An Intercomparison of the NASA DC-8 MMS with the NCAR G-V Met System and Nearby Vaisala GPS Radiosondes

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Introduction:

Intercomparisons of 1 Hz Static Pressure (P), Static Temperature (T), and 3-D Winds (U,V,W) from the NASA DC-8 Meteorological Measurement System (MMS) and the NSF/NCAR G-V Navigation/Meteorology System were obtained for five Deep Convective Clouds and Chemistry Project (DC3) flights, during which the two aircraft flew in wingtip formation at a constant altitude, as well as during climbs and turns. In addition, MMS P, T, and horizontal wind data during vertical profile maneuvers on four DC3 flights were compared with measurements of these variables obtained during Vaisala RS92-SGP radiosonde ascents over Colorado. Statistics were obtained to characterize the uncertainty of these measurements and to provide an accuracy estimate of the DC-8 MMS data.

DC-8 MMS Comparison with G-V Nav System:

Intercomparison legs were flown on 120525, 120530, 120601, 120605, and 120617, at 10 distinct GPS-derived altitudes ranging from 1.9 km to 12.45 km MSL. Because of close proximity between the two aircraft, differences in meteorological variables due to temporal and spatial separation can be neglected, and the outstanding biases can be attributed solely to instrument error. The following series of figures show time series of the MMS parameters in blue, and the G-V variables in red, for several different flight levels sampled, in order of altitude for the various flights.

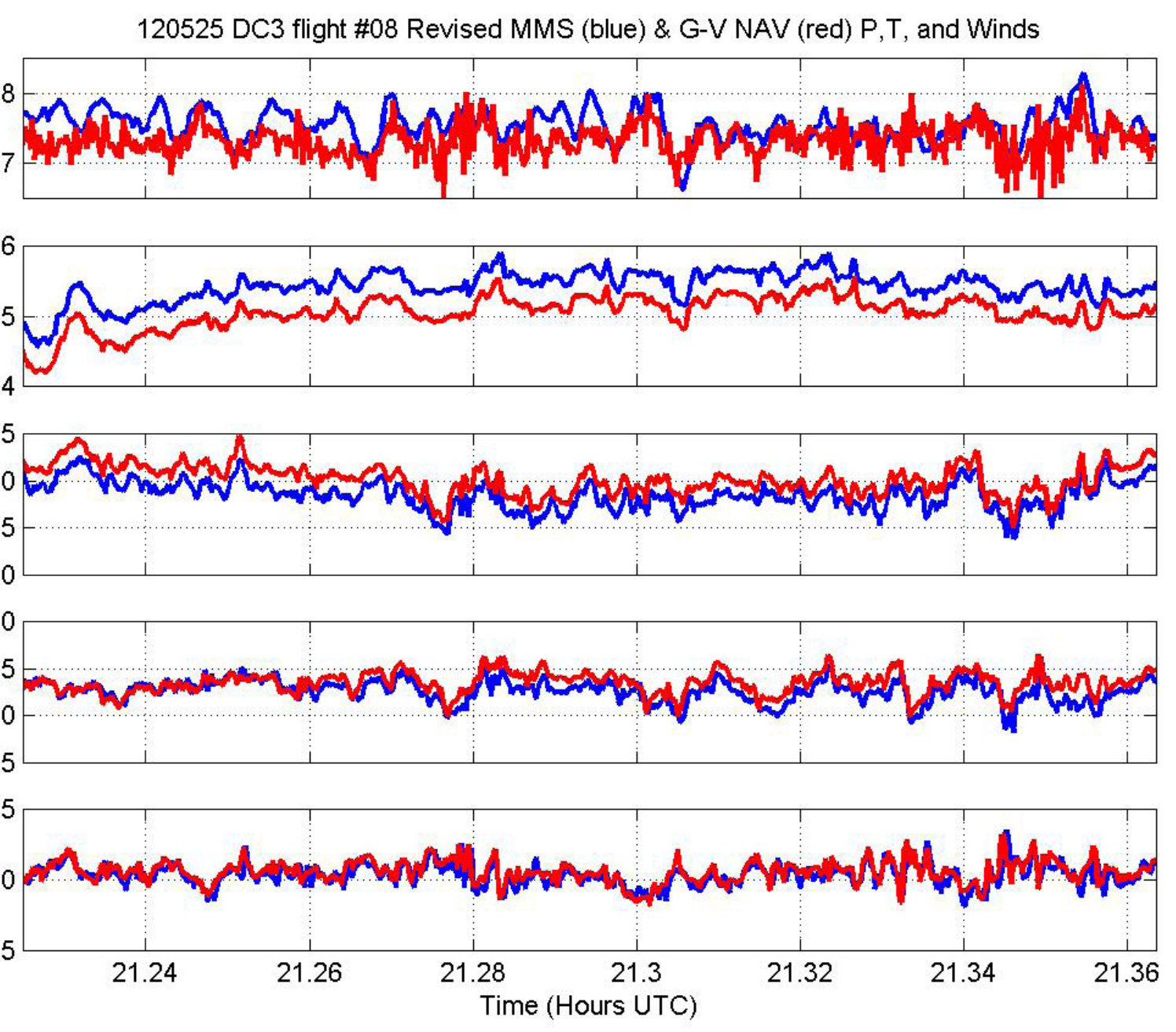

Figure 1 -- DC-8 MMS/G-V NAV Comparison at 1.9 km altitude on 120525. U,V, and W have similar variability; vertical winds are nearly identical. G-V static pressures exhibit high frequency variations (most likely instrument noise); this feature is not a characteristic of either the temperature or wind data.

