Alliance Icing Research Study II
(AIRS II)

Science Plan

July 2003

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Executive Summary

The Second Alliance Icing Research Study (AIRS II) is being planned for the winter of 2003/2004, and will be conducted out of Ottawa, Ontario and Mirabel, Quebec. AIRS II is a project endorsed by the Aircraft Icing Research Alliance (AIRA), which consists of government organizations within North America interested in aircraft icing. It is also being supported by the World Meteorological Organization (WMO) World Weather Research Program (WWRP) project on Aircraft In-Flight Icing. The First Alliance Icing Research Study (AIRS I) occurred during December 1999 to February 2000 in the same area. This project used 3 aircraft stationed out of Ottawa and remote sensing hardware located at both Ottawa and Mirabel (see http://airs-icing.org/) to investigate the remote sensing of aircraft icing and other aircraft icing issues.

AIRS II, which builds on the results of AIRS I, has operational objectives 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. In order to support the operational objectives, the following science objectives will be addressed to: a) investigate the conditions associated with supercooled large drop formation, b) determine conditions governing cloud glaciation, c) document the spatial distribution of ice crystals and supercooled water and the conditions under which they co-exist, and d) verify the response of remote sensors to various cloud particles, and determine how this can be exploited to remotely determine cloud composition.

It is anticipated that three instrumented research aircraft operating out of Ottawa will be used in this study. These aircraft will fly over a network of ground in-situ and remote-sensing meteorological measurement systems, located at Mirabel. Some prototype airport weather forecasting systems, which use satellite and surface-based remote sensors, PIREPS, and numerical forecast models, will be evaluated during the project. The aircraft will also provide data to verify the remote-sensing algorithms, numerical forecast models, and forecast systems, used to detect and predict icing conditions.

AIRS II is an exciting collaborative effort among many scientists and organizations. It will result in providing the aviation community with better tools to avoid aircraft icing, and to improve the efficiency of airport operations. It will also enable some unique basic science objectives to be addressed such as: how supercooled large drops form, how cloud ice forms, and how to better remotely detect cloud properties.

1. Introduction

The first Alliance Icing Research Study (AIRS I) was based in Ottawa, Ontario, using the National Research Council (NRC, see Appendix C for a glossary of acronyms) Convair-580 and the U.S. National Aeronautics and Space Administration's Glenn Research Center (NASA-GRC) Twin Otter, with instrument platforms located at Mirabel, Quebec, and Ottawa. The field phase was conducted between November 1999 and March 2000. The project emphasized studies of supercooled large drop (SLD – drops with diameters exceeding 50 μm, includes drizzle and rain) conditions during this climatologically favourable period. Preliminary results are summarized by Isaac et al. (2001a). Information regarding AIRS I, including the Science Plan and associated publications, can be found at http://www.airs-icing.org.

The second Alliance Icing Research Study (AIRS II) is being planned for the winter of 2003-2004, and will be conducted from a base at Ottawa, Ontario with flights around eastern Ontario and over Mirabel, Quebec. AIRS II, which builds on the results of AIRS I and other projects, has a mix of operational and scientific objectives.

The primary location for AIRS II is Mirabel, where many ground-based remote and in-situ sensors will be located. The remote-sensing equipment will consist of ground-based systems, located at Mirabel, as well as satellite-borne instrumentation. Microwave radiometers will measure total vapour and liquid paths, as well as profile temperature and vapour. Cloud and precipitation radars and a ground-based lidar (with Doppler, polarization and dual wavelength capabilities) will be used to remotely detect and classify zones of icing, snow, and freezing precipitation. The existing McGill Observatory S-band radar, which has both Doppler and polarization capabilities, and a new McGill mesonet of ground sites that measure surface precipitation, winds and temperature, make the Mirabel site very attractive. Some prototype airport weather forecasting systems which use satellite and surface-based remote and in-situ sensors, numerical forecast models and voice pilot reports will be evaluated during the project.

Three instrumented research aircraft will operate from Ottawa and a US base of operations. These aircraft will fly special flight operations over the network of in-situ and remote-sensing meteorological measurement systems, and in addition will provide long-range sampling well away from the instrument area to characterize the icing environment and to gather samples of cloud-active nuclei entering the local area. Aircraft measurements also will be collected to help develop improved models for predicting icing shapes on aircraft, and to verify numerical forecast models and integrated forecast systems used to predict icing conditions. The effect of icing on the performance and handling qualities of the research aircraft operating in well documented icing conditions will also be evaluated. All the instrument platforms will also enable basic science objectives to be addressed such as: how supercooled large drops form, how cloud ice forms, and how remote sensors react to different types and concentrations of ice and liquid.

2. Objectives

AIRS II builds on the work performed during AIRS I, as well as that from previous and related projects (CFDE I/II/III, SLDRP, WISP, MWISP, etc.). Through the previous work, investigators have been able to isolate specific problems to be addressed in this field effort. The main theme of AIRS II is the detection, diagnosis and forecasting of winter weather conditions affecting flight in the airport terminal area, specifically inflight icing (supercooled liquid water aloft) and surface precipitation (snow or freezing rain and freezing drizzle).

The objectives of AIRS II were endorsed at an AIRS Workshop held in Toronto, 26 June 2001, attended by 33 scientists from 17 organizations. There are two sets of objectives. The Operational Objectives are related to the development and evaluation of techniques to detect, diagnose, and forecast the terminal area weather environment. The Scientific Objectives in many ways support these Operational Objectives, but at the same time are intended to address specific scientific questions remaining from the previous work in the field.

Operational Objectives:

O1) Test and evaluate detection, diagnosis, and forecast systems for terminal-area winter weather hazards to aviation, with an emphasis on in-flight icing and snowfall;
O2) Improve forecasts of aircraft icing conditions;
O3) Better characterize the aircraft-icing environment; and
O4) Better characterize the accretion of ice, and the aerodynamic performance effect of the aircraft-icing environment.

Scientific Objectives:

S1) Investigate micro-, meso-, and synoptic-scale conditions associated with supercooled large drop formation both as drizzle, as from cloud coalescence, and as rain, from snow melt and supercooling as particles falls into a cold layer;
S2) Determine conditions governing cloud glaciation (conversion from liquid or mixed-phase to the ice phase);
S3) Document the spatial distribution of ice crystals and supercooled water, and determine the conditions under which they can co-exist; and
S4) Verify the response of remote sensors to various types and concentrations of ice crystals and liquid droplets, and how this can be exploited to remotely determine cloud composition.

These objectives differ substantially from those of AIRS I, which emphasized the characterization of the icing environment and had less of an emphasis on forecasting. With the development of several forecast systems for the detection and forecasting of hazardous conditions to aircraft at airports, AIRS II is an opportune time to verify their capabilities.

The Operational Objectives are consistent with goals and requirements of regulatory and advisory organizations including Transport Canada (TC), the Canadian Search and Rescue Secretariat, NASA GRC and the U.S. Federal Aviation Administration (FAA). These organizations are providing substantial funding for the project. The Scientific Objectives are being pursued by MSC, The National Center for Atmospheric Research (NCAR), and several Canadian and U.S. universities, and must be at least partially answered before any accurate and robust airport warning system can be developed.

This project has the endorsement of the Aircraft Icing Research Alliance (AIRA) whose founding members are the National Research Council of Canada, the Meteorological Service of Canada, TC, and NASA GRC. Although not a formal member of AIRA, the FAA has also endorsed the project. The Aircraft In-Flight Icing Project of the World Weather Research Program (WWRP) of the World Meteorological Organization (WMO) is also supporting the project. Through the WWRP, European participation is being encouraged and the British Meteorological Office has indicated that they intend to participate.

3. Motivation for the Study

Aircraft icing can pose a significant hazard to commercial aircraft operations over the North American continent. Approximately 30 fatalities and 14 injuries occur annually in the United States with $96 million in personal injury and aircraft damage (Paull and Hagy, 1999). The accident that occurred at Roselawn Indiana, in October 1994, involved costs of $195 million in personal injury and aircraft damage. Between 1978 and 1989, there were 298 fatalities in Canada (~25 fatalities/yr) where aircraft icing was recognised as a contributing factor in the accident. A recent analysis of 120 accidents or incidents resulting from in-flight aircraft icing conducted by Green (2003) showed that 90 % of the accidents or incidents took place during the take-off, approach, landing, holding or go-around phase of flight. This implies that a real-time icing detection/warning system at airports may reduce the icing hazard to aircraft, just where the threat is highest.

The current aviation weather forecasting systems in Canada and the U.S. do not meet the requirements of the aviation industry, since there is more emphasis in forecasting over the long term than providing short term, local forecasts. For example, the official U.S. forecasts, Airman's Meteorological Bulletins, or AIRMETs, tend to cover broad areas and long (6 h) time frames. As such, much more emphasis is placed on planning flight operations based on the predicted weather rather than on addressing problems posed by weather when it is encountered (i.e. avoidance or using holding patterns). Numerical weather prediction models are reasonably capable of forecasting ground-based or in-cloud icing conditions 6 h in advance. Two new systems provide a current depiction of inflight icing over the U.S., and 20-min snowfall forecasts for the terminal area. These systems respectively CIP, the Current Icing Potential and Weather Support for De-icing Decision Making or WSDDM are currently being evaluated. Development of forecast capability for inflight and ground-based icing on the 0-3 h time frame on small (< 5 km) spatial resolution is a considerable challenge. These more detailed, short-term forecasts, as well as real time detection or diagnosis require the type of knowledge of clouds that will be sought during AIRS II.

In addition to these operationally based motivations, there are significant scientific questions that remain regarding SLD and mixed-phase clouds. Previous field efforts such as WISP, MWISP, CFDE I/II/III and SLDRP were designed to address these and comprehensive data sets were gathered. Analyses of these data sets have led to the scientific objectives described above. While "classical" freezing rain and drizzle formation - involving a layer of warm, >0°C air, with ice crystals melting in this warm layer and supercooling in the cold air below is relatively easy to forecast, conditions associated with a condensation/coalescence or "non-classical" process are more difficult to forecast, and appear to be regionally variable. The details of the microphysics remain somewhat elusive as well, as do the mechanisms controlling the drop size distributions that are observed.

Conditions governing cloud glaciation are coming into question, particularly those involving heterogeneous mixes of ice crystals and supercooled water. There is some evidence of "clustering" of such regions and the scales on which the phase transitions take place appears to have a relation to the shape of accreted ice, as well as to more basic questions such as the nature of the microphysical transition through mixing.

The previous studies have also demonstrated that more detailed knowledge of the response of remote sensors to various types and concentrations of ice crystals and liquid droplets is needed. Much of this can be accomplished via radiative transfer modeling, however, realistic conditions must be simulated in order to achieve realistic results.

