

NASA/TM—2009-215503



Use of the X-Band Radar to Support the Detection of In-Flight Icing Hazards by the NASA Icing Remote Sensing System

*David J. Serke and Marcia K. Politovich
The National Center for Atmospheric Research, Boulder, Colorado*

*Andrew L. Reehorst
Glenn Research Center, Cleveland, Ohio*

*Andrew Gaydos
The National Center for Atmospheric Research, Boulder, Colorado*

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- **TECHNICAL PUBLICATION.** Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- **TECHNICAL MEMORANDUM.** Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- **CONTRACTOR REPORT.** Scientific and technical findings by NASA-sponsored contractors and grantees.
- **CONFERENCE PUBLICATION.** Collected

papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- **SPECIAL PUBLICATION.** Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- **TECHNICAL TRANSLATION.** English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include creating custom thesauri, building customized databases, organizing and publishing research results.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at <http://www.sti.nasa.gov>
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA STI Help Desk at 301-621-0134
- Telephone the NASA STI Help Desk at 301-621-0390
- Write to:
NASA Center for AeroSpace Information (CASI)
7115 Standard Drive
Hanover, MD 21076-1320



Use of the X-Band Radar to Support the Detection of In-Flight Icing Hazards by the NASA Icing Remote Sensing System

*David J. Serke and Marcia K. Politovich
The National Center for Atmospheric Research, Boulder, Colorado*

*Andrew L. Reehorst
Glenn Research Center, Cleveland, Ohio*

*Andrew Gaydos
The National Center for Atmospheric Research, Boulder, Colorado*

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA Center for Aerospace Information
7115 Standard Drive
Hanover, MD 21076-1320

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Available electronically at <http://gltrs.grc.nasa.gov>

Use of the X-Band Radar to Support the Detection of In-Flight Icing Hazards by the NASA Icing Remote Sensing System

David J. Serke and Marcia K. Politovich
The National Center for Atmospheric Research
Boulder, Colorado 80305

Andrew L. Reehorst
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Andrew Gaydos
The National Center for Atmospheric Research
Boulder, Colorado 80305

Overview

In-flight icing hazards from supercooled small drops, drizzle and freezing rain pose a threat to all aircraft. Several products have been developed to provide hazard warning of in-flight icing to the aviation community. NCAR's Current Icing Product (ref. 1) (CIP) was developed to provide a near-realtime assessment of the hazard presented by supercooled liquid water (SLW) aloft in an algorithm that combines data from satellites, the Rapid Update Cycle (RUC) model, the national two-dimensional composite of S-band NEXRAD radar reflectivity, surface observations and pilot reports (PIREPs). NIRSS (ref. 2) (fig. 1) was developed by NASA to provide a ground-based, qualitative in-flight icing hazard assessment in the airport environment with commercially available instrumentation. The system utilizes a multichannel radiometer (ref. 3), built by Radiometrics Corporation, to derive the temperature profile and integrated liquid water (ILW). NIRSS's radar is a modified airborne X-band model WU-870 made by Honeywell. The ceilometer used is a standard Vaisala CT25K Laser Ceilometer. The data from the vertically pointing ceilometer and X-band radar are only used to define the cloud bases and tops. The liquid water content (LWC) is then distributed within the cloud layers by the system software. A qualitative icing hazard profile is produced where the vertical temperature is between 0 and -20°C and there is measurable LWC.

None of these in-flight icing detection products currently employ radar reflectivity (REFL) fields other than to define vertical cloud boundaries, as is done in NIRSS, or to estimate the probable surface precipitation type and intensity, as is done in CIP. This may change as recent research is applied to these operational icing hazard products. Detection of SLW with radar is difficult, especially in mixed phase conditions where ice crystals can be much larger than liquid drops and thus result in higher REFL. Fabry et al. (ref. 4) discussed how in-flight icing signatures from supercooled liquid clouds present a very weak target for radars, but that that characteristic is unique at short wavelengths such as X-band. They found that SLW is evident in a vertically pointing X-band radar as REFL below -10 dBZ and as large vertical gradients in REFL. These gradients are caused by riming of SLW to snow, thus rapidly increasing the radar REFL below the SLW layer. Further work with McGill University's Doppler X-band (ref. 5) in wintertime, stratiform storm clouds during the AIRS-I field program found that a distinct fall velocity mode much slower than the accompanying rimed snow indicates the presence of SLW. Their work found that these clouds typically exhibited a scarcity of freezing nuclei and thus few new ice particles were formed, due to relatively mild (0 to -10°C) conditions at the cloud level. A study on mixed-phase clouds with a K_a -band radar (ref. 6) concluded that liquid-phase clouds routinely exist to much colder temperatures due to the scarcity of freezing nuclei. It is well known that general uplift associated with warm or cold fronts or low pressure troughs causes air to become saturated with respect to water, forcing

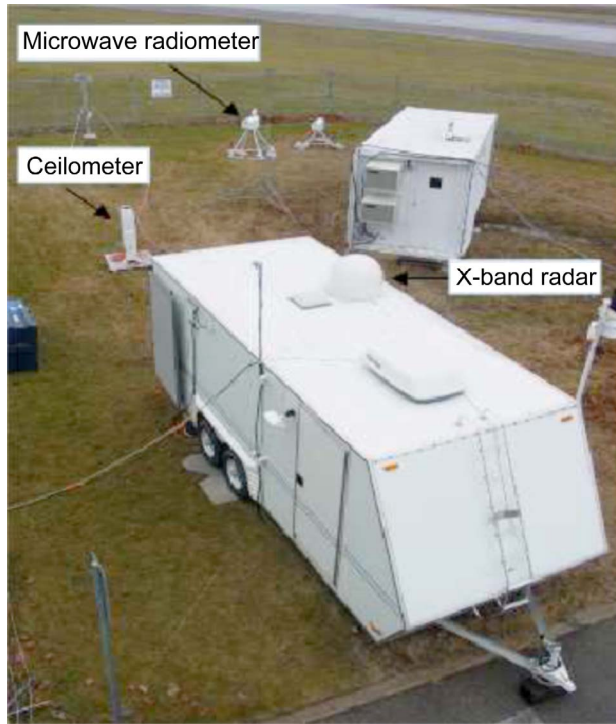


Figure 1.—NASA Icing Remote Sensing System hardware as installed for the AIRS-II field program.

water vapor to condense into water drops. If water drop generation exceeds the rate of deposition on ice crystals in a sub-freezing environment, the excess water will condense onto already existing cloud drops or form new ones.

Another recent study (ref. 7) showed that the S-band NEXRAD national radar mosaic, developed by the National Severe Storms Laboratory (NSSL), has the potential to add value in detecting in-flight icing to CIP by detecting large vertical REFL gradients within the CONUS. The possibility that the area of CIP hazard warning can be reduced in areas of horizontally and vertically-uniform REFL greater than 10 dBZ due to the dominance of scavenging of liquid by ice crystals was also explored.

