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FLUCTUATIONS IN ANNUAL SUMS OF WINTER COLD DAYS AND SUMMER WARM DAYS WITH SELECTED CENTRAL EUROPEAN STATIONS AS EXAMPLES AND THEIR CONNECTION TO THE LARGE SCALE CIRCULATION

Abstract: The paper presents the evaluation of the variability in the number of severely cold (t_{mean}<-10^{0}C), cold (t_{mean}<-5^{0}C), warm (t_{mean}≥20^{0}C) and very warm days (t_{mean}≥23^{0}C) in the years 1901-1995. The study used the mean diurnal air temperature records from four meteorological stations located in Central Europe: Cracow, Prague, Szeged and Mosonmagyaróvár. It was concluded that the number of cold days and severely cold days considerably decreased in all the analysed stations since the beginning of the study period. The number of warm and very warm days rose in Cracow and Prague, however it decreased in Szeged. The number of days with t_{mean}≥20^{0}C in Mosonmagyaróvár did not show a clear tendency to change in the analysed period, while the number of days with t_{mean}≥23^{0}C slightly increased. A strong connection between the course of cold and severely cold days and the types of circulation according to the Grosswetterlagen catalogue was determined. Such days took place most often during Central European high (HM), Fennoscandian high (HFA) and Central European ridge (BM). The influence of circulation on the frequency of appearance of days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C turned out to be much smaller.

Key words: air temperature, severely cold day, cold day, warm day, very warm day, atmospheric circulation, Central Europe.

1. Introduction

A considerable growth of the mean annual air temperature of about 0.3^0 to 0.6^{0}C has been observed all over the world since the end of the 19th century (Folland et al. 1990; Houghton et al. 1996; Jones, Briffa 1992). However, this global warming is not synchronous all over the whole globe. It is commonly known that there are zonal and regional differences, and that in certain parts of the world a decrease of the mean air temperature can be observed (Stefanicki et al. 1998; Jones, Briffa 1992). Lockwood (1980), Kożuchowski and Marciniak (1986) are among those who claim that climate changes are more evident in the higher latitudes than in the equatorial zone as well as in the winter months rather than in the summer months. Moreover, deviations from the mean multi-year values of air temperature are larger in the interior of the continents that are in the temperate and polar zones. Thus, the studies on climatic changes that are carried out in the regions located in the temperate and high latitudes as well as in the interior of continents become particularly important. According to Bryson (1974) climatic conditions of such border regions are particularly valuable indicators of climatic changes.

The territory of Central Europe to which Poland, the Czech Republic and Hungary can be included is located in the temperate latitude, in the area where oceanic and continental air masses come into contact. Orography of this area (lack of mountain ranges of the meridional configuration) favours dislocations of both humid air coming from above the Atlantic and the continental air masses from the east.

In the recent years many studies were presented in which the authors investigated climate changes in Europe on the regional scale on the basis of mean annual or seasonal air temperature values (Beniston et al. 1994; Brunetti et al. 2000; Schönwiese et al. 1994; Stefanicki et al. 1998; Weber et al. 1997). The studies prove that in the 20th century the growth of temperature in winter was the biggest, to 2.5^{0}C/100 years in Eastern Europe (Schönwiese et al. 1994). In the northern part of Europe the winter temperature decreased slightly. Also the tendencies presented by summer temperatures in Europe do not show the same direction of changes, although the tendency to temperature reduction prevails. Only in autumn in Europe there was an almost stable trend towards growth of air temperature in the last 100 years (Schönwiese et al. 1994). Thus, the question of the direction of changes of the multi-year air temperature on the regional or even local scale still remains open.

One of the elements that describe the thermal conditions of a given site is the analysis of the extreme air temperature values. According to Kłysik and Fortuniak (1995) the variability of the extreme temperature is the simplest measure of climate variability. In recent years there has been an increasing interest in the extreme values of various meteorological elements, which are supposed to be more sensitive measures of climatic changes than the mean values (Obrębska-Starkel, Starkel 1991). Thus, in the dispute about climate changes it seems inevitable to know the range of the amplitudes of the air temperatures in the multi-year course.

This paper attempts to determine the variability and tendencies of changes (trends) of days that are characteristic to the warm and cold season in Central Europe in the years 1901-1995. The relationship between the occurrence of the days under study and types of circulation has also been analysed.

2. Source materials and methods

The paper is based on the mean diurnal records of air temperature from four meteorological stations representing the climatic conditions of Central Europe: Cracow in Poland, Prague in the Czech Republic and Szeged and Mosonmagyaróvár in Hungary (Fig. 1, Tab. 1). The mean diurnal air temperature was calculated as the arithmetic mean of the maximum and minimum diurnal temperature ($t_{mean}=(t_{max}+t_{min})/2$). In the 20th

Fig. 1. The location of meteorological stations

Tab. 1. The location of meteorological stations

Station	Latitude	Longitude	Elevation (m a.s.l.)
Cracow	50°04' N	19°58' E	220
Prague	50°05' N	14°25' E	202
Mosonmagyaróvár	47°23' N	17°16' E	122
Szeged	46°15' N	20°09' E	80

century meteorological stations in Europe changed the times and methods of calculating the mean diurnal temperature. The way of calculating the mean diurnal air temperature which uses the diurnal maximum and minimum temperatures and which was used in this study turned out to be the most convenient to make comparisons.

The choice of stations seems to be the proper one to test thermal conditions on the regional scale (of the Central Europe). It includes stations which are located between the latitude 45^0 and 50^0N and between longitude 14^0 and 20^0E (Fig. 1, Tab. 1). The series of air temperature, which come from the stations, are homogeneous. The meteorological data used in the study represent climatic conditions of a contemporary European city. Apart from the natural factors such as relief, water conditions, vegetation etc., the climate of such cities depends on human activities (built-up areas, industry, and transportation). The transformation of the geographic environment, which results from urbanisation and industrialisation, causes significant changes in the natural climate.

When analysing the thermal conditions in Cracow, Prague, Mosonmagyaróvár and Szeged, one cannot forget about the influence of the anthropogenic factors, especially of the urbanised area of Cracow and Prague. Mosonmagyaróvár is a small town so there the conditions of meteorological measurements have not changed over the 20^{th} century. Szeged is a bigger town, but the strongest influence of the anthropogenic factors on the air temperature is certainly observed in Cracow and Prague. Unfortunately, Szeged station suffered from movements during the investigated period, and the relocations affect the data quality beyond the influence of the urbanisation.

According to the extreme opinions, the observed increase in the air temperatures could have been caused either exclusively by the urbanisation factors or exclusively by the natural factors. Morawska-Horawska (1991) is an advocate of the "typically urban" character of the temperature increase. She claims that the urban heat island and greenhouse effect on the local, not on the global scale, caused the increase in the air temperature in Cracow that was observed for the last hundred years. The reasons of the heating should be sought in the ascending population of the city, growth of the city and its industrialisation, and especially in the increased dust pollution. However, according to Trepińska and Kowanetz (1997) it seems impossible that the present-day warming results exclusively from the urban development. The influence of the progressing urbanisation is not strong enough to dominate over the natural processes occurring in the atmosphere. Thus, it seems that these factors are superimposed, and that the fluctuations of cold and severely cold days analysed in this study may prove this.

The study analysed the number of: severely cold days (t_{mean}<-10^0C), cold days (t_{mean}<-5^0C), warm days (t_{mean}≥20^0C) and very warm days (t_{mean}≥23^0C). It was assumed that they were the most representative in order to determine air temperature changes over such a big area as the region of Poland, the Czech Republic and Hungary. The first and second type events characterise the winter season in Central Europe fairly well (Domonkos, Piotrowicz 1998), while the other two types represent the summer season. After a detailed analysis it was determined that the number of days with t_{mean}≥23^0C characterises the warm season much better than of those with t_{mean}≥25^0C. Days with temperatures above 25^0C appear in Cracow and Prague very rarely. Keevallik et al. (1999) used the days with t_{mean}≥18^0C to analyse the thermal conditions in Estonia.

