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Comparison of Profiling Microwave Radiometer, Aircraft, and Radiosonde Measurements From the Alliance Icing Research Study (AIRS)

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Abstract
Measurements from a profiling microwave radiometer are compared to measurements from a research aircraft and radiosondes. Data compared is temperature, water vapor, and liquid water profiles. Data was gathered at the Alliance Icing Research Study (AIRS) at Mirabel Airport outside Montreal, Canada during December 1999 and January 2000. All radiometer measurements were found to lose accuracy when the radome was wet. When the radome was not wetted, the radiometer was seen to indicate an inverted distribution of liquid water within a cloud. When the radiometer measurements were made at 15 degrees instead of the standard zenith, the measurements were less accurate.

Introduction
This report is a review of the comparison of the Radiometrics profiling microwave radiometer (MP3000) (Reference 1), the NASA Glenn Research Center Twin Otter, and radiosonde data from the Alliance Icing Research Study (AIRS) during December 1999 and January 2000 (Reference 2).

The Radiometrics MP3000 radiometer was operated at Mirabel Airport outside of Montreal, Canada as part of the AIRS field test. The MP3000 is capable of producing vertical profiles of temperature, humidity, and liquid water. Also as part of AIRS, the NASA Glenn Research Center Twin Otter Icing Research Aircraft overflew the ground test site. The Twin Otter is equipped to measure the icing cloud environment with in-situ instrumentation that records latitude, longitude, altitude, temperature, cloud liquid water content, and cloud droplet size information, in addition to many other parameters. Data was acquired during spiraling descents centered near the radiometer ground location and missed approaches to a nearby runway. These maneuvers were designed to keep the aircraft as close to the airspace that the radiometer was sampling as possible. Also, radiosondes were released regularly during the active test periods of AIRS. The radiosondes provided profiles of wind direction and velocity, temperature, humidity, and pressure. The radiosondes were released from the same building that supported the radiometer operations. The radiosondes were released at predefined times and do not coincide with the aircraft and radiometer measurements presented. However, to allow comparisons, the profiles of temperature and humidity are assumed to not change dramatically during the test period. The following discussions relate to the comparison of data from these three sources. The accuracy of both vertical (zenith) profiles and those at 15 degrees above the horizon will be examined.

Vertical profiles

Temperature

In all cases, when the radiometer was not indicating rain, the MP3000 temperature profiles agreed well with both the radiosonde and the Twin Otter. As has been noted in earlier studies (Reference 1), the radiometer will smooth through temperature inversions. Some level of this kind of smoothing is visible in Figures 1 through 7. Temperature differences at the peak inversion location reached a maximum of around 5 K. In Figures 1-3 and 5-7, differences at higher altitudes are also seen. These could be caused by a smoothed inversion (Figures 1-3), or a gradual decay of accuracy with increasing altitude (Figures 5-7). These higher altitude errors typically rose to around 3K at 10km (Figures 1-3), but could be as great at 10K (Figure 5). Below 6km, the temperature profiles were typically better. Two cases are included where the radiometer was indicating rain. One shows no degradation in the temperature profile (Figure 3) while another shows considerable error above 1km (Figure 4). The radiometer had been indicating rain for a considerable time before the case shown in Figure 4, so the radome was likely very wet in that case; while the case shown in Figure 3 occurred at the very beginning of the "rain" indication, so the radome probably did not have a great deal of water contamination at the time of the scans.

