APPLICATION OF A DETECTION EFFICIENCY MODEL TO CORRECT CLOUD-TO-GROUND FLASH DENSITY MAPS IN SOUTHEASTERN BRAZIL

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1. INTRODUCTION

Cloud-to-ground flash density maps have been published in the literature since the lightning detection networks (LDN) began to operate in different countries around the world. However, none of these maps were corrected due to variations of the network detection efficiency (DE) over all the network coverage area. Basically, the DE depends on the peak current distribution (PCD) of the flashes and the relative location of the sensors, called network geometry (Cummins et al. 1995).

Several approaches for developing a detection efficiency model (DEM) were already proposed: Schulz and Diendorfer, 1996; Murphy et al., 2002; Rompala et al. 2003. All of them use a set of lightning data reported by the network to compute the relative detection efficiency (RDE) of the same network. Since the lightning dataset used as reference is collected over areas with known high detections efficiencies, the RDE assessed can be roughly approximated to the absolute detection efficiency (ADE). Schulz and Diendorfer (1996) consider the RDE of each network sensor in terms of the peak current and distance. Using these individual probability distributions, the DE of the network is computed based on the combined probability of each sensor to detect a stroke, considering its peak current intensity and distance from the sensor. Of course, the propagation effects are intrinsically taken into account, since the sensors RDE are computed based on stroke data detected by the network for different distances. Murphy et al. (2002) uses a very simple approach to estimate the improvement in the NLDN detection efficiency due to the 2002 upgrade. Two sets of lightning data were analyzed: one before and other after the upgrade for the same area and period of time. The cumulative PCD was then computed for the two datasets and the early PCD (before the upgrade) was fitted to the new PCD (after the upgrade), which was considered the reference (100% DE). The ratio between the reference PCD and the fitted PCD represents the RDE improvement of the network. Rompala et al. (2003) developed a method to estimate the DE contours for the Rondonian lightning detection network in Brazil. They first selected an area in the center of the network (composed only by 4 IMPACT sensors) that they assume to have the best DE. This region is called central quad (QUAD). The PCD for the lightning data in the QUAD is then computed and adjusted to a theoretical probability distribution function (PDF), which is considered to be representative of the event distribution at any location over the region. After that, the coverage area of the network is divided in blocks (cells) of a specified size and the PCD is computed for all the lightning data detected in each cell of this grid. The reference PCD is then applied to each cell to assess what proportion of the set would be detected at each of these points. Finally, the cell DE is taken as the ratio of the computed values and the total number of events.

This paper presents an alternate approach for a DEM, which combines the Murphy and Rompala methods. The result is a very simple method for computational implementation that can effectively assess the RDE of a LDN with relative high accuracy. Of course, like any other method that requires real lightning datasets, this DEM is highly dependent on the number of detected events to provide accurate results. Also, the higher the number of events, the longer will be the computational time.

2. THE DETECTION EFFICIENCY MODEL (DEM)

The LDN used to develop the DEM is shown in Figure 1. It is a hybrid network composed by 22 sensors: 11 LPATS III, 6 LPATS IV, and 5 IMPACT 141-T. This sensor network differs from the actual 25-sensors network, which has 3 new IMPACT ES/ESP added in 2001 and 2002. However, the old network was chosen because it remains unchanged since October/1998, thereby leading to a 5-year uniform CG lightning dataset (from October/1998 to October/2003). The CG lightning data was reprocessed using a central processing configuration that requires only 4-time information to compute the solutions. Of course, the 3 new IMPACT sensors were excluded from the solutions after 2001/2002 to keep the same sensor network configuration throughout the 5 years. Almost 13 millions CG lightning flashes were detected by the 22-sensor LDN in the 5-year dataset.

