

HAIL OCCURRENCE IN POLAND

KATARZYNA SUWAŁA

Adam Mickiewicz University, Institute of Physical Geography and Environmental Planning, Poznań, Poland

Manuscript received: April 18, 2011

Revised version: September 2, 2011

SUWAŁA K., 2011. Hail occurrence in Poland. *Quaestiones Geographicae* 30(3), Bogucki Wydawnictwo Naukowe, Poznań, pp. 115–126, 7 Figs., 2 Tabs. ISBN 978-83-62662-75-3. ISSN 0137-477X. DOI 10.2478/v10117-011-0031-z

ABSTRACT. The main objective of this study was to present the spatial and temporal distribution of hail in Poland covering the period of 1973–2009. The analysis was based on the data for 23 meteorological stations published by The Institute of Meteorology and Water Management (1973–1980) and National Climatic Data Center (for the years 1981 to 2009). The results are presented with the maps of mean monthly and annual number of hail days, histograms of the seasonal variation of hail and trend lines in temporal variability of hail. It shows that in Poland the mean annual number of hail days varies from 1,3 near Suwałki to 10 near Hel. Most of the hail cases occurred in March, when the number of mean monthly hail days amounted almost 15. When it comes to temporal variability it is characterized by increasing tendency with the maximum at the beginning of 2000.

KEYWORDS: hail, spatial and temporal distribution, Poland

Department of Climatology, Institute of Physical Geography and Environmental Planning, Adam Mickiewicz University, Dzięgielowa 27, 61–680 Poznań, Poland, suwak@amu.edu.pl

Introduction

In recent decades, research and climatological studies put more emphasis on extreme weather events; their origin, development and, basically, the implications for life and human activity and other components of the natural environment. One of the severe weather phenomena is hail, which is considered to be one of the most complex products of water vapour condensation. Changnon *et al.* (2009) provided a comprehensive study of this phenomenon and laid stress upon how great a threat hail represents to human life and property. Hence, prediction of the location and time of hail occurrence and the factors, determining its formation seems to be the most important.

According to Woś (1999), hail is precipitation of ice pellets, partially or completely opaque,

which diameter exceeds 5 mm. Hail usually appears during storms, mostly at an air temperature above 0°C (Schmuck 1949).

Zinkiewicz & Michna (1955) distinguished four atmospheric factors that may cause hail precipitation:

- strong convective instability with strong updrafts;
- low freezing levels;
- abundant moisture at low levels of atmosphere;
- high speed and intensity of convection currents, reaching a maximum of $15\text{--}30 \text{ m} \cdot \text{s}^{-1}$.

Many scientists are particularly interested in the most intensive and hazardous form of hail, which is called a severe hailstorm. What is the most characteristic for this phenomenon is a huge production of large-sized hailstones (more than 2 cm in diameter), causing devastating damage

to crops and property (Changnon *et al.* 2009, Tuovinen & Schultz 2008).

The early research on hail in Poland, particularly on hailstorms, was carried by Schmuck (1949). Author describes the formation of hailstones within Cb cloud and analyses the theories of the origin of hailstorms. Koźmiński (1964, 1965) studied the spatial distribution, the speed and direction of hailstorms movement of hailstorms, which extend exceeded 100 km².

In studies on the occurrence of hailstorms in Finland, Tuovinen & Schultz (2008) highlighted the necessity of creating a reliable datasets of severe weather, especially severe hailstorms and hail. According to their research, hail in Finland appear mostly in the southern and western part of the country, and the period of biggest frequency of hail lasts from May/June to the early August.

Battan (1974), Waldvogel (1979), Kennedy & Detwiler (2003) in their studies were focused mainly on the formation of hailstones and location of hailstone cells, using mathematical models and radar soundings of the atmosphere.

Among the regional studies on the occurrence and frequency of hailstorms in Poland the most comprehensive are works of Koźmiński (1968), and Zinkiewicz & Michna (1955). Authors analyzed the frequency of hailstorms, direction of their movement and features of hail streaks in Lesser Polish Upland and Lublin Voivodeship. Furthermore, they put an emphasis on the influence of orography, river systems, type of landcover and soil to the geographical distribution and frequency of hail. Koźmiński (1968) claimed that a significant number of hailstorms move along the river valleys, on the contrary the forests diminish the number of cases of hail. Zinkiewicz & Michna (1955) noticed the strong relation between the frequency of this phenomenon and the relative height of land, the correlation coefficient amounting to 0.9. The maximum frequency of hailstorms is also connected with the loessy, unforested areas and a small distance from the rivers.

Hail climatology has been thoroughly studied in Europe and North America (Changnon *et al.* 2009, Kotinis-Zambakas 1988, Sioutas 2007, Zhang & Zhang 2008). One of the most complex study provided Changnon *et al.* (2009) who showed the spatial and temporal characteristic

of hail and its damages in the U.S. According to long term observations, the destruction of crops and properties involving large hail stones exceeds other catastrophic events such as floods or tornadoes. Additionally, the authors pointed out that the principal hail area in U.S. is the Rocky Mountains, where hail is both intense and frequent.

Kotinis-Zambakas (1988) separated five hail regions in Greece, concluding that hail occur mostly in the northern part of the country as a result of the influence of continental climate. A supplement to this characterization is the study of Sioutas (2007), proving that hail in northern Greece usually occurred from April to August, and thus create great damage in agriculture. The author also pointed out the role of land relief to the frequency of hailstorms.

Zhang & Zhang (2008) studied the geographical distribution of mean monthly and annual number of hail days in the Republic of China, considering the influence of land relief to the occurrence of hail in south-eastern slopes of high mountains. The start of hail season varies from January - February in the south-western part of the country, to September in northern and north-western China.

Another study on hail in China was carried by Xie *et al.* (2010), in which the authors analyzed the size of hailstones along with the frequency of strong hailstorms. According to their research shows that most hailstorms occur from February to June. They highlighted the limited link between global climate variability and the hail size, stressing that the last is caused by many complex factors such as the height of the isotherm 0°C. The issue of modelling the size of hail was also raised by Brimelow *et al.* (2002) and Kennedy & Detwiler (2003).

Among the studies dealing with the phenomenon of hail that deserves special attention are those which emphasis the influence of atmospheric circulation on the frequency of its occurrence (Bielec-Bąkowska 2010, Simeonov *et al.* 2003).

The aim of this study is to characterize the spatial and seasonal distribution of the occurrence of hail in Poland and its temporal variability, designate the areas of highest frequency of hail and formulate the assumptions of its origin.

