5.20 AN OSSE STUDY OF TAMDAR DATA IMPACT ON MESOSCALE DATA ASSIMILATION AND PREDICTION

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1. INTRODUCTION

Mesoscale (10-2000 km) meteorological data assimilation and prediction are challenging due to sparse observations, especially in the upper atmosphere. A new source of sensor data called Tropospheric Airborne Meteorological Data Reporting (TAMDAR) has been introduced, and it can potentially fill these data-void regions. The TAMDAR sensors, developed by AirDat, LLC, in collaboration with NASA, FAA and NOAA, are specially designed for smaller commercial aircrafts that fly in the lower troposphere over the CONUS and other parts of the world. These sensors provide a full suite of meteorological measurements with very high space-time density, which include temperature, winds, humidity, icing, turbulence, and pressure. By 15 January 2005, AirDat had completed sensor installations on 63 Saab 340 aircraft operated by Mesaba Airlines, which executes ~400 flights a day, providing ~800 soundings. At present, AirDat is working with other airlines to field more TAMDAR sensors, and aims to complete the North America coverage within the next 1 – 2 years.

NCAR has been working with AirDat on the evaluation and optimization of the existing and future CONUS-scale TAMDAR (CONTAM) data impact on the NCAR 4DWX real-time, multi-scale, rapid-cycling, four-dimensional data assimilation and forecast (RTFDDA) system. This is being accomplished through real-time modeling and case studies. The 4-D continuous data-assimilation scheme of the model system is capable of weighting each observation according to its observation time and location, and thus it is able to assimilate the aircraft data measured along a flight leg, which can be very irregular in time and space. In this paper, the potential value of the future CONTAM observing systems, based on 12 airlines which conduct ~9000 flights per day, is studied using an Observing System Simulation Experiment (OSSE) approach.

2. NCAR RTFDDA MODEL

The NCAR RTFDDA (Real-Time FDDA and forecasting) system was originally built around the Penn State/NCAR Mesoscale Model version 5 (MM5) for support of ATEC (Army Test and Evaluation Command) test operations at the test ranges. By effectively incorporating detailed terrain, coastline masks, and land-use information, and using synoptic-scale model analyses from NWS and real-time mesoscale observations, the system has proven capable of forecasting many realistic local circulations, making it a great tool for supporting weather-sensitive applications, including various military tests at the test ranges, homeland security, emergency decision support, and many others. As of November 2006, in addition to running operationally at seven US Army test ranges and a few other sites related to homeland security, the RTFDDA systems have also been implemented at more than 20 other sites/regions globally to support various Department of Defense missions, industrial and public applications, and field experiments. In the last two years, the Weather Research and Forecast (WRF) model, developed by multi-agencies in the United States to combine the achievements of various existing operational and research mesoscale models, has been enhanced and integrated into the RTFDDA system (Liu et al. 2006). In this paper, the WRF-based RTFDDA system is employed for the CONTAM OSSE studies.

The core data assimilation engine of the RTFDDA system is a Newtonian-relaxation-based “observation nudging” scheme. The RTFDDA “observation-nudging” scheme (Cram et al. 2001; Liu et al. 2002, 2005) is a refined version of the “observation-nudging” FDDA module in the standard MM5, which was introduced by Stauffer and Seaman (1994). The main features of the nudging scheme included in the WRF RTFDDA system can be found in Liu et al. (2006). The data assimilation scheme forces the model solution toward observations according to observation time and location, which differs from the “analysis nudging” approach where the model is nudged towards a gridded analysis. This approach was chosen because observations on the mesoscale are sometimes sparse, and are not typically distributed uniformly in space, making objective analysis difficult. With station nudging, each observation is ingested into the model at its observed time and location with proper space and time weights, and the model spreads the information in time and space according to the model dynamics. This approach is able to take more advantage of highly space- and time- variable TAMDAR observations measured along flight tracks.

3. EXPERIMENT DESIGN

The CONTAM system that AirDat is developing is composed of a number of airlines and various aircrafts.

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In this paper, TAMDAR data from 12 airlines are simulated according to their flight schedules on a typical day (with a total of ~9000 flights) and current TAMDAR data sampling rate designed for the GLFE. CONTAM represents a huge increase in weather measurements in the lower troposphere, which can impact NWP under various weather situations. This paper focuses on winter weather. Two massive winter cold-air outbreak cases, 17-20 Jan. 2005 and 16-19 Feb. 2006, were selected to study the potential impact of the CONTAM data on 0-48 h forecasts. Only the 2005 case is discussed in this paper.

