PROCEEDINGS OF SCIENCE

# Autumn - diurnal variation of lightning over Black Sea and Bulgaria

**Savka Petrova**[a,*] **and Rumjana Mitzeva**[a]

[a] *Department of Meteorology and Geophysics, Faculty of Physics, Sofia University "St. Kliment Ohridski", 5 James Bourchier Blvd., Sofia, Bulgaria*

*E-mail:* asavita@phys.uni-sofia.bg

The analysis of land-sea contrast in lightning activity in autumn on a regional scale is presented here. The lightning data over Bulgaria and Black Sea in September, October and November for 10 years (2005-2014) are used. Data for the time and the position of lightning are provided by the ZEUS network operating at the National Observatory of Athens. The investigation reveals that flash density in autumn during the studied 10 years is about 2 times higher over the Black Sea than over land (Bulgaria) and the maximum flash density occurs in September over the Black Sea. Diurnal variation of flash density (at 3-h time intervals) shows that the maximum of lightning activity in autumn is observed over the maritime area (Black sea) in the morning interval (0600-0900UTC). According to the results, lightning activity in most of the considered time intervals is higher over the Black Sea than over land, with the exception for the afternoon hours: in time interval (1200-1500 UTC) it is vice versa and in (1500-1800 UTC) - the flash density values are equal. The spatial distribution reveals that there are much more number of lightning over the southern part of the Black Sea, compared to the northern part of the basin. Over Bulgaria, the centers with the maximum number of lightning are over the mountains.

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*Speaker





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## 1. Introduction

Studies of the global distribution of lightning show that the annual number of lightning over land is higher than over the sea [1, 2]. However, some research [3, 4] reveals that lightning activity is different over various geographical locations and is highly variable on timescales (annual, seasonal, monthly and daily). Numerous studies, focusing on the temporal - spatial variability of lightning activity in the Mediterranean area [2, 5–7] showed the predominance of lightning activity over the sea during winter and over the land during spring and summer. Kotroni and Lagouvardos [8] observed clear predominance of lightning activity over land in summer, but the opposite in autumn - predominance of lightning activity over Mediterranean Sea. Research of diurnal annual variations of lightning over Europe and the Mediterranean Sea [4, 9–12] showed that the maximum number of lightning over land is in the afternoon hours and over the sea – early in the morning. There are limited number of papers [13–15] analyzing lightning activity over Bulgaria. For the first time the land-sea contrast in lightning activity over Bulgaria and Black Sea in summer is analyzed in [16]. Using ZEUS lightning data, detected from 2005 to 2014 they established that summer-time flash density for each of the analyzed years is higher over Bulgaria than over the Black Sea, while diurnal variation of flash density shows that during the night and in the morning hours lightning activity is higher over the Black Sea. The present study is similar to that presented in Petrova and Mitzeva [16], but concerns lightning over Bulgaria and the Black Sea in autumn. The work is directed to reveal: i) whether there is a difference in autumn diurnal variations of flash density over land (Bulgaria) and over maritime area (Black sea); ii) locations and moments with maximum lightning over Bulgaria and over the Black Sea during the autumn period.

## 2. DATA

In the present work lightning data during autumn period (September, October and November) for 10 years (2005-2014) over Black Sea and Bulgaria are analyzed. Lightning data are provided from the ZEUS system operated by the National Observatory of Athens (NOA). The long-range lightning detection system, ZEUS, has been operating since 2005. ZEUS is a European-wide lightning detection network that records the radio noise (sferics) emitted by cloud-to-ground lightning discharges at very low frequency (VLF, between 7 and 15 kHz). [17, 18].
The maritime domain of the analysis is the Black sea (confined within 27° to 42°E and 41° to 47°N). The continental domain of the analysis is confined within 22.5° to 28.5°E and 41.25° to 44.25°N. Continental domain (land) in this work is noted as Bulgaria, because it includes the territory of Bulgaria and a very small part of the bordering areas (schematic location is surrounded by solid white lines in Fig. 1). The maritime area is approximately 3 times larger than continental area and for this reason in the present study the flash density (number of detected flashes during analyzed period divided by the corresponding surface area [flashes/km$^2$]) are used. The lightning data for the entire period are organized into 0.25x0.25 degree grid boxes and flash densities for each grid box are calculated. The number of recorded flashes and the flash density at 3-hour time intervals (corresponding to synoptic observations times: 0000 UTC, 0300 UTC, . . . , 2100 UTC) are determined. Each grid box is characterized as maritime (sea) or continental (land) depending on the

underlying surface of the area it represents.

