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IMPACT OF TAMDAR DATA ON RUC SHORT-RANGE FORECASTS

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1. OVERVIEW OF TAMDAR

Even though the amount and distribution of moisture in the lower troposphere is critical for many weather forecasts, accurate point observations of moisture above the surface are generally available only twice per day at widely spaced upper-air rawinsonde sites (hereafter, RAOBs). Wind and temperature data from aircraft, known as AMDAR (Aircraft Meteorological Data Relay), have been routinely used by forecasters and assimilated in numerical models, but until recently, there have been no routine aircraft measurements of moisture. This has changed with the development and experimental deployment of an aircraft sensor capable of accurate measurement of moisture, both in the boundary layer and aloft.

The NASA Aviation Safety Program funded the development of a sensor called TAMDAR (Tropospheric AMDAR) by AirDat, LLC, of Raleigh NC, designed for deployment on aircraft flown by regional airlines (Daniels et al., 2006), since 2005. The TAMDAR sensor package measures moisture as well as wind and temperature. In 2005, with the support of NASA and the FAA, these sensors were deployed on 63 commercial aircraft flying over the U. S. Midwest and Lower Mississippi Valley in an experiment called the Great Lakes Fleet Evaluation (GLFE). The GLFE officially concluded in early 2006, although the data have continued to be made available from the fleet of (now 49) aircraft flying with the TAMDAR sensor package.

In addition to the added measurement of moisture, the aircraft taking part in the GLFE fly out of many smaller airports (as well as major hubs) that typically do not have coverage from current aircraft data. This increases the number of ascent/descent soundings considerably. Furthermore, the flights are at levels well below the jet stream level of typical AMDAR aircraft, adding much data in the level between approximately 14 to 20 kft AGL. Typical coverage for TAMDAR flights is shown in Fig. 1. The three main TAMDAR hub airports, in Minneapolis, Detroit, and Memphis, originate numerous flights between the hours of

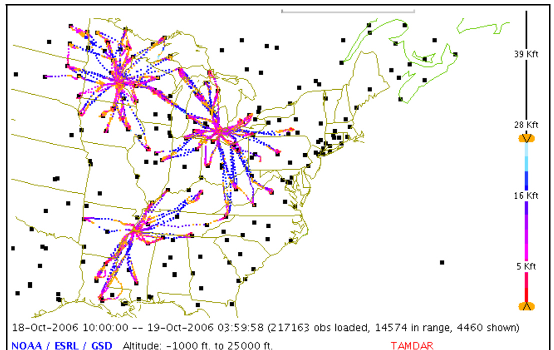

Fig. 1. Typical TAMDAR flight coverage, shown here for an 18-h period from 1000 UTC 18 Oct 2006 to 0400 UTC 19 Oct. Colors on the flight tracks depict the flight level (kft, AGL).

~1000 UTC and 0400 UTC. There are no TAMDAR flights during the late overnight hours.

One of the purposes of the GLFE was to evaluate the TAMDAR data, both in terms of the data quality as well as its potential utility for improving weather forecasting. TAMDAR data were made freely available, and ESRL's Global Systems Division (GSD) was a focal point for making the data available to many users through a familiar web page that has been used to distribute AMDAR observations (at http://acweb.fsl.noaa.gov/java/, restricted to governments and some research institutions). It is also possible for National Weather Service (NWS) Weather Forecast Offices (WFOs) to display TAMDAR data on their Advanced Weather Interactive Processing System (AWIPS) via the Meteorological Assimilation Data Ingest System (MADIS).

GSD has been evaluating both the quality of the TAMDAR data as well as its meteorological impact since the data became available. Objective and subjective comparisons with RAOBs on an ongoing basis initially identified a number of issues with data quality that were corrected via a close collaboration with AirDat (these were often caused by instrument problems that were then corrected). In terms of the meteorological studies, a major focus has been on the impact of TAMDAR data using the Rapid Update Cycle (RUC) model (Benjamin et al. 2004). As detailed in the next section, statistics have been calculated in real time for identical versions of the RUC model run with

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and without TAMDAR, comparing wind, temperature and humidity from the forecasts with coincident RAOB sites as verification points. In general, including TAMDAR data has demonstrated a consistent positive impact (the latest statistics are discussed at this conference by Moninger et al. 2007b).

While demonstrating model impact is important, the data can have a significant impact on human forecasting that is more difficult to demonstrate objectively. This is often the case for the potential impact that TAMDAR might have for forecasts issued by a typical NWS WFO. These range from public forecasts of "ordinary" weather, to aviation forecasts, and for severe storm potential. Case studies are perhaps the best means to evaluate the potential impact of TAMDAR in such situations. A number of cases have documented how TAMDAR soundings benefited the forecast, with some presented at recent conferences (Brusky and Kurimski 2006, Druse, 2007, Fischer 2006, Mamrosh et al. 2006, and Szoke et al. 2006, 2007). The Green Bay, Wisconsin WFO has been a focal point for collecting a number of these studies and organizing them on the official NOAA TAMDAR Web page (at http://www.crh.noaa.gov/tamdar/). A training CD can also be accessed from this Web site.

These cases point out the significant value to forecasters from the basic TAMDAR sounding data, which for the first time provides off-RAOB time information about the above-surface moisture profile, with the same resolution as a RAOB. Studies and examples gathered by the Green Bay WFO have also demonstrated other forecast applications, in addition to convective forecasting, that forecasters have found using the TAMDAR sounding data as they have become aware of this new source of information. These applications are important to note when evaluating the potential value of a new data source, since impact on numerical weather prediction models as measured by objective statistics can sometimes be difficult to interpret, or appear to be relatively small.

In this paper we will focus on both a subjective and objective evaluation of the impact of TAMDAR data on RUC short-term precipitation forecasts. We have considered a variety of weather systems from the last couple of years, some of which were high-impact events. The details of the model runs and verification are discussed in the next section.

TAMDAR data from the current Mesaba fleet will continue to be made available by AirDat to the U. S. government for at least the next year, and we expect they will be used in operational Numerical Weather Prediction models. TAMDAR will also be deployed on additional fleets over the next year. These fleets will cover Alaska and the Western US. The fleets will include jet aircraft, which will expose the TAMDAR sensors to higher altitudes and higher speeds than they have been exposed to thus far. Data from these new fleets will be made available to GSD so that we can evaluate the quality of the data and the impact of these new fleets and expanded coverage on weather forecasts.

2. VERIFICATION STUDIES

Since 2005, parallel versions of a 20-km horizontal grid resolution RUC have been run at hourly intervals, with one version ingesting TAMDAR and the other excluding TAMDAR (Moninger et al. 2006, 2007a, b; Benjamin et al. 2006, 2007). Otherwise, the model runs are the same. Currently, model forecasts are generated at 1-h intervals to 6 h, and at 3-h intervals out to 24 h. A number of images are made for each run, as well as several other RUC real-time runs at GSD, and posted online at http://ruc.noaa.gov/, with the RUC runs with TAMDAR labeled "20-km dev2 RUC", and those without TAMDAR "20-km dev RUC". The web images are displayed for the RUC TAMDAR/non-TAMDAR runs initialized at 0000 UTC, 0600 UTC, 1200 UTC and 1800 UTC, with forecasts out to 24 h.

We focused on cases where precipitating weather systems were moving across the Midwest and/or Ohio Valley, well within the main area of TAMDAR coverage (Fig. 1). Some of these systems were major cyclones, producing large swaths of rain or snow and/or severe convective weather. We chose RUC model start times when TAMDAR data would be available to the RUC initialization scheme. Typically the greatest amount of TAMDAR data would be present for the 1800 UTC and 0000 UTC RUC runs, with a lesser amount for the 1200 UTC run. In general, we examined 6-h forecasts of accumulated precipitation for the first 6 h of the model run, as this was the easiest short-term period to compare to available verification. We also compared individual 3-h and 6-h forecasts of various surface fields and precipitation to corresponding analyses overlaid with radar reflectivity.

In terms of verifying precipitation, we used the near real-time 6-h quantitative precipitation estimation available from the National Precipitation Verification Unit (NPVU), at http://www.hpc.ncep.noaa.gov/npvu/index.shtml. This estimation is a combination of precipitation observations and radar estimates, which results in some limitations in terms of representing the true accumulated precipitation (Schwartz and Benjamin 2000). We have been objectively scoring RUC forecasts with and without TAMDAR since 2005 for the fields of temperature, wind, and relative humidity. Precipitation was added for these TAMDAR/non-TAMDAR runs at the beginning of 2007, using the gridded precipitation fields available from the NPVU at 4x4-km resolution, similar to what has been done for some time now with other RUC precipitation forecasts (Schwartz and Benjamin 2000). As with the other fields, we verified the precipitation over two areas, shown in Fig. 2. The smaller domain contains the area where most of the TAMDAR flights are located, and is presumably where the greatest impact of TAMDAR on the short-term RUC forecast would be found. The bigger area encompasses the Memphis TAMDAR hub and most of the southern extent of the TAMDAR flights. In this study we will focus on the smaller domain in Fig. 2 when discussing the objective scores, but examine the entire region subjectively.

