9.5 EVALUATING THE BENEFITS OF TAMDAR DATA IN AVIATION FORECASTING

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1. INTRODUCTION

The TAMDAR (Tropospheric Airborne Meteorological Data Reporting) Sensor is an airborne atmospheric instrument developed under contract by AirDat for NASA. It is aircraft mounted and measures or calculates winds, temperature, humidity, turbulence, pressure altitude, airspeed and icing. A network of TAMDAR sensors are currently installed on 50 Mesaba Saab-340s.

Studies by the National Center for Atmospheric Research (NCAR) have shown an increase in forecasting skill of the NCAR Auto-Nowcaster, Variational Doppler Radar Analysis System (VDRAS), and the Current Icing Potential (CIP) algorithm when TAMDAR data is included in the data-ingest. TAMDAR data has also been found to be of value to National Weather Service Forecasters in an operational setting. In this paper, several brief case studies are presented to illustrate how the higher spatial and temporal resolution TAMDAR soundings can better enable forecasters to follow the evolution of temperature and humidity profiles, convective inhibition (CIN) fields, icing, and wind shear, which can lead to more accurate forecasts of aviation weather.

2. TAMDAR DATA

The TAMDAR sensor measures or calculates meteorological conditions during ascent, level flight, and descent; providing users with two vertical soundings of the atmosphere per flight, as well as data during cruising altitude. The following sections outline some critical convection forecasting parameters that are available from TAMDAR.

Temperature, relative humidity, and winds are measured or calculated from TAMDAR data and are reported every 10 millibars through the lowest 200 mb of the atmosphere on ascent. Once above the lowest 200 mb, TAMDAR reports every 25 mb, or every 3 minutes, until descent, where it resumes a frequency of 10 mb reports within the lowest 200 mb of the atmosphere. CIN can be calculated from the TAMDAR sounding data, which is discussed in Section 2.4.

2.1 Temperature

It is a necessity to accurately anticipate the atmosphere's temperature and relative humidity evolution to make a good aviation forecast, but the availability of current upper air data is sparse (Fischer 2006). National Weather Service forecasters have found the near-mesoscale availability of TAMDAR data helpful in more accurately evaluating the atmosphere and anticipating its evolution (Mamrosh et al. 2006a).

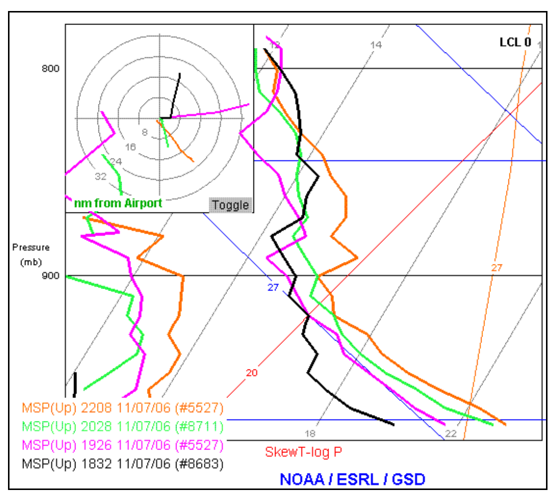

Figure 1. TAMDAR soundings from MSP on 7 July 2006 showing temperature evolution.

Figure 1 shows a series of TAMDAR soundings from the Minneapolis/St. Paul (MSP) airport on 7 July 2006. At 1823 UTC, TAMDAR (black) indicates a surface temperature near 20°C. By 2208 UTC, the surface has warmed to about 23°C (orange).

The Frequency of TAMDAR soundings keep the forecaster updated on the rapidly changing atmosphere, especially in the

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boundary layer. The current TAMDAR fleet rarely exceeds 500 mb due to aircraft limitations, but many publications agree that knowledge of the boundary layer and mid-troposphere is the most important part of accurately forecasting convection potential (Brusky and Kurimski 2006).

Figure 2 illustrates how TAMDAR can be used to monitor temperature inversions with respect to time. The 1200 UTC radiosonde launch from MPX (black) shows a strong nocturnal inversion over the region. Between 1200 UTC and 1600 UTC, surface temperatures increased causing the inversion to dissipate by the 1602 UTC TAMDAR sounding out of MSP (pink).

