DE GRUYTER OPEN

Environmental & Socio-economic Studies

DOI: 10.1515/environ-2017-0018

Environ. Socio.-econ. Stud., **2017, 5, 4: 29-39**

Original article

Atmospheric fronts over Poland (2006-2015)

Patryk Sykulski, Zuzanna Bielec-Bąkowska*

Department of Climatology, Faculty of Earth Science, University of Silesia, Będzińska Str. 60, 41-200 Sosnowiec, Poland

*E–mail address (*corresponding author): zuzanna.bielec-bakowska@us.edu.pl*

ABSTRACT

The paper presents the spatial and temporal variations in the occurrence of fronts and days with no fronts over Poland in 2006-2015. The research was based on a database of the atmospheric fronts that moved over five selected stations located in the outermost regions of Poland and in the centre of the country. The database was created as a result of an analysis of synoptic charts from the website of the German weather service (Deutscher Wetterdienst; DWD). As is shown by the results, atmospheric fronts moved over Poland on approximately 65% of days of the year. However, their frequency in the individual regions was almost half of this, ranging from 33-39%. The annual variations in the number of fronts depended largely on the location of a given area and the atmospheric circulation prevailing there. In most years the maximum frequency of occurrence of atmospheric fronts was observed in November-January, and the lowest frequency was seen in February and September. The research confirms that there is a clear predominance of cold fronts, with warm and occluded fronts forming at around half the frequency of cold fronts. One characteristic feature is a decrease in the number of occluded fronts and days with different types of fronts moving from the north of Poland southwards. In the period under study, more than 80% of the sequences of days with atmospheric fronts included up to 6 days, even though there were also cases when fronts passed over Poland on 20 consecutive days.

KEY WORDS: atmospheric fronts, circulation, Poland

ARTICLE HISTORY: received 22 October 2017; received in revised form 19 November 2017; accepted 6 December 2017

1. Introduction

Among the factors which determine Poland's climate, an important role is played by atmospheric circulation, notably by the frequency and high variability of the inflow of different air masses. They are responsible for the transient character of the climate in the study area, and the high changeability of the weather types, even over short time periods. Moving air masses are characterised by specific physicochemical properties which develop at the time when a given air mass is formed over the source area. The boundaries which separate different air masses, that is atmospheric fronts, are characterised by abrupt changes in the meteorological elements that describe the interacting air masses. As a result, the transformation of one weather type prevailing within a given air mass into another type, one that appears with the arrival of a new mass, is usually preceded by a spell of abrupt weather changes in the area. The changes often take the form of sever and even extreme climatic events which have an adverse effect on human health and life, as well as on the human economy (KATZ & BROWN, 1992; KOZŁOWSKA-SZCZĘSNA ET AL., 1997; HUTH ET AL., 2000; CORNFORD, 2002; LLASAT-BOTIJA ET AL., 2007; BŁAŻEJCZYK & KUNERT, 2011). It is for this reason, that it is so crucial to observe climate change across the world. Studies reveal that the frequency of severe climatic events has demonstrated a clearly upward trend for several decades (IPCC, 2007), especially in higher latitudes (EASTERLING ET AL., 2000). Usually, the changes are related to changes in atmospheric circulation, in particular shifts in the location of pressure systems (BHEND, 2005; PEZZA ET AL., 2007), changes in the occurrence of high-pressure systems (DAVIS ET AL., 1997; NIGAM & CHAN, 2008; CHANG &

LU, 2012; ZARRIN ET AL., 2010), or changes in the number and tracks of low-pressure systems with associated atmospheric fronts (LECKEBUSCH & ULBRICH, 2004; TRIGO, 2006; LECKEBUSCH ET AL., 2008; BIELEC-BĄKOWSKA, 2010).

The present-day changes in circulation are also observable in Poland (MAROSZ & USTRNUL, 2010). However, research in this area includes very few studies of long-term and spatial variations in atmospheric fronts. Most studies are devoted to the passage of fronts over individual regions of Poland. Examples include papers by MICHALCZEWSKI (1960) and NIEDŹWIEDŹ (2000) who analysed the frequency of different types of weather fronts in Upper Silesia and the Silesian Upland, as well as by ZINKIEWICZ & WARAKOMSKI (1960), and MICHNA & PACZOS (1986), who conducted similar research for the Lublin area. Research in the Polish Carpathians has been conducted by NIEDŹWIEDŹ (1968), MICHNA & PACZOS (1971), as well as DĄBROWSKI & JAGUŚ (2003). The frequency and types of atmospheric fronts over Poznań were analysed in 1994 by BUCHERT, and over the area of Bydgoszcz, by WIĘCŁAW (2013, 2016). Only one paper, by PARCZEWSKI (1965), covers the entire territory of Poland, but it spans a short period of one decade (1948-1957).

The significance of atmospheric fronts is also linked to their effect on living organisms, their association with electrical discharges and contribution to elimination of air pollution. The effect on living organisms comes from sudden changes in meteorological elements (i.e. in air pressure, wind speed and direction, cloudiness and insolation, atmospheric discharges) that are experienced by humans as strong adverse stimuli associated with pains, cardiologic and respiratory conditions, restlessness and anxiety (KOZŁOWSKA-SZCZĘSNA ET AL., 1997; BŁAŻEJCZYK & KUNERT, 2011). Dangerous weather phenomena (such as strong wind, heavy precipitation, sudden and considerable changes in air temperature, thunderstorms and other convective phenomena) can cause disruption in communications and transport and considerable material damage. Atmospheric fronts also play an important role in dispersing air pollution by eliminating thermal inversions and by mechanically displacing pollution away from the area through movement of air, or from the air to the surface through precipitation (NIEDŹWIEDŹ & USTRNUL, 1989; BOKWA, 2012; STEFAN ET AL., 2010; LEŚNIOK & CAPUTA, 2009; LEŚNIOK ET AL., 2010). For this reason their occurrence has a particularly beneficial effect on industrial and urban areas.

The absence of present-day research on the variations in the occurrence of weather fronts on a countrywide scale was the reason underlying the research presented in this paper. The aim of this study is to determine both the spatial variability and long-term changes in the prevalence of atmospheric fronts over Poland in the decade 2006-2015. Particular attention is paid to the occurrence of sequences of days with different types of atmospheric fronts passing over Poland and spells without fronts.

