LONG TERM CHANGES IN FREQUENCY OF THUNDERSTORMS IN THE BALTIC COUNTRIES, 1950-2004

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I. INTRODUCTION

Thunderstorms are among the major causes of weather-related damages and economic losses in tropical and mid-latitudes. Lightning, as well as straight-line winds, hail and sometimes even tornadoes are the main causes of thunderstorm-related damages in the Baltic countries (e.g. Merilain and Tooming, 2003; Marcinoniene, 2003).

Thunderstorm activity is thought to be influenced by changes in solar activity (Brooks, 1934; Mullayarov et al., 2009; Siingh et al., 2011) as well as by other climatic factors. Thus, general changes in climate may affect thunderstorm frequency (Williams, 2005).

Many regional studies have been published about long-term changes in thunderstorm climate (e.g. Changnon and Changnon, 2001; Bielec-Bakowska, 2003; Kunz et al., 2009). The annual and monthly numbers of thunderstorm days (TD) registered by human observers at meteorological stations have been the main data sources for such studies.

The Baltic countries are located in the north-eastern part of Europe along the eastern coast of the Baltic Sea. Enno et al. (2013) published the main statistics of thunderstorm occurrence in the Baltic countries during 1951-2000, indicating 12 to 29.5 TDs annually. The main thunderstorm season started in April, peaked in July and August, and ended in October.

Based on previous studies, long-term changes in TD frequency in the Baltic countries can be expected. Enno (2010) concluded that some of the Estonian weather stations had a statistically significant downward trend in TD frequency during 1950-2000. In addition, inhomogeneities were found in most of the data series of 59 meteorological stations in the Baltic countries over the period of 1951-2000 (Enno et al., 2013). As none of these inhomogeneities was associated with known artificial factors, some kind of natural change in the thunderstorm climate of the Baltic countries may be proposed.

The main objective of this study is to give a detailed overview of changes in the thunderstorm climate of the Baltic countries during 1950-2004 and to make sure whether the trends are statistically significant. We also want to compare changes in TD frequency with the climatic changes that have affected the study area.

II. PRESENTATION OF RESEARCH

Our study area encompasses three countries: Estonia, Latvia, and Lithuania; its approximate size is 650×495 km. The area lies in the north-eastern part of Europe, between 53–60°N and 20–29°E.

Thunderstorm data from 50 Estonian, Latvian, and Lithuanian meteorological stations were available for the study period. All the stations were manned 24 hours a day. According to the observation rules, a TD is registered at a meteorological station when the thunder is heard at least once during a 24-h period by the observer.

In addition, the data of Tartu station from 1901-2010 is also represented in this paper as an additional material. The Tartu station in Estonia is the only one in the Baltic countries to have a continuous TD data series since the beginning of the 20th century.

To remove TD series with unnatural changes and biases, comparative analysis was used. The analysis relies on the assumption that any climate change or fluctuation experienced by the candidate station will show up in the surrounding reference stations as well.

First, the relative frequency of thunderstorms was calculated for each station for every year. Relative frequency means that the annual numbers of TDs at a particular station were expressed as % of the 1950-2004 average at this station. Second, three nearest surrounding stations were determined for each of the 50 candidate stations. Relative storm frequencies of a candidate station and of the surrounding stations were plotted for a comparison. Third, the temporal behaviour of storm frequencies at each of the 50 candidate stations was visually compared with those at the surrounding stations. If the candidate station showed any abrupt change or systematic shift in TD frequency compared to the surrounding stations, then it was excluded from further analysis.

In addition to the visual comparison of the temporal behaviour of storm frequencies, the long-term trends of TD frequencies were also compared with those found at nearby stations. If the candidate station showed a linear trend with a different direction or with a remarkably different slope compared to that of the reference stations, then it was not used in further analysis.

As a result of the comparative assessment, ten stations were excluded from the main analysis. All of them had unusual biases or abrupt changes in their TD datasets. Hence they are not suitable for studying long-term changes in thunderstorm climate.

Sen's method (Sen, 1968) was used in the MS Excel template MAKESENS (Salami et al., 2002) to estimate the directions and magnitudes of changes in the annual numbers of TDs during 1950-2004. For individual stations, significance of the changes was checked with Mann-Kendall test (Mann, 1945; Kendall, 1975). In case of average TD numbers of many stations, significance of changes was checked with multivariate Mann-Kendall test in the MS Excel template MULTMK/PARTMK (Libiseller, 2002). This test takes into account the standard deviation of the data every year when calculating the significance of the trends. Trends were considered to be statistically significant at p<0.05. Decadal changes in TD numbers were calculated for each station for better comparison. In addition, a Fourier spectral analysis (Bloomfield, 1976) was used to detect possible periodic fluctuations in TD frequency.

III. RESULTS AND CONCLUSIONS

Our findings confirmed the assumption that there have been significant changes in the TD frequency in the Baltic countries during 1950-2004 (Fig. 1). Average annual TD number showed a statistically significant downward trend with the rate of change of 0.9 TDs per decade. Downward trends were stronger at stations located in the southern part of the study area. The highest thunderstorm frequency was observed around 1960 and the lowest around 1990.

