Comparison of Radiosonde and Profiler Data with ACARS Data for Describing the Great Plains Low-Level Jet

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ABSTRACT

A newer method of retrieving upper air data called the Aircraft Communications, Addressing, and Reporting System (ACARS), is slowly being incorporated into meteorological analysis. Ten cases in 2005 through 2006 were examined to see if ACARS compared to wind profilers and radiosondes in analyzing the Great Plains low-level jet. If proven, ACARS could be fully introduced as a usable source for atmospheric data in analyzing mesoscale features. However, the sparse population of much of the Great Plains appears to prevent busy enough airports to exist for adequate distribution of low-level data for analysis. The study did show a correlation between the ACARS and wind profilers’ observed wind speed and direction.

1. Introduction

The Aircraft Communications, Addressing, and Reporting System (ACARS) was introduced in the early 1990’s as a newer way to directly observe much of the atmosphere (Moninger 2006). Studies were conducted to check the accuracy, precision, and overall reliability of the system. I intend to test an aspect of the usability of the system by trying to observe a nocturnal mesoscale feature that is difficult to observe with other methods.

Before an observation source can be completely put into place as a trusted addition or replacement for another, it needs to be checked and compared for accuracy and precision. When comparing observational sources, it’s good to look at other observations that are taken in close proximity. It is also important to keep the observation times within reasonable differences.

Due to the velocity of the aircraft itself, ACARS has to derive its wind observations through navigation computers and Global Positioning Systems (GPS). Wind measurements obtained via an aircraft’s Inertial Navigation System (INS) measures aircraft acceleration, velocity, position, and angles of altitude. Measurements taken by the aircraft pitot-static system and outside air temperature measurement systems are combined to determine a true airspeed vector, which is subtracted from the ground speed vector to obtain the wind velocity (Lord et al. 1984).

In a comparison of wind direction between multiple data sets, it was indicated that the ACARS data compares to other observing
methods within the accuracy associated with those other observing methods (Lord et al. 1984). This study showed that the accuracy of ACARS wind direction observations is at an acceptable level.

The differences from a limited distance / time separation sample establish an upper bound on the combined observation error for ACARS and radiosondes data, and it is considerably low, indicating considerable accuracy for both platforms. However, the accuracy of ACARS temperature and wind observations is somewhat higher than from radiosondes (Schwartz and Benjamin 1995). This study showed that radiosondes could be replaced or combined with ACARS data and not lose much accuracy.

The next step in proving data as a useful and reliable source is to check the precision of the observations. The observations need to be consistent and show little variation between multiple measurements in close proximity. A collocation study for ACARS wind and temperature measurements was performed using pairs of observations with small separation in time and space. The study showed an estimated horizontal wind component (u or y) standard deviation error of 1.1 m s\(^{-1}\) for ACARS wind observations and about 0.5 K for temperature observations (Benjamin et al. 1999). Given that the average variance between observations is limited to these standard deviations, it is known that the majority of the time, the observing instruments are measuring temperature and wind speeds within an acceptable precision.

A study that can test the lower altitude range of most observational sources is analysis of the Great Plains low-level jet (LLJ). The LLJ is important because it attributes a crucial role in nocturnal thunderstorm occurrence over the Midwest to low-level convergence and associated vertical velocity fields (Bonner 1966).

To better locate and analyze the LLJ, an understanding of the physical processes is necessary. The phenomenon of the LLJ involves the convergence of low-level easterlies over the Mexican Plateau each evening from the Gulf of Mexico and of the low-level westerlies from Baja California and the Pacific Ocean. The easterlies turn anticyclonically toward the north to form the Great Plains low-level jet (Helfand et al. 1995). Therefore, the observations will have to be restricted to a domain defined by the Great Plains. Also, a limited timeframe is available for observation restricted to the overnight hours (for most studies, the timeframe was defined from 00 UTC to 12 UTC or 1800 LST to 600 LST).

ACARS could be considered to be a more reliable source for LLJ observations, as opposed to wind profilers or radiosondes. The average duration of a jet event was about 4 h for most observations in a wind profiler study. This indicates that many LLJ occurrences will be missed by the twice-daily conventional radiosonde network (Mitchell et al. 1995).

However, in a study conducted using radiosondes, it was found that more than 50% of LLJs have their wind speed maxima below 500 m. This fact calls into question the ability of the 404-MHz radar wind profiler network, with its lowest range gate at 500 m above ground level, to adequately sample LLJ events or to describe their vertical structure (Whiteman et al. 1997).

ACARS data are still a relatively new source for upper air data. Therefore, studies were done to accomplish the quality control for ACARS in proving that the data are accurate, precise, and – most important – reliable. I hypothesize that the higher spatial representation and more frequent measurements of the ACARS network will provide improved measurements of the LLJ.

