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Atmospheric parameters and lightning flash activity: Case studies

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***Abstract*— Twelve thunderstorms occurred at Metropolitan Area of Sao Paulo (MASP), on warm season from 2014 to 2015, were observed. Thunderstorms presented maximum peak of total flash rate higher than 10 flashes per minute, lasted about of 3 hours and were associated to flash flood, strong wind and large hail. Thermodynamic parameters (Convective Available Potential Energy and Convective Inhibition) besides to stability index (Showater Index, Lifted Index and SWEAT) were studied. Although these stability indexes classify these thunderstorms as an atmosphere moderately unstable with potential for thunderstorms with heavy rain according the standards of the middle latitude, the thunderstorm presented behavior similar to severe thunderstorm presenting strong wind (87 km/h) and hail with 3 cm in diameter. According Silva Dias (2002), differences in the climatology, in the height of tropopause and in the horizontal thermic gradients in the tropical region leads to instability indices with reference values not always significant to tropical region. A time series of the maximums peaks of the surface parameters and flash rate shows the Thunderstorms which presented CBH less or equal to 1700 m, presented beginning stage (CM stage) faster than the end stage (MD stage). The quick process of formation and cloud electrification favor the electricity activity and recording the higher CG flash rate per minute. The behavior of the total flash rate versus CBH to the thunderstorms was observed and it is similar to obtained by Williams et al. (2005) in tropical thunderstorms.**

Keywords—thunderstorm; stability index, flash rate

I. INTRODUCTION

Formation of thunderstorm is based on thermodynamic conditional instability of this boundary layer. Several stability indices have been developed to give some quantitative information about atmospheric instability, such as the traditional Showater (Showater 1947) and Lifted Indices (Galway 1956) and SWEAT (Severe Weather Threat). In this same sense, the Convective Available Potential Energy (CAPE) is particularly useful as a measure for the potential of an air parcel in ascending vertically, since it can be directly associated with the maximum kinetic energy that an air parcel, initially statically stable, can acquire (Hallak and Pereira Filho, 2012) .

The electrical activity in thunderstorms results of a complex interaction among CAPE, vertical air motion and larger depth of the mixed phase region where larger availability of liquid and solid phase particles may participate in the cloud electrification processes (Williams et al., 2002, 2005). In order for strong electrification to occur, there must be present in the late cumulus and early mature stages strong updrafts in a mixed phase region containing supercooled drops, ice crystals, and large riming particles such as graupel and hail. Several studies show a high positive correlation between surface temperature and lightning activity [Williams et al., 2005; Price and Asfur, 2006a; Sekiguchi et al., 2006; Penki and Kamra, 2012a, 2012b]

II. DATA AND METHODS

The thunderstorms presented in this work were monitored by the Weather station, Electric field mill (EFM) and Brazilian Lightning Detection Network (BrasilDat), simultaneously. The surface parameters were obtained by Davis weather station, the thermodynamics index was obtained by Campo de Marte airport´s vertical sounding, the total flashes rate were obtained by EFM (threshold of 5kV/m lasting more than 30 minutes) and the cloud-to-ground lighting flashes rate (CG flash) were obtained by Brasildat Network. The weather station and the EFM are installed at FEI and the Campo de Marte airport is located at 15km from FEI. The Brasildat Network locates of the CG flashes and estimates the CG flashes peak current. This system covers Sao Paulo State and exhibits an efficiency of lightning detection of 80% in this region [Beneti et al., 2004]. Weak positive flashes (peak current lower than 10kA) were not considered in this study due to flashes misinterpretation (Cummins et al., 1998 and Wacker and Orville, 1999[a], 1999b). All the sensors are synchronized by GPS.

Most of the thunderstorms had duration about of 3 hours, presented flash flooding at MASP, strong wind (upper to 45 km/h) and hail. Thunderstorms were predominantly negative CG flashes (95%), presenting average peak current of 30 kA to negative CG flashes and 25 kA to positive flashes, and flash rate per minute upper to 20 to total flashes and upper to 100 to CG flash , around of 30 km of FEI.

