ASSESSMENT OF THE LIGHTNING ACTIVITY RESPONSE TO THE AEROSOL LOAD

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Abstract - Lightning activity is one of the most intrigues atmospheric phenomenon. It depends on several factors simultaneously, and among them also on the aerosol load. The most important indicator which characterize aerosol load is its aerosol optical depth. Here, in this study, the impact of aerosol loading of lightning strikes was investigated over the region of the Central Europe. The season late spring, early summer for four consecutive years is analyzed. Lightning strikes data have been taken from the Network for Lightning and Thunderstorms in Real Time Blitzortung, while aerosol optical depth data from the Moderate Resolution Imaging Spectroradiometer. Here area-averaged data have been calculated.
Results show, the only slight relationship between aerosol optical depth and lightning strike activity was assessed.

Keywords - Lightning Activity, Aerosol Load, Relationships.

I. INTRODUCTION

Lightning activity is affected by several dynamic–thermodynamic variables and indices such as air temperature (Markson, 2007), convective available potential energy (CAPE) (Stolz et al., 2015; Bang and Zipser, 2016), wind shear (Williams et al., 2005; Fan et al., 2013; Igel and Heever, 2015), relative humidity (RH) in the lower and middle troposphere (Wall et al., 2014), etc.

Lightning depends on the perturbation of the dynamic and thermodynamic parameters such as the convective available potential energy (CAPE), air temperature, relative humidity, vertical wind shear, etc. (Boccippio et al., 2000; Williams and Stanfill, 2002; Christian et al., 2003; Markson, 2007; Bell et al., 2009; Wall et al., 2014; Guo et al., 2016; Thornton et al., 2017).

There are three main global sources of the atmospheric aerosol; desert (dust), biomass burning (smoke) and anthropogenic (air pollution). While the latter two aerosol types serve as cloud condensation nuclei (CCN) sources, aged dust particles coated with sulfur can serve also as giant CCN (Rosenfeld et al., 2000). Aerosols are primarily of natural origin (desert dust, sea salt, biomass burning products, volcanic aerosols, etc.), but also of anthropocentric origin (industrial activities, traffic, etc.) (Kneip and Lioy, 1980). Mineral dust mostly originated from the Saharan desert affects intensively the Mediterranean basin, but also the central Europe (Ansmann et al., 2003; Washington et al., 2003; Vukimirovic et al,. 2004; Lyamani et al., 2006; Papayannis et al., 2008; Papdimas et al., 2008, 2012; Schepanski and Knippertz, 2011; Pappalardo et al., 2014; Cachorro et al., 2016; Sicard et al 2016; Gkikas et al., 2016, Mandija et al., 2016, a.b, 2017, 2018).

One of the most intrigues atmospheric processes which can involve aerosols is atmospheric electricity (Betz et al., 2009; Altaratz et al., 2010). Connections between environment air pollution and lightning activity were first studed by (Westscott, 1995) and then by (Murray et al., 2000). The electrostatic interactions of the cluster ions with atmospheric aerosols, absorbing/scattering radiation, affect the thermodynamic stability, cloud presence and lifetime, giving so impact also on the lightning activity (Rosenfeld et al., 2008).

Frequent investigations have been carried out to assess the impact of atmospheric aerosols on the lightning activity (Khain et al., 2008; Altaratz et al., 2010; Yuan et al., 2011; Wang et al., 2011; Mansell and Ziegler, 2013; Gryspeerdt et al., 2014 Zhao et al., 2014; Storer et al., 2014; Guo et al., 2016). It must be mentioned that the majority of the research papers suggest a slight influence of the aerosols on lightning activity. However, controverse results have been found in other studies (Rosenfeld, 2000; Zhao et al., 2006). Moreover, Rosenfeld et al., (2008) suggesting e saturation effect of the aerosols on the lightning activity.