2. Source materials and methodology

The database used in this paper was prepared on the basis of an analysis of synoptic maps of the Deutscher Wetterdienst weather service (DWD; www.wetter3.de). The maps presented synoptic situations at four times of day (00.00, 06.00, 12.00 and 18.00 UTC). The complete dataset was created by identifying the types of atmospheric fronts which were moving over selected weather stations in the outermost regions of Poland and in the centre of the country (Szczecin-Dąbie, Suwałki, Łódź-Lublinek, Legnica-Bartoszów, and Rzeszów-Jasionka) in 2006-2015 (Fig. 1).

Fig. 1. Meteorological stations used in the study

During the analysis of the synoptic situations, the following types of weather fronts were distinguished: warm fronts, cold fronts, occluded fronts, and various fronts (when more than one type of front moves over a given area during the day), as well as absence of fronts. Fronts were identified primarily for 00.00 and 12.00 UTC, with charts for the other two times used as an aid. This paper investigates both the frequency of the individual types of atmospheric front or spells with no fronts within the areas represented by the above stations, and Poland as a whole. As regards the latter, a day with a given front type or with no front is defined as such when a front was observed

within at least one of the study areas or was not recorded in any area respectively. Furthermore, the study investigates the presence of sequences of days with atmospheric fronts and series of frontless days. The identified sequences of days with or without fronts were assigned to the month when they started.

3. The occurrence of weather fronts and frontless spells in Poland

The location of Poland within an area with the movement of active low-pressure systems, as well as the transitory character of its climate, which results from the interaction between air masses inflowing from different directions, give rise to the very frequent passage of atmospheric fronts across Poland's territory. Their presence produces – often highly dynamic – changes in the weather conditions, which can sometimes take the form of extreme events.

According to previous research, which comprised different areas of the country and spanned different periods, in Poland are noted on an average of 230 days with atmospheric fronts per year (WOŚ, 1996). Depending on the part of Poland, the figure ranges from about 120 days in the south to about 200 days in the north-east (PARCZEWSKI, 1965; MICHNA & PACZOS, 1986; BUCHERT, 1994; NIEDŹWIEDŹ, 2000; DĄBROWSKI & JAGUŚ, 2003; WIĘCŁAW, 2016). Over the years included in the study (2006-2015), atmospheric fronts were recorded on an average of around 239 days per annum (Tab. 1), which is fewer than in the mid-twentieth century (1948-1957), when approximately 300 such days were recorded on average (PARCZEWSKI, 1965). The annual number of days with atmospheric fronts ranged from 218 in 2015 to 254 in 2012 and 2013.

Table 1. Average monthly and annual number of days with atmospheric fronts in Poland and at selected stations in the period 2006-2015

Station	Number of days												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Szczecin	13.2	10.7	10.9	11.9	11.5	11.5	9.5	11.7	11.0	12.1	13.7	13.6	141.3
Suwałki	12.1	9.5	11.9	10.9	12.0	10.5	10.8	10.4	9.8	11.2	14.2	13.3	136.6
Łódź	12.2	9.0	11.9	11.0	11.4	10.0	9.8	9.5	9.4	9.5	12.6	13.2	129.5
Legnica	12.8	9.4	11.1	9.9	9.9	10.5	10.0	9.5	8.8	10.0	11.6	12.7	126.2
Rzeszów	12.0	9.0	11.2	11.0	11.1	10.6	9.4	8.7	8.6	8.9	11.0	11.6	123.1
Poland	19.5	17.5	19.8	20.5	20.6	19.3	19.6	20.5	18.5	19.5	21.4	21.9	238.7

In the individual regions of Poland, the average number of days with fronts was significantly lower and ranged from 123.1 in Rzeszów to 141.3 in Szczecin (33.7-38.7% of all days in the year respectively). Here as well, the values obtained were significantly lower than fifty years ago, with the differences reaching as many as 70 days (PARCZEWSKI, 1965), even though they were close to the results determined by the other authors mentioned above (MICHNA & PACZOS, 1986; BUCHERT, 1994; NIEDŹWIEDŹ, 2000; DĄBROWSKI & JAGUŚ, 2003). Most probably, such huge discrepancies are attributable to the slightly different source material and methods of determining the number of fronts for individual regions of Poland used by PARCZEWSKI (1965).

The annual number of days with or without fronts depends to a large extent on location of given area and prevailing circulation in the region. In the multi-annual period under study, atmospheric fronts were the most frequent in November and December (21-22 days on average) and the least frequent in February and September (17.5 and 18.5 days respectively, Tab. 1). In selected regions of the country, there were instances where the annual maximum and minimum of their frequency were recorded in other months, as is exemplified by the highest average number of days with fronts in Rzeszów – observed in January (12.0 days), or the annual minimum of frequency in Szczecin – recorded in July (9.5 days, Tab. 1). The differences from one year to another were even greater, which results from the highly dynamic changes in the types of circulation and associated weather over a given area at a given time. An example is the number of days with atmospheric fronts in Szczecin during the study period (Tab. 2).

Looking at the types of weather front passing over the study areas, there is a clear, commonly known, prevalence of cold fronts, which were recorded on around 52 days per year in the north of Poland and on about 54-55 in the south and centre of the country. Warm and occluded fronts were recorded over the stations included in the

study on an average of approximately 21-33 days per year, and there were 14-23 days annually with various types of fronts passing over the sites (Fig. 2). On a countrywide scale, warm and cold fronts occurred at a similar frequency, regardless of the geographic location of a given area, while the number of days with occluded fronts and with different fronts occurring on the same day showed a noticeable declining trend towards the south. The opposite can be observed for days with no fronts, the number of which declines with an increase in latitude (from an average of 242 days in Rzeszów to 224 days in Szczecin, which means 66.3-60.9% of all days in a year respectively).

