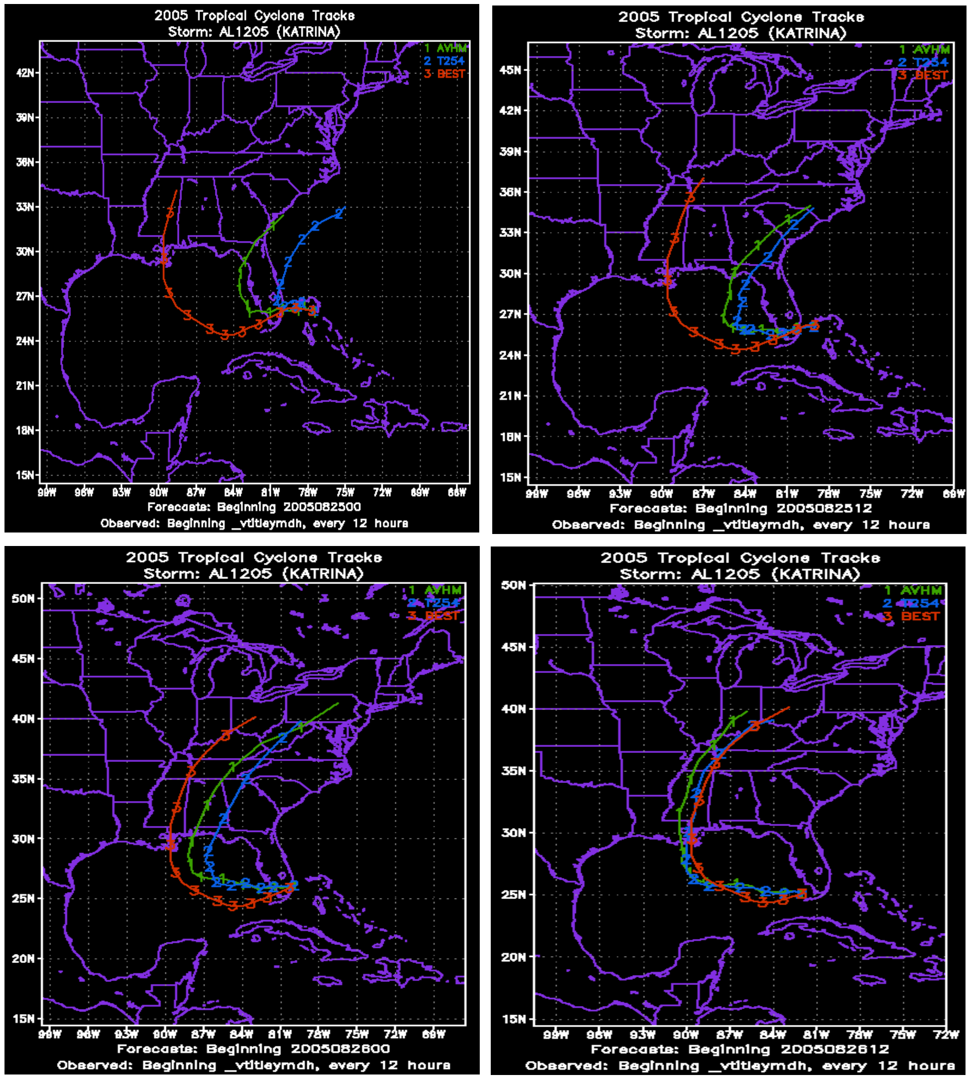

Figure 3: Plots of the GFS T254 track forecasts for (upper left) 0000 UTC 25 August, (upper right) 1200 UTC 25 August, (lower left) 0000 UTC 26 August, and (lower right) 1200 UTC 26 August for Hurricane Katrina. The operational (blue curve), parallel (green curve), and best track (red curve) tracks are indicated.