Aerosol microphysical and radiative effects have the opposite response of the lightning activity. This fact produces a non-linear boomerang-shaped curve of the aerosol optical depth and number of lightning strikes. The superimposed effect is dominated by the microphysical effects (ACI) under clean environments and by the radiative effect (ARI) under polluted environments (Rosenfeld, 2000; Wang, 2005; Koren et al., 2008; Khain, 2009).

Dust electrification occurs due to the charge separation mechanism through collisions of the particles involved (Inculet et al., 2006; Duff and Lacks, 2008). Because larger particles are positive with respect to the smaller ones, the gravitational force acts as charge separator. However, the collision rate independent of the density of the particles, which is higher in the vicinity the aerosol sources. Thus, it is expected that the dust electrification be more intensive nearby the desert areas.

In this study, the features of the correlation between lightning activity and the aerosol loading were taken into the investigation.

II. METHODS

Aerosol loading was assessed using the parameter Aerosol optical Depth. On the other hand, contemporaneous tools are used to assess the lightning activity (Christian et al., 2003; Cecil et al., 2014). The daily data of lightning strikes and Aerosol Optical Depth over two domains have been assessed. Also, the turning points (inflection points) of the relationship aerosol-lightning for several regions were assessed.
The data of the aerosol optical depth (AOD_550) are obtained from Moderate Resolution Imaging Spectroradiometer MODIS-Aqua, for both Ocean (best) and Land (corrected) (https://ladsweb.modaps.eosdis.nasa.gov/). Also, GIOVANNI tool (Earth Data) is used to provide the statistics of the AOD data (https://giovanni.gsfc.nasa.gov/giovanni/).

The study is focused on the spring season. This is a period with intense lightning activity and frequent aerosol events as well. Thus, data of lightning strikes and AOD during the periods April – August of the last four years has been analyzed.

For verification purposes, also model data and maps have been utilized. Thus, the Navy Aerosol Analysis and Prediction System (NAAPS) is used to assess not only aerosol load, but also to discriminate different aerosol types, such are smoke, sulfate, sea salt and dust.

Data of lightning strike count for the Central Europe area (1.93E, 45.08N, 17.93E, 54.14N) are provided by the Network for Lightning and Thunderstorms in Real Time Blitzortung (https://www.lightningmaps.org/blitzortung/europe/). Meteorological data used here are taken from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis product (Dee et al., 2011).



Fig.1. Investigated domain, central Europe.

III. RESULTS AND DISCUSSION

3.1. Lightning activity and aerosol load over the central Europe region

Monthly-averaged values of the number of lightning strikes (NS) and AOD at 550m (AOD_550) are presented in the Table 1.

	No. Strikes (NS)			
Month	2016	2017	2018	2019
APR	1290	1503	6278	3838
MAY	9687	11050	16296	2953
JUN	17410	15280	13723	10099
JUL	15059	20258	11400	11032
AUG	6144	15153	10890	11539
	AOD_550 MYD08_M3 V6.1			
APR	0.186	0.179	0.214	0.210
MAY	0.225	0.192	0.318	0.165
JUN	0.233	0.22	0.236	0.228
JUL	0.214	0.209	0.222	0.24
AUG	0.112	0.258	0.209	0.236

Table 1. Data of the number of NS and AOD_550, averaged for each month April, May, June, July and August, during four consecutive years: 2016 – 2019. Here, MODIS Aqua Atmosphere Monthly Global of AOD at 550nm have been analyzed.

Data of Table 1 indicate that the major lighting activity in the Central Europe region, during this period was observed in the period June – July, each of them with 14,000 strikes over the region. Lowest activity was observed during April, with only 3227 averaged value during the period 2016 – 2019. The highest lightning activity was registered during July 2017, with more than 20,000 strikes over the region.
On the other hand, aerosol optical depth does not exert much variation. However, its highest mean values have been obtained during the period May – July (around 0.23). During 2018, there are obtained the highest values of AOD with a mean value of 0.24 (11.6% higher than the whole investigation period). Moreover, in May 2018 is registered also the highest regional mean AOD_550, reaching up to 0.32.

