The impact of missing ACARS data on RUC wind forecast skill during 11-13 September 2001

Stan Benjamin
NOAA Forecast Systems Laboratory
Boulder, CO
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1. Introduction

In this report, the effect of loss of ACARS aircraft meteorological reports on RUC wind forecasts during the 11-13 September 2001 period is examined. The absence of ACARS reports resulted from the grounding of commercial aviation over the United States after the terrorist attacks of 11 September 2001. The intent of this study is to determine if RUC wind forecasts appeared to worsen without ACARS data during this period. To supplement this inquiry, the accuracy of RUC forecasts on weekends vs. weekdays was also investigated, since ACARS data volume decreases significantly on weekends due to fewer reports from package delivery carriers.

The Rapid Update Cycle (RUC) assimilation/model system is run by the National Weather Service at the National Centers for Environmental Prediction (NCEP) to take advantage of very frequent atmospheric observations over the United States in order to provide improved short-range numerical forecast guidance. The RUC exists because it has demonstrated the ability to assimilate these high-frequency observations and produce short-range forecasts that are generally more accurate than longer-range forecasts valid at the same time. Since 1998, the RUC has produced new analyses (combining the latest observations with the previous 1-h RUC forecast as a background) and numerical weather predictions of 3h-12h each hour. It is used for applications ranging from aviation to severe-weather forecasting.

The key high-frequency observation types assimilated into the RUC are data from commercial aircraft, wind profilers, surface stations (METARs and buoys), and satellites (cloud drift winds, precipitable water, and, in the upcoming 20-km RUC, cloud-top pressure). Most of the aircraft reports used within the RUC CONUS domain are downlinked through ACARS (Aircraft Communication, Addressing and Reporting System), formatted, and sent to NWS through the MDCRS data base at Aeronautical Radio, Inc. (ARINC) in Annapolis, MD. Although a careful and comprehensive data denial experiments for the RUC have not been performed recently, the data denial experiment by Smith and Benjamin (1994) showed substantial impact from both ACARS and profiler data over the central United States for a March 1992 period. Since that time, the number of ACARS reports has increased substantially, from about 10,000 per day to more than 60,000. Today, aircraft data are arguably the most important asynoptic (e.g., non-rawinsonde) observation type for the RUC hourly assimilation cycle.

2. ACARS data volume over the RUC domain for the period 2-15 September 2001

The hourly ACARS volume over the RUC domain (lower 48 United States and adjacent areas of Canada, Mexico, the eastern Pacific Ocean, and the western Atlantic Ocean) is shown for consecutive weeks in the first half of September 2001 in Figures 1 and 2.

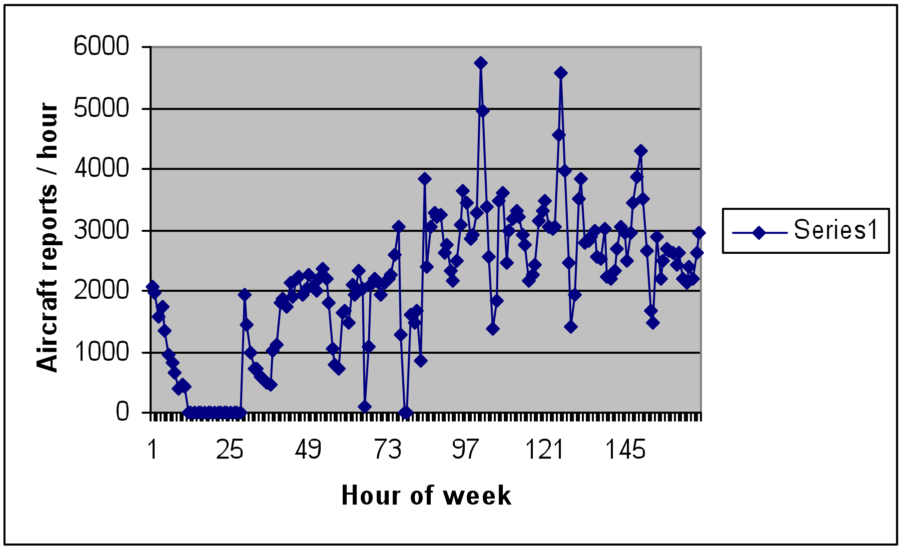

Figure 1. Number of ACARS reports hourly within RUC domain for 2-8 September 2001, Sunday through Saturday. Data records were missing from 1000 UTC Sunday 8 September through 0200 UTC Monday 3 September.

