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AN EVALUATION OF TAMDAR SOUNDINGS IN SEVERE STORM FORECASTING

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1. INTRODUCTION

Input from many sources is used in the short-term prediction of severe thunderstorms. One of the more critical observations needed continues to be a vertical sounding of temperature, humidity and wind. National Weather Service (NWS) forecasters often call for special rawinsonde (hereafter, RAOB) launches at 1800 UTC on a potential severe storm day because they want to observe recent changes in the vertical structure of the atmosphere. Those changes include the depth of the surface-based moisture, cap strength, and the vertical wind shear. Automated soundings made by aircraft on ascent and descent via the Meteorological Data Collection and Reporting System (MDCRS), provide vertical information for temperature and wind. These soundings are generally limited to major airports, and moisture information, a critical parameter, is not included. In fact, the distribution of moisture in the vertical has been difficult to measure with sufficient accuracy and vertical detail except via the standard RAOB, launched twice per day at widely spaced upper-air rawinsonde sites.

Over the past couple of years the NOAA/Earth Systems Research Lab (ESRL)/Global Systems Division (GSD), along with other groups, have been evaluating a new airborne sensor deployed on commercial aircraft, known as TAMDAR, for Tropospheric AMDAR (Aircraft Meteorological Data Relay). TAMDAR adds the critical measurement of moisture to wind and temperature observations in the vertical. In addition, the instrument, developed and deployed by AirDat, LLC, a private firm located in Raleigh, North Carolina, in part through funding from NASA, has been deployed experimentally on smaller regional aircraft. They fly lower than the larger commercial jets and service many more airports than the MDCRS fleet (Daniels et al., 2006). Furthermore, many of the flights are at levels well below the jet stream level of typical MDCRS aircraft, adding considerable amounts of data between approximately 14 to 20 kft AGL. These sensors have been deployed on 50 aircraft flying over the U. S. Midwest in an experiment called the Great Lakes Fleet Evaluation (GLFE). See the NOAA Web site at http://www.crh.noaa.gov/tamdar/. During this experiment more en route mid-tropospheric reports and sites for ascent/descent soundings were provided than had previously been available. This makes TAMDAR potentially valuable for forecasting the severe storm environment. In this paper we will show examples from the 2006 convective season of the potential value of TAMDAR soundings in GLFE area (see Fig. 1 for typical TAMDAR coverage). Comparisons will be made with standard and, when available, special RAOB launches.

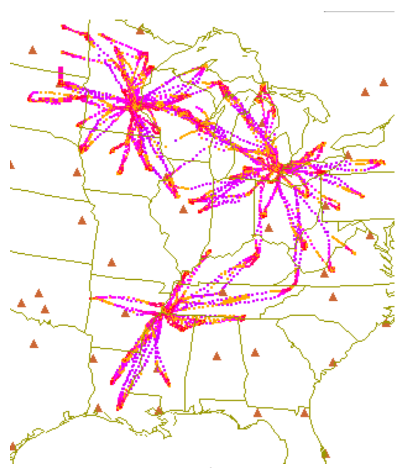

Fig. 1. Typical TAMDAR flight coverage, here for 1200 UTC 2 August to 0400 UTC on 3 August 2006. Triangles denote RAOB sites.

2. TAMDAR EVALUATION

GSD took a multifaceted approach to evaluate the potential impact of TAMDAR. Key to the evaluation was the objective study of TAMDAR's impact on the Rapid Update Cycle (RUC) model. The study used parallel versions of the 20-km horizontal grid resolution RUC (Moninger et al. 2006, Benjamin et al. 2006). Statistics have been running in real time for over two years, comparing wind, temperature and humidity for the two runs, using RAOB sites for verification points. In general, including TAMDAR data has demonstrated a consistent positive impact.

While demonstrating model impact is important, the data can have a significant impact

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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 Weather Forecast Office (WFO). These range from Public forecasts of "ordinary" weather to aviation to the potential for severe storms, or for forecasts from the NOAA Storm Prediction Center (SPC). 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 data benefited the forecast, with some presented at recent conferences (Brusky et al. 2006, Fischer 2006, Mamrosh et al. 2006, Szoke et al. 2006). The NOAA TAMDAR Web page has some of these studies along with others (at http://www.crh.noaa.gov/tamdar/). A training CD can also be accessed from this Web site.