The Alliance Icing Research Studies I and II were conducted near Montreal, Canada during the winters of 1999 and 2003, respectively. The primary research aircraft were dispatched from Ottawa and ground-based remote sensing instrumentation, including NIRSS (ref. 8) and McGill University's X-band radar (fig. 2), were based at Mirabel Airport (approximately 1 km apart). One of the icing research aircraft was a DeHavilland DHC-6 Twin Otter which was modified for sustained flight and data collection in icing environments. The outside air temperature was measured with a Rosemount model 102AU1P probe. Microphysical probes mounted on the aircraft collected data specific to icing research. LWC was measured with a CSIRO King probe and a Nevzorov LWC probe. Particle size was measured with a Forward Scattering Spectrometer Probe (FSSP-100) and an Optical Array Probe 2DC-Gray (2DG). REFL calculated from particle distributions collected from probes aboard the research aircraft from AIRS-I (ref. 9) (fig. 3) found that a bimodal distribution for liquid and glaciated cloud phase existed over the course of the field program, with REFL less than -10 dBZ generally indicative of small-drop icing conditions.



Figure 2.—McGill vertically pointing x-band radar as installed for the AIRS-II field program.

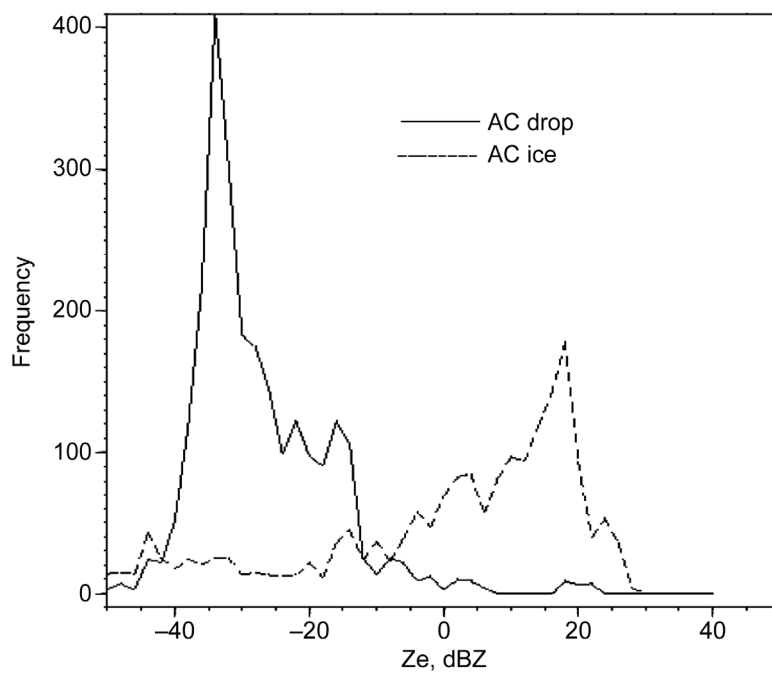


Figure 3.—Frequency of calculated reflectivities (Z_e) from all AIRS-I aircraft in situ particle distributions for liquid and ice cloud phase (ref. 5).

This study will examine X-band radar REFL profiles from NIRSS and McGill for consistency and compare them to microphysical data collected on vertical flight maneuvers by the research aircraft. Particle imagery and concentration distributions will be used to help illustrate that a qualitative small-drop in-flight icing hazard product can be derived from the vertical profile of X-band REFL. The following section presents several case studies from AIRS–II, followed by a case study from the 2005 winter icing program in Cleveland, Ohio. None of the cases show any evidence of bright band contamination.

Case Studies

November 11, 2003

The November 11, 2003, case had warm advection at 850 mb over Mirabel ahead of a surface warm front that was positioned over Ohio and low pressure over Lake Huron (fig. 4) and subfreezing conditions from 1.6 km to the highest altitude sampled during the vertical flight maneuver (fig. 5(a)). Very low LWC values were measured from the aircraft (fig. 5(b)). At the time of the vertical maneuver, the X-band profile showed uniform REFL values above 10 dBZ from 2 to above 7 km AGL (fig. 5(c), blue line). The McGill X-band profile (fig. 5(c), black stars) was reasonably similar to NIRSS's with no detectable directional bias. The 2DG particle image (fig. 5(d)) shows several seconds of imagery separated by time bars when the aircraft was at 2.5 km in altitude. The width of the plot is about 1 mm. The image for this case shows aggregates (top and bottom), columns, plates (middle) and many smaller irregular shapes. The combined FSSP and 2DG particle concentrations at 2.5 km altitude (fig. 5(e)) reflect the significant population of larger ice crystals as 2DG concentrations of particles with diameters between 100 and 1000 μm dropping off from 10^7 to 10^6 particles per m^4 . The high count of larger particles, low count of small particles and REFL above 10 dBZ all point to the cloud being glaciated and the crystal population actively scavenging out any small water drops as they condense. The calculated REFL value of this distribution was about 8 dBZ.

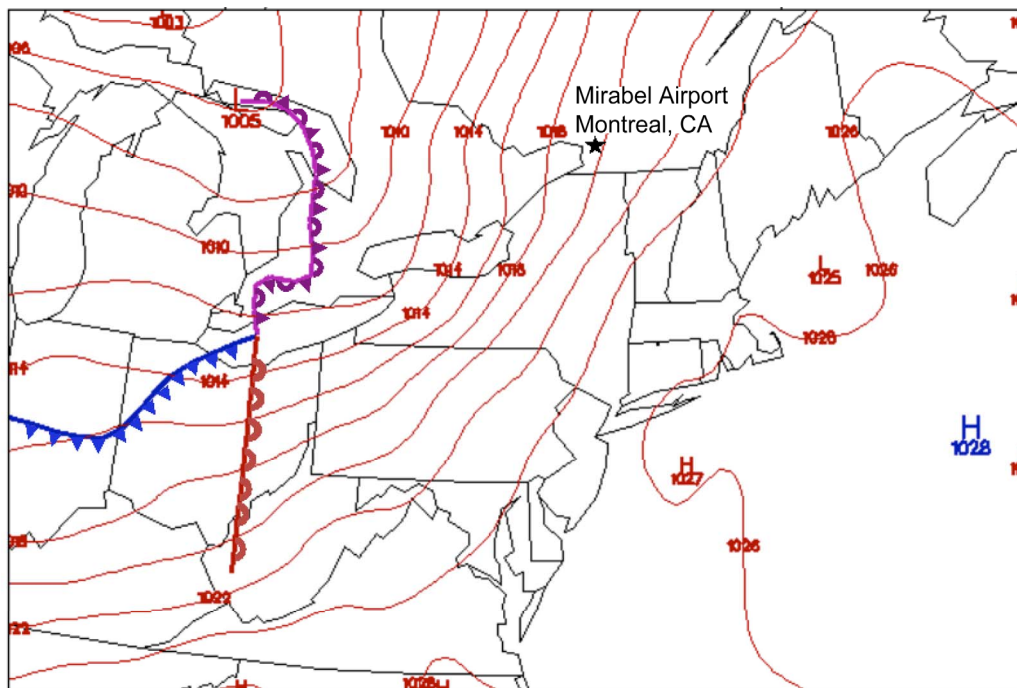


Figure 4.—Sea level pressure (red contours, mb) and NCEP frontal analysis (heavy red, blue, and magenta lines) at 15:00 UTC on November 11, 2003.