4. Objectives

a) Operational Objectives

O1) Test and evaluate detection, diagnosis, and forecast systems for terminal-area winter weather hazards to aviation, with an emphasis on in-flight icing and snowfall

Systems for forecasting winter weather at terminal areas are being developed at NOAA, NCAR, NASA GRC, and MSC. The MSC system (Fig. 1) is tentatively named the Airport Vicinity Icing and Snow Advisor (AVISA). It is envisioned as a rule-based system that will combine data from satellites, a microwave radiometer, a network Doppler radar, a high resolution numerical forecast model, a vertically-pointing Doppler radar (Fabry and Zawadzki, 2000), and surface observations including a Precipitation Occurrence Sensor System (POSS) for determining precipitation type (Sheppard and Joe, 2002) and a fast response hot plate snowgauge (Rasumssen et al., 2002). The Aurora nowcasting platform (Greaves et al., 2001) is used as a front end to the AVISA system. AVISA will diagnose whether snow exists at the airport, or whether in-flight icing is occurring aloft, and it will predict those features out to a few hours. The first test of the system will be during a special "AIRS 1.5" field project scheduled for winter 2002/2003. A full comparison with other systems will be made during AIRS II.

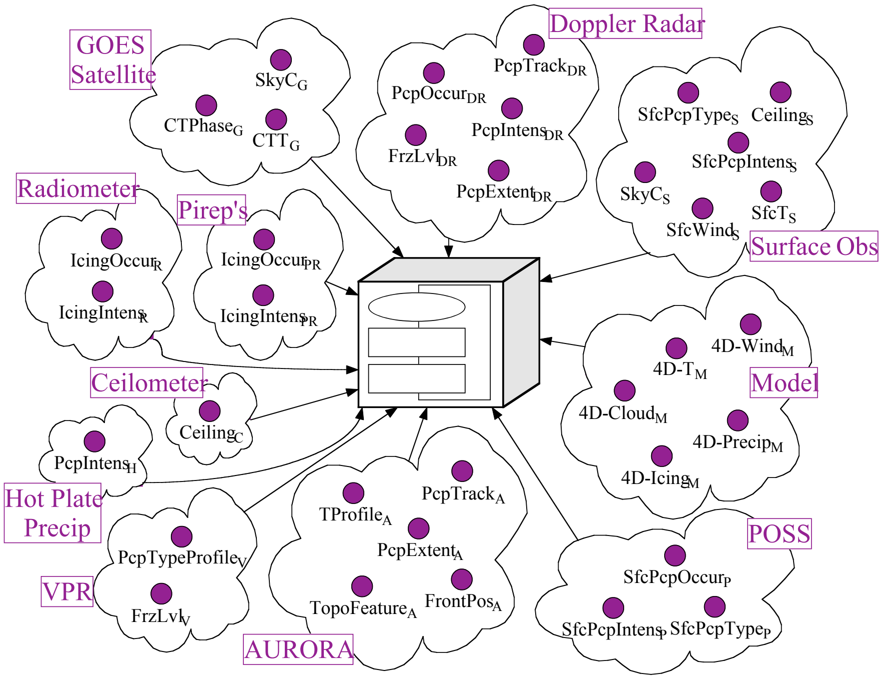


Fig. 1: MSC System for forecasting hazardous conditions at airports. It is tentatively named the Airport Vicinity Icing and Snow Advisor (AVISA).

For several years, NOAA's Environmental Technology Laboratory (ETL) has worked with the FAA to develop radar- and radiometer-based icing diagnostic techniques. Having demonstrated that a dual-polarized Ka-band radar can detect SLD, ETL has begun to design and implement an operational prototype demonstration system, the Ground-based Remote Icing Detection System (GRIDS, see NOAA, 2001). GRIDS integrates a Ka-band dual-polarized radar, a microwave radiometer, local surface meteorological measurements, and information from a numerical weather forecast model (the U.S. National Center for Environmental Prediction's Rapid Update Cycle Model, or RUC) ingested via the Internet. GRIDS will be deployed to Mirabel for AIRS II during IOP-1.

NASA Glenn is developing the NASA Icing Remote Sensing System (NIRSS) that will combine a vertically staring X-band radar, a multifrequency microwave radiometer, and a ceilometer (Reehorst and Koenig, 2001). The goal of this development effort is to demonstrate a relatively low cost, stand-alone icing condition detection system in the airport (terminal) environment. Individual NIRSS components will be tested during the winter of 2002/2003 in the Cleveland, OH region. The components are controlled by networked Windows based PCs, so the component data files will be available real-time to the AIRS II network. The radar will be operated as part of the ground-based remote sensing equipment at Mirabel.

Initial icing detection ground-to-air communication methodologies will also be evaluated during AIRS II, taking advantage of the presence of multiple research aircraft over the course of the study period. The primary communication to the aircraft will be an ATIS-type radio message over the NRC 'company frequency'. Remotely detected icing information will be transmitted to the flight crews at their initial (and possibly later) approach to Mirabel. Post flight debriefings will assess the accuracy, efficiency, and overall value of the communication. To ensure the acceptance of the information from remote sensing systems by flight crews, it is necessary for the instrumentation to meet their expectations, and thus must match their perceptions of cloud location quite accurately. Therefore the research aircraft flight crew will be requested to accurately define their perceived cloud tops and bases.

O2) Improve forecasts of aircraft icing conditions

New algorithms for forecasting icing within the MSC operational environment are showing improved skill (Guan et al., 2001 and 2002). Fig. 2 shows the True Skill Score for the old temperature/relative humidity scheme of Applemen, used five years ago, versus the Old Mix scheme which was a diagnostic package added to the Sundqvist scheme, and the newer prognostic schemes of Tremblay et al. (1996) and Kong and Yau (1997). The overall skills are still low and are limited by poor cloud forecasts. The ability to quantitatively predict cloud water amounts remains poor (see Guan et al., 2001 and 2002) and, as of yet, there is no accurate method of predicting SLD. Further tests of the model forecasts will be conducted during AIRS II; in-situ measurements from instrumented aircraft and remote measurements from radars and lidars will be used for verification.

Forecasts of in-flight icing in the U.S. have improved substantially over the past few years. The NCAR Current Icing Product (CIP, formerly known as the Integrated Icing Diagnosis Algorithm or IIDA, McDonough and Bernstein 1999) is now accepted as a fully operational product by the FAA and the National Weather Service (NWS). The CIP is a three-dimensional depiction of the likelihood of icing over the continental United States. It currently has a 40-km horizontal scale with 3000-ft vertical resolution. A finer-scale product is planned to be evaluated for the Mirabel area during AIRS-II. At that time an icing intensity and type product should also be available. CIP has shown considerable skill in determining regions where icing conditions are likely (see Fig. 3), and warns a smaller area with the same probability of detection as the current official forecasts (AIRMETs, or Airmen's Meteorological Bulletins) issued by the National Weather Service. A forecast version, FIP, is also running as an experimental product in the same output format as CIP.

It should be noted that different statistical tests are used, such as the True Skill Score (TSS) and the Probability of Detection (POD) due to differences in the verification data. In Canada, pilot reports are scarce, thus forcing the use of the TSS and in-situ data. However, one advantage of the TSS is that it takes into account False Alarms, which cannot be accurately represented when using pilot reports.

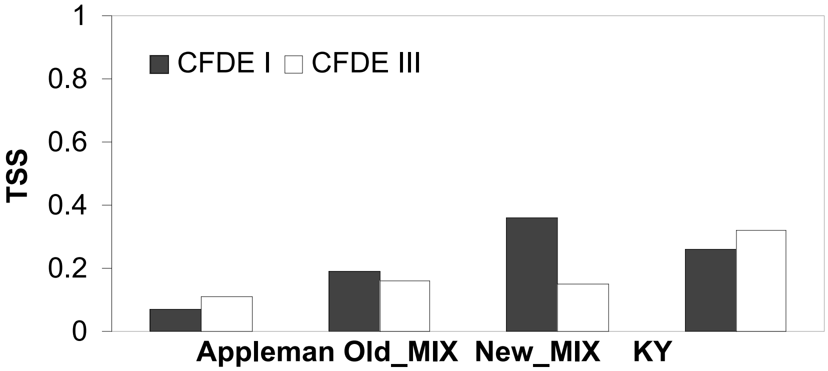


Fig. 2*: True Skill Scores for the prediction of in-flight icing conditions for the old schemes (Appleman and Old_Mix, and the new schemes (New_Mix and KY) used in the Canadian operational models.*

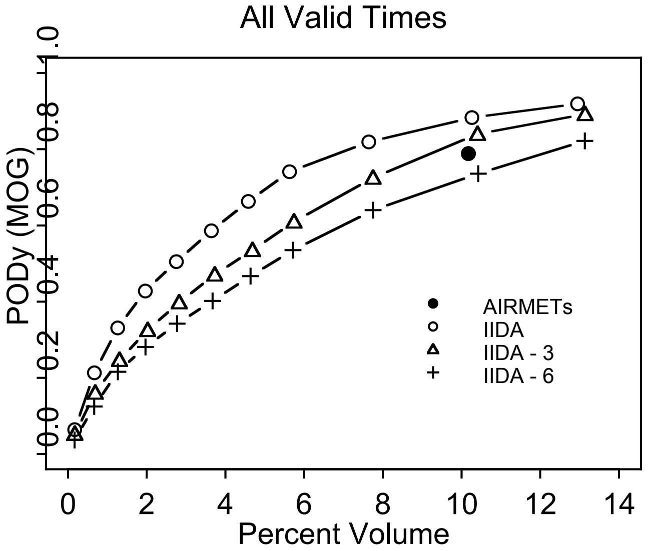


Fig. 3: Probability of detection of a "yes" icing pilot report (POD$_y$*) of moderate or greater severity (MOG) versus the percentage of total U.S. CONUS airspace covered. The points for IIDA are for different likelihood levels 0-1 in 0.1 increments. Current IIDA and 3- and 6-h persistence are shown for all valid times of the algorithm for 20 Jan – 21 Mar 2001.*

O3) Better characterize the aircraft-icing environment

Although substantial progress has been made in characterizing the icing environment, further information is needed. Isaac et al. (2001b) summarized measurements from the Canadian projects, including AIRS I. A more complete summary is given in Fig. 4. It is generally felt that the data set is large enough to assess whether the certification envelopes should be modified. However, the certification authorities are also interested in extremes in terms of cloud liquid water, median volume droplet diameter, cold temperatures, and encounter length. Ryerson et al. (2002 and 2001) have quantified clustering of supercooled liquid water using NASA-GRC flight data to assess their effects on radiometer and radar remote sensing ice detection systems. Koenig et al. (2002) have addressed effects of supercooled liquid water clustering on airfoil ice shape, and have demonstrated those effects in the NASA-GRC IRT. Spatial effects of drop size spectra and ice crystal habit clustering are also being addressed. AIRS II flight data, and radar and microwave radiometer data, would enable a more complete spatial characterization of icing cloud microphysical conditions. More details are provided in section S3. Within AIRS II, an effort will be made to expand our knowledge regarding the data set extremes, and under what conditions they occur.

This research should enable expanded and fuller characterization and description of atmospheric icing environments as experienced by aircraft and relating to the safe operation of aircraft. This includes characterization as depicted in Figure 4, but is not strictly limited to such characterization. The recognition and description of unusual environments that may be encountered can be of great value in the analysis of future incidents or accidents. Data will be collected and processed with this view always in mind.

