8A.5 # MXPOL MEASUREMENTS OF WEATHER SYSTEMS

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1. INTRODUCTION

This work presents measurements of precipitating systems monitored by the mobile dual polarization X-band Doppler weather radar (MXPOL) of the Laboratory of Hydrometeorology of the University of São Paulo, São Paulo, Brazil. The MXPOL was design to monitor and to nowcast weather systems over the Metropolitan Area of São Paulo (MASP) and the Mar Ridge in Eastern São Paulo State where floods, mood slides, heavy winds, lightning and hail cause significant social and economical impacts (Pereira Filho et al, 2004). Most summer floods are related to local circulation induced by urban heat, topography, land and sea breezes. The main characteristics of the MXPOL are described in Pereira Filho et al. (2007). It is one of the tools of a Hydrometeorological Forecast System (HFS) that is being developed to upgrade an existing forecast system for the MASP. Five measurement campaigns were carried out on Eastern São Paulo State during the testing and training with the MXPOL between February and May 2007.

2. METHODOLOGY

Five measurement campaigns were carried out to check the performance of MXPOL on clear air mode with just three low elevation angles, longer pulse widths and horizontal polarization only to monitor boundary layer features late in the morning, and on precipitation mode with eleven or more elevation angles, shorter pulse widths, horizontal and vertical polarization covering the whole troposphere after cloud returns were above 20 dBZ. The data was collected, archived, processed and displayed with the IRIS system by SIGMET. In the last campaign, passage of a cold front, the antenna was vertically pointing with low azimuthal rotation, short pulse width, high signal sampling rate, horizontal and vertical polarization. Available lightning data from RIDAT was used to compare with the polarimetric variables. Also, data from the São Paulo Weather Radar (SPWR) was used to check for rainfall spatial coherence and intensity given that the MXPOL can suffer from significant signal attenuation.

3. RESULTS

Fig. 1 shows a low elevation PPI and cross-section of specific differential phase (K_{dp}) and respective cross-section of radial velocity of a narrow line of thunderstorms over São Paulo City that were moving Northeastward at 1831 UTC on 09 February 2007. Negative K_{dp} is found on the right flack of the storm and, positive, on the left flack. The vertical cross-section in Fig. 1B shows negative K_{dp} above 7 km and on the rear side of the storm below 5 km altitude. This system was at its developing stage.

(A)

(B)

(C)

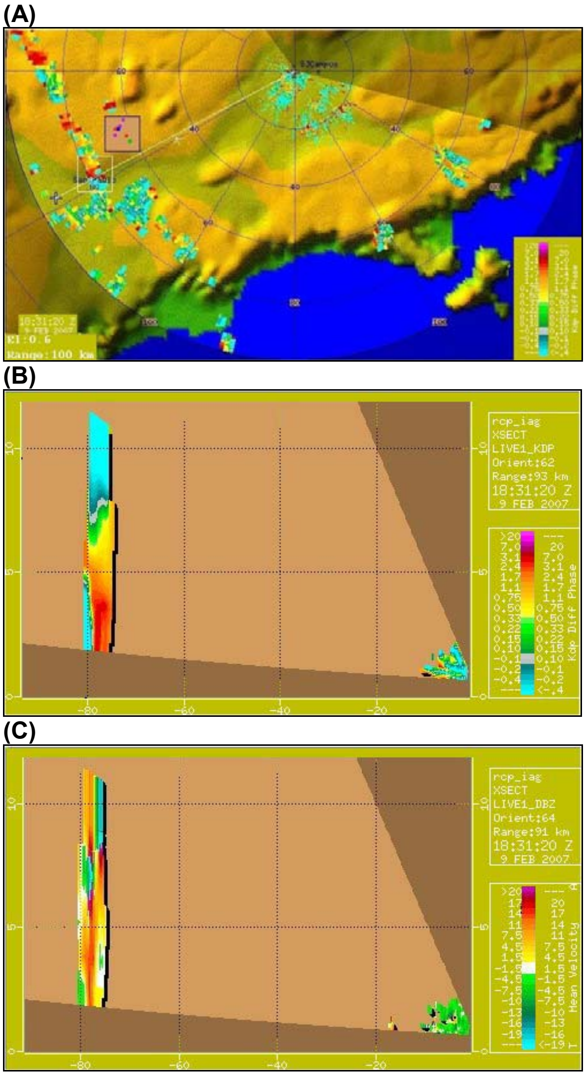

Figure 1: PPI of specific differential phase (K_{dp}) at 0.6° elevation at 1831 UTC on 09 February 2007 (A). The brown box with colored dots shows the location of lightning strikes every 5 minutes from 1830 UTC to 1850 UTC (red, blue, pink and green). The white rectangle on the south flak of the squall line over São Paulo City indicates the direction of vertical cross-sections of K_{dp} (B) and radial velocity (C). The topography, radial distances (km), azimuths (°), color scales of K_{dp} (° km^{-1}) and V_r (m s^{-1}) are indicated.

