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DISCRIMINATION BETWEEN RAIN AND SNOW WITH A POLARIMETRIC NEXRAD RADAR

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1. INTRODUCTION

Dual-polarization radar has unique capability to discriminate between different classes of hydrometeors including rain and snow (Ryzhkov and Zrnic 1998, Vivekanandan et al 1999, Straka et al 2000, Liu and Chandrasekar 2000). As part of continuous modernization of the nationwide network of the NEXRAD weather radars, US National Weather Service has decided to add polarimetric capability to existing operational radars. The proof-of-concept was tested on the NSSL's research KOUN WSR-88D radar, and its operational demonstration started in March 2002. An algorithm for classification of meteorological and non-meteorological radar echoes provides one of the key products that are delivered in real-time to the Norman NWS office for evaluation. In this paper, basic principles of the algorithm are outlined and results of discrimination between rain and snow are presented.

2. PRINCIPLES OF POLARIMETRIC CLASSIFICATION

Current real-time version of the classification alfgorithm enables discrimination between radar echoes caused by (1) ground clutter and anomalous propagation, (2) biological scatterers (including insects and birds), (3) dry snow, (4) wet snow, (5) stratiform rain, (6) convective rain, and (7) rain/hail mixture. The classification algorithm utilizes polarimetric radar data collected at two lowest elevation angles, 0.5° and 1.5°, to produce a field of classified scatterers at the elevation scan of 0.5°. These fields are regularly supplied to the NWS operational staff for evaluation and feedback. There are four radar variables that are used in the classification routine: radar reflectivity factor Z at horizontal polarization, differential reflectivity Z_{DR}, cross-correlation coefficient ρ_{hv}, and a texture parameter of the Z field SD(Z). To obtain SD(Z), we average raw Z data (sampled every 0.256 km) along the radial using 1-km-width running average window and subtract the smoothed estimates of Z from their original values.

Several classes of radar scatterers have very distinctive polarimetric properties and can be recognized easily if the fuzzy logic methodology is applied on a pixel-by-pixel basis. This means that no analysis of general pattern or surrounding pixels of data is needed. Ground clutter / AP, insects, birds, chaff, hail, wet snow (bright band) belong to this category of scatterers. All of them are characterized by anomalously low values of cross-correlation coefficient. Differential reflectivity is mainly negative for ground clutter / AP, very high positive for biological scatterers and chaff, and moderately high for wet snow. Combination of high Z and relatively low Z_{DR} is a distinctive feature of hail or rain/hail mixture. SD(Z) is usually much higher for non-meteorological scatterers (especially for ground radar returns) than for any weather hydrometeors.

A major problem is discrimination between stratiform rain and dry aggregated snow for which membership functions in the fuzzy logic formalism are heavily overlapped. Both classes are characterized by relatively low Z and Z_{DR} combined with high ρ_{hv} (Ryzhkov and Zrnic 1998). Furthermore, there is no distinction in terms of the texture of the Z field as well.

Fig. 1 illustrates three scatterplots of Z versus Z_{DR} obtained from the measurements with the KOUN radar for three different types of snow. Dry aggregated snow was observed on 6 February 2003 between 15 and 16 Z over the whole state of Oklahoma. Seven hours later, dry aggregated snow changed to more crystallized snow in a very cold air NW of the radar. It was characterized by much higher Z_{DR} and lower Z. Heavy convective snowfall occurred on 24 February 2003 in southern Oklahoma. The corresponding Z – Z_{DR} scatterplot for the period between 22 and 24 Z is also displayed in Fig. 1. Radar reflectivities over 50 dBZ are unusually high for snow in the latter case, but corresponding values of Z_{DR} are relatively low compared to the ones typically observed at the

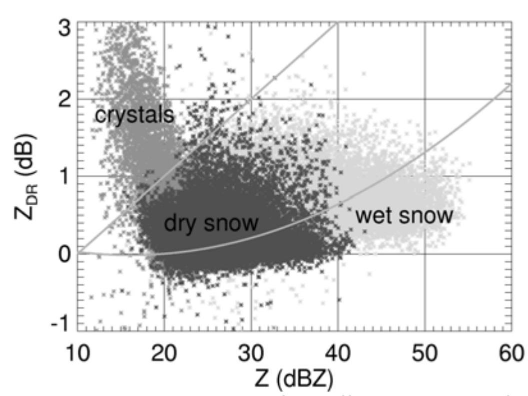

Fig. 1 Z – Z_{DR} scatterplots for different types of snow. Two curves confine “rain” area.