Currently the TAMDAR data are officially considered experimental, with the program in the evaluation phase (Daniels et al. 2006). At this point it is unknown whether the NWS will provide funding for TAMDAR, but nonetheless, the program is scheduled to expand to both a western and eastern CONUS fleet of regional aircraft in 2007, while continuing to send data from the GLFE fleet. TAMDAR and AMDAR data in general are viewable to NOAA and other selected users in real-time from a GSD Web site at http://acweb.fsl.noaa.gov/java/. Use of TAMDAR among forecasters is limited at this time; both because the data is only available currently in the middle of the nation, and also since it is not a part of the AWIPS data stream. The WFO at Green Bay, Wisconsin has been an NWS focal point for TAMDAR, and they have documented use of the data by various offices within the GLFE area (see the above-listed NOAA TAMDAR Web page). It is estimated that about a third of the forecasters at the SPC currently look at TAMDAR soundings (S. Weiss, 2006, personal communication).

3. CASES

Two cases from the most recent convective season are discussed below. The focus is on a scale of interest to the SPC, with an emphasis on evaluating the pre-convective environment as would occur when forecasters consider issuing a Watch or prepare a Convective Outlook.

3.1 *14 July 2006 – Ohio Valley Severe Weather*

Severe weather was a threat across the Ohio Valley region on this day with plentiful low-level moisture in place and a shortwave trough moving eastwards out of the Upper Midwest. The SPC included much of the Ohio Valley region within a Slight Risk (Fig. 2). Dewpoints were in the mid 70s (°F) across southern Indiana, with a 70 °F dewpoint extending as far north as central Michigan. Convection that had continued through the night

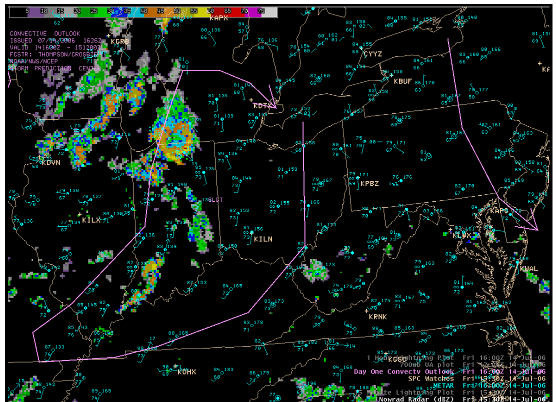

Fig. 2. NOWRAD radar reflectivity image at 1530 UTC with METARs for 1600 UTC and the 1600 UTC 14 July SPC Convective Outlook.

ahead of the approaching wave was scattered across the southwestern portion of the risk area, with a more substantial area of convection farther north across lower Michigan. The extent of this northern convection and cloudiness, and whether it would prevent conditions from later supporting severe storms, was an early issue facing SPC forecasters. A decision was made for the 1900 UTC Convective Outlook to remove most of Michigan from the Slight Risk area (Fig. 3).

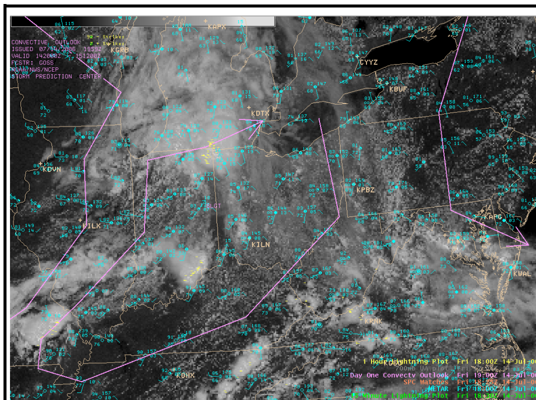

Fig. 3. Visible satellite image with METARS and 1-h lightning for 1800 UTC 14 July 2006, with the updated SPC 1900 UTC convective outlook.