The aim of this work is study the thermodynamic and stability index to thunderstorm which presented total flash upper to 10 flashes per minute and the possible relationship with diurnal variation of the surface parameters.

III. Results and Discussions

A. *thermodynamic parameter and stability index*

Thermodynamic parameter and the stability index were observed on twelve thunderstorms occurred on warm season of Metropolitan Area of Sao Paulo (MASP), from 2014 to 2015. These thunderstorms presented maximum peak of total flash rate higher than 10 flashes per minute and were associated to flash flood, strong wind and large hail. Thermodynamic parameters and the stability index studied to these thunderstorms are: Convective Available Potential Energy (CAPE), Convective Inhibition (CINE), Showater Index (SI), Lifted Index (LI) and SWEAT. The Table 1 shows the thermodynamic parameter, the stability index, the maximum peaks of total flash rate (total flash) and cloud-to-ground flash rate (CG flash) per minute, despite the maximum peaks of surface parameters: dry-bulb temperature (T), dew point temperature (Dew) and wind speed (wind). In this study, the thunderstorms were classified according to the Cloud Base Height (CBH).

TABLE I. THERMODYNAMIC PARAMETER AND STABILITY INDEX TO THUNDERSTOM OBSERVED FROM 2014 TO 2015

Thermodynamic and Stability Index						Maximum peak				
CBH	CAPE	CINE	SI	LI	SWEAT	Flash rate per min.		Surface parameter		
(m)	($J\ kg^{-1}$)	($J\ kg^{-1}$)	(°C)	(°C)		Total flash	CG flash	T	Dew	Wind
1200	985	-97	1	0	217	10	37	24	18	4
1400	686	-123	0	-2	203	10	122	23	18	10
1500	1552	-126	-1	-2	198	13	55	25	18	2
1600	1302	-36	-1	-2	214	20	124	26	18	0
1700	1953	-49	-1	-4	194	15	150	27	18	3
mean	1296	-86	-1	-2	205	14	98	25	18	4
3200	2288	0	-8	7	418	15	7	23	20	2
3300	1247	0	-1	12	222	12	24	22	20	2
3400	1395	0	-1	11	213	10	52	23	18	0
3500	1241	0	-1	12	249	20	67	25	19	0
3800	1249	0	-2	13	251	19	27	23	19	0
mean	1484	0	-3	11	271	15	35	23	19	1

According to standard indexes used to identify the atmosphere stability, obtained from the National Weather Service (http://www.weather.gov/lmk/indices), the thunderstorms here observed show an atmosphere moderately unstable with potential for thunderstorms with heavy rain (CAPE =1417J/kg, CINE = -57 J/kg, SI = -2°C, LI = -2 °C and SWEAT = 231). Thunderstorms which presented the lowest CBH show moderate CAPE, high index of the inhibition to convection and the higher CG flash rate per minute (CAPE = 1296 $J\ kg^{-1}$, CINE = -86 $J\ kg^{-1}$, LI = -2 and CG flashes = 98 fpm. In contrast to that, the thunderstorms which presented the highest CBH show moderate CAPE but no inhibition to convection and lower CG flash rate per minute (CAPE = 1484 $J\ kg^{-1}$, CINE = 0 $J\ kg^{-1}$, LI = -3 and CG flashes = 35 fpm. It is due to the critical role of the strong updraft in the mixed phase in high CBH, which the vigorous updraft vertically advects graupel so quickly that difficulty the collisions between graupel and ice crystals, decreasing the charging process at thunderstorms.

Figure 1 shows the frequency distribution of the stability indexes found in this study. These indexes are compared to indexes obtained by Beneti and Silva Dias (1986) observed in a period of six years at MASP. The frequency distribution of thermodynamic parameters shows a moderately unstable atmosphere without any inhibition to convection (CAPE = 1500 J/Kg and CINE = 0 J/Kg). The stability indexes show thunderstorms with heavy rain and possibility to the occurrence of hail, which is according with the observed by Silva Dias (2000) (SWEAT = 250).

