ON LIGHTNING CURRENT PROBABILITY DISTRIBUTION FROM SOUTHEASTERN BRAZILIAN MEASUREMENTS

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ABSTRACT: The estimated peak-current amplitude of brazilian southeastern lightning occurrences measured by LPATS, from 1988 to 1995, is analysed here. So the Log–Normal and the three parameter Weibull Probability Density Functions are used to investigate this data set. This work identified $\sim 62\%$ of negative, $\sim 37\%$ of positive and $\sim 1\%$. of bipolar lightning flashes. The mode of negative flashes is higher than the mode of positive ones. All lightning current distributions are leptokurtic distributions. The Log–Normal PDF fits better this current data set than the three parameter Weibull PDF. However, in consequence of its representative behaviour, the last one could be very usefull as an index for classification of thunderstorm events.

INTRODUCTION

In a few words, lightning consists basically of a high current ($\sim kA$), transient atmospheric electric discharge with a path length of about several kilometers. It is a consequence of a great amount of electric charge ($\sim$ 10 $-$ 100C) accumulated in the thunderclouds (cumulonimbus) and it occurs when the electric field exceeds locally the electric air insulation ($> 400\,kV/m$) – (Uman, 1987). Most of the fundamental physical processes of lightning are not well known yet. However a great amount of natural phenomena seem to follow a probability distribution function (PDF). So sometimes when an adequate PDF can be achieved, hidden physical mechanisms could be investigated or specific features could be quantified.

Adding a contribution to this understanding, this paper aims to examine two distribution functions: the more commonly used Log–Normal PDF (Wilks, 1995) and the recently improved three parameter Weibull PDF (Qiao and Tsokos, 1994, 1995). They are used to analyze the estimated peak-current amplitude of lightning flashes measured in the period from 1988 to 1995 in a wide region of the Southeastern Brazil. Thus concerning to the current distribution a result from the PDF comparison and some features of lightning are presented here.

DATA

During the last two decades, detection and location systems have been used in different parts of the world to determine the characteristics of cloud–to–ground lightning flashes. One of these systems, the Lightning Positioning and Tracking System (LPATS), is based on time–of–arrival of lightning electric signature (Bent and Lyons, 1984). This system records data of return stroke, which consist of date, time, sensors used to resolve stroke, latitude, longitude and estimated peak–current amplitude.

The data set used in this work, October–March (warm season) from 1988 – 1989 to 1994 – 1995, are from the Companhia Energética de Minas Gerais (CEMIG), Minas Gerais, Brazil. In this period the system worked with four sensors under the same technical condition (Diniz et al., 1996). In this work the region of strokes was limited to $14 - 23°$S and $39 - 52°$W to take advantage of estimated global efficiency of LPATS ($> 50\%$).

Lightning phenomena should be analysed as a whole because strokes are not an isolated element in the physical processes. For these analyses it was necessary to recuperate lightning flashes from stroke records through a numerical process, named lightning classification (Mendes and Domingues, 1998). So the following empirical criteria were adopted for the time and distance between strokes: subsequent strokes in a flash were considered to be within $500ms$ of the previous stroke and within $2s$ and $10km$ of the first stroke (Cook and Casper, 1992; Pinto et al., 1996). In this classification no restriction was imposed on the polarity of subsequent strokes, allowing to join strokes with different polarities in the same lightning (the so called bipolar lightning). For positive lightning perhaps a contamination by non-cloud-to-ground lightning occurs below $15kA$ (Zaima et al., 1997). However, no correction for this effect is made here.

METHODOLOGY

PDFs are abstract mathematical tools used to represent feature distribution of elements or events in a set of occurrences. Several PDFs have the properties of nonnegativity and positive skewness, that provide the adequate shape for the representation of lightning distributions. Among them there are: (1) the commonly used Log-normal PDF and (2) the flexible but laborious three parameter Weibull PDF.

The Log-Normal PDF is written as:

$$g(x;\sigma,\mu) = \frac{1}{x\,\sigma\sqrt{2\,\pi}} \exp\left[-\frac{(\log x - \mu)^2}{2\,\sigma^2}\right], \tag{1}$$

where x is the variable, μ and σ are the mean and standard deviation, respectively, of the variable $\log(x)$. It is often used in lightning research in order to provide distributions of some lightning measurements (Cianos and Pierce, 1972; Uman, 1987).

The other function is the Weibull PDF written as:

$$f(x;x_0,\alpha,\beta) = \alpha\frac{(x - x_0)^{\alpha-1}}{\beta^\alpha} \exp\left[-\left(\frac{x - x_0}{\beta}\right)^\alpha\right], \tag{2}$$

where x is the variable, x_0, α and β are the location, shape and scale parameters, respectively, and $(x - x_0) \geq 0$, $\alpha > 0$, $\beta > 0$. It has the advantage of having three adjustable parameters which allow to model satisfactorily several sets of measured data; but fitting parameters for the Weibull distribution requires interative methods. Recently this PDF was improved by new techninques of parameter estimation (Qiao and Tsokos, 1994, 1995).

