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Weather types in Sosnowiec (Poland) during the period 1999-2013

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ABSTRACT

The study presents the structure of weather types for the city of Sosnowiec during the period 1999-2013. The analysis was carried out on the basis of daily thermal data (the average daily air temperature, the minimum and maximum daily air temperature), cloudiness and precipitation. The data was obtained from a meteorological station belonging to the Department of Climatology at the Faculty of Earth Sciences at the University of Silesia. Weather types were established according to weather type classification after Woś (2010). 48 weather types were specified on the basis of a combination of 3 selected meteorological elements (temperature, cloudiness, precipitation). The number of days in the year and the frequency of particular thermal weather types, weather subtype, weather classes and weather types were characterized, and the changeability of weather types was analyzed. Furthermore, sequences of days with specific weather types were described. The analysis conducted has lead to the conclusion that, during the research period, the weather structure for the city of Sosnowiec was characterized by a great number of weather types observed, with relatively low frequency of occurrence. Weather throughout the year was dominated by warm weather types (3--, 2--, 2--), with weather marked as 310 – very warm, moderately cloudy, without precipitation (12.9%) recorded as the most frequent, followed by 221 – moderately warm, very cloudy, with precipitation (11.6%), and 210 – moderately warm, moderately cloudy, without precipitation (11.4%)as the least frequent one. A diversification in the number of particular classification units in consecutive years of the examined 15-year period does not display significant variability. Short sequences of 2 and 3 days dominated the selected sequences of specific weather types.

KEY WORDS: complex climatology, weather typology, Silesia

1. Introduction

The present study is a part of the complex climatology, which defines climate as a long-term regime of weather conditions, understood both as the entirety of weather conditions occurring and as the succession of weather changes, characteristic for a specific area. Weather, in turn, is defined as the concurrent occurrence of specific values of meteorological partitions (FERDYNUS, 2005). Applying this approach, with several simultaneously observed meteorological elements at hand, it is possible to establish the actual weather condition. Contrary to classic climatology which is based on standardized values of meteorological elements and their extremes, comprehensive methods of complex climatology provide information on the inter-relationship of particular weather elements (FERDYNUS, 2013). According to many climatologists, it is the interdependence of meteorological elements and their total comprehensive impact within a given geographical environment that provides a full image of the climate of a specific area and determines its type (PIOTROWICZ, 2010). Moreover, from the point of view of human life, the focus is naturally on a simultaneous interaction of weather elements, not on their separate occurrence. Therefore, the source of information on the features of the climate of a specific area includes the weather types observed and their occurrence in time. A weather type is defined as a generalized weather specification, expressed by the features and gradations of selected weather elements (WOŚ, 1999).

In the Polish literature, there are many papers about the application of complex climatology methods (WOŚ, 1970, 1996, 2010; FERDYNUS, 1997, 2004, 2007, 2013; KOSSOWSKI, 1968; MARSZ, 1992; OLSZEWSKI, 1967). The purpose of this work was to attempt to define the structure of weather types in Sosnowiec. In order to carry out the research,

it was essential that the types, subtypes, classes and types of weather were specified along with the frequency of their occurrence during the period 1999-2013. Changes in the frequency and type of weather in the defined area are not only very interesting from a cognitive point of view, but very important in terms of its application character. In fact, it is relevant to customize the many aspects of human life, eg. energy, transport, agriculture to changing climatic conditions and their consequences.

2. Study area

Sosnowiec is located in the eastern part of the Silesian Upland. In terms of climate, this area is attributed by WOŚ (1999) to the Silesian-Cracovian region. In turn, OKOŁOWICZ & MARTYN (1979) situate it in the Lesser Poland region whose climate is generally affected by the mountains, uplands and elevations with a noticeable impact from the Atlantic Ocean. The location of the Silesian Upland in temperate latitudes results in considerable variability of weather conditions, which is caused by an interaction of various air masses traveling across the region as well as a quick transfer of consecutive pressure systems. For 60% of the year, the weather of the Silesian Upland is affected by an inflow of polar – maritime air mass, bringing cooling weather and precipitation in the summer, and thaw, cloudiness and snowfalls in the winter. Moreover, the Upper Silesian area has recorded the lowest average annual sunshine rates in Poland – 1350 hours per year (ŁUPIKASZA & WIDAWSKI, 2008). The average annual air temperature in Sosnowiec is 8.0°C. Due to the fact that this area is highly urbanized, apart from natural climate-forming factors, temperature values in the region are also affected by anthropogenic factors. The warmest month is August (17.5°C), whereas the coldest month is January (-2.0°C). The mean annual sum of precipitation reaches 650 mm. Maximum precipitation takes place in July (100 mm), whereas the minimum occurs in January and February (30 mm). Average cloudiness is 6.2 (in a scale of 0-8) and does not deviate from the value of average cloudiness in Poland. The lowest values occur in the summer (4.2) and the highest – in the winter (7.5). The above specified data refers to the period of 1971-2000. The area, in which Sosnowiec is situated, is characterized by all features that are characteristic for the climate of Poland, which may be referred to as a transitional climate (DEGÓRSKA ET AL., 2009).

3. Materials and methods

The study examined data collected from the meteorological station in Sosnowiec (φ=50^{0}17'N, λ=19^{0}08'E, H=263 above sea level) belonging to the Department of Climatology at the Faculty of Earth Sciences at the University of Silesia. The data covers a period of 1999-2013. Weather types were determined according to the weather type classification of WOŚ (2010). Application of the above specified methodology provides a framework for comparing the study results with previous research carried out for Poland, including Katowice (WOŚ, 2010). The author of the classification has specified a weather type for each day, on the basis of the following meteorological elements: 1) air temperature (daily average ($T_{śr}$), maximum (T_{max}) and minimum (T_{min}), in °C); 2) average daily cloudiness (N, in %); 3) daily precipitation amount (Rd, in mm).

