6.1.4 A COMPARISON OF ACARS WVSS AND NWS RADIOSONDE TEMPERATURE AND MOISTURE DATA

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1. INTRODUCTION

Automated wind and temperature data from commercial aircraft have been available in increasing abundance since the late 1970s (Fleming, 1996). The data, often referred to as ACARS (Airline Communications Addressing and Reporting System), has proven to be valuable to both numerical weather prediction (Graham, 2000) , and to meteorologists in forecast offices (Mamrosh, et. al., 2001). The use of commercial aircraft to measure and report atmospheric moisture has been proceeding at a much slower rate, but has shown a great deal of progress in recent years. Feasibility studies in the early 1990s showed that commercial aircraft could accurately measure atmospheric water vapor. A sensor employing a thin film capacitor became known as the Water Vapor Sensing System (WVSS). It was installed on six United Parcel Service (UPS) aircraft between 1997 and 1999.

A two week study was conducted by the NWS in Louisville, Kentucky in the fall of 1999 that compared WVSS data from UPS aircraft with radiosondes launched from a nearby mobile sounding unit. A comparison was also made in the second half of 1999 of these six aircraft when they were near NWS radiosondes around the 00 and 12UTC sounding times. These studies showed that WVSS data to be comparable to NWS radiosondes.

The availability of sixteen WVSS aircraft sending good quality data in the spring of 2001 prompted the authors to compare this new data source with NWS radiosondes over a several month period.

Data was accessed from the Forecast Systems Laboratory's (FSL) ACARS web page and was compared to NWS radiosonde data that is also available at that site. The aircraft identification numbers were compared with a list (supplied by UPS) of aircraft known to have a properly functioning WVSS .

Nearly 1100 data comparisons were made at various mandatory sounding levels from 925 to 250 mb in the three month period from May through July 2001. The two data sources compare reasonably well, especially below 500mb. Air temperatures at 925, 850, and 700mb differ by an average of 0.97 degrees C at the three levels, with dewpoints differing between 1.31C and 1.74C. Larger differences occurred at higher levels, which can be explained by dynamic heating of aircraft at high Mach numbers, the normally larger spatial separation of the two systems at higher altitudes, and the known difficulties of measuring atmospheric moisture at very cold temperatures.

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2. THE WATER VAPOR SENSING SYSTEM

Aircraft have been used to measure atmospheric information since at least the 1930s. The U.S. Weather Bureau (now NWS) started a formal program of regularly scheduled aircraft soundings of the atmosphere (including temperature, pressure and relative humidity) in several cities in 1931 (Hughes, 1970). It eventually expanded to thirty locations before it was discontinued due to the hazards to the pilots and the availability of radiosondes about ten years later.

The advent of modern navigation and communication systems in the 1960s and 1970s sparked renewed interest in the use of aircraft to measure and report weather information. ACARS was first used to relay wind and temperature information in support of the Global Weather Experiment in August of 1979 (Fleming, 1996).

Automated aircraft reports of wind and temperature have been increasing ever since, and now total more than 100,000 per day. While the wind and temperature information has lead to numerical model and forecast improvements, the lack of water vapor information has hindered the system from reaching it's full potential to benefit the field of meteorology.

The effort to use commercial aircraft to measure atmospheric water vapor has been agonizingly slow. Part of the problem was that a hole had to be drilled into the aircraft to install a sensor. This required re-certification of the aircraft by the FAA, and was costly and time consuming. Once this problem was addressed, feasibility studies conducted in the early 1990s showed that commercial aircraft could accurately measure atmospheric moisture. A sensor using a thin film capacitor similar to NWS radiosondes became know as the WVSS.

This system, funded by the National Oceanic and Atmospheric Administration (NOAA), and Federal Aviation Administration (FAA) was installed initially on six UPS aircraft between 1997 and 1999 (Fleming, 2001). Figure 1 shows a picture of the WVSS sensor . The initial six aircraft were compared to radiosondes in an experiment sponsored by the NWS and conducted by the University of Wisconsin from a mobile facility at Louisville International airport in the fall of 1999. These aircraft were also compared to NWS radiosondes when the aircraft were near radiosonde locations around the 00UTC and 12UTC valid times during the period July 1-December 31, 1999. Data from these tests revealed that the WVSS has a slight warm bias (between .25C and .50C) in the lower half of the atmosphere, but was otherwise quite comparable to NWS radiosondes.