Data collection and analysis methods

the study area was chosen, mainly due to the small number of studies of this phenomenon in Poland in the last 50 years. This analysis was based on the information of the number of hail days in each month of the year, collected for 23 stations in years 1973–2009 (Fig. 1). Data were obtained from the Meteorological Yearbooks for the years 1973–1980, published by the Institute of Meteorology and Water Management and the database of National Climatic Data Centre (for the years 1981 to 2009). Unfortunately, most of the observation series were incomplete, therefore, 8% of all collected data are missing.

For each station the mean monthly number of hail days was calculated, and presented on contour maps. Additionally, the seasonal and temporal variation of hail occurrence was presented on diagrams.

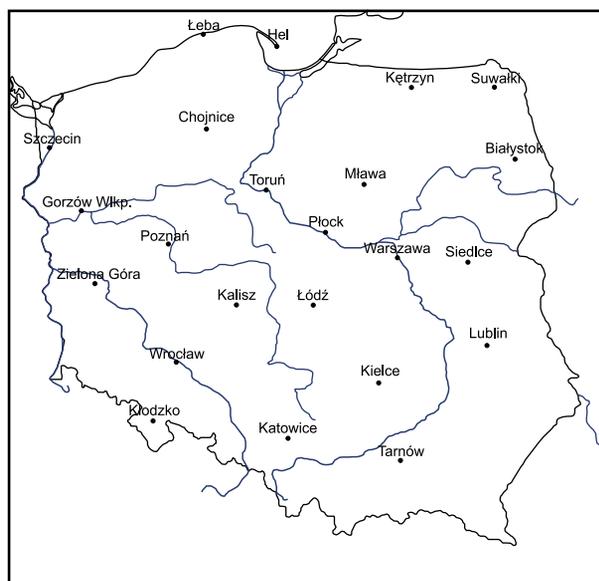


Fig. 1. Distribution of the 23 stations in Poland used in the analysis..

Results

Geographical distribution of hail frequency

Figure 2 and Table 1 show the average annual number of days with hail in Poland in the years 1973–2009.

There are big differences in frequency of hail in northern and southern parts of the country.

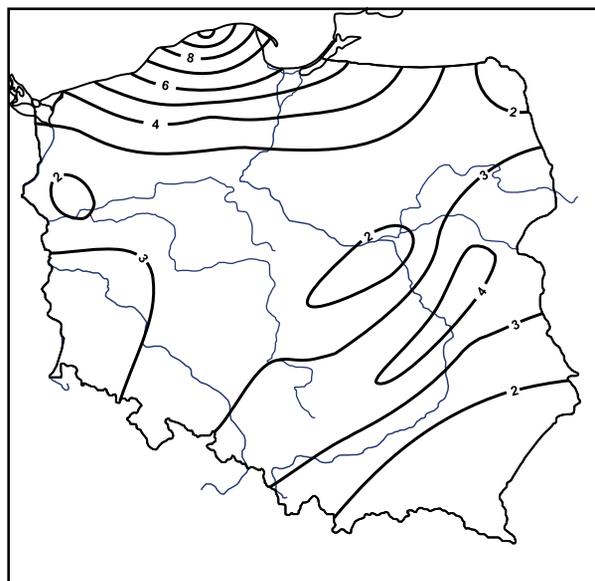


Fig. 2. The geographical distribution of mean annual hail frequency during 1973–2009.

The central part of Baltic coast, represented by meteorological stations in Łeba and Hel, is an area of the highest frequency of hail. In this region, hail appeared over 6 days in a year (Hel) on the average. The highest mean frequency amounted to about 10 days and it occurred in Łeba. The second area with the highest frequency of this phenomenon is between Siedlce and Malopolska Uplands, where the average annual number of days with hail was about 4.

Regions of the lowest hail frequency (less than 2 days) are scattered over the whole territory of Poland. They represent:

- part of the Mazovian Lowland between Warsaw and Łódź,
- Suwałki Lake District,
- the surroundings of Gorzów Wielkopolski and Lakeland Myślibórz,
- the area near Tarnów.

In the central part of Poland hail was observed less than 3 days per year, which is shown on the map of the average annual frequency of hail (Fig. 2).

Furthermore, the months in which hail occurred very often and the months, in which hail hardly appeared were distinguished for every station (Tab. 1).

Due to extremely local and irregular character of the described phenomenon, the maximum number of days with hail was analysed and shown in Table 2. It follows that despite hail being rare, sometimes it appears few times a month.

Table 1. Mean monthly and annual number of days with hail (years 1973–2009) (based on NCDC data).

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	ROK
Białystok	0.30	0.41	0.65	0.46	0.19	0.11	0.03	0.03	0.03	0.22	0.27	0.43	3.11
Chojnice	0.43	0.46	0.76	0.78	0.16	0.03	0.03	0.00	0.05	0.14	0.22	0.24	3.30
Gorzów Wlkp.	0.16	0.46	0.46	0.30	0.08	0.03	0.03	0.00	0.03	0.00	0.19	0.19	1.92
Hel	1.00	0.76	0.92	0.43	0.03	0.00	0.05	0.00	0.03	0.43	1.32	1.41	6.38
Kalisz	0.19	0.35	0.57	0.30	0.16	0.08	0.03	0.00	0.00	0.11	0.14	0.19	2.11
Katowice	0.68	0.68	0.76	0.30	0.05	0.05	0.03	0.03	0.00	0.03	0.35	0.46	3.40
Kętrzyn	0.24	0.49	0.95	0.62	0.16	0.05	0.08	0.03	0.08	0.35	0.43	0.38	3.86
Kielce	0.65	0.49	0.92	0.43	0.22	0.05	0.05	0.03	0.00	0.05	0.41	0.73	4.03
Kłodzko	0.57	0.54	0.57	0.35	0.16	0.05	0.03	0.05	0.03	0.11	0.27	0.24	2.97
Lublin	0.38	0.38	0.76	0.43	0.08	0.03	0.08	0.00	0.00	0.11	0.24	0.35	2.84
Łeba	1.89	1.24	1.19	0.76	0.08	0.03	0.08	0.00	0.05	0.73	2.30	2.05	10.40
Łódź	0.22	0.38	0.51	0.35	0.16	0.05	0.03	0.00	0.05	0.03	0.16	0.05	2.00
Mława	0.22	0.43	0.38	0.43	0.19	0.05	0.00	0.03	0.00	0.08	0.30	0.19	2.30
Płock	0.19	0.46	0.57	0.54	0.08	0.03	0.08	0.00	0.00	0.08	0.22	0.24	2.49
Poznań	0.27	0.27	0.57	0.54	0.14	0.03	0.03	0.19	0.05	0.05	0.27	0.38	2.78
Siedlce	0.84	0.95	0.68	0.54	0.03	0.00	0.00	0.05	0.03	0.24	0.65	0.62	4.62
Suwałki	0.08	0.22	0.27	0.30	0.08	0.00	0.05	0.00	0.00	0.03	0.14	0.14	1.30
Szczecin	0.14	0.46	0.57	0.38	0.14	0.00	0.05	0.03	0.00	0.08	0.14	0.22	2.19
Tarnów	0.35	0.14	0.38	0.30	0.08	0.03	0.03	0.05	0.00	0.11	0.19	0.14	1.78
Toruń	0.14	0.30	0.65	0.35	0.11	0.05	0.03	0.03	0.00	0.11	0.19	0.14	2.08
Warszawa	0.16	0.24	0.22	0.16	0.08	0.11	0.14	0.03	0.03	0.08	0.11	0.22	1.57
Wrocław	0.38	0.22	0.49	0.22	0.14	0.08	0.08	0.00	0.00	0.05	0.38	0.41	2.43
Zielona Góra	0.62	0.68	0.70	0.62	0.35	0.05	0.03	0.03	0.00	0.05	0.49	0.27	3.89