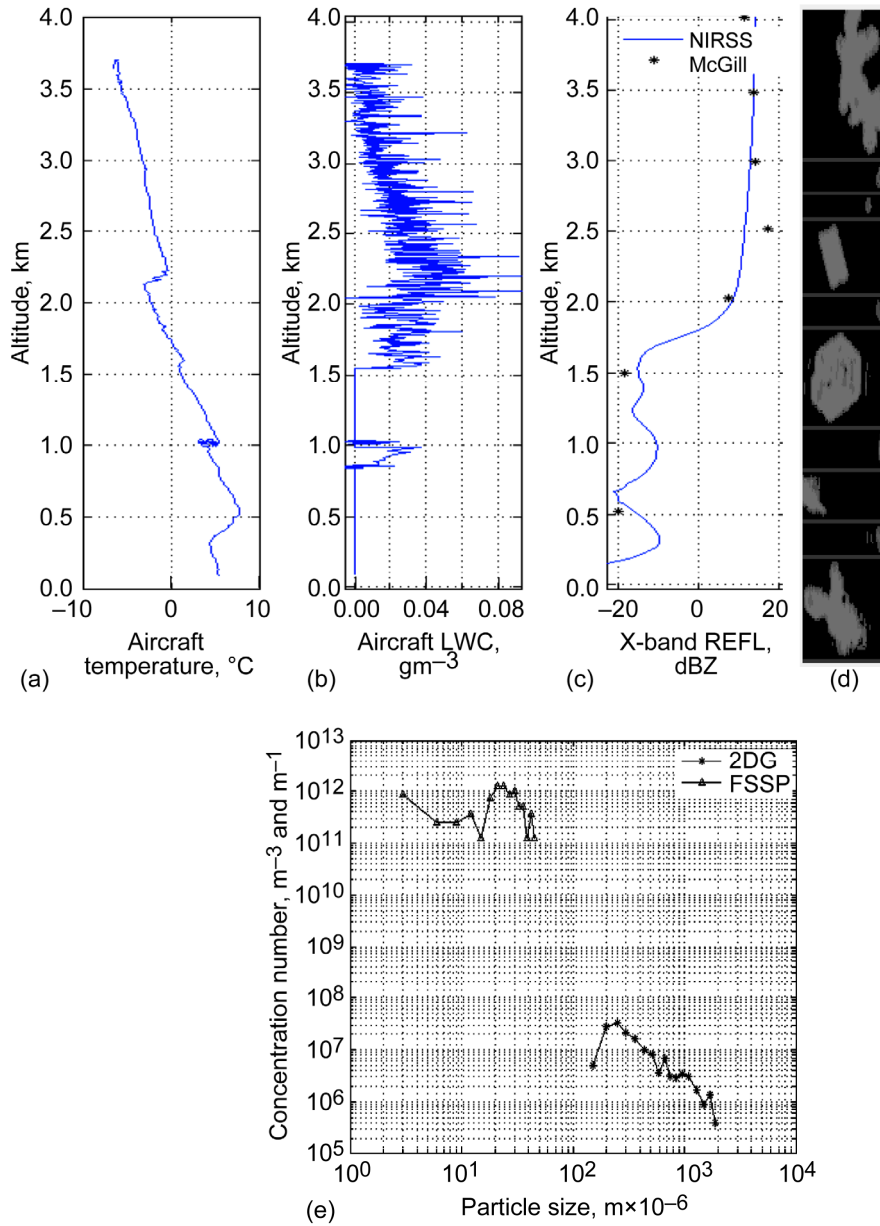


Figure 5.—(a) Twin Otter temperature, (b) CSIRO LWC, (gm⁻³), (c) NIRSS and McGill X-band REFL, dBZ, (d) 2DG particle image at 2.5 km, and (e) combined FSSP and 2DG particle distributions at 2.5 km, (m⁻⁴) at 16:45 UTC on November 11, 2003.

November 18, 2003

The November 18, 2003, case had warm advection at 850 mb over Mirabel ahead of a surface warm front positioned from Illinois to Kentucky and low pressure trough over from central Canada to Oklahoma (fig. 6). The temperature was below freezing at the surface (not shown) but ranged between 2 and 6 °C in the vertical flight maneuver profile (fig. 7(a)) due to an inversion. A wedge-shaped LWC profile with a maximum value above 0.4 gm^{-3} were detected by the aircraft (fig. 7(b)). Even though icing conditions could not exist at this time due to above freezing temperatures, it is still a useful exercise to explore the microphysical characteristics of this small drop case. At the time of the vertical maneuver, the X-band profile showed REFL values between -10 and -20 dBZ from the surface to the top of the liquid layer at 1.1 km AGL (fig. 7(c)). The REFL profile had a slight negative gradient with height through the liquid layer. The McGill X-band REFL values were mostly lower than the NIRSS X-band for this case. There were some larger liquid drops up to $200 \text{ }\mu\text{m}$ sensed by the 2DG (fig. 7(d)), with the characteristic donut-shaped particle shadow. The lack of shadow at the center of these larger drops is known as a Poisson spot and is caused by light diffraction. The concentration of drops (fig. 7(e)) sensed by the FSSP was two orders of magnitude larger than the November 11 glaciated case, and particles in the 2DG range were very limited.

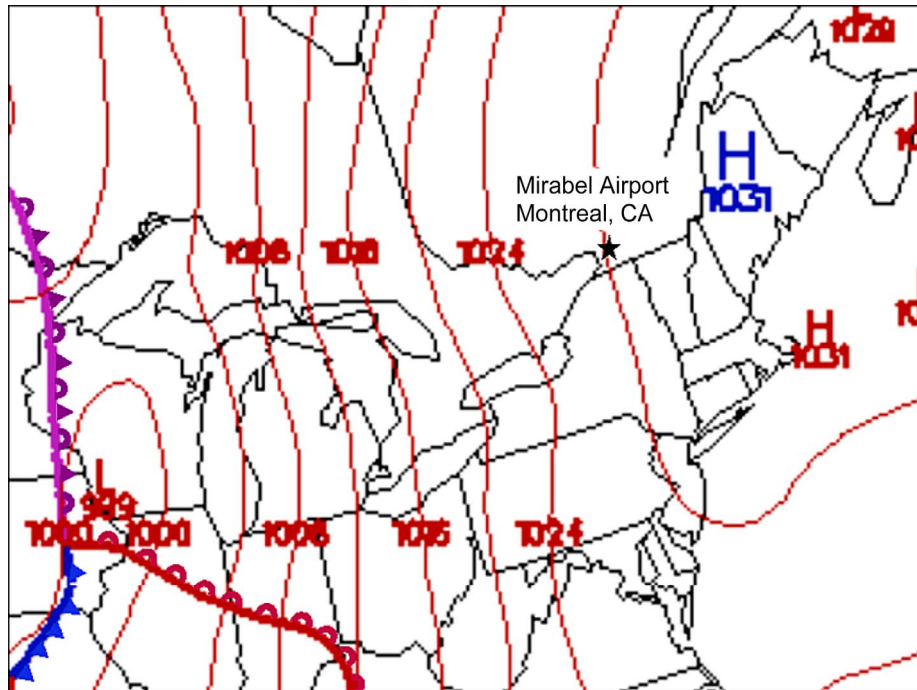


Figure 6.—Surface pressure (red contours, (mb)) and NCEP frontal analysis (heavy red, blue, and magenta lines) at 12:00 UTC on November 18, 2008.