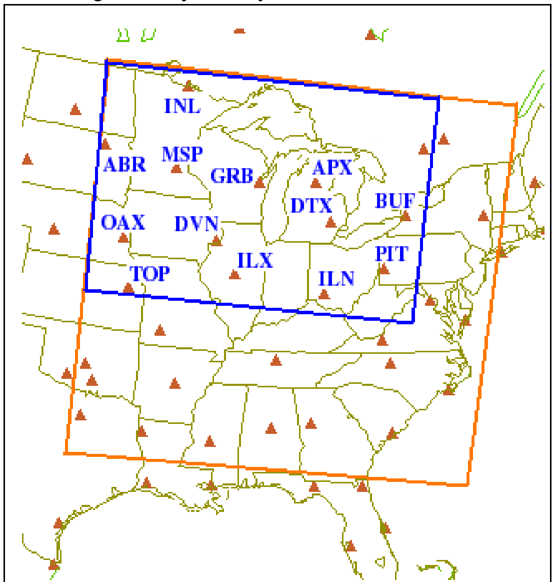

Fig. 2. Verification domains used for the objective scoring. Triangles denote RAOB sites.

3. CASES

Cases have been examined since 2005 for a wide variety of events, and a few of these will be shown here. The first case shown is from October 2005, and remains the most dramatic case where the RUC forecast using TAMDAR was distinctly better than the forecast without TAMDAR. Most of the cases had far less difference between the two model forecasts of 6-h accumulated precipitation than the October 2005 case. Typically, there might be one or two small areas in the overall precipitation forecast where the forecasts differed. Our general subjective assessment of the cases is that when differences were present verification tended to favor the runs with TAMDAR over those without. This was not always the case, however, with some examples found showing the opposite, at least in some areas. These conclusions are generally backed up for 2007 by our objective scores.

3.1 *4-5 October 2005: Midwest thunderstorms.*

When we first examined this case we were quite impressed by the large differences between the two forecasts, and the better verification for the RUC runs with TAMDAR. The main meteorological feature was a stalled front from central Minnesota eastward across northern Wisconsin (Fig. 3). Widespread thunderstorms formed on both sides of the front and persisted over the same area, producing heavy precipitation, with eleven reports of flooding in northern Wisconsin and over a dozen flood reports in Minnesota. Two 6-h periods were evaluated, one for the 1800 UTC 4 October forecasts ending at 0000 UTC, and another for the set of forecasts initialized 6 h later. In addition to the heavy rains, a distinct feature of this event was the very sharp cutoff to the precipitation, with basically nothing falling over central and southern Wisconsin in the periods of interest. This is depicted in the NPVU 6-h estimated precipitation, shown for the first period in Fig. 4. Precipitation

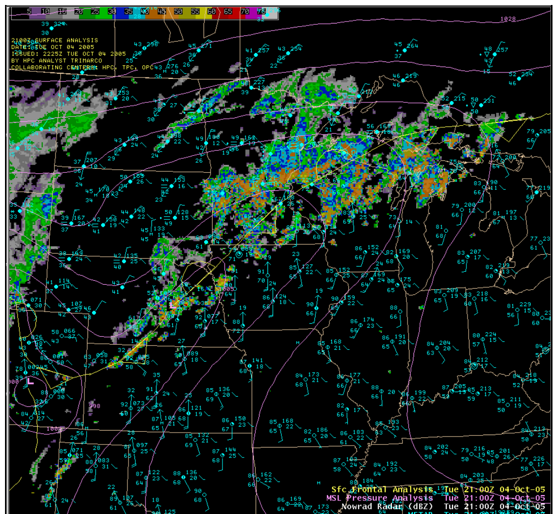

Fig. 3. Composite low-level reflectivity with surface mean sea level pressure and front analysis and METARs for 2100 UTC 4 Oct 2005.

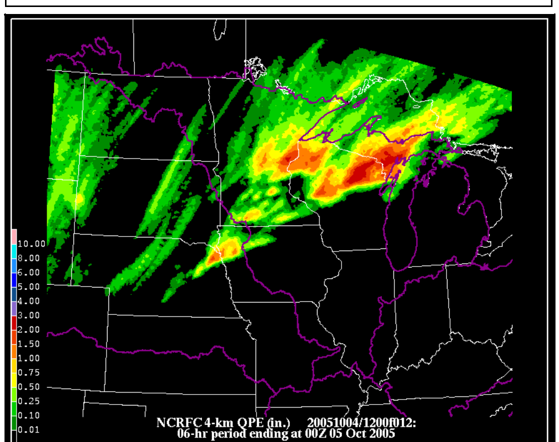

Fig. 4. NPVU precipitation estimate for the 6-h period ending 0000 UTC 5 Oct 2005, in inches.

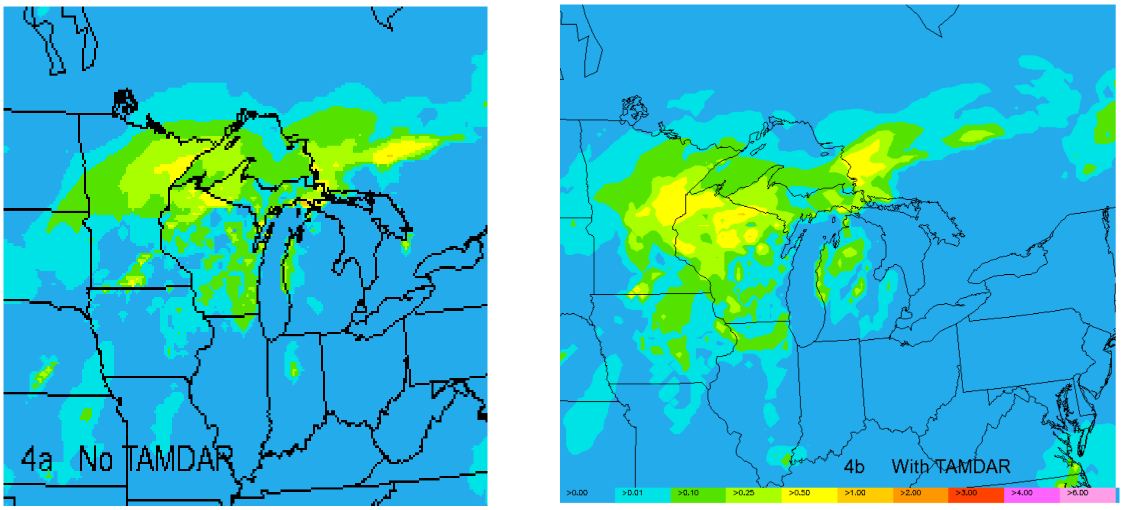

Fig. 5. Comparison of the 6-h accumulated precipitation forecasts from the 1800 UTC 4 October RUC runs without (a) and with (b) TAMDAR. The precipitation scale (inches) is the same for both images.

amounts in the 1.5-3-in range are found over much of northern Wisconsin into the Upper Peninsula of Michigan. There is a very sharp southern cutoff, however, to not only the heavy rains, but the precipitation in general across Wisconsin.

Forecasts from the two RUC runs (with and without TAMDAR), verifying for the same period as the precipitation estimate in Fig. 4, are presented in Fig. 5. Both forecasts have precipitation extending too far south and do not resolve the sharp southern edge to the precipitation. The main difference between the forecasts occurs across the northern half of Wisconsin, where the RUC run using TAMDAR more closely matches the observed area of heavy precipitation compared to the run without TAMDAR, which has the rainfall shifted too far north. The maximum rainfall in the run with TAMDAR is a small area of greater than one inch, still quite a bit less than what is estimated to have fallen, but more precipitation than the non-TAMDAR run predicts.

