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SOFIA UNIVERSITY -
MARKING MOMENTUM
FOR INNOVATION AND TECHNOLOGICAL TRANSFER

National Recovery and Resilience Plan
OF THE REPUBLIC OF BULGARIA

IMPACT OF THERMODYNAMIC CONDITIONS ON THE DEVELOPMENT OF CONTINENTAL AND MARITIME THUNDERSTORMS OVER BULGARIA AND THE BLACK SEA

Research Group: Cloud Physics
Research field: Thunderstorms-lightning

Abstract

Lightning observations are used as a proxy for thunderstorm occurrence. Diurnal-spatial variation of lightning activity over Bulgaria (land) and the Black Sea (maritime area) during the each season are analyzed. As a result, the locations and moments in time where maritime and continental thunderstorms occurred, as well as the diurnal distribution of the centers of maximum number of lightning, will be identified. The environmental conditions where lightning is detected will also be examined. General and stepwise discriminant analysis will be carried out to check whether some of the calculated thermodynamic indices together (or alone) with surface data are able to discriminate the thermodynamic conditions related to thunderstorms over the Black Sea from the corresponding conditions related to thunderstorm over land (Bulgaria).

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). For the first time the land-sea contrast in lightning activity over Bulgaria and the Black Sea in summer is analyzed in [5]. Using ZEUS lightning data (for 10 years period) they established that summer-time flash density for each of the analyzed years is higher over Bulgaria than over the Black Sea. However the results (presented in [6]) show that during autumn (September, October and November) the flash density is higher over the Black Sea than over the land surfaces of Bulgaria. One possible reason for this is the well-known difference in surface conditions over land and sea.

The aim of the present work is to investigate whether atmospheric conditions differ significantly in lightning detection locations over land compared to those over sea?

The answer to this question assumes that if the environmental conditions at the detection of lightning over land and sea are significantly different it should be possible:

- some of the calculated thermodynamic indices together (or alone) with the surface data are able to discriminate the thermodynamic conditions associated with lightning over the Black Sea from the corresponding conditions associated with lightning over land (Bulgaria).
- to derive a classification function which would be able to discriminate the atmospheric conditions (at surface and at higher levels) at the development of thunderstorms over sea and over land.

A positive result would demonstrate the “vitality” of thermal hypothesis for the explanation of difference in lightning activity over maritime and land areas.

Methodology

The territory of investigation includes the Black Sea (maritime area) and Bulgaria (land). Lightning data are provided from the ZEUS network operated by the National Observatory of Athens (NOA).

The number of recorded flashes and the flash density at 3-hours (or 6-hours) time intervals in grid boxes of 0.25x0.25 degrees over land and sea for each day of the study period are determined. Each grid box is characterized as continental or maritime depending on the underlying surface of the area it represents. As a result, the locations and moments in time where maritime and continental thunderstorms occurred will be identified.

The territory of the study:

Bulgaria - the continental domain of the analysis is confined within 22,5° to 28,5°E and 41,25° to 44,25°N.

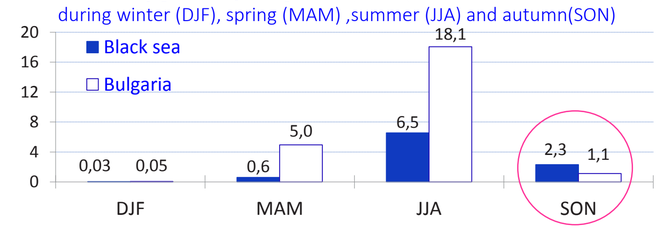
Black Sea -the maritime domain of the analysis is confined within 27 ° to 42°E and 41° to 47°N.

The surface data and temperature and humidity profiles will be taken from the ERA5 reanalysis of the European Centre for Medium-Range Weather Forecasts. This data can be downloaded in grid boxes of 0.25x0.25 degrees for the hours 0000UTC, 0600UTC, 1200UTC, 1800UTC for each day of the study period. Based on this data thermodynamic indices will be calculated, where thunderstorms have occurred over land and over sea. General and stepwise discriminant analysis will be carried out to check whether some of the calculated thermodynamic indices together (or alone) with surface data are able to discriminate the thermodynamic conditions related to thunderstorms over the Black Sea from the corresponding conditions related to thunderstorm over land (Bulgaria).

Results – First step

Lightning activity in winter, spring and summer is in accordance with the annual global distribution - the flash density over land surface (Bulgaria) is higher than over the maritime area (Black Sea). However in the autumn the flash density is higher over the Black Sea than over the land surface (Bulgaria).

