

The Impact of TAMDAR Observations on Hurricane Ike (2008) Forecast using WRFDA System

Hongli Wang, Xiang-Yu Huang, Yongsheng Chen, Xin Zhang, Don Stark
National Center for Atmospheric Research, Colorado, USA

Peter Childs
AirDat LLC, Morrisville, NC, USA

ABSTRACT

This study accessed the impact of atmospheric observations from Tropospheric Airborne Meteorological Data Reporting (TAMDAR) observing system on numerical forecasts of hurricane Ike (2008) using the 3D-Var component of the Weather Research and Forecast model (WRF) Data Assimilation (WRFDA) system. The track and intensity forecasts in the 6-hourly cycling data assimilation and forecast experiments are verified against the best track data.

The results show that, on average, assimilating TAMDAR observations has a positive impact on the forecast of hurricane Ike (2008). The track forecast errors are reduced when TAMDAR observations are assimilated. The averaged track error reduction is about 30 km for 72-h forecasts. The improvements in intensity forecast are also seen after 24-h. The mechanism of forecast improvement is briefly discussed.

1. Introduction

The quality of initial condition plays an important role in accurate numerical weather forecast. Observations with high spatial and temporal resolution are expected to improve the analysis and subsequent forecast skill. TAMDAR, developed by AirDat LLC and deployed on commercial aircrafts, is a multi-function atmospheric sensor, which measures atmospheric humidity, pressure, temperature, wind, icing, and turbulence (Daniels et al. 2006). In particular, TAMDAR observation system provides the humidity measurement, which is typically not available from many other upper-level observing systems such as ACARS. TAMDAR fills in some gaps in the current weather balloon network and other sources of upper air observing network. The temporal resolution of TAMDAR observations is 2 min (corresponding to spatial scale of 10-25 km).

The vertical resolution during ascent and descent is 10 hPa.

Several past works have shown promising positive impacts of TAMDAR data on severe weather forecasts over the continental United States (Jacobs et al. 2006, Moninger et al 2007, Liu 2007). In this study, we access the added value of TAMDAR data on tropical cyclone forecasts by assimilating TAMDAR observations in addition to other observations using 3D-Var component of WRFDA (WRF-3DVar). Hurricane Ike (2008) occurred in September 2008 was selected in this study.

This paper is organized as follows: section 2 introduces the data assimilation system WRFDA and TAMDAR observation operator. A brief description of hurricane Ike, model configuration, and experiment design are presented in section 3. Results are discussed in

section 4, and a brief summary is given in section 5.

2 Assimilating TAMDAR in WRFDA

2.1 WRFDA

The WRF data assimilation (WRFDA) system developed at NCAR is a unified (global/regional, multi-model, 3/4DVAR, variational-ensemble hybrid) model-space data assimilation system (Barker et al. 2006, Huang et al. 2009). A wide range of observation types including conventional observations, radar, satellite radiances, etc., can be assimilated into WRFDA. The variational scheme uses a multivariate incremental formulation. The control variables used in this study are streamfunction, "pseudo" relative humidity, and the unbalanced components of velocity potential, temperature, and surface pressure. The "unbalanced" control variables are defined as the difference between full and "balanced" (i.e., correlated with streamfunction) components of the field. In this study, the 3D-Var component of WRFDA is employed.

2.2 TAMDAR Observation Operator

TAMDA observation operator added in WRFDA is very similar to AIREP observation operator, except moisture observation is now included. The observation error statistics of wind and temperature for TAMDA is specified to be the same as AIREP. The observation error of relative humidity is set to 10%, which is comparable to the optimal error of 12 % used in the study by Moninger et al. (2007).

3 Experiment design

3.1 Hurricane Ike

Ike was a long-lived hurricane that caused extensive damage across parts of the northwest Gulf coast when it made landfall in Texas. Fig.1 shows the best track starting from 1200 UTC 07 to 0000 UTC 14 September 2008 and the mean wind field from GFS analysis at about 525 hPa averaged over the time period of 1200 UTC 07 to 0000 UTC 11 September 2008. The wind vectors indicate that storm motion is mainly influenced by the subtropical high.

