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NIRSS Upgrades: Final Report

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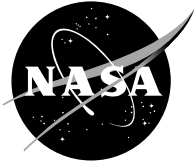
NIRSS Upgrades: Final Report

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Introduction

Under this contract work proceeded in these areas: NIRSS Upgrades and comparisons of Version 2 outputs with in situ data.

NIRSS Upgrades

This work was leveraged with a University of Colorado Computer Science Department Senior Project. Three students, Patrick Carmichael, Matt Hulse and Stephan Zednik, formed a team to work on this. Details of the Senior Project program can be found at http://www.cs.colorado.edu/ugrad/seniorproject/about/ and the NIRSS Project is summarized at http://www.cs.colorado.edu/ugrad/seniorproject/projects/nirss.html. Documents related to this project, including design requirements, system architecture, user manual and other, are available on a CD sent to QSS.

Stephan Zednik was also employed by NCAR as a student assistant under this contract. His work was divided as follows: Senior Project tasks were to rewrite the LabVIEW (National Instruments) code in C++, with subsequent testing and implementation at NASA Glenn Research Center (GRC); NCAR tasks were to implement bug fixes, corrections, upgrades to the cloud, liquid water and icing logic, and produce log files and plots for data comparisons.

A poster on the NIRSS was presented at the 12th Aviation, Range and Aerospace Meteorology Conference held in Atlanta, Georgia, in January 2006. The extended abstract focuses primarily on comparisons with the Version 1 system and can be found online at http://ams.confex.com/ams/Annual2006/techprogram/paper_100499.htm.

Comparisons of NIRSS2 with AIRS-2 Twin Otter Data Sets

The Alliance Icing Research Study 2nd-Field Project (AIRS-2) was conducted from November 2003 through February 2004. Most operations centered around Mirabel Airport near Montreal, Canada. The AIRS II operational objectives were to: a) develop techniques/systems to remotely detect, diagnose and forecast hazardous winter conditions at airports, b) improve weather forecasts of aircraft icing conditions, c) better characterize the aircraft-icing environment and d) improve our understanding of the icing process and its effect on aircraft.

An array of remote sensing instruments were sited at the Mirabel Airport, including NIRSS. The NASA Twin Otter (TO) and National Research Council (of Canada) Convair 580 flew in the vicinity to obtain in situ measurements of atmospheric parameters to compare with and/or verify the remote measurements. Spiral descents over the airport and missed approaches to the runway adjacent to the instrument suite were both flown. Eight cases from four days have both NIRSS retrievals and Twin Otter data sets as shown in table 1.

Overall Comparisons

NIRSS retrieves cloud base height from the ceilometer. These heights agreed well with the TO measurements (defined as FSSP drop concentration > 0.01 for more than 1 s during the ascent or descent). Height could also be derived from the IR cloud base temperature by matching to the radiometer temperature profile; the results are shown as IRTZ. The correlation coefficient (r) between the ceilometer and measurement is 0.95, between the IRTZ and measurement is 0.52 (fig 1).

TABLE 1.—THE COMPARISON DATA SET

Date	Time (UTC)	Notes
11 Nov	1630-1657	No cloud top
	1942-2009	No cloud top
	2009-2021	No cloud top
18 Nov	1233-1246	Cloud >0 °C
25 Nov	1809-1830	
	1852-1859	
10 Dec	1617-1637	
	1720-1732	

Cloud base temperature is estimated by matching the ceilometer-measured cloud base altitude to the retrieved temperature profile. These values were slightly higher values than those recorded from the TO by 2 to 5 °C. The correlation coefficient is 0.97. The IR sensor on the profiling radiometer does a better job at estimating cloud base temperature (IRTC) with r of 0.99 and measurements generally within 1 to 2 °C of the aircraft-measured value (fig. 2). There was a slight cold bias. The conversion to height shown above is compromised by inaccuracies in the retrieved temperature profile.

The NIRSS cloud top is defined as the altitude at which the X-band radar reflectivity is <1 dBZ above the noise level. This was not in as good agreement with the aircraft measurements, with overestimation by NIRSS at lower cloud top heights (<~2000 m). The correlation coefficient is 0.91 (fig. 3). There were several flights for which cloud top was not sampled by the TO (see table 1).

Similar to the cloud base temperature, the NIRSS cloud top temperature is found from the retrieved height and the radiometer sounding. The agreement is only as good as either estimation, and in this case the correlation coefficient is 0.87 (fig. 4). NIRSS temperatures are too high (warm) for the colder cloud tops.

Freezing level (height of T = 0 °C) determines the warm extent of the icing hazard. The radiometer sounding was used to determine this level, or in the 10 December cases, the multiple freezing levels. The correlation coefficient is 0.93 (fig. 5). The comparison is good, with one point estimated too high by ~500 m (second sounding, 11 November).

Integrated liquid water (ILW) was calculated from the two channels of the radiometer using the method of Hogg et al. (1983), and was derived from the aircraft measurements by integrating the measured liquid water content over the depth of the cloud. The values are in fairly good agreement (r = 0.81) (fig. 6). The point with NIRSS ILW at 0.47 is from the 10 December case, which will be discussed below and is the only point in strong disagreement.

