2.1 THE UTILITY OF AIRCRAFT SOUNDINGS IN ASSESSING THE NEAR STORM ENVIRONMENT

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1. INTRODUCTION

Much has been said in recent years about the importance of the near-storm environment in the formation of severe thunderstorms. While ground based mesoscale networks have been deployed in some areas to meet the need for more detailed surface conditions, the increase of tropospheric data have been largely limited to special radiosonde releases, satellite soundings, and Plains States wind profilers.

A relatively new type of real time tropospheric data can help meteorologists better understand the near storm environment. Commercial aircraft have been an increasing source of meteorological data for over ten years, yet many forecasters know little or nothing about these useful data. Atmospheric soundings from these aircraft can be utilized to generate convective indices such as CAPE, CIN, LI and heights of the LCL and LFC. Flight level wind data can show details of jet streaks, diffluence, and mesoscale vorticity centers.

The purpose of this paper is to simply raise awareness of aircraft as a valuable source of weather data, explain how these data are collected, quality controlled and displayed, and finally how they can be used to improve the forecasts and warnings of severe local storms. A comprehensive discussion of how aircraft soundings can be used in forecasting other weather phenomena is discussed by Moninger et al. (2003). Other papers at this meeting will provide detailed case studies from recent convective events.

2. AIRCRAFT DATA SOURCES

2.1 AMDAR

Automated wind and temperature data from commercial aircraft have been available in increasing abundance since the late 1970s (Fleming 1996). These data are now referred to as AMDAR (**A**ircraft **M**eteorological **DA**ta **R**elay), but have been previously called ACARS (Airline Communications Addressing and Reporting System), MDCRS (Meteorological Data Collection and Reporting System), and most recently TAMDAR (Tropospheric AMDAR).

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2.2 ACARS and MDCRS

As of Fall 2006, over 1,500 aircraft from eight United States airlines (American, Delta, FEDEX, Mesaba, Northwest, Southwest, United, and UPS) were collecting and reporting meteorological data. On all but the Mesaba Airlines aircraft, air temperature is collected from the total air temperature sensor, and ground relative wind speeds are calculated via the indicated airspeed and an inertial navigation system or Global Positioning System (GPS). In addition, about 30 UPS Airlines aircraft have sensors to measure water vapor, called WVSS-II (Water Vapor Sensing System - II).

These data are transmitted via a data link system (VHF radio over land and satellite over oceans) to ground stations where they are processed and distributed to the airlines and government centers.

2.3 TAMDAR

Meteorological data from sixty Mesaba airlines turboprop aircraft are acquired differently. These aircraft have been equipped with instruments designed and owned by a private company called Airdat LLC (Daniels et al. 2004). These instruments measure or calculate temperature, relative humidity, wind, icing and turbulence. Because the TAMDAR instruments were installed on regional aircraft serving smaller airports, the data is generally limited to below 500 mb. Data from these aircraft are transmitted via satellite to a ground station, where they are processed and provided to government and private sector users.

3. DATA QUALITY

FAA regulations require commercial airliners to have high quality air temperature sensors. In addition, modern navigation systems also permit very accurate ground relative wind calculations. Despite the high quality of aircraft sensors and avionics, suspect data do sometimes occur. Several methods are employed to flag erroneous data when it arrives at airlines, NCEP, Airdat, and other users.

Some airlines have automated systems that buddy check observations, and alert maintenance staff of faulty equipment. Airline meteorologists may also notice bad data and submit repair orders. In addition, National Center for Environmental Prediction (NCEP), Earth System Research Laboratory (ESRL), AIRDAT (Anderson 2006) and other users have programs that compare aircraft data to model first guess and radiosondes to find erroneous data.

NCEP rejects less than 3% of all AMDAR data for inclusion in the synoptic scale model runs. Model sensitivity tests of the ETA model showed that of all the upper air data that is input to the model, AMDAR wind data provide the greatest impact (even more than radiosondes), and is second only to radiosondes for temperature impacts (Zapotocny 2000). While AMDAR is important to synoptic scale models, Ballish (2006) discovered that AMDAR data quality varies with aircraft type, and possibly phase of flight (i.e., ascent or descent). ESRL studies show that off hour (non synoptic hour) RUC model runs have very little value without the inclusion of AMDAR.