Figure 1. The WVSS sensor

3. METHODOLOGY

ACARS data from the FSL web page at http://acweb.fsl.noaa.gov was downloaded periodically during the study to locate WVSS-equipped aircraft and compare them to nearby NWS radiosondes.

Moninger, et. al, (2002) will have a more complete description of the data source. Data collection was very convenient due to the web site's thirty day data archive. A comparison was made if an aircraft with a properly functioning WVSS made an ascent or descent to an airport within an hour of the 00UTC and 12UTC radiosonde valid time.

WVSS and radiosonde data were compared at the following levels (if available): 925, 850, 700, 500, 400, 300, 250mb. The lowest levels were naturally not available for comparison at higher elevation stations in the west (such as Denver and Albuquerque), and the highest levels were often not available when aircraft made short flights between cities in the east.

The data were rounded to the nearest degree Celsius, and input into a database program for statistical calculations. Because this study was conducted by meteorologists and staff in active forecast offices, an assumption was made for ease of data retrieval and calculation. Distances between the two data sources are therefore estimates, as all of the radiosonde data was assumed to be located at the radiosonde site, while the exact aircraft location was known. This should make little difference at lower pressure levels when the aircraft was in the vicinity of the airport, but radiosonde data from higher levels (400, 300, and 250 mb) could sometimes be 50 km or more from the radiosonde site.

4. DATA

For the period of May 1 to July 31, 2001, there were 313 soundings of WVSS equipped aircraft that were compared with nearby radiosondes. These soundings allowed 1,068 individual comparisons at different levels.

a.) Geographical distribution

Data comparisons were available at 18 NWS radiosonde locations (see Figure 2) in the continental United States. With the exception of the northern Plains states and the Ohio Valley, there is reasonable coverage of various geographic and climatological regions. Data was distributed fairly uniformly amongst the cities, with one very notable exception. Miami is one of UPS's main domestic and international hubs, as thus it accounted for almost one-half of all the comparisons.

