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STORMS IN EUROPE (1994–2005) – THEIR RELATIONSHIP WITH CONTINENTALITY OF CLIMATE

Abstract: The objective of the paper is to determine the influence of continentality of Europe's climate, increasing to the east, on the number of days with thunderstorms during the years 1994–2005 in ten chosen European cities.
In Europe, days with thunderstorms come from cities located in zones from the west to the east, beginning from Dublin, through London, Paris, Munich, Prague, Minsk, Kiev, Kharkov and up to Moscow. The well matched stations show the gradually increasing continentality of Europe's climate.
From an analysis of the number of days with thunderstorms, the Gorczyński continentality index and the long-term mean annual amplitude of air temperature it may be concluded that, in as much as the values of the amplitude and index increase with distance from the ocean, it is not always so with the number of days with thunderstorms. Despite greater climate continentality, Minsk, Kiev and Moscow have much fewer storm days than Warsaw or Prague.

Key words: storm, Gorczyński continentality index, number of days with thunderstorms, annually, Europe

During the last dozen years, extreme weather phenomena, which also include thunderstorms, have been occurring ever more frequently not only in Europe but throughout the world as well. People, by their involvement in global warming, have certainly participated in increasing the number of these catastrophes. However, such geographic and climatic factors as surface features, distance to the ocean, thermal input related to latitude or atmospheric circulation may not be forgotten.

In Poland, M. Stopa (1962), Cz. Koźmiński (1963), W. Wiszniewski (1973), L. Kolendowicz (1995), and Z. Bielec (2000) have earlier focused on thunderstorms. The number of storm days annually and their spatial distribution throughout Poland at different time intervals were discussed in these elaborations. The existence of days with thunderstorms was also associated with different types of atmospheric circulation.

In Europe, e.g. in Switzerland, Germany and Russia, singular storm occurrences, their annual as well as daily courses, their duration and approach directions were described. Also, thunderstorms were associated with air temperature and synoptic conditions, i.e. analyses of satellite pictures and synoptic maps.

The objective of the paper is to determine the influence of continentality of Europe's climate, increasing to the east, on the number of days with thunderstorms during the years 1994-2005 in ten chosen European cities.

- Source materials on the number of days with thunderstorms in the years 1994–2005 were taken from the calendar of Europe's most important occurrences (Kurek, 2001), as well as from the archive materials of the Institute of Meteorology and Water Management.
- In Europe, data on days with thunderstorms comes from ten selected cities located in zones from the west to the east, beginning from Dublin, through London, Paris, Munich, Prague, Minsk, Kiev, Kharkov and up to Moscow. The well-matched stations show the gradually increasing continentality of Europe's climate.
- The long-term mean annual amplitude of air temperature at each of the stations was used, followed by the Gorczyński continentality index.

During ten years (1994-2005), in the examined European cities, there were in total 2358 days with thunderstorms. The least storm days were in Dublin – only 61. This is just 1/5 of the storms in Kharkov (311), where the maximum number was recorded (Tab. 1). Not much fewer thunderstorms occurred in Warsaw (307) and in Prague (306) than in Kharkov. Besides these three stations with a large number of storm days, four other stations are characterised by mean storm activity comprising over 200 days in 12 years, i.e. Paris – 252, Munich – 257, Kiev – 240 and Moscow – 255. The remaining two stations are characterised by smaller thunderstorm activity, less than 200 days/12 years, i.e. London – 172 and Minsk – 197.

Table 1.
Annual course of the number of days with thunderstorms, the Gorczyński continentality index (Wk_G) and the average long-term annual air temperature amplitude (At) in selected towns of Europe (1994–2005).

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Average annual	Sum annual	Wk_G	At
Dublin	0,42	0,25	0,42	0,08	0,75	0,50	0,42	1,08	0,42	0,42	0,25	0,08	5,08	61	2,0	**10,6**
London	0,50	0,83	0,50	2,08	2,08	1,25	2,17	2,92	1,00	0,33	0,58	0,08	14,33	172	9,8	13,9
Paris	0,67	0,58	0,83	2,58	2,83	2,75	4,00	3,92	1,50	0,75	0,25	0,33	21,00	252	18,3	17,2
Munich	0,17	0,25	0,50	0,75	4,00	3,83	6,00	3,92	1,42	0,33	0,25	-	21,42	257	27,5	21,0
Prague	0,25	0,42	0,58	0,92	4,92	5,42	6,33	4,75	1,67	0,08	0,08	0,08	25,50	306	27,5	21,6
Warsaw	0,08	0,42	0,58	1,33	4,83	4,42	7,50	4,58	1,42	0,33	0,08	-	25,58	307	30,8	23,8
Minsk	-	0,25	0,08	0,58	2,75	4,17	4,58	2,58	1,08	0,25	0,08	-	16,42	197	36,0	26,8
Kiev	-	-	0,17	1,25	3,42	4,83	6,08	3,08	1,08	-	0,08	-	20,00	240	39,6	27,2
Kharkov	-	-	0,33	0,92	3,58	6,33	7,42	4,92	2,17	0,17	0,08	-	25,92	311	**43,5**	28,8
Moscow	-	-	0,25	0,75	3,33	5,33	6,83	3,67	0,92	0,17	-	-	21,25	255	39,9	29,3
														r = 0,738		
														R^2 = 0,545		