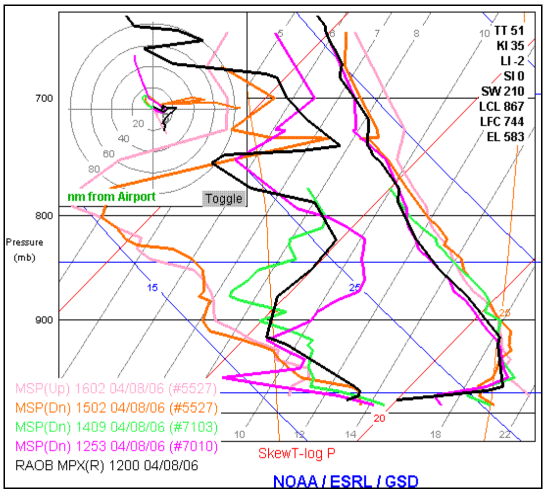

Figure 2. TAMDAR soundings from MSP and 1200 UTC radiosonde on 4 August 2006 showing the evolution of a temperature inversion.

2.2 Relative Humidity

One benefit of TAMDAR weather data over ACARS weather data is the availability of relative humidity data. The greatest moisture variation and strongest baroclinicity occurs at the levels in which TAMDAR flies. The variability of these stratified fields within these levels is one of the leading causes of numerical weather prediction error (Fischer 2006). The amount and distribution of moisture is critical in making an accurate forecast, but radiosondes do not provide forecasters with enough of this information (Szoke et al. 2006). TAMDAR provides forecasters with several upper-air relative humidity profiles per day on aircraft flight paths. This is especially helpful in areas that do not have a radiosonde launch station in close proximity.

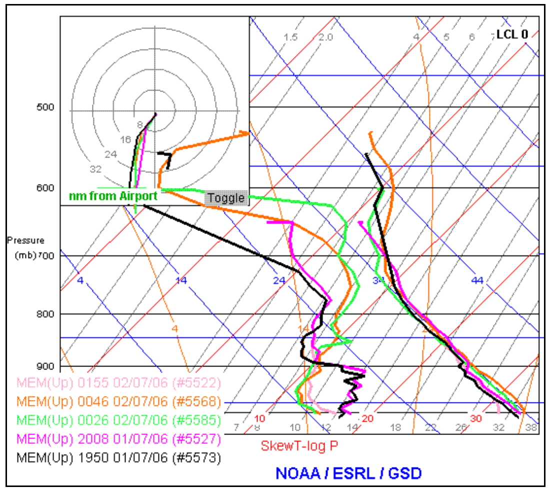

Figure 3. TAMDAR soundings from MEM between 2008 UTC 1 July 2006 and 0026 UTC 2 July 2006.

Figure 3 shows several TAMDAR ascents from Memphis, whose nearest radiosondes are out of Little Rock, AK (LZK), and Nashville, TN (BNA). The 1 July 2006 1950 UTC (black) and 2008 UTC (purple) soundings show dew point temperatures in the upper teens through 900 mb. By 2 July 2006, the 0026 UTC (green) dew point temperatures have dropped, and remain low through 0155 UTC. Additionally, note the increase in relative humidity between 900 mb and 600 mb after 0026 UTC.

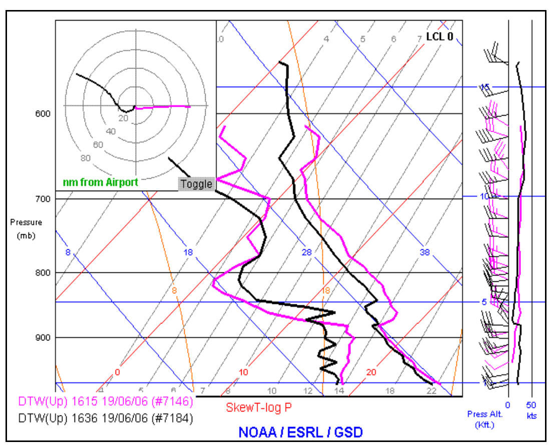

Figure 4. TAMDAR soundings going opposite directions (see hodograph) from 19 June 2006 showing the variation of temperature and dew point with respect to horizontal distance.

Figure 4 illustrates the usefulness of TAMDAR soundings ascending in opposite horizontal directions at a similar time. The 1636 UTC sounding (black) had a northwest heading after takeoff from Detroit. The 1615 UTC sounding (purple) headed east, and measured higher dew point temperatures than the 1636 sounding up to 875 mb. The 1636 sounding did not show a temperature inversion at 875 mb, which is evident to the east of Detroit. Also, note the difference in depth and magnitude of the dry air intrusion at 800 mb in both TAMDAR soundings and the variations in the wind profiles.

