16.2

Relative forecast impact from aircraft, profiler, rawinsonde, VAD, GPS-PW, METAR and mesonet observations for hourly assimilation in the RUC

Stan Benjamin, Brian D. Jamison, William R. Moninger,
Barry Schwartz, and Thomas W. Schlatter

NOAA Earth System Research Laboratory, Boulder, CO

1. Introduction

A series of experiments was conducted using the Rapid Update Cycle (RUC) model/assimilation system in which various data sources were denied to assess the relative importance of the different data types for short-range (3h-12h duration) wind, temperature, and relative humidity forecasts at different vertical levels. This assessment of the value of 7 different observation data types (aircraft (AMDAR and TAMDAR), profiler, rawinsonde, VAD (velocity azimuth display) winds, GPS precipitable water, METAR, and mesonet) on short-range numerical forecasts was carried out for a 10-day period from November-December 2006.

2. Background

Observation system experiments (OSEs) have been found very useful to determine the impact of particular observation types on operational NWP systems (e.g., Graham et al. 2000, Bouttier 2001, Zapotocny et al. 2002). This new study is unique in considering the effects of most of the currently assimilated high-frequency observing systems in a 1-h assimilation cycle. The previous observation impact experiments reported in Benjamin et al. (2004a) were primarily for wind profiler and only for effects on *wind* forecasts. This new impact study is much broader than that the previous study, now for more observation types, and for three forecast fields: wind, temperature, and moisture.

Here, a set of observational sensitivity experiments (Table 1) were carried out for a recent winter period using 2007 versions of the Rapid Update Cycle assimilation system and forecast model. The seven observing systems considered in this study include probably the six most dominant wind/temperature observation types over the United States: rawinsondes, all aircraft, TAMDAR aircraft, surface, wind profilers, and VAD (velocity azimuth display) wind profiles from WSR-88D radars. Five of these six (excepting rawinsondes) provide hourly data. It also includes the primary tropospheric moisture observation types (rawinsondes, GPS-PW). We also include relative effects of METAR and mesonet surface observations. We do not consider satellite radiances or retrieved soundings in this study, although GOES-based cloud-top temperature/pressure retrievals, cloud-drift winds, and precipitable water are also assimilated in the RUC 1-h cycle.

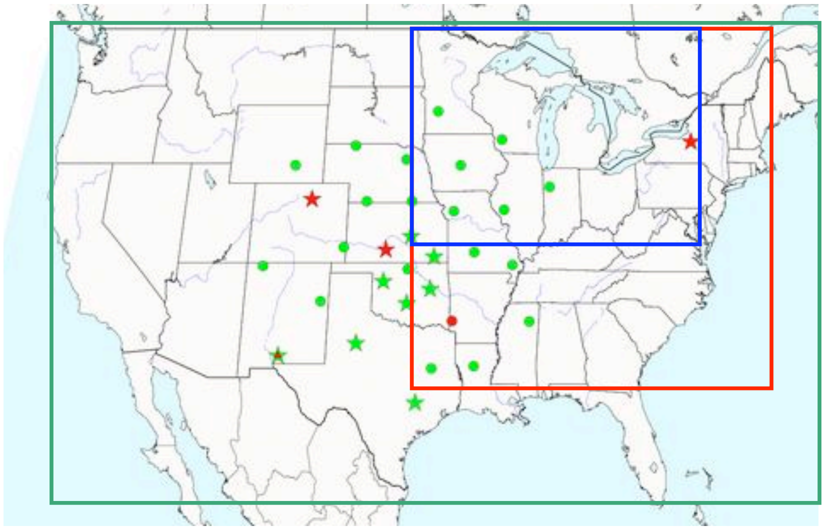

Figure 1. Location of three verification domains: National (green – Region 0), Eastern (Red – Region 1, Midwest (Blue – Region 2). Also shown is the location of the current NOAA 404-MHz profilers.

Experiment	**Variables observed for denied observations**
Control – all observations	
No rawinsonde obs	Z,T,V,RH
No profiler winds	V
No VAD	V
No aircraft (AMDAR and TAMDAR)	V,T (RH for TAMDAR only)
No TAMDAR only (AMDAR still included	V,T,RH
No GPS-PW	Precipitable water
No surface	P,T,V,Td
No mesonet	P,T,V,Td
No GOES cloud-drift wind	V
All obs but 8-km profiler	V
All obs but 12-km profiler	V
All obs but 4-km profiler	V

Table 1. Observation impact experiments in this study.