From maps on the number of days with thunderstorms in Poland during the year in the spring and summer, as compared with Europe, featured in M. Stopa's elaboration on *Burze w Polsce* [Storms in Poland] (1962), it may be concluded that, in comparison with Africa, Asia, Australia and America, Europe is a continent of weaker storm activity. It is also worth noting that the further we move to the north and west, the fewer days with thunderstorms occur. It, of course, is evident that the distribution of storm days is influenced by air temperature, i.e. access of solar radiation associated with latitude, presence of large and dense land area and varied surface features. Current research confirms the regularities described in literature.

In order to determine the scope of continentality of Europe's climate, the mean long-term annual amplitude of air temperature at each station was calculated, followed by the Gorczyński continentality index. Its author assumed that Wk_G = 100 for extremely continental temperature current in Wierkhoyansk (Kożuchowski et al., 2005). In the examined period of twelve years from 1994 to 2005, Wk_G changed from 2 in Dublin to 43.5 in Kharkov (Tab. 1). In the maritime climate this value is from 2 in Dublin to 18.3 in Paris. In transitional climate it is from 27.5 in Munich and Prague to 36 in Minsk. In continental climate, however, it is from 39.6 in Kiev to 43.5 in Kharkov. In the examined cities, with the exception of Kharkov and Moscow, as distance from the Atlantic Ocean grows, a gradual increase of the value of the continentality index is observed. As for the long-standing mean annual air temperature amplitude, it does not illustrate such "disturbances" and regularly increases with growing distance from the Atlantic, assuming 10.6°C in Dublin and 29.3°C in Moscow.

The ocean climate of the insular part of Europe generates a decrease in the number of days with thunderstorms during the year, as exemplified by Dublin (number of mean annual storm days – 5.08) and London (14.33). Maximum thunderstorm activity takes place there in August, as well as the maximum air temperature and on the average reaches, respectively, 1.08 and 2.92 (Tab.1, Fig.1). In maritime climate the heightened storm activity also shifts into the late autumn, winter and early spring months, i.e. from November to March, as opposed to the continental climate. However, it is necessary to remember that, in our climate zone, frontal storms may occur throughout the year. It is especially visible in Dublin because in winter, storms constitute as much as 28% of all storms, whereas in London only 17.4%. In Dublin, late spring and summer storms only account for 54.1% (V-VIII) of the total number and in London significantly more, i.e. 73.3% (IV-VIII).

During the year, Western Europe, largely influenced by ocean climate, represented by Paris (the mean annual LDB – 21) has numerous common characteristics with the annual thunderstorm course in Great Britain and Ireland, e.g. more numerous winter thunderstorms (still quite a few – 12.7%, XI-III) and fewer summer thunderstorms than in the East (similarly to London – 76.6%, IV-VIII). However, common to Western Europe as well as to Central and Eastern Europe is the storm maximum occurring in July (on the average, 4 days), as is in the six remaining stations.

To a large degree, thunderstorms in Munich have the annual course characteristic of continental climate. As in Eastern and Central Europe, a decided majority of thunderstorms occurs during the summer (as much as 82.9% in V-VIII), however fewer occur during the winter (only 5.4% in XI-III). On the other hand, Munich and more oceanic Paris have a similar annual mean number of thunderstorms – 21.42.

A characteristic visible in (Fig.1) in subsequent stations (from Munich to Moscow) situated further to the east, is a sudden increase in the late spring thunderstorm activity in May, while in London and Paris it already begins in April.

At all the examined stations a sudden decrease of thunderstorm activity begins in September. Only in cities under the influence of maritime climate this activity does not totally halt during winter, as is the case of Moscow, Kharkov, Kiev, Minsk and partially Warsaw and Prague.

In Prague itself, during the summer months (V-VIII), there is exactly the same number of thunderstorms (257 storm days /12 years, on the average 84% of the total number of storm days), as in Munich throughout the year. During winter and early spring, the number of days with thunderstorms approximates that of Munich and reaches 5.6%.

