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POLARIMETRIC RADAR OBSERVATIONS OF A MICROBURST−PRODUCING THUNDERSTORM DURING STEPS

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1. INTRODUCTION

On 23 June 2000, severe thunderstorms moved across the Severe Thunderstorm Electrification and Precipitation Study (STEPS) domain. One thunderstorm produced strong microburst winds, measured as high as 29 m s^{-1} by mobile mesonet vehicles. The National Center for Atmospheric Research, S−band, Dual Polarization Doppler Radar (S−POL) sampled the storm, detecting signatures consistent with a strong microburst, including a low−level peak−to−peak radial divergence signature approaching 20 m s^{-1}.

A *microburst* is defined by Fujita (1985) as a strong downdraft which induces an outburst of damaging, divergent winds at the surface extending 4 km or less in the horizontal. Aside from property damage at ground level, microbursts have been implicated in a number of aviation accidents. After the damaging winds spread out at ground level to a horizontal dimension exceeding 4 km, the wind event is referred to as a *macroburst.*

Techniques have been developed to predict and detect microbursts using conventional Doppler radar data, and by using differential reflectivity (Z_{DR}) data provided by polarimetric radar. Polarimetric variables other than Z_{DR} have not previously been assessed in the prediction and detection of microbursts.

S−POL data from the 23 June microburst case were studied using conventional Doppler radar techniques to determine the location and time of microburst development and impact. Next, Z_{DR}, specific differential phase (K_{DP}), and correlation coefficient ($|\rho_{HV}(0)|$), were examined to determine the bulk hydrometeor characteristics within the microburst downdraft column, and whether the latter two variables might be useful in the prediction and detection of microbursts.

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2. CONVENTIONAL RADAR TECHNIQUES

Wilson et al. (1984) developed a definition for a radar−detected microburst as having a divergent low level peak−to−peak radial velocity difference of at least 10 m s^{-1} over no more than 4 km. Using this definition, the 23 June microburst was first detected at approximately 22:10 UTC, at about 45 km range from S−POL. The microburst evolved into a macroburst, which was responsible for a 29 m s^{-1} gust measured at 22:25 UTC.

Studies by Roberts and Wilson (1989) and Eilts et al. (1996) found several precursors to microbursts using conventional Doppler radar data. These precursors included a rapidly descending reflectivity core, mid−altitude radial convergence, and rotation, all of which were detected in the 23 June case.

The descending core's impact with the ground was well−illustrated by the jump in the horizontal reflectivity factor (Z_H) that occurred simultaneous to the radar−indicated time of microburst impact (Figure 1). Strong radial convergence, with peak−to−peak velocity differences on the order of 20 m s^{-1}, was common in the half hour preceding the microburst impact. Finally, a strong mesocyclone developed about 4 to 5 km above the surface, with peak−to−peak velocity differences approaching 20 m s^{-1}. The development of the mesocyclone, however, was almost simultaneous to the time of microburst impact, limiting its predictive value.

3. OTHER POLARIMETRIC VARIABLES

To determine the possible utility of polarimetric radar variables in the detection and prediction of microbursts, three polarimetric variables from the 23 June S−POL data were studied.

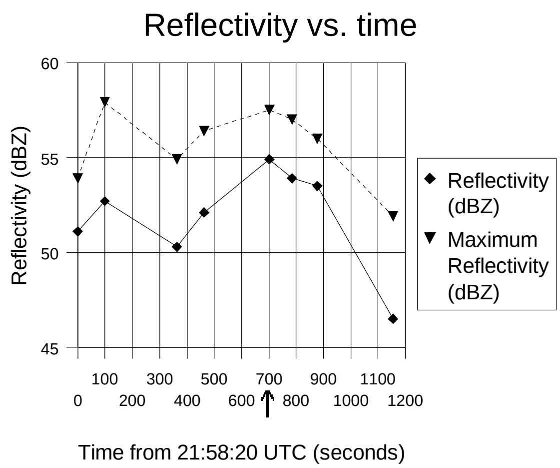

Figure 1. Horizontal reflectivity factor (Z_H) vs. time at the 0.5° elevation angle. Spatial averages were taken over a 1.5 km diameter circular area, centered at the location of the microburst impact, which occurred near t=700 sec. Maximum horizontal reflectivity factor within the 1.5 km diameter circular area is also shown.

