15B.1 TAMDAR-RELATED IMPACTS ON THE AIRDAT OPERATIONAL WRF-ARW

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1. INTRODUCTION

During the fall of 2007, AirDat added a version of the NCAR Advanced Research WRF (ARW) to the operational 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 built-in GPS (Daniels et al. 2004, 2006; Moninger et al. 2006). These observations are transmitted in real-time to a ground-based network operations center via a global satellite network. Ongoing data-denial studies, including parallel forecasts from the WRF-ARW, were conducted over the continental US. The 48-h experimental (control) operational forecasts included (withheld) the TAMDAR data. The objective of this study is to understand the impact, if any, that TAMDAR data has on the operational AirDat WRF-ARW forecast system. The next section will describe the components relevant to the AirDat WRF-ARW system, including the grid and physics configurations used in this study. A brief overview of the WRF-VAR system is also included in the next session followed by some preliminary results from the ongoing case studies.

2. MODEL OVERVIEW

a. WRF-ARW System

The 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.

The AirDat WRF-ARW model was designed to study the effects of TAMDAR data assimilation across the Continental United States (CONUS), with a primary focus covering the central and eastern regions, where data coverage is greatest. The model domain used in this study is shown in Fig. 1. The configuration included a 600 x 420 grid with a horizontal grid spacing of 8km. Forty hybrid-sigma levels were assigned with enhanced resolutions in the boundary layer and within the jet stream level.

The AirDat WRF-ARW configuration employs the latest physics packages. The WSM 6-class graupel scheme is employed to define grid-scale precipitation, while the Kain-Fritsch cumulus scheme is used to define the subgrid-scale water cycle. The Rapid Radiative Transfer Model (RRTM) scheme is used to specify long wave radiation, while the Dudhia scheme is employed for short-wave radiative processes. The Mellor-Yamada-Janjic boundary layer scheme is used to account for mixing layer fluxes and turbulence, while the NOAH model is employed for land-surface physics.

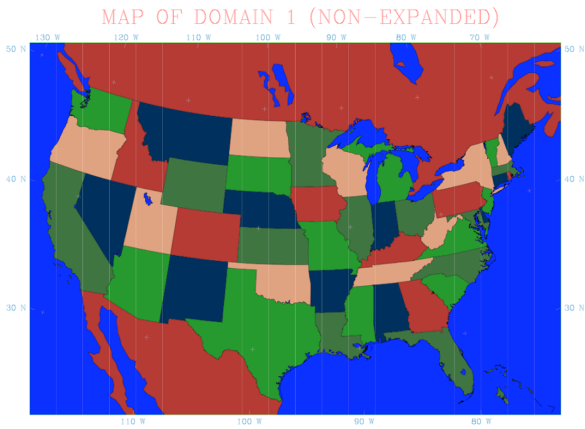

Fig. 1. The model domain of 600 x 420 with a grid spacing of 8 km used in this study.

b. WRF-VAR System

The WRF-VAR system is used to assimilate various data platforms into the AirDat WRF model. The goal of any variational data assimilation system is to determine an optimal estimate of the current atmosphere. This is achieved through the iterative solution of a prescribed cost function. The WRF-VAR 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 improvements have been made to the latest WRF-VAR system to better assimilate various observation platforms, including asynoptic aircraft data provided by TAMDAR. The previous version of the WRF-VAR system used height interpolation for all observation operators. For example, if an observation is reported as a function of pressure, then height is

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approximated using the hydrostatic relation. This introduces an unnecessary source of error. The new WRF-VAR system uses a vertical interpolation based on the original observed coordinate, height or pressure. In addition, a First Guess at Appropriate Time (FGAT) package has been introduced in the WRF-VAR 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.

3. PRELIMINARY RESULTS

Two parallel WRF-ARW forecasts were run operationally at AirDat this past December to study the impact of TAMDAR data on forecast quality in the 0-48 hour period. The first run (Control) included all available MADIS data, but withheld all TAMDAR observations. The second run (Experimental) included the full MADIS and TAMDAR data streams. All other modeling parameters were identical between the Control and Experimental forecasts.

Three days of WRF forecasts are analyzed for this study. All forecasts were initialized off the 0.5 degree grid from the NCEP Global Model (GFS) at the 1200 UTC synoptic hour. The study dates include 2, 3, and 4 December 2007. The models were integrated for 48 hours. These forecast dates were selected due to the presence of a somewhat active weather pattern across much of the central and eastern United States, an area rich in TAMDAR-equipped aircraft. Model forecasts will be compared with National Weather Service RAOB and ASOS data to determine the effect, if any, TAMDAR data has on high resolution WRF forecasts.

