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EXTREME WEATHER TYPES IN LUBLIN AND THEIR CIRCULATION CONDITIONS IN THE YEARS 1951–2015

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Abstract: To determine extreme weather types in Lublin, in the years 1951–2015, the typology of Woś was applied. It provided a basis for the designation of two extreme thermal types: one with hot and one with very frosty weather. Furthermore, a type of weather with intensive precipitation, not included in the original version of the classification, was analysed. Meteorological data used in the study were obtained from the Meteorological Observatory of the Department of Meteorology and Climatology of the Maria Curie-Skłodowska University in Lublin. The circulation conditions were determined based on the classification of circulation types for the area of Central-Eastern Europe.

In the years 1951–2015 extreme weather types occurred in Lublin for 5 days in a year on average. Days with the hot weather type were recorded most frequently. Their occurrence was favoured by air advection from the southern or eastern sector with a transitional or anticyclonic character. In the analysed multi-annual period an increasing tendency in the number of such days was observed. The number of days with the very frosty weather type, primarily related to the advection of air masses from the east, decreased. In the case of the number of days with the weather type with intensive precipitation no evident tendency of changes was determined in the analysed period.

Keywords: extreme weather types, hot days, very frosty days, days with intensive precipitation, Lublin

Introduction

In the 1920s a research trend developed in climatology, called complex climatology. It approached weather as a group of interrelated components and phenomena, and climate as a multi-annual weather regime (Piotrowicz 2010). In the same decade, both in Russia and the United States, first typologies, describing weather conditions by means of basic characteristics of meteorological components, were developed (Zinkiewicz 1953; Piotrowicz 2010; Wereski et al. 2017). Zinkiewicz (1953) performed the first analysis of weather complexes in Lublin. He studied the dependency between their daily variability and the level of air dustiness in the city. In the following years, based on measurement data for Lublin, other authors analysing climatic and bioclimatic conditions applied, among others, the method of Fiedorow-Czubukow (Niedziałek 1972), the typology of Woś (Kaszewski 1984, 1992; Woś 1996, 1998, 1999, 2010), as well as the biothermal-meteorological weather classification of Błażejczyk (Dobek et al. 2016; Wereski et al. 2017).

The objective of this paper is to determine the annual and multi-annual variability of extreme weather types in Lublin in the period 1951–2015, and their dependency on circulation types.

Material and methods

The determination of extreme weather types applied the classification developed by Woś (1999). According to Piotrowicz (2010), it is the most frequently applied methodology in Poland. Particular weather types were determined based on daily values of thermal characteristics (daily mean, maximum, and minimum air temperature), mean daily values of cloudiness and daily sums of precipitation. The meteorological data used for the designation of weather types were obtained from the Meteorological Observatory of the Department of Meteorology and Climatology of Maria Curie-Sklodowska University (UMCS) in Lublin, located in the city centre.

The classification of Woś was modified in the group of weather types with precipitation. A weather type with intensive precipitation, defined as a sum of daily precipitation equal to or higher than 30 mm, was added. The value is the bottom threshold of the first degree of meteorological warnings related to rainfall issued by the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB). Such precipitation can cause the occurrence of local floods (Buchert et al. 2013).

This way, the analysis of extreme weather types covered:
– hot weather types,
– very frosty weather types,
– weather types with intensive precipitation (Table 1).

The circulation conditions of the occurrence of extreme weather types were determined based on the classification of circulation types for the area of Central-Eastern Europe by Bartoszek (2015, 2017). The adopted classification partially employs

Table 1. Weather types according to Woś (1999)

Sign	Characteristic	Weather type
air temperature		
33	**t_{avg}>25.0°C; t_{min} and t_{max}>0.0°C**	**hot**
3	t_{avg} 15.1 – 25.0°C; t_{min} and t_{max}>0.0°C	very warm
2	t_{avg} 5.1 – 15.0°C; t_{min} and t_{max}>0.0°C	moderately warm
1	t_{avg} 0.1 – 5.0°C; t_{min} and t_{max}>0.0°C	cool
4	t_{avg} >5.0°C; t_{min} ≤ 0.0°C and t_{max}>0.0°C	ground-frost, moderately cool
5	t_{avg} 0.1 – 5.0°C; t_{min} ≤ 0.0°C and t_{max}>0.0°C	ground-frost, very cool
6	t_{avg} –5.0 – 0.0°C; t_{min} ≤ 0.0°C and t_{max}>0.0°C	ground-frost, moderately cold
7	t_{avg} <–5.0°C; t_{min} ≤ 0.0°C and t_{max}>0.0°C	ground-frost, very cold
8	t_{avg} –5.0 – 0.0°C; t_{min} and t_{max} ≤ 0.0°C	moderately frosty
9	t_{avg} –15.0 – –5.1°C; t_{min} and t_{max} ≤ 0.0°C	fairly frosty
0	**t_{avg} < –15.0°C; t_{min} and t_{max} ≤ 0.0°C**	**very frosty**
mean daily cloudiness		
0	≤ 20%	sunny or with little clouds amount
1	21–79%	cloudy
2	≥ 80%	very cloudy
daily sum of precipitation		
0	< 0.1 mm	with no precipitation
1[1]	0.1 – 29.9 mm	with precipitation
30[2]	**≥ 30.0 mm**	**with intensive precipitation**

Explanations: [1] weather type with precipitation was modified by the authors, [2] weather type with intensive precipitation was added by the authors.