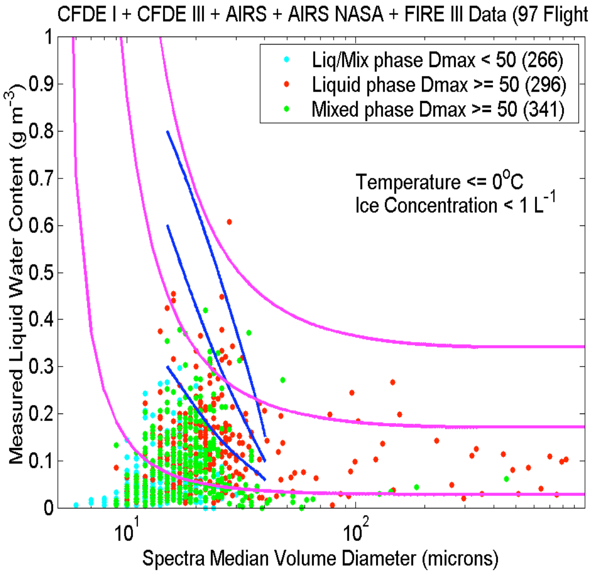


Fig. 4: Summary of 30-km average data from 97 flights. The three blue lines are for the FAR 25 Appendix C envelopes at 0, –10 and –20^{o}C. The curved lines show constant icing rates of 1, 6 and 12 g cm^2 h^{-1}.

O4) Better characterize the accretion of ice, and the aerodynamic performance effect of the aircraft-icing environment

In conjunction with an improvement in the characterization of the in-flight icing environment, particularly as an extension to the existing FAR/JAR 25 Appendix C envelope, further work is needed on the characterization of the effects of ice accretion in different environments, including SLD and very cold icing, upon overall airplane aerodynamics.

The means by which this will be realized are two fold. Firstly we will perform a maneuver with the AIRS II aircraft that will permit the determination of the lift dependent and non lift dependent drag coefficient C_D, as a function of the specific icing conditions encountered and, secondly through the conduct of a separate set of maneuvers we will develop the aircraft stability and control derivatives that characterize the aircraft immediately following an icing encounter. By conducting these maneuvers with all the AIRS aircraft in well-documented icing conditions, substantial knowledge of the impact of icing will be gained.

A number of icing accretion flight research programmes have investigated the effects of icing accretion upon airplane aerodynamics. Generally, for an assessment of aerodynamic effects, the overall drag coefficient C_D has been the principal metric (see for example Ashenden and Marwitz, 1997). However, differentiation of the effects upon C_D into profile and induced drag component effects, *i.e.* $C_D=\Im(C_L)$, is required for a greater understanding of aerodynamic performance icing effects and correlation with various icing environments. Research into the differentiation of induced and profile drag components, and the association with lift-curve slope loss requires the conduct of specialized maneuvers during icing accretion. Initial dry-air research into the required maneuvers has been conducted using the NRC Convair. From this research, early indications are that short-duration pitch-up maneuvers of ± 0.5g can provide an angle of attack range of about four degrees, sufficient to provide differentiation of profile and induced drag increments.

Time histories of high fidelity inertial states particularly linear accelerations, airspeed vector quantities and engine state quantities are required for the subsequent analysis. The three AIRS II aircraft have been verified to possess the necessary instrumentation suites.

In addition to characterizing the aircraft response in icing from the point of view of C_D components, we will examine how accretion may affect the stability and control characteristics of airplanes, even well away from angle of attack and sideslip magnitudes at which premature flow separation can occur.

Stability and control derivatives are a set of coefficients, which describe the dynamics of the aircraft. In order to estimate the aircraft's stability and control derivatives the aircraft's characteristic modes must be excited in all three axes (Hui et al., 1992). A simple approach to accomplish this excitation is to make control inputs in alternating steps of 2,3,1 and 1-second duration in each control axis. The full maneuver set in three axes will require approximately 2 minutes of flight time, each time it is conducted.

To develop a significant database yet remain compatible with the other AIRS II objectives, the C_D maneuver will be conducted routinely, during otherwise straight and level flight, while in icing conditions with the aircraft ice protection systems operating normally. The stability and control maneuver set will be performed in a predetermined, aircraft configuration – namely enroute - flaps up landing gear retracted - following exposure to icing conditions, with ice protection systems operating normally, most probably at the end of a horizontal transect over the Mirabel site.

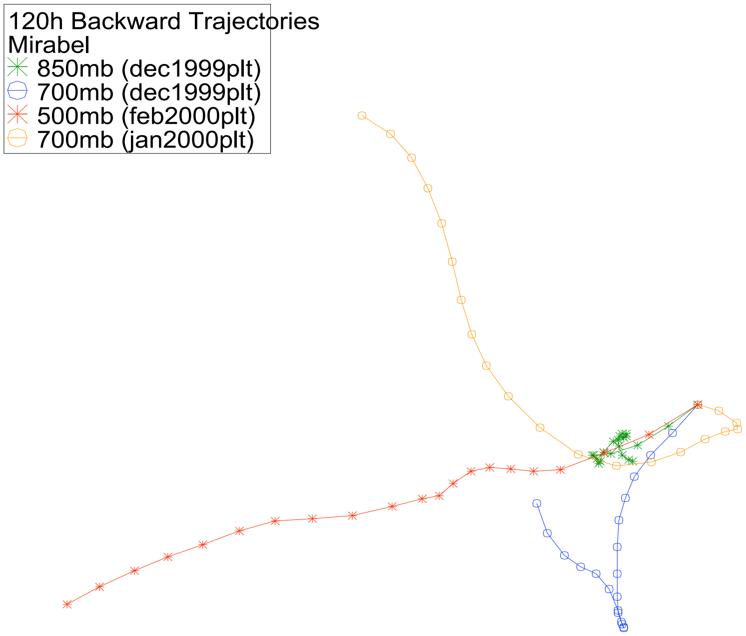
Subsequent to the icing flights, these data will be analyzed in order to characterize the aircraft effect as a function of different icing environments. We anticipate that performing the analysis for data collected in a broad range of icing conditions, with as many of the AIRS aircraft as practical, will yield a unique data set from which conclusions can be drawn about the specific atmospheric conditions that result in the most profound effect upon overall airplane aerodynamics, with certificated ice protection systems functioning normally.

Associated with the measurement of overall aerodynamic performance effects, the opportunity will be available to measure ice shape evolution using the NASA Twin Otter. for the verification and validation of new icing accretion code, most notably runback icing code, methodologies. In addition, the detailed accretion process of both ice crystals and supercooled drops on aircraft surfaces both at the stagnation point and at surfaces back from the stagnation point having different angles for accretion will be investigated using modified versions of the DRI Cloudscope onboard the Convair-580 and the C-130.

b) Scientific Objectives

S1) Investigate micro-, meso-, and synoptic-scale conditions associated with supercooled large drop formation

Clouds containing supercooled large drops (SLD, defined as diameter >50 μm, both as drizzle and rain) readily form in the atmosphere and persist in the absence of significant in-situ ice formation (heterogeneous ice formation) and any secondary ice formation process. SLD has been a major, if not central theme of several past field efforts including AIRS I, the Winter Icing and Storms Project (WISP, see Rasmussen et al., 1992), MWISP, and the SLD Research Project (SLDRP, see Miller et al., 1998). Through these studies much has been learned about the mesoscale environment supporting SLD, as described by Cober et al. (2001b), Rasmussen et al., (1995), Politovich and Bernstein (1995), Bernstein et al. (2000), and Hallett and Isaac (2002). As Fig. 5 shows, trajectories of airmasses producing moderate to severe icing conditions over Mirabel, Quebec, can come from a variety of sources. The impact of meso and synoptic scale systems on ice formation needs further study and this will be done during AIRS II, and by tracing air mass trajectories using the longer endurances of the C-130. Of course, the microphysical conditions leading to SLD may also be affected by the large scale, and this possibility will also be examined.



Θ 10 December, Start at 12Z 10 December, Run at 700mb
* 16 December, Start at 18Z 16 December, Run at 800mb
Θ 25 January, Start at 00Z 26 January, Run at 700mb
* 16 February, Start at 12Z 16 February, Run at 500mb

Fig. 5: Back trajectories for 120 hours (6 hour intervals) at the indicated pressure altitude for 4 days where moderate to severe icing was observed at Mirabel, Quebec. These cases have been described by Isaac et al. (2001b). The altitudes were chosen based on where icing was observed at Mirabel. For 10 December and 25 January, SLD was observed and for 16 December and 16 February, Appendix C conditions were observed.

Several hypotheses regarding the formation and persistence of SLD conditions will be pursued during AIRS II. Often, SLD are observed in elevated cloud decks well above the polluted boundary layer such as in upslope clouds observed in north-eastern Colorado by Rasmussen and Cooper (1995). Presumably the upper air masses are relatively clean and well suited for SLD, especially if moist source air (such as from farther south) overruns the boundary layer. Detailed ice nucleus measurements in inflow air are needed to substantiate this, as are measurements of cloud condensation nuclei and ultra-giant nuclei (CCN/UGN) to provide insight into the drizzle formation process.

The existence of UGN (>1-2 micron dry size, which may also act as ice nuclei) has been demonstrated by Meyers and Hallett (2001) in the Arctic. These measurements showed concentrations of a few per liter – sufficient to lead to drizzle – and also regions of less than 60 per liter, clearly demonstrating the need to make systematic measurements under supercooled cloud conditions. Such nuclei could be the immediate precursors of drizzle; in their absence drizzle formation may be a more extended process. The presence of such nuclei in drizzle drops is clearly demonstrated by the presence of residue following evaporation on capture by the cloudscope; the presence of such particles in clear air above cloud top provides evidence of a possible continuous source through entrainment.

Further evidence of the presence of ice nuclei will be obtained by direct measurement both processed by drying and heating above 0°C and also by measurement of particles not so processed. Should there be preactivated nuclei (as from ice falling from above), which evaporated, with nuclei incorporated into a lower supercooled cloud top (see Roberts and Hallett 1968) it is necessary to retain temperatures below –5°C and ice relative humidity above a critical value (about 35%), requiring cooled inlet, prior to measurement. Otherwise they will be deactivated. This requires a short cooled connection between the inlet and the IN counter; this will be designed and installed and should be available on the C130.

The droplet size distribution in any cloud follows from activation of CCN in updrafts, either from relatively gentle large-scale processes (such as low pressure centers or overrunning), or from more rapid rise in convective motions associated with instability. A tail may exist in the cloud condensation nuclei (CCN) spectrum that may be governed by hygroscopic particles 1 to >10µm dry size, which grow faster than smaller particles. The largest of these, ultragiant nuclei, result in the largest activated droplets and may form the basis for drizzle-sized droplets important for icing. In a sufficiently deep cloud these droplets work rapidly to coalesce with other cloud droplets to produce supercooled drizzle or rain. The working hypothesis for AIRS II is that ultragiant nuclei are necessary in these clouds to form SLD.

