Spatial and Temporal Patterns of Cloud-to-ground lightning in Portugal and their relationship with geographical factors

António Lopes[1], Eusébio Reis[1], Sandra Correia[1], Marcelo Fragoso[1], Ezequiel Correia[1]
[1]Institute of Geography and Spatial Planning/Centre of Geographical Studies, University of Lisbon, Portugal

Abstract. This work aims to present an overall characterization of the geographic incidence and temporal rhythms of lightning activity in mainland Portugal territory from 2003 to 2009. A brief characterization will focus on the cloud-to-ground lightning (CGL) activity, analyzing the total number of flashes, the temporal rhythms and annual spatial patterns. It was found a strong interannual variability among the seven-year period with regard the total number of flashes. The relationship between the CG flashes observed in 2003 and surface features (elevation and vegetation) will be investigated in more detail. The analysis between the different surface characteristics and flashes density served as input to build a database that will allow us to assess the social impacts of atmospheric lightning activity in Portugal.

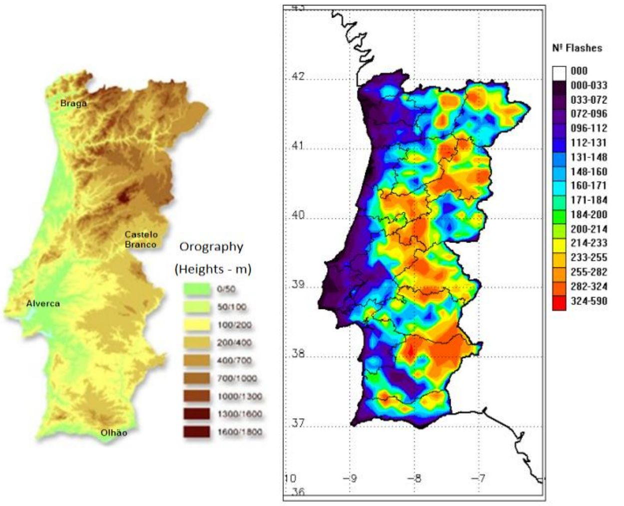
Introduction

Portugal is located in the western part of the Iberian Peninsula and has a Mediterranean climate. According to Köppen classification two main tempered climate regions can be observed from the 1961-91 normal's: one (predominantly in the south and interior of the country), with rainy winters and hot and dry summers (Csa); and another (Csb), also with rainy winters and dry but not so warm summers in the north and littoral areas more exposed to the Atlantic influence. The highlands (mountains and plateaus) prevail in the central/northern part of Portugal (fig. 1a), especially in the interior where altitude reaches 1993m asl (Serra da Estrela). The southern part of the country is predominantly plain, with lowlands, but the interior part of the Algarve region has two mountainous areas (Monchique - 902 m asl and Caldeirão – 580m asl).

The present research has been developed under the RAIDEN project (www.raiden-project.org) that aims to increase the scientific knowledge of lightning activity in Portugal. This research was started after the studies initiated in the Spanish regions of Iberian Peninsula (Rivas Soriano et al, 2005). The first steps in the Portuguese territory are very recent (Fragoso et al, 2010, Leite et al, 2010; Ramos et al, 2011, Santos et al, 2011).

Thunderstorms and lightning activity are very frequent in Portugal and can have severe impacts to humans and their activities. Several accidents and injuries have been reported in the last years. Just to mention the last two years (2010 and 2011), nine accidents took place over the territory, with a total of 38 victims (2 deaths and 7 injured). Among other events, one was largely divulged by the media (on the 24th April 2011), when 28 persons got stuck in a cable car in Guimarães (northern Portugal), because the power supply of the system was damaged by a "severe thunderstorm". One week before, another accident let in shock the city of Coruche (central Portugal), when an electrician worker was found dead after a lightning had hit him during a thunderstorm. Therefore, the impacts of CGL activity should not be neglected, and all the efforts should be made to recognize its spatial patterns and characteristics.