assumptions proposed by Lityński (1969). According to the author, circulation types can be divided in terms of sea-level pressure values into three classes, namely cyclonic, transitional, and anticyclonic. Therefore, each pressure value from a grid point located in eastern Poland (φ=51°15'N and λ=22°50'E) was ascribed to one of three classes depending on whether the pressure values were below the norm (cyclonic class), around the norm (transitional class), or above the norm (anticyclonic class). The threshold for the classes were the 33rd and 66th percentile of sea-level pressure from the period 1871–2010, calculated separately for each month and each of the five series of data. The directions of air flow and non-directional patterns (pure cyclonic/anticyclonic and the undefined type) were determined based on the equations by Jenkinson and Collison (1977). The method is based on a set of indices related to the velocity and direction of geostrophic flow, as well as the total shear vorticity, which were calculated using a gridded set of sea-level pressure data (Kalnay et al. 1996). In this paper, daily gridded fields (5°x5° longitude-latitude) of the mean sea-level pressure were used over an area from 5°20' to 40°20'E and from 41°15' to 61°15'N. This way, twenty-seven CTs were obtained, i.e. 8 of each of the directional cyclonic, transitional, and anticyclonic types, as well as one of each of the non-directional cyclonic, anticyclonic, and undefined types. For the purpose of generalisation of the study results, circulation types in this paper were accordingly grouped by direction and the character of circulation (Table 2). Table 3 presents the frequency of the occurrence of circulation types over Central-Eastern Europe in the period 1951–2015.

The application of the hierarchical grouping method by Ward (1963) permitted a determination of baric situations most frequently favouring the occurrence of extreme weather types in Lublin. This method is based on Euclidean distances, merging a pair of clusters. After merging, this process provides the minimum of the sum of squares of all deviations from the centre of gravity of the new cluster (Tomczyk et al. 2015). The preparation of maps presenting the distribution of atmospheric pressure at sea level over Europe applied data obtained from the NCEP/NCAR Reanalysis (Kalnay et al. 1996).

In order to identify the occurrence of changes in the number of days with particular weather types in the studied period, the sequential t-test analysis of regime shift (STARS) proposed by Rodionov (2004) was used. The STARS method determines whether the next value in the investigated time series is signficantly different from the previous regime. If so, this year in the time series can be possibly marked as the year where a new regime started. Subsequent observations are used to confirm or reject the regime shift (Grbec et al. 2009).

Table 2. Grouped circulation types applied in the study

Circulation types	Description
N+NEc, E+SEc, S+SWc, W+NWc	Directional cyclonic types
$N+NE_0$, $E+SE_0$, $S+SW_0$, $W+NW_0$	Directional transitional types
N+NEa, E+SEa, S+SWa, W+NWa	Directional anticyclonic types
C	Cyclonic non-directional type
A	Anticyclonic non-directional type
x	Undfined non-directional type

Table 3. Frequency (%) of circulation types over Central-Eastern Europe (1951–2015)

Circulation types		Winter	Spring	Summer	Autumn	Year
Directional cyclonic types	N+NEc	2.3	3.3	5.6	2.5	3.4
	E+SEc	2.8	6.4	4.1	2.9	4.0
	S+SWc	10.3	8.8	6.7	11.1	9.2
	W+NWc	11.9	7.6	9.9	11.2	10.1
Directional transitional types	N+NEo	4.4	6.1	7.5	3.6	5.4
	E+SEo	5.8	9.1	5.7	5.4	6.7
	S+SWo	8.9	8.4	6.2	10.4	8.4
	W+NWo	12.6	7.3	10.6	11.7	10.5
Directional anticyclonic types	N+NEa	3.8	6.3	8.7	4.3	5.8
	E+SEa	6.7	11.6	7.4	7.0	8.2
	S+SWa	5.9	5.2	3.6	6.7	5.4
	W+NWa	10.0	4.3	5.7	7.3	6.8
Directional non-directional types	A	8.2	7.1	9.8	9.7	8.7
	C	5.7	6.5	4.5	4.7	5.4
	x	0.7	2.0	4.0	1.5	2.0
SUM		100	100	100	100	100

Extreme weather types in Lublin and their circulation conditions

In the years 1951–2015, the hot weather type (33_ _) was observed in Lublin for 2.6 days a year on average (Table 4). The highest number of such days was recorded in 2015 – 19, including 12 days in August. A high number of hot days also occurred in 2006 (16 days) and 2010 (15 days). The analysed multi-annual period included also years when no day met the thermal criterion allowing for qualifying it to this weather type. Such a situation occurred 20 times. Furthermore, based on the STARS method, authors distinguished three homogeneous periods: 1951–1991, 1992–2005 and 2005–2015, which suggest a rise in the number of days with the hot weather type in the analysed multi-year (Fig. 1).