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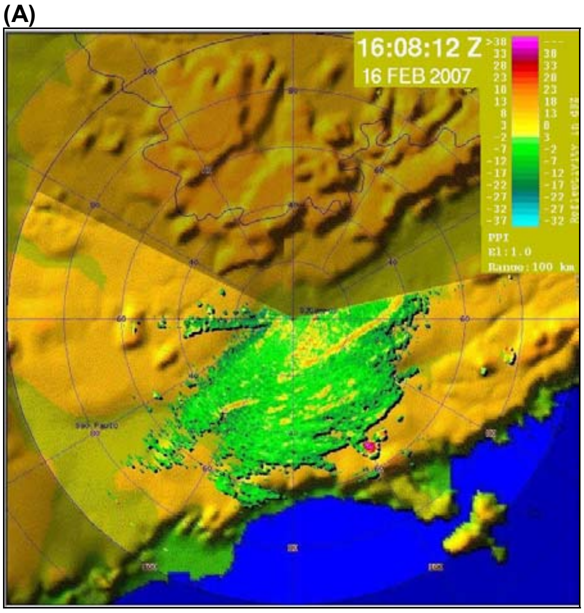
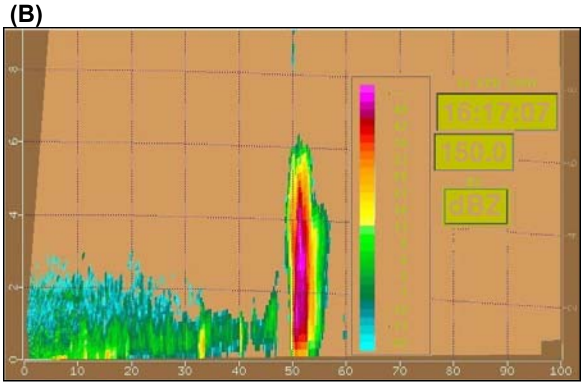
Negative aloft is most probably related to vertically oriented ice crystals before lightning discharge (Caylor and Chandrasekar, 1996). The small brown rectangle in the PPI map (Fig. 1A) shows the location of lightning strikes detected by the RINDAT network between 1830 UTC and 1850 UTC. They are within the area of the thunderstorm with negative K_{dp}. The radial velocity (Fig. 1C) indicates convergence near the surface and divergence aloft. Velocity folding is observed between 6 and 8 km altitude. Turbulence was higher above 7km altitude (not shown). The differential phase (Z_{dr}) was above 3.5 dB near the surface where convergence was highest decreasing to 0 dB between 5 and 8 km and becoming negative aloft (not shown). Thunderstorms have high lightning density over the MASP (Gin et al., 2004), so K_{dp} and Z_{dr} might be used in nowcasting lightning activity.

Fair weather clouds above the boundary layer can be seen at the 1^{o} elevation PPI at 1608 UTC on 16 February 2007 and cross-sections of Fig. 2. Cloud roles are oriented NE-SW on a day of weak synoptic forcing. An ordinary cell also is apparent near the 50 km range and 150^{o} azimuth. Fair weather clouds at 210^{o} azimuth with Z_h as low as -12 dBZ were detected beyond the 60-km range for a pulse width of 2,0 μs. The cross-sections of Z_h and V_r in Fig 2B and C indicate clouds below 2 km height with reflectivities ranging from -12 to 25 dBZ and radial velocities varying from -3 to 3 m s^{-1}. Radial divergence near the surface is co-located with the ordinary cell that has a maximum Z_h of 45 dBZ half way to its top. Fig. 2D shows a photo of these fair weather clouds at 1601 UTC on 16 February 2007. Thus, MXPOL was able to monitor fair weather clouds beyond the 60 km range. Since one of the important tasks of MXPOL is to anticipate the formation of deep convective clouds over the MASP, it can be placed outside the MASP where ground returns are less significant.

