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IMPACT OF TAMDAR ON RUC FORECASTS: CASE STUDIES

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1. INTRODUCTION

The amount and distribution of moisture in the lower troposphere is critical for many weather forecasts. However, accurate measurements of 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 ingested in numerical models, but until recently, there were 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 recently 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). This sensor package measures moisture as well as wind and temperature. For the past year (15 January 2005 to 15 January 2006), with the support of NASA and the FAA, these sensors have been deployed on 63 aircraft flying over the U. S. Midwest in an experiment called the Great Lakes Fleet Evaluation (GLFE).

In addition to the added measurement of moisture, the aircraft taking part in the GLFE fly out of many smaller airports (in addition to major hubs) that typically do not have coverage from the current aircraft data, adding a considerable number of ascent/descent soundings. Furthermore, many of 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 purpose of this study is to examine the impact of TAMDAR on numerical weather prediction through the use of the Rapid Update Cycle (RUC, Benjamin et al. 2004) assimilation and model system. Other studies presented at this conference will examine the use of TAMDAR by forecasters (Mamrosh et al. 2006, Brusky et al. 2006), and a statistical evaluation of the impact of TAMDAR on RUC forecasts (Benjamin et al. 2006). This paper focuses on a subjective evaluation of the impact of TAMDAR through case studies evaluating RUC short-term forecasts for runs made with and without TAMDAR. The methodology for choosing cases and evaluating them are discussed in the next section.

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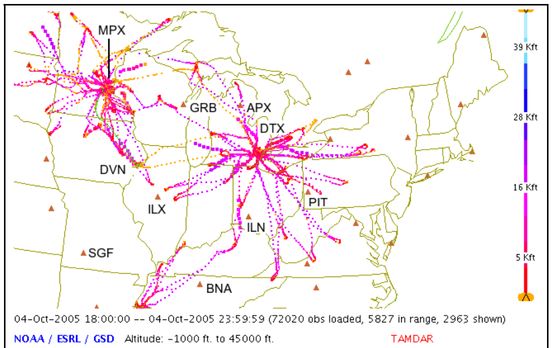

Fig. 1. TAMDAR flight coverage for the 6-h period ending ~0000 UTC 5 Oct 2005. Triangles denote RAOB sites (selected ones labeled).

2. METHODOLOGY

In order to test the impact of TAMDAR, the RUC model is currently being run in real-time at 20-km horizontal grid resolution (Moninger et al. 2006, Benjamin et al. 2006). The RUC analysis independently assimilates the data to include TAMDAR for one model run and identical data without TAMDAR for the other run. Model forecasts are made at 1-h intervals to 3-h, and at 3-h intervals out to at least 12 h. A number of pregenerated images are made for each run, as well as several other RUC real-time runs, at the Global Systems Division (GSD), and are available 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”.

We focused on cases where weather systems producing precipitation were moving across the Midwest and/or Ohio Valley, well within the main area of TAMDAR coverage (Fig. 1). Emphasis was placed on examining model forecast fields that are of concern to aviation, including surface wind, especially as it relates to frontal position, cloud ceiling height and surface visibility, and precipitation. Model analyses as well as observations were used to verify the surface wind, ceiling, and visibility forecasts.

For precipitation, near real-time quantitative precipitation verification is available from the National Precipitation Verification Unit (NPVU) at http://www.hpc.ncep.noaa.gov/npvu/index.shtml, as 6-h or 24-h accumulated precipitation ending at 0000, 0600, 1200, and 1800 UTC. One of the RUC forecast fields is 6-h accumulated precipitation, so we chose initialization times that allowed for easy verification with the NPVU analyses. The other issue in choosing specific RUC runs was to pick times where TAMDAR could influence the analysis. TAMDAR flights generally start around 1100 UTC and taper off after 0000 UTC with limited coverage overnight, so the 0600 UTC initialization time was not used. The RUC run initialized at 1800 UTC was of particular interest as we could then make direct comparisons between 6-h forecast soundings and observed soundings.

3. CASES

A sampling of some of the cases that were evaluated is discussed in this section. Some of the most notable differences are found in the precipitation forecasts. Three sets of RUC forecasts are examined from the period 4-6 October 2005, when very heavy rains hit the Upper Midwest.

3.1 *1800 UTC 4 October 2005 runs.*

A stalled front produced excessive precipitation across southern and central Minnesota eastwards across the northern portion of Wisconsin and into the Upper Peninsula of Michigan on 4-5 October, before the front swept eastward later on 5 October. A composite radar snapshot at 2100 UTC on 4 October is shown in Fig. 2. Heavy convective precipitation is falling on both the cold and warm sides of the stalled front, leading to the 6-h accumulation shown in Fig. 3. Precipitation amounts in the 1.5 to 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 analysis in Fig. 3, are presented in Fig. 4. Both forecasts have precipitation extending too far south and do not resolve the sharp southern edge. 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

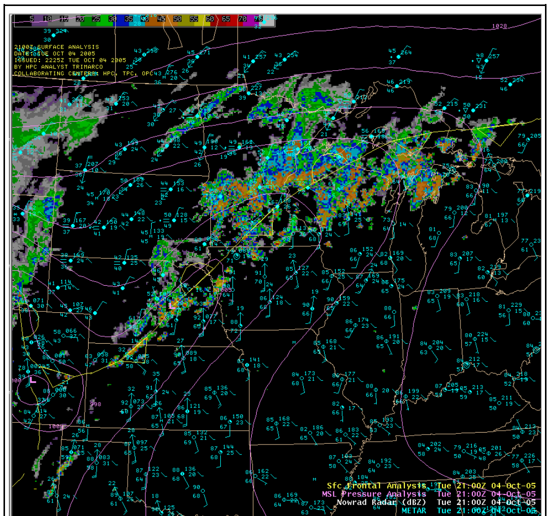

Fig. 2. Composite low-level reflectivity with surface mean sea level pressure and front analysis and METARS for 2100 UTC 4 October.

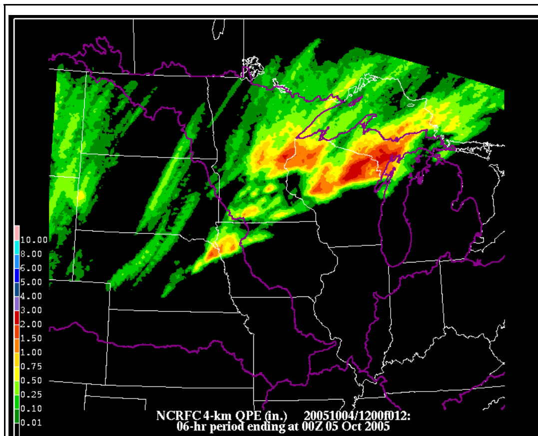

Fig. 3. NPVU precipitation analysis for the 6-h period ending 0000 UTC 5 October, in inches.

precipitation compared to the run without TAMDAR, which has the rainfall shifted to the 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 observed, but much closer than what the non-TAMDAR run predicts.