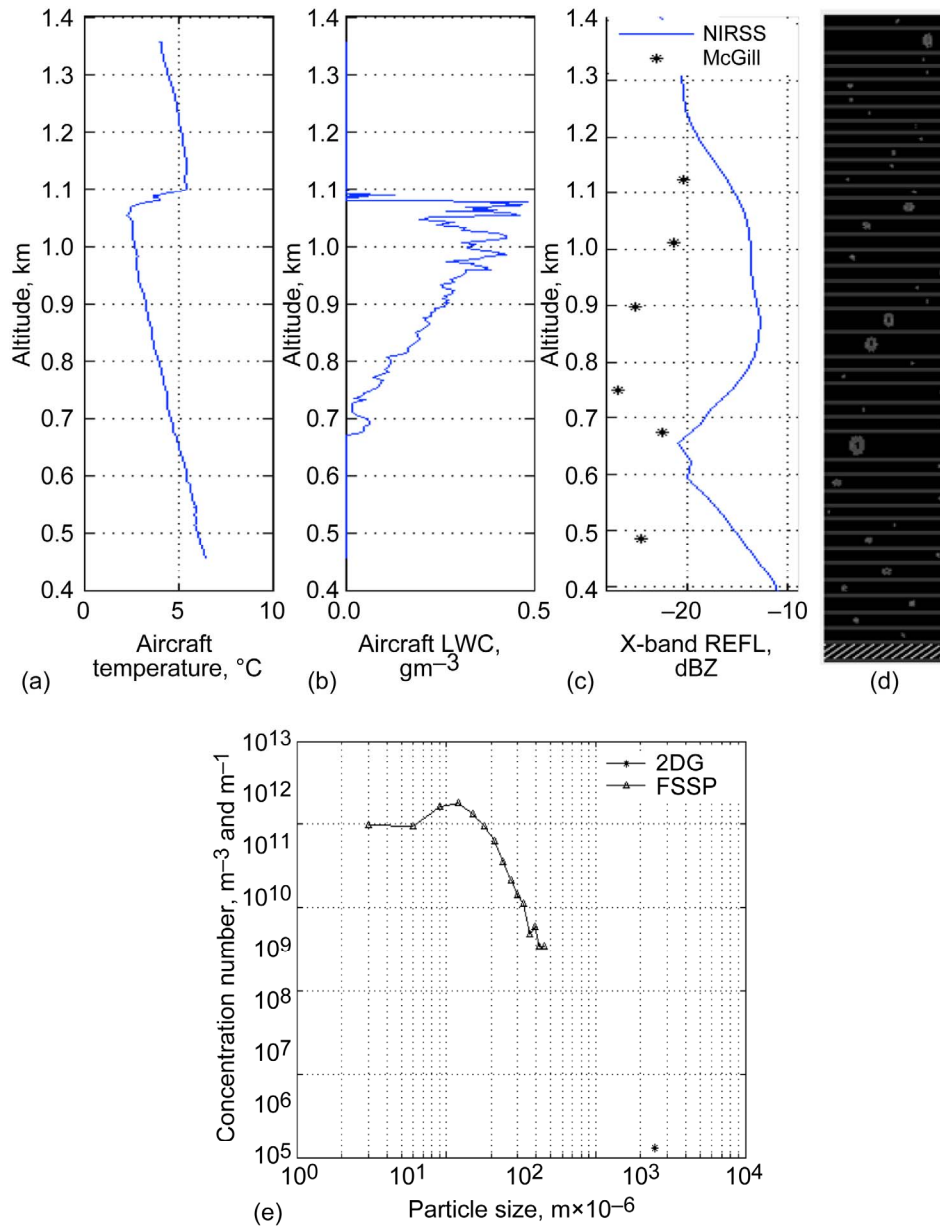


Figure 7.—(a) Twin Otter temperature, (b) CSIRO LWC, (gm⁻³), (c) NIRSS and McGill X-band REFL, dBZ, (d) 2DG particle image at 1.0 km, and (e) combined FSSP and 2DG particle distributions at 1.0 km, (m⁻⁴) at 12:40 UTC on November 18, 2003.

November 25, 2003

The November 25, 2003, case involved a trough and cold front which had moved over Mirabel several hours before 18:00 Z (fig. 8). Cold advection through the depth of the profile led to the development of a weakly convective stratocumulus layer. The aircraft conducted a vertical spiral over Mirabel centered at 18:55 Z. The aircraft detected a wedge shaped liquid water profile, a capping temperature inversion at 1.7 km and subfreezing conditions down to 0.3 km altitude (fig. 9(a)). A thin liquid water layer between 1.3 and 1.7 km in altitude had a maximum LWC (fig. 9(b)) value at the top of the layer of 0.2 gm^{-3} . Over the course of the day, the radar detected the intermittent passage of the cumuliform features as REFL above 10 dBZ (not shown). Between these crystal-dominated clouds are time periods when the REFL profile was below -10 dBZ (fig. 9(c)), which have been shown in previous research (ref. 5) to be associated with ice crystal-sparse conditions where supercooled liquid exist. The McGill X-band profile was reasonably similar the NIRSS for this case, with no detectable directional bias. The several second long 2DG particle image (fig. 9(d)) from 1.6 km altitude illustrates nonspherical ice shapes, some rimed dendrites (middle) and spherical water drops. The combined particle concentration distribution at 1.6 km altitude was similar to the November 18 case but with a quicker decrease in concentration of small drops above $10 \mu\text{m}$ and a larger range of sizes of larger glaciated crystals in the 10^5 particles per m^4 range associated with the irregular and rimed dendrite ice shapes. The calculated REFL at this time was -2 dBZ .

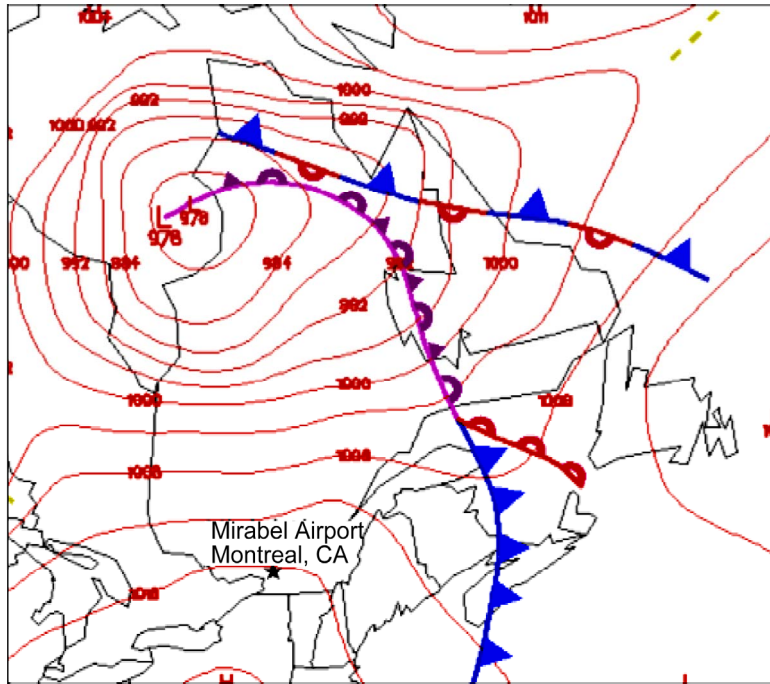


Figure 8.—Surface pressure (red contours, (mb)) and NCEP frontal analysis (heavy red, blue, and magenta lines) at 18:00 UTC on November 25, 2003.

