4.2 AUTOMATED WEATHER REPORTS FROM AIRCRAFT: TAMDAR AND THE U.S. AMDAR FLEET

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1. INTRODUCTION

AMDAR (Aircraft Meteorological Data Relay) is a worldwide program providing automated real-time reports of atmospheric conditions from commercial airliners. AMDAR data have been available, and used by weather forecasters and in weather models, for nearly two decades. For a full discussion of AMDAR, particularly its U.S. component, see Moninger et al. (2003).

AMDAR has improved weather forecasting, but the data from the commercial jetliners that comprise the bulk of AMDAR-producing aircraft leave data gaps. Over the contiguous United States these gaps are generally below 20,000 ft. between major airline hubs.

In an attempt to fill these gaps, 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). 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). We report here on the properties of the data compared with traditional AMDAR data, and present a brief overview of some of the results of the analyses of these data. More detailed results will be given in other presentations at this annual meeting.

2. TRADITIONAL AMDAR DATA

2.1 Spatial and Temporal Variations

Figure 1 shows AMDAR (not including TAMDAR) data over the contiguous U.S. for a typical day. Coverage is apparently quite good, but if we look only at altitudes below 20,000 ft (Fig. 2), we see substantial gaps between major airline hubs. (North of the U.S. border, some regional Canadian aircraft may be seen to provide relatively good low-altitude coverage.)

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There are also diurnal and weekly variations in traditional AMDAR data. Fig. 3 shows the hourly distribution of data during a typical weekday. The peak occurs at 21 UTC, or 5 pm Eastern Standard Time, dominated by North American AMDAR data and the North American commercial flight structure. The daily minimum occurs around 6 UTC, but rises rapidly due to package carriers that fly in the very early morning.

Figure 4 shows the variation in AMDAR reports by day of the week, where the "day" has been started at 06 UTC--the time of the daily minimum. Thus, day "0" starts at 06 UTC on Sunday. The substantial dip on the weekend is caused by the absence of the package carriers, which don't generally fly on weekends.

2.2 Data and Data Quality

Typical AMDAR data include winds aloft and temperature referenced to the location and pressure altitude of the aircraft. Static and total air pressure are measured by an electronic barometer in the aircraft's pitot static probe. Total air temperature is typically measured by an immersion thermometer probe. Wind speed is deduced from knowledge of the air speed (via the pitot static probe) and ground speed (usually from an inertial navigation system). (Painting, 2002)

These instruments generally sample at one to several Hz. The samples are averaged for from one to 30 seconds, depending on the aircraft and its altitude, for each observation. The resulting instrumental uncertainty has been calculated by Painting (2002) as follows:

- For pressure, 4 hPa at low altitudes decreasing to 2 hPa at 30,000 ft.
- For temperature, 0.4ºC, but as much as 3ºC if probe wetting occurs. In addition, many aircraft fleets exhibit temperature bias, as reported by Ballish and Kumar (2006) at these meetings.
- For horizontal winds, 2-3 m s^{-1}, but more during maneuvers.

In addition, some traditional AMDAR aircraft measure additional atmospheric parameters, including:

- Water vapor. The WVSS-2 sensor deployed on some United Parcel Service aircraft, discussed at these meetings, e.g., by Petersen and Moninger (2006),
- Icing. Several aircraft from Delta Airlines report the existence of icing.

- Eddy Dissipation Rate. More than 100 United Airlines aircraft report this measure of atmospheric turbulence.
- Derived Equivalent Vertical Gust (DEVG). This measure of turbulence is reported by some European and Australian aircraft, but few such reports are taken over the contiguous United States.