Since this case involves an 1800 UTC run, it is possible to compare forecast soundings with observed soundings. A better forecast sounding by the RUC run using TAMDAR for soundings near or upstream of the precipitation region would 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. 5. It is quite clear from Fig. 5 that the forecasts of moisture from the RUC runs using TAMDAR (labeled dev2) are much better than those that did not use

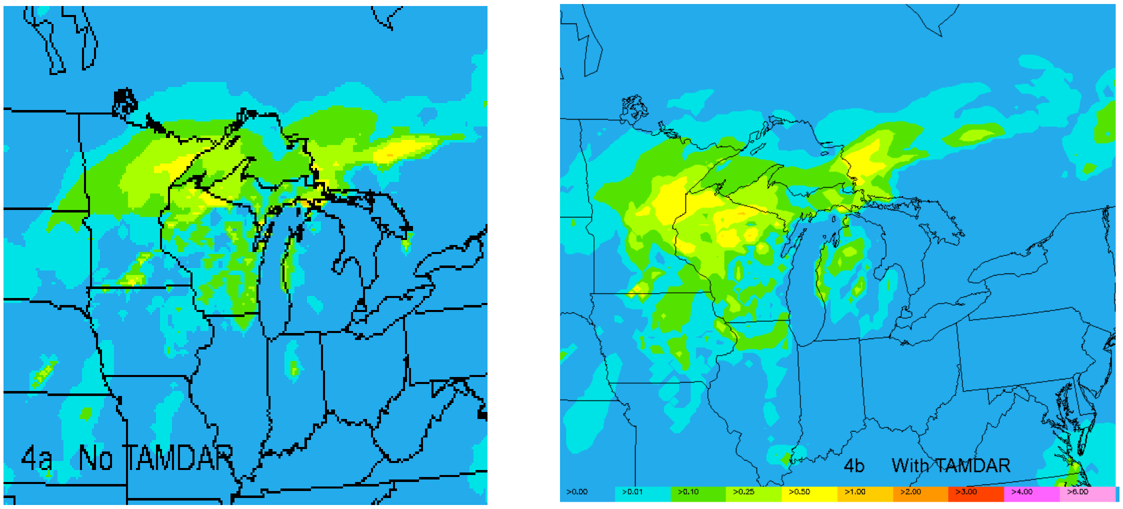

Fig. 4. Comparison of the 6-h accumulated precipitation forecasts from the 1800 UTC 4 October RUC runs without (4a) and with (4b) TAMDAR. The precipitation scale (inches) is the same for both images.

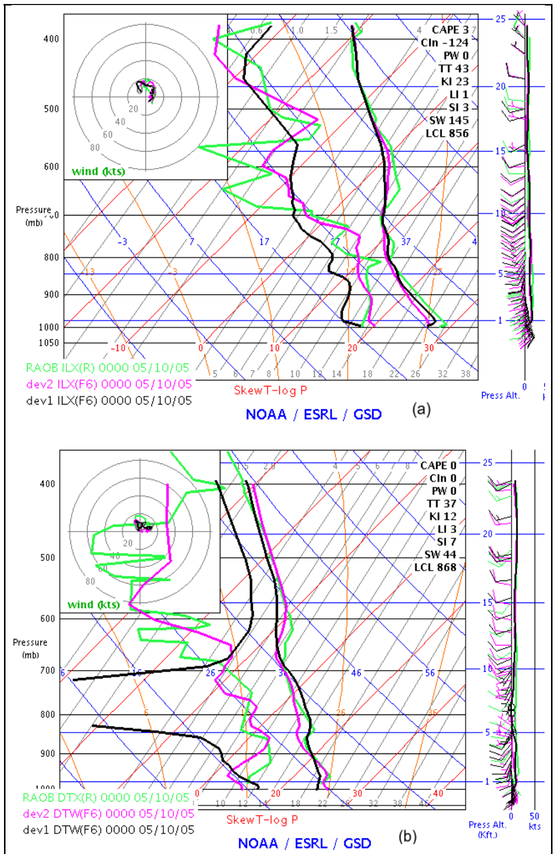

Fig. 5. Comparison of 6-h forecast soundings from the RUC 1800 UTC runs with (labeled dev2) and without (labeled dev) TAMDAR, compared to observed soundings at Lincoln, Illinois (ILX, (a)), and Detroit, Michigan (DTW, (b)).

TAMDAR (labeled dev). The dev2 sounding forecasts of dewpoint quite closely match the observed dewpoint through the lowest ~200-300 mb at both locations. The difference in the 700-850 mb layer at DTW is particularly striking, with the dev forecast having a very dry layer that is not present in the observations or the RUC forecast using TAMDAR. Temperature differences between the two runs are, by contrast, not very large, and both runs compare about as well to the observed temperature sounding. Though not easily seen from Fig. 5, the same can also be said for the wind.

3.2 *0000 UTC 5 October 2005 runs.*

The heavy precipitation continued through the next 6-h period across basically the same area of Wisconsin and Minnesota. A radar image overlaid with a frontal analysis is shown in Fig. 6, illustrating 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 observed precipitation accumulation in Fig. 7, with maximum values in the 2-3 in range over northwest Wisconsin.

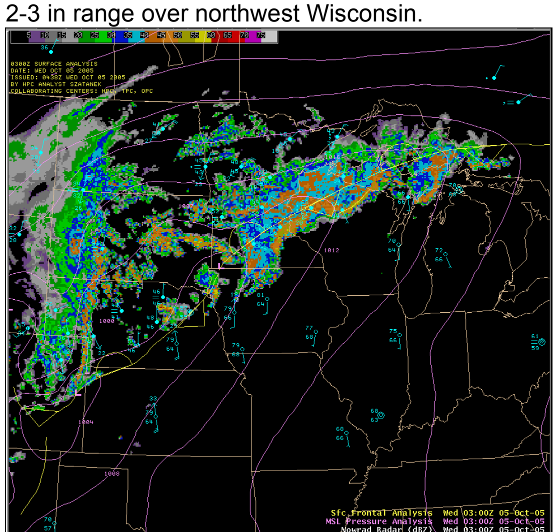

Fig. 6. As in Fig. 2, for 0300 UTC 5 October.

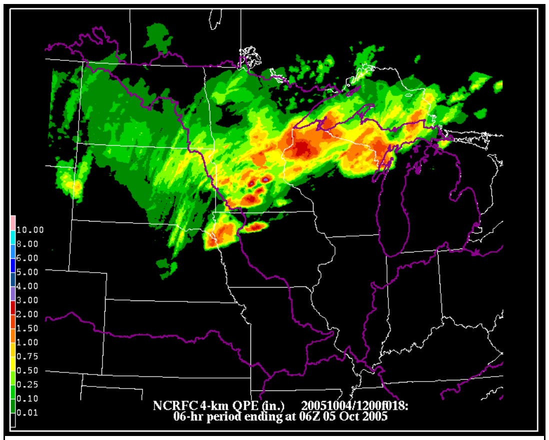

Fig. 7. NPVU precipitation analysis for the 6-h period ending 0600 UTC 5 October, in inches.