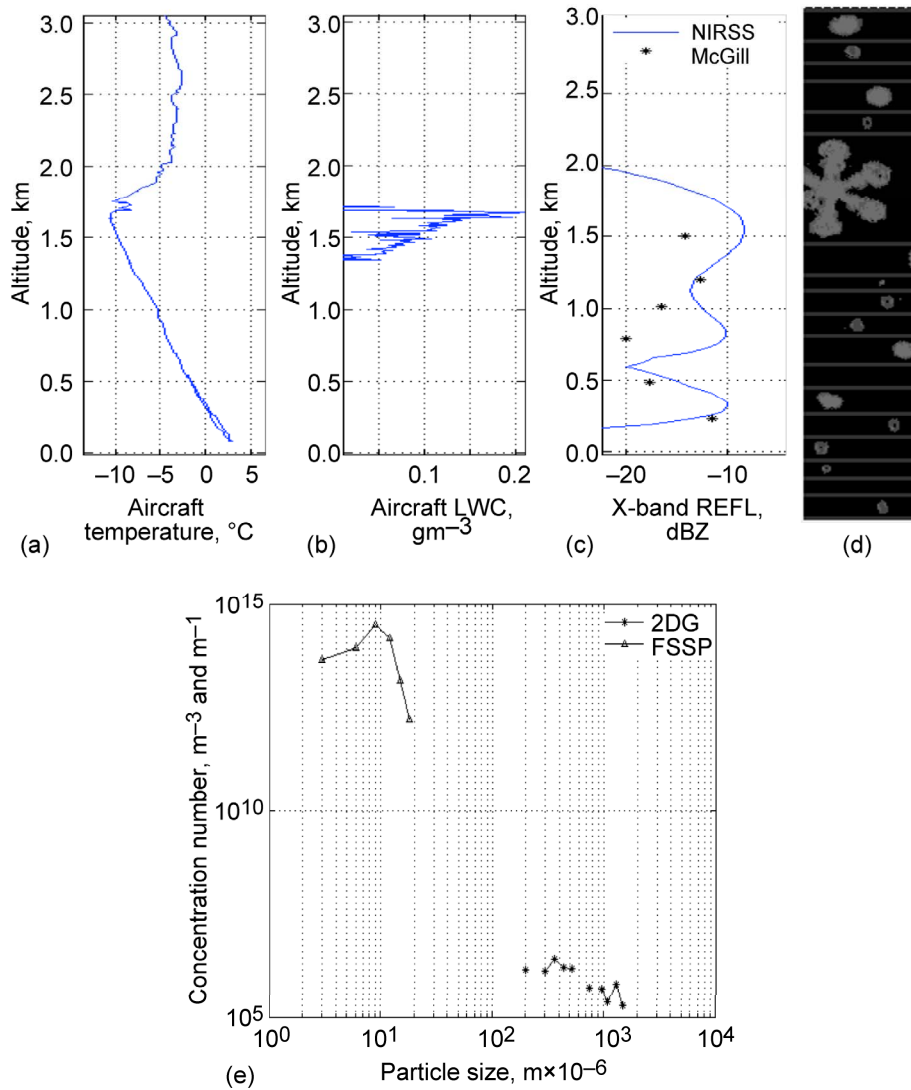


Figure 9.—(a) Twin Otter temperature, (b) CSIRO LWC, (gm⁻³), (c) NIRSS and McGill X-band REFL, dBZ, (d) 2DG particle image at 1.6 km, and (e) combined FSSP and 2DG particle distributions at 1.6 km, (m⁻⁴) at 18:55 UTC on November 25, 2003.

December 10, 2003

The December 10, 2003, case involved a surface low pressure over Illinois and a warm front extending from Michigan to southern Ontario, Canada. The surface chart shows warm air advection affecting the region around Mirabel (fig. 10). The aircraft conducted a vertical spiral over Mirabel centered at 16:27 UTC and detected three distinct water layers with the highest two being at or below freezing (fig. 11(a)). The maximum LWC values (fig. 11(b)) of the layers were 0.25, 0.4, and 0.45 gm^{-3} , respectively from bottom to top. REFL values within the layers (fig. 11(c)) ranged from -15 to -27 dBZ. Each layer showed a significant negative REFL gradient with height. The McGill X-band profile was reasonably similar to the NIRSS with no detectable directional bias. Nonspherical ice shapes, rimed dendrites and spherical water drops are seen within the LWC layer at 2.6 km (fig. 11(d)). Rimed aggregates, smaller irregular ice shapes and water drops were detected in the LWC layer at 2.1 km (fig. 11(e)). Aggregates, smaller irregular ice shapes, melting plates and water drops were seen in the above freezing layer at 1.2 km (fig. 11(f)). The distributions from the three layers decreased rapidly above 30 μm . Cloud-sized liquid drop concentrations below 10 μm increased from the top to the middle to the bottom layer.

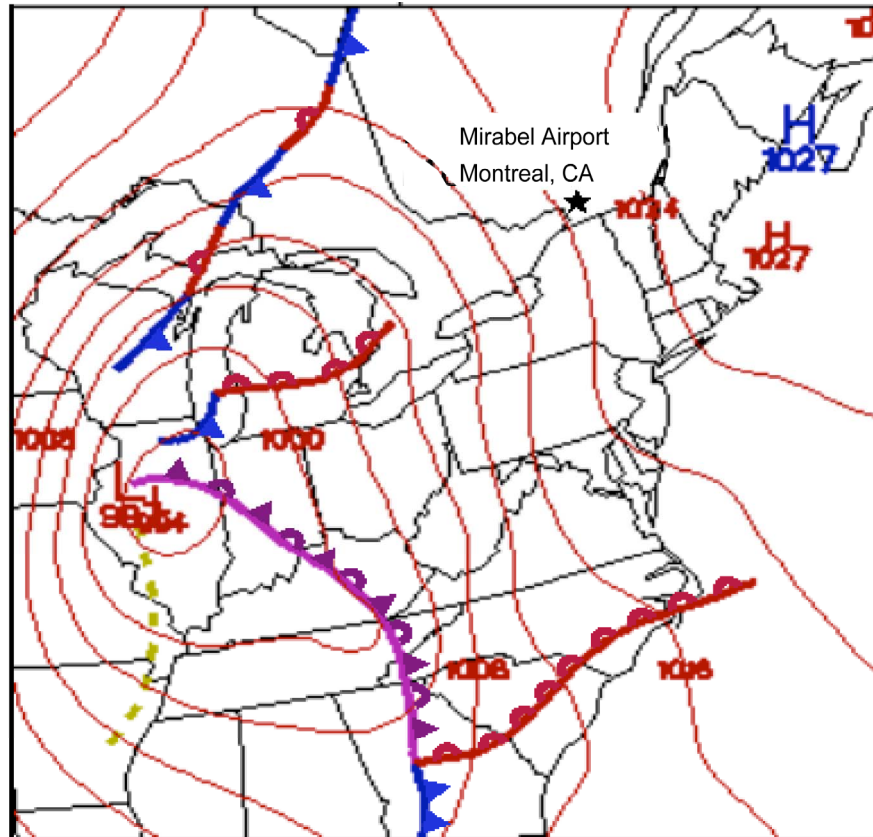


Figure 10.—Surface pressure (red contours, (mb)) and NCEP frontal analysis (heavy red, blue, and magenta lines) at 15:00 UTC on December 10, 2003.

