13.3 RADAR SIGNATURES OF WINTER CLOUDS FROM AIRCRAFT IN-SITU DATA AND GROUND-BASED RADAR OBSERVATIONS

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1. INTRODUCTION

The first Alliance Icing Research Study (AIRS I) was conducted during the winter of 1999/2000 in the areas of Mirabel airport near Montreal, Quebec. It provided a valuable data set of coordinated ground radar and aircraft observations. A primary objective of AIRS I was to characterize aircraft icing environments, particularly those associated with supercooled large drops. Details of the AIRS I field project are contained in Isaac et al. (2001a, 2001b). During AIRS I, two-research aircraft, the National Research Council (NRC) Convair-580 and the NASA Twin Otter, collected in-situ data primarily in cloud systems colder than 0°C while an array of ground-based remote sensing systems (radars, lidars and radiometers) measured cloud properties over the study site.

Analysis of cloud phase using ground-based radar polarimetric Doppler data collected during AIRS I was presented by Hudak et al. (2002). In this study, radar signatures of mixed-phase and glaciated winter clouds derived from in-situ microphysics data using the T-matrix scattering model are compared with measurements from a ground-based radar.

2. NRC CONVAIR-580 RESEARCH AIRCRAFT

The in-situ microphysics data used in this study were collected using the NRC Convair-580 (Fig. 1) which was instrumented by the Meteorological Service of Canada (MSC) and NRC. The aircraft in-situ microphysical data were averaged over 30 s corresponding to a horizontal resolution of approximately 3 km. For each aircraft data point, the cloud phase was identified and classified as liquid, mixed or glaciated and the drop and ice spectra were determined. Details of the methodology are contained in Cober et al. (2001). The AIRS I flight maneuvers consisted of combinations of spiral descents overhead of Mirabel airport, missed approaches, and horizontal transects at constant altitude on headings parallel to the runways at Mirabel, out to a range of 20 km from the runway intersection.

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Fig. 1. NRC Convair-580 Research Aircraft

3. MRO S-BAND RADAR

The polarimetric radar data used in this study were collected by the McGill University S-band radar (MRO), located about 30 km south from Mirabel. The MRO radar employs a fast scanning strategy doing a full 24-elevation volume scan in 5 min. With range averaging, this amounts to about 20 independent samples per measurement at a resolution of 1 km in range and 1° in azimuth. The polarization scheme employed is the slant 45 scheme, or hybrid mode as described in Bringi and Chandrasekar (2001). The specific differential phase values (k_{DP}) were obtained after averaging total differential phase (Φ_{DP}) over a running 5 km data window. Further information is contained in Zawadzki et al. (2001).

In matching the aircraft and MRO radar data, the center of the aircraft swath and the center of the radar resolution volume had to be within 250 m. A 5x5 B-scan array of radar data around the acceptable resolution volume was considered in the subsequent analysis. De-spiking techniques, frequently to remove the aircraft pixel from the radar data, and removing data beyond one standard deviation of the median box value, were applied prior to the averaging of any radar parameter.

4. IN-SITU DATA AND T-MATRIX MODEL RESULTS

The data selected for this analysis were collected on December 10, 1999 over the Mirabel airport between 1730 and 1830 UTC. During this segment, the aircraft performed a spiral descent and a missed approach over Mirabel airport as well as a horizontal transect. The aircraft altitude, temperature, liquid water content and samples of 2D-C images taken at various altitudes of the flight are shown in Fig. 2. The cloud composition included regions of planar crystals and aggregates (T < -10°C), needle crystals (-7 < T < -1°C) and pockets of mixed phase clouds.

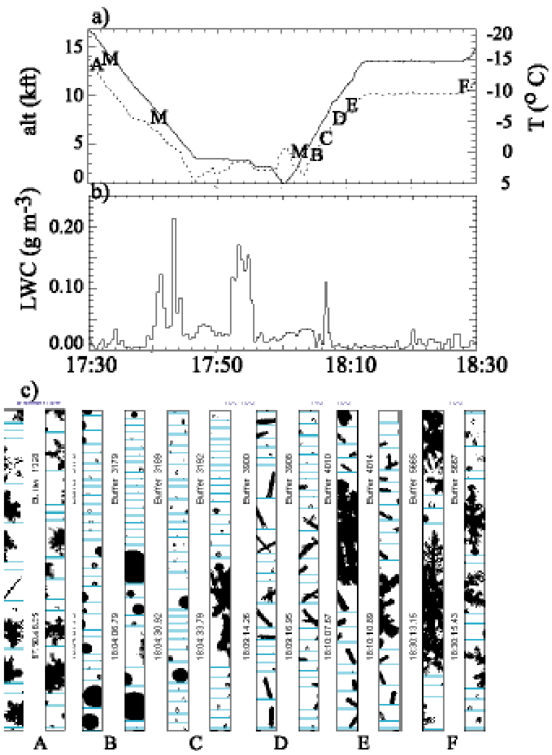

Fig. 2 (a) Time series of aircraft altitude and temperature (dashed line). Mixed phase regions are indicated by the letter M, the letters A-F indicate altitudes of the sample 2D-C images shown in (c), (b) Liquid Water Content, and (c) Samples of 2D-C images taken on Dec 10, 1999 at various altitudes.