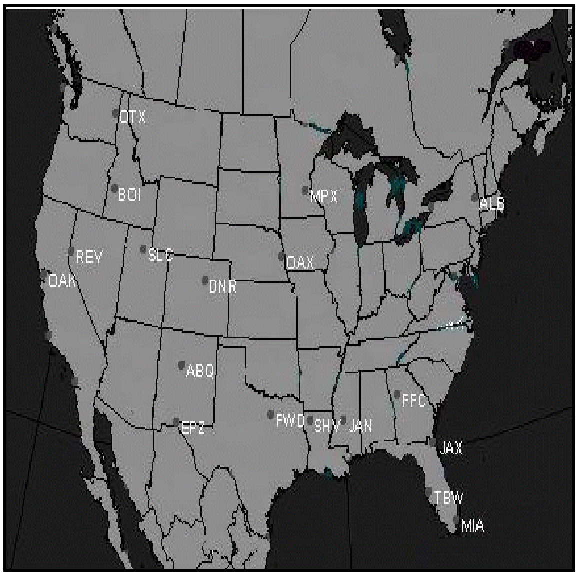

Figure 2. Geographic distribution of comparisons

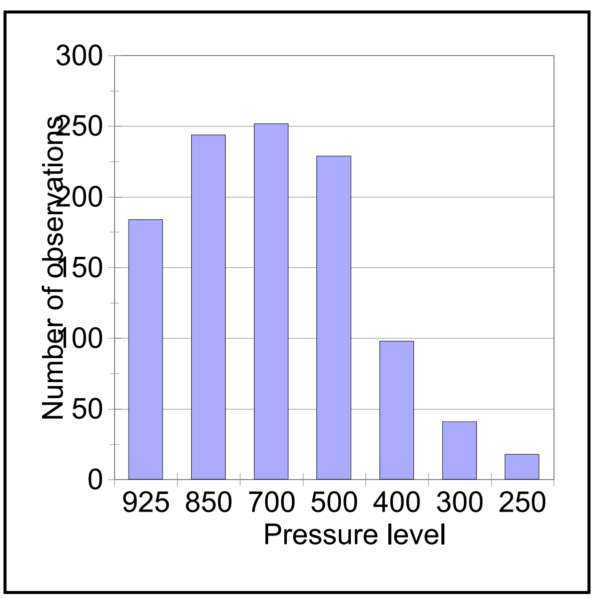

Figure 3. Number of observations by pressure level

b.) Vertical distribution

Data was most abundant below 400mb, as many of the aircraft were making short flights where cruising altitudes were less than 25,000 ft MSL. Figure 3 shows the distribution of data by pressure level.

5. RESULTS

Statistics were compiled to measure differences in the data sources at different pressure levels, and at different horizontal separations. Statistics based on temporal differences were not computed due to the fact that exact times of the radiosonde data were not available to compare with the ACARS WVSS. By the design of the study, all of the comparisons are less than two hours apart.

The temperature differences in this study (Table 1) are about .5C larger than those reported in a comparison of ACARS and radiosonde temperatures reported by Schwartz and Benjamin (1995), and the more recent comparison of the first six WVSS-equipped aircraft with radiosondes in 1999 (Fleming, personal communication). This is likely due to the significant warm biases of four of the sixteen aircraft (discussed later).

Differences (aircraft-radiosonde) and standard deviations based on distance

Distance (Km)	Temp (C)	Std Dev	Dwpt (C)	Std Dev	# Obs
<=10	0.96	1.14	1.76	2.87	213
<=25	1.02	1.13	1.97	3.61	512
<=50	1.00	1.21	1.96	3.79	682
> 50	1.13	1.27	0.99	8.97	386

Table 1. Temperature and dewpoint differences based on distance.

The dewpoint differences in our study agree well with data gathered in the 1999 comparison of WVSS aircraft and NWS radiosondes. That study found dewpoint differences of +1.4C at distances of 10 km or less, +2.1C at 30 km, and +2.4C at distances of 50 km or less (Fleming, personal communication).

Differences (aircraft-radiosonde) and standard deviations based on pressure level

Pressure (mb)	Temp (C)	Std Dev	Dwpt (C)	Std Dev	Avg Dist (km)	Obs #
925	0.92	1.20	1.74	2.37	14	181
850	0.81	1.31	1.31	3.86	18	244
700	1.17	1.15	1.71	5.02	29	252
500	1.07	1.12	1.83	7.55	67	229
400	1.03	1.22	2.13	9.27	91	98
300	1.73	1.31	-1.92	11.31	130	41
250	1.72	1.88	-3.88	11.46	174	18

Table 2. Temperature and dewpoint differences based on pressure level

As shown in table 2, temperature differences increase only slightly with increasing altitude and distance, while dewpoint differences (especially the standard deviations) increase more significantly. Likely explanations are that temperature is usually more conservative in the atmosphere than moisture, and measuring atmospheric moisture is regarded as much more difficult than measuring temperature (especially at very cold temperatures). The data also reveal that the aircraft have a warm temperature bias compared to the radiosondes, and a warm dewpoint bias except above 400mb, where the bias is cold. This cold bias at higher altitudes can probably be explained by the fact that the aircraft WVSS sensor is effected by the heating due to compression of air at high Mach numbers. The warming of the sensor helps it respond quicker than radiosondes at high altitudes and the accompanying very cold temperatures. It allows the WVSS to more accurately depict the very cold, dry air at high altitudes than radiosondes.

As mentioned earlier, the temperature differences for the entire fleet of WVSS aircraft are probably influenced by the warm bias of just a few aircraft. This is demonstrated when the data are separated by aircraft number (see Table 3).