Figure 1b illustrates the overall spatial distribution of CGL activity (including negative and positive flashes) in Portugal between 2003 and 2009.



a) b)

Figure 1. a) Orography, and lightning sensors network in Portugal; b) Total amount of CG flashes between 2003 and 2009.

This pattern clearly shows that lightning activity is relatively strong in the interior of the country, while in the littoral areas it is generally much lower. The pattern of CG flashes clearly divides Portugal into its east-west halves (Fig.1b); the eastern half is more continental, with high lightning activity, while the western half is exposed to strong maritime influence and generally lower lightning activity. In the eastern half, two absolute maximums were identified, one in southern Portugal (over Alentejo) and another in the north interior.

Regarding the seasonal rhythm, the temporal distribution of CGL activity exhibits a maximum in late summer (September) and a minimum in winter. The diurnal cycle is marked by a maximum activity at mid-afternoon (16:00-17:00h). The interannual variability in the study period was quite stronger, and the maximum total number of CG flashes was registered in 2007 (equivalent to about the triple of the CG flashes in 2005). This strong interannual variability also regards the spatial distribution of CG flashes, whose patterns may show a higher activity over the interior southern regions, as occurred in 2005 and 2007, or over the northern mountainous areas, as it happened in 2003, 2004 and 2009. Positive flashes tend to be more destructive, as they are commonly (higher current intensity) than the negative flashes (Santos et al, 2011).

A more detailed quantitative and geospatial analysis, as well as the identification of the major effects of surface features (especially altitude and vegetation) on lightning activity in Portugal, are the main goals of this research. In order to assess those impacts a database containing the accidents (total victims, deaths, injuries, etc) was created, and added to the flashes database.

Data and methods

Since 2002, the Portuguese Institute of Meteorology has been operating a lightning network that comprises 4 sensors (Braga, Castelo-Branco, Alverca and Olhão – fig 1a). The first complete year is now analyzed (2003). The first attempt to correlate CG lightning activity and land cover classes was made with a 10x10km grid. Several layers were obtained to identify the relation between CGL and surface characteristics: a) CGL – the observations (2003) were summarized to each cell of 10x10 km grid; b) topography – this layer was obtained from SRTM/USGS (http://srtm.usgs.gov). With an original spatial horizontal resolution of 90m, altitudinal classes (0-100m, 100-250; and 250 m of increment on, until 2000 m asl) slopes and aspects were derived; b) vegetation – monthly NDVI composites were averaged for the whole year of 2003. This information was retrieved from the Deutschen Zentrum für Luft- und Raumfahrt (DLR) EOWEB portal (eoweb.dlr.de:8080/index.html). NDVI data was derived from NOAA-16, NOAA-17 and NOAA-18 AVHRR satellites (http://eoweb.dlr.de/short_guide/D-NDVI.html).

All operations of rescaling grey values to NDVI and georeferencing were made with a raster GIS (Idrisi, v15.0). All data was resampled to a 10x10 km grid. In a future research all data will be resampled to a 1x1grid. After the construction of the databases, several regression techniques were used, in order to establish possible causes between the CGL activity and the surface variables.

Results and discussion

As can be seen in table 1, all the parameters of the analyzed year (2003) are below the average (2003-2009), and less than half the total occurrence of 2007, when a maximum annual occurred in the period. Therefore, 2003 was a relative low CGL activity year in relation to the others during that period.

Surfaces can act as trigger convection. Several authors state that two factors can have a strong influence on that process: vegetation and altitude (Dissing and Verbyla, 2003; Bourscheidt et al, 2009). For that reason, these two factors were studied and will be presented in this analysis.

Because of the grid size that was used in this preliminary study (10x10km), other important physiographic variables (like aspects, slopes and other topographic features) were not analyzed. This should be done with smaller grids size (1x1 km).

Primarily results with 10x10 km grid show a good non linear correlation between altitudinal classes and total flash observation and densities. This can be seen especially in the northern part of the country (fig.2).

Table 1. Comparison between the characteristics of CGL in 2003 and the period of the network operation (2003-2009).