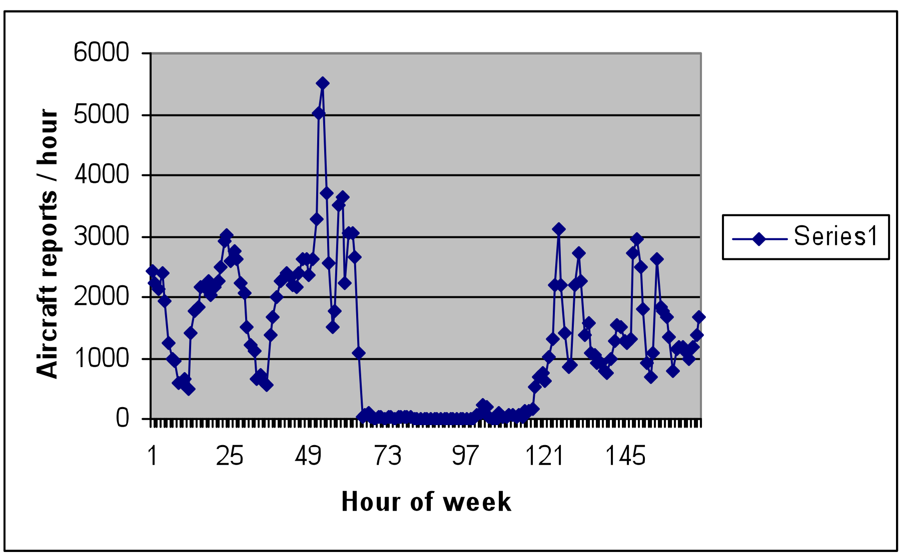

Figure 2. Same as Fig. 1 but for 9-15 September 2001, Sunday through Saturday.

The 2-8 September ACARS volume (Fig. 1) is fairly typical for the latter half of the week, but not typical in the early part of this week, for which Monday was the Labor Day holiday. ACARS volume in the RUC domain is typically 2000-3500 per hour, although a peak/low couplet typically occurs at 0800 and 0900 UTC, times at which the hourly volume is dominated by the flight structure for package delivery carriers (UPS and FedEx). The package delivery carriers do not fly as extensively on Saturday or Sunday nights (or Monday night on Labor Day week) as on other evenings of the week.

After the attacks on the World Trade Center in New York City and the Pentagon near Washington, DC from 1336-1430 UTC on 11 September 2001, the volume of ACARS reports dropped to nearly zero as all commercial aircraft were grounded immediately. The dot in Fig. 2 of 1080 reports at hour 63 corresponds to the 1400-1500 UTC period, as commercial aircraft were landing. From 1500-1600 UTC, only 44 ACARS reports were received. The hourly volume was less than 50 through 0700 UTC 12 September, and then was zero until 0200 UTC 13 September (hour 100 in Fig. 2). Not until Thursday afternoon 13 September (2100 UTC, hour 118 – Fig. 2) did the hourly volume increase to over 500, as a few commercial flights resumed. For the rest of that week, the volume was about half that from the previous week.

3. A measure of the impact of asynoptic data on short-range forecasts

As described in Section 1, the purpose of the Rapid Update Cycle is to assimilate high-frequency (~hourly) observations so as to produce short-range forecasts that are more accurate than longer-range forecasts valid at the same time. This advantage from the RUC is lost if high-frequency observations with sufficient spatial coverage and accuracy are not available. Asynoptic observations refer to observations available more often than every 12 h, the frequency for rawinsonde observations.

A measure of success of a high-frequency assimilation cycle is the reduction of forecast error from longer-range to shorter-range forecasts valid at the same time. For the RUC, a reasonable measure is the difference in forecast error between 12-h and 3-h forecasts valid at the same time. The 3-h forecasts, of course, have had access to an additional 9 h of observations. The standard of verification is rawinsonde data, which are available generally only at 0000 and 1200 UTC. This means comparing the skill of RUC 3-h forecasts initialized at 0900 or 2100 UTC valid at 1200 and 0000 UTC, respectively, with RUC 12-h forecasts initialized at 1200 or 0000 UTC.

Since the RUC is heavily used for upper-level wind forecasts and ACARS reports are most plentiful in the upper troposphere, it was decided to examine the difference between 12-h and 3-h wind forecast errors at 250 hPa in search of an effect from changes in volume of ACARS data. Note: Although this report uses the term ‘forecast error’, these scores actually include the effect of both model forecast error and observational error.

4. Behavior of the 12-h/3-h RUC wind forecast error difference for June-September 2001

This 12-h/3-h difference at 250 hPa is shown for a 4-month period from June-September 2001 in Fig. 3. The difference is almost always positive, indicating a positive (e.g., more accurate forecast) effect from asynoptic data. It averages over 1 m/s and exceeds 2 m/s about 30 times (12% of occurrences) during this period. The 12-h/3-h difference generally increases in winter, when jet winds are stronger and forecast RMS vector error is larger.

There are only five verification times in this 4-month period when the 12-h/3-h difference is negative. Three of these are immediately after the interruption to commercial aviation activity over the US on 11 September (around event 211 in Fig. 3).