Humidity

As with temperature, the radiometer generally agreed well with the aircraft and radiosonde humidity measurements except where the humidity changed quickly with altitude. In Figure 1 the radiometer does very well in identifying the area of maximum humidity (saturation), but misses the dry band between 300 and1500 meters. It also misidentifies an area of much lower humidity above 8km. However, the air is so dry at these altitudes, that the error would have little consequence for remote detection of icing. Other than the error with the dry zone at low altitudes, the radiometer agrees within the allowable error margins of the radiosonde (Reference 3). In Figure 2 the radiometer does not agree well with the radiosonde (10 to 20% errors). However, based upon the aircraft measurements, the conditions may have been changing fairly rapidly, so the error levels are not conclusive. However, it does appear that the radiometer again misses the dry bands at 300-1500 and above 8km. The case shown by Figure 3 indicates results similar to Figure 1 and 2. The radiometer captures the saturation region, but is 0.5km high for both the lower and upper boundaries. It should be noted that again the radiometer seemed to do a good job with this case although it was indicating rain. However, Figure 4 shows significant error along with an indication of rain on the radome. Again, these two cases demonstrated the same trend regarding rain indication and error as did the temperature profiles, so the amount and time of moisture on the radome is likely the key to rain induced error. Figure 5 shows the best agreement for humidity. The largest errors in this case were caused by the rapid humidity drop at 5.5 km. Figure 6 demonstrates a similar trend, but with the addition of a l.2-2km dry zone that the radiometer identified, but did not capture fully. Figure 7 shows the radiometer capturing the proper trends with reasonable accuracy, but as in all cases, smoothing through the areas of rapid change.

Liquid Water

The typical profile for liquid water in an icing cloud has the greatest amounts of water near the cloud tops (Reference 4). However, the LWC profiles exhibited by the neural net output for the cases examined were predominantly the opposite of this. This is most easily seen in Figures 2 and 6, where they are compared to the Twin Otter measured profiles (which follow the typical cloud liquid water profile). However, the general trend of the radiometer profiles can also be seen in Figures 5,7,8,9,10, and 11.

As discussed earlier, the radiometer looses accuracy when the radome is wet. The relationship between the "rain" indication and liquid water profile inaccuracy appears to be even stronger than the relationship for temperature and humidity. Similar to the temperature and humidity measurements, the liquid water profile is significantly inaccurate in Figure 4. However, the liquid water profile seen in Figure 3 (which had fairly accurate temperature and humidity profiles) is also significantly inaccurate.

The radiometer output liquid water profiles all appear to include signature errors at higher altitudes. The liquid water profile above 5 km seen in Figure 1 is present in all profiles (although it may be hidden with x-axis scale changes in some cases). Although they represent a very low LWC, these measurements are obviously an artifact of the neural net processing since they are present in all cases.

15 degree profiles

Figures 8 through 11 show the comparison between vertical profiles and profiles made at 15 degrees above the horizon. These figures show the profile data for times when the radiometer was switched from one mode to the other fairly quickly. The third line on these figures is the radiosonde trace from the balloon launch closest in time to the two radiometer profiles. For all four figures the accuracy of the vertical temperature and humidity profiles can be seen to be much better than those of the 15 degree profile. Interestingly, the liquid water profiles do not show similar differences. In fact the profiles in Figures 8 and 11 are remarkably similar. When the liquid water profiles showed a difference (Figures 9 and 10), the vertical pointing profile showed higher levels of liquid water. The accuracy of these cases cannot be judged, because no liquid water measurement is available for comparison to the radiometer data. However, since the neural net is trained to liquid water profiles derived from temperature and humidity profiles, it would be surprising to find the less accurate temperature and humidity profiles associated with better liquid water profiles.

Conclusions

Liquid water profiles

Liquid water profiles from the radiometer appear inverted within an indicated cloud. The radiometer typically shows higher liquid water at the cloud base with decreasing LWC with altitude, while experience and Twin Otter profiles indicate that the LWC should peak at or near cloud tops, decreasing with decreasing altitude. Since the neural net consistently produces profiles with this shape, it must be assumed that the neural net training is the source of the error. An effort should be made to verify the training method for liquid water profiles, and if found to be inadequate, corrective action should be undertaken.

15 degree elevation profiles

Profiles taken at an elevation angle of 15 degrees above the horizon typically show significantly lower accuracy than the vertical profiles. Analysis should be conducted to determine if non-vertical profiles can produce the same levels of accuracy as vertical profiles, and if so, if there are limits to the angle or effective range (or profile height) that are imposed on the results by this method.