For each meteorological element gradation ranges of possible values were introduced. In order to characterize the thermal conditions 8 ranges of the daily mean values of air temperature were taken into account. To determine cloudiness conditions 3 ranges of daily amount of cloudiness of the sky were adopted, and for the precipitation conditions 2 ranges described as a day with precipitation and day without precipitation (Tab. 1).

Table 1. Weather classification after A. Woś (2010)

Weather element	Symbol	Names of weather	Partition
Air temperature (T)	3--	very warm	$T_{min} > 0°C$, $T_{avg} > 15.0°C$,
	2--	moderately warm	$T_{min} > 0°C$, $5.1°C \le T_{avg} \le 15.0°C$,
	1--	cool	$T_{min} > 0°C$, $0.1°C \le T_{avg} \le 5.0°C$
	5--	moderately cold	$T_{min} \le 0°C$, $T_{max} > 0°C$, $T_{avg} > 0.0°C$
	6--	very cold	$T_{min} \le 0°C$, $T_{max} > 0°C$, $T_{avg} \le 0.0°C$
	8--	moderately frosty	$T_{max} < 0°C$, $-5.0°C \le T_{avg} \le 0.0°C$
	9--	fairly frosty	$T_{max} < 0°C$, $-15.0°C \le T_{avg}$,$< -5.0°C$
	0--	very frosty	$T_{max} < 0°C$, $T_{avg} < -15.0°C$
Cloudiness (N)	-0-	sunny	$N \le 20\%$
	-1-	moderately cloudy	$21\% \le N \le 79\%$
	-2-	very cloudy	$N \ge 80\%$
Precipitation (Rd)	--0	without precipitation	$R_d < 0.1$ mm
	--1	with precipitation	$R_d \ge 0.1$ mm

In the adopted classification, the basic qualification unit is the weather type, which assumes that days are uniform in terms of all 3 features – air temperature, cloudiness and precipitation. However, the following auxiliary units were also distinguished: 1) thermal weather types – assuming days with similar thermal characteristics; 2) weather subtypes – assuming days with an identical description of thermal and cloudiness conditions; 3) weather classes – combining all days that are uniform in terms of cloudiness and precipitation.

A classification of weather types was conducted on the basis of the results of measurements performed during the research period. Each weather type is defined by three digits. The first of these expresses the thermal relations, the second one gives information about the general cloudiness, and the third one – about the precipitation. Therefore, a weather type defined as *300* stands for very warm and sunny weather without precipitation on a given day. A combination of 8 temperature partitions, 3 cloudiness partitions and 2 precipitation partitions has thus produced 48 basic weather types. This classification additionally assumes: 8 weather types on the basis of air temperature value (thermal weather types), 16 types on the basis of air temperature and precipitation values (weather classes) and 24 types on the basis of the thermal criterion only, plus cloudiness (weather subtypes). This way, 40 consecutive weather types were specified, totaling to 88 weather types. With such a simplified classification, the weather condition may be poorly specified. Numerical markings of auxiliary weather types replace an unknown criterion with a dash ("-"). A weather type presented as *3*-- informs us that the air temperature only (thermal weather type) served as the sole distinguishing criterion, which, according to the principles of the classification, stands for very warm weather. In turn, a weather type marked with *11*- informs us that air temperature and cloudiness (weather subtype) served as the distinguishing criteria symbolizing cool, moderately cloudy weather. A weather type presented as *-00* (weather class) stands for sunny weather without precipitation. When specifying this weather type, the air temperature criterion was not considered. All of the weather types listed in the classification were divided into 3 weather units:

1) warm (beginning with the digit 3, 2, or 1 in the three-digit code, that is all types of very warm, moderately warm and cool weather, respectively);

2) cold (beginning with the digit 5 or 6 in the three-digit code, that is all types of moderately cold and very cold weather, respectively);

3) frosty (beginning with the digit 8, 9 or 0 in the three-digit code, that is all types of moderately frosty, fairly frosty and very frosty weather, respectively) (Woś, 1999).

The following values were calculated for the weather type analyses for Sosnowiec:

1) mean annual number of days with particular weather types;

2) the frequency of occurrence of weather types within a year;

3) number of weather types recorded in consecutive decades of the year in order to specify the weather types determining weather variability (for the purposes of this study, a decade will stand for a ten-day period, therefore each month was divided into 3 decades, whereas the first decade assumes the first 10 days of the month, the second one – day 11 to day 20, the third one – from day 21 to day 28, 29, 30 or 31, depending on the length of the month);

4) a sequence of days with the same weather type – in order to specify the types which increase weather stability;

5) the number of thermal types, classes, and weather types in consecutive years and the changes in the frequency of occurrence of thermal types and weather classes in particular years of the research period.

4. Structure of weather types in Sosnowiec

4.1. Thermal weather types

Thermal weather type is the highest taxonomic unit, characterized by identical air temperature description in this study. In Sosnowiec, the research period of 1999-2013 was dominated by days with moderately warm weather (2--), in which temperature was within the range 5.1 to 15°C – an average of approximately 130 days a year (35.5%). The second most frequent weather type was the warmest weather – very warm (3--), with an average daily temperature exceeding 15°C – the mean annual number of days was 108 (29.6%). Both of them were frequently accompanied by moderate cloudiness. The remaining weather types were recorded considerably less frequently. Approximately one fifth of the days of the year, were observed to be days with moderately cold (5--) and cool (1--) weather, the former occurred with moderate cloudiness, and the latter with high cloudiness (very cloudy). There was an average of 26.5 days (7.3%) with very cold weather (6--),

most of which were very cloudy. The least frequent were days with the coldest weather types – 8--, 9--, 0-- (respectively, for 17.8, 14.5 and 0.4 days). The value for the annual mean number of days was 0.4 for very frosty weather (0--) with average daily temperature above -15.1°C means that days with this thermal weather type did not occur every year. Moderately frosty (8--) days were usually very cloudy. To a similar extent, fairly frosty weather (9--) was accompanied by moderate and high cloudiness, whereas very frosty weather (0--) was recorded as sunny on 3 days during the research period and as moderately cloudy (Tab. 2).

