P6.9 SEVERE STORM SIGNATURES OBSERVED BY DOPPLER RADAR IN THE STATE OF SÃO PAULO, BRAZIL: FROM SYNOPTIC SCALE TO MICROBURST

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1. INTRODUCTION

The Bauru S-band Doppler radar is located at Lat: 22° 21' 28" S, Lon: 49° 01' 36" W, 624 m amsl and forms part of the IPMet radar network for continuous precipitation monitoring in the State of São Paulo. It has a 2° beam width and a range of 450 km for surveillance, but when operated in volume-scan mode every 15 minutes (or less) it is limited to 240 km, with a resolution of 1 km radially and 1° in azimuth, recording reflectivities and radial velocities.

The characteristics of the Doppler velocity field associated with storms are examined for the existence of convergence/divergence of radial velocities and possibly associated cyclonic/anticyclonic rotation, all of which are essential indicators of the severity of a storm tracked by radar. Efforts are concentrated on identifying specific signatures during severe storm events, which can then be used by the forecaster as indicators of storm severity.

The structures of severe storms which occurred on three different days in the State of São Paulo, Brazil, are described. On two of the days, these storms were linked to large-scale frontal activity, some of them producing large hailstones, resulting in the loss of three lives and causing vast destruction and damage. The third case describes a devastating microburst which developed during post-frontal convection. At least one long-lasting storm could be classified as a super-cell storm.

2. CHARACTERIZATION OF STORMS

The synoptic situations leading to the development of severe storms and the respective radar observations of the three selected case studies are discussed in chronological order. All times quoted in this paper are Local Brazilian Time (LT) which is three hours behind Universal Time (UT – 3 hrs). The heights of storm features described are above mean sea level (amsl).

The original analysis of radar data was done with IMAGE software and the output can be viewed at the linked URL. The figures in this paper were reproduced as closely as possible using NCAR's CEDRIC package.

2.1 *Supercell Storm on 14 May 1994*

A frontal system extending from an Atlantic Ocean Low across the southern States of Brazil and an associated cut-off low over the State of São Paulo induced strong convergence at the surface, which triggered and maintained a supercell storm with radar reflectivities exceeding 60 dBZ for five hours along its southward path. It caused extensive damage to property (US $ 11 million) and life, killing three people and injuring 130 along its path of destruction. Numerical meso-scale modeling of the vorticity budget for this day indicated that the divergence term was dominating the low-level vorticity tendency and that the horizontal advection of vorticity was working against the cyclonic vortex evolution (Silva Dias *et al.,* 1996).

During the early afternoon on this day, radar observations already indicated the development of isolated precipitation cells in the central and far north-eastern area of the State of São Paulo. The convective activity intensified from 15:00 onwards with the majority of storms developing during the late afternoon and early evening. Maximum reflectivities exceeded 55 dBZ and echo tops were on average above 8 km. In contrast to the supercell, they generally moved in south-easterly directions with average speeds of 50 km.h^{-1}, producing severe hail falls and strong surface winds along their paths. Significant damage to houses and people, as well as great damage to coffee plantations in the central and southern parts of the State, was reported as a result of these storms. Several of these severe storms have been described in detail by Gomes *et al*. (2000), but the emphasis in this discussion will be on the supercell storm only.

Radar surveillance indicated very strong convective activity over southern Minas Gerais at 16:30, moving southwards along an unusual north - south trajectory at an average speed of 62 km.h^{-1} (Gomes *et al.*, 2000). At least one cell of this long-lasting storm complex could be classified as a supercell storm, because radar reflectivities exceeding 60 dBZ were recorded for five hours. When the reflectivities of this particular cell were analyzed in conjunction with the radial velocity fields, rotation signatures that could be related to the observed severity were identifyable.

The supercell storm was first detected at 5.5 km (48 dBZ) at 21:47. For most of its five-hour life cycle the maximum reflectivity exceeded 60 dBZ and echo tops varied between 10 and 13 km. Figure 1 shows the reflectivities and radial velocities of this storm at 23:02, clearly indicating an anticyclonic rotation, coincidental with the echo core ("couplet"). Considering that the storm was more than 150 km north-east of the radar, the rotation was evident between 0.3° and 1.7° elevation, corresponding to 4 – 6 km height, but most prominent at 4 km (Figure 1). It should be noted that in the south-eastern part of the rotation core radial velocities of up to +10 m.s^{-1} (outwards) were observed, while on the opposite side the radial velocities varied between –9 and

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–14 m.s^{-1} (towards the radar). The centers of velocity maxima were about 6 km apart (Figure 1), thus implying a local shear of $-3.5 \times 10^{-3} s^{-1}$. Such values are generally associated with mesocyclones/mesoanticyclones and are precursors for the formation of tornadoes (Nielsen-Gammon *et al*., 1995).