CGL general statistics (10x10 km grid)					
Year/ period	Max. occur.in a grid	Avg	Max density CG/km^2	Avg density CG/km^2	Total occur. (+)and(-)
2003	142.0	20.3	1.5	0.21	20532
2003-2009 (avg.)	186.3	25.9	2.0	0.27	26259
2007*	330.0	45.6	3.4	0.47	46009

* Year with more total CGL occurrences in the period 2003-2009. Source: Portuguese Institute of Meteorology.

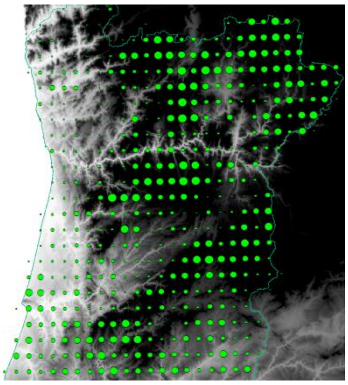


Figure 2. Total CGL observations in the mountainous northern part of Portugal (2003). The circles are proportional to total CGL.

This relation is generally positive up to a maximum average altitude of 1000 m and negative above that altitude (fig.3), although a second peak can be observed in the class 1250-1500 m (this can be related to the grid size effect). Above this altitude CGL activity seems to be very scarce or absent.

However, these elevations can be underestimated because the large grid size computes lower altitude values over a large area.

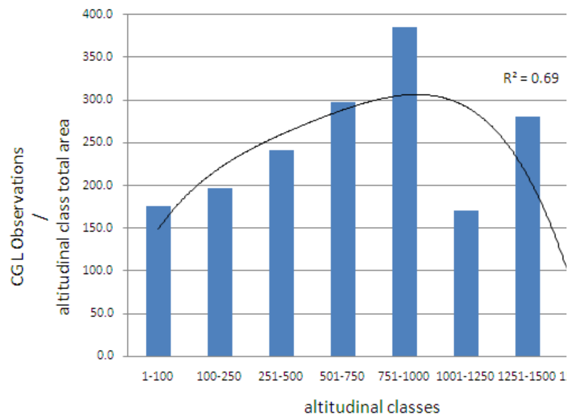


Figure 3. Total CGL observations per total area of each altitudinal class.

Forests can also affect the environment conducive to thunderstorms and consequently lightning activity, by means of heat fluxes, although it can be less important than elevation factor. NDVI was used to correlate the vegetation effect with CGL observations. As can be seen in figure 4, the great CG density occurs in areas of NDVI between 0.3 and 0.5 (96%), suggesting also a good relation with forest areas. Low NDVI, corresponding to urban and other mineralized surfaces without vegetation and water bodies, shows, comparatively, lower CG flashes density. However more investigation is needed to assess the influence of these surfaces.

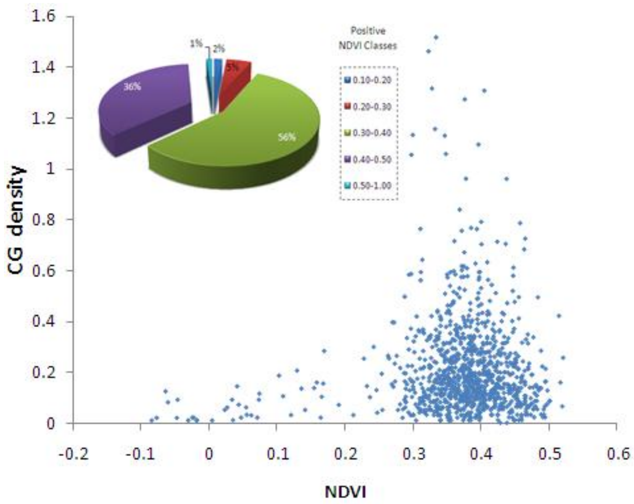


Figure 4. Relation between CGL density and NDVI.

