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On the seasonal variability and the spatial distribution of lightning activity over the broader Greek area and their connection to atmospheric circulation

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ABSTRACT

The spatio-temporal regime of lightning strokes over the broader Greek area is studied using 15-day ZEUS cloud-to-ground lightning data for a 10-year period (2005–14). The multivariate statistical method Factor Analysis (S-mode and T-mode) is applied on the mean intra-annual variation of lightning in order to reveal: i) the main modes of intra-annual variation of lighting activity that correspond to specific sub-regions of the Greek area and ii) the main characteristic patterns of strokes prevailing during specific periods of the year ("seasons"). According to the results there are three main modes of intra-annual variation: a) the continental one with maximum lightning activity in early summer, b) the Ionian Sea one with maximum in early autumn and c) the Aegean Sea one with maxima in middle autumn and late May. Also, according to the patterns of strokes, three main "seasons" are found: a) the summer one (early May–middle August) with highest lightning activity over the continental regions of the country due to the atmospheric instability associated with the intense land heating and the persistence of cool upper air masses, b) the winter one (middle December–middle February) with the maximum of lightning activity over the sea where instability is high due to the frequent prevalence of cold air masses over the warm sea-surface and the associated passages of Mediterranean depressions and c) the autumn one (early September–middle October) with maximum over northwestern Greece associated with the early cold season low pressure systems, the warm sea body of Ionian Sea and the essential role of topography.

1. Introduction

Lightning has received a lot of attention in the scientific literature during the last decades, not only because it is an impressive atmospheric phenomenon, but also because it is associated with severe storms that may cause fire ignitions, damages to electric power networks and properties and even loss of lives (e.g. Wotton and Martell, 2005; Holle, 2016). Until the end of the 20th century, researchers were investigating lightning activity indirectly, via studies on thunderstorm observations, but in the last decades the evolution of technology and eventually the efficient remotely detection and monitoring of lightning activity gave the opportunity to study strokes incidents directly. Continuous monitoring of lightning activity and especially of cloud-to-ground (CG) strokes, is of great interest, for two main reasons: a) lightning data can be used as a proxy of convective activity, permitting thus to perform a large number of studies related to convection, and b) real-time detection of lightning activity permit the monitoring of the formation and evolution of convective storms, contributing thus to a better protection of life and property, especially in areas with poor weather radar coverage. For these reasons, the National Observatory of Athens (NOA) developed in 2005 and operates since then the ZEUS lightning detection system, covering Mediterranean and a large part of the Central/Southern Europe. For the Mediterranean region, located in a climatically transitional zone and presenting geophysical characteristics which favor a variety of weather conditions, there is a considerable number of contemporary studies focusing on the spatial and temporal variability of lightning activity, contributing to the construction of a reliable lightning climatology for the area (e.g. Holt et al., 2001; Anderson and Klugmann, 2014; Kotroni and Lagouvardos, 2016). In addition, a large number of studies have been devoted to the relation of lightning occurrence in the Mediterranean with the prevailing synoptic and mesoscale patterns, with the aim to contribute to a deeper understanding of the phenomenon. For instance, Soriano et al. (2005) conducted a study on the lightning activity in the Iberian Peninsula using 10-year data and showed that 84% of all cases occurred during the period May–September, affected by the thermal instability. For the eastern Mediterranean, Altaratz et al. (2003) and Shalev et al. (2011) focused on lightning activity during winter storms. According to their

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results, the factors governing the occurrence of lightning in Israel are: the synoptic weather systems, the thermodynamic conditions of the atmosphere, the elevated orography and the sea–land temperature contrast. Recently, Galanaki et al. (2016) quantified the contribution of intense cyclones to lightning over the Mediterranean region and found that one third of the tracked intense cyclones are associated with lightning activity close to their centre. Those cyclones which are associated with lightning were found to present in average 35% more ice and 15% more liquid cloud water content within the upper and lower atmospheric levels, respectively, while they are also related to approximately three times greater values of convective available potential energy in average, than the intense cyclone without lightning activity. Finally, the last years many authors (Mazarakis et al., 2008; Pawar et al., 2012; Galanaki et al., 2015) highlighted the importance of the thermodynamic structure of the atmosphere and more specifically the convective available potential energy (CAPE). Ziv et al. (2009), who revealed the dominant atmospheric factors during thunderstorms over eastern Mediterranean Sea, stated that CAPE, which affects the updraft velocity, drives to deep convection and consequently to lightning generation, plays the major role in the lightning activity in comparison with the dynamic factors.

For the Greek area, the atmospheric conditions favoring lightning activity have been studied by various researchers focusing on time scales of the conventional seasons (summer, autumn, winter, spring) i.e., on a quarterly basis. According to their results, the main seasonal characteristics of lightning activity are the following. During conventional summer, strokes are detected over continental Greece and their pattern is related with the convective and unstable weather conditions over the mainland due to insolation. During winter, lightning activity is maximized over the maritime areas of Greece and it is regulated by the paths of wintertime mesoscale low pressure systems over the Ionian and Aegean Seas and the instability conditions over there. During autumn, the majority of lightning activity is observed over north-western Greece, because of the depression activity over the warm waters of the Ionian Sea and the orography of Greece, which limits the lightning activity west of Pindus mountain range. As for the conventional spring, it retains most of the winter characteristics with a noteworthy increase in the continental thunder days due to the increasing solar radiation, mainly during May (Chronis, 2012; Nastos et al., 2014; Galanaki et al., 2015; Matsangouras et al., 2015).

