FINAL REPORT

Results of the

June 2005 WVSS-II – Rawinsonde Intercomparison Study

Submitted to NOAA/NWS/OST by

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Background – The University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS) conducted a ground-truth assessment of the WVSS-II systems being flown on UPS aircraft at Louisville KY for an approximately 2 week period from 13-24 June 2005. This report is intended to provide an early look at the general results of the experiment, in terms of the success of the planned observing strategies and some first intercomparison results.

Observing Systems Available for WVSS-II Validation - All non-aircraft observations were made from a site on the Kentucky Air National Guard (ANG) facility immediately adjacent to the Louisville airport. Observations were taken from the portable "AERIbago" vehicle 24 hours/day during weekdays throughout the full period. Primary observational systems included a portable surface station reporting temperature, dewpoint temperature and wind, a NWS standard Ceilometer, a GPS receiver for use in calculating total precipitable water (GPS-TPW), an upward looking AERI infrared interferometer to measure boundary layer temperature and moisture at 10 minute temporal resolution, and a Vaisala RS-92 GPS rawinsonde system.

Most of the automated observing systems provided data continuously throughout the two-week co-location experiment, with the exception of the GPS-TPW system, which experienced several outages due to temporary power failures at the ANG facilities.

All data taken by the UW-CIMSS systems have been archived at UW-CIMSS for future use. These data are available at: ftp://ftp.ssec.wisc.edu/validation/exper/wvssii/

A full set of aircraft data has also been collected from the FSL MADIS data retrieval system for use in the UW-CIMSS assessment.

Status of Rawinsonde vs. Aircraft Co-location Data - The most critical observations for this initial report of results were the rawinsonde reports. Three rawinsonde launches were scheduled for each night, one immediately before the majority of the UPS arrivals at about 0240 UTC, another between the rush of descents and ascents at about 0645 UTC and a third after the majority of departures at about 0915 UTC. Exceptions were made on Mondays and Fridays, when scheduling of WVSS-II equipped aircraft by UPS supported only 2 launches on several occasions. The schedule was designed in part to focus on ascents, since there are known problems with descent reports, as discussed later.

A total 27 of the 28 attempted launches were successful, with the one unsuccessful attempt due to equipment failure. Thirteen rawinsondes were launched during the first week and 14 during the second. The rawinsonde data were sent in real time to FSL for display on their ACARS display web site. On a typical day, about 5-10 aircraft co-locations were available, but not all fell within the tightest time window used in this report.

Constraints of initial assessment - Comparisons of the WVSS-II data with the rawinsonde standard were limited by the following constraints.

1 – Prior to the experiment, an occasional problem was identified in the WVSS-II instrument. This problem produced erroneous reporting in areas of high humidity and clouds, but only in descent. This problem will be addressed through a future hardware change. However, since the objective of the experiment was to assess the difference in good quality reports made by both the aircraft and rawinsonde, it was decided to focus the comparison on rawinsonde co-locations with aircraft ascents.

2 – A second problem was also discovered in some of the early installed WVSS-II units in which a small amount of moisture was entering the laser sensing unit and thereby biasing the moisture reports upward. This bias was especially apparent in areas of extremely low mixing ratio (typically at higher altitude and colder temperatures). This problem was addressed in some of the units that were installed later and are available for some of the experiment, but was not corrected for all units before the end of the experiment. As such, could be calculated either by a) excluding data from sensors with known and very large biases and/or 2) limiting assessments of WVSS-II performance to regions where the observed mixing ratio was greater than 2 g/kg. Option 2 was used for this report.

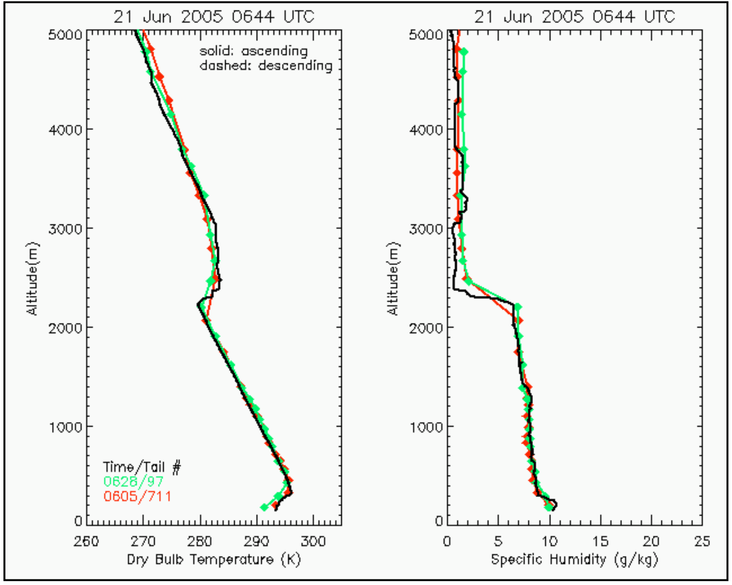
3 – Since WVSS-II sensors continued to be installed on the UPS aircraft throughout the experiment, the number of available matches and mix of reporting units daily varied during the test period.

4 – A number of the aircraft had biases in their temperature sensors, which would cause errors in calculated Relative Humidity. Therefore, initial assessments of moisture were made in terms of the primary WVSS-II water vapor observation, which is mixing ratio (as reflected in specific humidity).

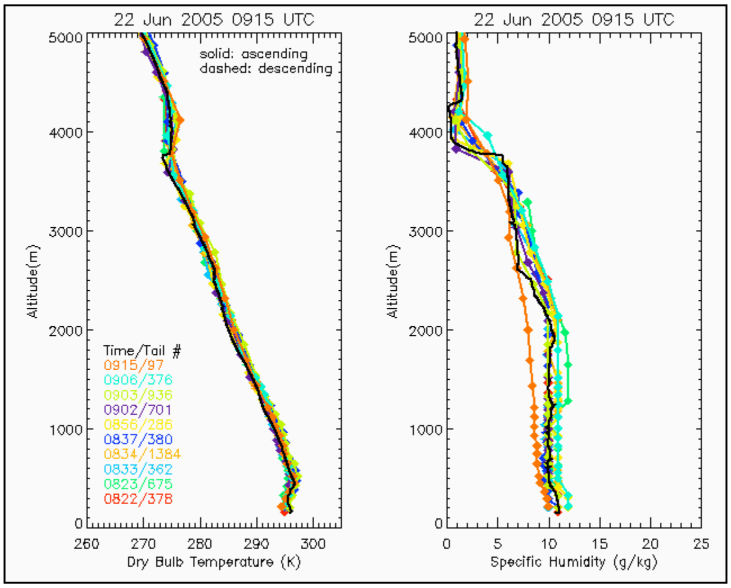
5 – It should also be noted that a deficiency was noted in the way the WVSS-II observations are being reported to the ground. Reports of less than 10 g/kg had precision of at least 0.1 g/kg, while reports greater than 10 g/kg had precisions of only 1 g/kg. As such, the accuracy of the assessments had limits that varied from +/-0.05k/kg for reports between 0 and 10 k/kg to +/-0.5g/kg for values above 10 g/kg. This factor will erroneously amplify the variability in the co-location results. Attempts will be made to stratify the assessments statistics to reflect these differences in the future.

Conventions for identifying aircraft/rawinsonde co-locations - Based upon experience gained in the 3 previous aircraft/rawinsonde co-location tests performed by UW-CIMSS, all co-location data used for the initial assessment were limited to time and space windows of +/- 60 minutes and 50 kilometers. This was done to minimize the impact of transient weather features in the area, such as frontal passages, while assuring that an adequate number of reports were available for statistical calculations.