So this work uses a large data set and does a lightning classification before any stroke distribution analysis. Next, using this adequate approach, it takes into account the single stroke flashes and the first to the fifth stroke of multiple stroke flashes for both positive and negative lightning. Finally, concerning to the estimated peak-current distribution this work examines those distribution functions, analysing the performances and some characteristics, and also allows to obtain some features of these brazilian lightning.

RESULTS AND DISCUSSIONS

This eigth year analysis identified $4,951,480$ flashes: $\sim$ 62% of negative polarity, $\sim$ 37% of positive polarity and $\sim$ 1% of bipolar polarity lightning. Due to the ambiguity and small percentage of bipolar lightning, only the negative and positive lightning are considered in this study.

Lightning flashes can be formed by multiple strokes. Figure 1 presents the distribution of strokes per flash. The $\sim$ 69% of lightning flashes consist of only one stroke (single stroke). Negative flashes present more multiple events than the positive ones. Although the multiplicity distribution for negative flashes seems to obey a discrete exponential-kind PDF, a fitting for multiplicity was not found yet.

Figures 2 and 3 present the current distribution for negative and positive flashes, respectively. According to the importance of the multiplicity discussed earlier, from the identified lightning flashes the first five strokes in multiple flashes and the single stroke are analysed. All distribution are leptokurtic, although the shapes of higher order strokes seem to be platykurtic due to the figure scale. The mode of higher order strokes presents a tendency to shift slightly to low values of current. For all order of stroke in negative lightning the mode ($\sim 20\,kA$) is higher than the mode for positive lightning ($\sim 10\,kA$).

Table 1 shows the calculated distribution parameters of Log–Normal and three parameter Weibull PDF for negative flashes. For positive flashes there is a similar result. A calculation is made for negative and positive flashes taking into account the first five and three strokes, respectively. The Log-Normal PDF gives a better fit to the analysed data set than the three parameter Weibull (an example is shown in Figure 4).

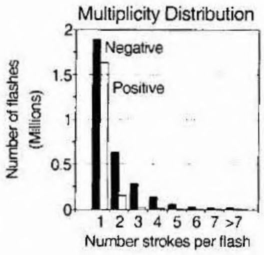

Figure 1. Flash Distribution.

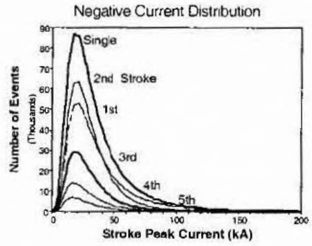

Figure 2. Negative Current Distribution.

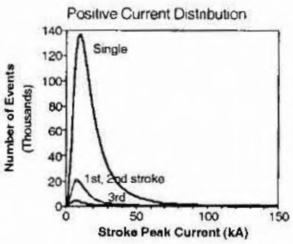

Figure 3. Positive Current Distribution.

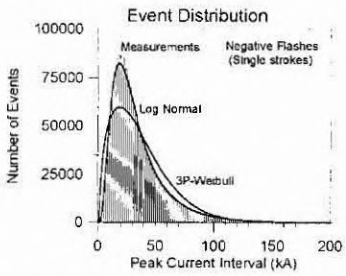

Figure 4. PDFs.

TABLE 1. Parameters of Probability Density Function from Negative Flashes, Oct.–Mar., 1988–1995.

Stroke	Log–Normal		3p Weibull		
	μ	σ	x_0	α	β
Single	1.453	0.292	~ 5	1.427	38.713
$1^{st.}$	1.478	0.286	~ 5	1.449	40.896
$2^{nd.}$	1.413	0.242	~ 5	1.768	33.196
$3^{rd.}$	1.404	0.247	~ 5	1.721	32.668
$4^{th.}$	1.393	0.256	~ 5	1.651	32.241
$5^{th.}$	1.379	0.257	~ 5	1.635	31.201

CONCLUSIONS

The data distribution shows that for all order of stroke the mode of negative ligthning is higher than the mode for positive lightning and the mode of higher order strokes shift slightly to lower values of current. All strokes present leptokurtic distribution.

The Log–Normal PDF fits better this current data set than the three parameters Weibull PDF. However, in consequence of its representative behaviour, the last one could be very usefull as an index for classification of thunderstorm events.

So this work motivates the investigation of other physical features of lightning and also contributes to a preliminary picture of climatology of lightning in brazilian region.

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