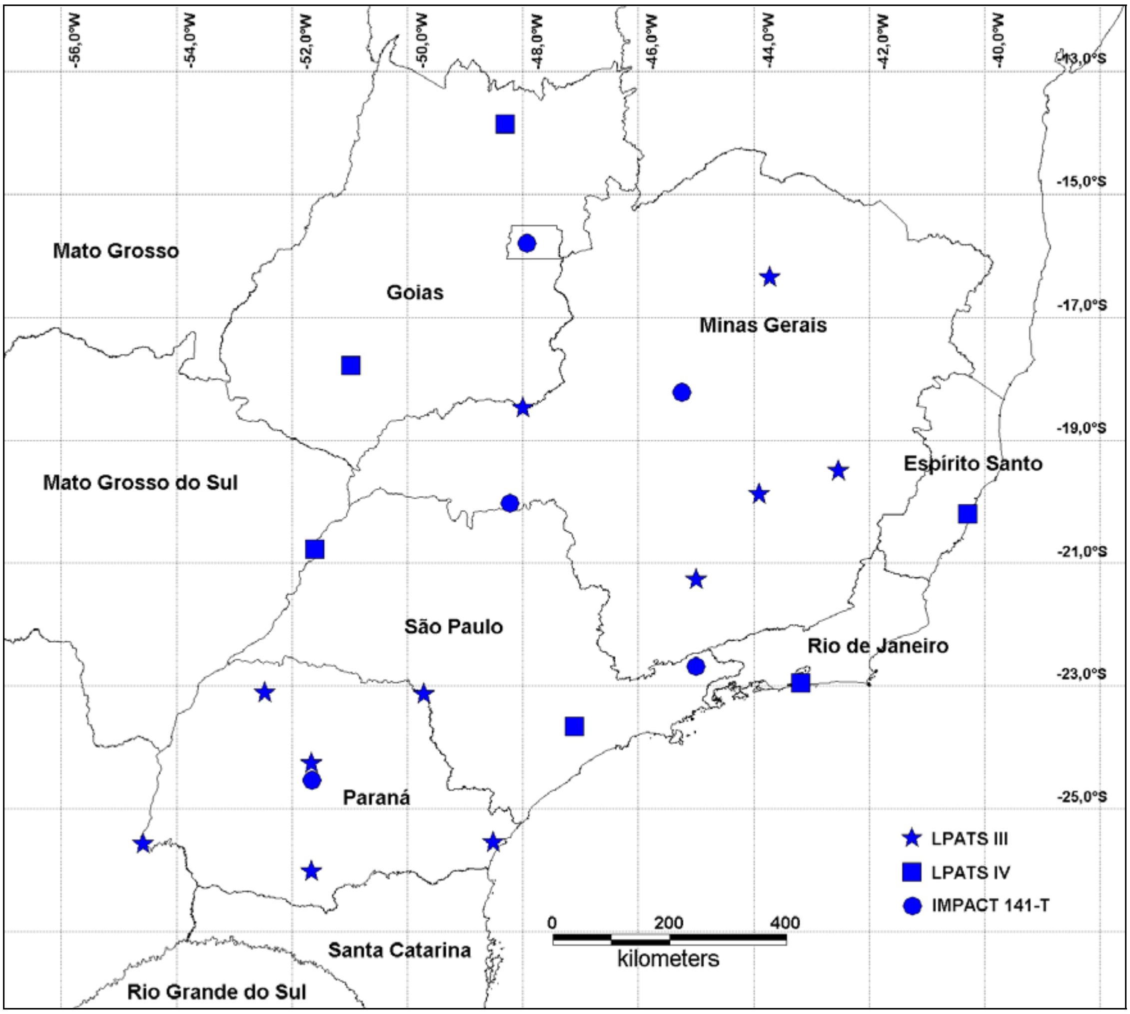

Figure 1. The 22-sensor hybrid LDN used in the development of the DEM.

Figure 2 presents the QUAD area used for the computation of the reference cumulative PCD. This area (with 450 x 450 km) was chosen in a region that is known to have a high network DE. Over 1.2 million CG flashes (exactly 1,255,667) were detected in the QUAD region, resulting in the reference cumulative PCD, shown in Figure 3. This distribution was normalized to the total number of detected events and represents the proportion of events above a specified peak current value.