## 3. Results

Topographical map of the studied area and the spatial distribution of number of flashes for the 10 years in the autumn period are presented in Fig. 1 and Fig. 2, respectively. The analysis shows that in the autumn (2005-2014) there is less lightning over the land (Bulgaria) in comparison with number of lightning events over the Black Sea. The results confirm earlier findings over Mediterranean region that lightning activity over sea is more frequent than over land during the autumn [8].

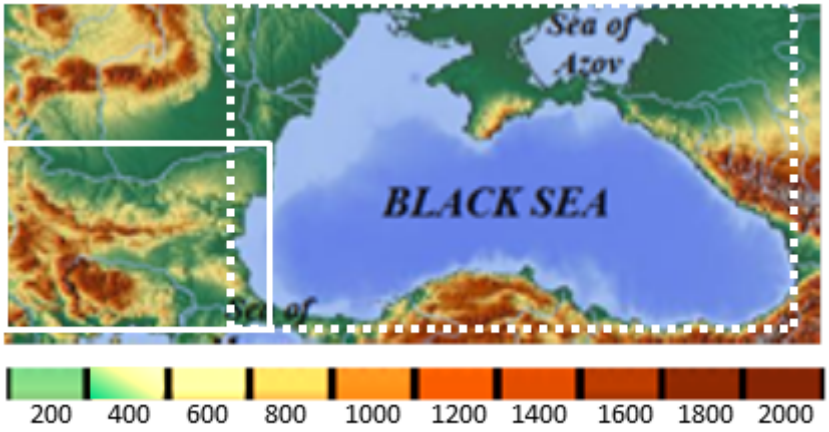


**Figure 1:** Topographical map of the studied area.

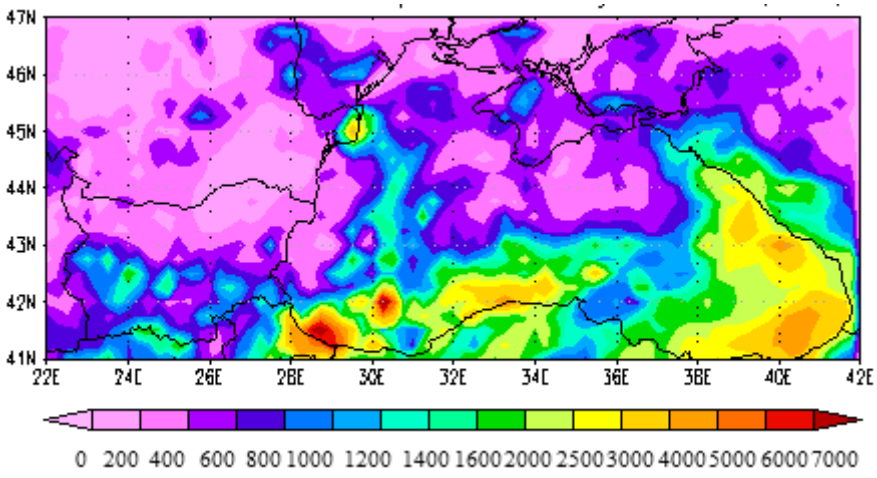


**Figure 2:** Spatial distribution of number of recorded flashes in boxes of 0.25°×0.25° over Bulgaria and Black sea for the autumn (SON) period for 10 years (from 2005 to 2014).

The autumn-spatial distribution reveals that there are much more number of lightning over the

southern part of the Black Sea, compared to the northern part of the basin. Greater lightning activity is observed mostly in the part of Black Sea bounded by land area with high mountains. Fig. 2 also shows that over land area (Bulgaria), the centers with the maximum number of lightning are over the mountains.

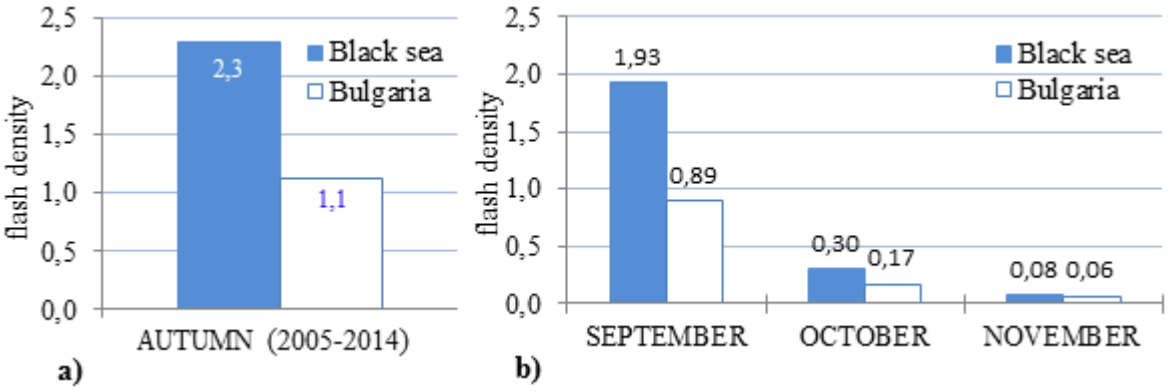


**Figure 3:** Flash density (flashes/km$^2$) over Black sea and over Bulgaria during: a) autumn period (SON) for 10 years (2005-2014); b) autumn months: September, October and November in the same period.