From the data of the Table 1, it seems that NS is positively related with the aerosol presence. The correlation coefficients (CC) between NS and AOD data averaged by each month are significantly higher, 0.73. However, this consideration is not completely fulfilled for each of the months under investigation. Thus, during April, May and August, correlation coefficients are very high, ranging between 0.89 and 0.96. But this is not valid for June, whose CC is very low (0.06) and July whose CC is highly negative (-0.81). CC values are negatively correlated with NS and AOD, with correlation coefficients of -0.70 and -0.54.
In short, lightning activity is more related to the aerosol presence in the case of lower lightning activity, but also in clean environment conditions (boomerang effect).

Not similar results are obtained in the case we used the daily averaged NS and AOD data. In this case CC between the daily values of NS and AOD_550 during the periods April – August 2016 – 2019, was lower, only 0.45. This value predicts a slight relation between these quantities, and not significative impact of the aerosols over lightning activity.

The 2-axes graphs of the Fig.2shows monthly-averaged values of the number of lightning strikes and AOD for the entire investigation period.

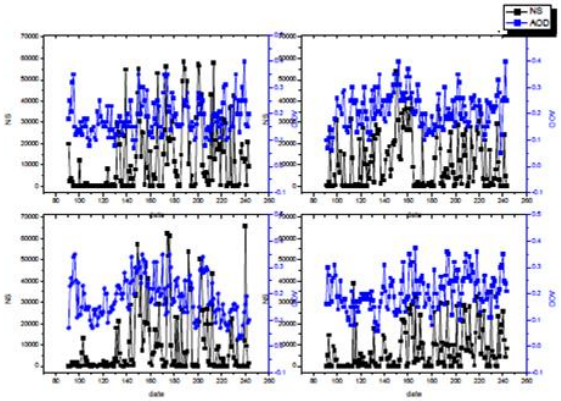
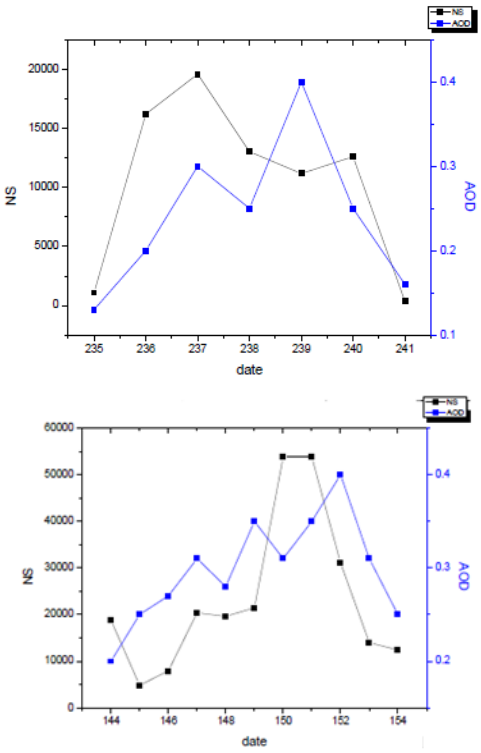


Fig.2. NS and AOD monthly-variations during the period April-August, for four consecutive years 2016 – 2019. Lower left 2016, upper left 2017, upper right 2018 and lower right 2019.

3.2. Special cases; intense aerosol events

There are selected three events with higher aerosol loading in terms of AOD for more detailed analyzes. Let nominate these events as; IAE1 (23-29-AUG-17), IAE2 (24-MAY-3-JUN-18) and IAE3 (26-31-AUG-18). Fig.3 shows the variations of the NS and AOD during these aerosol events.



