4.7 RAIN-SNOW DISCRIMINATION WITH POLARIMETRIC RADAR

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1. INTRODUCTION

Dual-polarization radars typically transmit horizontally and vertically polarized electromagnetic waves and receive backscattered signals. Because illuminated hydrometeors are not exactly spherical and similarly oriented, their radar backscatter cross-sections are not the same for the different polarizations. The propagating waves are subject to scattering, differential attenuation, differential phase shifts, and depolarization. Signal properties change continuously as the waves propagate yielding information that can be used to estimate particle size, shape, orientation, and thermodynamic phase.

A capability to automatically designate radar-sensed precipitation as rain or snow would be of importance to the aviation community because of airport capacity, economic, and safety issues. Discrimination between rain and snow with current operational radars that measure only radar reflectivity and Doppler measurements is difficult, particularly at low antenna elevations. Precipitation type designations typically are based on additional information such as temperature reports, visual observations, and the presence or absence of a radar reflectivity "bright band". However, bright bands may not be present with some convective events or may simply be undetectable at distances of a few tens of kilometers and more. Because polarimetric measurements provide more information regarding hydrometeors, a program has been initiated to determine potential applications. Rain-snow discrimination is an important first step in a larger effort to develop capabilities for general hydrometeor classification (Vivekanandan et al. 1999), for improving the quantitative estimation of warm and cold season precipitation, and for detecting some icing conditions (e.g., Ellis et al. 2000). The work is timely given efforts within the National Weather Service and at the National Severe Storms Laboratory to modify the WSR-88D for polarimetric capability.

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2. POLARIMETRIC MEASUREMENTS

Measurements used in this study are radar reflectivity at horizontal polarization (Z_H), the differential reflectivity (Z_{DR}), the linear depolarization ratio (LDR), the correlation coefficient between reflectivities at horizontal and vertical polarization (ρ_{HV}), and the differential propagation phase (Φ_{DP}). [For a detailed parameter description and typical observed values for various precipitation types see Doviak and Zrnić (1993).] Measurements presented here were obtained with the National Center for Atmospheric Research's S-band, dual-polarization radar (S-Pol) during field programs in Florida and Colorado.

Radar reflectivity is related to the 6th power of hydrometeor diameters and their density. Reflectivity for dry snow is typically < 35 dBZ and for pristine ice crystals Z_H < 25 dBZ. Wet snow can have reflectivity values > 45 dBZ. Reflectivity for rain is generally between 25 and 60 dBZ. Differential reflectivity is defined as the logarithm of the ratio of reflectivities at horizontal and vertical polarization when expressed in linear units. For raindrops Z_{DR} is usually > 0.3 dB but < 2.0 dB. At the leading edges of convective showers Z_{DR} can be 4 dB. Snow, depending on whether it is wet or dry and the amount of riming and aggregation can range from 0 to 3 dB. For pristine ice crystals Z_{DR} can be > 5 dB. Although Z_{DR} for ice particles varies considerably, typical values are often between 0.1 and 0.5 dB. Graupel and hail have a Z_{DR} near 0 dB. Depolarization occurs whenever the primary axes of the hydrometeors are not aligned with the transmitted signals, and a small amount of the signal leaks into the orthogonal polarization. Typical LDR values are -34 to -25 dB for raindrops and snow particles. Melting and water-coated ice particles behave as liquid particles of equivalent size and can have LDR values as

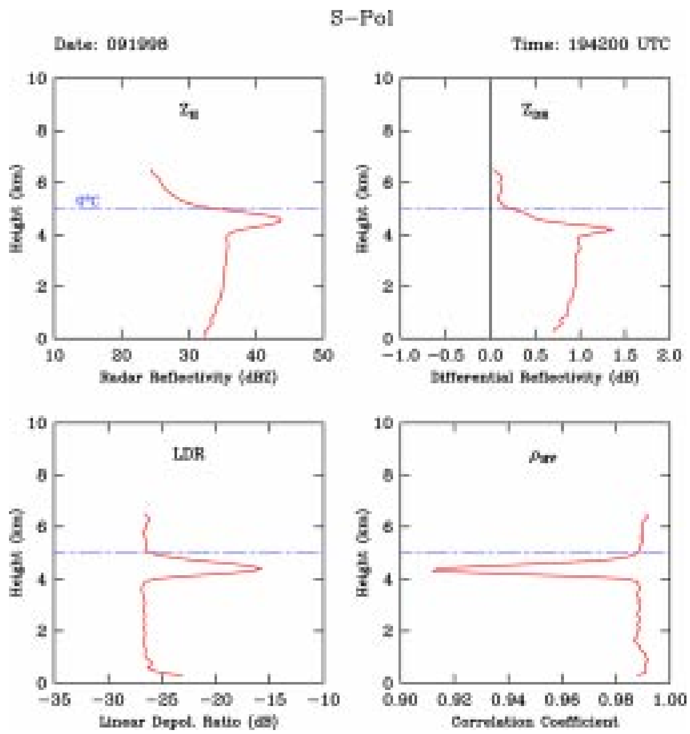

Fig. 1: Vertical profiles of polarimetric measurements obtained in the convective debrisregion of a storm observed in Florida. The freezing level is denoted by a dashed line.

