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A climatology of cloud-to-ground lightning over Estonia, 2005–2009

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ABSTRACT

This paper presents the spatial and temporal distribution of cloud-to-ground lightning over Estonia and the adjacent sea for the period 2005–2009. Data collected by the NORDLIS (NORDic Lightning Information System) lightning detection network was used. The spatial distribution of lightning was calculated in a 10×10 km grid. A total of 172,613 cloud-to-ground flashes were registered in the area under observation during 2005–2009. The annual mean cloud-to-ground flash density over the area was 0.34 flashes km^{-2} year^{-1}. The lowest values found were less than 0.10 flashes km^{-2} year^{-1} and the highest flash densities were 0.80–1.01 flashes km^{-2} year^{-1}. The monthly distribution of lightning showed the highest activity in July and August. Of all the registered flashes, 99.4% were reported from May to October. The daily distribution of flashes showed single days on which thunderstorm activity was very high, against a background of much lower everyday activity. The diurnal distribution of lightning showed an evident peak between 15:00 and 17:00 local time over land. Over the sea, a flatter maximum lay between 13:00 and 21:00. Minimum lightning activity occurred between 22:00 and 06:00 over land and from 02:00 to 09:00 over the sea. Our work revealed that the spatial and temporal characteristics of cloud-to-ground lightning over Estonia generally resemble the characteristics found at other mid-latitude study sites.

1. Introduction

Thunderstorms are among the most damaging weather events. Thus, it is useful to know the spatial and temporal characteristics of the occurrence of thunderstorms and lightning. Nowadays, a variety of data sources are available for use in studying the spatial and temporal distribution of thunderstorms. Visual observations at meteorological stations are the oldest available records. At many locations, the data for annual and monthly numbers of thunderstorm days go back further than 100 years, thereby making long-term climatic studies possible. For example, Changnon and Changnon (2001) used data of 86 stations for the period 1896–1995 to study long-term fluctuations in the annual numbers of thunderstorm days in the contiguous United States. However, it has been demonstrated that the intensity of thunderstorms, as well as exterior factors, such as the background noise and daylight, significantly affect visual observations (Reap and Orville, 1990). Hence, it is wise to use data sets that are more reliable.

Lightning detection networks allow the collection of continuous lightning data that has high spatio-temporal accuracy and enable discrimination between cloud-to-ground and cloud flashes. The data is processed and made available in real time. Cummins et al. (1998) describe in detail the different lightning sensors and properties of lightning detection networks. The development of national and international lightning detection systems over the last 20 to 30 years has made it possible to study thunderstorm climates by using flash density as the main measure. Flash density is the average number of (usually cloud-to-ground) lightning flashes per area unit per time unit. The measure that is used most widely is the annual number of flashes per square kilometre. It is more accurate than the traditionally used average annual number of thunderstorm days, because it not only reflects the presence of thunderstorms, but also gives an overview of the number and spatial distribution of lightning flashes.

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Diurnal (hour-to-hour), seasonal (day to day or month-to-month) and annual (year-to-year) variations in lightning activity are widely used for temporal analyses (Tuomi and Mäkelä, 2008a). It is also possible to calculate the annual number of thunderstorm days or thunderstorm hours from the lightning detection data. Huffines and Orville (1999) did so for the USA, while Rivas Soriano and De Pablo (2002b) made similar calculations for the Iberian Peninsula.

Many reports of regional studies on the spatial and temporal distribution of lightning have been published. The most widely used spatial grid spacing for calculating flash densities seems to be 0.2°×0.2°. This spacing has been used for the USA (Orville and Huffines, 2001), the USA and Canada (Orville et al., 2002), the Iberian Peninsula (Rivas Soriano et al., 2005) and Sweden (Sonnadara et al., 2006). However, the areas of the cells in this kind of grid are unequal; they decrease towards high latitudes. Many authors prefer equal-area grid cells. Burrows et al. (2002) used a 20×20 km grid for Canada, and Antonescu and Burcea (2010) used the same grid spacing for Romania. Tuomi and Mäkelä (2008a) used a 10×10 km spatial grid to calculate flash densities when analyzing the thunderstorm climate of Finland. Schulz et al. (2005) used 10×10 and 1×1 km grids for geographical plots when studying the cloud-to-ground lightning over Austria from 1992 to 2001. The 1×1 km grids were too small, because individual radio towers and mountain summits create noise that clearly affect the results.

