TAMDAR THERMODYNAMIC AND DYNAMIC STATE VALIDATION USING RAWINSONDE DATA FROM TAVE

Sarah T. Bedka*, Wayne F. Feltz, Erik R. Olson, Ralph A. Petersen, and Kristopher M. Bedka

Cooperative Institute for Meteorological Satellite Studies, Madison WI

1. INTRODUCTION

The accuracy of weather forecasts is largely dependent on reliable vertical profiles of meteorological data such as temperature, moisture, and wind. These profiles may be acquired from weather balloons, however, the scarcity of weather balloon data in both space and time poses a problem. To attain a greater number of meteorological profiles, instruments have been deployed aboard some commercial aircraft. The TAMDAR (Tropospheric Airborne Meteorological Data Report) instrument measures temperature, moisture, icing, turbulence, and wind. TAMDAR sensors have been mounted on 64 MESABA Airlines Saab 340 commuter planes, and are currently being tested as a part of the TAMDAR Great Lakes Fleet Experiment (GLFE).

This paper details the results from the two TAMDAR AERIbago Validation Experiments (TAVE I and II). The goal of these experiments was to provide a ground-truth assessment of the accuracy of the TAMDAR instruments by comparing the temperature, moisture, and wind profiles to co-located rawinsonde data. During TAVE, the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies deployed a mobile research laboratory to the Memphis Air National Guard base, adjacent to the Memphis International Airport. Observations were collected over 27 total days (TAVE-I: 22 February – 8 March, TAVE-II: 16 May – 27 May), and included 98 rawinsonde launches. Launch times were planned to correspond as closely as possible to TAMDAR aircraft arrival/departure times, without disrupting normal tower operations. Rawinsonde and TAMDAR profiles were matched in time and space for comparison.

*Corresponding author address:
Sarah T. Bedka
Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison
saraht@ssec.wisc.edu

2. TAVE EXPERIMENT DETAILS AND METHODOLOGY

The experiment details described will focus on those that are particularly important when reviewing the comparisons and results presented here. For complete instrument description and a more thorough experiment overview, please refer to Feltz et al, P2.11 at this meeting.

During TAVE-I and TAVE-II, the University of Wisconsin Space Science and Engineering Center's AERIbago was deployed to the Memphis Air National Guard base, directly adjacent to the Memphis International Airport. Vaisala RS-92 rawinsondes were launched from this location and provide profiles of temperature, water vapor, and wind speed and direction. Sondes were launched five times daily during TAVE-I, and four times daily during TAVE-II, for a total of 51 and 47 total launches, respectively. Through analysis of the Memphis TAMDAR departure/arrival schedule, the number of daily rawinsonde launches was reduced by 1 from TAVE-I. Two of the launch times were also adjusted from TAVE-I to increase the number of TAMDAR/rawinsonde matches. Table 1

	TAVE-I	TAVE-II
Dates	24 Feb – 08 Mar	16 May – 27 May
# Sondes/day	5	4
Total # Sondes	49	46
Total # Matches	163 90 Ascent 73 Descent	234 142 Ascent 92 Descent
Launch Times (UTC)	0100, 1430, 1615, 2015, 2300	0000, 1505, 1915, 2215

Table 1. Key experiment details.

contains a brief summary of TAVE-I and TAVE-II.

A full set of aircraft data including both TAMDAR and ACARS data were collected from the FSL MADIS data retrieval system for use in this study. Aircraft and rawinsonde measurements were matched in space and time for analysis. A match was considered a flight that met the following criteria:

1) Initial reporting time was within +/- 30 minutes of the rawinsonde launch time.
2) The distance between the aircraft and the rawinsonde was less than 50 km.
3) During the TAVE-I analysis, it was noted that data from several of the sensors contained abnormally large biases. These data (from aircraft tail numbers 5580, 5598, and 5552) were excluded from the TAVE-I analysis. These sensors were corrected in time for TAVE-II.

