16.6 PENAIR-BASED TAMDAR-RELATED IMPACTS ON SHORT-RANGE MESOSCALE FORECASTS OVER ALASKA

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1. INTRODUCTION AND MOTIVATION

The rugged and topographically-diverse terrain of Alaska, in conjunction with the data-sparse regions surrounding this area, make short-range mesoscale forecasting extremely challenging. The substantial lack of observations in this region has long plagued the success of numerical weather prediction in Alaska. Additionally, the complex mountainous terrain and land-sea interface warrant specific tuning of model physics and parameterization to properly utilize what few observations do exist.

The Alaska-based airline PenAir began equipping a fleet of 10 Saab 340s with Tropospheric Airborne Meteorological Data Reporting (TAMDAR) sensors in late June 2007. The 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. The planes mainly fly between McGrath Airport, Anchorage, King Salmon, and Dillingham, AK. The objective of this study is to quantify the impacts that TAMDAR data may have on high-resolution short-range mesoscale forecasts over Alaska.

This study presents only one case, and is seen as a snapshot of potential data-denial differences. It may, or may not, be representative of typical forecast skill. AirDat is just beginning to run parallel forecasts and study the output. Over the next several months, we will have a much better grasp on the nuances involved in TAMDAR-related NWP impacts over Alaska. A collaborative experiment between AirDat, NOAA-GSD/ERSL, PenAir, and local Alaska NWS WFOs, called the Alaska PenAir Experiment (APE) will begin in January 2008. Multiple sensitivity tests will be conducted throughout the year with the goal of quantifying the added value of high resolution TAMDAR in Alaska.

On 13 November 2007, two records were broken in Valdez, AK: 12.9 inches of snow fell, breaking the previous record of 6.0 inches (152.4 mm) of snow set in 1988. The snow was melted down to 0.95 inches (24.13 mm), which breaks the previous record precipitation amount of 0.93 inches (23.62 mm) set in 1993, which consisted of rain, not snow.

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 TAMDAR sensor. The model configuration details are discussed in the following section.

For this particular case, the AirDat WRF model was initialized at 00 UTC on 13 November 2007, approximately 3 pm local time 12 November. There were only 81 individual observations assimilated into the experimental (EXP) run during initialization.

It should be noted that in locations across the continental U.S., this number of observations would not typically produce a noticeable difference in the forecast (Bengtsson et al. 2004; Liu et al. 2007); however, due to the extreme lack of observational data available over Alaska, even a small amount of additional data can have a significant impact.

2. METHODOLOGY AND MODEL CONFIGURATION

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 discrimination 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.

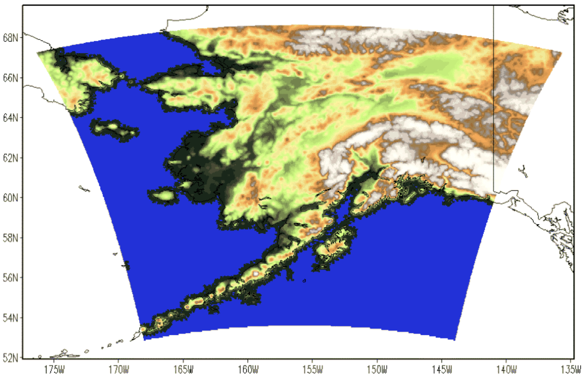

Fig. 1. The model domain of 2380 x 988 with a grid spacing of 8 km used in this study.

The AirDat WRF-ARW-Alaska model is designed to study the effects of TAMDAR data assimilation across Alaska. A domain measuring 2380 x 988 grid points with a horizontal grid spacing of 8km is configured. Forty hybrid-sigma levels are used to specify the vertical atmosphere with the highest resolutions within the mixed layer and jet stream level. The model domain is shown in Fig. 1.

The AirDat WRF-ARW-Alaska 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

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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.