When the above conditions are applied to the full set of available data, a total of 49 ascending rawinsonde/WVSS-II matches were still available for comparison (from aircraft ascents only). The matches included data from 13 (there were 16 w/ matches, but 3 of them were descending only) rawinsonde releases and up to 50% of the approximately 25 aircraft that could have been available in the study any day. Numerical differences between the aircraft and rawinsonde data were calculated at each aircraft reporting level and then 'binned' into 10 hPa deep layers for display and statistical calculations.

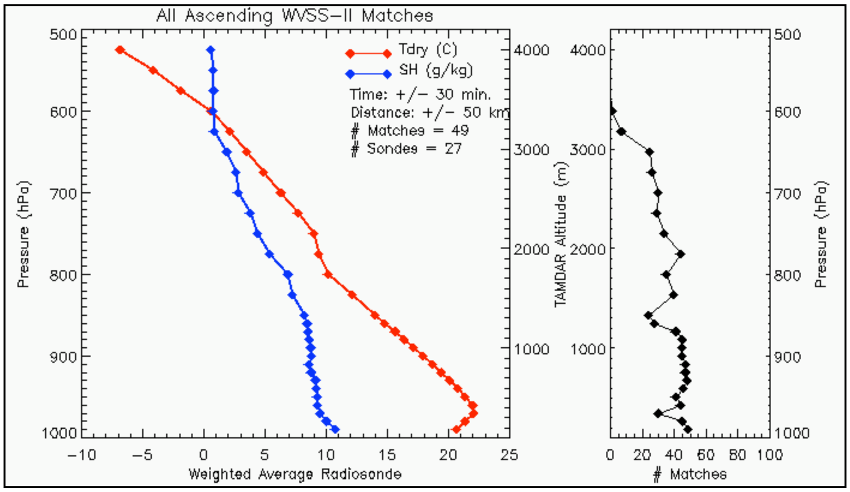


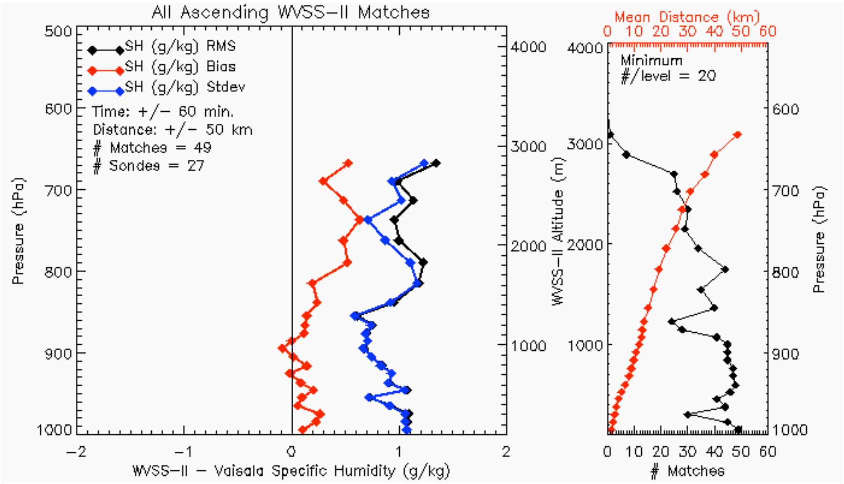
Displays of rawinsonde and aircraft profiles of temperature and specific humidity were made for each of the 13 rawinsonde-aircraft match-up times (See Appendix). The individual sounding comparisons showed a range of similarity and dissimilarity between the 2 observing systems, related apparently to the specific mix of aircraft reporting and the consistency of the weather regime present each day. For example, the two ascents that occurred just before the 0644 UTC rawinsonde launch on 21 June showed excellent agreement between the aircraft data and the rawinsonde data, both for temperature and for specific humidity. Both data sets captured the change in conditions above and below the inversion near 2300m for both temperature and humidity. These two sets of aircraft reports, taken 23 minutes apart, also showed excellent agreement with one another.



By contrast, the reports taken around the 0915 UTC rawinsonde launch on 22 June showed a much greater spread not only between the individual reporting aircraft, but also between the aircraft and the rawinsonde report. In this case, the majority of the reports reflected the rawinsonde values very closely. However, two of the aircraft reports differed from the rawinsonde data by from 1 to 2 g/kg. It should be noted that one of these 'outlying' reports was taken significantly before the rawinsonde launch.

Summary Statistics for the full period - Weighted average rawinsonde reports were compiled for the full test period. The averages were weighted according to the number of aircraft matches that occurred for each rawinsonde launch. In this way, an individual sounding during an extreme weather event but with only 1 aircraft match-up would have less influence on the average than a report with many aircraft matches. The temperature profile of these nighttime soundings showed weak temperature inversion in the lowest 50 hPa, capped by a nearly adiabatic layer. A weak secondary temperature inversion is also present between 800 and 750 hPa. The moisture profiles showed nearly constant (slightly decreasing) specific humidity for the surface to the base of the secondary temperature inversion, a structure consistent with a boundary layer that had been thoroughly mixed during daytime. Above that level, specific humidity decreases steadily to 500 hPa. The plot of number of matches on the right panel shows the decrease in number of reports used in the intercomparison due to the 2 g/kg lower limit that was imposed. It should also be noted that since the average specific humidity in the lowest 150 hPa was near 10g/kg, truncation error might have affected comparison in this region.