The coverage area of the LDN was defined as a rectangular area that extends 150km away from the outmost sensors, located at north, south, east, and west (also shown in Figure 2). The resulting region has 1,800 x 1,700km and covers about 90% of the actual LDN coverage area. Over 10 million (exactly 10,409,502) CG flashes were detected in this rectangular region, which was then divided in blocks of 50 x 50km and the number of lightning events was computed for each block (or cell). In order to guarantee a good statistical significance, the number of events for each cell is calculated as the sum of the events of the 8 surrounding cells plus the events of the cell itself. As a result, the average number of events for each cell was 73,205. Then, the PCD for each cell is computed individually and adjusted to the reference PCD, using a minimum chi-square fitting method. Figure 3 illustrates the reference PCD, the PCD for a specified cell and the adjusted PCD. The ratio between the adjusted and the reference PCD at the 0kA point correspond to the RDE of the network at that cell. In this case, the RDE was 0.7436 or 74.36%.

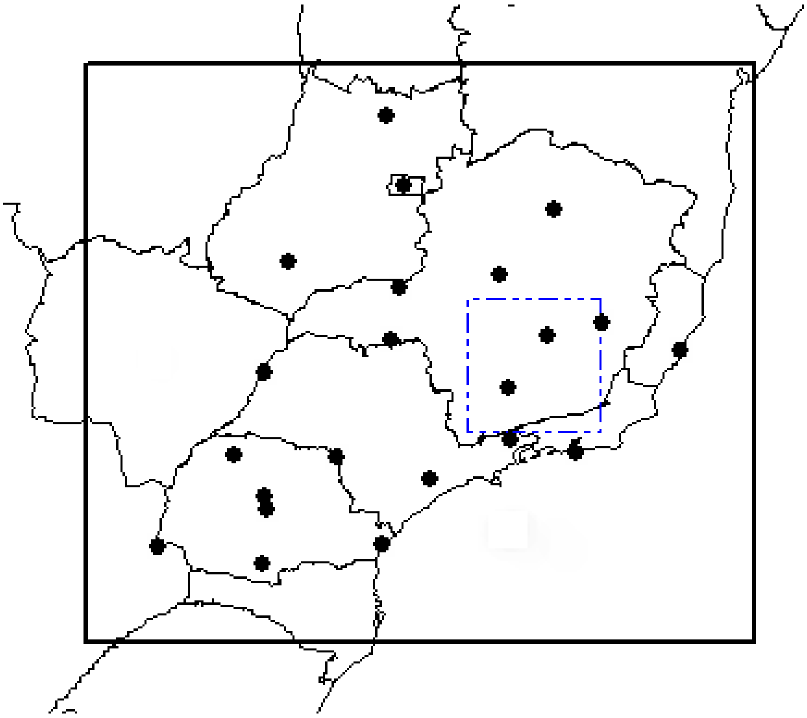

Figure 2. Definition of the QUAD area (dashed blue line) with 450 x 450km used to compute the reference cumulative PCD. The black rectangle defines the model coverage area of the LDN, which extends 150km away from the outmost sensors.