Three approaches may be used to provide information on these large hygroscopic particles:

Collect and evaporate drizzle drops to reveal the presence of such nuclei, lower limit ~1µm dry diameter;

Collect nuclei leading to the formation of the cloud; *lower* limit about 1μm dry size; and

Measure the CCN spectrum extended *up* to about 1 μm, the limit of the first approach above, to characterize intermediate particle sizes for formation of collected droplets and collector droplets of intermediate size.

The first approach utilizes the DRI cloudscope (Meyers and Hallett, 2001; Hallett et al., 1998), the last requires a CCN spectrometer (Hudson, 1989). In parallel to these measurements we will examine data from appropriate electrical optical probes, the analysis being subject to the caveats of Lasher – Trapp et al. (2002). To complement these measurements it will be necessary to run coalescence models of droplet growth to provide rate processes for the measured concentrations. The facilities and instrumentation available at NCAR and Colorado State University (CSU) will enable these measurements to be obtained. In parallel, measurements will be made of cloud droplet nuclei using CVI (REF) through both CCN spectrometers and local CN as required providing insight into their possible origins. The NCAR C-130 will be the main platform for these measurements.

S2) Determine conditions governing cloud glaciation (conversion from liquid or mixed-phase to the ice phase)

Mixed-phase clouds in general can result from insufficient ice nuclei. As cloud top temperature decreases, ice-forming nuclei should on average become more prevalent, and riming processes and secondary ice formation processes are more likely (<~ -4 to –8°C). Under these conditions ice particles become more numerous and eventually remove the supercooled liquid water. For any given set of ice forming nuclei, ice forms more readily at the coldest part of the cloud in the local updraft maximum near cloud top. These nuclei may be measured directly and a correlation with ice crystals and LWC may be expected in local updrafts. Ice crystals originating aloft (i.e., from an overlying cloud layer) may also be present and provide a more random injection of ice throughout the cloud layer. The glaciation fraction (ice/water) will be different and will evolve differently in these differing scenarios; each needs consideration.

Microphysical considerations suggest that a large (or ultragiant) hygroscopic nucleus would first dilute as a solute droplet as saturation with respect to liquid water increases. Should a uniform or homogeneous mix of ice and hygroscopic nuclei be present (possible but arguable), these diluted ultragiant nuclei may be the first to freeze as the freezing point depression of the soluble component reduces. A correlation of these large nuclei and ice crystal concentration is to be sought in the subsequent analysis. It is noted that such hygroscopic particles may be predictable from knowledge of the history of the moist air and likely sources of such nuclei.

Many flights will be made into glaciated and mixed phase clouds during AIRS II. By examining ice/water ratios, particle size distributions, particle shape, IN contents, giant nuclei concentrations, etc, and correlating the data with the measurement location within clouds and cloud systems, it is expected that knowledge will be obtained about ice formation processes. Vertical profiles of significant parameters will be made as often as possible in order to obtain spatial distributions in the vertical and possibly time histories. The aircraft in-situ data will be augmented by remote sensing information, which can give information on the larger scale, and with much more detailed time resolution.

S3) Document the spatial distribution of ice crystals and supercooled water, and determine the conditions under which they can co-exist

The spatial distribution of ice /supercooled water in icing clouds is very important as both ice and water may contribute to the icing problem (Hallett and Isaac, 2002). High- resolution instruments are necessary to characterize the sharpness of the spatial gradients during aircraft penetration and also in remote sensing analysis over spatial distances of meters to tens of meters of aircraft flight path. Thus aircraft measurements of ice and water are necessary with such resolution.

Using data from past aircraft icing projects, Cober et al. (2001a) and Korolev et al. (2002) have shown that mixed-phase clouds occur for as much as 40% of the in-cloud measurements at temperatures between 0 to –30°C. The presence of mixed phase clouds makes forecasting of supercooled liquid water, and thus inflight icing conditions, more difficult. Perhaps more significantly, remote detection of supercooled water can be complicated by the presence of ice. It is essential to understand when and where such mixed phase conditions exist. Moreover, the scales of discontinuities between all-ice and all-water and mixed regions are crucial in understanding the existence and depletion of the supercooled water by varying degrees of mixing.

Variations of cloud liquid water will affect the operation of remote sensing devices and their ability to provide accurate information about potential icing conditions ahead of an aircraft. For example, cloud water variations will affect each frequency of an airborne multi-wavelength radar system differently. Low liquid water contents may not be detected by an X-band radar, for example, because of small backscatter, and yet be detectable by a Ka-band radar. High liquid water content, however, can severely attenuate a W-band or higher-frequency radar signal while having a lesser affect on Ka-band, for example. An airborne microwave radiometer system will also be affected by a fluctuating e-folding distance as an aircraft traverses clusters of high and low liquid water content. The magnitude and spatial scale of liquid water fluctuation will determine how reliably a remote sensing system predicts icing conditions ahead of an aircraft. In addition, as reported by Koenig et al. (2002) from cloud water cluster statistics and experimental research in the NASA-GRC Icing Research Tunnel, cloud water variations also affect the *shape* of ice that forms on airfoils. Clustered and Poissonian distributions of supercooled liquid water with the same average and integrated LWC result in different ice shapes, and thus potentially different aerodynamic responses from aircraft. Cluster effects could have implications in how aircraft flying qualities are evaluated in models and wind tunnels.

Ryerson et al. (2002 and 2001) assessed the fluctuation of cloud water for 33 flight segments of the NASA GRC Supercooled Large Drop Research Program (SLDRP) flown during the winters of 1997-98 and 1998-99 using techniques developed by Jameson and Kostinski (2000) and other techniques developed at CRREL. The work was conducted largely to support remote sensing development, and thus was conducted with data measured at ~70-m resolution. At this resolution, few icing clouds were Poissonian, with most exhibiting cloud water clustering ranging from a few hundred meters to >20 km in length. Assessment of additional flight segments, such as acquired from AIRS II, would allow improved statistical assessment of cloud water clustering conditions and, perhaps, development of cluster climatologies. In addition, cluster analyses may be able to be performed with radar and microwave radiometer data. Similar cluster analysis is being conducted on flights conducted in the Ohio valley by the NASA GRC Twin Otter. The analysis is applied to total hydrometeor concentration measurements and to characteristics of the droplet size distribution, and is planned for regions of similar ice crystal habit. Aircraft microphysical data, and radar and microwave radiometer data from AIRS-II would provide a broader basis for characterizing clouds in this manner.

Airborne millimeter wave radars can provide finer scale cloud structure than is possible by using conventional ground-based centimeter wave radars (Vali et al., 1998). In AIRS II, a polarimetric W-band Cloud Radar will be installed on the NRC Convair-580. This radar will be configured to provide finescale cloud structure along horizontal and vertical planes up to 7.5 km away from the aircraft. The W-band measurement combined with the in-situ microphysical data will be used to document spatial distributions of ice crystals and supercooled water in winter clouds. This capability will permit the documentation of detailed structure of large cloud volumes as the aircraft flies from cloud top to cloud base using the predetermined flight maneuvers.

S4) Verify the response of remote sensors to various types and concentrations of ice crystals and liquid droplets, and how this can be exploited to remotely determine cloud composition

The conventional wisdom is that (with some exceptions) the hazard to the aircraft depends solely on supercooled liquid water. This is reflected in the aviation regulations and guidance information. This implies that it is highly desirable that any icing detection system includes instrumentation that makes it possible to determine LWC accurately, even if ice particles are present. This problem of accurately detecting supercooled liquid water has applications beyond aircraft icing, for example weather modification, and hydrometeorology. Several Canadian and U.S. organizations have active programs in this area which included testing in WISP, MWISP, and AIRS-I. This work will be continued in AIRS-II.

An X-band radar system is being developed at NASA. This will also use information from a lidar ceilometer and a multi-channel profiling radiometer to determine the location of cloud and the total amount of liquid it contains. Algorithms are being developed to partition the liquid appropriately.

Polarization techniques work on the premise that different hydrometeor types have different, and somewhat unique, shapes. These differences are especially pronounced when considering them as a function of elevation angle from the radar; the polarization return changes with the elevation angle and this can be used, for example, to distinguish drizzle and raindrops from ice crystals. Using airborne W-band polarimetric cloud radar, Wolde and Vali (2001a, 2001b) have shown that polarimetric signatures as a function of elevation angle can provide information regarding ice crystal types and degree of riming from larger cloud volumes than can be observed with in situ probes. During AIRS II the airborne polarimetric radar data combined with the in situ data will be used to develop cloud particle identification algorithms based on polarimetric radar data. Tests to date of ground-based systems have been somewhat promising but limited due to sensitivities of the test radars.

Preliminary results using remote sensors in AIRS I have been reported by Hudak et al. (2001) and Isaac et al. (2001a). The McGill Vertically Pointing Radar (see Zawadzki et al., 2001) will become a key component of the MSC AVISA system being developed. The Defence Research Development Canada at Valcartier (DRDC-Valcartier) lidar system, which was used during MWISP and AIRS I is also expected to participate in AIRS II (Bissonnette et al, 2001, Bissonnette et al, 2002).

An NRC hyperspectral imaging system operating in the 850-2450 nm band will be deployed to the ground site at Mirabel to image the cloud base during AIRS flights. This system, called SASI, will permit the evaluation of the potential for spectral and spatial discrimination of cloud phase. This overall objective will be divided in two parts with the first being based on the fact that the spectra of various phases of water is well defined through laboratory spectral measurements under ideal conditions. Using this information the potential for detection of cloud phase will be assessed. The second objective – that of mapping regions of liquid water within clouds, relies on the success of the first objective. If cloud phase discrimination is possible based on the SASI measured spectra, then the inherent ability of the SASI instrument to spatially map, provides a means of identifying areas of differing phase and will become a potentially a very useful method for remote sensing of aircraft icing.

The instrument will be used in a scan mode primarily during low approaches when aircraft correlation of a corresponding cloud mass is possible. Once the data has been collected, the scientific objectives of the project will be addressed by investigating the measured spectra retrieved from pixels that have sampled the clouds surrounding the aircraft influenced pixels. Pixels that contain the aircraft itself will consist of highly mixed spectra and will not be used for this initial analysis. Investigation of the absorption spectra for water phase discrimination will then begin and will be compared with the known locations according to the lab spectra. Assuming that there is a suitably statistical agreement between the measured and lab spectra then isolating the phase characteristics in surrounding pixels will be attempted in order to provide an indication of spatial extent for various phases.

Additionally spectral information on the water and ice content within the cloud will be analysed through simultaneous ground and aircraft based measurements. On the ground, a zenith-looking Fourier Transform Spectrometer (DA 8 FTS) will be operated from Mirabel while from the Convair 580 a Magna 550 FTS (downward viewing) as well as the NIR 512 spectrograph (straight up and downward viewing) will be used to obtain vertical profile reflectance measurements of the cloud. Coordinated measurements from the MODIS instrument on the AQUA satellite will be retrieved to assist with analyses. Also, in a fashion similar to the AIRS I project, oxygen A-band measurements for photon path length will be taken by the spectrometers to validate the upcoming CLOUDSAT and OCO (Orbiting Carbon Observatory) satellite experiments.

