2B.4 Microphysical Characteristics of Winter Storms Using Ground-based Polarimetric Radars and Aircraft Observations

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1. INTRODUCTION

Winter storms in south central Canada are characterized by deep cloud systems, widespread precipitation and a variety of precipitation types. Mixed phase cloud conditions are typical (Cober et al., 2001).

The Alliance Icing Research Study (AIRS), whose primary objectives are concerned with the study of wintertime aircraft icing regions (Isaac et al., 2001), provides a great opportunity to investigate the microphysical properties of these storms (http://www.airs-icing.org). The first AIRS field project was conducted during the winter of 1999/2000 near Montreal, Canada (Figure 1).

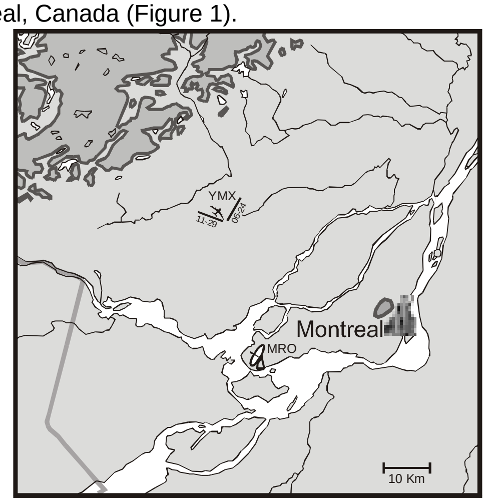

Figure 1: A map of the AIRS experimental area. The McGill S-band radar (MRO) is on the extreme west end of the island of Montreal. Mirabel airport (YMX) was the main observing site including the McMaster IPIX radar. The runway orientation at Mirabel is also shown. Northwest of Mirabel, there is an increase in terrain height.

This paper is concerned with showing the character of a typical winter storm and demonstrating the potential of polarimetric radars to identify significant precipitation formation processes.

2. OBSERVING SYSTEMS

The two ground-based radars used in this study (shown in Figure 1) are (1) the McGill University S-band scanning Doppler radar (http://www.radar.mcgill.ca/) using the slant-45 polarization scheme and located about 20 km west of Montreal (MRO), and (2) the McMaster University scanning portable X-band Doppler radar (Hudak et al., 1999) using an alternate H-V polarization scheme (IPIX) and located at Mirabel airport about 30 km NNW of the S-band radar.

The complete suite of instrumentation at Mirabel airport is given in Isaac et al. (2001) and includes the McGill University vertically pointing X-band Doppler radar (VPR) (Fabry et al. 2001), the University of Massachusetts dual frequency cloud radar (CPRS) (Sekelsky and McIntosh,1996), and an upper air station.

Two cloud physics research aircraft, the NASA Twin Otter and National Research Council of Canada Convair-580 (Isaac et al., 2001) were deployed during AIRS to collect in-situ data.

The aircraft focused their in-situ data collection in the vicinity of Mirabel. The flight plans called for a combination of spiral descents from cloud top over Mirabel and reciprocal horizontal transects at various altitudes within the cloud system on headings parallel to the main runway at Mirabel. Figure 2a depicts a portion of a typical flight track.

The S-band radar carried out 24-angle volume scans every 5 min throughout the project. The X-band radar focused data collection on the region in the vicinity of the aircraft in a series of stares, RHIs and sector volume scans. When the aircraft were not in the vicinity of Mirabel, data collection was concentrated to the southwest in the area of best dual Doppler coverage.

3. RESULTS

Comparisons of the polarimetric data collected by the S-band and X-band radar systems were made under a wide variety of cloud conditions. Because of the inherent difference in the two systems as well as the differing scanning strategies, the comparison must be done on a feature-by-feature basis as opposed to a point-by-point comparison of radar parameters.

The case on Dec. 10, 1999, was representative of cloud conditions during a major precipitation event. In this case, there was both a warm and cold frontal passage. Precipitation began as rain near the warm front, changed to a mixture of rain and snow at the cold front, and then ended as all snow behind the cold front. The wind profile prior to the passage of the warm front shows easterly winds in the low levels with a sharp veering of winds to southwest aloft (Figure 3).