The WRF-VAR system is used to assimilate various data platforms into the AirDat WRF-ARW 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 assimilation system 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 approximated using the hydrostatic relation. This introduces an unnecessary source of error. The new WRF-VAR system uses a vertical interpolation in terms of 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. This allows for a more optimal use of observations when their valid time differs from that of the analysis, which happens frequently with TAMDAR data.

Two WRF-ARW forecasts were run operationally at AirDat this past November to study the impact of TAMDAR data on forecast quality over the domain presented in Fig.1 in the 0-60 hour period. The first run, the Control (CTL), included the full MADIS data feed, but withheld all TAMDAR data. The second run, the EXP, included the full MADIS and TAMDAR data streams. All other modeling parameters were identical between the CTL and EXP forecasts.

3. PRELIMINARY RESULTS

Due to the lack of verification data over Alaska, the CTL and EXP runs will primarily be verified using North American Regional Reanalysis (NARR; Kalnay et al. 1990; Mesinger et al. 2006), RAOB observations, and limited surface observations. The NARR was obtained from NCDC's NOMADS[1] archive. It uses the high resolution NCEP Eta Model (32km/45 layer) together with the Regional Data Assimilation System (RDAS).

For this study, the model-generated soundings were verified against RAOB observations when available (i.e., 00 and 12 UTC); otherwise, moisture and temperature profiles were obtained from the NARR. The RH value is derived from the RAOB temperature and dewpoint using the calculation outlined in Bolton (1980), and the NARR-based RH value is derived from specific humidity, temperature, and pressure following Rogers and Yau (1989).

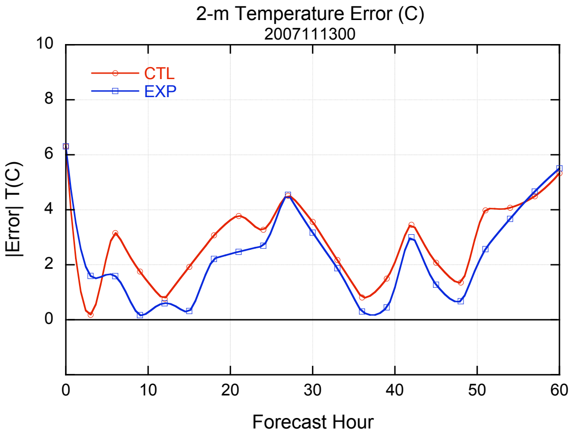

Fig. 2. 2-m temperature error for 60 h model run averaged over 9 ASOS stations for verification.

The average 2-m temperature of nine ASOS stations across the southern region of Alaska was compared to the average forecasted 2-m temperature at the same locations. The average improvement of the EXP over the CTL for the duration of the 60 h forecast was 0.56 C, which is approximately a 19% reduction in error. It is uncertain at this time if this unexpectedly large increase in forecast skill is case-specific, a function of the limited TAMDAR observations in an otherwise observation-void region, or just a fluke. If the former is the case, the improvement may have been feeding down to the surface, as the EXP 2-m temperature improvement at forecast hour-0 (i.e., analysis) was -0.07% -- a decrease in skill. A time series of the error is shown in Fig. 2. The most significant improvements occurred during forecast hours 06-24.

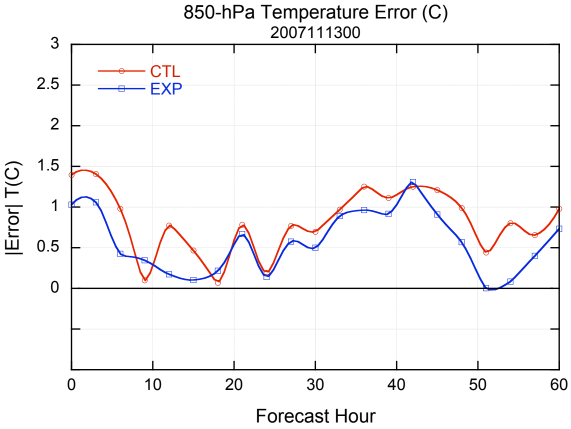

Fig. 3. 850-hPa temperature error of 3-station average for CTL and EXP verified against NARR and RAOB data.

