2A.3 # MEASUREMENTS OF DROP SIZE DISTRIBUTION IN A MEGACITY

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1. INTRODUCTION

The Metropolitan Area of São Paulo (MASP) is a megacity environment composed of 39 cities (Fig. 1). It has been increasing in area continuously since the beginning of the 20 century mainly due to economic prosperity, an adequate environment and abundant water supply by Alto Tietê River Watershed; flowing across MASP westward. Fig. 1 shows the geographic contour of cities within MASP. There are over 35,000 builds just in São Paulo City alone with very limited vegetated areas.

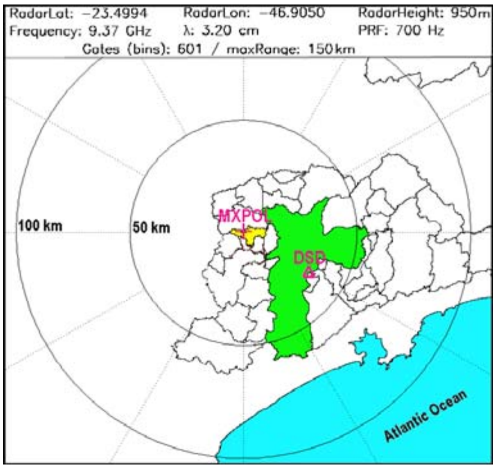

Figure 1: MXPOL surveillance area in the Metropolitan Area of São Paulo. Cross and triangle indicates the location of MXPOL and the JW Disdrometer at Parque Estadual Fontes do Ipiranga (PEFI), respectively. Green and yellow areas are São Paulo and Barueri Cities, respectively.

MASP anthropic growth has caused changes in the local climate (Pereira Filho et al., 2007). An average of 22 major floods (Fig. 2) has been causing major social-economical problems and unfortunately many human loses every year.

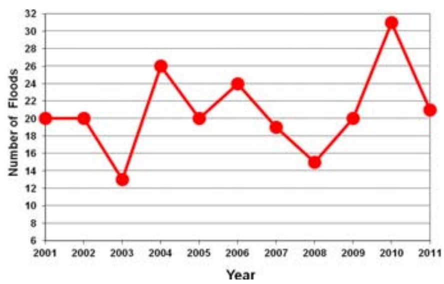

Figure 2: Time evolution of the number of major flood events is São Paulo City between 2001 and 2011.

Fig. 3 shows the number of floods against the monthly precipitation accumulation between 1999 and 2011. It indicates that the number of floods is proportional to the monthly rainfall. Generally, floods occur between late spring and early fall.

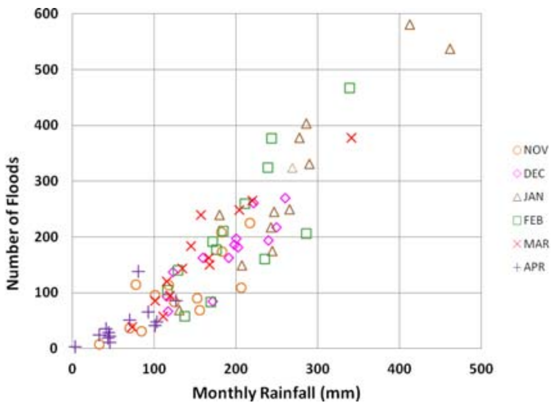

Figure 3: Number of Floods in São Paulo City as a function of monthly areal average of rainfall accumulation between 1999 and 2011.

About 70% of all major flash floods in the MASP were caused by convective system between 1999 and 2013. It is one of the largest urban environments of the world where the diurnal cycle of diabatic heating and sea breeze circulation are ingredients for very deep thunderstorms in summer time (Pereira Filho at al., 2007). An instance of such episode simulated by the ARPS system is shown in Fig. 4.

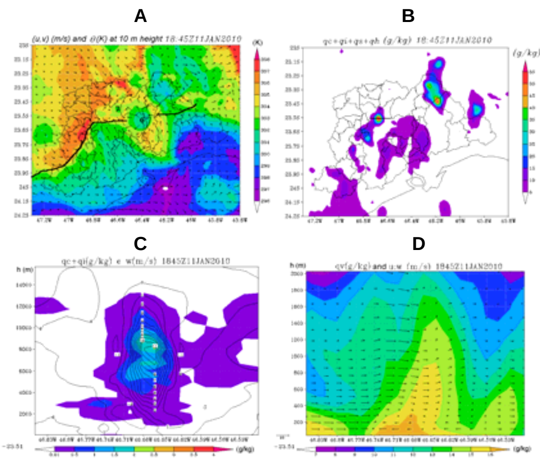

Figure 4: ARPS system sea breeze simulation (A), and respective thunderstorm rainfall rate (B), and vertical cross sections AA of total water content and vertical velocity (C) and specific humidity and zonal and vertical winds (D) for the 11 JAN 2010 flood event. Scales are indicated. After Vemado (2012).