3. Experiment design for observation impact experiments

The experiments carried out for this 10-day data assimilation period are shown in Table 1.

The version of the RUC used in these experiments uses the same code as the 13-km version run operationally at NCEP as March 2007, including 50 hybrid isentropic-sigma vertical levels and advanced versions of model physical parameterizations, but run at 20-km resolution to improve computational efficiency. An hourly intermittent assimilation cycle allows full use of hourly profiler (and other high-frequency) observational data sets. The analysis method is the three-dimensional variational (3DVAR) technique implemented in the operational RUC in May 2003. Additional information about the 20-km RUC is provided by Benjamin et al. (2004a, 2007). The cold-season experiment period began at 0000 UTC 26 November 2006 with the background provided from a 1-h RUC forecast initialized at 2300 UTC 25 Nov 2006. Lateral boundary conditions were specified from the NCEP NAM (North American Mesoscale) model initialized every 6 h and available with 3-h output frequency. The high-frequency observations used include those from wind profilers, commercial aircraft, Doppler radar velocity azimuth display (VAD) wind profiles, and surface stations.

a. Experiments performed

Verification was performed using conventional 12-hourly rawinsonde observations over two domains. The first domain contains all the rawinsondes located within the RUC domain; the second is a limited area enclosing all of the Midwest profiler stations (see Fig. 1). Forecast minus observed (f-o) residuals for 3-, 6-, 9-, and 12 h temperature, relative humidity, and wind forecasts were computed at all rawinsonde sites which are used to compute average error statistics for each experiment.

Verification was performed using conventional 12-hourly radiosonde data over the three domains depicted in Fig. 1. For each RUC experiment, residuals (forecast minus observed) were computed at all radiosonde locations located within each respective verification domain. Next, the rms (root mean square) difference between forecasts and observations was computed for each 12-h verification time. This difference is sometimes referred to below as 'forecast error', but in fact also contains a contribution from observation error (including representativeness "error" from the inability of a grid to resolve sub-grid variations sometimes evident in observations).

The impact of observation types is limited in this study by use of the same set of lateral boundary conditions in all experiments. Weygandt et al. (2004) show that about half the regional impact of a simulated lidar wind observing system is from the larger-scale effect in an accompanying set of global OSSE experiments. In this study, the observations considered are generally more densely available over the United States than over oceans and other land areas, but the actual impact is underestimated in this study because of the common lateral boundary conditions in these experiments.

In the following results, **increase in forecast error from denying a given observation type** can be considered *equivalent* to the **added forecast skill when that observation type is added to other existing observations.**

4. Results

a. Wind forecasts

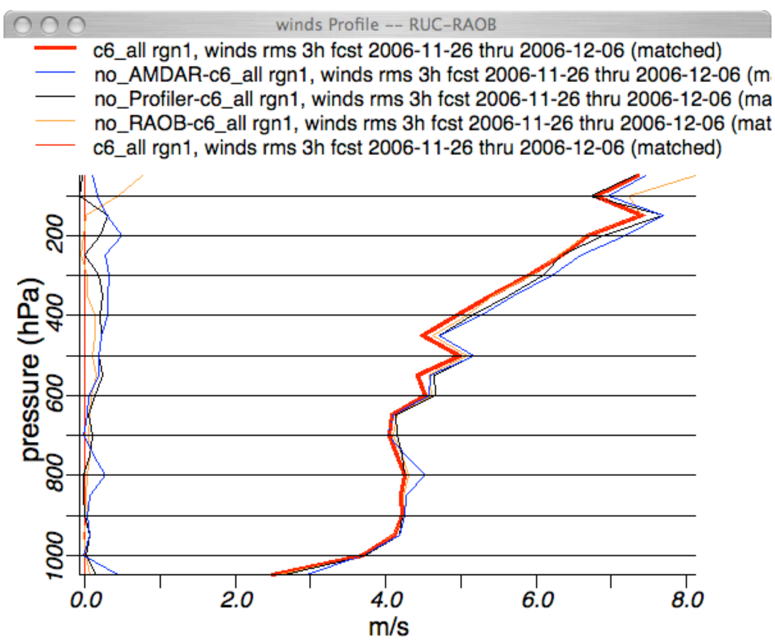

Figure 2. Wind forecast error for 3-h forecast over Region 1 (eastern US, see Fig. 1) from control (C6_all, all observations used) and from denial experiments for aircraft (no_AMDAR), profiler (no_profiler), rawinsonde (no_RAOB). The differences relative to the control experiment are also shown near the left axis.