Flash density [flashes/km²] for 10 years (March 2005-February 2015) during winter (DJF), spring (MAM) ,summer (JJA) and autumn(SON)



These results lead to the next question and the following task in the present work:

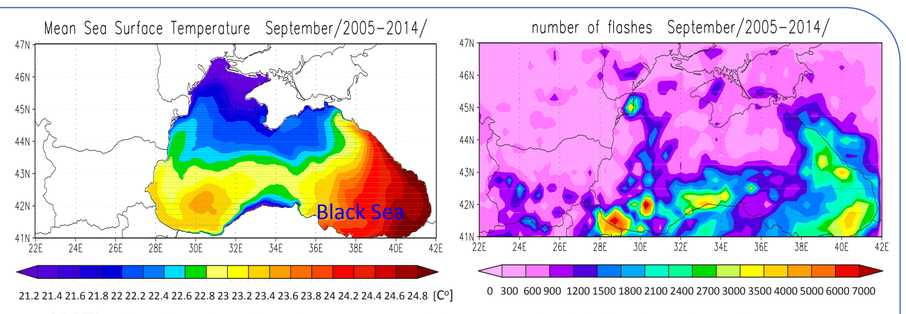
? What are the reasons for the higher flash density over sea compared to over land during the autumn season?

! One possible reason could be that the sea surface temperature (SST) in autumn is higher than the land surface temperature.

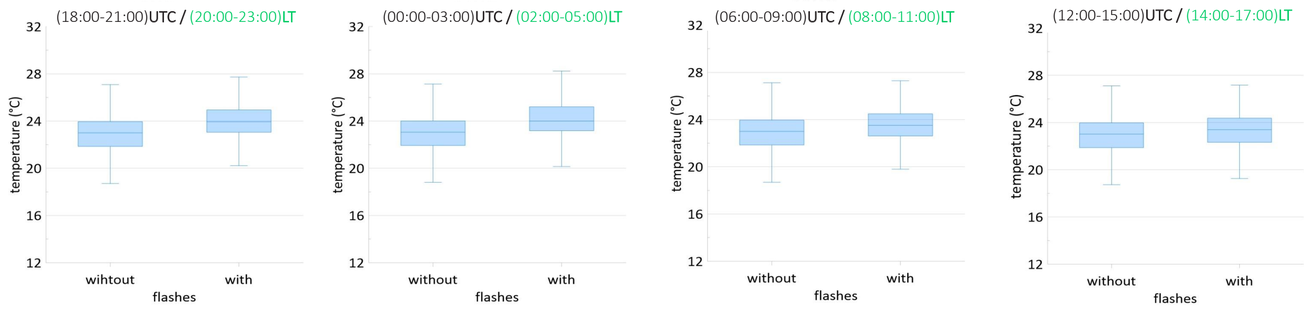
First step: To investigate if there is a relationship between lightning activity and sea-surface temperature (SST) of the Black sea in autumn.

In the autumn, 84 % of lightning was observed in September of the studied 10 year period. A combined analysis of sea-surface temperature (SST) and lightning activity is presented using data from September (2005-2014). Cloud cases (25 598) with lightning were used in this study.

The spatial distribution of number of lightning and mean SST in September (2005-2014) shows that the warm waters of the southern part of the Black Sea are associated with a higher number of lightning, compared to the relatively colder waters of the northern part of the basin, which are associated with a much lower number of lightning.



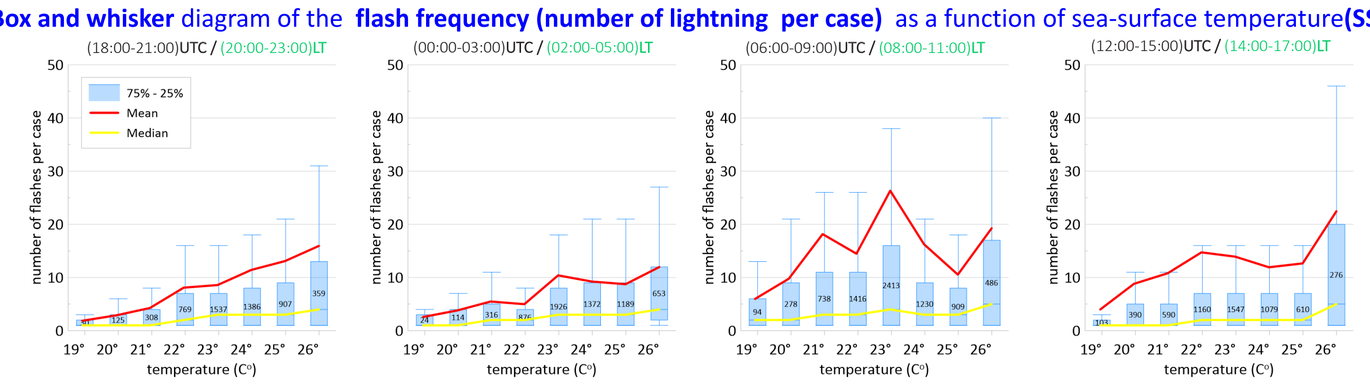
Box and whisker plot of the sea-surface temperature (**SST**) distribution for the cases **without** and **with** flashes for all four investigated time-intervals from September (2005-2014).