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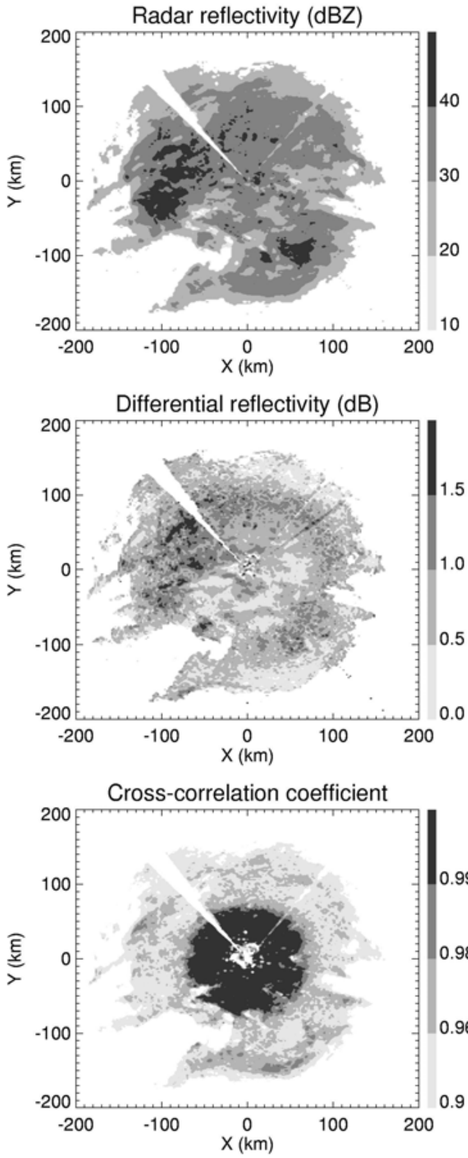

Fig. 2 Composite plot of Z, Z_{DR}, and ρ_{hv} at El = 1.5° for stratiform rain on 24 October 2002 (1832 Z).

bottom of the bright band. The region between two curves in Fig. 1 represents locations of Z – Z_{DR} pairs for pure rain as derived form the multi-year statistics of DSD measurements in central Oklahoma.

It is evident that rain and snow are heavily overlapped in the Z – Z_{DR} plane for reflectivities between 20 and 40 dBZ. There is no clear distinction between these two classes in K_{DP} and ρ_{hv} as well. A clue for successful discrimination between these classes lies in the fact that stratiform rain and aggregated snow are usually separated by the bright band that has very pronounced polarimetric signatures and can be easily detected. Therefore, rain / snow delineation is contingent on reliable identification of the bright band.

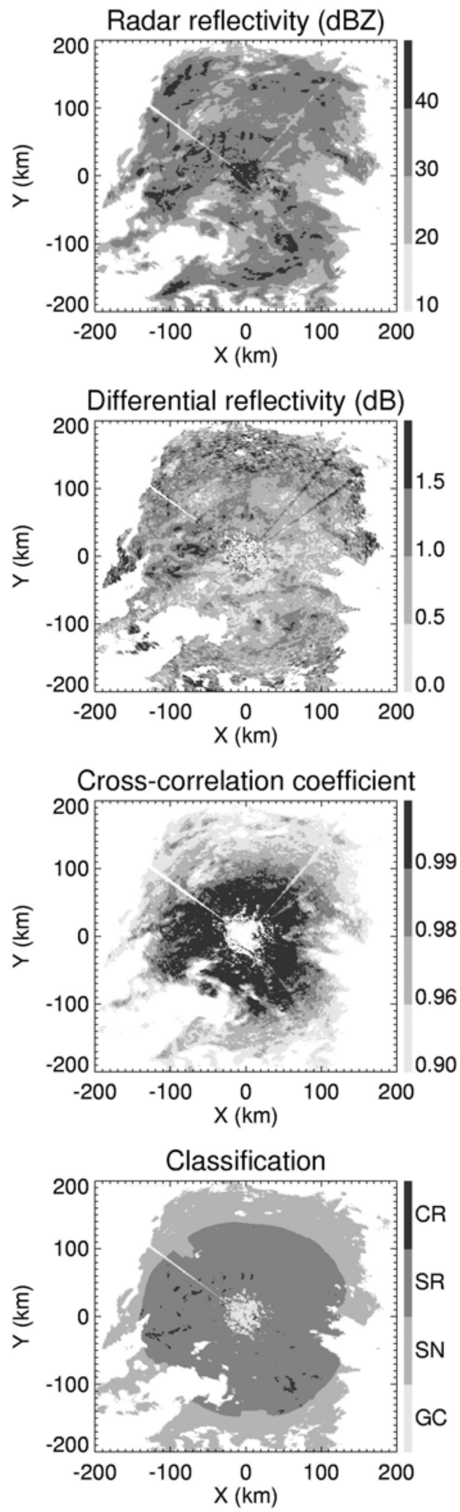

Fig. 3 Composite plot of Z, Z_{DR}, $\rho_{hv,}$ and results of classification at El = 0.5° for stratiform rain on 24 October 2002 (1832 Z). GC stands for ground clutter, SN – for snow, SR – for startiform rain, and CR – for convective rain.