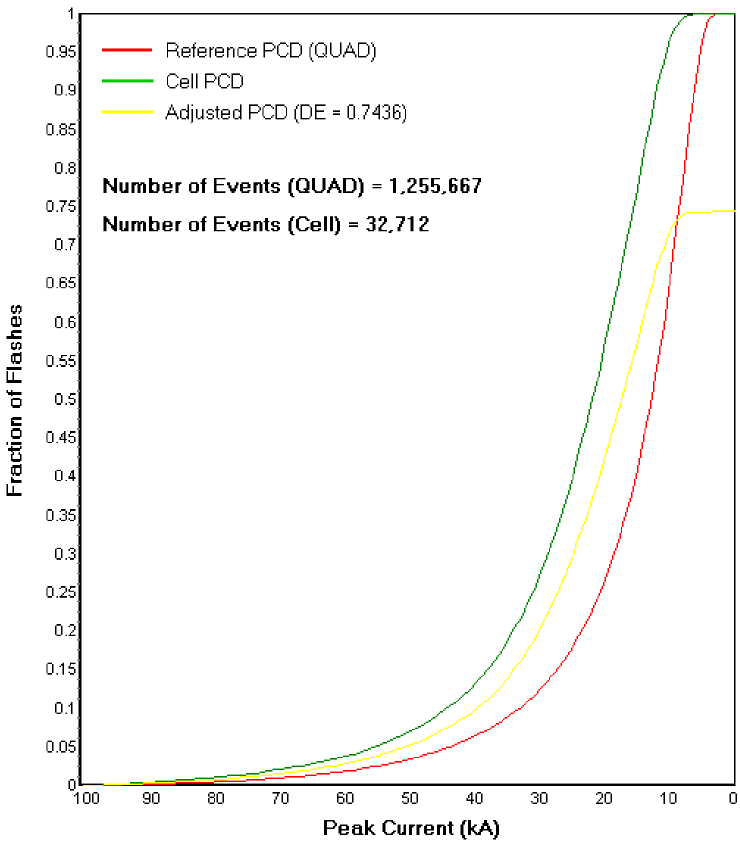

Figure 3. Peak current distributions (PCDs) for the QUAD area (red) and for a particular cell of the grid (green). The adjusted PCD (yellow) was computed using the minimum chi-square fitting method.

3. RESULTS AND DISCUSSIONS

Figure 4 presents the DE map for the DEM described above. Since this model provides the RDE of the network, the red color represents the region of maximum DE, or, 100%. One can see that the model can identify the regions of maximum DE and then describe the continuous decrease in the DE as one gets far away from the sensors. In addition, regions outside the network have DE values below 55%. It is important to note that the south region (state of Paraná) has a DE of about 70-80% despite the great number of sensors. There are two possible explanations for this result: (1) the shape of the country in this area (which is too narrow) leads to a deprived network geometry, which reduces the ANSR (average network sensor reporting) as shown by Naccarato et al. (2003); (2) the lack of IMPACT sensors (only one) in all state of Paraná and south of São Paulo.

Another aspect found in Figure 4 was the low DE (about 55%) in State of Goiás, despite the 3 sensors installed in that area. Analyzing the number of days that each network sensor was operational, those 3 sensors in Goiás were down about 35% of the 5-year period thus affecting the DEM result. This fact also reveals the dependence of the DEM on the operational status of the sensors. However, for the south region, it was found that the 6 sensors in state of Paraná were up for about 97% of the 5-year period. Hence, this could not explain the slightly reduction of the DE in the State of Paraná, which might be related to the factors described above.