3.1 Differential reflectivity (Z_{DR})

Z_{DR} is a measure of the reflectivity−weighted mean axis ratio of the hydrometeors within a radar volume. In regions of high Z_H within convection, Z_{DR} values well above zero indicate the bulk presence of oblate scatterers, most likely falling raindrops (Vivekanandan et al. 1999). On the other hand, Z_{DR} values close to zero indicate the bulk presence of isotropic scatterers, most likely tumbling hailstones (Straka et al. 2000).

Wakimoto and Bringi (1988) found a low−level local minima in the Z_{DR} field within the storm's larger high Z_H area. Their "Z_{DR} hole" was a region composed of hail and melting hail reaching the ground and was well−correlated with a radar−indicated microburst, as well as surveyed divergent wind damage to ground vegetation.

In the 23 June case, a 2 to 3 km wide Z_{DR} minima was detected at low levels, simultaneous to the appearance of a surface divergence signature, similar to the cases described by Wakimoto and Bringi (1988). In this case, the low level Z_{DR} values were in the 2 to 2.5 dB range, indicating the hydrometeors were mostly liquid upon reaching the ground. Between the microburst's ground impact location and the ambient freezing level, however, a decrease in Z_{DR} occurred at the same time as the radar−indicated microburst, as shown at the 0.5° and 1.6° elevation angles in Figure 2.

A core of near−zero Z_{DR} descended along with the elevated Z_H core, a strong indicator of hail reaching well below the ambient melting level within the downdraft column. A rapid increase in Z_{DR} approaching the ground indicates the hail melted in the last kilometer of its descent.

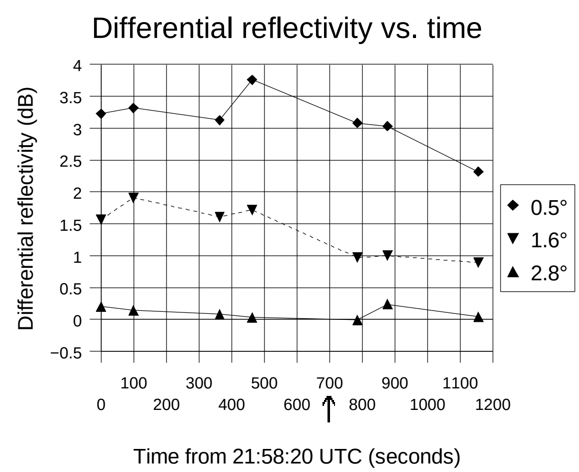

Figure 2. Differential reflectivity (Z_{DR}) at the 0.5°, 1.6°, and 2.8° elevation angles vs. time. Spatial averages were taken over a 1.5 km diameter circular area, centered at the location of the microburst impact, which occurred near t=700 sec.

3.2 Specific differential phase (K_{DP})

Specific differential phase (K_{DP}) is defined as the difference between propagation constants for horizontally− and vertically−polarized radar pulses. K_{DP} values well above 0° km^{-1} indicate that the horizontally−polarized pulse has slowed down more than its vertically−polarized counterpart over a given range. This means there is more hydrometeor content in the horizontal plane, i.e., oblate hydrometeors, such as falling raindrops (Straka et al. 2000).

K_{DP} has been found to be a very reliable indicator of rain rate (Zrnic' and Ryzhkov 1999), particularly when used along with Z_H. In the 23 June case, the microburst impact time and location corresponded to a large increase in K_{DP}. Values increased from 1.5° km^{-1} to more than 3° km^{-1} (Figure 3). It is speculated this rapid K_{DP} increase in the minutes prior to the microburst may have been due to the addition of hail meltwater to the rain already falling within the downdraft.

In the vertical, the large K_{DP} values occurred entirely below the level where the rapid change in Z_{DR} with height was noted. This increases confidence that the microburst downdraft column contained hail meltwater. The large low−level K_{DP} suggests the microburst was accompanied by a period of intense rainfall at the surface.