Data from both ascending and descending flights were analyzed. Due to the unique characteristics of the two types of profiles, a separate analysis was performed for each. RMS, Bias and Standard Deviation statistics were calculated for temperature, humidity, wind speed, and wind vector at common pressure levels between 1000 mb to 540 mb. During TAVE-II, the TAMDAR instruments were in high sampling mode, and therefore reported data at a much higher vertical resolution (37 common pressure levels) than during TAVE-I (18 common pressure levels). To ensure statistically significant results, a minimum of 25 reports was required for each level.

3. TEMPERATURE AND MOISTURE PROFILE COMPARISONS

Figure 1 shows two sample TAMDAR temperature and relative humidity profiles (red and green) plotted with their corresponding rawinsonde profile (black), from 0Z on 18 May. The red profile (tail number 5434) is plotted at the TAVE-I reporting vertical resolution, while the green profile (tail number 7168) is plotted with the TAVE-II reporting vertical resolution. This image clearly shows the importance of higher vertical resolution for the accurate assessment of moisture inversions (or temperature inversions).

Higher vertical resolution of TAVE-II data allows for closer inspection of instrument biases, and thus the results presented here will be focused on TAVE-II. Figure 2 shows a sample RH profile and RH difference (TAMDAR – Rawinsonde), for 3 ascending TAMDAR profiles taken near 1915 on 16 May. All 3 of the TAMDAR profiles show a dry bias with respect to the rawinsonde throughout the boundary layer, where the RH is decreasing. In addition, the TAMDAR placement of the top of the moisture inversion is slightly higher than the rawinsonde placement, causing a strong positive spike in the difference plot. These things suggest a slight instrument lag in relative humidity, causing a lower than actual RH report during ascent (where RH is increasing with time).

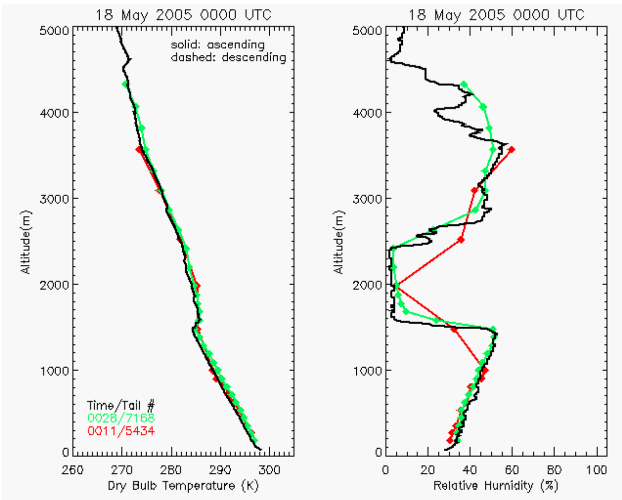

Figure 1. Sample TAMDAR profiles showing the importance of high vertical resolution reporting levels for the detection of moisture inversions.

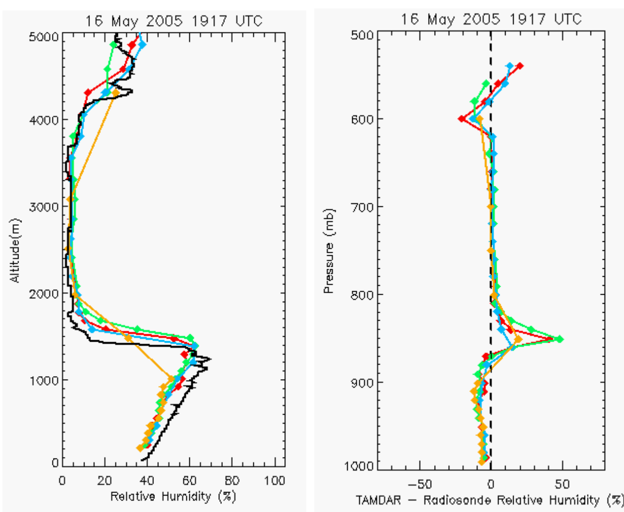

Figure 2. Sample ascending TAMDAR RH profiles, showing instrument dry bias throughout the boundary layer.