In the annual cycle, days with hot weather were recorded from May to September. Such a day was observed on May 28th (in 1958) at the earliest, and on September 1st (in 2015) at the latest. The type of hot weather in Lublin occurred in May only

Table 4. Average monthly and annual number of days with extreme weather types in Lublin (1951–2015)

Weather type	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
33 – –	-	-	-	-	0.0	0.4	1.5	1.1	-	-	-	-	2.6
0 – –	0.9	0.5	0.0	-	-	-	-	-	-	-	-	0.3	1.7
– – 30	-	-	-	0.0	0.1	0.2	0.3	0.2	0.2	0.1	-	-	1.1

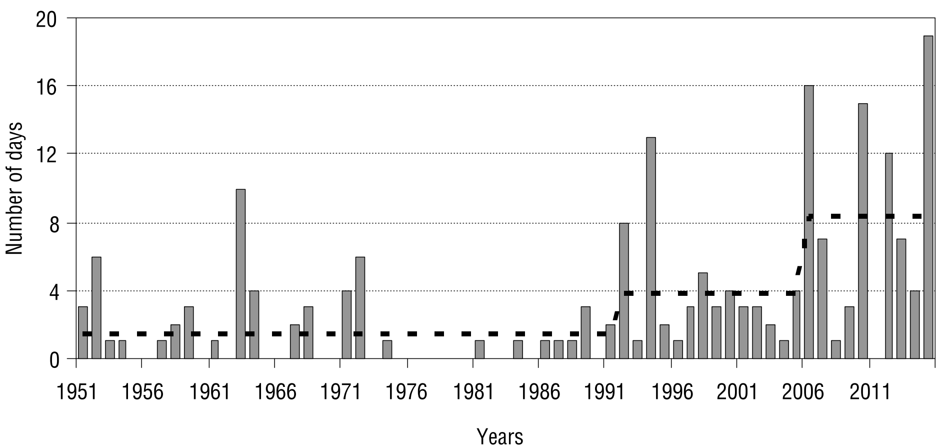

Fig. 1. Multiannual variability of the number of days with the hot weather type in Lublin (1951–2015). The dotted line illustrates changes in the number of days with the hot weather type based on the STARS method

three times: on May 28th, 1958 and May 29th–30th, 2005, which was related with the incidence of a blurred pressure field over Central-Eastern Europe. The highest number of days with the mean daily temperature exceeding 25°C occurred in July – 1.5 days on average, and in August – 1.1 days on average (Table 4). Similar results were obtained by other authors. According to Woś (1999), days with hot weather usually occur in Poland in the summer months (from June to August), however in the southern and south-eastern part of the country they can also be recorded in May, as confirmed by the research conducted for Kraków (Piotrowicz 2010). In Poland, in the years 1951–1980, the hot weather type was the most frequently observed in the regions of Wielkopolska, Mazowsze, and Kotlina Sandomierska – from one to two days per year on average (Woś 1999). In Kraków, the average number of such days in the period 1901–2008 amounted to 1.8, whereas their frequency evidently increased since the 1980s (Piotrowicz 2010). Among the days with hot weather in Lublin, the following types were recorded most frequently: cloudy with no precipitation (33 1 0) and sunny with no precipitation (33 0 0). During the analysed multi-annual they occurred 94 (47.7% of the days with hot weather) and 79 (40.5% of the days with hot weather) times, respectively. The most seldom observed types with hot weather (only once during the analysed 65–year period) included: sunny or with little cloud amount with precipitation (33 0 1) on June 30th, 1997;

Table 5. Number of days with extreme weather types in Lublin (1951–2015)

Weather type	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
hot weather													
33 0 0	-	-	-	-	2	7	30	39	1	-	-	-	79
33 0 1	-	-	-	-	-	1	-	-	-	-	-	-	1
33 1 0	-	-	-	-	1	12	55	26	-	-	-	-	94
33 1 1	-	-	-	-	-	2	12	3	-	-	-	-	17
33 1 30	-	-	-	-	-	-	-	1	-	-	-	-	1
33 2 0	-	-	-	-	-	1	1	-	-	-	-	-	2
33 2 1	-	-	-	-	-	1	-	-	-	-	-	-	1
Total	-	-	-	-	3	24	98	69	1	-	-	-	195
very frosty weather													
0 0 0	16	8	-	-	-	-	-	-	-	-	-	9	33
0 0 1	4	1	-	-	-	-	-	-	-	-	-	-	5
0 1 0	18	11	-	-	-	-	-	-	-	-	-	6	35
0 1 1	15	4	1	-	-	-	-	-	-	-	-	2	22
0 2 0	3	4	1	-	-	-	-	-	-	-	-	-	8
0 2 1	5	2	-	-	-	-	-	-	-	-	-	3	10
Total	61	30	2	-	-	-	-	-	-	-	-	20	113
weather with intensive precipitation													
33 1 30	-	-	-	-	-	-	-	1	-	-	-	-	1
3 1 30	-	-	-	-	1	4	2	1	1	-	-	-	9
3 2 30	-	-	-	-	2	5	17	10	3	-	-	-	37
2 2 30	-	-	-	1	6	2	2	4	6	4	-	-	25
5 2 30	-	-	-	1	-	-	-	-	-	-	1	-	2
Total	-	-	-	2	9	11	21	16	10	4	1	-	74

cloudy with intensive precipitation (33 1 30) on August 3rd, 1998 and very cloudy with precipitation (33 2 1) on June 12th, 2010. Hot and cloudy weather with no precipitation (33 2 0) occurred twice: on July 23rd, 1998 and June 27th, 2006 (Table 5).