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Figures

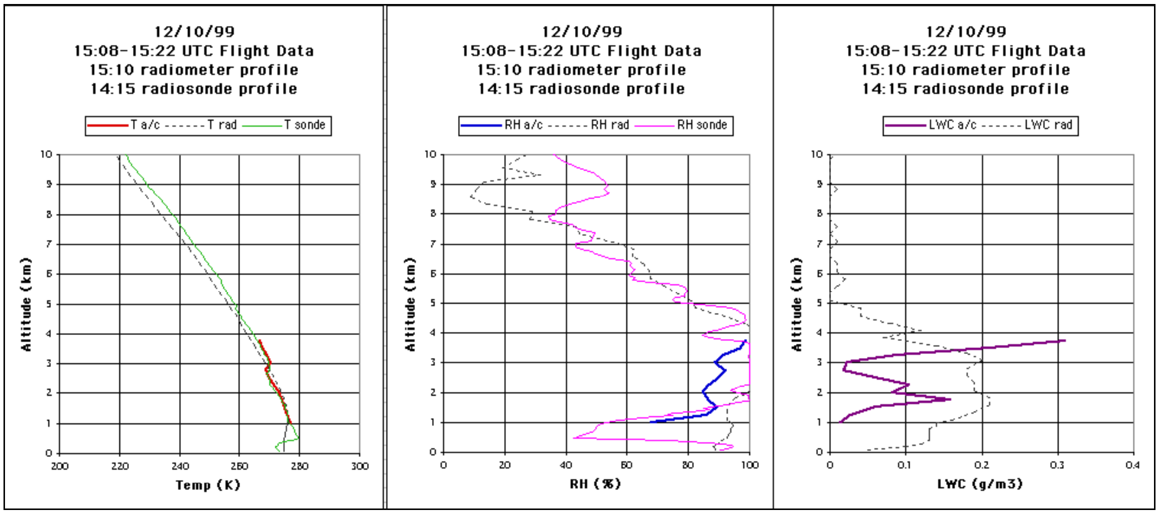
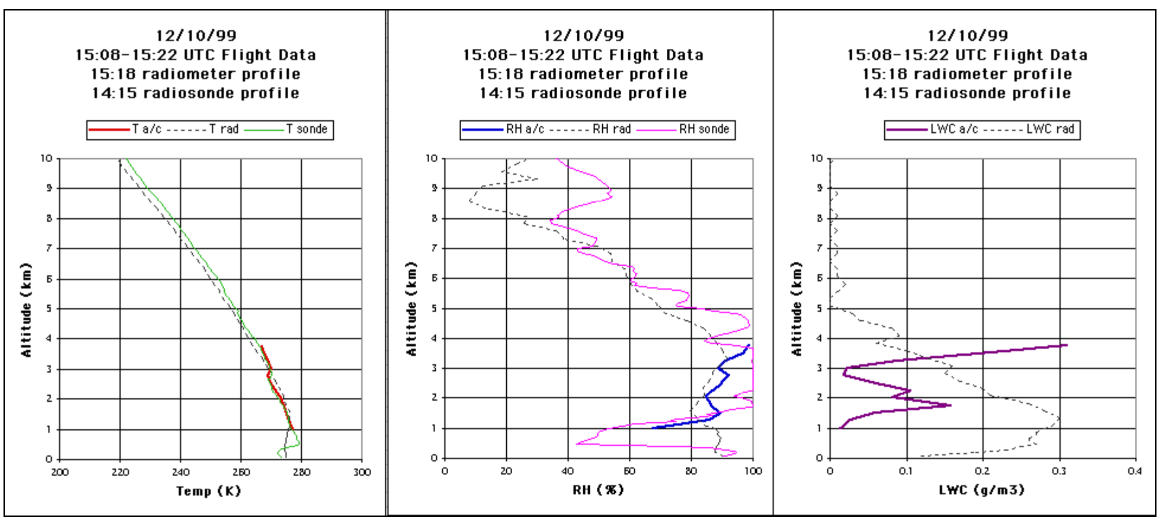