An OSSE process typically consists of four components or steps. First, a nature run (NR) is conducted to generate a virtual nature that is as close as possible to the nature. Normally, a very high resolution model with a refined physics package is employed to conduct the NR. In this paper, the full-physics WRF model was run on a 4-km CONUS domain (Fig. 1, D2) over three days for the selected cases. With the high-resolution model, cloud and precipitation are explicitly simulated (i.e., no cumulus parameterization is activated). The NRs are used for simulating observations of the hypothetic and real platforms in addition to serving as a baseline for evaluating data impact for the data assimilation experiments. The NR output was generated every 30 minutes.

The second component of the OSSE is data extraction or observation simulation. An interpolation module is developed to extract the model data at the observation sites and times from the NR outputs according to the hypothetical/given observation time and locations. These "observations" are then assimilated in data assimilation and forecast experiments, and they need to be precisely interpolated from the model output. After being extracted from the NR output, random errors are introduced to mimic the instrumentation and observation handling errors. For the purpose of comparison and OSSE validation, radiosondes at the current stations are extracted from the NRs along with the CONUS TAMDAR data. Random error perturbations of 1.5 m s^{-1} for the wind components, 0.5 C for temperature, and 5 % for relative humidity are added to the retrieved radiosonde and TAMDAR observations.

In the third step, the data assimilation and forecast experiments are performed to evaluate TAMDAR data impact. Four experiments were performed: a control run (CTRL) that does not assimilate TAMDAR observations, a reference run using the simulated radiosondes for the existing radiosonde stations (SND), a data impact run assimilating the simulated CONTAM data (TAM), and another run using both the simulated radiosondes and CONTAM (SNDTAM). All simulations were initialized with the same initial conditions as those of the NRs, but with the addition of analysis errors. The analysis errors were generated according to the horizontal gradients of wind and temperature fields, which resulted in larger errors in the regions of steep terrain and weather regime transitions such as frontal zones. For the 17-20 Jan. 2005 case, data assimilation for the reference and data impact runs was conducted on 17 Jan. from 0000 to 1800 UTC, after which began the free forecasts.

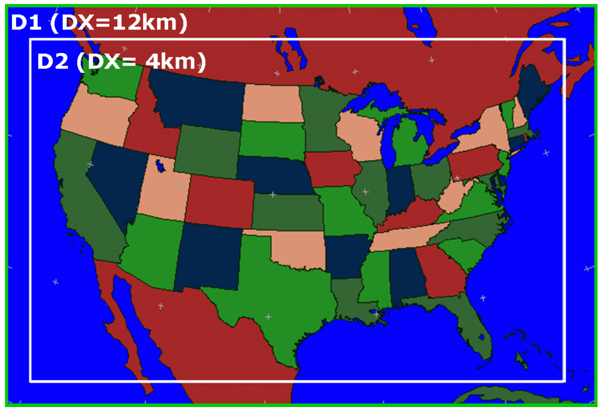

Fig. 1. Model domain configuration for the OSSEs. The nature run (NR) was carried out with the 4-km Domain 2 using explicit moisture physics and fine resolution terrain, land use, and soil properties, whereas the data impact runs were done with the 12-km Domain 1 only, with coarser underlying forcing and implicit diabatic processes.

Finally, the fourth component is to evaluate the data impact by analyzing experiment results. The analyses and forecasts of the CTRL, SND, TAM an SNDTAM experiments are compared with the NR to quantify the impact of TAMDAR data. At this stage, careful interpretation of the OSSE results, based on a good understanding of the limitations of OSSE associated with the particular settings, are needed.

One well-known problem is that OSSEs are subject to "identical twin" issues when using the same model for the NR to generate simulated observation and for data impact experiments to test the effectiveness of these observations. The "identical twin" causes an over-optimistic estimate of data impact and can sometimes render the experiment results meaningless. In this paper, a different physics package, resolutions, and underlying forcing of WRF were used in the NR and data impact experiments, respectively, which greatly mitigate the "identical twin" issues. To test the difference between the models, we repeated the NR with the version of WRF used in the data impact experiment. The results display a reasonable differences after a 12-hour simulation. Figure 2 shows the temperature difference between the two model runs on the 4th eta level (at a height of ~120m AGL), valid at 1200 UTC 17 Jan. 2005, 12 hours into the simulation. It can be seen that the two models generate different mesoscale perturbations in the western mountainous regions, and to a lesser extent, in the middle and eastern states. These errors are generally similar to the typical magnitude of differences between a model and nature atmosphere. The wind and humidity fields show similar relative error magnitudes (not shown).

