# 3.5 TAMDAR-RELATED IMPACTS ON THE AIRDAT OPERATIONAL WRF-ARW AS A FUNCTION OF DATA ASSIMILATION TECHNIQUES

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## 1. INTRODUCTION

During the fall of 2008, AirDat added a new version (Version 3.01) of the NCAR Advanced Research WRF (ARW) to the fleet of grid-scale mesoscale models that currently assimilate atmospheric measurements performed by the Tropospheric Airborne Meteorological Data Reporting (TAMDAR) sensor. The TAMDAR sensor measures humidity, pressure, temperature, winds aloft, icing, and turbulence, along with the corresponding location, time, and altitude from a built-in GPS unit. These observations are transmitted in real-time to a ground-based operations center via a global satellite network. NCAR and AirDat scientists developed a new TAMDAR observation assimilation capability in the WRFDA data assimilation system. Several data-denial studies, including parallel forecasts from the WRF, were conducted. The 84-h experimental (control) forecasts included (withheld) the TAMDAR data. The objectives of this study are to understand the impacts, if any, that TAMDAR data has on the AirDat WRF forecast system. An overview of the TAMDAR-enhanced WRFDA system is included in the next section, followed by a brief description of the model grid and physics configurations used in this study. Some preliminary results from our case studies are then presented.

## 2. MODEL OVERVIEW

### a. WRFDA System

WRFDA uses an incremental formulation, in model space, for the variational problem. Previous forecasts, observations and physical laws are combined to produce an analysis increment which is added to the first guess to provide an updated analysis (Barker et al, 2004). Following the assimilation of all of the observational data, an analysis is produced which must be merged with the existing lateral boundary conditions before the WRF forecast can begin. Several updates have been introduced to the latest WRFDA system. These include, improved assimilation of asynoptic observation platforms, including TAMDAR. In addition, a revised First Guess at Appropriate Time (FGAT) package has been implemented in the WRFDA system (Lee et al, 2004). This procedure allows for a more accurate calculation of innovation vectors and a more optimal use of observations when their valid time differs from that of the analysis.

NCAR and AirDat scientists developed and implemented several new modules into the latest WRFDA system. These components were developed to assist in the assimilation and evaluation of TAMDAR data using the NCAR WRFDA package. They include: 1) A TAMDAR observation ingest interface and quality control module in the OBSPROC (observation processing) component of the WRFDA system, and 2) a TAMDAR observation forward, tangent linear and adjoint operator. The TAMDAR observation variables include wind, temperature and relative humidity. The TAMDAR observation operator uses a bilinear interpolation, the same as the radiosonde operator used in the OBSPROC program. Several adjoint checks of the TAMDAR operator were performed to test that the TAMDAR operator was configured correctly.

### b. WRF-ARW System

WRF-ARW is a fully compressible, nonhydrostatic mesoscale modeling system with a run-time hydrostatic option. WRF is conservative for scalar variables and uses a terrain-following, hydrostatic-pressure vertical coordinate with the top of the model being defined along a constant pressure surface. The WRF horizontal grid uses the Arakawa-C staggering definition. The time integration scheme in the model employs the third-order Runge-Kutta scheme, and the spatial discretization includes 2nd to 6th order schemes. The current WRF-ARW release supports full physics, two-way, one-way and two-way moving nests as well as analysis and observation nudging.

Several case studies were performed to understand the impact, if any; TAMDAR data has on the WRF model forecasts. AirDat scientists configured a modeling grid over the western Atlantic Ocean and Caribbean Sea to study tropical cyclone formation and evolution during the autumn months of 2008. The tropical model domain used in this study is shown in Fig. 1. The configuration included a 400 x 255 grid with a

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horizontal grid spacing of 18km. 42 hybrid-sigma levels were assigned with enhanced resolutions in the boundary layer and within the jet stream level.