Table 2. Thermal weather types and weather subtypes in Sosnowiec during the period 1999-2013

No	Thermal weather type (symbol)	Weather subtype (symbol)	Thermal weather types		Weather subtypes	
			Mean annual number of days	Frequency [%]	Mean annual number of days	Frequency [%]
1	3--	30-	108.0	29.6	11.9	3.3
		31-			75.5	20.7
		32-			20.5	5.6
2	2--	20-	129.6	35.5	8.5	2.3
		21-			66.4	18.2
		22-			54.7	15.0
3	1--	10-	30.6	8.4	0.2	0.1
		11-			7.9	2.2
		12-			22.5	6.2
4	5--	50-	37.9	10.4	5.3	1.5
		51-			17.1	4.7
		52-			15.5	4.2
5	6--	60-	26.5	7.3	2.4	0.7
		61-			10.3	2.8
		62-			13.9	3.8
6	8--	80-	17.8	4.9	0.3	0.1
		81-			3.0	0.8
		82-			14.5	4.0
7	9--	90-	14.5	4.0	2.3	0.6
		91-			6.1	1.7
		92-			6.0	1.6
8	0--	00-	0.4	0.1	0.2	0.1
		01-			0.2	0.1
		02-			0.0	0.0

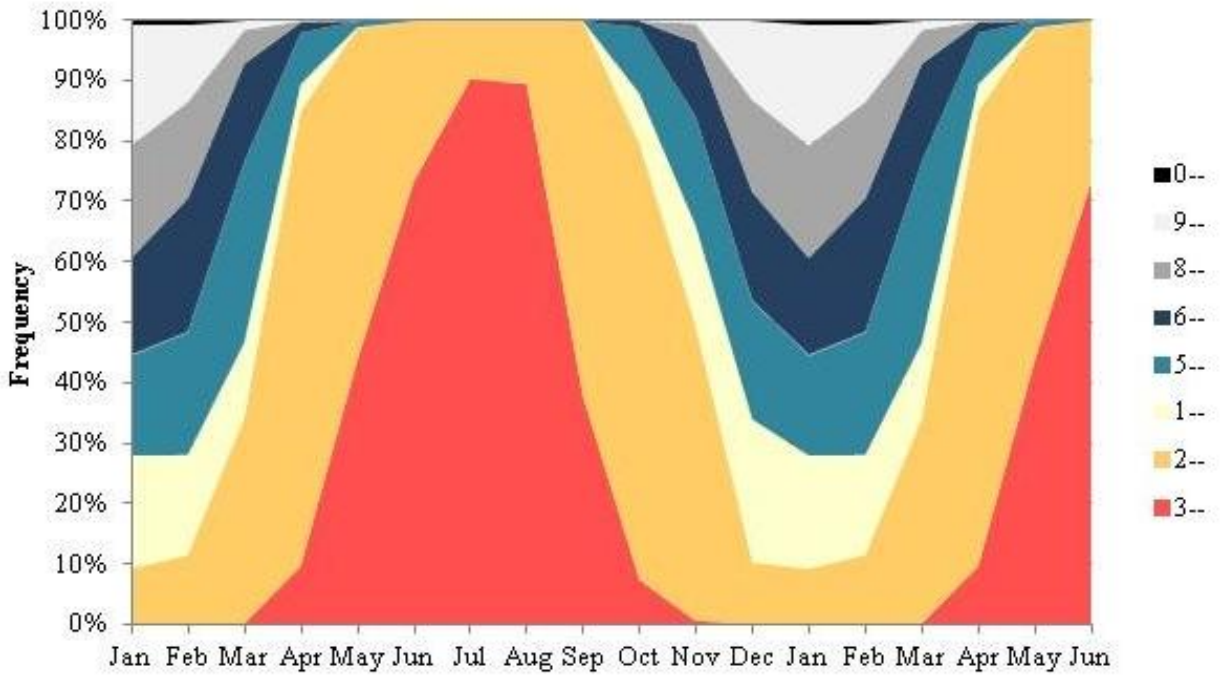

Fig. 1. Annual structure of thermal weather types in Sosnowiec during the period 1999-2013

The distribution of the frequency of occurrence of thermal weather types in particular months of the year is presented in Figure 1. According to this analysis, the one and only thermal weather type observed in all months of the year was moderately warm weather (2--). Very warm (3--) and moderately cold weather (5--) was recorded in 8 months of the year. The former occurred from April to November, whereas the latter – from October to April. Furthermore, for 7 months of the year (from October to April), days were recorded with cool (1--) and very cold weather (6--). For six months of the year (from November to April), moderately frosty weather (8--) was observed. Fairly frosty weather (9--) occurred for 5 months of the year (November-March), and the coldest weather type – very frosty weather (0--) was only observed in January and February.

4.2. Weather subtypes

A weather subtype is formed by uniform days in terms of temperature and cloudiness. The most frequently observed weather subtype was very warm and moderately cloudy weather (31-) for an average of 75.5 days a year (20.7%). Together with the next two subtypes – moderately warm, moderately cloudy (21-) and moderately warm, very cloudy weather (22-), these constitute nearly a half of all days in a year. Cool, very cloudy (12-) weather, very warm, very cloudy weather (32-) as well as moderately cold, moderately cloudy weather (51-) were observed on average for approximately 20 days a year. Moderately cold, very cloudy (52-), moderately frosty, very cloudy (82-), very cold, very cloudy (62-), very warm, sunny (30-) and very cold, moderately cloudy weather (61-) were recorded for 10 to 15 days a year. The remaining weather subtypes were observed less frequently than the average of 9 times per year, including 4 subtypes: moderately frosty, sunny (80-), cool, sunny (10-), very frosty, sunny (00-) and frosty, moderately cloudy (01-) weather types were recorded only on a few occasions during the research period. Very frosty, very cloudy (02-) weather did not occur, which is not surprising, since it is one of the weather subtypes, which are rarely found in reality (Tab. 2). Frosty weather types were usually accompanied by anticyclonic circulation, which hinders the formation of clouds. Irrespective of air temperature, moderately cloudy (51.0%) and very cloudy (40.4%) weather days dominated throughout the year. Sunny days were found to have been the least frequent (8.5%).