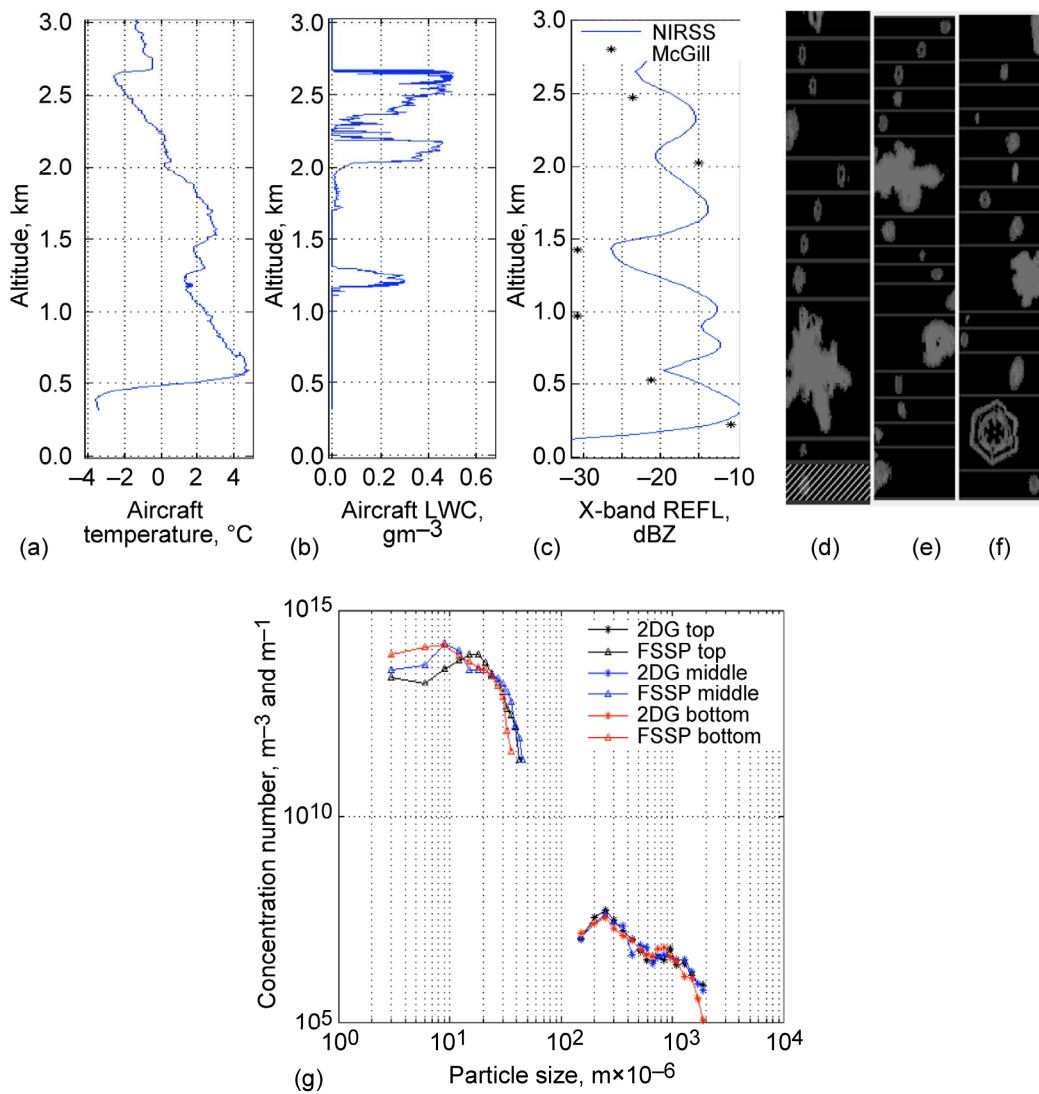


Figure 11.—(a) Twin Otter temperature, (b) CSIRO LWC, (gm^{-3}), (c) NIRSS and McGill X-band REFL, dBZ, (d) 2DG particle image at 2.6 and (e) 2.1 km. (f) Combined FSSP and 2DG particle distributions at 2.6 (g) black, (m^{-4}), 2.1 (blue), and 1.2 km (red) at 16:27 UTC on December 10, 2003.

February 16, 2005

The February 16, 2005, case involved a surface low pressure over northeastern Pennsylvania and a cold front that had previously passed over northern Ohio now extending southwestward over West Virginia. The 850 mb map shows cold air advection affecting the region around Cleveland's Hopkins International Airport (fig. 12). The aircraft collected vertical profile data on takeoff centered at 15:10 UTC and on a missed approach centered on 17:15 UTC.

Temperatures were subfreezing (fig. 13(a)) from the surface through the maximum altitude of the aircraft's vertical maneuver. The aircraft detected a wedge-shaped SLW profile from 0.6 to 1.7 km in altitude at 15:10 UTC (fig. 13(b)). Maximum LWC values at several heights reached 0.4 gm^{-3} . REFL values were -20 dBZ at the bottom of the layer and dropped to the minimum detectable value of -35 dBZ near 1.2 km (fig. 13(c)). The large REFL gradient (ref. 4) was likely due to the effects of diffusional growth and cloud drop accretion decreasing with height. The particle imagery at 1.6 km (fig. 13(d)) shows mostly very small liquid drops with virtually no ice particles. Imagery from 0.8 km (fig. 13(e)) shows mostly small drops and a $400 \mu\text{m}$ rimed aggregate. The combined particle concentration distribution (fig. 13(f)) at 1.6 km (blue line) depicts a wide, uniform population of supercooled cloud water drops up to $30 \mu\text{m}$ in diameter. The rapid decrease in concentrations above $100 \mu\text{m}$ is due to the presence of the few larger supercooled liquid drops and nearly complete absence of more irregularly shaped glaciated particles. At 0.8 km, there is a more pronounced peak in population at $10 \mu\text{m}$, and a more rapid decrease after $10 \mu\text{m}$. The 0.8 km distribution had some particles above $300 \mu\text{m}$, whereas the distribution at 1.6 km ended at $300 \mu\text{m}$. A theoretical REFL value of -23 dBZ results from the particle distribution from 1.5 km and a value of -10 dBZ from the distribution from 0.8 km.

By 17:15 UTC, the temperature profile had cooled slightly due to continued cold advection (fig. 14(a)) and the SLW had decreased to two layers (fig. 14(b)) at 0.6 and 0.8 km with maximum values above 0.1 gm^{-3} . Some LWC amounts were also located above 1.5 km but the aircraft did not sample much above that altitude. REFL values (fig. 14(c)) decreased from -18 dBZ just below the primary SLW layers to -23 dBZ just above them. It is unknown whether the negative vertical REFL gradient from 0.6 to 0.8 km is significant or a variation due to noise in the radar return. The combined particle concentration distribution shows no detected particle population in the 2DG range (fig. 14(d)), so no particle images are available. The theoretical REFL for the particle distribution at 0.8 km is -29 dBZ .