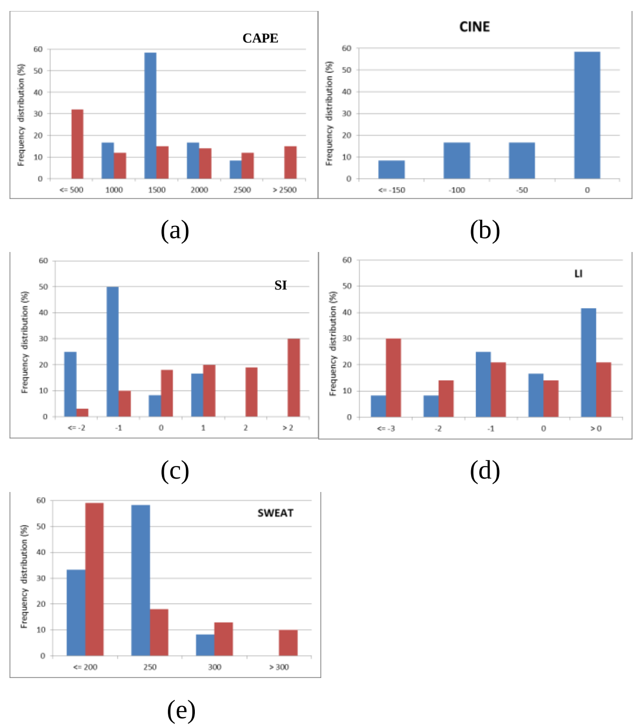

Fig.1. Frequency distribution of the thermodynamic parameter and stability index to this work (blue blocks) and Beneti and Silva Dias (1986) (red blocks): (a) CAPE, (b) CINE, (c) SI, (d) LI and (e) SWEAT.

From the comparison with Beneti and Silva Dias (1986), it is observed that the thunderstorms here observed shows indexes with greater potential energy and greater possibility for the occurrence of hail. The stability indexes observed in these thunderstorm are according with observed at India (Jayakrishnan and Babu, 2014; Penki and Kamra, 2013).

In the literature, most of stability index, refer to severe storms occurred in middle latitudes observed on Grain plains of US Midwest. A thunderstorm is classified as “severe” when it contains one or more of the following: hail one inch or greater (~2.5 cm), winds gusting in excess of 50 knots (~90 km/h), or a tornado (http://www.nssl.noaa.gov/education/svrwx101/thunderstorms/). The thunderstorms here observed are not severe thunderstorms like as severe thunderstorms in middle latitudes but the impacts over MASP are similar (flash flood events, strong winds of until 85 km/h and large hail: 3 cm in diameter). It is due to differences between the tropical region and the middle latitude, which difficulty the use these standards index. Differences in the climatology, in the height of tropopause (tropical region is higher than the middle latitude) and in the horizontal thermic gradients (in the tropical region are less intense than those observed in middle latitudes) in the tropical region leads to instability indices with reference values not always significant (Silva Dias, 2000).

Figure 2 shows an example of thunderstorm which presents high instability values, strong wind and hail presence (3 cm in diameter). January 14th 2015 was marked by an unstable synoptic situation in São Paulo State, with high values of heat and water vapor mixing ratio (r_v) in low levels.