However, such days are too frequent at the Hungarian stations so it would not be a proper criterion to characterise the summer season in the region under study. Thus, for the purpose of determining the air temperature changes in Cracow, Prague, Mosonmagyaróvár and Szeged the criterion of days with t_{mean}≥23⁰C called very warm days was applied.

As it was already mentioned in the introduction numerous studies emphasised that the winter temperature has the largest influence on the increase of the mean annual air temperature (Kożuchowski, Marciniak 1987; Kędziora 1995; Ostrožlík et al. 1995). Thus, a definite decrease in the number of days with t_{mean}<-10⁰C and t_{mean}<-5⁰C should be expected. The summer temperature in Central Europe, on the other hand, does not show a definite tendency to change (Kożuchowski, Marciniak 1987; Schönwiese et al. 1994; Trepińska 2000). According to Chrzanowski (1995) the long-term course of summer temperature is in contradiction to the theory of climate warming. Perhaps the number of days with t_{mean}≥20⁰C and t_{mean}≥23⁰C does not change significantly during the multi-year period because of the stability of summer temperature?

It is assumed that atmospheric circulation, particularly in the temperate zone, is the main factor which influences the contemporary changes and fluctuations of air temperature (*The Global*... 1995; *Climate Change*... 1996). This is why also changes in atmospheric circulation were analysed in order to find the reasons of variability in the number of days with the given threshold values. The German calendar of synoptic situations (*Katalog der Grosswetterlagen*... 1999) was used for this purpose. It consists of 30 types of synoptic situations denoted by the letter symbols (Tab. 2). They represent large-scale circulation patterns over Europe and eastern part of North Atlantic for each day. The frequency of the synoptic situation types was also calculated for the analysed days.

Tab. 2. Types of atmospheric circulation for Central Europe (*Katalog der Grosswetterlagen*... 1999)

No	Abbreviation	Description of the type	No	Abbreviation	Description of the type
1	WA	West, anticyclonic	16	HB	British Islands high
2	WZ	West, cyclonic	17	TRM	Central European trough
3	WS	Southern West	18	NEA	Northeast, anticyclonic
4	WW	Angleformed West	19	NEZ	Northeast, cyclonic
5	SWA	Southwest, anticyclonic	20	HFA	Fennoscandian high, anticyclonic
6	SWZ	Southwest, cyclonic	21	HFZ	Fennoscandian high, cyclonic
7	NWA	Northwest, anticyclonic	22	HNFA	Norwegian Sea-Fennoscandian high, anticyclonic
8	NWZ	Northwest, cyclonic	23	HFNZ	Norwegian Sea-Fennoscandian high, cyclonic
9	HM	Central European high	24	SEA	Southeast, anticyclonic
10	BM	Central European ridge	25	SEZ	Southeast, cyclonic
11	TM	Central European low	26	SA	South, anticyclonic
12	NA	North, anticyclonic	27	SZ	South, cyclonic
13	NZ	North, cyclonic	28	TB	British Islands low
14	HNA	Norwegian Sea-Iceland high, anticyclonic	29	TRW	Western Europe trough
15	HNZ	Norwegian Sea-Iceland high, anticyclonic	30	U	Unclassified situations

Climatological literature still does not give final solutions to the problems connected with the definition and interpretation of such notions as climate change, variability, vacillation, fluctuation, tendencies and trends (Kożuchowski 1990; Pruchnicki 1999; Trepińska 2000). Following these authors in this study it was assumed that:

- temperature variability or variability of number of days with given threshold values is the internal characteristics of these climate elements defined by their change in time;
- fluctuations are natural air temperature changes, which do not determine climate change; the notions fluctuation and vacillation can be used alternatively although they have a much wider meaning than variability;
- tendencies (trends) are climate changes connected with its evolution and not with fluctuation, which is characterised by increase or decrease of the value of the meteorological element under study.

3. Cold and severely cold days

On the basis of the materials from the years 1901-1995 it is possible to conclude that in Central Europe, represented by Cracow, Prague, Szeged and Mosonmagyaróvár, there were 2.7 to 6.4 days per year with t_{mean}<-10^{0}C and from 11.9 to 20.9 days per year with t_{mean}<-5^{0}C on the average (Tab. 3). The largest number of severely cold and cold days was in Cracow while the smallest – and almost two times smaller in comparison to Cracow – was in Prague. The largest number of cold and severely cold days was recorded at the tested stations in 1940. On the other hand, such days do not occur in Central Europe each year. The only exception are the days with t_{mean}<-5^{0}C in Cracow, which occurred each year in the examined period, with the lowest number in 1974 (1 day). During the analysed 95 years severely cold days did not occur in 21.0% of winters in Cracow, 51.6% in Prague, 43.2% in Mosonmagyaróvár and in 40.0% in Szeged. Days with t_{mean}<-5^{0}C did not occur in 4.2% of winters in Mosonmagyaróvár and in 6.3% in Szeged and Prague.

On the basis of the 10-year running averages it is possible to trace the tendency of changes of the analysed days and to trace their variability over time (Fig. 2).

In Central Europe, represented by the four stations, during the first 20 years of the 20th century there was a period during which cold and severely cold days declined (Fig. 2). In this particular period, the lowest values occurred in Cracow around the year 1915 while at the remaining stations they took place 5 years later, in about 1920. In the subsequent years, the number of cold days and severely cold days increased significantly, reaching the largest values in the years 1935-1945 at all the stations. Since

Tab. 3. Mean number of cold and severely cold days at particular stations for the years 1901-1995

Days	Cracow	Prague	Mosonmagyaróvár	Szeged
t_{mean}<-5^{0}C	20.9	11.9	14.3	13.8
t_{mean}<-10^{0}C	6.4	2.7	2.9	3.5