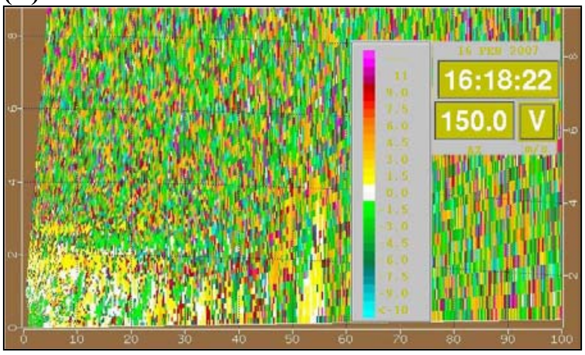
(A)



(B)



(C)



(D)

Figure 2: PPI sector of Reflectivity (Z_h) at 1.0^{o} elevation angle obtained with the MXPOL at 1608 UTC on 16 February 2007 (A) and cross-sections of Z_h (B) and radial wind (C) at 150^{o} azimuth as well as a photo of clouds at 120^{o} azimuth from MXPOL site (23^{o}11.7'; 45^{o}57.9') in São José dos Campos (D). The topography, cities, radial distances (km) and angles (^{o}) are indicated. Color scales of Z_h (dBZ) and V_r (m s^{-1}) are also shown.

The fast eastward moving squall line monitored with the MXPOL on 26 April 2007 produced heavy rainfall rates, lightning and strong winds. Fig. 3 shows a 4.5^{o} elevation PPI and cross-sections of polarimetric and velocity variables at 1956 UTC while the system was passing over São Paulo City. The PPI field of Z_h shows corresponding SPWR 3-km CAPPI of rainfall rates (bottom left) and location of lightning strikes (top right) close to 1955 UTC. Apparently, attenuation by heavy rainfall is significant