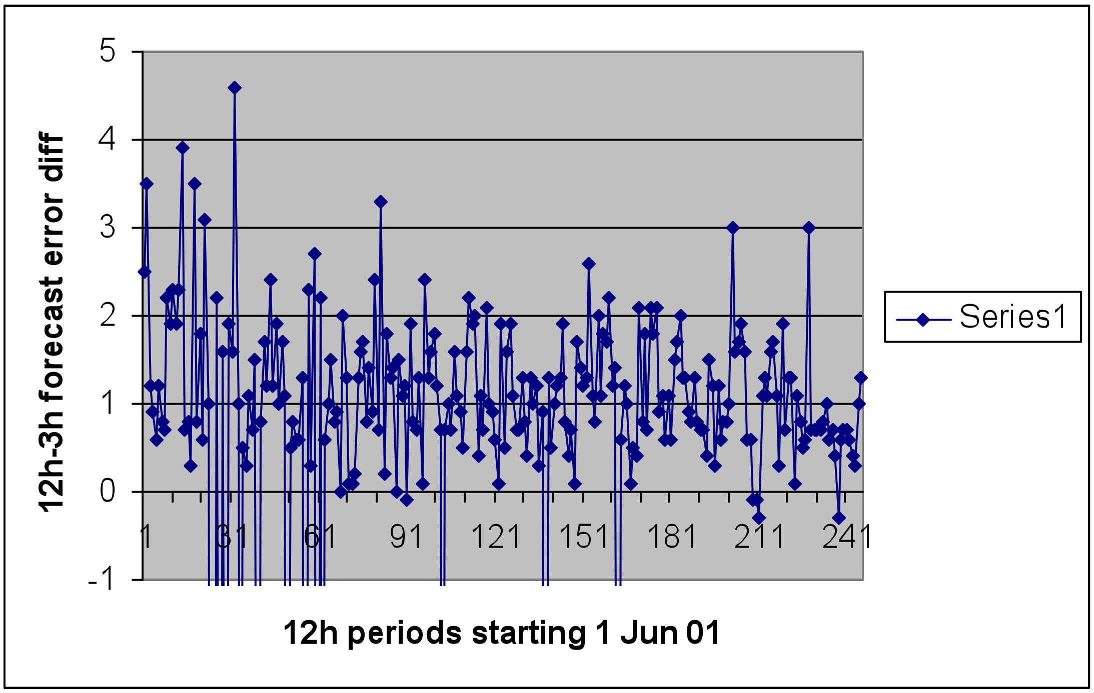

Figure 3. Difference of 12-h minus 3-h forecast error at 250 hPa for RUC wind forecasts. Verification is against rawinsonde data for 1 June – 30 September 2001. Forecast error is defined as RMS vector difference in m/s between observations and gridded data interpolated to observation points (strictly, this includes both true forecast error and observation error). A new event is plotted every 12 h when rawinsonde data are available (0000 UTC and 1200 UTC daily); 244 times are shown for the 122 days in this 4-month period. Missing verification times extend below a value of –1.

In Figure 4, the 12-h/3-h difference for 250 hPa wind forecast error is examined for the period from 1-21 September. This repeats the data of Fig. 3, but on an expanded time scale. During this period, the only times for which this measure of the impact of asynoptic data becomes negative is from 0000 UTC 12 September through 0000 13 September. For comparison, the same 12h/3h difference is also presented for verification statistics from the backup RUC run at NOAA Forecast Systems Laboratory (Fig. 5. A parallel run of the RUC at NOAA-FSL provides an official backup to the operational RUC run at NCEP.) The backup RUC statistics in Fig. 5 show the same general pattern, with the only negative 12-h/3-h difference for forecasts valid at 1200 UTC 12 September and a smaller difference for the period from 0000 UTC 12 September through 1200 UTC

13 September. This corresponds well with the period of virtually no ACARS data from 1500 UTC 11 September through 1900 UTC 13 September, and suggests that the decreased ACARS data did result in poorer RUC wind forecasts than would have otherwise occurred.

