Atmospheric Research 169 (2016) 485–496

Contents lists available at ScienceDirect

Atmospheric Research

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

Cloud-to-ground lightning activity over Greece: Spatio-temporal analysis and impacts

I.T. Matsangouras [a,b,*], P.T. Nastos [a], J. Kapsomenakis [c]

[a] Laboratory of Climatology and Atmospheric Environment, Faculty of Geology and Geoenvironment, University of Athens, University Campus, GR-15784 Athens, Greece
[b] Hellenic National Meteorological Service, Hellinikon, GR-16777 Athens, Greece
[c] Research Center of Atmospheric Physics and Climatology, Academy of Athens, GR-10680 Athens, Greece

ARTICLE INFO

Article history:
Received 30 December 2014
Received in revised form 6 August 2015
Accepted 6 August 2015
Available online 14 August 2015

Keywords:
Cloud-to-ground lightning
TRMM
Lightning impacts Greece

ABSTRACT

Cloud-to-ground (CG) lightning activity recorded by the Hellenic National Meteorological Service (HNMS) Precision Lightning Network (PLN) is analysed over the wider area of Greece. In addition, the spatial and temporal relationships between TRMM 3B42 (Tropical Rainfall Measuring Mission) datasets and lightning are presented. The analyses concern the period from January 14, 2008 to December 31, 2012. The Laboratory of Climatology and Atmospheric Environment, University of Athens, has established a detailed dataset of lightning impacts over Greece from 1895 to 2013, based on digitized archive editions of newspapers. The mean seasonal variability of CG lightning activity revealed autumn as the most dominant season with 303 LD, while the mean monthly variability of CG indicated October as the most lightning active month and May as the month with a mean of 27 LD. The mean annual spatial distribution of CG lightning per km^2, depicted the maximum frequency over Pindus mountain range (>7 CG/km^2). During the autumn season, the northern Ionian Sea experienced a mean frequency of more than 5 CG/km^2, compared to the southern Ionian Sea and NW Peloponnesus, where values of more than 7 CG/km^2 are depicted. During the summer season, the maximum frequency appeared along Pindus mountain range, around Attica, Thessaly and central Macedonia highlands. The spatial distribution of seasonal correlations between the number of CG flashes/day and gridded (TRMM 3B42) daily rainfall totals for the period 2008–2012 over Greece, indicated that correlations were mainly positive all over the under study area, within all seasons, and especially during summer and autumn. Regarding the lightning impacts in Greece, based on the 1895–2013 study period, more than 343 fatalities and at least 224 injured people have been recorded. The spatial analysis of lightning impacts, showed that the majority of events has been recorded over Greek mainland and only few scattered events have been reported over Ionian and Aegean Seas. The results of the performed research for Greece, during 1895–2013 (2000–2013), indicated that fatalities/injuries caused by lightning, were estimated at 2.9 (2) deaths/1.9 (1.6) injuries per year, respectively.

1. Introduction

Lightning is an atmospheric discharge of electricity accompanied by thunder, and has got a mass of attention either in the chronicle of human cultivation or in the scientific literature. Lightning is considered as one of the most powerful and spectacular natural phenomena in the atmosphere, thus, its power was ascribed to several mythic deities (e.g., in ancient Greece, lightning was ascribed to the god Zeus, in Norse mythology to Tor, in Maya to god K, in Finnish mythology to Ukko, in Aztec to god Tlaloc and in ancient Rome to Fulgora goddess).

Lightning holds a special place in the scientific literature, since it might cause fatalities, injuries and damage. Hence a detailed knowledge of the occurrence and impact of lightning is essential for the general public, as well as special users, like aviation and power services. High-resolution climatology of lightning activity and impact enables a fuller understanding of lightning occurrence and may be applied for risk assessment by various internal services or private companies dealing with atmospheric natural hazard events and lightning risk vulnerability.

