

THE ELECTRICAL AND METEOROLOGICAL CONDITIONS OF THUNDERSTORMS IN SAO PAULO'S URBAN AREAS, BRAZIL

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1. INTRODUCTION

Recent studies of lightning flash densities in Southern and Southeastern Brazil showed that the Metropolitan Area of Sao Paulo (MASP) and surrounding areas are heavily affected by lightning [e.g., Gin et al, 2004; Gin et al., 2003]. This region presents both high lightning activity and high lightning density. About 6.3 flashes $\text{km}^{-2} \text{year}^{-1}$ occur in Sao Bernardo do Campo, within the MASP [e.g., INPE, 2005]. Several floods occur in this region due to summer afternoon convection [e.g., Pereira Filho, 1999]. According to Lobardo [1984] the heat island caused by the MASP indicate temperature differences in excess of 10 °C during afternoon hours. This high temperature contributing for the convergence zones formation not only over these areas but also in remote regions [e.g., Freitas and Silva Dias, 2005]. The heat island effect associated with the sea breeze reinforce the source of moisture causing severe floods in the MASP and on vicinity regions [e.g., Sales and Pereira Filho, 2005].

The monitoring of local electric field on the ground can show the cycle life of nearby storms and the total flash rate. In the life cycle of thunderstorms it is showed the initial, active and dissipating stages storms. According to Krehbiel [1986] an electric field measured on the ground of about 100Vm^{-1} was found in New Mexico in the absence of storms and identified as a fair weather (FW) condition. The initial stage is identified by a sign reversal in the electric field from fair weather and a rapid increase in magnitude caused by the accumulation of dominant lower negative charge in these storms. The active stage begins with the occurrence of the first lightning

discharges and can last from a few minutes to an hour or more depending on the size and convective vigor of storm. During the dissipating stage of the storm the lightning activity ceases and the electric field exhibits a large oscillation or swing to negative values, called an end of storm oscillation (EOSO) (Moore and Vonnegut, 1977). The flash rate can be used to as a measure of the vigor of these storms [e.g., Williams, 2001].

The electric field changes and measurement of channel luminosity can identify continuing current of lightning flashes. Continuing currents in negative CG flashes are of significance in that most flashes contain at least one short or long continuing current interval and roughly 50% of all flashes contain a long continuing current component [e.g., Uman, 1987]. Those flashes transfer to earth about twice the charge that flashes without a long continuing current do. Kitagawa et al. [1962] and Brook et al. [1962] defined long continuing current CG lightning flashes lasting in excess of 40ms, a typical time from interstroke interval.

The aim of this paper is to show the behavior of storms by the monitoring of local electric field associated with specific meteorological conditions. These storms occurred in the vicinity of University of FEI Campus, Sao Bernardo do Campo, within the MASP. The period of this study is within the warm season of 2004-2005.

2. INSTRUMENTATION

The local monitoring consists of two electric field mills (EFM), three videos cameras (VC) and sensor of temperature synchronized by Global Positioning System (GPS). The EFM

detects the ambient electric field at ground level and estimates the total flash rate over an area with radius of 20km from FEI Campus [e.g., Uman, 1987]. The ambient electric field is presented as a positive value where the transient of field shows the occurrence of storms. In this paper the records of electric field are obtained with a time resolution of about 4 ms and the electric field from storms is represented by positive polarity caused by the unipolarity of the instrument electronics. Some lightning were observed by EFM and VC, simultaneously. The images by video camera are recording continuously at 30 frames per second. However, some events are recorded using a motion detection system. In these cases the first stroke of a flash can be lost.

This set of information is complemented by cloud-to-ground lightning data, obtained by a Lightning Detection System (LDS) from the Integrated Network of Lightning Detection in Brazil (RINDAT), and by meteorological conditions obtained by a Weather Radar covering a 240-km radius circumference. Figure 1 shows the location of the FEI, the LDS sensors and the weather radar covering an area with radius 240 km (illustrated by the circle). The LDS identifies and locates the stroke of a cloud-to-ground lightning flash and estimates the stroke's peak current. Positive flashes with peak current less than 10kA were not considered for the analysis (e.g.; Cummins et al.,1998; Wacker and Orville ,1999a, b). This system covers Sao Paulo State and exhibits an efficiency of lightning detection of 80% in this region [e.g., Beneti et al., 2004] .

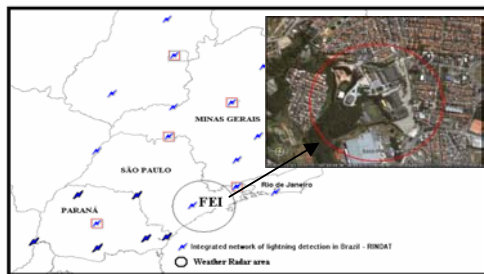


Figure 1. Map of FEI location, LDS sensors and the weather radar covering (black circle) are shown.

