

FA 1A.2 ACARS QUALITY CONTROL, MONITORING, AND CORRECTION

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1. INTRODUCTION

The problem: Numerical weather prediction models can only be as good as the data that go into them. A primary source of data for several important models is received from commercial aircraft, made available through the ACARS system (Bisiaux et al., 1983). Although these are very high quality data, occasional erroneous reports can cause substantial distortion of model fields.

Our solution: Quality control of individual observations based on agreement with nearby observations from other sensors is very helpful, but is not sufficient because nearby sensors can occasionally be erroneous too. We have developed a system to reject aircraft that have a history of producing spurious data. The reject list keeps faulty sensors from contaminating two of our assimilation systems: MAPS (Benjamin et al. 1991, 1994), and LAPS (McGinley et al. 1991). The reject list is dynamic because new aircraft continually come on line and instruments occasionally fail and/or are repaired.

2. BACKGROUND

The ACARS system currently provides approximately 13,000 observations per day over the continental United States from over 400 aircraft operated by major airlines. This very high quality data stream (approximately 1.3% errors) includes the following information on a frequency of 5 - 10 minutes:

- tail number (aircraft ID)
- flight number
- observation time (to the nearest minute)
- latitude and longitude (to the nearest tenth of a minute)
- pressure altitude (to the nearest hundred feet)
- temperature (to the nearest 0.1 °C)
- wind direction (to the nearest degree)
- wind speed (to the nearest 0.1 kt)

MAPS is both a data assimilation system and prediction model. Its domain covers the continental

United States with a 60-km grid and 25 levels in the vertical. MAPS produces an analysis and several forecasts every three hours, using observations from surface stations, radiosondes, profilers, and ACARS.

We briefly summarize only the relevant aspects of MAPS quality control (QC) here. This topic is discussed in more detail in Miller and Benjamin (1991).

The primary QC check in MAPS is a buddy check against neighboring observations. The buddy check is performed by interpolating measured values from other sensors to the location of the sensor being checked. Nearby observations made by the same aircraft are not used to produce this field. We interpolate the differences between each observation and the background field, rather than the observations themselves. This decreases the chance that differences in meteorological conditions between the locations of a sensor and its buddies will bias the interpolation. Observations are declared good or bad according to the difference between the observed and buddy-check values.

3. NO-REJECT MAPS RUNS AND THE 40-DAY MAPS/ACARS ARCHIVE.

The operational MAPS runs use a reject list to exclude aircraft with known errors. This improves the quality of MAPS analyses because the rejected aircraft cannot contribute incorrect data. On the other hand, no information about the rejected aircraft can be gathered from these runs. In order to monitor both rejected and non-rejected aircraft, we use versions of the MAPS data ingest and QC software that do not exclude any aircraft. The disadvantage of this is that the buddy checking can sometimes be affected by "bad" aircraft; the advantage is that we can tell when the bad aircraft become good again. We monitor the aircraft data every three hours and accumulate the following information for each ACARS observation that occurs in the MAPS domain: 1) tail number (aircraft ID), 2) latitude and longitude, 3) observation time, 4) pressure of the MAPS level in which the observation occurred, 5) meteorological parameters (virtual potential temperature, u and v components of the wind) for the observation, 6) corresponding parameters from the buddy-check interpolation, 7) corresponding parameters from the 3-h MAPS forecast from the previous run, and

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8) MAPS QC failure code, which indicates if and why an observation failed the QC check.

We maintain a 40-day long archive of these records. This facilitates time-history analysis of individual aircraft, each of which may only provide a few observations in any individual MAPS run.

We also maintain a database that contains (with some short gaps) the following information on each aircraft that has been used in a MAPS run since 0600 UTC 1 December 1993:

- tail number
- time of first appearance in MAPS
- time of most recent appearance in MAPS
- time of most recent error (QC failure)
- total number of observations by this aircraft used in MAPS
- number of errors in virtual temperature
- number of errors in u or v component of wind

Currently (3/14/1994), this database lists 471 aircraft. The most prolific aircraft has produced more than 5697 observations since 1200 UTC 1 December 1993.

4. PERIODIC ERROR ANALYSIS

Every two weeks we produce a report on behavior of "rejected," "suspicious," and "new" aircraft during the past 14 days. Rejected aircraft are those that are currently being rejected from the operational MAPS runs. New aircraft are those that are not already in our database. Suspicious aircraft are those whose data meet at least one of the following criteria:

Number of obs since first error	errors
> 100	> 3% of observations
41-99	> 2 errors
10-40	> 1 error
< 10	> 0 errors

In addition, we produce detailed error statistics for suspicious and rejected aircraft which include the means and standard deviations of: 1) ground speed, 2) absolute u and v wind errors, 3) relative u and v wind errors, and 4) pressure.