Because this period ends at 0000 UTC, it is possible to compare 6-h forecast soundings with observed soundings. A better forecast sounding by the RUC run using TAMDAR for soundings near or upstream of the precipitation region might help explain the superior precipitation forecast for the RUC run with TAMDAR. Comparison sounding forecasts for Lincoln, Illinois (ILX), and Detroit, Michigan (DTX) are illustrated in Fig. 6. While the temperature profiles for both forecasts are similar, the moisture profiles are not. For both locations the RUC run with TAMDAR (labeled dev2) is more moist, and closer to the collocated RAOB, than the forecasts from the RUC run that did not use TAMDAR (labeled dev1). The difference in the 700-850 mb layer at DTW is particularly striking, with the dev1 forecast having a very dry layer that is not present in the observations or the sounding from the RUC forecast using TAMDAR. The drier

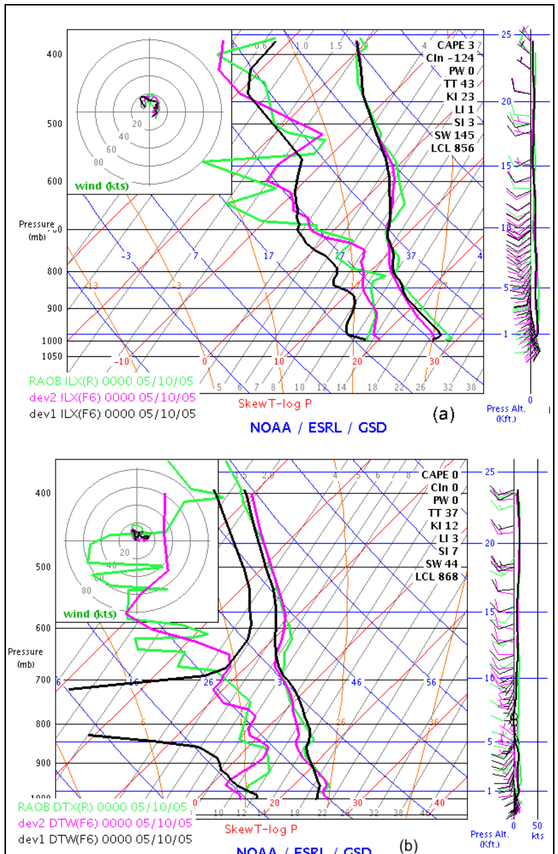

Fig. 6. Comparison of 6-h forecast soundings from the RUC 1800 UTC 5 Oct runs with (labeled dev2) and without (labeled dev1) TAMDAR, compared to observed soundings at Lincoln, Illinois (ILX, (a)), and Detroit, Michigan (DTW, (b)).

environment in the RUC forecast for the run not using TAMDAR might explain both the smaller maximum rainfall amounts and the northward shift in the precipitation area, in the sense that a drier air mass would require greater lift to reach saturation, which would tend to occur further north of the stalled frontal boundary.

The second verification period brackets the next RUC forecast run initialized at 0000 UTC on 5 October, when more heavy precipitation continued through the next 6 h across basically the same area of Wisconsin and Minnesota. The radar image overlaid with a frontal analysis in Fig. 7, illustrates that the rain continued to fall especially hard across northern Wisconsin, with a very sharp cutoff to the precipitation at its southern end. This is also seen in the 6-h estimated precipitation accumulation in Fig. 8, with maximum values in the 2-3 in range over northwest Wisconsin.

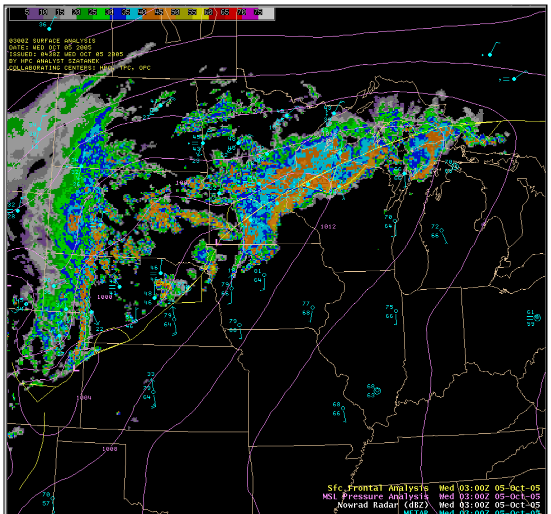

Fig. 7. As in Fig. 3, for 0300 UTC 5 Oct 2005.

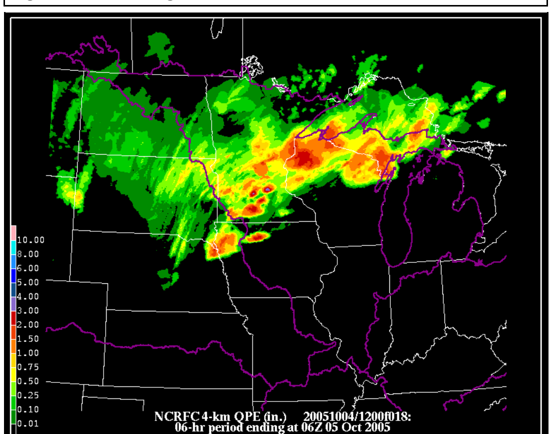

Fig. 8. NPVU precipitation estimation for the 6-h period ending 0600 UTC 5 October, in inches.

A comparison between the two RUC forecasts of 6-h accumulated precipitation for the same 6-h period ending at 0600 UTC on 5 October is shown in Fig. 9. The differences between the forecasts with and without TAMDAR are even more distinct for this period than they were for the forecasts from the previous run. The most apparent difference is

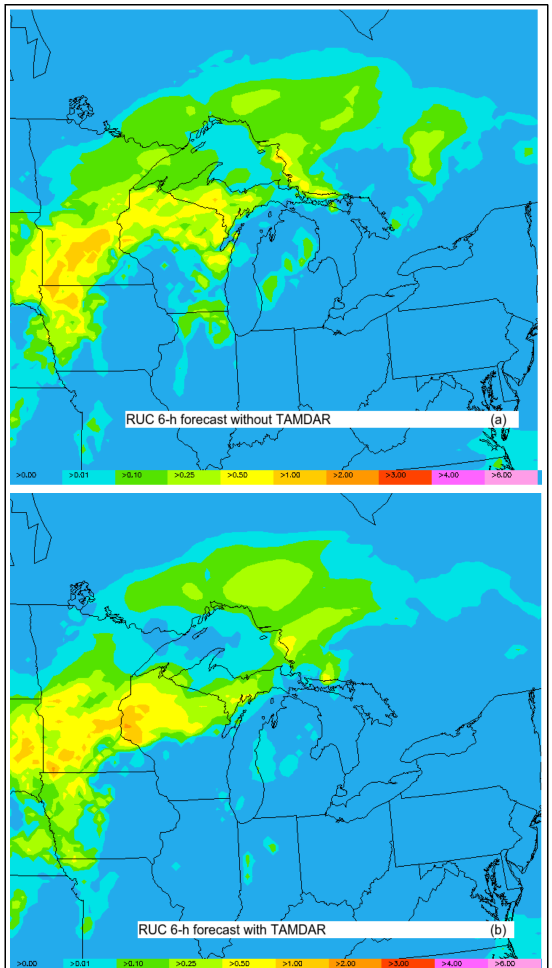

Fig. 9. RUC 6-h forecasts, ending 0600 UTC 5 October, of accumulated precipitation (in) without (a) and with (b) TAMDAR.

that the RUC forecast from the run that includes TAMDAR very nicely captures the very sharp southern cutoff of precipitation for this 6-h period, while the forecast from the run that did not have TAMDAR has scattered areas of rainfall all the way south into northern Illinois. Similar to the previous 6-h period, there are differences in the location of the heavy rain, with the RUC forecast for the model that uses TAMDAR data focusing the heavy rain over northwestern Wisconsin near to where it occurs, while the other forecast shifts the heavier precipitation to over Minnesota.

3.2 *20-21 January 2006: Midwest snowstorm.*

One winter case that displayed obvious differences between the two RUC forecasts occurred in early 2006. A radar composite along with pressure analysis and surface observations for 2100 UTC on 20 January is shown in Fig. 10. Several NWS WFOs issued various winter weather warnings for this event, extending from Kansas to Michigan (Fig. 11). Snowfall (Fig. 12) occurred in

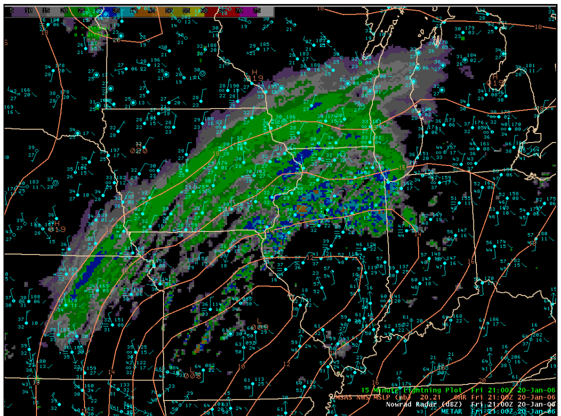

Fig. 10. As in Fig. 3, for 2100 UTC 20 Jan 2006.

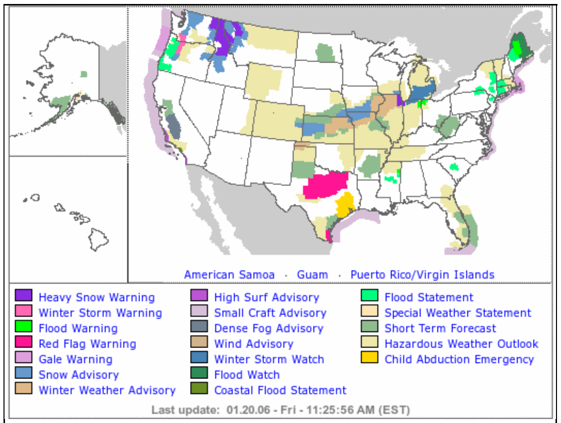

Fig. 11. Depiction of various NWS Watches, Warnings and statements in effect on 20 Jan 2006.