A consistent scenario is evident in the TAMDAR descending profiles. Figure 3 shows the RH profile from 16 May at 2215 UTC, along with 9 descending TAMDAR matches. A moist bias throughout the boundary layer (where RH is decreasing with time) is apparent in almost all of the profiles. The magnitude of the bias is lower than for the ascending profiles because aircraft descent is generally more gradual than ascent.

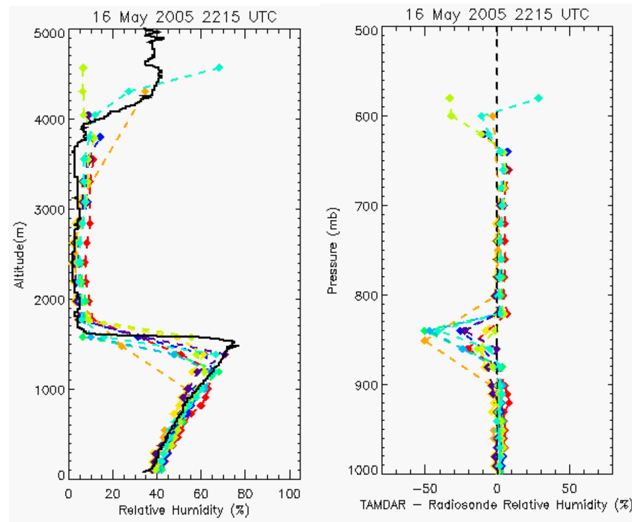

Figure 3. Sample descending TAMDAR RH profiles, showing instrument moist bias throughout the boundary layer.

Analysis of TAMDAR and rawinsonde temperature profiles reveals s similar result. For ascending profiles, the TAMDAR reported temperature is generally warmer than the rawinsonde temperature. The opposite is true for descending profiles. This is apparent in the two difference plots shown in Figure 4. These plots show the differences between TAMDAR ascending (left) and descending (right) reported temperatures and rawinsonde temperatures from 16 May (1917 UTC for ascent, 2215 UTC for descent). An instrument lag could cause signatures similar to those observed in this figure.

Figure 5 shows the weighted mean rawinsonde values for all of TAVE-II. This was derived by averaging the rawinsonde temperature and moisture profiles, weighting according to the number of TAMDAR matches for each sonde. Thus a profile that had 10 TAMDAR matches would be more represented in the mean than a profile with only 5 matches. This gives an indication of the average environment sampled during this experiment. The average temperature profile was roughly adiabatic, with no significant inversions. The moisture profile showed a nearly constant decrease in RH until the top of the boundary layer, which was located just above 900 mb. The slightly bimodal structure apparent in this profile is due to the fact that the boundary layer expanded throughout the day, causing the inversion to be higher in the evening than in the morning. It should be noted that the descending matches only occurred around the 2215 UTC rawinsonde, and ascending matches only occurred around the other 3 launch times.

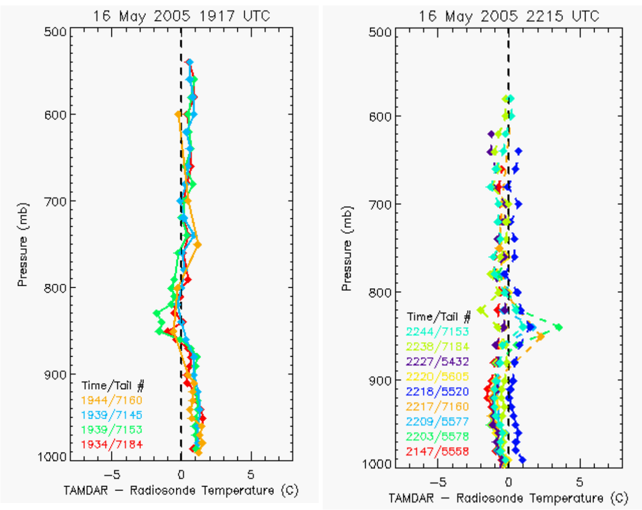

Figure 4. Difference between TAMDAR and Rawinsonde temperature profiles. Ascending profiles are shown on the left, descending on the right.