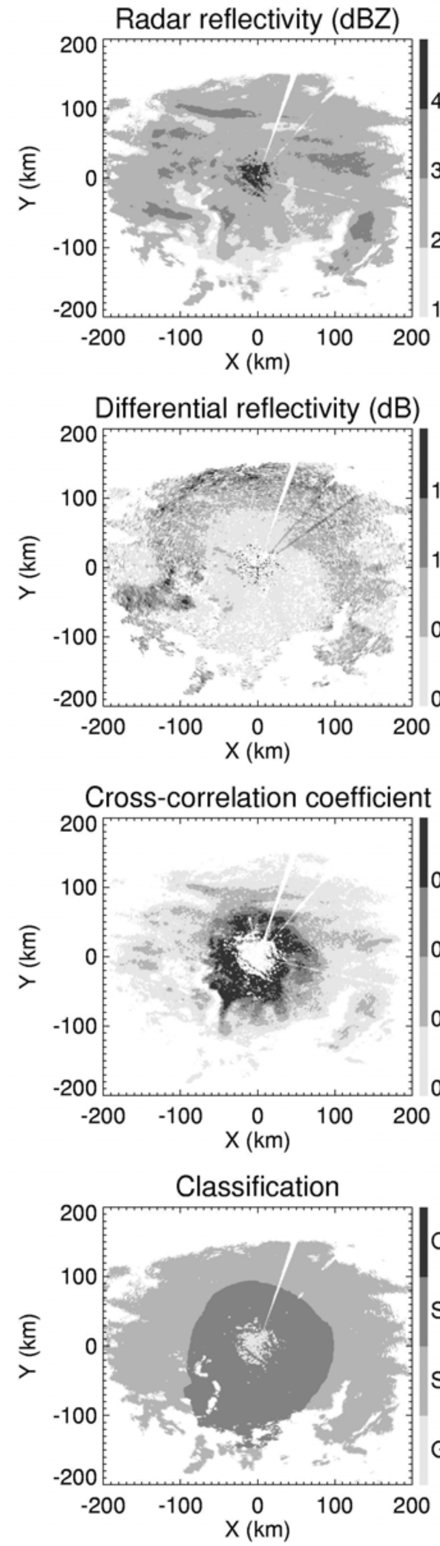

Fig. 4 Same as in Fig. 3 but for the 3-4 December 2002 snow event (12/03/02, 1803 Z)