During the days with hot weather types, transitional and anticyclonic circulation types were usually recorded, determining air inflow from the southern as well as the eastern sector (Table 6, Fig. 2). This kind of situation favours the occurrence of positive anomalies of air temperature in Lublin in the summer (Bartoszek et al. 2014; Bartoszek and Węgrzyn 2016; Bartoszek and Krzyżewska 2017). The system of high pressure from Eastern Europe, which contributed to the occurrence of almost half of all days with hot weather (48%), was significant. At the time, advection of very warm tropical or polar continental air masses from the south towards Poland

Table 6. Frequency of the occurrence of circulation types during extreme weather types in Lublin (1951–2015)

Hot weather			Very frosty weather			Weather with intensive precipitation		
circulation type	number of days	frequency (%)	circulation type	number of days	frequency (%)	circulation type	number of days	frequency (%)
S+SW$_0$	37	19.0	E+SEa	44	38.9	C	18	24.3
E+SE$_0$	29	14.8	A	26	23.0	N+NEc	12	16.2
S+SWa	28	14.3	E+SE$_0$	12	10.6	E+SEc	9	12.1
E+SEa	23	11.8	N+NEa	9	7.9	N+NEa	6	7.9
S+SWc	19	9.7	E+SEc	5	4.4	N+NE$_0$	5	6.8
A	15	7.7	W+NW$_0$	4	3.5	E+SE$_0$	5	6.8
x	12	6.2	N+NEc	3	2.7	x	4	5.4
E+SEc	9	4.6	S+SWa	3	2.7	S+SWc	3	4.1
W+NW$_0$	7	3.6	C	3	2.7	W+NWc	3	4.1
W+NWa	5	2.6	N+NE$_0$	2	1.8	S+SW$_0$	3	4.1
N+NE$_0$	4	2.1	S+SW$_0$	1	0.9	W+NW$_0$	3	4.1
C	4	2.1	W+NWa	1	0.9	E+SEa	3	4.1
N+NEa	2	1.0	S+SWc	0	-	S+SWa	0	-
W+NWc	1	0.5	W+NWc	0	-	W+NWa	0	-
N+NEc	0	-	x	0	-	A	0	-
SUM	195	100.0	SUM	113	100.0	SUM	74	100.0

was observed (Fig. 3a). In approximately 20% of the days with hot weather, the centre of the high pressure system was located over the north-eastern part of the continent, favouring the inflow of warm air from the south-east and east over the Lublin region (Fig. 3b). A similar contribution of days with hot weather also referred to baric situations in which an area of low pressure appeared over the Scandinavian Peninsula, and a high over South-Eastern Europe. Such a situation resulted in the inflow of warm air from the south-east over eastern Poland (Fig. 3c). The lowest contribution (approximately 5%) was characteristic of a synoptic situation determining the advection of air masses from the southern sector in the frontal part of a low moving over Central Europe (Fig. 3d). It should be emphasised that, in Lublin, during the advection of air masses from the northern sector, days with hot weather were only observed incidentally (Fig. 2).

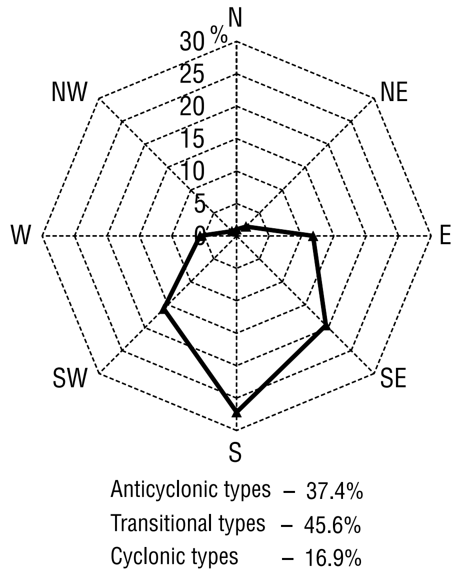

Fig. 2. Frequency (%) of air flow directions during the days with the hot weather type in Lublin (1951–2015)

The very frosty weather type (0 _ _) occurred in Lublin in the analysed multi-annual for 1.7 day per year on average (Table 4). At least one such day in a year was recorded 27 times, and more than 10 very frosty days in a year occurred only three times: 11 days in 1956 and 1986, and 12 days in 1963. During 65 years a slight reduction in number of days with very frosty weather types was observed (Fig. 4). In the annual cycle, days with the mean daily air temperature lower than –15°C and with the maximum daily air temperature lower than 0°C were observed from December to March with a maximum in January – on average 0.9 day in a month (Table 5). The earliest days with very frosty weather were recorded in mid-December – in 1963. Such a day occurred on the 14th day of the month. The latest when this weather type was observed was on March 3rd (in 1987). According to Woś (1999) the very frosty weather type, in the years 1951–1980 in Poland, was most frequently observed in the Karkonosze and Tatra Mountains, and in the north-eastern part of the country – on average 4 days in a year, particularly in the winter months from December to February. In Kraków, in the period 1901–2008, such days were observed from December 4th to March 2nd, whereas their average number amounted to 1.3 day per year (Piotrowicz 2010).