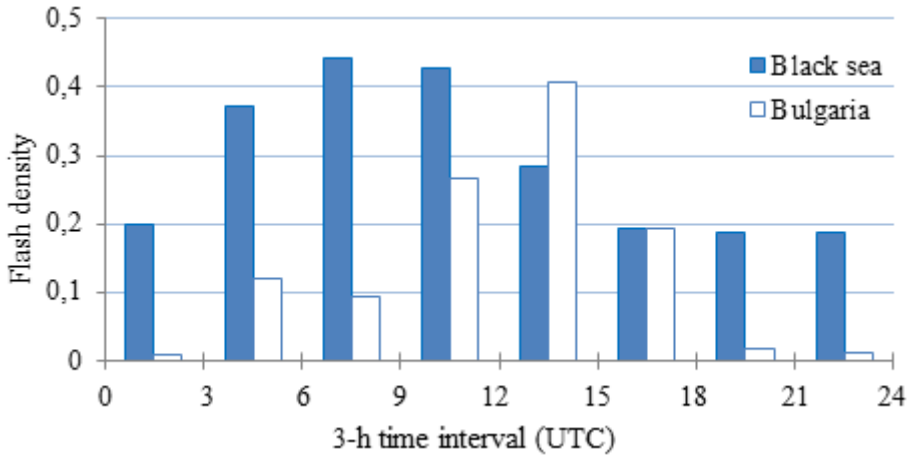


**Figure 4:** Diurnal variation of flash density (flashes/km$^2$) at 3-hour time intervals in the autumn (September-October-November) of the 10 years (from 2005 to 2014).

The flash density over Black Sea and over Bulgaria of 10 years autumn period is presented in Fig. 3. The results show that flash density is about 2 times higher over the Black Sea than over Bulgaria (land) in autumn season (Fig. 3a). The opposite result about the summer - 3 times lower flash density over the Black Sea than over Bulgaria is established in [16]. Fig. 3b illustrates that during each month (September, October and November) flash density is higher over sea than over continental area, although the large variation in lightning activity is visible. The comparison of the flash density in the autumn months reveals that the maximum flash density occurs in September over the Black Sea.

Diurnal variation of flash density at 3-h time intervals (Fig. 4) shows that lightning activity in autumn is higher over the Black Sea than over the land with the exception of afternoon hours. During