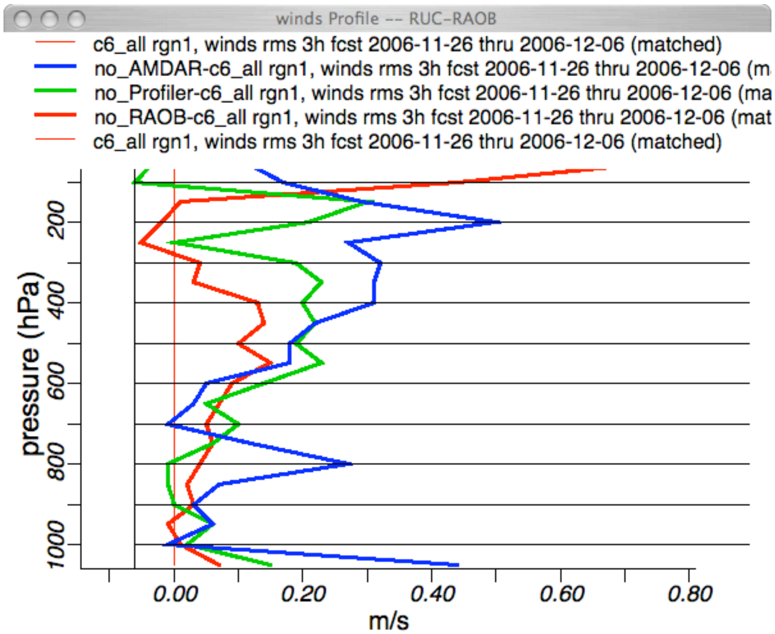

Figure 3. Same as Fig. 2 (3-h wind forecast impact) but for differences relative to control experiment only.

The largest observational impact for 3-h wind forecasts over the eastern US is from aircraft data (combined AMDAR and TAMDAR), over 0.4 m/s at 200 hPa, approximately the maximum jet level and probably the peak level for aircraft data report density (close to FL350 – flight level at 35,000 ft in Standard Atmosphere). The second largest impact for 3-h wind forecasts over the eastern US is from wind profiler reports, especially in the middle troposphere from 300-600 hPa. The relative impact of rawinsonde observations appears to be relatively small for tropospheric wind forecasts, but this comparison is misleading since it is only for forecasts initialized at 0900 and 2100 UTC, when no rawinsonde observations are available.

Since rawinsonde observations are only available every 12 h, we also show 12-h impact in Fig. 4. Now, the rawinsonde data appears to be the backbone observational data set for 12-h wind forecasts. Aircraft and profiler data appear to be more important than rawinsonde observations for 3-h forecasts. These results would change if verified at times other than 0000 and 1200 UTC (showing more relative impact for raobs in such 3-h forecasts) or if taken over the full national domain (Region 0, Fig. 1) (less impact of profiler data, which are largely available only over the central US).