Table 2. Number of days with atmospheric fronts in Szczecin in the period 2006-2015

Year	Number of days												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
2006	7	13	7	17	10	10	7	7	9	17	17	16	137
2007	21	13	13	12	18	8	12	11	12	8	13	11	152
2008	16	13	13	11	5	10	6	19	9	14	12	13	141
2009	9	7	15	8	13	10	11	9	12	9	19	12	134
2010	5	10	11	12	11	9	8	12	9	12	14	7	120
2011	17	7	10	14	11	14	10	17	9	8	5	16	138
2012	13	12	12	9	9	15	12	11	16	19	16	15	159
2013	14	8	6	14	16	14	13	12	12	14	17	16	156
2014	13	15	10	13	9	14	3	9	13	13	7	14	133
2015	17	9	12	9	13	11	13	10	9	7	17	16	143
Average	13.2	10.7	10.9	11.9	11.5	11.5	9.5	11.7	11.0	12.1	13.7	13.6	141.3

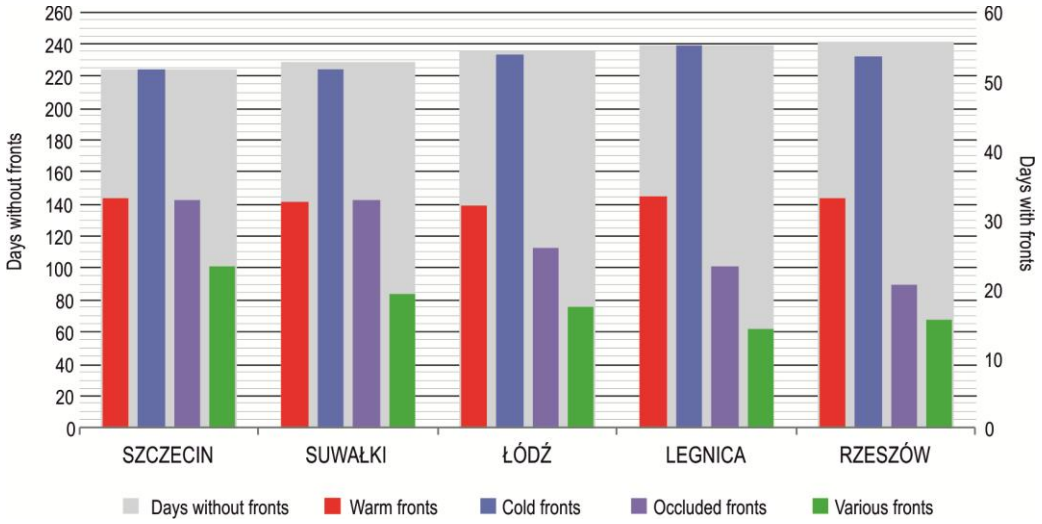

Fig. 2. Average annual number of days with particular types of atmospheric fronts at selected stations in the period 2006-2015

As in the 1948-1957 period (PARCZEWSKI, 1965), in the years 2006-2015 cold fronts were the least frequent in February – 2.5 to 3.0 days per month on average (Fig. 3A), although their frequency in the other months of the cold season was also lower than in the warm season. Cold fronts were the most frequent over Poland in spring: in April and May (from 4.5 to 5.6 days on average), but they occurred with a similar frequency in August and October (4.3-5.2 days). The difference between the average monthly number of days with a cold front from one station to another is small and ranges from 0.5 days in February and September to 1.3 days in July. It is also difficult to identify a clear trend in the annual variability of the passage of cold fronts depending on the geographical location. The southern areas of Poland stand out in some months (June and July), while the northern areas – in other months (September and November).

As mentioned above, warm fronts occur nearly half as frequently as cold fronts, and were recorded most frequently from November to January (Fig. 3B). The highest number of days with warm fronts was recorded in December and ranged from an average of 3.4 days in Szczecin to 4.4 days in Łódź. The lowest number of warm fronts moved over Poland in

February and in autumn – in September and October (1.6-3.0 days on average). As can also be observed, in the south of the country, warm fronts were recorded more frequently in the first half of the year, while in the north, in the second half.