Detroit (DTX) is one of the major hubs for TAMDAR flights, as shown by the coverage plot in Fig. 4. Thus, frequent soundings were available. A collection of some of the TAMDAR soundings for DTX is shown in Fig. 5, overlaid with the 1200 UTC RAOB. As might be expected with the approaching convection, the atmosphere below 700 mb at DTX moistens considerably. This is depicted by the 1447 UTC TAMDAR sounding, with the dry layer that had been present just below 800 mb disappearing. But with the main convection passing south of DTX (see Fig. 3), the air dries and warms from ~700 mb to 850 mb during the late morning, while at lower levels below 900 mb the air warms all morning.

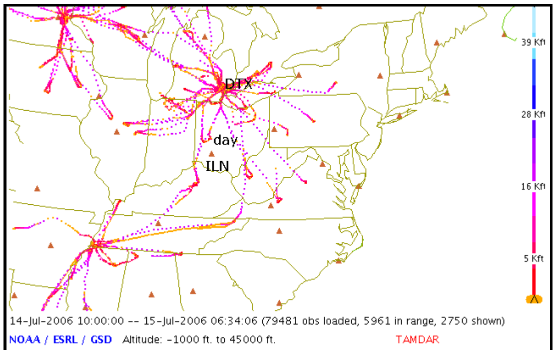

Fig. 4. TAMDAR coverage near the area of concern from 1000 UTC 14 July to 0630 UTC on 15 July 2006. Selected RAOBs (capital letters) and airports (small letters) labeled.

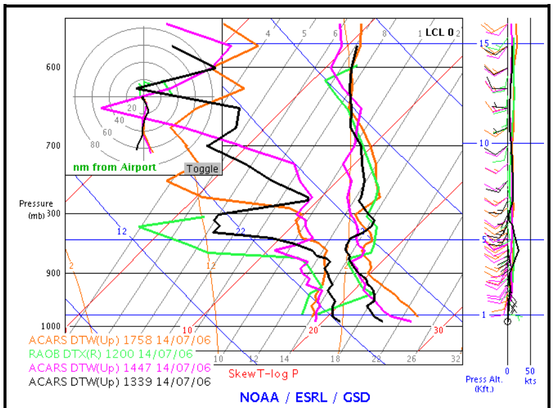

Fig. 5. TAMDAR soundings from Detroit, Michigan, overlaid with the 1200 UTC RAOB from 14 July 2006.

How accurate are these changes depicted in the TAMDAR soundings? A special 1800 UTC RAOB was in fact requested because of the potential for severe weather, allowing for a comparison to be made with one of the TAMDAR soundings from DTX (Fig. 6). The comparison is good, with the differences that do exist possibly

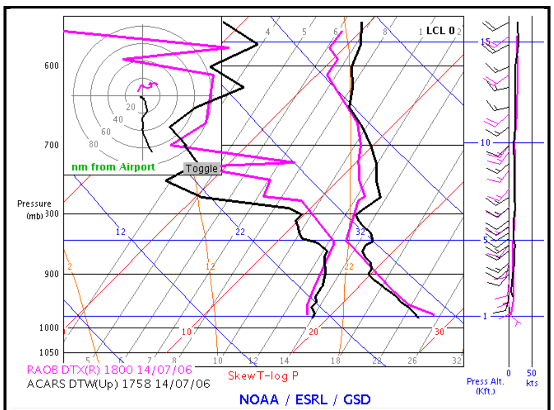

Fig. 6. TAMDAR sounding from Detroit (DTW) at 1758 UTC on 14 July 2006 with the Detroit 1800 UTC special RAOB (from the nearby DTX).

resulting from the TAMDAR aircraft ascending to the south, while the balloon drifted with the winds to east-northeast. By using TAMDAR soundings, changing conditions could have been continuously monitored as opposed to waiting for the single 1800 UTC RAOB.

Shortly after 1800 UTC a north-south line of storms began to develop in western Ohio (Fig. 7), with the line progressing eastward and accounting for many of the severe wind reports (Fig. 8) on this day. Other severe reports just to the southwest over the Ohio border into Indiana and Kentucky were associated with a separate small bowing line. Most of the severe wind reports with these two features occurred between 1820 UTC and 2100 UTC. By 2100 UTC other convection was developing to the south and west, and three separate Severe Thunderstorm Watches had been issued (Fig. 9).