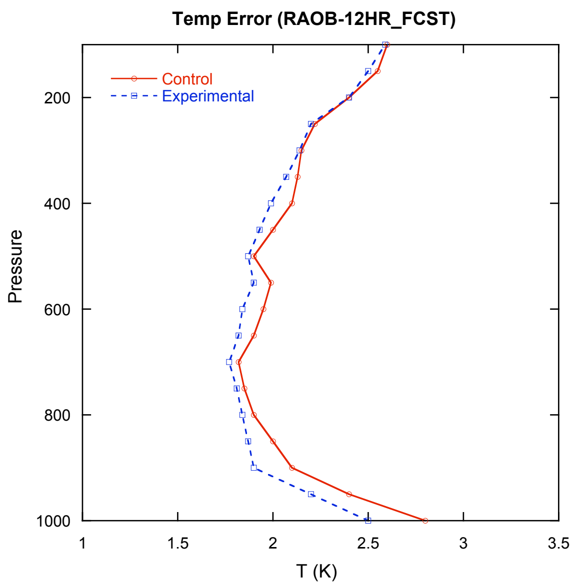

Fig. 2. Vertical profile of 12-h temperature RMS error verified against 00 UTC RAOBs. Average of the three locations KMPX, KDTX, KGRB for 2, 3, and 4 Dec 2007.

A vertical profile of the average temperature error of the 3 12-hr Control and Experimental forecasts compared with observations from three RAOB stations, KMPX, KGRB and KDTX is seen in Fig. 2. The Control forecast is shown in red, while the Experimental forecast is shown in blue. Slight improvement is seen in the Experimental forecast over the Control forecast from the surface through 400 hPa, with the greatest improvements seen between 850 and 900 hPa. The improvements are reduced at the 700 and 500 hPa levels. It is assumed that this is a result of greater non-TAMDAR observation density on mandatory levels.

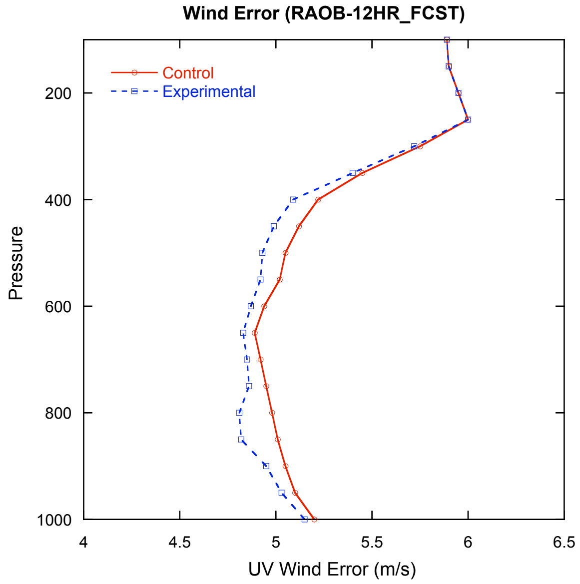

Fig. 3. Vertical profile of 12-h <U,V> wind RMS error verified against 00 UTC RAOBs. Average of the three locations KMPX, KDTX, KGRB for 2, 3, and 4 Dec 2007.

The average wind speed (UV) error of the 3 12-hr Control and Experimental forecasts compared with observations from three RAOB stations, KMPX, KGRB and KDTX is shown in Fig. 3. The Control forecast is shown in red, while the Experimental forecast is shown in blue. Slight improvement is seen in the Experimental forecast over the Control forecast from the surface through 400 hPa, with the greatest improvements seen between 800 and 850 hPa. This is consistent with Figure 2, which shows the greatest temperature improvements seen around 850 hPa.

Figure 4 shows the average relative humidity error of the 3 12-hr Control and Experimental forecasts compared with observations from three RAOB stations, KMPX, KGRB and KDTX. The Control forecast is shown in Red, while the Experimental forecast is shown in Blue. Slight improvement is seen in the Experimental forecast over the Control forecast from the surface through 300 hPa, with the greatest improvements seen near the 450 to 500-hPa layer. This result was somewhat different than those seen in Figs. 2 and 3, where the greatest temperature and wind speed improvements were seen around 850 hPa.

While the previous figures showed slight to moderate improvement in the vertical prediction of temperature, moisture and momentum with TAMDAR data, we will now investigate whether the improvements are seen closer to the surface. Figure 5 shows the absolute error of 2-m temperature from the Control and Experimental forecasts. The model 2-m temperatures were calculated as an average of the 3 48-hr forecast periods used in this study. The error was calculated based on observations from 10 ASOS stations from across the Midwest that were representative of the various climates featured across the region. Temperatures from the Control forecast are shown in red, while temperatures from the Experimental forecast are shown in blue. The Experimental forecast shows consistent improvement in the prediction of 2-m temperatures throughout the 48 forecast period with the greatest improvements seen at forecast hours 42 through 48.