4. DATA DISTRIBUTION

Because costs have historically been shared between the airlines and United States government agencies (NOAA and the FAA), use of the data has been limited to airline, government and university meteorologists. There are plans for the government to fully reimburse the airlines for the cost of data acquisition and distribution. After this occurs, aircraft data will be available to private sector meteorologists and the general public.

AMDAR (ACARS, MDCRS) are transmitted in real time to the National Weather Service (NWS) telecommunications gateway for distribution to NWS forecast offices for display on the AWIPS system. TAMDAR data are also made available to NWS forecast offices for display in AWIPS via the Meteorological Assimilation Data Ingest System (MADIS). Data are also sent to NOAA's Earth Systems Research Laboratory (ESRL) in Boulder, Colorado where they are made available on an internet web page. Because AWIPS is a proprietary NWS System, and future public access will likely be via the internet, we will limit our examples to data from the ESRL web page.

5. ESRL AMDAR DISPLAY CAPABILITY

Authorized users can access the ESRL AMDAR web page at (http://amdar.noaa.gov/java). By default, it will return a map of all the data in much of North America for the last 2 to 3 hours. An example is shown in figure 1 below.

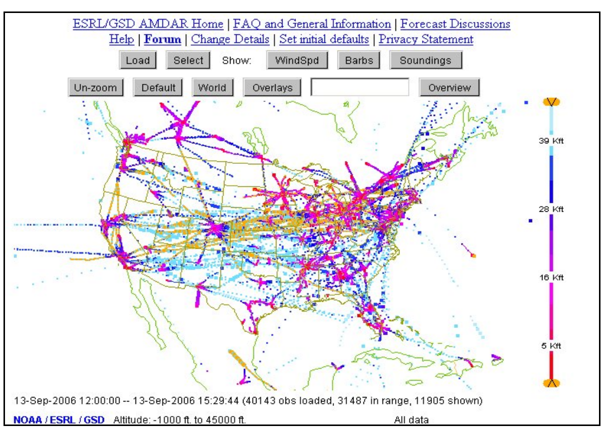

Fig. 1 Example of ESRL AMDAR Web Page Display.

The gray shaded buttons located at the top of the display (Fig. 1) allow the user to do the following:

a) Load data from any time period desired within the last several years
b) Select only certain data (water vapor, turbulence, data source)
c) Display the data as color coded wind barbs
d) Display aircraft soundings
e) Show data from around the world
f) Overlay airport locations , cities, VORs

The ability to display real time winds is very useful in severe weather forecasting to determine the location of the jet, upper diffluence, mesoscale vorticity centers, etc. Slider bars on the bottom and right sides of the web page allow the user to stratify data by wind speed and/or flight level. Figure 2 (below) shows the upper wind field for a typical day.

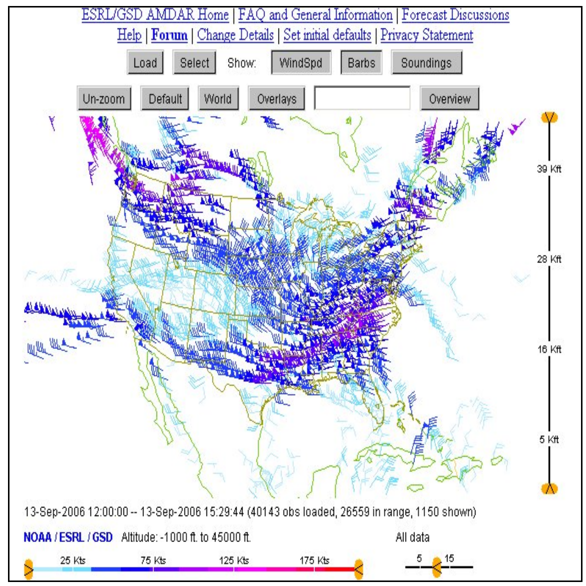

Fig. 2 Example of ERSL wind barb display.

Soundings can be generated by clicking on a flight path near an airport. All soundings include temperature and wind. TAMDAR and some ACARS/MDCRS aircraft also provide dewpoints. An example of a TAMDAR-equipped aircraft that landed at Memphis, TN is shown in figure 3. This sounding shows temperature, dewpoint, winds and the flight track (upper left insert in figure 3) of the aircraft as it approached the airport. You can also easily toggle the displayed flight track to a hodograph of the winds. Because this sounding is from a turboprop aircraft making short hops (at lower cruising levels than large, jet aircraft), data are typically only available to 500 mb.