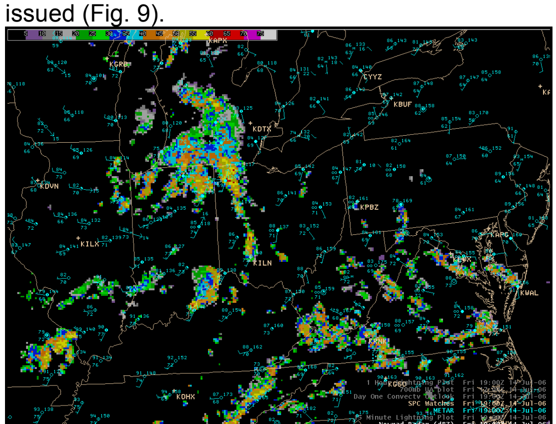

Fig. 7. NOWRAD radar reflectivity image at 1900 UTC with METARs for 1900 UTC.

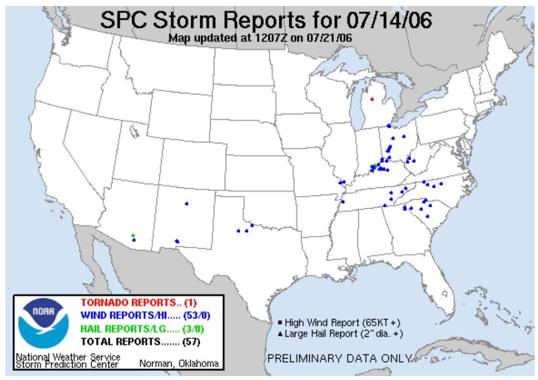

Fig. 8. SPC storm reports for 14 July 2006.

TAMDAR coverage into Ohio (Fig. 4) is far less frequent than at Detroit, but there are some interesting TAMDAR soundings available. In Fig. 10 three TAMDAR flights into Dayton (day), Ohio are shown with the nearby 1200 UTC Wilmington (ILN), Ohio RAOB. Two of the TAMDAR flights occur within about 30 min of each other (one ascent and one descent). A special 1800 UTC RAOB was not available from ILN, but at nearby Dayton there is a TAMDAR sounding from 1839

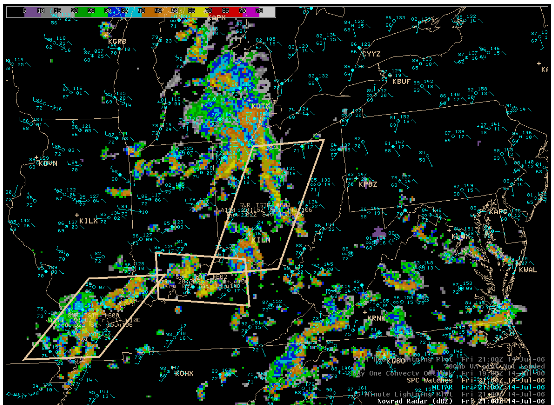

Fig. 9. NOWRAD radar reflectivity image at 2100 UTC with 2100 UTC METARs and SPC watches.

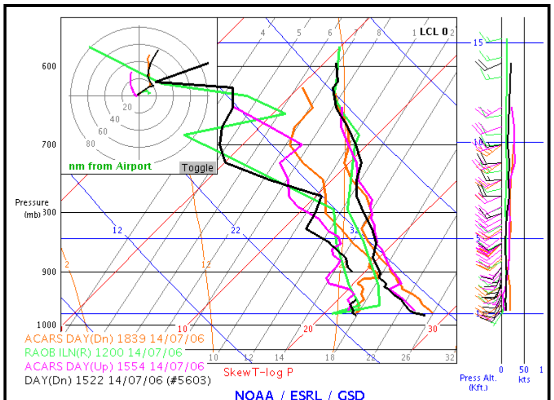

Fig. 10. TAMDAR soundings from Dayton (day), Ohio on 14 July, with the 1200 UTC Wilmington (ILN), Ohio RAOB.

UTC. This TAMDAR sounding has a 100 mb surface-based layer that is very moist, while the temperature in the boundary layer warmed to the point of basically removing any inhibiting inversion. A surface parcel raised from this sounding has a mere 6 Jkg^{-1} of Convective Inhibition (CIN). This lack of CIN agrees with the quick development of severe convection beginning near this time. It is possible that knowledge of these conditions based on the TAMDAR soundings might have led to an earlier issuance of the Severe Thunderstorm Watch in Ohio, issued at 2015 UTC, and captured more of the severe wind events on this day.