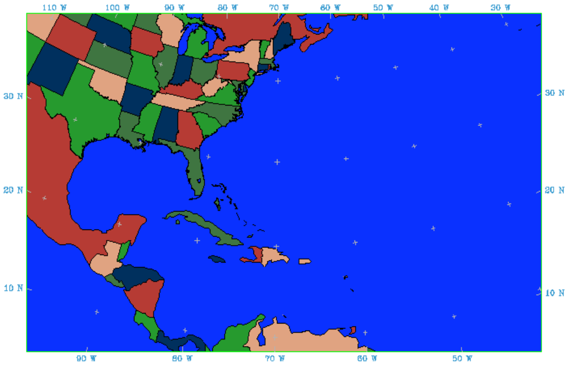

Fig. 1. The model domain of 400 x 225 with a grid spacing of 18 km used in this study.

The AirDat WRF configuration included the latest physics packages. The WSM 5-class scheme was employed to predict grid scale precipitation, while the Kain-Fritsch cumulus scheme was used to define the subgrid scale water cycle. The Rapid Radiative Transfer Model (RRTM) was used to specify long wave radiation, while the Dudhia scheme was employed for short-wave radiative processes. The Mellor-Yamada-Janjic boundary layer scheme was used to account for mixing layer fluxes and turbulence, while the NOAH model was employed for land-surface physics.

## 3. PRELIMINARY RESULTS

Two WRF forecasts were run at AirDat during early September, 2008, to study the impact of TAMDAR data on forecast quality over the Gulf of Mexico, Caribbean Sea and Western Atlantic. This period covers much of the life-cycle of devastating Hurricane Ike, which made final landfall along the upper Texas coastline. The first run, the Control, included all available MADIS data, but withheld all TAMDAR observations. The second run, the Experimental, included the full MADIS *and* TAMDAR data streams. All other modeling parameters were identical between the Control and Experimental forecasts.

Forecasts were initialized off the ½ degree grid from the NCEP Global Forecast System (GFS). The forecasts started at 00Z, September 7th and were cycled every 6 hours (to 84 hrs) through 00Z September 11th. This study will focus on the 00Z runs from September 10, which were the first WRF forecasts that showed Ike making landfall on the United States coastline. Model forecasts will be compared with observations and best track data from the Tropical Prediction Center to determine what, if any; impact TAMDAR data has on AirDat WRF forecasts.

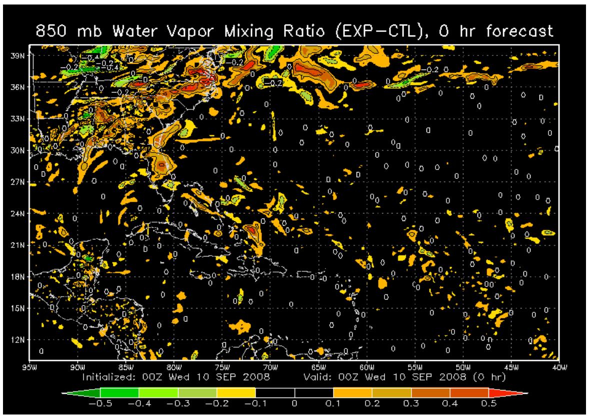

Fig. 2. 850 mb Mixing Ratio difference (kg/kg) between the Control and Experimental Forecasts valid at the model analysis time, 00Z 10 September 2008.

Figure 2 shows the difference in 850 mb mixing ratio (kg/kg) between the Control and Experimental forecasts valid at the analysis time, 00Z 10 September 2008. The largest differences are observed across the Ohio Valley and southeastern US, which coincides with the highest density of TAMDAR observations. It is interesting to note the differences in the mixing ratio across the western Atlantic and Bahamas region, well east of the observation locations. This is likely a result of the 6-hr cycling nature of the forecast system, allowing the observations to begin impacting the forecast downstream of the observing platforms.

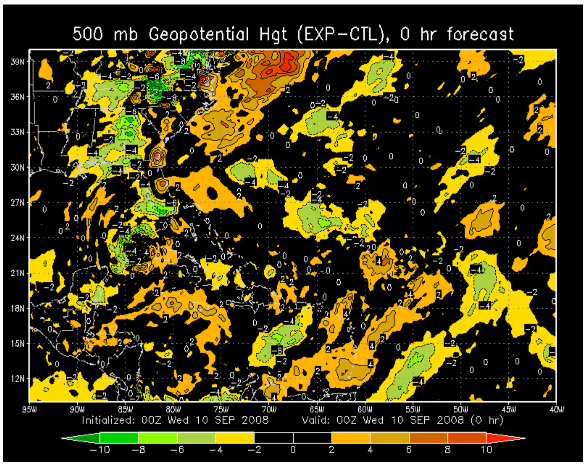

Fig. 3. 500 mb Geopotential Height difference (m) between the Control and Experimental Forecasts valid at the model analysis time, 00Z 10 September 2008.

