Structure of time series of thunderstorm days

V.P. Gorbatenko

Scientific Research Institute of High Voltages at Tomsk Polytechnic University

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Time series of thunderstorm activity at territories of Western Siberia, Kazakhstan, and Germany for the period from 1936 to 1995 have been analyzed statistically. To reveal periodic components in meteorological series, visual observational data of hydrology and meteorology services have been used. Periodic changes (cycles) in the thunderstorm series have been found for each territory under study. Long-period (18 years and longer), medium-period (from 7 to 10 years), and short-period (from 2 to 6 years) cycles have been revealed.

Thunderstorm activity, visually observed at meteorological stations, is characterized by the number of thunderstorm days and the total duration of thunderstorms for a year. The technique of recording a thunderstorm as a natural phenomenon has not been changed significantly since 1912, although since 1966 thunderstorms have not been longer subdivided into close and remote ones. It should be noted that instrumental observations of thunderstorms were conducted at a series of sites of the European territory of Russia, in Eastern Siberia, and some regions of Western Siberia and Kazakhstan. However, reliable data on the density of strikes to the surface have not been obtained yet because of short duration of the observations. Consequently, when solving the problems of monitoring the thunderstorm activity as an element of the global electrical circuit in the atmosphere, the analysis of long-term data of visual observations of thunderstorms has no alternative.

Periodic changes in the behavior of meteorological parameters are confirmed by numerous researches into natural phenomena. The thunderstorm activity is not an exception. At the same time, the structure of long-term fluctuations of such meteorological elements as air temperature, atmospheric precipitation, and atmospheric circulation are studied rather thoroughly and used in practice for long-term forecasting. However, this is not true for the thunderstorm activity. Time series of the thunderstorm activity are characterized by a complex statistical structure. Among the most interesting papers on the structure of time series, the works by Kleimenova (Ref. 1) and Pavlova (Ref. 2) can be mentioned. In these papers, the temporal variability of the number of thunderstorm days is studied in connection with the 11-year cycle of solar activity. A wide variety of the periods revealed earlier in time series of thunderstorm activity and the methods used for this revealing does not allow one to make unambiguous conclusions on the presence or absence of similar cyclicity in thunderstorm series in different geographic regions.

Comparing experimental data for different territories,[1–5] we can conclude that cycles of different lengths are observed at different territories. What's more, the cycles of the same length do not always characterize the series obtained at the stations situated even within a mesoscale territory (about 100 km in radius).[6] Periods of different amplitudes can be observed at a territory of the same region. The correlation between the temporal behavior of the thunderstorm and solar activities is observed not for all territories. To understand the reason for these differences, thorough studies of the temporal behavior of the thunderstorm activity at a closely spaced network of stations situated in different physical-geographic conditions are needed.

In this paper, the statistical structure of the time series of the number of thunderstorm days at territories different in their geographical position and physical and geographic conditions is considered. General regularities, connected, possibly, with space factors and local peculiarities caused by atmospheric circulation or some other factors, are also revealed.

The research considered in this paper has been performed at the southeastern territory of Western Siberia (Tomsk Region and adjacent territories), northern, central, southern, and eastern parts of Kazakhstan (10 regions), and southern part of Germany. To study the temporal variability of the characteristics of the thunderstorm activity over Western Siberia, we used the data from 17 meteorological stations for 1936–1995 and 23 stations for the period of 1966–1995. For the southern territory of Germany, we analyzed high-quality data from 41 regular meteorological stations for the period of 1951–1997. These data were obtained at German Weather Service. For the territory of Kazakhstan, we used the data from 74 stations (17 stations at the northern territory, 22 stations at the central territory, 15 stations at the eastern territory, and 20 stations at the southern territory) for 1936–1985.