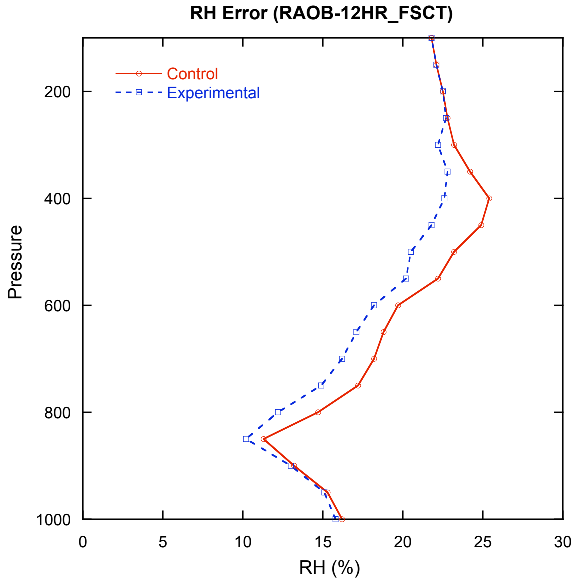

Fig. 4. Vertical profile of 12-h relative humidity RMS error verified against 00 UTC RAOBs. Average of the three locations KMPX, KDTX, KGRB for 2, 3, and 4 Dec 2007.

More specifically, Fig. 6 shows percent error improvement of the Experimental forecast over the Control forecast. The Experimental forecast is 7-10 percent more accurate with surface temperature prediction in the 0-48 hour period than the Control Forecast. Interestingly enough, the greatest improvements are seen in the 42-48 hour period, with the smallest improvements shown in the 12-24 hour period. These are likely magnified by diurnal effects, which enhance low-level thermal variability during daylight hours. As the variability acts as noise in the data set, it masks the trends needed to quantify model skill difference.

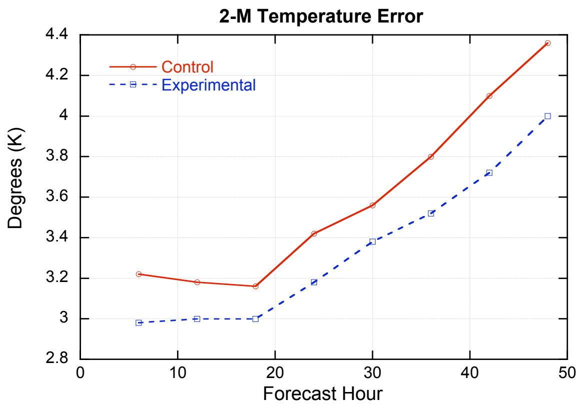

Fig. 5. Time series of 2-m temperature forecast absolute error verified against ASOS in the domain for 2, 3, and 4 Dec 2007 runs out to 48 h.

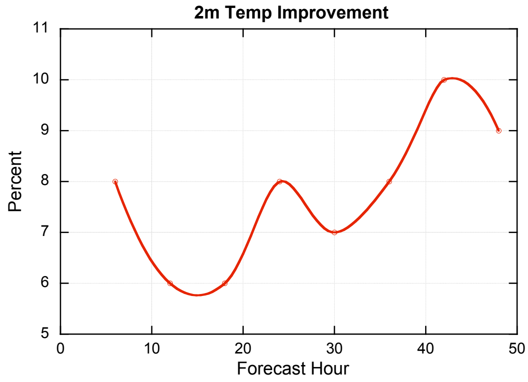

Fig. 6. Time series of 2-m temperature forecast percent improvement between the experimental and control forecasts using the absolute error verified against ASOS in the domain for 2, 3, and 4 Dec 2007 runs out to 48 h.

4. SUMMARY AND PERSPECTIVE

Preliminary TAMDAR data assimilation capability in the operational AirDat WRF-VAR system has been implemented. Several forecast periods were investigated to determine the impact of TAMDAR data on high resolution WRF forecasts. The results show a general positive impact from the assimilation of TAMDAR data on the model prediction of wind, temperature and momentum when compared to National Weather Service RAOB data. The greatest improvements in temperature and wind prediction were seen around 850 hPa, while the largest improvements in relative humidity were seen near 500 hPa.

TAMDAR data is also shown to positively impact the prediction of 2-m temperatures in the 6-48 hour forecast period when compared with area ASOS stations. General improvements of 7-10% were seen in the 6-48 hour forecast period, with the greatest improvements realized in the 42-48 hour forecast. It is not fully known whether these improvements are a result of improved model cloud forecasts, precipitation distribution, or a combination of two.

Additional research is needed to fully understand, and quantify, the impact of TAMDAR data on high resolution WRF forecasts. Future research includes the generation of our own background error covariances for our operational WRF grid configuration, which should greatly improve the analysis fit to the observations. Additionally, we will begin transitioning our operational WRF forecasts over to a rapid cycling FDDA (Four-Dimensional-Data-Assimilation) system based on “observational-nudging”. The efficacy of 4D-variational assimilation will also be investigated. It is the belief of AirDat scientists that both FDDA and 4DVAR assimilation techniques offer much greater appeal in maximizing the benefit of high-resolution TAMDAR observations on mesoscale forecast models.

5. ACKNOWLEDGEMENTS

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