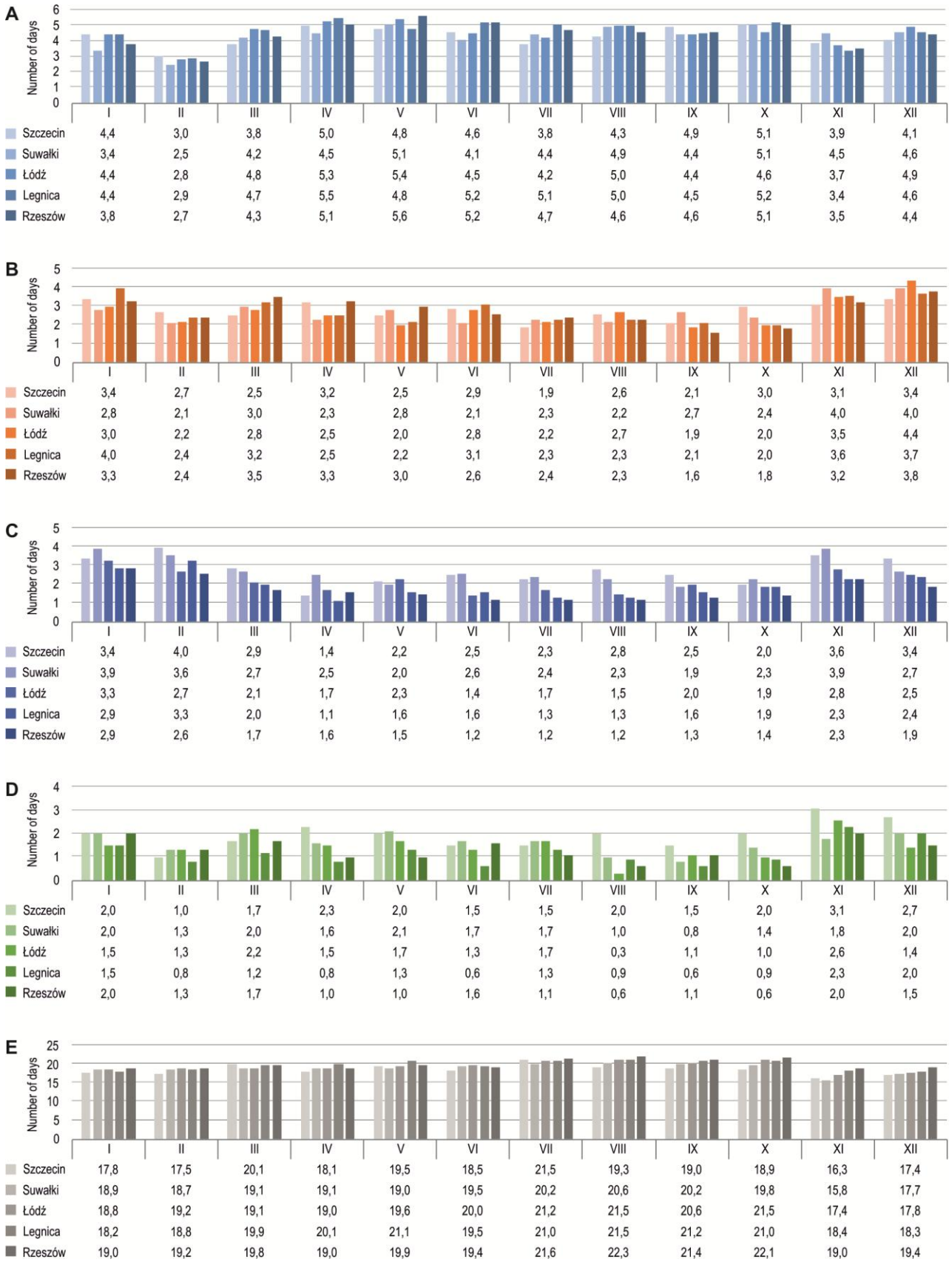

Fig. 3. Average monthly number of days with atmospheric fronts: (A) cold, (B) warm, (C) occluded, (D) various fronts and (E) days without fronts at selected stations in the period 2006-2015

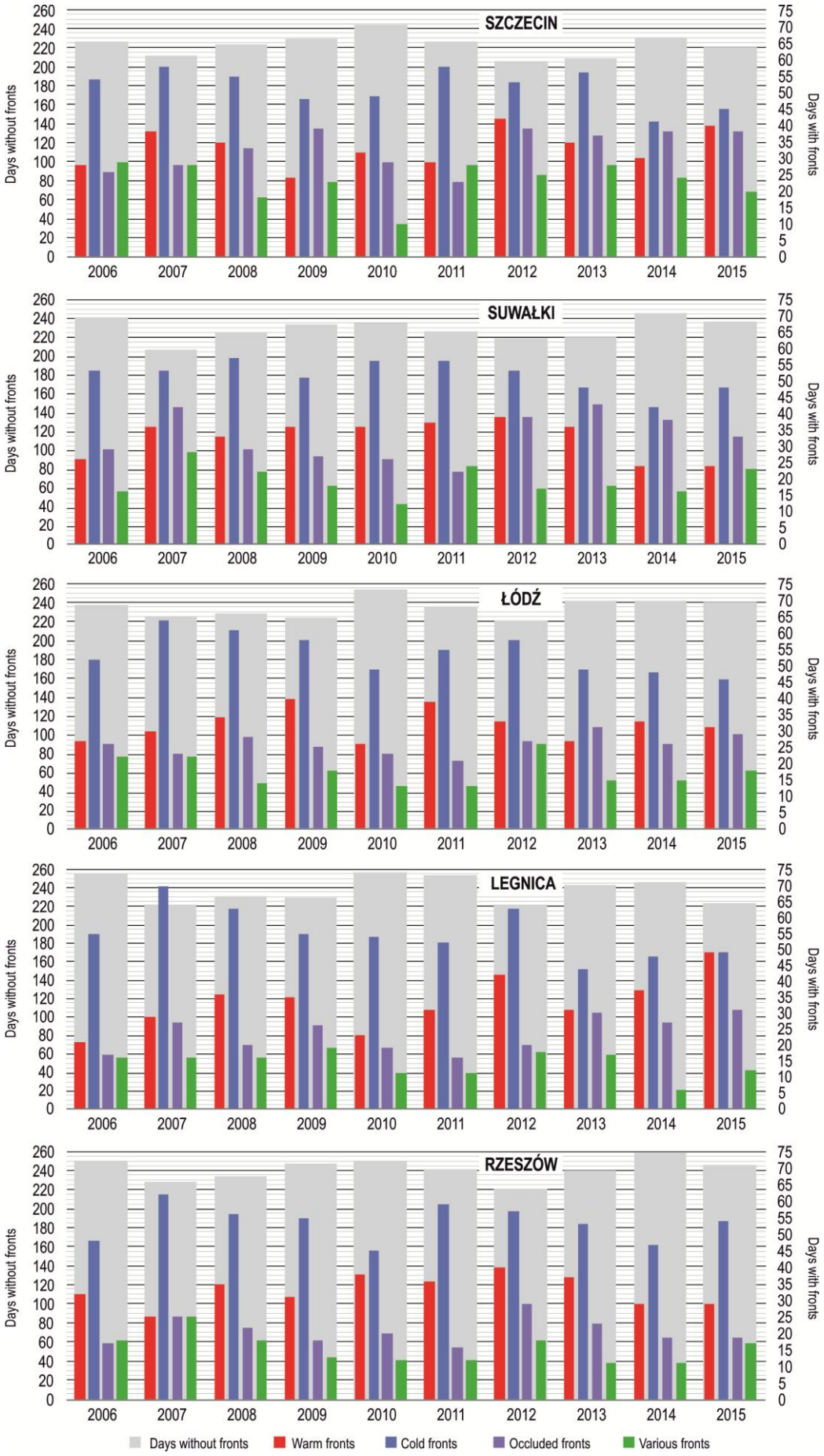

Fig. 4. Average annual number of days with particular types of atmospheric fronts at selected stations in the period 2006-2015 – inter-annual variability

A greater and more noticeable spatial variability (increased frequency in the north of Poland) can be observed for the occurrence of occluded fronts and situations where several different atmospheric fronts passed over a given area on the same day. Both occluded fronts and days with different fronts were mainly recorded in the cold season (Figs. 3C and D). For the former, this was the period between November and February (1.9-4.0 days per month on average), and for the latter – from November till January (1.4-3.1 days on average). Usually, the lowest number of days in question are seen from April to August for occluded fronts (from 1.1 to 2.8 days per month on average) and from August to October – for different front types (0.3-2.0 on average).

The least pronounced quantitative and spatial differences are seen in the context of days with no fronts (Fig. 3E). The lowest number of such days is to be expected in winter months (15.8-19.4 days on average), when intensive cyclonic activity is occurred over Poland, while the highest number is most likely in summer and autumn (18.9-22.3 days), when high-pressure systems predominate (Woś, 1996).

The long-term variability of the number of days with atmospheric fronts differed slightly from one study area to another (Fig. 4). Over the period analysed, the lowest number of days with atmospheric fronts (106-137 days per year), and consequently the highest number of days with no fronts, was recorded in 2006, 2010 and 2014 (from 228 frontless days in Szczecin /2006/ to 259 days in Rzeszów /2014/). In those years, central and southern Poland saw an exceptionally low number of fronts. In these regions, the number of days with fronts only slightly exceeded 100 per year, while in the north it did not drop below 120 days in any of the years.