4.3. Weather classes

Average daily cloudiness and total daily precipitation values were used to determine weather classes. In the annual structure of weather classes, 2 classes were distinguished: moderately cloudy weather without precipitation (-10) and very cloudy weather with precipitation (-21). In total, these classes were observed on average for approximately 2/3rds of the days of the year. Days with moderately cloudy weather with precipitation (-11) constituted approximately 1/5th of the year. Very cloudy weather without precipitation (-20) and sunny weather, without precipitation (-00) was recorded equally frequently (respectively 9.6% and 8.1%). Sunny weather with precipitation (-01) was found the least frequently (0.5%). Analyzing the frequency of weather classes in terms only of the frequency of precipitation, it could be said that weather with precipitation slightly dominated the year (50.3%) (Tab. 3).

Table 3. Weather classes in Sosnowiec during the period 1999-2013

No	Weather class (symbol)	Mean annual number of days	Frequency [%]
1	-10	117.1	32.1
2	-21	112.6	30.8
3	-11	69.3	19.0
4	-20	35.0	9.6
5	-00	29.5	8.1
6	-01	1.7	0.5

4.4. Weather types

Weather type is the most basic classification unit in the adopted typology. It groups all days with uniform thermal, nephological and precipitation conditions, into one category. Of the 48 possible weather types, 42 were recognized as having occurred in the city of Sosnowiec. The distribution of occurrence of particular types is very uneven. Figure 2 presents the frequency of all weather types recorded in Sosnowiec during the research period, ordered according to decreasing frequency,

with a sequence of cumulative frequency also marked. The data presented in the figure is shown in Table 4, which presents the names of the most frequent weather types.

The frequency curve displays four visible thresholds – at the level of ~8, ~5, ~3.5 and ~2%. The first one includes 3 weather types. The highest mean annual number of days recorded with very warm weather, moderately cloudy, without precipitation (310) was 47.2 (12.9% of days in a year). A relatively similar frequency was recorded for the next 2 weather types: moderately warm weather, very cloudy and with precipitation (221) – 42.2 (11.6%) and moderately warm weather, moderately cloudy and without precipitation (210) – 41.5 days (11.4%). In total, the above specified weather types occurred on average on 1/3rd of all the days in a year. Between the first and second threshold 2 types, which were recorded for over 20 days in a year contained. These were: very warm weather, moderately cloudy and with precipitation (311) – 28.3 (7.8%) and moderately warm weather, moderately cloudy and with precipitation (211) – 24.9 (6.8%). Two types occur between the second and third threshold. These were the weather types marked with the symbol 121 (cool weather, very cloudy, with precipitation – 18.0 days, 4.9%) and 321 (very warm weather, very cloudy, with precipitation – 15.5 days, 4.3%). Seven weather types were characterized by an average number of days in the year of 13 to 8. Their frequency was 3.5-2.0% days a year. These were marked with the following symbols: 220, 521, 510, 300, 621, 821 and 200. The frequency of the next 28 types was below 2% (7 days a year). The types with symbols 610 and 511 occurred 5-6 times a year, and as many as 17 weather types occurred for an average of 1 to 5 days within a statistical year. Moreover, 9 types were recorded once in several years, as their average number of days per annum was lower than 1. Such types may be considered accessory in the weather type structure for the city of Sosnowiec. They bear marginal importance in the formation of local weather, contributing only to inter-yearly and inter-monthly variation of the weather conditions. Five types with the following symbols: 001, 011, 020, 021, 101 and 801 were not observed at all. The core of the structure of weather types (70% of all observations) consisted in only 10 to 42 of the recorded weather types, wherein the first 3 types may be considered dominant in terms of frequency (Tab. 4).

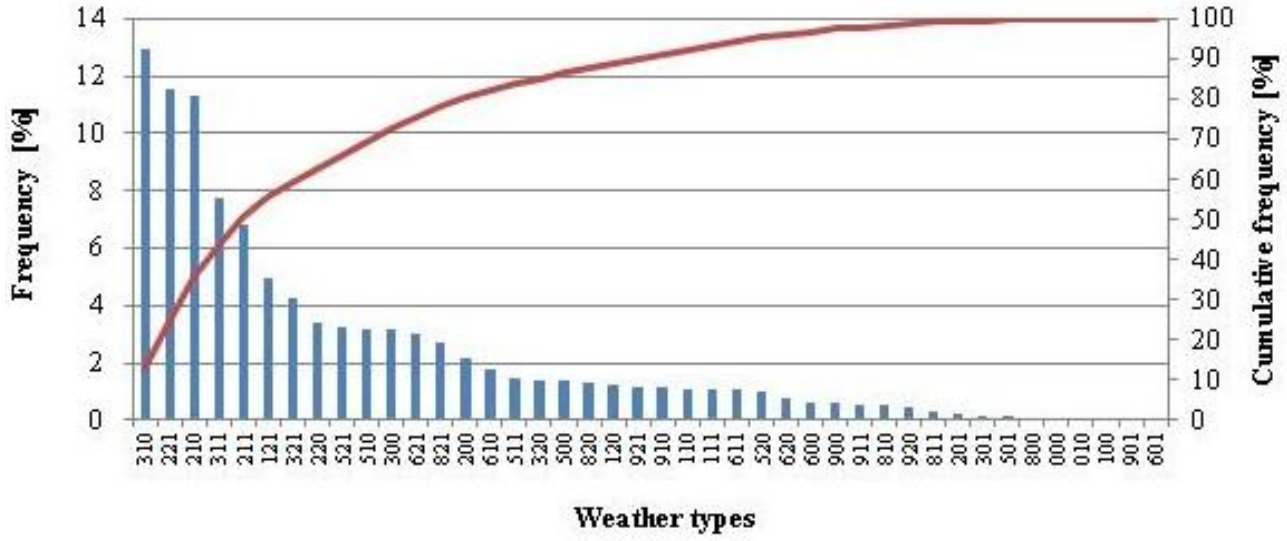

Fig. 2. Frequency [%] of occurrence of weather types in Sosnowiec during the period 1999-2013

The number of weather types observed in consecutive decades of the year was used to specify the weather variability in Sosnowiec. The higher the value, the higher the variability of weather conditions may potentially be in a specific decade, year after year. Further, the number of occurrences of the recorded weather types was presented for particular decades of the year. The occurrence of a number of weather types of 10 and more in a given decade indicates that the average duration of any of the weather types is shorter than 1 day. This means that the weather types specified for a given decade do not occur every year. In the research period, during 1999-2013, the sequence of the number of weather types in consecutive decades (Fig. 3) displays considerable seasonal variation. The lowest number of observed weather types occurs in the summer – approximately 9.