Figure 1



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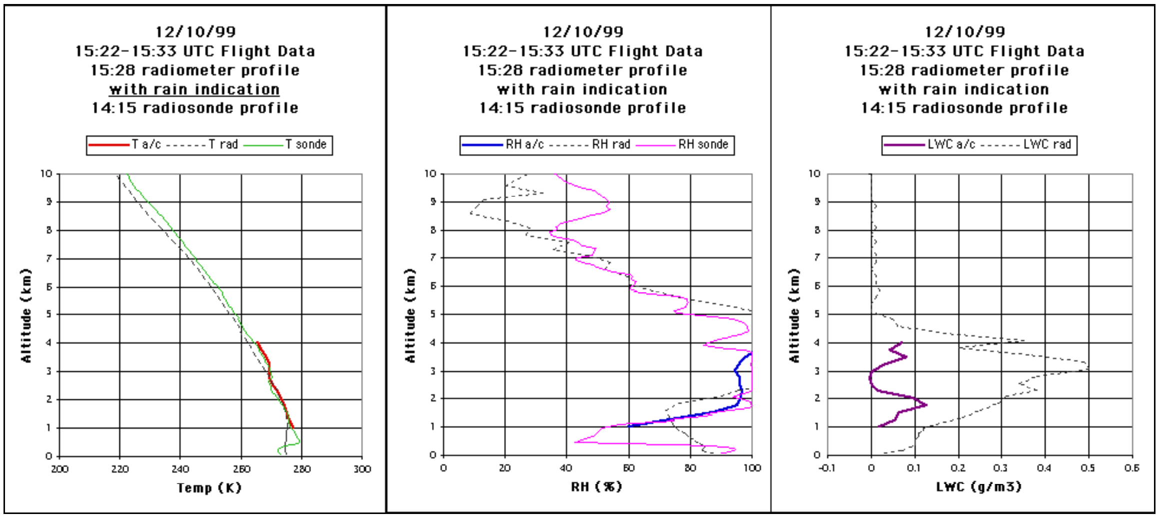

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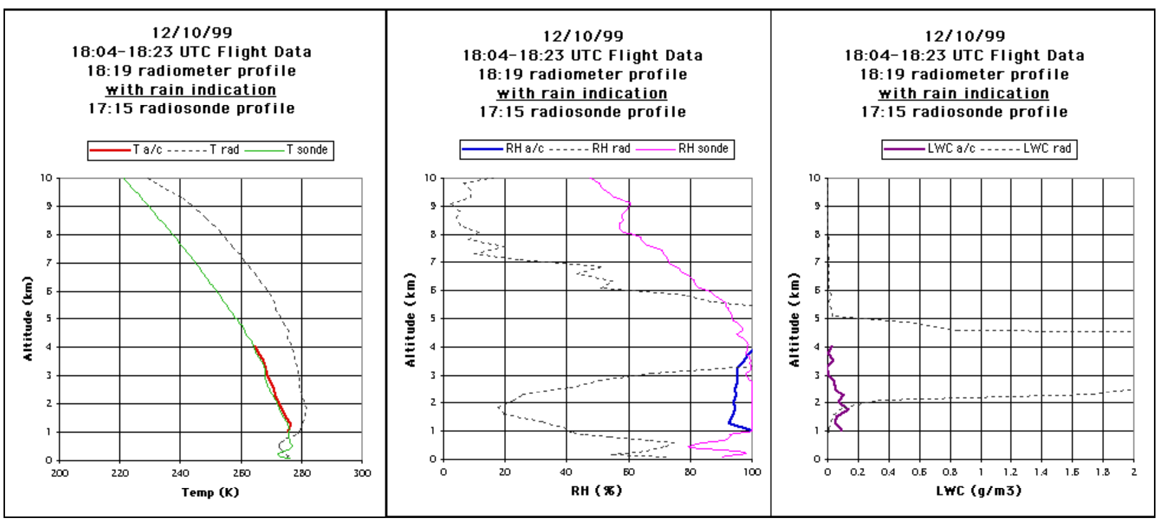