Relationships between lightning activity and other atmospheric factors or synoptic situations have also been examined extensively in modern lightning climatology. Tuomi and Mäkelä (2008a) studied the relationships between synoptic weather types and lightning activity. A similar analysis was made for the Iberian Peninsula by Clemente et al. (2004). Tuomi and Larjavaara (2005) used lightning detection network data to identify and analyze flash cells in thunderstorms. Characteristics of cloud-to-ground flashes over the Iberian Peninsula were compared with geographical latitude and longitude (Rivas Soriano et al., 2002), and with the sea surface temperature (De Pablo and Rivas Soriano, 2002). The effect of urban pollution on cloud-to-ground lightning activity was analyzed for the Midwestern USA (Westcott, 1995) and central Spain (Rivas Soriano and De Pablo, 2002a).

The first weather and thunderstorm records in the archive of the Estonian Meteorological and Hydrological Institute (EMHI) date back to the 18th century, but regular observations with continuous data rows were started in the second half of the 19th century. These records also include the occurrence of thunderstorms. The annual numbers of thunderstorm days for the entire 20th century are available at some weather stations. However, until 2005, the only type of thunderstorm data that was collected in Estonia was visual records. Many local-scale studies have been written on the basis of visual thunderstorm observations. It is known that, on average, there are 15–25 thunderstorm days per year in Estonia. Unfortunately, none of the Estonian thunderstorm studies have so far been published internationally.

The study reported herein yielded the first results for the spatial and temporal distribution of cloud-to-ground lightning over the Estonian landmass and the adjacent sea, including islands. Estonia was incorporated into the NORDLIS lightning detection network at the end of 2004. Thus, in the interests of using the most reliable data, data from 2005 to 2009 were used.

The remainder of the paper is organized as follows. In Section 2, the data and methods are described. In Section 3, the results are presented. In Section 4, the results are discussed. Section 5 concludes.

2. Data and methods

The study reported herein used data from the NORDLIS, which incorporates lightning sensors in Norway, Sweden, Finland, and Estonia. The central unit of the system operates in Finland and belongs to the Finnish Meteorological Institute (FMI). Fourteen sensors in Norway, nine in Sweden, seven in Finland, and one in Estonia are connected to the central unit (Fig. 1). The system uses mainly IMPACT sensors, with some of its successor model, the LS7000, also deployed. These sensors use low-frequency electromagnetic radiation to detect lightning. NORDLIS is mainly capable of locating

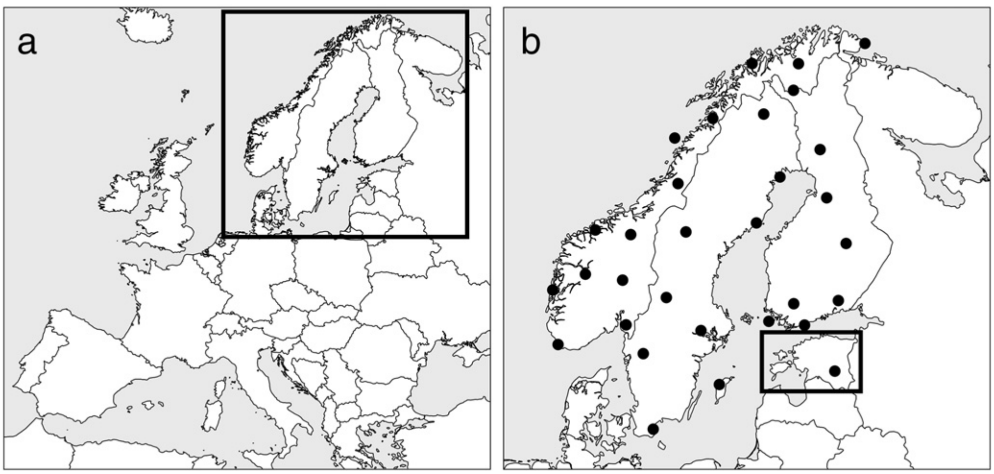

Fig. 1. a) Location of the NORDLIS lightning detection network (black rectangle). b) Locations of the NORDLIS sensors in 2009 (black circles) and our study area (black rectangle).