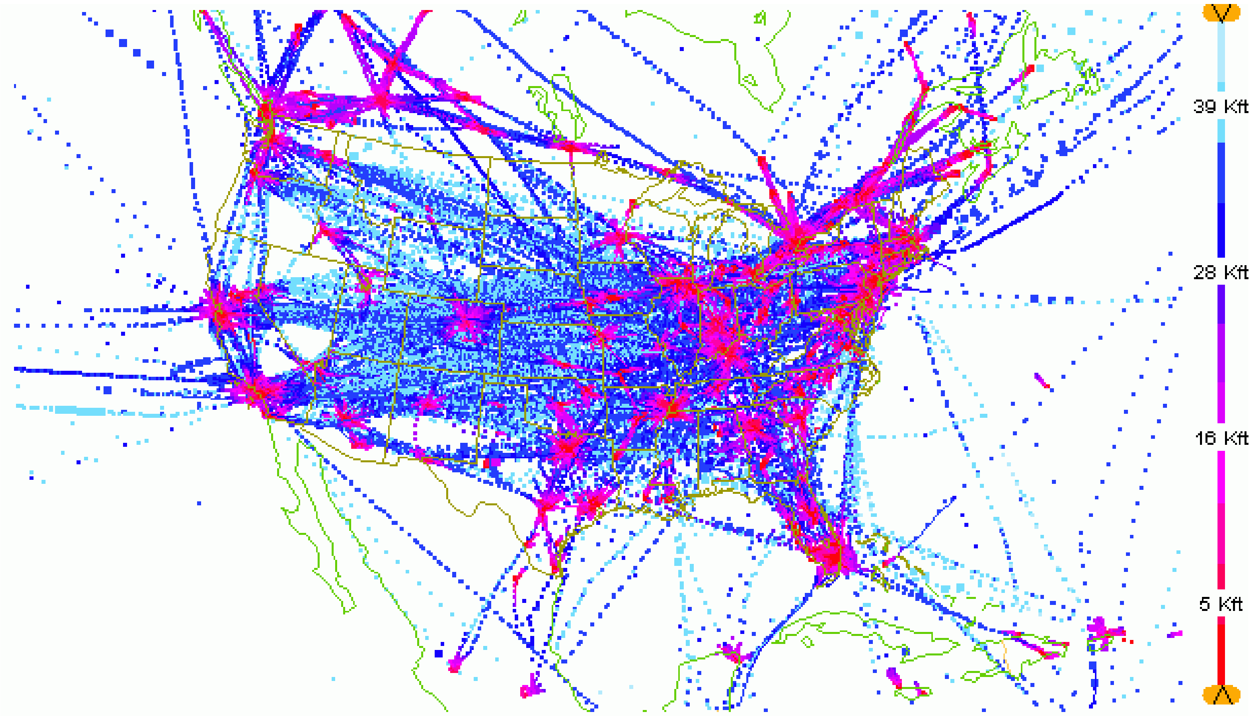

Figure 1. AMDAR data (not including TAMDAR) for 19 October 2005. Good wind and temperature observations only. All altitudes. 140754 observations in this geographic region.