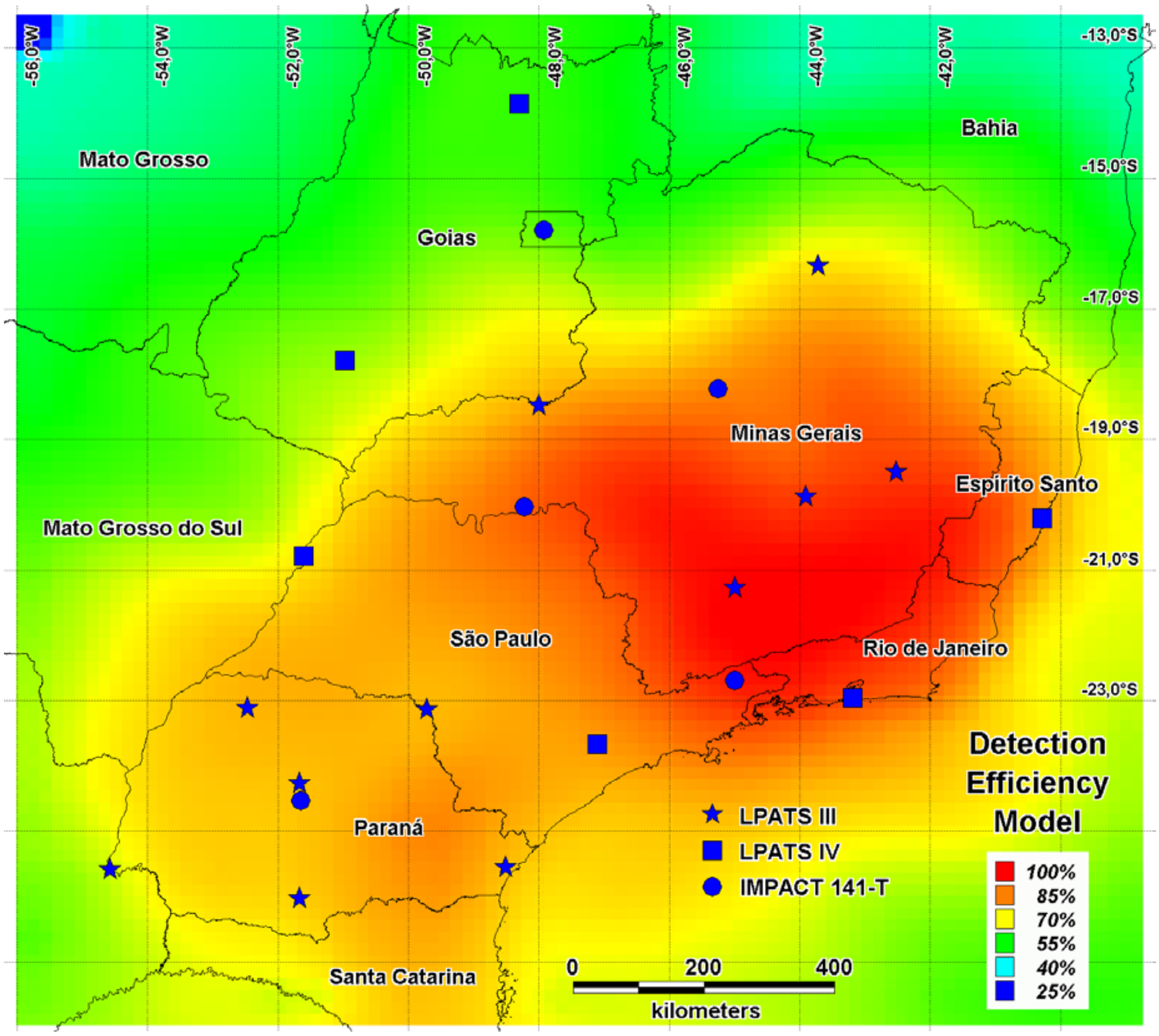

Figure 4. Map of the DE computed by the model for the 22-sensor hybrid LDN. The grid resolution is 50 x 50km.

These results can then be used to correct CG flash density maps in order to minimize the relative geographical variation associated to the network geometry. Thus, relative differences on the CG flash density should be most likely due to physical factors than to the influence of the LDN. Figure 5 shows CG flash density map without correction (original map) for the defined rectangular coverage area. This map was obtained only by a 5-summers CG lightning flash dataset (from 1999 to 2003) that comprises about 10 millions events. The summer season was extended to a 6-month period (from October of one year to March of the next year), which characterizes the lightning season in the network coverage area. Since this lightning season stands for 80% of the CG lightning activity of the year, the values of the CG flash rates should be corrected by a factor of 1.25 to have them given in flashes / km^2.year. Figure 6 shows the same map of Figure 5 but now taking into account the RDE of the network (corrected map). Over 14 millions CG flashes were obtained after DE correction.