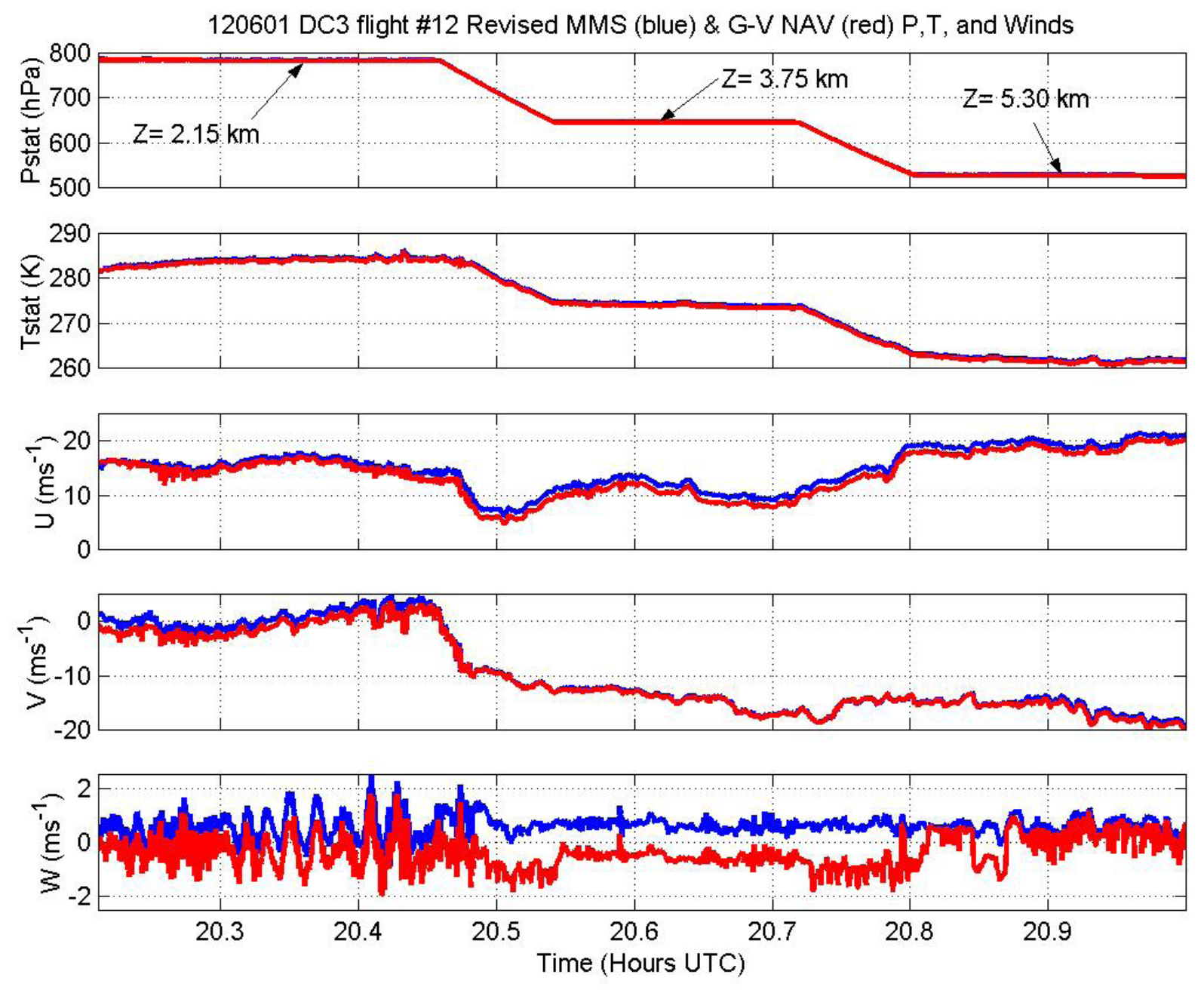

Figure 2 -- DC-8 MMS/G-V NAV Comparison during a stairstep climb from 2.15 to 5.3 km altitude on 120601. G-V vertical winds show larger high frequency variability and a downward bias during aircraft ascents. U,V and T data have relatively smaller biases at this level.

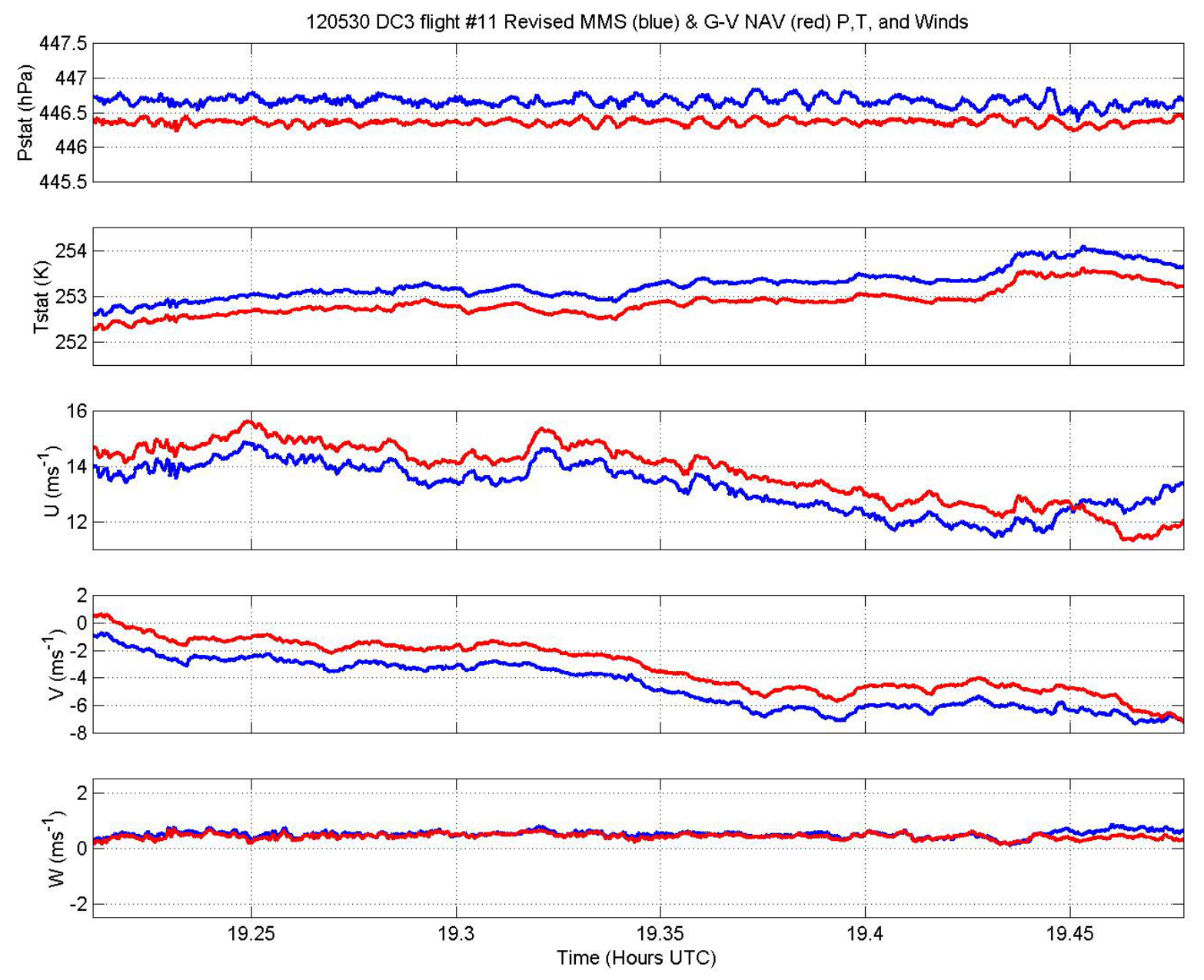

Figure 3 -- DC-8 MMS/G-V NAV Comparison at 6.6 km altitude on 120530. At this level, P, T, U and V data all show discernable biases. Vertical winds are nearly the same, but data from both instruments show a small positive bias. Dynamic response to small short-period (10-30 sec) atmospheric oscillations is nearly the same for both.