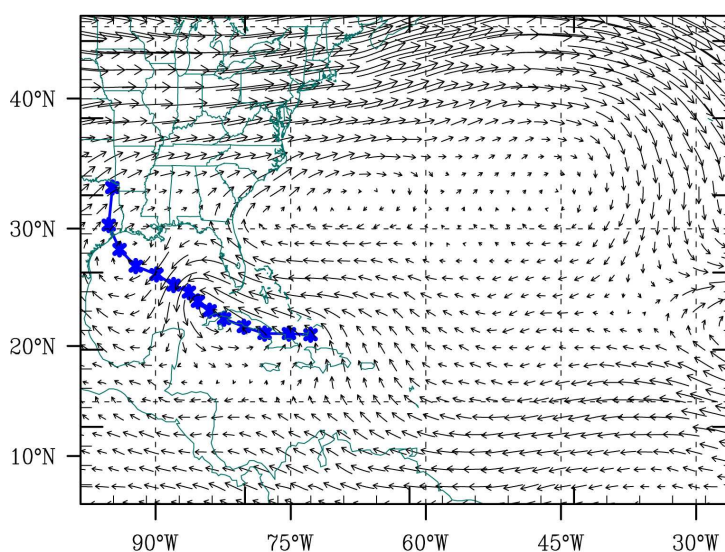


Fig. 1 Best-track positions from 1200 UTC 7 to 0000 UTC 14 Sep 2008 overlaid averaged

stream of GFS analysis from 1200 UTC 7 to 0000 UTC 11 Sep 2008 at about 525 hPa.

3.2 Experiment setup

The WRF model is used as the forecast model. The WRF is the next generation mesoscale model designed for cloud and mesoscale applications over a limited area, as well as for global numerical weather prediction (Michalakes et al. 2001, Skamarock, et al. 2005). The model uses a third order Runge-Kutta time integration, third to fifth order advection operators, and split-explicit fast wave integration conserving both mass and energy. One domain with resolution 18 km was configured for all the simulations (see Fig. 1). The domain had 400×255×42 grid points. The physics packages chosen for this study include the WSM5 microphysics scheme and the Kain-Fritsch scheme for cumulus parameterization.

Two 6-hourly cycling data assimilation and forecast experiments were carried out. In the first experiment (CNTR), operational observations (including sounding, surface, ship, buoy, AMDAR, AIREP, SATOB, QSCAT, GPSRO) are assimilated. In the second experiment (TAMDAR), TAMDAR observations are also assimilated in addition to observations used in CNTR. The analysis and forecast cycles start at 1200 UTC 7 and end at

0000 UTC 11 September. The analyses at 0000 UTC and 1200 UTC everyday are used to initialize 96-h (72-h for the last day) forecasts. The initial conditions and boundary conditions are generated from GFS analysis. The first guess is a 12-h forecast initialized at 0000 UTC 7 September. Verifications against best track data (center location, minimum sea level pressure, and maximum wind speed) were performed.

4. Results

4.1 Assimilated Observations

We found that the data used during the assimilation and forecast cycling with the largest numbers are SATOB, AIREP and TAMDAR data. Fig. 2 shows the observation counts of these three observation types at the assimilation times. The numbers of upper air observations vary from cycle to cycle, more at 00Z, 12Z, 18Z, and few at 06Z. The data distributions for these three types are illustrated in Fig. 3. TAMDAR data has the least amount among these three types and it is only over the continent of United States.