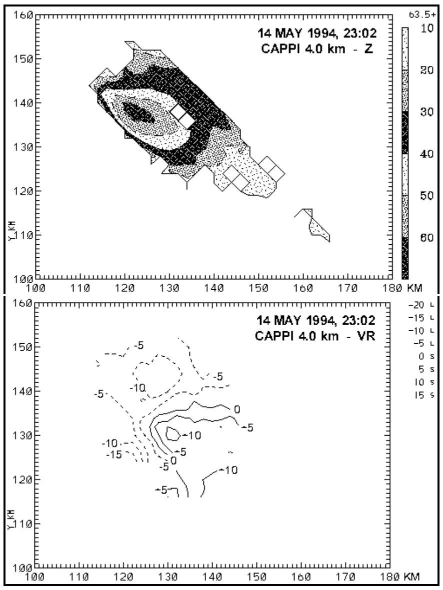

Figure 1. Reflectivity and radial velocities of the super-cell storm on 14 May 1994, 23:02, 4.0 km CAPPI. The radar is situated 150 km to the south-east of the storm.

2.2 *Frontal Squall Line on 17 October 1999*

A similar frontal system as on 14 May 1994, with a surface trough extending over the south-south-eastern States of Brazil, resulted in a line of precipitation over the State of São Paulo on this day. A closed cyclonic vortex was positioned over eastern Mato Grosso do Sul, associated with strong convergence from the surface up to 200 hPa over northern Paraná and central São Paulo, resulting in high instability. Again, severe hail falls from several individual storms were noted and extensive damage to property and life was reported.

Radar observations indicated an extensive area of stratiform precipitation with several intense cells forming along the leading edge of the squall line, as shown in Figure 2 at 13:16.

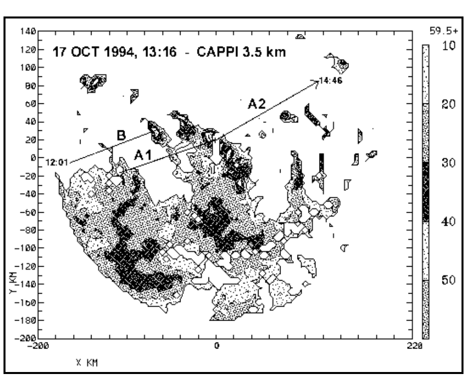

Figure 2. Multicellular storm embedded in a squall line on 17 October 1999 at 13:16, as well as trajectories of the 30 dBZ contour envelopes of Cells A and B (A1 & B: 12:01-13:16; A2: 13:16-14:46).

The most intense cells are labeled A and B and the trajectories for the 30 dBZ contours envelope are shown for the subsequent 75-minute period. The hail-producing Cell A moved at 60 km.h^{-1} to the north-east, with reflectivities mostly in excess of 55 dBZ (maxima 62-70 dBZ) and echo tops (10 dBZ) between 13 and 16 km height. These characteristics are associated with strong vertical air flows, resulting in a destructive hail path along its trajectory. Radial velocities in the vicinity of the maximum reflectivity core indicated a signature of strong convergence at about 4 km, reaching its most intense phase at 14:01, when large hailstones fell in the town of Tibiriçá (Figure 3).

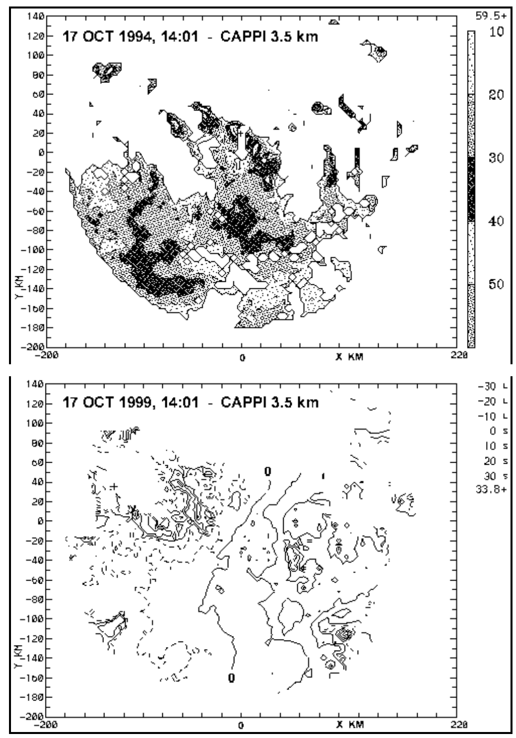

Figure 3. Reflectivity (top) and radial velocities of the hailstorm on 17 October 1999, 14:01, 3.5 km CAPPI.

2.3 *Microburst on 22 November 1999*

While most severe hail or rain storms are generally embedded in large-scale frontal systems traversing the southern and eastern parts of Brazil, as shown in the previous case studies, a microburst was observed near Bauru in a post-frontal situation on 22 November 1999. An anticyclonic vortex between 700 and 200 hPa over central Brazil (classical Bolivian High), in conjunction with a surface low, which dominated central Brazil and which was associated with a cyclonic vortex over north-western Mato Grosso do Sul, induced strong convection from there, across São Paulo State into Rio de Janeiro.