The fewest are recorded in the first decade of July – 8. Such low values are attributed to the repeatability of recorded types every year. This, in turn, is associated with the types of cyclonic circulation, which reaches a minimum frequency of occurrence in the end of spring and in the summer, causing greater stability of weather conditions. In contrast, the highest variability in the number of weather types is observed in the winter, in the beginning of spring and in the end of autumn (decades from 1 to 9 and from 34 to 36) – approximately 26 types. This, in turn, results from the maximum occurrence of cyclone systems above the Silesian Upland (NIEDŹWIEDŹ, 1999). In this period, the highest number of types observed in a 10-day period is 28. This number occurred for the following decades: 2, 4 and 36. The average number of weather types per decade is 17. This proves that, in the analyzed 15 years, the average duration of a given weather type per decade is 0.17 of a day. Since the day is accepted as the classification unit, we may infer that at least 7 out of 17 weather types did not occur every year in a given decade.

Table 4. Weather types in Sosnowiec during the period 1999-2013

No	Weather type (symbol)	Mean annual number of days	Frequency [%]	No	Weather type (symbol)	Mean annual number of days	Frequency [%]
1	310	47.2	12.9	25	611	3.8	1.0
2	221	42.2	11.6	26	520	3.6	1.0
3	210	41.5	11.4	27	620	2.9	0.8
4	311	28.3	7.8	28	600	2.3	0.6
5	211	24.9	6.8	29	900	2.2	0.6
6	121	18.0	4.9	30	911	1.9	0.5
7	321	15.5	4.3	31	810	1.9	0.5
8	220	12.5	3.4	32	920	1.7	0.5
9	521	11.9	3.2	33	811	1.1	0.3
10	510	11.7	3.2	34	201	0.7	0.2
11	300	11.5	3.1	35	301	0.5	0.1
12	621	11.0	3.0	36	501	0.4	0.1
13	821	9.7	2.7	37	800	0.3	0.1
14	200	7.9	2.2	38	000	0.2	0.1
15	610	6.5	1.8	39	010	0.2	0.1
16	511	5.4	1.5	40	100	0.2	0.1
17	320	4.9	1.4	41	901	0.1	0.0
18	500	4.9	1.4	42	601	0.1	0.0
19	820	4.8	1.3	43	001	0.0	0.0
20	120	4.5	1.2	44	011	0.0	0.0
21	921	4.3	1.2	45	020	0.0	0.0
22	910	4.2	1.1	46	021	0.0	0.0
23	110	4.0	1.1	47	101	0.0	0.0
24	111	3.9	1.1	48	801	0.0	0.0

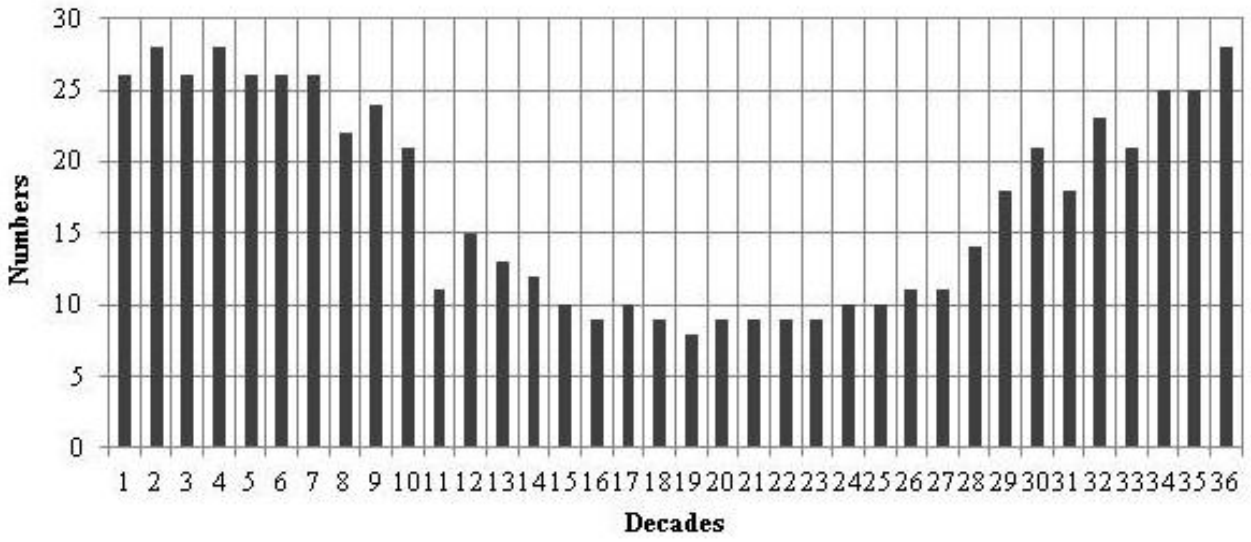

Fig. 3. Number of weather types observed in consecutive decades in Sosnowiec during the period 1999-2013

5. Variability of weather types in Sosnowiec

In the research period of 1999-2013, the variability of weather types was analyzed using several methods. Figure 4 presents the number of thermal weather types, weather classes and weather types observed in the consecutive years of the research period. A lower number of types may indicate a higher monotony of weather conditions. Variability for thermal types and weather classes was not recorded. Only 7 thermal weather types were usually observed in all years, whereas in 2002, 2006 and 2012, there were 8 of these. A similar observation was made with weather classes, 6 of which were usually observed, whereas in 2005, 2008, 2009 and 2012 – there were 5 of them. These minor differences result from the observation of very rare weather conditions in some of the years. In terms of weather types, we are observing the minor variability in their numbers in consecutive years. An average of 33 weather types was observed. In 2007-2010, their number did not exceed the average. The occurrence of weather types was more concentrated in that period.