Another factor that may affect OSSE results is the difference of representativeness errors between simulated and real observations. Here, we consider both the radiosonde and TAMDAR observations as in-situ point-wise measurements. however, the simulated observations are not, as they are interpolated from the 4-km grid model which represents a grid-box average. In this case, the simulated observations are "more representative" than real-observations when being assimilated into the 12-km grid model for the data impact experiments. This outcome can somehow lead to over-optimistic data impact results. OSSE validation experiments (Atlas et al. 2001) are being conducted to evaluate the credibility of the OSSEs testbed. The validation experiments consist of conducting real data assimilation and forecasts and performing OSSEs with the currently available platforms, such as radiosondes and ACARS data. Analysis of these experiment results are in progress.

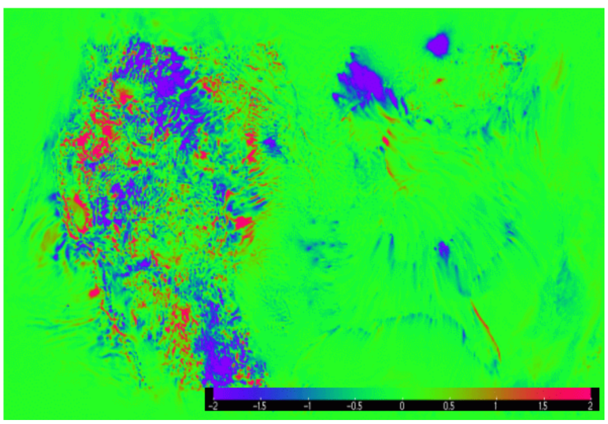

Fig. 2. Temperature difference at 4th eta levels (~ 120 AGL) between the nature runs and WRF, the model used for the data impact study. The time valid at 1200 UTC 17 January, 12 hour forecast from the same initial conditions.

4. RESULTS

During 17-20 January 2005, a massive cold-air outbreak occurred over the northern America. Figure 3 shows sea-level pressure, surface temperature and surface wind (barbs) valid at 0000 UTC 17 January 2005. Intense cold air from Canada advected south and east of the Rockies to the Gulf of Mexico. On 18 January, another smaller, yet still intense, trough marched into the northern states from Alberta, Canada. The two waves of cold air pushed eastward and an associated cold front wiped through the eastern states during the following two day, causing cold weather and snow. The Rockies and the western states were less affected by the cold air. The four data impact experiments started data assimilation at 0000 UTC 17 January 2005, and the forecasts began 1800 UTC 18 January. Figures 4 and 5 compare the 2-m and 850-hPa temperature errors of the 18-h forecasts of the three experiments with simulated radiosondes (SND), simulated CONTAM (TAM), and no observations (CTRL), respectively. It can be seen that the CTRL forecasts present the largest temperature errors in the upper air and at the surface as well. Assimilation of the simulated radiosonde data obviously reduced the forecast errors, and the assimilation of the simulated TAMDAR data reduced the errors even more dramatically.

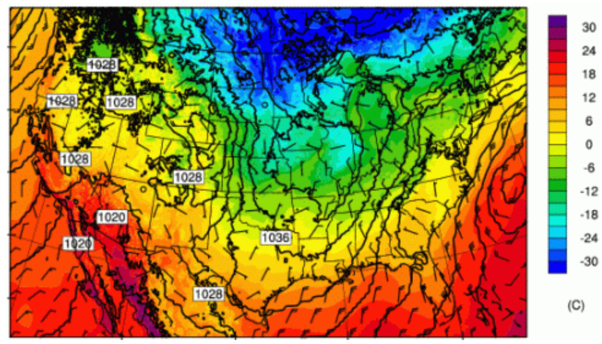

Fig. 3. NCEP analyses of sea-level pressure (hPa), surface temperature (C) and surface wind (barbs), valid at 0000 UTC 17 Jan. 2005.