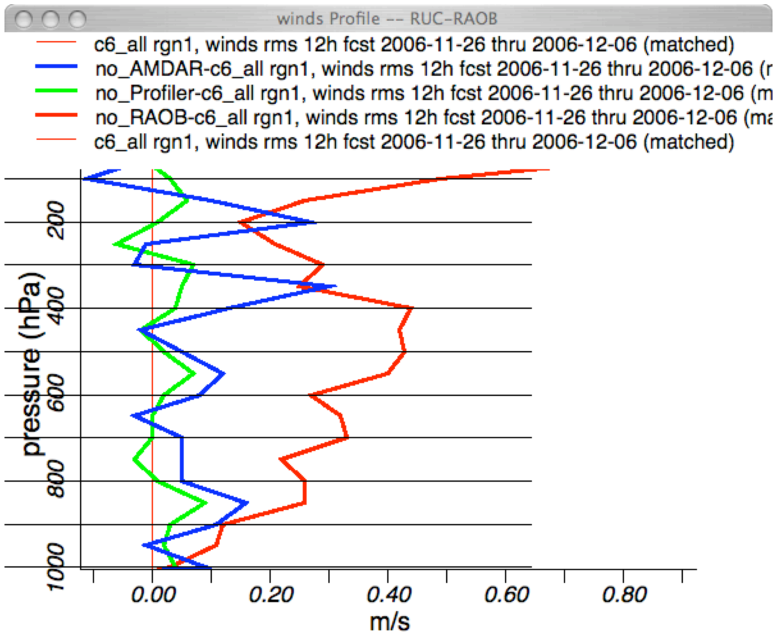

Figure 4. Same as Fig. 3 but for 12-h forecast impact.

b. Temperature

The primary observation types contributing directly to temperature forecasts over the US are rawinsondes, aircraft, and surface data.   We first consider the relative effects of these observation types for temperature (Fig. 5), again for 3-h forecasts over the eastern US, similar to those shown for winds in Fig. 3.

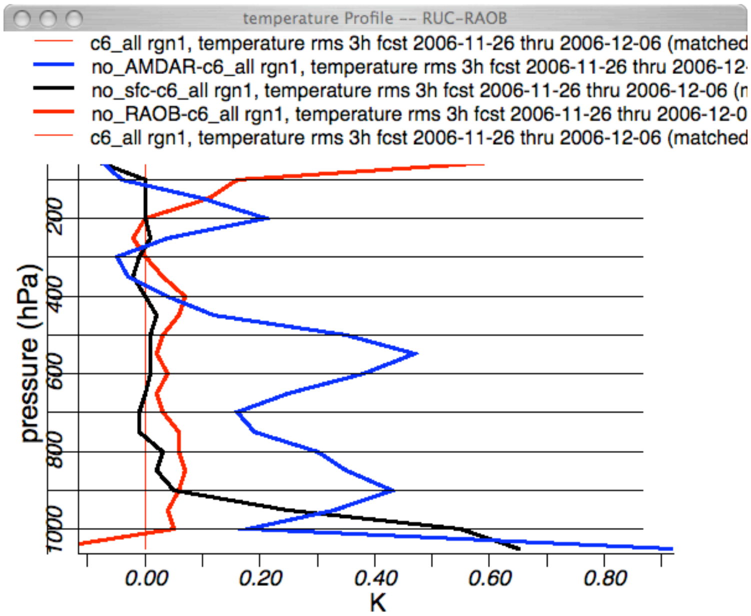

Figure 5.   Relative impact for 3-h temperature forecasts over the eastern US (similar to Fig. 3 but now for temperature).

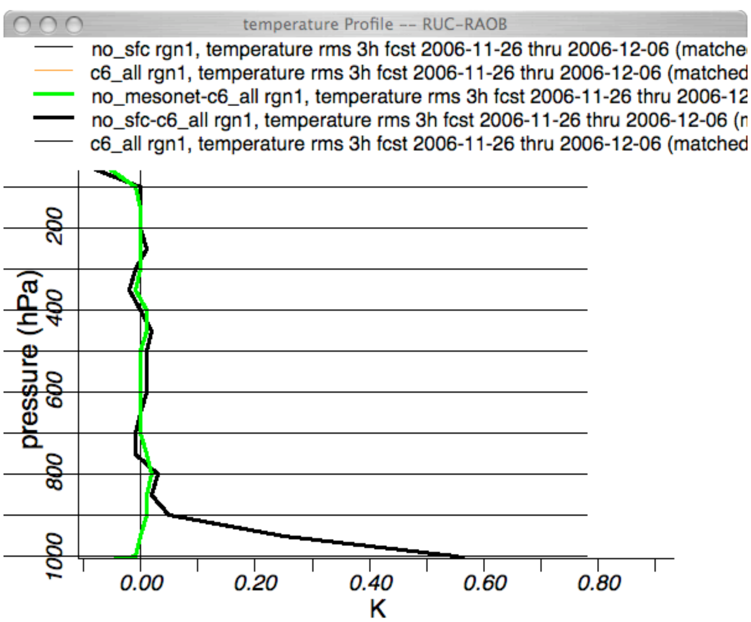

Figure 6. Same as Fig. 5 but for all surface data (black) and mesonet only (green).

