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SPATIAL DISTRIBUTION OF LIGHTNING STRIKES IN THE STATE OF PARANÁ, BRAZIL

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Abstract:
The annual spatial distribution of lightning strikes in the State of Paraná, Brazil, for the years 2012 to 2015 was analyzed using spatial statistics tools to determine the level of correlation between the areal number of strikes and the topography, and the distribution of strikes in different years. A topographic map and maps of the density of lightning strikes were compared using Pearson's correlation coefficient. Results suggest a weak or non-existent correlation between the number of strikes and altitude, and between the spatial distribution of lightning strikes for different years.

Keywords: Lightning discharges; spatial statitics; correlation.

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Introduction:

It is estimated that at any given time there are about 1000 to 2000 thunderstorms in progress simultaneously over the surface of Earth [Volland 1984; Uman 1987], resulting in a global discharge rate of 30 to 100 strikes every second. Because of their widespread occurrence and the energy delivered by each event, lightning strikes are a leading cause of weather-related fatalities [Cardoso et al. 2014]. Lightning strikes also cause important economic losses; they may affect power lines, initiate wildfires and disrupt many aspects of modern life [Curran et al. 1997]. Thus, as a matter of public and economic safety, it is important to have a good knowledge of the spatial and temporal distribution of lightning strikes.

It is known that topography has an effect on atmospheric circulation [Egger and Hoinka 1992], the occurrence of precipitation [Baopu 1995], and the climate [Murakami 1987]. In this light, a correlation between the occurrence of lightning strikes and ground relief is also expected. Several authors have investigated this question. For instance Pinto Jr. et al. (1999) reported the existence of a statistically significant correlation between the number of lightning strikes and altitude over Southeast Brazil; and Wagner et al. (2006) observed a correlation between strikes and altitude when the wind direction and frequency are also taken into account. However, Bourscheidt et al. (2009) found no significant correlation between the occurrence of lightning strikes and topography over the State of Rio Grande do Sul, Brazil.

In this study, the existence of a correlation between lightning strikes and topography was investigated by comparing maps of annual distribution of lightning strikes and a topographic map of the State of Paraná using spatial statistical tests

Methodology:

In Brazil, the detection of lightning strikes is carried out by the National Integrated Network for the Detection of Atmospheric Discharges (RINDAT). RINDAT has a network of detectors distributed throughout most of the country. Two types of detectors are used by RINDAT: the lightning position and tracking system (LPATS) and improved accuracy from combined technology (IMPACT). LPATS detectors are based on the time-of-arrival technology (TOA), which measures the time of occurrence of radio signals produced by strikes. If a strike is detected by detectors located on at least three different sites, its location can be determined by triangulation. IMPACT detectors combine the TOA technology with magnetic direction finding (MDF) technology to obtain better precision in determining the position of a strike. In the State of Paraná, the RINDAT has a detection efficiency equal to or better than 90%, average location accuracy of 500 m, and time accuracy of 300 ns [Lima and Gomes 2009].

The lightning strike data sets analyzed in this study were provided by SIMEPAR (Paraná's Meteorological System) and consisted of tables containing the position and time of occurrence of each strike detected within the State of Paraná by RINDAT. Maps (raster files) showing the number of lightning strikes per km² (density) per year were prepared for the years 2012 to 2015. A topographic map of the State of Paraná was also prepared using the same resolution (1' x 1') as the strike density maps.

The correlation and similarity between the topographic and lightning strike density maps were analyzed using Pearson's correlation coefficient (ρ) [Brundson and Comber 2015].The coefficient ρ is a measure of the statistical dependence between altitude and the number of lightning strikes, and the number of strikes that occurred in different years at the same geographical location. The level of significance of this test was set at an alpha level of 0.05 ($P < 0.05$).

Resultados e Discussão:

A topographic map of the State of Paraná is shown in Figure 1. The area of the state is approximately 199709 km². Paraná's geography is characterized by plateaus with altitudes as high as 1000 m, with the highest elevation in the state being Pico do Paraná (1877 m; 25.249722° S, 48.813056° W). Landforms, orography and land use are diverse. The coastal plains are narrow (width, 20 km) and delimited to the West by the Serra do Mar mountain range. Paraná's climate is subtropical with average annual temperatures ranging from 17° C to 20° C and an average precipitation ranging from 1200 mm to 1500 mm annually [Maack 1981].

The annual distribution of lightning strikes over the State of Paraná for the years 2012 to 2015 is shown in Figure 2. Basic data (total number and average areal density) related to the strikes recorded by RINDAT are listed in Table 1.