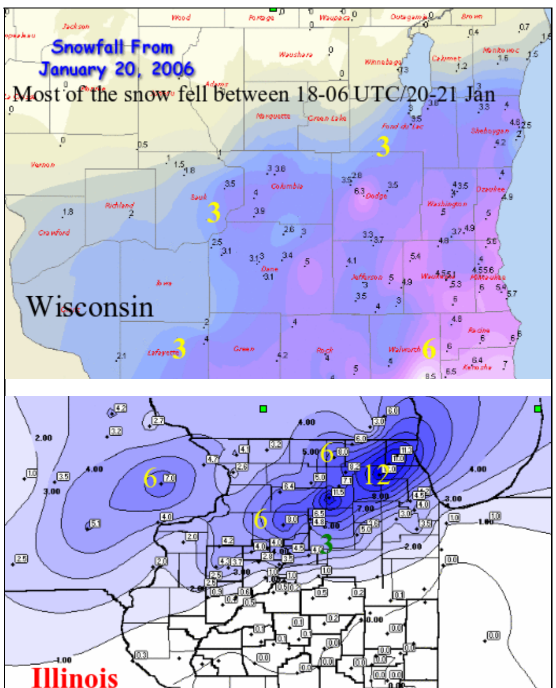

Fig. 12. Snowfall reports for the 24-h ending ~1200 UTC on 21 Jan 2006, in inches, for Wisconsin (top) and northern Illinois (bottom).

an extensive swath, as well as an area of ice accumulation that, coupled with the snow, resulted in power outages across portions of Iowa and Illinois.

Two sets of RUC forecasts were examined, one for runs initialized at 1800 UTC on 20 January and the other for runs from 0000 UTC on 21 January. For the first period there were only small differences between the 6-h precipitation forecasts ending at 0000 UTC on 21 January. The timing of the snowfall was such that most of the snow in the area of interest fell between 1800 UTC on 20 January and 0600 UTC on 21 January, and we were therefore able to use storm total snow reports (Fig. 12) to compare to 12-h model forecasts of snowfall. The comparison of the model forecasts of snow are in Fig. 13, with areas of differences highlighted.

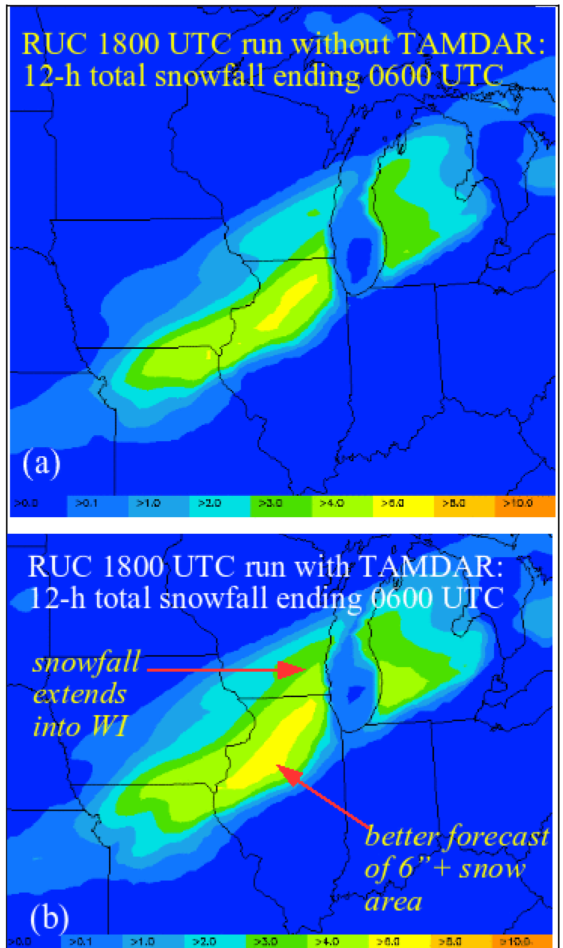

Fig. 13. Snowfall forecasts (in) from the 1800 UTC 20 Jan RUC runs without (a) and with (b) TAMDAR for the 12-h period ending 0600 UTC on 21 Jan.

Significant snow fell in a fairly narrow band across portions of northern Illinois, with up to a foot of snow just north of Chicago. Almost 5 in of snow fell at Chicago's O'Hare Airport. A very sharp southern gradient of snowfall occurred, with temperatures such that the precipitation fell more as freezing rain and then rain south of the snow band. Both RUC forecasts resolve the sharp southern gradient, but overall the RUC forecast that used TAMDAR is better in extending the heavier snowfall into southeastern Wisconsin, and producing heavier snowfall across northern Illinois.

As was done for the October case, forecast soundings from the 1800 UTC runs were compared with selected 0000 UTC RAOBs. The comparison for Green Bay, Wisconsin is shown in Fig. 14, and the one for Peoria, Illinois in Fig. 15. Notable differences are seen in the two forecast soundings for Green Bay, with the run using TAMDAR (labeled dev2) this time drier than the forecast sounding for the run that did not use TAMDAR (dev). The drier sounding is much closer to the Green Bay RAOB, which has a dry layer centered near 850 mb. The comparison with the Peoria, Illinois RAOB in Fig. 15 indicates very little difference between the two forecast soundings.

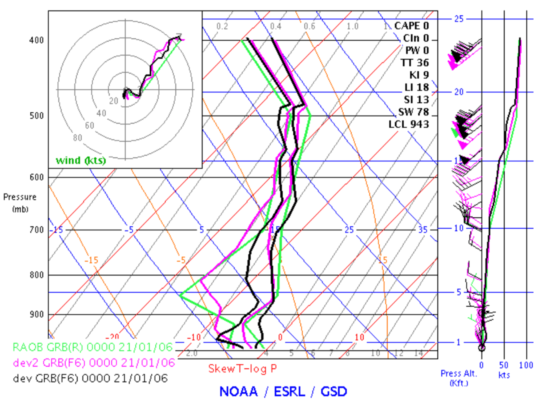

Fig. 14. Comparison of 6-h forecast soundings as in Fig. 6, but compared to the 0000 UTC 21 Jan Green Bay, Wisconsin RAOB.

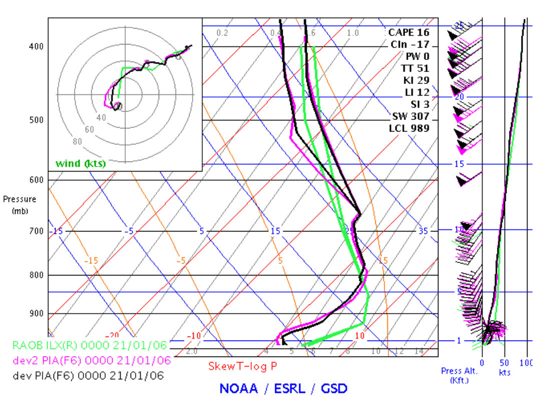

Fig. 15. Comparison of 6-h forecast soundings as in Fig. 6, but compared to the 0000 UTC 21 Jan Peoria/Lincoln, Illinois RAOB.

The second verification period is for the 6-h precipitation forecasts from the 0000 UTC 21 January RUC runs ending at 0600 UTC. The NPVU estimated precipitation for this period is given in Fig. 16. For this period there were differences between the TAMDAR and no-TAMDAR RUC runs (Fig. 17). The areal coverage of the 0.25-0.49 in precipitation interval is considerably greater for the RUC TAMDAR run, which is in better agreement with the estimated precipitation than the forecast from the run without TAMDAR data. This area is highlighted in Fig. 17.

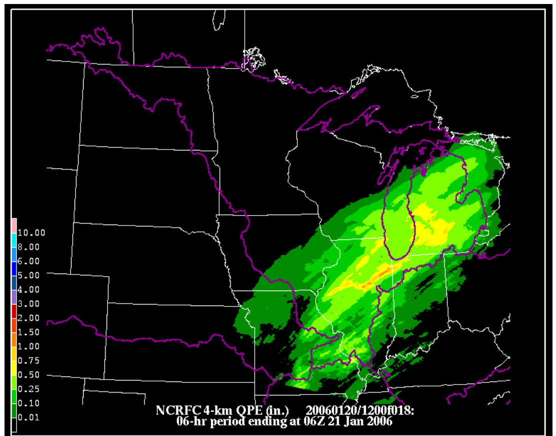

Fig. 16. NPVU precipitation estimate for the 6-h period ending 0600 UTC 21 January, in inches.

