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A ten-year analysis of cloud-to-ground lightning activity over the Eastern Mediterranean region

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ABSTRACT

Lightning activity is analysed in a sector covering the Eastern Mediterranean (16–32°E, 34–46°N) for the years 2005–2014. The study is based on the use of cloud-to-ground (CG) lightning activity data retrieved from ZEUS system, operated by the National Observatory of Athens, and examines the seasonal, diurnal and spatial variability of the lightning activity. The effect of elevation, terrain slope, vegetation cover and convective available potential energy (CAPE) on the distribution of the CG lightning strokes is also investigated. Lightning is modulated by the diurnal cycle of insolation and the underlying topographic features of the region. The lightning strokes are more numerous over the mainland than over the sea. CG lightning activity is dominant over the land and the coastal areas during spring and summer while during the coldest period of the year it is dominant over the sea. The maximum value of lightning activity is observed in June and mostly in the afternoon. The orography and the terrain slope affect the distribution of lightning. During the warmest period of the year, the forested areas have an increased "lightning yield". The number of CG lightning strokes increases with increasing CAPE and the high correlation between them indicates that CAPE values could be used as a proxy for the presence of lightning activity, at least over the eastern Mediterranean region.

1. Introduction

The analysis of the spatiotemporal distribution of lightning has been the subject of numerous studies. Holt et al. (2001) presented a lightning climatology over Europe for the years 1990–1999 and pointed out the orographic influence on the spatial distribution of lightning. Anderson and Klugmann (2014) investigated the spatial distribution of lightning activity throughout Europe for the years 2008–2012. They found that the lightning activity follows the yearly insolation and occurs in different places relative to the season of the year. During the coldest months, lightning occurs mainly over the Mediterranean Sea, while in the warmest months it occurs mainly over land. Defer et al. (2005) who analysed cold period cases of lightning activity over the Eastern Mediterranean found that cloud-to-ground (CG) flashes were mostly located over the sea and CG density was found to follow the North African and Turkish shorelines. Katsanos et al. (2007) have also shown that during autumn and winter the lightning activity occurs over the maritime area and near the coasts, delineating the Mediterranean coastline. The occurrence of winter storms is related with the advection of unstable and cold air masses over the relatively warm Mediterranean water and resemble with the winter thunderstorm over the Sea of Japan (Kitagawa and Michimoto, 1994; Shalev et al., 2011; Yair et al., 2014; Ziv et al., 2009). Shalev et al. (2011) studied the spatio-temporal distribution of lightning activity over Israel and the neighbouring area and pointed out the high density of lightning activity over the Mediterranean Sea. Chronis (2012) studied the regional, seasonal and diurnal variability of the CG lightning activity over Greece with one year data, which were derived from the lightning detection network of the Hellenic National Meteorological Service, and concluded that the maximum lightning occurrence is from 15:00 to 18:00 local time over land. Nastos et al. (2014) using data from 2008 to 2009 from the same local network indicated that the seasonal distribution of lightning activity coincides well with the regional climatic convective characteristics of Greece.

A number of studies have been also devoted to the investigation of the relation of lightning with the physiographic characteristics. Soriano et al. (2001) highlighted the dependence of lightning in Castilla–Leon (Spain) with orography. Soriano et al. (2005) indicated the strong correlation between the distribution of CG lightning activity and orography over the Iberian Peninsula. Mazarakis et al. (2008) investigated the lightning activity over Greece during the warm season (May–September) of the years 2003–06, using data from the Met Office Arrival Time Difference system and found that the lightning activity

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increases with elevation along the slopes of terrain features. Kotroni and Lagouvardos (2008) studied the lightning activity in the Mediterranean and the relation with physiographic features, using one year of data (June 2006 – May 2007) derived from ZEUS system, and found that there is a strong correlation between the lightning activity and the terrain slope. Bourscheidt et al. (2009) concluded that terrain slope has a greater effect in storms and lightning activity than elevation, in South Brazil. Goswami et al. (2010) revealed that the steep topographic gradient rather than altitude is responsible for producing deep convection. Santos et al. (2013) analysed the climatology of lightning activity over the Iberian Peninsula for the period from 2003 to 2009 and the effect of various forcing factors in the lightning occurrence, including terrain elevation. They indicated that the lightning activity occurs predominantly over land and is associated with orographic lifting, during the warmest months, while it occurs over the Mediterranean Sea and is linked with near-surface thermal contrasts, during the coldest months.

Furthermore, some studies link the lightning activity and the associated convection with vegetation. O'Neal (1996) studied the relationship between land cover and convective clouds over the Midwest USA and argued that deciduous forests on the hills have significantly greater cloud cover than those in flat areas, while farmlands located in flat areas have more cloud cover than those in hilly areas. In northern Australia, Kilinc and Beringer (2007) revealed that there was a noticeable difference in the distribution of the CG lightning strokes on the various types of vegetation. Kotroni and Lagouvardos (2008) found that the forested areas present an increased potential for producing lightning activity.