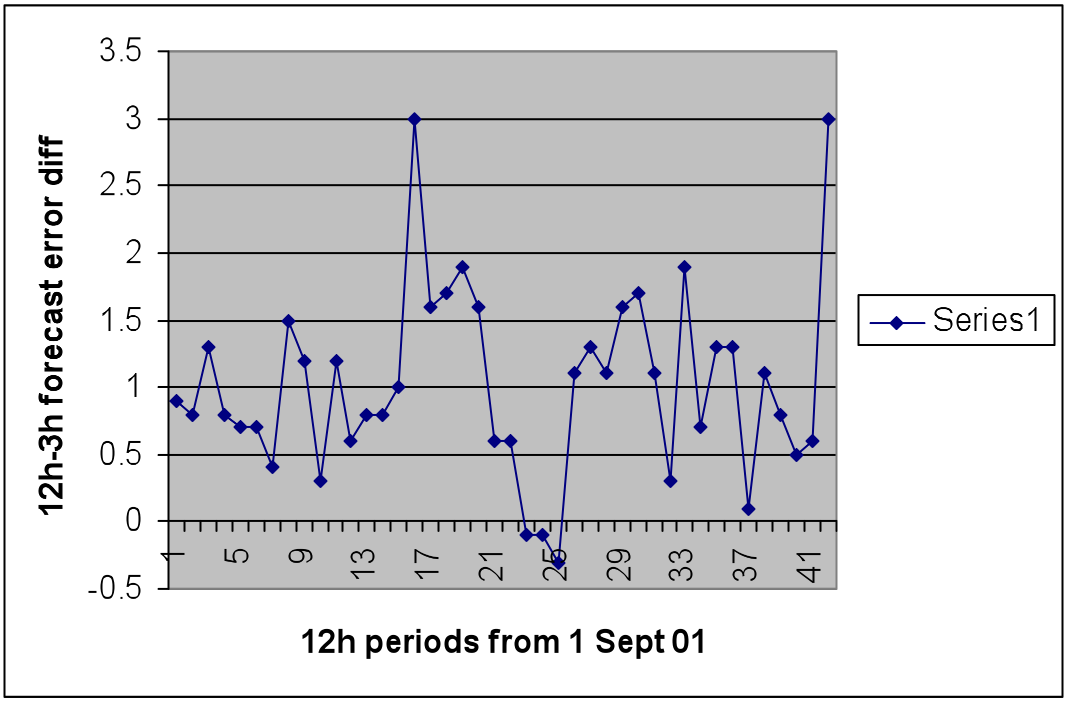

Figure 4. Same as Figure 3 but for period from 1-21 September 2001. From the operational RUC model run at NCEP.

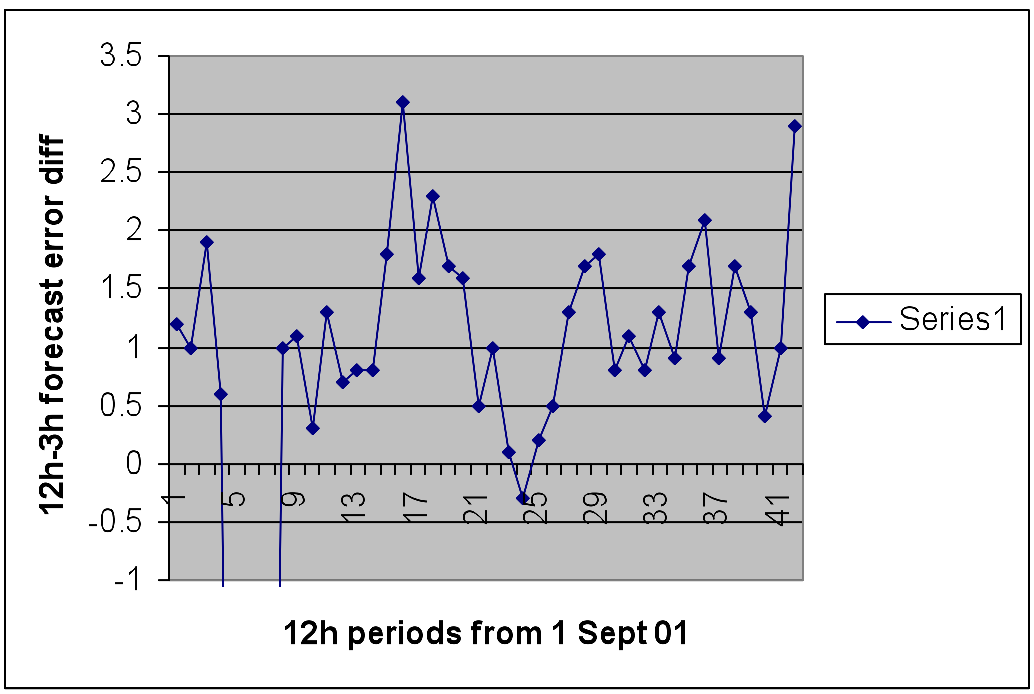

Figure 5. Same as Figure 4 but using backup RUC run at FSL instead of operational RUC run at NCEP. Values between periods 5 and 8 are missing.

The potential for improvement of 3-h forecasts over 12-h forecasts is larger in more difficult forecast situations. This is reflected in Fig. 6, which depicts the 12-h/3-h forecast difference at 250 hPa compared to the 12-h persistence forecast error for the June-September 2001 period. The 12h persistence forecast error is an indicator of the change in a given field over a 12-h period, and is larger in synoptically active periods and smaller in synoptically quiescent periods. In Fig. 6, the persistence forecast error for 250 hPa winds is reflective of typical seasonal variations of synoptic activity. It shows higher persistence forecast errors from 1 June through about 10 July (~event 81), a calm period from then through early September (with a brief period of higher persistence forecast error in mid-August), and increasing activity for the rest of September.