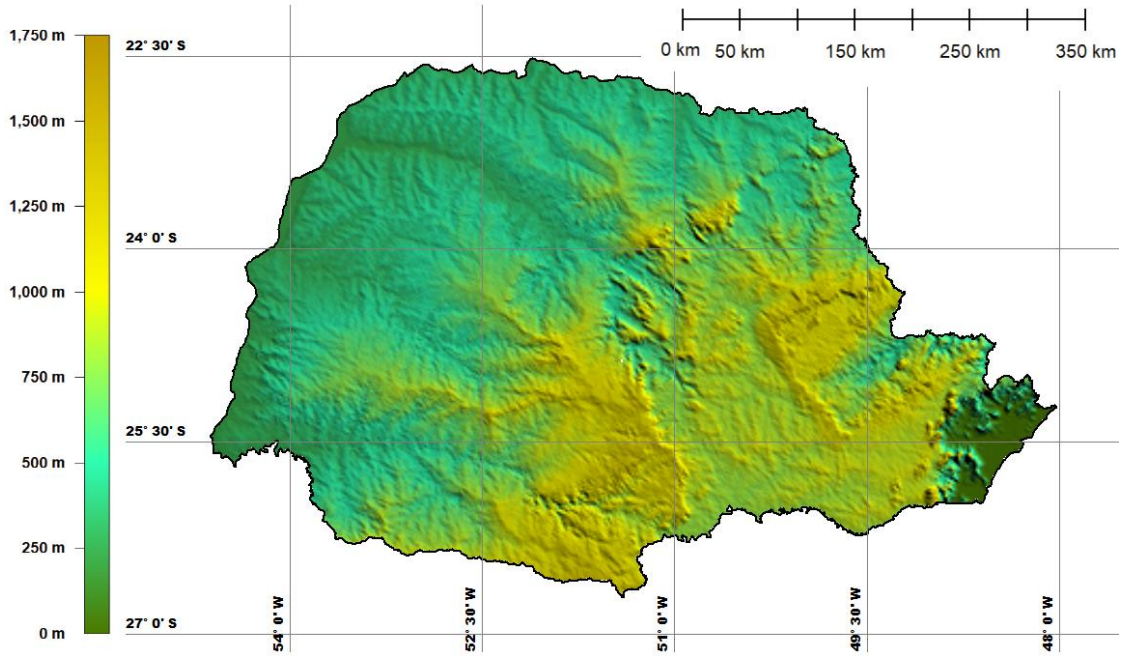

Figure 1. Map of the State of Paraná. The blue and red diamonds indicate locations where the number of recorded lightning strikes was relatively high.

Table 1. Total number and average density of lightning strikes

	2012	2013	2014	2015
Total number of strikes	1171241	1303589	1514887	1887280
Average density (strikes/km^2)	5.86	6.52	7.56	9.45

The results listed in Table 1 and a visual inspection of Figures 1 and 2 clearly show that there is a large variability in both the number and distribution of lightning strikes. Consistently, a large number of strikes occurred in the Serra do Mar mountain range and the region surrounding the highest peak in the state (Pico Paraná, marked with a blue diamond in Figure 1). This is a consequence of storms formed over the Serra do Mar caused by orographic effects. Over the remaining areas of the state, the distribution of lightning strikes does not seem to follow a pattern, except for a location (marked by a red diamond in Figure 1; altitude, 950 m) that experienced a large number of lightning strikes during 2012 and 2014, and the southwest part of the state where the density of strikes seem to be lower than average.

The results of Peason's correlation test are summarized in Table 2. This test was used to determine the correlation between altitude and density of strikes, and compare the density of strikes in different years. This test was carried out using the raster files (matrices with 402 columns and 258 rows) used to prepare the maps in Figures 1 and 2.

Results in Table 2 suggest an overall weak correlation between the distribution of strikes and altitude and between strike distributions in different years.

Figure 3 shows examples of plots for the correlation between the elements of the raster files used to make the maps in Figures 1 and 2. The values were obtained by pairing the elements of the data matrices. Although the results in Table 2 indicate a weak correlation between the data, the results in Figure 3 facilitate its interpretation since the random nature of the phenomena is easily visualized.

Table 2. Pearson's correlation (ρ) values between strike density and altitude

	2012	2013	2014	2015	Altitude
2012	1.00	0.10	0.03	0.19	-0.04
2013	0.10	1.00	0.19	0.27	-0.31
2014	0.02	0.19	1.00	0.16	-0.12
2015	0.19	0.27	0.16	1.00	-0.31
Altitude	-0.04	-0.31	-0.12	-0.31	1.00