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The sea breeze front, wind circulation and potential temperature (K) fields at 1845 11 Jan 2011 is shown in Fig 4A, together with corresponding total mass of water (g kg^{-1}) in the column (Fig. 4B). Vertical cross sections of vertical winds (m s^{-1}) and total ice and liquid water (Fig. 4C), and horizontal winds and specific humidity (Fig. 4D) at line AA in Fig. 4B illustrates the extension and strength of horizontal and vertical flux of momentum and mass caused the inertial circulation over the complex terrain near shore in São Paulo State. Following a perpendicular line from seashore to inland, the topography is flat and at sea level for 20 km where a steep scarp climbs up to a second plateau at about 800 m altitude where the MASP is located.

This work deals with a microphysics analyses based on weather radar polarimetrics and disdrometer measurements of convective systems in the MASP region aimed at characterizing thunderstorms drop size distributions, their evolution from development to the decaying phases between 09 September 2009 and 11 January 2010. In this manuscript, the microphysics of the 10 JAN 2010 sea breeze & heat island related flood event is analyzed and contrasted with the 02 JAN 2010 flood event related to the heat island effect only.

2. METHODOLOGY

A total of 76 rainfall episodes during the spring and early summer of 2009 and 2010 were used in this study. Polarimetric measurements (Z, Z_{DR}, ϕ_{DP} and K_{DP}) made with the mobile XPOL weather radar – MXPOL (Pereira Filho, 2012), were analyzed together with concomitant JWD and raingauge measurements (Fig. 1). The morphology and the vertical structure of these very deep convective systems were analyzed with the assistance of conceptual models of cloud dynamics, thermodynamics, and microphysics under favorable mesoscale and synoptic conditions to trigger thunderstorms in the afternoon.

ZR relationships were estimated with all spectra classified as convective, transition, stratiform and all of them combined. A convective spectrum was arbitrarily classified by examining one-minute JWD measurements with raindrop diameters above 3.2 mm. The stratiform phase was for spectrum with raindrops below 3 mm and the transition phase in between the convective and stratiform phases. Rainfall accumulation estimates with the overall ZR relationship (PR) were compared to tipping bucket raingauge measurements nearby the JWD.

Spectrum-time-averages were estimated with 5 min. JWD integration for a time window during the two case studies of heavy rainfall rate and for all 76 rainfall events in between 0000 LT and 2400 LT. It was also obtained the concentration of drops for all rainfall events as well as convective and stratiform.

MXPOL PPIs and vertical profiles of Z, Z_{DR}, ϕ_{DP} and K_{DP} were obtained for two instances of convective system triggered by intense diabatic heating under high boundary layer dew point temperature and low environmental wind shear (02/01/2010) and another with intense diabatic heating under low boundary layer moisture content and sea breeze circulation (11/01/2010). The vertical profiles were obtained by averaging all values at a given PPI within a 750 m radius right above the JWD site (Fig. 1). MXPOL scan strategy includes eleven elevation angles between 0.6^o and 25.0^o. MXPOL measured reflectivities were also compared to the ones estimates with the JWD for 21 JAN 2010. MXPOL measurements of this independent rainfall event along the radial passing over the JWD were analyzed to check for discrepancies caused by attenuation and effects on Z, Z_{DR}, ϕ_{DP} and K_{DP}. Z_{DR} vertical measurements under light rainfall indicate a bias of -0.36 dB that was not removed from the data shown in this study.

3. RESULTS

Fig. 5 shows 5 min. JWD total number of drops spectra between 0000 LT to 2400 LT for all 76 rainfall events. The spectra with bigger and higher drop concentration starts at around 1700 LT (2000 UTC) and ends at around 2000 LT (2300 UTC); also the smaller and lower drop concentration from about 1300 LT to 1500 LT. Since all rainfall events are displayed in this spectra-time diagram, there are events of cold front, squall line, rain-bands, ordinary convection and sea breeze & heat island related events (Pereira Filho and Silva, 2005) in the time span used for this study.