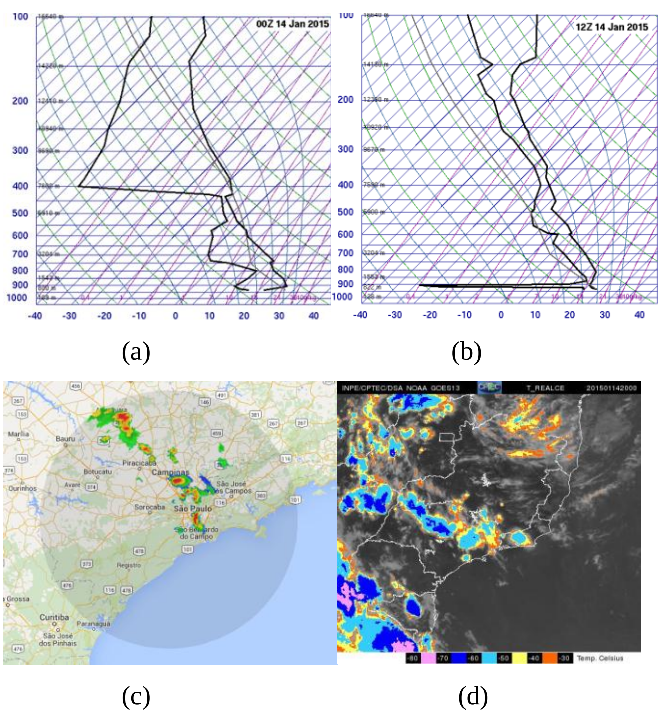

Fig.2. Atmospheric vertical sounding at Campo de Marte Airport: (a) 00UT and (b) 12UT ; (c) Sao Roque weather radar at 1945UT and (d) GOES infrared image at 2000 UT , at MASP.

The development of organized mesoscale convective systems was favored by a series of factors, as will be discussed in the sequence. The atmospheric vertical sounding at Campo de Marte Airport, at MASP (Fig. 2a 00 UT and Fig. 2b 1200 UT), show values of r_v between 15.8 g kg^{-1} next to surface to 10 g kg^{-1} at 776 hPa, characterizing great moisture availability for convection development. The São Roque radar reflectivity at 3 km level (Fig. 2 c) shows a mesoscale system organized in a line of thunderstorms (squall line) in a northwest-southeast direction at 1945 UT. In fact, the GOES infrared image taken at 2000 UT of the same day (Fig. 2d) shows clearly the squall line feature on the north of São Paulo State driven to MASP. In synoptic scale, two high level circulations dominated part of South America: the 250 hPa Bolivia High, at the central and west part of the continent, and the higher levels cyclonic vortex centered over Minas Gerais State. This cyclonic vortex typically has greater convective activity in its borders. In the analyzed case, its southern border was exactly over the north part of São Paulo State in that day (figure not shown), which gives dynamical support for the observed convective system.

B. *Time series of the surface parameters and lightning flash rate*

A time series of the maximums peaks of the dry bulb temperature (T), dew point temperature (Dew), surface wind speed (Wind), Total flash rate and CG lightning flashes rate (CG) were observed. All the thunderstorms presented the same temporal sequence of the maximums peaks beginning with: Temperature, Dew point temperature, Total flash rate, Wind speed and then CG flash rate. The time of duration between the maximum peaks of the surface parameters and of the flashes rate were studied according to Cloud Base Height (CBH) and the duration of the process. The stages of development of the thunderstorms are recorded here by interval time between the maximum peak of the temperature and total flash rate, here denominated as Cumulus-Mature stage (CM stage), and by interval time between the maximum peak of total flash rate and CG flash rate, here denominated as Mature-Dissipating stage (MD stage). The CM stage of thunderstorm is characterized by an updraft throughout the cell, which produces small water and ice particles, and later updraft, cloud particle growth and interactions reach maximum intensity, which the cell reaches its maximum height. The MD stage of thunderstorm is characterized by downdrafts develop in the lower part of the cell and precipitation falls to the ground. Thunderstorms which presented CBH less or equal to 1700 m, presented CM stage (30 minutes) faster than MD stage (50 minutes). The quick process of formation and cloud electrification favor the electricity activity recorded as the higher CG flash rate per minute (until 150 fpm). In contrast, the thunderstorms which presented CBH higher than 1700 m, presented CM stage (80 minutes) slower than MD stage (30 minutes), which means no favor to electrification process, recorded here as lowest CG flash rate (7 fpm). That means the duration of process electrification versus CBH can favor the activity electricity of the thunderstorm.

Figure 3 shows the diurnal variation of the dry-bulb temperature, dew point temperature, surface wind speed and CG flash rate per minute, occurred February 13th, 2015. This thunderstorm presented CBH lower than 1700m and recorded about 120 CG flashes per minute. Temperature and dew point reached their maximum value at 1540 UT. Maximum peak of the total flash rate per minute were recorded 1610UT, 30 minutes after peak of temperature. According Williams et al. (1991 and 1999) suggest that the maximum total flash rate coincide with maximum vertical development of the thunderstorm and the peaks of total lightning are connects the strong mixed-phase updrafts. After the maximum vertical development of the thunderstorm the downward are dominant and the maximum peak of the wind speed were recorded 1630UT followed by maximum peak of the CG flash rate (1640UT).