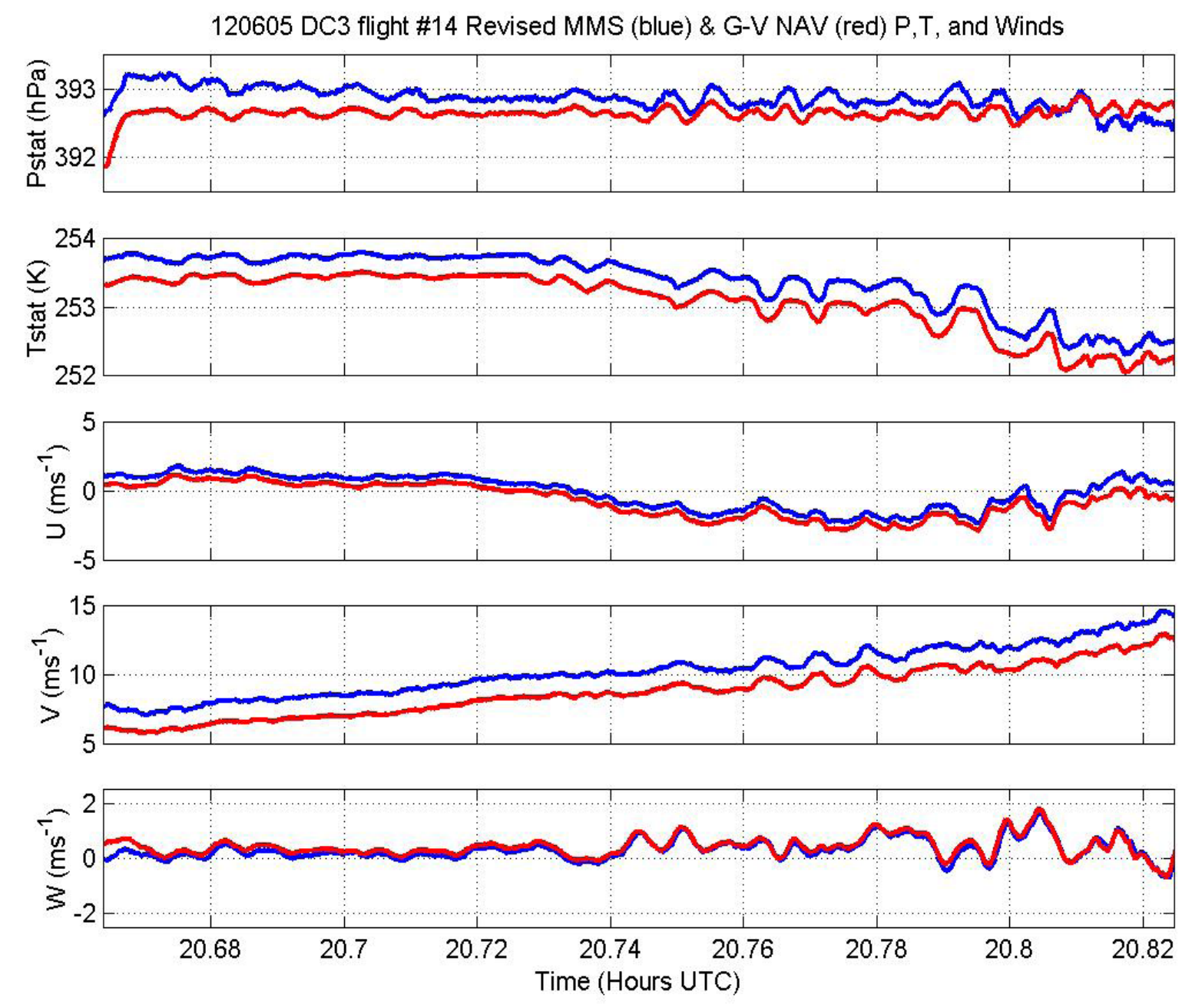

Figure 4 -- DC-8 MMS/G-V NAV Comparison at 7.65 km altitude on 120605. The static pressure bias changed by ~1.0 hPa between the start and end of this flight leg. But at this altitude, temperature gradients drove changes in T much more so than errors in P. Horizontal wind biases are relatively constant, with most of the error in the V component. Vertical wind data are a close match.

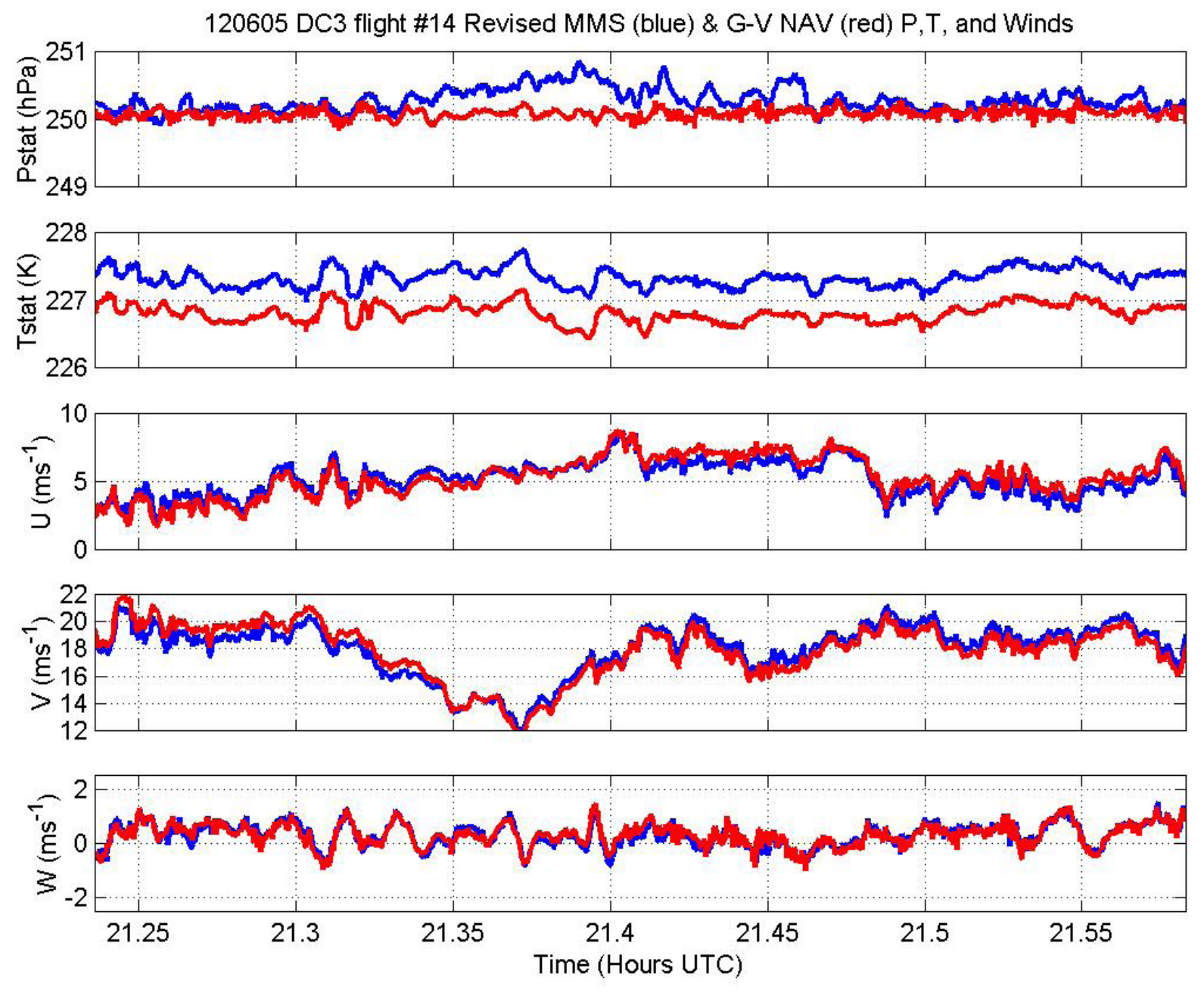

Figure 5 -- DC-8 MMS/G-V NAV Comparison at 10.8 km altitude on 120605. The two aircraft executed a coordinated turn between 21.35 and 21.45 hours (UT), causing the DC-8 altitude to drop slightly. MMS temperatures are warmer. All three wind components closely track each other before, during, and after the turn.

