8B.4 POLARIMETRIC RADAR SIGNATURES IN MICROBURST-PRODUCING THUNDERSTORMS

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1. INTRODUCTION

Prediction and detection of microbursts in thunderstorms has long been a challenge for operational meteorologists. Microbursts, and their associated wind shear, have been found to play a role in a number of aviation accidents (Fujita 1985). In addition, the associated wind damage at ground level can reach a level comparable to an F3 tornado on the Fujita scale of tornado intensity (Fujita 1985).

A number of studies (e.g., Srivastava 1987) have found that hydrometeor characteristics in the downdraft column can be key to the initiation and strength of a microburst. In particular, melting hail has been found to be a major contributor to downward accelerations in wet microbursts (Srivastava 1987). Unfortunately, using conventional radar to deduce hydrometeor characteristics is, at best, difficult. In particular, to discriminate between rain, hail, or a mixture of the two over small scales requires knowledge about particle size distributions that are typically unknown to the radar operator.

Fortunately, a polarimetric radar (PR) can be employed to partially solve this problem. Deduction of bulk hydrometeor characteristics is possible by examination of the differences in scattering and propagation characteristics between pairs of radar pulses with orthogonally-oriented electric fields. The quality of research PRs has improved in recent years, as has our understanding of PR signatures of meteorological echoes and their relation to hydrometeor type.

Enough progress in each arena has been made that upgrades to the national WSR-88D network may now be considered (Zrnic 1996). An operational proof-of-concept test, known as the Joint Polarization Experiment (JPOLE) took place in central Oklahoma during Spring 2003 (Schuur et al. 2003). This marked the first opportunity for operational meteorologists to use PR information in warning decision-making. This advance allows forecasters to determine whether the deduction of hydrometeor type with a PR can be combined with our knowledge of microbursts to improve severe thunderstorm warnings.

Two microburst-producing thunderstorms were examined with a research polarimetric radar. The "S-Pol" radar is an S-band, portable research polarimetric radar operated by the National Center for Atmospheric Research (NCAR). The S-Pol radar is capable of a variety of scan strategies, including sectored plan position indicator, sectored range height indicator (RHI), or surveillance scans. The specific scan strategies, pulse repetition frequencies (PRFs), and scan rates employed can be tailored to the goals of the project. In these two cases, S-Pol used a PRF of 960 s^{-1} with a scan rate of 6 deg s^{-1}. Beam spacing was held between 0.8 and 1.0 deg. Range gates were 150 m in length.

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2. 23 JUNE 2000 COLORADO STORM

Figure 1 shows an S-Pol range-height indicator (RHI) cross-section of a microburst-producing thunderstorm in eastern Colorado on the afternoon of 23 June 2000. Note the vertical storm core, with maximum reflectivity of about 60 dBZ (Figure 1a), shows little tilt with height. The differential reflectivity (Z_{DR}) image (Figure 1b) shows a well-defined “trough”, the base of which coincides horizontally with the location of the reflectivity core. The 1.5 dB Z_{DR} contour is shown in the figure to highlight the location of the trough. The specific differential phase (K_{DP}) image (Figure 1c) shows a maximum of 3 deg km^{-1} near the base of the Z_{DR} trough.

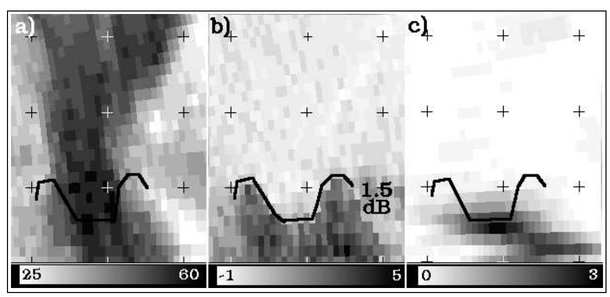

Figure 1. S-POL RHI scan of a microburst-producing thunderstorm near Burlington, Colorado at 2106Z 23 June 2000. **a)** Reflectivity (dBZ); **b)** Differential reflectivity (Z_{DR}, dB); and **c)** Specific differential phase (K_{DP}, deg km^{-1}). Tick mark spacing is 2 km. Each panel shows a contour of 1.5 dB differential reflectivity as a heavy black line.

