Lightning activity over anthropogenic and natural landscapes

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Abstract. The analyses specific threshold of lightning discharges density and thunderstorms days for different type of landscape and level of altitudes were determinate. For Central Europe from 9° W to 20° E and from 42° to 56° N (11° x 14° sectors) for April–September period from 2001 to 2014 were investigated. For Europe for the altitude range from 10 m below sea level (bsl) to 200 m above sea level (asl) the highest lightning discharge density is associated with the forest, shrub and wet, urban areas. For the altitude range 200–1000 m asl the highest lightning discharge density is associated with water (river, lakes), urban and forest areas. For the altitude range level from 1000 m asl to 2000 m asl the highest lightning discharge density is associated with the water, forest and grass types. A dense forest on the track of the flow of a moist air mass can promote the rise of air and the formation of convective clouds and lightning strokes. The effect of rivers, channels and large lakes on moisture and development of thunderstorm clouds may account for impact on cloud-to-ground (CG) lightning activity. For three flat 3º x 5º areas with similar meteorological and synoptic conditions, increased CG lightning activity is possible if there is a difference in altitude between different types of landscapes. The altitude difference further contributes to the development of convective clouds producing lightning.

Introduction

Atmospheric extreme events, such as deep moist convection, thunderstorms, heavy precipitation, hail, convective wind gusts are often associated with serious impacts for the society and economy. The main feature of all the events is a strong spatial and temporal variability. In particular, it has been reported that the lack of homogeneity of the surface plays a role in the forcing and development convection through heat, moisture and momentum fluxes [1, 2]. Some areas that have suffered the strong impact of human activity (urban, mining and industrial) were associated with the increase of CG lightning activity. When considering vegetated areas, areas with non-agricultural vegetation, arable land and permanent crops, it was showed a greater CG lightning activity [3].

The spatial variability of lightning is due to the synoptic situation, the geographical latitude, and orographic effects on the mountain slopes, temperature and moisture conditions of surface and vertical profiles. But the other factors such as natural and anthropogenic landscapes, anomalies of Earth’s gravity [4], and iron extraction sites can additional act to explain the spatial inhomogeneity of thunderstorm activity.

A landscape is the visible features of an area of land, its landforms and how they integrate with natural or man-made features. A landscape includes the geomorphological elements such as
mountains, hills, plains; hydrological elements (rivers, lakes, bogs, sea, and glaciers); and elements of land cover including indigenous vegetation; man-made elements including different forms of land use, buildings, constructions and infrastructures. In Europe the types of landscapes are very varied. Temperate and subtropical regions of Europe has a vast range of natural landscapes, including mountain and lowland landscapes, islands and coastal landscapes (lagoons and estuaries), or forest landscapes including broad-leaved forests and coniferous forests, and rivers and lakes landscapes. There are many types of man-made landscapes with different areas and lengths. For example, densely urban cities, road and rail networks, airports, mineral extraction sites, agricultures areas, channels and water reservoirs.

**Lightning and landscape data**

A 14-year analysis of the spatial variability of lightning strokes and thunderstorms days are presented. The area of investigation are grid with longitudes between 9° W to 20° E and with latitudes between 42° to 56° N and covers Germany, Austria, France, Switzerland, Benelux and northwest of Italy. The investigation based in the thunderstorm season (April–September) for period from 2001 to 2014. The information of the number of cloud-to-ground lightning per day in a 10 x 10 km² grid cell was provided lightning detection system BLIDS (BLitz-Information-Dienst Siemens), which is part of the EUCLID (EUropean Cooperation for Lightning Detection) network. For all subsequent investigation a day from 00 to 00 LT (local time) on the next day is classified as thunderstorm day (TD, days/year per grid cell) if at least 15 strokes were registered inside a 10 x 10 km² grid cell. The satellite data about the different landscape was provided by Eionet network National Reference Centre Land Cover (NRC/LC) [5–7] from satellite include features greater than 250 m for 2012.

**Spatial distribution of CG lightning activity**

Figure 1 shows the mean annual number of CG lightning strokes per km² (N, year⁻¹ km⁻²). For all investigation area, the distribution is dominated with northwest-to-southeast horizontal gradient [8].