As before, we present a comparison between the two RUC forecasts of accumulated precipitation for the same 6-h period in Fig. 8. There are clear differences between the two forecasts in Fig. 8. The RUC forecast with TAMDAR captures the very sharp southern cutoff of precipitation nicely 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/TAMDAR forecast coming closer to having the focus of heavy rain over northwestern Wisconsin. For this time period it is not possible to compare forecast soundings with RAOBs.

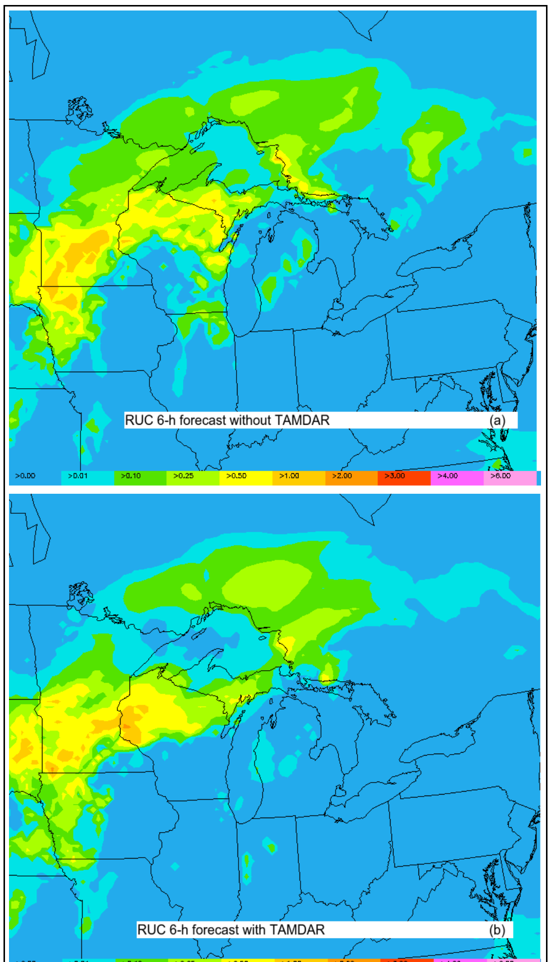

Fig. 8. RUC 6-h forecasts, ending 0000 UTC 5 October, of accumulated precipitation (in) without (a) and with (b) TAMDAR.

3.3 *1800 UTC 5 October 2005 runs.*

The final set of RUC forecasts from the 4-6 October event are for those initialized at 1800 UTC on 5 October. We again will focus on 6-h accumulated precipitation forecasts and compare various forecast soundings to observed soundings. By midday on 5 October, the frontal system was finally pushing eastward (Fig. 9), moving across Wisconsin and the middle of the nation with a more transient line of showers and thunderstorms near and behind the front (Fig. 10).

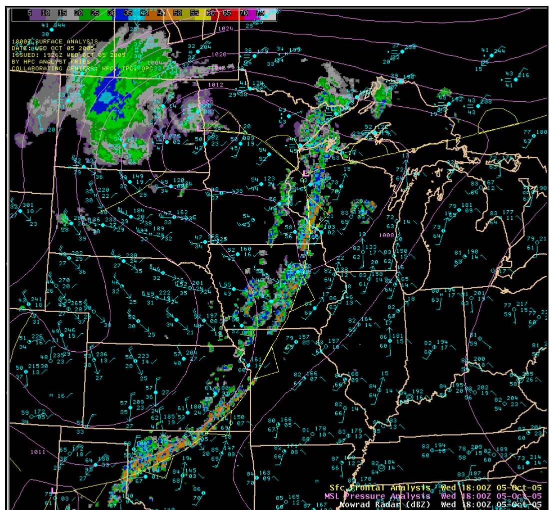

Fig. 9. As in Fig. 2, for 1800 UTC on 5 October.

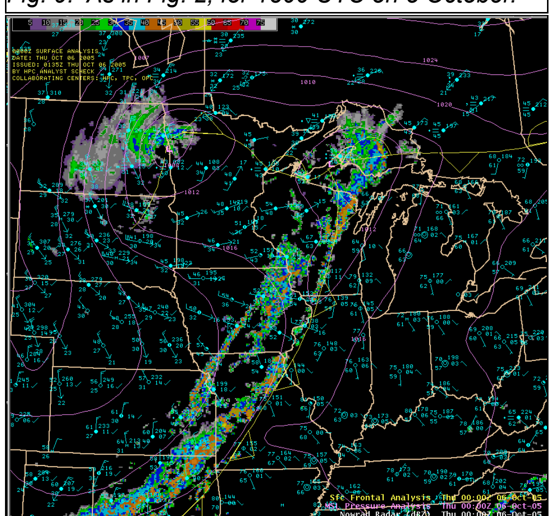

Fig. 10. As in Fig. 2, for 0000 UTC on 6 October.

The accumulated precipitation for the 6-h period ending at 0000 UTC on 6 October is much more north-south oriented than for the previous two periods considered, but there is still a maximum of over an inch extending across northern Wisconsin northward through the Upper Peninsula (Fig.11). Forecasts from the two RUC runs for the same period are shown in Fig. 12.

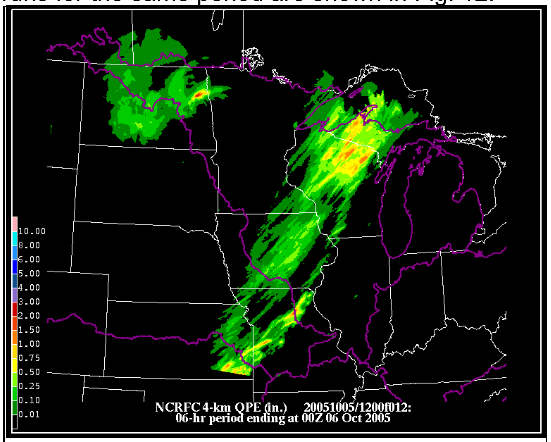

Fig. 11. NPVU precipitation analysis for the 6-h period ending 0000 UTC 6 October, in inches.

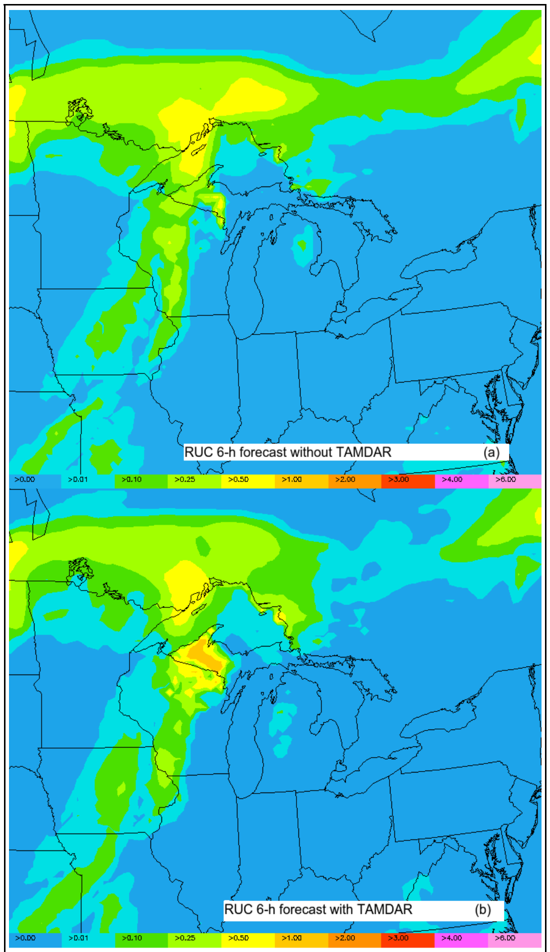

Fig. 12. As in Fig. 8, for 6-h period ending 0000 UTC 6 October 2005.