Finally, maximum liquid water content (LWC) from both NIRSS and the TO were compared. The retrieved LWC are over 100-m depths; the TO measurements are 1-s values. From that difference in scaling, we'd expect the TO values to be higher. However, the agreement is fairly good (r=0.53) (fig 7), with one point (18 Nov) having high measured maximum LWC and low derived value. This will be discussed below.
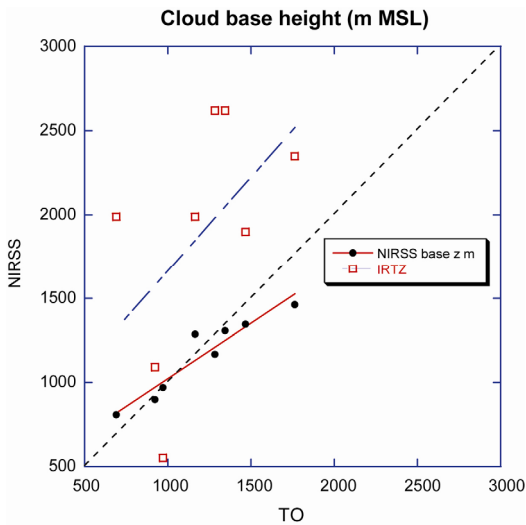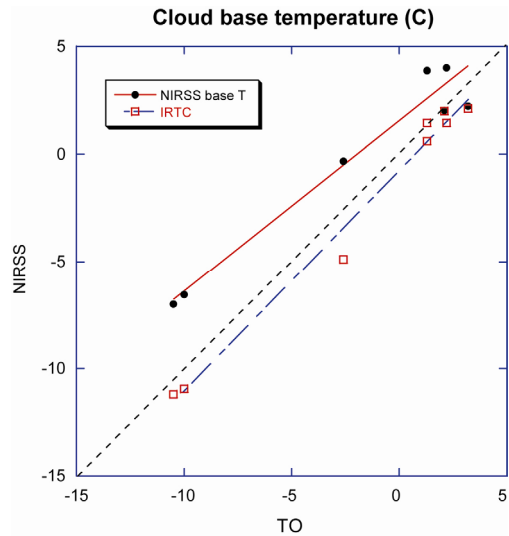
Cloud base height (m MSL)

Figure 1.—NIRSS to TO cloud base height comparison.

Cloud base temperature (C)

Figure 2.—NIRSS to TO cloud base temperature comparison.
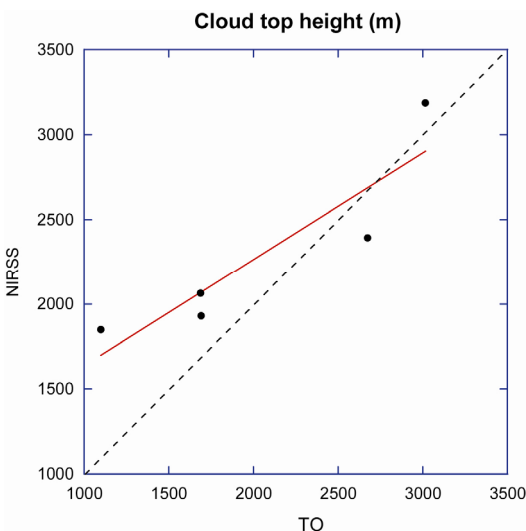
Cloud top height (m)

Figure 3.—NIRSS to TO cloud top height comparison.

Cloud top temperature (C)
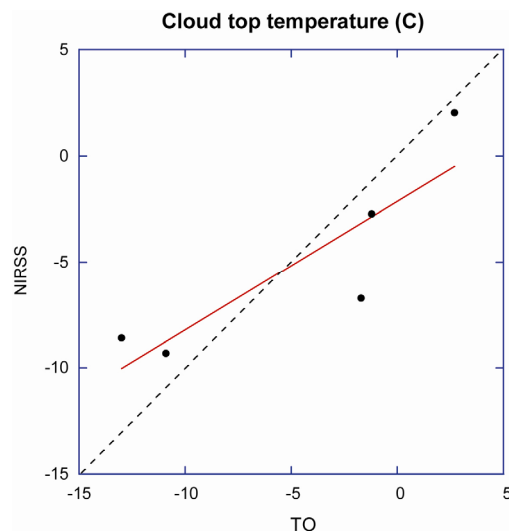
Figure 4.—NIRSS to TO cloud top temperature comparison.
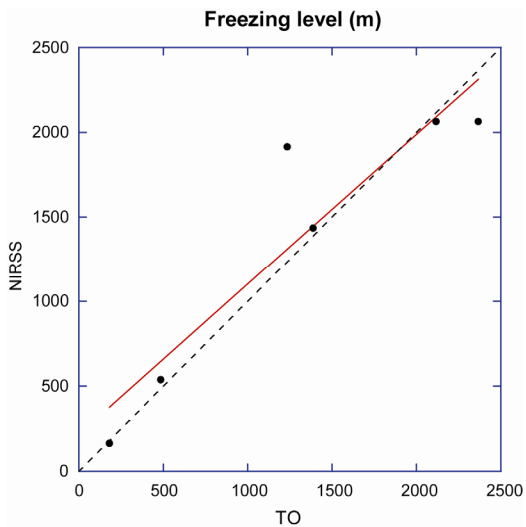
Freezing level (m)

Figure 5.—NIRSS to TO freezing level comparison.

Integrated liquid water (mm)

Figure 6.—NIRSS to TO ILW comparison.