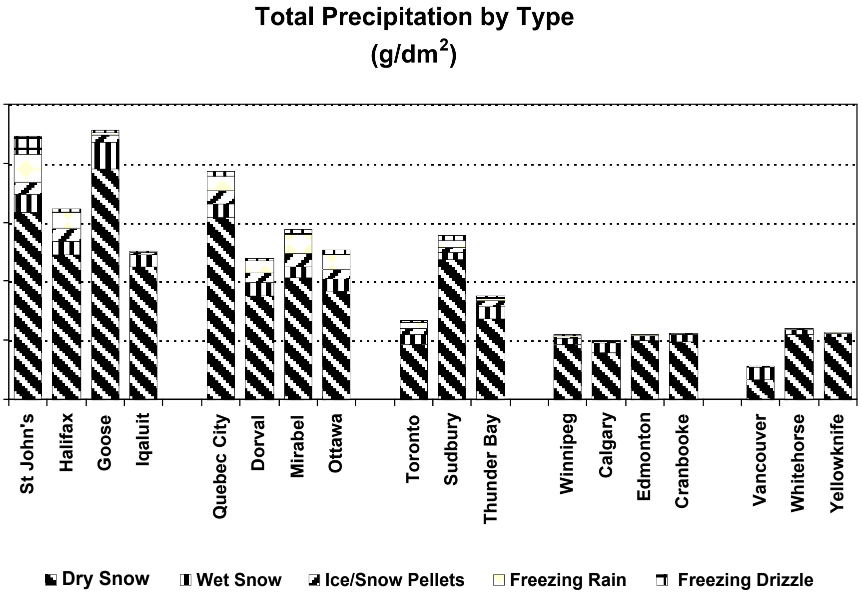


Fig. 6: Total precipitation amount as a function of hazard type for selected Canadian airports (Stuart and Isaac, 1994).

A ground-based GPS receiver will be used to characterize total integrated water vapour as part of the SuomiNet network. This system will be installed either at Sainte Anne de Bellevue or at Mirabel and maintained by McGill University and will return high resolution estimates of total water vapour along the path between the ground site and any GPS satellite in view.

5. Climatological Considerations

A climatology of freezing precipitation across North America (Strapp et al., 1996; Stuart and Isaac, 1999) shows a maximum of occurrence near the Great Lakes and over Newfoundland. The maximum frequency of occurrence reaches 150 h/year in eastern Newfoundland and approximately 75 h/year near the Great Lakes. Freezing precipitation can be taken as a surrogate of where supercooled large drops aloft might occur. Partly because of this analysis, and the high aircraft traffic in the Great Lakes area, the regulatory agencies (FAA and TC) have encouraged work in the Montreal-Ottawa area and near Cleveland, the home base of the NASA GRC Twin Otter. Fig. 6 suggests that Mirabel is an excellent location for other potential winter hazards to aviation. Only the Canadian Maritimes can be considered more extreme, but again the higher frequency of air traffic in the Great Lakes area makes the Montreal-Ottawa area more desirable for this type of work.

Table 1: Freezing precipitation in hours per month for Ottawa, Mirabel, St. Agathe and Dorval. ZR-freezing rain, ZL-freezing drizzle.

Location	Nov	Dec	Jan	Feb	Mar	
Ottawa	9 4	21 11	12 6	10 5	11 5	ZR+ZL ZL
Mirabel	12 3	24 11	10 5	12 6	12 4	ZR+ZL ZL
St. Agathe	14 5	26 14	16 10	9 5	13 6	ZR+ZL ZL
Dorval	4 2	17 8	8 3	8 4	8 3	ZR+ZL ZL

Table 2: Frequency of occurrence (%) of Icing and SLD in a column above the surface calculated according to Bernstein and McDonough (2002) (Table courtesy of Bernstein)

Location	Nov		Dec		Jan		Feb		Mar	
	Icing	SLD	Icing	SLD	Icing	SLD	Icing	SLD	Icing	SLD
Maniwaki	39.1	4.2	30.9	5.0	21.9	2.3	18.7	2.1	22.5	2.6
Albany	40.3	4.5	39.7	3.2	30.4	2.6	27.7	3.0	29.3	3.1
Buffalo	51.9	8.2	46.2	5.4	41.5	5.2	36.8	5.7	37.2	4.9
Caribou	39.5	5.5	29.9	4.0	18.0	2.1	22.5	2.2	29.4	5.5

Table 1 shows that the maximum frequency of occurrence near Mirabel occurs in December, with November, January, February and March showing similar frequencies (10-12 h/month). It should be noted that this data set does not include the Ice Storm of 1998 that caused billions of dollars worth of damage, during which time freezing precipitation fell for extended periods. Table 2 shows the predicted frequency of occurrence (%) of icing and supercooled large drops with the column above selected upper air sounding stations for the months indicated. This analysis shows the best month for icing is November, with the peak frequency of SLD being in December.

6. Facility Requirements

During the AIRS II workshop in June 2001, instrumentation required to meet the Operational and Science Objectives were described. The investigators desired to make as much use of already-existing facilities in the Mirabel area as possible, both to reduce costs and for possible future consideration as an operational system. In addition, supplemental instrumentation to be supplied by participating organizations was discussed. The following lists the existing instrumentation as well as general requirements for an effective Operations Centre, and Table 3 summarizes the instrumentation requirements.

Existing Observing Systems near Mirabel (YMX):

S-band dual polarization Radar at MRO
Hourly weather observations at YMX and YUL
915 MHz wind profiler/RASS at McGill University main campus
Surface mesonet in Montreal/Mirabel vicinity

General Requirements for the AIRS-II Operations Centre:

Real time telemetry of the aircraft location
High-Speed Internet access
Reliable communications links to the aircraft (VHF radio, cell phone, Satphone)
Workstation running the Aurora Nowcasting System

Table 3: Instrumentation Requirements for AIRS II

Measurement Platforms	Minimum Requirements	Highly Desirable	Useful Addition
Radar	McGill VPR *MSC scanning X-band* *MSC non-scanning Ka band* Note: italicized items will not be necessary if these frequencies bands are suitably covered with radars from the highly desirable category.	GRIDS scanning Ka band NCAR scanning S-Pol with Ka band Note: All radars have some dual polarization capabilities	NASA vertical staring X and Ka band
Lidar		DRDC dual frequency lidar	

Radiometer	At YMX: one vertically pointing and one pointing at ~15° elevation angle; At YOW: one vertically pointing. Note: Possible sources are NASA, ATTEX, MSC, and Radiometrics	Additional radiometer at each of YOW and YMX.	Addition of 89 and/or 150 GHz frequencies to Radiometrics 3000
Wind Profiler		McGill 50 MHz VHF profiler at MRO	MSC 915 MHz UHF profiler/RASS near YMX
Surface Observations (T, P, wind speed and direction, visibility)	Hourlies at Dorval, Mirabel, etc. , AWC Mesonet	Real-time communications of all surface obs to central site for model data ingest	Additional surface stations with dataloggers in vicinity, visibility meter
Ceilometer	MSC or NASA instrument at YMX Note: Not necessary if DREV lidar involved		
Precipitation Amount	DRI "hot plate"	Precipitation gage network around Dorval or Mirabel	
Precipitation Type	POSS	Video camera Rosemount icing detector (CRREL); Rosemount Freezing Rain Detector (Mt. Washington) –	Human observer
Upper Air Observations	Radiosonde System (MSC or NCAR)	LWC sonde	tethersonde
Space-based	GOES	AVHRR MODIS	LANDSAT SSM/I
Aircraft			
NRC Convair-580	AIRS-I suite of sensors, no lidar	Aerosol, IN and CCN measurements	Second cloudscope
NASA Twin Otter	AIRS-I suite of sensors + 2D-P probe	ProSensing radar; performance indicators (SMARTICE)	
NCAR C130	Standard instrument suite with full cloud		

	physics and aerosol package. Also		

Participating organizations are currently working on plans to deploy these instruments for AIRS II. MSC is in charge of coordination and preparation of the instrument sites.

7. Flight Plans

The use of instrumented aircraft is integral to meeting the Operational and Scientific Objectives. Three aircraft will be involved during AIRS II; the NRC Convair-580, the NASA GRC Twin Otter and the NCAR C-130. The NRC Convair-580 and NASA Twin Otter aircraft will be stationed in Ottawa where suitable hanger facilities exist, and where a weather forecast team will be located. The project base of the NCAR C-130 will be at Cleveland (NASA GRC). Ottawa is only a short distance to Mirabel where most of the remote sensing equipment and the forecast systems will be located (Fig. 7). The Convair-580 and Twin Otter will mainly be used for sampling in the Mirabel vicinity to complement and verify the remote measurements obtained there. This requires a full suite of instruments for measurement of state variables (temperature, pressure and moisture) and cloud physics parameters (ice and liquid concentrations, size distributions, total liquid and ice contents, and habit identification). The primary role for the larger C130 will be to investigate longer-range transport (as far as 1000 km) of moisture and aerosols to the region where freezing precipitation is taking place. Their secondary role will be to investigate local regions where supercooled precipitation is occurring from the viewpoint of continuity with the aerosol measurements. This requires the measurements included on the other two aircraft as well as specialized IN, CN and CCN-measurement equipment.

As with AIRS I, there will be several sets of flight plans including:

Spiral descents and ascents over vertically pointing remote sensors at Mirabel. Missed approaches to the airport will be made if required for sampling the lowest levels of cloud and precipitation.

Constant-altitude flight legs over the Mirabel instrument site: The aircraft will be positioned within the beams of the instruments as much as possible; instrument viewing angles will need to be adjusted for the weather conditions. Close communication between the scientists on the ground and those onboard the aircraft will be necessary.

Stacked flight patterns involving two or more aircraft: For special studies, two aircraft will be flown on constant-altitude legs with one aircraft above and trailing the other. This will allow comparisons to be made of remote sensors on one aircraft with in-situ measurements on the other aircraft. These flight legs will also be ideal for assessing the spatial properties of the clouds. This could be done while both aircraft are enroute to Mirabel from Ottawa, or in clouds of opportunity nearby.

A racetrack and a four lobe pattern centered over the intersection of the runway, or with one leg in the direction of the runway: These patterns will permit effective two-dimensional sampling of clouds over Mirabel for characterizing icing extent or patchiness during an event.

Special flight plans for adjunct studies: Some flights will be made to characterize clouds where icing is forecast to be exceptional (large horizontal extent, high liquid water contents, large quantities of SLD, unusually cold temperatures). These flights will not necessarily take place over the Mirabel site.

Past experience during AIRS I has shown that Air Traffic Control is quite cooperative and will assist as much as possible to allow such flights. A pre-project meeting between AIRS II investigators and ATC staff will be conducted to coordinate the flight plans. Traffic at Mirabel is quite light, and tends to be concentrated during the evening hours.