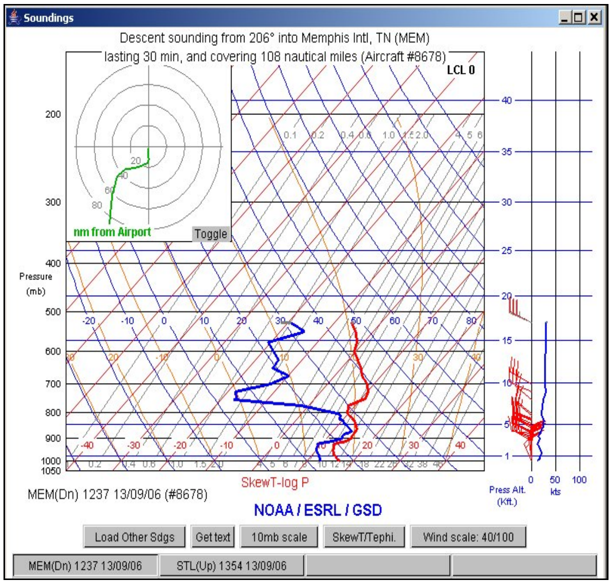

Fig. 3. Example of a TAMDAR descent sounding from Memphis, TN

Figure 4 (below) shows a MDCRS sounding from St. Louis, Missouri. Notice that it has temperature and wind data to 300mb, but no moisture information.

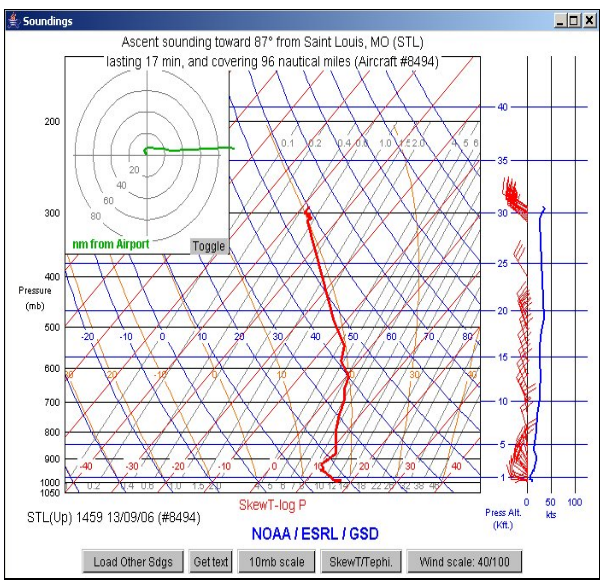

Fig. 4. Example of a MDCRS ascent temperature sounding from St. Louis, MO.

One can compensate for the lack of moisture data in a number of ways. The first is by left clicking on a point in the sounding and inserting a dewpoint in a pop up window (not shown). The program will then lift a parcel and generate various stability indices (Fig. 5). Notice the various stability indices located in the upper, right hand corner of the sounding in figure 5.

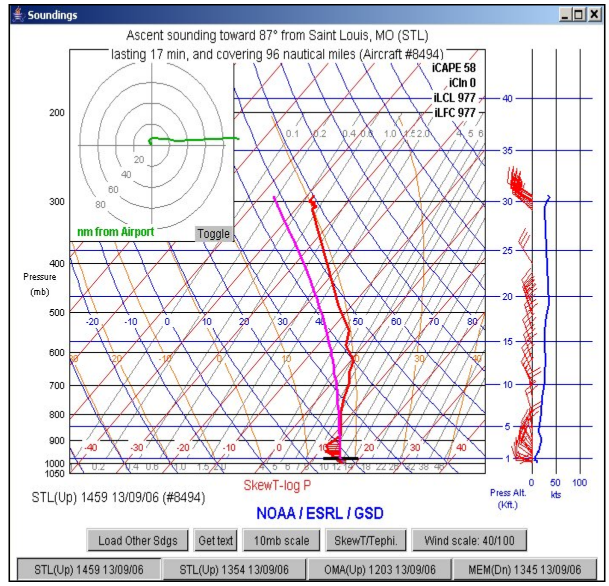

Fig. 5 Same as Fig. 4 except with parcel trace (pink) that was generated from the surface dewpoint input by the user. Stability indices are located in the upper right-hand corner of the display.