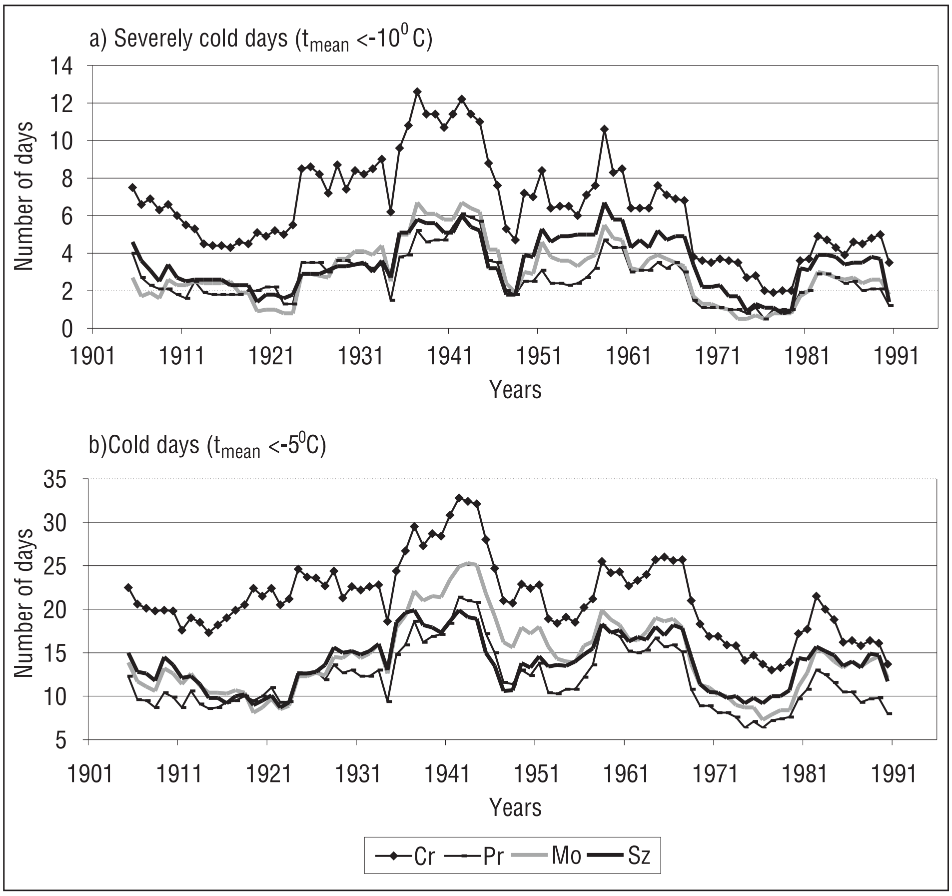

Fig. 2. Ten-year running averages of the number of days with t_{mean}<-10^{0}C (a) and t_{mean}<-5^{0}C (b) in Cracow (Cr), Prague (Pr), Mosonmagyaróvár (Mo) and Szeged (Sz) in the period 1901-1995

the 1940s there was a period of warming which was manifested by the decline of the number of days under the given threshold values. Only in the 1960s and 1980s the number of days with t_{mean}<-10^{0}C and t_{mean}<-5^{0}C slightly increased. In Cracow, Prague, Szeged and Mosonmagyaróvár during these two periods their number was only slightly higher than the multi-year average of the analysed days.

Taking into consideration the multi-year course of the cold and severely cold days it is possible to notice a strong correlation between the number of the analysed days at the particular stations (Fig. 2). This can be confirmed also by correlation coefficients between the number of days with t_{mean}<-10^{0}C and t_{mean}<-5^{0}C that were additionally calculated for all the possible "combinations of pairs" of the stations under study. The correlation coefficients are above 0.8, and they are significant at the 0.01 level.

Only in the case of both types of the analysed days in Cracow and Szeged did the correlation coefficients decrease to 0.75. However, that is not surprising as it results from the geographic location of these stations. These are not only the northernmost and southernmost towns but also they are at the lowest and the highest elevation a.s.l. of the four stations (Tab.1, Fig.1). The values of the correlation coefficients confirm the thesis that in the winter period in Central Europe the coincidence of thermal anomalies has a very large range (Kożuchowski, Marciniak 1986). If a severe winter appears it affects a significant part of Europe.

Since the beginning of the 20th century the observed decline in the number of days with t_{mean}<-10^{0}C was: 4.3 days per 95 years in Cracow, almost two times less in Prague – 2.2 days, 1.4 days in Mosonmagyaróvár and only slightly more in Szeged – 1.6 days /95 years. In the case of cold days the decline was noticed as well. However, this decline was almost 1.5 times higher in comparison to the number of days with t_{mean}<-10^{0}C in Cracow and Prague. The number of days with t_{mean}<-5^{0}C diminished in these cities by 7.8 and 3.2 days per 95 years, respectively. However, the number of the cold days decreased only very slightly in Mosonmagyaróvár (1.5 days/95 years) and in Szeged – 0.9^{0}days/95 years. The larger decrease in the number of cold days is connected to the very mild winters that occurred since the 1970s while the smaller decline in the severely cold days, especially in Cracow and Prague, should be explained by very likely occurrence of 2-4 days with t_{mean}<-10^{0}C, which is a value close to the multi-year mean, during relatively warm winters.

As it has already been mentioned severely cold days do not appear each year in Central Europe. On the basis of the analysed data from the four stations it turned out that, excluding Cracow, also the cold days do not appear each winter. The largest number of the days with t_{mean}<-5^{0}C and t_{mean}<-10^{0}C occurred at all the stations in January and in the remaining two months of winter – and was slightly bigger in February than in December (Tab.4).

Table 4 shows that the days with t_{mean}<-10^{0}C can occur at the analysed stations even in March, and apart form Prague and Mosonmagyaróvár also in November. However, they are much more frequent in March than in November. It is also clear from table 4 that the potential period of occurrence of the discussed days can last from November to

Tab. 4. Mean number of cold and severely cold days in particular months for the years 1901-1995

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Severely cold day (t_{mean}<-10^{0}C)												
Cracow	3.2	2.0	0.1	-	-	-	-	-	-	-	0.0	1.1
Prague	1.2	0.8	0.0	-	-	-	-	-	-	-	-	0.7
Mosonmagyaróvár	1.6	0.9	0.1	-	-	-	-	-	-	-	-	0.5
Szeged	1.9	1.0	0.0	-	-	-	-	-	-	-	0.0	0.5
Cold day (t_{mean}<-5^{0}C)												
Cracow	8.6	5.7	1.1	-	-	-	-	-	-	0.0	0.8	4.6
Prague	5.6	3.3	0.3	-	-	-	-	-	-	-	0.1	2.6
Mosonmagyaróvár	6.9	3.8	0.4	-	-	-	-	-	-	0.0	0.3	2.9
Szeged	6.7	3.6	0.4	-	-	-	-	-	-	-	0.3	2.8

March. In Central Europe the earliest occurrence of the first severely cold day in the 20th century was on 18 November 1965, while the latest occurrence of the day with t_{mean}<-10^{0}C was on 5 March 1971. The potential period of the occurrence of the days with t_{mean}<-5^{0}C is only slightly longer (Tab. 4), as such days can appear in Cracow and Mosonmagyaróvár already by the end of October as in the year 1920. At that time the cold wave spread over the whole Central Europe and caused the decrease in the mean diurnal air temperature at the discussed stations from -3.4^{0}C in Prague to -6.1^{0}C in Cracow.

4. Warm and very warm days

During 1901-1995 there were, on average, 32.2 days with t_{mean}≥20^{0}C in Cracow, 38.3 in Prague, 46.9 in Mosonmagyaróvár and 71.1 in Szeged. The number of recorded very warm days was much smaller (Tab. 5). Namely, the number of warm days in Szeged was two times bigger than in Cracow, while in the case of the very warm days – four times bigger. Thus, the number of such days was evidently increasing from the north to the south.

Tab. 5. Mean number of warm and very warm days at particular stations for the years1901-1995

days	Cracow	Prague	Mosonmagyaróvár	Szeged
t_{mean}≥20^{0}C	32.2	38.3	46.9	71.1
t_{mean}≥23^{0}C	6.7	10.3	12.7	27.5

Just like in the case of cold and severely cold days also the tendency of changes of the number of warm and very warm days was examined on the basis of the 10-year running average course (Fig. 3). The warm and very warm days show relatively large fluctuations, especially in the case of the Hungarian stations. During the first 10 years of the 20th century as well as in the 1920s and 1940s there were concentrations of years with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C. Since the mid-1970s, a period showing an increase in the discussed days manifested itself again, and taking into consideration the whole 95-year period the annual total of such days was the largest in the 1990s, except for Szeged. At this Hungarian station the largest number of the analysed days occurred in the mid 1940s.