To reveal the periodic component in the series of interannual variations of the number of thunderstorm days, applied methods of the correlation theory of stationary random processes were used. The hypothesis of stationarity of the process under analysis was

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checked using the inversion criterion.[7] After elimination of non-stationarity, the autocorrelation and spectral functions were estimated in order to find periodic oscillations in the time series of interest.[8]

To estimate the spectral densities at the territories under study, a number of independent realizations of the process (the series of the number of thunderstorm days for every meteorological station with subtracted mean and remote trend) were used. These realizations can be considered as recorded under almost the same conditions, because synoptic processes causing the thunderstorm activity inside each territory are the same. In this case, values of all realizations taken at the same time can be considered as an independent sample of random values and, consequently, as a consistent and asymptotically unbiased estimate[9] of the spectral density. The normalized standard error in estimation of the spectral density for each territory was calculated by the equation from Ref. 10. It is equal to 23% for Western Siberia, 15% for Germany, and 12% for Kazakhstan.

If necessary, the series for each station were reduced to the standard form, and the mean was subtracted. The Hemming window was used as a spectral one. The periodograms (and their confident intervals at $\alpha = 0.05$) of the annual number of thunderstorm days at the territories under study are shown in Fig. 1. The peaks in the periodogram for the Tomsk region fall on 2.9, 3.4, 4.9, 8.8, and 22 years (Fig. 1*a*). Consequently, the shortest cycle of the thunderstorm activity for the Tomsk region lasts 3 years; the 5-year and 10-year cycles, as well as the cycle about 18 years long are also probable. For the territory of Southern Germany (Fig. 1*b*), the peaks correspond to 3.8, 4.6, 5.8, 9.2, and 23 years. Consequently, the shortest cycle is equal to 4–5 years; the 6- and 9-year cycles and the cycle about 22–23 years long are also possible. For the territory of Kazakhstan (Fig. 1*c*), the shortest observed cycle of thunderstorm activity is about 3 years; the 4- and 5-year cycles are also possible, as well as 8- and 17-year cycles.

Before discussing the obtained results, let us briefly characterize the cycles found in the temporal behavior of most meteorological processes.

Quasibiennial variations were found in the temporal behavior of almost all meteorological elements. This cycle and its possible causes are discussed widely,[11] although statistically it is classified as "red noise," because it is characteristic of random processes.

One of the most pronounced cycles in hydrological and meteorological processes is the 5–6-year cycle, which is usually associated with the solar activity (a half of the 11-year solar cycle).[12]

The cycles of 10–12 years long were also found in the behavior of many atmospheric characteristics, such as the air temperature, precipitation, air pressure, and circulation. Undoubtedly, this is a result of the generally known 11-year cycle of the solar activity. However, this cycle often has lower amplitude than the 5–6-year and 22–23-year cycles.[11] Besides, there exist regions where this cycle is not found at all.