3.2 *2 August 2006 – Midwest severe weather*

Severe weather on 2 August formed near and ahead of a cold front moving across the Midwest in relatively fast upper-level flow riding over a broad upper-level ridge. A large area with a slight risk for severe storms was included in the early morning SPC Convective Outlook (Fig. 11). The outlook area was ahead of ongoing convection at 1200 UTC along and near the advancing cold front. TAMDAR availability for the entire day, from 1200 UTC 2 August 2006 through 0400 UTC on 3 August, is shown in Fig. 12. Note that Minneapolis (mpx), Minnesota, is another one of the major

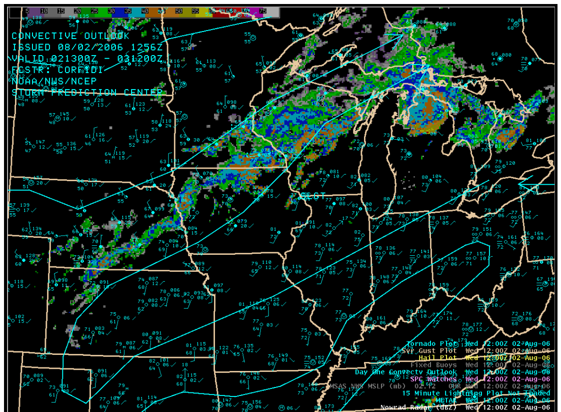

Fig. 11. NOWRAD radar reflectivity image and METARs at 1200 UTC with the SPC 1200 UTC Convective Outlook on 2 August 2006.

TAMDAR hubs, with numerous flights. There is good TAMDAR coverage in Iowa and northern Illinois, within the area of the SPC slight risk for severe storms. This is an interesting case in that it illustrates the considerable variability in the environment in space and over a short time that can occur within the fairly coarse RAOB spacing to create both favorable and unfavorable conditions for strong convection.

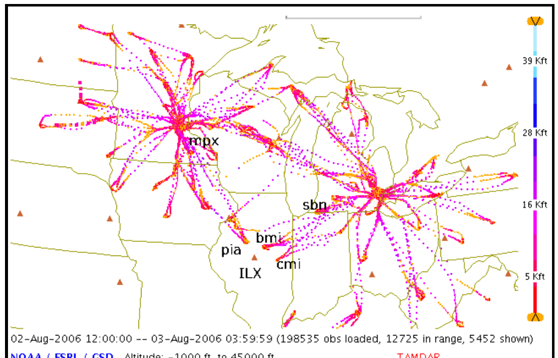

Fig. 12. TAMDAR coverage near the area of concern from 1200 UTC 2 August to 0400 UTC on 3 August 2006. Labels as in Fig. 5.

During the morning and into the afternoon hours the cold front continued to advance slowly eastward. The solid line of storms at 1200 UTC (Fig. 11) became a broken line as early as 1500 UTC. By 1800 UTC the cold front had advanced eastward to a line from extreme southeastern Nebraska northeastward to near Green Bay, Wisconsin, with a gap in convection across much of Iowa into the southern half of Wisconsin. The next (1600 UTC) SPC convective outlook remained pretty much the same (not shown), as did the following one at 1900 UTC. Potential for severe storms continued to exist, but there was a strong cap in place, as depicted by some of the TAMDAR soundings in the mid to late morning across the area (Fig. 13).

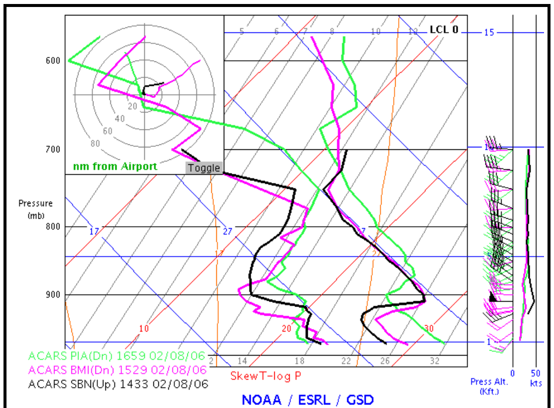

Fig. 13. TAMDAR soundings from central Illinois into northern Indiana between 1433 to 1659 UTC.