2.3 Wind

National Weather Service forecasters have noted the helpfulness of TAMDAR data in evaluating winds aloft, especially between 700 mb and 800 mb (Brusky and Kurimski 2006). Benefits of TAMDAR wind data have also been shown for aviation forecasts of fog, stability, and wind shear (Mamrosh et al. 2006a).

Figure 5 shows two TAMDAR soundings from Memphis on 1 May 2006. The 1247 UTC sounding shows light southerly winds at the surface, veering to westerly by 700 mb. The 1516 UTC sounding shows winds have backed at the surface. At 700 mb and above, the 1516 UTC winds have shifted to northwesterly, increasing the magnitude of the directional wind sheer with respect to time.

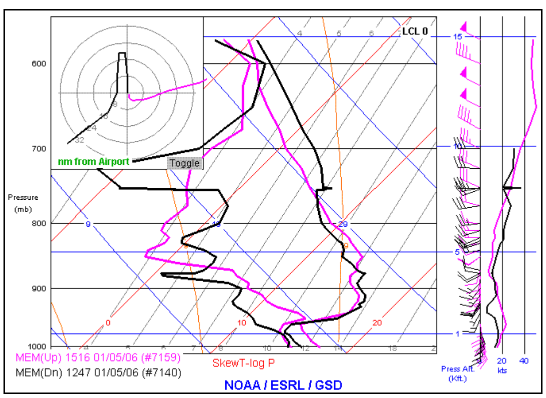

Figure 5. TAMDAR soundings from MEM on 1 May 2006 showing an increase in directional wind sheer from 1247 UTC to 1516 UTC.

2.4 CIN

National Weather Service forecasters have noted on several occasions the added value of TAMDAR soundings in monitoring the evolution of the CAP, CIN, and CAPE for convection forecasts (Brusky and Kurimski 2006; Mamrosh et al. 2006a). CAPE cannot be precisely measured due to the altitude limitations of the TAMDAR fleet; however, it can be estimated.

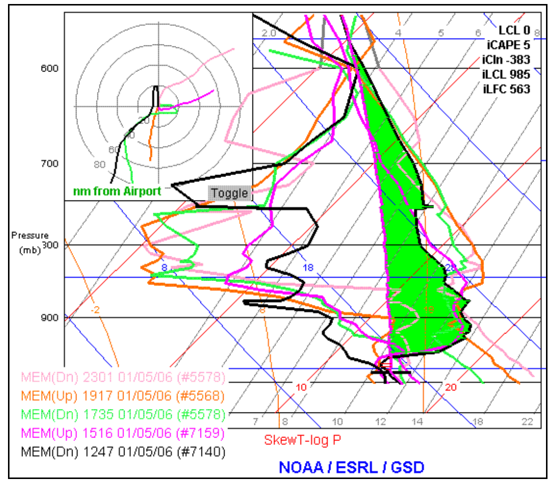

Figure 6. TAMDAR soundings from MEM on 1 May 2006 showing a large amount of CIN in the 1247 UTC TAMDAR sounding.

Figure 6 shows a series of TAMDAR soundings available between the 1200Z and 0000Z radiosonde launches. As the day progresses, surface temperatures increase, the strong nocturnal inversion dissipates, and the 800 mb layer dries out. The area of CIN estimated from the 1247 UTC TAMDAR sounding is in green.

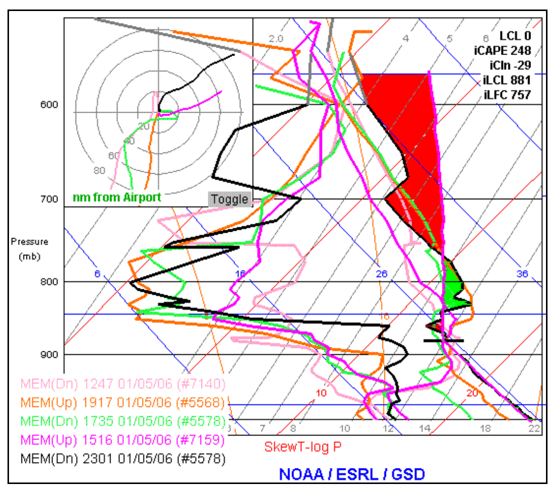

Figure 7. TAMDAR soundings from MEM on 1 May 2006 showing how CIN has decreased by 2301 UTC and CAPE has increased.