The Mediterranean basin, is characterized as a region of frequent cyclonic activity, associated in many cases with precipitation extremes, driven by local factors such as the orography, the latent heat release at the sea surface, and the established synoptic conditions. Precipitation studies have been carried out either by the analysis of rain gauge data, from individual stations, or by gridded precipitation data, in order to smooth the spatial discontinuities. A significant contribution to precipitation monitoring, from space, is the Tropical Rainfall Measuring Mission (TRMM) (Kummerow et al., 1998). The TRMM satellite passes over the Mediterranean region about six times a day, with a relatively small field-of-view, observing a few hundred km wide swath (spatial resolution < 10 km) for a period of less than 90 s. TRMM products have been used in many studies to analyze and interpret precipitation

* Corresponding author at: Laboratory of Climatology and Atmospheric Environment, Department of Geography and Climatology, Faculty of Geology and Geoenvironment, University of Athens, University Campus, GR-15784 Athens, Greece. Tel./fax: +30 210 7274191.
E-mail address: john_matsa@geol.uoa.gr (I.T. Matsangouras).

http://dx.doi.org/10.1016/j.atmosres.2015.08.004
0169-8095/

patterns and features. Nastos et al. (2013) studied the seasonal and annual variability and intercomparison of precipitation extremes (percentile, absolute and duration indices), based on both space borne TRMM (3B42) and the respective high resolution gridded precipitation E-OBS datasets over Mediterranean region, for the period 2000–2011. Mehta and Yang (2008), presented precipitation climatology over the Mediterranean Basin from ten years of TRMM measurements. Lagouvardos and Kotroni (2007), showed that the synergistic use of various space borne (TRMM) and ground based lightning-detection instruments (ZEUS lightning-detection network) could be useful for the observation of low pressure system over the eastern Mediterranean.

Lightning detection networks and on-board satellite sensors, robust the scientific research during the last decade, thus lightning climatologies have been carried out in various parts of globe revealing high-resolution analyses, regarding lightning activity. As new techniques have been applied for lightning detection, such as the use of Very Low Frequency (VLF) radio atmospheric waveform bank, experimental networks have been set up. World-Wide Lightning Location Network (WWLLN) has been developed through collaborations with research institutions across the world, providing global real-time locations of lightning discharges (Rodger et al., 2006). In Europe the long-range lightning detection system ZEUS, operated by the National Observatory of Athens, is based on detection of sferics and consists of a network of six VLF receivers located around the periphery of Europe (Kotroni and Lagouvardos, 2008; Chronis and Anagnostou, 2003; Chronis and Anagnostou, 2006; Lagouvardos et al., 2009).

Moreover, during the last decade, several National Meteorological Services have developed national lightning detection networks for operational and forecasting usage, such as the United States Precision Lightning Network (USPLN), the Canadian Lightning Detection Network (CLDN), the Italian Air Force Meteorological Service with the LAMPINET lightning network, etc. Thus, a significant number of studies have been carried out analysing the characteristics of lightning using different lightning detecting networks; namely, in Finland (Tuomi and Mäkelä, 2008), in Sweden (Sonnadara et al., 2006), in Estonia (Enno, 2011), in Austria (Schulz et al., 2005), in Czech Republic (Novak and Kyznarova, 2010), in Romania (Antonescu and Burcea, 2010), in Portugal (Santos et al., 2012), and in Spain (Soriano et al., 2001a, 2001b; Soriano and De Pablo, 2002). Christian et al. (1999) using the Lightning Imaging Sensor (LIS) on the TRMM, demonstrated that lightning activity over the eastern Mediterranean Sea can easily be detected from space and the Mediterranean was exhibited as a major centre of electrical activity during winter and autumn season. In addition, Christian et al. (2003) based on the Optical Transient Detector (a space-based instrument, the payload of the MicroLab-1 satellite, specifically designed to detect and locate lightning discharges as it orbits the Earth) revealed that central Mediterranean area (especially the Ionian Sea over west Greece) exhibits more than 10 flashes $km^{-2}\,yr^{-1}$ during autumn season.

By the end of 2007, Hellenic National Meteorological Service (HNMS) established its first operational Precision Lightning Network (PLN). The HNMS-PLN encompasses the Greek continental area and island complexes of the Ionian and the Aegean Seas, and it has been used since then as an operational lightning detection system supporting the daily now-casting procedure in HNMS.