Although the above studies present satisfactorily the main seasonal characteristics of lightning, the possible fluctuations in time scales smaller than 90 days are obscured and have not been revealed. The revelation and the explanation, if possible, of these fluctuations are very important for Greece, a country with a very complex topography and variable weather conditions during all seasons. For this reason, the present study aims at a more detailed intra-annual analysis, using as a main tool 15-day period (fortnight) data. Moreover, in order to take another step forward, the atmospheric conditions and the circulation patterns connected to each characteristic lightning pattern are investigated.

The present research effort focuses on three issues. First, the intra-annual variation of lightning activity over Greece is studied, defining areas with characteristic intra-annual variation of strokes. Second, the non-conventional ‘seasons’ of lightning activity, i.e. the sub-periods of the year presenting characteristic spatial distribution of strokes, are revealed and third, for every ‘season’, the patterns of some basic atmospheric parameters in the middle and the lower troposphere over the Mediterranean Sea are presented in order to conclude about the atmospheric conditions favoring lightning activity over the broader Greek area. The novelty of the study refers mainly to the use of fortnight data and thus to a more precise identification of the actual time span of the seasons, with respect to lightning activity, which was not possible to be revealed by using lower time resolution data (e.g. monthly or seasonal). Thus, a complete illustration of the spatiotemporal characteristics of the regime of lightning activity over Greece will be given, an important tool for the understanding of lightning occurrences over the studied area.

2. Data and methodology

Cloud-to-ground (CG) lightning data are used provided by ZEUS long-range lightning detection system, operated by NOA (Kotroni and Lagouvardos, 2008; Lagouvardos et al., 2009; Giannaros et al., 2015). ZEUS system comprises six receivers in Europe located in Chibolton (UK), Roskilde (Denmark), Iasi (Romania), Larnaka (Cyprus), Athens (Greece) and Lisbon (Portugal) that has been relocated to Mazagon (Spain) in 2014. ZEUS receivers record the radio noise (sferics) emitted by lightning strokes in the very-low-frequency (between 7 and 15 kHz). The lightning location is retrieved using the arrival time difference triangulation technique. System's detection efficiency varies between 25% and 35% and the average location error of the impacts is calculated to be approximately 7 km (Lagouvardos et al., 2009). It has been reported that ZEUS has a tendency to under-detect the actual number of CG strokes, especially during night-time, however it allows the real-time detection and the location of the active thunderstorms over Europe and Mediterranean (Lagouvardos et al., 2009; Price et al., 2011).

The CG strokes database used in the present work consists of daily values of lightning activity (number of CG strikes) over Greece (19°–29°E, 34°–42°N) at 320 0.5° × 0.5° grid boxes (Fig. 1, Domain 2), for the 10-year period 2005–14. The original lightning activity data (number of strokes per day and per grid box) were transformed to 15-day sums (sums over shorter than 15-day periods presented too high variability/noise) and then the number of CG strokes of each of the 24 fortnights of the year were averaged over the 10-year period and the mean intra-annual variation of lightning activity for each grid box was constructed; viz. the final data matrix consists of 24 rows (the fortnights of the year) and 320 columns (the grid boxes of the broader Greek area). Note that the second value of the months with 31 days, i.e. the 16-day mean, was transformed to 15-day mean in order to have equal weights for each fortnight in use (similar transformations were applied for Februaries with 28 or 29 days as well as for fortnights with missing values (less than 5% of the days)).

For the synoptic conditions in the middle and the lower troposphere over the Mediterranean Sea, the ECMWF's (European Centre for Medium-Range Weather Forecasts) climatic database ERA-Interim is utilized (Dee et al., 2011). More specifically, daily values (at 12UTC) of: i) 500 hPa and 1000 hPa geopotential heights (gpm), ii) 500 hPa air temperature (°C) and iii) Convective Available Potential Energy (CAPE) (J/kg) are used over the broader Mediterranean region (8°W–40°E, 27°–50°N) at 1176 1.0° × 1.0° grid points (Fig. 1, Domain 1).

In order to study the spatiotemporal characteristics described in the first section, the multivariate statistical method of Factor Analysis (FA) is used. FA enables us to decrease the dimensionality of a large data set reducing noise and retaining only the main modes of variation of the data. This method, with its various modes and options, has been extensively used and described in the past by many researchers (see e.g. Jollife, 1986; Manly, 1994; Richman, 1986; Bartzokas et al., 1994), therefore it is only briefly described.

FA describes a set of p correlated variables, $X_1, X_2, \ldots, X_p$, in terms of a smaller number of new uncorrelated indices, elucidating the relationship between the original p variables and the new ones, the so-called *factors*. Each of the p initial variables can be expressed as a linear function on m ($m < p$) factors, i.e. $X_i = a_{i1}F_1 + a_{i2}F_2 + \ldots + a_{im}F_m$, where $F_1, F_2, \ldots, F_m$ are the factors and $a_{i1}, a_{i2}, \ldots, a_{im}$ are the factor loadings, which in fact express the correlation between the initial variables X_i and the new ones F_j. The values of each factor are called factor scores, and they are presented in standardized format, i.e. with zero mean and unit variance (Jollife, 1986; Manly, 1994). In climatology, when the initial variables are time-series of a specific parameter corresponding to different locations the type of FA is called S-mode (S for space), while when the initial variables are space-series (patterns) of a specific parameter corresponding to different time the type of FA is