The lowest maximum monthly number of days with hail (lower than 2 days), occurred from June to September. In the remaining months hail was reported more often. The most distinctive in this regard is January, November and December, in which the maximum number of days with hail was respectively 7, 8 and 8 days. They relate to coastal stations Łeba and Hel, where the rainfall was recorded most frequently.

Siedlce also belongs to the stations with a high frequency of occurrence of hail (Tab. 1) and high value of the maximum monthly number of days with this phenomenon. During the most "hail" months, from January to April and from November to December, this kind of precipitation occurred about 4 times a month.

March is the month, in which hail occurred most often. The maximum number of days with hail amounted to 6 in Katowice and Zielona Gora. In other stations hail appeared at least

twice a month, and in most of the stations (14) at least four times a month. However, in June and September hail was recorded up to once a month, and in large number of stations, this phenomenon did not occur.

Considering the frequency of occurrence of hail in Poland in particular months of the year, it can be observed that the maximum values usually appear in the coastal part of the country between Łeba and Hel as well as in Siedlce in the central part of the country. Other areas are characterized by a greater variation of the appearance of this phenomenon (Tab. 1).

The spatial distribution of the average number of days with precipitation of hail in January (Fig. 3) is characterized by a system of belts. The area from Szczecin through Great Poland Lakeland, the northern part of the Mazovian Lowland to the Masurian Lakeland and Suwałki Lake District has a minimum value of the average number of hail

Table 2. The maximum monthly number of hail days in 1973–2009 (based on NCDC data).

Station	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Białystok	2	3	3	3	1	1	1	1	1	2	2	4
Chojnice	2	3	4	2	2	1	1	0	1	1	2	3
Gorzów Wlkp.	2	3	4	2	2	1	1	0	1	0	2	2
Hel	7	4	4	4	1	0	1	0	1	3	7	6
Kalisz	2	3	4	6	1	1	1	0	0	1	1	2
Katowice	3	4	6	2	1	1	1	1	0	1	3	2
Kętrzyn	2	2	5	4	2	1	1	1	1	2	3	2
Kielce	6	3	5	2	2	1	1	1	0	1	2	3
Kłodzko	5	4	3	3	2	1	1	1	1	1	3	3
Lublin	2	4	4	2	2	1	1	0	0	1	2	2
Łeba	6	6	5	5	1	1	2	0	1	4	8	8
Łódź	2	2	4	3	3	1	1	0	1	1	1	1
Mława	3	3	2	4	2	1	0	1	0	1	3	2
Płock	2	3	2	2	1	1	1	0	0	1	3	3
Poznań	3	3	2	4	1	1	1	2	1	1	2	3
Siedlce	4	4	4	4	1	0	0	1	1	2	4	3
Suwałki	1	1	2	3	2	0	2	0	0	1	1	1
Szczecin	1	3	4	3	1	0	1	1	0	2	1	3
Tarnów	5	3	3	2	1	1	1	1	0	1	2	2
Toruń	2	4	4	2	1	1	1	1	0	1	1	1
Warszawa	1	3	2	2	1	1	1	1	1	1	2	3
Wrocław	1	2	2	2	1	1	1	0	0	1	2	4
Zielona Góra	6	4	6	5	2	1	1	1	0	1	3	3

days (about 0.2 days). The values are increasing to the north, where in Łeba and Hel they exceed 1 day of hail. The maximum rate (1.8 day) was observed in Łeba. The remaining area (to the south of the lowlands) is characterized by an average of over 0.5 days with hail, especially in the area of Zielona Góra and the Lesser Polish Upland.

In February hail occurred with similar frequency as in January (Fig. 3). The lowest values (less than 0.4 day) are related to the area of Great Poland Lakeland and Mazovian Lowland, but also to the Silesian Lowland and southeast parts of the country. A minimum of 0.1 days (Tab. 1.) was reported in Tarnów. The hail was most common (more than 0.6 day) in the region of Katowice, Zielona Góra, Siedlce and on the coast with the maximum frequency of 1.2 days in Łeba (Tab. 1).

March is characterized by a greater homogeneity in terms of incidence of hail than the previous months. The mean monthly number of hail days

varies from 0.2 days in Warsaw, to 1.2 days in Łeba (Fig. 3). Over 0.6 day with hail was reported in Zielona Góra, Pomeranian Lake District and the Malopolska Upland and in Lublin. The average frequency of hail occurrence, computed for the whole country, amounts to 0.6 day, which is the highest value of all months (Tab. 1).

April is the month with much less spatial diversity of hail frequency. This phenomenon occurred the least often in the southern part of the country (less than 0.4) and in Warsaw, with a minimum rate of 0.16 day (Tab. 1). The area of the highest average number of days with hail includes the stations Łeba and Hel, reaching nearly 0.8 days (Fig. 3). Since April, the frequency of hail is clearly decreasing.

May is the last month of the warm half of the year in which hail had been reported more than 0.1 day (Fig. 3). The maximum number of about 0.4 days (Tab. 1) was recorded in Zielona Góra.