Because the ascending and descending TAMDAR profiles exhibit differing error characteristics with respect to the rawinsonde, statistics will be calculated separately for each profile type. Because the errors for ascent and descent are of opposite sign, the bulk statistics for the entire experiment may be deceptively low, and thus will not be presented here.

Statistics calculated for each level are RMS, Bias, and Standard Deviation. Figure 6 (top) shows the temperature statistics for all of the ascending matches during TAVE-II. The number of matches and the mean distance of the aircraft from the rawinsonde at each level is shown on the right. These statistics clearly show that a positive temperature bias is present in the TAMDAR data set. The magnitude of this bias is between about 1 and 2 degrees C until about 800 mb, and tapers to about 1 degree C above that. The bias in the TAVE-I ascending data is slightly lower (about 1 degree C tapering to roughly 0 bias above 850 mb), most likely because the atmosphere is more isothermal in March than in May.

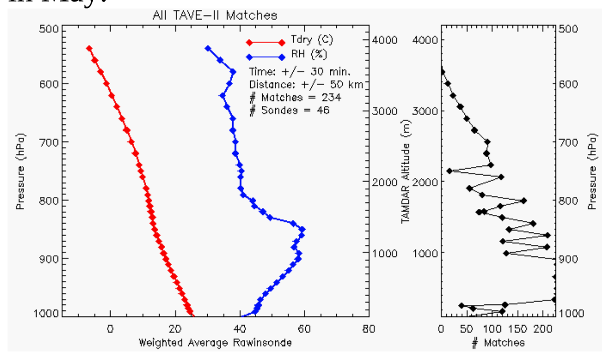

Figure 5. Weighted mean rawinsonde profile for TAVE-II.

Figure 6 (bottom) shows the ascending RH statistics from TAVE-II (left) and the number of matches/distance from sonde on the right. This figure shows a negative bias in RH until the top of the boundary layer (between about 850 and 900 mb, as shown in Figure 5), and a slightly positive bias above. A nearly identical feature is apparent in the TAVE-I moisture statistics. This is consistent with the previous assertion that the TAMDAR instrument has a slight lag with respect to the environmental temperature and moisture.

Similar but opposite features are apparent in the TAMDAR descending data. Figure 7 shows the TAVE-II descending temperature (top) and RH (bottom) statistics. Note that fewer matches are available for descending data, and all descending matches were from around 2215 UTC. In addition, descending flight tracks are more gradual than ascending ones. Thus, the descending profiles do not extend as high into the atmosphere as ascending profiles (the aircraft is more than 50 km away from the sonde). However, a

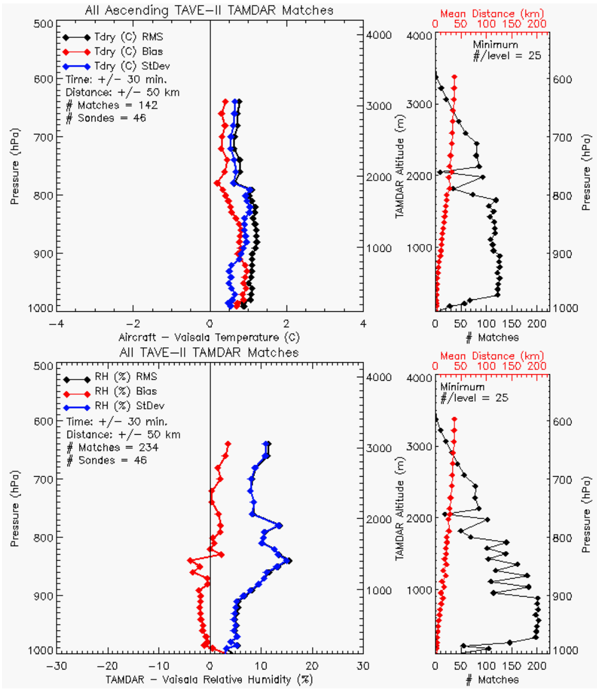

Figure 6. TAVE-II ascending Temperature (top) and RH (bottom) error statistics.