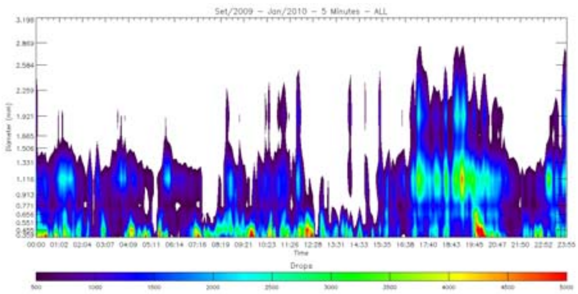

Figure 5: Time evolution (LT) of JWD total number of drop sizes with diameters between 0.359 and 5.373 mm from 03 SEP 2009 to 11 JAN 2010 at PEFI, São Paulo City (Fig. 1). Number of drops integrated every 5 min. indicated on color scale. [UTC = LT+ 2 h].

Fig. 6 shows 5 min. JWD number of drops spectra between 1600 LT to 2200 LT 02 JAN 2010 together with vertical profiles of average reflectivity measured with MXPOL for different phases of the convective system (Fig. 7). An ordinary cell developed right above the JWD site at around 1820 UTC followed by another deeper and more intense convective system that moved southward. The drop spectra of the later is monomodal with drops reaching the upper end of the spectrum (Fig. 6-A), then becomes bimodal (Fig. 6-B) and monomodal again (Fig. 6-C) indicating its evolution from convective to stratiform precipitation.

The vertical profiles are consistent with the vertical profiles of reflectivity nearby the JWD measurements. At the bimodal drop distribution phase, the diameter peaks at 1 mm and 2 mm with about 500 drops at each. This spectrum is similar to the one of a squall line in Amazon Forest during LBA (Pereira Filho et al., 2002).

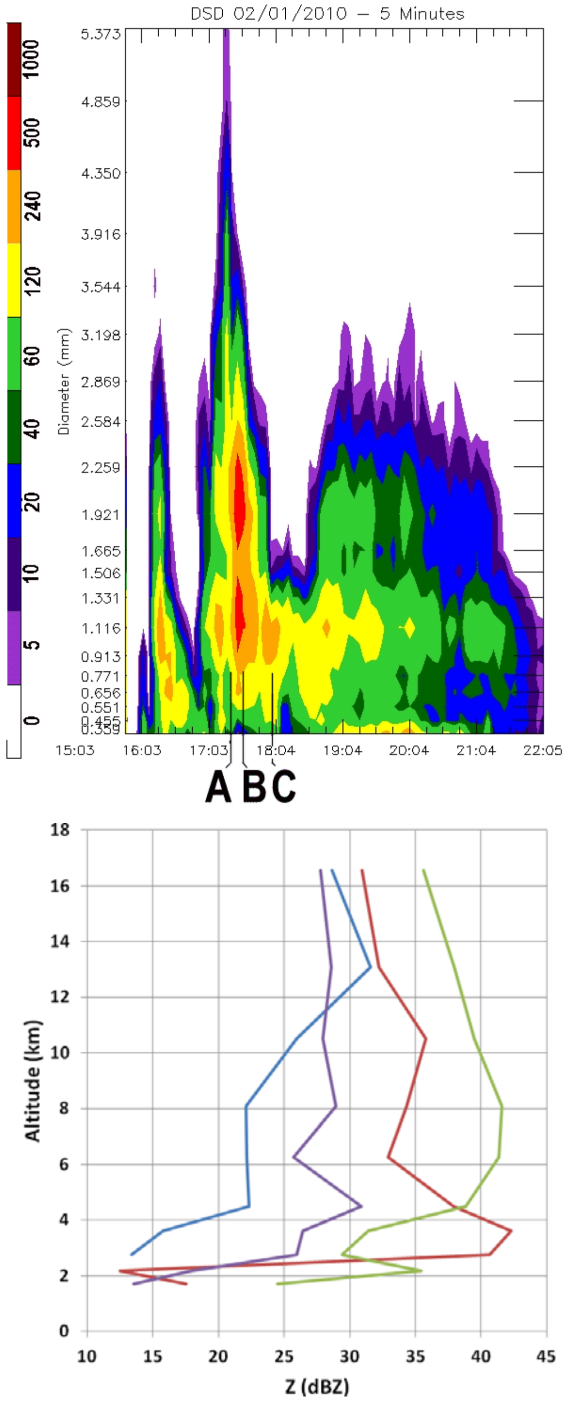

Figure 6: Time evolution (LT) of JWD total number of drop sizes with diameters between 0.359 and 5.373 mm at PEFI (Fig. 1) for the 02 JAN 2010 Flood episode (TOP) and vertical profiles of MXPOL Reflectivity measurements (dBZ) at 1920 UTC (A, Blue), 1930 UTC (B, Red), 1940 UTC (Green) and 2000 UTC (C, Purple). [UTC = LT+ 2 h].