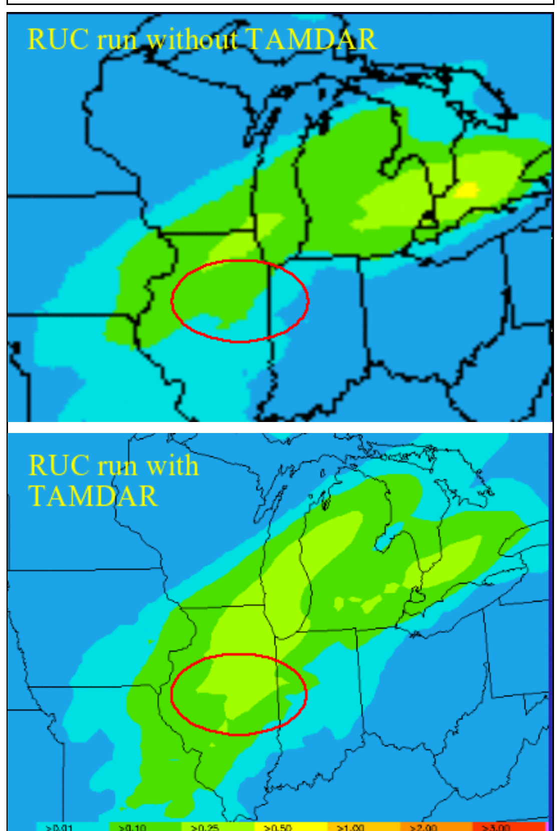

Fig. 17. RUC 6-h forecasts, ending 0600 UTC 21 Jan 2006, of accumulated precipitation (in) without (a) and with (b) TAMDAR.

3.3 *13-14 February 2007: Midwest to Ohio Valley Snowstorm.*

Another significant winter storm occurred in 2007 and was examined for three separate 6-h periods (3 different sets of RUC forecasts). For this storm, however, there was very little difference seen both subjectively and in the objective scores between the RUC forecasts that used TAMDAR and those that did not. One of the periods is shown here for comparison with the previous winter case from 2006.

At 1800 UTC on 13 February a surface low was centered over western Tennessee, producing a huge area of winter precipitation stretching from Iowa all the way to the East Coast (Fig. 18). This was a significant high-impact storm, with numerous winter weather watches and warnings issued, including a blizzard warning across northern Illinois and Indiana (Fig. 19).

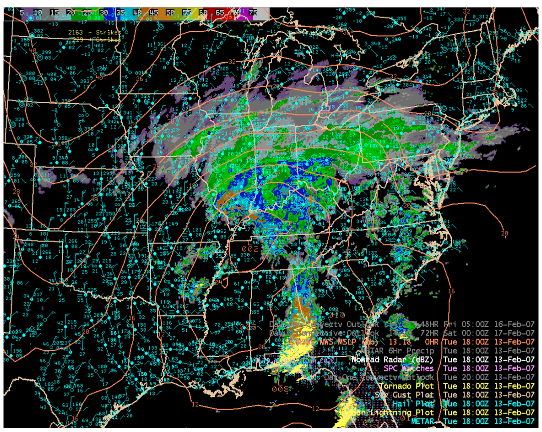

Fig. 18. As in Fig. 3, for 1800 UTC 13 Feb 2007.

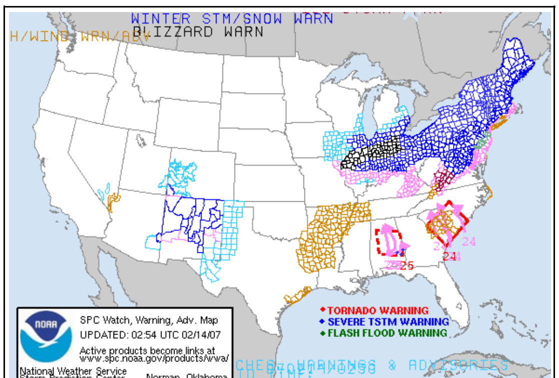

Fig. 19. Depiction of various NWS Watches and Warnings in effect as of 0300 UTC 14 Jan 2006.

Forecasts of 6-h accumulated precipitation from the 1800 UTC 13 February 2007 RUC runs with and without TAMDAR are shown in Fig. 20. The corresponding NPVU precipitation estimate for the same period is in Fig. 21. The two forecasts are very close across the Midwest and Ohio Valley in the main area of precipitation associated with the storm. Both forecasts do well in this region in terms of the amount of precipitation and the areal extent. One area of disagreement is with the convection along the trailing cold front farther to the south, especially across central Tennessee and into northern Mississippi/Alabama. Here the RUC forecast that uses TAMDAR is better, although both forecasts have some trouble in this region. Objective scores for the two forecasts, which do not extend south of Kentucky and so do not include the differences noted above (see Fig. 2

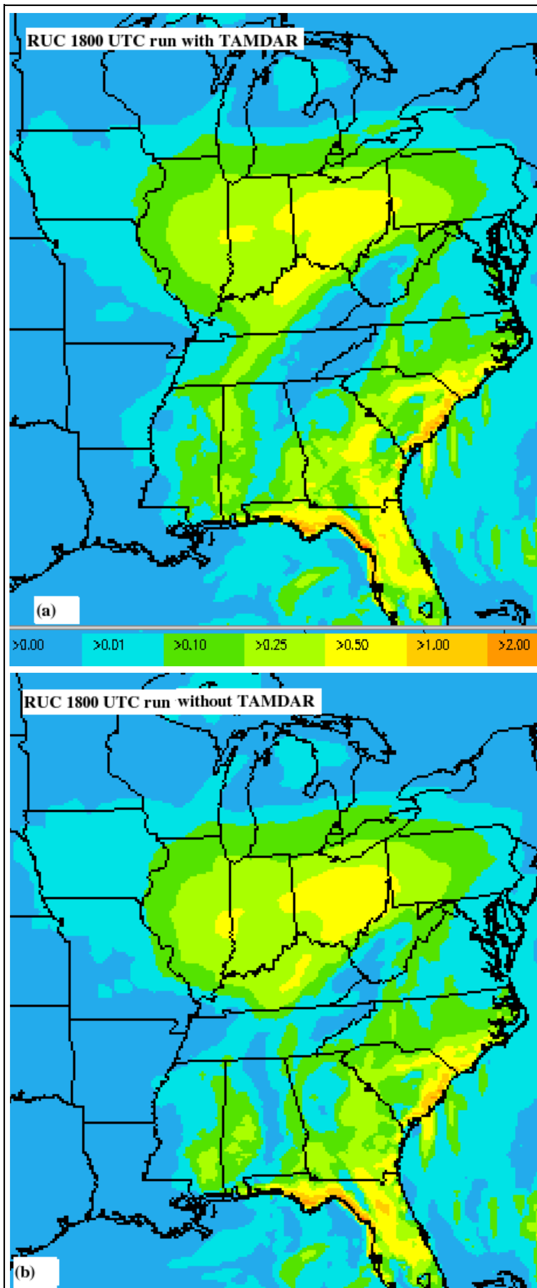

Fig. 20. RUC 6-h forecasts of accumulated precipitation (in), ending 0000 UTC 14 Feb 2007, with (a) and without (b) TAMDAR.

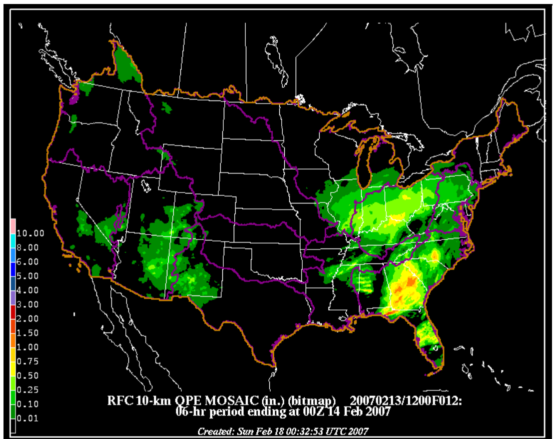

Fig. 21. NPVU precipitation estimate for the 6-h period ending 0000 UTC 14 Feb 2007, in inches.

for the verification area) were also very close, in agreement with the subjective impression of the two forecasts in Fig. 20. Similar agreement between the forecasts was found for the next forecast period (initialization at 0000 UTC on 14 February).

One reason for the lack of difference between the TAMDAR and non-TAMDAR RUC forecasts for this case could be that the snowstorm caused a cancellation of flights (Fig. 22). To investigate whether this might have been the case, we examined TAMDAR flight coverage in the area of interest for a 3-h period prior to 1800 UTC on 13 February and then on a weekday when the weather was benign, 15 February 2007. Comparison of these two days in Fig. 22 indicates that several flights out of Detroit into Illinois and western Ohio are missing on 13 February and were presumably canceled because of the storm. Other flights into Ohio and western Illinois are also missing. For the 1800 UTC RUC runs, then, the snowstorm resulted in considerably less TAMDAR data available within the area of the snowstorm than would typically be present.