The number of days with cold fronts, which are the most frequent type in Poland, ranged from 41 days in 2014 in Szczecin to 70 days in 2007 in Legnica (Fig. 4). Except for the region represented by the station in Suwałki, the fronts were recorded most frequently in 2007, with a slight decline in their frequency noticeable over the ten-year period, notably in the west and the centre of the country.

Greater variations in the annual number of days are noted for warm fronts. During the period under analysis, it ranged from 21 to 49 days per year, with the smallest or highest values recorded in different years for different regions (Fig. 4). The only noteworthy fact is a slight increase in the number of days in question in Legnica, and their much lower frequency in the east of Poland (in Suwałki and Rzeszów) over the last two years.

During the decade under study even greater differences are observable in the number of days with occluded fronts and with various types of fronts on the same day. The lowest number of days with occluded fronts was recorded in 2008-2011 (only 16 days in Legnica and Rzeszów in 2011), and the greatest towards the end of the decade under study, with Suwałki ranking first in this respect – 43 days in 2013. Days when several different atmospheric fronts passed over Poland were even less frequent, with their number ranging from 6 days in Legnica (2014) to 29 days in Szczecin (2006). At all the stations under study, there was a slight decrease in the number of such days during the first half of the study period, and a slight increase in their number later on, with Legnica being the only location where the number of days with different types of fronts showed a declining tendency towards the end of the study period.

4. Sequences of days with atmospheric fronts and front-free periods of specific duration in Poland

An interesting aspect of the climate conditions of a given area is provided by the weather dynamics associated with changes in air masses arriving over the area, along with the weather fronts which separate such masses. The occurrence of longer periods with atmospheric fronts moving continually over a study area, or longer spells with no fronts over the area, deserves special attention.

A total of 602 spells with fronts of different duration were recorded in Poland during the study period. As many as 22.6% of them were single days, and a slightly lower percentage (19.9% and 15.6% respectively) spells lasting 2 and 3 days (Fig. 5). In the individual years, the number of such sequences of days (lasting 1-3 days) varied from 4 to 20 per year. Longer uninterrupted periods were recorded less frequently. In total, sequences of up to 6 days accounted for 84.2%, and those shorter than 14 days for 98.7% of all the cases. Usually, there were few longer sequences during the year, and those lasting more than 13 days were recorded sporadically (16 times in total), and not more than once a year.

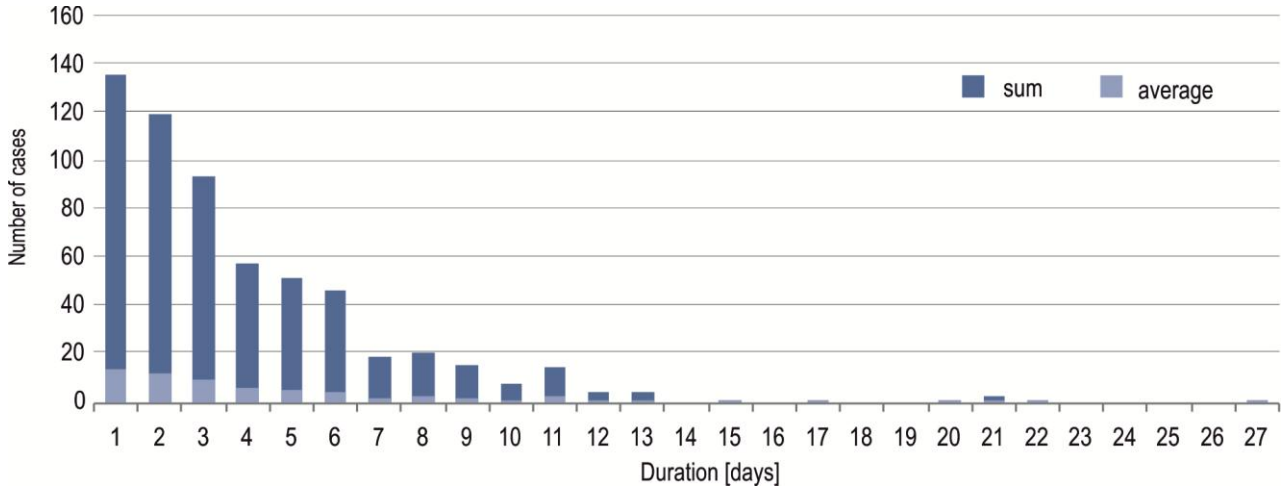

Fig. 5. Number of sequences of days with atmospheric fronts in Poland in the period 2006-2015

The annual trend in the number of uninterrupted spells in question show little variation. The only notable fact is that shorter sequences (≤4 days) were slightly more frequent in June, March and October, and those of more than 4 days were the least frequent in February and the summer: in June and July. It is also worth noting that among the 8 longest sequences (lasting 15 days or more), 6 were recorded in the period from November to January, and the remaining ones in April and June respectively. The longest sequence of days with atmospheric fronts began on 13 November 2009 and lasted 27 days. It resulted from a very strong westerly flow, which was accompanied by a series of dynamic low-pressure systems moving from the west to the east and north-east of Europe and extending over the entire territory of Poland. The pressure in the centres of the systems dropped at times to as low as 960 hPa, despite the fact that only some of the systems were moving directly over the territory of Poland, and were filling slowly at the time.

The spells with atmospheric fronts described above were typically separated by a single day without a front (51.2% of all cases; on average approximately 30 cases per year; Fig. 6). Periods of weather that did not involvle a change in air masses (i.e. non-frontal days) that lasted between 2 and 3 days occurred much less frequently (22.8% and 10.6% respectively; on average 14 and 6 cases per year). On the whole, front-free periods with four or less days accounted for 91.2% of cases in the study. Front-free periods longer than four days were typically recorded only a few times per year and the longest of these (≥7 days; 18 cases in total) occurred once, or, exceptionally, twice per year.

Similarly to short series of days with atmospheric fronts (≤4 days), spells with no fronts predominated in March, June and October, even though the year-long variations in their frequency were not significant, except for increased frequency of longer sequences of frontless days in January and February, and from July to October. The longest such spells lasted 10 days and began on 27 November 2014 as a result of a strong and extensive high-pressure system over Russia, with pressure in its centre exceeding 1035 hPa.