From the level flight data, overall difference profiles in P, T, U, V, W and GPS altitude (Z) are displayed in figure 6 below. Weighted mean differences are statistically significant for P and T. For the winds, overall biases are small relative to their uncertainties, which are larger at low altitudes. The uncertainty in W is half of that for U or V. If we could assume that one of the instruments could be used as a measurement standard, the accuracy of the other would be estimated as

$$E = \sqrt{B^2 + U^2}$$

where E is the overall error, B is the bias, and U is the uncertainty. For example, the accuracy of P would be ± 0.30 hPa; for T, it would be ±0.41 K. However, this assumes the source of error is from one platform. More likely, each instrument has independent indeterminate errors which sum in quadrature like B and U.

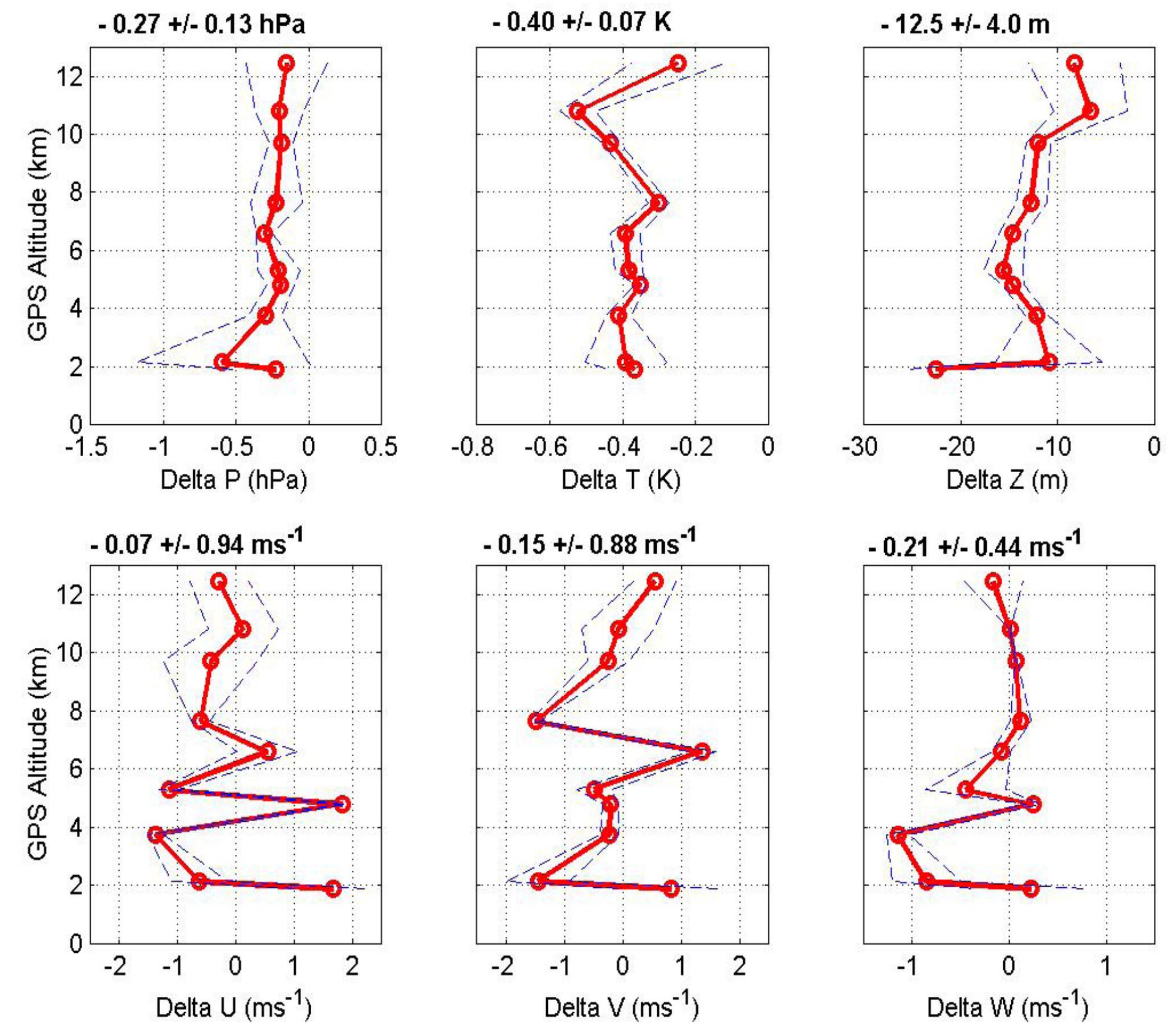

Figure 6 -- Overall differences between the NSF/G-V NAV system and the NASA DC-8 MMS, for the 10 level flight legs described in the text. Flight level means are depicted by the solid red line, while the uncertainty of those means are indicated using dashed lines to the left and right throughout the composite profile. The overall weighted mean and the estimated population standard deviation are shown above each panel.

DC-8 MMS versus Vaisala RS92-SGP Radiosondes:

During DC3, the NASA DC-8 performed numerous spiral ascents and descents to sample the convective environment. Four of these profiles were flown in close proximity to Vaisala RS92-SGP radiosondes launched by two NCAR sounding stations: the Mobile Integrated Sounding System (MISS) based at Fort Morgan, CO, and the Mobile GPS Advanced Upper Sounding System (MGAUS) launched at various locations around northern and central Colorado. These sondes provide P, T, U and V, as well as GPS altitude (Z) data that were used as a reference height. The uncertainty of the RS92-SGP is ± 0.5 hPa (Pressure), ± 0.2K (Temperature), and ± 0.15 ms^{-1} (Wind Velocity), based on standard deviations of differences between twin soundings. Accounting for bias, the overall accuracy is ± 1.0 hPa (Pressure), ± 0.5K (Temperature), and ± 20 m for Z (no figure of merit is provided for winds). The figures below show P, T, U and V differences between each sonde and the MMS:

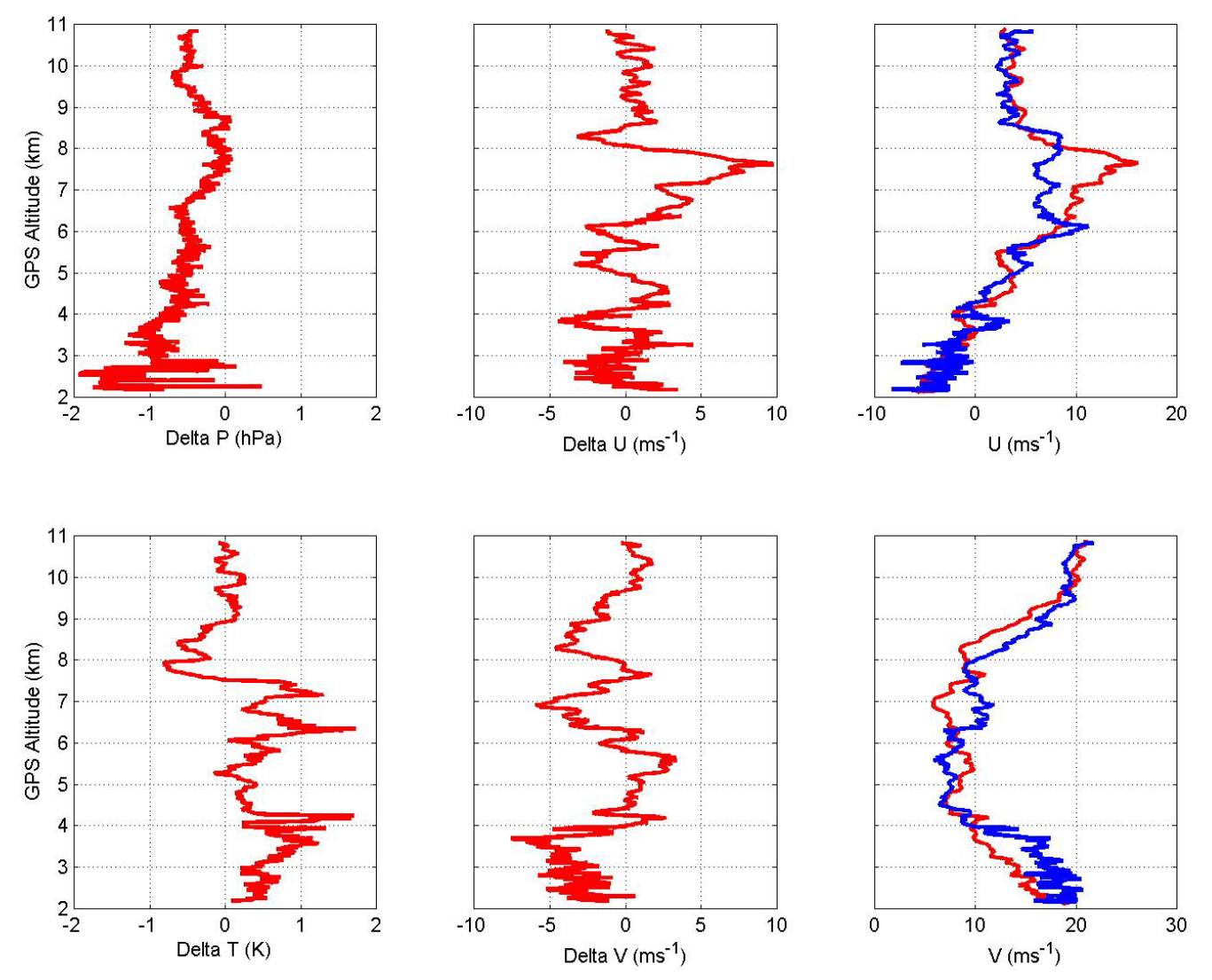

Figure 7 -- DC-8 MMS/NCAR MGAUS comparison for 20120605 (launch at 21:58:54 UT). The launch site was at 40.336 N latitude, 104.69W longitude. This placed the launch only ~24 km and just 6 minutes away from the mean DC-8 position during its spiral descent from 10.9 to 2.1 km altitude. Spatially and temporally, this was the closest of the four sondes, resulting in optimal agreement between the measured fields.

The right panels of this figure as well as figures 8,9, 10 & 12 show the sonde winds in red and MMS winds in blue.