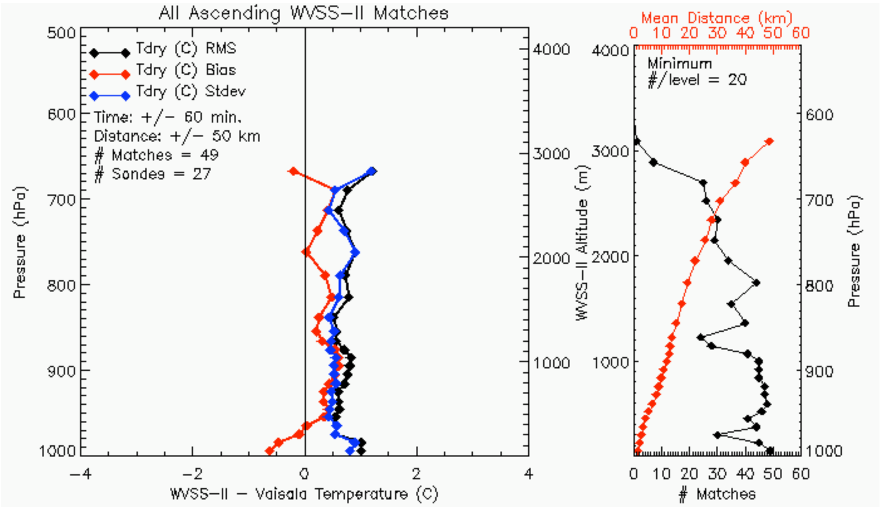


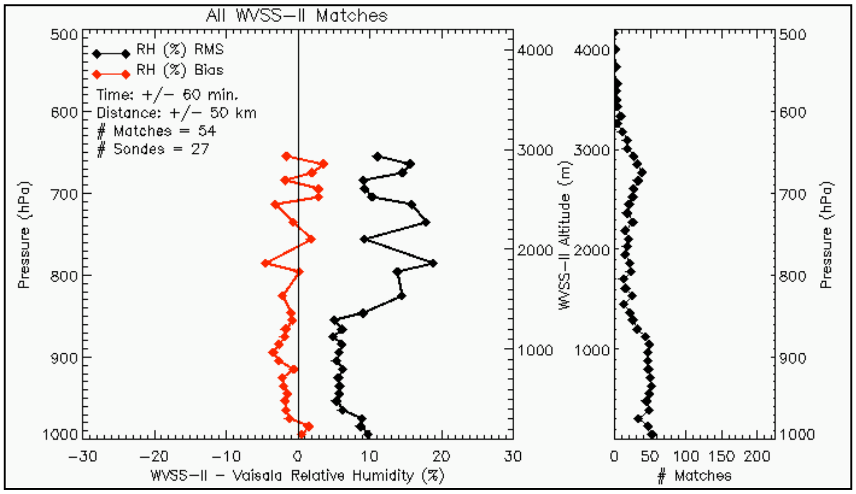
Statistical fits of the WVSS-II specific humidity data to the rawinsonde reports for all of the ascending aircraft were made for the full observation period. Although a minimum of 20 match-ups was needed to calculate significant statistics, most levels used between 30-40 observational matches. All ascending aircraft data with specific humidity measurements greater than 2 g/kg were included, independent of known specific instrument errors.

Specific Humidity bias results show very small, though generally positive biases (0.1 to 0.2 g/kg) from the surface up to nearly 800 hPa. Above that level, the bias increases to between 0.2 and 0.4 g/kg. Analysis of this bi-modal bias structure has not yet been undertaken.

The Root Mean Square (RMS) fits of the aircraft data to the rawinsonde reports showed variability of about 1 g/kg from the surface to 800 hPa. Above 800 hPa, RMS values increase to between 1 and 1.5 g/kg, due in large part to the increased biases found in the region.

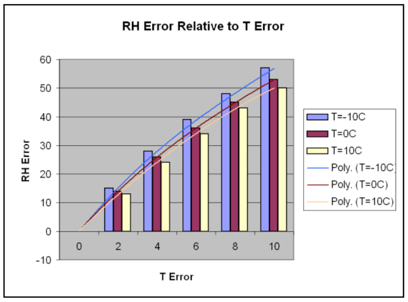
Although not part of the WVSS-II system itself, statistics were also obtained for the aircraft temperature data. These data show a clear warm bias at all levels above the immediate boundary layer. Values range from about 0.0 to 0.5^{o}C. RMS measures of variability ranged from about 0.5 to 1.0^{o}C.



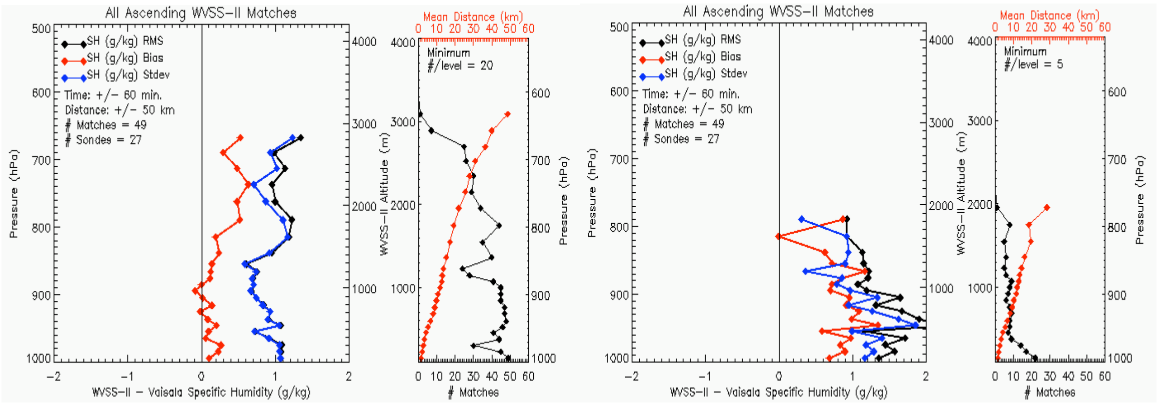


If the mixing ratio data had been converted to Relative Humidity as a means of providing comparisons with earlier WVSS-I assessment results, the warm bias shown in the temperature data would have been transferred to the humidity observation incorrectly by making the derived Relative Humidity data appear too dry.

The RH results below confirm this assumption. Indeed, the derived Relative Humidity data show a dry bias of about 2-3% at almost all levels. Calculations were made that compare the amount of error expected in the derivation of RH, relative to specified errors in temperature. These results indicate that biases in temperature of 0.5^{o}C will produce biases in calculated RH of 3.5 to 4%.



If the mixing ratio intercomparisons were further partitioned between WVSS-II values less than 10 g/kg and those above 10 g/kg, the detrimental effort of the change in data reporting precision from 0.1 g/kg to1.0 g/kg (which occurs at 10 k/kg) becomes readily apparent. Although only a few reports fall within the larger category during the Louisville test (and the RMS and SD statistics may therefore not be entirely representative), a degradation in bias (increasing to nearly 1 g/kg) and the near doubling of the low-level RMS and SD are readily apparent for values greater than 10 g/kg.

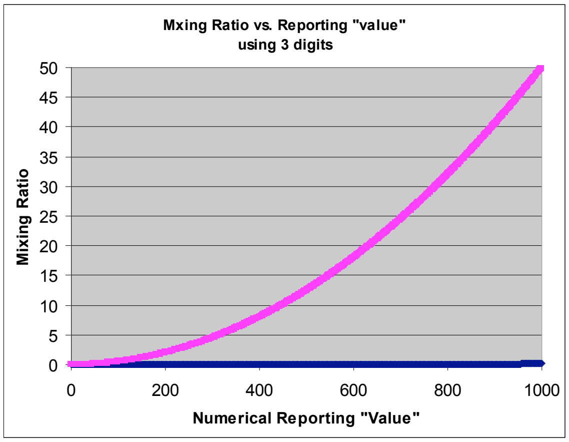


Comparisons of Bias, RMS and SD for specific humidity co-locations divided between observations less than 10 g/kg (left) and greater than 10 g/kg (right).

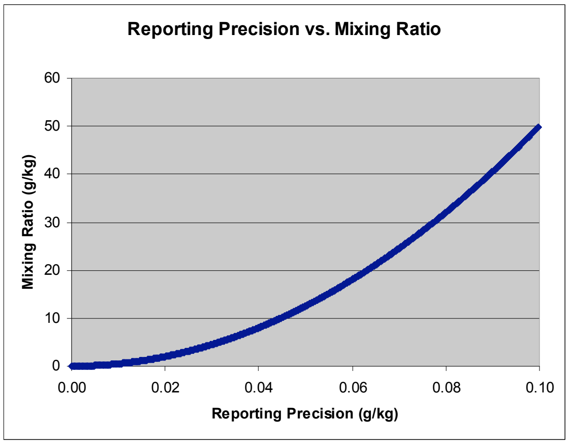
For reported values less than 10 g/kg values (where reporting precision is greater and where abundant match-ups were available), the RMS fits of the aircraft data to the rawinsonde reports were reduced by nearly 50% to about 0.5 g/kg from the surface to 800 hPa, instead of the bulk values of nearly 1 g/kg. Similarly, above 800 hPa, RMS values were closer to 1.0 g/kg. The biases also changed slightly at lower levels, with marginally negative biases below 850 hPa. As such, mixing ratio values reported using 0.1 g/kg precision showed that the WVSS-II systems performed well within NWS and WMO requirements during these tests.