Regarding lightning activity focused on the Mediterranean, several studies have been conducted revealing lightning spatial–temporal distribution. Kotroni and Lagouvardos (2014), based on measurements from the long-range lightning detection network (ZEUS) during 2005–2012, presented that lightning activity over the Mediterranean area, is dominant during the autumn season and it is shifted over eastern Mediterranean waters from September to December. Altaratz et al. (2003) presented a research focused on the differences in properties of lightning that occur during four winter seasons (1995–1997) by thunderstorms over the coastal region of the eastern Mediterranean. Tomás et al. (2004) based on 9 years dataset lightning activity (1990–1998), examined CG lightning activity over the Iberian Peninsula in relation to synoptic situations, revealing that the cyclonic situation (centred over Iberian peninsula), despite not being the most frequent, is the one with the greatest flash frequency 15.5% of the total CG flashes in that period. Petrova et al. (2014) based on summer seasons period of 2005 and 2006, analysed the lightning activity and precipitation at 3-hour time intervals in grid boxes of $0.25 \times 0.25^{\circ}$ over East and Central Mediterranean, revealing that the peak of flash density over the continental and coastal areas was in the afternoon hours, while over the maritime areas the peak was in the morning hours.

Chronis (2012), based on 2008–2010 HNMS-PLN dataset, exhibited that the Greek seasonal maps of thunder days are in good agreement with the regional climatic convective characteristics of the study area. These results are also in agreement with Nastos et al. (2014) outputs, regarding the spatial–temporal analysis of cloud-to-ground (CG) lightning activity over Greece, based on a preliminary 2 year dataset (2008–2009) from HNMS-PLN.

The aims of this study are threefold. First, to present an updated CG lightning analysis over Greece, based on HNMS-PLN archive data from January 2008 to December 2012, and secondly, to examine the annual and seasonal spatial correlation of between TRMM 3B42 and the abovementioned lightning activity dataset. Finally, in this paper, a spatio-temporal analysis of the lightning impacts is presented for Greece, based on historical and recent records from 1895 to 2013.

2. Data and methodology

2.1. Lightning data

In the late of 2007, HNMS established its first operational HNMS-PLN, consisted of 8 Precision Lightning Sensors (PLS) covering a broader area than Greek territory. Thus, HNMS-PLN covers not only the Greek mainland and surrounding sea waters (Ionian Sea on the west, Aegean Sea on the east), but also the southern Balkans, Turkey, Italy, Cyprus and the coast of northern Africa. The network has been used in operational procedure since January 14, 2008, and till now it is the only operational network dedicated to the lightning detection by Greek forecasters not only over Greece but also in the eastern Mediterranean.

HNMS PLS sensitivity is ranging from 1.5 kHz–400 kHz (Low Frequency–Very Low Frequency) and it retrieves the stroke location based on the Time of Arrival (TOA) method (Lee, 1986; Koshak and Solakiewicz, 2001; Hu et al., 2010). The demonstration of the technical characteristics of HNMS-PLN, PLS and archive procedure is beyond of this paper, as they have been further already discussed by Chronis (2012) and Nastos et al. (2014), in previous studies. In general, HNMS extended archive of lightning data concerns the retrieval of geographical location, as well as other products such as the CG associated peak current (in kA), polarity (e.g., −CG/+CG) and several parameters that determine the accuracy of the stroke's location retrieval (e.g., major/minor axis, etc.).

In this paper our analysis shed light on the CG lightning activity recorded by HNMS-PLN and encompasses an area extending between NW (41.5 °N, 19.5 °E), NE (41.5 °N, 28 °E), SW (35 °N, 19.5 °E) and SE (35 °N, 28 °E). With the use of Geographical Information System (GIS) all CG lightning records were spatially analysed and further temporal assessments were conducted in terms of annual, seasonal and monthly distribution. During the study period of 2008–2012 more than 5,487,350 CG flashes were occurred in the above-mentioned grid box, in more than 1381 lightning days. For the purpose of a thorough study, the authors suggested the term of “lightning day” (LD) defined as a day with at least one lightning flash.

2.2. TRMM 3B42 data

In the present study TRMM 3B42 3-hourly gridded rainfall data were used for the area of Greece for the period 2008–2012. The TRMM (Huffman et al., 2007) 3B42 product comprises 3-hourly gridded rainfall