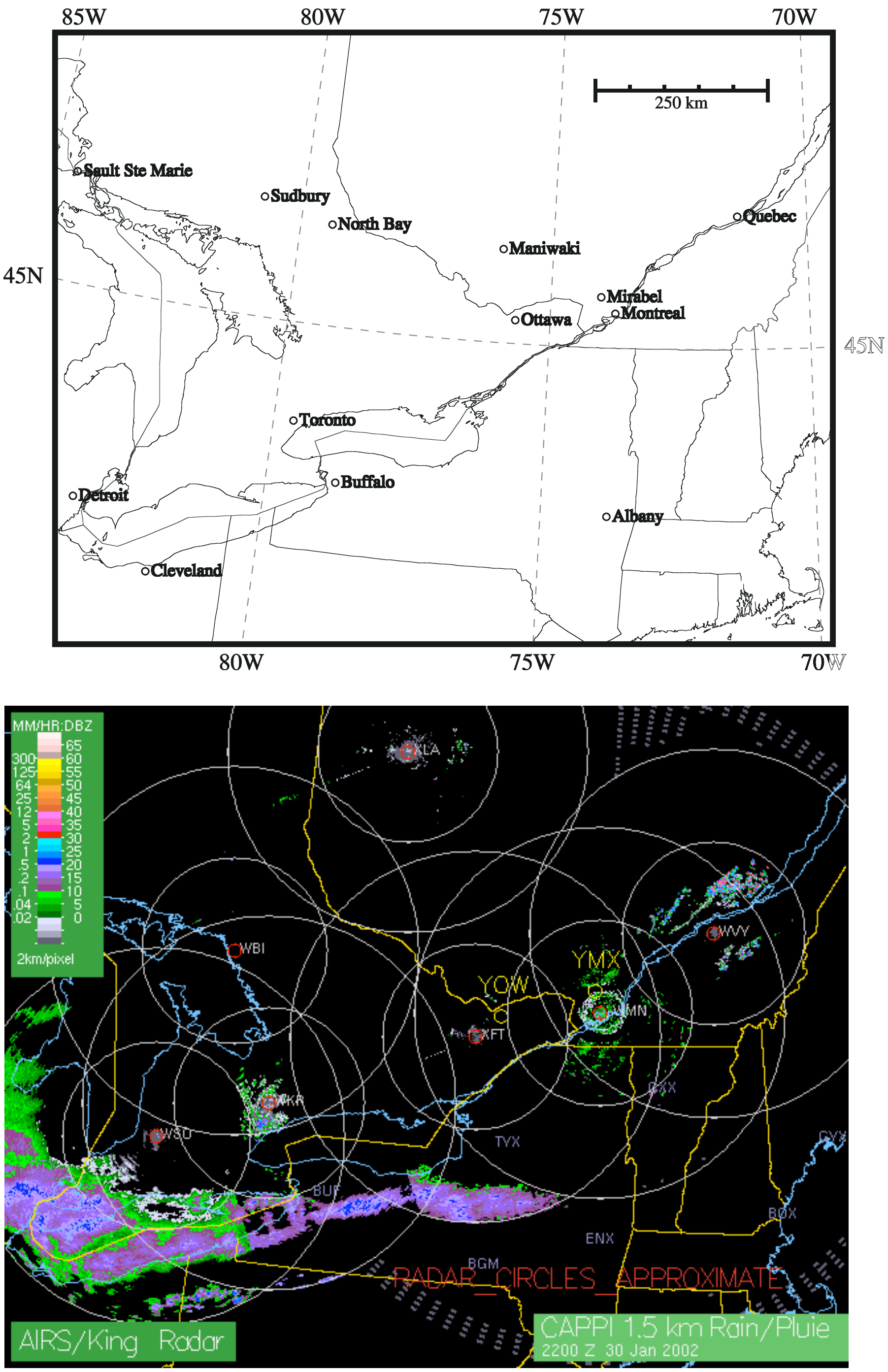


Fig 7a,b: a) Project area showing Ottawa and Mirabel. Maniwaki is the closest regular upper air station. b) Composite of the Canadian weather radar network. The outer circles represent conventional radar coverage while the inner circles represent Doppler coverage. The locations of the nearest U.S. NEXRAD radars are also indicated by appropriate blue symbols.

8. Planning

To effectively deploy and optimize the use of the instruments, a somewhat aggressive schedule of milestones is needed as indicated in Table 4. The participants, listed by organization below, are aware of this schedule and are working together to secure funding and complete hardware development for AIRS II. Currently two intensive operational periods (IOPs) had been identified for AIRS II as follows:

IOP1: 3 November to 12 December 2003
IOP2: 19 January to 13 February 2004

Many organizations will only be able to participate in one IOP. However, the Mirabel site, with most of the Canadian organizations' equipment, will be available for both IOPs. It is anticipated that the NRC Convair will be used for both IOPs although the NASA Twin Otter and the C-130 will be available for IOP1 only.

Participating Organizations
Canada:
Meteorological Service of Canada
Institute for Aerospace Research, NRC
Transport Canada
Canadian National Search and Rescue Secretariat
Defence Research and Development Canada - Valcartier
McGill University
Trent University
Communication Research Centre
Canadian Foundation for Climate and Atmospheric Sciences

United States:
NASA-Glenn Research Center
National Center for Atmospheric Research
NOAA – Environmental Technology Laboratory
Federal Aviation Administration
National Science Foundation
US Army Cold Regions Research and Engineering Laboratory CRREL
Mount Washington Observatory
Desert Research Institute
University of Colorado
Colorado State University
Purdue University
University of Illinois at Urbana-Champaign
Massachusetts Institute of Technology
Oregon State University

Europe:
British Met Office

Table 4 : Timetable for AIRS II Planning

Date	Action
June '01	Initial Workshop
July '02	Completion of Science Plan
November '02	AIRS II Workshop
November '02	Setup for AIRS 1.5
December '02 - February '03	AIRS 1.5 Field Project (MSC and NRC)
December '02	Revise Science Plan
March –July '03	Various subgroup planning meetings
May '03	AIRS II Workshop
November '03	Installation of Equipment for AIRS II
December '03 - February '04	AIRS II Field Project
April '04	AIRS II Workshop
April '05	AIRS II Workshop
April '06	AIRS II Workshop

9. Data Management

MSC will manage the AIRS II Data Archive and will follow the Data Protocol outlined in Appendix B. Whenever possible, all data will be sent to the AIRS II Archive and will be distributed freely among project participants. Publication rights of the individual scientists will be protected and the data will not be publicly released until it has been fully quality controlled and the contributing scientists have had an opportunity to summarize and publish their results.

10. Summary

AIRS II offers a unique and excellent opportunity for a combination of operational and scientific investigation of winter weather. The participants have considerable experience needed to conduct the field study: aircraft instrumentation, remote and in-situ sensor design, detection and forecast algorithm development, and verification of results. They also have successfully collaborated on previous experiments such as AIRS I, MWISP, WISP, and others. The objectives are focused on development of winter weather diagnosis and forecast systems, particularly for local airport terminal areas, and on persistent scientific questions that must be addressed to insure the robustness of these systems.

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APPENDIX A: INSTRUMENTATION

Aircraft
NRC Convair-580

Temperature	Rosemount (x2), Reverse Flow
Dew Point	Cambridge EG-G Dew Point
	LI-COR Dew Point
Pressure/Air speed	Pitot (x3)
3-axis wind measurement	Rosemount-858
Navigation	IRS Litton, GPS Apollo, Novatel, Trimble
Angle of Attack/slip	Rosemount 858
Liquid Water	CSIRO King LWC Probes (x2)
	Nevzorov TWC/LWC Probe
Aerosol	PCASP 100 0.1-3 microns
Droplets	FSSP 100 3-45 microns
	FSSP 100 5-95 microns
Hydrometeors	PMS 2DC Mono 25-800 microns
	PMS 2DC Grey 25-1600 microns
	PMS 2DP Mono 600-6400 microns
	DRI Cloudscope
	SPEC Cloud Particle Imager
Remote Sensing	SATCOM Satellite Receiver
	3 cm Aircraft Weather Radar
	8 mm Ka-Band Doppler Cloud Radar
	3 mm W-band Cloud Radar
	Trent FT Spectrometer
	LANDSAT simulator
	IR Pyrgeometers and VIS Pyranometer (up/down)
	CRREL 35 and 94 GHz polarizing radiometer?
Icing	Rosemount Icing Detector
	Vibro-meter Icing Detector
	Airbus Certification Cylinder
	Video system for ice accretion observation on top of fuselage and underwing

NASA GRC Twin Otter

Temperature	Rosemount OAT Model 102AU1P
Dewpoint	General Eastern Dewpoint Hygrometer
Altitude	Rosemount 542K
Airspeed	Rosemount 542K
Linear Accelerations	Sundstrand QA-700
Angle of Attack	Rosemount 858 probe
Heading	Ship heading gyro
Position	Trimbull TNL-2000 GPS
Liquid water content	CSIRO-King probe model KLWC-5
Cloud liquid and Total Water	Nevzorov LWC/TWC probe model IVO-2
Forward Scattering Spectrometer	PMS FSSP 3-47 [m
Icing Rate	Rosemount ice detector model 871FA211

2D Optical array spectrometer	PMS OAP 2D-G 15-960 [m
Ice Accretion	Wing stereo photography system Over wing video system Tail video system Hand held 35 mm camera

C-130 - AIRS-II Configuration

RAF-Supplied Instrumentation:

I. Aircraft Position, Velocity and Attitude.
  A. Honeywell Model HG1095-AC03 Laseref SM Inertial Reference System.
  B. Garmin Global Positioning System (GPS 16).

II. Dynamic Pressures.
  A. Rosemount Model 1221F1VL.
  B. Rosemount Model 1221F1VL.
  C. Rosemount Model 1221F1VL.

III. Static Pressures.
  A. Rosemount Model 1501 Digital Pressure Transducer.
  B. Ruska Model 7885 Digital Pressure Transducer.
  C. Rosemount Model 1201F1 Pressure Transducer.

IV. Temperatures.
  A. Rosemount Type 102 Non-deiced Sensor -- Rosemount Model 510BF Amplifier.
  B. Rosemount Type 102 Non-deiced Sensor -- Rosemount Model 510BF Amplifier.
  C. Rosemount Type 102E Deiced Sensor -- Rosemount Model 510BF Amplifier.
  D. OPHIR-III Radiometric Near-field Temperature Sensor.

V. Flow Angle Sensors, Radome.
  A. Attack - Rosemount Model 1221F1VL Differential Pressure Transducer.
  B. Sideslip - Rosemount Model 1221F1VL Differential Pressure Transducer.

VI. Dew Point and Humidity.
  A. General Eastern, Model 1011B Dew Point Hygrometer.
  B. General Eastern, Model 1011B Dew Point Hygrometer.
  C. SpectraSensors Open Path TDL Hygrometer.
  D. NCAR Model LA-3 Crossflow Lyman-alpha Hygrometer.