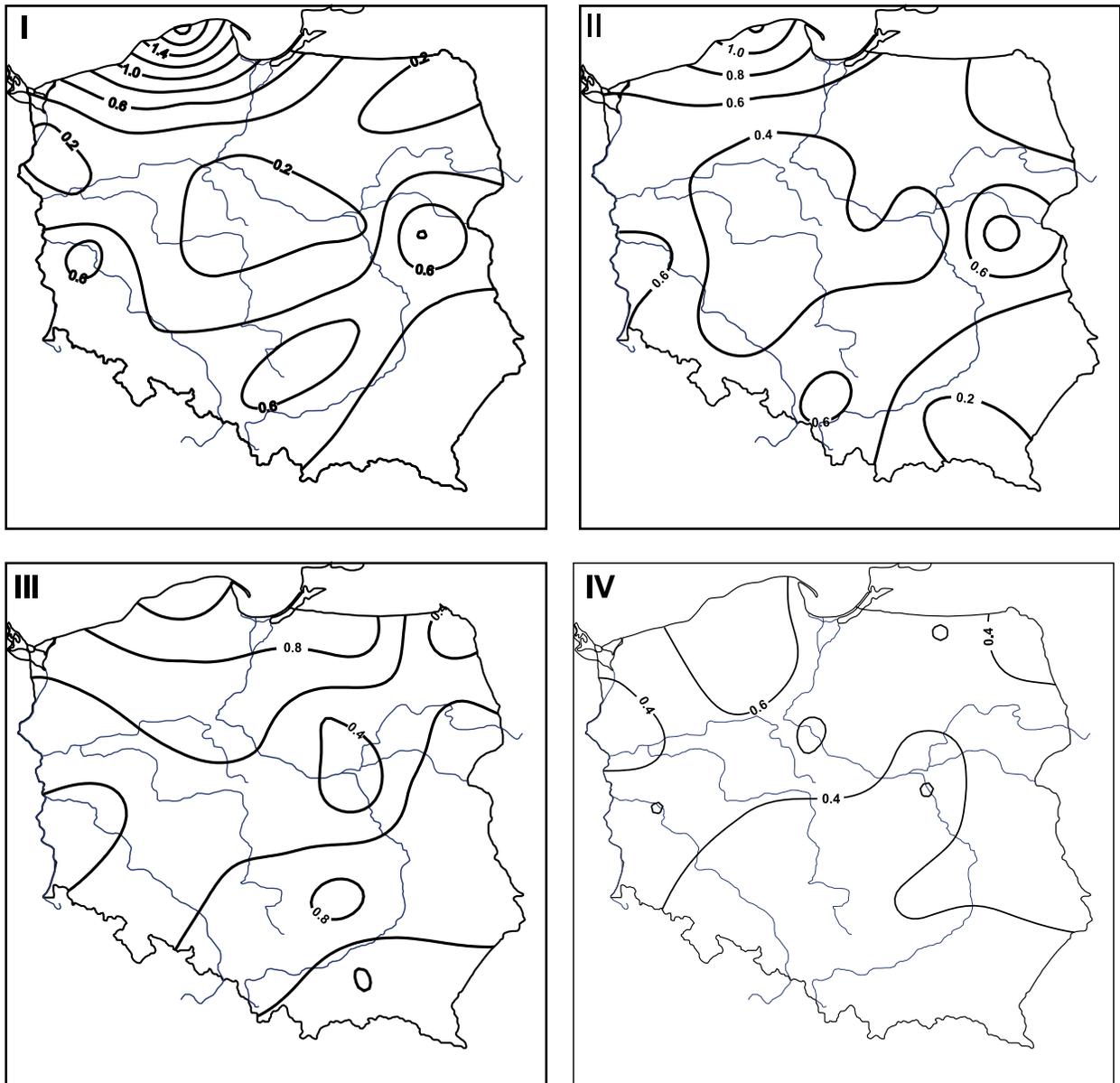


Fig. 3. The geographical distribution of mean monthly hail frequency during 1973–2009 in selected months (I–V and X–XII).

From June to September hail almost did not occur, so the average number of days with this phenomenon does not exceed 0.1 days (Tab. 1). The only exception is Poznan, where in August, the frequency of hailstorms reached 0.18 day.

The increase of the mean monthly number of hail days was observed from October to December (Fig. 3). At the beginning of this period, the highest frequency of hail related to Hel and Łeba with a maximum of more than 0.7 days (Tab. 1), as well as in the area of Siedlce and Białystok (over 0.2 days). Outside of this area hail hardly appeared (on average 0.1 days).

The map of hail frequency in November (Fig. 3) reveals large disproportions between the northern and southern parts of Poland. In this case values vary from less than 0.2 days in the central part of the country, the Suwałki Lakeland and Podkarpacie to 2.3 day in Łeba (Tab. 1), which is the maximum average value during the year.

The last month of the year is also characterized by a large spatial variability of hail frequency, although not as significant as in November. The mean monthly number of hail days range from 0.1 to almost 2.1 (Tab. 1). The smallest average number of days with hail is noted in the central