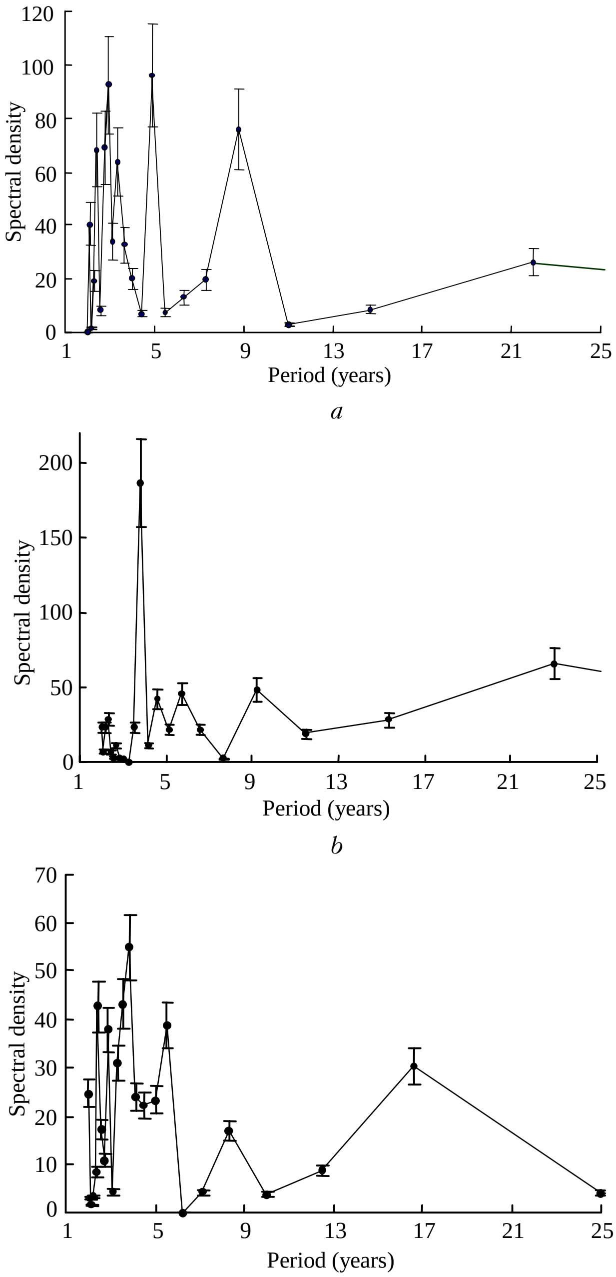

Fig. 1. Periodograms of the annual number of thunderstorm days for Southwestern Siberia (*a*), Southern Germany (*b*), and Kazakhstan (*c*).

The 22-year cycle of the solar activity manifests itself in the sign of the magnetic field polarity of sunspots. It was found in the series of air temperature,[13] forms of atmospheric circulation,[14] and pressure.[15] In the opinion of Vitinskii et al.,[12] the alternation of magnetic polarity on the Sun proves to be more significant factor than simply the amount of sunspots.

Cyclic 30–35-year oscillations of the climate were detected in a series of researches,[16] but they are not considered here, as well as the secular and longer cycles, because the available data on the number of thunderstorm days do not allow us to identify them.

It should be noted that although the 11-year and 5–6-year cycles in the series of thunderstorm activity are also related to the cycles of solar activity,[1–5] and the possible nature of other cycles is likely not revealed, the question on the influence of the solar activity on atmospheric processes is still open.

Analyzing the periodograms shown in Fig. 1, note that each territory is characterized by a set of cycles having different lengths. A medium-period cycle (the 9-year cycle for Siberia and Kazakhstan and 8-year cycle for Germany) is general for all the territories under study. The long-period cycle for Kazakhstan does not exceed 19 years, whereas it is 22–23 years for Siberia and Germany. The widest variety is observed in short-period cycles: cycles similar to those observed in Western Siberia (5 years) and in Germany (4 years) have been found at the territory of Kazakhstan. In the amplitude of the spectral density, the 3–4-year cycle at all the territories is the most pronounced and is likely due to some cyclic component in repetition of synoptic processes causing thunderstorms. The similar analysis of the annual series of thunderstorm days for stations of Eastern Siberia [4,5] also revealed both the 5-year and 11-year cycles.

Consequently, the 5–6-year cycle, which is usually associated with a half of the 11-year cycle of the solar activity, is characteristic of meteorological series of thunderstorm activity at territories of Western and Eastern Siberia and some territories of Kazakhstan. In Germany this cycle is 4 years long. In the series of thunderstorm activity for Kazakhstan, the 22-year cycle of solar activity does not manifest itself, but cycles with the length multiple of 4 years are rather typical.

Along with the wide variety of forms of cyclicity, there exists a lot of methods for studying them. Since the series of thunderstorm activity under analysis are not too long, some other methods of analysis of meteorological series should be applied to confirm the existence of the revealed cycles in them. Therefore, in the series of the number of thunderstorm days for each station, the cyclicity has been revealed by calculating the autocorrelation function, which is known as a function of time shift (estimates of the autocorrelation function are the correlation coefficients for the terms of a time series separated by some time interval). For 47 values (45 degrees of freedom) the highest value of the empiric correlation coefficient was 0.28; for 50 values it was 0.27, and so on.