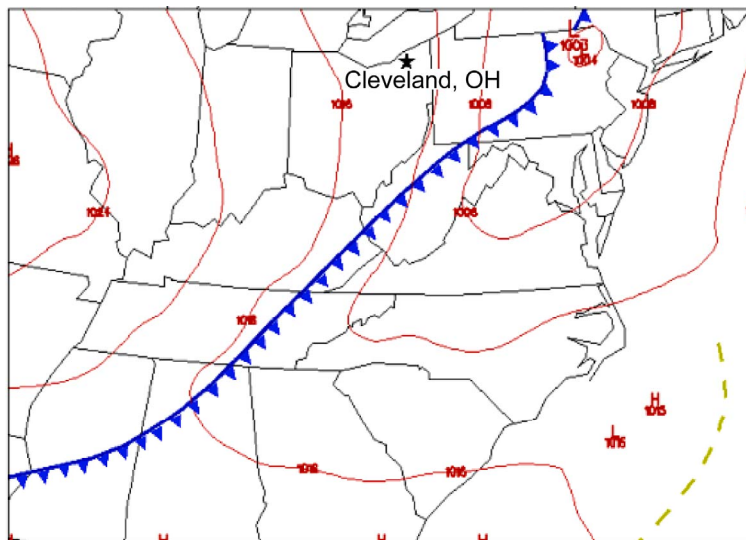


Figure 12.—Surface pressure (red contours, (mb)) and NCEP frontal analysis (heavy blue line) at 15:00 UTC on February 16, 2005.

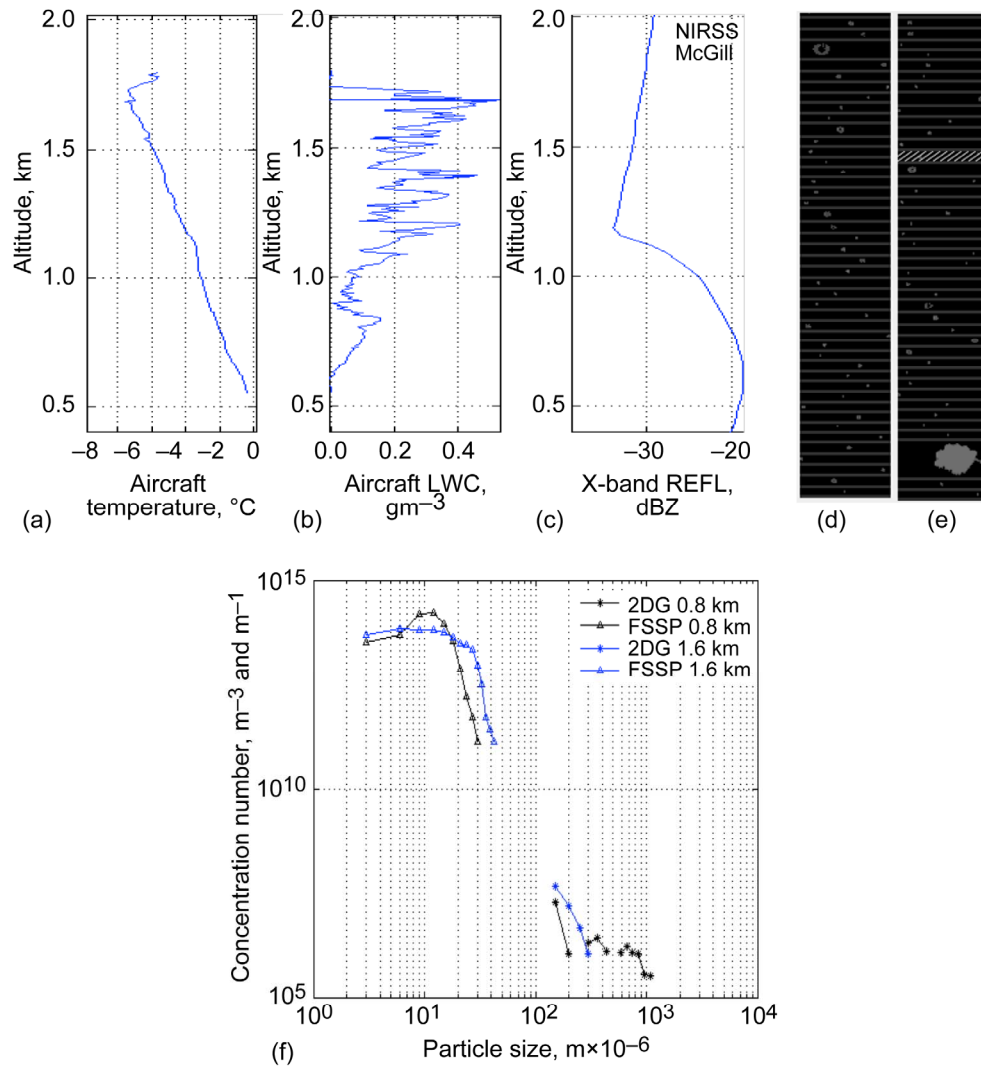


Figure 13.—(a) Twin Otter temperature, (b) CSIRO LWC, (gm^{-3}), (c) NIRSS and McGill X-band REFL, dBZ, (d) 2DG particle imagery at 1.6 and (e) 0.8 km. (f) Combined FSSP and 2DG particle distributions at 1.6 km, (f) blue, (m^{-4}) and 0.8 km (black) at 15:10 UTC on February 16, 2005.

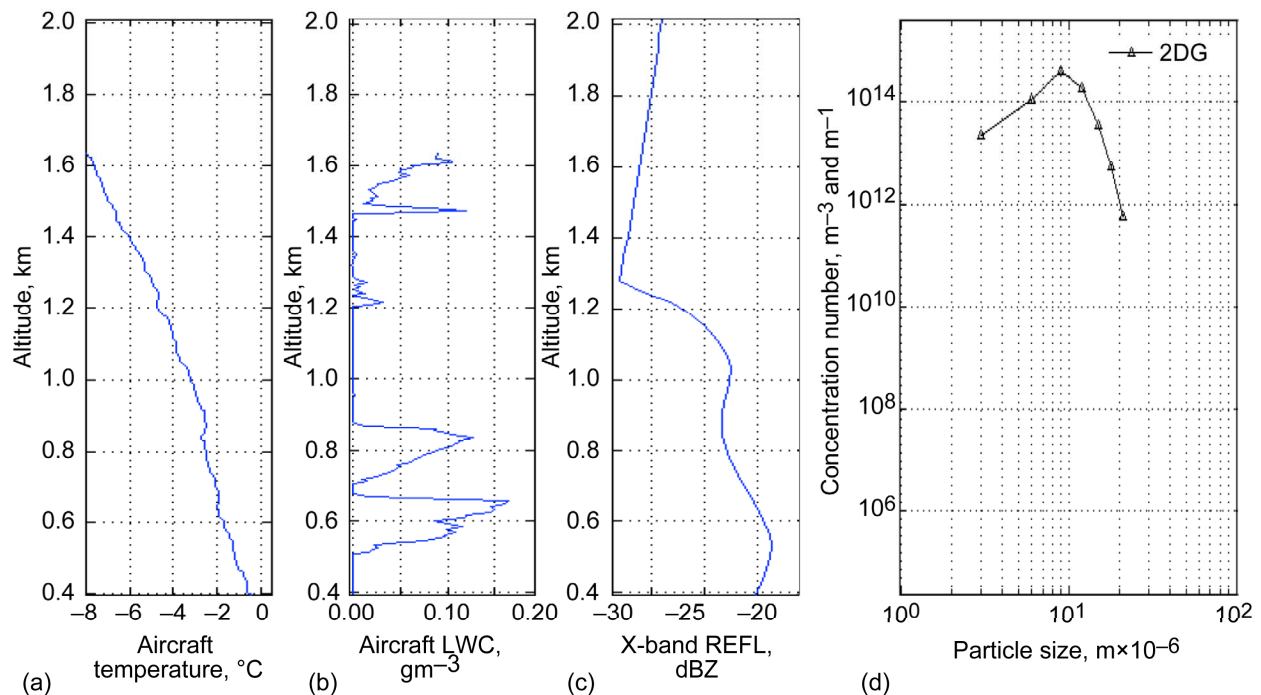


Figure 14.—(a) Twin Otter temperature, (b) CSIRO LWC, (gm^{-3}), (c) NIRSS and McGill X-band REFL (dBZ), and (d) combined FSSP and 2DG particle distributions at 0.8 km, (m^{-4}) at 17:15 UTC on February 16, 2005.

