4.5 IMPACT OF TAMDAR HUMIDITY, WIND, AND TEMPERATURE OBSERVATIONS IN RUC PARALLEL EXPERIMENTS

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1. INTRODUCTION

Expansion of the aircraft fleet contributing meteorological reports is the most important observational need for improving aviation weather forecasts. One of the major efforts in this direction has been the TAMDAR (Tropospheric AMDAR) sponsored by the NASA Aviation Safety Program (Daniels et al. 2006, Moninger et al. 2006), and the NASA-sponsored development of a TAMDAR sensor by AirDat LLC.

As part of the NASA- and FAA-sponsored Great Lakes Fleet Experiment (GLFE, Mamrosh et al. 2006a,b) with experimental TAMDAR observations, NOAA/FSL (NOAA/ESRL/GSD since October 2005) has conducted real-time parallel experiments with hourly Rapid Update Cycle (RUC) runs to test the impact of these data. These experiments started in March 2005 and results through the first six months are described here.

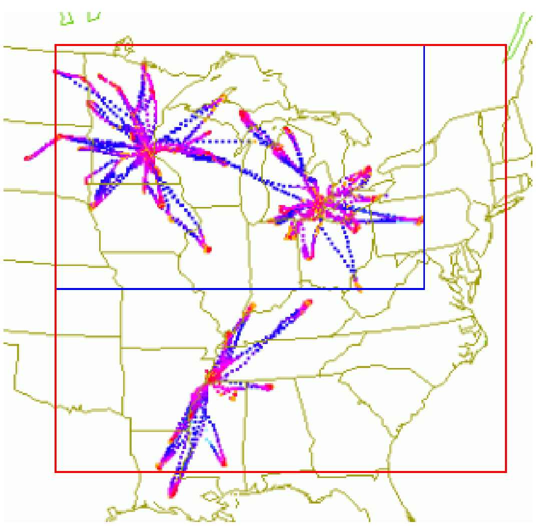

Figure 1. TAMDAR observations over 24h period. Verification areas shown for blue rectangle (Great Lakes area – 14 raobs) and red rectangle (Eastern US area – 38 raobs).

The potential value of any observations toward improving numerical weather forecasts must be measured as value added to pre-existing observations. The RUC is well-suited for regional observation impact experiments due to its complete use of hourly observations and diverse observation types. The current TAMDAR observations cover a regional area (Fig. 1), covering the flight structure of the 63 equipped aircraft operated by Mesaba Airlines, operating as Northwest Airlink (Moninger et al. 2006).

2. PARALLEL REAL-TIME RUC CYCLES TO STUDY TAMDAR IMPACT ON FORECASTS

Two parallel experimental versions of the 20-km resolution Rapid Update Cycle were run at ESRL/GSD differing only in the following:

- 'Dev' (or 'development version 1') assimilated all hourly non-TAMDAR observations (profiler, aircraft, surface, satellite, GPS-IPW, rawinsonde)
- 'Dev-2', same as dev but adding TAMDAR aircraft observations.
- Same NAM-based lateral boundary conditions used for both Dev and Dev-2 experiments

These RUC experiments have used up-to-date assimilation/model techniques (generally corresponding to the new 13-km RUC implemented operationally at NCEP on 28 June 2005, but run at 20-km resolution). The RUC version used for the TAMDAR experiments also includes complete assimilation of all observation types (as used in the RUC13, including cloud analysis (GOES and METAR), full METAR assimilation with effects of boundary-layer depth, GPS precipitable water, GOES precipitable water, all other aircraft, profiler, and rawinsonde). A summary of the characteristics of the 13-km RUC is available at http://ruc.noaa.gov/ruc13_docs/RUC13-summary.html. More details on the RUC assimilation cycle and the RUC model are available in Benjamin et al. (2004a,b).

Running these parallel cycles in real-time has proven to be beneficial for TAMDAR evaluation by allowing immediate comparison with other real-time data by GSD scientists (Szoke et al. 2006) and the TAMDAR community including the National Weather Service (Mamrosh et al. 2006a).

The forecast experiments were strictly controlled to isolate the effects of TAMDAR data:

- Dev and Dev2 cycles were initialized at the same time to ensure that input observations were identical other than TAMDAR observations.
- Background fields (1-h forecasts) for Dev and Dev-2 cycles were reset as equal every 48h to ensure that no unanticipated processing differences (e.g., disk space) could have prolonged undesirable effects.