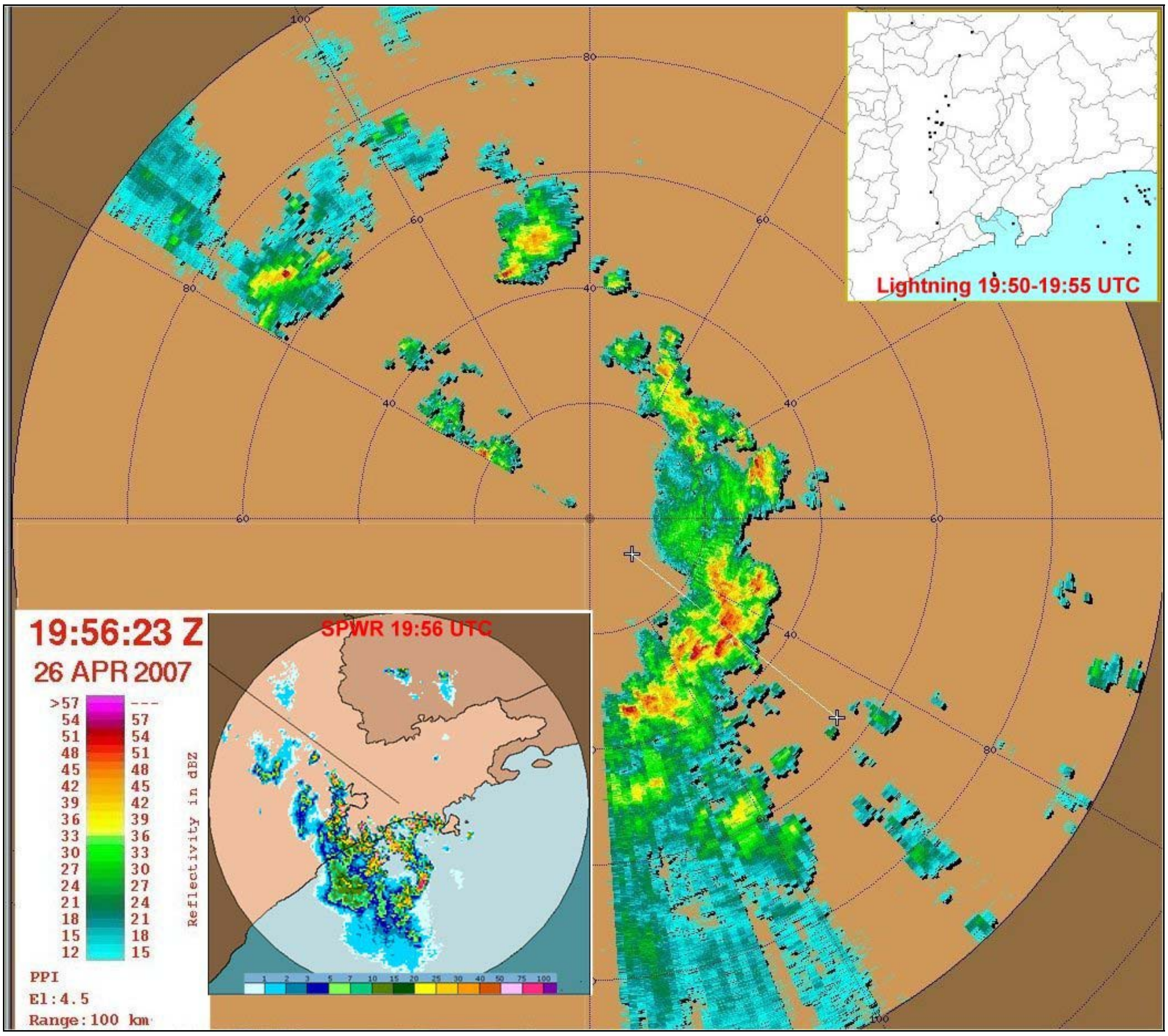


Figure 3: PPI of Reflectivity (Z_h) at 4.5^o elevation angle at 1956 UTC on 26 April obtained with the MXPOL. Radial distances (km) and angles (^{o}) in relationship to the MXPOL (23^{o}32.2'S; 46^{o}52.8'W) are indicated as well as the direction of cross-sections shown in Fig. 4. Color scales of Z_h (dBZ) is shown (bottom left). The bottom left detail is a 3-km CAPPI of rainfall rates with 2-km x 2-km resolution at 1956 UTC obtained with the São Paulo Weather Radar (SPWR). Scale indicates rainfall rates (mm h^{-1}). Top left detail shows the location of lightning strikes between 1950 UTC and 1955 UTC on 26 April 2007 detected by Lightning Detection Network (RINDAT).

between azimuths150^o and 180^o and between ranges 80 km and 100 km. Lightning strikes are located at the leading edge of the squall line where voltage measurements peaked at 10k V m^{-1} with negative discharges of about 35 kA (not shown). The white line in Fig. 3A indicates the direction of the cross-sections trough the highest dome where updrafts penetrate the tropopause. The cross-section of Z_h (Fig. 4A) shows cores of high reflectivity near the surface at 30 km range and another at 7 km altitude and 35 km range. This last elevated core of high reflectivity is associated to the region of strongest updraft. The thunderstorm's anvil precedes the heaviest rainfall at surface in about 20 km. The anvil indicates that the divergence was highest at 9 km altitude. Fig. 4H shows a photo of the anvil 40 minutes early as it raced over the radar site. Fig. 4B shows the cross-section of radial velocities. They are in general positive and close to the surface in the rear are between 10 to 15 m s^{-1}. The highest speeds are within the anvil region (~25 m s^{-1}). Radial convergence is highest at 2 km altitude and 35 km range. Divergence signatures are apparent near the overshooting dome and at the base of the anvil. The spectral width in Fig. 4C shows that the turbulence is higher near the main updraft and at the anvil and lower at the rear. The differential reflectivity (Fig. 4D) is above 3.5 dB near region of highest reflectivity at the surface at 35 km range. A core of high negative (<-3.5 dB) is at the leading edge of the squall line from 2 km to 5 km altitude and 33 km to 40 km range. Apparently,