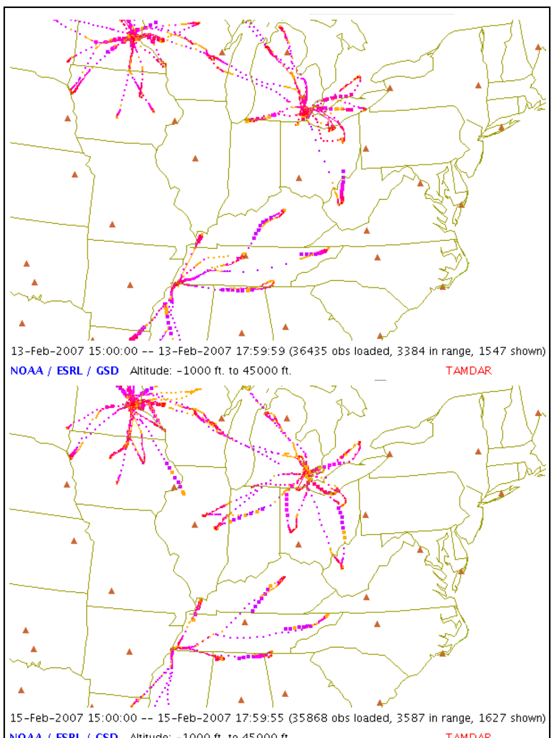

Fig. 22. Comparison of TAMDAR flight coverage for 1500-1800 UTC on 13 Feb 2007 (top) and 15 Feb 2007 (bottom).

The missing TAMDAR data may help explain the forecast vs. RAOB sounding comparisons shown in Fig. 23. For the comparison of the RUC 6-h forecasts from the 1800 UTC runs with (labeled dev2) and without (labeled dev) TAMDAR data with the Pittsburgh RAOB we find that the two forecast soundings are virtually identical. This was also true for other sites within the area of snow, with the forecast soundings in very close agreement with each other for ILN (Wilmington, Ohio) and ILX (Lincoln, Illinois; see Fig. 2 for RAOB locations). However, away from this area, in regions where TAMDAR data were available, differences in the forecast soundings were found, for example, at Nashville (BNA), Tennessee (Fig. 23, bottom). For the Nashville comparison the sounding from the RUC run that used TAMDAR

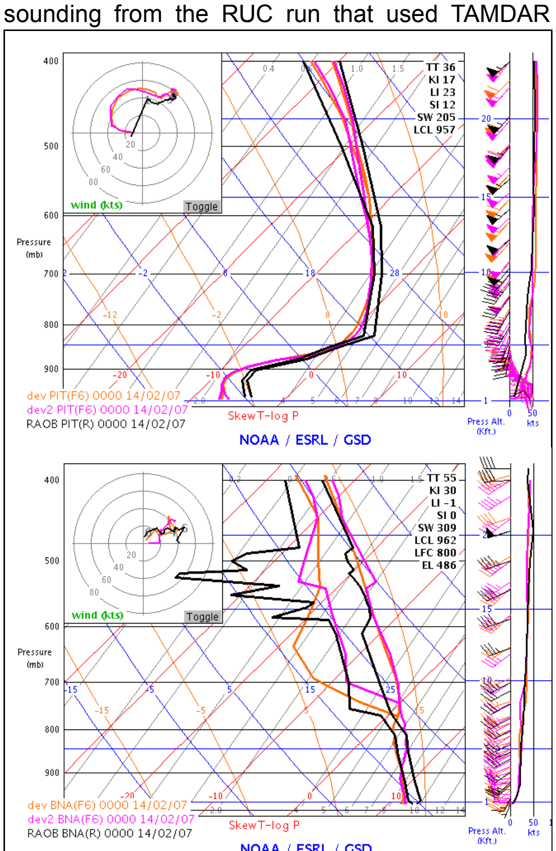

Fig. 23. Comparison of 6-h forecast soundings as in Fig. 6, but compared to the 0000 UTC 14 Feb 2007 Pittsburgh (PIT), Pennsylvania RAOB (top) and Nashville (BNA), Tennessee RAOB (bottom).

data was for the most part closer to the RAOB than the RUC run without TAMDAR. Other sounding comparisons in regions with TAMDAR in general were similar to the Nashville comparison, with differences apparent between the two RUC runs. It is interesting to note that there were differences in the two RUC precipitation forecasts (Fig. 20) from Kentucky southwards, in the area where there was more TAMDAR data.

Our speculation that the similar forecasts of precipitation in the area of snowfall are related to the lack of TAMDAR in that area becomes a bit suspect, however, when a forecast comparison is made for Detroit, where many TAMDAR flights occurred. This comparison, shown in Fig. 24, is similar to the comparison for PIT in Fig. 23 and other comparisons for the RAOB sites in the TAMDAR-limited regions. While this does not necessarily mean that our speculation is invalid, it raises the possibility that something else may be responsible for the similar precipitation forecasts.

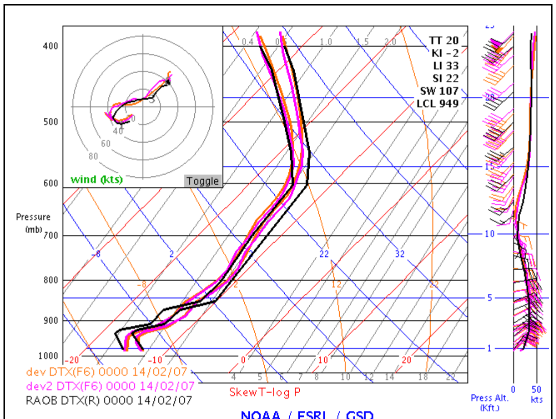

Fig. 24. Comparison of 6-h forecast soundings as in Fig. 6, but compared to the 0000 UTC 14 Feb 2007 Detroit (DTX), Michigan RAOB.

3.4 *21-23 March 2007 slow-moving cold front.*

This was a multi-day event as a cold front first pushed eastward across the Midwest then stalled east-west across the TAMDAR area from northern Missouri to New England by late in the day on 22 March. Four different 6-h periods were examined, beginning with the 6-h period ending 0600 UTC on 22 March through the 6-h period ending 0000 UTC on 24 March. For the most part, differences between the RUC forecasts with TAMDAR and those without were small, and the objective scores reflected this as they were also close. Here we show the first period, when there were some differences between the forecasts.

As the cold front pushed into the Midwest on 21 March there was quite a bit of severe weather in the form of hail. Surface observations overlaid with a composite radar image are shown for 0000 UTC 22 March (Fig. 25) and 0300 UTC 22 Mar (Fig. 26). The severe hail occurred both ahead of the advancing cold front and to a lesser extent in storms developing north of the warm front that extended from near Minneapolis to Chicago. Severe reports for the entire day (24 h ending 1200 UTC on 22 March) are shown in Fig. 27.

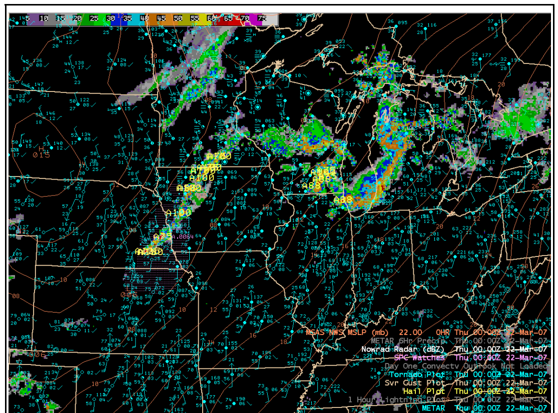
Fig. 25. Composite low-level reflectivity with surface mean sea level pressure and front analysis and METARs for 0000 UTC 22 Mar 2007. Severe weather reports are shown for hail (A, with size in inches), wind (W, with gusts, where reported, in mph), and tornadoes (T).

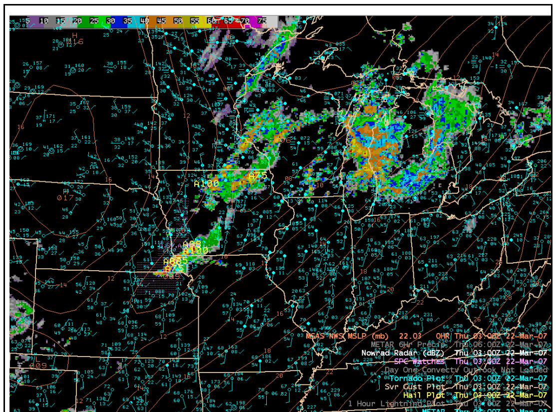
Fig. 26. As in Fig. 25, for 0300 UTC 22 Mar 2007.

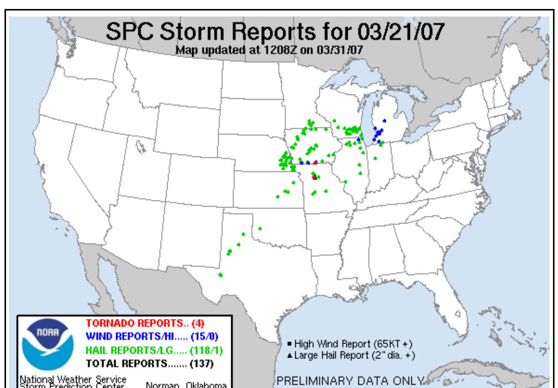

Fig. 27. Official severe weather verification from the Storm Prediction Center (SPC) for the 24-h period ending at 1200 UTC on 22 Mar 2007.