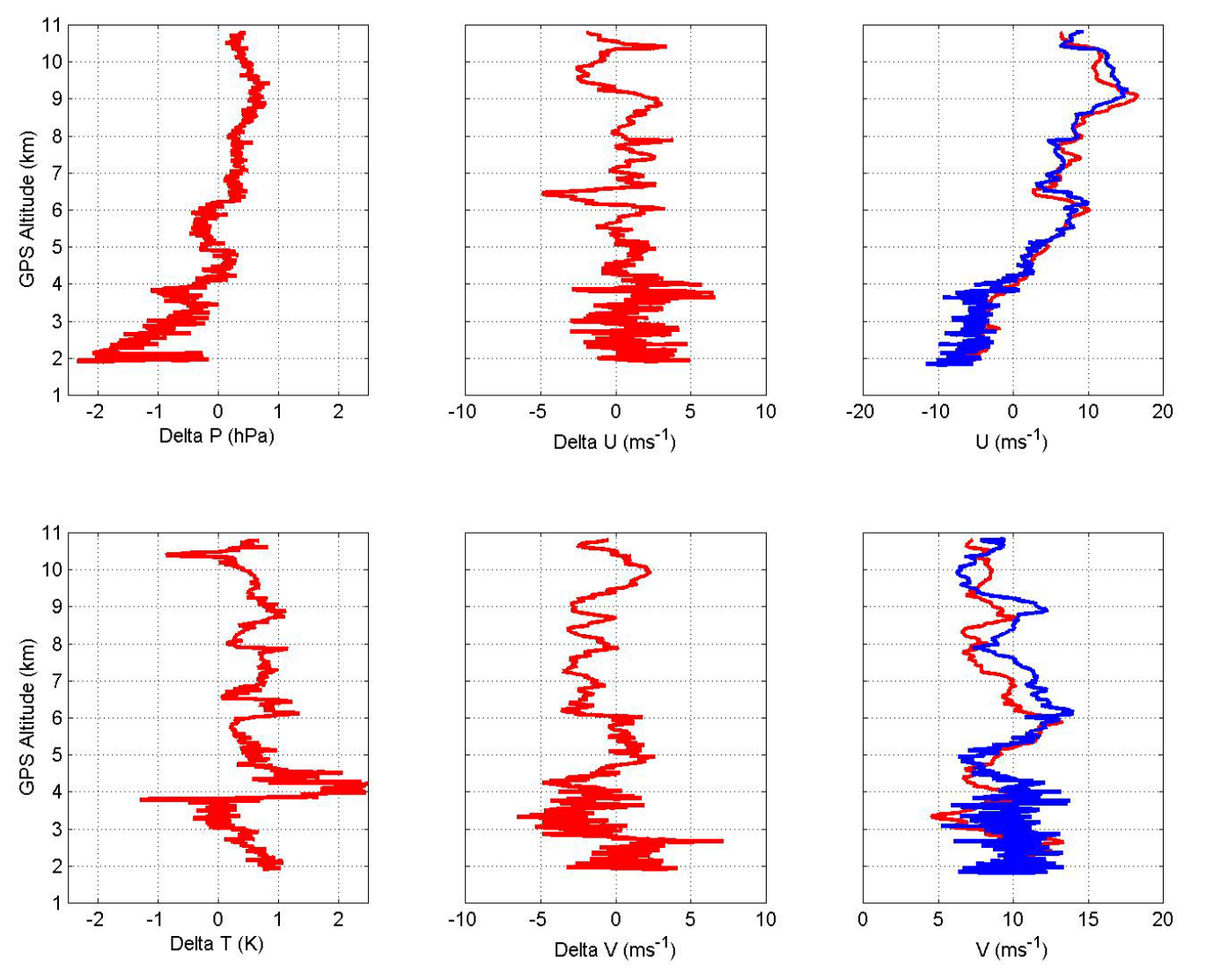

Figure 8 -- DC-8 MMS/NCAR MISS comparison for 20120606 (launch at 19:48:38 UT). The launch site (at Fort Morgan Airport) was at 40.329N latitude, 103.806W longitude. This placed the launch 52 km south of the mean DC-8 position, 29 minutes before the profile was flown by the aircraft. Because of prevailing southerly winds, the sonde was blown toward the DC-8, plausibly reducing the overall wind differences to some degree.

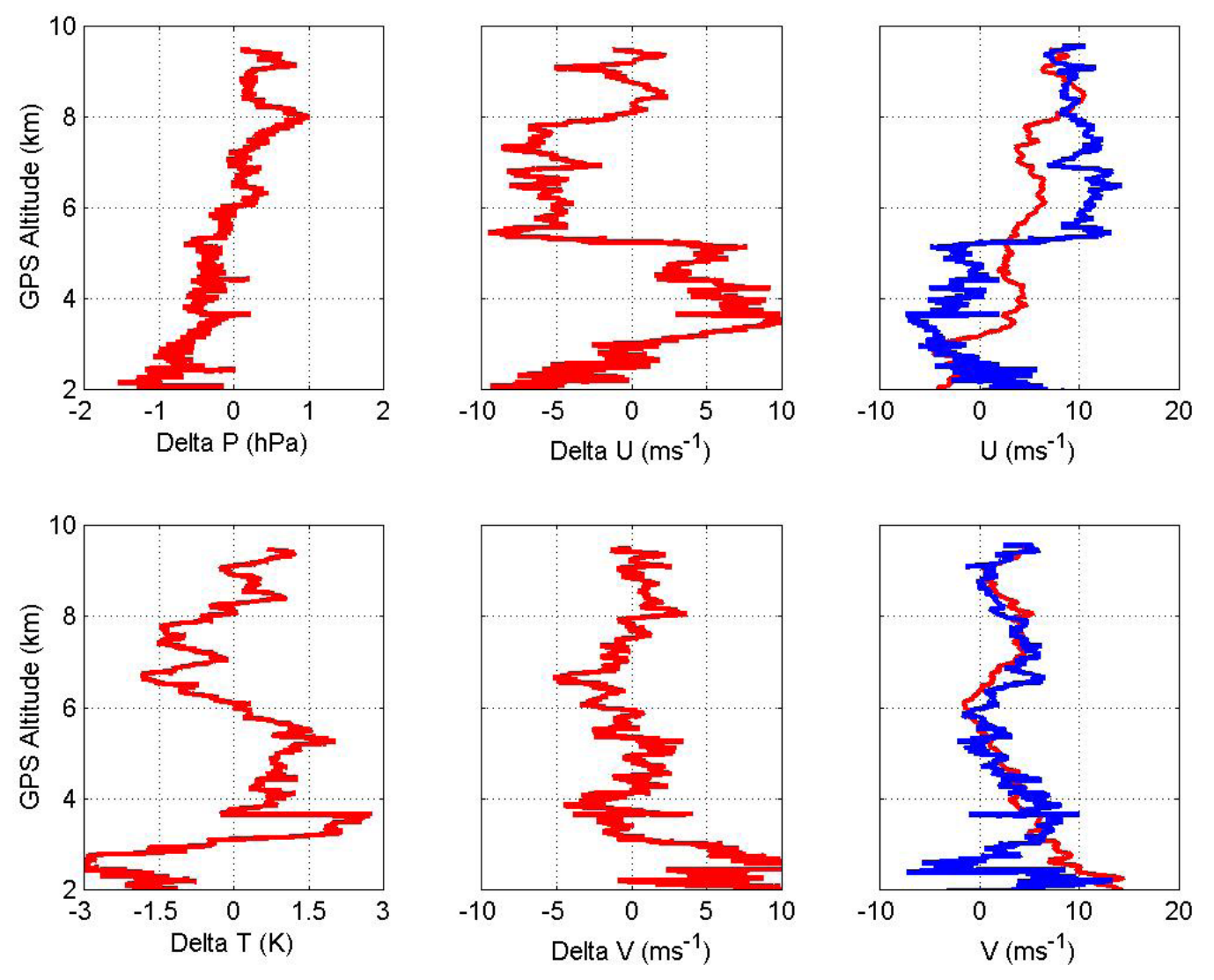

Figure 9 -- DC-8 MMS/NCAR MISS comparison for 20120615 (launch at 19:58:05 UT). The launch site was also from the Fort Morgan Airport (ref. figure 8). While the DC-8 was in the middle of its spiral descent when this sonde was launched, the aircraft position was over the front range of the Rockies at Tibbits Lake (near Fort Collins), 137 km west of the MISS site. While the V wind component at the two locations is similar, a terrain effect on the U component is evident below 8 km MSL. Faster zonal winds are evident aloft, but have been blocked by the mountains below. An MGAUS sonde profile released at 20:48:08 UT was in closer proximity to the aircraft, but was missing much of its data.