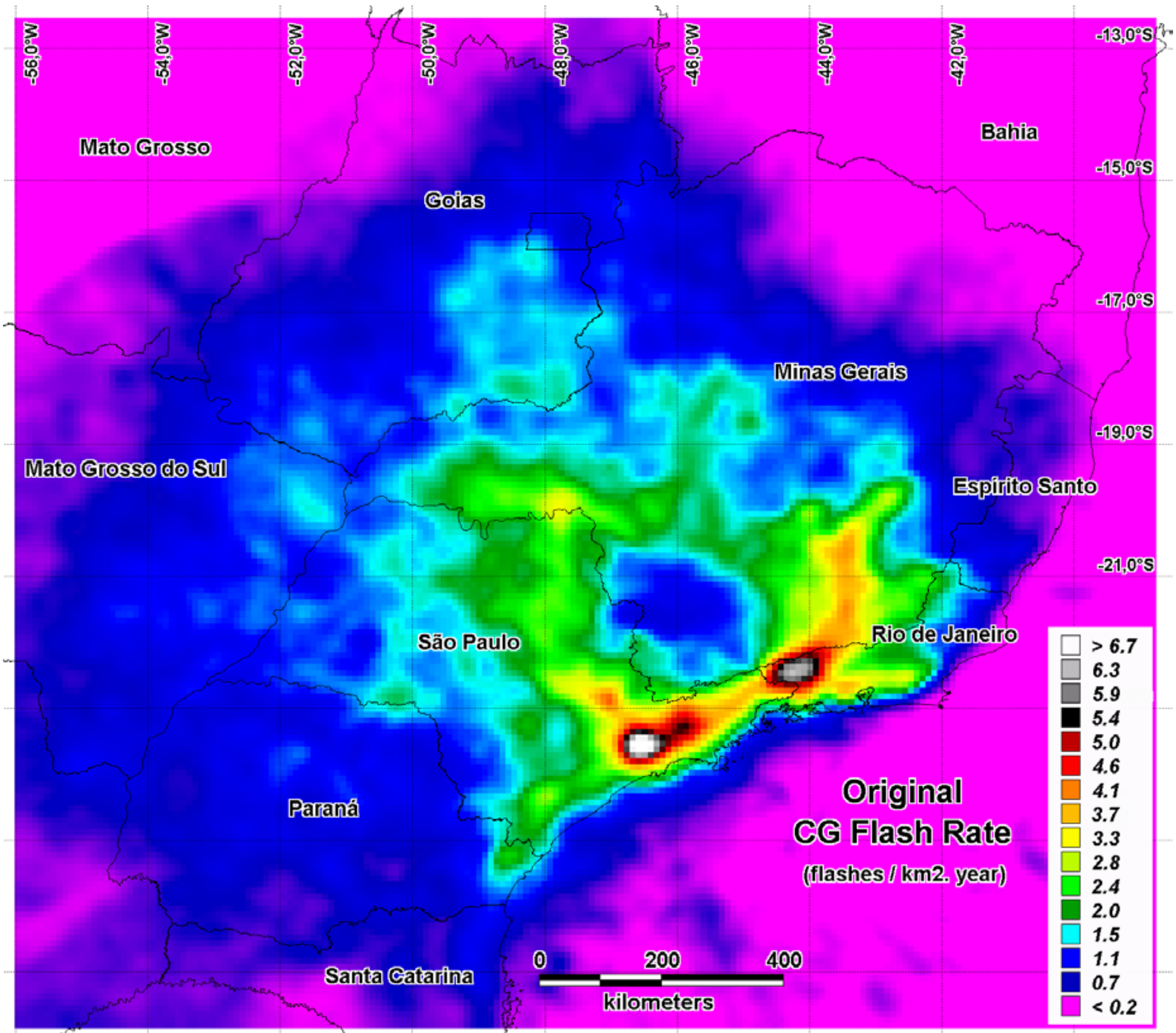

Figure 5. CG flash rates map (flashes / km^2.year) for a 5-summer lightning dataset (1999-2003) without correction by DE (original map). The grid resolution is 10 x 10km.