In contrary to the cold and very cold days the correlation between the courses of days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C is not so strong between particular stations. The highest values of the correlation coefficient (significant at the 0.01 level) were obtained for the data from Cracow and Prague, namely over 0.7, and for Prague and the Hungarian stations – over 0.4. In the cases of both types of warm days the correlation coefficient for Cracow and Szeged was of a low negative value (-0.1), which is not statistically significant. However, there is a clear difference between the stations located not far from the latitude 50^{0}N and those that are more southerly. This difference is also apparent when we consider the tendencies to changes of the examined days in the years 1901-1995. The number of such days definitely increases in Cracow and Prague – 19.7

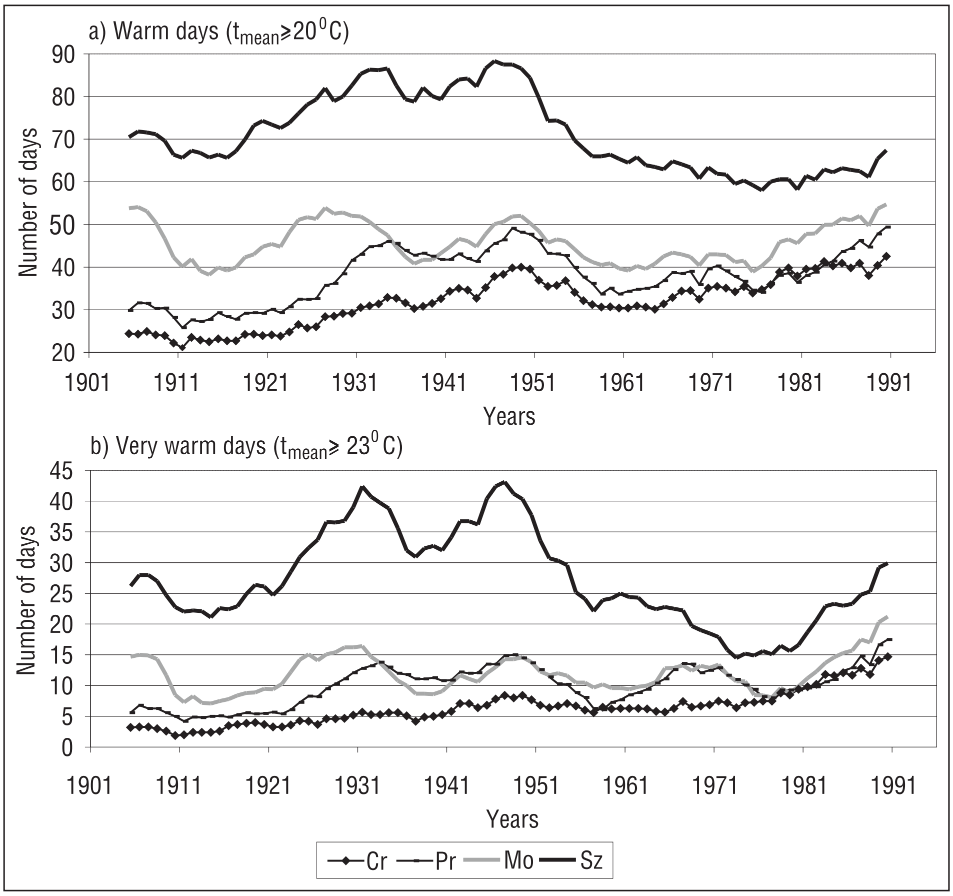

Fig. 3. Ten-year running averages of the number of days with t_{mean}≥20°C (a) and t_{mean}≥23°C (b) in Cracow (Cr), Prague (Pr), Mosonmagyaróvár (Mo) and Szeged (Sz) in the period 1901-1995

and 14.8 days/95 years respectively in the case of the days with t_{mean}≥20^{0}C, and 10.4 and 9.1 days/95 years for t_{mean}≥23^{0}C. In Mosonmagyaróvár the number of warm days does not show any clear tendency to change during the whole examined period, but the number of very warm days slightly increased (4.1 days/95 years). The tendencies to changes in the number of the analysed days in Szeged is different. At this Hungarian station, which is southernmost and easternmost of the four investigated stations, the number of warm and very warm days decreased from the beginning of the examined period, in the case of the warm days by 11.9, and the very warm days by 6.3 during the 95 years. The thesis, that during the observed global warming of the 20th century, when the air temperature in summer does not show a clear overall tendency to change, or even when this temperature drops in some cases, the number of the days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C will not rise as well, has not been fully confirmed. After analysing the records from four stations representing Central Europe one can risk the thesis, that in the north of the region which is represented by Cracow and Prague, even in the summer period the results of the air temperature increase can be observed. The trend of the mean multi-year air temperature values in summer in these cities was close to zero (Trepińska, Kowanetz 1997; Trepińska 2000) but the number of warm and very warm days was growing (Matuszko et al. 2001). Thus, in the recent years, the summer temperature was showing great variability. The increase in temperature was much smaller in the summer period than in the winter period.

Both the warm and very warm days occurred at the analysed stations each year and their largest number was in July (Tab. 6). In the extreme cases days with $t_{mean} \geq 20^0$C and $t_{mean} \geq 23^0$C occurred already in April and as late as in October (Tab. 6).

Tab. 6. Mean number of warm and very warm days in particular months for 1901-1995

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Warm day ($t_{mean} \geq 20^0$C)												
Cracow	-	-	-	0.1	1.7	6.9	12.4	9.4	1.7	0.0	-	-
Prague	-	-	-	0.0	2.2	8.2	14.3	11.2	2.3	0.0	-	-
Mosonmagyaróvár	-	-	-	0.1	2.6	9.3	16.8	14.2	3.7	0.1	-	-
Szeged	-	-	-	0.3	5.9	14.6	22.3	20.1	7.6	0.5	-	-
Very warm day ($t_{mean} \geq 23^0$C)												
Cracow	-	-	-	-	0.2	1.2	3.1	2.1	0.1	-	-	-
Prague	-	-	-	-	0.2	2.0	4.8	3.1	0.2	-	-	-
Mosonmagyaróvár	-	-	-	-	0.1	1.9	5.8	4.4	0.4	-	-	-
Szeged	-	-	-	0.0	0.9	5.1	10.8	9.2	1.5	0.0	-	-

5. Atmospheric circulation

In numerous climatological works particular attention is paid to the atmospheric circulation as the factor initiating a change in the course of the air temperature (Kożuchowski 1996; Ustrnul 1997; Wibig 2001).

Atmospheric circulation, especially the frequency of deep cyclones (<990 hPa) and very strong anticyclones (>1035 hPa) (Kłysik 1993), have a significant influence on the thermal conditions in the scale of the whole European continent. In the years 1900-1990 it was possible to observe the decrease in the frequency of strong anticyclones, which were exclusively limited to the winter seasons, mainly from January to March (Kłysik 1993). The frequency of deep cyclones shows a constant increasing tendency.

The cause of the increase in the air temperature in Central Europe, which is manifested by the decrease in the number of the days with $t_{mean} < -10^0$C and $t_{mean} < -5^0$C may be a strengthening of the zonal westerly circulation. The variability in the zonal circulation can provide an explanation for 12.8% of the variability in the air temperature in Central Europe, and in the case of the temperature in January even up to 27.8% (Kożuchowski, Marciniak 1994). According to these authors only 9.2% of the temperature variability in this region may be attributed to the changes in the global temperature.

Nevertheless, the changes in the air temperature in Central Europe correspond to the changes in the air temperature on the global scale, but they have their individual character (Kożuchowski, Marciniak 1987; Jones, Briffa 1992).