Suggestion for alternative compression for air-to-ground data communication – As noted earlier, the convention used to transmit the WVSS-II data from aircraft to ground limits the precision of the reports to only 2 digits. In practice, however, a total of three digits are available for the data transmission, two for the mantissa of the report and 1 for the power of 10 (assumed to always be negative). Part of the reasoning for the decision to use this type of format was probably related to desires both to reduce communication costs by limiting the number of digits added to the weather data messages, and to obtain reports of very low moisture amounts.

Unfortunately, the process of rounding or truncating data to the nearest two digit integer can add substantial error to the reports, as has been noted above. Additionally, this error varies according to the value of the reported humidity itself. For example, observations of both 10.6 and 11.4 g/kg would be reported as 11 g/kg, even though the measurements themselves were separated by 0.8 k/kg. Theoretically, this should add between 0.25 and 0.30 g/kg to the RMS comparisons. Expressed in another way, if the saturation mixing ratio in this case was 12k/kg, the transmitted 11 g/kg data would convert to 91.6%, instead of showing relative humidity values of 88.3% and 95% respectively. This range of values of +/- 3.3% has an effect equivalent to a random temperature error of almost 0.5°C. By contrast, if the report had been 9.5 k/kg with the same saturation value, the range of possible observations would have only varied from 9.45 to 9.55 g/kg or 78.75% to 79.58% - a range of only +/- 0.4%.



As an alternative use of the 3 digits that are currently reserved to the coded mixing ratio, a scaled lookup table similar to that shown here, could be used which would spread the typical range of mixing ratio reports over the full 1000 intervals available. This approach would allow values less than 1 g/kg to be reported at about 0.01 g/kg precision, while improving the precision of observations greater than 10 g/kg to vary smoothly form 0.045 to 0.1 g/kg, a major improvement over the current arbitrary precision reduction for weather forecasting and numerical weather prediction applications.



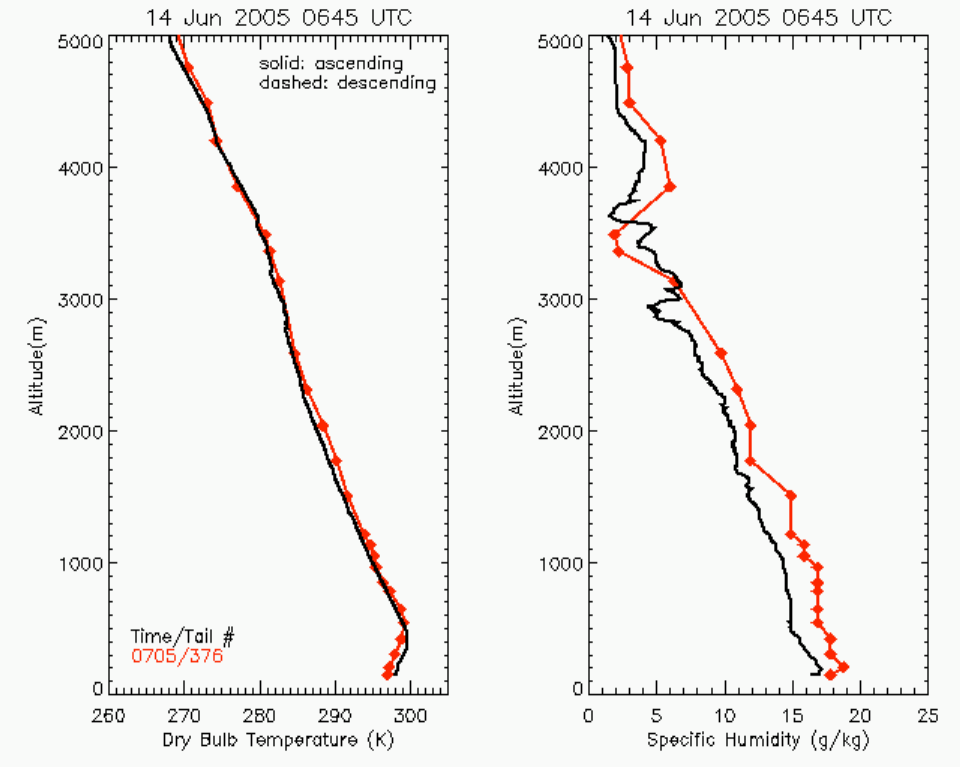
The major negative aspect of this approach is that the data will not be immediately readable directly from the report. However, this should not be a major limitation since most, if not all, users of these data will be receiving the data in BURF messages - which already need to be decoded with computers.

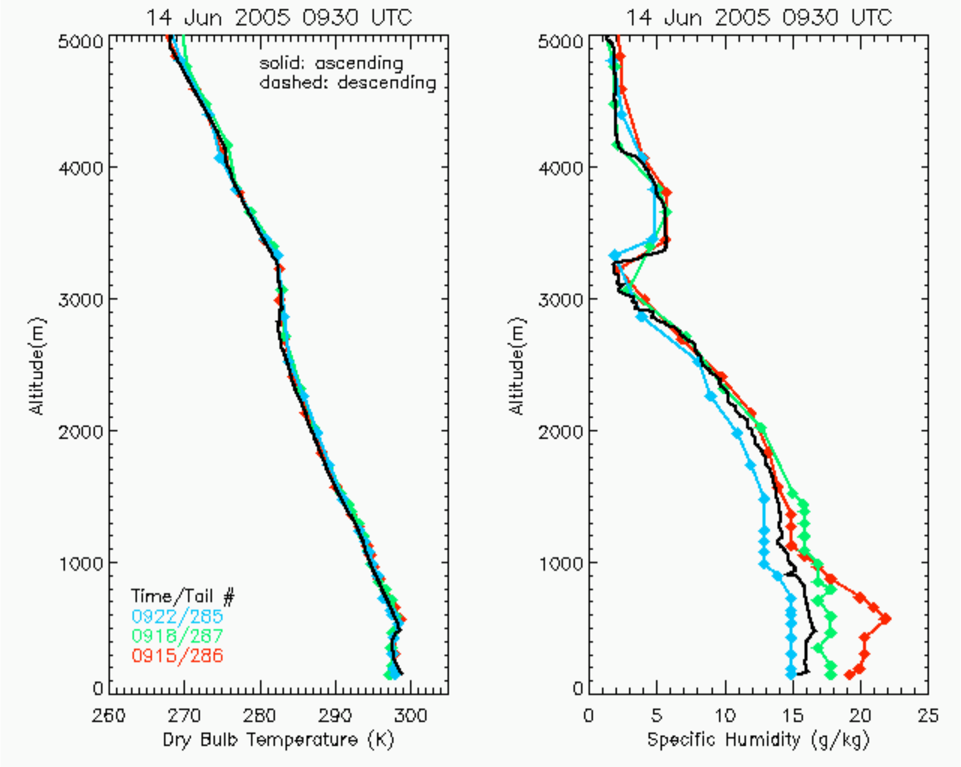
A more detailed working report and proposal are being circulated within the WVSS-II community, the NWS and the WMO at this time. A complete report will be prepared upon approval of the approved new reporting scheme.