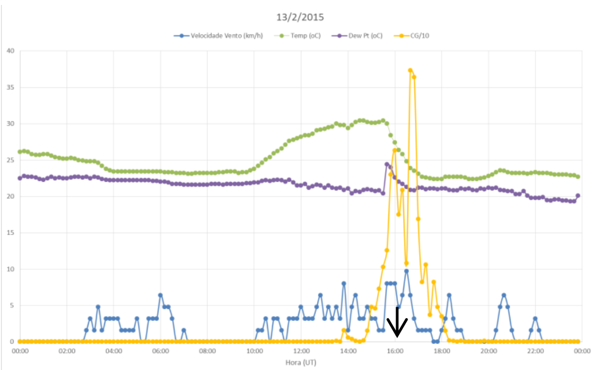

Fig.3. Diurnal variation of the dry bulb temperature (green curve), dew point temperature (lilac curve), wind speed (blue curve) and CG flash rate per minute (orange curve) to February 13th 2015. The maximum peak of the total flash rate per minute is identified by arrow.

C. *Cloud base height versus surface parameters and lightning flashes*

According to Williams et al. (2005), in the tropics, cloud base height is dominated by the dry-bulb temperature over the wet-bulb temperature as the lightning-regulating temperature in regions characterized by moist convection. An elevated cloud base height may enable larger cloud water concentrations in the mixed-phase region, a favorable condition for the positive charging of large ice particles that may result in thunderclouds with a reversed polarity of the main cloud dipole. Figure 4 shows the behavior of the mean of the total flash rate versus CBH to thunderstorms here observed.

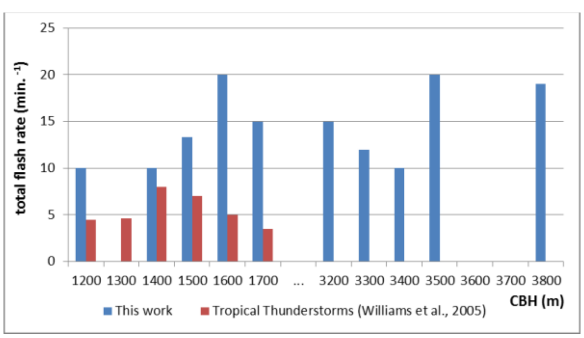

Fig. 4. Mean of the total flash rate versus CBH to thunderstorms here observed (blue blocks) and to the tropical thunderstorm (red blocks) obtained by Williams et al. (2005).

This behavior is compare to obtain by Williams et al. (2005) which studied tropical thunderstorm from 2002 to 2004.

IV. Conclusions

Twelve thunderstorms were recorded on warm season of the Metropolitan Area of Sao Paulo (MASP), from 2014 to 2015. These thunderstorms presented maximum peak of the total flash rate higher than 10 flashes per minute and were associated to flash flood, strong wind and large hail. Thermodynamic parameters and the stability index showed an atmosphere moderately unstable with potential for thunderstorms with heavy rain. However, when compare with other studied at Brazil showed indexes higher than obtained to Beneti and Silva Dias (1989) and potential to occurrence of hail (Silva Dias, 2000). A time series of the maximums peaks of the surface parameters and flash rate shows the Thunderstorms which presented CBH less or equal to 1700 m, presented beginning stage (CM stage) faster than the end stage (MD stage). The quick process to formation and cloud electrification favor the electricity activity and recording the higher CG flash rate per minute. The behavior of the total flash rate versus CBH to the thunderstorms was observed and it is similar to obtained by Williams et al. (2005) in tropical thunderstorms.

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References

Beneti, C.A.A.; Calvetti, L.; Jusevicius, M.; Gin, R. B.B. (2004), The integration of radar, lightning and satellite information for thunderstorm analysis and nowcasting. In: 18th International Lightning Detection Conference, 2004, Helsinki. CD_ROM

Beneti,C.A.A. and M.A.F.Silva Dias (1986), Análise da performance de índices de instabilidade como previsores de tempestades na região de Sao Paulo.Anais do IV Congresso Brasileiro de Meteorologia, Brasília, DF, 20-24 outubro, v.2, 65-70.