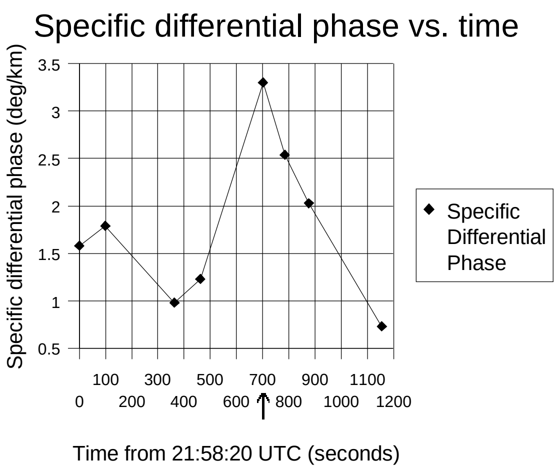

Figure 3. Specific differential phase (K_{DP}) vs. time at the 0.5° elevation angle. Spatial averages were taken over a 1.5 km diameter circular area, centered at the location of the microburst impact, which occurred near t=700 sec.

3.3 Correlation coefficient (|ρ_{HV}(0)|)

The correlation coefficient (|$\rho_{HV}(0)$|) is a measure of the degree of decorrelation at zero lag between horizontally− and vertically−polarized echoes. Values of |$\rho_{HV}(0)$| significantly below unity indicate regions where the horizontal and vertical backscattering fields are not proportional.

In a field of isotropic hydrometeors of uniform type and size, |$\rho_{HV}(0)$| values should approach unity. Straka et al. (2000) state that a mixture of rain and hail, or hail of variable size and shape, may lead to |$\rho_{HV}(0)$| values nearer 0.90.

In the 23 June case, vertical cross sections indicate a general decrease in |$\rho_{HV}(0)$| with decreasing height throughout the time period studied (Figure 4). The higher values aloft likely indicate the hailstones are of fairly uniform size and shape. As the hailstones fall through the melting layer, water shed from the hailstones changes the characteristics of the horizontally−polarized echoes (specifically, it increases their lag time) more than the vertically−polarized echoes. This decorrelation suggests small hailstones might be melting, while larger hailstones survive.

The vertical cross section of |$\rho_{HV}(0)$| allows increased confidence in the hydrometeor types within the downdraft column. The small change over time limited the predictive power of |$\rho_{HV}(0)$| in this case.

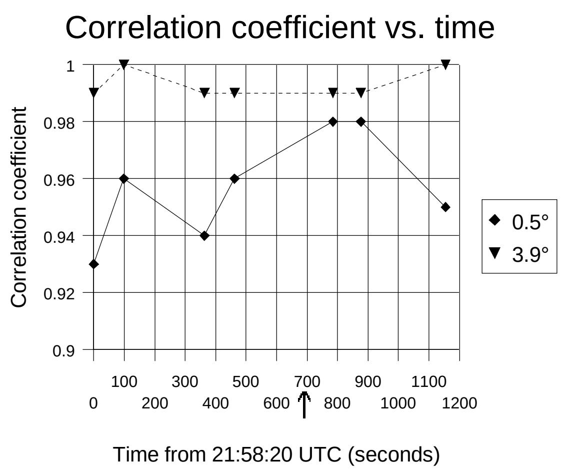

Figure 4. Correlation coefficient (|$\rho_{HV}(0)$|) vs. time at the 0.5° and 3.9° radar elevation angles. Spatial averages taken over a 1.5 km diameter circular area, centered at the location of the microburst impact, which occurred near t=700 sec.

4. CONCLUSIONS

Within the downdraft column, a local minima in the Z_{DR} field, co−located with a local maxima in Z_H, suggests the presence of hail. A downward decrease in |$\rho_{HV}(0)$|, along with a local maxima in the K_{DP} field at low levels, increases confidence that some of the hail was melting before reaching the surface. While the |$\rho_{HV}(0)$| signature was observed throughout the time period studied, the other signatures were most pronounced at the time of the radar−indicated microburst. The absorption of latent heat from melting hail within the downdraft may have helped drive the microburst, consistent with model simulations by Srivastava (1995, 1997).

When coupled with a descending reflectivity core, strong mid−altitude radial convergence, and a mid−altitude mesocyclone, the polarimetric observations yield high confidence in the time, location, and hydrometeor characteristics of this microburst.

On the other hand, the predictive value of these parameters is still uncertain. Obviously, a large number of other cases, including a variety of environments and storm types, need to be studied to further determine which polarimetric variable(s) might provide the most value in microburst prediction and detection.

5. ACKNOWLEDGEMENTS

Don Burgess and Kim Elmore provided many helpful comments during the preparation of this manuscript.

This research is in response to requirements and funding by the Federal Aviation Administration (FAA). The views expressed are those of the author and do not necessarily represent the official policy or position of the FAA.

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