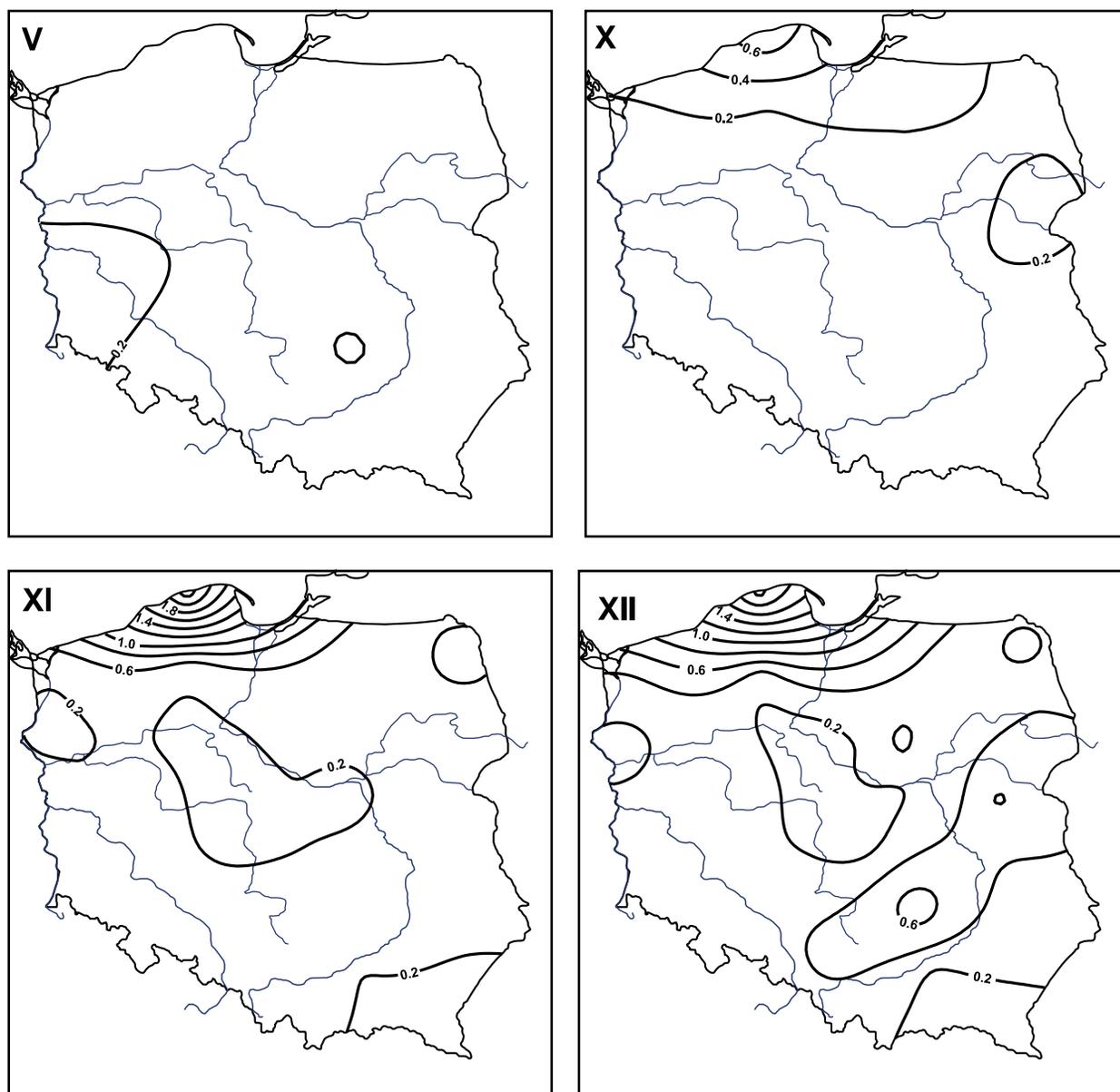


Fig. 3. cont.

and south-eastern Poland, Suwałki and Gorzów Wielkopolski. Between the Małopolska and Lublin Upland average number of days with hail exceeded 0.4, with the maximum in Kielce (0.7 days) (Tab. 1). In the northern part of Poland the highest values range from 0.4 to 2.1 days, with a maximum in Łeba (Fig. 3).

Seasonal variation of hail occurrence

Figure 4 and 5 present histograms of the annual mean monthly hail days totals for the whole

country (Fig. 4) and in selected stations (Fig. 5), which were chosen due to a different course of the frequency of hail per year.

As shown in Figure 4, the highest value of mean annual number of cases of hail in entire Poland appeared in March – more than 14 instances. Broadly speaking, hail in Poland occurred most often in January, February, March, April, November and December (about 9 cases). In May and October hail occurred with a frequency of about 3 instances per year. The minimum (less than 2 cases) was noted in summer months from June to September.

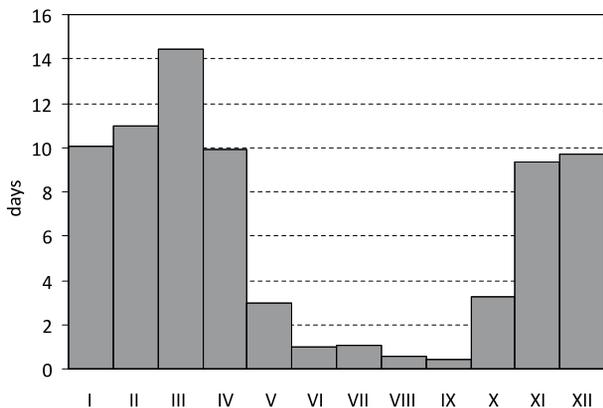


Fig. 4. The annual course of mean monthly hail days during 1973-2009,

The stations in Figure 5 were chosen according to the variable annual course of hail frequency.

Siedlce is characterized by a significant disproportion of hail occurrence between the cool and warm season (Fig. 5). Maximum occurs in February, when the mean number of days with hail reaches almost 1. This kind of precipitation appeared from January to April and from November to December. Minimum values exceeded 0.1 day and were recorded in the warmest months of the year.

In Szczecin hail appeared in March (nearly 0.6 days with hail). Months, in which hail occurs