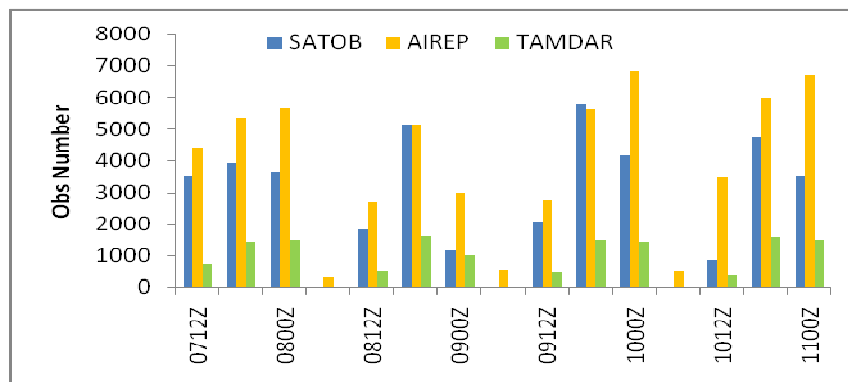


Fig. 2 Observation used during 1200 UTC 7 to 0000 UTC 10 Sep

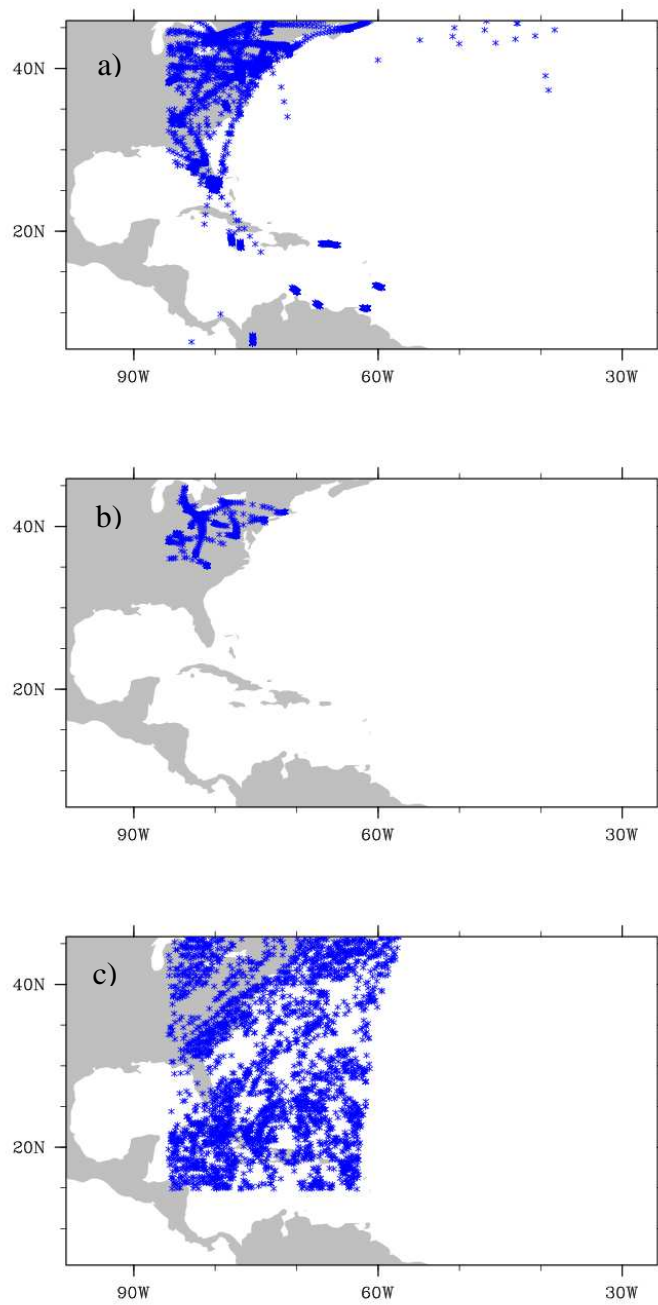


Fig. 3 Data distribution of a) AIREP, b) TAMDAR, c) SATOB within a 2-h time window (1100 UTC 7 to 1300 UTC 7 September 2008).

4.2 Impact on forecast

The 96-h or 72-h track forecasts of hurricane Ike at four different times are shown in Fig. 4. The control forecast has a persistent northward bias. This bias is reduced significantly in TAMDAR experiment. The improvement only becomes obvious after

24-hour cycling. It is because that TAMDAR data are over continental United States and far away from the Ike to influence it immediately. After 24 hours, Ike starts to feel the upstream analysis difference caused by adding TAMDAR observations as shown in Fig. 4b, c and d.