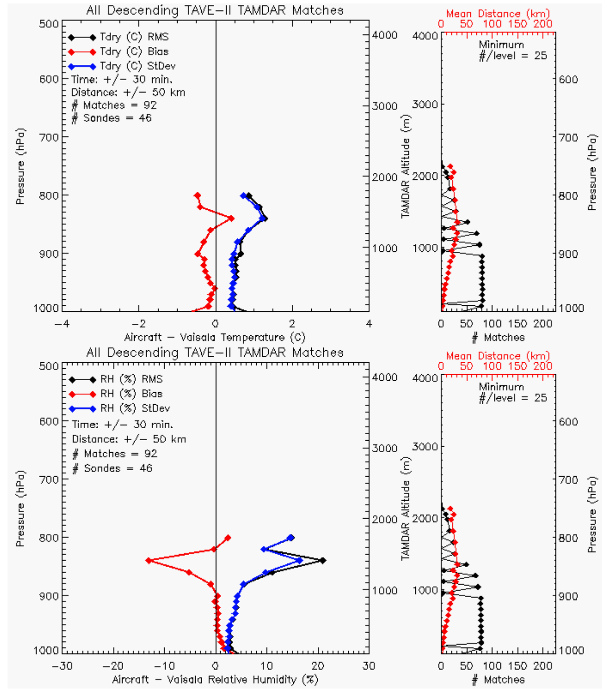

Figure 7. TAVE-II descending temperature (top) and RH (bottom) error statistics.

negative temperature bias of between 0.5 – 1 degree C is apparent, as well as a slight positive RH bias. Spikes in both RH and temperature error correspond to the top of the boundary layer (just above 850 mb), due to errors in the TAMDAR placement of the moisture inversion. Similar biases are exhibited in the TAVE-I data.

3. WIND PROFILE COMPARISONS

Recent analysis of TAMDAR data includes a preliminary investigation into the accuracy of the TAMDAR wind speed and direction reports. Figure 8 shows the magnitude of the error vector between the TAMDAR and rawinsonde for both the ascending (red) and descending (blue) matches. Note that the minimum threshold distance from the sonde was increased to 75 km, so that statistically significant number of matches could be attained for more levels. The errors in the lowermost 50 mb are consistent between both ascending and descending flights, just over 3.5 m/s. After this point, the error in the descending data begins to rapidly increase, while the ascending data stabilizes at around 4 m/s. The higher degree of error in the descending data could be due in part to a larger average distance from the rawinsonde.

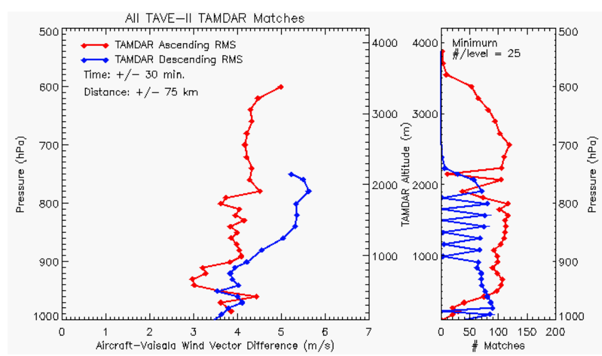

Figure 8. TAVE-II wind vector error between the TAMDAR and Rawinsonde for both ascending and descending profiles.