Figure 7 shows this same evolution mentioned above. Now, CIN (green) and CAPE (red) are estimated from the 2301 UTC TAMDAR sounding.

TAMDAR data has the ability to help fill an information void. Historically, forecasters had to rely on model-generated soundings to estimate atmospheric profiles between radiosonde launches, but a model is not "truth". Now, forecasters have an aviation data source to evaluate before making an aviation forecast.

National Weather Service forecasters have also used TAMDAR data to evaluate model performance. Model biases and error have been found when comparing output to TAMDAR (Fischer 2006), but agreement between TAMDAR and the models can give the forecaster greater confidence in the model forecast (Mamrosh et al. 2006a).

2.5 Icing

TAMDAR Icing sensors contain two independent infrared emitter/detector pairs mounted on the leading edge of the probe. Once 0.025 inches of ice accretes, TAMDAR sends out a positive icing observation. Once ice is detected, internal heaters melt the ice from the probe.

Figure 8 below is a screen shot of AirDat's AirMap. Icing reports from 23 September 2006 are displayed below. The various colors of the icing observations represent different altitudes. Light blue observations represent icing reports near 20,000 ft, while the magenta observations are near 10,000 ft. This information can be very helpful to aircraft that need to identify locations of in-flight icing.

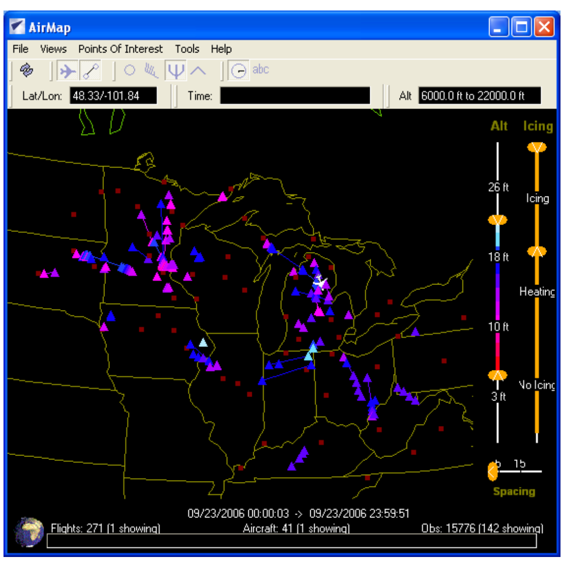

Figure 8. AirDat's AirMap displays icing observations by altitude over the Great Lakes Region.

The Current Icing Potential (CIP) algorithm group at NCAR compared TAMDAR's icing data to a NASA Glenn Research Twin Otter equipped with instrumentation able to measure icing, liquid water content, and many other cloud parameters. This reference data was matched to TAMDAR data if their observations were within one hour, 2000 vertical feet, and 200 horizontal kilometers of each other.

Figure 9 below shows TAMDAR's fraction correct (PC) and critical success index (CSI) when compared to the NASA Glenn Twin Otter data. Area above the horizontal line represents added skill in using TAMDAR as an icing forecast tool. When using TAMDAR data to forecast icing over a horizontal area, as seen in the top plot of Figure 9, it had a positive impact on forecasts up to a radius 125 km away. When forecasting icing over a vertical area, TAMDAR had a positive impact on the forecast up to 500 ft from the TAMDAR observation. These statistics were also compiled for time, but the results were found to be negligible (Polotovich et al. 2006).

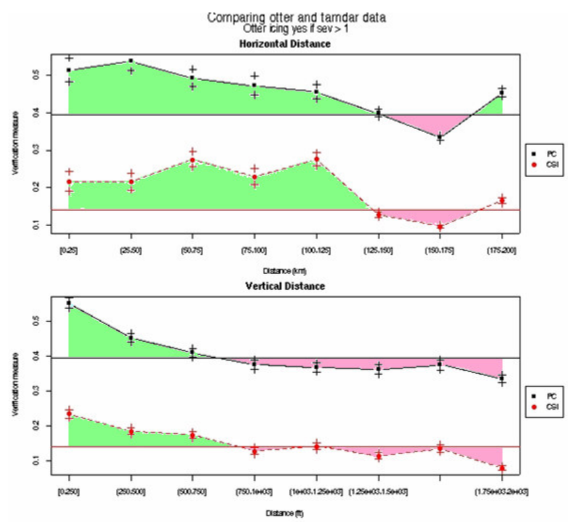

Figure 9. TAMDAR fraction correct (PC) and critical success index (CSI) when compared to Twin Otter data is seen above. Areas above the horizontal lines represent added skill in using TAMDAR as an icing forecasting tool.