While not as dramatic as in the two previous time periods, there are differences between the two RUC forecasts over Wisconsin and the Michigan Upper Peninsula. The RUC run that used TAMDAR is a little faster moving the precipitation to the east across Wisconsin, and has a heavier rainfall maximum over the Upper Peninsula. For both differences the RUC run with TAMDAR verifies closer to the observed precipitation.

For this time period the sounding comparisons were more mixed than for those previously discussed from the forecasts 24-h earlier. For example, at GRB (Green Bay, Wisconsin, Fig. 13), there is little difference between the two 6-h forecast soundings below ~600 mb in both temperature and dewpoint, with both forecasts

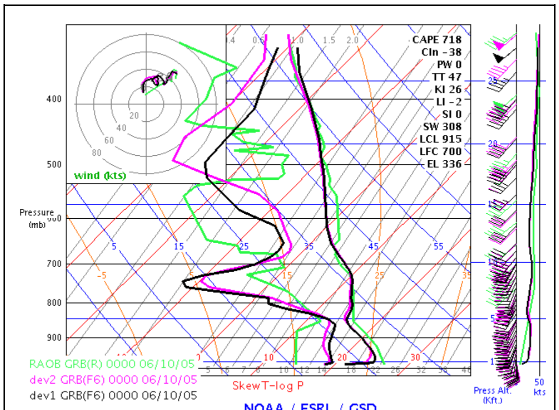

Fig. 13. RAOB comparison, as in Fig. 5, between GRB and 6-h forecasts from the two RUC models.

considerably more moist below 850 mb than what was observed. The same overall situation is found at ILX (Lincoln, Illinois. Fig. 14), with similar forecasts by both RUC runs through most of the sounding (in Fig. 14 the sounding extends to about 350 mb). The difference for both runs between the forecasts and the observed RAOB is similar to that found at GRB, with the forecast temperature cooler than observed, and the dewpoint more moist than

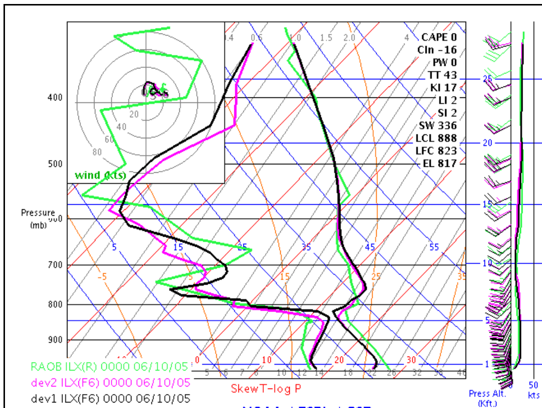

Fig. 14, as in Fig. 13, for station ILX.

observed below ~820 mb. The biggest forecast differences occur at DTX (Detroit, Fig. 15), where the RUC run with TAMDAR has a better moisture forecast in the lowest 100 mb or so. At some higher levels, particularly near 500 mb, the forecast without TAMDAR is closer to the DTX RAOB. For both runs, there is very little difference between the temperature forecasts.

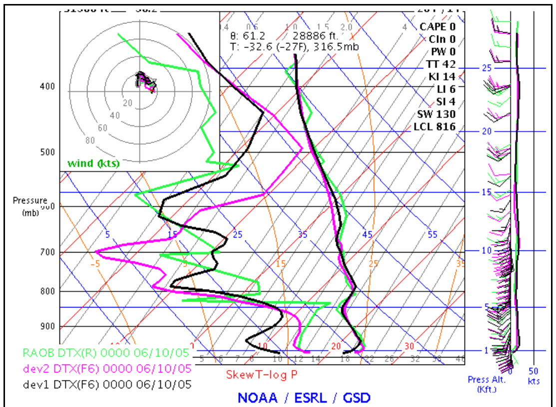

Fig. 15. As in Fig. 14, for station DTX (Detroit).

Forecast soundings for the DTX site were also examined for other RUC initialization times to determine if the better forecast from the RUC run with TAMDAR was also found for shorter term forecasts. In Fig. 16 is a comparison of 3-h

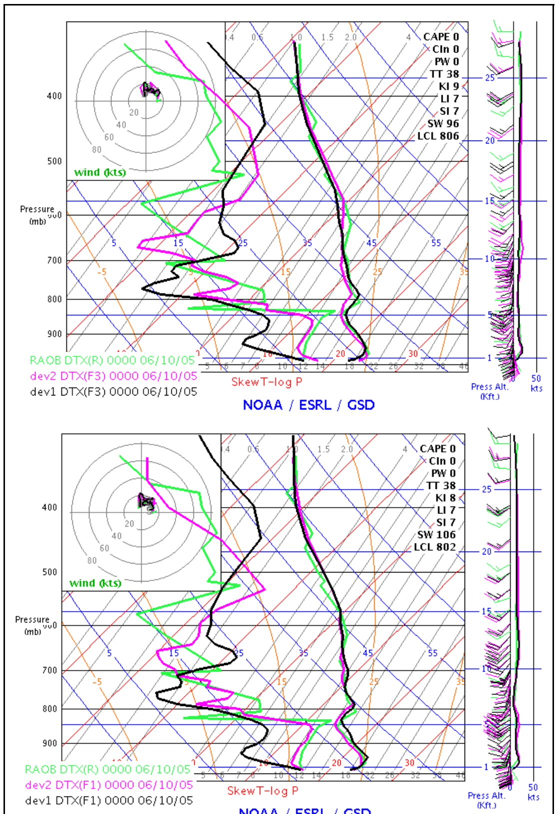

Fig. 16. As in Fig. 15, but for 3-h (top) and 1-h (bottom) forecasts from the two RUC runs compared to the DTX 0000 UTC 5 October RAOB.

forecasts from the 2100 UTC 5 October runs, and 1-h forecasts from the 2300 UTC runs. The differences in the 3- and 1-h forecasts are consistent with those found in the 6-h forecast, with an increasingly better match with time to the moisture in the lowest ~150 mb for the RUC runs with TAMDAR. There is actually a slightly worse forecast for the 1-h RUC run without TAMDAR than for its 6-h forecast, with a trend towards even drier conditions in the lower levels, opposite to what is observed.