In Central Europe, the atmospheric circulation in winter is controlled mainly by Icelandic Low and Asian High. The predominance of one of these pressure systems contributes to the occurrence of mild (Icelandic Low) or cold (Asian High) winters. Thus, the most significant factor informing about the main forms of circulation which control the weather in Central Europe is the W-index – the index of zonal westerly circulation, also known from the literature as the zonal index or as the progression index (P) (Niedźwiedź 1996; Ustrnul 1997). This index reaches its highest values if there is an intensive circulation with a western component, and the negative values when the circulation with eastern component predominates. The correlation coefficient calculated by Niedźwiedź (1995) between the W index and the mean winter temperature in Cracow was 0.65 in the years 1873-1994, and in the case of the maximum and minimum temperatures in winter it was even higher, 0.76 and 0.73, respectively.

In the 20th century over the Central Europe a great variability of the zonal circulation frequency was observed (Niedźwiedź 1995). The greatest intensity of the westerly circulation was in the years 1891-1904, 1924-1932 and since the mid-1970s to the end of the century. The W index had its highest value in 1990 (Niedźwiedź 1996; Ustrnul 1997). Together with the growth of the frequency of zonal circulation in the 1980s and in the early 1990s it was possible to observe a clear decrease of the frequency of easterly circulation during the cold half of the year, which manifested itself by the occurrence of exceptionally mild winters in 1988/89 and 1989/90 in the whole region.

According to Ustrnul (1997) the growth of the mean annual value of the westerly circulation index in Central Europe at 50^{0}N since the 1970s was the reason of a considerable positive trend of this index during the whole 20th century. However, this rise has not marked itself at 45^{0}N, where in the advection following the parallels, a significant role is played by the eastern component, as the W index reaches the negative values.

During the search for the reasons of the diversification of the number of days at the four stations which represent thermal conditions of Central Europe it seemed necessary to determine the influence of atmospheric circulation on the occurrence of severely cold, cold, warm and very warm days. A detailed analysis of the relationships between the discussed days and synoptic situations was performed on the basis of the frequency of particular "Grosswettrelagen" circulation types (*Katalog der Grosswetterlagen…* 1999).

On the basis of the "Grosswettrelagen" calendar it is evident that in the years 1901-1995 in Central Europe out of the 30 types of synoptic situations, the West cyclonic situation WZ (15.3%), Central European high – HM (9.0%) and Central European ridge – BM (7.8%) occur most often (Fig. 4). Other synoptic situations are characterised by much smaller frequencies of the occurrence.

As the high number of the circulation types makes the analysis and the following synthesis difficult, they are sorted into defined groups, i.e. zonal, mixed and meridional circulation (Tab. 7) or, as proposed by Baur et al. (1944), Central European high (H) and all anticyclonic situations (A), Central European low (T) and all cyclonic situations (Z, Tab. 7).

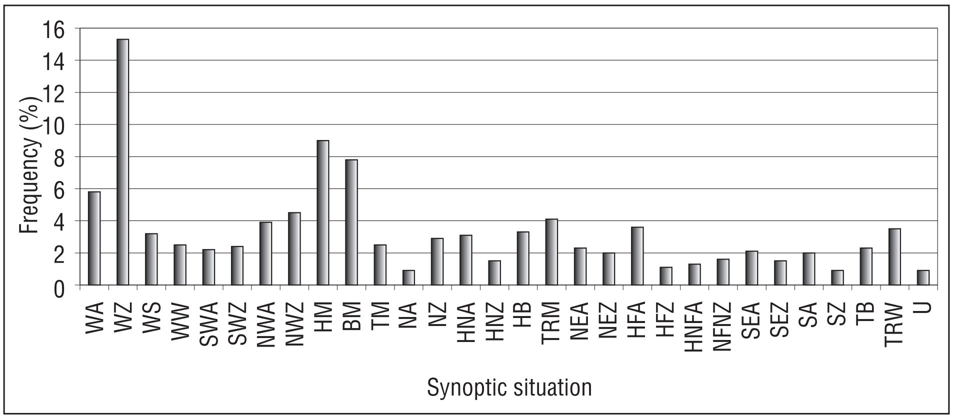

Fig. 4. Frequency (in %) of the types of synoptic situation over Central Europe in the period 1901-1995 (*Katalog der Grosswetterlagen*... 1999)

This study takes into consideration both divisions (Tab. 7). In the first one the particular types of synoptic situations were joined according to the general advection direction: zonal, when tropical anticyclone is in its normal position, mixed, when this anticyclone is displaced to the north or north-west from about 50^0N, and meridional circulation when there is an anticyclonic blockade between 50^0N and 70^0N. Baur et al. (1944) proposed to combine the circulation types according to the pressure systems into anticyclonic and cyclonic and additionally separated Central European high and Central European low.

The calculations show that on average in Central Europe during a year, cyclonic situations (T+Z, 51.8%) predominate over the anticyclonic ones (H+A, 47.3%). The high centres (H, 30.3%) are much more frequent than the low centres (T, 14.3%).

Tab. 7. Frequency (in %) of the synoptic situation types over Central Europe in the period 1901-1995 (*Katalog der Grosswtterlagen*... 1999)

Group	Circulation types	Frequency (in %)
Zonal	WA, WZ, WS, WW	26.8
Mixed	SWA, SWZ, NWA, NWZ, HM, BM, TM	32.3
Meridional	NA, NZ, HNA, HNZ, HB, TRM, NEA, NEZ, HFA, HFZ, HNFA, HNFZ, SEA, SEZ, SA, SZ, TB, TRW	40.0
Central European high (H)	HM, BM, NEA, SA, SWA, SEA, HFA, HNFA	30.3
All other anticyclonic (A)	NA, NWA, HNA, HB, WA	17.0
Central European low (T)	TM, TRM, HNZ, HNFZ, HFZ, NEZ, SEZ	14.3
All other cyclonic (Z)	WZ, WS, WW, SWZ, NWZ, SZ, NZ, TRW, TB	37.5
Unclassified situations	U	0.9

The meridional situations amount to 40.0%, and the mixed ones to 32.3% while the zonal to 26.8% (Tab. 7). The undetermined situations (U) amounted only to 0.9 in the analysed multi-year period. When analysing the frequency distribution of the particular groups of the synoptic situations during the multi-year period one can conclude that in the first half of the 20th century the anticyclonic situations (H+A) predominated over the cyclonic ones (T+Z, Fig. 5). The maximum number of the anticyclonic situations occurred in 1921 (70%) while the minimum was in 1966 and 1981 (30.1%). From the beginning of the 1960s the anticyclonic situations exceeded the frequency of 50% only in 1986,

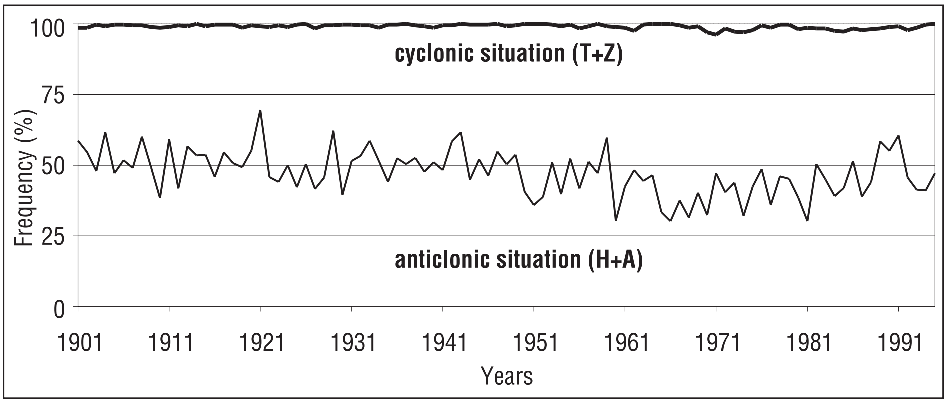

Fig. 5. Frequency (in %) of the cyclonic (T+Z) and anticyclonic (H+A) situation types over Central Europe in the period 1901-1995 (*Katalog der Grosswetterlagen*... 1999)