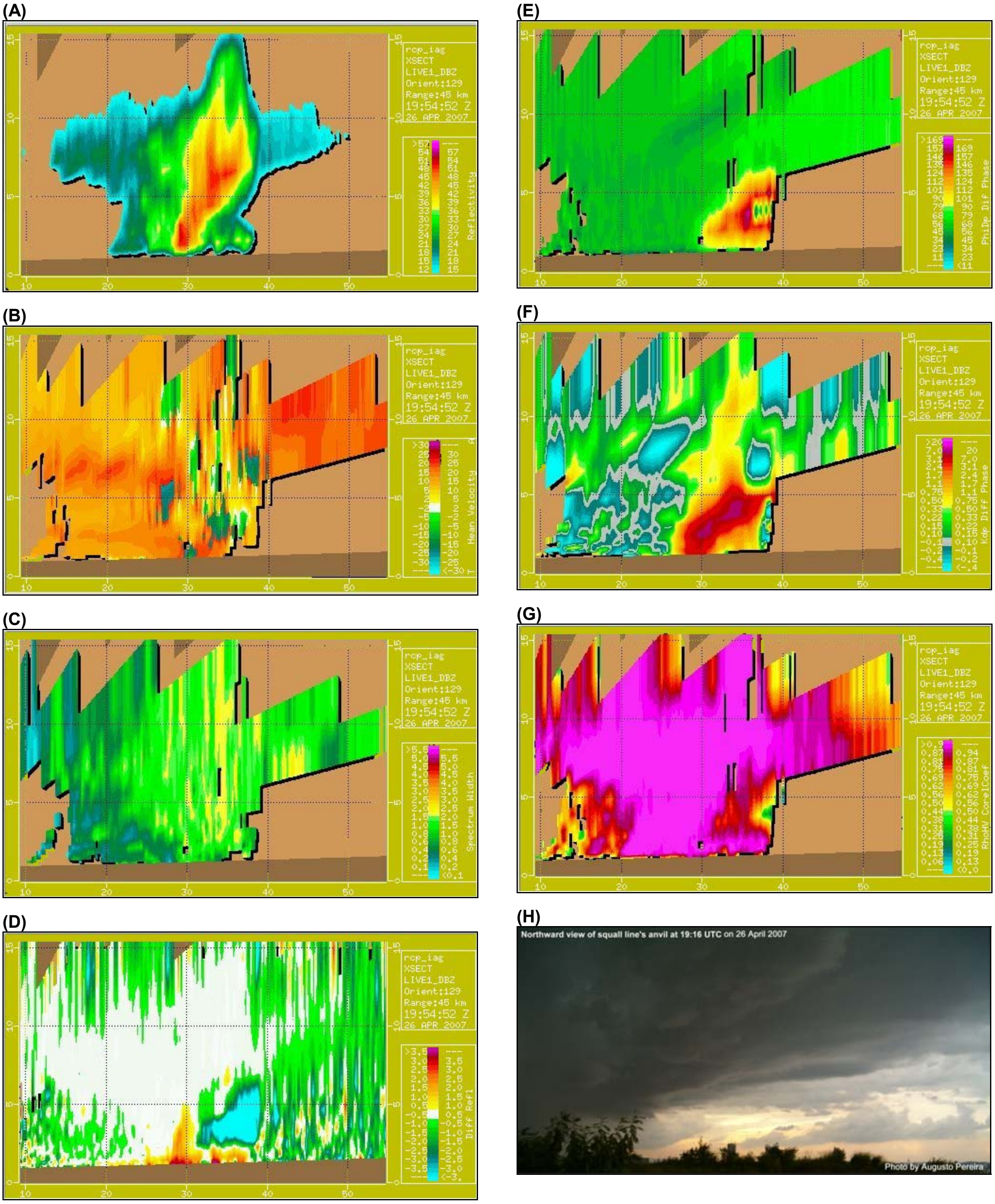


Figure 4: Cross-sections of reflectivity - Z_h (A), radial velocity – V_r (B), spectral width – W (C), differential reflectivity – Z_{dr} (D), differential propagation phase – ϕ_{dp} (E), specific differential phase – K_{dp} (F) and correlation coefficient VH - ρ_{oHV} (G) obtained with MXPOL at 1954 UTC on 26 April 2007. Color scales are indicated in each cross-section. The photo of the anvil of the squall line (H) was taken looking Northward from MXPOL site at 1916 UTC on 26 April 2007.

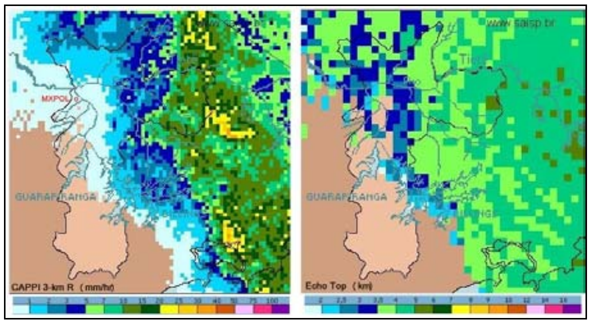
droplets and small drops that form at the leading edge of the storm are stretched in the vertical direction by the strong updraft and negative horizontal relative vorticity (Fig. 4C) centered at about 2 km altitude an

33 km range. The differential propagation phase, the specific differential phase and correlation HV are shown in Fig. 4 E, F and G, respectively. At the leading edge of the storm where Z_{dr} is negative, ϕ_{dp} is K_{dp} are highly positive while Z_h and ρ_{oHV} are fairly low and turbulence is relatively high. These characteristics suggest a mixture of hydrometeors with different shapes coexist within the region of significantly negative Z_{dr}, most probably graupel and ice crystals are being brought down by turbulent eddies and mixed with growing small droplets at the leading edge of the thunderstorm. Pockets of negative *Kdp* above 6 km altitude indicate the presence of ice crystals oriented vertically perhaps by the cloud electric field. The area of lighting strikes in Fig. 3 is near the leading edge of the thunderstorm and that indicates that it might be inferred that the cloud was electrically charged aloft near leading edge.