Another way to estimate dewpoint for an aircraft sounding without dewpoint data is to overlay the sounding with a model sounding, such as the Rapid Update Cycle (RUC). This is easily done by clicking the 'Load other Sdgs' button located at the bottom of a sounding display (Fig. 6). A separate window will pop up, allowing the user to select a RUC initial analysis or RUC forecast sounding, a wind profile plot, or RAOB.

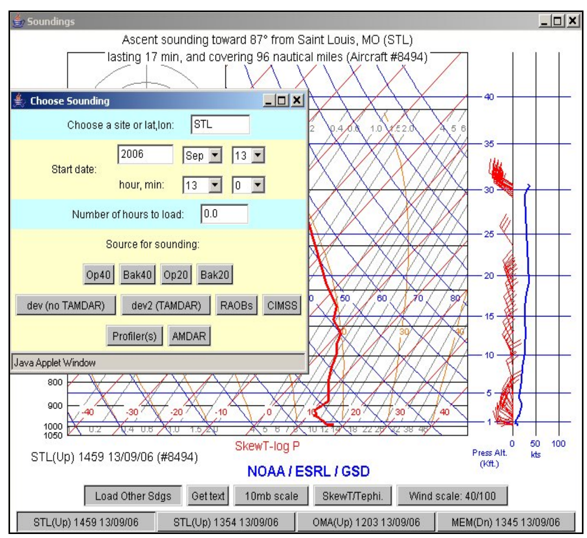

Fig. 6. Same as Fig. 4 except with the user interface for displaying other types of soundings data.

The 'op20', button (Fig. 6) will allow the user to display a 20km RUC analysis or forecast sounding (Fig. 7).

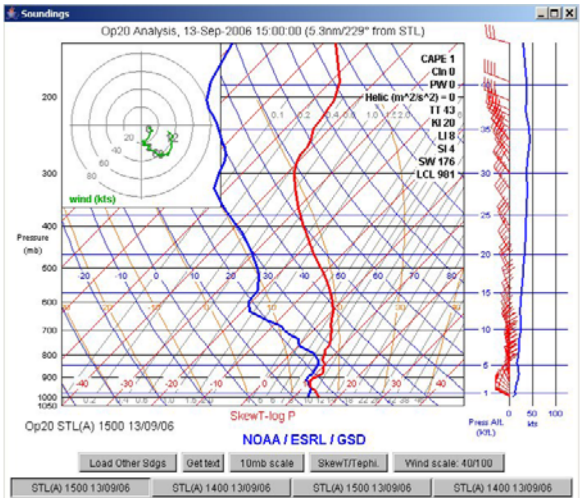

Fig. 7. 20 km RUC 1500 UTC initial analysis sounding for St. Louis, Missouri.

Note that in this example, the temperatures and winds in RUC 1500 UTC analysis sounding (Fig. 7) are very close to the 1459 UTC aircraft ascent sounding. The user can overlay the two soundings by left clicking on the gray buttons near the bottom of the display (Fig. 8).

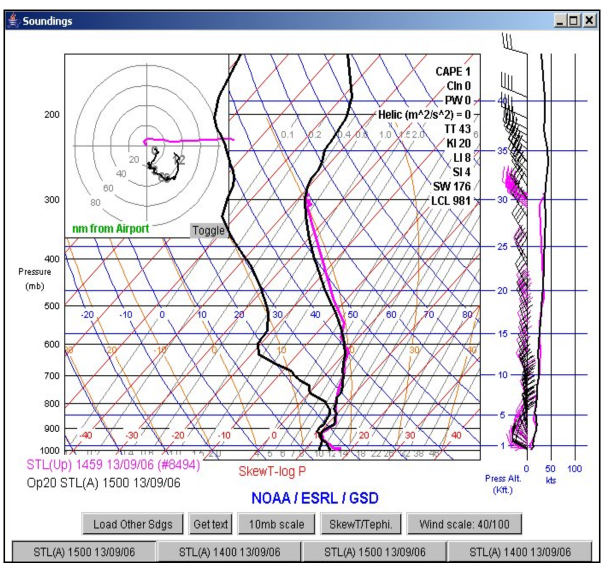

Fig. 8 Aircraft ascent and RUC analysis soundings valid at 1500 UTC.

Note how well the aircraft sounding agrees with the RUC initial analysis. This shouldn't be surprising, as the RUC uses most aircraft data that are available.

Whether the user examines only the aircraft soundings, or aircraft soundings combined with model analysis, model forecast or nearby RAOB soundings, it is easy to see how valuable these data can be in assessing the near storm environment in a convective situation.

