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Nordic Lightning Information System: Thunderstorm climate of Northern Europe for the period 2002–2011

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ABSTRACT

A 10-year statistics (2002–2011) of the Nordic Lightning Information System (NORDLIS) are presented. NORDLIS is a joined lightning location network between Norway, Sweden, Finland, and Estonia, comprising in 2011 of 32 lightning location sensors. Our data set contains a total of 4,121,649 cloud-to-ground (CG) flashes. We show the regional and temporal distribution of lightning in Northern Europe during the study period. Our results indicate that the average annual ground flash density values are greatest in Southern Sweden, Baltic countries and Western Finland. The average number of thunderstorm days is largest in the Baltic countries and Southwestern Sweden, and the annual number of ground flashes has varied during the study period from 250,000 to 620,000. The largest observed daily number of ground flashes is 51,500, and the largest daily ground flash density is about 5 CGs km^{-2}; this has occurred in southern Sweden in July 2003. The average daily number of ground flashes peaks in mid-July–early-August. Cold season (October–April) thunderstorms occur frequently over the North Sea west of Norway and in the west coast of Denmark. Our results also show that an intense thunderstorm may occur practically anywhere in the Northern Europe except for certain maritime and mountain areas.

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1. Introduction

The climate of Northern Europe (about 55–71°N, 0–31°E) is governed by the moist, Atlantic maritime climate zone and the Asian continental climate zone (see e.g., Kottek et al., 2006). Because of the differences of these two climate zones, the synoptic weather scenarios in the summer time in the northern Europe contain large variation, depending on the propagation of airmasses. Summers are moist and less hot when the airmasses flow from the Atlantic. A hot and often drier summer is experienced when the airmasses have Asian continental properties. The majority of airmasses approach from the west or southwest (Heino, 1994).

Because of the clear division between summer and winter, the main thunderstorm season in the northern high latitudes is practically limited to May–September. Above the Arctic Circle (about 65°N), the seasonal variation is even more pronounced: the summertime is short, although it may be hot. However, a thunderstorm occurring outside the summer period shows in the thunderstorm day statistics, because a single flash is enough to comprise one thunderstorm day. Furthermore, a winter thunderstorm, no matter how rare, is a sudden and dangerous phenomenon.

The statistical analysis of high-latitude thunderstorms in Europe has been started already some centuries ago. For example, Hamberg (1915) summarized thunderstorm day statistics 1730–1915 in Sweden. Statistics of thunderstorm days for Finland were first shown by Sundell (1887). In Finland, Oksanen (1921a, 1921b) studied the arrival directions of thunderstorms, and also more specific statistics of thunderstorms in Helsinki (Oksanen, 1948). These early data sets are based on human observations at geophysical-meteorological observation stations. Later in the 20th century, the automatic observations of thunderstorm and lightning were achieved

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with lightning flash counters (Prentice, 1972). In Sweden, the flash counter network was established is 1958, and in Norway and Finland in 1959 (see e.g., Müller-Hillebrand et al., 1965). Time series of thunderstorm days and average annual ground flash density since 1960 in Finland have been shown by Tuomi and Mäkelä (2008) and Mäkelä (2011). At present, lightning observations in the Northern Europe are made with the Nordic Lightning Information System (NORDLIS), which started its full operation in 2002. NORDLIS is discussed more in Section 2.

In the Baltic countries, the visual thunderstorm observations at weather stations were the only available data source until 2005. First such observations were performed in the 19th century and continuous data series with rather good quality date back to the end of 1940s at most stations. Data records contain the information about thunderstorm days and the beginning and end times of individual storm events. Since 2005, Estonia is a member of NORDLIS and visual thunderstorm observations have ended at most weather stations. In Latvia and Lithuania, visual observations have still continued.

Only few local studies were published about thunderstorms in the Baltic countries during the 20th century. The first comprehensive study about thunderstorm climate in the Baltic countries during 1951–2000 was by Enno et al. (2013). Cloud-to-ground lightning statistics over the Estonia during 2005–2009 were published by Enno (2011).

