2B.3 DOPPLER RADAR SIGNATURES OF IN-FLIGHT ICING CONDITIONS

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1. OVERVIEW

In-flight icing occurs when aircraft fly in regions where supercooled cloud, freezing rain, and especially freezing drizzle are present. Work on the detection of such conditions by remote sensing is being sponsored in many countries and resulted in dedicated field experiments such as the Alliance Icing Research Study (AIRS) that occurred in the Montreal area during the 1999-2000 winter. Detection of supercooled cloud and drizzle is particularly difficult, especially in the presence of ice crystals of much larger size and stronger reflectivity (Table 1).

Although direct detection is difficult, the occurrence of icing conditions can often be determined by Doppler radars as supercooled water leave clues of its presence via its interaction with the snow crystals. When snowflakes fall through a supercooled cloud, they first grow quickly, resulting in larger dZ/dh (Fig. 1), and then get rimed, resulting in denser crystals that fall faster. Furthermore, when rimed crystals melt, the resulting bright band will be considerably weaker (Fig. 2). Warm echo tops (-10ºC ≾ T ≾ 0ºC) also point to the presence of supercooled liquid water (Fig. 3). Conventional scanning radars can detect some of these conditions, but a vertically pointing radar is required for best results. For example, supercooled drizzle in the presence of snow can be detected by vertically pointing radars as it forms a distinct Doppler mode considerably slower than that of the rimed snow (Zawadzki and Fabry 2001; Fig. 4). Comparisons of prediction of icing conditions with radiometers and aircraft data show that these techniques have considerable potential.

2. REFERENCE

Zawadzi, I., and F. Fabry, 2001: Observations of supercooled water and of secondary ice generation by a vertically pointing X-band Doppler radar. *Atmos. Res.*, submitted (ICCP special issue).

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Icing condition	Detection problems with radar
Supercooled cloud (< -20 dBZ)	Very weak target (but unique in that respect at short wavelengths)
Freezing drizzle (-10 to 10 dBZ)	May be confused with snow
Freezing rain	None
Cloud mixed with snow (> 0 dBZ)	Echo reflectivity and polarization characteristics dominated by snow; differential attenuation technique affected by large "Mie" snowflakes
Drizzle (and maybe cloud) mixed with snow	Similar problems as with cloud and snow (both cases are hard to distinguish)

Table 1: Five possible combinations of hydrometeors causing in-flight icing, and the difficulties in detecting them by radar. All remote sensors have problems both detecting and locating supercooled water, and even more distinguishing cloud, drizzle, and rain that have very distinct effects on aircraft control surfaces.

dZ/dh = Vapor diffusion + Aggregation + Cloud accretion

Term in reflectivity growth equation	Importance without cloud present	Importance with clouds present
Vapor diffusion	Moderate	Increased (higher saturation)
Aggregation	Low (< -15º C) to high (> -10º)	Similar (decreased below?)
Cloud accretion	None	Moderate to high

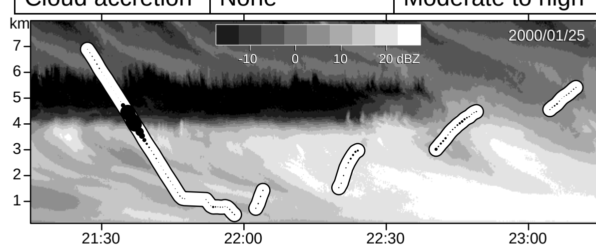


Fig. 1: Top: Table illustrating the change in the contribution to the reflectivity gradient with height by the three main terms. When liquid clouds are present, snow reflectivity increases more rapidly with depth.
Bottom: Time-height section of reflectivity from a vertically pointing radar during a snowfall event. Overlaid is the altitude of a research aircraft when over the radar (white band) and the measured liquid water content in the form of dark circles (circles of diameter equal to the band width indicate 0.1 g/m^3). Note how regions with high liquid water content are found where snow reflectivity changes the fastest.

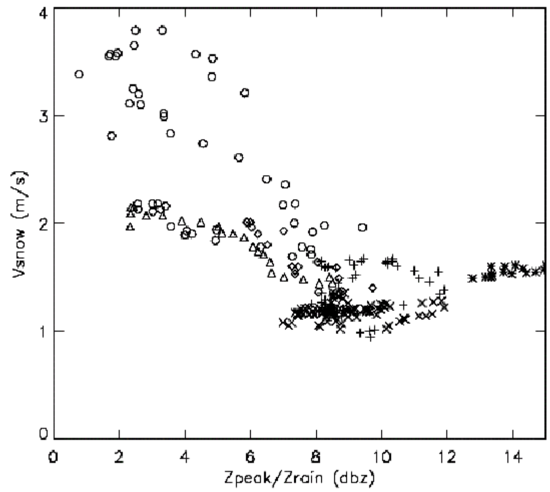


Fig. 2: Fall velocity of snow as a function of bright band peak enhancement (Z_{peak}/Z_{rain}) for cases with unrimed (+,x) and rimed snow. When snow is rimed, its fall velocity is greater than normal (a signature detectable by a vertically pointing Doppler radar) and the bright band peak intensity is smaller than normal (a signature detectable by all radars).