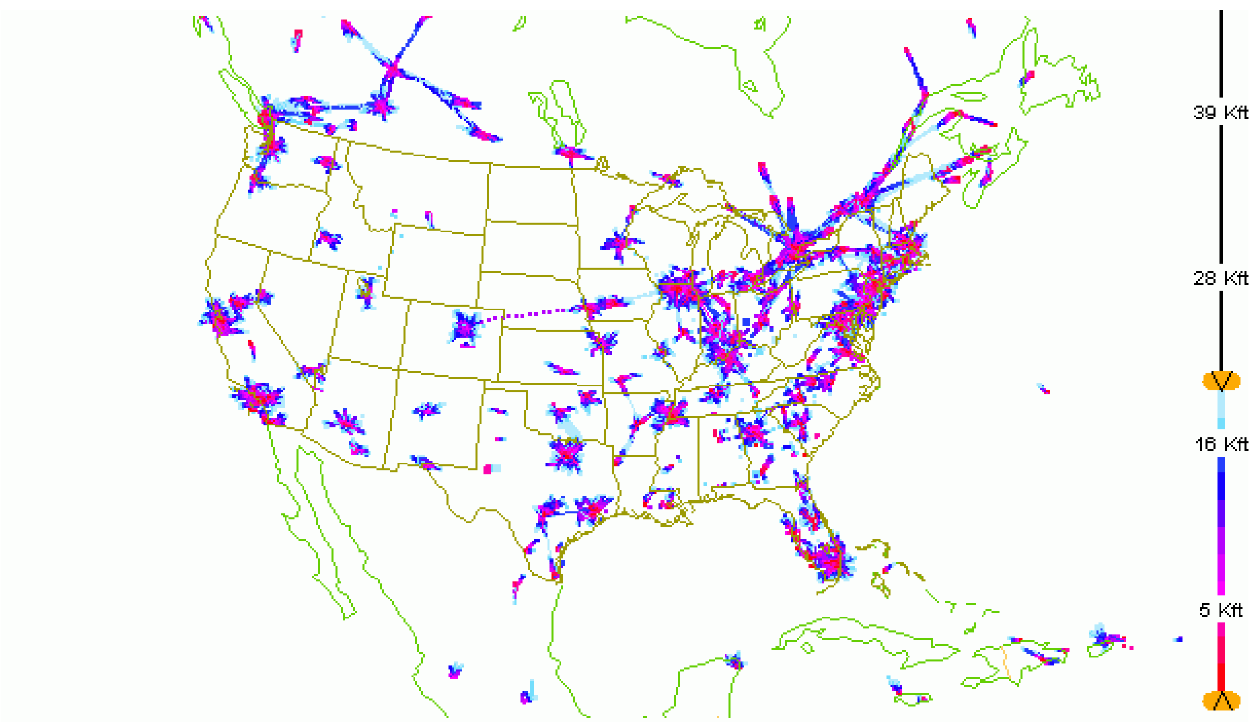

Figure 2. As in figure 1, but for altitudes below 20,000 ft.

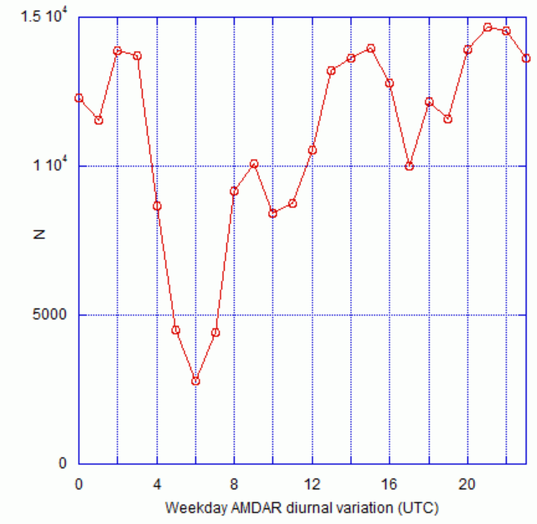

Figure 3. Diurnal variation in the number of AMDAR reports for a typical Wednesday.

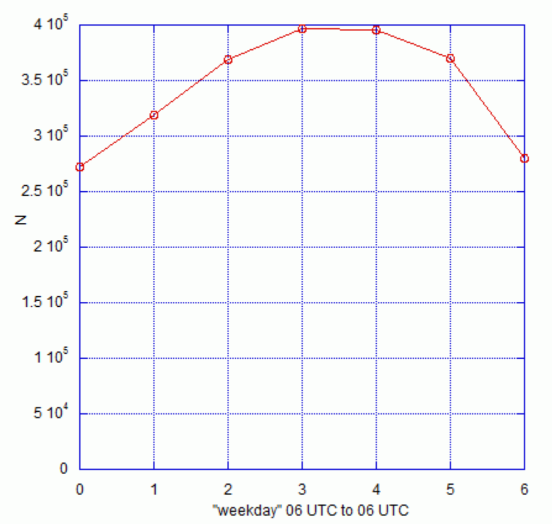

Figure 4. Variation in the number of AMDAR reports over the week. Day 0 represents 06 UTC Sunday to 06 UTC Monday