The DTX comparison displayed the greatest difference between the RUC forecasts with and without TAMDAR, but some of the other RAOB comparisons for sites in the Midwest also exhibited a trend to better forecasts with time, mainly for moisture, for the runs with TAMDAR. There are a large number of TAMDAR flights that would have been available for the various RUC forecasts initialized from 1800 to 2300 UTC.

Other fields from the images generated in real-time were also examined and, while differences are found between the forecasts with and without TAMDAR, it is more difficult than with the point sounding comparisons or the precipitation forecasts to make definitive statements as to which forecast is better. For example, 850 mb height and wind forecast differences are sufficiently subtle to make it difficult to subjectively determine which is the better forecast with the available non-TAMDAR observations. Added together, however, the analysis differences can make for significant distinctions between forecasts of a field that is the end result of how the model accounts for differences in all the initial fields, such as precipitation.

Since more detailed observations are also present at the surface, and this period involved a progressive cold front, an attempt is made in Fig. 17 to see if there are any detectable differences between the pressure and surface wind forecasts. There are only slight differences between the surface pressure forecasts, and virtually no difference seen in the position of the cold front. Both forecasts compare favorably to what is observed (Fig. 10) at 0000 UTC on 6 October.

3.4 *1800 UTC 20 October 2005 runs.*

For this period, the focus is on cloud and visibility forecasts with the system shown in Fig. 18. These parameters affect aviation operations, and here we use a derived forecast product from the RUC that combines both visibility and cloud ceiling into a product called “Aviation Flight Rules”. The RUC analyses and forecast categories include the standard aviation categories of LIFR (ceiling < 500 ft, and/or visibility < 1 mi), IFR (ceiling between 500 to <1000 ft, and/or visibility from 1 to < 3 mi), MVFR (ceiling between 1000 and 3000 ft, and/or visibility between 3 to 5 mi), and VFR

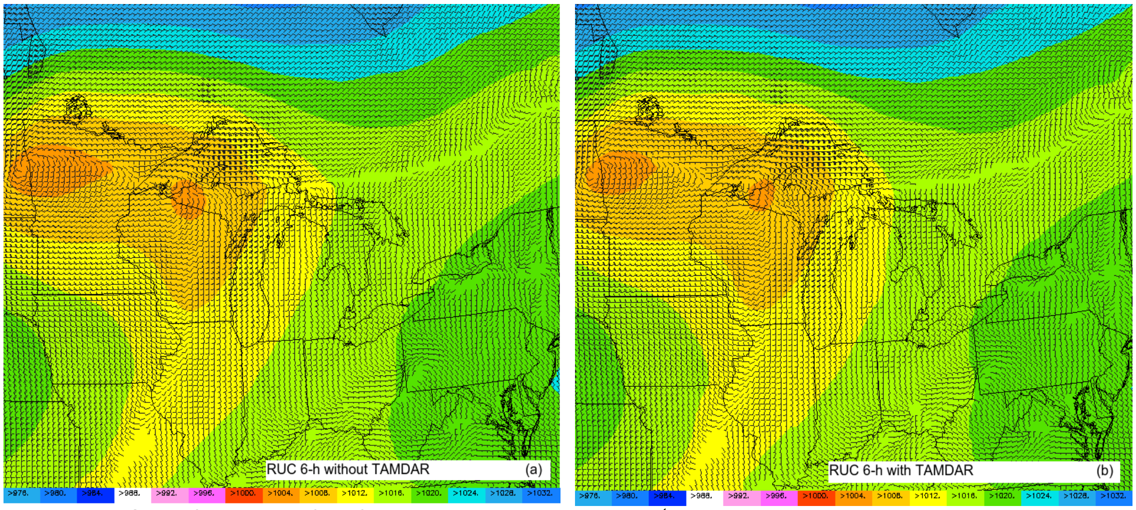

Fig. 17. RUC 6-h forecasts of surface wind (long-barb = 5 ms^{-1}) and mean sea-level pressure (image, in mb) without (a) and with (b) TAMDAR, valid at 0000 UTC 6 October.

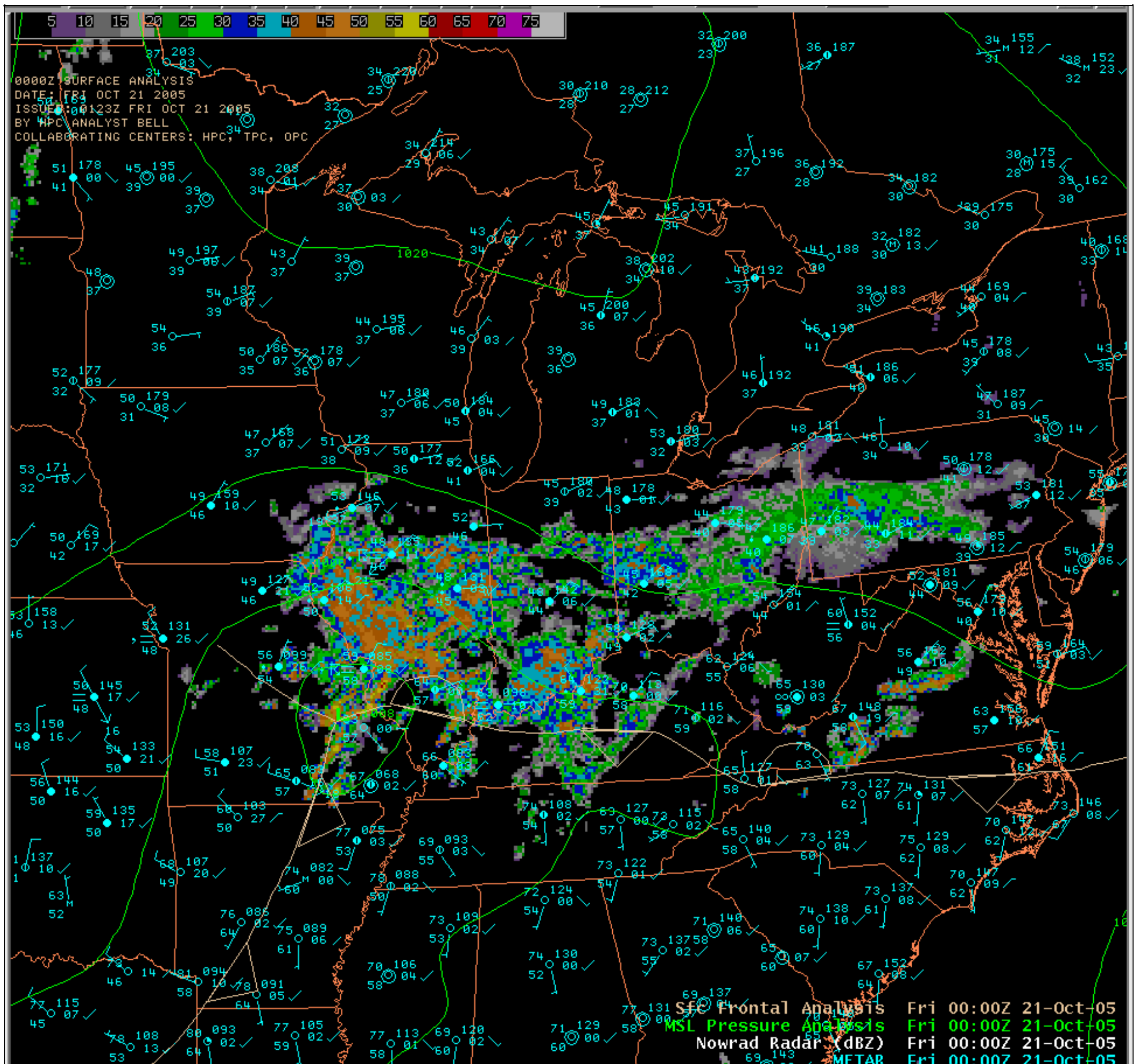

Fig. 18. MSLP and front analysis and METARS with composite radar for 0000 UTC 21 October 2005.