Maximum liquid water content (g m⁻³)
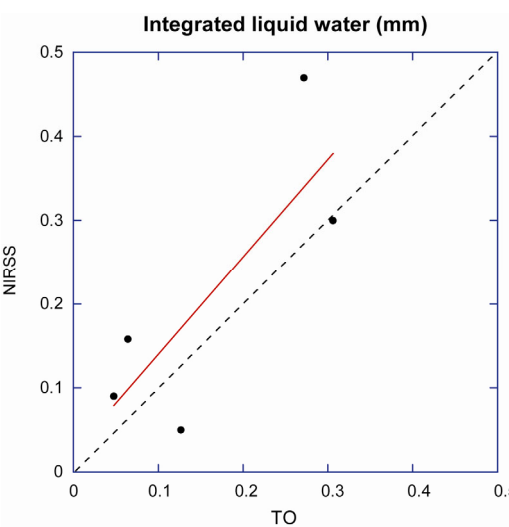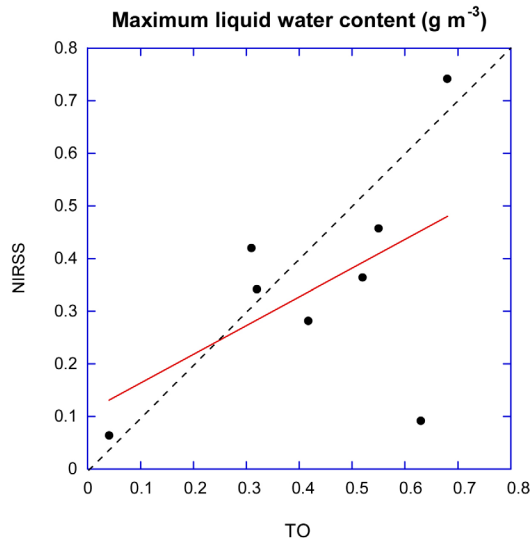
Figure 7.—NIRSS to TO maximum LWC comparison.

11 November 2003

This case was covered extensively in the 12th Aviation, Range and Aerospace Meteorology Conference sponsored by the American Meteorology Society (see http://ams.confex.com/ams/Annual2006/techprogram/session_19313.htm).

Three Twin Otter missed approaches were made to the Mirabel Airport during this storm event.

First, a word on the formats of these plots (figs. 8 to 15). The left hand side shows the temperature comparisons. The black line is static air temperature (Ts) from the Twin Otter. The darker line is the average radiometer temperature profile during the sounding time (table 1) and the lighter lines are the minimum and maximum during that time. The orange line shows the IR temperature from the 3005 radiometer. On the right the liquid water profiles are shown. Black is from the TO FSSP, which includes drop sizes in the 5 to 45 μm range (no drizzle). Grey is from the CSIRO liquid water probe, which is a hot-wire instrument. Both are shown to suggest the uncertainty in the liquid water measurements. Again, the darker and lighter lines in color (pink in this case) are the average and min/max of the retrieved NIRSS values. Various other features are pointed out on the plots and are discussed for the different case studies.

During the first sounding on 11 November (fig. 8), the cloud was mostly ice crystals with some drizzle. Altitude ranges of different ice crystal types recorded by the 2–D-grey probe are shown. Since the drizzle was observed well above the freezing level (at ~1600 m MSL according to NIRSS), it was not formed from melting ice. The aircraft did not fly to the top of the cloud. Temperature retrieved from the profiling radiometer was close to the aircraft-measured profile, but the radiometer did not identify numerous small inversions. These are probably not significant for liquid water distribution or icing hazard analysis. Cloud bases (black and purple double-headed arrows) were in fairly good agreement: NIRSS at ~2 °C, TO at ~–0.5 °C. Freezing levels were (ZLN and ZLTO) nearly the same, although the TO just barely descended to 0 °C. The IR temperature was –4.9 °C; with a poorly-defined cloud of mostly ice crystals and little liquid, the IR detector had problems detecting a good cloud base. There was very little liquid water in this cloud; total integrated value from the radiometer was 0.16 mm. The measured liquid water content values fell within the range of retrieved values, although both are < 0.1 g m⁻³, with most < 0.04 g m⁻³.

The second sounding (fig. 9), which was a descent to the Mirabel airport, showed temperatures again in reasonable agreement, with the greatest differences near 0 °C. This is important for identifying the freezing level and thus the altitude range for icing. The radiometer-retrieved freezing level was ~800 m

higher than that measured from the TO, but there was excellent agreement in temperatures below 1000 m (although they are >0 °C). Again, the aircraft didn't climb to cloud top. This was another deep cold cloud with the NIRSS-detected top at –17 °C. In the lower part of the cloud (base to about 2500 m), the agreement between observed and retrieved LWC was good, but above~2700 m the retrieval retained high LWC whereas the measurements included much lower values. NIRSS did not separate the two cloud layers but rather analyzed one thick cloud. All cloud bases were in good agreement.