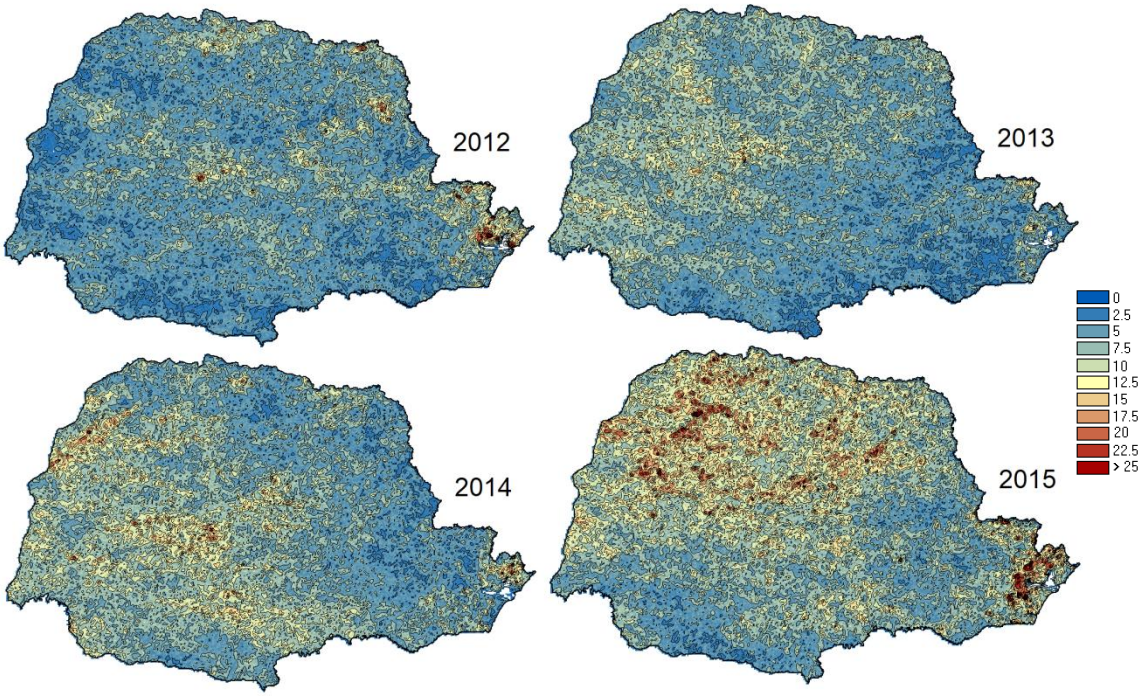

Figure 2. Distribution of lightning strikes over the State of Paraná for the years 2012, 2013, 2014 and 2015.

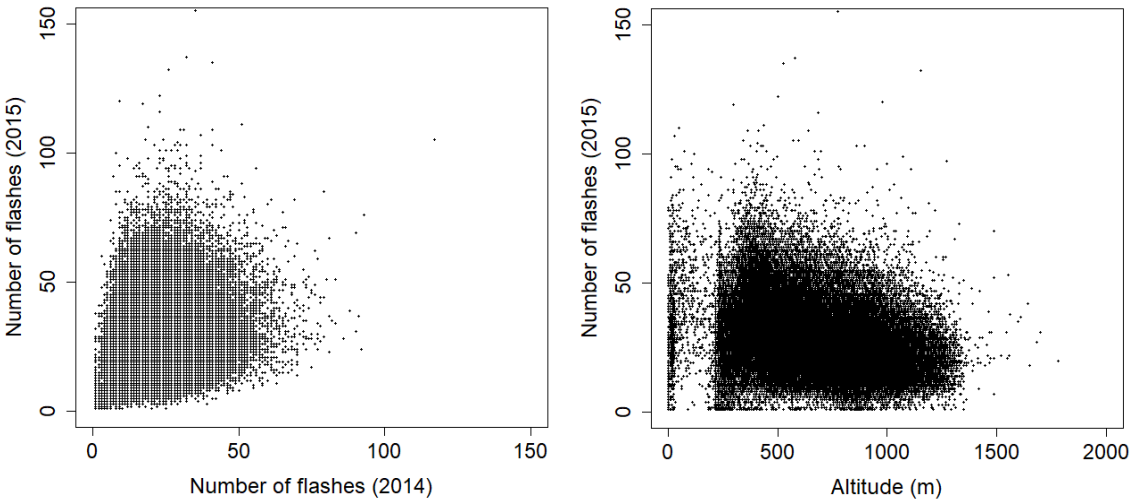

Figure 3. Correlation between the density of strikes for the years 2014 and 2015 (left), and between density of strikes in 2015 and altitude (right).

Conclusions:

Although the sample was limited (4 years of lightning data), no strong correlation was found between the density of lightning strikes and altitude. There were areas, such as Serra do Mar and a few other locations, where the strike density was higher than average. Also, a low strike density was observed in the southwest part of the state. But when the overall annual strike density distribution was compared, a significant annual variation

was observed, especially in the central and northern areas of the state. This is relevant because it demonstrates the high variability and the random nature of the occurrence of lightning strikes, which limits the ability to forecast the occurrence of these events.

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