Vertically pointing measurements were made with the MXPOL during the passage of a precipitating system associated to a cold front on 22 May 2007. Fig. 5 shows a 3-km CAPPI of rainfall rates and respective echo tops estimated with the SPWR at 1616 UTC as well as the sounding of Campo the Marte, São Paulo, at 1200 UTC, a few kilometers away east of the MXPOL. The precipitating system was moving eastward with higher rainfall rates (<40 mm h^{-1}) observed towards the East and lower towards the West (< 2 mm h^{-1}) with 18 dBZ echo tops between 6 km and 3,5 km in the two regions, respectively. The MXPOL measurements were made at the rear site of the precipitating system. The location of the MXPOL is shown in the CAPPI of Fig. 5A. The sounding indicated a deep layer of moisture from the surface all the way at least to 300 hPa. The vertical profile of the wind indicates a 145 knot westerly jet around 150 hPa with very small directional shear. Norwest winds at the surface veering indicate warm advection still at the time of the sounding. The zero degree isotherm was at 3792 m.

Fig. 6 shows vertical profiles of Z_h, V_r, Z_{dr} , W, ϕ_{dp}, K_{dp} , and ρ_{oHV} measured at 1616 UTC on 22 May 2007. The profiles are displayed in radials with the time growing clockwise. Fig. 6A shows vertical profiles of Z_h in relationship to the ground level. The altitude of MXPOL was 760 m so relative heights can be changed to altitudes by adding 760 m to the heights. Clouds tops of 5 dBZ were at 5760 m altitude. The meeting layer is between 3940 m and 3760 m or 180 m deep that agrees well with altitude of the 1200 UTC sounding given the warming of the lower troposphere by latent heating release. Ice crystals right above the meeting layer have Z_h ~25 dBZ while below the melting layer Z_h ~ 33 dBZ and at the melting layer Z_h ~ 40 dBZ. The profile of Z_h was measured in less than one minute and it indicates very small and fast changes in reflectivity. An ascending airplane passed right over MXPOL at approximately 4500 m as it can be seen in Fig 6A where Z_h> 43 dBZ. A three body scattering effect on

(A)



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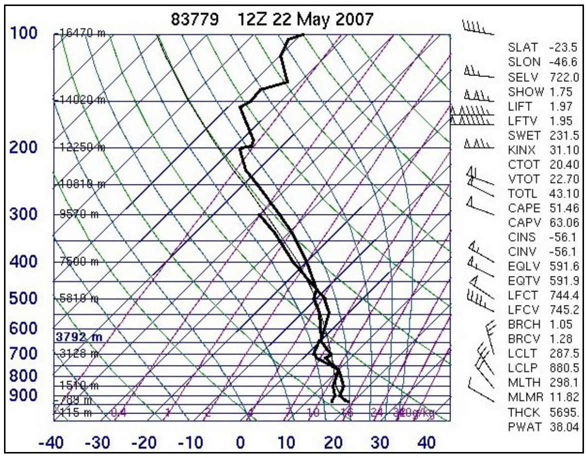
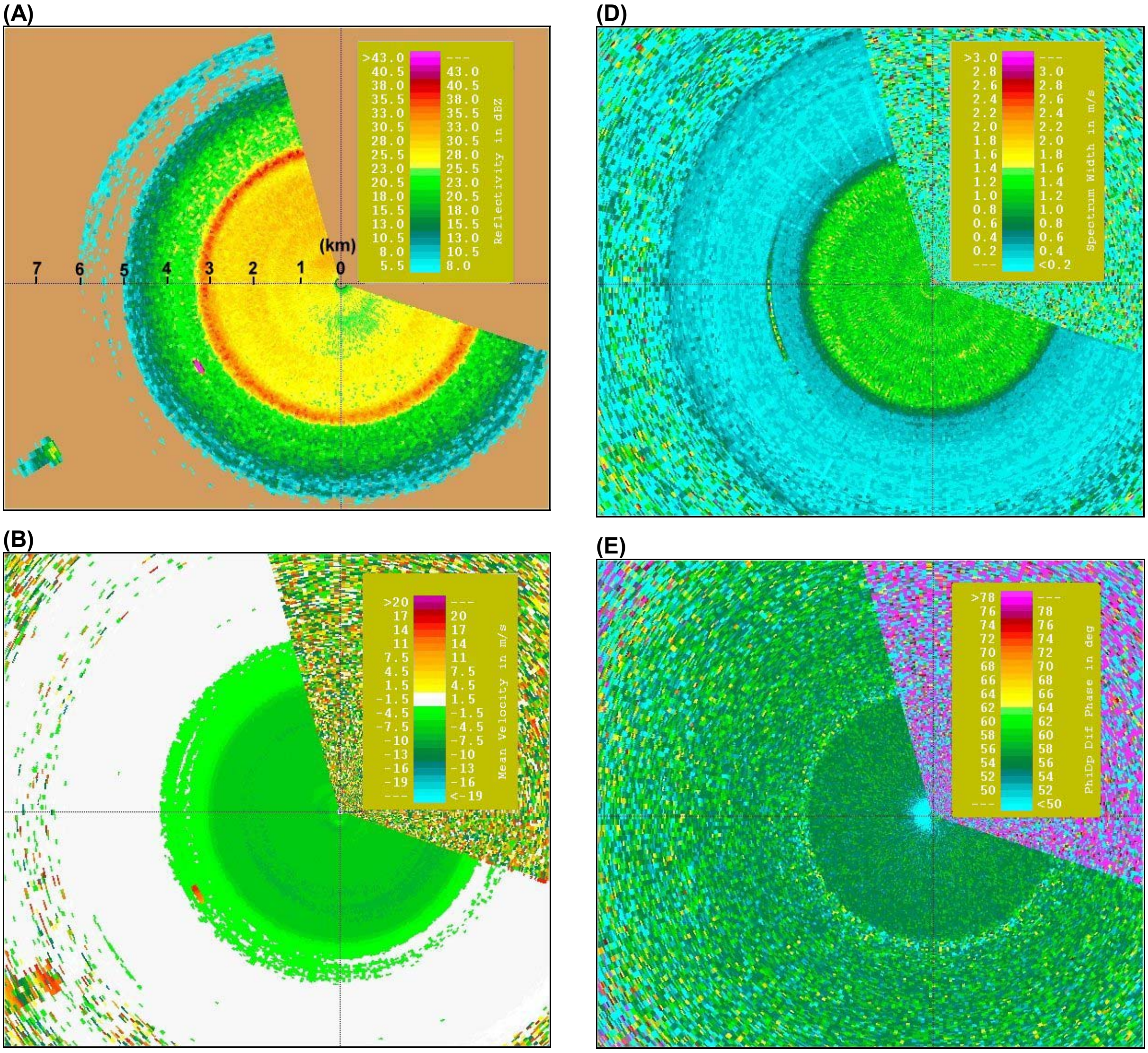