The Table presents the periods of different length in the time series of the number of thunderstorm days for different territories. It includes both our results and the literature data,[4,5] but only those, which were obtained by the methods similar to the methods used in this work. The time series from stations were studied not for the Kazakhstan territory as a whole, but for each its part separately, because all territory is too large and thunderstorms in its different parts are caused by different synoptic processes. The data given in the Table show that almost all the territories are characterized by short-period cycles in the series of the number of thunderstorm days. A set of cycles of different lengths for Europe is close to that for Siberia. The most significant differences are observed in the medium-period and long-period cycles.

Table. Cycles in a series of the number of thunderstorm days for different territories

Territory under study	Period (in years)						
	2–3	3–4	5–7	8–9	10–13	14–17	18–22
Krasnoyarsk Krai[4,5]	3	4	–	–	11	–	–
Baikal Region[4,5]	3	4	–		11	–	–
Yakutiya[5]	–	–	5	8	–	–	–
Baikal[5]	–	–	5	8	–	–	–
Western Siberia	–	3	5		10	–	19
Northern Kazakhstan	2	–	–	9	–	–	18
Central Kazakhstan	–	4	6	–	11	17	–
Southern Kazakhstan	–	4	7	–	10	16	–
Eastern Kazakhstan	–	–	–	8	–	15	–
Southern Germany	–	4	6	9	–	–	22

It should be noted that the method of autocorrelation function revealed for each territory the periods of cyclicity other than those given in the Table. At the same time, we failed to find the cyclicity in the series of 60 years and longer at five stations situated in southwestern Siberia and in the series of 40–46 years at nine stations in Kazakhstan. In spite of the marked difference in the results, some general regularities can be revealed. Short (from 2 to 7 years long) cycles were found in the series of more than 50% stations for each territory under study (60% for Tomsk Region, 45% for Germany, and 70% for Kazakhstan). Cycles of 9–13 years long were detected at 35% stations of Western Siberia, 53% stations in Northern Kazakhstan, 30% stations in Central Kazakhstan, 40% stations in Southern Kazakhstan, 50% stations in Eastern Kazakhstan, and 40% stations of Southern Germany. Cycles of 20–25 years long were revealed for 60% stations in Western Siberia, 70% stations in Germany, and 20% stations in Northern Kazakhstan. At the same time, cycles of 16–18 years long are characteristic of 65% stations. As far as concerned the localization of cycles with the same period, it should be noted that the Kyzyl-Ordinsk Region stands out against the rest of the territory of Kazakhstan. In this region, cycles with the period of 4 and 16 years were found. There are no short cycles in the series recorded at the stations of Eastern Kazakhstan.

Meteorological stations, in whose series of thunderstorm activity no cyclicity has been found, are mostly localized in the southern and eastern parts of Kazakhstan. We failed to reveal the localization of similar cyclicity at the territories of Western Siberia and Germany. Stations with different cyclicities may be situated close to each other. This result cannot be considered as a consequence of only visual observation of thunderstorms, because all questionable data were excluded from the analysis. Various ways of development of a thunderstorm situation are mostly caused by peculiarities of the underlying surface. Together with the orography, the temperature and humidity inhomogeneity play an important role.[17] We believe that the cycles of different lengths at neighboring stations are caused just by these peculiarities.

The results obtained suggest that even if the cycles of solar activity affect the thunderstorm activity, their influence is not direct (or not everywhere direct), but indirect – through circulation or some other processes.

So, short, medium, and long cycles can be found at the territories under study, although the periods of these cycles do not coincide for different territories.

The 3–4 years long cycle is most pronounced in the amplitude of the spectral density. This cycle is most likely caused by the presence of the cyclic component in repetition of synoptic processes causing thunderstorms above one or other territory.

The cycles of 5–6, 11–12, and 22–23 years long, which are usually associated with the solar activity, are observed in far from all regions.

The medium-period cycles are largely 5 and 8 years long, and both cycles can simultaneously manifest themselves in the series of thunderstorm activity for the same territory. Consequently, one of these cycles can be caused by some reasons different from the solar activity.

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