2. Data and methodology

a. Locating the LLJ

Acquisition of data for this project was based on the location of the relative wind velocity maximum of the LLJ, as located by wind profilers in the Great Plains. The date, time, location, and duration of each jet analyzed was acquired from climatological records available online through the National Weather Service. These records were searched for evidence of nighttime thunderstorm events in the summer months in the vicinity of southeastern Nebraska. If such events were
found, wind profiler data and radiosonde upper air data were acquired through an Iowa State University online meteorology data archive and viewed through Gempak.

For the purpose of this study, I defined a LLJ as a wind speed maximum that was present between 00 UTC and 12 UTC and only existed anywhere from the surface up to 3000 meters. Many profilers throughout Oklahoma, Kansas, and Nebraska showed evidence of the LLJ. However, for the most conclusive results, I tried to locate the profiler closest to the jet’s relative maximum.

b. Data retrieval

ACARS archived data are available by request through the Earth Systems Research Laboratory, Global Systems Division (Moninger 2006). Due to the organization of the ACARS archive, I had to specify an airport that would define the domain for the data I requested. Due to the nocturnal occurrence of the LLJ itself, I needed an airport big enough to have overnight flights, like cargo shipments, and was close enough to the wind profilers. Using these criteria, Wichita Mid-Continent Airport in Wichita, KS (KICT) was chosen as the most likely candidate even though it lies 150 km or more from most of the profilers used in the study.

Ten instances of the LLJ were documented and data acquired in the Central Plains from 24 June 2005 to 10 August 2006 (each instance is separately listed in Table 1). I wanted to use the most recent events possible due to the relatively select data of the ACARS system (ACARS sensors are continuously being installed on airplanes. More data are available in the most recent portion of the archive).

The final data set includes the date and time of the report, in UTC and local time; the latitude, longitude, and altitude of the airplane at the time of the report (giving a three-dimensional location); the distance between the ACARS report and the profiler; and the airplane’s observed wind speed and direction (for a list of all observations made see Table 2).

In addition to the ACARS data collected, I have profiler and radiosonde wind speed and direction reports at the same altitude as the ACARS report. The wind profiler and radiosonde reports needed to be collocated by altitude with the ACARS data to allow data comparison. Also, reports were not continuously reported through time, so I collocated the 00 UTC and 12 UTC radiosonde reports to the nearest corresponding report time of the ACARS/profiler reports.

3. Analysis and results

a. Data point separation

The distance between sensors affects margin of error. The overall mean distance between the Wichita airport and the profilers used in the study was 187 km and the standard deviation was 48 km (see Table 2). Schwartz and Benjamin (1995) found that wind speed differences increase sharply at a distance separation greater than 60 km. Therefore, the distances in my study fall outside what Schwartz and Benjamin consider acceptable limits.

Of the ten cases studied, the case with the least separation was 10 August 2006. The mean distance was 93 km and the standard deviation was 42 km (see Table 2). This case is close to the allowable margin for an acceptable range. The case with the farthest separation was 17 July 2005. The mean distance was 390 km and the standard deviation was 58 km (see Table 2). This case is far outside what is acceptable.

The airport chosen for this study was the closest to the profilers to yield sufficient data. Therefore, the separation between the observations indicates that ACARS might not have adequate placement of measurements to comply with acceptable accuracy. However, the normal size of the LLJ would dictate that 150 km is still somewhat reasonable.

b. Airplane altitude

Much of the altitude data suggest the majority of the flights sending ACARS data
were cross-continental flights. They would be just passing overhead and not landing or taking off, which means observations near the surface would be neglected.

The mean altitude of the airplanes reporting in the study was 8,770 m and the median altitude was 10,556 m, which would generate observations around the 200 hPa to 300 hPa pressure surfaces in a standard atmosphere. However, there was a relatively large standard deviation of 3,530 m (see Table 2). This shows that much of the altitude data was confined to the upper levels of the atmosphere, but there was considerable variance in individual reports.

A comparison was made between the altitude of the airplane and the ACARS observed wind speed. I found in many of the cases that there was a large spike in the wind speed observed when the reported altitude was at a minimum that fell below 3000 m. This suggests that the airplane could be flying through and observing the LLJ.

c. Observed winds

1) WIND DIRECTION

In all 10 cases combined, ACARS observed a mean wind direction of 217° with a standard deviation of 79°, the profilers observed a mean direction of 210° with a standard deviation of 68°, and the radiosondes observed a mean direction of 216° with a standard deviation of 41° (see Table 2). All three of the observation sources correspond very well in the direction of the wind which agrees with Lord et al. (1984). Furthermore, the direction of the wind observation is consistent with the flow of a normal LLJ.

2) WIND SPEED

The overall wind speed observed by the ACARS sensors, given the altitude distribution discussed, was a mean velocity of 10.18 m s^{-1} with a standard deviation of 4.96 m s^{-1} and the average velocity maximum for all cases was 23.21 m s^{-1}. Compare that with the mean for the profiler which was 10.76 m s^{-1} with the same standard deviation of 4.96 m s^{-1} and the same average velocity maximum observed with 23.21 m s^{-1} (see Table 2). The radiosonde disagrees the most, although this was likely due to the difference in number of data points available. The radiosonde had a mean wind velocity of 15.86 m s^{-1} a standard deviation of 2.58 m s^{-1}, with an average velocity maximum of 17.67 m s^{-1} (see Table 2). The similarity between the wind profiler and the ACARS data, given the aforementioned separation between observations, shows a very strong positive correlation.