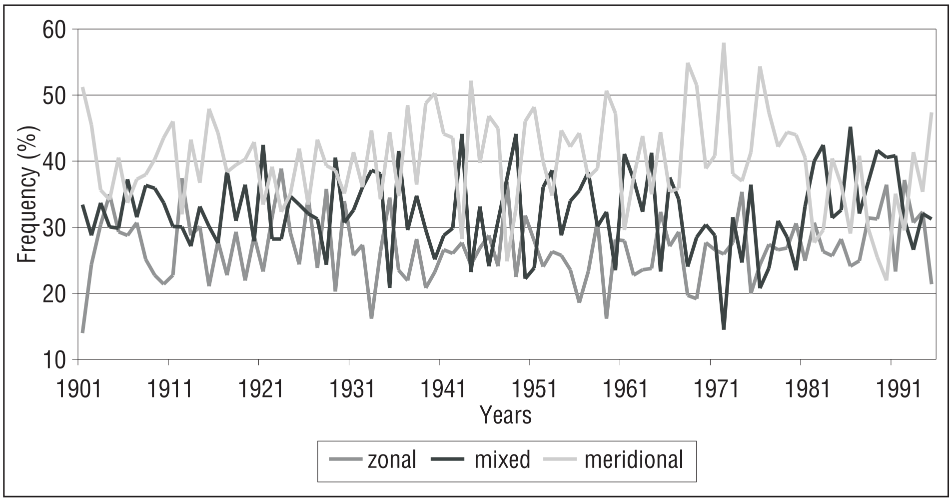

Fig. 6. Frequency (in %) of the zonal, mixed and meridional situation types over Central Europe in the period 1901-1995 (*Katalog der Grosswetterlagen*... 1999)

1989, 1990 and 1991 (Fig. 5). The frequency of the meridional situations declined as well and they reached their lowest value in 1990 (21.9%, Fig. 6).

When analysing the relationships between the discussed days and the synoptic situations it is important to determine the frequency distribution of particular types and their groups in the cold (November-April) and warm (May-October) seasons of the year. There is a definite predominance of certain frequencies in particular seasons; namely SEZ, SZ and WS mostly occur in the cold season, and NEA and NA in the warm season (Fig. 7).

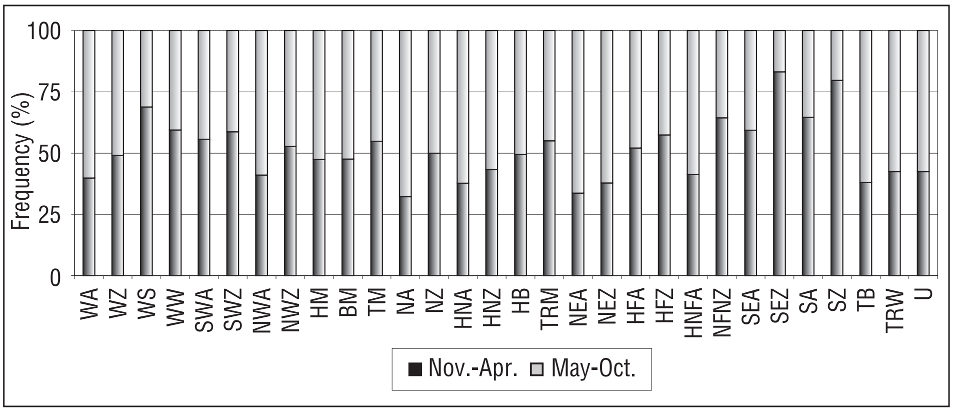

Fig. 7. Frequency (in %) of the synoptic situation types over the Central Europe in the particular half-year periods for 1901-1995 (*Katalog der Grosswetterlagen*... 1999)

6. Frequency of severely cold, cold, warm and very warm days in particular types of synoptic situations

In this paper, the type of the synoptic situation from the "Grosswetterlagen" catalogue was assigned to each of the analysed days for the period from 1901-1995. It has been stated that the cold and severely cold days in Cracow, Prague, Mosonmagyaróvár and Szeged appear most often during Fennoscandian high, anticyclonic situation – HFA, Central European high – HM and Central European ridge – BM (Tab. 8). Summing up, these three synoptic situations determine as much as 40.7% days with t_{mean}<-10^{0}C and 35.3% days with t_{mean}<-5^{0}C in Cracow, 49.7% and 41.6% in Prague, 42.3% and 37.3% in Mosonmagyaróvár and 39.4% and 35.5% in Szeged.

The connection between the number of severely cold and cold days and the three synoptic situations was also analysed by comparing the multi-year course of days with t_{mean}<-10^{0}C and t_{mean}<-5^{0}C (Fig. 2) to the frequency of appearance of the three situations together (HFA, HM and BM) in the period November-March (Fig. 8). The decrease of the number of cold and severely cold days in the years 1901-1920 and 1960-1995 correlates quite well with the fall of synoptic situations that favour the occurrence of these days (Fig. 2 and 8).

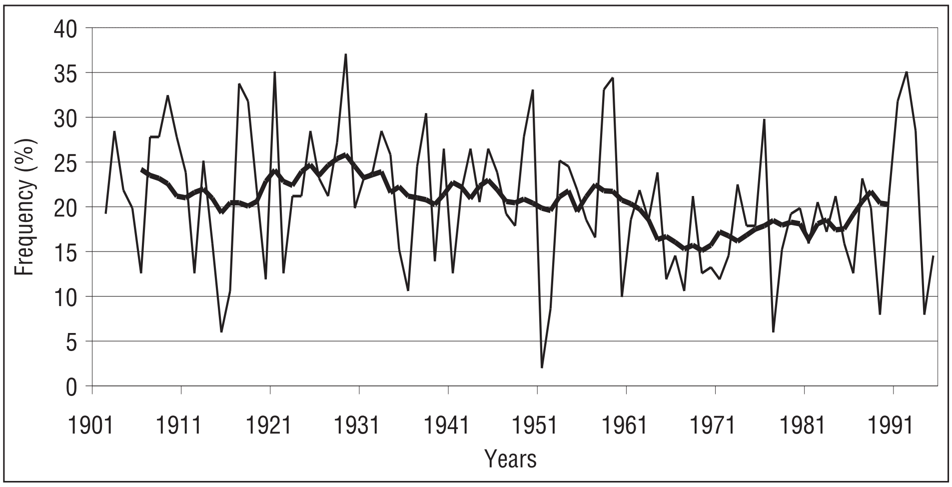

Fig. 8. Frequency (in %) of three synoptic situation types (HFa+HM+BM) over the Central Europe and its ten-year moving averages in the season November-March in the period 1901-1995 *(Katalog der Grosswetterlagen...* 1999)

Strict connections of the number of days with t_{mean}<-10^{0}C and t_{mean}<-5^{0}C with the atmospheric circulation can also be illustrated with the extreme cases. As it was mentioned in chapter 3 the smallest number of cold and severely cold days was in Cracow in the year 1915 and at the other stations five years later. Just these years were characterised by a very low frequency of appearance of HFA, HM and BM situations. During the winter season 1914/15 (November- March) there was only 6.0% of these situations and in 1919/20 –11.9% altogether (Fig. 8). The greatest frequency of HFA, HM and BM, that is 31.7%, was in winter 1928/29 (Fig. 8). This was one of the most severe winters in Europe in the 20th century (Piotrowicz 2000).

More than half of the cold and severely cold days is coupled with meridional situations. The rate is 61.8-67.5% for Cracow and Prague and 53.0-63.7% for Mosonmagyaróvár and Szeged. Rate of anticyclonic situations (H + A) in these specified days is as high as 65-75% at each of the stations. This also may be evidence for the strong dependence of the occurrence of the cold and severely cold days on the atmospheric circulation.