Figure 4

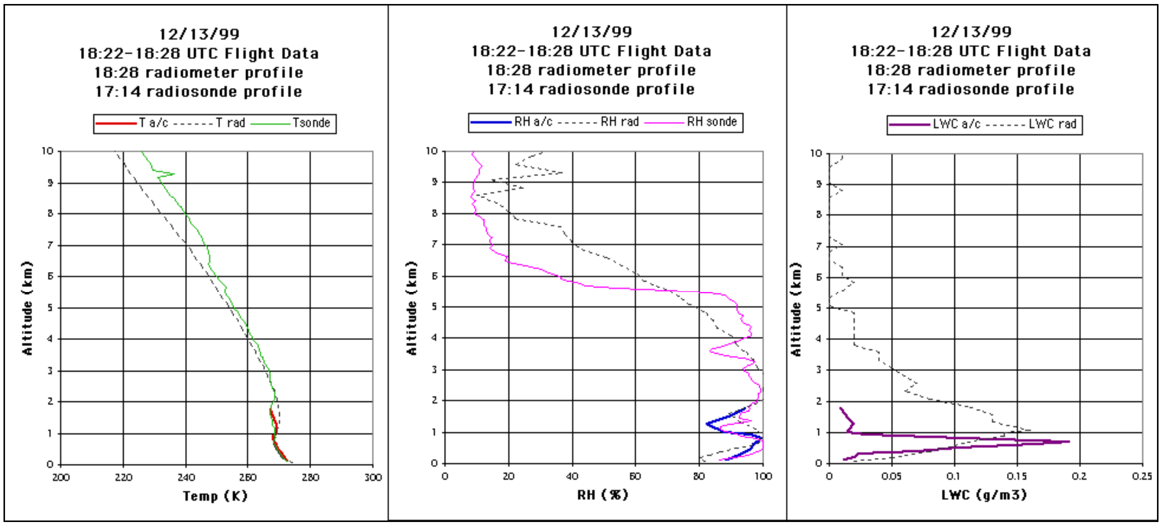

Figure 5

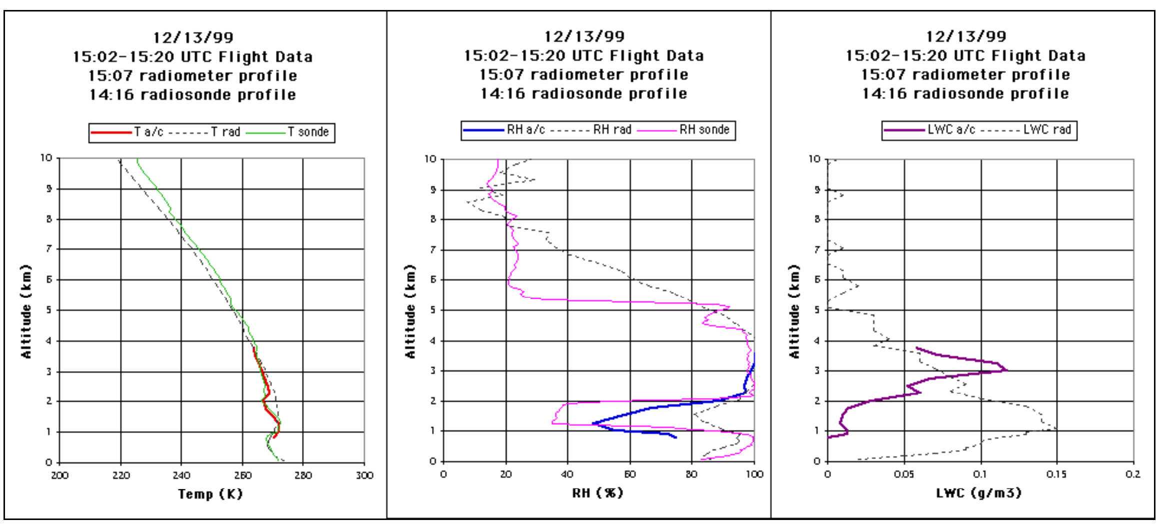

Figure 6

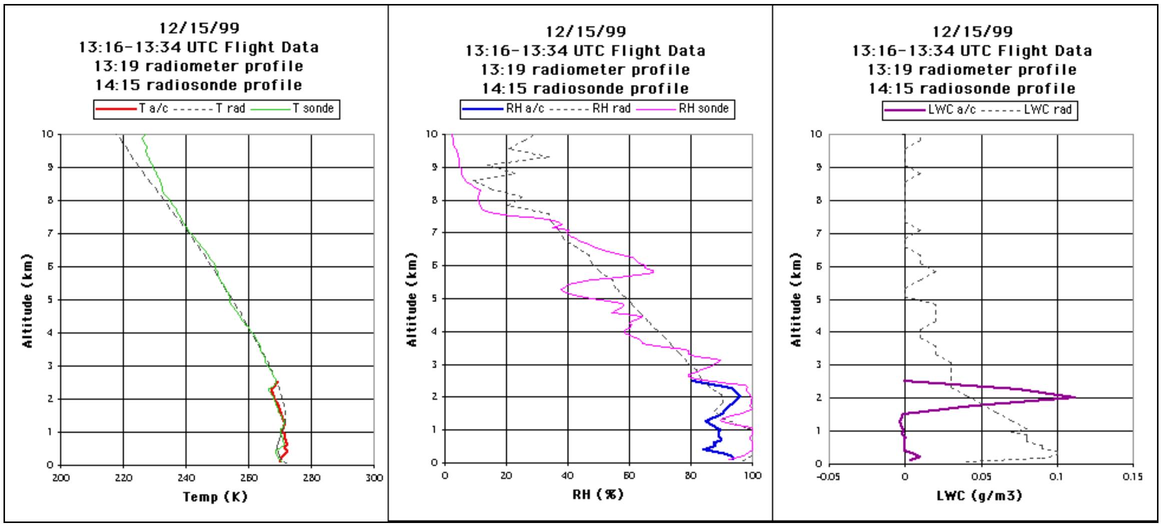

Figure 7