![Figure 1](image_url)

**Figure 1.** Mean annual number of lightning discharges density to the ground (year⁻¹ km⁻²) during thunderstorm season (April–September) 2001–2014
The main reason for this spatial distribution of thunderstorm activity is the general circulation of the atmosphere in Europe. Due to the high lightning rate of some thunderstorms individual events are still visible during 14-year analysis. Overall, the highest number of lightning with up to 10 year\(^{-1}\) km\(^{-1}\) occur three focus areas. The largest N is in the Alpine region of Austria, the second focus area is in northwest of Italy’s Alps and the third, small focus area in Mediterranean southeastern coast of France. The maximum of N can be associated with an increased atmospheric instability and a mechanism for triggering convection up the slopes of mountains oriented perpendicularly to the direction of the flow of air masses. An additional factor for higher lightning discharges near the coast of France can be the flow of moist and warm air from the Mediterranean.

The lowest number of lightning is present in western France (less than 1 year\(^{-1}\) km\(^{-1}\)) and along coast of North Sea and Baltic Sea (Benelux and northern Germany) with 1–2 year\(^{-1}\) km\(^{-1}\).

The average values of N (3–4 year\(^{-1}\) km\(^{-1}\)) are located in southwest (between Black Forest and Swabian Jura) and south of Germany (pre-alpine region). In general, thunderstorm activity for southern Germany shows more small-scale variations than for northern Germany. This is due to the variety of relief forms (mountains, hills, plateaus, lowland valleys) in southern Germany compared to the monotonous relief in northern Germany (flatland, seenplatte and lowlands).

The spatial distribution of thunderstorm days is similar to distribution of lightning discharges density (Figure 2). The highest number of thunderstorm days occur in the Alpine region of Austria and northwest of Italy with up to 12 days/year per grid cell. The lowest number of thunderstorm days is present in areas of western France and along the North Sea and Baltic Sea with 2–4 days/year per grid cell.

![Figure 2. Mean annual number of thunderstorm days (TD) (with at least 15 strokes inside a 10x10 km\(^2\) grid cell) during thunderstorm season (April–September) 2001–2014](image)

**Spatial distribution of types of landscapes**

Six prevailing types of landscapes were defined for investigation from the 44 classes of land cover and land (CORINE Land Cover) use with the largest area fraction. The types of landscapes are the following: agricultural land, forest areas, grass areas, woodland shrub and wetland areas, water areas
and urban (industrial) areas. There is 73.3% of the area of investigation. In addition, a seventh mixed landscape type for the remaining 26.7% of the area was introduced.

In the west of Europe agricultural area above grass type of landscapes prevails (Figure 3). The largest urban centers are Paris, Belgium and Dusseldorf. The south-eastern part the area of investigation alternate from agricultural, forests and grass.

![Figure 3. Prevailing landscape type per each grid 10 x 10 km² cell](image)

**Analysis of thunderstorm activity over different types of landscapes**

The threshold of CG lightning activity for four ranges of altitudes are presented (Table 1).

**Table 1. Thresholds of lightning activity (N, TD) for different types of landscapes and altitudes above (below) sea level**