The performance of the GFS in forecasting intensity has been assessed for the storms that have been completed as of the date of this report (Arlene, Emily, Irene, Katrina, and Rita). Again, these parallel GFS runs were run at a lower resolution (T254) and compared with lower resolution (T254) GFS operational runs, in order to normalize the comparisons. It should be noted that the large scale models (e.g. the GFS) tend to exhibit little to no skill at forecasting TC intensity. Limitations associated with these models include an insufficient resolution to resolve the smaller scale processes that are associated with TC dynamics. However, it was still important to identify differences in the intensity forecasts made by the T254 GFS parallel and operational runs. Figure 3 shows the performance of these runs and indicates that the parallel runs performed similarly to the operational runs. The probabilities for model intensity differences (T254 operational versus parallel runs) range from 50% at T=84 hr to 96% at T=12 hr (adjusted for 24 hr serial correlation). These values are expected to stabilize as additional

2005 storms are added to the dataset. These preliminary results suggest that the addition of the GPS dropwindsonde humidity data to the GFS will not adversely affect intensity forecast performance of the GFS. However, since other TC forecast intensity models (e.g. SHIPS and GFDL) use the GFS to define the TC environment, any changes in the GFS initial and forecast fields could significantly affect these models. This is possibility is addressed in the next section.

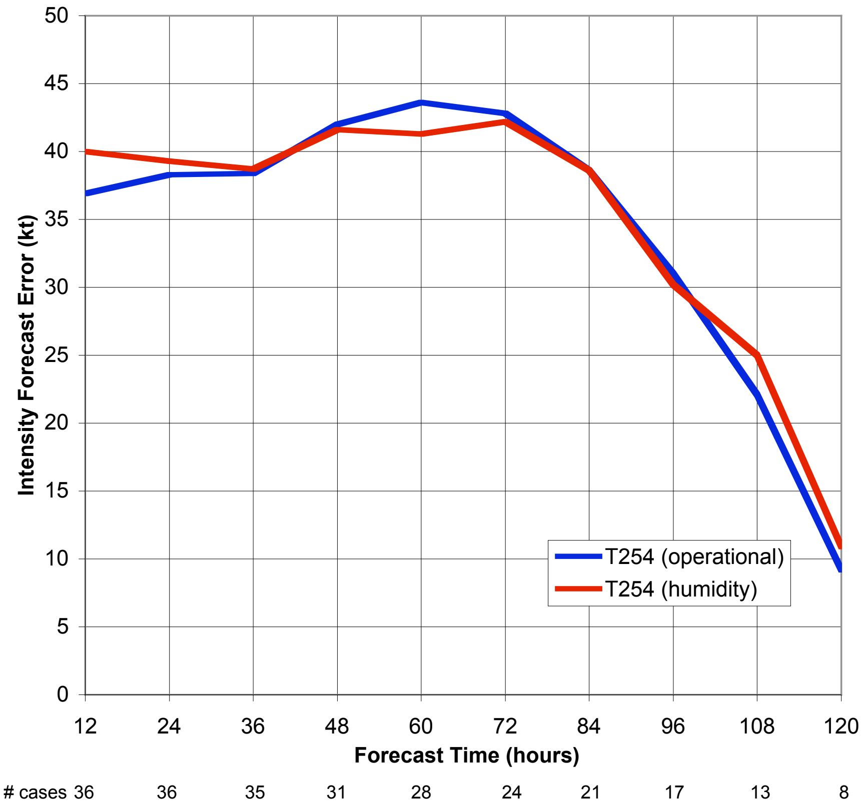

Figure 3: Plots of GFS T254 parallel (red curve) versus operational (blue curve) intensity forecast errors for the TCs that have been completed as of the time of this report (Arlene, Emily, Irene, Katrina, and Rita). The performance of both runs is quite similar. The number of cases that contributed to each forecast time is indicated below the x-axis for this homogeneous sample.