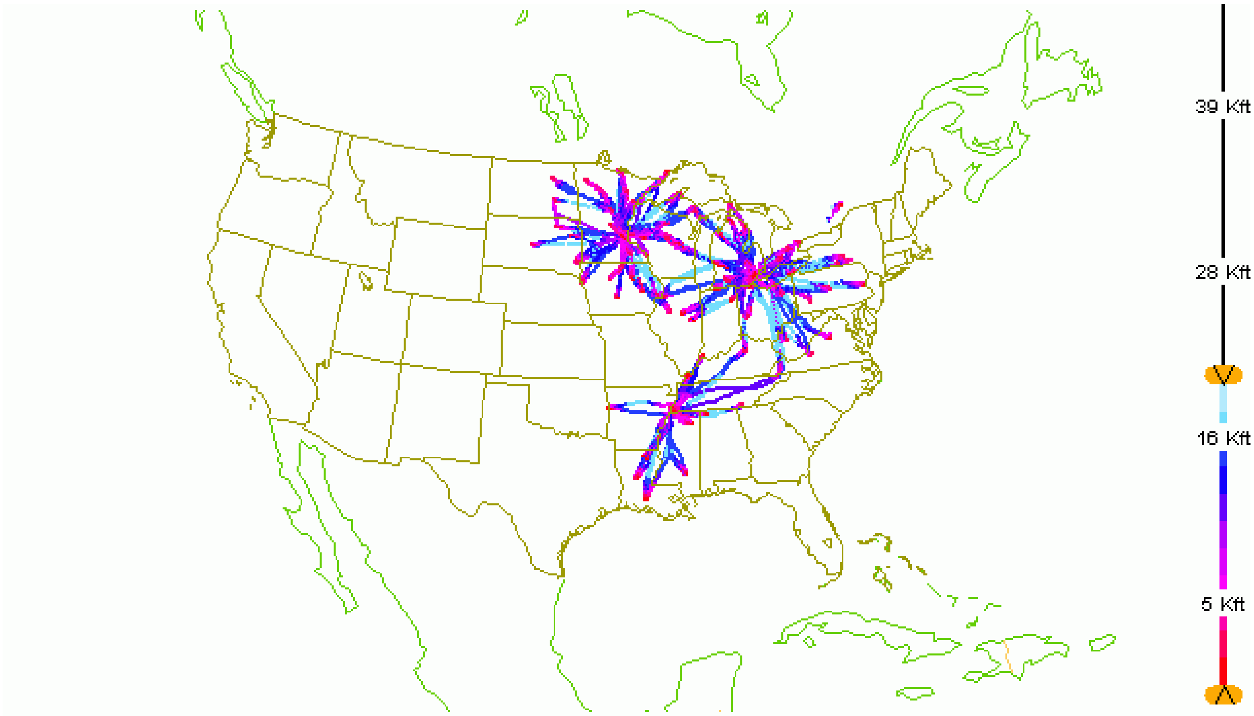

Figure 5. TAMDAR data below 20,000 ft for 19 October 2005. Good wind and temperature observations only. 13121 observations in this geographic region.

3. TAMDAR

3.1 Geographic Distribution

Since late 2004 TAMDAR sensors have been deployed on 63 aircraft operated by Mesaba airlines, a regional carrier for Northwest Airlines. Figure 5 shows the distribution of TAMDAR data for 19 October 2005, below 20,000 ft. (Nearly all TAMDAR data occur below 20,000 ft.; only 28 observations occurred this day above that.) Comparison with Fig. 2 reveals that TAMDAR nicely fills gaps left by the traditional AMDAR fleet at low altitudes between major hubs in the Midwest.

3.2 Temporal Distribution

Figure 6 shows the hourly distribution of TAMDAR data summed over several weekdays. It is interesting to note the rapid rise in data after 09 UTC, which is 03 local standard time (LST) in the US Midwest. By 11 UTC (05 LST), a substantial number of TAMDAR data are available--and this early-morning availability has been helpful to forecasters.