strong as -13 dB. The correlation coefficient responds to the dispersion in hydrometeor eccentricities, canting angles, irregular shapes, and the presence of mixed-phase precipitation. Measurements with the S-Pol radar show correlations of ~0.99 for rain and snow. Values for melting or wetted ice particles can be less than 0.90. Of more use than Φ_{DP} is its range derivative the specific differential phase (K_{DP}). This propagative parameter is sensitive to anisotropic media like rain or pristine ice crystals. Signatures are strongest for rain and large wetted ice particles. The dimensions of aggregates in melting layers can be in the Mie scattering range even at S band and cause large fluctuations in the Φ_{DP} measurements. Notice that there is overlap in the polarimetric signatures for rain and snow and that mixed-phase precipitation signatures are fairly strong, especially for LDR and ρ_{HV}.

3. VERTICAL PROFILES OF POLARIMETRIC MEASUREMENTS

Because of the rapid changes that occur over short distances, rain-snow discrimination is most readily made with the vertical distribution of radar measurements. Figure 1 gives an example for stratiform precipitation representing the final stages of a summer event (observed in Florida on 19 September 1998) that began as convective. Pronounced melting layer signatures are apparent with all parameters, including Φ_{DP} (not shown). The profiles were constructed at a range of 15 km and do not extend to storm top. Inspection of the reflectivity profile suggests that hydrometeors grew in size as they fell to the 0^{o}C level (roughly 5 km) and melting ensued. [A 1500 UTC sounding found the freezing level at 5.058 km.] A marked increase in reflectivity begins at ~5.3 km-probably due to increased aggregation as the particles "warm" and their stickiness increases. The reflectivity bright band maximum (43.7 dB, 4.6 km), a long-recognized feature of melting layers, arises from a combination of melting and size effects. In the rain-only surface layer reflectivity decreases slowly toward ground, perhaps due to evaporation. Differential reflectivity in the ice layer is ~0.1 dB. Because reflectivities are low, the particles are most likely dry snow. Profiles at more distant ranges show that Z_{DR} in the uppermost levels of the storm was close to 1 dB, evidence that particles there were more pristine. The rapid increase in Z_{DR} beginning at 5.3 km also implies aggregation. As is often seen, the peak value (~1.4 dB at 4.2 km) is lower is altitude than the reflectivity maximum, an indication that the maximum eccentricity of the melting hydrometeors, i.e., the ratio of their horizontal

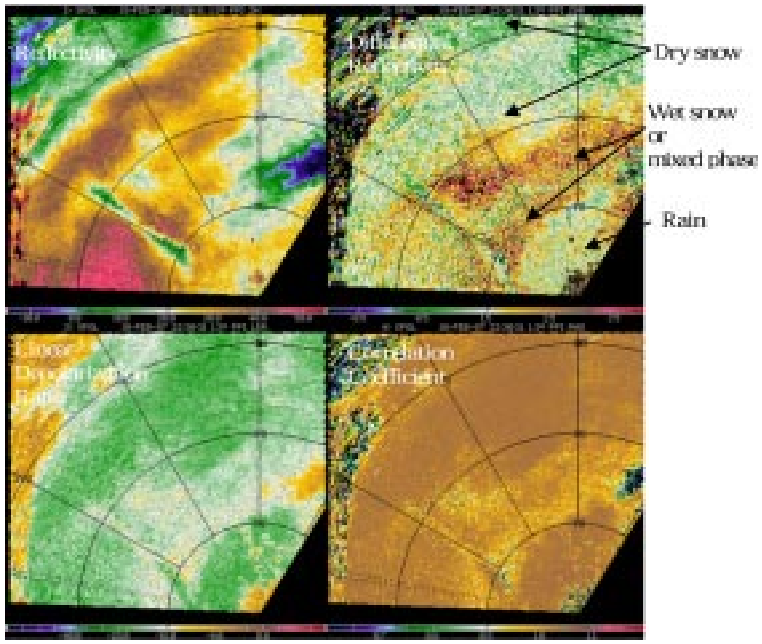

Fig. 2: Polarimetric radar measurements from a winter storm in Colorado. Range rings are 10 km.

and vertical axes, takes place at a lower level than their maximum size. In the rain layer, differential reflectivity values are slightly smaller than 1 dB. In this storm there are distinct Z_{DR} signatures for the snow and rain layers. While beam broadening dictates that the pronounced Z_{DR} maximum fades as distance increases, rain and snow signatures persist.

Experience has shown that the melting layer is often best delineated by LDR and ρ_{HV}. These parameters frequently can be used in convective precipitation to designate the 0^{o}C level when vertical mixing and hydrometeor types preclude the use of reflectivity or differential reflectivity. Examination of the individual profiles reveals that melting first appears in the LDR measurements at 5.0 km and in the ρ_{HV} field at 4.9 km. The profiles indicate that by the time the hydrometeors reached 3.9 km all ice had melted. A melting layer of ~1 km seems a little thick. Radar beam smoothing undoubtedly contributes to this result-the beam width is roughly 250 m at 15 km, but particle sizes are large for this event.