Figure 3 shows the difference in 500 mb geopotential height (m) between the Control and Experimental forecasts valid at the analysis time, 00Z 10 September 2008. Similarly to the 850 mb mixing ratio figure above, the largest differences are observed across the Ohio Valley and southeastern US. However, some rather significant differences, over 10-m, are seen over the Northwestern Atlantic. Smaller differences are also seen over the central and eastern tropical Atlantic Ocean, consistent with the TAMDAR data slowly influencing the atmosphere well downstream of the observing location.

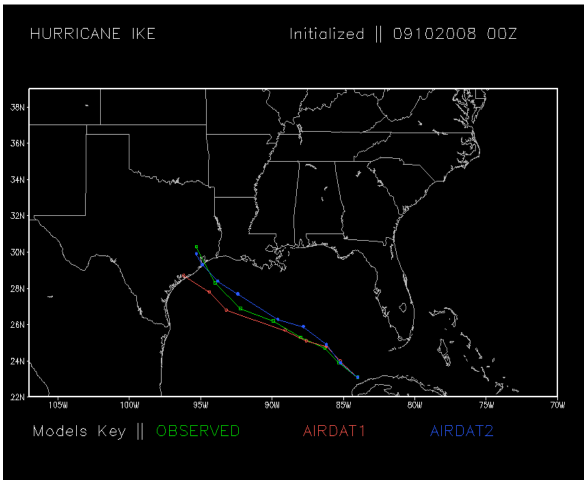

Fig. 4. 00Z 10 September 2008 Control (AIRDAT1) and Experimental (AIRDAT2) forecast tracks of Hurricane Ike. The TPC best track (OBSERVED) is plotted for comparison.

Figure 4 shows the forecast track of Hurricane Ike from both the Control (AirDat1) and Experimental (Airdat2) WRF models, as well as the observed track as determined by the Tropical Prediction Center. While the Control forecast matches the observed track fairly well through 36 hours, it begins to deviate to the south and west of the observed track after 48 hours. The Control forecast shows landfall near Matagorda Bay, Texas around 12Z 13 September. The Experimental forecast matches the observed track, and Control forecast, closely through 24 hours. It then begins to deviate slightly to the north of the observed track, before showing landfall near Galveston around 08Z 13 September. While the Experimental track was north of the observed track between forecast hours 30 and 60, the forecast track matched the observed track closely after hour 60. In fact, the Experimental forecast was accurate within one model grid point (18km) of the observed landfall location near Galveston, Texas. Additionally, the Experimental forecast predicted landfall near 08Z 13 September, while the Tropical Prediction Center recorded landfall just after 06Z 13 September.

More specifically, Figure 5 shows the track error for both the Control and Experimental forecasts. It is interesting to note that the Control forecast was more accurate than the Experimental forecast within 48 hours. However, after 48 hours, the Experimental forecast was consistently more accurate than the Control forecast, right up until landfall. The Control forecast track was roughly 95 km south of the observed landfall location, while the Experimental forecast was around 15 km south of the observed landfall location. This author feels that assimilating the TAMDAR data likely resulted in a better defined analysis of the steering-level wind field across southeastern United States and Gulf of Mexico, resulting in a more accurate forecast of the hurricane track.