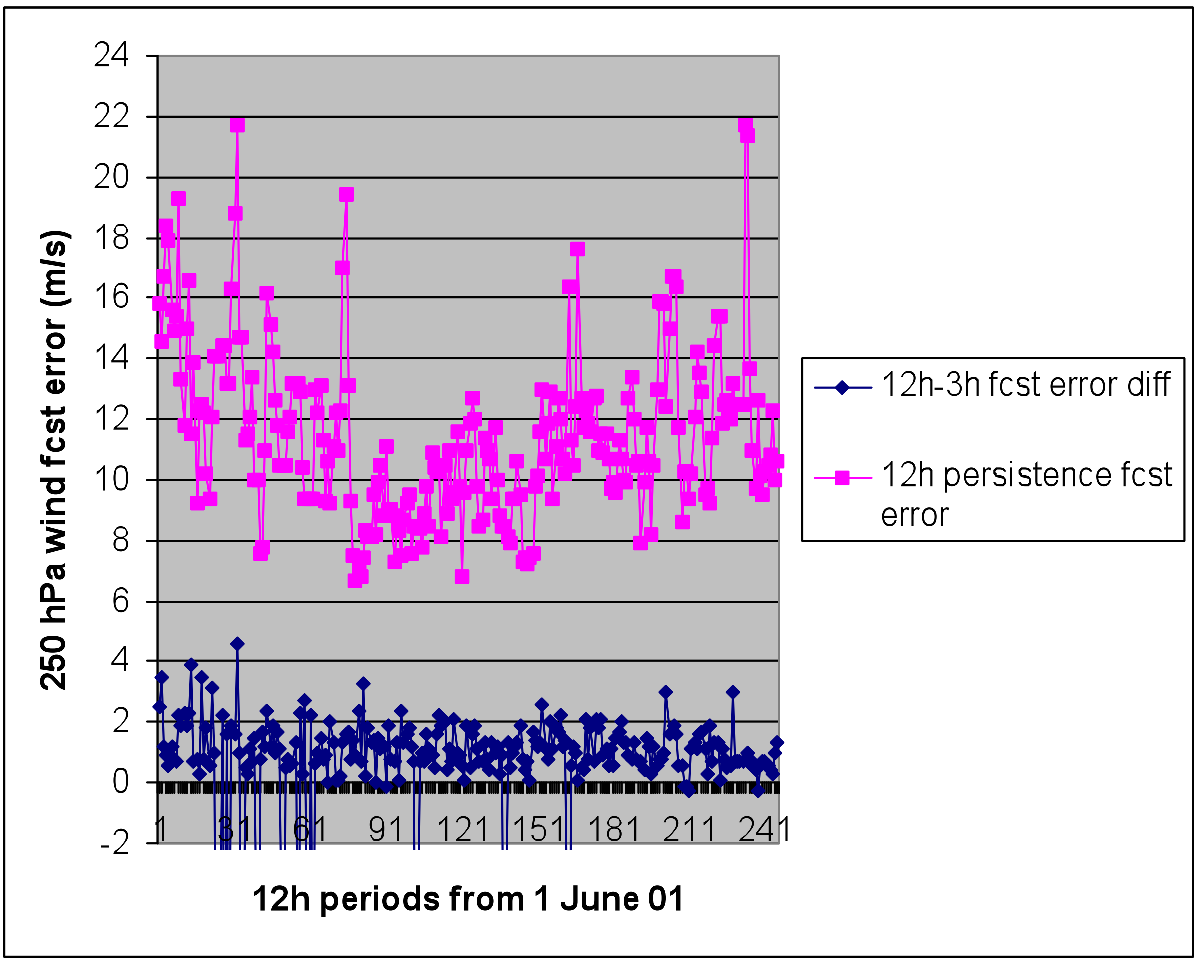

Figure 6. 12-h persistence forecast error vs. 12-h/3-h forecast error difference for 250 hPa winds for June – September 2001. Forecasts are from the RUC, and persistence error uses the RUC analysis valid 12 h previous to the verification time.

A closer examination of 12-h persistence forecast and 12-h RUC forecast error for 1-21 September in Fig. 7 shows that the 11-13 September period was one of low activity and smaller persistence forecast error. Thus, even though the 3-h 250 hPa forecasts were virtually the same in skill as the 12-h forecasts in this period, they were still relatively accurate since it was a quiet period synoptically.