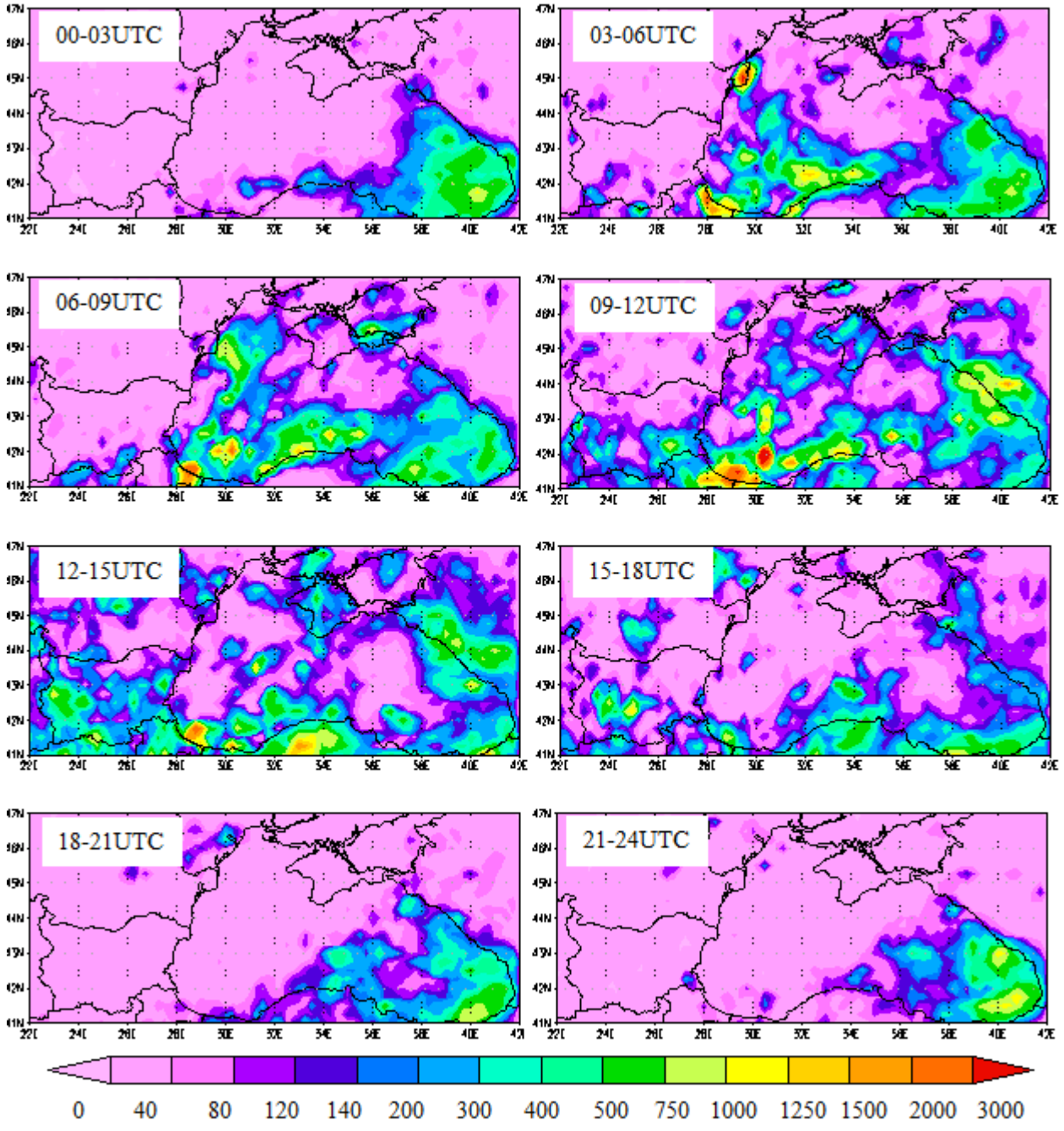


**Figure 5:** Spatial-diurnal distribution of flashes at 3-hour time intervals in boxes of 0.25°×0.25° for the period September-October-November of the 10 years (from 2005 to 2014).

the afternoon (1200-1500 UTC) there is dominant presence of lightning over land (Bulgaria), while between (1500-1800 UTC) the lightning activity is the same over land and over sea. The observed maximum flash density over the Black Sea is in the morning interval (0600-0900 UTC), while over Bulgaria - in the afternoon (1200-1500 UTC). This is similar to the results obtained by Petrova and Mitzeva [16] for the summer season. The authors demonstrated that the maximum flash densities over sea and over land are in the same time intervals (0600-0900 UTC) and (1200-1500 UTC), respectively.

The spatial distribution of flashes at 3-hour time intervals in boxes of $0.25^\circ \times 0.25^\circ$ for the 10 years during the autumn period is presented in Fig. 5. The results show that during the night (1800-0300 UTC) lightning activity is observed mostly in the eastern part of the Black Sea, in the region surrounded by the land area with high mountains. In the morning and noon hours (0300-1200 UTC), different centers with a large number of lightning (>1000) are scattered over the Black Sea. Only in the time interval (1200-1500 UTC) flash density is higher over Bulgaria than over the Black Sea. According to the results higher flash density over land is associated with lightning activity close to the location of mountains in Bulgaria. A detailed analysis of spatial distribution (Fig. 5) indicates that flashes detected in the time interval (1500-1800 UTC) are predominantly over the coastal area rather than over the sea. Over Bulgaria, the centers with the maximum number of lightning are also over the mountains.

## 4. Conclusion

In this study the autumn – diurnal variations of lightning over two different areas: continental (Bulgaria) and maritime (Black Sea) are presented based on a 10 year long dataset (2005-2014) provided by the ZEUS network. The number of recorded flashes and the flash density at different time intervals (seasonal (autumn), monthly and 3-hour period) in grid boxes of 0.25x0.25 degrees over land and sea are determined. Analysis of the results reveals the following:

• In the autumn, there is less lightning over the land (Bulgaria) in comparison with lightning over the Black Sea.

• Over the southern part of the Black Sea there are much more lightning, compared to the northern part of the basin. Greater lightning activity is observed mostly in the part of Black Sea bounded by land area with high mountains. Over land area (Bulgaria), the centers with the maximum number of lightning are over the mountains.

• During each autumn month (September, October and November) flash density takes higher values over sea than over continental area. The maximum flash density occurs in September over the Black Sea.

• The maximum number of lightning over the Black Sea is observed in the morning hours (0600-0900 UTC) and over Bulgaria - in the afternoon (1200-1500 UTC).

• At the hours between 1800 UTC and 0300 UTC the maximum of the lightning activity is detected mostly in the eastern part of the Black Sea bounded by land area with high mountains.

## 5. Acknowledgments

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