6. CONVECTIVE FORECAST APPLICATIONS

Although aircraft soundings were used in severe weather forecasts at a few NWS offices many years ago (Mamrosh 1998), their use has accelerated in recent years due to the increased spatial and temporal coverage of soundings, and the availability of moisture data from some aircraft.

A joint NASA/FAA/AIRDAT/NWS project called the TAMDAR Great Lakes Fleet Experiment (GLFE) (Daniels et al 2006) showed that a dense network of soundings obtained from regional aircraft measuring water vapor, could provide meteorologists with near real time mesoscale upper air data. These data gave forecasters a greater appreciation of the limitations of the current radiosonde network and forecast model soundings in assessing convective potential in many severe weather situations (Brusky and Kurimski 2006; Fischer 2006; Szoke 2006).

The authors believe that increased use of aircraft soundings can provide meteorologists with better and timelier near storm environmental data, which can result in improved short-term severe weather outlooks, watches and warnings.

TAMDAR soundings were used extensively in the Northern Plains and Great Lakes to monitor moisture content and stability of the atmosphere during the GLFE. Many WFOs monitored TAMDAR soundings throughout the day to determine whether or not mid level capping inversions were strengthening or weakening. The erosion of a mid level cap often was the determining factor as to whether convection developed or not. TAMDAR data was instrumental in the decision made by WFO Sioux Falls, South Dakota to lower the threat of thunderstorms and severe weather on 23 June 2005. A timely TAMDAR sounding from Aberdeen, South Dakota, at 1951UTC (Fig. 9) showed a significant capping inversion around 800 mb that would require surface temperatures of 104°F to overcome.

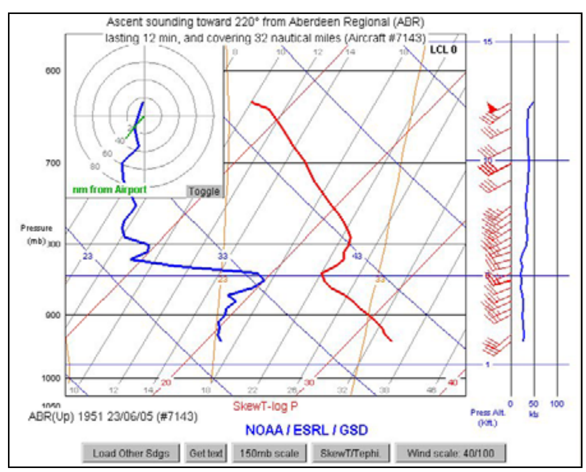

Fig. 9. Aberdeen, S.D. sounding from 1951UTC 23 June 2005 showing strong capping inversion.

This was discussed in their area forecast discussion, an excerpt of which is presented below:

AREA FORECAST DISCUSSION
NWS SIOUX FALLS SD
315 PM CDT THU JUN 23 2005

.DISCUSSION... CONCERNS FOR THIS PACKAGE ARE MULTIPLE CHANCES FOR THUNDERSTORMS AND WITH EACH ONE WHETHER OR NOT THE CAP WILL SUPPRESS ACTIVITY. 19Z TAMDAR SOUNDING FROM ABR SHOWS CAP AROUND 800MB...WITH PLENTY MORE WARMING NEEDED TO BREAK THROUGH.

The availability of multiple soundings at different times of the day can show a capping inversion strengthening or eroding. Figure 10 (below) shows a capping inversion gradually eroding as boundary layer temperatures climbed between 1549 UTC and 1812 UTC at Sioux City, Iowa on August 5, 2006.