VII. Radiation Fluxes.
  A. Visible Radiation. RAF Modified Eppley Model PSP Pyranometers - 2 units: Upward looking, Downward looking.

Multipurpose Radiometer Housings.
- B. Ultraviolet Radiation. RAF Modified Eppley Model TUVR Pyranometers - 2 units: Upward looking, Downward looking.
  Multipurpose Radiometer Housings.
- C. Infrared Radiation. RAF Modified Eppley Model PIR Pyrgeometers - 2 units: Upward looking, Downward looking.
  Multipurpose Radiometer Housings.
- D. Remote Surface Temperature. Heiman Model KT19.85 Radiometer - 2 units: Down looking.
- E. Remote Sky Temperature. Heiman Model KT19.85 Radiometer. Up looking.

VIII. Cloud Physics.
- A. Rosemount Model 871FA Icing Rate Detector.
- B. PMS Liquid Water Sensor (King Probe).
- C. PMS Liquid Water Sensor (King Probe).
- D. Particle Measuring Systems Model PCASP/SPP-200.
  Size Distribution, 0.12 to 3.12 um.
- E. Particle Measuring Systems Model FSSP/SSP-100.
  Size Distribution, 3 - 45 um.
- F. Particle Measuring Systems Model 2D-C.
  Size Distribution, 25 to 800 um.
- G. Particle Measuring Systems Model 260X.
  Size Distribution, 50 to 640 um.
- H. Particle Measuring Systems Model 2D-P.
  Size distribution, 200 to 6400 um.
- I. TSI Model 3760 CN Counter - Separation Inlet.
  Particle concentration, 0.01 to 1 um size range.
- J. SPEC HVPS: Images with 200 um resolution, 256 channels.
- K. Nevzorov Dual Channel Total Water Sensor.
- L. NCAR CVI Droplet Residual Nuclei Analyzer.

IX. Geometric Altitude.
- A. Steward-Warner Model APN-232(v).
  0 to 1,500 m AGL; 0 to 15,000 m AGL.

X. Photography.
- A. Sony XC-999 SVHS Color Camera with JVC Model HR-S4700U Super VHS Recorder (2 pairs), Horita GPS Video Titler, Forward facing Cockpit Mount, Side Looking, Down Looking.

XI. Remote sensing.
- A. SABL Scanning Aerosol Backscatter Lidar.

XII. User Supplied Instrumentation.

A. DRI Large Cloud Scope and Small T-Probe.
B. DRI Standard Cloud Scope.
C. DRI Large T-probe. Liquid water and ice water content.
D. CSIRO Giant Nuclei Impactor.
E. OSU/DMT CSI Droplet Residual Nuclei Analyzer.
F. DRI CCN spectrometer.
G. CSU CFDC Ice Nuclei Counter.
H. DRI Angled Cloud Scope. (Not on every flight).

Radars, Lidar and Spectral Systems

McGill Radars

Radar:	**McGIll X-band**	**McGIll S-band**
Freq:	X-band = 9.394 GHz	S-band = MHz
Ant. & power:	Peak power: 25 kW Avg. power: <15 W PRF: 1300 Half-pulse-length, selectable: 7.5; 37.5; 150 m Typical sampling time: 2 s Antenna Diameter: 1.2 m Beam width: 2°	Peak power: 850 kW PRF: 1200/600 (alternate elevations) Beam width: 0.9 Unambig. range: 120km (Doppler); 240 (reflectivity) both within the same cycle Half-pulse-length, 150 m Typical sampling time: 24 elevations/5 minutes Doppler: PP processing Nyquist vel.:32m/sec Polarization: transmit 45°, receive V&H

GRIDS

The NOAA-ETL Ground-based Remote Icing Detection System (GRIDS) incorporates a cloud radar, microwave radiometer and data system. At present GRIDS employs borrowed radar and radiometer components and is thus referred to as Upgradable-GRIDS.

The radar will run in two modes: GRIDS (fixed) and scanning. The purpose of the GRIDS mode is to demonstrate the concept of GRIDS and it's products. The scanning mode provides data for research/science. The application of these modes and the individual scan patterns will be determined in conjunction with the other sensors and, especially, aircraft operations.

NOAA/K Radar Characteristics

Mode	GRIDS	Scanning
Frequency	34.66 GHz (8.6 mm wavelength)	
Antenna	1.8 m diameter, center feed	
Beam Width	0.3° circular	
Polarization	45° slant linear	
Peak/Average Power	80 kW/40 W	
Sensitivity* *Enhanced in post processing using new pulse-pair algorithm.	~ -15 dBZ @ 10 km range	~ -30 dBZ @ 10km range
Range Resolution	149.9 m	37.5 m
Temporal Resolution	1 minute	1/8 second
Scanning	Fixed: Elevation = 40°; Azimuth = aligned with active runway.	Elevation: 0°→180° Azimuth: 0°→360° (*Scans:* PPI; VAD; RHI; sector; fixed beam; scan rates up to 30 deg/s.)
Doppler Processing	pulse pairs	pulse pairs or time series (spectral).
Platform	15-m flatbed trailer	

Radiometer Characteristics

Frequencies (3 channels)	23.87 GHz; 31.65 GHz; 90.0 GHz
Scanning	Elevation only; azimuth aligned with axis of principle runway for aircraft operations (anticipated: 06-24).
Beamwidth	2.5°
Products	Integrated vapor, liquid and mean liquid temperature; Surface meteorology: T, P, RH
Features	Spinning flat to shed precipitation
Platform	6.1-m seatainer

Convair-580 W-band Cloud Radar Operational Modes

The Wyoming W-band cloud radar on the Convair will have two antennas, one side-looking through one of the windows located on the starboard side and one down-looking through the a/c belly port (lidar port). The radar will operate in two different modes.

Mode 1-Dual-polarization: This will employ only the side-looking antenna and will be used most of the time (>65%). When the radar is in this mode the sampling strategy is to maximize collection of polarimetric data in various cloud particle types (mixed phase, ice, aggregates, single particle types etc) at various elevation angles, i.e., a/c banking angles. This will involve either a full 360° right turn at 15° & 30° bank angles in different cloud regions or short duration (30-40 seconds) ±40° rolls. These maneuvers will be done during or following the reciprocal runs or cloverleaf maneuvers.

Mode 2-single-polarization: Both the side-looking and down-looking antennas will be active. This mode will be used to document vertical and horizontal cloud structures whenever the a/c is above or near cloud top and in clouds with no measurable polarimetric signatures. The a/c operational mode can be one of the pre-determined modes (reciprocal runs, clover leaf, spirals and missed approach) and no additional maneuvers (rolls) will be required.

Wyoming Cloud Radar on the NRC Convair-580

Transmit frequency	94.92 GHz
Power source	Extended interaction klystron amplifier
Peak Power	1.6 KW
Pulse length	100, 250, 500 ns
PRF	1-20 KHz
Polarization	Liner: H or V
Transmitted Pulse Packet	4 or 6 sequenced H or V pulses
Antenna	• Type: 1) Dual Polarized Gaussian Optics Lens – side-looking 2) Single Pol Gaussian Optics Lens - Down –looking • Diameter [m]: 1) 0.3048 2) 0.3408 • Gain [dB]: 1) 47 2) 47 • Sidelobes [dB] (azimuth/elevation)<: 1) –20.0/-22.5 & -20.5/-21.5 3) –26.5/-21.8 • Beamwidth [°]: 1) 0.8 2) 0.718 • Cross pol [dB]: 1) 30.0/36.0 & 32.0 / 36.0
Receiver dynamic range	> 70 dB
Unambiguous Velocity	± 15.8 m s^{-1} (@ 20 KHz PRF)
Est. sensitivity @ 1km	-30 dBZ

Ground-Based NRC Scanning Hyperspectral Imager Specifications:

- 850nm-2450nm spectral range
- Linear detector array with 600 spectral pixels
- 10nm spectral resolution
- 37.7 ° Field of View
- 14-bit image
- 20ms frame rate
- Data throughput at 600 MB /min
- Integrated C-MIGITIII GPS/INS system
- Scanning rate TBD

NASA Icing Remote Sensing System

X-band radar

Standard Honeywell WU-880 airborne radar
Operating Frequency: 9.35 GHz
Antenna Diameter : 24 inch
Antenna Gain : 32 dB
Transmit Power: 10 kW (Peak)
Pulse Length: 1 μs
PRF: 350 pps
Radar Constant : 87.76

Ceilometer

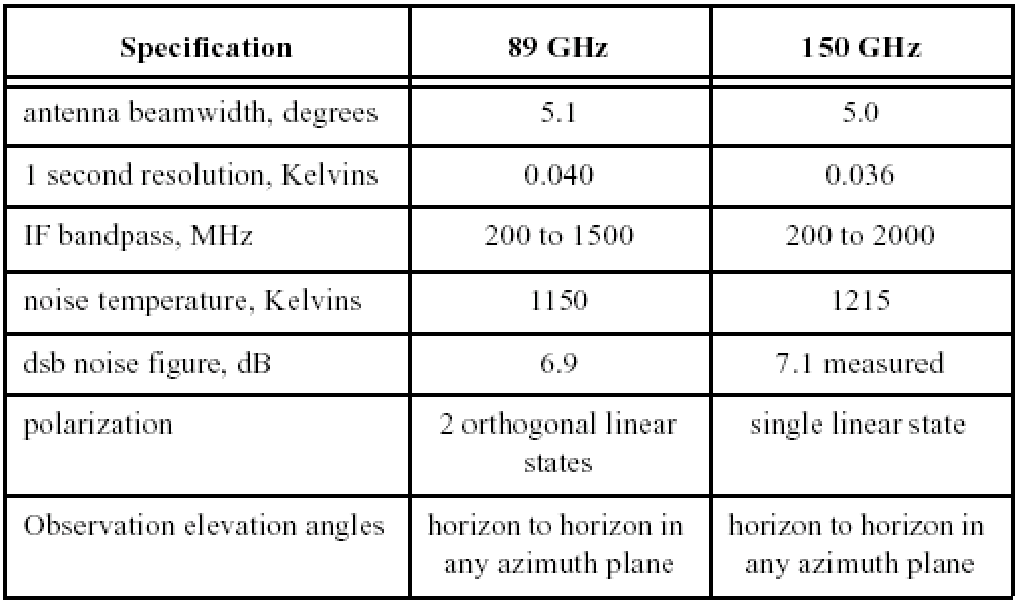
Standard Vaisala CT25K ceilometer
Wavelength: 905 nm
Transmit Energy: 1.6 μWs
Transmit Power: 16 W (peak)
Transmit Power: 8.9 mW (average)
Effective Lens Diameter: 145 mm
Measurement Range: 0 to 25,000 ft
Resolution: 50 ft
Output: Number of detected cloud layers
    Height of detected cloud layers
    Or if ceiling undefined, vertical visibility
    Backscatter profile
    Sky condition