The relation between the total observations per class of NDVI and the areas of each class was also analyzed (fig.5). It became clear the influence of vegetation on the total lightning flashes and the result is a very good model of this relation. With typical values of NDVI between 0.30 and 0.50, is clearly seen that forests have an important role in this system.

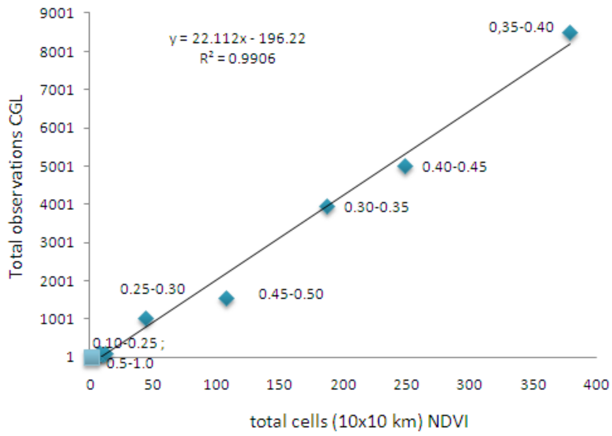


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Figure 5. Relation between the total number of cells of each positive NDVI class and the total CGL observations.

Conclusions

In this study the relationship between cloud-to-ground lightnings registered in 2003, with elevation and vegetation, was examined. It was found that there is a positive correlation with altitude (up to a maximum of 1000/1500 m). It was also found a strong relation between CGL density and high values of a vegetation index (0.30<NVDI<0.50) with a maximum of flashes over areas with 0.35-0.40, which is consistent with other works (Dissing and Verbyla, 2003; Bourscheidt et al, 2009).

The next step of this research will extend these methods and results to the period 2003-2009, and will be conducted with a more fine resolution (1x1 km). This scale will allow us to analyze other layers of climatic information (heat fluxes, albedo, and surface temperatures among others), topographic derived models (slopes, aspect and other landform variables) and environmental state (burned areas, aridity, etc), that would be used to continue the research about CGL spatial distribution.

Acknowledgements

The current research was developed under the project "*Lightning Activity in Portugal: Variability Patterns and Socio-economic Impacts* (RAIDEN)", with contract number FCT: PTDC/CTE-ATM/101931/2008.

References

Bourscheidt, V.; Pinto Junior, O; Naccarato, K.; Pinto, I., The influence on the cloud-to-ground lightning density in south Brazil, in Atm. Res., 91, pp 508-513, 2009.

Dissing, D.; Verbyla, D., Spatial patterns of lightning strikes in the interior Alaska and their relation to elevation and vegetation, in Can. J. For. Res., 33, pp 770-782, 2003.

Fragoso, M., Leite, S.M., Corte-Real, J. and RAIDEN Project, Lightning atmospheric in Portugal: Patterns of

Variability and Socio-economic impacts, in II International Congress of Risk / Risk VI National Meeting, Coimbra, Portugal, 2010.

Leite, S.M., Santos, J.A., Pablo, F., Rivas, L., Tomás, C., Garcia, E., Fragoso, M. and RAIDEN Project, Contribution to the analysis of the distribution of cloud-ground flashes in the Iberian Peninsula, in II Workshop Climate and Natural Resources in Portuguese-speaking Countries, Book of Abstracts, Bragança. Portugal, 2010.

Ramos, A., Ramos, R., Sousa, P., Trigo, R.M., Janeira, M., Prior, V., Cloud to ground lightning activity over Portugal and its association with circulation weather types, in Atmospheric Research, 101, 84-101, 2011

Rivas Soriano, L., de Pablo, F., Tomas, C., Ten-year study of cloud-to-ground lightning activity in the Iberian Peninsula. In J. Atmos. Sol. Terr. Phys. 67, 1632–1639, 2005

Santos, J.A., Leite, S.M., Fragoso, M., Sousa, J., Reis, M., Correia, S. and RAIDEN Project, Lightning activity in Portugal: RAIDEN Project overview, in Geophysical Research Abstracts, vol. 13, EGU2011-2685-2, 2011