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Forecast skill in these parallel RUC cycles with and without TAMDAR data has been evaluated by verification against rawinsondes. Initial results have shown a positive impact in the lower troposphere, especially near 850 mb, especially for temperature, and to a lesser degree, for humidity and winds. The results have varied over time due to variations in TAMDAR data resolution, quality procedures for data, and geographical and diurnal variations in data density. The TAMDAR RUC experiments have helped, along with the case study investigations discussed by others, to identify initial TAMDAR problems and improve the data quality through interaction with the collaborating groups in the TAMDAR project.

An example of Dev vs. Dev-2 differences attributable to assimilation of TAMDAR observations is depicted in Fig 2.

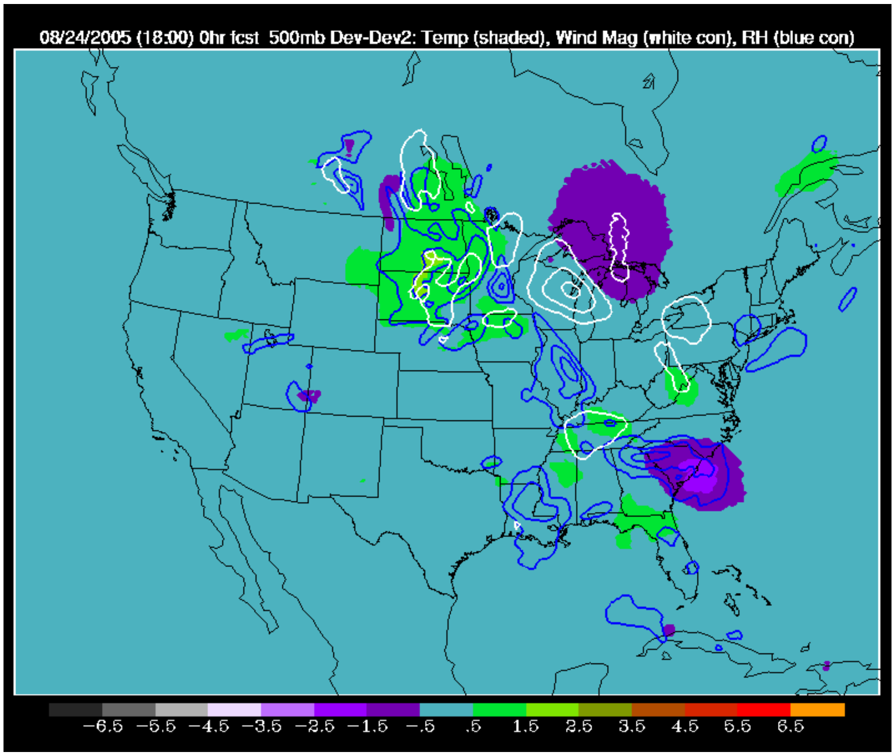

Figure 2. Dev vs. Dev-2 difference at 500 hPa for 0h analysis valid at 1800 UTC 24 Aug 2005. Temperaure (shaded using colors at bottom legend), wind (white – 2 m/s contour interval), RH (blue – 10% contour interval).

Figure 2 is a typical impact from TAMDAR data between the Dev (no TAMDAR) and Dev-2 (with TAMDAR) RUC cycles, in this case, 8 hours after resetting Dev and Dev-2 cycles with the same background forecast. Differences are in the region of the Mesaba flights (e.g., Fig. 2) and generally downstream. However, due to slight differences in gravity waves, Dev vs. Dev-2 differences in convection or near-surface temperatures often become evident over the entire RUC domain. Also, by 48 h, the impact from TAMDAR usually spreads more widely than shown in Fig. 2 due to nonlinear interactions in the analysis and forecast model components of the RUC system.

3. EVALUATION

In this report, we found it useful to stratify results into 4 different phases characterized as follows:

- Phase 1: 9 Feb – 21 April 2005 – winter-early spring – lower vertical resolution in TAMDAR reports (every 10 hPa in lowest 100 hPa, every 50 hPa above lowest 100 hPa)
- Phase 2: 22 April – 1 June – spring – higher vertical resolution in TAMDAR data (10 hPa in lowest 200 hPa)
- Phase 3: 2 June – 22 July – summer – higher vertical resolution, as for Phase 2. New aircraft reject list added.
- Phase 4: 23 July – 24 August – lower vertical resolution, as for Phase 1, resumed.