| Altitudes, [m] above sea level (asl) or below sea level (bsl) | Types of landscapes with the highest lightning activity | Lightning discharges density to the ground (N) [year⁻¹ km⁻²] | Thunderstorm days (TD) [days/year per grid cell] |
|---------------------------------------------------------------|--------------------------------------------------------|-------------------------------------------------------------|--------------------------------------------------|
|                                                               | Mean value                                           | 25–75% percentile values | 95% percentile values | Mean value | 25–75% percentile values | 95% percentile values |
| 10 m bsl – 200 m asl                                          | forest                                               | 1.8                                        | 1.2 – 2.2            | 0.2 – 3.7  | 2.7                         | 2.1 – 3.3               | 0.7 – 4.8               |
|                                                               | shrub and wet                                        | 1.7                                        | 1.5 – 2.0            | 1.1 – 2.6  | 2.5                         | 2.3 – 3.1               | 1.7 – 3.4               |
|                                                               | urban                                                | 1.6                                        | 1.1 – 2.1            | 0.1 – 3.6  | 2.2                         | 1.7 – 2.9               | 0.2 – 4.6               |
| 200 – 500 m asl                                               | water                                                | 2.8                                        | 2.1 – 3.1            | 0.6 – 4.0  | 4.2                         | 3.7 – 4.8               | 2.7 – 5.3               |
|                                                               | urban                                                | 2.2                                        | 1.7 – 2.8            | 1.0 – 4.5  | 3.4                         | 2.8 – 4.1               | 1.7 – 5.3               |
|                                                               | forest                                               | 2.1                                        | 1.6 – 2.5            | 0.1 – 2.6  | 3.2                         | 2.7 – 3.8               | 1.0 – 5.7               |
| 500 – 1000 m asl                                              | urban                                                | 2.8                                        | 1.9 – 3.5            | 0.6 – 5.9  | 4.3                         | 3.1 – 5.6               | 1.0 – 9.8               |
|                                                               | water                                                | 2.7                                        | 1.9 – 3.0            | 0.7 – 6.6  | 4.1                         | 2.9 – 4.9               | 1.1 – 8.5               |
|                                                               | forest                                               | 2.5                                        | 1.9 – 3.1            | 0.5 – 6.7  | 3.9                         | 3.1 – 4.7               | 0.4 – 7.3               |
| 1000 – water                                                 | mixed                                                | 3.9                                        | 2.4 – 5.6            | 0.5 – 8.3  | 6.2                         | 4.4 – 8.8               | 1.1 – 11.9              |

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The highest values of N and TD for the altitude range 10 m bsl–200 m asl were recorded about forest, shrub and wet, urban areas. Often lightning discharges density for the altitude range 200–500 m asl were about urban, water and forest areas. For the altitude range 500–1000 m asl CG lightning discharges density often were about urban, water and forest areas. But highest of thunderstorms days were recorded about urban, water and mixed areas. Note the average values of thunderstorm days (3.9–4.3) similar for mixed, forest and grass areas. But this difference was not very significant.

The higher values of lightning activity are about urban areas in agreement with the result other authors (Orville, 2001; Chagnon, 2001; Kar and Liou, 2014; Prieto, 2018; Westcott, 1995) [3, 9-12], where it was explained in terms of pollution and frictional lifting of air. For period 2001–2014 on the altitude range 1000–2000 m asl the value of N often were about water areas, forest on the mountains and grass areas (Figure 4). But highest values of TD were recorded about mixed areas. For the altitude range 1000–2000 m asl records the highest average value of N (4 year⁻¹ km⁻¹) and highest values of TD (4–6 days/year per grid cell) (Table 1).

![Figure 4](image.png)

**Figure 4.** The lightning discharges density N (year⁻¹ km⁻²) (mean, median, 25–75% percentile value, 95% percentile value) for different types of landscapes for altitudes 1000–2000 m asl

Three grids 3° x 5° on the flat areas (10 m bsl–200 m asl) in the northwestern France (49.5–46.5° N and 2° W to 3° E), Netherlands and Belgium (53.5–50.5° N and 2.5–7.5° E), northeastern Germany (51–54° N and 10-15° E) were selected for analysis. This flat areas are the simile atmospheric front activity.

A feature of the distribution of thunderstorm activity in north-eastern grid of Germany (Table 2) is not a significant difference in thunderstorm activity between types of landscapes with a relatively high level of thunderstorm activity compared to other flat areas. The value of N is about 2 year⁻¹ km⁻¹ and value of TD is 3 days/year per grid cell. For grid of north-western France thunderstorm activity has low values. Over urban and forest areas N is 1.1-1.2 year⁻¹ km⁻¹ and TD is 1.7 days/year per grid cell. For grid of Netherland and Belgium highest number of N and TD under urban area. The average value
of N is 1.6 year\(^{-1}\) km\(^{1}\) and TD is 2.3 days/ year per grid cell. The higher number of N and TD under agriculture and forest.

A possible cause of intensive development of deep moist convection and increased lightning activity over northeastern Germany is a significant difference in altitudes for different types of landscapes, exceeding one type of landscape (shrub) over another (grass) is 80 meters. For grid north-western France, this excess is only 25 meters, and for grid Netherlands and Belgium is 67 meters. Over the more homogeneous grid of north-western France, the development of convection is less likely.