The third sounding was the ascent part of the missed approach to Mirabel airport and sampled the same deep cold cloud (fig. 10). The TO did not sample the top so only lower levels (<2100 m) of the cloud can be compared. The temperatures, freezing levels, and cloud bases (including IR detector) again are in fairly good agreement. LWC estimates from NIRSS are lower than measured, with liquid distributed through a deep cloud. It is not known if there was a layered structure during the ascent time.
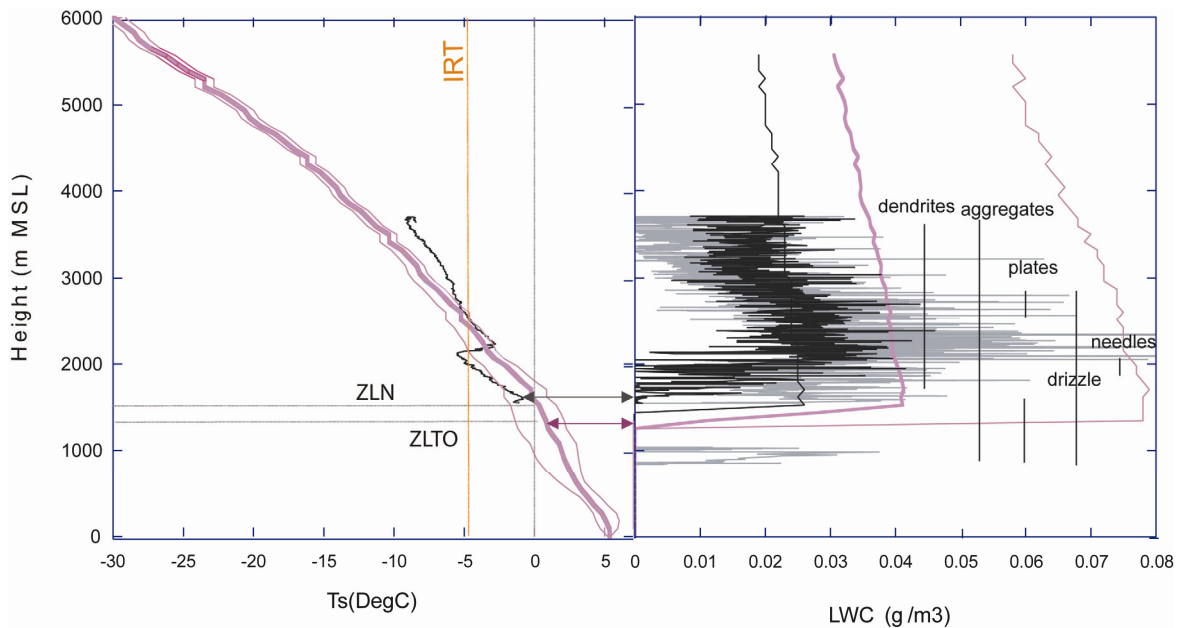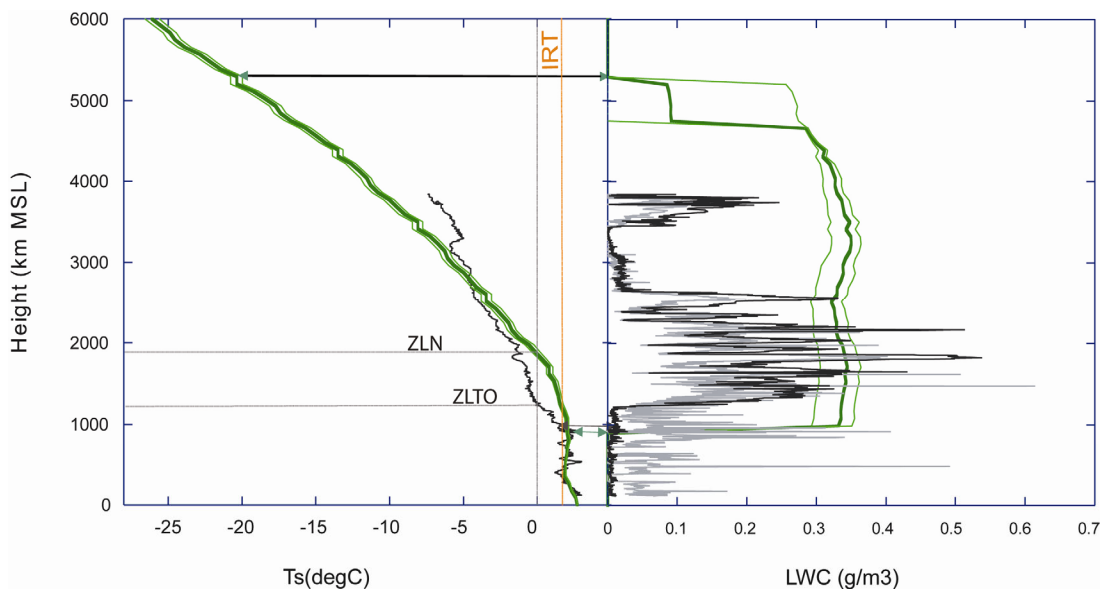