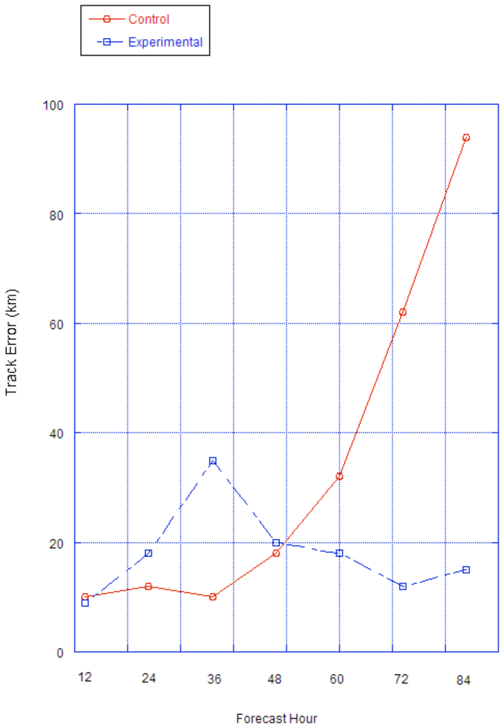

Fig. 5. Control (Red) and Experimental (Blue) Forecast track errors (km) of Hurricane Ike.

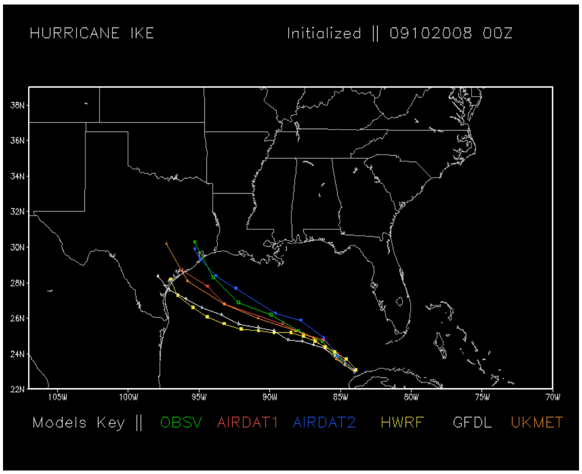

Fig. 6. 00Z 10 September 2008 Control (AIRDAT1) and Experimental (AIRDAT2) forecast tracks of Hurricane Ike, along with the numerical guidance from the GFDL, HWRF and UKMET models. The TPC best track (OBSV) is plotted for comparison.

While the previous figures compared the forecast tracks of the Control and Experimental models, we will now include several additional numerical prediction forecast models in the evaluation. Figure 6 shows the forecast track of Hurricane Ike from the Control (AirDat1) and

Experimental (Airdat2) WRF models, as well as the forecast tracks from several well-respected dynamical forecast models often used by operational forecasters. The observed track is included for comparison. With the exception of the Experimental forecast, the numerical guidance showed a pronounced south bias compared with the observed track. More specifically, the AirDat Control forecast matched closely with the UKMET Global Model forecast, while both the NCEP GFDL and HWRF track forecasts were even further to the south. The Experimental forecast was much closer to the observed location of landfall than the other numerical guidance from 00Z 10 September 2008.

## 4. SUMMARY AND PERSPECTIVE

Preliminary TAMDAR data assimilation capability in the AirDat WRFDA system has been implemented. Several forecast periods were investigated to determine the impact, if any, of TAMDAR data on high resolution WRF forecasts. The preliminary results show a general positive impact from the assimilation of TAMDAR data on the model prediction of the steering-level wind flow and track of Hurricane Ike. The Experimental forecast was significantly more accurate, over 80 km, with the landfall location of Hurricane Ike than the Control forecast. This is likely a result of an improved atmospheric analysis as a result of the assimilation of TAMDAR observations.

Additional research is needed to fully understand, and quantify, the impact of TAMDAR data on high resolution WRF forecasts. Future research includes a more robust matrix of background error covariances for the AirDat WRF tropical grid configuration, which should further improve the analysis fit to the observations. Additionally, we will also continue developing a TAMDAR enhanced 4DVAR assimilation system based off the latest WRFDA release; while simultaneously continue development on a rapid cycling FDDA (Four-Dimensional-Data-Assimilation) system. It is the belief of AirDat scientists that both 4DVAR and FDDA assimilation techniques offer greater appeal in maximizing the benefit of high-resolution TAMDAR observations on mesoscale forecast models.

## 5. ACKNOWLEDGEMENTS

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