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Assessing currents of upward lightning measured in tropical regions

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ABSTRACT

Negative upward lightning events in tropical regions are discussed based on the records of six currents measured recently at a short instrumented tower in Brazil. Only one event exhibited a return stroke following the initial stage. According to available correlated records of electric-field change, all events were triggered by nearby lightning. The parameters of the measured upward lightning were compared to the counterparts measured in temperate regions. They transferred small charge (typically, 6 C), had large average current (geometric mean of 271 A) and short duration (geometric mean of 18 ms). This charge coincides with the geometric mean of the charge of negative cloud-to-ground first strokes measured at the tower.

1. Introduction

Upward lightning is typically object initiated. Under the influence of charged clouds, high structures positioned on elevations develop extremely high electric fields that are conducive to yielding upward leaders, which may evolve into upward lightning discharges.

The production of such upward leaders requires overcoming the effect of the space-charge layer yielded by corona discharges around the structure top, which inhibits the leader initiation. The literature reports that this effect can be overcome in different ways, i.e.: (i) an intense enhancement of the electric field due to the slow charge build-up in the cloud; (ii) a very strong and fast electric field change resulting from nearby lightning; and (iii) the removal of the space-charge layer over the structure due to a very strong wind or fast movement of the structure, for instance: the rotating blade of windmills (Wang et al., 2008; Zhou et al., 2012a,b). This led Wang to classify upward lightning as either self-triggered or triggered by nearby events (Wang et al., 2008).

A large number of upward lightning events occur in temperate regions and, frequently, their currents have been measured at instrumented towers of the Northern Hemisphere, such as Gaisberg, and Peissenberg towers (Diendorfer et al., 2009, 2011; Manhardt et al., 2010). In the last few years, currents of upward lightning initiated from wind turbines have also been measured, for instance (Wang et al., 2008; Wang and Takagi, 2012).

Apparently, the measurement of upward-lightning currents in tropical regions has not been reported yet. Such events used to be rarely detected at Morro do Cachimbo Station (MCS), in the Brazilian Southeast. It is not clear whether this was due to their low frequency of occurrence in that region, attributed to a higher altitude of the −10 °C isotherm, or to the inability of the old measuring system of MCS to detect them. Presumably, at least to a certain extent, geographical aspects exert some influence on the frequency of upward lightning, considering the very large number of events measured at Mount San Salvatore Station, whose short towers (70 m) were relatively similar in height and altitude to that at MCS (Rakov and Uman, 2003).

This apparent lack of data of upward-lightning currents in tropical regions has motivated the authors to develop this work, presenting records of currents measured recently at

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the instrumented tower of MCS and to consider their parameters in relation to those of upward lightning events measured in temperate regions.

2. Summary of events measured at MCS recently

Table 1 summarizes the total number of events, whose currents were measured at Morro do Cachimbo Station from the end of 2008 to April 2013, all of which of negative polarity.

Table 1 denotes some interesting aspects in light of the previous results of measurements at MCS, where practically all measured events consisted of cloud-to-ground negative lightning, as commented in Visacro et al. (2004).

First, the average number of flashes measured in this five-year period (4.4 flashes/year) is much lower than the historical average of 7 flashes/year (Visacro et al., 2004). At least partially, this low number is attributed to the loss of records associated to the station's operational failures that were frequent in 2008 and 2009. In the last two years, no records of lightning events have been lost and the number of measured flashes has increased (7 flashes from October 2012 to April 2013).

Secondly, the frequency of upward lightning has increased significantly. In particular, in 2011 four upward lightning events were recorded against only one negative downward lightning. All events occurred in November and December. Average daily temperatures are typically high these months, about 24 °C at the station. During the convective season in 2011, when the unusual number of upward lightning events occurred, it was over 3 °C lower than the historical values.