Figure 8.—11 November 2003—Case 1 sounding.
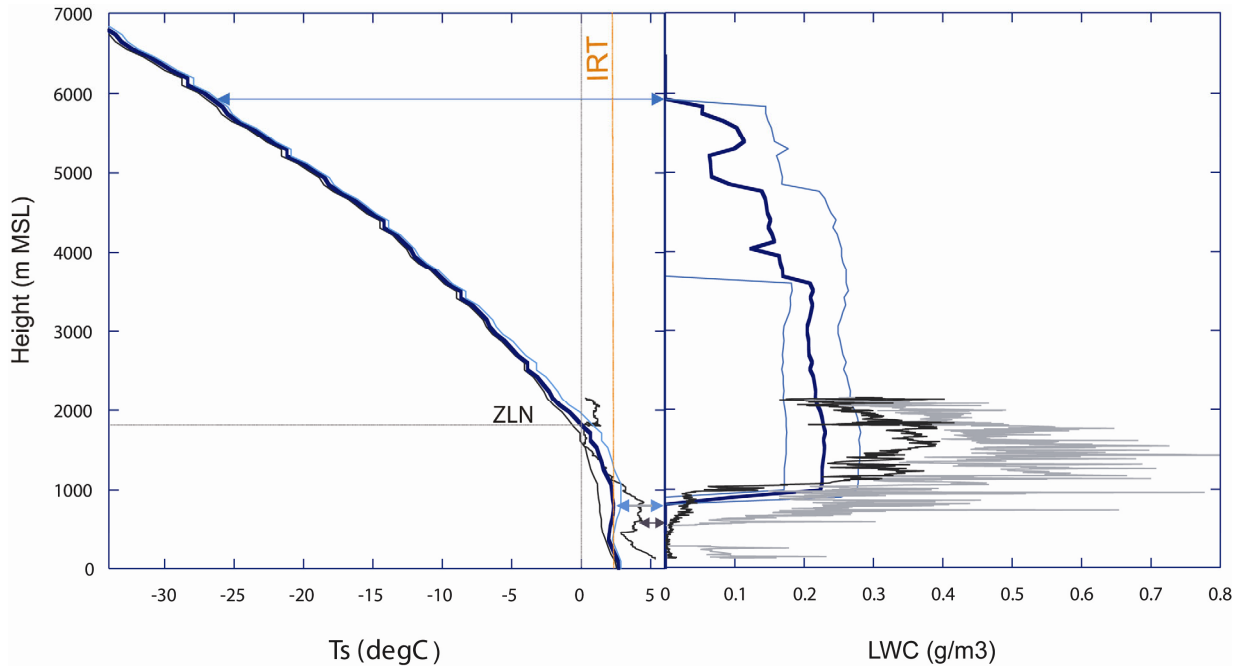

Figure 9.—11 November 2003—Case 2 sounding.

Figure 10.—11 November 2003—Case 3 sounding.
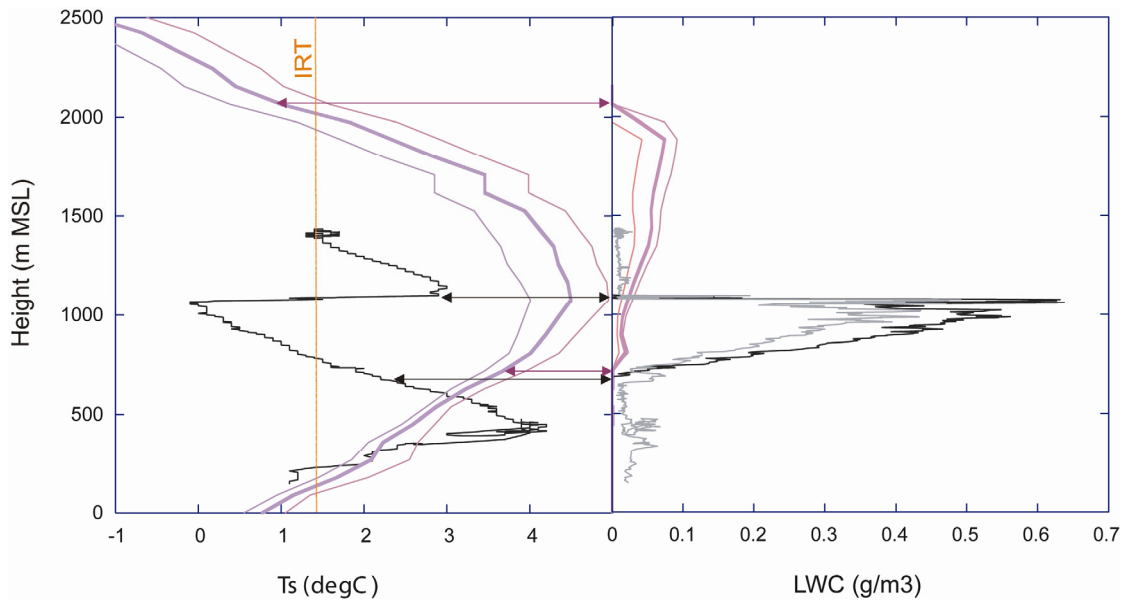

Figure 11.—18 November 2003 sounding.

18 November 2003

All of the cloud sampled 18 November was at T>0 °C, and the TO-measured profile was the wedge shape often seen in more simple stratiform cloud layers (fig. 11). There were two temperature inversions—one near the surface and one at the cloud top. The retrieval smoothed these inversions with the warmest temperature similar to the TO measurement, but about 500 m higher; it is not a good retrieval. NIRSS placed the cloud base at an altitude similar to that observed but detected deeper cloud—however, the TO sounding only went to ~1500 m so there may have been higher cloud aloft. The IR temperature of 1.5 was not very different from the TO-measured temperature of 2.2, but matching this to

the retrieved temperature profile would give large errors in cloud base height (either too high or low because of the strong inversion). The radiometer ILW was 0.05 mm; the TO-integrated value was 0.127 mm. The effect of higher cloud top and lower ILW in the NIRSS retrieval is seen as smaller LWC over a greater depth.