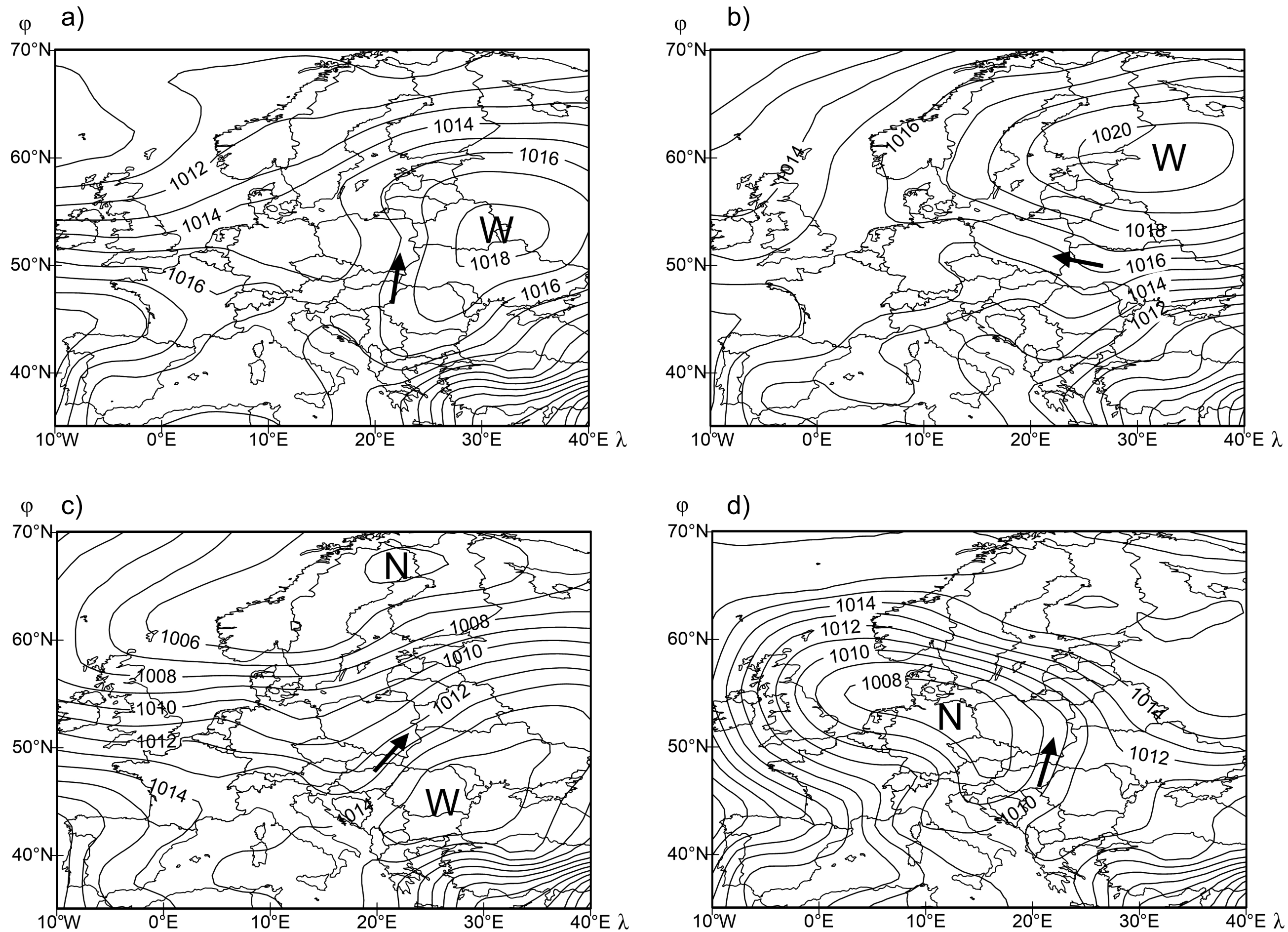

Fig. 3 (a–d). Average atmospheric pressure field at sea level (hPa) during synoptic conditions favourable for the occurrence of the hot weather type in Lublin (1951–2015)

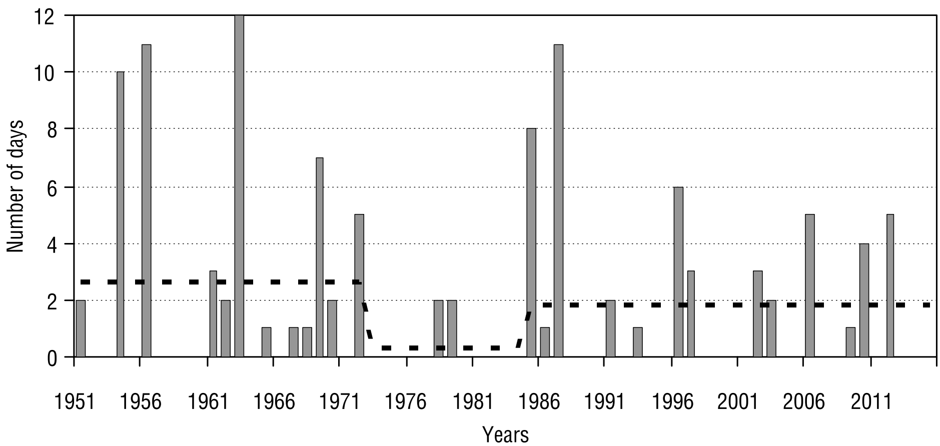

Fig. 4. Multiannual variability of the number of days with the very frosty weather type in Lublin (1951–2015). The dotted line illustrates changes in the number of days with the very frosty weather type based on the STARS method

In Lublin, the days with very frosty weather were usually cloudy with no precipitation (0 1 0), and sunny or with little cloud amount with no precipitation (0 0 0). Their number amounted to 35 (31.0% of days with very frost weather) and 33 (29.2% of days with very frost weather) days in the analysed multi-annual, respectively. The days with very frosty weather, sunny or with little cloud amount and precipitation (0 0 1), and very cloudy and with precipitation (0 2 1) occurred most seldom – 5 and 8 times in the 65-year period, respectively (Table 5).