Profiling Radiometer

Radiometrics TP/WVP-3000 profiling radiometer
Frequencies: 5 frequencies between 22 and 30 GHz and 7 between 51 and 59 GHz
Accuracy: 0.5 K
Resolution: 0.25 K
Radiometric Range: 0 to 700 K
Output: Brightness Temperatures for each frequency
0-10km profiles for Temp, Humidity, and LWC

89 and 150 GHz Radiometer

Custom manufactured by Radiometrics



Specification	89 GHz	150 GHz
antenna beamwidth, degrees	5.1	5.0
1 second resolution, Kelvins	0.040	0.036
IF bandpass, MHz	200 to 1500	200 to 2000
noise temperature, Kelvins	1150	1215
dsb noise figure, dB	6.9	7.1 measured
polarization	2 orthogonal linear states	single linear state
Observation elevation angles	horizon to horizon in any azimuth plane	horizon to horizon in any azimuth plane

DRDC-Valcartier Multiple-Field-of-View (MFOV) Lidar

Source:

Laser Type	Nd:YAG
Laser Wavelengths	1.06 _m and 0.532 _m
Pulse Energy	25 mJ at each wavelength
Pulse Length	12 ns
Pulse Repetition Rate	Selectable, maximum 100 Hz
Beam Diameter	25 mm
Beam Divergence	0.5 mrad FWHM
Polarization	Linear

Receiver:

Telescope Type	Off-axis Parabola
Telescope Diameter	200 mm
Detectors	Avalanche Photodiodes
Amplifiers	Logarithmic, 4.5 decades
Field of View	Variable, 0.1-12 mrad
Polarizations	Parallel and Perpendicular

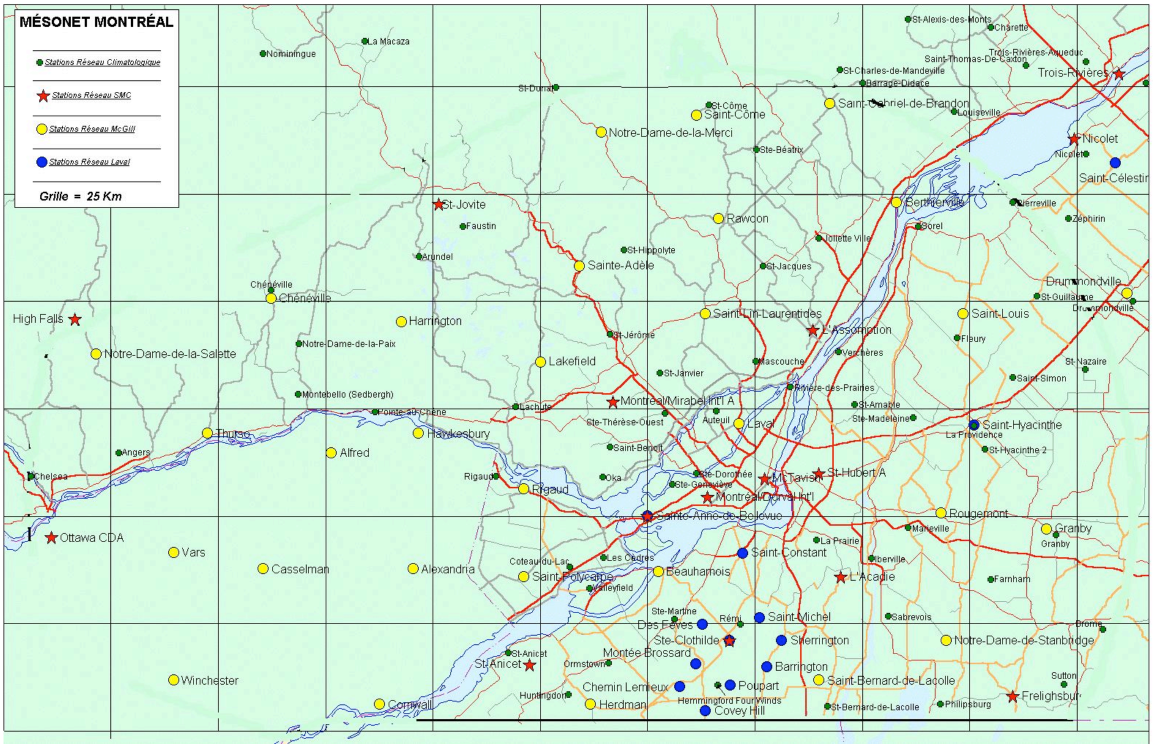
Scanner:

Diameter	200 mm
Azimuth	0 to 450 degrees
Elevation	-10 to 90 to –10 degrees
Speed	Selectable, maximum 160 degrees/s

Mesonet

The new mesonet stations (yellow and blue dots) have:

- Wind speed and direction
- Temperature and dewpoint
-
- Tipping bucket precipitation
- Data is archived every 5 minutes, and transmitted to BSME every hour.



APPENDIX B: ALLIANCE ICING RESEARCH STUDY (AIRS) II DATA PROTOCOL

1. All AIRS participants must agree to the AIRS II protocol. All publications using AIRS data will be required to acknowledge the funding agencies. All publications should be listed on the AIRS Web site.

2. Alliance Icing Research Study participating organizations will have free and timely access to the data acquired during the project. The normal vehicle for data dissemination will be a transfer of data via the main archive established at the Meteorological Service of Canada; however, direct transfer of data between investigators (organizations) is also encouraged. The types of data provided to the AIRS Archive will be determined at a special meeting of participating scientists. It may be necessary for some organizations to archive some specialized data sets, and retain them within their organizations. In that case, a summary of that data, and the procedures for obtaining copies, would be transmitted to the AIRS Archive. All data in the AIRS Archive, and sub-archives of participating organizations, should include a description of how it was obtained, a description of the data itself, calibration procedures and results, and an assessment of the data quality.

3. Each investigator's data is proprietary until the data appear in publication or, if the data are included in the archive, until this archive is published/released to the scientific community. Organizations who collect AIRS data are responsible for the reduction, analysis, interpretation and publication of their data and research results.

4. An investigator whose unpublished data are to be used in an investigation has the right to be included among the authors of any resulting publication. The investigator may refuse co-authorship but not the use of this data. The investigator must provide information concerning the quality of the data and may require that suitable caveats regarding the data be included in the publication. It is the responsibility of the sponsoring investigator to solicit the participation of the investigator whose data are to be used as early as possible during the formative stages of the investigation.

5. AIRS participating organizations may release their own data to whomever they wish. They may not release the data of other organizations (investigators) without consent.

6. Any data sets resulting from collaborative investigations among AIRS participants will be made available to the AIRS Archive. This includes all collaborative efforts both within and outside the AIRS organizations. 7. Scientists who are not employed by AIRS participating organizations, co-investigators, or associates may participate in investigations using unpublished AIRS data provided they are sponsored by an AIRS organization, and they make available whatever data they plan to use to the AIRS Archive at the beginning of the participation.

8. Selected sets of reduced data obtained by investigators participating in collaborative research will be made available to AIRS participants within 9 months following acquisition. A data status report will be issued every three months by each “data collecting agency” following the end of the project, or until the data reside in the

Archive. The AIRS Archive, and the archives of individual organizations, would be made publicly available, with nominal charges for filling requests, after a period of time to be determined by AIRS participants, but not longer than 3 years after the field project.

APPENDIX C: GLOSSARY OF ACRONYMS

AIRS	Alliance Icing Research Study
AIRA	Aircraft Icing Research Alliance
ALPA	Air Line Pilots Association
AVISA	Airport Vicinity Icing and Snow Advisor (AVISA).
CFDE	Canadian Freezing Drizzle Experiment
CCN	Cloud Condensation Nuclei
CN	Cloud Nuclei
CSU	Colorado State University
CRREL	Cold Regions Research & Engineering Laboratory
DRDC	Defence Research and Development Canada
FAA	(U.S. Federal Aviation Administration)
FAAM	Facility for Airborne Measurements
IN	Ice Nuclei
MSC	Meteorological Service of Canada
MWISP	Mt Washington Icing Sensors Project
NASA GRC	(U.S) National Aviation and Space Administration Glenn Research Center
NCAR	(U.S.) National Center for Atmospheric Research
NOAA	(U.S.) National Oceanic and Atmospheric Administration
NRC	National Research Council of Canada
POSS	Precipitation Occurrence Sensor System
SLD	Supercooled Large Droplets (Diameters > 50 μm)
SLDRP	SLD Research Program
TC	Transport Canada
WISP	Winter Icing and Storms Project
WMO	World Meteorological Organisation
WWRP	WMO Weather Research Project

APPENDIX D: PARTICIPANTS

AIRS II Scientific Participants

Name	Organization	Primary role/interest
George Isaac	MSC	Lead PI, cloud microphysics
Stewart Cober	MSC	Environment characterization
Dave Hudak	MSC	Remote sensing measurements
Walter Strapp	MSC	Radiometer measurements
Ismail Gultepe	MSC	Satellite measurements
Peter Rodriquez	MSC	Remote sensing measurements
Monika Bailey	MSC	Cloud spectra
Norbert Driedger	MSC	AVISA analysis
Brian Greaves	MSC	AURORA analysis
Mark Couture	MSC	Data archive
Anna Glazer	MSC	Model analysis
Janti Reid	MSC	AVISA development
Zlatko Vukovic	MSC	Radiometer analysis
Alexei Korolev	SkyTech	Cloud microphysics
Dave Marcotte	NRC	Aircraft systems, NRC project manager
George Leblanc	NRC	Hyperspectral imager
Mengistu Wolde	NRC	Aircraft radar measurements
Anthony Brown	NRC	Aircraft performance, Convair pilot
Jim Jordan	NRC	Aircraft systems
John Aitken	NRC	Convair pilot
Tim Leslie	NRC	Convair pilot
Marcia Politovich	NCAR	Remote detection of SLD
Ben Bernstein	NCAR	SLD forecasting
Tom Ratvasky	NASA-Glenn	Aircraft performance
Tom Bond	NASA-Glenn	Aircraft icing
Andrew Reehorst	NASA-Glenn	Remote sensing
Fred Fabry	McGill	Remote sensing
Isztar Zawadzki	McGill	Remote sensing
Dave Rogers	CRC	Profilling radiometer
Tim Schneider	NOAA	GRIDS
Luc Bissonnette	DRDC	Lidar measurements
Chris Ferguson	Trent	A-band spectrometer
Wayne Evans	Trent	A-band spectrometer
John Hallett	DRI	Aerosol physics
Charles Ryerson	CRREL	Cloud properties
John Hansman	MIT	Product human factors
Cynthia Twohy	Oregon State University	CVI for nucleus composition
Paul Demot	Colorado State Univ	Ice nucleus measurement

Sonia Lasher-Trapp	Purdue University	Assessment of optical probes for UGN content
Greg McFarquar	Univ Illinois	Ice characteristics climatology
Jim Hudson	DRI	Cloud drop and haze CCN spectrometer
Matt Bailey	DRI	Microstructure of mixed phase cloud