

NASA/TM—2006-214118



Comparison of Balloonsonde and Remote Sensing Atmospheric Measurements

David J. Brinker and Andrew L. Reehorst
Glenn Research Center, Cleveland, Ohio

Jack Power
Meteorological Service of Canada, Downsview, Ontario, Canada

The NASA STI Program Office . . . 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 Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published 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's 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 that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, 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 Access Help Desk at 301-621-0134
- Telephone the NASA Access Help Desk at 301-621-0390
- Write to:
NASA Access Help Desk
NASA Center for AeroSpace Information
7121 Standard Drive
Hanover, MD 21076

NASA/TM—2006-214118



Comparison of Balloonsonde and Remote Sensing Atmospheric Measurements

David J. Brinker and Andrew L. Reehorst
Glenn Research Center, Cleveland, Ohio

Jack Power
Meteorological Service of Canada, Downsview, Ontario, Canada

Prepared for the
11th Conference on Aviation, Range, and Aerospace Meteorology
sponsored by the American Meteorological Society
Hyannis, Massachusetts, October 4–8, 2004

National Aeronautics and
Space Administration

Glenn Research Center

February 2006

Trade names or manufacturers' names are used in this report for identification only. This usage does not constitute an official endorsement, either expressed or implied, by the National Aeronautics and Space Administration.

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

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

COMPARISON OF BALLOONSONDE AND REMOTE SENSING ATMOSPHERIC MEASUREMENTS

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

Jack Power
Meteorological Service of Canada
Downsview, Ontario, Canada M3H 5T4

1. INTRODUCTION

The most effective deterrent to the hazardous build up of airframe ice is the avoidance of those atmospheric regions where meteorological conditions make its accretion possible. This avoidance is only possible through forewarning the pilot, which today is accomplished through the use of pilot encounter reports or weather analysis. A better method is the measurement of actual atmospheric conditions, which requires either the widespread deployment of in-situ measurement devices or the development of remote sensing instrumentation. As part of its aircraft icing research program, the NASA Glenn Research Center is conducting a program to develop technologies for the remote sensing of atmospheric conditions that are conducive to icing (Reehorst, 2003). The goal of the program is to develop an integrated package of instruments, suitable for incorporation into the aircraft, which would provide the flight crew with sufficient warning to avoid a region of potential danger (Reehorst, 2001). A suite of instruments, currently ground based, is used to identify a region of supercooled liquid water which is labeled as hazardous if its water content is sufficiently high.

During the recently completed Alliance Icing Research Study (AIRS II), these instruments were deployed in conjunction with those of other U.S. and Canadian researchers at the Mirabel Airport near Montreal, Quebec. As part of the study, balloonsondes were employed to provide in-situ measurement of the atmospheric conditions that were being concurrently remotely sensed. Balloonsonde launches occurred daily at 1200 UTC to provide AIRS forecasters with local data, and, additionally when research aircraft were present in the airspace. Data from the soundings

are compared with the processed data from the NASA remote sensing instruments, which include an X-band radar, a ceilometer and radiometers.

2. EXPERIMENTAL INSTRUMENTATION

2.1 Balloonsonde System

The balloonsonde system used in the AIRS II study is a commercially available product from the VIZ Meteorological Systems Group of Sippican, Inc. The Model W-9000 Meteorological Processing System is an integrated hardware and software package that provides meteorological profiles through the use of telemetered radiosonde data and Global Positioning Satellite (GPS) location data.

The balloon-borne radiosonde sensors, transmitters and GPS receiver are contained in a molded foam case, approximately 500 grams in weight, including a water-activated battery that is typically good for two hours of flight. Temperature and humidity are directly measured, while pressure is calculated from GPS data and the Standard Atmosphere. Temperature is obtained using a standard rod thermistor fabricated from mined iron oxide, positioned at the end of an arm to remove it from the close proximity of the sonde case. Heating from solar radiation, as well as the wet bulb effect from water retention, is minimized by the application of reflective, then surfactant, coatings on the sensor. The range of measurement is +50 °C to -100 °C with an accuracy of 0.2 °C. A deposited carbon film on an acrylic substrate is used for humidity measurement. This configuration is well known for superior performance at higher humidity levels (>20%). Recent development has improved the performance of the sensor at lower humidity levels; after calibration at both 33% RH and 11%

RH a linear interpolation is used for this range. The sensor is installed in a tube integral to the foam sonde case. This location prevents direct solar radiation from warming the element and rain from impinging on the carbon film. Response time is typically less than one second.