The average 850-hPa temperature from three RAOB launch sites is used to verify the 850-hPa forecasted temperature with NARR data, or actual RAOB observations (when available). The three RAOB stations employed were Anchorage (PANC; 61.17N, 150.02W), McGrath Airport (PAMC; 62.97N, 155.62W), and King Salmon (PAKN; 58.68N, 156.65W).

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[1] http://nomads.ncdc.noaa.gov/

A time series of temperature error for the CTL and EXP is shown in Fig. 3. The most significant improvements seen in the EXP occurred between forecast hours 10-18, and after hour 30. The average improvement for the duration of the forecast was approximately 13% -- a 0.25 C reduction in average error magnitude. The notable percentage of improvement is largely a mathematical artifact of both the CTL and EXP having fairly low error, so a small variance results is a significant percentage-based value.

The improvement in the 850-hPa temperature analysis (forecast hour-0) is 0.37 C, or 26%. Interestingly, this value is verified by RAOBs at a launch site, which also was assimilated into the analysis. It is likely that the improvement in skill for this space and time is a result of additional TAMDAR soundings, as two of the three RAOB sites are also PenAir hubs.

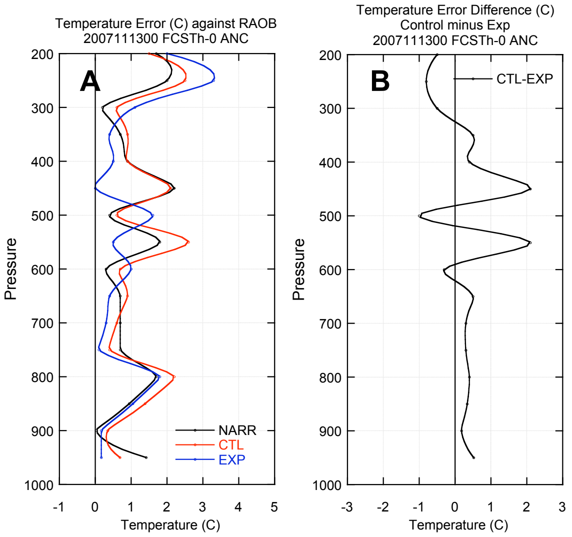

Fig. 4 Vertical temperature profile (A) from PANC at forecast hour-0, and the temperature error difference (B) verified against the PANC 00 UTC RAOB.

To further verify the influence of TAMDAR data, we examined the individual vertical profiles at each RAOB site against the CTL and EXP runs. The vertical temperature error profile from PANC forecast hour-0 (analysis) is shown in Fig. 4A. The EXP, CTL, as well as the NARR error against the PANC 00 UTC RAOB shows that all models were subject to the nose of error on the 800-hPa level, but in general, were fairly low with the EXP posting slightly less error. This difference is more evident in the error difference plot (Fig. 4B) of the CTL minus EXP. Positive values show TAMDAR-related improvement. The large values swinging back and forth above 600 hPa are case-specific. A long-range climatological study would produce much more meaningful results. The positive values below 700 hPa are probably more representative of expected skill increase. A profile of 6-hour forecasted relative humidity for PANC is shown for the EXP, CTL, and the NARR in Fig. 5, and the corresponding vertical temperature error (and error difference) profile against NARR from PANC forecast hour-6 is shown in Fig. 6A (Fig. 6B).