Although the TAMDAR soundings depict a very strong cap, temperatures by afternoon were quite high, nearing 100 ºF in some spots (Fig. 14), and dewpoints were in the 70's (ºF) across much of the area. In fact, there were some extreme combinations of moisture and heat; note the 97/79 reading south of Chicago in Fig. 14. The SPC remained concerned about the potential for rapid development along the cold front in such conditions, issuing the Mesoscale Convective Discussion (MCD) shown in Fig. 15 at 1742 UTC. This was followed at 1950 UTC by a Severe Thunderstorm Watch for much of southern Wisconsin and the northern half of Michigan.

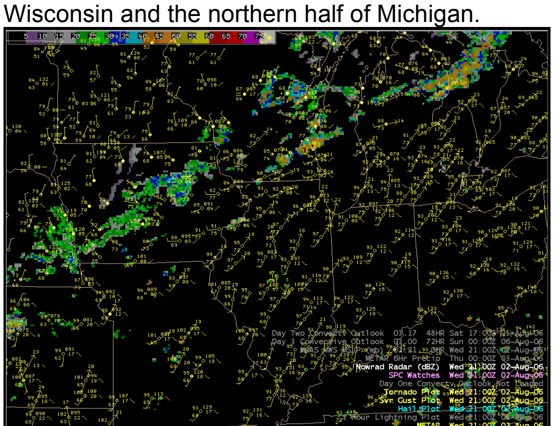

Fig. 14. NOWRAD radar reflectivity image and METARs at 2100 UTC. SPC Watches not shown.

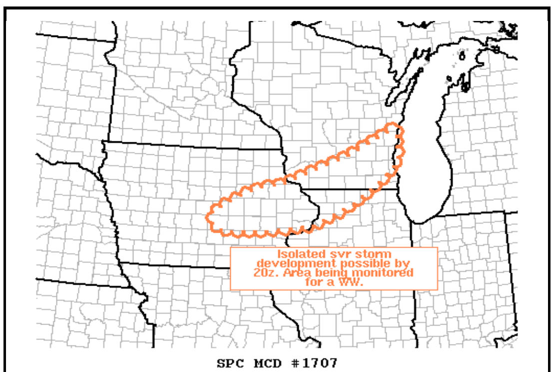

Fig. 15. SPC MCD graphic issued at 1742 UTC.

The SPC never did issue a watch during the afternoon for Illinois, keeping the watch farther north, which turned out to be an excellent forecast. TAMDAR soundings were available for several spots in the northern half of Illinois during the late afternoon and early evening, and displayed some interesting changes as the cold front approached. The Peoria (pia), Illinois airport had the most TAMDAR flights, and a time series of these soundings are shown in Fig. 16, along with the 0000 UTC Lincoln (ILX), Illinois RAOB.

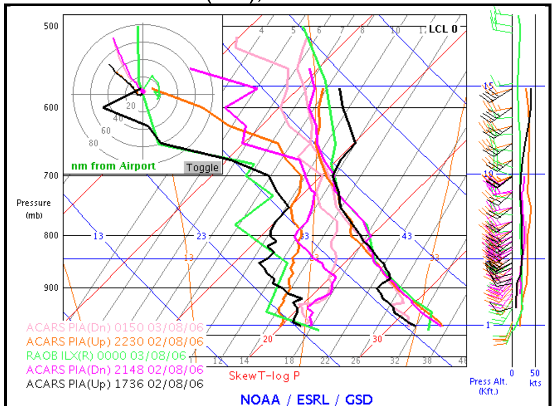

Fig. 16. Series of TAMDAR soundings from pia, with the ILX 0000 UTC 3 August 2006 RAOB.