Direct measurement of the ambient pressure is not employed in the sondes used in this study. The sondes are instead equipped with a GPS receiver, which acquires the signal from 5-7 satellites prior to launch. The base station also uses GPS to determine its location. The resulting comparison of positional data is used to calculate sonde altitude, latitude and longitude, its velocity with respect to the launch site and rate of ascent. An additional spare data channel was available on the sonde, which was not utilized.

The meteorological data, calibration values and GPS parameters are sampled and transmitted to the ground station once per second, with the data set retransmitted a second time for reliability. The transmitter operates at 403 MHz, tunable over a range of 400 to 406 MHz. The sonde transmitter has a nominal radiated power of 250 milliwatts, sufficient to allow for data collection over a range of 200 km when using the directional, six element Yagi antennas. The ground station includes the 403 MHz receiver and antenna controller, a GPS receiver and an serial interface for initializing the radiosonde. System control and data display and storage is accomplished through the use of laptop computer. Data can be viewed during the flight in either a graphical or tabular mode. WMO coding is available for processing the data into coded messages for transmission, with all flight data



Figure 1, Balloonsonde system ready for launch, ground station and data acquisition system is on table at left.

stored on the hard drive of the computer. The ground station and a balloon sonde ready for launch is seen in Figure 1. Figure 2 shows a launch of the balloon sonde. The multi-element direction antenna is visible on the roof of the building.

2.2 Remote Sensing System

Four instruments currently comprise the NASA icing remote sensing system: two radiometers, one that measures multiple frequencies between 22 and 59 GHz and another that measures at 89 and 150 GHz; a vertically staring X-band radar and a lidar ceilometer. Instrument control and data acquisition for all instruments is through individual personal computers.

Two Radiometrics Corporation microwave radiometers were deployed at Mirabel Airport. The TP/WVP-3000 profiling radiometer provides temperature and water vapor profiles from the surface to 10 km, and low-resolution liquid water profiles. Observations using seven frequencies



Figure 2, Launch of balloonsonde at Mirabel Airport, multi-element direction antenna is visible on the building roof.

from 52 to 59 GHz are used to determine temperature measurement as a function of altitude. Cloud water vapor content is determined through the observation of five frequencies in the 22 to 30 GHz range. Information on the liquid water content of the cloud is obtained by measurement of microwave energy as a function of frequency near 22 GHz and by scanning on either side of 60 GHz. The second radiometer, operates at 89 and 150 GHz with elevation scanning capability and dual polarization at 89 GHz. Its purpose is to discriminate ice from liquid water in meteorological conditions that may be associated with aircraft icing. Both radiometers are free standing, as is the ceilometer.

The X-band radar is a Honeywell WU-870 airborne weather radar unit which utilizes a 24-in diameter, flat-plate antenna operating at 9375 MHz. The radar is configured in a vertical staring mode. It has been modified to allow the use of a



Figure 3, Remote sensing system deployed at Mirabel Airport. The radar dome is seen on the roof of the trailer in the foreground, with the ceilometer on the ground directly behind it. The two radiometers are at the center rear of the photograph.

PC running under the Windows XP operating system for data acquisition instead of the standard Honeywell flight control/display unit. The radar transmitter/receiver antenna is mounted in the roof of the trailer, protected from the weather by a radome.

Cloud base and height as well as vertical visibility are measured using a lidar ceilometer. The instrument, a Vaisala Model CT25K, employs a pulsed diode laser operating in the infrared wavelengths (905 nm) and is able to detect up to three cloud layers simultaneously. The data acquisition systems for all of the remote sensing instruments are located in a trailer which is also used for equipment transportation. The trailer and instruments, Figure 3, were situated about 1 km from the balloonsonde launch site.