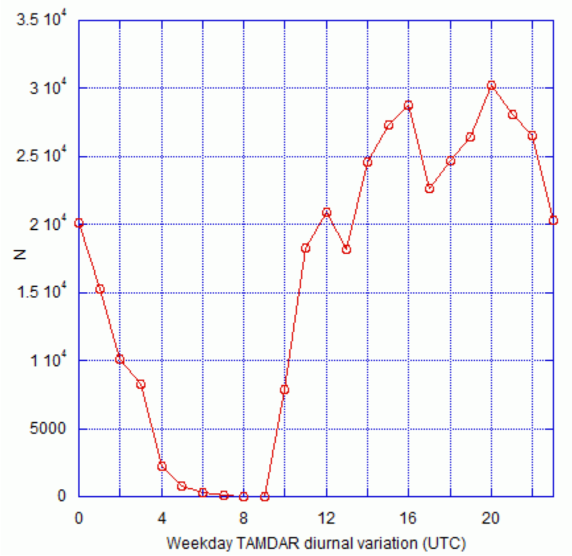

Figure 6. Diurnal variation in the number of TAMDAR reports, summed over several weekdays.

3.3 Data Provided

TAMDAR is a self-contained unit (with one exception described below) and so does not rely on the equipment of the aircraft carrying the TAMDAR unit for pressure, temperature, and position information. See Daniels et al. (2004) for a full description of the TAMDAR sensor and the testing it was subjected to before deployment.

The sensor is capable of measuring temperature, relative humidity, pressure, and icing. It can compute pressure altitude, indicated air speed, true air speed, turbulence (eddy dissipation rate), and winds.

In order to compute winds, TAMDAR uses its internal Global Positioning System to calculate ground speed, and heading information provided by the aircraft's avionics. On the SAAB 340 aircraft on which TAMDAR is currently installed, this heading information is provided by the aircraft's magnetic compass.

Humidity is measured by two capacitive humidity sensors. How closely the two sensors track each other provides an estimate of the uncertainty of the humidity estimate.

Ice accretion is measured by two independent infrared emitter/detector pairs mounted in a leading edge recess. Internal heaters melt the ice and the measurement cycle repeats.

Eddy dissipation rate is calculated from fluctuations in the indicated airspeed using a method developed by MacCready (1964). Evaluation of these measurements (for a test installation on the UND Citation jet aircraft) will be reported by Cornman et al. (2006) at this conference.

4. TAMDAR AND TRADITIONAL AMDAR RELATIVE DATA QUALITY

During the GLFE we compared both TAMDAR and traditional AMDAR measurements against 1-h forecasts from the Rapid Update Cycle (RUC) interpolated to the aircraft observation point. Observations were matched with the 1h forecast for the nearest hour, which allowed a time discrepancy of up to 30 minutes. We do not claim the RUC model is "truth", but it does provide an independent benchmark against which the relative error characteristics of various fleets can be tested.

Figure 7 shows temperature bias (with respect to the RUC) for traditional AMDAR observations and TAMDAR. The lines with solid points show the bias for the traditional AMDAR fleet (including Canadian regional jets but not Canadian Dash-8 turboprops which are known to have a temperature problem). These data show a slight positive temperature bias on ascent and a generally slight negative bias on descent. It is thought that these biases are due to hysteresis in the temperature sensing systems.

The TAMDAR data show substantially greater biases. On ascent the bias averages approximately 0.5ºC and on descent -0.3ºC. AirDat has been working to analyze and correct this situation; we expect to have more current results to report at the meeting.