It is perhaps not entirely unexpected that GFS intensity forecasts for the operational versus parallel runs were overall quite similar. Since the GFS is not able to resolve many of the smaller scale processes that can affect TCs (e.g. dry air entrainment), any changes in the humidity fields that result from the dropwindsonde humidity data would likely not affect the GFS intensity forecast. However, other TC forecast intensity models that use the GFS global field to diagnose the environment surrounding the TC (e.g. SHIPS and GFDL) could be significantly affected by any changes in the GFS analyses and forecasts. Specifically, changes to the moisture fields related to the dropwindsonde data could have large impacts on intensity forecasts produced by these models.

Figure 4 shows the difference fields (GFS T254 parallel minus operational) of the mean 500-850 hPa RH for 2005 Hurricane Rita. Even at the initial time (00h), there are 10-20% RH differences in the fields. By the 72 hr forecast period, these RH differences have increased to as much as 20-35%. This suggests that even at the initial time, the humidity data from the GPS dropwindsondes can significantly affect the GFS analysis field and that these differences grow with successive forecast periods. The Tropical Storm Irene fields (not shown) exhibited similar difference field trends. The differences are probably large enough to have a significant impact on intensity forecast models such as SHIPS and GFDL and could easily be studied further.

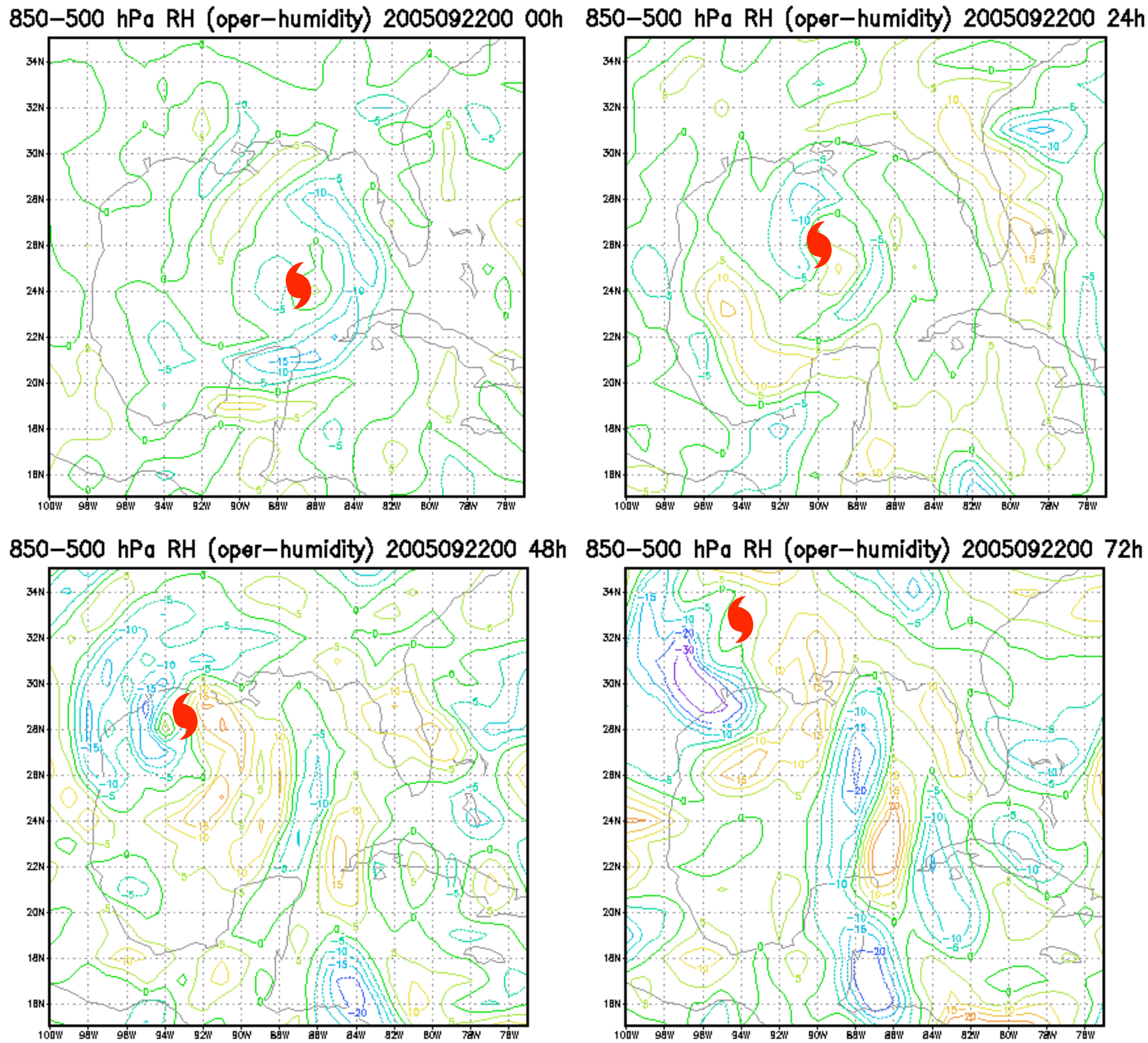

Figure 4: Difference fields (GFS T254 parallel minus operational) showing the mean 500-850 hPa RH for 2005 Hurricane Rita at 0000 UTC 22 September 2005 for the (upper left) analysis time (00h), (upper right) 24-h forecast (24h), (lower left) 48-h forecast (48h), and (lower right) 72-h forecast (72h). The differences are contoured in +/- 5% RH intervals and the best track position for Rita at each forecast time is overlaid for reference.