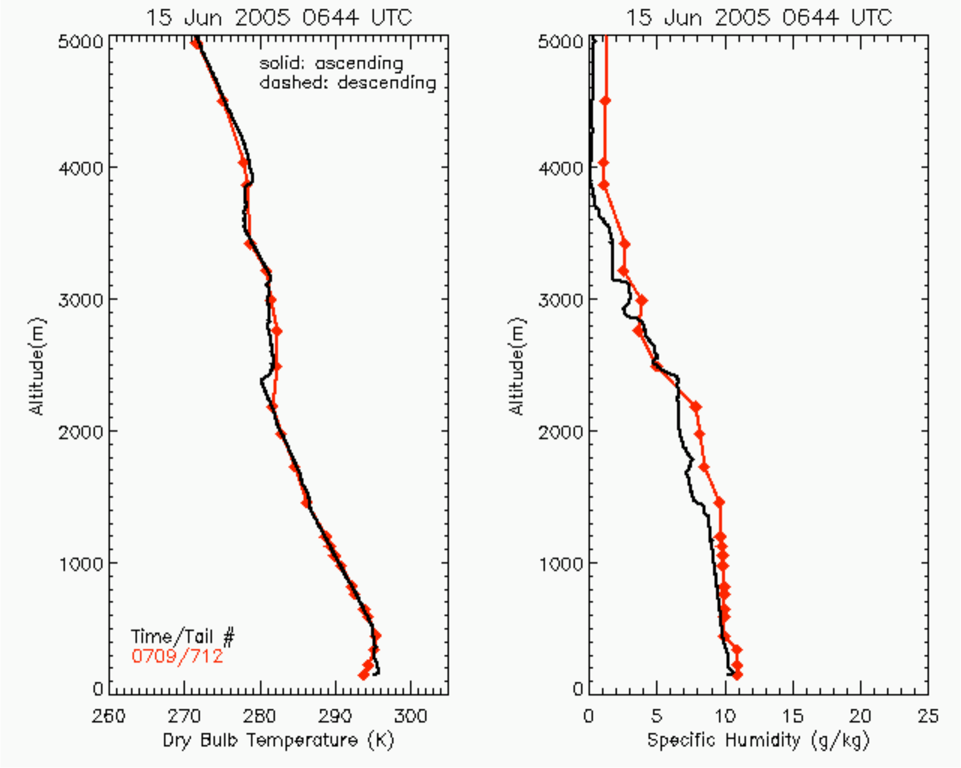
Summary – This report presents a summary of the accuracy of mixing ratio observations made by WVSS-II equipped commercial aircraft during a two-week period in June 2005. The results show a small, but slightly positive bias in the boundary layer, with slightly larger values above. RMS fits average around 1 g/kg. Part of the variability may be the result of encoding conventions used in constructing the transmitted reports for higher moisture values. When statistics are calculated only for reports made with at least 0.1 g/kg precision, the RMS accuracy of the reports increases to between 0.5 and 1.0 g/kg. This accuracy is well within NWS and WMO requirements. As a result of these tests, a formal proposal for changing the reporting precision scheme is forthcoming.

Formal presentations of these results have been made at the 2005/2006 AMS annual meetings, the spring 2006 TAMDAR review and the 2006 Tropospheric Profiling conference. Copies of these presentations are available upon request. The authors would like to acknowledge NOAA Grant 144PH46 and Dr. David Helms for support needed to conduct this study.

Appendix - Comparison for Aircraft Temperature and Specific Humidity data with Co-located rawinsonde data for each rawinsonde launch.