Differences based on aircraft

Aircraft	Obs #	T diff (C)	FSL T Diff (C)	Dwpt Diff (C)
283	22	0.9	0.6	3.4
284	37	1.3	1.2	-1.3
285	68	0.7	0.2	3.3
291	77	2.0	1.3	2.0
294	9	0.3	-0.1	1.6
362	46	0.4	-0.3	5.5
375	90	0.7	0.3	2.3
380	152	2.3	2.0	3.7
444	91	0.7	0.4	1.3
445	170	1.2	0.9	-2.0
495	25	0.6	-0.1	0.6
675	101	0.2	-0.3	1.7
701	21	0.3	0.2	3.6
711	58	1.2	1.4	4.7

Table 3. Differences of temperature and dewpoint based on aircraft

Aircraft numbers 284, 291, 380, 445, and 711 all have warm temperature biases of 1 to 2C. These statistics agree with a comparison made by FSL of these aircraft with 1 hr temperature forecasts from the Rapid Update Cycle (RUC) model (Caracena, personal communication).

Dewpoint differences vary much greater than temperature, as moisture in the atmosphere is not dynamically constrained as temperature. In addition, many of the differences in the two systems can be explained by sharp gradients in dewpoint near the levels used in this study.

Figure 4 shows an ACARS sounding from Oakland, California (OAK) from 1205UTC on July 17, 2001 . Notice the sharp dewpoint gradient between 900 and 800 mb. The accompanying text data shows that the dewpoint at 850 mb is -6.7.

Contrast this to Figure 5, which shows the NWS radiosonde plot valid at 1200UTC. It too shows the sharp dewpoint gradient between 900 and 800 mb, but the dewpoint curve crosses the 850 mb line at -35.2C, a difference of nearly 30C in dewpoint!

It likely that both systems are depicting the shallow marine layer of moisture well; the difference being that the aircraft was several miles northwest of Oakland at 850mb and the radiosonde balloon was a few miles to the east. In addition, radisondes are usually launched about one hour before their valid time, so the 850mb conditions from the balloon were likely from around 1110UTC, while the data from the aircraft was from 1208UTC at 850 mb.

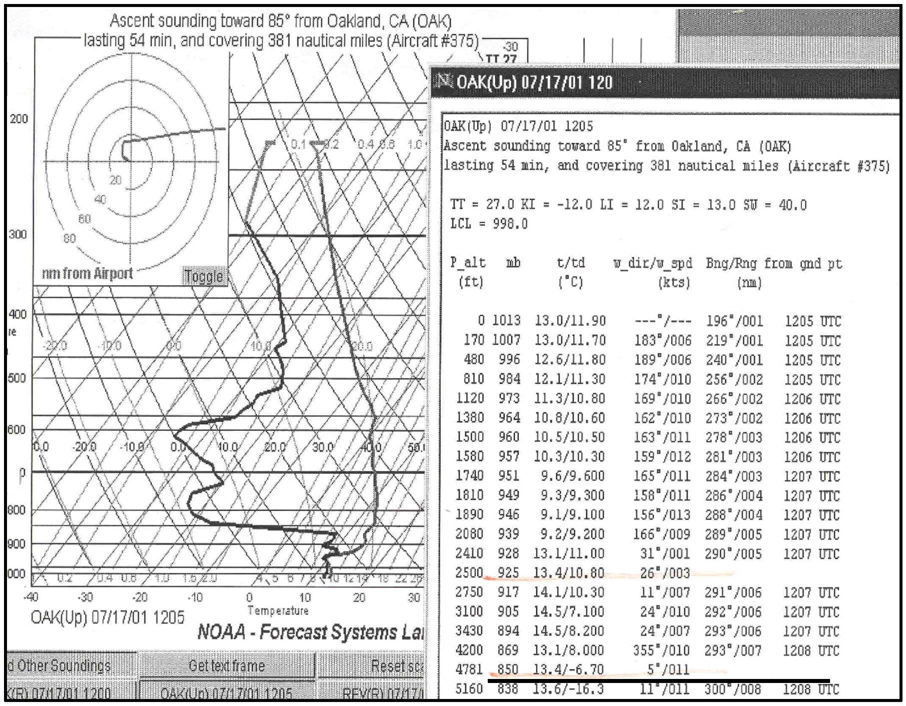

Figure 4. ACARS sounding from Oakland, California around 1205UTC on July 17, 2001 shows a sharp dewpoint gradient between 900 and 800mb, and an 850mb dewpoint of -6.7C.