3. RESULTS AND DISCUSSION

Although the AIRS II field test program ran from November, 2003 through February, 2004, the NASA remote sensing system was operational on-site only during the 2003 portion of the study. During this period, 70 of the 89 balloonsonde launches took place, with nine of these coincident with the optimum datasets from the remote sensing system. Optimum conditions in this case encompass rain free conditions and dry radiometer windows. In this paper the results of two representative flights are examined. Temperature and relative humidity as a function of altitude through 10 km from the TP/WVP 3000 radiometer and balloonsonde are compared.

Comparisons of this data for a November 11, 2003, 15:35 UTC launch are shown in Figures 4.1 (temperature) and 4.2 (relative humidity). Sonde initial ascension rates were about 5 m/s, so the data covering the first 10 km of altitude were collected over a 30-35 min period of time. The radiometer data were taken from a single scan during the middle of the sonde ascent through 10 km. The temperature profile of the radiometer agreed well with the balloonsonde data. The average difference in values over the data set is 1.7 °C with the greatest difference 4.45 °C at about 2 km altitude. Above 6 km, the radiometer read consistently colder by about 2.5 °C, which agrees well with earlier results (Reehorst, 2001A). A probable cause is the training of the artificial neural network used in retrieving water vapor, cloud liquid water and temperature profiles from the radiometric data. Although it was trained using

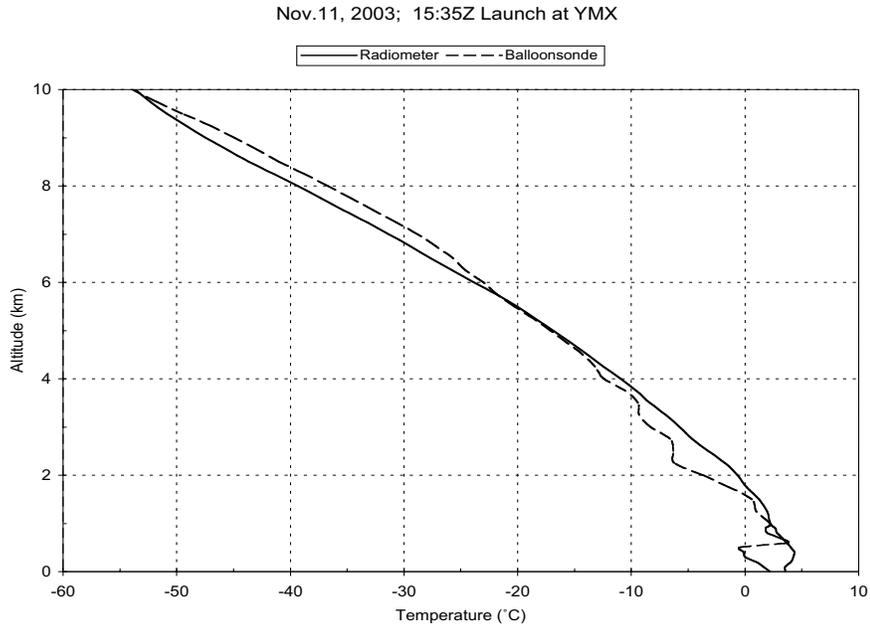


Figure 4.1, Temperature comparison for November 11, 2003, 15:35 UTC launch.

