Atmospheric Research 166 (2015) 233–238

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Observed impact of land uses and soil types on cloud-to-ground lightning in Castilla-Leon (Spain)

Manuel Mora García [a], Jesús Riesco Martín [b], Luis Rivas Soriano [c], Fernando de Pablo Dávila [c,*]

[a] Spanish Meteorological Agency (AEMET), Oviedo, Spain
[b] Spanish Meteorological Agency (AEMET), Malaga, Spain
[c] Department of Atmospheric Physics, University of Salamanca, Salamanca, Spain

ARTICLE INFO

Article history:
Received 21 January 2015
Received in revised form 20 April 2015
Accepted 9 July 2015
Available online 21 July 2015

Keywords:
Lightning/land index
Land cover
Soil types

ABSTRACT

The impact of land use on lightning activity has mainly been studied for urban areas; however the number of authors addressing the impact of vegetation on lightning is fairly limited. The relationship of different types of land use and soil (thirteen categories of land use and fourteen major soil types were considered) on cloud-to-ground lightning activity was studied in the Spanish region of Castilla-León from 2000 to 2010. To do this, urban, mining, and industrial areas were found to be associated with enhanced CG-lightning activity. With respect to natural land uses, forest and shrubland were the categories where CG-lightning was seen to be increased. By contrast, non-agricultural vegetated areas and pastures displayed the lowest CG-lightning activity. When the major soil types are considered, rendzinas, podzols, and phaeozems were found to be associated with a slight increase in CG-lightning activity and gleysols and solonchaks seem to decrease it. Assuming there are a plethora of factors which can indirectly affect the charging electromicrophysics and cloud dynamics, the authors provide evidence that soil type shows a significant correlation on CG-lightning flash density and weather characteristics are affected by land uses. It is suggested that the influence of vegetation and soil on surface moisture is one of the main effects contributing to explain the impact of land cover on CG-lightning.

1. Introduction

Many studies (e.g. Pielke et al., 2011; Bounoua et al., 2010; Raddatz, 2007; Hirota et al., 2011; Giannakopoulou and Toumi, 2012) have reported that surface weather characteristics, even at large scale, are influenced by the moisture balances of the surface and the atmosphere and by the energy budget of the surface. The physiological and physical properties of the vegetation and their impact on soil moisture affect the transfer of heat, moisture, and momentum between the surface and the atmosphere. Arora and Boer (2014) stated that the main physiological parameters are leaf area, stomatal resistance, and rooting depth and that the main physical properties are albedo and surface roughness. There is a considerable body of literature that addresses the ways in which the land surface affects weather and climate (e.g. Raddatz, 2007 and references therein), including modeling (at global and regional scales) and observational studies. Almost all of these studies have focused on the effect of the transformation of natural vegetation.

The impact of land use on lightning activity has mainly been studied for urban areas. Increased cloud-to-ground lightning over urban areas and/or downwind has been reported both for large cities (e.g. Westcott, 2006; Kar and Liou, 2014) and small urban areas (Rivas Soriano and de Pablo, 2002). However, the number of authors addressing the impact of vegetation on lightning is fairly limited. Kilinc and Beringer (2007) analyzed the effect of vegetation on lightning in the Northern Territory of Australia and reported an increase in lightning strike density from woodland to shrubland to grassland, explaining this in terms of the greater surface heating of grassland with respect to other vegetation types. Kotroni and Lagouvardos (2008) studied the impact of the vegetation cover on lighting activity in the Mediterranean and found that for woodland areas, lightning increased while over bare ground lightning activity was low. They suggested that the maintenance of soil moisture in forested and wooded areas, especially during the Mediterranean dry, warm period, might explain their findings. Ray et al. (2011) reported that in agricultural areas adjacent to the natural vegetation in Southwest Australia, cumulus clouds were more frequent over areas with the highest soil moisture content. By contrast, we have not found any previous study exploring the impact of soil types on lightning activity, although the impact of lightning activity as a geomorphic agent has been studied (Knight and Grab, 2014). Nevertheless, some of the causes invoked to explain the influence of land use on lightning, as maintenance of soil moisture and greater surface heating, could also

* Corresponding author at: Departamento de Física de la Atmósfera, Facultad de Ciencias. Universidad de Salamanca, Pl. de la Merced s/n, 37008 Salamanca Spain. Tel.: +34 923294438.