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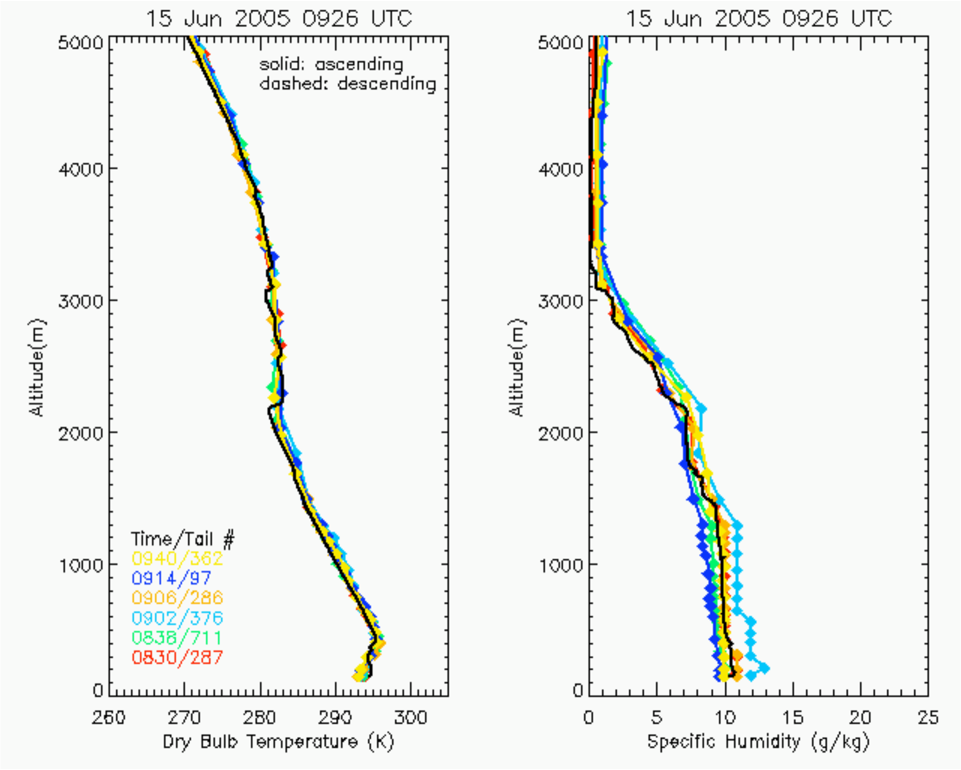
Specific Humidity (g/kg)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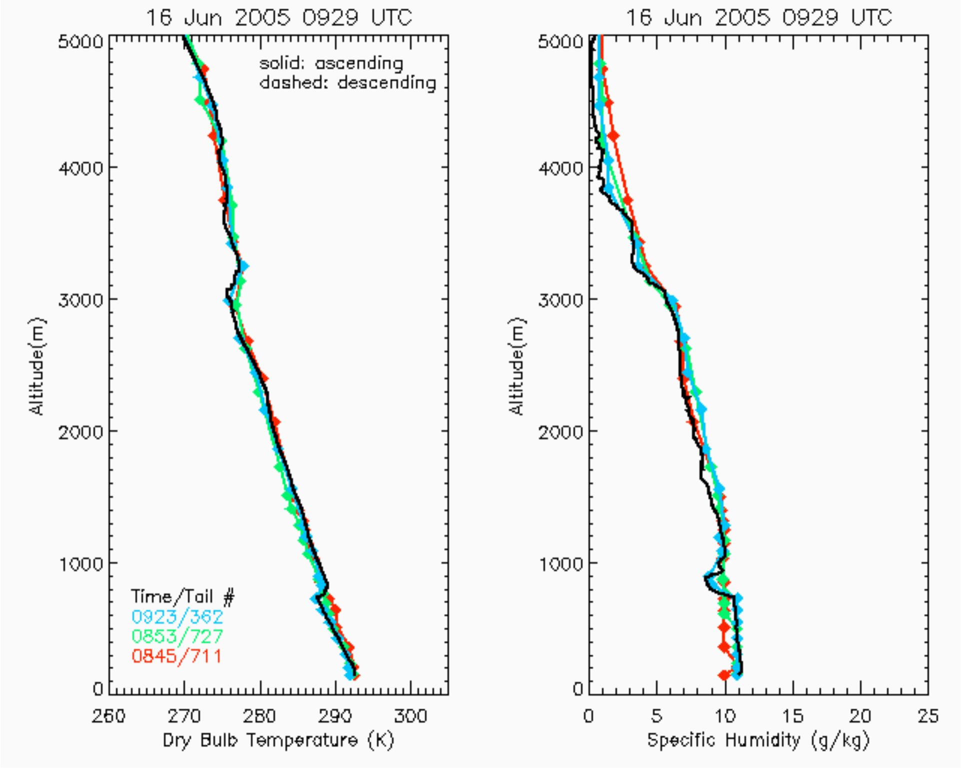
Specific Humidity (g/kg)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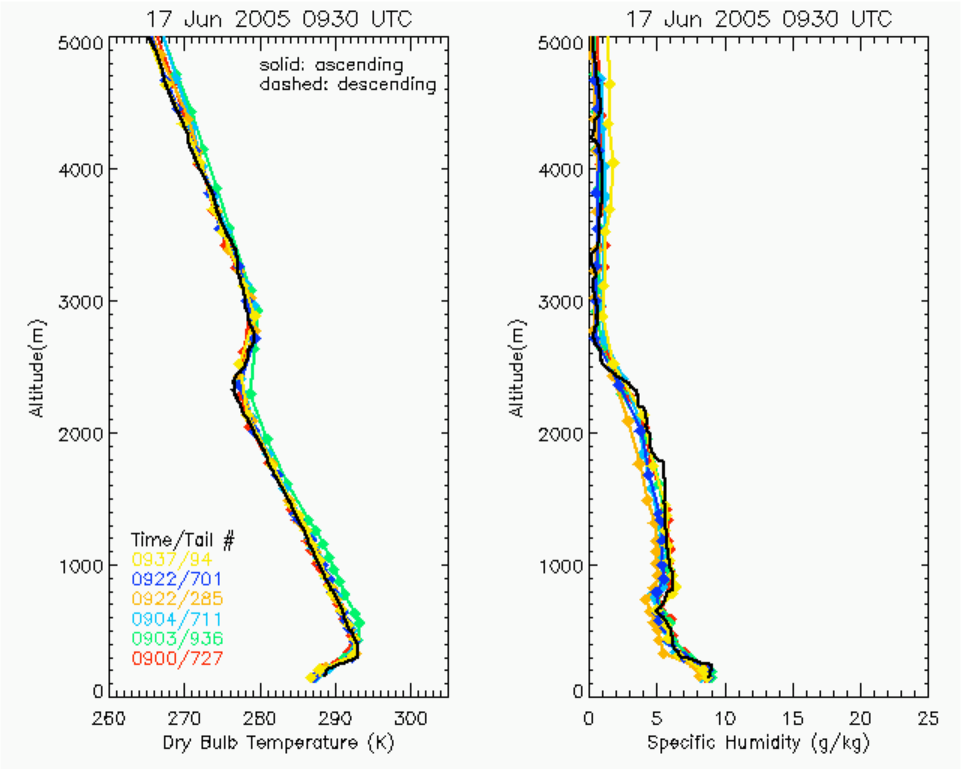
Specific Humidity (g/kg)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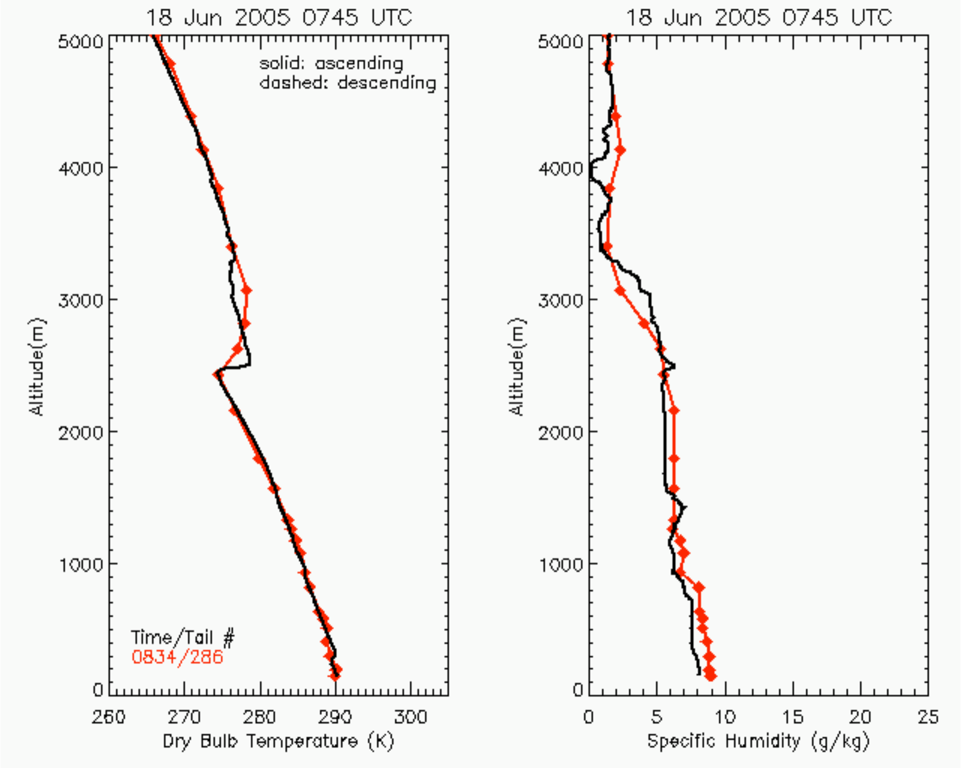