3. TAMDAR DATA USERS

Several weather research facilities and forecast offices have been using TAMDAR data and evaluating its performance. The National Center for Atmospheric Research, Earth System Research Lab, National Weather Service, and other agencies have used

TAMDAR data and documented its positive impact toward their efforts, which are discussed below.

3.1 NCAR: Auto-Nowcaster and VDRAS

The Auto-Nowcaster (ANC) provides 60 minute nowcasts of storm initiation by detection and extrapolation of surface convergence boundaries that trigger thunderstorm initiation. TAMDAR sounding data was included in the data-ingest due to a lack of high spatial and temporal resolution soundings from current NWS radiosondes. Moisture information within, and above, the boundary layer is crucial for an accurate convection initiation forecast, and could increase probability of detection, thus reducing false alarm rates. This type of data is highly useful near airports.

TAMDAR CIN and relative humidity fields were compared against RUC CIN and relative humidity fields. The two-dimensional TAMDAR CIN fields were calculated from TAMDAR sounding data and surface observations, then run through the ANC. According to NCAR's results, false alarm rates decreased, and probability of detection increased, in case studies where TAMDAR data was used in the data-ingest. The averaged TAMDAR relative humidity field also showed some value in estimating moisture content more accurately. TAMDAR impact depends heavily on the location and timing of convection, as well as the proximity to TAMDAR soundings. If storms initiated far from TAMDAR, the impact was negligible (Cai et al. 2006).

The Variational Doppler Radar Analysis System (VDRAS) was developed at NCAR for assimilation of multiple WSR-88D radars and initialization of cloud-resolving numerical models. For these experiments, TAMDAR data were used in a mesoscale analysis to obtain the storm environment before the 4D-Var radar data assimilation. TAMDAR data thirty minutes before, and after, the analysis time were used. It is important to note the horizontal variation along the sounding was neglected (i.e., data was assimilated as a vertical profile).

Results indicate that the TAMDAR observations modified the analysis (especially humidity and temperature) significantly, which improved the prediction of convective systems. The TAMDAR data enhanced the convective initiation and more precisely predicted the location of the convective system in several case studies (Sun and Zhang 2006).

3.2 ESRL: The RUC Model

At the Global Systems Division of ESRL, TAMDAR data was assimilated into 20-km grid RUC model (Dev2) that ran in parallel with another RUC (Dev), which did not include the TAMDAR data. Their case studies showed that Dev2 forecasts better matched observed areas of heavy precipitation, produced more accurate forecast soundings, especially in the lowest 300 mb, more accurately forecasted precipitation timing and magnitude, and had the most substantial impact on the 0-6 hour precipitation forecasts. There were much smaller differences found in wind and temperature forecasts due to existing ACARS. Relative humidity is unique to TAMDAR, allowing it to have the greatest impact on a case by case basis (Szoke et al. 2006).

The Global Systems Division of ESRL also conducted a statistical analysis of the improvement Dev2 had over Dev at 850, 700, and 500 mb for temperature, winds, and relative humidity. The results showed that from 9 February 2005 until 24 August 2005, TAMDAR relative humidity improved the forecast by 12% at 850 mb. Wind forecasts were improved by 10% at all levels, and temperature forecasts improved by 15-20% at 850 mb. It was also noted that TAMDAR impact results improved throughout this time period (Benjamin et al. 2006). Current statistics will be provided at the presentation of this paper.

3.3 NCAR: the CIP Algorithm

The Current Icing Potential (CIP) algorithm gives an hourly, three dimensional diagnosis of the potential for icing over the continental United States and southern Canada. It uses decision trees and fuzzy logic to combine RUC model data with information from satellite, radar, surface observations, voice pilot reports (PIREPs), and lightning sensors in order to calculate these potentials (Braid et al. 2006).

As part of a NASA contractual obligation, three versions of a High Resolution CIP were run to evaluate the performance of TAMDAR. The examples below only features two of these types: high resolution CIP without TAMDAR and high resolution CIP with positive and negative TAMDAR icing reports.