Conclusion

Since the McGill X-band radar was calibrated before the field program but had up to a 15-min. time recording error in an unknown direction (personal communication with I. Zawadzki) and a 1-km horizontal separation from the NIRSS radar, a precise comparison between the two radars was not possible. The NIRSS X-band REFL profiles agreed reasonably well with McGill’s X-band profiles. No clear calibration bias in the NIRSS radar was detectable with the limited number of cases examined. This leads to the conclusion that the off-the-shelf X-band radar was good enough to detect cloud levels and small-drop icing conditions over time without significant calibration biases effecting the measured REFL field.

The cases examined for this study represent mostly small drop (MVD less than $50 \mu\text{m}$) icing scenarios. No large concentration of ice crystal populations were reported in any case study except November 11, 2003. This particular case study showed that profile times that had large populations of larger crystals and REFLS above 10 dBZ had negligible LWC. Any LWC that condensed into drops was quickly scavenged out by the large crystals by deposition or accretion processes. Case studies with significant SLW in one or more layers had REFL that were between the minimum detectable REFL value and -10 dBZ. The case studies showed that an operational system like NIRSS could provide a qualitative in-flight icing warning for X-band REFL profiles that were uniformly low. Negative vertical gradients of REFL with height occurred in several of the cases where the small drop SLW layers existed. It is not understood at this time what caused these gradients. These wintertime cases all had weak lift associated with pre-warm frontal, post-cold frontal or trough passage. The lift led to saturation with respect to liquid water and generation of water vapor in excess of that being deposited on the sparse population of small ice crystals (as evidenced by low REFL, low 2DG counts and no precipitation). The excess water vapor led to the condensation of supercooled liquid cloud which could be detected by NIRSS’s X-band as REFL profiles less than perhaps -10 dBZ.

Future work will include a module in the NIRSS software to create an icing hazard field based solely on times when REFL are uniformly less than about -10 dBZ and/or sharp vertical REFL gradients exist. This hazard field should be validated against further cases when positive PIREPs, research flight data, NIRSS radiometer and icing severity data exist. The addition of Doppler capabilities to the NIRSS vertically pointing radar would enhance NIRSS's in-flight icing hazard detection by allowing for the discrimination between SLW, pristine snow and rimed snow particle populations.

References

1. Bernstein, B., McDonough, F., Politovich, M., Brown, B., Ratvasky, T., Miller, D., Wolff, C., and Cunning G., "Current Icing Potential: Algorithm Description and Comparison to Aircraft Observations," *Journal of Applied Meteorology*, 44, pp. 969–986, 2005.
2. Reehorst, A., Politovich, M., Zednik, S., Isaac, G., and Cober, S., "Progress in the Development of Practical Remote Detection of Icing Conditions," NASA/TM—2006-214242, 2006.
3. Solheim, F., Godwin, J., Westwater, E., Han, Y., Keihm, S., Marsh, K., and Ware, R., "Radiometric Profiling of Temperature, Water Vapor and Cloud Liquid Water Using Various Inversion Methods," *Radio Science*, 33, pp. 393–404, 1998.
4. Fabry, F., Zawadzki, I., Bell, C., and Cote, C., "Doppler Radar Signatures of In-Flight Icing Conditions," 30th International Conference on Radar Meteorology, Munich, Germany, July 19–24, 2001.
5. Zawadzki, I., Fabry F., and Szyrmer, W., "Observations of Supercooled Water and of Secondary Ice Generation by a Vertically Pointing X-Band Doppler Radar," *Atmospheric Research*, 59–60, 343–359, 2001.
6. Verlinde, J., Harrington, J., McFarquhar, G., Yannuzzi, V., Avramov, A., Greenberg, S., Johnson, N., Zhang, G., Poellot, M., Mather, J., Turner, D., Eloranta, E., Zak, B., Prenni, A., Daniel, J., Kok, G., Tobin, D., Holz, R., Sassen, K., Spangenberg, D., Minnis, P., Tooman, T., Ivey, M., Richardson, S., Bahrmann, C., Shupe, M., DeMott, P., Heymsfield, A., and Schofield R., "The Mixed-Phase Arctic Cloud Experiment," *Bulletin of the American Meteorological Society*, 88, pp. 205–221, 2007.
7. Serke, D.J., McDonough, F., and Politovich, M., "Analysis of 3-D NEXRAD Mosaic Reflectivity Data Colocated With Research Aircraft and Satellite Data: Implications on In-Flight Icing," AMS, New Orleans, LA, January 20–24, 2008.
8. Reehorst, A.L., Brinker, D.J., Ratvasky, T.P., "NASA Icing Remote Sensing System: comparisons from AIRS-II," NASA/TM—2005-213592, 2005.
9. Hudak, D., Currie, B., Rodriguez, P., Cober, S.G., Zawadzki, I., Isaac, G.A., and Wolde, M., "Cloud Phase Detection in Winter Stratiform Clouds Using Polarimetric Doppler Radar," *Proceedings of ERAD*, pp. 90–94, 2002.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE (DD-MM-YYYY) 01-03-2009		2. REPORT TYPE Technical Memorandum		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Use of the X-Band Radar to Support the Detection of In-Flight Icing Hazards by the NASA Icing Remote Sensing System				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Serke, David, J.; Politovich, Marcia, K.; Reehorst, Andrew, L.; Gaydos, Andrew				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER WBS 609866.02.07.03.04	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration John H. Glenn Research Center at Lewis Field Cleveland, Ohio 44135-3191				8. PERFORMING ORGANIZATION REPORT NUMBER E-16691	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001				10. SPONSORING/MONITORS ACRONYM(S) NASA	
				11. SPONSORING/MONITORING REPORT NUMBER NASA/TM-2009-215503	
12. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified-Unlimited Subject Categories: 03, 35, and 47 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301-621-0390					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT The Alliance Icing Research Study-II (AIRS-II) field program was conducted near Montreal, Canada during the winter of 2003. The NASA Icing Remote Detection System (NIRSS) was deployed to detect in-flight icing hazards and consisted of a vertically pointing multichannel radiometer, a ceilometer and an x-band cloud radar. The radiometer was used to derive atmospheric temperature soundings and integrated liquid water, while the ceilometer and radar were used only to define cloud boundaries. The purpose of this study is to show that the radar reflectivity profiles from AIRS-II case studies could be used to provide a qualitative icing hazard.					
15. SUBJECT TERMS Aircraft icing; Meteorological radar; Microwave radiometers; Optical radar; Multisensor fusion; Aircraft hazards; Cloud physics					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			19b. TELEPHONE NUMBER (include area code)
U	U	U	UU	21	STI Help Desk (email:help@sti.nasa.gov) 301-621-0390