The PANC 24-h forecast relative humidity profile, valid 14 UTC November 2007, for the CTL and EXP is shown in Fig. 7 along with the NARR, and the 00 UTC

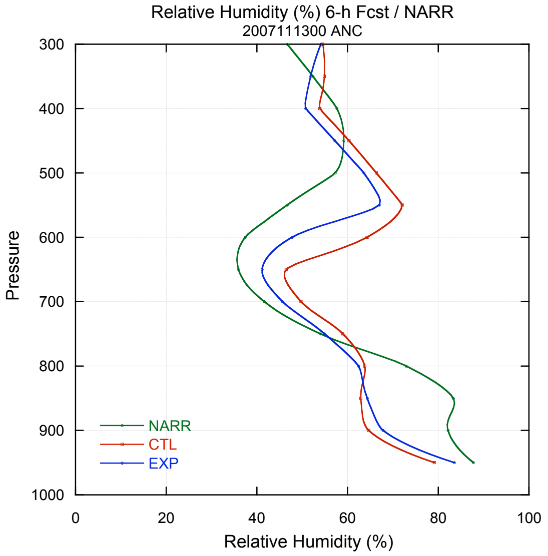

Fig 5. Relative humidity vertical profile at PANC for forecast hour-6.

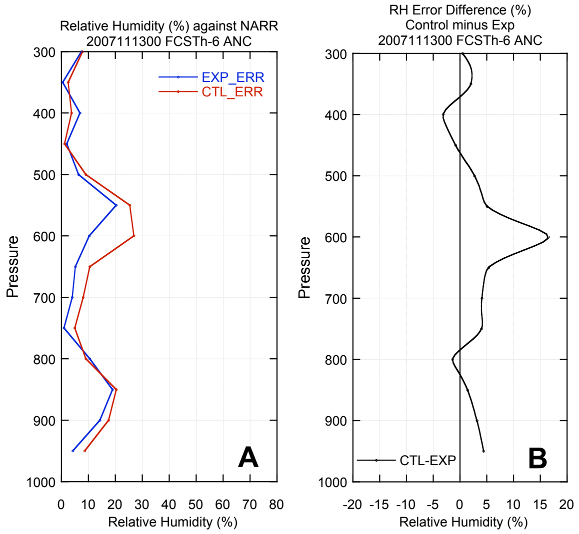

Fig. 6. Vertical RH profile (A) from PANC at forecast hour-6, and the RH error difference (B) verified against NARR.

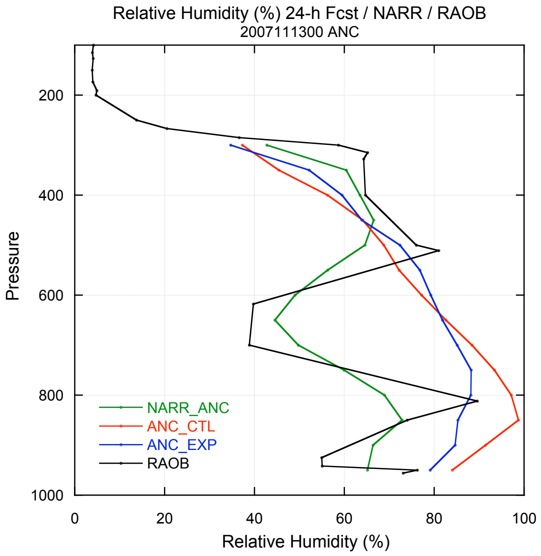

Fig 7. Relative humidity vertical profile at PANC for forecast hour-24.

PANC RAOB. Both the CTL and the EXP fell short of capturing the drier layers below 500 hPa; however, the EXP was on the more accurate side of the profile, which is evident when looking at the error profile in Fig. 8A. In Fig. 8B, the CTL error minus the EXP error, positive values show TAMDAR-related impacts, and the expected level of maximum improvement around 850 hPa is consistent with previous TAMDAR findings.