Lightning activity has been additionally studied relatively to the thermodynamic structure of the troposphere. Indeed, the convective available potential energy (CAPE) affects the updraft velocity in deep convective systems and determines the electrical charge separation rates in the thunderstorms clouds (Williams, 1995). Ziv et al. (2009) examined the main atmospheric factors controlling lightning activity over Israel and the adjacent sea and found out that the thermodynamic factors play the main role in the lightning activity in comparison with the dynamic factors. Several studies focused on the relationship between lightning activity and CAPE and found a noticeable increase in lightning activity with increasing CAPE values (e.g. Goswami et al., 2010; Kucienska et al., 2014; Mazarakis et al., 2008; Pawar et al., 2012). Romps et al. (2014) stated that the lightning flash rate is proportional to CAPE times the precipitation rate in the United States and thus CAPE value can be used for the prediction of the initialization and intensification of thunderstorms. More recently, CAPE has been successfully used by Giannaros et al. (2015) in their work on lightning forecasting in order to better delineate the areas were lightning is expected. Finally in a climate context, CAPE has been used as a proxy for the study of the projected changes in lightning activity by Boorman et al. (2010). The authors tried to predict future changes in the lightning activity in the UK, using a threshold for the daily maximum CAPE (250 J/kg), below which lightning is assumed not to occur, and found increase in the projected number of lightning days during the 21st century.

The current study focuses on the analysis of lightning activity during a 10-year period (2005–2014) over a sector of the Eastern Mediterranean that includes the major part of the Balkan Peninsula (16–32°E, 34–46°N). The purpose of this study is twofold: (a) to determine the lightning climatology, including the mean spatial and temporal distributions and the daily and monthly variability of the CG lightning over the Eastern Mediterranean region; (b) to investigate the influence of the forcing factors (elevation, terrain slope, vegetation and CAPE) on lightning activity. The next sections of the paper are structured as follows: Section 2 describes the data used in this work. Section 3 presents the results of the spatial and temporal distribution of lightning over the Eastern Mediterranean and the analysis relating the CG lightning strokes with the physiographic characteristic and the CAPE. Section 4 is devoted to the concluding remarks.

2. Data and methodology

The CG lightning data used in this study are provided by ZEUS long-range lightning detection system, which is operated by the National Observatory of Athens. ZEUS system comprises six receivers in Europe located in Birmingham (UK), Roskilde (Denmark), Iasi (Romania), Larnaka (Cyprus), Athens (Greece) and Lisbon (Portugal) that has been relocated to Mazagon (Spain) in 2014. ZEUS detects the impulsive radio noise emitted by a lightning stroke in the Very Low Frequency (VLF) spectrum between 7 and 15 kHz. In the VLF portion of the radio spectrum, sferics propagate thousands of kilometres through the earth-ionosphere waveguide. The lightning location is retrieved by using the arrival time difference triangulation technique. The detection efficiency of ZEUS is of the order of 25% while the location error is about 6.5 km (Lagouvardos et al., 2009). The detection efficiency has not changed throughout the period as the number of sensors of ZEUS system has not changed either. The same authors underlined the tendency of ZEUS to under-detect lightning during the night. While ZEUS does not detect all the lightning strokes, it allows the real-time detection and the location of the active thunderstorms (Lagouvardos et al., 2009; Price et al., 2011). For further details on ZEUS see also Kotroni and Lagouvardos (2008).

The study period spans from 2005 to 2014. This 10-year long database contains some small gaps from individual days of missing data (but not continuous periods) that correspond to less than 5% of the total number of days. The percentage of the missing data is too short to jeopardize the robustness of the results. The lightning data have been distributed in $0.1° \times 0.1°$ grid boxes for the needs of the analysis.

For the analysis of the relation of lightning activity with the physiographic characteristics of the study area, elevation and vegetation data have been derived from www.ngdc.noaa.gov/mgg/topo/globe.html (GLOBE Task Team and others et al., 1999) and www.landcover.org (Hansen et al., 2000) respectively, with a resolution of 30 arcs. The vegetation database includes 14 categories: evergreen needleleaf forest, evergreen broadleaf forest, deciduous needleleaf forest, deciduous broadleaf forest, mixed cover, woodland, wooded grassland, closed shrubland, open shrubland, grassland, cropland, bare ground, urban and water bodies. The slope data were calculated from the elevation database with the method described by Burrough (1986). For the analysis of the influence of physiographic features (topography, terrain slope, vegetation cover) on the lightning activity the aforementioned datasets have been upscaled from 30 arcs to the $0.1° \times 0.1°$ grid by attributing at each grid point the mean value of altitude and terrain slope and the dominant vegetation cover. The CAPE dataset is obtained from the European Centre for Medium range Weather Forecasts (ECMWF) at a resolution of $0.5° \times 0.5°$ and at 6 h intervals (00:00, 06:00, 12:00 and 18:00 UTC) for the whole study period.

The analysis domain has been restricted in the area 16–32°E, 34–46°N (Fig. 1a). The study area includes part of the Eastern Mediterranean: Greece, Albania, FYROM, Bulgaria, Bosnia and Herzegovina, Montenegro, west Turkey and part of Romania, Serbia and Croatia. It is surrounded by the southeastern Adriatic Sea, the Ionian Sea, the Aegean Sea, the western region of the Black Sea and the western Levantine Sea. Within this area the land surface equals the surface of maritime areas so as to facilitate the discussion about the distribution of lightning activity over land compared to that over sea.

3. Results and discussion

3.1. Spatial distribution of lightning activity

The annual cloud-to-ground stroke density (strokes/km^2/year) over the study domain range from 0.1 up to 6 strokes/km^2/year (Fig. 1b).The highest densities are detected over the land, while over the sea lightning occurrence is more frequent over the central part of the Ionian Sea and the coastal areas of the west Balkans (Fig. 1b). The highest stroke