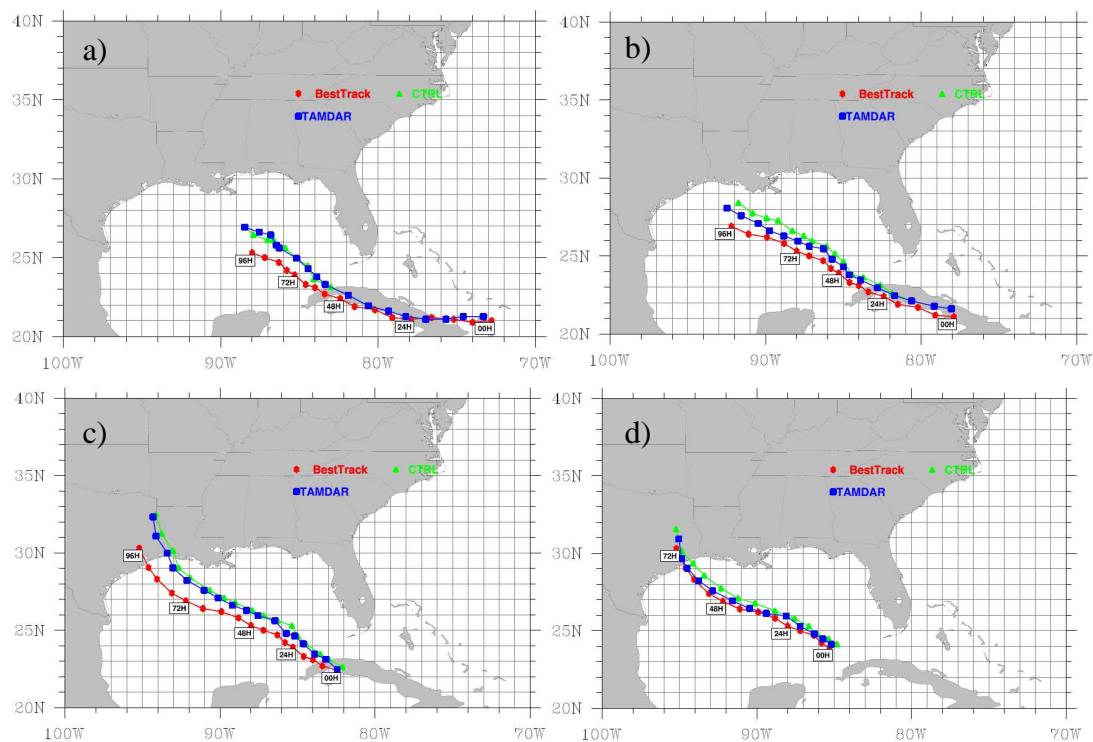


Fig. 4 96-hTracks of best estimation and forecast of experiment CTRL and TAMDAR initiated at a) 1200 UTC 7, b) 1200 UTC 8, c) 1200 UTC 9 and d) 1200 UTC 10 September 2008. Only 72-h forecasts were made after 0000 UTC 10 Sep.

The center location errors in the analysis and 72-h track forecast errors in two experiments are compared in Fig 5 and 6 respectively. Although TAMDAR shows the positive effect on track forecast after 24-h cycling, it is until 48-h cycling that there is clear impact on Ike initial location specification.

Error statistics of track, minimum sea level

pressure (SLP) and maximum wind speed (MWS) is given in Table.1. On average, TAMDAR data has a positive impact on hurricane initial location specification, but a neutral impact on the intensity analysis. TAMDAR data improves the track forecast with an average value of 30 km at 72-h. The forecasts of SLP and maximum wind speed are improved as well after 24-h cycling period.