In Warsaw, theses disproportions are even greater, even though there are not many more thunderstorms than in Prague. Thunderstorms in the cold period account for 4.6% of the total number of storm days and of the warm period to 83.4%. The month with the greatest number of days with thunderstorms, from the ten examined stations, is July (on the average 7.5 days). In comparison with an earlier period from1951 to 1990 (Grabowska, 2002), the average number of storm days in Warsaw in July has increased by 1.5 day (from 6.0 to 7.5).

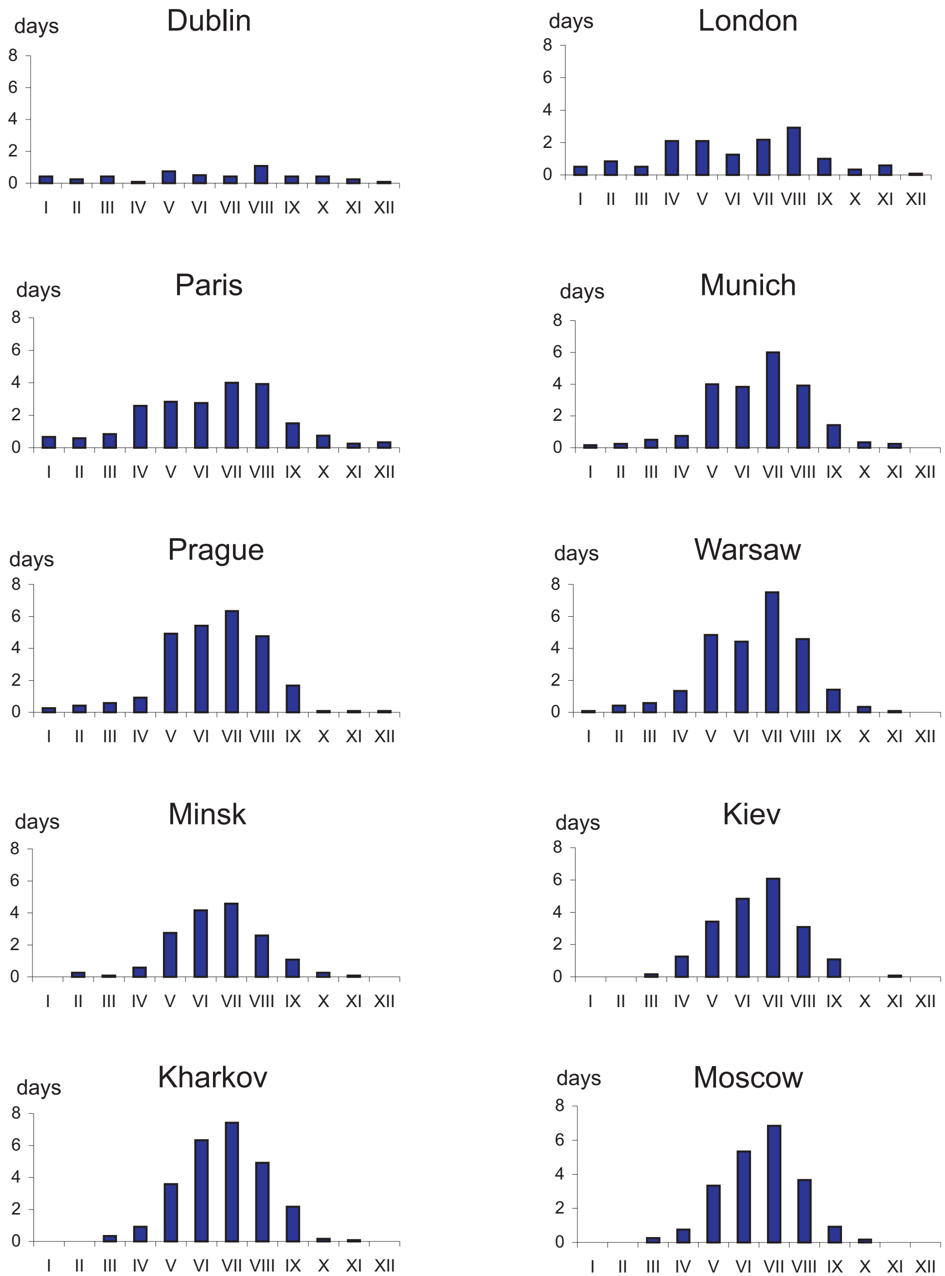

Fig. 1. Annual course of the number of days with thunderstorms in selected towns of Europe (1994–2005).