I plotted the profiler data and the ACARS data against each other in a scatter plot for statistical comparison (see Fig. 1). The line of best fit was calculated, which came out with a linear equation of \(Y = 0.89X + 1.54\) and an \(R^2\) value of 0.69. With a Y-intercept of 1.54 and the slope of the line being 0.89, this comparison is a positive correlation. The \(R^2\) value of 0.69 indicates that approximately 69% of the variation in the data can be explained by the trend line. The remaining 31% can be explained by natural variability.

The single case with the least correlation is 10 August 2006; where the trend line is described by the equation \(Y = 0.23X + 3.47\) and the \(R^2\) value is 0.08 (see Fig. 2). The single case with the best correlation is 31 July 2006; where the trend line is described by the equation \(Y = 1.04X − 0.62\) and the \(R^2\) value is 0.74 (see Fig. 3). This would indicate that there is a great deal of variation between the individual cases.

4. Discussion and conclusions

a. Availability of Data

One of the issues in locating the LLJ is that it exists primarily in rural areas of the Great Plains such as western Kansas. These areas tend to be data sparse with respect to upper air observations. The ACARS data near the surface is sparse due to the lack of large airports supporting major airlines and freight carriers needed to supply the observations. The ACARS observations in that area of the United States are at high altitudes where cross-continental flights are passing overhead.
The airport used in this study was in Wichita, KS and was chosen because there were enough flights per day to support a practical amount of data, while staying within a reasonable distance of the other data sources. However, the airport still only had a minimal number of flights due to the sparse population. Wichita’s Mid-Continent Airport averages 436 flights per day. Compare that to a major international airport like Chicago’s O’Hare Airport that supports 2661 flights per day (Airnav 2006).

The issue with radiosondes is that they are only launched at 00 UTC and 12 UTC, which is usually outside the time when the LLJ occurs. Also, the radiosondes are only launched at certain locations governed by the National Weather Service. For example, the state of Kansas only has two stations that launch radiosondes continuously throughout the year.

The national wind profiler network provided the most data that was effective in locating the LLJ in this study. The network is centered over the central plains and the profilers are more densely located than radiosondes. Also, the profilers record observations every six minutes and at every 250 m. A problem with profilers might be that most of them don’t make their first observation until 500 m above the surface. However, Bonner (1968) found that the average level for maximum winds was 785 m, with a standard deviation of 127 m. This suggests that data beginning at 500 m are adequate to detect most of the LLJ occurrences (Mitchell et al. 1995).

If the ACARS data were limited to only show observations made between the surface and 3000 m, we would only see small spaces in time where the LLJ is observed and large gaps would be left between observations. If we moved to a larger airport in the Central Plains where there are more flights to gather observations from, the separation between the airplane and the LLJ’s wind speed max would be too great to consider it an accurate depiction of that jet. That is because the nearest airports with a high enough volume of air traffic are near large population centers like Dallas or Denver.

These analyses suggest that my hypothesis is false. ACARS data do not have enough observations at night when the LLJ is at a maximum, nor do the data have enough observations near the surface. Also, I was able to show, as Mitchell et al. (1995) did, that the radiosonde network in place is not reliable in finding the LLJ either. It is noteworthy that the recent LLJ study by Song (2005) did not use ACARS data.

In the future, more airplanes could be fitted with ACARS weather sensors (like personal aircraft, not just commercial), then we could have a more dense spread of observations. If that happened, ACARS data might be abundant enough and reliable enough to use in expanded analysis and research.

c. Future studies

This study only used one airport for acquiring ACARS data and only used profiler and radiosonde data from the points nearest the wind maximum. Further studies could be conducted that include more airports or a wider range of data. Also, it would be interesting to see research done, in this same fashion, which looks for and studies other mesoscale phenomenon with ACARS data.
5. Acknowledgements

I would like to thank Daryl Herzmann (Iowa State University, Ames, IA) for his time and effort in helping acquire and compile the data. Also, I would like to thank Dr. Eugene Takle (Iowa State University, Ames, IA) for his guidance in completing the project. Thank you both greatly for the help.

6. References

Airnav, cited 2006: The pilot’s window into a world of aviation information. [Available at http://www.airnav.com/]


7. Tables and figures

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Table 2. Statistical comparison associated with each observation for all data combined.

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Figure 1. Scatter plot of ACARS wind speed against profiler wind speed for all cases combined (1882 reports).

Figure 2. Scatter plot of ACARS wind speed against profiler wind speed for 10 August 2006 (330 reports).

Figure 3. Scatter plot of ACARS wind speed against profiler wind speed for 31 July 2006 (154 reports).