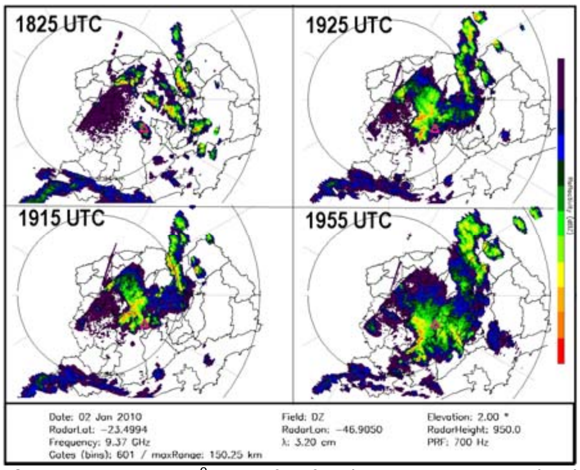

Figure 7: MXPOL 2° PPI of Z for the 02 JAN 2010 Flood episode. Scale, Geographic contours and UTC times are indicated. MXPOL centered circumferences at Δr= 50 km.

Unfortunately, only reflectivity and radial winds were available in 02 JAN 2010; MXPOL vertical channel was not operational.

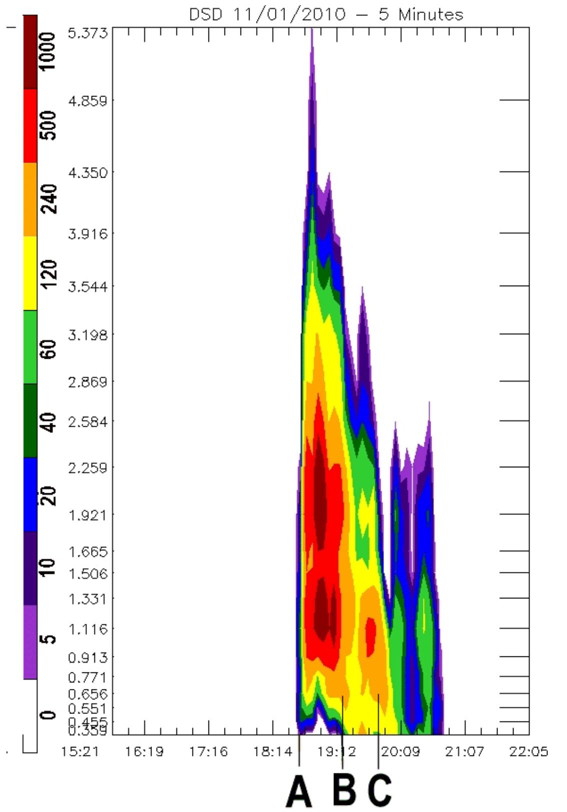

Figure 8: Time evolution (LT) of JWD total number of drop sizes with diameters between 0.359 and 5.373 mm at PEFI (Fig. 1) for the 11 JAN 2010 Flood episode (TOP) and profiles of MXPOL reflectivity measurements (dBZ) at 2050 UTC (A, Blue), 2105 UTC (B, Red), 2105 UTC (Green) and 2140 UTC (C, Purple) and Z_{DR} (D), K_{DP} (E) and Φ_{DP} (F) at 2145 UTC. [UTC = LT+ 2 h].