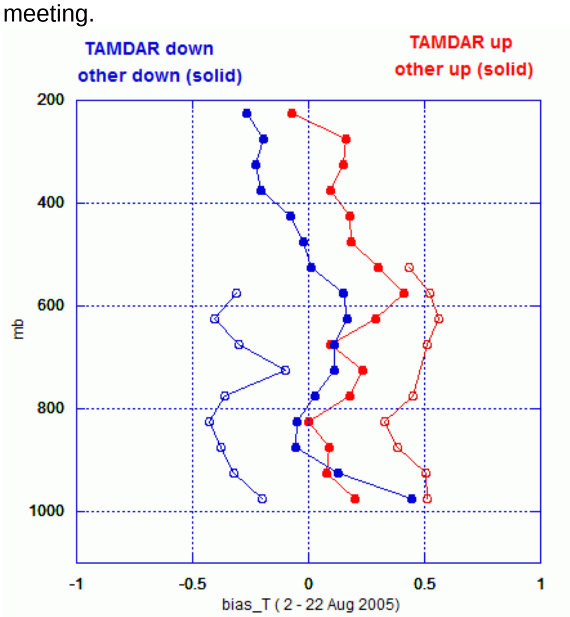

Figure 7. Aircraft temperature bias (observed minus RUC 1-h forecast) for ascents (red) and descents (blue). TAMDAR are shown as open circles, traditional AMDAR as closed circles. Data for 2 - 22 Aug 2005.

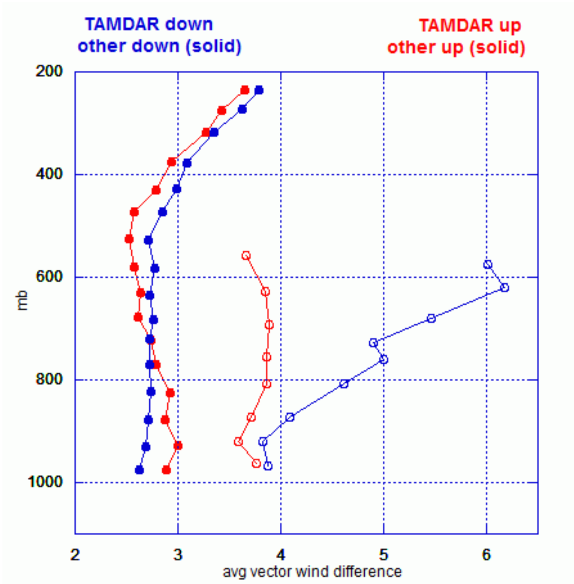

Figure 8. Aircraft-RUC vector wind difference magnitude for ascents (red) and descents (blue). TAMDAR are shown as open circles, traditional AMDAR as open circles. Data for 1 - 17 Aug 2005.

Figure 8 shows the magnitude of the observed minus RUC vector wind difference for traditional AMDAR observations (as defined for Fig. 7) and TAMDAR. TAMDAR shows substantially higher wind differences with respect to RUC than does the traditional AMDAR data, particularly on descent. We surmise that the large differences on descent may be due to maneuvers that typically occur more often on descents than on ascents. Also, we surmise that the heading information--critical for calculating winds aloft--may be less accurate on the small turboprop aircraft on which TAMDAR are installed than on the larger jet aircraft of the traditional AMDAR fleet. AirDat has been working diligently since August to improve the quality of their wind measurements and we expect to have more recent results to present at the meeting.

It is important to note that in spite of these data quality issues, TAMDAR data have already been shown to have a positive impact on forecasting as described in Section 6.

5. DATA AVAILABILITY

TAMDAR data availability after the 15 Jan 2006 end of the GLFE is uncertain. **If AirDat chooses to continue to make their data available as they have during the course of the GLFE**, the data will be available in the following ways.

- Directly from AirDat (http://www.airdat.com/)
- Via web displays operated by ESRL (http://amdar.noaa.gov/). However, because the web displays contain data from other airlines as well, access to the real-time portions of this site are restricted as described at http://amdar.noaa.gov/FAQ.html.
- Via ESRL's Meteorological Assimilation Data Ingest System (MADIS) (http://madis.noaa.gov/).

Regardless of AirDat's decision about future data availability, archival data from the GLFE will remain available from the MADIS program. Data may be requested at http://madis.noaa.gov/data_application.html.

6. IMPACT OF TAMDAR DATA

The impact of TAMDAR data on bench forecasting at NWS offices has been positive, and will be discussed by Mamrosh et al. (2006) in the following presentation.

TAMDAR data have been ingested into a development version of the RUC model, and the behavior of this model has been compared with an identical RUC model that does not ingest TAMDAR. The effects of TAMDAR on the RUC have generally been positive, as will be discussed by Benjamin et al, (2006a, 2006b) at these meetings.

7. ACKNOWLEDGEMENTS

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