E-mail addresses: mmoray@aemet.es (M. Mora García), jriescom@aemet.es (J. Riesco Martín), ljrs@usal.es (L. Rivas Soriano), fpd123@usal.es (F. de Pablo Dávila).

http://dx.doi.org/10.1016/j.atmosres.2015.07.009
0169-8095/

act for some soil types. In fact, Liu and Shao (2013) found that soil-layer has a great impact on the simulated atmospheric boundary layer dynamics. Lightning science is very complex, and in regards to the soil types, there is no demonstration of how the soil affects. It is known that the flash rates to ground are explicitly determined by a complex combination of physical (outside and within the cloud), kinematic, and dynamic processes occurring within the cloud, which give rise to electric fields structure conductive to cloud-to-ground lightning activity. However, the development of convective clouds is affected by the state of the boundary layer, which is influenced by the ground–atmosphere interaction which, in turns, depends on the soil type.

We note that the objective of present study is not to provide evidence of how environmental changes caused by land and soil types affect the electrical development of storms. Otherwise, we explore the relationship of different categories of land use, and for the first time soil types, on cloud-to-ground (CG) lightning activity in the Spanish territory of Castilla-Leon (CL, see Section 2). It is worth mentioning that CL is located on the Spanish plateau, which has been recognized as one of the regions in Europe of greatest frequency of severe thunderstorms (Brooks, 2013).

2. Area of study and data

The area considered in this study is CL, which is one of the 17 regions in which Spain is organized. It is located in the northwestern Iberian Peninsula (IP) (Fig. 1), extending from 40°N/1°W to 42°N/7°W, with a total area of 94,193 km^2. The orography of CL is complex. It is a plateau at approximately 700 m above the sea (the Northern Plateau of the IP), surrounded by mountain systems: the Cordillera Cantabrica (northern), the Sistema Ibérico (northern and northeastern), the Sistema Central (southern and southeastern), and the Portuguese mountains (western). The Duero is the most important river and it crosses the region from east to west.

The CG-lightning data used here belong to the time period spanning from 2000 to 2010. The lightning data were obtained from the lightning detection network operated by the Spanish Meteorological Agency (Agencia Estatal de Meteorologia, AEMET). This network consists in 15 sensors model IMPACT (14 in the IP and 1 in the Balearic Islands). In January 2003, 4 Portuguese sensors were incorporated to the network (Pérez Puebla, 2004). The probability of detecting a lightning flash occurring within an ellipse of 700 m^2 of area is 50%, 90% for an area of 2 km^2, and 99% if the area is lower than 5 km^2. Only the CG-lightning data of highest quality were considered in this study. To obtain these data, the full database was filtered taken (chi-square) $\chi^2 < 3$ as threshold value, and the major and minor semi-axes of the error ellipse of less than 1 and 0.5 km, respectively. From a total of 570,382 CG-lightning flashes counted by detection network over CL, the abovementioned filter retained 367,714.