c. Assess how effectively the 2005 GFS operational versus parallel fields represent dry layers such as the SAL through direct comparisons with dropwindsonde data.

The NOAA/AOML/Hurricane Research Division conducted first-ever missions of its Saharan Air Layer Experiment (SALEX) using the NOAA G-IV jet in 2005. The first of these missions (050807n) investigated Tropical Storm Irene and several areas of Saharan air that surrounded the storm at this time. The flight plan was designed to investigate several areas of

SAL air around Irene, including "older Saharan air to its west (Fig. 5, *SAL 2*) and a "new" SAL outbreak that was impinging on the inner core region from the east (Fig. 5, *SAL 3*).

Figure 5 shows that several GPS dropwindsondes were launched in the environment of the SAL 2 and SAL 3 outbreaks. The SAL 2 dropwindsondes (e.g. Fig. 5 & 6; A) exhibited extremely dry profiles and both the GFS T254 operational and parallel runs also indicated that extremely dry low to mid-level air was present in this area. In fact, both GFS runs appear to have been depicting the dry SAL air remarkably well (Fig. 6, top left). The area north of Irene (e.g. Fig. 5 & 6; B) was associated with very moist air in the low to middle levels. Both GFS runs were underestimating the low to mid-level moisture in this region. Finally, the SAL 3 dropwindsondes (Fig. 5 & 6; C and D) depicted very dry low to mid-level dry SAL air just east of Irene. Figure 6 (C and D) shows that the dropwindsonde profiles exhibited a classic SAL sounding in these areas (wedge of extremely dry air from ~500-850 hPa). Once again, the GFS T254 operational and parallel runs were representing this dry air associated with the SAL 3 outbreak remarkably well.

Figures 5 and 6 indicate that even at time zero, the GPS dropwindsonde humidity data from the G-IV is affecting the humidity profiles of the GFS and that the GFS (T254 operational and parallel runs) appears to be representing the low humidity of the SAL fairly well. Further comparisons will be made during year 2 of this project so that these preliminary results can be further substantiated.