The very frosty weather was usually determined by anticyclonic circulation with the advection of air masses from the eastern sector (Table 6, Fig. 5). Then, the centre of a stable high was located over the Scandinavian Peninsula

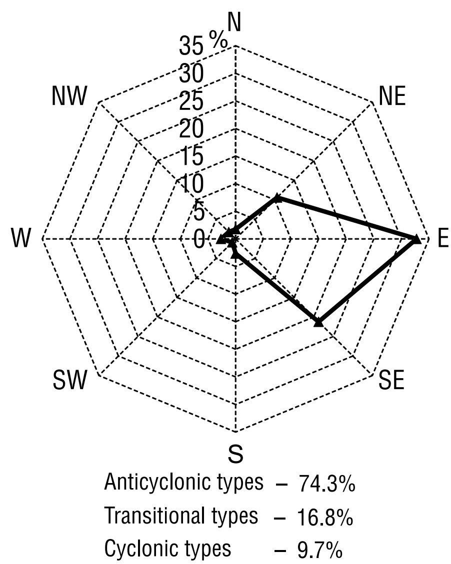

Fig. 5. Frequency (%) of air flow directions during the days with the very frosty weather type in Lublin (1951–2015)

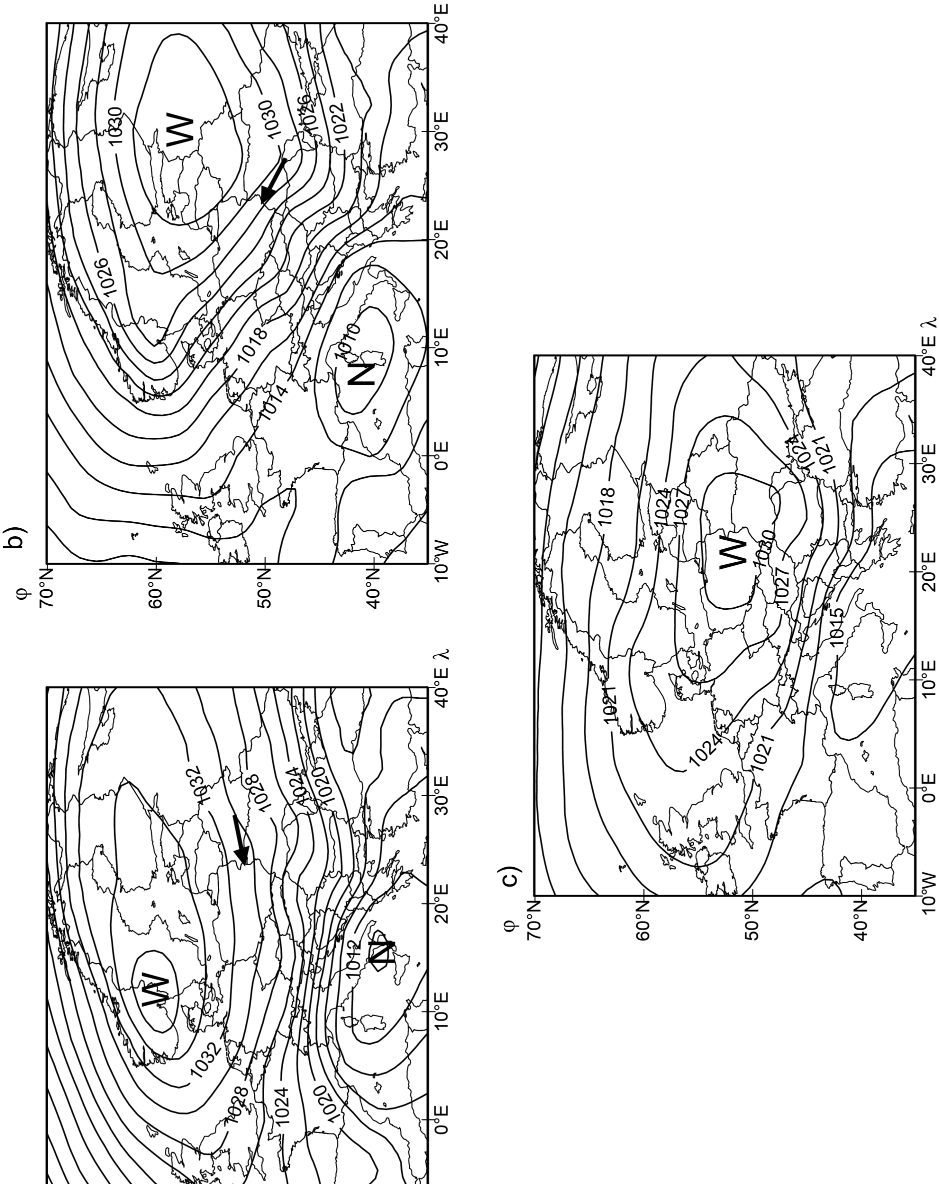

Fig. 6 (a–c). Average atmospheric pressure field at sea level (hPa) during synoptic conditions favourable for the occurrence of the very frosty weather type in Lublin (1951–2015)

(31% of cases; Fig. 6a) or over Eastern Europe (22%; Fig. 6b). This kind of baric situations also favours the occurrence of days with cold stress in Lublin (Bartoszek et al. 2017). The very frosty weather was also quite frequently recorded (23% of cases) when the centre of the high pressure system was located above Central-Eastern Europe (Fig. 6c). Days with this weather type did not occur during the westerly cyclonic circulation (Table 6).