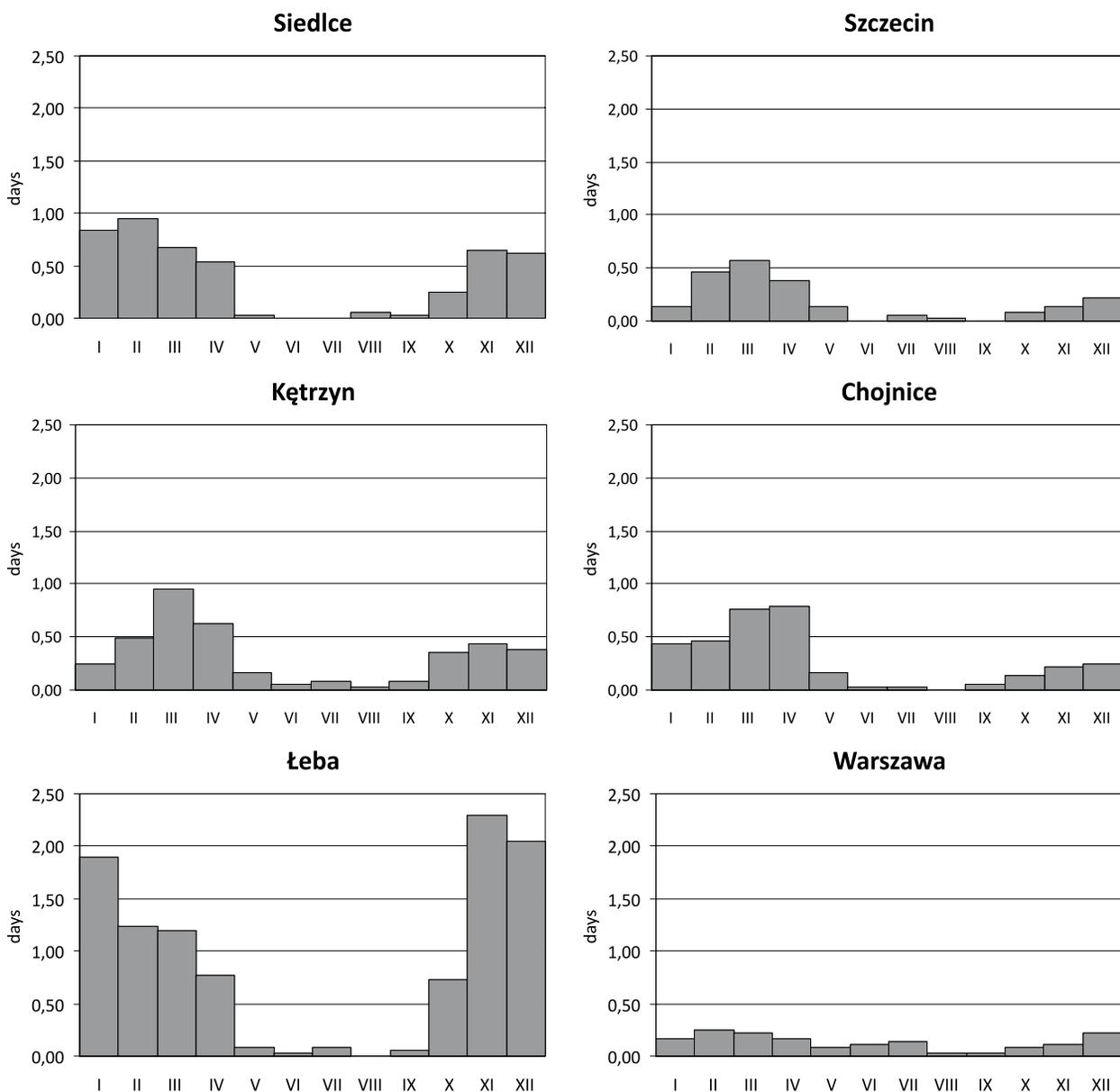


Fig. 5. The mean annual monthly hail days during 1973-2009 in selected station.

most frequently are February, March and April (0.5 days), meanwhile the lowest frequency of hail (less than 0.3 days) was recorded in the rest of the year (Fig. 5).

A hail peak month in Kętrzyn is March (almost 1 day with hail). Similarly to Szczecin, hail usually appears from February to April. In the remaining months of the year hail was rare and did not exceed the values greater than 0.2 days (Fig. 5). However, considering the summer months it can be noted that hail occurred more often in Kętrzyn than in other stations.

Chojnice represents the spring type of hail occurrence, which takes place in March and April (Fig. 5). The highest number of mean monthly hail days in this case is about 0.8. In the remaining months, hail occurred less than 0.4 day per month, and during the year does not exceed the higher value than 0.1.

In Łeba the highest frequency of hail occurred in November, December and January. The maximum value of 2.3 day was recorded in November, and during five months of the year (I-II, XI-XII) hail frequency exceeded 1 day (Fig. 5). A clear minimum of hail frequency appeared in the summer months, where hail occurred less than 0.2 days per month. Thus, Łeba can be described as the station with the greatest amplitude hail incidence – 2.1 days.

Finally, Warsaw is the station with the smallest differentiation between the highest and lowest hail frequencies. In addition, there were recorded the lowest values among all selected stations. A clear maximum cannot be pointed, as the values during the year ranged from 0.25 to 0.1 days (Fig. 5).

Summing up, in selected stations hail occurred most frequently in winter and spring months, while in summer this phenomenon was rare.

Temporal variability of hail

Figures 6 and 7 display the annual number of hail days with linear trends for the 1973–2009 period. This revealed some marked differences across the country.

Analysing the timing of the highest and lowest values of hail occurrence in Poland and six selected stations, it can be noticed that the tem-

poral variability of hail is greatly skewed. Figure 6 shows remarkable increase in the number of hail days across the nation between 1973 and 2009. The analysed 37-year period of time can be divided into four cycles of maximum and minimum number of hail days. The first cycle with the peak in 1973 lasted till 1979 when the number of hail days decreased from 85 to 24. The second cycle started in 1980 piling up to 85 days with hail in 1981, after which it declined reaching the lowest value (23 days). The third cycle peaked in 1995 with the value of 100 days with hail. The last cycle with the highest values lasted from 1999 to 2006. In this period of time the peak values reached 162. During last three years the number of hail days rapidly decreased.

Figure 7 presents the annual number of hail days during the 1973–2009 period for six previously analysed stations, each of them representing a different hail seasonal and annual characteristics. The distribution in Siedlce (Fig. 7) shows a gradual increase in the number of hail days from about 1990 to 2001 with a peak values in 1995 and 2001. Szczecin (Fig. 7) represents small variability in the number of hail days, but with a slowly increasing tendency within the analysed period of time. The highest values occurred between 1999 and 2006, with peak values, amounting 6 days, in 2002 and 2004. Kętrzyn distribution (Fig. 7), peaked in the early 1990s and then gradually decreased to lower values in the late 1990s and 2000s with a flat time trend. Chojnice values (Fig. 7) are similar to Szczecin's, but with more visible peak between 2000 and 2005 reaching 10 days with hail in 2002. The lowest values account for the 1970s and early 1980s. Łeba distribution (Fig. 7), typical of the coastal area of highest hail incidences in Poland, is the most variable among all stations. It shows an increasing tendency with

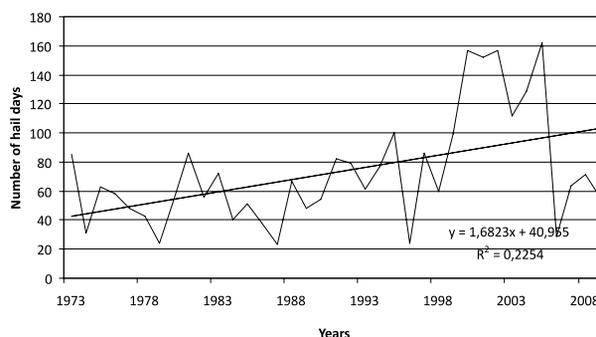


Fig. 6. Annual number of hail days in Poland for 1973–2009.