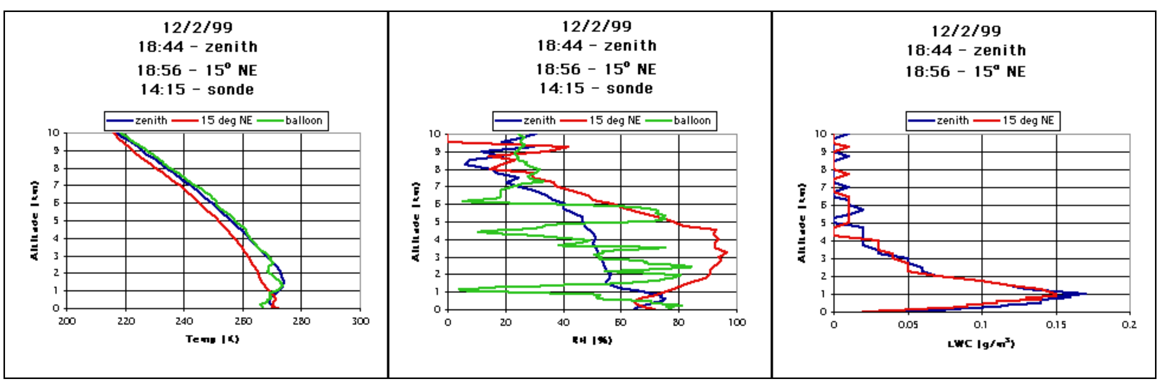

Figure 8

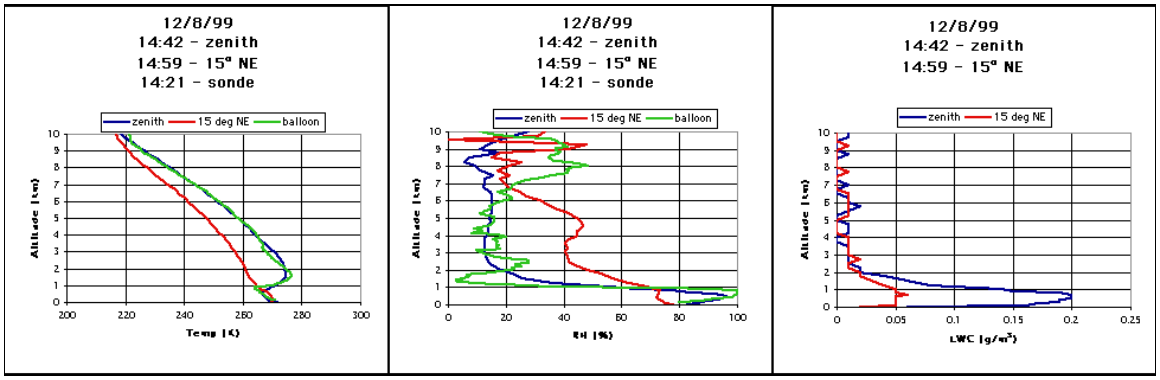

Figure 9

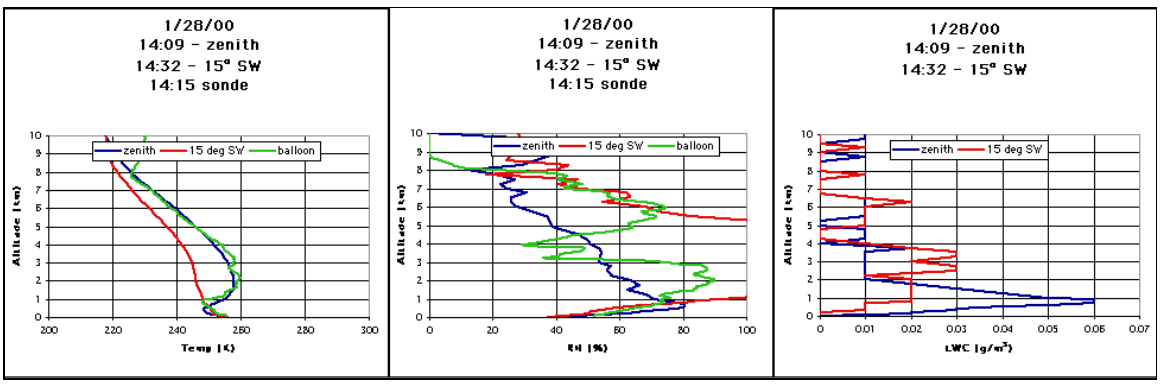

Figure 10

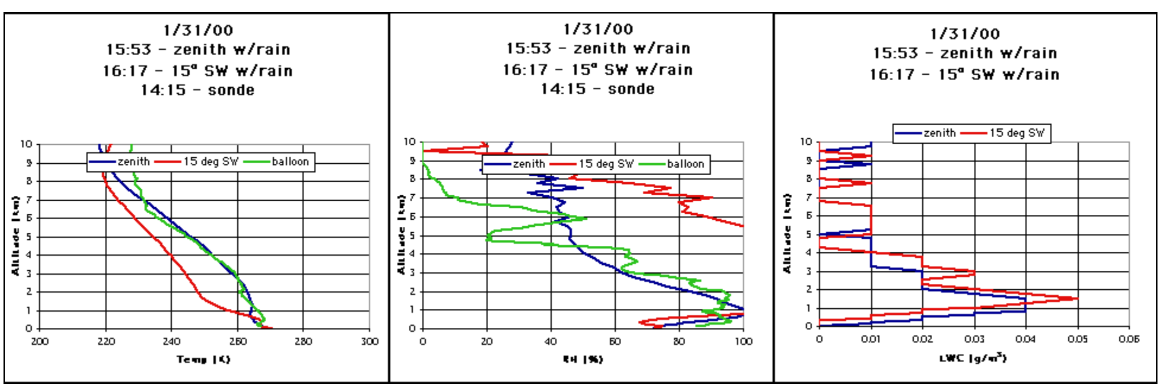

Figure 11

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13. ABSTRACT ***(Maximum 200 words)***

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