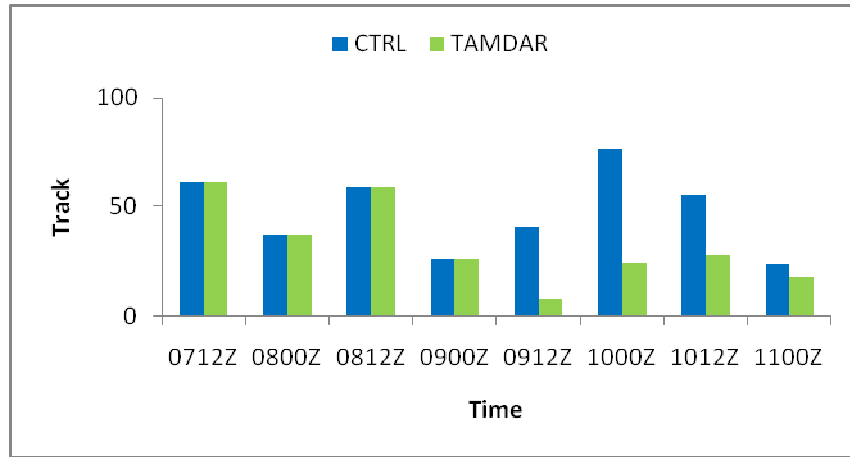


Fig. 5 Ike location error at analysis time

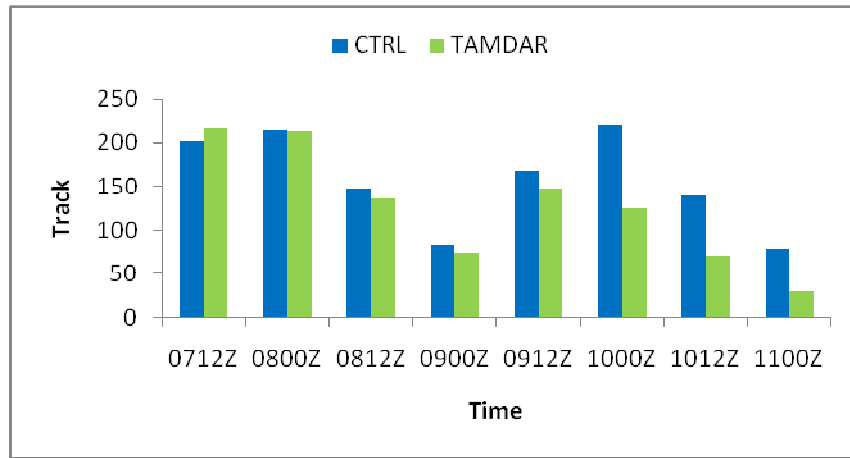


Fig. 6 Ike track forecast error at 72-h

Table 1. Statistics of Ike forecast at varies time

Index	EXP	Analysis time		24-h		48-h		72-h	
		Average	RMSE	Average	RMSE	Average	RMSE	Average	RMSE
Track	CTRL	47.629	50.67	76.016	78.637	114.717	118.797	156.506	164.712
	TAMDAR	32.876	37.364	67.276	68.704	98.777	107.413	126.67	141.112
SLP	CTRL	10.824	16.093	3.751	7.213	-2.933	8.387	3.58	8.645
	TAMDAR	10.958	16.277	3.448	7.997	-1.937	7.929	2.074	8.008
MWS	CTRL	-10.576	20.675	0.393	7.017	2.776	4.435	-5.763	15.009
	TAMDAR	-10.658	20.835	0.595	7.029	1.075	3.364	-3.829	11.046

The reason leading to improvement of forecast using TAMDAR data is explored here. The track forecast in CTRL experiment has a northeastward bias compared with the real track. Since the key synoptic system which influences Ike motion is the subtropical high over the North Atlantic, the differences in the wind fields between two experiments (TAMDAR - CTRL) are plotted in Fig. 7. For

comparison, the differences between GFS analysis and CTRL are also given in Fig. 8. The differences are time-averaged over 8 analyses (at 0000 and 1200 UTC) from 1200 UTC 07 to 0000 UTC 11 Sep 2008, and vertically average over Eta levels from 0.8435 (about 850 hPa) to 0.3825 (about 350 hPa).