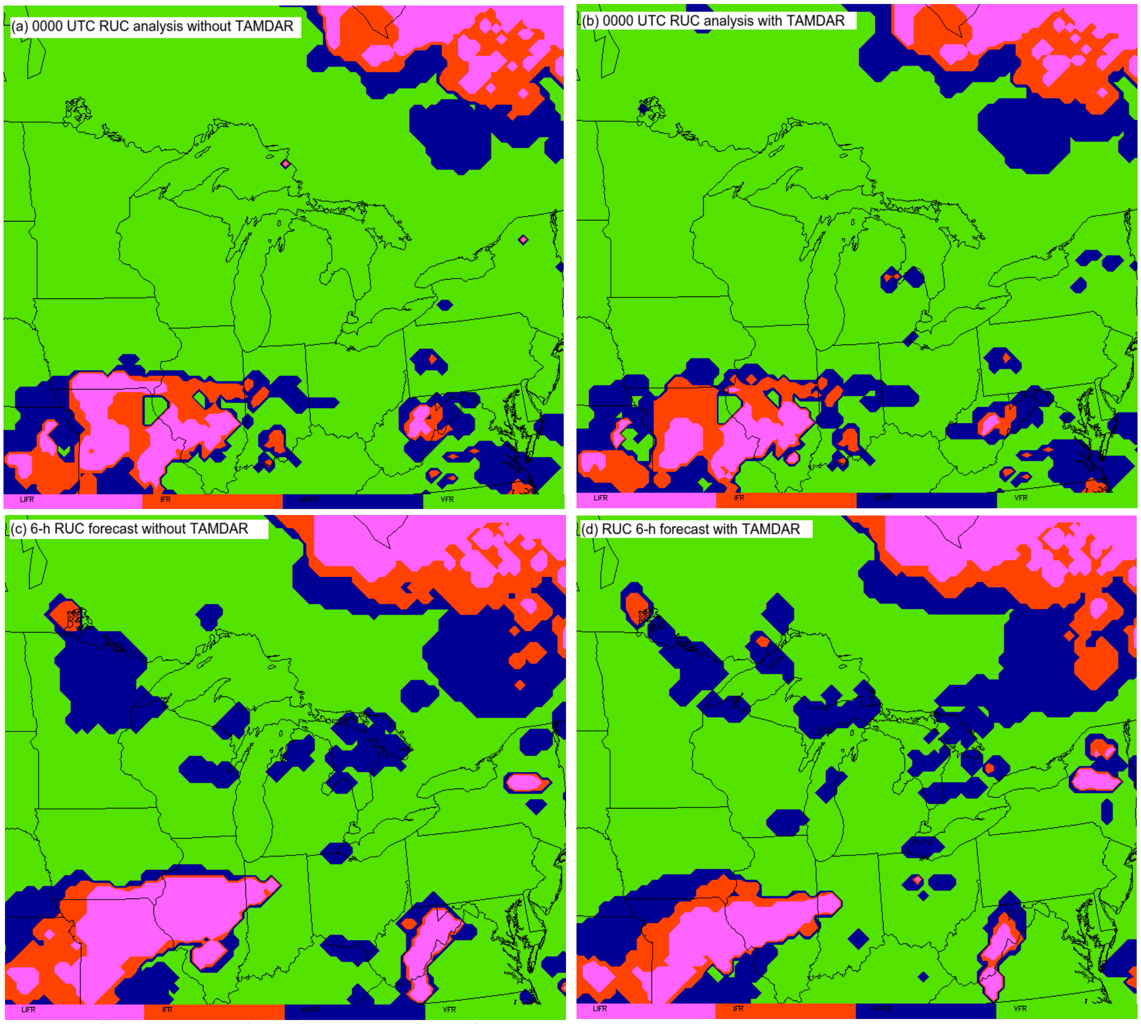

Fig. 19. Comparison of RUC 0000 UTC 21 October analyses without (a) and with (b) TAMDAR compared to 6-h RUC forecasts of Aviation Flight Rules valid at 0000 UTC without (c) and with (d) TAMDAR.

(ceiling > 3000 ft and visibility > 5 mi). The storm system of interest for this case moved across the southern half of the TAMDAR coverage area, producing a large area of chilly rain and embedded convection. Precipitation forecasts for this case (not shown) were not dramatically different, but for both runs, there was far too little precipitation predicted.

Both low clouds and areas of fog resulted in an extensive area of low visibility and ceilings at 0000 UTC 21 October. A comparison of 6-h forecasts of the flight rules with accompanying analyses are shown in Fig. 19 for the RUC forecasts with and without TAMDAR. RUC analyses for 0000 UTC are used to verify the 6-h forecasts from the 1800 UTC RUC runs. RUC analyses typically do a good job representing actual conditions, and are used for verification here. TAMDAR can influence the analyses, and so both are shown, though in this case they generally agree, except over southern Iowa.

The forecasts do display some differences. The main difference near the storm system occurs over Missouri and Illinois and into southern Iowa, where the RUC forecast with TAMDAR has a smaller area of LIFR (the lowest category) with a northern edge that is shifted slightly to the south, compared to the RUC forecast without TAMDAR. In this area, the verification indicates that the RUC forecast with TAMDAR is better across much of Missouri and Illinois. Across southern Iowa, the RUC forecast without TAMDAR has lower conditions forecast (LIFR) compared to the RUC with TAMDAR, but here the analyses disagree, so we cannot say which forecast is better in southern Iowa. Both sets of analyses indicate LIFR conditions at the major airport of St. Louis, and the RUC forecast with TAMDAR (19d) comes closest to forecasting the poorer conditions, while the forecast without TAMDAR (19c) predicts VFR conditions at the airport.

Another area where the forecasts are different is over northern Minnesota, where the RUC forecast without TAMDAR has a large area of MVFR conditions that is much smaller in the RUC forecast that uses TAMDAR. Neither analysis has anything below VFR over nearly all of the Upper Midwest, so less is a better forecast in this area.