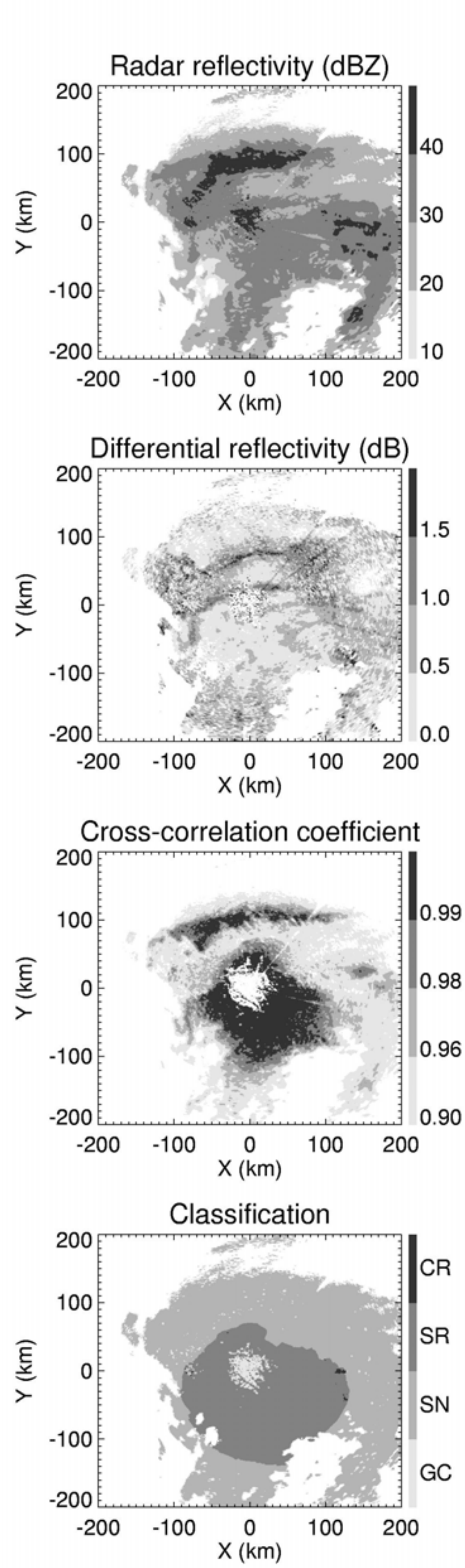

Fig. 5 Same as in Fig. 3 but for the 3-4 December 2002 snow event, 0302 Z (12/04/02, 0302 Z).

Although it is easier to perform bright band identification at RHI, we have to do classification at PPIs because RHI antenna scanning is not accepted in the NEXRAD mode of operations. Fig 2 and 3 demonstrate how the melting level is exhibited in the fields of Z, Z_{DR}, and ρ_{hv} at two lowest elevation tilts: 0.5 and 1.5° in the case of a stratiform rain with relatively low bright band.

At both elevations, radar reflectivity gives little clue about location and height of the melting level. The bright band signature is more pronounced in the Z_{DR} fields, particularly at higher elevation. However, the best indication of the melting level is given by ρ_{hv} at 1.5°. The cross-correlation coefficient drops abruptly from 0.99 to less than 0.96 at the slant range where a radar beam intersects the bottom of the melting layer. After dropping in the melting layer, ρ_{hv} tends to increase in dry snow aloft. This increase, however, might be masked with a general decrease of ρ_{hv} with range due to weakening of radar signal and broadening of the radar beam. It can be shown that ρ_{hv} is negatively biased if signal-to-noise ratio is less than 20 dB. The same is true for Z_{DR}. Thus, the appropriate correction of ρ_{hv} and Z_{DR} at low SNR is crucial for rain / snow discrimination.

In the current version of the classification algorithm, slant ranges separating rain and melting snow are determined at every azimuth from the radial profiles of corrected ρ_{hv} at the elevation of 1.5°. After some editing and median filtering in azimuth, the "bright band contour" is generated at 1.5°. The corresponding "bright band contour" at lower elevation is obtained from the one at 1.5° using simple geometric considerations and an assumption of horizontal uniformity. Then traditional "fuzzy logic" approach is applied for classification on a pixel-by-pixel basis at both elevations using all available radar variables. However, categories of rain and non-meteorological scatterers are prohibited beyond the "bright band contour" where snow is expected. Similarly, snow is not allowed to appear below bright band.

The bottom panel of Fig. 3 represents results of rain / snow discrimination for the case of 10/24/02.

3. FREEZING RAIN CASE

The performance of the classification algorithm is demonstrated for the winter storm on 3 – 4 December 2002 (Fig. 4-5). This storm was associated with the passage of a cold front accompanied by the transition from rain to freezing rain and snow in the Oklahoma City metropolitan area. During this event, the melting layer was slowly subsiding with much lower height of the bright band in the cold air pool N – NW from the radar. This feature is manifested by the pronounced asymmetry of the "rain" area with respect to the radar location.

At 1803 Z (12/03/02), differential reflectivity gives clear indication of the bright band in the northern sector (Fig. 4). More precise determination of the bright band localization was possible from the ρ_{hv} data at the elevation of 1.5°. About nine hours later, the height of the melting layer remained almost the same in the southern sector, but noticeably decreased to the north from the radar (Fig. 5). Note the bright band signature in the Z field associated with increase of Z_{DR} and drop in ρ_{hv} in that direction.

At 0302 Z (12/04/02), rain was recognized up to the distances 50 – 60 km at the lowest elevation scan NW from the radar. At the same time, surface temperature fell below zero and freezing rain was reported on the ground. This freezing rain caused significant damage in the Oklahoma City metropolitan area.

Note that after dropping in the melting layer, the cross-correlation coefficient restored high values exceeding 0.99 at higher levels aloft where snow is dry (Fig. 5c). Corresponding lower values of Z_{DR} in dry snow are very similar to those observed in rain below the melting level. This again underlines importance of the bright band identification for separation between dry aggregated snow and light rain.

More detailed meteorological interpretation of polarimetric variables and its use by the forecasters at the Norman NWS office for this winter storm is described in the paper of Scharfenberg and Maxwell (2003).

4. REFERENCES

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