From Fig.7 we can find considerable

westward and southward flow components when assimilating TAMDAR. The southwest quart of subtropical high was also strengthened. These will drive the Ike move southward and westward. Comparing Fig. 7 to

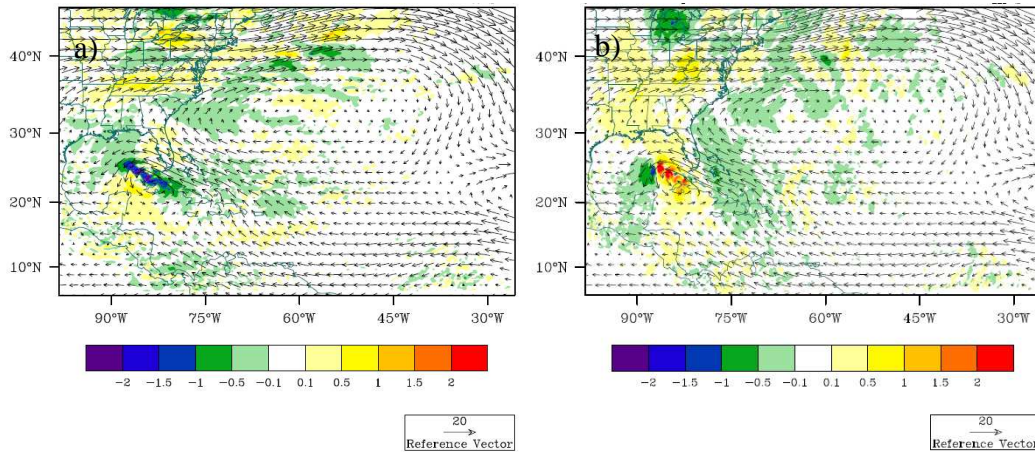


Fig. 7 The time and vertically averaged differences between experiments TAMDAR and CTRL of a) u and b) v . The averaged wind vectors in CTRL are overlaid.

Fig. 8, it is clear that assimilating TAMDAR improves the analysis over continent U.S., along the east coast and along the Ike track also.

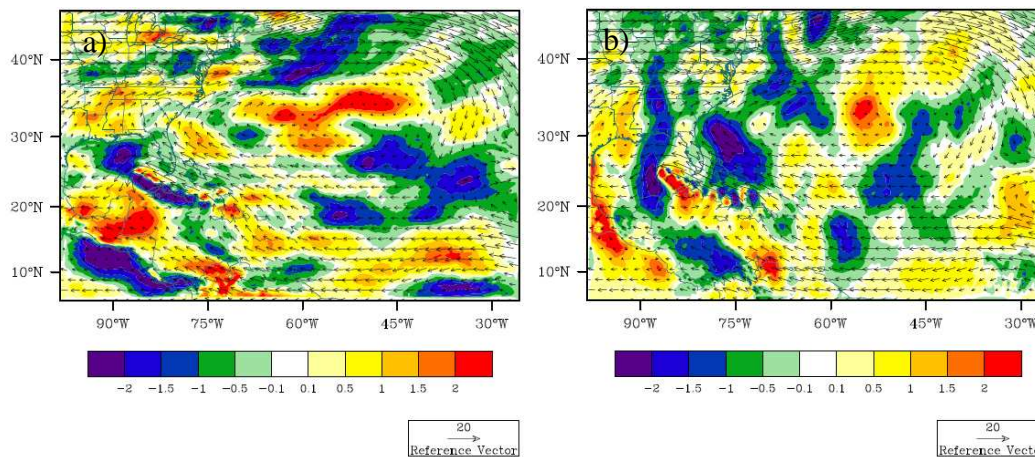


Fig. 8 The time and vertically averaged differences between GFS analysis and experiment CTRL of a) u and b) v . The averaged wind vectors in CTRL are overlaid.

5. Summery and discussion

The TAMDAR assimilation capability is expended in WRFDA. A TAMDAR observation operator and the corresponding observation process code were added into WRFDA. Two 6 hourly 3D-Var cycling experiments of Ike case had been performed. The data assimilation period is 3.5 days starting from 07/12Z Sep. to 11/00Z Sep 2008.

The track and intensity analysis and forecast are verified against the best track estimates.

The results from data assimilation experiment show that WRFDA system works well with TAMDAR data. On average, the qualities of analysis and forecast skills on hurricane Ike are improved. At the analysis time, TAMDAR data has a positive impact on hurricane initial location specification but neutral impact on the intensity analysis.

TAMDAR data improves the track forecast by 30km at 72 h. After 24-h cycling period, intensity forecasts are improved as well. The results presented here are based only on one case study, and more studies are required in order to draw general conclusions on the added values of TAMDAR observations.

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