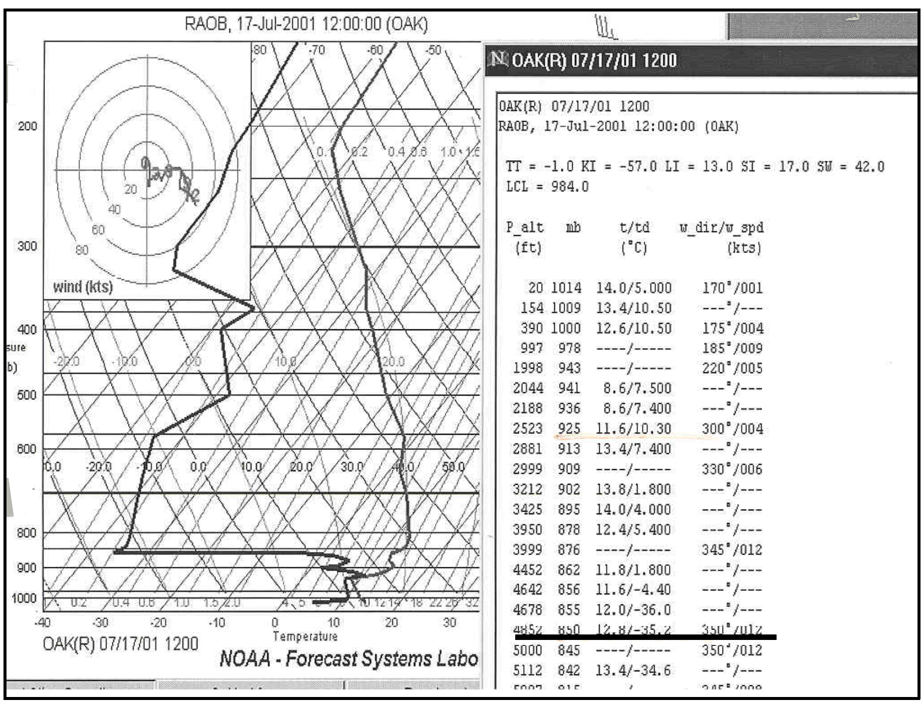

Figure 5. NWS radiosonde from Oakland, California valid at 1200UTC on July 17, 2001 shows a sharp dewpoint gradient between 900 and 800mb, and an 850mb dewpoint of -35.2C

6. WVSS-II

While the current WVSS can provide data that is comparable or slightly better than NWS radiosondes, they must be re-calibrated every six months and replaced every two years . New installations also require a hole to be drilled into the aircraft. A new system known as WVSS-II employs a diode laser, and fits into the existing total air temperature sensor space on commercial aircraft. This system is expected to only need re-calibration every two to three years. It should be able to report relative humidities to within five percent at all levels in the troposphere and lower stratosphere. By comparison, WVSS-I is accurate to within five percent in the boundary layer to seventeen percent in the higher troposphere, and radiosondes are accurate to within three percent in the boundary layer and thirty percent in the upper troposphere. Installation of the first WVSS-II units is expected in 2002.

7. CONCLUSIONS

This study of sixteen WVSS-equipped aircraft and nearby NWS radiosondes found that temperature differences averaging slightly less than 1C and dewpoint differences of 1.9C at distances of 50 km or less. Temperature differences increase only slightly with increasing distance and/or altitude, while dewpoint differences increase significantly with increasing distance and/or altitude. The temperature differences in this study are about .5C higher than earlier studies. This is likely due to a few aircraft with large war, biases affecting the averages of the whole fleet. The dewpoint differences compare favorably with an earlier study of WVSS and NWS radiosondes.

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