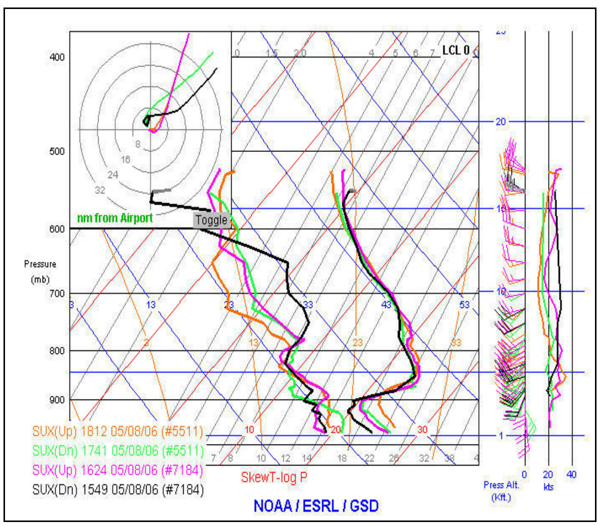

Fig. 10. TAMDAR soundings from Sioux City on August 5, 2006

Hub airports with very frequent flights can depict the variability of temperature, moisture and wind in a local area. Busy hubs like Minneapolis, Minnesota (MSP) can have up to 100 aircraft soundings per day! Figure 11 shows three aircraft soundings from MSP within a 40 minute period. Note how the moisture and temperature profiles vary depending on the flight path into or out of the airport (upper left-hand insert in Fig. 11). Also note how the low level moisture is greater to the west (green sounding), but that winds are weaker. Finally, notice that the mid level cap is weakest to the north (black sounding in figure 11).

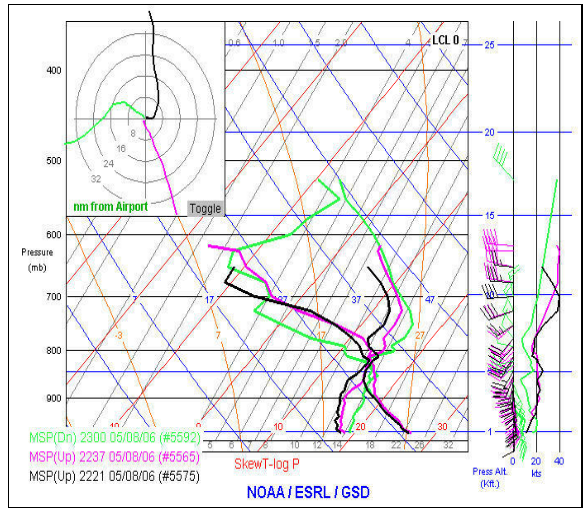

Fig. 11. Three TAMDAR soundings at Minneapolis on August 5, 2006. 2221 UTC sounding (black), 2237 UTC sounding (pink) and 2300 UTC sounding (green).

Even at the smaller regional airports, more frequent soundings are available that can be quite helpful in assessing short-term convective potential. For example, the three soundings at Brainerd, MN (BRD) on July 23, 2005 show that despite a favorable wind shear profile and a substantial increase in low-level moisture between 1930 UTC and 2259 UTC, a persistent and strong mid-level capping inversion prevented severe convection from developing later in the day (Fig. 12).

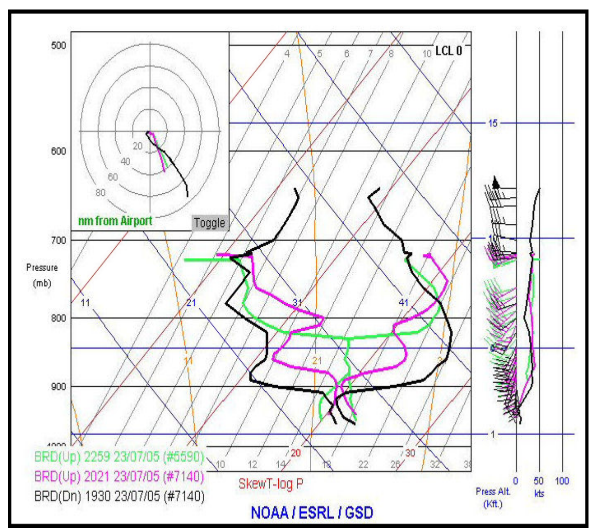

Fig. 12. Three TAMDAR soundings at Brainerd, MN on July 23, 2005. 1930 UTC sounding (black), 2221 UTC sounding (pink) and 2259 UTC sounding (green).

Many other convective applications of TAMDAR are presented in great detail by Brusky and Kurimski (2006), Fischer (2006) and Szoke et al. (2006).

7. OTHER APPLICATIONS

Many WFOs find aircraft data useful in updating the environmental wind and temperature table used in their WSR-88D radars. The radar software requires users to input a “first guess” wind field to assist the radar in calculating wind speed and direction from the radar radial velocities. The software also needs the heights of the freezing level and -20 ℃ level. These are used in several hail and precipitation estimation algorithms. The accuracy of these algorithms depends in part on the accuracy of the user input variables. Most WFOs have used nearby radiosonde or model data as input for the radar, but are increasingly using aircraft data.

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