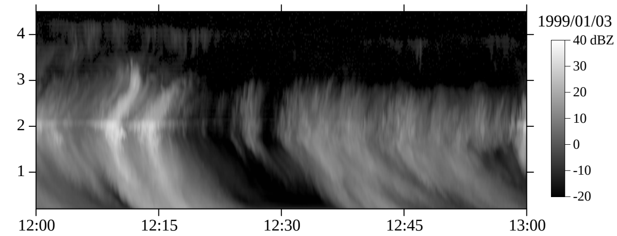
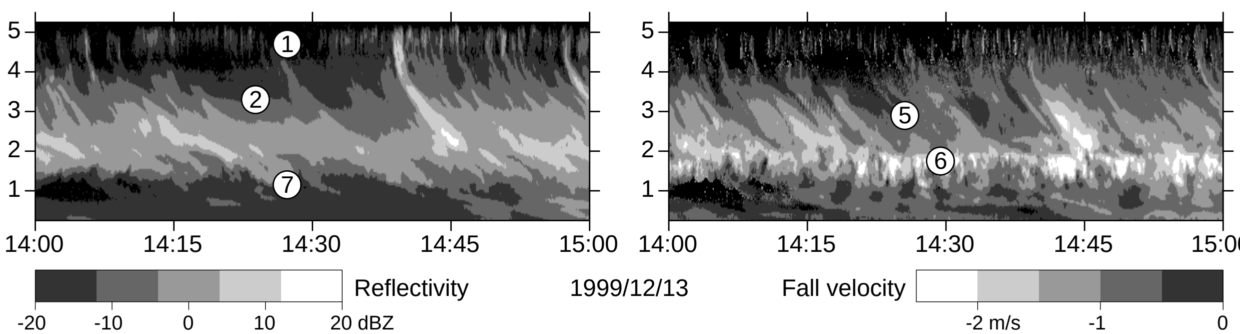
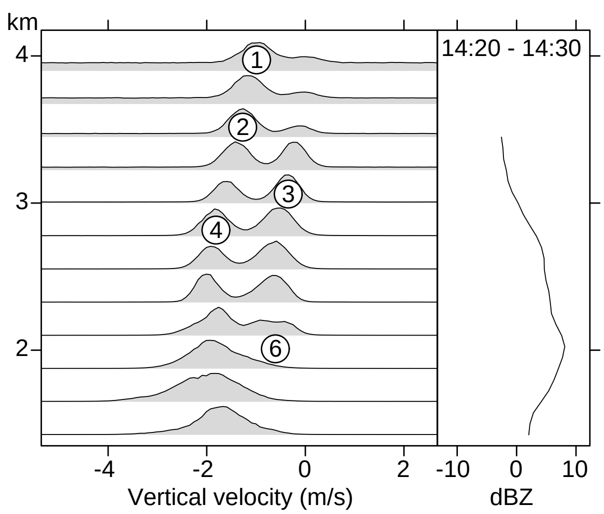


Fig. 3: Height-time section of reflectivity in a warm echo top event. Before 12:25, precipitation starts as snow. However, because of the warm temperatures (echo top at around –10ºC), the number of ice nuclei is small; liquid cloud hence forms in addition to the snow, and the snow becomes rimed as seen from the weak bright band. After 12:25, precipitation forms at even warmer temperatures where no ice nuclei exist. Excess vapor can only condensate in liquid cloud droplets (invisible to the radar); these become numerous enough that autoconversion starts and supercooled drizzle forms (note the lack of a bright band). While these two situations are distinct in terms of precipitation microphysics and signatures in the radar data, both will lead to in-flight icing.





At echo top, precipitation starts as snow that falls near 1 m/s ❶. But between 3 km and 4 km, its reflectivity and fall speed increase quickly ❷ as snowflakes are getting rimed by undetected cloud droplets. These cloud droplets also collide with each other, resulting in the formation of supercooled drizzle ❸ that falls considerably more slowly. Despite the fact that rimed snow speeds up to 2 m/s ❹, this cannot be observed on the Doppler HTI ❺ as it measures the average fall velocity of both modes. Only when the drizzle will have evaporated ❻ will high fall velocity be observed on the Doppler map. Quickly after drizzle has evaporated, rimed snow sublimates in the drier air at low levels ❼.

Fig. 4: Height-time section of reflectivity (top left) and of fall velocity (top right) during an event where snow and drizzle are mixed. In the lower right, a Doppler spectrum is displayed. Each of the 12 curves illustrates, at different altitudes, the relative contribution of targets with a given vertical velocity to the total reflectivity measured. Two modes can be observed, a faster falling one caused by snow, and a slower one caused by supercooled drizzle.