The study also includes a calculation of the frequency of occurrence of thermal weather types in consecutive years of the research period (Fig. 5). Of note are days with frosty weather (8--, 9--, 0--). Fairly frosty (9--) and very frosty weather (0--) was not observed every year. Usually, a higher frequency of moderately frosty weather (8--) involved a drop in the frequency of cool weather (1--).

Similar to thermal weather types, the weather classes presented in Figure 6 indicate low variability on a year-after-year basis. The occurrence of moderately cloudy weather with and without precipitation (-10 and -11) was characterized by similar frequency in successive years. The more frequent occurrence of sunny days without precipitation (-00) usually involved a decrease in the number of very cloudy days with precipitation (-21). Sunny weather with precipitation (-01) was not recorded in any of the years.

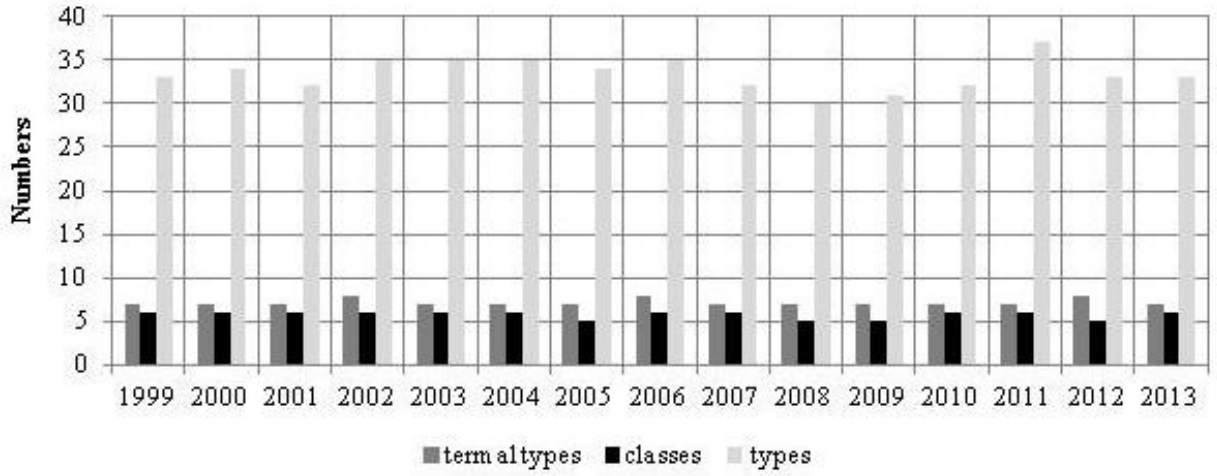

Fig. 4. Number of thermal weather types, weather classes and weather types observed in Sosnowiec in consecutive years during the period 1999-2013

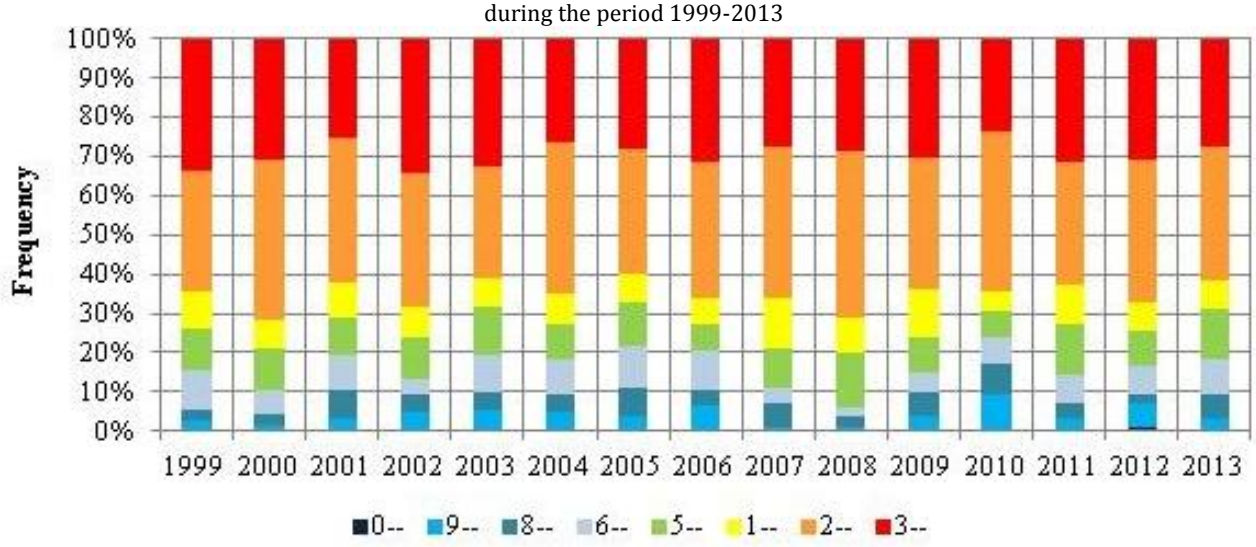

Fig. 5. Frequency of occurrence [%] of thermal weather types in Sosnowiec in consecutive years during the period 1999-2013