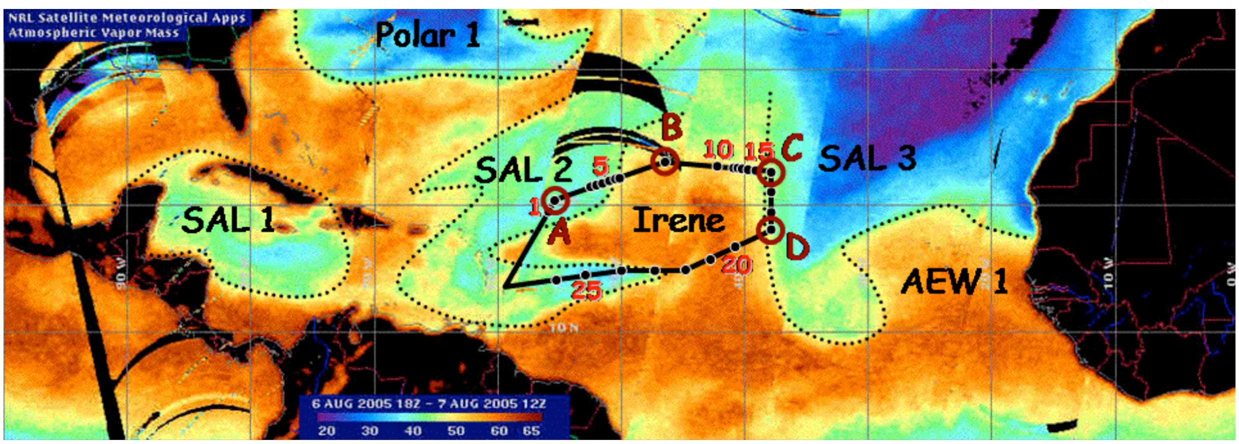

Fig. 5: Mosaic of total precipitable water (TPW) from the constellation of SSM/I satellites (1200 UTC 07 August 2005). Regions where TPW values are <45 mm (dotted lines) indicate dry air in the low to mid-levels of the atmosphere (~600-925 hPa). Three distinct areas of dry SAL air (*SAL 1, 2, & 3*) and one area of dry polar air (*Polar 1*) are indicated in the imagery. The G-IV flight track and dropsonde points are overlaid on the imagery. Four specific drop points are outlined by red circles (A, B, C, D). Irene was located at ~21.0N 47.0W at this time. Imagery courtesy of NRL-Monterey.