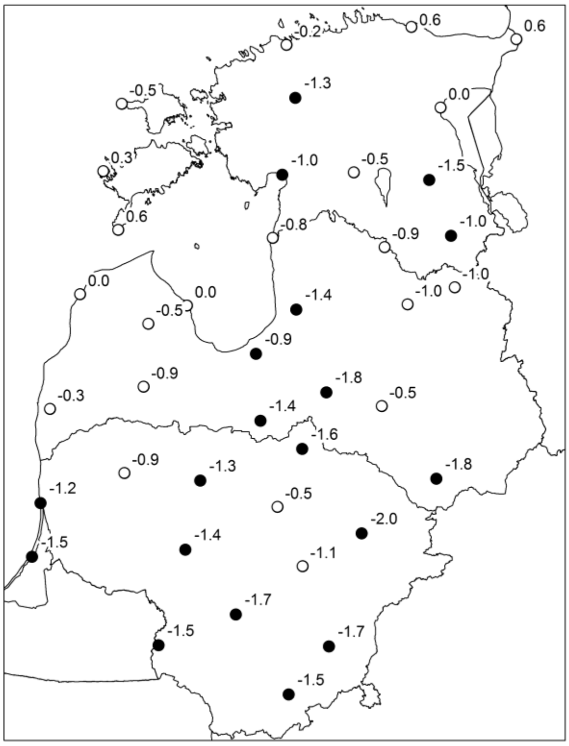

FIG. 1: Decadal changes in the annual TD frequency at 40 meteorological stations in the Baltic countries during 1950-2004. Stations with statistically significant trends (p<0.05) are marked with filled circles.

Thunderstorm frequency in the Baltic countries was also characterized by a remarkably large inter-annual variability and by fluctuations with an average periodicity of 13 years (Fig. 2). In addition to the primary TD maximum around 1960 and minimum around 1990, some secondary maxima and minima appeared. Secondary maxima were at the beginning of the 1970s, in the mid-1980s and around 2000. Secondary minima appeared at the beginning of the 1950s and at the end of the 1960s and 1970s.

The primary TD minimum coincided with a positive anomaly of the NAO index around 1990 and was suspected to be associated with the prevalence of cool westerly airflow in northern Europe. The increase in TD frequency since the mid-1990s coincides with increased summer air temperatures.

The primary TD maximum around 1960 was associated with a relatively strong mid-century peak in the annual numbers of TDs which was obvious from the 110-year data of Tartu (Figure 3). The mid-century peak was detected not only in the Baltic countries, but also at many other regions like in the United States (Changnon and Changnon, 2001), Russia and Kazakhstan (Gorbatenko and Dulzon, 2001) and China (Zhang and Niu, 2009; Wei et al., 2011). Thus we suspect that it may be associated with global atmospheric conductivity anomalies caused by frequent nuclear tests during the 1950s and at the beginning of the 1960s (e.g. Pierce, 1972; Harrison, 2003).

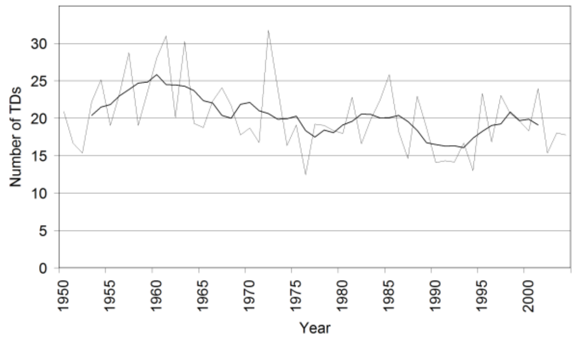

FIG. 2: Average annual number of TDs in the Baltic countries and its 7-year smoothed average during 1950-2004.

The secondary maxima and minima in TD frequency were found to be different in their nature. Some of them were associated with high or low thunderstorm activity during summer, whereas others appeared only during spring and autumn. The idea that fluctuations in TD frequency may be related to the 11-year solar cycle does not seem to be supported by our data. The period of thunderstorm frequency cycles was usually longer than 11 years. As a result, the highest TD frequency around 1960 and the lowest TD frequency around 1990 both occurred during the peak of the 11-year solar cycle.

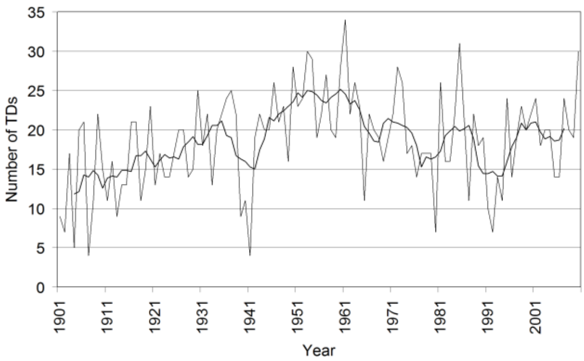

FIG. 3: Average annual number of TDs at the Tartu station and its 7-year smoothed average during 1901-2010.

Based on the present paper we can conclude that the downward trend in TD frequency in the Baltic countries during the second half of the 20th century was probably temporal. As a result of global warming, more frequent presence of warm summers may lead to a continuing increase in TD frequency in the future.

Further study with a synoptic classification of thunderstorms over the Baltic countries is needed to understand better the reasons for changes and fluctuations in TD frequency. A possible relationship between atmospheric nuclear tests and thunderstorm frequency during the 1950s and around 1960 also seems to be worth of investigation on a wider global scale.

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