The juxtaposition of high reflectivity, low Z_{DR} and low K_{DP} at 4 km altitude in the storm core suggests hail is the primary hydrometeor type at that altitude

(Straka et al. 2000). Below that altitude, the K_{DP} increases as reflectivity remains high and Z_{DR} remains low. This suggests a mixture of rain and hail is present (Balakrishnan and Zrnic 1990a and 1990b). Finally, near the surface, high reflectivity, high Z_{DR} and moderate K_{DP} values suggest the precipitation is mostly rain.

These observations strongly suggest the PR fields are depicting the melting of falling hailstones within the vertical precipitation core. This is not surprising, as simulations by Srivastava (1987) found that diabatic cooling due to melting hail is a large contributor to the downward acceleration associated with wet microbursts. In this case, the observations were corroborated by increasing radial divergence in the velocity fields, and a downward decrease in the correlation coefficient. The latter signature suggests an increasing diversity of hydrometeor type toward the ground (Straka et al. 2000).

3. 13 AUGUST 1998 FLORIDA STORM

S-Pol observed another microburst-producing thunderstorm on the afternoon of 13 August 1998 over Melbourne Florida. Figure 2 presents an RHI of reflectivity (Figure 2a), Z_{DR} (Figure 2b), and K_{DP} (Figure 2c). As in the Colorado storm, there is a well-defined trough in the Z_{DR} field with enhanced K_{DP} near the base of the Z_{DR} trough. In this case, K_{DP} values are higher, reaching 6 deg km^{-1}. Unlike the Colorado storm, the high reflectivity column has not yet descended to the surface, and the Z_{DR} and K_{DP} signatures are aloft.

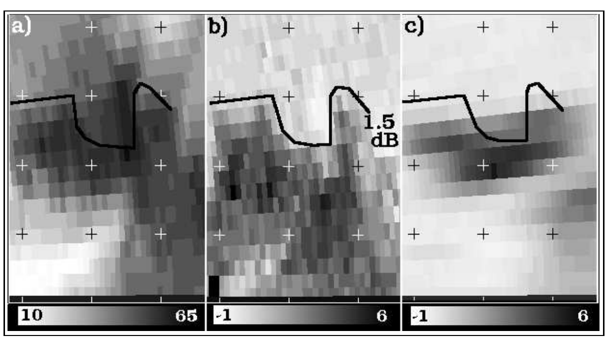

Figure 2. S-POL RHI scan of a microburst-producing thunderstorm near Melbourne, Florida at 2132Z 13 August 1998. **a)** Reflectivity (dBZ); **b)** Differential reflectivity (Z_{DR}, dB); and **c)** Specific differential phase (K_{DP}, deg km^{-1}). Tick mark spacing is 2 km. Each panel shows a contour of 1.5 dB differential reflectivity as a heavy black line.

As in the Colorado microburst, the signature of a melting hail column was associated with a downward decrease in the correlation coefficient, confirming a mixture of hydrometeor types. Unlike the Coloardo storm, there was strong radial convergence detected below the signature at the time of Figure 2, but this quickly reversed to strong radial divergence in the ensuing minutes as the reflectivity core descended.

4. DISCUSSION

Wakimoto and Bringi (1988) examined a microburst-producing thunderstorm in northern Alabama. Although their radar did not measure differential phase shifts, they documented a Z_{DR} “hole” associated with the location of a microburst impact. They reasoned this signature was associated with a small region of hail reaching below the ambient melting level in the vicinity of the downdraft. Although the Z_{DR} signatures in the Colorado and Florida storms can better be described as a “trough” when viewed in a vertical cross-section, the Z_{DR} and differential phase measurements strongly support Wakimoto and Bringi's assertion.