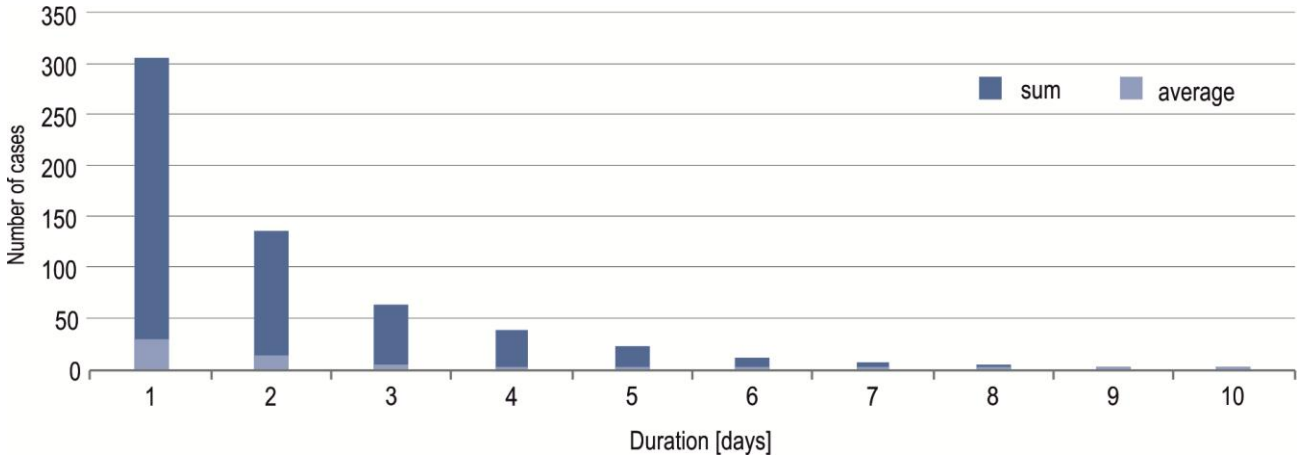

Fig. 6. Number of sequences of days without atmospheric fronts in Poland in the period 2006-2015

The frequency of sequences of days with and without fronts at the individual stations differs slightly from the countrywide results. Naturally, the differences are attributable to the size of the area for which the passage of fronts was identified and the number of fronts that moved over it (e.g. after a front passed a given station, it kept moving across Poland on the next day).

The period under study saw a predominance of isolated days with fronts, which represented approximately 55-65% of all the spells of days with fronts at each station (Fig. 7). Two-day spells with fronts were nearly three times rarer (accounting for ca. 20-24% of the cases), and three-day spells represented only approximately 7-10% of the series studied. In total, sequences of days with atmospheric fronts lasting fewer than 5 days accounted for about 96-98% of the cases analysed, while series of more than 6 days were extremely rare, with none of the stations recording more than 7 such cases in the decade under study. The longest of them was one recorded in Suwałki, which began on 9 January 2007 and lasted 15 days. It was a result of a series of deep cyclones (with the pressure in the centre dropping even below 960 hPa) moving from the west directly over Poland or over the Baltic Sea, and Scandinavia.

Comparing front-free periods across the country with those for the individual stations, one can observe a pronouncedly higher number of longer series of days with no fronts in the different regions of the country. In this context, single days account for merely ca. 34-38% of the spells with no fronts studied, while for Poland as a whole, they represented over half of the cases. Two- and three-day spells occurred with a frequency of approx. 21-24% and 13-15% of the cases while those of up to 4 days represented 79-83% in total (Fig. 8). Periods in which the stations included in the study recorded no fronts for more than 9 days were very rare, and their number ranged from 1 to several times in the study period. The longest spell without a single front was recorded in Suwałki. It started on 15 January 2014, and lasted for 22 days. The movement of atmospheric fronts over that region was blocked by a vast and very strong high-pressure system which had formed over Scandinavia and then moved to Russia and further south-east. The pressure in the centre of the system exceeded 1055 hPa, but the air temperature did not drop below -20°C.

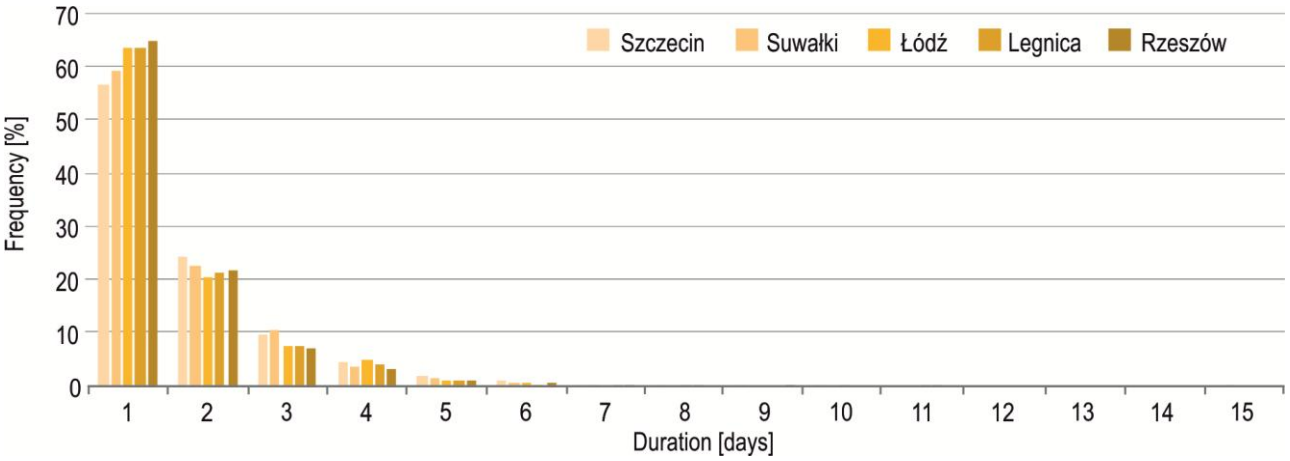

Fig. 7. Number of sequences of days with atmospheric fronts at selected stations in the period 2006-2015