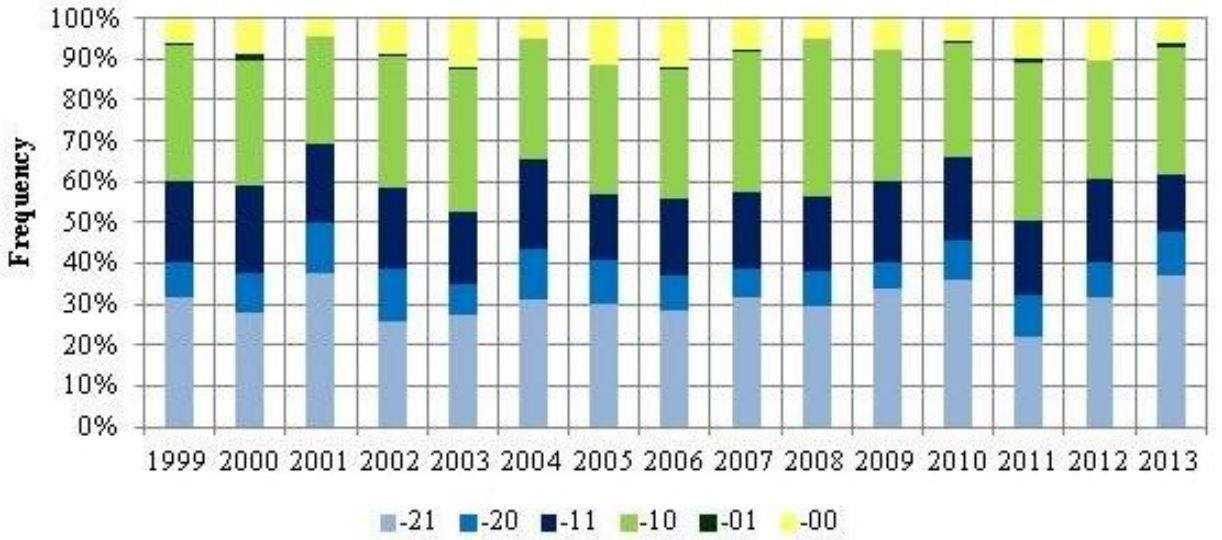

Fig. 6. Frequency of occurrence [%] of weather classes in Sosnowiec in consecutive years during the period 1999-2013

Table 5. Frequency of occurrence [%] of sequences of days with regard to their length with particular types of weather in Sosnowiec during the period 1999-2013

No	Weather type	The number of days within sequence									Sum
		2	3	4	5	6	7	8	9	10	
1	310	10.4	3.3	1.3	0.5	0.9	0.3	0.1	0.1	0.0	16.9
2	210	8.8	3.0	1.0	0.6	0.5	0.1	0.0	0.0	0.0	14.0
3	221	7.8	3.6	1.2	0.5	0.3	0.3	0.0	0.0	0.1	13.8
4	311	5.6	1.4	0.3	0.1	0.0	0.0	0.0	0.0	0.0	7.4
5	121	4.2	1.0	0.5	0.0	0.1	0.0	0.1	0.0	0.0	5.9
6	211	4.1	0.9	0.5	0.1	0.0	0.0	0.0	0.0	0.0	5.6
7	321	2.5	1.2	0.2	0.0	0.1	0.0	0.0	0.1	0.0	4.1
8	300	2.3	0.6	0.6	0.1	0.0	0.0	0.0	0.0	0.0	3.6
9	510	2.5	0.5	0.3	0.0	0.0	0.0	0.0	0.0	0.0	3.3
10	621	1.7	0.9	0.2	0.0	0.0	0.0	0.0	0.0	0.0	2.8
11	821	1.7	0.7	0.1	0.1	0.1	0.0	0.0	0.0	0.0	2.7
12	200	1.7	0.8	0.1	0.0	0.0	0.0	0.0	0.0	0.0	2.6
13	220	1.5	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
14	521	2.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3
15	610	1.1	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5
16	921	1.2	0.2	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.5
17	500	1.2	0.1	0.2	0.0	0.0	0.0	0.0	0.0	0.0	1.5
18	820	0.7	0.4	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.2
19	910	0.9	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	1.0
20	120	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
21	320	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9
22	611	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
23	900	0.6	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.7
24	600	0.4	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.6
25	520	0.3	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
26	620	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
27	110	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
28	111	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
29	511	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
30	911	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
31	000	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
32	201	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
33	800	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
34	810	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
35	920	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Sum		67.1	20.7	6.9	2.1	2.0	0.7	0.2	0.2	0.1	67.1

6. Sequence of days with weather types

In order to define which weather types increase the stability of the weather conditions in the city of Sosnowiec, the length and the number of sequences of days with specific weather types were calculated. A weather type sequence is defined as at least two consecutive days with the identical weather type. Therefore, a day is the basic sequence length unit. Weather conditions will become increasingly stable when the sequence of days is longer, since the possibility of observing days with other weather types will be limited in a given decade or month.

1001 sequences of days with the same weather description were recorded in Sosnowiec in the research period. These were observed for 35 out of 42 of the weather types occurring during 1999-2013. The remaining weather types occurred on single days only, thus do not affect the stabilization of weather conditions. The largest number of sequences occurred for the 3 most frequent weather types (310 – 16.9%, 210 – 14.0% and 221 – 13.8%).

The length of the observed sequences fluctuated from 2 to 10 days. The majority of sequences recorded were short ones – lasting 2 days (67.1%). One-fifth of all the observed sequences lasted 3 days (20.7%), whereas 7% of the sequences lasted 4 days. 5- and 6-day sequences constituted up to 1%. An 8-day sequence was observed only twice in the entire research period. The first time, it was formed by cool, very cloudy weather and with precipitation (121), and the second time – by very warm, moderately cloudy weather without precipitation (310). A sequence of nine days occurred twice as well with very warm, very cloudy weather with precipitation (321) and with very warm, moderately cloudy weather without precipitation (310). The first one was recorded in July 2001, the second one in August 2003. A sequence of 10 days occurred only once, in May 2010, with moderately warm, very cloudy weather with precipitation (221). A stabilization of weather conditions was largely affected by very warm, moderately cloudy weather without precipitation (310). The sequences featuring this weather type occurred the most often and lasted for 2 to 9 days (Tab. 5).