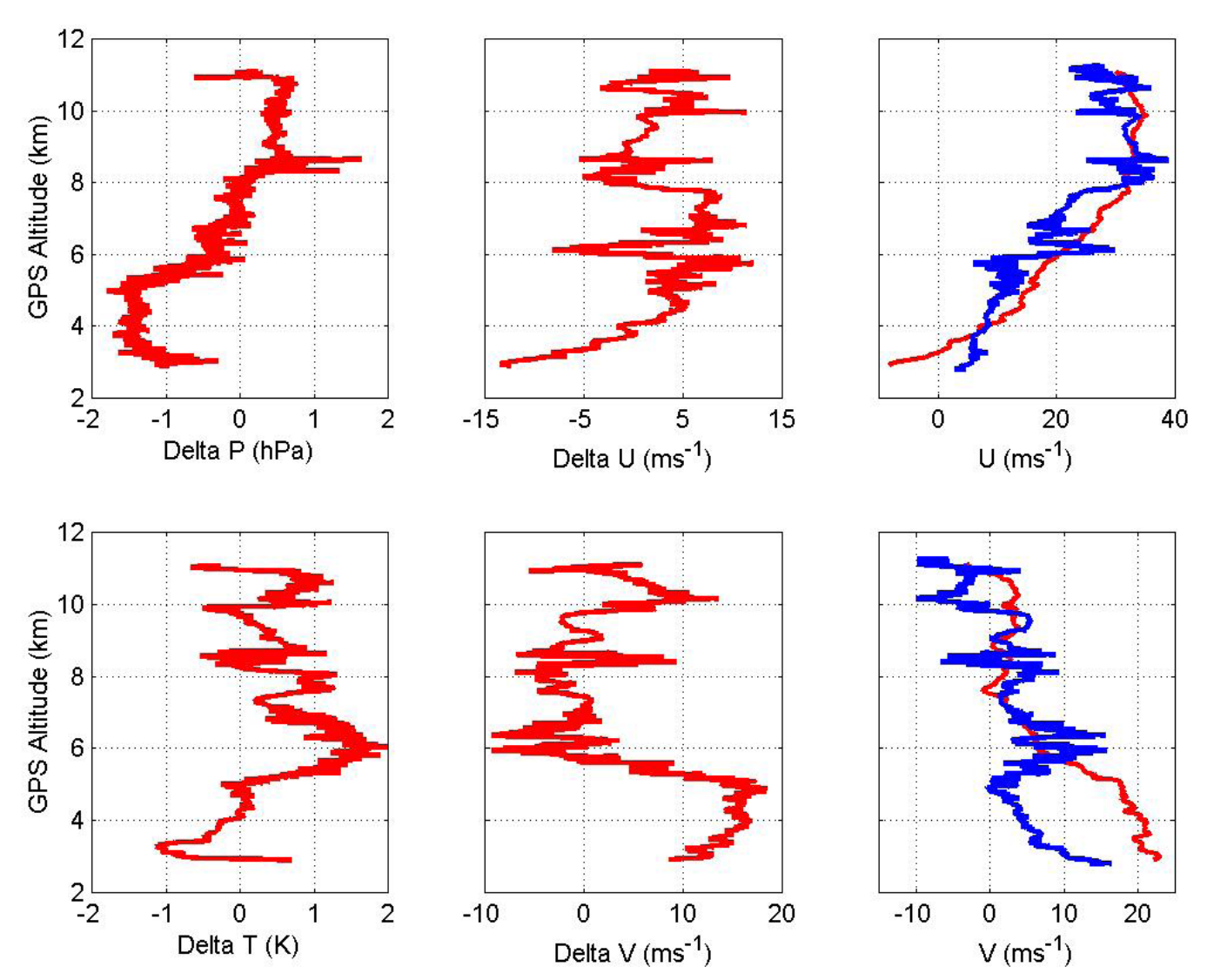

Figure 10 -- DC-8 MMS/NCAR MGAUS comparison for 20120622 (launch at 23:38:03 UT). The launch site was at 40.501N latitude, 103.263W longitude. This placed the launch 30 minutes prior to, and ~84 km west of the mean DC-8 position during its spiral ascent from 2.9 to 11.1 km altitude. Strong wind differences between platforms are evident, especially at low levels.

DC3 Instrument / P.I. / Platforms Involved In This Study:

MMS	P. Bui	NASA DC-8
NAV/Met System	A. Schanot	NSF/NCAR G-V
MISS & MGAUS*	K. Young	Vaisala RS92-SGP

*Courtesy of NCAR Earth Observing Laboratory (EOL)

To compute statistics on the differences between the radiosonde and MMS, data from the profiles were classified in layers up to 2 km deep. Means and uncertainties of the combined differences for each layer were computed; a weighted mean and standard deviation were then calculated from the data in each composite profile.

Figure 11 shows the result of this analysis. Differences in P have a systematic height dependence, but the overall mean is not significantly biased. Radiosonde T is warmer than the MMS temperature by nearly 0.4K. While U & V from the two platforms are within 1 ms^{-1} on average, the differences are highly uncertain.

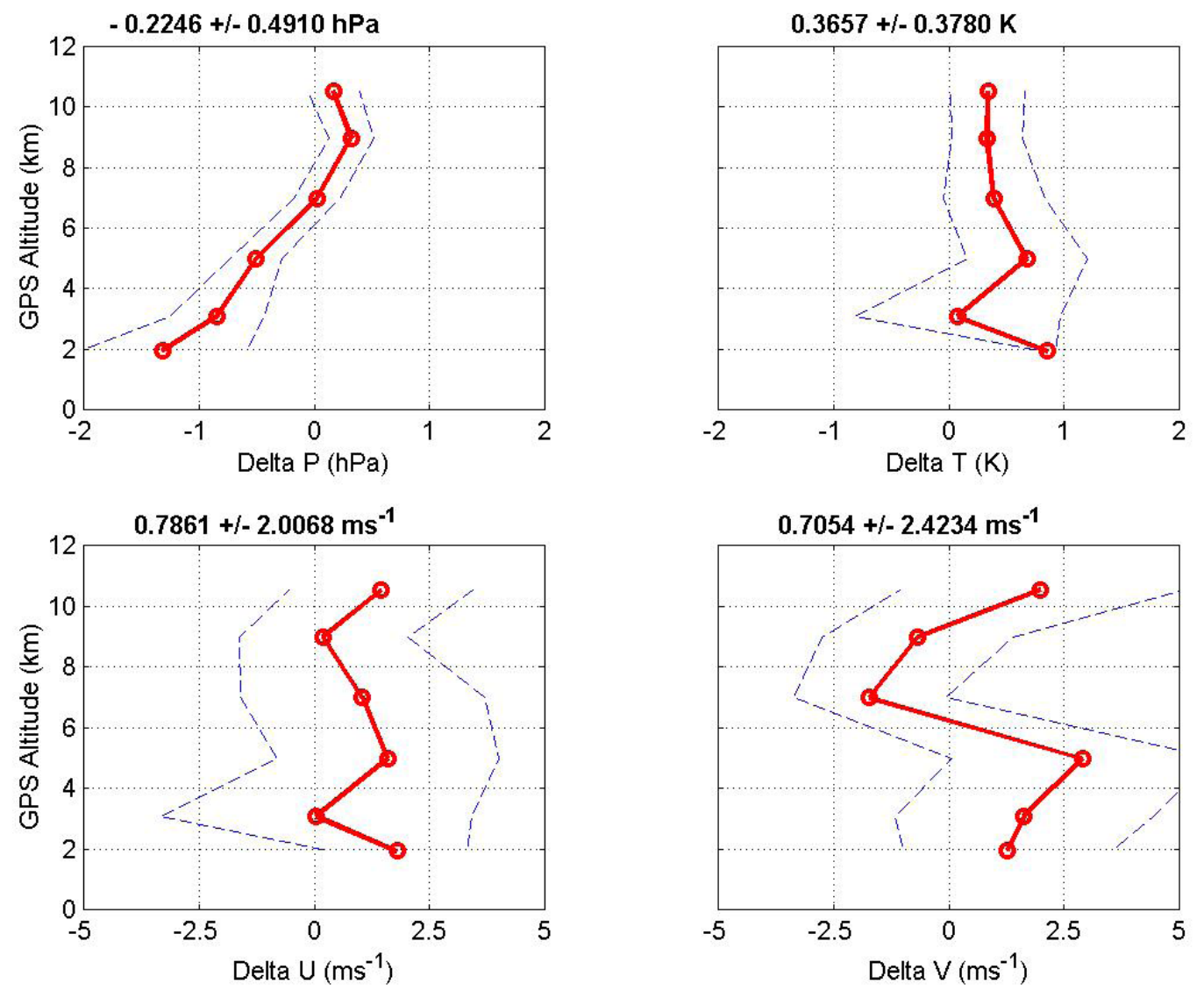

Figure 11 -- Mean and standard deviation of differences between Vaisala RS92-SGP radiosondes and the DC-8 MMS, combining all profile data. The solid red line shows layer means; dashed lines show the layer standard deviations. The weighted mean and estimate of the population standard deviation are shown at the top of each panel for P, T, U and V.