4. THE 18 FEBRUARY 1997 STORM

Measurements obtained on 18 February 1997 for a winter storm are presented in Fig. 2. As is common along the eastern foothills in Colorado, precipitation began in many locations as rain and then changed to snow as evaporative cooling lowered temperatures. At the time of data collection rain fell close to the radar (ranges < 7-12 km), snow dominated beyond 18-22 km, and mixed-phase precipitation fell in between. This event is particularly challenging because radar signatures in the rain-only and snow-only regions are nearly identical. From the radar reflectivity field shown there is no way to discriminate between precipitation types. The antenna elevation angle (1.3^{o}) is too low and the precipitation intensity too variable to reveal a bright band. In the rain region, e.g., azimuths of $0\text{-}10^{o}$ and ranges of 8.5-11 km, and the snow region ($340\text{-}350^{o}$, 18-22 km) Z_{DR} varies from 0 to 0.6 dB (Fig. 3). The Z_{DR} values for snow are about 0.2 dB smaller than be expected for rain having a reflectivity of 30-35 dBZ. Generally, subtle rain-snow differences can be retrieved by areal averaging. For pristine ice crystals Z_{DR} can be considerably larger than that for rain raindrops with the same radar reflectivity. For this event LDR is close to -25 dB and $\rho_{HV} > 0.98$ in both the rain and snow regimes. In some storms small rain-snow differences appear in these measurements as well.

Mixed-phase precipitation in Fig. 2 is characterized by $Z_{DR} \geq 2$ dB, LDR of -22 to -14 dB, and low ρ_{HV} (below 0.90 in some areas). The spatial distribution of the measurements indicates that hydrometer characteristics vary considerably throughout the transition zone. The region is more than 10 km wide in some areas. Mixed-phase signatures help define the rain-snow

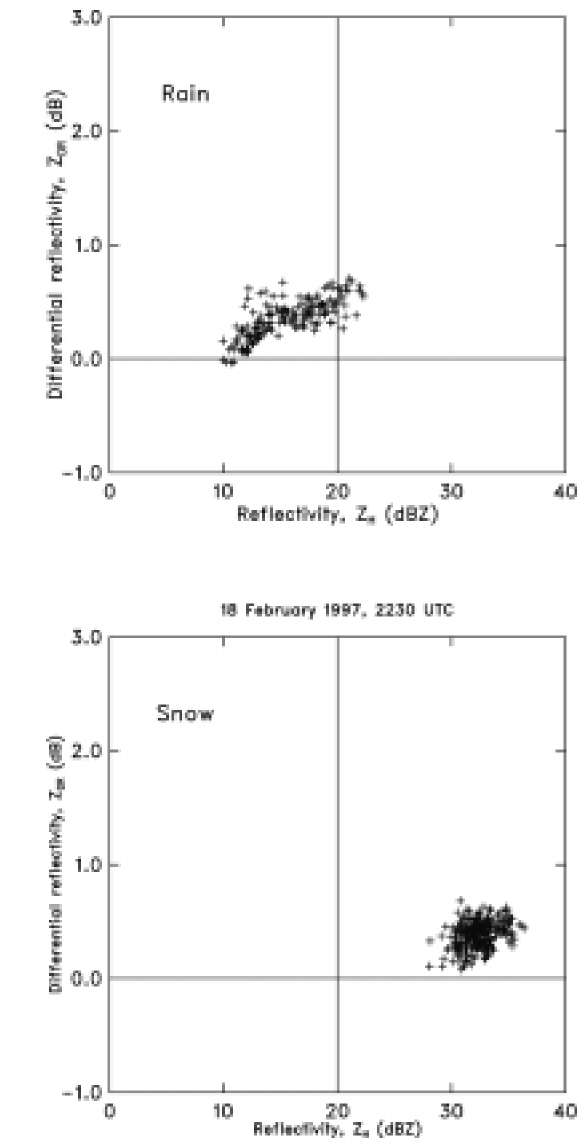

Fig. 3. Distribution Z_H and Z_{DR} in rain and snow regions.

regimes. An elevated melting layer, similar to that in Fig. 1, existed in the rain region (at 0.5 km AGL) but was absent in the snow region.

5. SUMMARY

Polarimetric radar capabilities for probing winter storms are being investigated. Potential benefits include improved rain-snow discrimination, detection of some icing conditions, and better quantification of winter precipitation. Foremost in this effort is the development of algorithms to discriminate among precipitation types. By capitalizing on known signatures for rain and snow, unambiguous rain-snow designations often can be made directly from differential reflectivity measurements at low antenna elevation. When there is considerable overlap in the signatures for rain and snow, designations can be made or facilitated by retrieving the 0^{o}C surface. The advantage of polarimetric radar over conventional radar comes from a capability to make rain-snow designations in a greater variety of storms and over greater distances.

Few winter storms have been probed with polarimetric radars. Measurements are needed for a variety of storm types. Supplement observations of frozen hydrometeor characteristics and liquid equivalents are also required.

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