The study by Müller-Hillebrand et al. (1965) seems to be the most recent study regarding Scandinavian (defined in their paper as Norway, Sweden and Finland) thunderstorms. The spatial distribution and density was such that the 90 Norwegian counters covered up to about 65°N latitude (about half of the country), the 105 Swedish counters up to 62°N latitude (about one third of the country), and the 49 Finnish counters covered all of Finland, but with much lower counter density than in Sweden and Norway.

The results of Müller-Hillebrand et al. (1965) are based mainly on one year of flash counter measurements (1963), but some results are shown for years 1959–1962, and for the average of 1959–1963. However, despite the small period of observations and the non-homogenous network density, their results show similar features than which will be presented in our study. Interesting subject in their paper is the definition of "lightning intensity" or "thunderstorm intensity", i.e., the local ratio between ground flashes and thunderstorm days; this parameter indicates the average intensity of a thunderstorm, measured with the number of flashes the storm produces. This topic is studied more recently in the United States and in Finland by Mäkelä et al. (2011). In this paper, we will show the values of this parameter for the whole northern Europe.

2. Data and methods

2.1. NORDLIS network

The NORDLIS network is a joined lightning location system (LLS) covering Norway, Sweden, Finland and Estonia (Mäkelä et al., 2010; Fig. 1). The lightning sensor data from these countries are shared between national operators and the actual processing of located lightning data is done separately on each country. This is possible as all operators are using lightning detection technology from the same manufacturer and therefore the sensors are compatible for all operators. The result of this cooperation is that all participating network operators can use all lightning sensors on the area regardless of who owns and maintains the sensor. During the study period the number of NORDLIS sensors has varied between 30 and 34. The variation in the number of sensors may raise question about its effects on our statistics; we will discuss this in Subsection 2.2.

The located NORDLIS lightning data are formed by processing the sensor observations from the whole NORDLIS sensor network. The central processor combines correlating sensor observations together and calculates the most probable (optimized) position of a lightning strike. As the used lightning sensors are LF frequency band sensors and their baselines (i.e., distance between sensors) are relatively long, the system is detecting mainly cloud-to-ground (CG) strokes and only a small fraction of intracloud (IC) lightning. Cloud-to-ground strokes are combined into flashes using space and time correlation criteria. The located coordinates are expressed according to the WGS-84 coordinate system and for CG-lightning the position should closely match to the actual ground contact point of the lightning channel. The central processor also provides estimates for lightning current peak value and for the uncertainty related to each calculated location (i.e., often termed as location accuracy).

As processing is done separately on many processors, the actual NORDLIS lightning data are not exactly the same for all participants. The differences on located lightning data arise from (possibly) different processing parameters, data communication faults affecting to the availability of sensor data and from slightly different sensor network used on each country. Although all sensors on the NORDLIS area are being shared between parties, there are differences on the sensor data set used for processing because some sensor models have limited compatibility with certain central processor models and because also sensor data outside the NORDLIS area are being used by some operators.

In this study our data set consists of CG flashes. This means that although the basic unit of detection is a stroke, we use only the first located stroke in case of a multi-stroke flash. Also, we have filtered out all events classified as intracloud, and all positive first-strokes with peak current less than 10 kiloamperes (kA). The latter arises from the notion that many of the low peak current positive flashes may actually be intracloud flashes (see e.g. Cummins et al., 1998). The total data set covering the ten-year period 2002–2011 consists of 4,121,649 CG flashes.

2.2. NORDLIS performance

The NORDLIS lightning detection network has gone through many configuration changes which have been thoroughly discussed in Mäkelä et al. (2010): sensor locations, sensor models, upgrades on central processors and processing parameter changes have been affecting the located lightning. As a summary, the quality of lightning location data is not homogenous in space and time over the NORDLIS network area; actually, this issue is related generally to any ground-based lightning location network.

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