Computations of radar polarimetric radar observable from the in-situ data were done using the T-matrix approach (e.g., Vivekanandan et al., 1991). For the T-matrix model input, the in-situ data are subdivided into three specific particle size intervals (<0.5 mm, 0.5-1.0 mm and >1mm) and particle types. These were used to characterize model inputs (e.g. effective dielectric constant, aspect ratio) and to determine their influence on the computed polarimetric variables. For planar and needle crystals, a size dependent aspect ratio (Auer and Veal, 1970) with dielectric constant corresponding to a constant density of 0.9 g cm^{-3} is used. For larger crystals (D>1mm) the aspect ratio of plates with a dielectric constant corresponding to density of 0.2 g cm^{-3} is used. All ice particles less than 500 μm are assumed to be spherical with a density of 0.9 g cm^{-3}.

The radar observables, equivalent reflectivity factor (Z_e), differential reflectivity factor (Z_{DR}) and specific differential phase (K_{DP}) computed from the in-situ spectral data using the T-matrix approach (symbol) and the MRO measurements (line) are shown in Fig. 3. The trends in the equivalent radar reflectivity factor (Z_e) computed from the in-situ data generally agree with trends measured by the MRO radar. The computed Z_e values in the mixed phase regions (Fig 2b-LWC>0.05 g m^{-3}) and drizzle (T>0°C) agree with the MRO Z_e values. However, there are regions where the computed values differ from the measurements by more than 10 dBZ. For example between 1732-1740 UTC the range of the computed Z_e in regions of plates and dendrites range from 20 to 35 dBZ while the measured values range from 15 to 25 dBZ.

The computed Z_{DR} values range from near 0 dB in drizzle or in mixed phase clouds to approximately 2 dB in clouds regions composed of planar and needle ice crystals. In contrast, the MRO data show higher variability than Z_{DR} values derived from the in-situ data. Running the T-matrix code with an aspect ratio of one as input for the larger particles instead of a size dependent aspect ratio gives Z_{DR} values less than 1 dB (not shown) with increased variability in Z_{DR} values. This indicates the sensitivity of Z_{DR} to the aspect ratio input of the ice particles in the T-matrix result.

The ranges of K_{DP} values (Fig. 3c) derived from the in-situ data agree with the ranges of K_{DP} measured by the MRO radar. The model output show elevated values of K_{DP} (> 0.5 °km^{-1}) in cloud regions consisted of dendrites and also in some pockets of mixed phase regions.

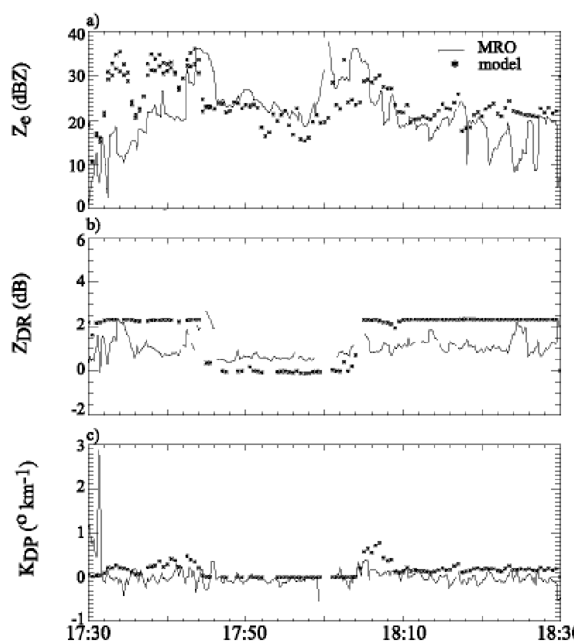

Fig. 3 MRO radar measurement (line) and T-matrix model output (symbol) of (a) Z_e, (b) Z_{DR} and (c) K_{DP} for the Convair-580 flight on Dec 10, 1999.

5. SUMMARY DISCUSSION

Scattering properties of cloud particles from in-situ data collected using a research aircraft in winter clouds were computed using the T-matrix approach. The comparison of the model output with the measurements of a ground-based S-band radar show mixed results. Out of the three radar observables (Z_e, Z_{DR}, K_{DP}) considered in this study, Z_e computed from the in-situ data show a good agreement with the MRO Z_e values, while Z_{DR} agree with the MRO data only in few segments. The difference between the values of measured radar observables and values derived from the in-situ data can be attributed to a number of factors including a mismatch of the radar and in-situ sample volume and misrepresentation of the shape, density and canting properties of the cloud particles.

The limited analysis presented in this study show T-matrix can be used to characterize icing signatures of winter clouds from in-situ microphysics data. We plan to perform sensitivity studies on inputs to the T-matrix model to determine "effective" shape, values of density and canting properties of various cloud compositions observed by the in-situ probes. We will then analyze the entire AIRS I data by using more stringent criteria for matching the in-situ and the ground radar data which will ultimately be used to characterize microphysical processes that are associated with icing conditions.

6. ACKNOWLEDGMENTS

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