Land use types and major soils were obtained from the CORINE land cover (CLC) raster data (CLC 2007 release, available at http://www.eea.europa.eu/data-and-maps/data/corine-land-cover-2006-raster) (Büttner et al., 2002) and AEMET (Fig. 2). This dataset provides a high-resolution description of land use patterns and major soils that Fig. 2 shows, which are numerous different categories, especially of soil types, in the domain studied. However, several categories cover small percentages of area in the studied zone, and their impact on CG-lightning activity is therefore expected to be no significant, and in consequence, they are not taken into account. We finally selected 13 categories of land use (urban, mining, industrial, non-agricultural vegetated areas, arable land, permanent crops, pastures, heterogeneous agricultural areas, forest, shrubland, open spaces, inland wetland, and water) (see Fig. 2b), and 16 of soil types (luvisol, litosol, combisol, regosol, gleysol, rendzina, ranker, arenosol, fluvisol, acrisol, podzol, vertisol, solonchak, solonetz, kastanozem, phaeozem) (see Fig. 2a) present in the domain studied at a spatial resolution of 100×100 m^2. Information about the characteristics of the different soil types can be found in Driessen et al. (2001).

3. Results and discussion

The spatial pattern of CG-flash density in CL is depicted in Fig. 3. The mean flash density is 0.5 fl km^{-2} yr^{-1}, ranging from 0 fl km^{-2} yr^{-1} to 3.4 fl km^{-2} yr^{-1}, and Fig. 3a shows that CG-lightning activity tended to be concentrated over mountainous areas. Generally, lightning strike frequency increases with increased land surface elevation (i.e. mountain height) and shows strong seasonal and diurnal patterns related to the timing of the most intense convective storms (Rivas Soriano et al., 2005; Mattos and Machado, 2011). This is clearly seen in Fig. 3b, where the relationship between the total (2000–2010) CG-flash density and altitude is shown. CG-lightning activity increases from 750 m to approximately 2100 m. It is worth mentioning that altitudes higher than 2100 m and lower than 700 m are rare in CL. It should be noted that the outlier point is over 2500 m, which is probably caused by the very small area of the domain studied with altitude around 2500 m. The increase of convective activity over complex terrain has been reported in a number of studies (e.g. Barthlott et al., 2006; Santos et al., 2013),

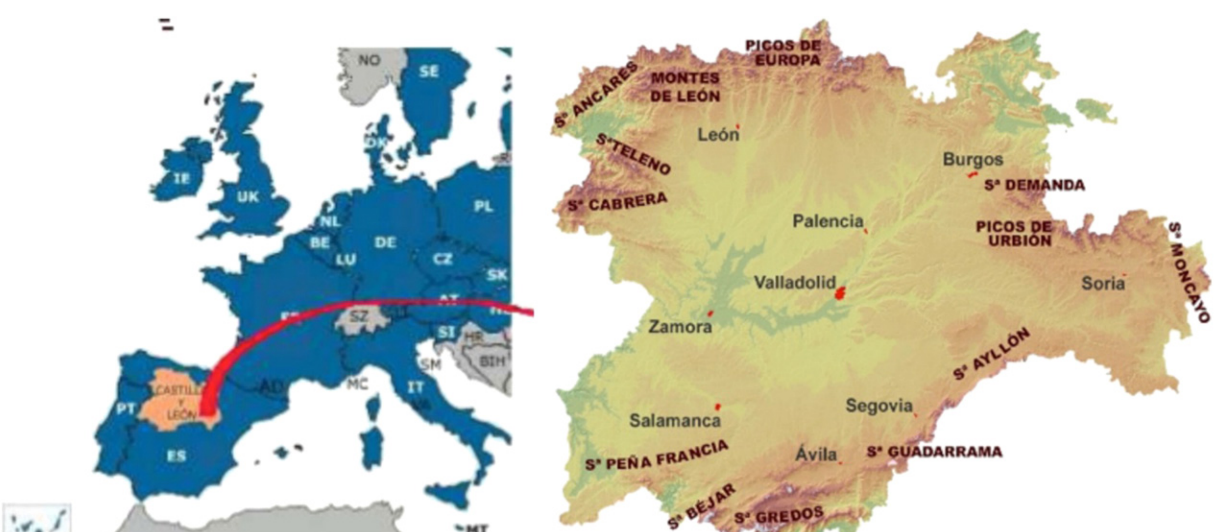

Fig. 1. Left: Location of the study area. Right: Orography of Castilla-Leon.