TAVE-I and TAVE-II were designed specifically to maximize the number of co-located TAMDAR and rawinsonde measurements. However, some co-located ACARS and rawinsonde measurements are also available from this period. Traditional

ACARS instruments fly aboard larger jet aircraft than do TAMDAR instuments, and report measurements of temperature and wind only. By examining the difference between ACARS and TAMDAR wind errors (with respect to rawinsonde measurements), we may attain an idea of the impact of aircraft size on wind speed and directional error.

Figure 9 (top) shows a scatter plot of TAMDAR and ACARS wind speed vs. rawinsonde wind speed for co-located TAVE-II data. In this plot, red pixels indicate TAMDAR matches, and blue pixels indicate ACARS matches. This plot indicates that during this experiment, ACARS provided a more accurate speed measurement than TAMDAR, with the distinction being more notable at higher wind speeds. ACARS had a tendency to underestimate wind speed with respect to the rawinsonde, while TAMDAR slightly overestimated it. Figure 10 (bottom) shows the corresponding plot of U and V wind measurements. Again, this plot makes clear the improvement in wind measurement attained by ACARS over TAMDAR. For this particular experiment, both TAMDAR and ACARS had larger errors in the U direction than the V direction, with the difference being larger for TAMDAR. This error is most likely influenced by factors such as prevalent wind direction and relative aircraft direction. In addition, this plot suggests that while TAMDAR V measurements tend to exceed the rawinsonde measurements, the U differences are roughly evenly distributed between positive and negative. The ACARS differences are roughly evenly distributed in both the U and V directions.

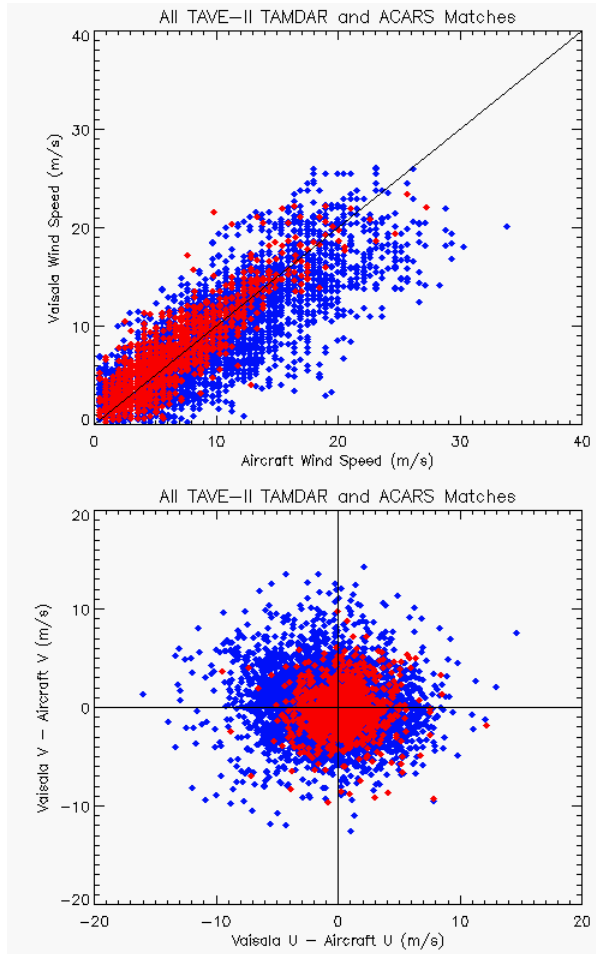

Figure 9. Top: Aircraft wind speed (TAMDAR in blue, ACARS in red) vs. Rawinsonde wind speed, in m/s. Bottom: Rawinsonde – Aircraft U and V differences. Both plots are of TAVE-II co-located measurements.

ACKNOWLEDGEMENTS

Thanks to all involved in the planning and implementation of both TAVE experiments, including Bill Wagner at the FAA, Lt. Norvel Adkins at the Tennessee Air National Guard, Taumi Daniels at NASA Langley, and numerous scientists and graduate students at CIMSS. Thanks also to Mike Barth and Patty Miller at FSL for facilitating the TAMDAR data acquisition through MADIS.