25 November 2003

This was another case with strong inversion and wedge-shaped LWC profile (fig. 12). The retrieved temperature is close to that measured in the lowest (<500 m) levels, then deviates perhaps in reaction to that inversion. The IR temperature is near the TO-measured value but matching that temperature to its height on the retrieved sounding would place the cloud base more than a kilometer too high. In reality, the atmospheric temperature inversion marks the cloud top detected by the FSSP. The CSIRO probe detects some hydrometeors (possible larger than detectable by the FSSP) both above and below the FSSP cloud which may explain the deeper NIRSS cloud. The ILW values were 0.09 mm from NIRSS, 0.0477 mm from the TO. The base heights were similar. Thus, the NIRSS cloud depth was about twice that of the real cloud, with about double the ILW to distribute so the actual LWC values were actually similar, but misplaced in height. The assumption of a wedge-shaped profile for this stratiform cloud was a good first-guess.

For this day's second sounding (fig. 13), the temperature comparison looks very bad until you consider this as being a tiny part of the sounding shown in the previous sounding (taken ~20 to 30 min earlier). There is a strong inversion hinted at the top of the TO sounding, and again the retrieval did not include that feature but smoothed the profile throughout its depth. The NIRSS cloud base is within 100 m of the TO-measured base. ILW from the radiometer was 0.158 mm, from the TO, 0.0642 mm. The top altitudes were in better agreement than for the first sounding. The NIRSS LWC had a wedge shape similar to the TO measurements, although the values had considerable variability. There may have been hydrometeors above and below the FSSP cloud as in the first sounding but since the aircraft sampled such a small depth the information is not available.
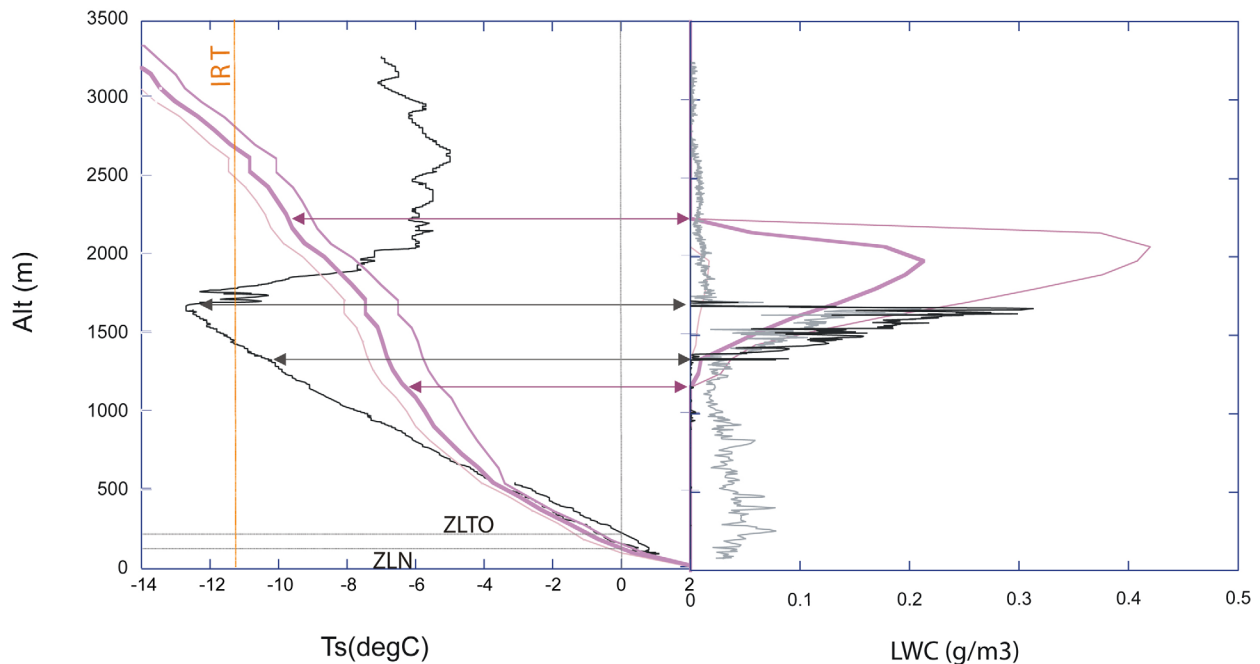

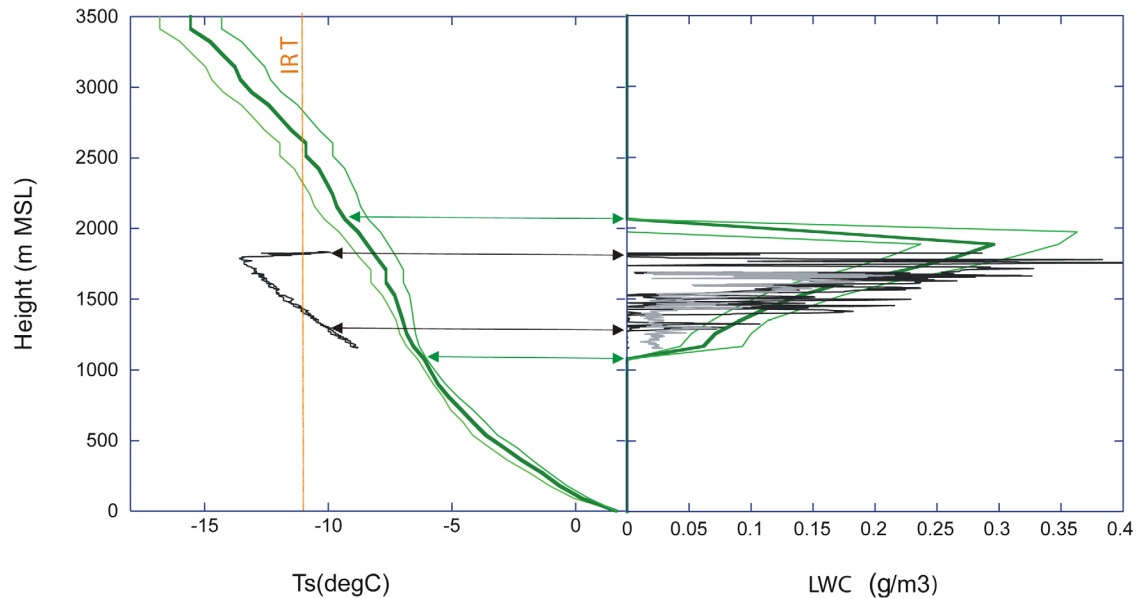Figure 12.—25 November 2003—Case 1 sounding.