Sounding comparisons were also made for this case, and five of these are shown in Fig. 20 for 6-h forecasts from the RUC runs with (labeled dev2) and without (labeled dev) TAMDAR initialized at 1800 UTC on 20 October 2005. Consistent with the other cases shown thus far, the most substantial difference occurs at DTW (Detroit, Michigan, Fig. 20b), where the RUC forecast from the run without TAMDAR is much drier in the lowest 200 mb. The differences are not as great

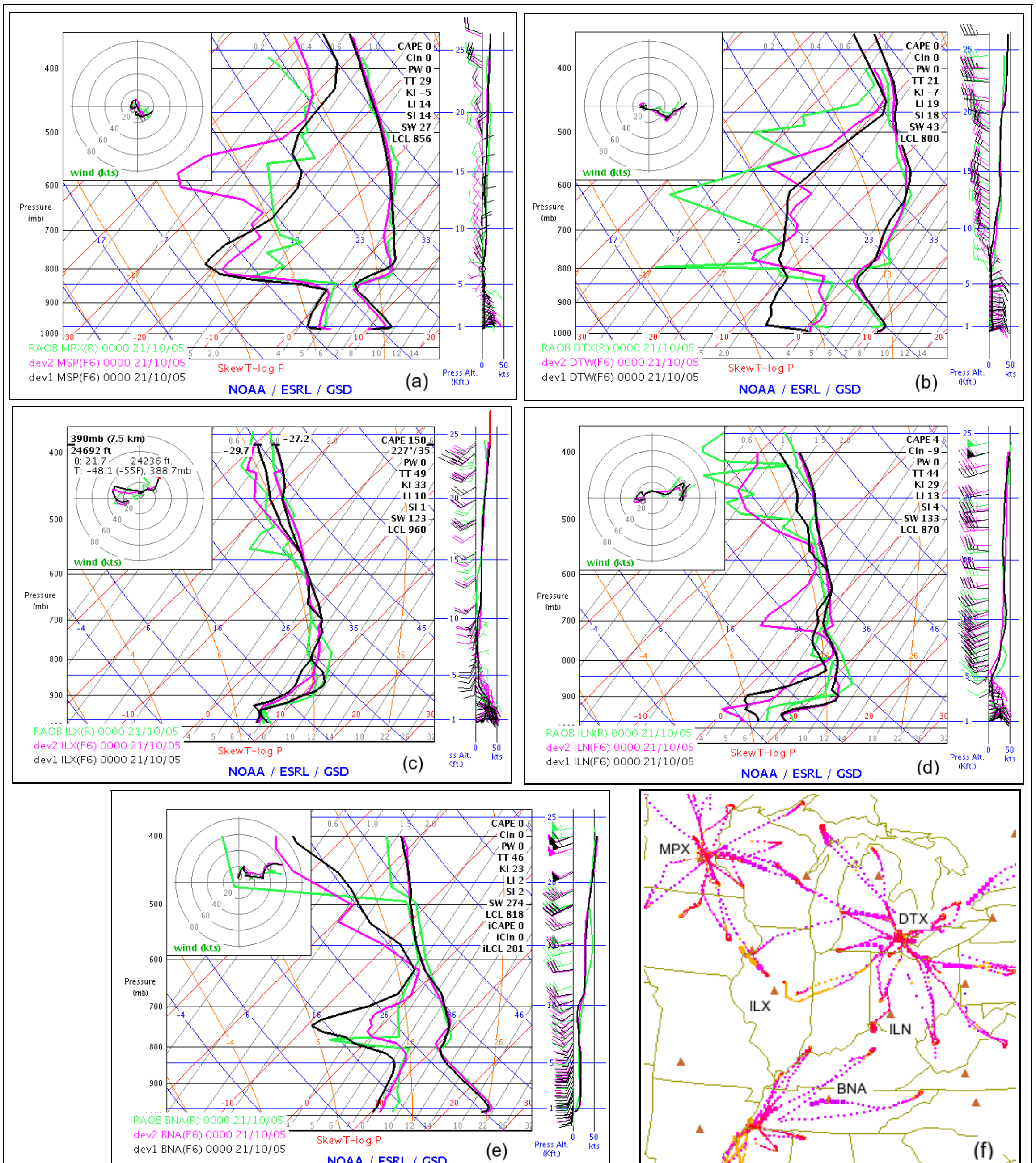

Fig. 20. Sounding comparisons for five different RUC 6-h forecasts with (dev2) and without (dev) TAMDAR, valid at 0000 UTC 21 October. Soundings are arranged geographically relative to their location, as shown on the map in (f), which displays the TAMDAR flights in the 3 h leading up to the 1800 UTC initialization time. The top two soundings (a and b) are across the north portion of the TAMDAR area, from MSP (a, Minneapolis, Minnesota) to DTW (b, Detroit, Michigan). The next two soundings (c and d) are in the middle of the area, from west (ILX (c), Lincoln, Illinois) to east (ILN (d), Wilmington, Ohio). Finally, the southernmost sounding (BNA, Nashville, Tennessee) is displayed in (e).

for MSP (Minneapolis, Minnesota, Fig. 20a) and BNA (Nashville, Tennessee, Fig. 20e), but in both cases, the moisture in the lower levels is a better forecast for the RUC model that included TAMDAR. At ILN (Wilmington, Ohio, Fig. 20d) the differences between the two runs are quite small, at least below 700 mb, with the RUC run without TAMDAR actually better with the moisture forecast in the 600-700 mb layer, but then too moist near and above 500 mb. In all the comparisons discussed above, the differences in the temperature profiles (and for the most part the winds) are far less than for dewpoint, with no real pattern as to which might be better.

ILX (Lincoln, Illinois, Fig. 20c) is located within the area of lower category aviation flight rules both in the analyses and forecasts, and is somewhat of an exception to the cases above, with differences in dewpoint as well as temperature and wind. The verification for central Illinois (Fig. 19 a and b) is between the two forecasts (Fig. 19 c and d), with a slight underforecast by the RUC run using TAMDAR and somewhat of an overforecast for the run without TAMDAR. There are differences in the temperature forecasts at ILX between 850 and 900 mb, with the forecast from the run without TAMDAR more closely matching the observed sounding. Although the temperature is better, within the entire layer between 800 to 900 mb the forecast from the run without TAMDAR is too dry, while the RUC forecast from the run using TAMDAR is more moist between 850 and 900 mb, closer to the observed temperature/dew point spread, but then becomes erroneously saturated above 850 mb, perhaps owing to the stronger east-southeast flow centered near 850 mb. In fact, both forecasts are too moist, indeed saturated, in a layer between 700 to ~850 mb. The varied differences between the two model forecasts for ILX, including temperature and wind, are greater than for most comparisons that we analyzed.