An interesting situation occurs in Minsk, where the mean annual number of days with thunderstorms significantly increases to 16.42, despite the fact that this station is located further to the east than Warsaw and Prague. We may also observe this characteristic in Kiev (20 storm days) and in Moscow (21.25 storm days) while in Kharkov it is the greatest of all the ten stations. Whereas, in Minsk and Moscow, we may interpret this phenomenon by the fact that both these cities are located further to the north as well as to the east, where it is colder and probably there are fewer low pressure centres with thunderstorm fronts over this area. On the other hand, in the warmer Kiev, besides both smaller depressional activity and frontal activity, as is the case in the remaining two cities, its lowland location is undoubtedly decisive. Subsequently, Kharkov situated on the edge of the Central Russian Upland, because of its higher altitude location and more varied surface features, is characterised by a great thunderstorm frequency. In July, one may observe there the second to Warsaw, mean thunderstorm frequency of 7.42 days, as calculated for all of the stations. Also, Kharkov is located close to the Black Sea Lowlands and the atmospheric lows, with frontal storms incoming from the Black Sea do not come upon numerous territorial obstacles and without difficulty, reach this city.

In Minsk, Kiev and Kharkov, the thunderstorm frequency during both the warm and cold periods has similar values and is, respectively 85.8 and 2.5%, 87.1 and 1,2%, 85,8 and 1,6%. The continentality of climate is most visible in the winter thunderstorm course in Moscow – 90.2 and 1,2% of the total number of storm days (Tab.1, Fig. 1 and Fig. 2), even though the Gorczyński continentality index is somewhat smaller (39.9) than in Kharkov (43.5).

After an analysis of the number of days with thunderstorms, the Gorczyński continentality index and the long-term annual mean air temperature amplitudes, it may be concluded that, as much as the amplitude and index values increase with distance from the ocean, it is not always so in case of the number of days with thunderstorms. Minsk, Kiev and Moscow "break" with the gradual increase in the number of storm days.

Two growth lines of days with thunderstorms among stations, located according to the increasing continentalization of climate, may be observed in Fig.2. The first includes cities from Dublin to Warsaw and the second cities from Minsk to Kharkov. For all their greater climate continentality, Minsk, Kiev and Moscow have much fewer days with thunderstorms than Warsaw and Prague. Therefore, also testifying to this interesting situation, the correlation coefficient calculated between the continentality index and the long-term number of storm days (1994–2005), which is r = 0.738 and the determination coefficient R^2 = 0.545, showing that in the case of six stations, i.e. Dublin, London, Paris, Prague, Warsaw and Kharkov, this relation may have materialized, however in the case of the remaining four. i.e. Munich, Minsk, Kiev and Moscow, other geographic or climatic factors prevail.

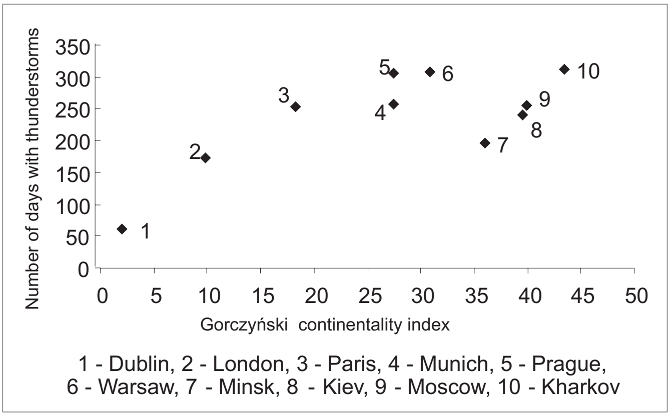

Fig. 2. Dependence of the long-term number of days with thunderstorms on the Gorczyński continentality index in selected European cities (1994-2005).

In closing, one may conclude that regularity of influence of the growing distance from the ocean on the increasing number of days with thunderstorms has been confirmed at most of the examined stations. It should also be remembered that other geographical and climatic factors are decisive in the case of Minsk, Kiev and Moscow. With the exception of Kharkov, among the selected cities, Warsaw and Prague, both located in the moderate warm transitional climate, have shown intense thunderstorm activity (Okołowicz, 1991). Also in Dublin and London, the share of cold season thunderstorms is clearly visible. They are frontal storms accompanying intense cyclogenesis. In particular months, this is goes together with limited differentiation of the warm period, with a small maximum in August. Whereas in continental climate, winter thunderstorms almost do not occur and storm cumulation takes place in the four warm months (V-VIII, foremost thermal storms – air masses), with a visibly marked July thunderstorm maximum. Also of interest is the decrease of the number of days with thunderstorms in June in Dublin, London, Paris, Munich and Warsaw. This phenomenon is not to be observed anywhere else. Perhaps this is the influence of the "European pseudomonsoon".

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