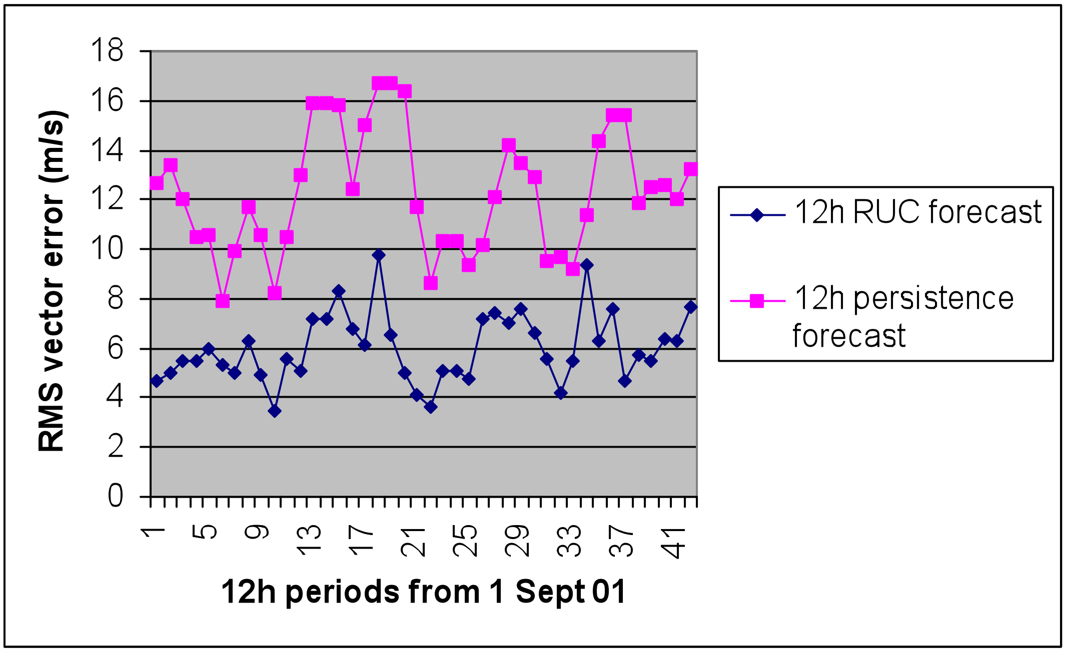

Figure 7. RMS vector error (m/s) for 250 hPa forecasts for 1-21 September from 12-h RUC forecast and 12-h persistence (based on RUC analysis 12 h old)

5. Weekday vs. weekend differences in RUC 12h/3h forecast error differences

As discussed in section 2, since package delivery carriers operate fewer flights on Saturday and Sunday nights than other nights of the week, there are intra-weekly variations in the volume of ACARS. These variations are apparent in Figs. 1 and 2, despite the unusual interruptions during the periods depicted in those figures. The daily volume of ACARS reports reduces from over 60,000 reports/day during 2001 during weekday periods to less than 40,000 reports/day during weekend periods. Weekends are defined here as 24-h periods between 1200 UTC Saturday through 1200 UTC Monday, and weekdays are defined as 24-h periods during the rest of the week.

It is possible to use this intra-weekly variation in ACARS report volume as another opportunity to check for the effect of ACARS volume on RUC forecast accuracy. No other observation types assimilated into the RUC have this intra-weekly variation, so intra-weekly variations in forecast skill can be attributed to changes in ACARS report volume.

Figure 8 shows that this difference in ACARS volume does indeed result in a difference in the 12h/3h forecast error difference measure discussed in sections 3 and 4. The reduced ACARS volume over the weekend results in a 0.19 m/s RMS vector error increase in the 12h/3h forecast error difference at 200 hPa, averaged over a nearly 10-month period.

[Need significance testing results here. Difference should be highly significant, since verification is for 290 day period, with about 115 verification times for weekend periods and about 450 verification times for weekday periods, with about 50 rawinsonde observations at each verification time.]

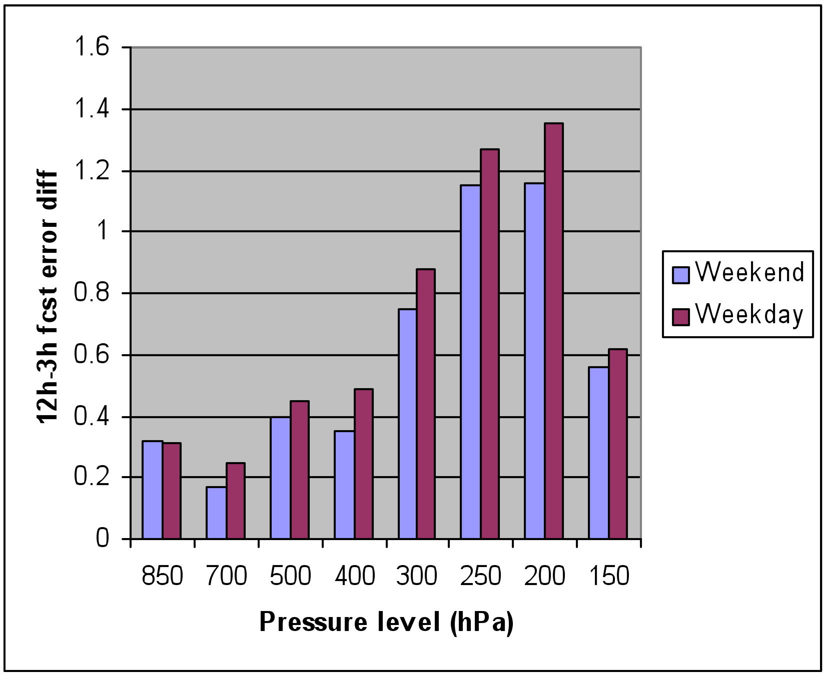

Figure 8. 12-h/3-h forecast error differences for RUC 250 hPa wind forecasts for weekend vs. weekday. For 1 January – 20 October 2001.