3.5 *1800 UTC 21 October 2005 runs.*

For the final case, we show only the precipitation forecasts for one time to contrast the forecasts with and without TAMDAR for a case at the far southeastern edge of the TAMDAR domain. The main point of this example was to see if there was any discernible difference in the forecasts for a system away from the main area of the TAMDAR network. A weak surface low was moving across the lower Ohio Valley at 1800 UTC on 21 October (Fig. 21), with an area of generally light rain across much of Ohio and Indiana extending eastwards into southern Pennsylvania, and scattered convective precipitation south of the stalled front over portions of Kentucky and Tennessee. There were embedded areas of heavier rain in the widespread rain across Ohio and Indiana, leading to some bands of > 0.25 in and even > 0.50 in over southern Ohio south into West Virginia in the 6-h period ending at 0000 UTC on 22 October that will be the focus here (Fig. 22).

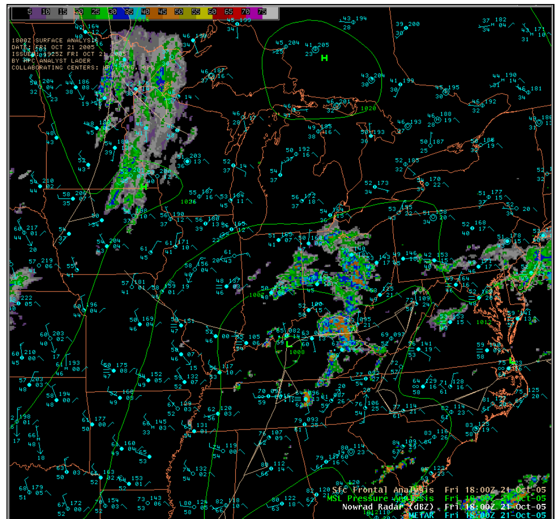

Fig. 21. Surface front and pressure analysis with METARs and composite radar image for 1800 UTC on 21 October 2005.

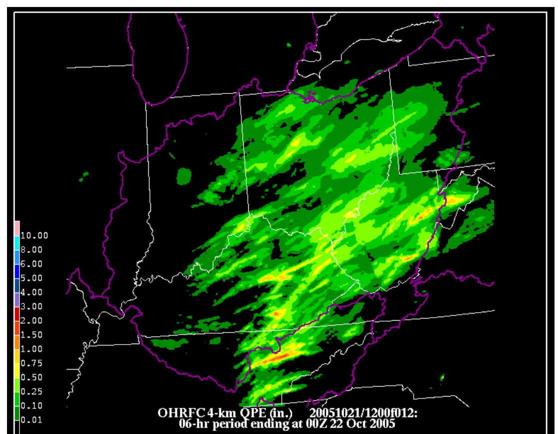

Fig. 22. NPVU precipitation analysis for the 6-h period ending 0000 UTC 22 October, in inches.

The 6-h accumulated precipitation forecasts with and without TAMDAR for the same 6-h period are shown in Fig. 23. Both RUC runs tended to underpredict the amount of rain, both in the cold and warm sectors of this system, and failed to produce enough precipitation into northern Ohio. It should be noted, however, that significant portions of Indiana and Ohio received less than 0.10 in of rain in the 6-h period, so the RUC forecasts were correct in the aspect of not predicting widespread coverage. The RUC run that used TAMDAR has more of its precipitation farther south near the Ohio/West Virginia border, where the precipitation analysis in Fig. 22 indicates the heaviest area of rain is found. Thus, while the RUC forecast from the run using TAMDAR is somewhat better than the run without TAMDAR, the differences for this case are not as striking as for the cases discussed

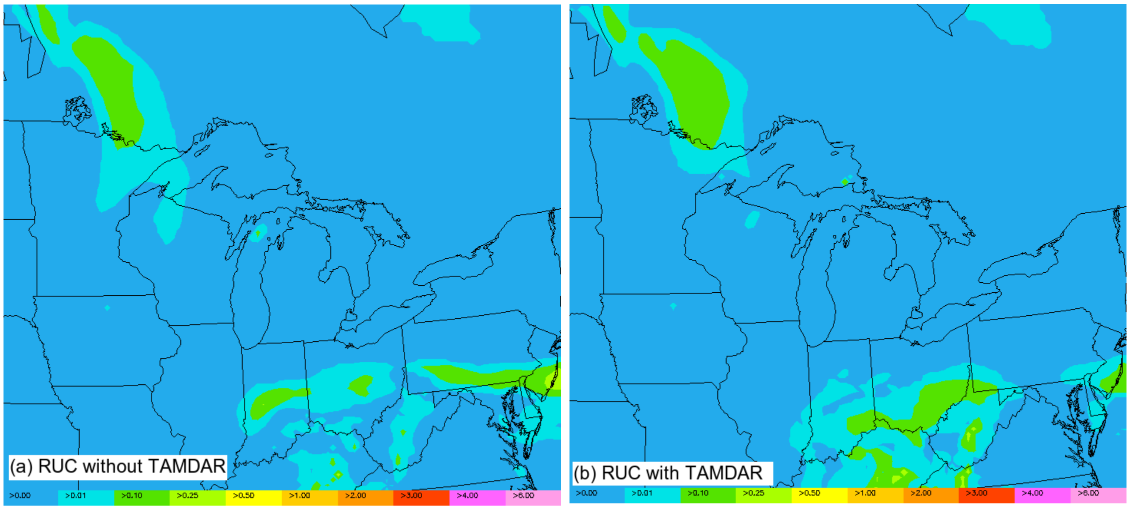

Fig. 23. 1800 UTC RUC 6-h forecasts of accumulated precipitation (in) without (a) and with (b) TAMDAR.

earlier that were more centered over the TAMDAR network, consistent with a greater influence of TAMDAR data on the forecast when more data exists.

4. SUMMARY AND CONCLUSIONS

A subjective evaluation of RUC model forecasts with and without TAMDAR data has demonstrated that notable differences were found in some of the forecasts when active weather systems were present within the area of TAMDAR coverage. The most impressive differences were found in the 0-6 h precipitation forecasts, and in almost all cases the best forecast came from the run using TAMDAR.

Examination of sounding comparisons for some of the cases using 6-h forecasts from the two RUC runs compared to RAOBs often indicated much better agreement between the observed moisture and the RUC run using TAMDAR than the run without TAMDAR, particularly for the lowest approximately 200 mb. Better forecasts of moisture in the areas near and upstream of the precipitation are consistent with the better forecasts of precipitation for the RUC runs using the TAMDAR data. There were no systematic differences found with the temperature and wind forecasts using the sounding comparisons, and these differences were generally much smaller than for moisture. This is probably a consequence of both RUC runs ingesting AMDAR wind and temperature data, while moisture data from aircraft was unique to the RUC runs using TAMDAR.

Better precipitation forecasts can be critical to aviation needs, both from the direct impact of precipitation, and the low ceilings and visibility that often accompany precipitation. Wintertime precipitation typically has an even greater direct impact on aviation concerns, and we hope to show some winter precipitation forecasts at the conference.

Other forecasts that can have a significant impact on aviation were also examined, such as surface wind, cloud ceiling, and visibility. Significant differences were not found in surface wind forecasts. Some differences were found in the cloud ceiling and visibility forecasts, though for our set of cases, the differences were not as dramatic as with precipitation.

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