The warm and very warm days also appeared at the high (HM) and Central European ridge (BM) and additionally at the westerly circulation, both cyclonic and anticyclonic (WZ, WA) and at the cyclonic trough over Western Europe (TRW) (Tab. 8). In this case, the five aforementioned synoptic situations determine from 49.7 to 54.4% of the days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C in Central Europe (Tab. 8). In the case of these days, they occur with almost the same frequency at the high pressure situations and at the low pressure situations as well as at the meridional and mixed ones. Therefore, the occurrence of the warm and very warm days depends to a lesser degree on the synoptic situations than in the case of the cold and severely cold days.

Tab. 8. Frequency of cold, severely cold, warm and very warm days in particular types of synoptic situations in Cracow (Cr), Prague (Pr), Mosonmagyaróvár (Mo) and Szeged (Sz) in the years 1901-1995

Abbreviation	t_{mean}<-10°C				t_{mean}<-5°C				t_{mean}≥20°C				t_{mean}≥23°C			
	Cr	Pr	Mo	Sz	Cr	Pr	Mo	Sz	Cr	Pr	Mo	Sz	Cr	Pr	Mo	Sz
WA	0.7	0.0	1.8	2.4	1.6	1.2	2.1	2.8	**8.9**	**9.4**	**9.6**	**8.4**	**9.8**	**8.9**	**9.8**	**9.4**
WZ	1.3	1.1	2.5	5.1	3.5	1.5	4.4	5.6	**15.3**	**14.7**	**16.9**	**17.8**	**12.2**	**10.8**	**14.0**	**18.1**
WS	1.3	1.9	2.5	0.9	1.7	1.8	2.0	1.4	1.0	0.9	1.1	1.7	0.8	1.2	1.0	1.5
WW	1.8	0.8	1.1	3.6	2.2	1.7	2.2	2.1	3.0	2.3	2.4	2.7	1.7	1.8	2.2	2.1
SWA	2.6	3.8	3.2	3.6	2.1	1.7	2.5	2.8	3.6	3.8	2.8	2.1	5.1	5.3	4.3	2.9
SWZ	0.2	0.0	0.4	0.3	1.0	0.2	0.6	1.2	3.1	2.7	2.5	2.2	4.6	3.5	3.8	2.6
NWA	0.3	1.1	0.4	1.5	1.6	1.1	1.2	2.1	3.2	3.3	3.8	4.4	2.0	2.4	3.9	3.6
NWZ	1.3	0.0	0.7	1.8	1.9	1.1	1.5	3.1	2.4	2.0	2.4	3.5	3.0	1.4	2.1	3.1
HM	**11.7**	**16.2**	**16.1**	**16.7**	**11.9**	**15.6**	**15.5**	**16.1**	**8.4**	**11.5**	**8.7**	**8.5**	**5.1**	**13.4**	**9.6**	**7.6**
BM	**9.9**	**12.3**	**7.2**	**6.0**	**10.0**	**10.5**	**9.1**	**8.2**	**9.7**	**11.1**	**10.3**	**8.7**	**12.0**	**11.8**	**11.0**	**9.4**
TM	0.2	0.0	0.4	0.9	0.6	0.5	0.5	0.5	1.9	1.4	1.6	2.1	1.9	1.4	1.8	2.3
NA	0.5	0.4	0.7	0.0	0.4	0.5	0.5	0.4	0.4	0.4	0.6	0.6	0.0	0.1	0.4	0.6
NZ	2.0	1.1	2.2	2.7	2.8	2.1	2.7	3.4	0.7	0.5	1.1	1.9	0.3	0.3	1.0	1.4
HNA	4.6	5.0	5.4	6.0	5.1	6.8	5.3	4.7	2.6	3.1	3.3	3.2	1.6	2.8	2.7	2.6
HNZ	2.3	4.6	4.6	3.0	2.1	3.0	2.4	1.9	1.4	0.9	1.3	1.7	0.8	0.8	0.6	1.3
HB	5.0	1.9	3.9	6.9	4.6	3.8	5.6	6.2	1.1	1.2	1.3	1.6	0.9	1.0	0.6	1.2
TRM	1.0	1.1	1.8	1.2	2.3	1.9	2.7	2.0	4.2	1.9	3.0	3.8	4.9	1.7	4.0	4.6
NEA	2.3	1.5	1.4	1.2	2.6	2.3	2.0	1.4	2.2	3.1	2.6	2.7	1.3	1.8	1.2	1.5
NEZ	0.8	0.8	0.4	0.9	1.4	1.2	1.1	1.3	2.6	2.3	2.5	2.8	2.5	1.8	2.7	2.8
HFA	**19.1**	**21.2**	**19.0**	**16.7**	**13.4**	**15.5**	**12.7**	**11.2**	3.3	4.0	3.6	2.8	1.6	4.8	2.7	2.6
HFZ	1.8	2.3	1.1	0.9	2.5	2.7	1.8	1.6	1.1	1.0	1.0	0.9	1.1	1.6	0.8	0.8
HNFA	5.0	5.8	3.9	2.4	3.6	4.2	3.2	2.8	1.7	2.2	1.5	1.4	3.6	2.7	1.9	1.1
HFNZ	3.9	6.2	7.2	4.2	3.4	4.6	4.0	2.7	1.3	1.3	1.2	1.1	1.7	1.4	1.2	0.7
SEA	6.8	2.3	3.2	3.3	5.6	4.7	4.8	4.4	0.7	0.9	0.7	0.7	0.8	1.1	0.8	0.7
SEZ	3.6	2.3	3.2	1.8	3.7	3.3	2.7	2.4	0.3	0.3	0.3	0.3	0.6	0.4	0.2	0.3
SA	5.3	3.5	3.9	3.0	3.8	3.0	3.2	3.7	0.5	0.9	0.7	0.7	1.1	1.1	0.6	0.5
SZ	2.0	0.8	1.4	0.6	2.1	1.2	1.4	1.6	0.1	0.1	0.1	0.1	0.5	0.2	0.2	0.1
TB	0.5	0.4	0.0	0.9	0.6	0.5	0.5	0.5	5.5	4.6	5.0	4.5	6.0	4.2	4.8	5.7
TRW	1.0	0.8	0.4	0.3	0.7	0.5	0.7	0.8	**8.8**	**7.3**	**7.2**	**6.3**	**11.4**	**9.5**	**9.3**	**8.2**
U	1.2	0.8	0.0	1.2	1.2	1.3	1.1	1.1	1.0	0.9	0.9	0.8	1.1	0.8	0.8	0.7

The highest values are indicated in bold

7. Conclusions

The variability of the severely cold, cold, warm and very warm days in Cracow, Prague, Mosonmagyaróvár and Szeged, as analysed in this paper, corresponds to the tendencies of changes in the thermal conditions in the area of the whole Central Europe. The largest number of the cold and severely cold days occurred in the 1940s while the lowest number – from the 1970s till the end of the analysed period. The calculated correlation coefficients between the number of days under study for the particular stations and the extreme cases of the occurrence of the days with t_{mean}<-10^{0}C and t_{mean}<-5^{0}C, support the claim that there is a high resemblance of the thermal anomalies in the winter period over a fairly large part of Europe.

Cold and severely cold days do not occur in Central Europe every winter, except for the days with t_{mean}<-5^{0}C in Cracow. The potential period of their occurrence is from October to March.