The weather types with intensive precipitation (_ _ 30) were observed in Lublin for 1.1 day per year on average (Table 4). During 27 years no day with this weather type was recorded. 5 days, which is the highest number in one year, were observed in 1962 and 1998. No significant changes were found in the number of days with weather types with intensive precipitation in the analysed multi-year. Only the period 1998–2001 was characterised by a higher number of those days (Fig. 7). In the annual cycle, days with the sum of precipitation equal or higher than 30 mm were observed in Lublin from April to November, with no evident maximum (Table 4). The days with the weather with intensive precipitation were usually very warm and very cloudy (3 2 30), or moderately warm and very cloudy (2 2 30) – 37 (50.0% of days with intensive precipitation weather) and 25 (33.8% of days with intensive precipitation weather) days in the analysed multi-annual, respectively. The type of warm and cloudy weather with intensive precipitation (33 1 30) was recorded only once, on August 3rd, 1998. Ground-frost, very cool and very cloudy weather with intensive precipitation (5 2 30) occurred on April 6th, 2000 and November 19th, 2004 (Table 5). On those days, the N + NEc type was recorded, often accompanied

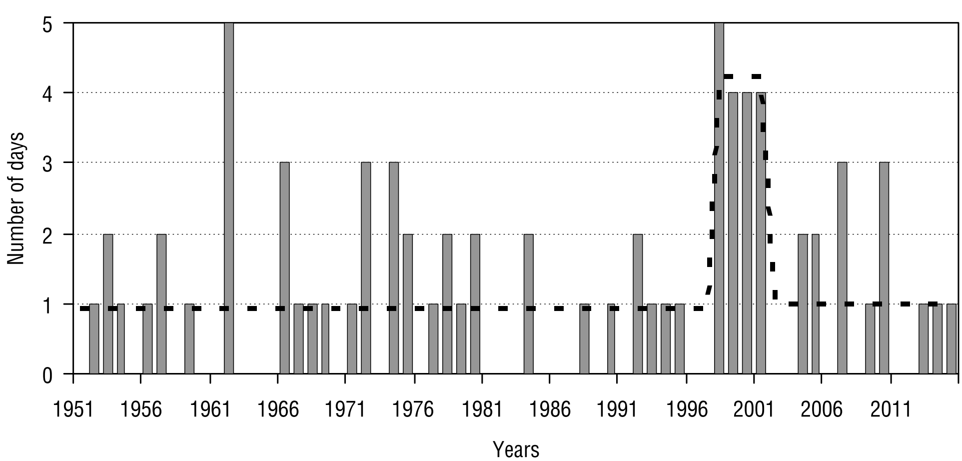

Fig. 7. Multiannual variability of the number of days with the weather type with intensive precipitation in Lublin (1951-2015). The dotted line illustrates changes in the number of days with the weather type with intensive precipitation based on the STARS method

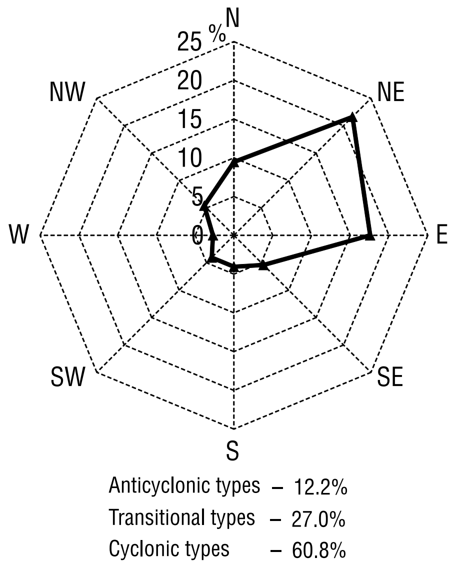

Fig. 8. Frequency (%) of air flow directions during the days with the weather type with intensive precipitation in Lublin (1951–2015)

by heavy rainfall in Lublin (Bartoszek and Skiba 2016), and the highest probability of advection of the Arctic air mass over Central-Eastern Europe (Kaszewski et al. 2017).

The weather with intensive precipitation in Lublin was largely determined by a cyclonic circulation with the inflow of air masses from the north-east and east (Table 6, Fig. 8). The situations generally corresponded with the movement of low pressure systems developed over the Mediterranean or the Black Sea towards higher latitudes (56% of days; Fig. 9a). This kind of lows rich in water vapour located in the area of the eastern borders of Poland very often favours long-lasting and extensive rainfall in many regions of the country (Łupikasza 2010; Twardosz et al. 2011; Bartoszek and Skiba 2016). Substantial but short frontal rainfall often occurs in the summer period during the transition towards the east of a trough related to the low over Northern Europe (18% of days; Fig. 9b). The weather with intensive precipitation was also observed during the inflow of very warm masses of polar continental air from the east (16%; Fig. 9c). In this case, however, precipitation is usually observed during intra-mass storms, i.e. not related to atmospheric fronts.