In conclusion, the same weather types, displaying the highest annual frequency, also create the most frequent sequences of days, determining weather stability in Sosnowiec. Further research will concern the seasonal distribution of the sequences of days formed by particular weather types.

7. Discussion

The application of weather type classification after Woś (2010) in this study provides a framework for comparing the study results with previous research carried out for Poland, including Katowice (Woś, 2010). A comparison of the structure of thermal weather types for the city of Sosnowiec for 1999-2013 and for the city of Katowice for 1951-2000 allows a display of their possible variability in the last 15 years, in relation to the second half of the 20th century. This idea is proven by the fact that these cities are located very close to one another (about 10 kilometers). It may therefore be claimed that they are characterized by similar weather conditions throughout the year. Moreover, instead of daily values of weather elements, the study applies a complex approach to meteorological values (weather types), hence the differences in absolute values for particular parameters do not necessarily have to affect any differences in weather types. The results obtained will contribute to a presentation of weather types over a much longer period of 63 years.

According to the completed analysis, the structure of thermal weather types for Sosnowiec and Katowice displays certain differences in the research periods. The most significant change to be observed is the increase of days with very warm weather (3--) from on average 87.7 during 1951-2000 to 108 during 1999-2013. This means that there are statistically 20.3 more days with weather exceeding 15°C a year. An increase by 2 in the mean annual number of days is also recorded for moderately frosty weather (8--). In contrast, a decrease in the mean annual number of days is recorded for cold weather types (5-- – moderately cold and 6-- – very cold) – by 10.9 and 5.7 days, respectively. A similar pattern was observed for the coldest thermal weather types (9-- – fairly frosty and 0-- – very frosty weather). Their number dropped by 4.9 and 0.7 days, respectively. Two weather types (2-- – moderately warm and 1-- – cool) are characterized by a similar average number of days a year, differing by only 0.3 of a day (Tab. 6).

The most frequent weather types considered in terms of thermal weather types repeat at both stations in 5 cases. Both in Katowice and, later on, in Sosnowiec, very warm weather (3--) types were dominated by very warm, moderately cloudy weather without precipitation (310). As regards cool weather (1--), both cities displayed an occurrence of days with cool, very cloudy weather with precipitation (121). In terms of very cold (6--) weathers, most days in the year displayed very cold, very cloudy weather with

precipitation (621). Similarly, in the case of moderately frosty (8--) and fairly frosty (9--) weather types, the most frequent were very cloudy and with precipitation (821 and 921). In terms of very frosty weather (0--), 2 types of weather were equally frequent. In Katowice, this was very frosty, sunny weather without precipitation (000) and very frosty, moderately cloudy weather with precipitation (011), and in Sosnowiec – this was also very frosty, sunny weather without precipitation (000) and very frosty, moderately cloudy weather without precipitation (010). The differences in the structure of weather types for both areas apply to moderately warm and moderately cold (5--) weather. In Katowice, the above mentioned thermal types were usually accompanied by moderately cloudy weather without precipitation (210 and 510), whereas in Sosnowiec – by very cloudy weather with precipitation (221 and 521). The two stations also differ in terms of the weather type characterized by the highest frequency in a year. In Katowice during 1951-200, the most frequent type included moderately warm, moderately cloudy weather without precipitation (210 – 40.7 days), whereas in Sosnowiec during 1999-2013 – it was very warm, also moderately cloudy weather without precipitation (310 – 47.2 days).

Table 6. The mean annual number of days with thermal types of weather in Sosnowiec (1999-2013) and Katowice (1951-2000)

No	Thermal weather type (symbol)	Mean annual number of days	
		Katowice (WOŚ 2010) 1951-2000	Sosnowiec 1999-2013
1	3--	87.7	108.0
2	2--	129.7	129.6
3	1--	30.3	30.6
4	5--	48.8	37.9
5	6--	32.2	26.5
6	8--	15.8	17.8
7	9--	19.4	14.5
8	0--	1.1	0.4

8. Conclusions

The study presents the structure of weather types in Sosnowiec during 1999-2013. Moreover, the analysis assumes the variability of weather types and the length and number of sequences of days with specific weather types. Weather types were established according to the weather classification after Woś (2010), which is based on three weather elements: air temperature (daily average, minimum and maximum), average cloudiness and precipitation. According to the results of the analyses, the structure of weather types recorded at the meteorological station in Sosnowiec is characterized by considerable variability in the weather conditions, which is in turn manifested by a high number of weather types occurring within the year. Furthermore, a high number of weather types means that they display a relatively low frequency of occurrence, which means that a given weather type usually lasts for a very short time. Among 42 observed weather types, 26 occur on average for up to 5 days a year. Moreover, the scope of observed thermal weather types is very broad – from very warm to very frosty weathers. Such high variability of the weather conditions of the city of Sosnowiec may be caused by the location of the city in temperate latitudes as well as by circulation factors, including very frequent and active flows of air masses from the west and relatively fast transfer of air pressure systems. The variability of weather types differs in particular seasons. The highest variability is recorded in the winter, when low pressure systems dominate in Sosnowiec. In contrast, the lowest variability occurs in the summer, when cyclone circulation is weakest in the year. Apart from the temperature criterion, considerable variability in terms of the number of observed weather classes has also been recorded, determining the visual perception of weather conditions. These are dominated by 2 classes – moderately cloudy weather without precipitation (-10) and very cloudy weather with precipitation (-21), on average, these occur for 2/3rds of the year. In turn, such situations, despite considerable diversification of weather types, point to monotony in the weather. Throughout the year, we can claim a dominance of days with moderately cloudy weather, with a minor advantage of days with precipitation. The most frequent weather type was very warm, moderately cloudy weather without precipitation (310). This

type had the greatest impact on stabilization of the weather conditions, which manifested itself in a frequent repetition of this weather type on successive days. 1001 sequences of days with the same weather type were recorded for Sosnowiec. These were dominated by short sequences of two and three days. Series with the same weather conditions, lasting for 7 days or more, were recorded most of all in the summer, which is indicative of the stable weather conditions at this time of year.

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