Figure 10 below displays the CIP algorithm output for 24 January 2005 at 1500 utc for 575 mb. This run of CIP does not include any TAMDAR data. Note the magnitude and area of the icing potential over northern Ohio and northern Kentucky. Figure 11 shows an equivalent CIP run, but includes TAMDAR in the data ingest. The icing potential over northern Ohio has increased with the addition of TAMDAR data. Icing potential has also increased in area and magnitude over the northern Kentucky region.

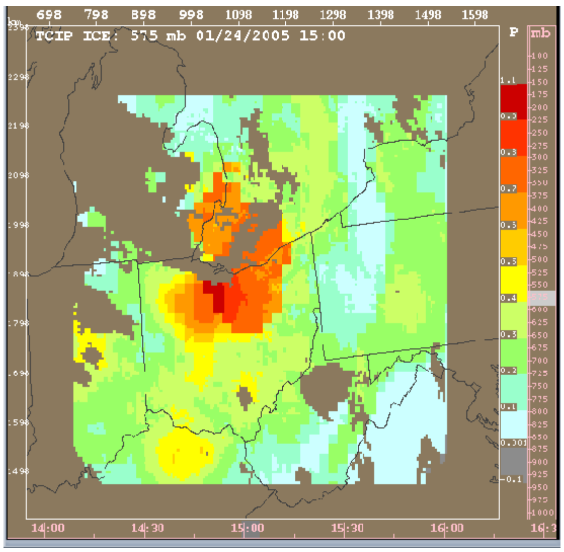

Figure 10. An icing potential forecast at 575 mb for 24 January 2005 15:00 utc. This forecast does not include TAMDAR data.

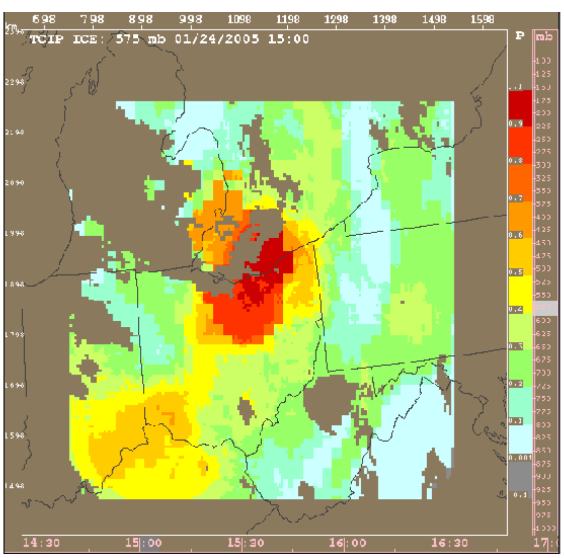

Figure 11. An icing potential forecast at 575 mb for 24 January 2005 15:00 utc. This forecast does include both positive and negative TAMDAR icing observations.

Figure 12 below shows the same 1500 utc 24 January 2005 icing potential forecast, except we are now looking at the 625 mb level. Again, note the differences between Figure 12 and Figure 13 in the northern Ohio and northern Kentucky regions. In these examples, the addition of TAMDAR data decreased the magnitude of the forecast icing potential over the Ohio region, and increased the area of icing potential near Kentucky. Differences in the forecast can also be seen in Indiana.

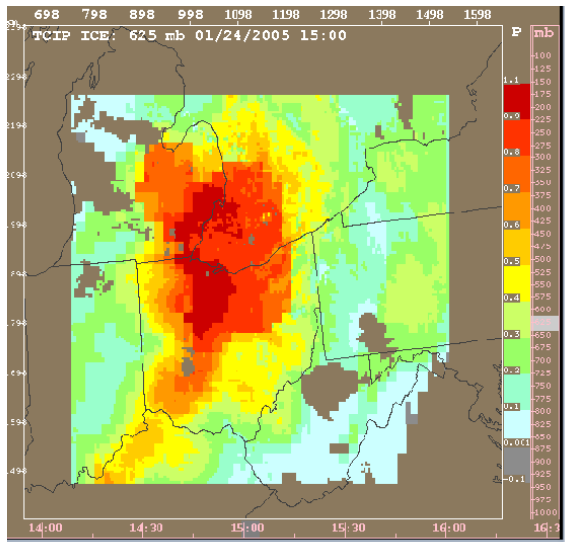

Figure 12. An icing potential forecast at 625 mb for 24 January 2005 15:00 utc. This forecast does not include TAMDAR data.