Since the weekend reduction of ACARS data is primarily at night from fewer package delivery flights operating, it is useful to stratify this weekend vs. weekday difference into the total difference at 0000 and 1200 UTC, and, alternatively, the difference only at 1200 UTC, when the difference might be expected to be larger. The difference in ACARS volume between weekday and weekend nighttime 12-h (0000-1200 UTC) periods is substantial, with about 35,000 reports during weekday (Mon-Fri nights) 12-h periods, to only about 15,000 reports during weekend 12-h nighttime periods. Fig. 9 shows the weekend-weekday difference in 12h/3h forecast error difference for verification at both 0000 and 1200 UTC vs. that at 1200 UTC only. The differences between weekday and weekend statistics in Fig. 8 corresponds to the values for combined 0000 and 1200 UTC statistics in Fig. 9. The fact that the difference in weekend vs. weekday forecast errors is much larger at 1200 UTC than for both verification times combined suggests further that reduced ACARS report volume on Saturday and Sunday nights results in a reduction of RUC forecast skill at 1200 UTC on Sunday and Monday.

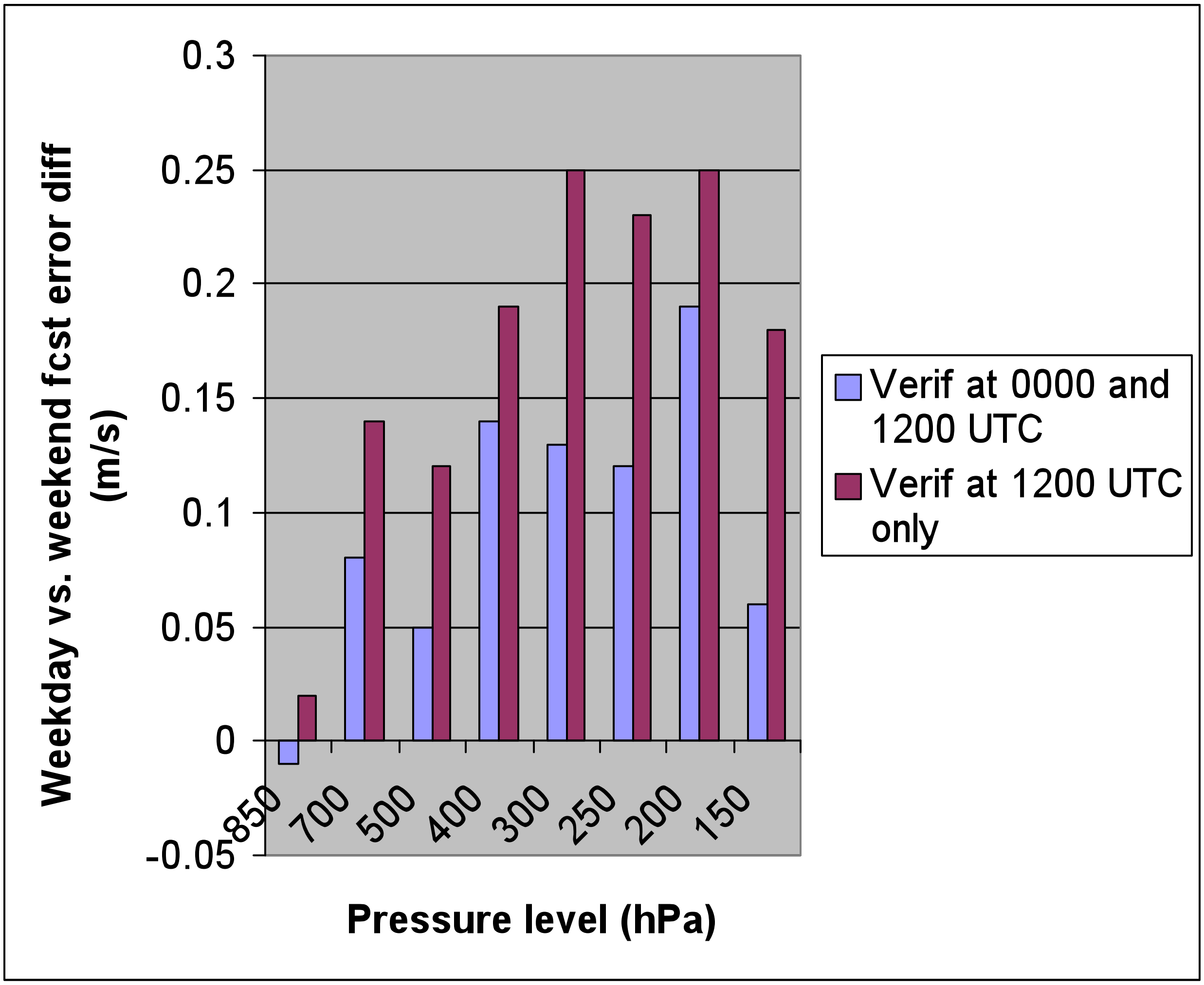

Figure 9. Weekend minus weekday 12-h/3-h RUC wind forecast error differences. Columns are shown for these weekend-weekday differences at 0000 and 1200 UTC together and for the differences at 1200 UTC only. For 1 January – 20 October 2001.