Conclusions

Extreme weather types, i.e. with hot, very frosty weather, or with intensive precipitation, were observed in Lublin in the period 1951–2015 for 5.4 days per year on average. Hot weather types were most frequently observed – on average 2.6 days a year. They occurred from May to September, with the highest number in July – 1.5 days on average, as well as in August – 1.1 day on average. Days with very frosty weather were recorded for 1.7 days a year, from December to March with a maximum in January (0.9 day a month on average). Days with the weather with intensive precipitation were observed for 1.1 days a year. They occurred from April to November, with no evident maximum.

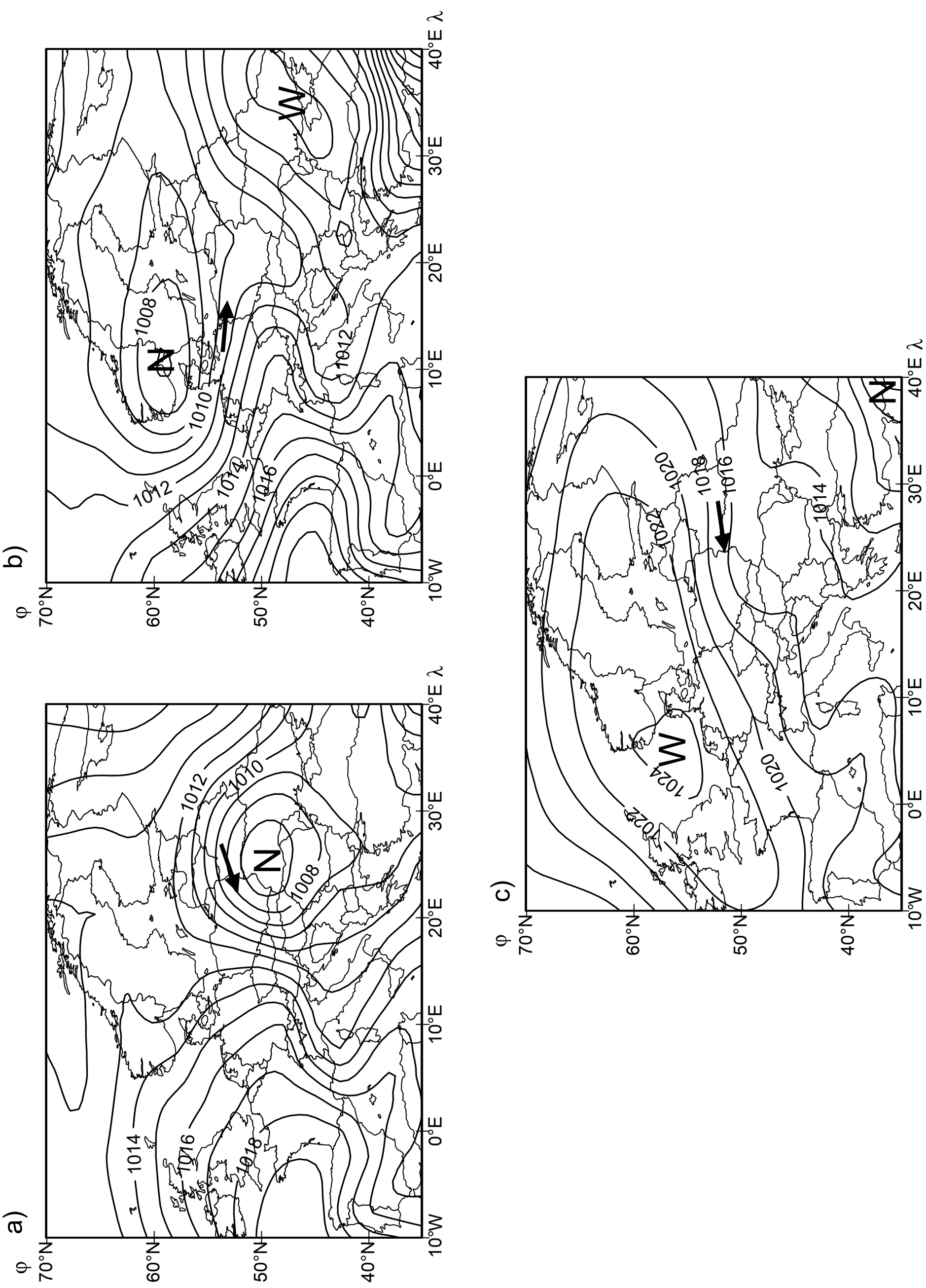

Fig. 9 (a–c). Average atmospheric pressure at sea level (hPa) during synoptic conditions favourable for the occurrence of the weather type with intense atmospheric precipitation in Lublin (1951–2015)

The occurrence of days with hot and very frosty weather in Lublin is largely determined by the influence of anticyclonic circulation and inflow of air masses from the southern and eastern sector, respectively. In the case of days with intensive precipitation, the cyclonic circulation types play a substantial role, however the genesis of such precipitation can be varied.

In the analysed period, an evident increase in the number of days with hot weather occurred but no substantial changes were recorded concerning the number of days with very frosty weather and intensive precipitation. It should be emphasized that there was no statistically significant relationship between the tendency in the frequency of all extreme weather types and the number of days with individual types of circulation. According to Kaszewski (2006, 2008), in the Lublin Region, in the second half of the 20th century, an increase in the mean annual air temperature was observed. Moreover, in recent years, a significant increase in the frequency of advection of tropical air masses was noted in the summer (Kaszewski et al. 2017). This can partly explain an increase in the number of days with hot weather, however, a more detailed study of air mass characteristics and synoptic scale meteorology is needed to confront the problem.

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