Figure 5: CAPPI of rainfall rates at 3-km altitude (left) and echo tops (right) with 1-km x 1-km horizontal resolution estimated with the São Paulo Weather Radar (SPWR) at 1616 UTC (A) and the 1200 UTC sounding at station 83779 in São Paulo City (B) on 22 May 2007. It is indicated the site (23^{o}33.4'S; 46^{o}44.1'W) of the MXPOL (A) during the event.

Z_h is seen at about 8200 m altitude. The vertical velocity profiles in Fig 6B show near zero speeds above the meeting layer and negative speeds below reaching terminal speeds of about -4.5 m s^{-1} close to the surface. The radial velocity indicates cloud tops above 9 km. The ascending speed of the airplane varied between 14 m s^{-1} and 20 m s^{-1} in just a few seconds. The three body scatterings effect is also clearly seen in Fig. 6B. The profiles of Z_{dr} show fluctuations between -0.5 dB to 0.5 dB through the profile with a tendency for negative values at the meeting layer. The change in Z_{dr} from positive to negative below 1 km height is a near-field effect. The airplane is also seen in the profiles of Z_{dr}. The spectral width profiles in Fig. 6D shows that turbulence is lower above the meeting layer (< 0.6 m s^{-1}) and higher below it (0.8 m s^{-1}< V_r < 1.6 m s^{-1}). One can notice that the airplane increased the turbulence for a few seconds on its path as clearly seen in Fig. 6D. The differential propagation phase shown in Fig. 6E is very constant below the melting layer (~56^o). The melting layer tends to have large variation of ϕ_{dp}. On the other



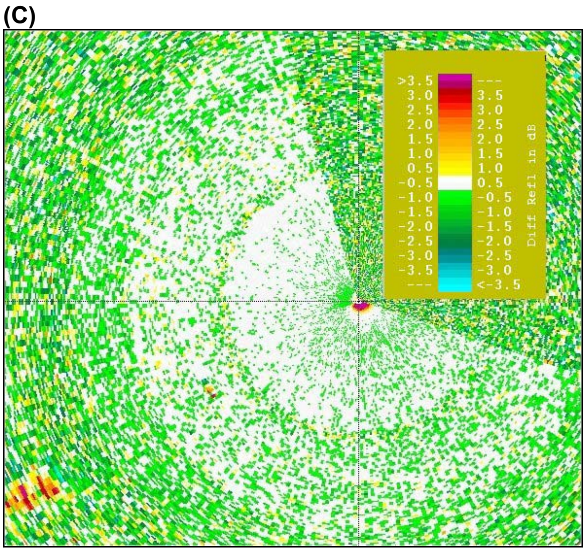
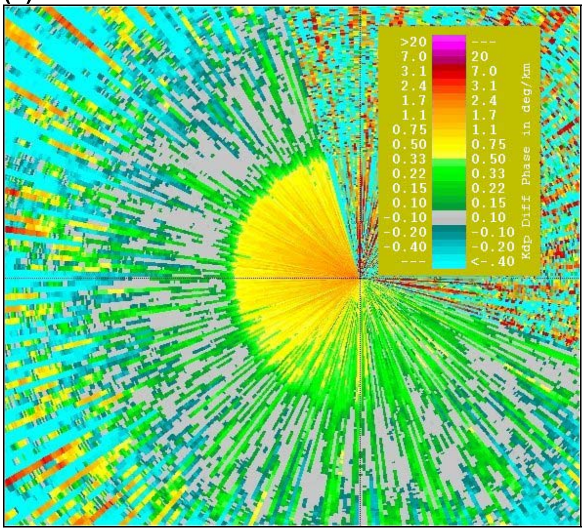