Weekend minus weekday 3-h forecast error differences at 1200 UTC only are plotted directly in Fig. 10. This result shows that most of the difference from reduced ACARS volume is on RUC 3-h wind forecasts (with much less difference on RUC 12-h wind forecasts). The effect of reduced ACARS volume on RUC 3-h wind forecasts peaks at 200 hPa, is strongest in the 250-150 hPa layer, but is still moderate (as wind forecast error differences go) at 850-700 hPa and 400-300 hPa, suggesting some influence from reduced ascent and descent ACARS data.

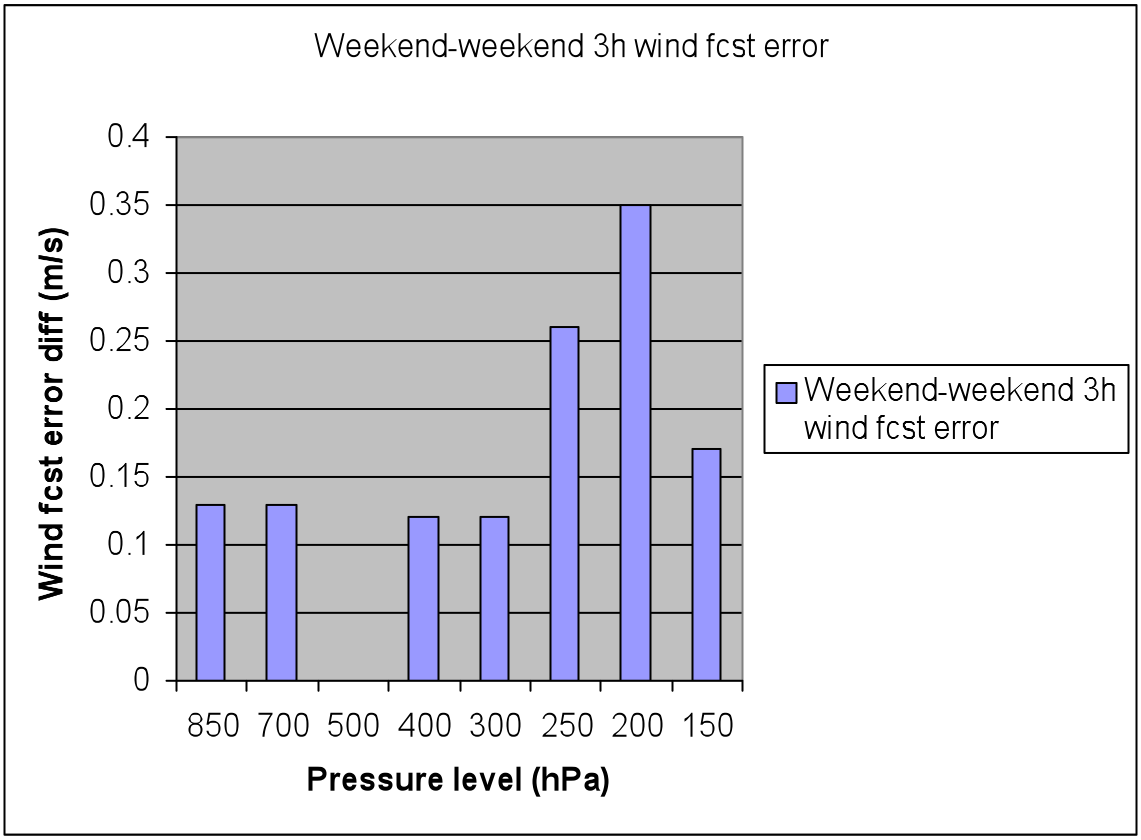

Figure 10. Weekend-weekday RUC 3-h wind forecast errors. For 1 January – 20 October 2001.

6. Conclusions

Decreases in ACARS volume in the 11-13 September period and on weekend evening periods during 2001 both correspond to periods with lower RUC wind forecast skill. Since the RUC generally produces more accurate 3-h forecasts than 12-h forecasts valid at the same time due to assimilation of recent high-frequency observations, the 12h/3h forecast error difference was used as a measure for the impact of those observations. This measure for forecasts at 250 hPa averaged about 1.2 m/s RMS vector error for the January-October 2001 period, and about 1.0 m/s for September 2001. For the 11-13 September period, the ACARS meteorological report volume dropped to virtually zero, and this difference dropped to near or below zero for 250 hPa wind forecast errors. This measure was also shown to be somewhat smaller for forecasts valid at 1200 UTC on Sunday and Monday morning after 12-h periods with lower ACARS report volume. Most of this difference was in reduced skill for RUC 3-h wind forecasts (rather than in 12-h forecasts), for which the impact of reduced ACARS data on weekends was 0.35 m/s. Overall, results from both the 11-13 September and weekend/weekday studies support the hypothesis that ACARS reports help produce more accurate RUC (and presumably other) model forecasts, which in turn leads to improved forecast guidance for aviation and other short-range forecast users.

7. References

Smith, T.L., and S.G. Benjamin, 1994. Relative impact of data sources on a data assimilation system. Preprints, Tenth Conference on Numerical Weather Prediction, Portland, OR, American Meteorological Society, 491-493.