Specific Humidity (g/kg)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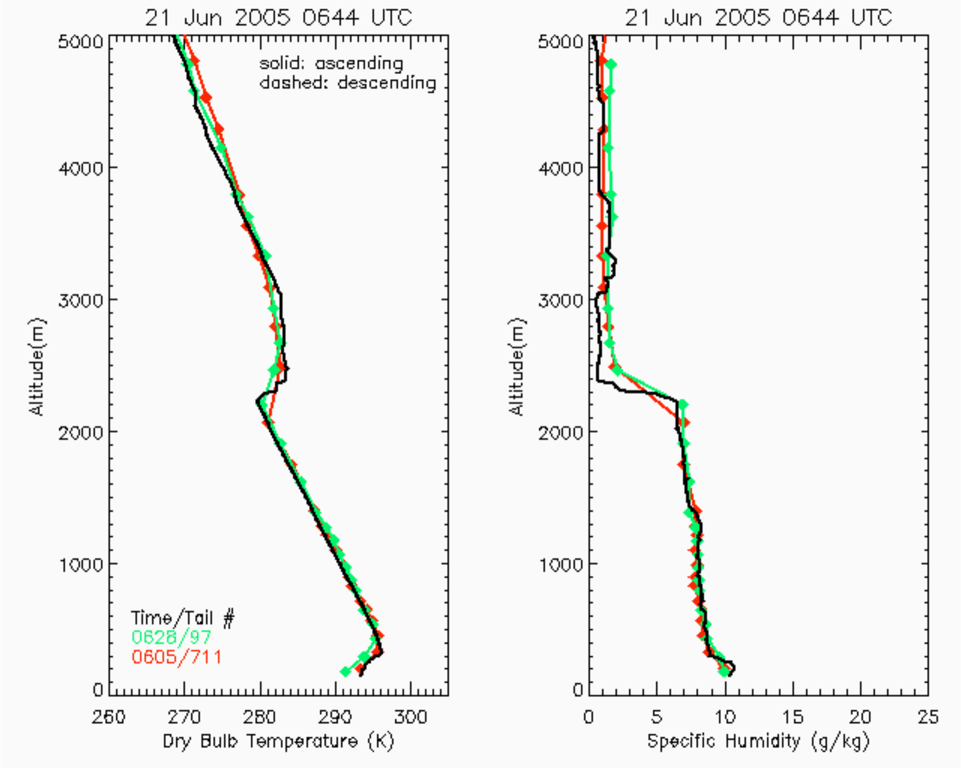
20
25
Specific Humidity (g/kg)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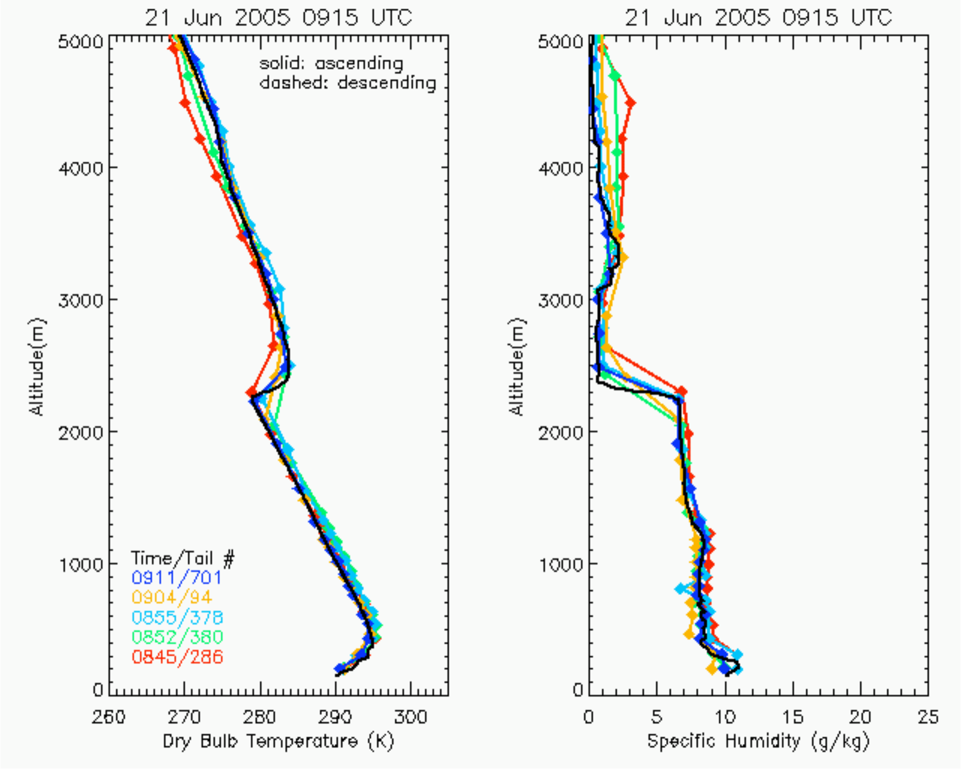
Specific Humidity (g/kg)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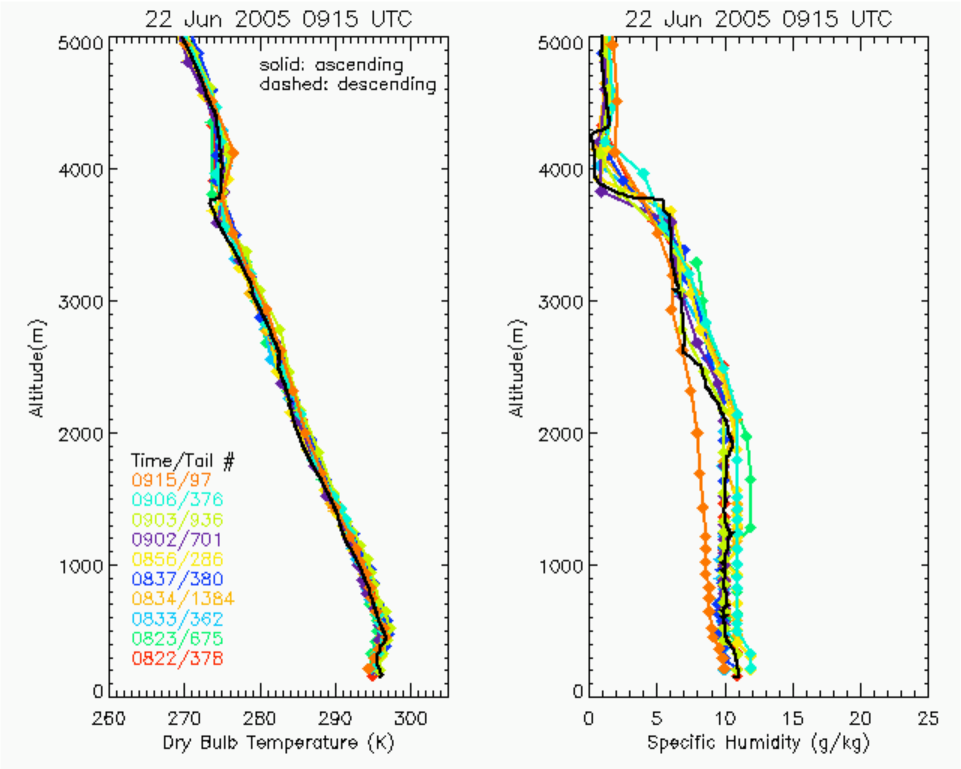
Specific Humidity (g/kg)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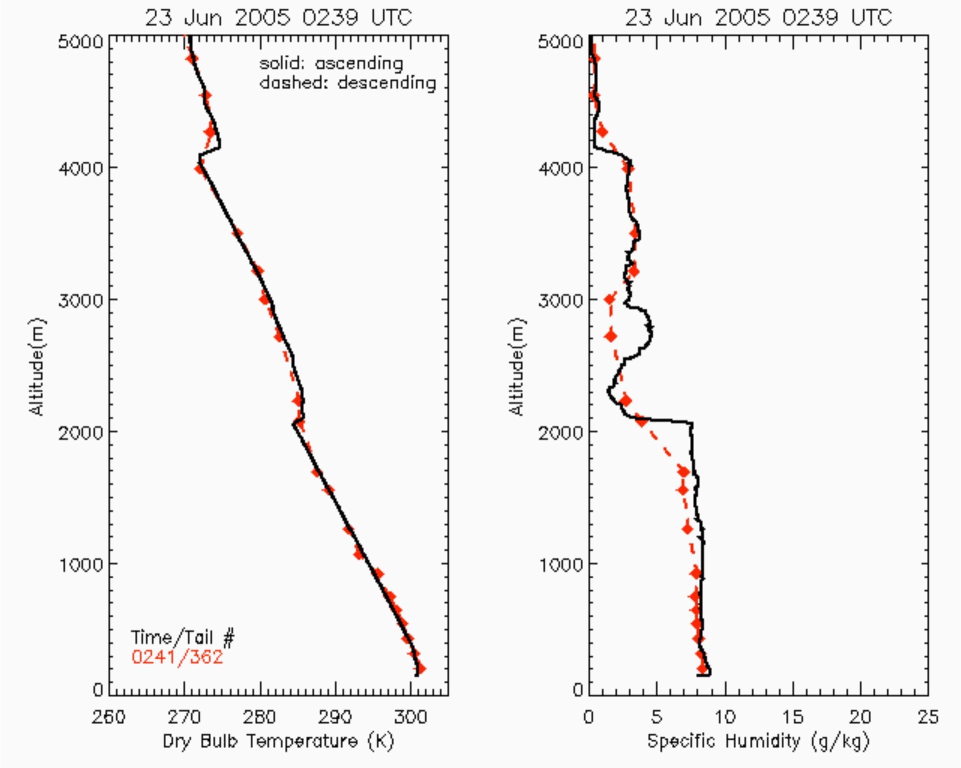