By tracking the error growth through the data assimilation and forecast period, it is found that assimilating the large-volume of frequent CONTAM data can suppress the analysis error/noise effectively during the data assimilation period and avoid rapid growth of forecast errors in unstable regions during the forecast. For example, large errors developed in the Texas-Mexico border region, and over the Rockies in Colorado and Wyoming, in the CTRL (Fig. 4a). These errors were mitigated slightly by assimilating radiosondes (Fig. 4b); however, they were almost completely suppressed with assimilation of CONTAM data (Fig. 4c). Another notable feature is that the 4-D continuous observation nudging scheme corrected the forecast errors the most in the region nearest the observations, and the positive effects of these corrections are propagated downwind. In regions with thin TAMDAR data density, such as over the Rocky Mountains, the forecast errors are relatively larger.

5. SUMMARY AND FUTURE WORK

In this paper, the potential value of the future CONUS-scale TAMDAR observing system is studied using an Observing System Simulation Experiment (OSSE) approach. A massive winter cold-air outbreak event is chosen for the OSSE study. The model results show very encouraging positive impacts of the TAMDAR observing system on mesoscale NWP. With a much higher temporal and spatial coverage of TAMDAR data, as compared to conventional radiosondes, the

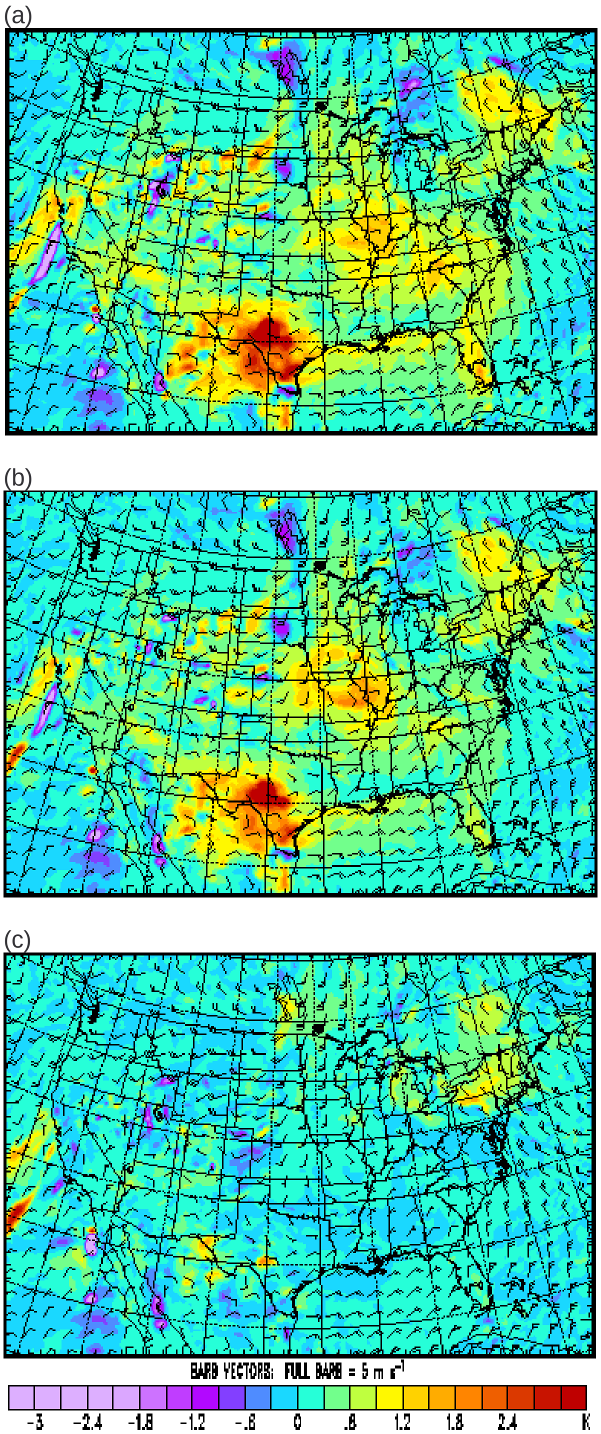

Fig. 4. Errors (differences between forecasts and the natural run) of 2-m temperature of 18-h forecasts, valid at 1200 UTC 18 Jan., 2005, initiated with no observation (upper-panel), with FDDA using simulated radiosondes (middle panel), and with simulated CONUS TAMDAR observations (lower panel).