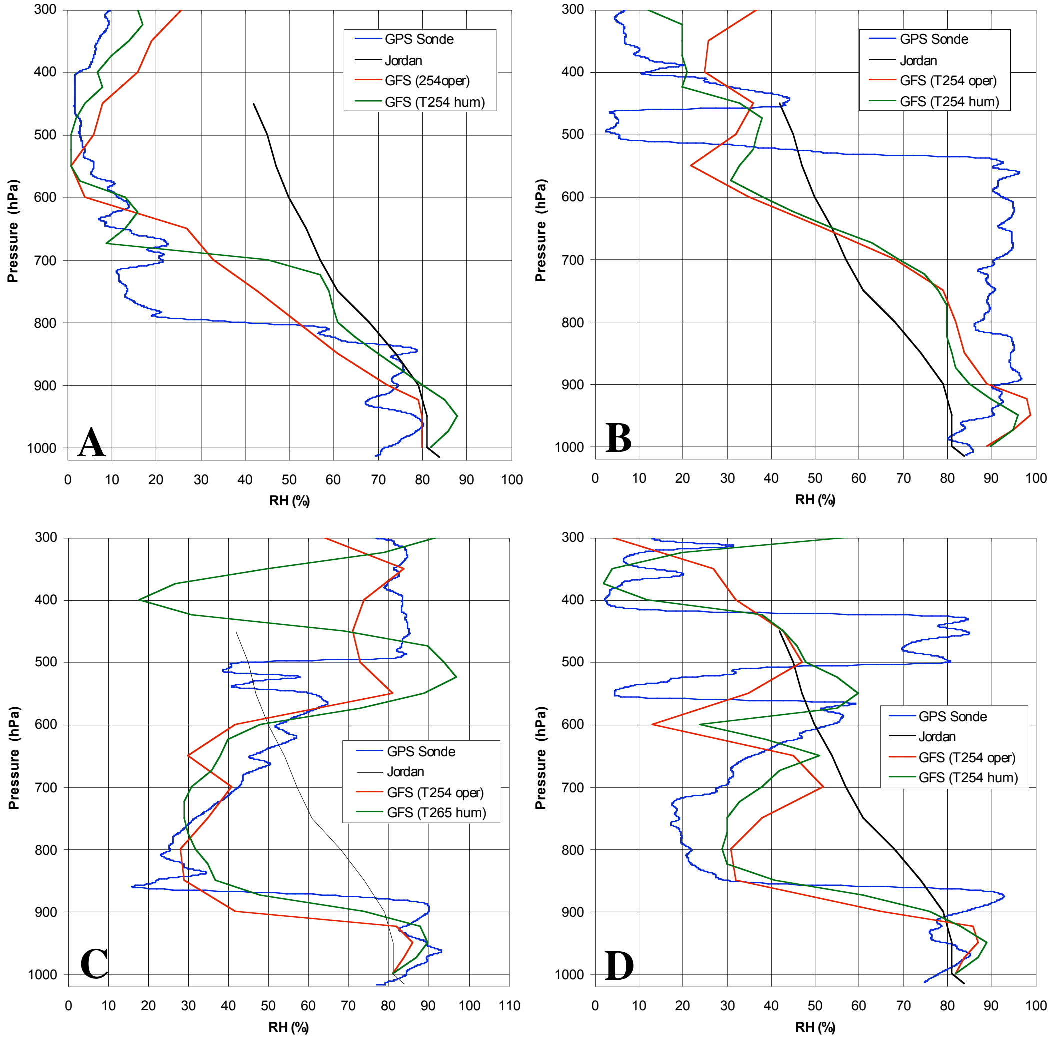

Figure 6: Dropwindsonde humidity profiles from SALEX mission 050807n. The four profiles shown (A-D) correspond to those locations shown in Figure 5. The GPS dropwindsonde profile (blue curve), Jordan mean tropical sounding (black curve), GFS 254 operational run (red curve), and GFS T254 parallel run (green curve) are depicted in each plot.

Figure 7 shows the temperature and wind profiles at drop point number 19 of SALEX mission 050807n (Fig. 5 & 6; D). Although not part of this JHT project, it is interesting to note that the GFS (T254 operational and parallel runs) were not effectively capturing the strong (4.7°C) temperature inversion at the base (~850 hPa) of SAL 3 (Fig. 5) or the strong (~30 kt) 700 hPa easterly jet associated with the southern boundary of SAL 3 (Fig. 5). Strong temperature inversions and mid-level easterly jets are commonly associated with SAL outbreaks and both can act to suppress TC formation (Dunion and Velden 2004). In this case, neither atmospheric component was being particularly well depicted in the GFS and might have led to poor intensity forecasts by models that use the GFS fields to define the surrounding TC environment (e.g. SHIPs and GFDL). This finding may warrant further research in the future.