### Table 2. Thresholds of lightning activity (N, TD) for different types of landscapes for three groups of flat area with altitudes 10 m below sea level – 200 m above sea level

| Name of grid flat area | Types of landscapes with the highest lightning activity | Lightning discharges density to the ground (N) [year\(^{-1}\) km\(^{1}\)] | Thunderstorm days (TD) [days/ (year per grid cell)] |
|------------------------|------------------------------------------------------|-------------------------------------------------|--------------------------------------------------|
|                        | Mean value                                           | 25–75% percentile values | 95% percentile values | Mean value | 25–75% percentile values | 95% percentile values |
| North-western France    | urban 1.2                                           | 0.8 – 1.5                  | 0.4 – 2.1             | 1.7        | 1.3 – 2.4                  | 0.5 – 2.9                  |
|                        | forest 1.1                                          | 0.9 – 1.3                  | 0.5 – 1.7             | 1.7        | 1.5 – 2.1                  | 0.9 – 2.6                  |
|                        | water 1.0                                           | 0.7 – 1.2                  | 0.4 – 1.4             | 1.6        | 1.0 – 2.0                  | 0.7 – 2.2                  |
| Netherlands, Belgium, Western Germany | urban 1.6 | 1.2 – 2.2 | 0.7 – 2.9 | 2.3 | 1.7 – 2.3 | 1.3 – 4.2 |
|                        | agricultur e 1.3                                     | 1.1 – 1.6                  | 0.5 – 2.3             | 2.0        | 1.7 – 2.2                  | 0.7 – 3.1                  |
|                        | forest 1.2                                          | 1.2 – 1.4                  | 0.8 – 1.5             | 1.7        | 1.6 – 1.8                  | 1.6 – 1.8                  |
| North-eastern Germany   | forest 2.2                                          | 1.7 – 2.7                  | 0.4 – 3.7             | 3.0        | 2.5 – 3.6                  | 1.6 – 4.4                  |
|                        | grass 2.0                                           | 1.5 – 2.5                  | 1.2 – 2.7             | 2.9        | 2.2 – 3.5                  | 2.2 – 4.3                  |
|                        | urban 1.9                                           | 1.6 – 2.2                  | 1.0 – 2.7             | 2.7        | 2.4 – 3.2                  | 1.8 – 3.4                  |

### Summary

The impact of different types of landscapes on lightning discharges density over Central Europe is explored in the present paper. We considered 14-years data of cloud-to-ground lightning in the thunderstorm season between 2001 and 2014 and satellite data about types of landscapes from 2012. The main conclusions are the following:

1. The highest CG lightning activity with up to 10 year\(^{-1}\) km\(^{1}\) occurs in three focus areas. The largest is in the Alpine region of Austria, the second focus area is in the northwest of Italy’s Alps and the third small focus area near the Mediterranean on the southeastern coast of France. The spatial variability of lightning is due to the synoptic situation, the geographical latitude, orographic effects, temperature conditions and moisture conditions. An additional factor in strengthening lightning activity may be man-made urban landscape with high constructions (TV towers and other towers, wind turbines). High buildings and constructions can be a trigger mechanism for discharging lightning.

2. In the altitude range from 10 m bsl to 200 m asl, the highest lightning discharges density is associated with the types forest, shrub and wetland and urban areas. For the altitude range 200–1000 m asl the highest lightning discharges density is associated with the water, urban and forest areas. For the altitude range 1000–2000 m asl the highest lightning discharges density is associated with the water, forest and grass types.

3. A dense forest on the track of the flow of a moist air mass can promote the rise of air and the formation of convective clouds and lightning strokes.

4. The effect of water areas (rives, channels and large lakes) on moisture and development of thunderstorm clouds may account for impact on CG lightning activity.
5. For three flat areas grid 3° x 5° sectors with similar meteorological and synoptic conditions, increased CG lightning activity is possible if there is a difference in altitude between different types of landscapes. The altitude difference further contributes to the development of convective clouds producing lightning.

6. The justification of the increase of the CG lightning discharges density for the grass type (natural grasslands and pastures) in landscapes at altitudes 1000–2000 m a.s.l requires additional studies. Increased thunderstorm activity at altitude may be associated with increased exposedness or electrical conductivity of the soil and underlying rocks.

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