Carvalho, L. M. V., Jones, C., Liebmann, B. (2002), Extreme precipitation events in Southeastern South America and large-scale convective patterns in the South Atlantic convergence zone. Journal of Climate, v. 15, 2377-2394

Cummins, K.L., M.J. Murphy, E.A. Bardo, W.L. Hiscox, R.B. Pyle and A.E. Pifer (1998), A combined TOA/MDF technology upgrade of the US National Lightning Detection Network , J. Geophys. Res., 103, 9035-9044.

Coning, E., M. Koenigb and J. Olivierc (2011), The combined instability index: a new very-short range convection forecasting technique for southern Africa, *Meteorol. Appl.* 18: 421–439, DOI: 10.1002/met.234.

Galway, J. G. (1956) The lifted index as a predictor of latent instability. Bull. Amer. Meteor. Soc., v. 43, p. 528-529.

Hallak, R. and A. J. Pereira Filho (2012), Análise de desempenho de índices de instabilidade atmosférica na previsão de fenômenos convectivos de mesoescala na região metropolitana de são paulo entre 28 de janeiro e 04 de fevereiro de 2004, Revista Brasileira de Meteorologia, v.27, n.2, 173 – 206.

Jayakrishnan, P. R. and C. A. Babu (2014), Assessment of Convective Activity Using Stability Indices as Inferred from Radiosonde and MODIS Data, *Atmospheric and Climate Sciences*, 2014, 4, 122-130.doi.org/10.4236/acs.2014.41014.

Johnson, R. H., Mapes, B. E. (2001) Mesoscale processes and severe convective weather, in severe convective storms, Charles A. Doswell III, Editor. Meteorological Monographs, A. M. S., Vol. 28.

Lang, T. J. and S. A. Rutledge (2002), Relationships between Convective Storm Kinematics, Precipitation, and Lightning, Montly Weather Review

Marwitz, J. D., 1972: Precipitation efficiency of thunderstorms on the High Plains. J. Rech. Atmos., 6, 367-370

Penki, R.K. and Kamra, A.K. 92013), The lightning activity associated with the dry and moist convections in the Himalayan Regions. J. Geophys. Res., VOL. 118, 6246–6258, doi:10.1002/jgrd.

Silva Dias, M. A. F. (2000) Índices de Instabilidade para previsão de chuva e tempestades severas. São Paulo/SP: Departamento de Ciências Atmosféricas, Instituto Astronômico e Geofísico, Universidade de São Paulo.

Sheridan, S.C., J. F. Griffiths and R. E. Orville (1997), Warm season cloud-to-ground lightning–precipitation relationships in the south-central united states, American Meteorological Society

Showater, A. K. (1947), A stability index for forecasting thunderstorms. Bulletin of the American Meteorological Society, v. 34, p. 250-252.

Williams, E., B. Boldi, A. Matlin, M. Weber, S. Hodanish, D. Sharp, S. Goodman, R. Raghavan and D. Buechler (1999), The behavior of total lightning activity in severe Florida thunderstorms, Atmospheric Research 51, 245–265

Williams, E. R. and S. Stanfill (2002), The physical origin of the land-ocean contrast in lightning activity. Comp. Rend. Phys., 3, 1277-1292.

Williams, E. R., V. Mushtak, D. Rosenfeld, S. Goodman, and D. Boccippio (2005), Thermodynamic conditions that lead to superlative updrafts and mixed-phase microphysics. Atmos. Res., 76, 288- 306.

Wacker, R.S. and R.E. Orville,(1999a), Changes in measured lightning flash count and return stroke peak current after the 1994 US National Lightning Detection Network upgrade. Part I: Observations. J. Geophys. Res.,104 2151-2157.

Wacker, R.S. and R.E. Orville (1999b), Changes in measured lightning flash count and return stroke peak current after the 1994 US National Lightning Detection Network upgrade. Part II Theory. J. Geophys. Res.,104, 2159-2162.