The RUC impact experiments were evaluated over each of these 4 phases. Any dates with questionable results were screened out (due, for example, to missing RUC runs for either cycle). The results of the 4 phases include combined effects of TAMDAR data quality, use of the revised aircraft reject list, and seasonal variations in forecast error. Monitoring of aircraft-RUC differences (Moninger et al. 2006) revealed certain aircraft with larger systematic errors. From this, a 'reject list', including some TAMDAR-equipped aircraft, was developed and then applied to the Dev and Dev-2 runs starting in Phase 3.

In general, forecast errors tend to be smaller in summer than winter. Accordingly, the potential for improvement from assimilation of any given observation type is also generally smaller.

Results are shown below only for 00 UTC verification over the Great Lakes region (Fig. 1) where TAMDAR impact is strongest. There was less impact at 12 UTC and for the full eastern U.S. region. Mesaba/TAMDAR flights generally did not occur between 03-10 UTC.

4. RESULTS

RMS differences between forecasts and rawinsonde observations were calculated for each RUC cycle. These differences were calculated every 12h over each verification region, and then averaged over longer multi-week periods. These differences can be roughly interpreted as forecast errors, although in fact they include components from both forecast and observation errors. Then, the differences in these errors scores between the Dev and Dev-2 experiments are calculated and shown below to show *TAMDAR impact.*

Differences are calculated as Dev error minus Dev-2 error. Thus, positive numbers mean that the error is smaller with assimilation of TAMDAR data, indicating a positive impact from TAMDAR data.

4.1. Temperature

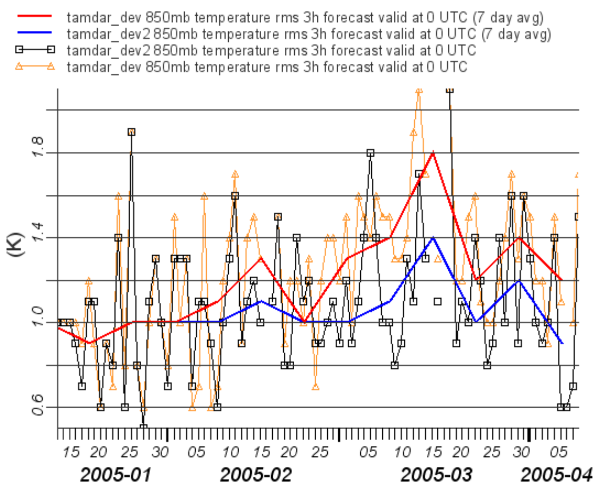

Figure 3. Phase 1 (Feb-Apr 2005) - 850 hPa temperature errors for 3-h forecasts valid at 00 UTC from Dev and Dev-2 experiments in Great Lakes verification region. Weekly averages are shown for Dev (red) and Dev-2 (blue).

The strongest impact for TAMDAR observations has been for temperatures compared to other variables (wind and RH). We first show a smoothed time series of forecast errors for Dev and Dev-2 experiments from Phase 1 (early spring) for 850 hPa temperature 3-h forecasts (Fig. 3).

The TAMDAR impact for 850 hPa temperature 3-h forecasts has been fairly consistent on a day-to-day and week-to-week basis (Fig. 3). Generally, 850 hPa temperature RMS errors (forecast-rawinsonde differences) are generally 0.8-1.5 K. Improvement in 3-h forecasts is generally ~0.2 K, larger in some cases. TAMDAR impact was slightly smaller in

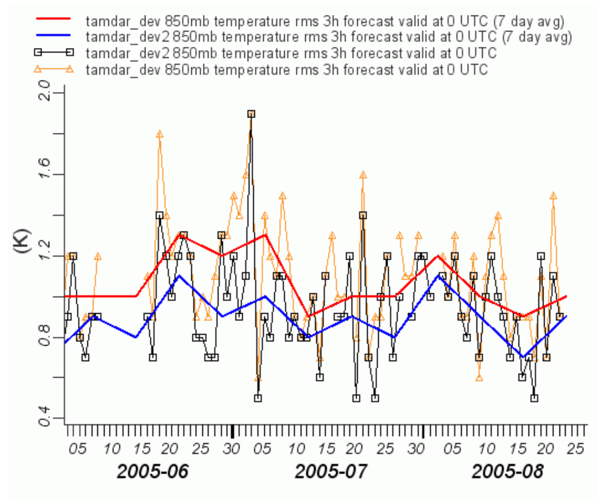

Figure 4. Same as Fig. 3 but for Phase 3-4 (summer).