For 3-h forecasts, aircraft data have the largest impact, although there is also a significant impact from surface observations near the surface.   None of these forecast types seem to have much effect on forecasts between 300-400 hPa. Aircraft reports have 3 separate peaks in improving 3-h temperature forecasts, two of which are levels of largest temperature in general (at inversion or cloud level above surface near 900 hPa, and at the tropopause, averaging about 200 hPa for this test period).

We also investigated the additional value of mesonet observations to temperature forecasts (Fig. 6) and found that they added very little. We conclude that for 3-h forecasts, surface stations other than mesonet (primarily METAR) adequately definite forecast error for improved model forecasts.

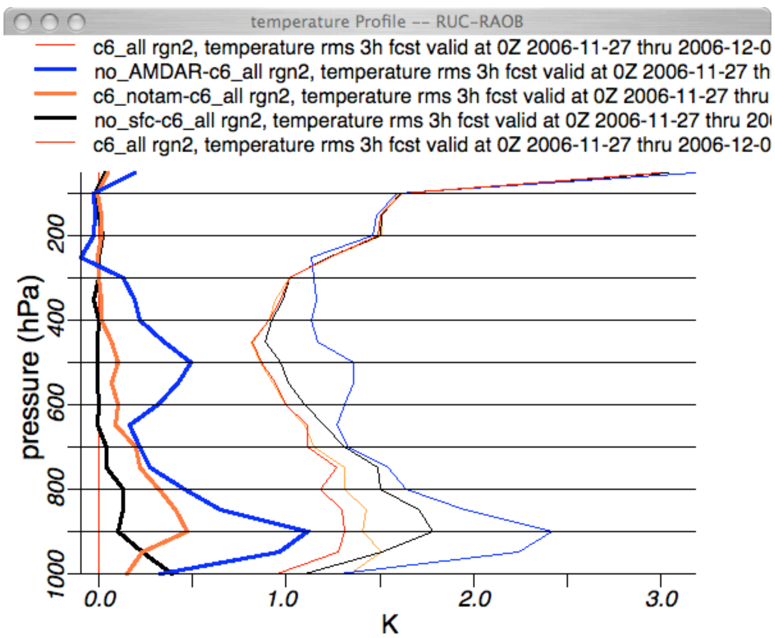

Figure 7. Relative impact on 3-h temperature forecasts at 0000 UTC only from all aircraft (blue), TAMDAR only (orange) and surface (black) for Midwest domain (Region 2 in Fig. 1) .

Finally, we also investigated the relative impact of TAMDAR compared to all aircraft data for the Midwest domain only at 0000 UTC, when impact of TAMDAR data is strongest (Moninger et al. 2008). Fig. 7 shows that TAMDAR clearly strengthens the overall aircraft impact from 900-700 hPa, and that non-TAMDAR aircraft are still most important even with this stratification focusing on current TAMDAR impact.

c. Relative humidity

Finally, we look at impact on relative humidity forecasts. For this variable, there are significant contributions from each of the observation types examined. GPS-PW has the largest impact between 800-650 hPa, TAMDAR is largest from 600-500 hPa, and surface data has the largest at the surface. Excepting 250 hPa and above, in almost every layer, there are significant contributions for at least two observation types for relative humidity forecasts.