Figure 6: Vertical profiles of reflectivity - Z_h (A), radial velocity – V_r (B), spectral width – W (C), differential reflectivity – Z_{dr} (D), differential propagation phase – ϕ_{dp} (E), specific differential phase – K_{dp} (F) and correlation coefficient VH - ρ_{oHV} (G) obtained with MXPOL at 1616 UTC on 22 May 2007. Full clockwise antenna scan (6.0^{o} s^{-1}) at 90^{o} elevation for pulse width = 0.2 μs, PRF=1000 Hz and 256 samples, Δz=35.

hand, the differential phase (Fig. 6F) is positive in the melting layer and below and slightly negative above it. The airplane is not seen in both of the profiles of ϕ_{dp} and K_{dp}. Finally, the correlation coefficient HV in Fig. 6G shows fairly constant high values (> 0.94) below and above the melting layer and slightly lower at the melting layer and close to the cloud top. The airplane produces a lower ρ_{oHV}.

(F)



(G)

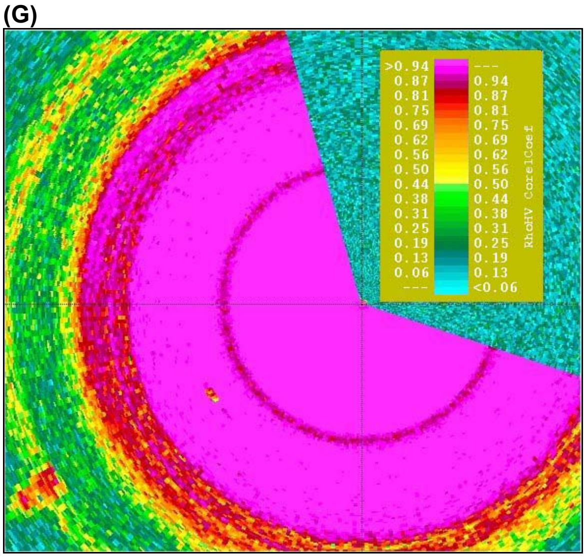


Figure 6: continued.

4. CONCLUSION

The inedited polarimetric measurements with MXPOL in the tropics presented in this work reveal characteristics of weather systems with high spatial and temporal resolution. The MXPOL was able to detect boundary layer circulation and shallow convection up to 60 km in range, convergence, divergence, vorticity and turbulence within cloud systems and advection signatures (not shown), could and warm microphysics, the melting layer and electric charge signatures. The MXPOL measurements are consistent with SPWR measurements of the over all structure of precipitating systems, RINDAT lightning spatial distribution, and soundings.

The MXPOL is the first Brazilian weather radar of its kind to be used on an operational basis to provide real time high spatial resolution polarimetric data for hydrometeorological applications. The MXPOL will also be essential in several research studies of cloud microphysics, electricity and dynamics, rainfall quantification and verification, 3D retrievals, inter-comparison studies, field experiments, mesoscale and synoptic studies, modeling, data assimilation and integration among other research topics of interest.

Furthermore, the MXPOL is an excellent tool for teaching under-graduate and graduate courses as well as training programs. The MXPOL can also be applied on survey studies to implement new radar sites in Brazil. Therefore, the MXPOL is an important new academic, research and operational tool made available by the Government of São Paulo State, Brazil.

ACKNOWLEDGMENTS

The authors are thankful to Mr. Paulo Lopes da Costa, Civil Engineer of Paratehy condominium, São José dos Campos, São Paulo, for providing a site to operate the MXPOL during its pre-operation and testing. The Department of Water and Electrical Energy (DAEE), São Paulo, Brazil, provided this research with the SPWR data and The Institute of Meteorology of Paraná (SIMEPAR) for providing lightning data through its RINDAT network. This research and the MXPOL are sponsored by The State of São Paulo Research Support Foundation (FAPESP) under granted 13952-2 and by National Research Conceal-CNPq under grant 300456/2005-0.

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