On this day, medium-sized, multicellular storms were developing at random within a more or less stationary air mass throughout the radar range from late morning till evening. Although most of the storms did not exceed 50 dBZ with echo tops below 10 km, some were severe in terms of extremely strong gust fronts and short, but heavy downpours. Some were short-lived, but others lasted for up to 3 hours, generally moving in north-easterly directions at average speeds of 25 $km.h^{-1}$, although some cells moved as fast as 40 $km.h^{-1}$, while others were almost stationary (Gomes *et al.*, 2000).

One of the storms, about 40 km north-west of the Bauru radar, drew attention due to its strong divergence fields displaying typical microburst features coinciding with the collapse of the echo core. Figure 4 shows the 4.0 km CAPPIs (reflectivity) of the storm at 13:01 (maximum reflectivity >55 dBZ) and 13:16, respectively, as well as vertical sections of reflectivity and radial velocities along the base line. The sudden collapse of the echo core at 13:16 was associated with strong divergence, and the resultant microburst is clearly visible in the cross-section around –30km. The resulting strong surface winds and downpour caused severe damage to plantations and houses in the small town of Avaí.

3. CONCLUSIONS

The structure of severe storms have been studied during the past few years in the central State of São Paulo, using observations from the S-band Doppler radar in Bauru, with the goal of developing suitable Nowcasting methods. Analyzing the radar reflectivity structures in conjunction with the radial velocity fields, signatures that can be related to the observed severity, viz. rotation (14 May 1994), intense convergence (17 October 1999) and strong divergence fields displaying typical microburst features coinciding with the collapse of the echo core (22 November 1999) could be identified. Most severe hail or rain storms are generally embedded in large-scale frontal systems traversing the southern and eastern parts of Brazil (14 May 1994 & 17 October 1999). However, a microburst was observed in a post-frontal situation on 22 November 1999, when an anticyclonic vortex at 200 hPa over central Brazil (Bolivian High) induced strong convection. All cases had in common a well-defined low pressure system at the surface and a strong jet stream above 300 hPa from a northerly, westerly and south-westerly direction, respectively.

This highlights the importance of Doppler radar observations on the one hand, but, on the other hand, the possible development of extremely severe rain, hail or wind storms should already be identified at synoptic scale prior to the formation of radar echoes in order to become a useful tool for Nowcasting techniques.

4. ACKNOWLEDGEMENTS

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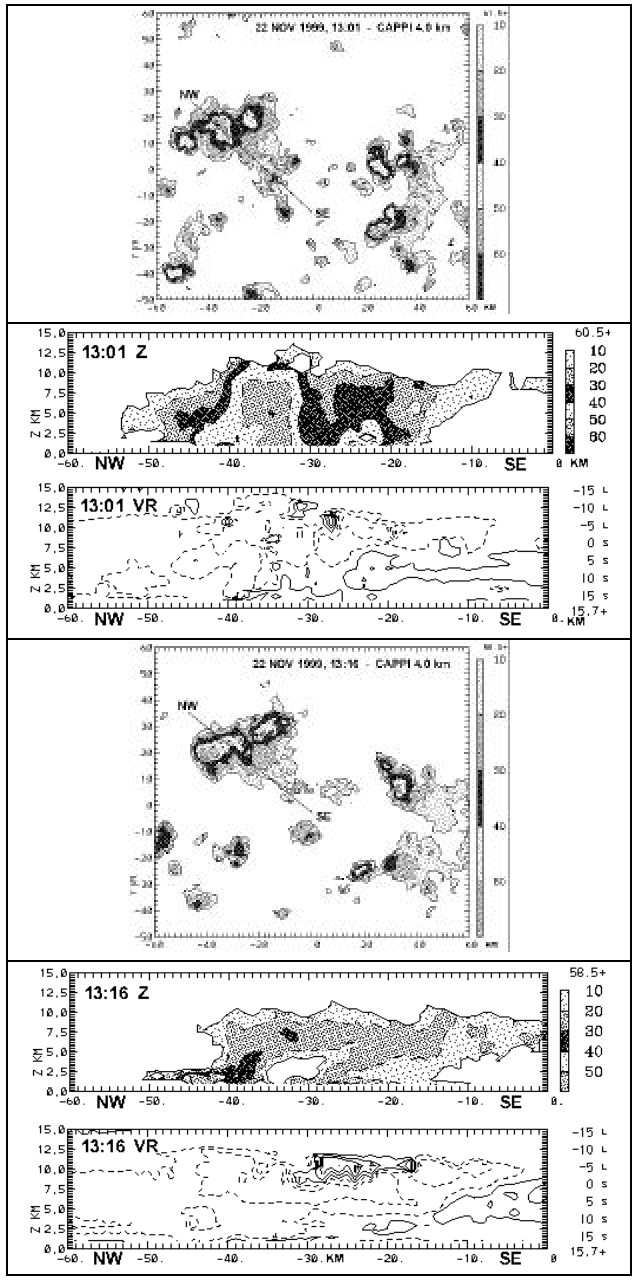

Figure 4. CAPPI at 4.0 km and vertical cross-sections through the Microburst storm on 22 November 1999 at 13:01 and 13:16, respectively. Reflectivity (Z) and radial velocities (VR) are shown in separate cross-sections.

5. REFERENCES

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