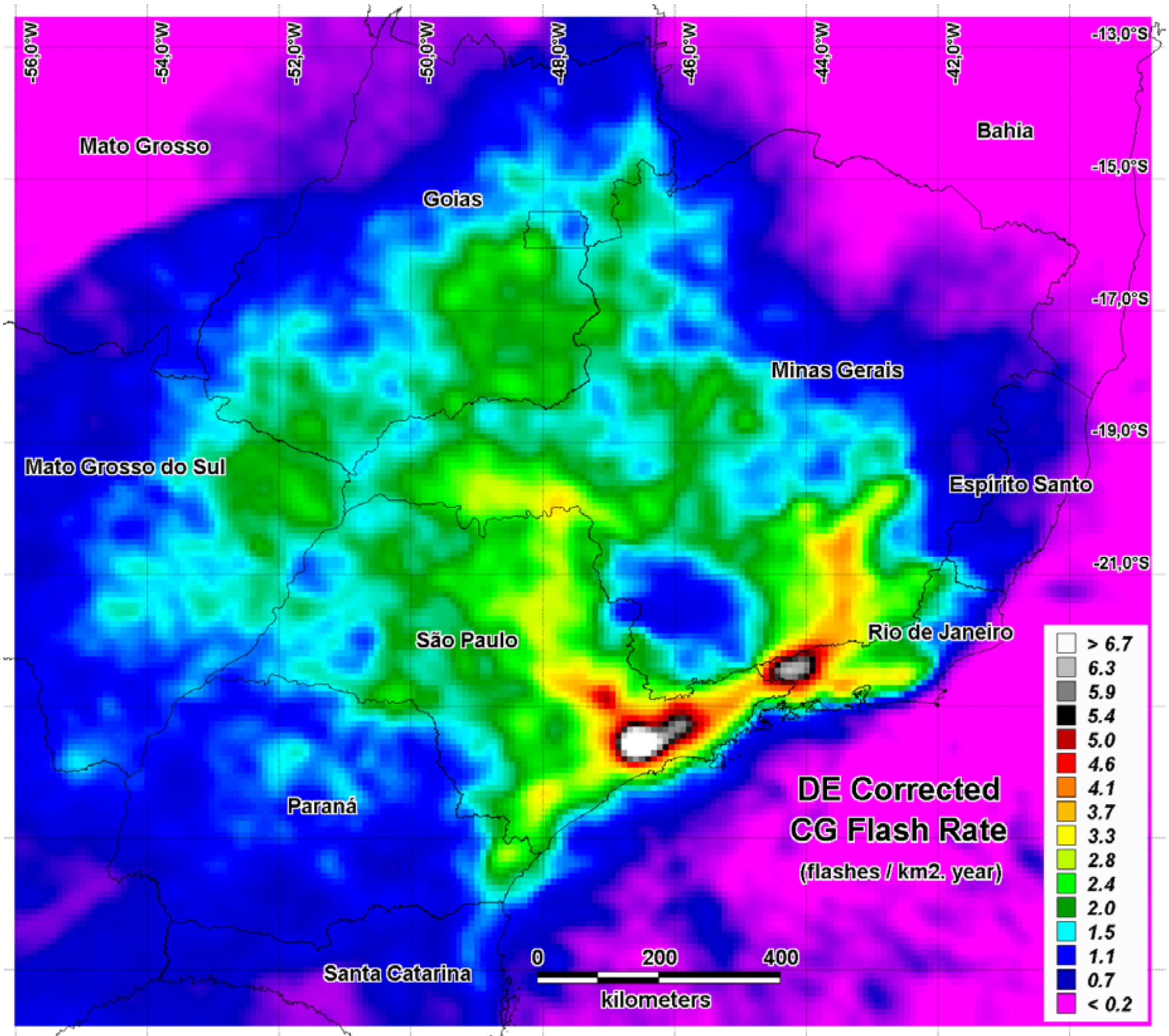

Figure 6. CG flash rates map (flashes / km^2.year) for a 5-summer lightning dataset (1999-2003) after correction by DE (corrected map). The grid resolution is 10 x 10km.

Comparing Figures 4 and 6, it can be noted that the correction of the number of events in a density map is effective only for regions with DE between 60% and 80%. For DE values smaller than 60%, the correction cannot counteract the reduced number of events detected by the network, leading to values slighter then expected. Hence, one can say that, for regions of lower DE values, it is quite impossible for a DEM to recover the CG lightning flash density which its closer to the actual values. By the other hand, for regions with high DE values (above 80%), the correction does not increase appreciably the number of events, again reducing the capacity of the DEM to approximately recover the actual values of CG flash rates.

In order to evaluate if the DEM reflects the real behavior of the DE for the LDN studied, the corrected CG flash density map was compared to the total lightning density map gathered by OTD/LIS sensors (shown in Figure 7) from April 1995 and February 2003. Comparing Figures 6 and 7, it seems that the DEM cannot actually retrieve the CG lightning rates for regions of low DE (< 60%). For the other areas, the DEM apparently well assesses the CG flash rates and its geographical distribution.