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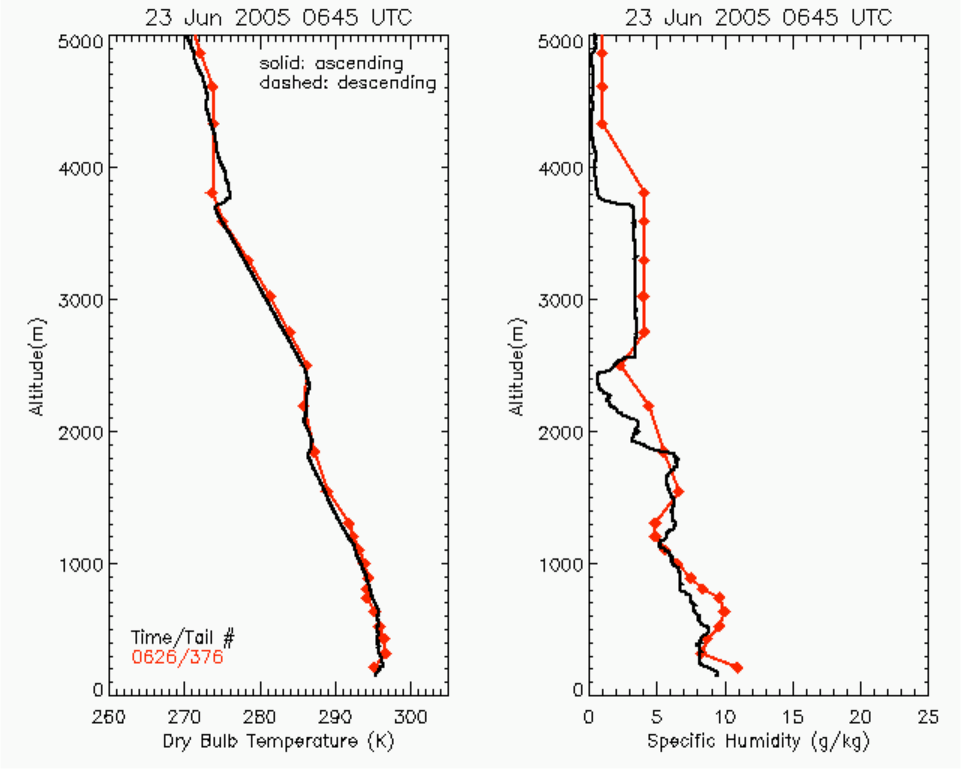
Specific Humidity (g/kg)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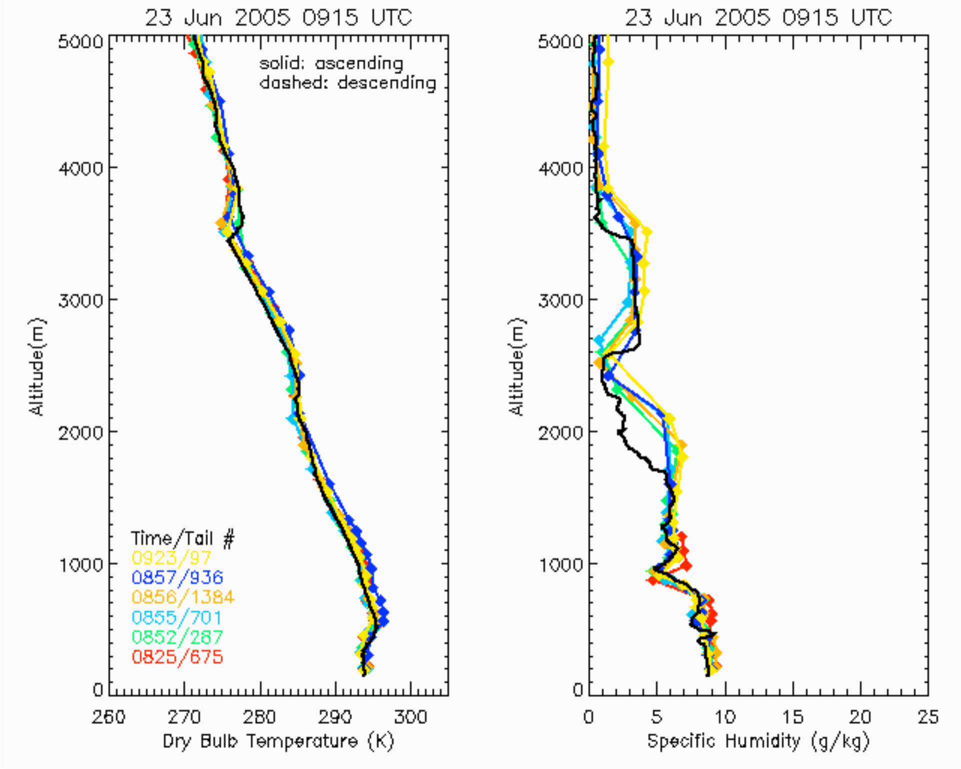
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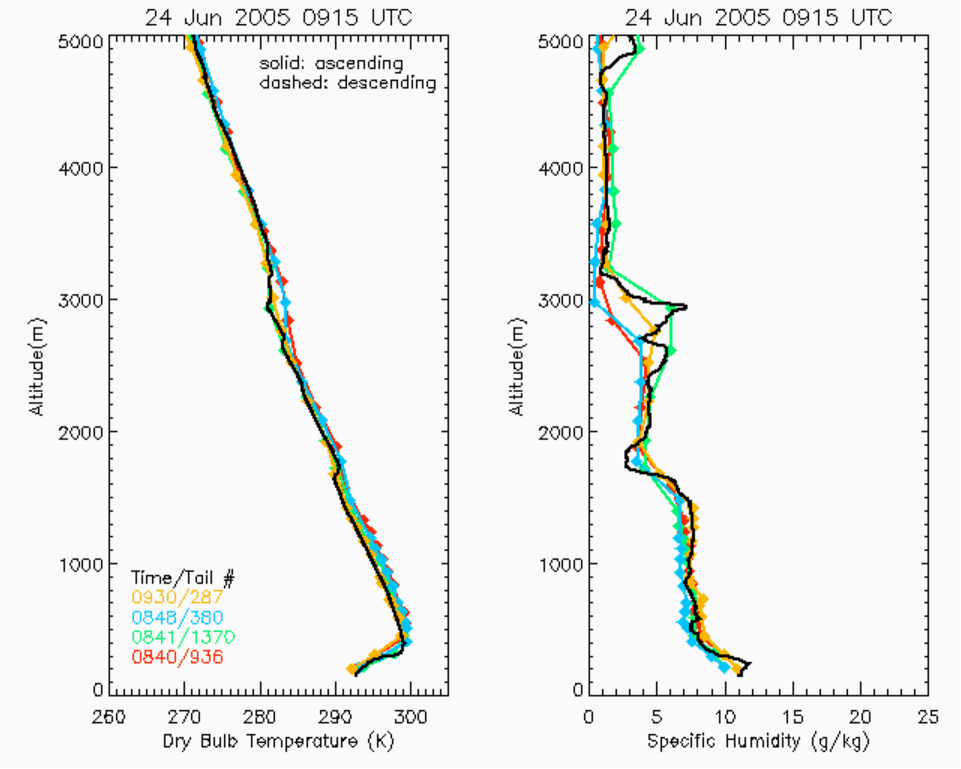
Specific Humidity (g/kg)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Altitude(m)
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Specific Humidity (g/kg)