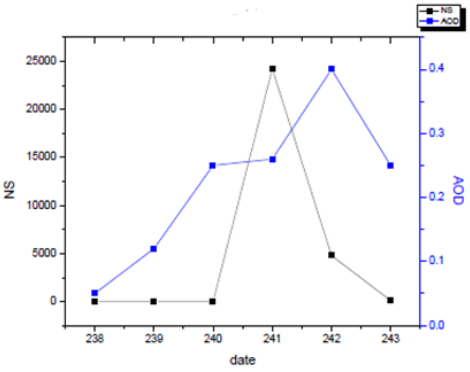
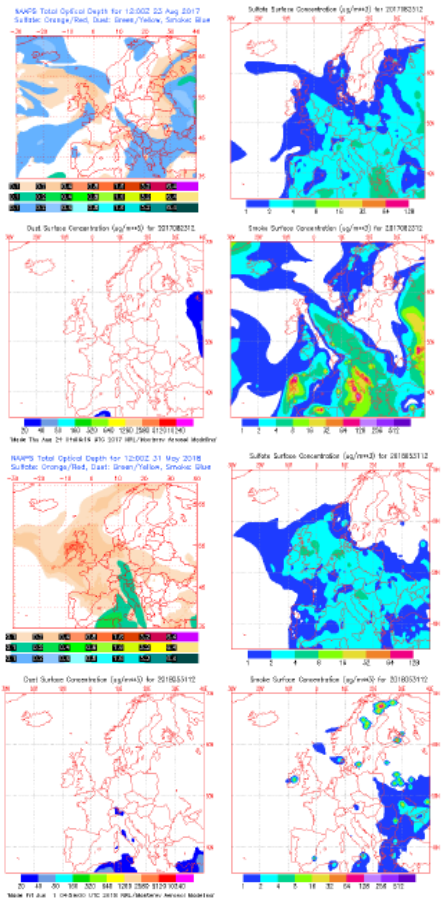


Fig.3. Daily variations of the NS and AOD during the three major aerosol events (IAE1, IAE2 and IAE3). Here, the whole lifespan of the dust events in considered.

All the special cases suggest that the passage of the aerosol load may stimulate lightning strikes over the area. In both cases it is evidenced an abrupt increase of the NS after AOD_550 exceeds the value 0.2. The supposed impact of aerosols on lightning activity depends not only on their abundance (in terms of AOD) but also on their type. For this purpose, maps of the NAAPS model have been used.

Model NAAPS doesn't predict dust intrusion during the first event; IAE1 (Fig. 4). This model suggests that the major aerosol contribution during this event in the Central Europe comes from smoke and sulphate.



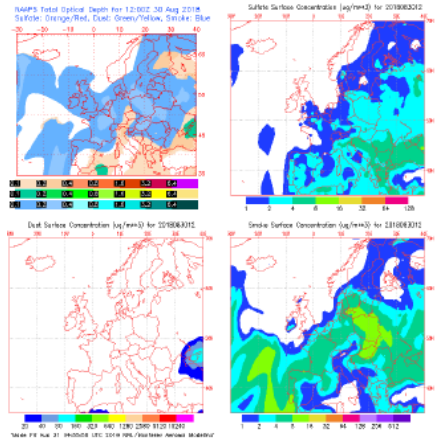


Fig.4. NAAPS maps during the IAE1 (25-Aug-2017), IAE2 (31-May-18) and IAE3 (30-Aug-18).

The major contributor on AOD during the second aerosol event is sulphate in combination with dust. While smoke is the major contributor on AOD during IAE3.

GIOVANNI products of Aerosol Optical Depth (AOD_550; MYD08_M3 V6.1) and Aerosol Index (OMI OMTO3d v003), give more insight over the aerosol presence and determine their types over the region during these three intense events (Fig. 5).