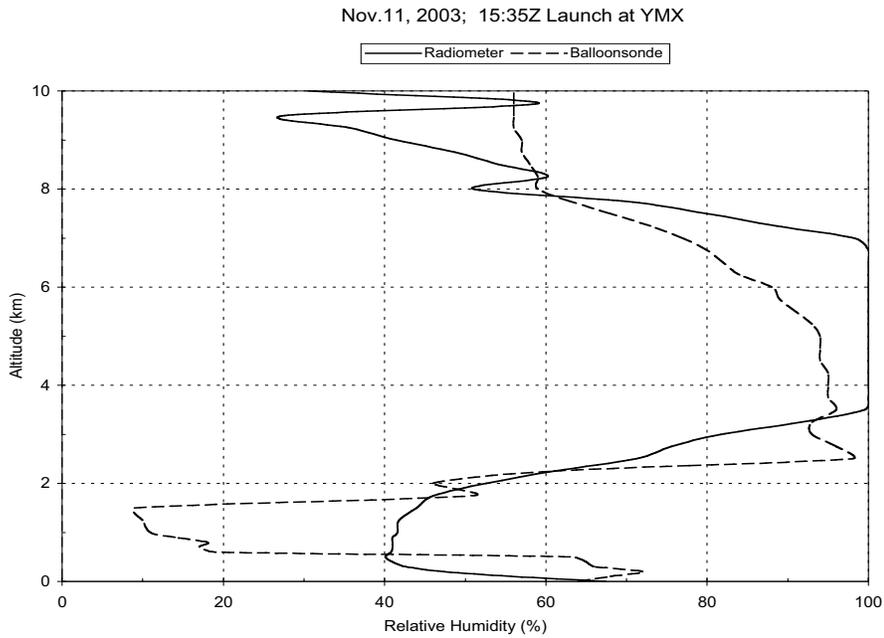


Figure 4.2, Relative humidity comparison for November 11, 2003, 15:35 UTC launch.

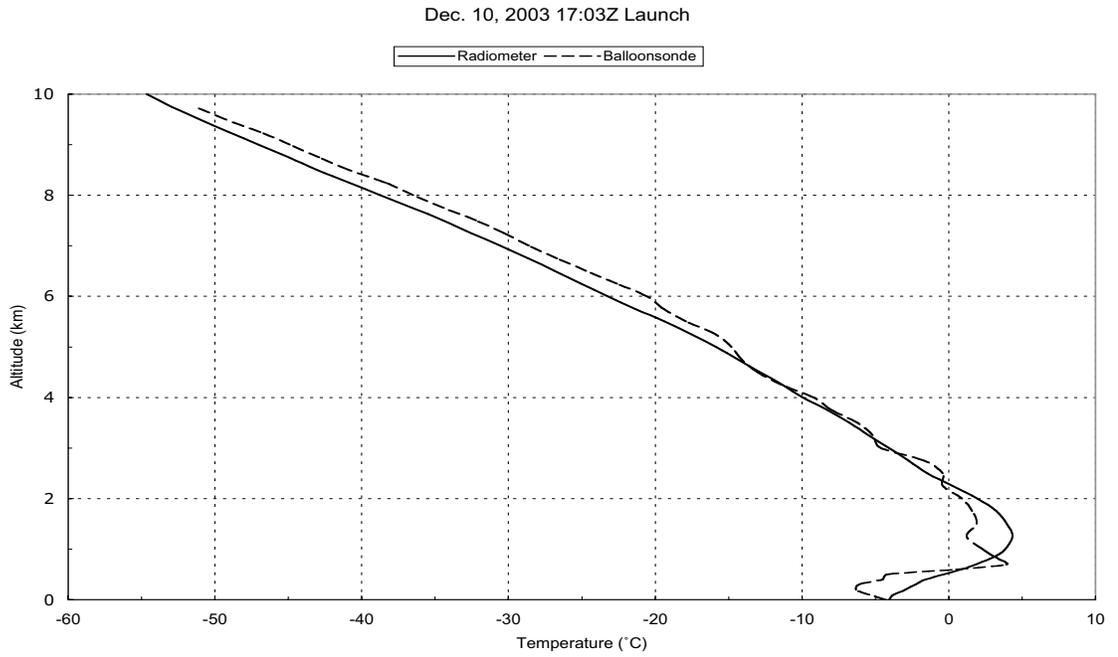


Figure 5.1, Temperature comparison for December 10, 2003, 17:03 UTC launch.