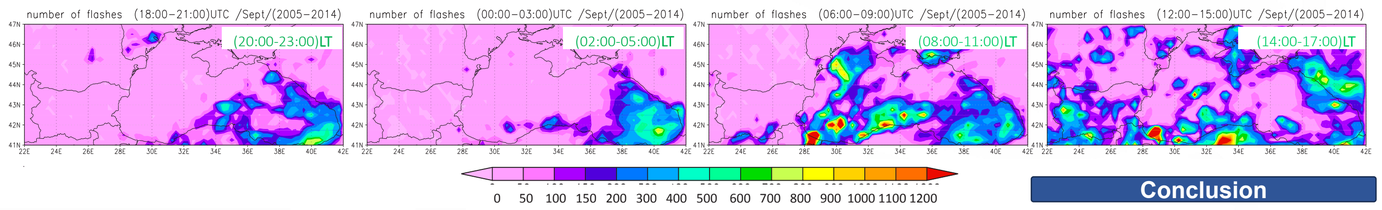
median–blue line; **box**:25% and 75% ; **upper whisker**: P(75%) + 1,5*IQR; **bottom whisker:** P(25%) – 1,5*IQR; **interquartile range:** IQR = P(75%) – P(25%)

The mean and median of SST are higher in the cases with flashes compared to the corresponding values in the cases without flashes. The differences are more pronounced in the night intervals: (20:00-23:00)LT and (02:00-05:00)LT.

Box and whisker diagram of the **flash frequency (number of lightning per case)** as a function of sea-surface temperature**(SST)**



At **nigh**t, in the investigated intervals (20:00-23:00)LT and (02:00-05:00)LT, there is a clear trend of the increase of mean flash frequency per case with the SST increase. The established linear correlation coefficients for these night intervals are very high, respectively R=0.99 and R = 0.92. During the **daily** intervals (08:00-11:00)LT and (14:00-17:00)LT, this trend is not well pronounced especially in the (08:00-11:00)LT, with visible fluctuations of the mean frequency per case with the SST increase. The correlation coefficients are lower – R=0.47 for (08:00-11:00) LT and R=0.83 at (14:00-17:00)LT.



Conclusion

The analysis indirectly shows that the influence of the SST on the formation of thunderstorms is different depending on the diurnal time interval. The results indicate that during the day there are, also, other favorable atmospheric processes for the formation of thunderstorms with greater significance than the influence of sea-surface temperature. However in the night the higher SST values probably play a more significant role in thunderstorm formation at particular orographic conditions. From the spatial distribution of the flashes for these night time-intervals ((20:00-23:00) LT and (02:00-05:00) LT), one can see that the largest number of flashes is detected over the southeastern part of Black sea. This part of the Black sea is located between mountains and one can assume that the combination between warm sea surface and mountain sea breeze (slope winds and sea breeze) during night intervals create favorable conditions for cloud formation. These conditions are associated with a bigger temperature gradient between the warmer air, located just above the “warm” sea surface, and the colder air, cooling faster due to the closeness of the mountains, above it.

- The mean and median of SST over the Black Sea in autumn are higher for the cases when lightning occurred than when it is absent. This difference is more pronounced during the night intervals.
- For the investigated night intervals when the mean sea-surface temperature increases, the mean values of the flash frequency also increases, while for the daytime hours such tendency is not clearly evident.
- The results indirectly show that the influence of SST on the formation of thunderclouds is more significant during the night than during the day.

Expected Outcomes

- The results will show which of the environmental conditions have the most significant importance in cloud formation and development of thunderstorms over Bulgaria and the Black Sea.
- The analysis of the results will reveal whether the studied thermodynamic parameters can be used to discriminate the conditions responsible for the formation and development of maritime and continental thunderstorms. This will lead to confirmation or rejection of the so-called thermal hypothesis.
- The results are of fundamental importance because they are directly related to new knowledge about the main factors and processes leading to the formation and electrification of thunderstorms.
- The determination of thermodynamic parameters or a combination of them, that govern the formation of maritime and continental thunderstorms over Bulgaria and the Black Sea can contribute to the improvement of now-casting. This is extremely important in connection with the timely warning of the population about the development of thunderstorms associated with dangerous meteorological phenomena.

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