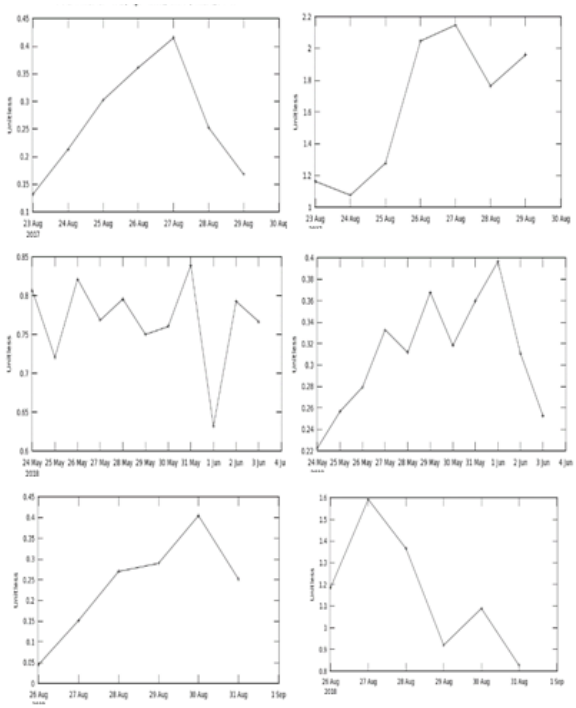


Fig.5. Time-series of the Aerosol Optical Depth (Combined Dark Target and Deep Blue AOD at 0.55 micron for land and ocean: Mean daily 1 deg. [MODIS-Aqua MYD08_D3 v6.1]) and Aerosol Index (OMI OMTO3d v003) during three IAE under investigation. a) IAE1, b) IAE2 and c) IAE3.

The gradual increment of AOD accompanied by a decrease of AI in the Fig.4 suggests the arrival of the air masses containing fine aerosol in the region during the IAE1. Nevertheless, co-variations of the AOD and AI values during IAE2 and IAE3, suggest the presence of the coarse mode aerosols during these events.

No clear evidence of their relationship was found when NS during IAEs were compared with their monthly mean. Thus, NS was significantly higher than the monthly mean, during the first two IAE (32% and 134%, respectively). However, during the IAE3, NS was 33% lower than the August mean.

3.3. AERONET validations

Another plan of this analysis is the assessment of the relationship between lightning activity and aerosol optical depth over specific observation sites. For this purpose, there are selected stations which are part of the AERONET network and are part of the lightning network too.

In this section, there are correlated data of AOD_550 provided by the Brussels AERONET station with those of lightning strikes over the Belgium region.

Statistical results don't show any significant correlation between NS and AOD in this area.

This result may be caused by several factors. First, here are using a limited data, only monthly-averaged data of NS and AOD, for 20 months (April-June 2016-2019). Despite this, Brussels and Belgium represent very restricted areas compared to the Central Europe region, whose data were used in the section 3.1. Moreover, AOD in Brussels presents a point-like data, whereas NS over Belgium presents averaged area data, thus not having both the same spatial scale.

IV. CONCLUSION

The correlation features between lighting activity and the aerosol optical depth were taken into analyses. An investigation was conducted over the period late spring – early summer. The central Europe region was taken into the investigation.

Values of number of lightning strikes and aerosol optical depth averaged for each month over the entire region, suggest that the lightning activity is related to the aerosol loading, especially in the case of lower lightning activity and clean environment. However, lower correlations were retrieved when daily averaged data were used, which don't suggest any aerosol impact on lightning strike rates.

Furthermore, intense aerosol events were taken into consideration to verify the impact of the aerosols on lightning activity. The three events don't show similar patterns of the aerosol-lightning relationships. In two of them, lightning strike count and AOD were positively related, while in the last one, they were negatively related.

Even more, when the area of investigation was restricted, and AOD was retrieved from AERONET stations, the statistical results don't show a significant correlation between strikes count and aerosol optical depth.

Thus, this investigation has found a slight positive relationship between aerosol loading and lightning activity.

This study focussed on the influence of the AOD data (not of CCN concentrations) on the lighting activity. However, slight relationships between the lightning activity and the aerosol optical depth may be attributed to the fact that perturbation of the CCN number concentration which is essential for the cloud microphysics don't influence much on the AOD values, especially in the clean environments.

However, to take more accurate response to the question how the aerosols impact these processes, larger database must be elaborated, and distinct aerosol types must be considered.

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