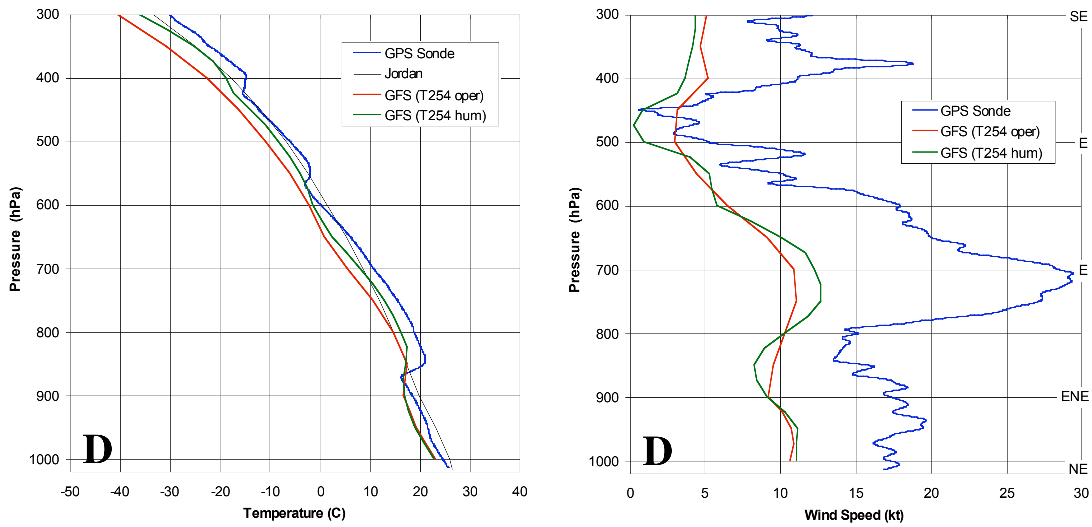

Figure 7: Dropwindsonde (left) temperature and (right) wind profiles from SALEX mission 050807n. Both profiles shown are from drop point number 19 (D) and correspond to the location shown in Figure 5. The GPS dropwindsonde profile (blue curve), GFS 254 operational run (red curve), and GFS T254 parallel run (green curve) are depicted in each plot.

4. References

Dunion, J.P., and C.S. Velden, 2004: The impact of the Saharan Air Layer on Atlantic tropical cyclone activity. *Bull. Amer. Meteor. Soc.*, **85 no. 3**, 353-365.

5. Second year proposal (April 2006 – March 2007)

a. Work Plan

The overall outline for the second year of this proposal is nearly identical to that which was submitted in the original proposal. The time line is slightly pushed back from the previous proposal due to the relatively large number of storms being examined from the 2005 Atlantic hurricane season and the GFS forecast failures that have been problematic for a few of the 2005 storm cases. Close cooperation is needed between the PI and Co-I and NOAA/NCEP/EMC to resolve this ongoing _problem, so that this project can continue to move forward.

The proposed 2006 efforts include:

April-June 2006	Finish performing parallel GFS runs that include dropwindsonde humidity and archive results
April-August 2006	Assess performance of 2005 GFS operational vs parallel track/intensity forecasts and any other fields required by EMC.
April-Sept 2006	Assess how effectively the 2005 GFS operational vs parallel fields represent dry layers such as the SAL through direct comparisons with dropwindsonde data.
Aug 2006-Mar 2007	Assess feasibility of performing targeted observations of humidity to improve GFS forecasts.
March 2007	Present year 2 results at the IHC.

b. Schedule and needs for expected travel

No significant changes to those outlined in the original proposal are anticipated.

c. JHT staff requirements

No significant changes to those outlined in the original proposal are anticipated.

d. Budget

No changes are requested for the budget that was submitted in the original proposal. The original budget information is included here for reference.

JHT (Aberson)		FY05			FY06			
		mm			mm			
S. Aberson	AOML	3.0	22.9		3.0	24.2		
J.Dunion	CIMAS	2.0	9.7		2.0	10.2		
Total Salaries			32.6			34.4		
Fringe Benefits	AOML		5.9			6.5		
	CIMAS		3.0			3.3		
Salaries + Fringe			41.6			44.3		
Indirect Costs	AOML		11.3			12.1		
	CIMAS		3.3			3.5		
Total Labor			56.2			59.9	2-yr Labor	116.0
Equipment			0.0			0.0	2-yr Equipment	0.0
Travel			2.0			2.0	2-yr Travel	4.0
Publications			0.0			0.0	2-yr Publications	0.0
Other			6.0			6.0	2-yr Other	12.0
Total			64.2			67.9	2-yr Total	132.0