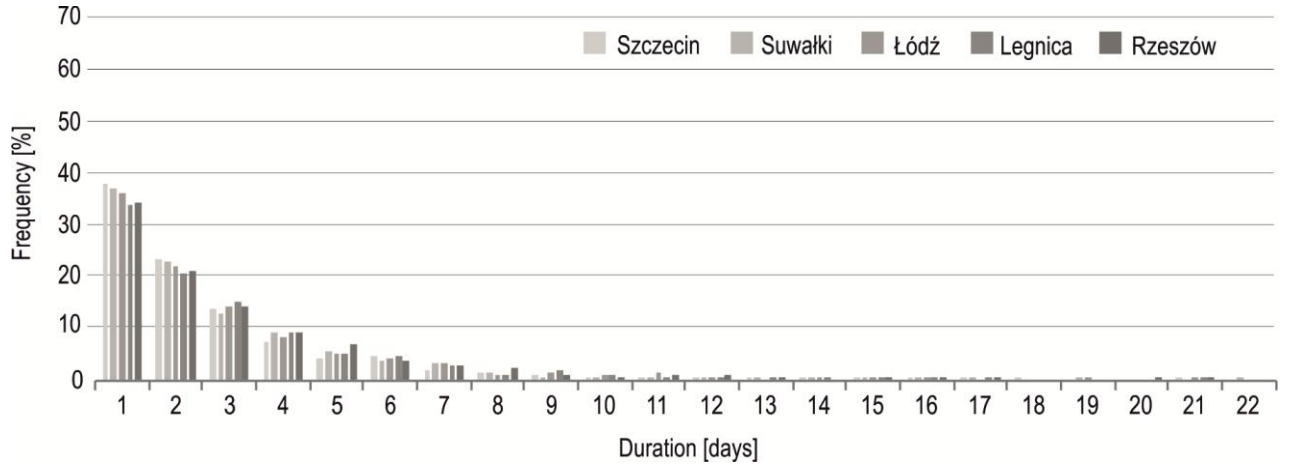

Fig. 8. Number of sequences of days without atmospheric fronts at selected stations in the period 2006-2015

When analysing the spatial variations in the occurrence of days with or without fronts, it can be observed that the southern areas of Poland can expect more isolated days with fronts than the rest of the country. At the same time, the areas experience more prolonged periods with no fronts. This is most likely associated with the greater frequency and effect of high-pressure systems in the south of Poland. By contrast, in the north the frequent moving of cyclonic systems, which is mainly observable in autumn and winter, causes an increase in the number of longer spells of days with atmospheric fronts.

5. Summary

The results of the research span a short, ten-year observation period (2006-2015) and cover, on the one hand, the whole of Poland and on the other individual areas represented by selected weather stations. In the chosen decade, the total annual number of days with atmospheric fronts across Poland was similar to that observed in the various regions of Poland and in other time periods. The only exception is revealed by a comparison with the results of a study by PARCZEWSKI (1965), which indicated a much higher frequency of atmospheric fronts in the mid-twentieth century (1948-1957).

In 2006-2015, an average of approximately 239 days with atmospheric fronts were recorded in Poland (64% of all days in a year), but in the different areas of the country under study this share ranged from around 33 to 39%. The results of the present study confirm the prevalence of cold fronts, which represent – depending on the region – about 42-45% of all the cases of days with atmospheric fronts. There were almost half the number of warm fronts (26-27%) and occluded fronts (17-27%), while days with the passage of several different types of atmospheric fronts represented merely 11-19%. The results differ slightly from those obtained for other regions and study periods, with the most pronounced differences observed for cold fronts, the share of which was usually higher than presented in this study, and amounted to 44-59%. However, the values analysed were also higher for warm fronts and occluded fronts, ranging from 30-35% and 10-22% respectively (NIEDŹWIEDŹ, 2000, DĄBROWSKI & JAGUŚ, 2003, WIĘCŁAW, 2016). Differences in the annual number of days with atmospheric fronts were also caused by the circulatory conditions prevailing in various periods. While in the years 2006-2015, most of days with fronts were recorded from November to January, other studies demonstrate their highest frequency in January and/or February (NIEDŹWIEDŹ, 2000; DĄBROWSKI & JAGUŚ, 2003). The annual minimum number of days with fronts, which was mainly recorded in February and September over the period under analysis, was observed in March or in the summer months for other regions (NIEDŹWIEDŹ, 2000; DĄBROWSKI & JAGUŚ, 2003; WIĘCŁAW, 2016).

When looking at the spatial variations in the number of days with atmospheric fronts, an increased frequency in the number of days with cold and warm fronts in southern Poland should be noted. In the northern part of the country, as a consequence of an increased frequency of passage of low-pressure systems over the region, the number of days with occluded fronts and with different types of fronts is significantly higher than in the south.

The changes in the number of days with the individual types of fronts over the decade under study were associated with the changes in atmospheric circulation over the study area in the period concerned. The most noticeable changes can be seen for days with cold fronts, the number of which declined over the ten years under consideration. The number of days with warm and occluded fronts did not reveal a distinct change trend in the decade under examination, whereas the number of days with different types of atmospheric fronts decreased in the first half of the period and increased in the years that followed.

When analysing changes in atmospheric circulation over Poland, attention was also paid to spells with atmospheric fronts moving over Poland for a number of consecutive days and to the presence of series of days with no fronts. The research presented in this study demonstrates that in both cases short sequences of days with or without atmospheric fronts predominate. In the period concerned, slightly more than 80% of the series of days with atmospheric fronts were those lasting not more than 6 days, and only less than 2% were spells continuing two weeks or longer. At the same time, in most cases, the days with atmospheric fronts were separated by single days (approx. 51% of cases) or very short (up to 4 days) spells of frontless weather (overall, more than 90% of cases). In the different areas of the country, the share of sequences of days showed certain differences compared to Poland as a whole or to other regions, but the general relationship remained similar. Usually, the longest spells with atmospheric fronts (up to 15 days) or their absence (up to 22 days) were recorded in autumn or winter. As regards days with fronts, they were associated with a series of – usually deep – low-

pressure systems moving over Poland or Scandinavia from the Atlantic eastwards or north-east. By contrast, long periods of frontless weather resulted from the effect on Poland of vast and strong high-pressure systems from Russia or Scandinavia.

References

Bhend J. 2005. *North Atlantic and European Cyclones: Their Variability and Change from 1881 to 2003*. Diplomarbeit der Philosophisch-Naturwissenschaftlichen Fakultät der Universität Bern.