Figure 13.—25 November 2003—Case 2 sounding.

10 December 2003

For this day's first sounding, the TO-measured temperature profile was very complex with several inversions (fig. 14). These are smoothed out considerably by the radiometer profile. The inversion crosses the 0 °C isotherm, so placement of temperatures is important in this case to determine where icing will occur. The warm layer had a maximum temperature of nearly 8 °C in the retrieval, but only 5 °C in the measurement. However, the depth of the warm layer was similar in both cases. The cloud was also complex with three layers. The retrieval appeared to diagnose the layers but had considerable cloud in between. ILW values were similar (NIRSS = 0.30 mm, TO = 0.31 mm) but NIRSS distributed the liquid though a greater depth. The IR temperature was slightly lower than that measured by the TO; the instrument detected the base of the uppermost cloud layer rather than the thin lower layer.

The second sounding was nearly an hour later, and the TO didn't fly low enough to sample the low-level inversion (fig. 15). The retrieved temperature profile was similar to the first sounding. This time the TO-measured warm layer extended much higher than the retrieved warm layer. The cloud retained its multi-layer structure which NIRSS smoothed into one cloud, with top and base close to the highest top and lowest TO-measured base. Values of LWC were similar although the high LWC in the lowest layer was missed—NIRSS would have warned for less icing hazard than was really present. ILW values were 0.47 mm for NIRSS and 0.272 mm for the TO. The IR detector matched the cloud base well, but if this were used to determine cloud base from the sounding it would have placed the cloud either well below or above the real cloud due to the retrieved inversion.
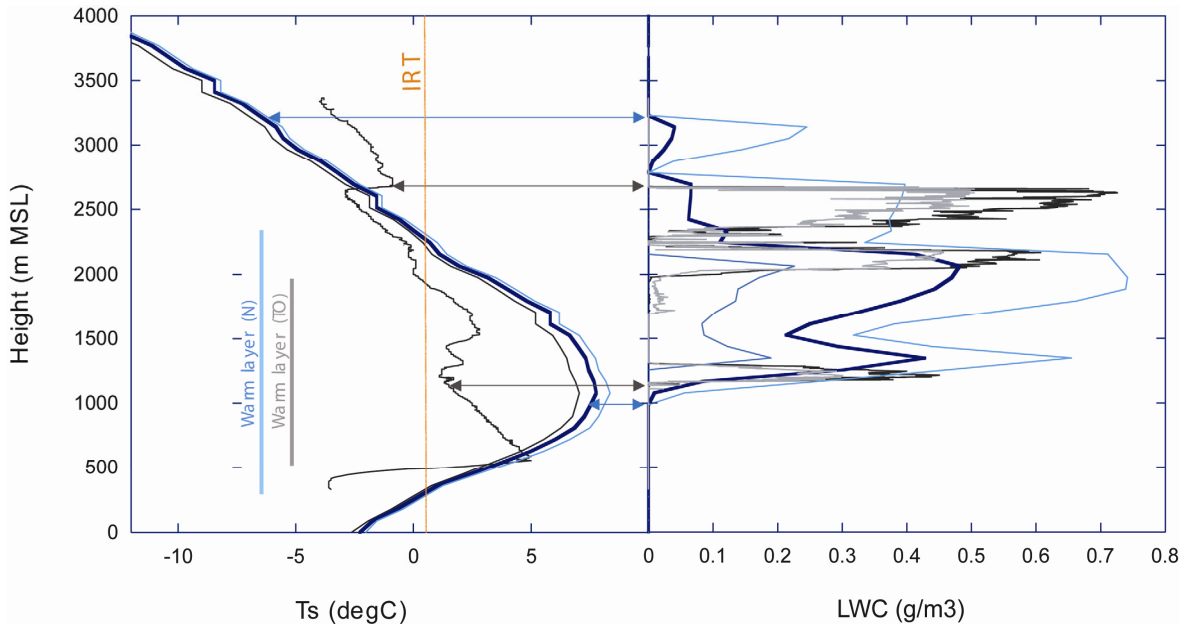
Figure 14.—10 December 2003—Case 1 sounding
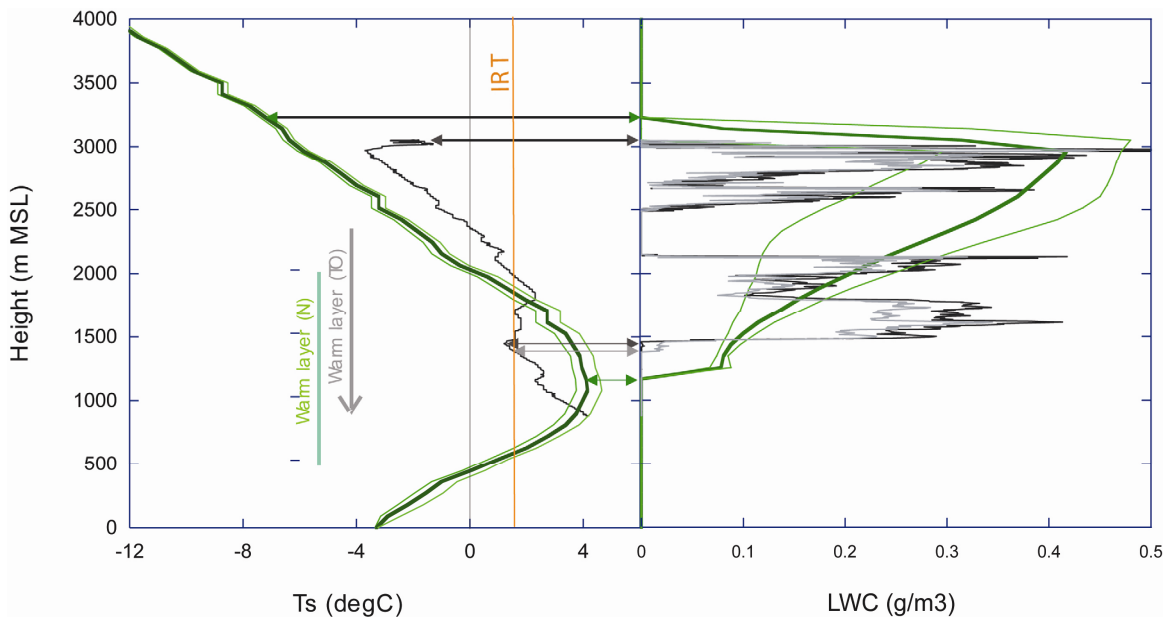
Figure 15.—10 December 2003—Case 2 sounding