Conditions actually become more conducive to potential strong storms between the 1736 UTC TAMDAR sounding and the next available one from pia at 2148 UTC, with greater moisture that actually increases in depth, coupled with boundary layer warming. A cap still remains at 800 mb in the 2148 UTC sounding, but it is much reduced in strength, suggesting the atmosphere was poised at this time for severe storms. However, by the time of the next TAMDAR sounding at 2230 UTC (Fig. 16) the moisture in the boundary layer had decreased substantially, creating a less favorable environment for severe storms. Was this drying real? The nearby 0000 UTC RAOB from ILX suggests it was accurate, matching nicely the moisture profile in the 2230 UTC TAMDAR sounding for the ~850 to 950 mb layer. Surface observations gave no good indication of such significant drying ahead of the cold front, although there was a weak wind shift to more westerly winds ahead of the front, present as early as 2100 UTC (Fig. 14). In this case, the TAMDAR observations led the RAOB by more than an hour in identifying this drying.

With drier conditions apparent across some of the threat area at 0000 UTC, the problem was whether a severe weather threat remained farther to the north as the front continued to advance eastward. At 2252 UTC the SPC issued another MCD (not shown) for the area of northern Illinois eastwards into southern Michigan, indicating a watch might be needed for the area south of the ongoing Severe Thunderstorm Watch, and indeed a watch was issued (Fig. 17). A collection of some

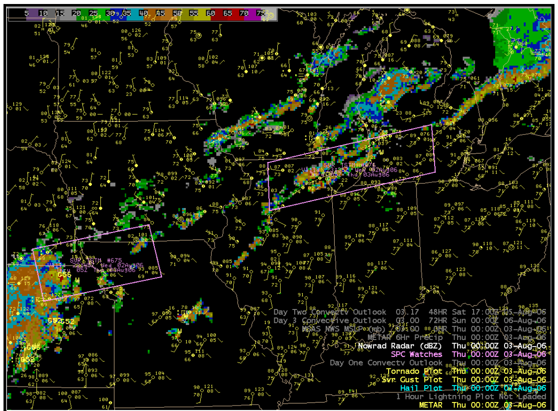

Fig. 17. NOWRAD radar reflectivity image and METARs at 0000 UTC, 3 August 2006, with severe reports and SPC Severe Thunderstorm Watches.

TAMDAR soundings from near 0000 UTC across northern Illinois and out of South Bend (sbn), Indiana is shown in Fig. 18, along with the 0000 UTC Lincoln, Illinois RAOB (ILX).

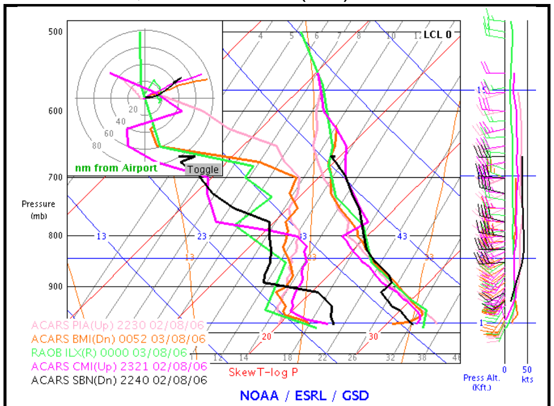

Fig. 18. TAMDAR soundings near 0000 UTC, with the 0000 UTC 3 August ILX RAOB.

Conditions were the most potent farthest north, with the sbn 2240 UTC TAMDAR indicating very high low-level moisture, still capped by an inversion just above 900 mb. The other TAMDAR soundings farther to the south were much drier in the lower layers. Shortly after 0100 UTC there were numerous severe weather (mainly wind) reports within the SPC Watch across northern Illinois into Michigan shown in Fig. 17, while farther south only isolated storms occurred, consistent with the TAMDAR soundings.

4. SUMMARY AND CONCLUSIONS

Two cases from 2006 were discussed illustrating the utility of TAMDAR data for diagnosing the pre-storm environment on days with severe weather potential. The TAMDAR soundings diagnosed aspects of the above-surface environment in a time and space resolution that were not possible with standard and even special RAOB launches. On 14 July the eroding cap was diagnosed by a series of TAMDAR soundings from Dayton, Ohio, providing useful lead time for a forecast of convective initiation. On 2 August TAMDAR soundings showed significant above-surface drying, consistent with a lack of storms in Illinois. Comparisons of TAMDAR soundings with available RAOBs were favorable.

5. ACKNOWLEDGMENTS

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