Since the beginning of the 20th century there was a clear decrease of the number of severely cold and cold days at all the stations. The biggest fall during the 95 years under study was in the case of days with t_{mean}<-5^{0}C in Cracow (7.8 days) and Prague (3.2 days) as well as the number of days with t_{mean}<-10^{0}C in the same two cities, 4.3 and 2.2 days respectively. This may lead to a suggestion that the influence of urbanisation is the main reason of the decrease in the number of the analysed days. Prague and Cracow are much bigger in comparison to Szeged and Mosonmagyaróvár. Nonetheless the analysis of frequency of appearance of severely cold and cold days during the particular synoptic situations according to the "Grosswetterlagen" calendar suggests that the atmospheric circulation variability may constitute one of the main reasons of the decrease. However, in Cracow and Prague the circulation factors were strengthened by the influence of the anthropogenic ones.

The cold and severely cold days occurred at the Central European high (HM), the Fennoscandian high (HFA) and the Central European ridge (BM). In total, these three synoptic situations determined from 35.5% to 49.7% of the days with t_{mean}<-5^{0}C and t_{mean}<-10^{0}C at the analysed stations. The influence of the atmospheric circulation on the frequency of the warm and very warm days seems to be much smaller.

In the summer season characterised in this paper by the number of the warm and very warm days, there is a strong dependence of the course of the discussed days on the latitude. Their number increases significantly from the north to the south.

The multi-year course of the days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C shows quite regular fluctuations, particularly at the Hungarian stations. The lowest number of warm and very warm days was in the decade 1911-20, and for Szeged also in the 1970s. Since 1975 there was a clear growth of the number of days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C at all the stations. In the 1990s their number was the highest in the whole period of 95 years, except for Szeged.

The course of warm and very warm days at the particular stations is not as strongly correlated as in the case of cold and severely cold days. Also the particular tendencies to change during the 95 years under study are different at the analysed stations. The number of days with t_{mean}≥20^{0}C and t_{mean}≥23^{0}C increased in Cracow (19.4 and 10.4 days/95 years respectively) and in Prague (14.8 and 9.1 days/95 years). In Mosonmagyaróvár the days with $t_{mean} \geq 20^0C$ did not show any clear tendency to change, and the number of days with $t_{mean} \geq 23^0C$ increased very slightly (4.1 days/95 years). In Szeged the number of warm and very warm days decreased by 11.9 and 6.3 days respectively during the 95 years. However, it turned out that although there was no clear tendency to temperature changes in summer or it decreased slightly in certain regions of Europe, the number of warm and very warm days in Cracow and Prague clearly increased.

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Fluktuacje rocznych sum dni zimnych zimowych i ciepłych letnich na podstawie wybranych stacji w Europie Środkowej i ich związek z wielkoskalową cyrkulacją

Streszczenie

W opracowaniu dokonano oceny zmienności liczby dni bardzo zimnych (t_{mean}<-10^{0}C), zimnych (t_{mean}<-5^{0}C), ciepłych (t_{mean}≥20^{0}C) i bardzo ciepłych (t_{mean}≥23^{0}C) w latach 1901-1995. Wykorzystano średnie dobowe wartości temperatury powietrza z czterech stacji meteorologicznych położonych w Europie Środkowej: Kraków, Praga, Szeged i Mosonmagyaróvár.

Największa liczba dni zimnych i bardzo zimnych występowała w latach 40. XX stulecia, najmniejsza od lat 70. do końca analizowanego okresu. Obliczone współczynniki korelacji pomiędzy liczbami omawianych dni na poszczególnych stacjach oraz ekstremalne przypadki występowania dni z t_{mean}<-10^{0}C i t_{mean}<-5^{0}C świadczą o zgodności anomalii termicznych w okresie zimowym na znacznym obszarze Europy.

Dni zimne i bardzo zimne nie pojawiają się w Europie Środkowej każdej zimy, z wyjątkiem dni z t_{mean}<-5^{0}C w Krakowie. Ich potencjalny okres występowania przypada na październik-marzec. Od początku XX stulecia zaobserwowano wyraźny spadek dni zimnych i bardzo zimnych na wszystkich analizowanych stacjach. Najbardziej w badanym 95-leciu zmniejszyła się liczba dni t_{mean}<-5^{0}C w Krakowie (7,8 dni) i Pradze (3,2 dni) oraz dni z t_{mean}<-10^{0}C w tych dwóch miastach, odpowiednio 4,3 i 2,2 dni. Może to sugerować, że główną przyczyną zmniejszenia się analizowanych dni jest wpływ urbanizacji. Praga, a po nim Kraków są znacznie większymi miastami w porównaniu do Szegedu i Mosonmagyaróvár. Niemniej jednak analiza częstości pojawiania się dni zimnych i bardzo zimnych w poszczególnych typach sytuacji synoptycznej według kalendarza Grosswetterlagen sugeruje, że jedną z głównych przyczyn może być właśnie zmienność cyrkulacji atmosferycznej nad Europą Środkową w sezonie zimowym. Niewątpliwie jednak w Krakowie i Pradze czynniki cyrkulacyjne zostały wzmocnione oddziaływaniem czynników antropogenicznych.

Najczęściej dni zimne i bardzo zimne pojawiały się przy wyżu nad Europą Środkową (HM), wyżu nad Skandynawią (HFA) oraz przy klinie wyżowym nad Europą Środkową (BM). W sumie te trzy sytuacje synoptyczne określają od 35,5% do 49,7% dni z t_{mean}<-5^{0}C

i t_{mean}<-10^{0}C na analizowanych stacjach. Wpływ cyrkulacji atmosferycznej na częstość dni ciepłych i bardzo ciepłych okazał się znacznie słabszy.

W sezonie letnim, charakteryzowanym w niniejszym opracowaniu przez liczbę dni ciepłych i bardzo ciepłych, występuje wyraźna zależność w przebiegu omawianych dni od szerokości geograficznej. Liczba tych dni zdecydowanie rośnie z północy na południe. Wieloletni przebieg dni z t_{mean}≥20^{0}C i t_{mean}≥23^{0}C wykazuje dość regularne fluktuacje, szczególnie na stacjach węgierskich. Najniższa liczba dni ciepłych i bardzo ciepłych wystąpiła w dziesięcioleciu 1911-1920, a w przypadku danych z Szeged również w latach 70. Od 1975 r. na wszystkich analizowanych stacjach zaznaczył się wyraźny wzrost liczby dni z t_{mean}≥20^{0}C i t_{mean}≥23^{0}C. Z wyjątkiem Szeged ich liczba w latach 90. była najwyższa w całym 95-leciu. Przebieg liczby dni ciepłych i bardzo ciepłych na poszczególnych stacjach nie jest już tak silnie skorelowany jak w przypadku liczby dni zimnych i bardzo zimnych. Również określone tendencje zmian w całym badanym 95-leciu są różne na analizowanych stacjach. Dni z t_{mean}≥20^{0}C i t_{mean}≥23^{0}C rośnie w Krakowie (odpowiednio 19,4 i 10,4 dni/95 lat) i Pradze (14,8 i 9,1 dni/95 lat). W Mosonmagyaróvár dni z t_{mean}≥20^{0}C nie wykazały wyraźnej tendencji zmian, a liczba dni z t_{mean}≥23^{0}C nieznacznie wzrosła (4,1 dni/95 lat). W Szeged natomiast liczba dni ciepłych i bardzo ciepłych zmniejszyła się odpowiednio o 11,9 i 6,3 dni w ciągu 95 lat. Okazało się jednak, że pomimo braku wyraźnej tendencji zmian temperatury lata lub przy jej niewielkim spadku w niektórych regionach Europy, liczba dni ciepłych i bardzo ciepłych wyraźnie wzrasta w Krakowie i Pradze.

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