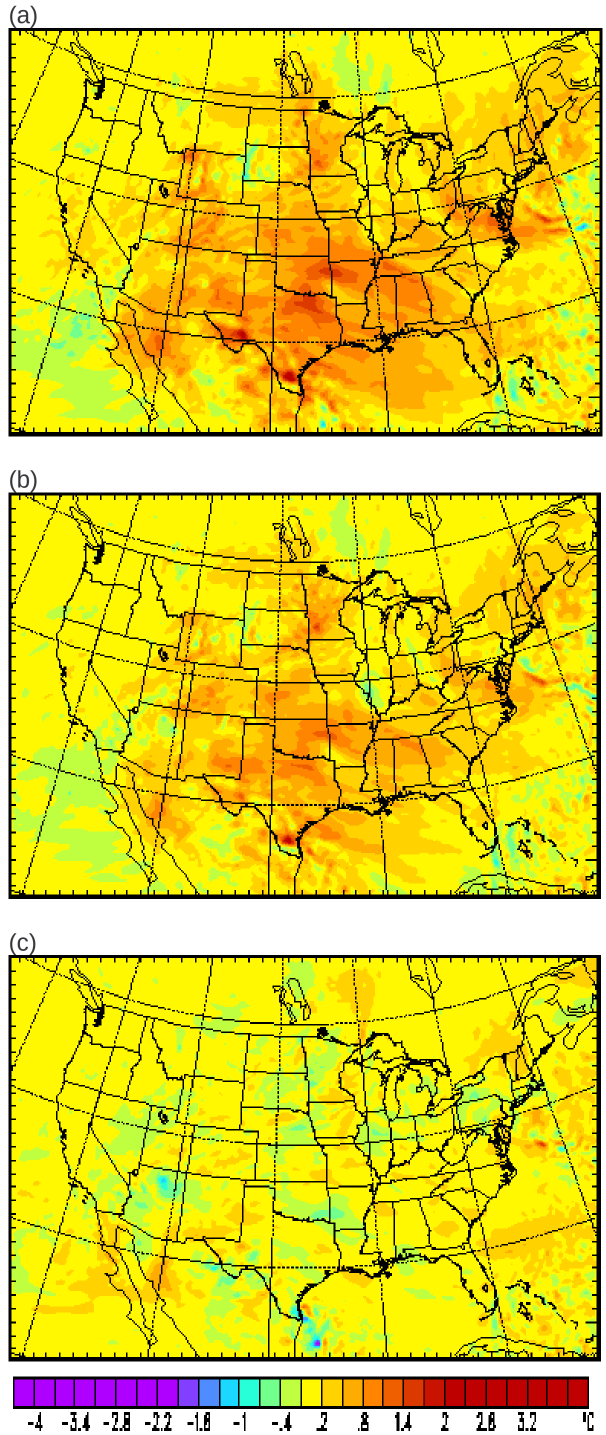

Fig. 5. Same as Fig.4, but for temperature at 850 hPa.

assimilation of TAMDAR data can lead to a greater effective reduction of analysis and forecast error. Based on this particular case study, TAMDAR alone is able to reduce the analysis error by ~40% in 18 hours of data assimilation, while radiosondes only result in a 20% error reduction. Of course, presently over the CONUS region, there are also many other operational platforms (e.g., wind profilers, ACARS, satellite measurements, etc.), so the additional value of TAMDAR above these existing platforms for mesoscale NWP will also be quantified and will be presented in a separate paper.

As stated earlier, OSSE results are both weather case and model dependent. There are a few factors that can lead to over-optimistic estimate of data impacts. Further experiments for OSSE validation will be conducted and calibration of the impact results may be performed (Hoffman et al., 1990, Atlas et al. 2001). Nevertheless, we believe the current study indicates an overall impressive value of the CONUS-scale TAMDAR data assuming the data are within precision specification.

6. FUTURE PLANS

As discussed earlier, although OSSE is an effective and valuable tool to study the potential value of a new observation technology/system, results from a single case study are less conclusive. Our plan is to conduct OSSEs with more cases and with different weather scenarios to generalize the conclusions. Furthermore, with the OSSE testbed, many important data assimilation aspects/issues can be explored. In particular, it is of great interest to study the potential value of TAMDAR data for warm-season convection prediction and to estimate the impact of additional TAMDAR data on NWP in data sparse countries/regions. Additionally, OSSE experiments can be performed to investigate the effectiveness of data assimilation strategies, fine-tune data weights to maximize the data value, and to provide guidance on TAMDAR data sampling and transfer schedules. Finally, the OSSE tool can also be employed to estimate impact of representativeness errors of TAMDAR observations, and aid in the development of new methods to mitigate these impacts on data analyses and NWP.

7. REFERENCES

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