Conclusions

These revisions to the NIRSS logic are progressing toward more accurate retrievals of cloud, liquid water, and icing hazard from a remote sensing system. Further work is needed to establish how the retrievals could be improved, either by limiting the system to its own components (X-band radar, ceilometer and profiling radiometer) or allowing external data to be used (satellite, NEXRAD radar,

METARS, model output). Supercooled large drop conditions have not yet been examined nor has the effect of precipitation on the retrievals. The icing hazard index should also be made compatible with icing products such as CIP, and/or the present thinking about the relation of atmospheric variables to ice accretion and subsequent performance loss.

Cloud top height and temperature retrieval are the most obvious areas of improvement. Many of the discrepancies seen in these comparisons arose from the retrieved cloud top being unrealistically high. In the cold cloud case of 11 November, the radar may well have detected ice crystals in glaciated cloud where liquid was not present; a warmer limit on liquid distribution (the current temperature limit is –25 °C) may help in those cases. Or, incorporation of new satellite-based cloud products developed by the NASA Langley Research Center may help determine the nature of the cloud top—whether it's ice or liquid. For the warmer clouds of 18 and 25 November it is not likely that the radar detected ice cloud above any water cloud. The source of the error in cloud top is not well understood and needs to be pursued.

Overall Summary and Suggestions for Future Studies

his year we were able to further the NIRSS program by re-writing the data ingest and display code from LabVIEW to C++ and Java. This was leveraged by a University of Colorado Computer Science Department Senior Project. The upgrade made the display more portable and upgradeable.

Comparisons with research aircraft flights conducted during AIRS-2 were also done and demonstrate reasonable skill in determining cloud altitudes and liquid water distribution. Improvements can still be made to the cloud and liquid logic. Some specific areas needing attention are:

- More in situ aircraft data are needed for comparisons with NIRSS profiles to enable upgrades in cloud and liquid water distribution logic.
- Cloud top height and temperature are problematic; satellite imagery ingest may help.
- Cloud base temperature is well-detected by the IR sensor and cloud base height is well-determined by the laser ceilometer (both in non-precipitating clouds). Conversion of temperature to height and vice-versa depends on the accuracy of the radiometer-derived temperature profiles. Perhaps the profile could be adjusted to match the IR temperature at the ceilometer-measured cloud base. Also, the performance of the IR sensor and the ceilometer has not been fully examined in precipitation.
- SLD conditions have not yet been incorporated into the NIRSS and should be considered in light of possible future regulations for certification of flight into those environments.

The icing hazard index was not evaluated here since that represents work in progress and needs to be made compatible with the new CIP-Severity algorithm. CIP is the Current Icing Potential product (Bernstein et al., 2005) that uses a combination decision tree/fuzzy logic algorithm to combine numerical weather model output with operational sensor data (NEXRAD, GOES, METARs and voice pilot reports) to produce an hourly icing diagnosis across the CONUS. The new severity algorithm seeks to diagnose liquid water production through rising, cooling air, and depletion by ice processes. The information used by CIP is very different from that ingested by NIRSS but some common ground does exist.

Additionally, the role of NIRSS and the information it both needs and provides needs to be determined in context of the Next Generation Air Traffic System (NGATS). The Weather Integrated Products Team has a plan for an Initial Operating Capability to take place in 2012. NIRSS is not explicitly a part of that IOC but should be considered as a follow-on as part of the development path to a 2025 full capability.

Publications and Presentations

12th Aviation, Range and Aerospace Meteorology Conference Poster
See http://ams.confex.com/ams/Annual2006/techprogram/paper_100499.htm

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