3. RESULTS AND DISCUSSION

Nine thunderstorms are presented at Table 1 identifying the cloud-to-ground lightning (CG) activity and the meteorological conditions. The area these storms exceeded 2500 km² , they were active for about of 3-4 hours. About 41 thousand cloud-to-ground lightning flashes were analyzed. From this total set, about 93% presented negative polarity and the average of maximum CG flash rate recorded was 35 flashes per minute. The average peak current of the negative and positive strokes are about 25 kA and 30kA, respectively. This lightning peak current have been observed in other storms in this same region [e.g., Gin et al, 2004; Gin et al., 2003]. These storms were produced mainly by local air mass convection (LC) or are associated with a cold front (CF) .

Table1. Thunderstorm cases in Sao Paulo 's urban area

Date of cases	Lightning Strokes (by LDS)				Synoptic condition
	Neg.	Pos.	Maximum CG flashes rate		
			flashes rate per min	Period in UT	
06 Dec. 2004	2980	17	30	1630-1700	*LC
07 Dec 2004	2081	43	20	1730-1800	LC
12 Dec. 2004	2488	104	8	1900-1930	LC
25 Febr.2005	4278	53	30	1810-1840	*LC
14 March 2005	3839	150	15	1850-1920	CF
15 March 2005	7359	940	15	0100-0140 1940-2000 2250-2400	CF
16 March 2005	3789	546	15	0100-2100 0240-0320	CF
17 March 2005	882	17	8	2050-2150	LC
14 Oct. 2005	10390	1097	80	2040-2120	*CF
Code:Local convection (LC),Cold Front (CF),Flood at Sao Bernardo (*)					
Total	38086	2967			

3.1. THUNDERSTORMS LIFE CYCLE BY LOCAL ELECTRIC FIELD

The electric field recorded at ground level can identify the thunderstorm's life cycle efficiently. The initial stage of this storm was identified by the small increase of the fair weather electric field and by the absence of cloud-to-ground lightning activity. The active phase could be identified by the high magnitude of electric field around 16 kV m⁻¹. This large field magnitude may have a contribution from the distortion by the building

on which the electric field is measured. A high lightning rate was observed in this phase too. The maximum total lightning rate and the maximum CG lightning rate were coincident in time. A large electric field oscillation and absence of flashes identified the dissipating stage. No CG flashes were observed in the initial and dissipating stages.

A decreased electric field coinciding with the precipitation phase is observed in some thunderstorms. These events presented a 30-minute difference between the maximum electric field recording and the precipitation phase characterized by a temperature decrease. Figure 2a shows the decrease of electric field (left scale) coinciding with a rapid decrease in temperature (right scale shows the temperature in °C) at 0536 UTC (0236 A.M. LT) on 14 March 2005. This behavior is similar to the one observed by Krehbiel [1986] and Carey and Rutledge [2000]. The dissipating stage also coincided with a decrease of temperature. Both phases are associated with the cooling effect of downdrafts. Figure 2b shows the daily-accumulated rainfall rate estimated through Sao Paulo's urban area by weather radar to this event. This storm was produced by cold fronts (CF) and presented accumulated rainfall higher than 20 mm.

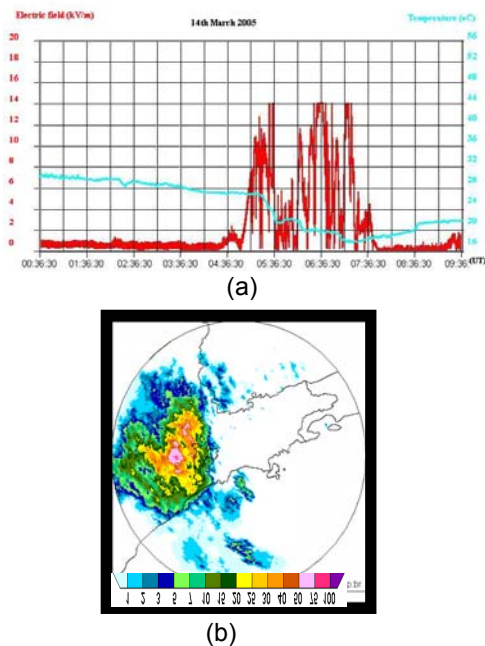


Figure 2. Time evolution of the local electric field (line red) and temperature (cyan line) (a) and daily rainfall accumulation estimated

through Sao Paulo's urban area by weather radar on 14 March 2005 (b). Color scale indicates the accumulated in mm.