Figure 3 depicts a possible hydrometeor evolution in the downdraft column that may contribute to such PR signatures. In the early part of the thunderstorm's life (Figure 3a), an updraft carries liquid drops in a column above the ambient melting level

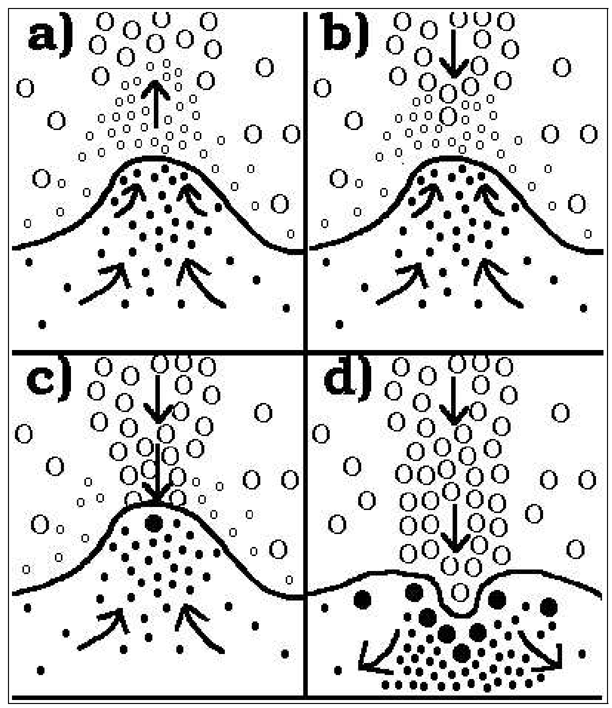

Figure 3. Schematic of the evolution of hydrometeor types and melting level altitude in the vicinity of a developing microburst downdraft column. Solid line denotes melting level. Large open circles depict dry hail, large filled circles depict melting hail, small filled circles depict liquid drops, and small open circles depict supercooled liquid drops. **a)** Updraft stage; **b)** Collapsing stage; **c)** Cooling stage; **d)** Microburst stage.

(represented by small open circles in the figure), above which hailstones form (represented by large open circles). Eventually, the mass of liquid and hailstones becomes greater than the updraft can support, and the column begins to collapse (Figure 3b).

As the first hailstones fall below the melting level (large filled circles in Figure 3c), they begin to form a water coat and shed drops (Rasmussen et al. 1984). The latent heat sink onto the surface of the ice cools the air, contributing to downward acceleration and a lowering of the melting level (Figure 3d). The negatively buoyant mass of cold air, filled with melting hail and shed liquid drops then impacts the ground as a microburst.

In their wind tunnel simulations, Rasmussen et al. (1984) found that melt water forms a torus around the equator of falling hailstones. The total particle diameter can increase to nearly 1 cm. The stable fall orientation for such a particle is with its major axis oriented in the horizontal. The addition of a large number of shed liquid drops, with major axes of up to 4.5 mm also oriented in the horizontal, will cause a very strong differential phase shift (Balakrishnan and Zrnic 1990a) and, therefore, high values of K_{DP}. Z_{DR} remains low in this region of melting because there is still a mixture of hailstones, which have no preferred fall orientation. In addition, Z_{DR} is reflectivity-weighted, so the Z_{DR} contribution from the hailstones dominates the returned power signal over the liquid drops in the mixture.

The polarimetric signatures in the two storms studied are remarkably similar, despite significant differences in reflectivity structure and storm environment. The higher ambient melting level in the Florida storm allowed the signature to be detected aloft before the strongest winds reached the surface, while the hail melting process and associated diabatic cooling began much closer to the ground in the Colorado storm. This technique may offer limited lead time, particularly in cases like the Coloardo microburst. Srivastava (1987) found a microburst's life cycle from development to ground impact may take place in less than ten minutes.

The short life span of a microburst is a limitation this radar technique cannot address. In addition, the melting layer may be close enough to the ground in some cases such that radar horizon issues may also be a concern. Finally, Wakimoto and Bringi (1988) and Srivastava (1987) found wet microbursts downdraft columns can have a very small horizontal dimension – perhaps measuring only 1 km in diameter at the ground. Therefore, any signature in such a narrow column may be more narrow than the beamwidth of a radar at long range.