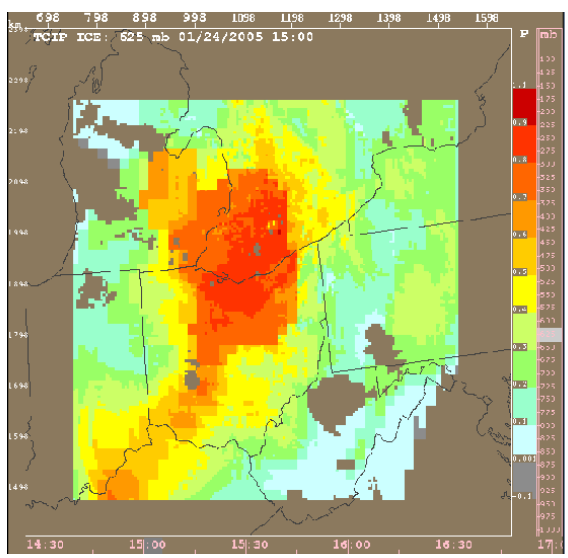

Figure 13. An icing potential forecast at 625 mb for 24 January 2005 15:00 utc. This forecast does include both positive and negative TAMDAR icing observations.

3.4 National Weather Service

Meteorologists at National Weather Service forecast offices (NWSFOs) and at the Storm Prediction Center (SPC) found TAMDAR beneficial. Over 97% of NWS forecasters polled would recommend TAMDAR data, and over 94% said TAMDAR data enabled them to make better forecasts. Forecasters like the near-mesoscale availability of TAMDAR data to monitor temperatures, moisture, inversions, winds, LCL, CAPE, and the CAP (Mamrosh et al. 2006a).

TAMDAR data has also helped forecasters better interpret numerical weather model output. If TAMDAR agrees with a model forecast, the forecaster's confidence in that model would increase. If there is a discrepancy, it suggests model error. TAMDAR also lets forecasters see how accurately the models initialize, and can educate them about model biases. Like any data source, TAMDAR needs to be understood and interpreted properly by the forecaster in order for it to benefit them (Fischer 2006). Brusky and Kurimski (2006) describe, in detail, several case studies where National Weather Service forecasters used TAMDAR data in their forecasts.

3.5 Other Users

Several other organizations use TAMDAR data in their operations. The Air Force Weather Agency (AFWA) in Omaha, Nebraska, uses TAMDAR data to assist them with icing forecasts. Center Weather Service Units (CWSU) in Indianapolis use TAMDAR to determine atmospheric moisture content used in stability index calculations for thunderstorm forecasts. TAMDAR data is also used to forecast ceilings, visibility, turbulence, fog, and low-level wind shear (Mamrosh et al. 2006b).

AirDat LLC has also used TAMDAR data in a real-time four-dimensional data assimilation (RT-FDDA) system. When compared to a control, results show that the addition of TAMDAR data improves RT-FDDA forecasts. Experiments were also conducted to see how the TAMDAR impact changes when RT-FDDA sigma-levels were increased from 36 to 48. Results showed significant improvements through the 12 hour forecast with geopotential height, temperature, and winds from the surface to 500 mb. The most notable improvements occurred between 900 mb and 800 mb; where there is a lack of meteorological information. Additional information can be found in Jacobs et al. (2006).

4. CONCLUSIONS

Due to the high temporal and spatial resolution of TAMDAR data, meteorologists can more easily monitor changes in the boundary layer and mid-troposphere with regards to temperature, relative humidity, winds, and CIN, as well as observe the evolution of other meteorological phenomena. The TAMDAR data aids to fill a knowledge gap that was previously estimated by numerical models, where finding truth or verification was very difficult. With the rapidly changing atmosphere, the frequency of TAMDAR aircraft soundings can help meteorologists make better, more accurate, aviation forecasts.

Several organizations have found TAMDAR data to be useful in their work. NCAR, GSD, NWS, CWSU, AFWA, and AirDat have all shown how TAMDAR data has a positive effect on their efforts. Whether TAMDAR data is used as an ingest source for a forecast, evaluated in real-time, or used as verification, it provides meteorologists with a tool to better evaluate the atmosphere and better prepare pilots for what they may expect along their route.

5. ACKNOWLEDGEMENTS

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