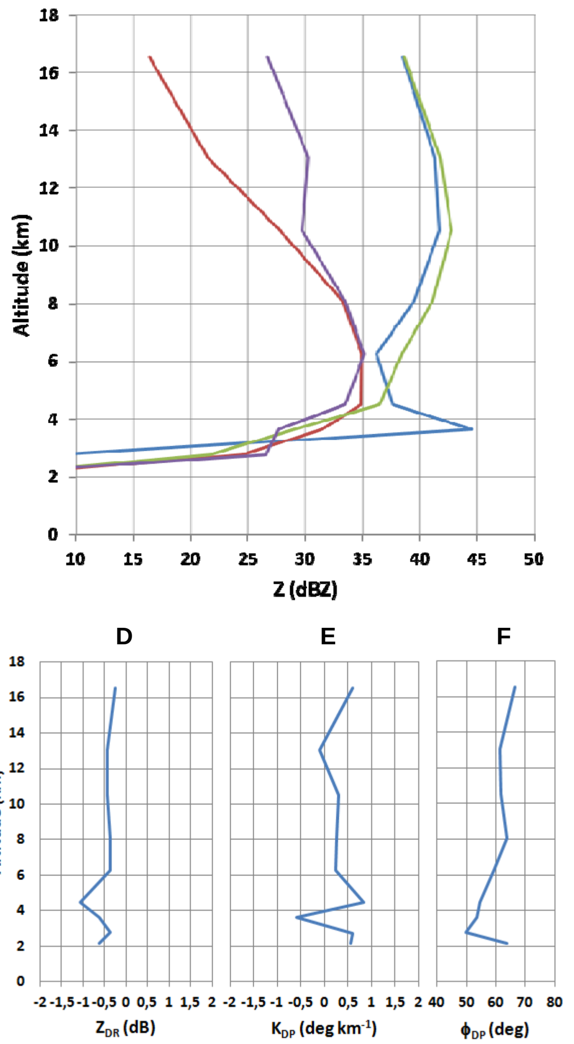

Figure 8: continued.

Figs. 8 and 9 shows similar graphics for the 11 JAN 2010 flood event related to sea breeze and heat island effects. The sea breeze had just passed over the JWD at 1840 UTC (Fig. 9). A first convective cell developed right above de JWD location at 1950 UTC. JWD measurements of the main convective cell started at 2050 UTC (Fig. 8). By 2145 UTC, the dominant rainfall was of the stratiform type. The vertical profiles of Z, Z_{DR}, K_{DP} and ϕ_{DP} are also indicated in Fig. 8. Reflectivity profiles are consistent with JWD measurements, as well the other three polarimetric profiles, though a negative biases is present in the Z_{DR} profile as indicated earlier in this manuscript.

The time evolution of the drop spectra clearly indicates the convective, transition and stratiform phases of this deep convective system. More importantly, it is interesting to notice the higher concentration of drops trough out the spectrum in relationship to the deep ordinary cells of 02 JAN 2010. It suggested that the injection of a deeper layer of moisture as well as boundary layer shear induces a higher drop concentration at all diameters. Furthermore, the level of air pollution increased significantly in between the two convective events. The profiles of reflectivity indicate higher values that also lasted longer, given to its more organized structure.

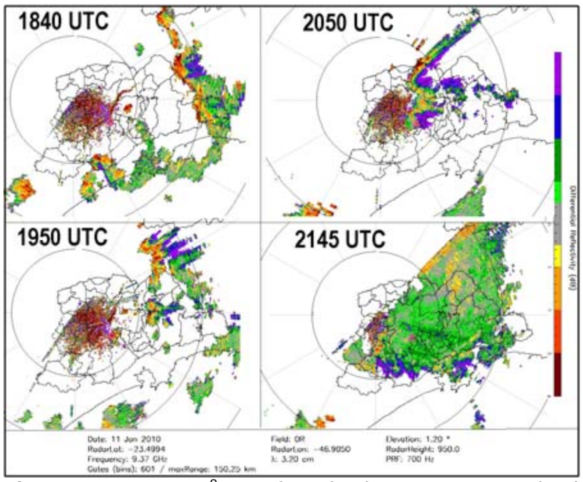

Figure 9: MXPOL 1.2° PPI of Z_{DR} for the 11 JAN 2010 Flood episode. Scale, Geographic contours and UTC times are indicated. MXPOL centered circumferences at Δr= 50 km.

The concentration of drops for all 76 rainfall events is shown in Fig. 10. The events were also divided up into convective and stratiform types. This result is surprising since concentrations are an order of magnitude higher than the one observed in convective system in the Amazon forest during the LBA fields experiment (Tokay et al., 2002). Two relative peaks are observed at diameters around 1 mm and 2 mm as in the two case studies shown in this manuscript. The convective and stratiform drop concentrations are remarkably different from each other.

No drops were observed above 3.5 mm in diameter in the stratiform phase with greater concentration of smaller raindrops, in general, associated with snow and ice falling through the melting layer, for instance, as shown at 1955 UTC 02 JAN 2010 (Fig. 7) and at UTC 2145 UTC 11 JAN 2010 (Fig. 9).