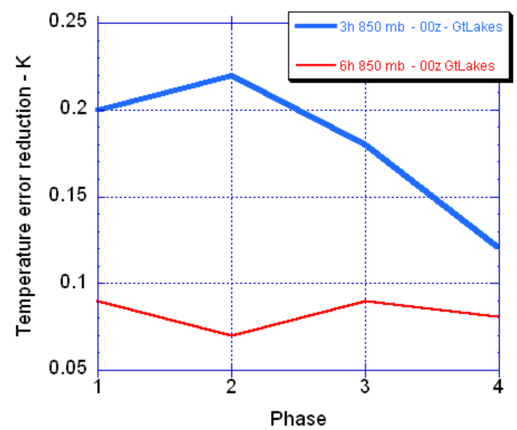

Figure 5. Error reduction for 850 hPa 3-h temperature forecasts valid at 00 UTC (Dev error minus Dev-2 error) for each of 4 phases.

summer (Phases 3-4, Fig. 4) than in Phase 1, probably a result of weaker and less frequent temperature inversions at 00 UTC in summer than in spring.

Fig. 5 suggests the seasonal variation of TAMDAR impact on temperature forecasts, presumably a result of the lower temperature errors themselves in the warm season. We do not attribute this to any degradation in TAMDAR temperature observations over this period.

4.2. Wind

Wind observation accuracy from TAMDAR has shown more problems than for temperature (Moninger et al. 2006, Mamrosh et al. 2006a). This has been attributed primarily to contamination from maneuvers, particularly on descent, and AirDat is working on rectifying the problems.

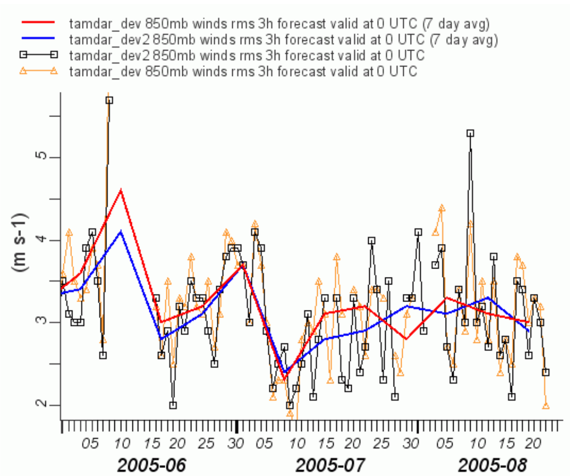

Figure 6. 850 hPa 3-h wind forecast rms vector errors for Dev (red) and Dev-2 (blue) for June-Aug 2005 (Phases 3-4). Valid 00 UTC

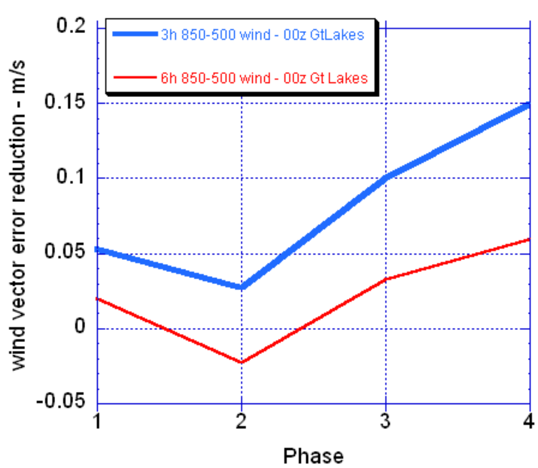

Figure 7. Error reduction for mean 850-500 hPa 3-h wind forecasts (Dev error minus Dev-2 error) for each of 4 phases. (Valid 00 UTC)

Results from the summer period (Phase 3-4) show a modest improvement in 850 hPa wind forecasts resulting from assimilation of TAMDAR observations (Fig. 6). Averages of wind forecast impact over the 4 evaluation phases show that there has been an increase in positive impact in Phases 3 and 4 (Fig. 7). This is attributed to improved monitoring of aircraft errors and subsequent development of a reject list starting in Phase 3.