Bielec-Bąkowska Z. 2010. Strong high pressure systems influencing the weather in Poland during the period 1971-2000. *Badania Fizjograficzne, Seria A - Geografia Fizyczna*, A (61): 93–107.

Błażejczyk K., Kunert A. 2011. *Bioklimatyczne uwarunkowania turystyki i rekreacji w Polsce*. 2 wyd., Monografie IGiPZ PAN, 192.

Buchert L. 1994. Występowanie mas powietrza, frontów atmosferycznych oraz układów barycznych nad Poznaniem w latach 1965–1980. *Bad. Fizjogr. nad Polską Zach., Ser. A, Geografia Fizyczna*, 45: 43–52.

Chang Ch.-P., Lu M.-M. 2012. Intraseasonal Predictability of Siberian High and East Asian Winter Monsoon and Its Interdecadal Variability. *J. Climate*, 25: 1773–1778.

Cornford S.G. 2002. Human and economic impacts of weather events in 2001. *Bull. WMO,* 51: 257–277.

Dąbrowski D., Jaguś A. 2003. Występowanie układów barycznych, mas powietrza i frontów atmosferycznych nad regionem pienińskim. *Pieniny - Przyroda i Człowiek,* 8: 53–61.

Davis R.E., Hayden B.P, Gay D.A., Phillips W.L., Jones G.V. 1997. The North Atlantic subtropical anticyclone. *J. Climate*, 10: 728–744.

Easterling D.R., Evans J.L., Groisman P.Y., Karl T.R., Kunkel K.E., Ambenje P. 2000. Observed Variability and Trends in Extreme Climate Events: A Brief Review. *Bull. Am. Meteorol. Soc*., 81, 417–425.

Huth R., Kyselý J., Pokorná L. 2000. A GCM simulation of heat waves, dry spells, and their relationships to circulation. *Climatic Change*, 46: 29–60.

IPCC 2007. In: *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Solomon S., Quin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M., Miller H.L. (eds.), Cambridge Univ. Press: Cambridge, United Kingdom and New York, NY, USA, 996.

Katz R.W., Brown B.G. 1992. Extreme Events in a Changing Climate: Variability is More Important than Average. *Climatic Change*, 21: 289–302.

Kozłowska-Szczęsna T., Błażejczyk K., Krawczyk B. 1997. *Bioklimatologia człowieka,* IGiPZ PAN, Warszawa.

Leckebusch G.C., Ulbrich U. 2004. On the relationship between cyclones and extreme windstorm events over Europe under climate change. *Global Planetary Change*, 44: 181–193.

Leckebusch G.C., Weimer A., Pinto J.G., Reyers M., Speth P. 2008. Extreme wind storms over Europe in present and future climate: a cluster analysis approach. *Meteorol. Zeitschrift*, 17: 67–82.

Llasat-Botija M., Llasat M.C., Lopez L. 2007. *Natural hazards and the press in the western Mediterranean region*. *Adv. Geosci*., 12: 81–85.

Marosz M., Ustrnul Z. 2010. Zmienność warunków cyrkulacyjnych nad Polską na tle obszaru atlantycko-europejskiego (1951–2008). Rezultaty projektu KLIMAT. [In:] Bednorz E., Kolendowicz L. (eds.) *Klimat Polski na tle klimatu Europy. Zmiany i ich konsekwencje*. Bogucki Wyd. Nauk., Poznań, 23–38.

Michalczewski J. 1960. Powtarzalność typów pogody na obszarze Górnego Śląska. *Przegl. Geofiz*., 5 (13), 3: 199-210.

Michna E., Paczos S. 1971. Częstość występowania mas powietrznych i frontów atmosferycznych nad Bieszczadami Zachodnimi. *Biul. Lub. Tow. Nauk., Ser. Geografia*, 12: 93–97.

Michna E., Paczos S. 1986. Częstość występowania mas powietrznych i frontów atmosferycznych nad Lubelszczyzną. *Biul. Lub. Tow. Nauk., Ser. Geografia,* 1, 28: 3–8.

Niedźwiedź T. 1968. Częstotliwość występowania układów barycznych, mas powietrza i frontów atmosferycznych nad polskimi Karpatami Zachodnimi. *Przegl. Geogr*., 40, 2: 473–478.

Niedźwiedź T. 2000. Częstość występowania układów barycznych, mas powietrza i frontów nad Regionem Górnośląskim. [In:] Jankowski A.T., Myga-Piątek U., Ostaficzuk S. (eds.) *Środowisko przyrodnicze regionu górnośląskiego – stan poznania, zagrożenia i ochrona.* Wydział Nauk o Ziemi Uniw. Śląskiego, Oddz. Katowicki Pol. Tow. Geogr., Sosnowiec: 71–77.

Nigam S., Chan S.C. 2008. On the Summertime Strengthening of the Northern Hemisphere Pacific Sea Level Pressure Anticyclone. *J. Climate*, 22: 1174–1192.

Parczewski W. 1965. Fronty atmosferyczne nad Polską. *Wiad. Służby Hydrol. Meteorol*., 59, 4: 20–36.

Pezza A.B., Simmondsa I., Renwickb J.A. 2007. Southern Hemisphere cyclones and anticyclones: Recent trends and links with decadal variability in the Pacific Ocean. *Int. J. Climatology*, 27: 1403–1419.

Trigo I.F. 2006. Climatology and interannual variability of storm tracks in the Euro-Atlantic sector: a comparison between ERA-40 and NCEP/NCAR reanalyses. *Climate Dynamics*, 26: 127–143.

Więcław M. 2013. Występowanie frontów atmosferycznych nad Bydgoszczą w latach 1996-2005. *J. Health Sci*., 3, 14: 21–26.

Więcław M. 2016. Występowanie mas powietrza i frontów atmosferycznych w rejonie gminy Mrocz*., J. Educ. Helath Sport*, 6, 10: 741–753.

Woś A. 1996. *Zarys klimatu Polski.* Wyd. Nauk. UAM, Poznań.

Zarrin A., Ghaemi H., Azadic M., Farajzadeh M. 2010. The spatial pattern of summertime subtropical anticyclones over Asia and Africa: A climatological review. *Int. J. Climatology*, 30: 159–173.

Zinkiewicz W., Warakomski W. 1960. Zarys klimatu Lublina. *Annales UMCS*, sec. B, 14: 47-130.

Deutscher Wetterdienst (DWD), [online], http://www.wetter3.de, [access 01.08.2017]