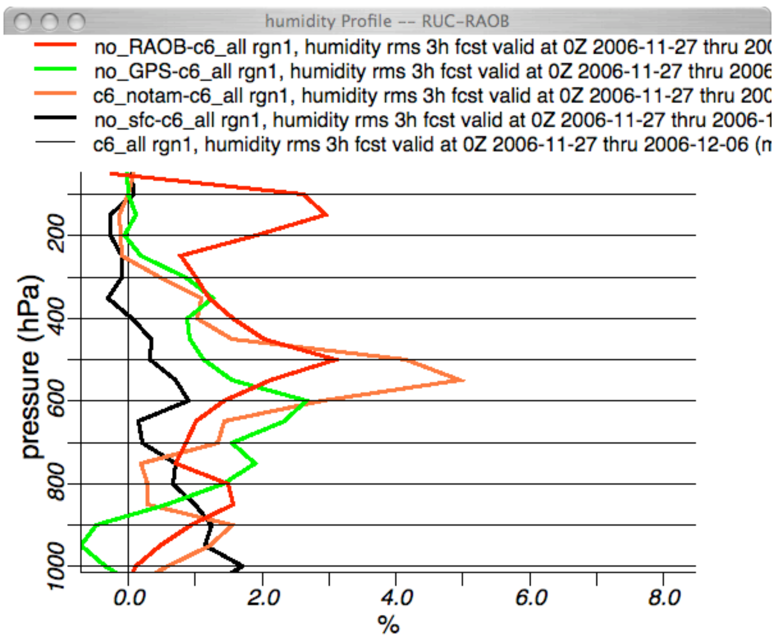

Figure 8. Relative impact for 3-h relative humidity forecasts over the eastern US for raobs (red), GPS-PW (green), TAMDAR (orange), and surface (black).

5. **Conclusions**

A wide range of observation impact experiments were carried out for a winter-season 10-day test period in November-December 2006. The heterogenous observation system over the US is represented in the results, with significant contributions for 3-h forecasts from different components evident for winds, temperature and humidity forecasts.

6. **References**

Benjamin, S.G., B.E. Schwartz, E.J. Szoke, and S.E. Koch, 2004a: The value of wind profiler data in U.S. weather forecasting. *Bull. Amer. Meteor. Soc*., **85**, 1871-1886.

Benjamin, S.G., D. Devenyi, S.S. Weygandt, K.J. Brundage, J.M. Brown, G.A. Grell, D. Kim, B.E. Schwartz, T.G. Smirnova, T.L. Smith, and G.S. Manikin, 2004b: An hourly assimilation/forecast cycle: The RUC. *Mon. Wea. Rev.*, **132**, 495-518 (Feb. issue). PDF

Benjamin, S.G., B.E. Schwartz, E.J. Szoke, and S.E. Koch, 2004d: The value of wind profiler data in U.S. weather forecasting. Case studies. (online supplement) *Bull. Amer. Meteor. Soc*., **85**, E21-E29. http://ruc.fsl.noaa.gov/pdf/profiler-paper-25feb04.pdf

Benjamin, S.G. and B.E. Schwartz, 2004: Regional OSE impact with hourly assimilation in the RUC. 3rd WMO Workshop on the Impact of Various Observing Systems on Numerical Weather Prediction, Alpbach, Austria, 9-12 March 2004.

Bouttier, F., 2001. The use of profiler data at ECMWF. *Meteor. Zeit.*, **10**, 497-510.

Graham, R.J., S.R. Anderson, and M.J. Bader, 2000. The relative utility of current observations systems to global-scale NWP forecasts. *Quart. J. Roy. Meteor. Soc*., **126**, 2435-2460.

Moninger, W. R., S. G. Benjamin, B. D. Jamison, T. W. Schlatter, T. L. Smith, and E. J. Szoke, 2007: TAMDAR and its impact on Rapid Update Cycle (RUC) forecasts. 22nd Weather Analysis and Forecasting Conf., June, Park City, Utah, AMS, pdf

Weygandt, S.S., T.W. Schlatter, S. E. Koch, S.G. Benjamin, A. Marroquin, J. R. Smart, M. Hardesty, B. Rye, A. Belmonte, G. Feingold, D. M. Barker, Q. Zhang, and D. Devenyi, 2004: Potential forecast impacts from space-based lidar winds: results from a regional observing system simulation experiments. *Preprints 8th Symp. Integ. Obs. Systems.*, Seattle. PDF

White, A.B., F.M. Ralph, J.R. Jordan, C.W. King, D.J. Gottas, P.J. Neiman, L. Bianco, and D.E. White, 2007: Expanding the NOAA Profiler Network: Technology evaluation and new applications for the coastal environment. Proc. 7th Conf. Coastal Atmos. And Oceanic Pred. and Processes, 10-13 Sept, San Diego, AMS.

Zapotocny, T.H., W.P. Menzel, J.P. Nelson, and J.A. Jung, 2002: An impact study of five remotely sensed and five in situ data types in the Eta Data Assimilation System. *Wea. Forecasting*., **17**, 263-285.