We use this summary information to update the reject list used in the operational runs. Our goal is to automate this process, but we are currently making updates by hand, and putting a new reject list into operation about every month. We are satisfied with our criteria for removing aircraft from the reject list: all rejected aircraft that have produced 10 or more

observations with fewer than 3% errors during the last 14 days are slated for removal.

Our criteria for adding new aircraft to the reject list are still in flux. In most cases, aircraft have fewer than 1% errors or more than approximately 50% errors. We add aircraft with more than 30% errors to the reject list without further analysis. Aircraft that have between 1 and 30% errors are dealt with subjectively. As we discuss below, some of these intermittent errors are true erroneous measurements and others are false errors due to bad MAPS buddy checks or to errors in MAPS.

5. RAW ACARS 40-DAY DATABASE

To facilitate studying suspicious aircraft in detail, we maintain a database of raw ACARS observations. These are records transmitted to the Forecast Systems Laboratory from Aeronautical Radio, Inc. We use these records to uncover decoding and data conversion errors, to look at temporal and spatial continuity for individual aircraft, and to look at continuity between nearby aircraft. Some of the kinds of errors described in Section 6 were first identified through these raw ACARS reports.

6. ERROR TAXONOMY

Our statistical and case studies have revealed several kinds of errors in the ACARS data. Two points should be kept in mind: First, this taxonomy should not be considered exhaustive, because we have only been studying these errors for a few months. Second, ACARS is very high quality data. When looking at errors in detail, it is easy to forget that only 1.3% of ACARS data are in error (as indicated by QC flags on the 937,000 observations we have analyzed since 1 December 1993). Unfortunately, just one bad observation can play havoc with a numerical model, so we must focus on these rare events. Three types of errors are listed below:

Errors that effect all observations from particular aircraft (and so are potentially easily correctable). These errors are apparently due to on-board processing of the observed data and report formatting (Schwartz, 1994).

1. Wind direction off by 180 °.
2. Reversed u-component of wind □ only.
3. Temperature too small in absolute value. The problem appears to be that temperatures are too low by a factor of 10 (e.g., -4.6°C reported when nearby aircraft are reporting temperatures around -46°C.)
4. Clock not working: all observation times reported as 0000 UTC.

Intermittent errors (that may be easily flagged, and

possibly corrected, by looking at temporal and spatial continuity of observations from individual aircraft).

5. Bit-shifting of flight level, wind speed and wind direction. The flight level will occasionally halve or double for one to a few contiguous observations, then return to its previous value. When this occurs, the wind speed and/or wind direction may also be similarly affected.

6. Stuck bits. Several of the reported parameters (latitude, longitude, flight level, wind speed, and wind direction) may assume constant values for several hours, corresponding to one or more flight legs. Not all parameters are necessarily affected.

7. Garbled tail number. This can be particularly critical if the correct tail number is on the reject list. In general, the garbled tail number will not match anything on the reject list, so the aircraft's data will be included in the model when it should not be.

8. Missing values. Occasionally, temperature is reported (in the raw data reports) as "....". This probably can happen with other parameters as well.

9. Garbled reports. Rarely, the entire report is garbled.

Apparent errors due to bad comparison fields or bad data conversion in MAPS.

10. Buddy-check in error. If several aircraft exhibiting errors of types 1-3 are near one another, they can dominate the buddy-checking. This can cause observations from a correctly-reporting aircraft to be flagged as bad.

11. MAPS data ingest problems. Observations must be converted to MAPS variables and to the MAPS coordinate system. One such conversion (from temperature to virtual potential temperature) was found to create an error due to a bug (now corrected) in MAPS in which the moisture below 19000 ft MSL was occasionally too large.

7. PLANS AND RECOMMENDATIONS

ACARS QC monitoring and correction should be performed in two phases. The first should apply temporal and spatial continuity checks to the raw data from each aircraft. Errors of types 4, 5 and 6 (Section 6) can easily be detected, and possibly corrected, here. Errors of types 1-3 can be corrected at this stage. Correcting the raw data immediately after receipt will make higher quality ACARS data available in near real-time to any model that requires it.

The second phase looks for more subtle errors by comparing each observation with other observations. This phase can detect errors of type 1-3, 5, and 6. The advantage of this phase is thoroughness; a disadvantage is that it is somewhat more complex than the first phase, and may take more time, making it more difficult to provide the QC information to other real-time systems.

However, the output is necessary for maintaining reject lists.

Reject lists should be generated automatically, but with human intervention allowed in order to deal with unanticipated kinds of errors.

The reject lists should distinguish among various kinds of errors. An aircraft that produces bad temperature readings, for example, can still provide useful wind information.

Researchers should communicate with airlines regarding aircraft with systematic reporting errors, so that correction can be expedited. This type of interaction already occurs, but can be improved.

We believe that error information should be shared freely among the community of workers in the field. Electronic mail makes rapid and accurate communication convenient. We offer and look forward to useful collaboration with other modelers who are interested in the issues surrounding ACARS quality control, monitoring, and correction.

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