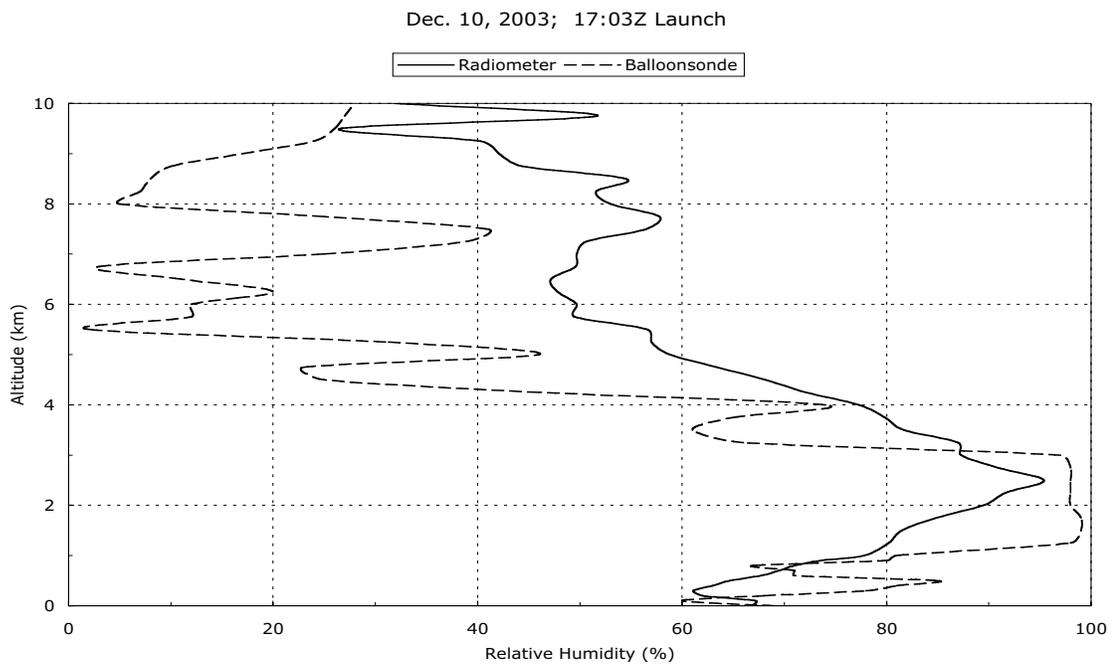


Figure 5.2, Relative humidity comparison for December 10, 2003 17:03 UTC launch.

data from the Montreal area, accuracy is directly dependent upon the close match of the training data with those conditions encountered during the field study. Other possible sources of error are the gradual decay of radiometer accuracy with increasing altitude and the continuous drift of the sonde during flight; horizontal wind speed reached 40 m/s above 6 km. Similar results are seen in Figure 5.1, the temperature profiles from a December 10, 2003, 17:03 UTC launch. In this case the average temperature difference was 1.6 °C with a maximum difference of 3.85 °C at 0.5 km. Above 5 km, the difference was about 2 °C, similar to the previous case. Winds were lighter in this case, reaching 14 m/s near 10 km.

With regard to relative humidity, larger discrepancies are seen between the radiometer and balloonsonde data than were seen in the temperature comparison. Figures 4.2 and 5.2 show relative humidity as a function of altitude for the two launches. For the November 11 data, there was a dry zone from just above ground level to 1.75 km. The radiometer is not particularly good in tracking this rapid decrease in humidity nor does it accurately track the lowest humidity portions of the band. Ceilometer data for this time period shows a cloud deck with a lower boundary at 2.1 km, which agrees well with both the radiometer and sonde data. The radiometer generally tracks well with the sonde up to 8 km. Above 8 km, the radiometer data deviates again from the sonde, as in the temperature cases, possible causes are the training of the radiometer neural-net, drift of the sonde from its launch position and increasing inaccuracy of the radiometer with altitude.

For the December 10 case, ceilometry shows a layer of clouds with a base at about 1.2 km. Both the radiometer and sonde track this well, although the radiometer deviates significantly at the upper and lower boundaries of the cloud, which are areas of rapid change of humidity. Above this layer, the air becomes quite dry, with dew points in the -60 °C range. The radiometer consistently mis-measures the humidity under these increasingly dry conditions.