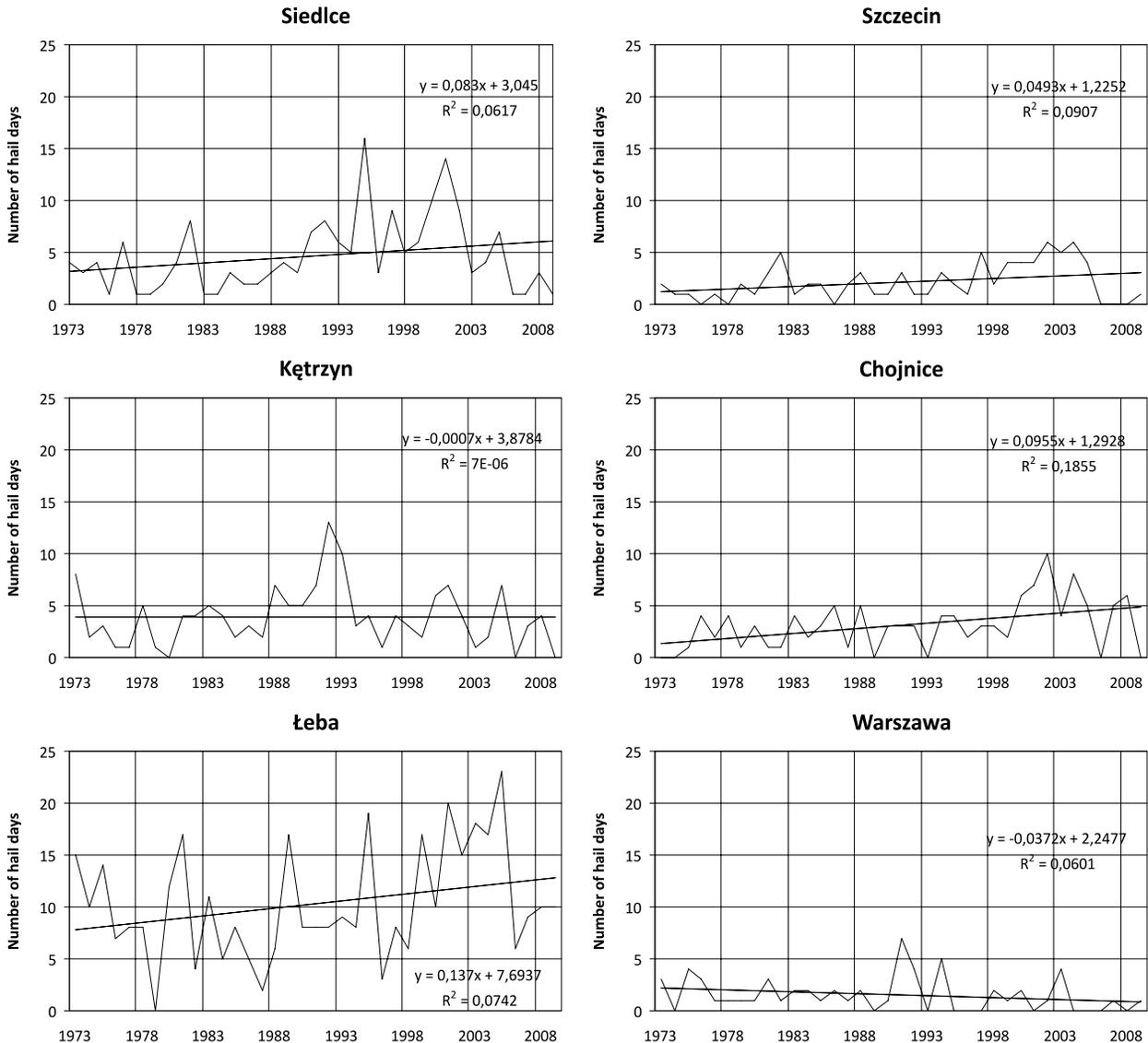


Fig. 7. The number of hail days during 1973–2009 period for six stations in Poland.

highest values from 1999 to 2006 and peaks in 2001 and 2005. The lowest values of hail days occurred from 1983 to 1989 and between 1995 and 1998. Hail did not occur in 1979. Warsaw (Fig. 7) represents the decreasing tendency in occurrence of hail with the smallest values of hail days within all six stations. During the 37-year period of time hail did not occur 11 times. Hail peak year was in 1991 when the number of hail days reached 7.

Summary

The greatest obstacle in analyzing the phenomenon of hailstorms, both in terms of geographical

and seasonal distribution, is its local and transitory character. What makes matters worse is the low density of surface meteorological observational network and lack of individual storm spotters. In such conditions, many occurrences of hail certainly have not been reported. Nevertheless, the undertaken research led to some conclusions about the spatial and seasonal characteristics of hail in Poland.

According to the great temporal variation of hail, the attempts were made to determine the months, in which hail appeared most and least frequently during the year. However, the attempts to carry out a regionalisation of hail seasonal distribution, similar to Zhang & Zhang

(2008) and Changnon *et al.* (2009), came out as unavailing. Yet, it was possible to separate a few stations with similar characteristics of hail frequency distribution, as illustrated in the histograms in Figure 5.

Summarising, the mean annual geographical distribution of hail frequency and seasonal variation of hail occurrences can be concluded as follows:

1. Hail in Poland is most common in stations Łeba and Hel, the values of which differ significantly from the situation in other parts of the country. Similar observations were made by Tuovinen & Schultz (2009), whose study shows that in Finland hail most frequently occurred in the south-western part of the country. This suggests a link between the frequency of hail and the movement of low pressure systems around the Baltic Sea (Woś 2010). Such a situation fosters intensive processes of frontogenesis, which in 60% of cases favours the occurrence of hailstorms (Bielec-Bąkowska 2010).

In this region the maximum average number of haildays is 2.3, which is the largest value during 1973–2009 for the entire country. The maximum number of days with this phenomenon in a given month is 8 and it was recorded in November in Łeba. For comparison, Kozminski (1964) says that the maximum frequency of hailstorms in Poland (for the years 1946–1956) was 9.0 (July). In terms of seasonal distribution, Pomerania region is characterized by the prevailing rainfall in November, December and January, which can be related to barometric situation, described by Woś (2010), as the western cyclonic. It fosters the movement of water fronts and may cause an increase in temperature in winter up to 10°C. Winter hail appears also on the south-western coasts of Northern America and in the Colorado Plateau (Changnon *et al.* 2009).

2. In several cases, a high frequency of hail appeared in Siedlce. The maximum number of days with hail during a month is 4 and it was observed from January to March and in November. This shows the prevalence of hail occurrence in spring. The largest value of the average number of days with hail in Siedlce is 0.95 and it appeared in February.

3. The lowest frequency of hail is noted in the middle of Poland. The mean annual number of hail days is between 2 or 3 days.
4. The month in which hail occurs most often in the years 1973–2009, is definitely March, followed by February, January and April. The same month shows Zhang & Zhang (2008) for the area of south-western China and Kotinis-Zambakas (1988) in the area of Central Greece. However, most of the studies indicate that June, July and August, are the months with the highest frequency of hail (Tuovinen & Schultz 2007, 2008, 2009).
5. Within the 37-years period of observations the frequency of hail in Poland represents the increasing tendency with the highest values of hail days at the beginning of 2000 (except for Warsaw with a downward trend line).
6. The temporal variability of hail is greater in Łeba and Siedlce which highlights the dissimilarity of these stations to other parts of the nation.

Comparing the results obtained in this study with the results of Koźmiński (1964, 1968), Tuovinen (2008), *et al.*, a large discrepancy can be easily noticed, as most of these studies show that hail occurred mostly in the months from May to August. Quite contrary, this study shows that during the years 1973–2009 warm months (from May to August) were characterized by the lowest frequency of this phenomenon, with the value of the average number of days with hail, not exceeding 0.35 (Zielona Góra) in May. In the three summer months, the average number of days with hail was about 0.1, and in many stations it did not occur.

Many authors put emphasis on the impact of orography, the river systems, the type of land-cover and soil to the occurrence of hailstorms (including Kozminski 1964, 1965, 1968; Zinkiewicz & Michna 1995). Similar observations were made by Zhang & Zhang (2007), Kotinis-Zambakas (1988) and Sioutas (2007). In China the highest frequency of hail occurrence relates to the central part of the Tibetan Plateau and in Greece, to the mountainous northern part.

In conclusion, it should be emphasized that the previous hail climatology, especially for Poland, was rarely discussed and based on the observations from 1946 to 1970. Therefore it is necessary

to supplement the available literature with further attempts, to find relationship between this type of precipitation and other components of the environment. There is a significant lack of studies on temporal variability of this phenomenon and the impact of atmospheric circulation on the occurrence of hail, as it is very interesting issue, which certainly leaves a vast field for further research (Bielec-Bąkowska 2010, Simeonov 2003).

References

- BATTAN L., 1974. Doppler radar observations of hailstorm. *Journal of Applied Meteorology* 14: 98–108.
- BIELEC-BĄKOWSKA Z., 2010. Występowanie gradu w Polsce w świetle cyrkulacji atmosfery w latach 1966–2006. *Woda w badaniach geograficznych*: 359–374.
- BRIMELOW J.C., REUTER G.W. & POOLMAN E.R., 2002. Modelling Maximum Hail Size in Alberta Thunderstorms. *Weather and Forecasting* 17: 1048–1062.
- CHANGNON S.A., CHANGNON D. & HILBERG S.D., 2009. *Hailstorms across the nation. An atlas about hail and its damages*. Illinois State Water Survey. Report 2009–12: 1–92
- KENNEDY P. & DETWILER A., 2003. A Case Study of the Origin of Hail in a Multicell Thunderstorm Using In Situ Aircraft and Polarimetric Radar Data. *Journal of Applied Meteorology* 42: 1679–1690.
- KOTINIS-ZAMBAKAS S.R., 1988. Average spatial patterns of hail days in Greece. *Journal of Climate* 2: 508–511.
- KOŹMIŃSKI C., 1964. Geograficzne rozmieszczenie większych burz gradowych zanotowanych na obszarze Polski w latach 1946–1956. *Przegl. Geogr.* 36 (1): 87–102.
- KOŹMIŃSKI C., 1965. Próba wydzielenia obszarów źródłowych tworzenia się termicznych burz gradowych na terenie woj. kieleckiego. *Przegl. Geogr.* 37(3): 521–532.
- KOŹMIŃSKI C., 1968. *Studia nad opadami gradu i wyrządzanymi przez nie szkodami w zbożach na terenie Wyżyny Małopolskiej*. Wyższa Szkoła Rolnicza, Szczecin, Rozprawy, 8: 1–65.
- PAUL A., 1980. Hailstorms in southern Saskatchewan. *Journal of Applied Meteorology* 19: 305–314.
- Roczniki Meteorologiczne, 1973–1980*. IMGW, Warszawa.
- SCHMUCK A., 1949. Burze gradowe. *Czas. Geogr.* 20(1–4): 260–267.
- SIMEONOV P. & GEORGIEV C.G., 2003. Severe wind/hail storms over Bulgaria in 1999–2001 period: synoptic- and meso-scale factors for generation. *Atmospheric Research* 67: 629–643.
- SIOUTAS M.V., 2009. Hail frequency and intensity in northern Greece. *Atmospheric Research* 93: 526–533.
- TUOVINEN J. & SCHULTZ D., 2008. Climatology of Severe Hail in Finland: 1930–2006. *Monthly Weather Review* 137: 2238–2249.
- TUOVINEN J. & SCHULTZ D., 2009. Building a database of severe weather phenomena: Severe hail in Finland. *5th European Conference on Severe Storms*.
- WALDVOGEL A., 1979. Criteria for the detection of hail cells. *Journal of Applied Meteorology* 18: 1521–1525.
- WOŚ A., 1999. *Meteorologia dla geografów*. Wyd. Nauk. PWN, Warszawa.
- WOŚ A., 2010. *Klimat Polski w drugiej połowie XX wieku*. Wyd. Nauk. UAM, Poznań.
- XIE B. et al., 2010. Observed Characteristics of Hail Size in Four Regions in China during 1980–2005. *Journal of Climate* 23: 4973–4982.
- ZHANG C. & ZHANG Q., 2007. Climatology of hail in China: 1961–2005. *Journal of Applied Meteorology and Climatology* 47: 798–804.
- ZINKIEWICZ W. & MICHNA E., 1995. Częstotliwość występowania gradów w województwie lubelskim w zależności od warunków fizjograficznych. *Annales UMCS B*, 10, 223–300.