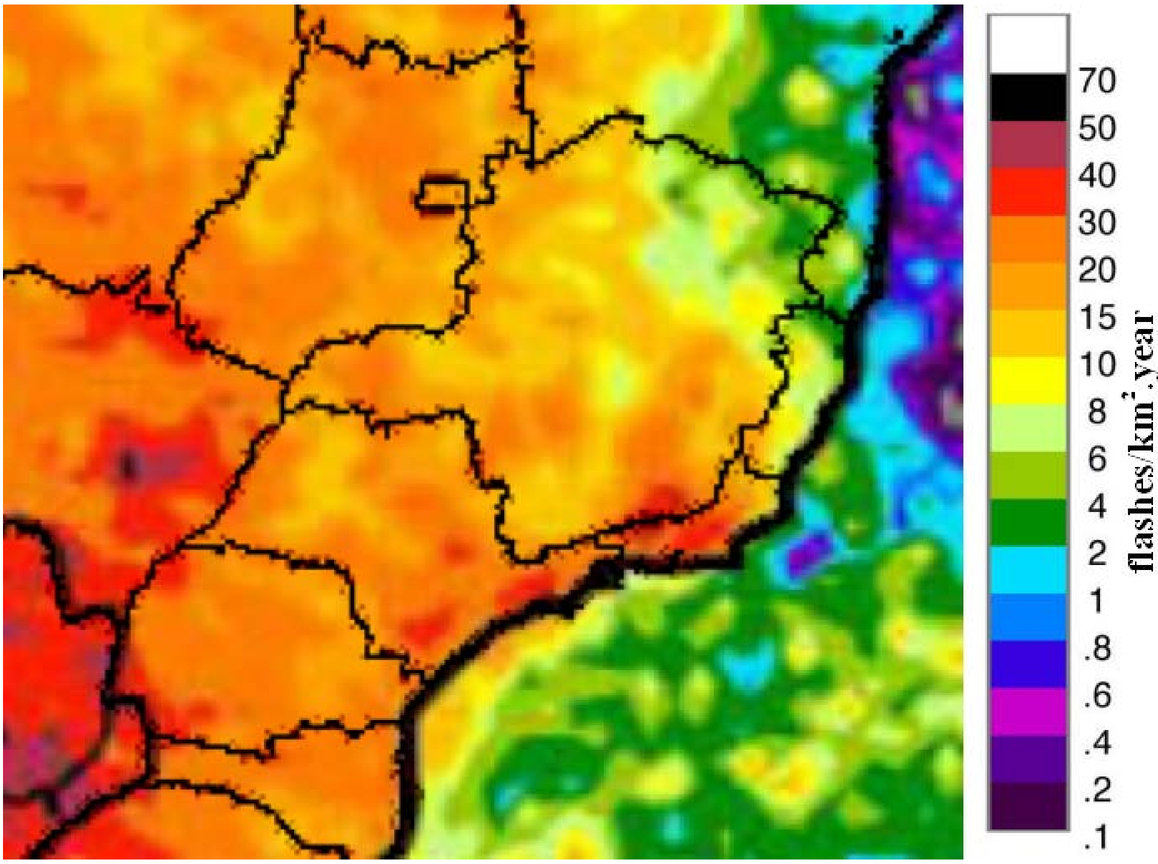

Figure 7. Total lightning flash rate map achieved by OTD/LIS sensors from Apr. 1995 to Feb. 2003. The grid resolution is approximately 55 x 55km.

4. CONCLUSIONS

It was presented an alternate approach for a DEM, which combines two other approaches proposed by Murphy et al. (2002) and Rompala et al. (2003). Over 10 millions CG lightning flashes detected by a 22-sensor hybrid LDN were used to compute the DE map. The results of the DEM roughly reflect the DE dependence on the network geometry and were used to correct a flash density map obtained from a 5-summer lightning flash dataset. It was observed that the DEM effectiveness in correcting CG flash density maps depends on the values of DE. The CG flash rates for regions with reduced DE values (< 60%) cannot be actually recovered. On the other hand, the lightning density correction for regions with higher DE (> 60%) appears to be successful, showing patterns in reasonable agreement with those observed by the OTD/LIS in 8 years of data.

In future works, it is planned to improve the DEM implementation by considering negative and positive flashes separately, by including the 3 new IMPACT sensors in the LDN, and by taken a greater CG lightning dataset. Eventually, the reduction of the grid and changes in the QUAD definition could also help verify the sensibility of the model in terms of the PCD of the CG lightning data.

5. ACKNOWLEGMENTS

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