4. CONCLUSION

Comparison of remotely sensed (radiometer) temperature and relative humidity

with in situ measurements (balloonsonde) during the AIRS II field program reveals strengths and shortcomings. The ability of the radiometer to accurately track temperature was good, particularly at lower altitudes. The discrepancy from sonde data above 5 km was generally constant and could be due to mismatch between the dataset used to train the radiometer neural-net and actual conditions, drift of the sonde with time or decreasing inaccuracy of the radiometer with altitude. Agreement with regard to relative humidity was not as good. The radiometer is not able to track rapid changes in humidity and appears to return consistently high humidity values in area of very dry air. In all cases, both systems accurately measured the boundaries of cloud layers as delineated by the ceilometer. Despite these deficiencies, the results from the AIRS II field test demonstrated the soundness of the basic concepts of the remote sensing system.

Future work includes the automation of methods of comparison of the large volumes of data generated by these systems, which at present are not easily compared. The radiosonde system will be installed in the aircraft hangar at NASA Glenn in Cleveland for the upcoming icing flight season, in close proximity to the remote sensing system. This will allow for simultaneous remote and in situ (both the balloonsonde system and the icing research aircraft) sensing of the conditions of interest. The development of a liquid water content sensor for integration into the radiosonde is also of interest and is under study.

5. REFERENCES

Reehorst, A.L. and Koenig, G.G., 2001: Ground-based Icing Condition Remote Sensing System Definition. NASA/TM-2001-211102, 43 pp.

Reehorst, A.L., 2001A: Comparison of Profiling Microwave Radiometer, Aircraft, and Radiosonde Measurements From the Alliance Icing Research Study (AIRS), 15 pp.

Reehorst, A.L. and Politovich, M.K., 2003: Development of Icing Condition Remote Sensing Systems and their Implication for Future Flight Operations. SAE 2003-01-2096, 6pp.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

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 Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (<i>Leave blank</i>)	2. REPORT DATE February 2006	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Comparison of Balloonsonde and Remote Sensing Atmospheric Measurements		5. FUNDING NUMBERS WBS-22-728-41-05	
6. AUTHOR(S) David J. Brinker, Andrew L. Reehorst, and Jack Power			
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-15453	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) National Aeronautics and Space Administration Washington, DC 20546-0001		10. SPONSORING/MONITORING AGENCY REPORT NUMBER NASA TM-2006-214118	
11. SUPPLEMENTARY NOTES Prepared for the 11th Conference on Aviation, Range, and Aerospace Meteorology sponsored by the American Meteorological Society, Hyannis, Massachusetts, October 4-8, 2004. David J. Brinker and Andrew L. Reehorst, NASA Glenn Research Center; and Jack Power, Meteorological Service of Canada, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4. Responsible person, David J. Brinker, organization code RTI, 216-433-2236.			
12a. DISTRIBUTION/AVAILABILITY STATEMENT Unclassified - Unlimited Subject Category: 03 Available electronically at http://gltrs.grc.nasa.gov This publication is available from the NASA Center for AeroSpace Information, 301-621-0390.		12b. DISTRIBUTION CODE	
13. ABSTRACT (<i>Maximum 200 words</i>) As part of its aircraft icing research program, the NASA Glenn Research Center is conducting a program to develop technologies for the remote sensing of atmospheric conditions. A suite of instruments, currently ground-based, are used to identify a region of supercooled liquid water which is labeled as hazardous if its liquid water content is sufficiently high. During the recently completed Alliance Icing Research Study (AIRS II), these instruments were deployed in conjunction with those of other U.S. and Canadian researchers at the Mirabel Airport near Montreal. As part of the study, balloonsondes were employed to provide in-situ measurement of the atmospheric conditions that were being concurrently remotely sensed. Balloonsonde launches occurred daily at 1200 GMT to provide AIRS forecasters with local data and additionally when research aircraft were present in the airspace. In this paper, we compare the processed data from the NASA remote sensing instruments, which included an X-band radar, lidar and two radiometers, to the data gathered from the 70 soundings conducted while the NASA instruments were active. Among the parameters compared are cloud upper and lower boundaries, temperature and humidity profiles and freezing levels.			
14. SUBJECT TERMS Aircraft icing; Aviation meteorology; Remote sensing; Radiosondes; Atmospheric sounding; Radiometers			15. NUMBER OF PAGES 12
			16. PRICE CODE
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT