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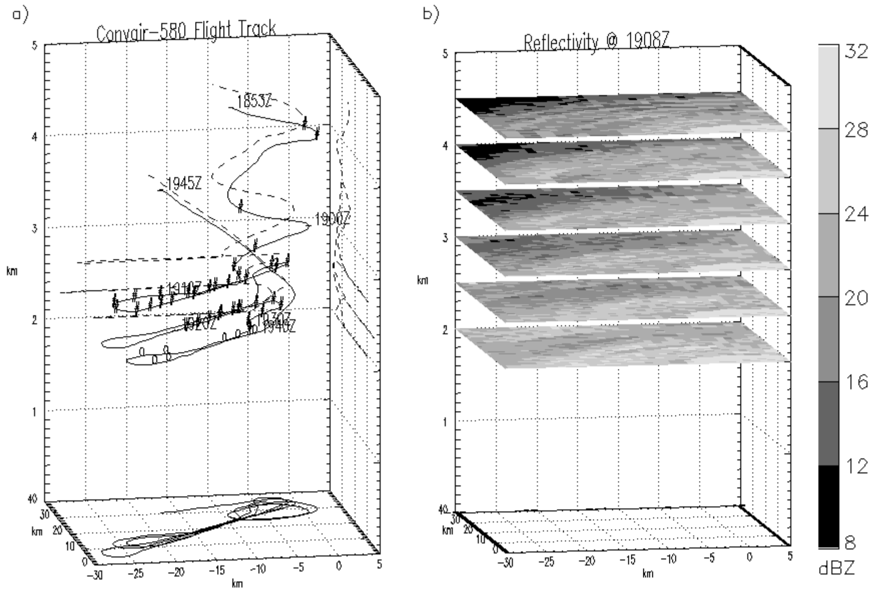

Figure 2: (a) a portion of the Convair-580 flight track on Dec. 10, 1999. A spiral descent over Mirabel was followed by three reciprocal transects to the southwest and back at 2.6 km, 2.3 km, and 2.0 km in altitude. The projections of the flight track on the three side planes are also shown. The “#” symbol indicates areas in which the aircraft detected ice water contents > 0.13 g m^{-3} and the “O” symbols liquid water contents > 0.13 g m^{-3}; (b) stacked CAPPIs derived from the MRO volume scan data at 1908Z.

Figure 2a shows the flight track of the Convair-580 taken just prior to the passage of the warm front. Significant concentrations of ice particles were found around 4 km altitude, primarily dendritic in nature. A second well-defined region of enhanced ice concentrations, this time mostly needles and irregular ice particles, was detected in the layer between 2.3 km and 3.0 km. The nature of these particles, detectable liquid water content, and an ambient temperature ~ -5ºC (Figure 3) is suggestive of an active secondary ice-production mechanism at work (Mossop, 1985). The horizontal transect by the aircraft near 2.0 km detected significant liquid water as well as some irregular ice particles.

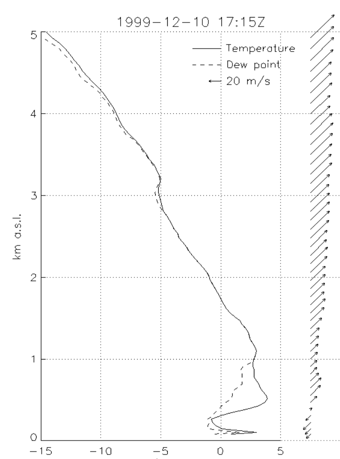

Figure 3: The temperature, dewpoint and wind profile from the sounding at Mirabel. Station height is 82 m.

Figure 2b shows the non-uniformity of reflectivity field during that time period. This illustrates the spatial patchiness inherent in these cloud systems.

Figure 4 gives the derived vertical profiles of Z, Z_{DR} and ϕ_{DP} from the two radars taken in the region in which the aircraft was operating. The only prominent feature in the Z field is the bright band around 1.5 km. There is a significant bias in the Z values between the two radars that is yet to be adequately explained.