3.2. HIGH FLASHES RATE PRESENTED IN FLOODS EVENTS

Two thunderstorms produced by LC and one produced by CF presented heavy rainfall and strong floods in Sao Bernardo do Campo and in the vicinity of MASP. Figure 3 shows the daily rainfall accumulation on 25 February 2005. About 25% of the total rainfall for February occurred in this event where a maximum rainfall rate of 100 mm h^{-1} was observed. This storm was produced by local convection caused by strong sea breeze circulation in shore. About 4330 CG lightning flashes were analyzed on 25 February 2005. This event exhibited negative cloud-to-ground lightning cells exceeding 50-km x 50-km in size, remaining active for about 4 hours. From this total set, about 98% presented negative polarity lightning and average peak current of about 20 kA. A maximum cloud-to-ground lightning rate of 30 flashes per minute was noted around 1820 UT (0320 P.M. local time). This event presented a lightning density of $0.007 \text{ flashes km}^{-2}$, a density similar to storms in Florida [11]. The higher CG flashes rate per minute were produced by floods events (Table 1)

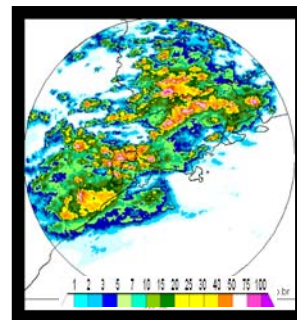


Figure 3. Daily rainfall accumulation estimated with the SPWR on 25 February 2005. Color scale indicates the accumulated in mm.

3.3 SEVERITY THUNDERSTORMS OBSERVED BY BEHAVIOR OF LIGHTNING.

Intra-cloud and cloud-to-ground lightning are predominant lightning types in ordinary thunderstorms [e.g., Williams, 2001]. Some lightning transients recorded by electric field mill were observed by video camera simultaneously. These cases serve to identify

the waveforms of negative cloud-to-ground lightning flashes and intra-cloud flashes. Figure 4 shows negative cloud-to-ground lightning transients occurring on 25 February 2005. The field changes for some lightning flashes exceeded 12kV m^{-1} and identified with average flash peak current of about 15 kA. No positives CG lightning were identified by electric field. The waveforms found in this paper are similar to these identified by various authors [e.g., Jacobson and Krider, 1978; Livingston and Krider, 1978; Rakov and Uman, 1994; Villanueva et al., 1994; Uman, 1987] . About of 10 total flashes and 06 CG flashes were recorded per minute in this time. This total flash rate suggests ordinary nonsevere thunderstorms [e.g., Williams, 2001].

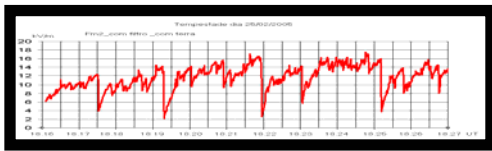


Figure 4. The electric field record (red line) shows the storm on 25 February 2005.

Some of the events observed by video camera indicate flashes with long continuing luminosity lasting more than 100 ms. This persistent luminosity is evidence long continuing current in the flash. These events have been observed by many authors as Kitagawa et al. [1962], Rakov and Uman [1994] and Parker and Krider [2003]. A long continuous luminosity lasting more than 500 ms was observed at 2041UT on 14 October 2005. Figure 5 shows the first frame (left picture) recorded at 02.281s and the last frame (right picture) recorded at 02.813s. This event presented continuing luminosity lasting about 532ms. This extensive thunderstorm was associated with a cold front event.



Figure 5. Long continuing luminosity observed at 2041UT on 14 October 2005. The left picture recorded the first frame at 02.281s and the right picture recorded the last frame at 02.813s this flash.

[14] Some horizontal discharges were seen by the video camera too. These discharges show how extensive the storms are laterally and occur especially in the anvil in the storms final stage. Figure 6 shows a spider discharge observed by video. This discharge occurred during the dissipating stage of a storm on 15 March 2005. The persistent luminosity was sustained for around 60 ms. No cloud-to-ground lightning flash was found on the LDS for this final stage of this storm, and this absence remains a mystery. It's possible that the waveform did not satisfy standard criteria for this unusual flash.



Figure 6. Laterally extensive 'spider' lightning observed by video camera on 15 March 2005 over the FEI Campus.

3. Conclusions

This paper described some electrical and meteorological characteristics of thunderstorms within the MASP during the warm season of 2004-2005. The electrical aspects of thunderstorms were monitored by local electric field, video camera and Lightning Detection System and the meteorological aspects were observed by the SPWR. The life cycle of thunderstorms were identified by local electric field including the precipitation phase. Most of floods were produced by the local sea breeze circulation. Thunderstorms produced by a cold front on 14-16 March 2005 did not present produce floods in the MASP.

Cloud-to-ground lightning flashes were identified. The negative and positive cloud-to-ground flashes presented peak currents of around 25kA and 30 kA, common for this region. Intracloud could be identified too. This is important additional information to study the electrical aspects of thunderstorms. The total flash rate, 10 flashes per minute, suggests ordinary non-severe thunderstorm on 25 February. Most of thunderstorms present the same total flash rate.

Some thunderstorms presented long continuing luminosity of CG flashes that

suggest long continuing current of flashes. Those flashes transfer more charge to earth than other ones and can indicate lateral extensive structure of thunderstorms. Those events can produce sprites and can be observed by waveguide in Schumann Resonance. Spiders were observed too identifying long horizontal extensive thunderstorms. However, no positive cloud-to-ground flash waveform could be identified in this study, and remains puzzling.

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