The 6-h precipitation forecasts from the two RUC runs initialized at 0000 UTC on 22 March are shown in Fig. 28. Precipitation for this period from the NPVU estimate is in Fig. 29. Differences in the forecasts, while not large, are seen in several areas, including northwestern Iowa, central Wisconsin, central Iowa, southeastern Wisconsin, and southeastern Ohio into West Virginia and eastern Kentucky.

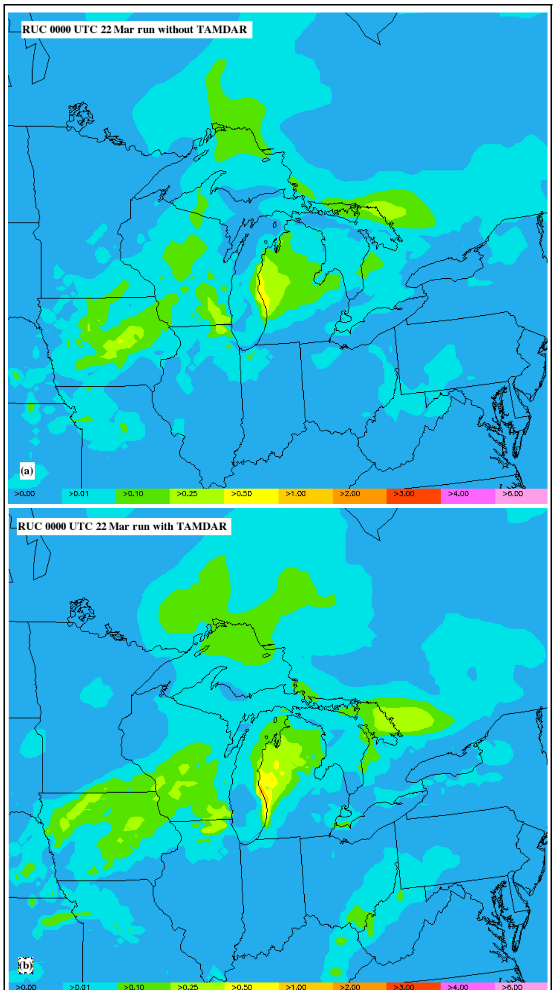

Fig. 28. RUC 6-h forecasts of accumulated precipitation (in), ending 0600 UTC 22 Mar 2007, without (a) and with (b) TAMDAR.

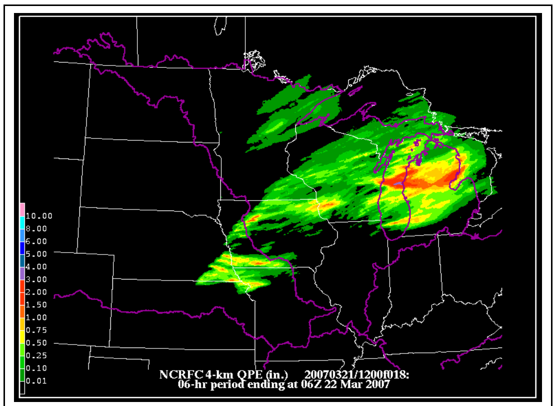

Fig. 29. NPVU precipitation estimate for the 6-h period ending 0600 UTC 22 Mar 2007, in inches.

Comparison of the forecasts in Fig. 28 with the verification in Fig. 29 indicates a mixed picture, with the RUC run with TAMDAR verifying better in some areas, such as northwestern Iowa and central Wisconsin. It is not as good as the run without TAMDAR in spots like eastern Kentucky north into Ohio. Still, the overall subjective impression would favor the forecast using TAMDAR, and this is borne out in the objective scores as well, for precipitation amounts at and above 0.1 in (Table 1).

Table 1. Objective verification for 6-h precipitation ending 0600 UTC on 22 March 2007.

RUC 0000 UTC run without TAMDAR							
Threshold	Obs	Fcst	Hits	Bias	POD	FAR	EQTS
no rain	5789	5203	4816	.899	.832	.074	.185
0.01	894	1480	507	1.655	.567	.657	.185
0.10	252	288	81	1.143	.321	.719	.157
0.25	105	70	12	.667	.114	.829	.067
0.50	41	11	0	.268	.049	.818	.039
1.00	11	0	0	0	0	0	0
1.50	2	0	0	0	0	0	0
RUC 0000 UTC run with TAMDAR							
Threshold	Obs	Fcst	Hits	Bias	POD	FAR	EQTS
no rain	5789	5207	4809	.899	.831	.076	.178
0.01	894	1476	496	1.651	.555	.664	.178
0.10	252	332	98	1.317	.389	.705	.181
0.25	105	78	18	.743	.171	.769	.102
0.50	41	15	4	.366	.098	.733	.075
1.00	11	1	0	.091	0	1	0
1.50	2	0	0	0	0	0	0

Obs = number of observations
Fcst = number of forecasts in this category
POD = Probability of Detection
FAR = False Alarm Ratio
EQTS = Equitable Threat Score

Other aspects of the objective scores in Table 1 include an under-prediction of the heavier amounts for both models, though to a little lesser extent for the RUC run with TAMDAR, as seen by the somewhat higher bias and POD scores for precipitation at and above 0.25 in. It is probably not surprising that the RUC model at a horizontal grid resolution of 20 km has difficulty predicting the heavier precipitation amounts in a convective situation such as this one, with a considerable under-prediction for both runs for the 0.50-0.99 in category and only one forecast of one inch amounts or greater in this 6-h period. In agreement with the general subjective assessment favoring the RUC forecast with TAMDAR, the EQTS is better for the TAMDAR run for the 0.10 in and greater categories.

3.5 *25-27 April 2007: Strong slow-moving cyclone.*

The final event summarized here was a slow-moving high-impact storm that produced both a large area of general rainfall as well as severe weather. A strong surface low moved out of the Central Rockies on 24 April into the Southern Plains on 25 April, then slowly eastward to be centered near St. Louis by 1200 UTC 26 April, before finally lifting northeastward across Michigan and into Canada by 27 April. The slow movement of the system enabled nine 6-h periods to be examined. This included periods when very few TAMDAR were available, for the purposes of seeing if forecast differences would still exist between the two RUC runs. For the most part, the forecasts for these "off-hour" runs were quite similar, as would be expected.

For the other five periods when TAMDAR data were available, forecast differences ranged from small to more substantial, though still nothing like the magnitude seen for the first case discussed here (4-5 October 2005). The 6-h period ending at 0000 UTC on 27 April will be examined. A composite radar image with observations for 2100 UTC on 26 April is shown in Fig. 30, when the surface low had moved to eastern Illinois. Several lines of convective storms are seen east of the surface low, in addition to the extensive line extending from the Gulf of Mexico northwards to western Pennsylvania. These storms produced much severe weather, with tornadoes reported near 2100 UTC just east of Chicago and tornado watches (hatched area) covering a large area. A map showing all the severe reports on this day is given in Fig. 31, and it includes many hail reports along with several tornado sitings.

In addition to the convective precipitation from the lines noted above, a widespread area of more

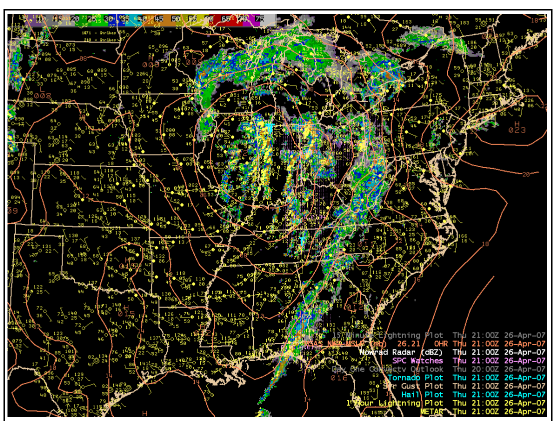

Fig. 30. As in Fig. 25, for 2100 UTC 26 Apr 2007.

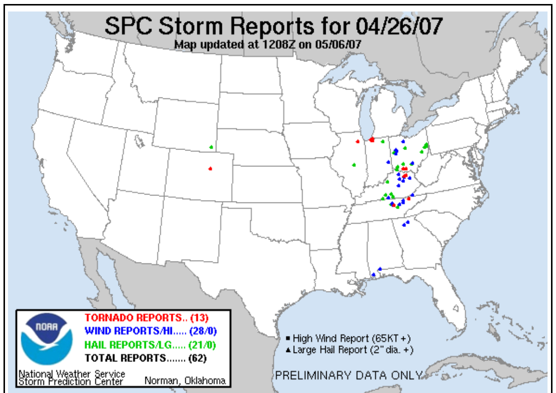

Fig. 31. Official severe weather verification from the Storm Prediction Center (SPC) for the 24-h ending 1200 UTC 27 Apr.

general rain occurred from Wisconsin to northern New York. The 6-h estimated precipitation from the NPVU for the period ending at 0000 UTC on 27 April is shown in Fig. 32. Maximum amounts exceeded an inch in the in the Ohio Valley. The forecasts from the two RUC runs for this same period are in Fig. 33. Differences can be seen between the two forecasts, for example, within the general precipitation area across Wisconsin and Michigan, with subjective evaluation of the two forecasts somewhat mixed, favoring the RUC forecast with TAMDAR in Michigan while going the other way in Wisconsin. Even in Wisconsin, however, the verification is mixed, with a forecast by the RUC run with TAMDAR of less precipitation in southern Wisconsin being a better forecast.