In addition, the currents of a large number of unconnected upward leaders have been measured recently, after the measuring system's trigger was set to 60 A. In most cases, such currents were limited to about 450 A, lower than the old system's trigger (800 A).

All the measured upward events, comprising both unconnected leaders (21 since 2011) and upward lightning (6 since November 2010), are negative, meaning that the charge displaced upward was positive.

3. Measuring facilities and instrumentation

Morro do Cachimbo Station (MCS) was installed in 1985 at the top of a mountain in the Brazilian Southeast. It boasts a 60-m-high free standing mast, supported by insulating wires. Two pairs of Pearson coils are installed at the tower base to measure the currents of strikes to the tower.

After the improvement of the measuring systems of MCS at the end of 2008, two redundant systems were installed in the main shelter of the station to record lightning currents within a range from 20 A to 200 kA, with a resolution of around 5 A in the 9-kA scale (for a noise level of ±10 A) and of 72 A in the 200-kA scale. The frequency limits of the coils are 0.25 Hz–4 MHz and 3 Hz–1.5 MHz. The coils feed an eight-channel data acquisition board with a sampling rate of 60 MS/s. The measuring system stores 1-s records of current, with a time resolution of 33 ns and a 30 ms pre-trigger period. It can also be configured to store 0.5 s long records with a 17 ns resolution and 15 ms pre-trigger period. Details of the measuring system are found in Visacro et al. (2010).

The electric-field-change measuring system, consisting of whip antennas horizontally installed 45 m away from the tower, detects the variation of the field associated to nearby strokes, up to 10 km away (Mazur and Ruhnke, 2008). The frequency limits of the system are 0.3 Hz and 50 kHz. A field mill installed in the station is used to measure the ambient electric field and to calibrate this system.

An optical sensor installed on the main shelter roof, 20 m away from the tower and 4 m above the ground, is pointed to the tower top to record the changes of luminosity at the channel base.

A single data-acquisition board installed in the main shelter records the synchronized data obtained from the whip antennas, field mill and optical sensor, along with GPS information, at a sampling rate of 100 kS/s.

A FASTCAM-X 1280 PCI high-speed digital camera had been installed in a secondary shelter, 600 m away from the tower. It was set to acquire 4-s continuous video-records of the strikes to the tower at a rate of 4000 frames/s. The detection of a 200-A threshold current flowing along the tower was used to command the transmission of a communication signal to the secondary shelter to trigger the camera.

All the measuring systems were synchronized by GPS.

Table 1
Summary of records of currents measured recently at MCS (negative polarity).

Event	Number	Percentage
Total number of records	42	100%
Associated with downward lightning	36	86%
Connected leaders (flashes since 2008)	15	36%
Unconnected upward leaders (since 2011)	21	50%
Upward lightning (since 2010)	6	14%

4. Typical profiles of lightning currents

In order to characterize the typical profiles of currents of lightning events, records of currents measured recently at MCS are presented along with details of their pre-return stroke phase.

Fig. 1 shows the record of current of a first return stroke in a negative cloud-to-ground lightning measured at MCS. The current's profile is typical, except for the peak about 60 kA, higher than the median value of 45 kA (Visacro et al., 2004, 2012), though values up to 153 kA were measured there in 2008 (Visacro et al., 2012).

Typical first-stroke currents start with a slow concave-shaped front followed by an abrupt rise around the half-peak. This leads to the first peak, followed by a second peak, usually higher than the first. Then, the current decays slowly with some subsidiary peaks, ceasing typically before 1 ms. A few milliseconds prior to the return stroke, the record of current shows a sequence of unipolar pulses of current (from 20 to 200 A) with an average interpeak interval in the range of 30 to 60 μs, as commented by Visacro et al. (2010). Presumably such positive pulses are developed in response to the steps of the downward leader approaching the ground. A few hundred microseconds prior to the return stroke, an uprising continuous current appears. The pulses continue, now superimposed on this current. The evolution of the process leads to the return stroke.