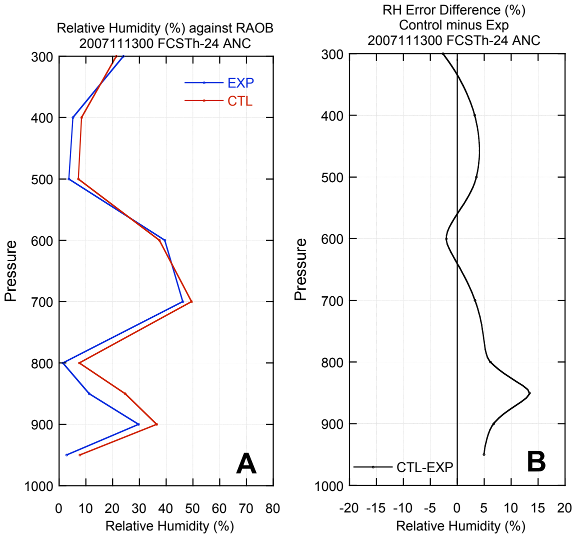

Fig. 8. Vertical RH profile (A) from PANC at forecast hour-24, and the RH error difference (B) verified against the PANC 00 UTC RAOB.

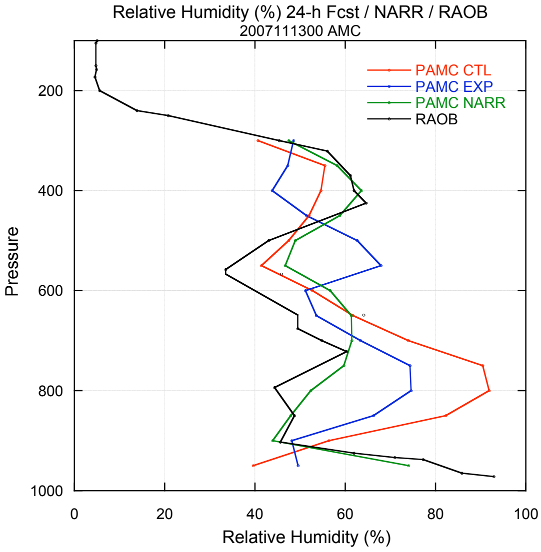

Fig 9. Relative humidity vertical profile at PAMC for forecast hour-24.

The PAMC 24-h forecast relative humidity profile, valid 14 UTC November 2007, for the CTL and EXP is shown in Fig. 8 along with the NARR, and the 00 UTC PAMC RAOB. The trend of better forecast skill between 700 and 900 hPa with the EXP continues. Once above the 500 hPa level, the opposite takes place, where the CTL does a much better job with RH. The EXP looks almost like a mirror image. There are very few, if any, observations at this level, but it is evident that despite improving the forecast at some levels, the chance exists for problems to arise elsewhere. This is likely a case of the model being very sensitive to the low observation count.

4. SUMMARY AND CONCLUSIONS

This is a limited study with only one time period examined, and a small (81 observations) dataset of additional TAMDAR data assimilated to the EXP run. Despite this limited quantity, the data produced encouraging results that demonstrate the potential impact additional TAMDAR observations may have over such a data-sparse region like Alaska.

Unfortunately, this can also serve as a disadvantage because with so few observations, the potential for a single observation to swing the analysis is very large. Thus, if the observation is of utmost quality and accuracy, the forecast skill can increase greatly; however, with even a small amount of error, the same observation can induce large model errors. This is likely the reason for such erratic differences between the EXP and CTL throughout the analysis field. The bottom line is the observations must be quality controlled to a degree higher than typical COUNS observations. This brings up another hurdle in that one of the best methods of quality control, buddy checking, is limited by the lack of asynoptic observations.

We are in the very initial stages of exploring what impacts a high resolution data set can have on a region such as Alaska. More case studies need to be conducted to better understand degrees of impact and limitations. Long-term statistical analysis is underway to isolate trends from the noise of day-by-day cases. Much will be learned in the following year, and results will be made available throughout the ongoing study.

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