4.3. Relative humidity

By summer (Phases 3-4), TAMDAR assimilation was producing a positive impact (about 1% RH) for 3-h RH forecasts at 850 hPa (Fig. 8). The 3-h 850 hPa RH error was typically 10-14% RH for this summer period. RUC analysis fit to rawinsonde observations is typically about 10%, accounting for expected 'error' from spatial representativeness. The application of the aircraft reject list including TAMDAR aircraft beginning in Phase 3 is credited for the positive impact showing up at that point (Fig. 9). Note that

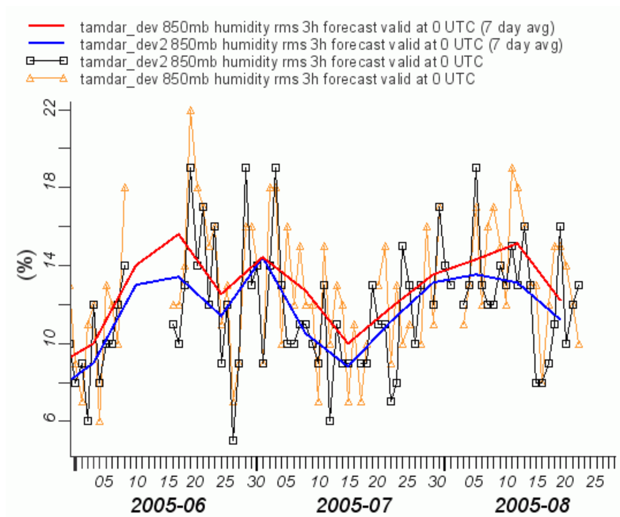

Figure 8. Same as Fig. 6, but for relative humidity forecasts.

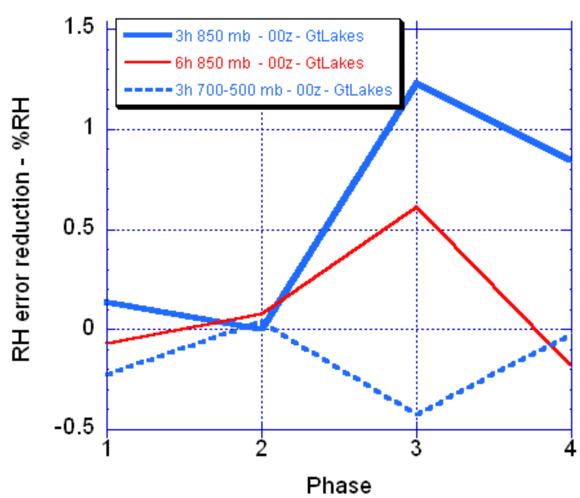

Figure 9. Same as Fig. 7 except for relative humidity. Also shown is the TAMDAR impact for 700-500 hPa RH (blue dotted line).

the effect in Phases 1 and 2, even at 850 hPa, was negligible. Even in the summer period (Phases 3 and 4), the impact of TAMDAR data on RH forecasts was nil to slightly negative at 700 and 500 hPa levels (Fig. 9), but consistently positive at 850 hPa.

5. SUMMARY FROM PRELIMINARY RESULTS

Initial TAMDAR impact RUC parallel experiments have been conducted from February 2005 through current date (November 2005). Results are described in Section 4. These results can be normalized using analysis fit to observations as equivalent to a perfect forecast score (Benjamin et al. 2004c, eqn 3). Following Benjamin et al. (2004c, Fig. 11c) we have used the following values as appropriate:

- 850 hPa wind - 3.0 m/s
- 850 hPa temp - 0.5 K
- 850 hPa RH - 10% (RH)

Including use of this normalization, we draw the following preliminary conclusions on the TAMDAR impact experiments:

- TAMDAR impact results have improved during the continuing GLFE.
- The TAMDAR impact experiments using RUC have contributed to the shakedown of the TAMDAR observation quality.
- Temperature impact from TAMDAR
    - Strongest results at 850 hPa – 15-20% improvement for 3-h forecasts over Great Lakes area (using normalization.
    - Less positive impact at 700-500 hPa.
- RH impact
    - Strongest at 850 hPa – about 12% normalized improvement for 3-h forecasts
    - Little or even slight negative impact for 700-500 hPa.
- Temperature and RH impact appeared to improve with higher vertical resolution (Phases 2 and 3).
- Wind impact
    - Averaged 10% improvement for 850-700-500 hPa layer.
- Diurnal variations
    - More impact for 3-h forecasts at 00 UTC than at 12 UTC
    - More impact for 6-9h forecasts at 12 UTC than at 00 UTC
- Results should further improve with additional improvements in TAMDAR data accuracy (e.g., reducing ascent vs. descent temperature biases – Moninger et al. 2006, wind errors)

6. ACKNOWLEDGMENTS

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