It is also important to consider the method of calculating K_{DP}. The S-Pol radar caluclated K_{DP} over 20 gates with a gate spacing of 150 km, yielding a calculation of K_{DP} over a range of 3 km along each radial. As mentioned, wet microburst downdraft columns may be as narrow as 1 km, so the true differential phase shift may be “smoothed out”, particularly if a K_{DP} measurement is calculated over a longer range interval.

Finally, a forecaster must use all available information when there is a potential for microbursts, rather than relying on signatures from a single radar. A strong signature of a column of melting hail may not be associated with strong outflow winds at the surface if, for example, a layer of cold air near the ground reduces the virtual potential temperature difference between the environment and the downdraft.

5. CONCLUSIONS AND FUTURE WORK

In the two microbursts observed, a trough (in horizontal cross-section) of Z_{DR} was coincident with high reflectivity, indicating hail was falling below the ambient melting level in the downdraft column. At the base of the Z_{DR} trough, an enhanced area of K_{DP} was also noted. This suggests liquid water, which falls in an oblate manner with major axis in the horizontal, was also present with the hail.

These observations were corroborated by a downward decrease in the correlation coefficient, indicating a downward increase in diversity of hydrometeor types. This set of PR signatures coincided with the location of a low-level radial velocity divergence signature, indicating the location of the microburst impact.

Although these results are preliminary and based on a small number of cases, it is clear that in these cases, melting hail is present within the microburst column. It is generally accepted that melting hail, along with condensate loading, is a major contributor to wet microburst development and strength. It is surmised diabatic cooling from melting hail was a dominant contributor to these microbursts.

More downburst cases must be observed with PRs before any meaningful statistics or thresholds can be offered. This includes a variety of environmental temperature lapse rates and relative humidities. This also includes "dry" microbursts, which are often not associated with melting hail but with evaporating rain drops. Such dry microbursts will certainly have different PR signatures.

In addition "null" cases must be considered. These should incorporate both cases where microbursts occurred but these signatures were not present, and cases where similar signatures cannot be associated with microbursts.

The PR observations in these cases suggest the hail melting process in wet microbursts may now be directly observable, which has the potential to benefit operational warnings.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Balakrishnan, N., and D.S. Zrnic, 1990a: Estimation of rain and hail rates in mixed-phase precipitation. *J. Atmos. Sci.,* **47,** 565-583.

Balakrishnan, N., and D.S. Zrnic, 1990b: Use of polarization to characterize preciptitation and discriminate large hail. *J. Atmos. Sci.,* **47,** 1525-1540.

Fujita, T.T., 1985: *The Downburst.* SMRP Research Paper No. 210, University of Chicago, 122 pp. [NTIS PB-148880].

Rasmussen, R.M., V. Levizzani, and H.R. Pruppacher, 1984: A wind tunnel and theoretical study of the melting behavior of atmospheric ice particles: III. Experiment and theory for spherical ice particles of radius > 500 μm. *Atmos. Sci.,* **41**, 381-388.

Schuur, T.J., D.W. Burgess, and A.V. Ryzhkov, 2003: The Joint Polarization Experiment – An operational demonstration of the polarimetric KOUN WSR-88D radar. *Preprints, 31st Intl. Conf. On Radar Meteor.*, Seattle, WA, Amer. Meteor. Soc., in this preprint volume.

Srivastava, R.C., 1987: A model of intense downdrafts driven by the melting and evaporating of precipitation. *J. Atmos. Sci.*, **44,** 1752-1773.

Straka, J.M., D.S. Zrnic, and A.V. Ryzhkov, 2000: Bulk hydrometeor classification and quantification using polarimetric radar data: synthesis of relations. *J. Appl. Meteor.,* **39,** 1341-1372.

Wakimoto, R.M., and V.N. Bringi, 1988: Dual polarization observations of microbursts associated with intense convection: The 20 July storm during the MIST project. *Mon. Wea. Rev.,* **116,** 1521-1539.

Zrnic, D.S., 1996: Weather radar polarimetry – trends towards operational applications. *Bull. Amer. Meteor. Soc.,* **77,** 1529-1534.