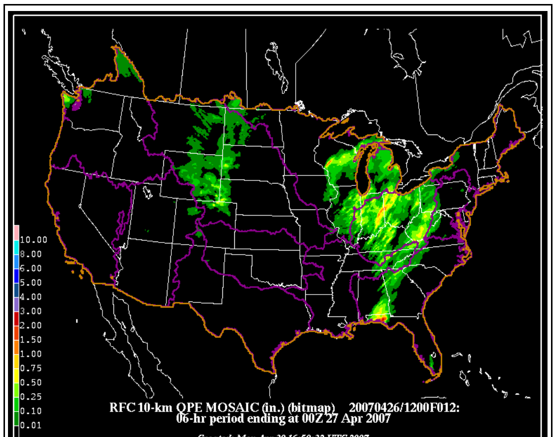

Fig. 32. NPVU precipitation estimate for the 6-h period ending 0000 UTC 27 Apr 2007, in inches.

Where convective precipitation occurs, differences are seen from Indiana to Kentucky, where the RUC run using TAMDAR produces more precipitation, while farther south along the main convective line, the opposite occurs in Alabama. In both these areas, the better forecast appears to be from the RUC run using TAMDAR.

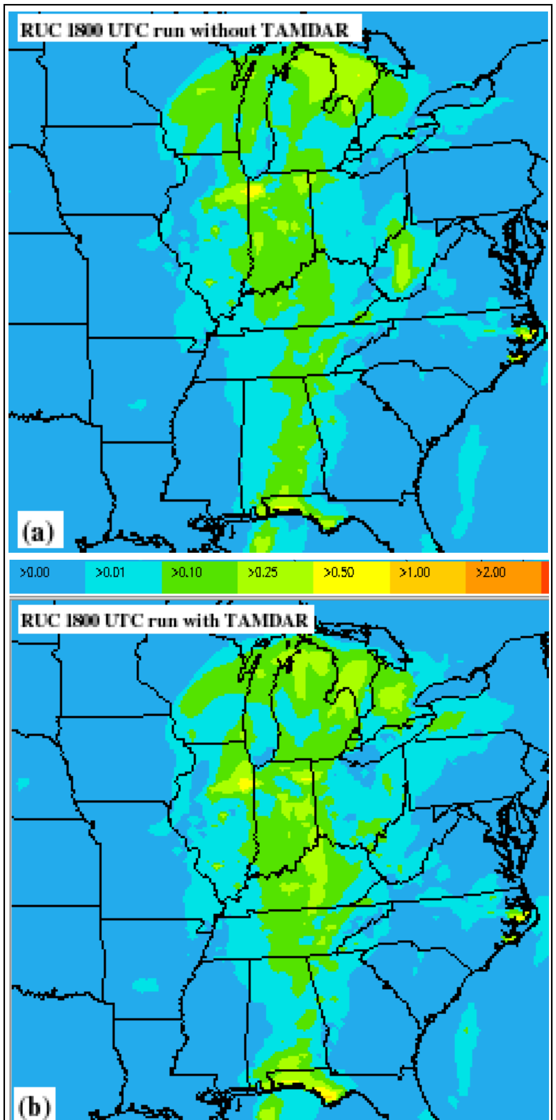

Fig. 33. RUC 6-h forecasts of accumulated precipitation (in), ending 0000 UTC 27 Apr 2007, without (a) and with (b) TAMDAR.

Objective scores for this period are given in Table 2. The scores do not differ by much, favoring the RUC run with TAMDAR for the lowest category and the 0.25-0.5 in category, but better for the RUC run without TAMDAR for the 0.10-0.25 in category. For this period neither run performed well in forecasting the heavier precipitation amounts of 0.50 in or greater. Although both runs did in fact predict some small areas in the 0.5 to 1.0 in range, as shown both in Fig. 33 and in the "Hits" column in Table 2, none of these areas matched where such amounts fell. The scores in Table 2 do not cover the southern portion of the domain where the RUC run with TAMDAR appeared to perform better.

Since this period involved an 1800 UTC run, we can make comparisons of forecast soundings with RAOBs. Two of these are shown in Fig. 34. The

Table 2. Objective verification for 6-h precipitation ending 0000 UTC on 27 April 2007.

Threshold	Obs	Fcst	Hits	Bias	POD	FAR	EQTS
RUC 0000 UTC run without TAMDAR							
no rain	5484	5279	4857	.963	.886	.080	.331
0.01	1191	1396	769	1.172	.646	.449	.331
0.10	480	428	187	.892	.390	.563	.226
0.25	176	100	17	.568	.097	.830	.056
0.50	28	32	0	0	0	1	-.002
1.00	4	0	0	0	0	-	0
1.50	0	0	0	-	-	-	-
RUC 0000 UTC run with TAMDAR							
Threshold	Obs	Fcst	Hits	Bias	POD	FAR	EQTS
no rain	5484	5194	4825	.947	.880	.071	.352
0.01	1191	1481	822	1.243	.690	.445	.352
0.10	480	465	213	.969	.444	.542	.257
0.25	176	126	21	.716	.119	.833	.064
0.50	28	33	0	1.179	0	1	-.002
1.00	4	0	0	0	0	-	0
1.50	0	0	0	-	-	-	-

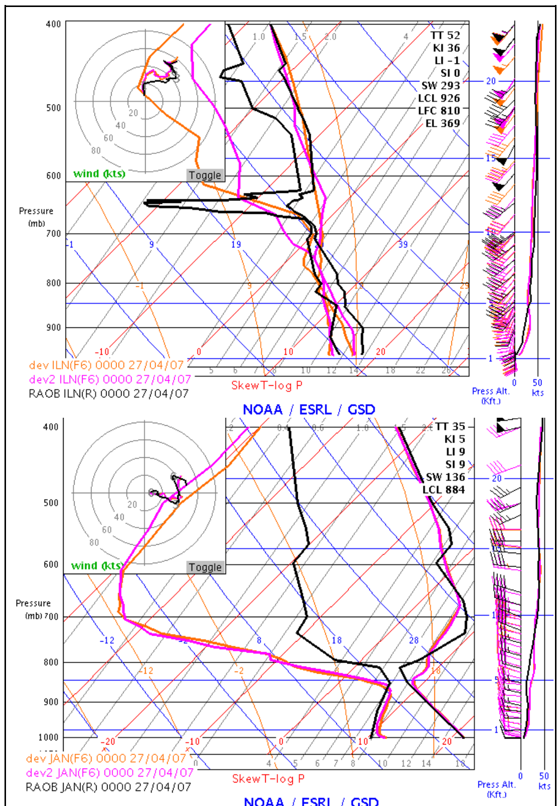

Fig. 34. Comparison of 6-h forecast soundings as in Fig. 6, but compared to the 0000 UTC 27 Apr 2007 Wilmington (ILN), Ohio RAOB (top) and Jackson, Mississippi (JAN) RAOB (bottom).

larger sampling of forecast soundings generally showed some differences for most of the sites examined, though not all. In the sampling shown, this is true except for the comparison at JAN (Jackson, Mississippi), where the two forecast soundings are virtually identical, even though in this area differences were seen in the precipitation forecasts.

4. SUMMARY AND CONCLUSIONS

Better precipitation forecasts from numerical model predictions can be critical to aviation and general weather forecasting. A large number of cases have been examined since 2005, when TAMDAR data first became available, with objective verification of precipitation added in 2007. Subjective evaluation of these cases indicates an overall improvement in the forecasts of shorter-term (6 to 12-h) forecasts of precipitation by the RUC model when TAMDAR data were used in the model initialization. For a few cases the differences have been quite noticeable, but for most cases differences between the two RUC forecasts are more subtle, occurring in some but not all the areas of precipitation. Indeed, for many cases the RUC run that used TAMDAR does a superior job overall, but in some locations the opposite occurs. For a limited number of cases the RUC run without TAMDAR performed better overall.

Our subjective assessments have for the most part been confirmed by objective scoring that has been under way since the beginning of 2007. Often the objective scores will vary by a rather small amount, although they generally favor the RUC run with TAMDAR.

Overall it appears the TAMDAR data has a positive impact on forecasts of precipitation using the RUC model. Comparison of point sounding forecasts from the two RUC runs with corresponding RAOBs often shows distinct differences, favoring the RUC run that uses TAMDAR. These differences do not necessarily translate into large differences in precipitation forecasts, but suggest that forecasters using forecast soundings from the RUC model would benefit by using a version of the model that ingests TAMDAR data. The current operational version of the RUC does not use TAMDAR as the data has been considered to be experimental, but this will change in the near future.

5. ACKNOWLEDGMENTS

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