Discussion and Conclusions:

Because P differences diminish with altitude, the ±20 m uncertainty in the sonde's GPS altitude may bias the pressure comparison between the sondes and MMS. If we assume the G-V NAV system has the same P error as MMS, the accuracy of either is ± 0.21 hPa. If we assumed negligible altitude bias in the sonde data, its pressures would be accurate to ± 0.49 hPa, in agreement with its specifications.

MMS T is cooler than the sonde T by 0.37K, but warmer than the G-V NAV T by 0.41K. If we make the same assumptions as stated above, the accuracy of either the MMS or G-V temperature is ± 0.29K, and the sonde T is accurate to ± 0.44K.

Following the same logic, the accuracy of either the MMS or G-V wind components are ± 0.66 (or 0.63) ms^{-1} for U (or V). This means horizontal wind velocity on either aircraft is accurate to ± 0.91 ms^{-1}, but is ±2.25 ms^{-1} for the sonde. For vertical wind, assigning equal error to MMS and G-V systems leads to an accuracy of ± 0.34 ms^{-1}. Combining all (U,V,W) components, the 3-D wind velocity accuracy is ± 0.97 ms^{-1}.

While the assumptions made may be idealistic, an aircraft intercomparison always has an advantage over a sonde comparison, as separation effects are negligible. Figures 10 and 12 show how two Vaisala sondes, just 30 km apart, have vastly different wind and temperature profiles. Sonde data can provide constraints for an aircraft intercomparison such as this, but since balloon-borne data exhibit inconsistent quality, many profiles are needed to obtain statistically useful results.

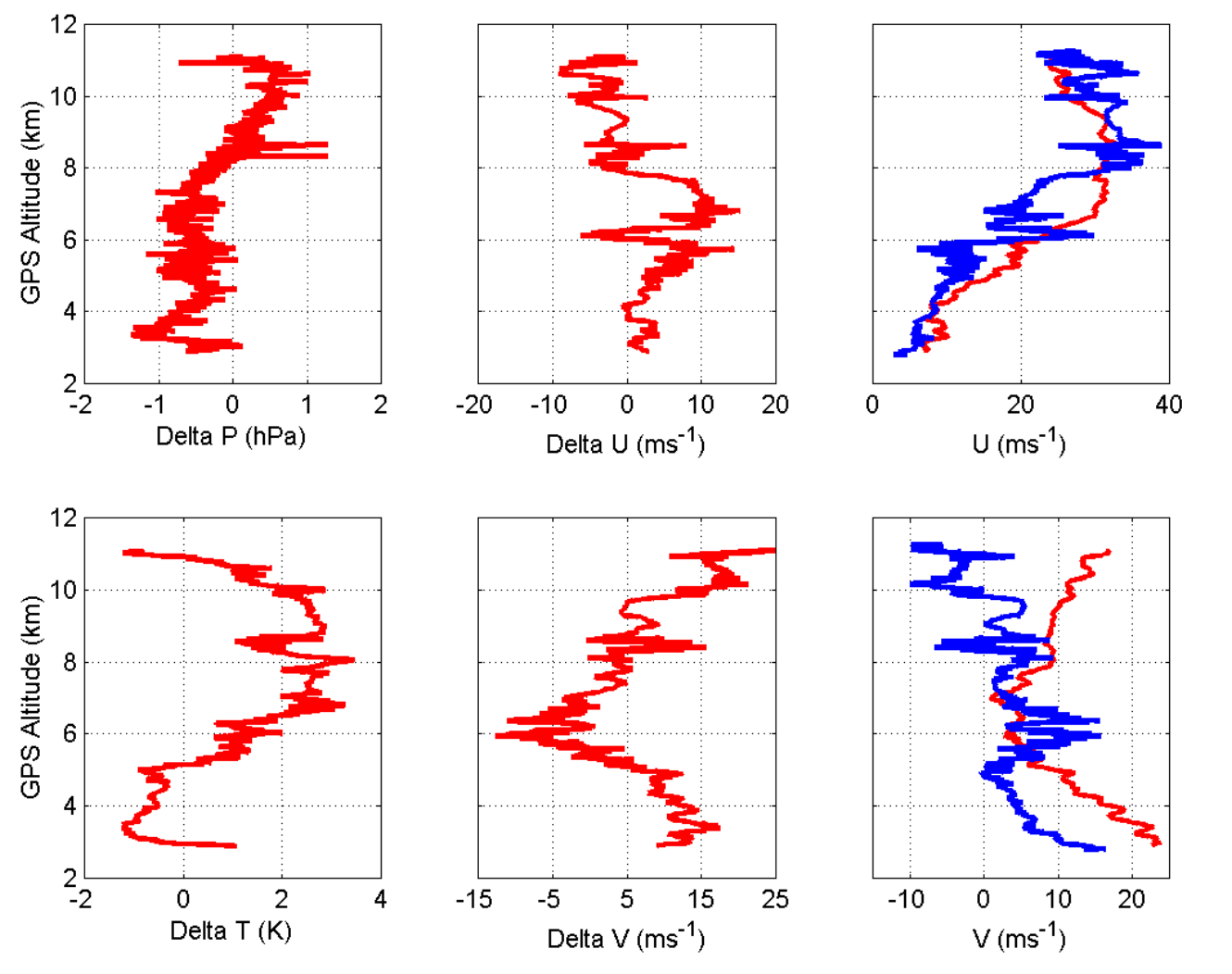

Figure 12 -- DC-8 MMS/NCAR MGAUS comparison for 20120622 (launch at 00:34:08 UT on 20120623). The launch site was at 40.748N latitude, 103.114W longitude, just ~30 km NNE and 0 hours, 56 minutes later than the MGAUS launch shown in figure 10. This sounding was rejected from this analysis because of questionable data. Mid-level temperatures were 1.5K warmer, and the V wind component was nearly 15 ms^{-1} greater at the highest altitudes, relative to the prior sounding.

Acknowledgment:

This work is funded through, and has been made possible by, the recently enacted ARC-CREST Cooperative Agreement between NASA Ames Research Center, with the Bay Area Environmental Research Institute (BAERI).

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