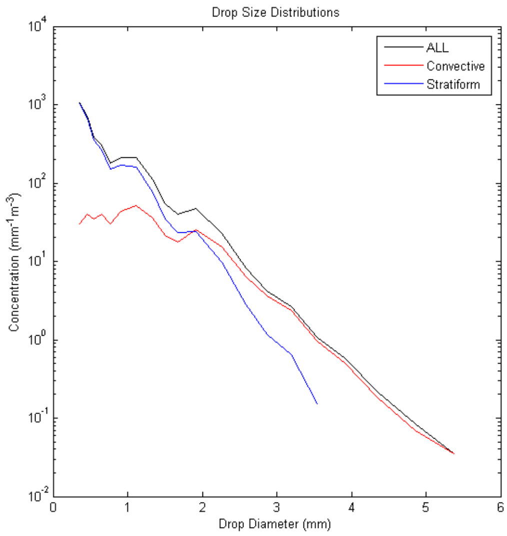

Figure 10: Averaged drop size distributions estimated with JWD measurements of 76 rainfall episodes from 03 SEP 2009 to 09 JAN 2010 at PEFI, São Paulo City (Fig. 1).

The drop spectra were used to estimate parameters *a* and *b* of the ZR relationship. Table 1 indicates the obtained parameters for the three rainfall rate phases and all of them together. The best fit was obtained for the stratiform type of rainfall (r^2=0.99).

Table 1: JWD ZR relationships for convective, stratiform, transition and all rainfall types obtained with 76 rainfall episodes between 03 SEP 2009 and 09 JAN 2010 at PEFI, São Paulo City (Fig. 1).

	R_{max} (mm h^{-1})	Z_{max} (dBZ)	a	b	r^2
Overall	85	53	165	1.46	0.93
Convective	73	53	258	1.38	0.96
Transition	85	52	247	1.38	0.97
Stratiform	2	21	35	1.19	0.99

The overall ZR relationship (PR) was used to estimate rainfall accumulations at 5 minute time intervals (Fig. 11). They were compared to rainfall measurements by a nearby tipping bucket raingauge as well as with the MP ZR relationship. The PR ZR relationship underestimates rainfall accumulation by 10%; while the MP by 35%.

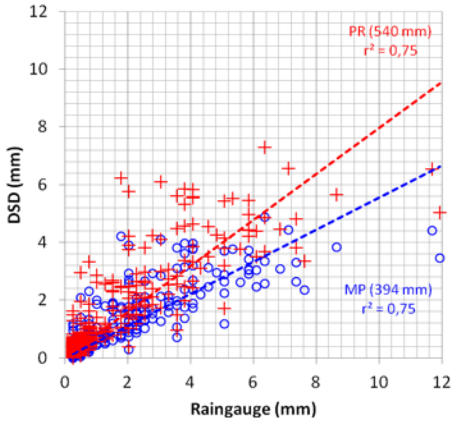

Figure 11: Scatter diagram of 5 min. raingauge accumulation against DSD estimates with MP (blue) and PR (red) ZR relationships for the month of January 2010. The total rainfall accumulation measured by the raingauge was 611 mm.

MXPOL Z measurements and Z JWD estimates with the PR relationship are shown in Fig. 12 for the 21 JAN 2010 convective event.

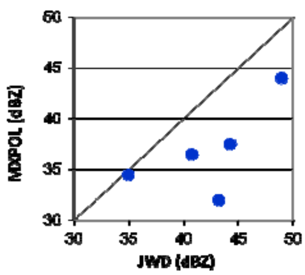

Figure 12: Scatter diagram of DSD Z (dBZ) estimates and MXPOL measurements for 21 January 2010. Comparisons made with MXPOL azimuth=118º, Δr = 32,750 m and lag time Δt=1 min. After Tanaka (2013).

In general, MXPOL underestimated reflectivities given high rainfall rates along the azimuth 118^o radial from the radar site to the JWD at 32 km (not shown).

4. CONCLUSION

The JWD measurements over MASP together with raingauge and MXPOL presented in this study reveal remarkable characteristics of convective systems influenced by heat island and sea breeze effects during spring in summer. Ordinary convection tends to be deeper because of the extra sensible heat that produces stronger updrafts. But, with the addiction of the sea breeze flow with increased environmental shear and moisture and urban rich CCN augmentation by air pollution, the drop concentration is in general greater than the ones observed in the Amazon Forest during LBA. MXPOL polarimetric measurements are qualitatively consistent with JWD, and clearly this late is strongly affected by rainfall attenuation. Rainfall accumulation obtained with the PR relationship yielded better results but still underestimated in relationship as pointed out by Tokay et al. (2002).

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