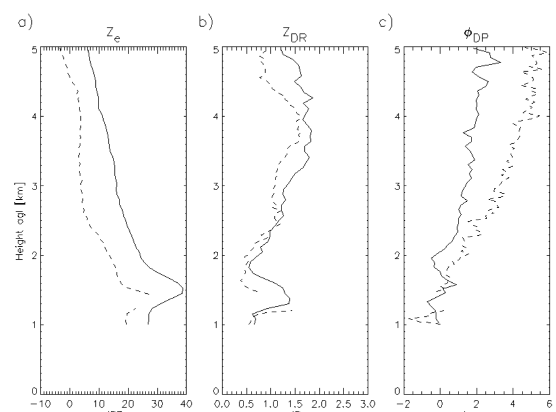

Figure 4: The profiles of (a) Z; (b) Z_{DR}; (c) ϕ_{DP} for the IPIX (dashed) and the MRO (solid) radars. The IPIX data was derived from a series of stares from 1915Z to 1925Z at 15º elevation angle towards the southwest along the track of the aircraft reciprocal transects. Slant range was then converted to height. The MRO data was derived from an average of 2 low level PPI scans at 1918Z and 1923Z over a 45º sector to the northwest in the area where the aircraft operations were taking place.

The polarimetric properties provided additional detail about the cloud system. Proceeding upwards, the Z_{DR} profile from both radars shows the maximum in the bright band, a minimum near 2 km, then a second maximum near 4.0 km. Additionally, there is a shoulder in the profile, slightly more prominent in the IPIX radar, between 2.3 km and 2.6 km. These features show a good correspondence with observed heights of high ice water contents (> 0.1 g m^{-3}) from the aircraft observations.

The ϕ_{DP} profile from both radars shows a small, but measurable increase in values with height/range above the bright band. The inferred k_{DP} value from the ϕ_{DP} measurements for the IPIX radar was 0.5 ° km^{-1}. For the MRO radar the k_{DP} value was 0.1 ° km^{-1}. The differences in these two values are due to the differing radar frequencies and to the different elevation angle (and hence slant range interval for the determination of k_{DP}) between the two radar systems. That k_{DP} was measurable suggests the cloud system was mixed phase with a significant moisture content. The gradual increase in the Doppler velocities from the VPR in the layer from 2.0 to 4.0 km suggests an active accretion process (Hudak and Nissen, 1996) and provides additional evidence for the presence of mixed phase cloud conditions.

Earlier in the day, the NASA Twin Otter aircraft encountered a cloud layer comprised almost entirely of supercooled liquid drops. In this case, the IPIX radar showed a Z_{DR} vertical profile near zero above the bright band and no measurable gradient of ϕ_{DP}. The Z field was very weak (≤ 0 dBZ) around this time and near the limit of detection for the MRO radar. During the evening, with the passage of the cold front, precipitation changed from rain to snow. The IPIX radar was able to follow the evolution of the descent of the bright band as the cold front passed Mirabel. The MRO radar was not able to detect the low level features due to ground clutter. Above the bright band, the profile of Z_{DR} from both radars was lower than shown in Figure 4 (< 1.0 dB). This is suggestive of irregular ice particles in the cloud system. During this period, there was no detectable gradient in ϕ_{DP} with either radar. This implies that the cloud was glaciated with relatively low moisture content. The Doppler velocity profile from the VPR at this time was constant near 1.0 m s^{-1} and also suggests a glaciated cloud (Fabry et al., 2001).

4. SUMMARY

The consistency of the various data sets collected during the AIRS field program points out the richness of this experiment in terms of the remote sensing of winter precipitation. The information contained in Z_{DR} and ϕ_{DP} fields provided considerable insight into the nature of the particles and their spatial extent. In the example shown here, the presence of a layer of secondary ice production has potential impact on the depletion of supercooled drops from the layer below. This illustrates the challenge to existing radar-based precipitation type algorithms to account for the spatial/temporal variability of microphysical properties both in the horizontal and vertical. Issues such as sharp gradients of reflectivity, weak reflectivity and the importance of processes in the lowest levels of the atmosphere where ground clutter can be a problem need to be adequately addressed.

During the AIRS field program, data were collected on 23 precipitation events. Future work will assess the value of radar polarization diversity in an operational setting during winter storms with a focus on the identification of heavy snowfall, freezing precipitation (both rain and drizzle) and hazardous in-cloud icing conditions.

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