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# THE ROLE OF ATMOSPHERIC CIRCULATION IN THE DEVELOPMENT OF THE LONG-TERM THUNDERSTORM OCCURRENCE VARIABILITY IN POLAND DURING 1949-1998

*Abstract*: The paper attempts to assess an impact of atmospheric circulation on the variability of days with thunderstorm occurrence in Poland, both in space and time. The analysis has been based on data recorded at 56 Polish meteorological stations during 1949-1998. Other sources used in the project included the typology of atmospheric circulation by B. Osuchowska–Klein and synoptic maps from the Institute of Meteorology and Water Management. The results indicate that the conditions most conductive to the development of thunderstorms include southern advection of air masses related to cyclonic situations and, in the south of the country, also eastern-sector advection. The variability of circulation types, however, was not found to have any significant impact on the long-term changes in the occurrence of days with thunderstorms.

*Key words*: atmospheric circulation, thunderstorm, long-term variability.

## 1. Introduction

The majority of Polish research into thunderstorms had been concerned with their spatial patterns and monthly and annual courses (Kolendowicz 1996; Smosarski 1952; Stopa 1962; Wiszniewski 1949). Attempts had also been made to identify meteorological conditions conductive to the development of thunderstorms, the focus being on the impact of air masses, atmospheric fronts, temperature and humidity (Kolendowicz 1996, 1997; Michałowski 1962; Stopa 1964; Wróbel 1985). Until recently the long-term variability in the occurrence of thunderstorms and the causes that trigger that phenomenon drew little attention. Studies were made into the influence of synoptic conditions on the occurrence of this phenomenon and it was determined which of them were most conductive to the occurrence of days with thunderstorms (Bielec 1996; Kolendowicz 1999; Wesołowska 1997). So far, however, no literature has been devoted solely to the overall relationship between thunderstorms and synoptic

conditions, or to the impact of the atmospheric circulation types on the long-term thunderstorm pattern changes.

This study aims to present the role of atmospheric circulation in the long-term variability of thunderstorms in Poland. The research was based on meteorological records on thunderstorms gathered by 56 stations during 1949-1998. The chief indicator analysed in the study was the *day with a thunderstorm* defined as a 24-hour period, from 00:01 UTC to 00:00 UTC on the next day, with at least one thunderstorm. Other sources used during the project included the typology of atmospheric circulation by B. Osuchowska–Klein (1999) and synoptic maps and synoptic bulletins from the Institute of Meteorology and Water Management (IMGW) covering the studied period.

## 2. Frequency of Circulation Types on the Days with Thunderstorm

First the occurrence frequency of circulation types in Poland between April and September during 1949-1998 was analysed. This six-month period was selected because a vast majority (97% on average) of all thunderstorms in Poland occur during this period, very few being recorded during the remaining part of the year. As a result, it was determined that during this period (also known as the maximum thunderstorm activity period) the dominant circulation types were those linked to the advection of air masses from the western, through northern and eastern directions (Tab. 1). Poland was most frequently influenced by the north-eastern anticyclonic circulation (E) – 17.9% of all cases, north-western cyclonic circulation (CB) – 14.6%, as well as western ($C_2D$) and north-eastern and eastern anticyclonic circulation ($E_0$), 12.3% and 12.2% respectively. The least frequent circulation types prevailing over Poland during that period were: the southern circulation, transitional between cyclonic and anticyclonic

Tab. 1. Frequency [%] of circulation types by B. Osuchowska–Klein in Poland in the period 1949-1998.

| circulation types | A | CB | D | B | F | $C_2D$ | $D_2C$ | G | $E_2C$ | $E_0$ | E | $E_1$ | BE | X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| frequency [%] | 6.9 | 14.6 | 5.0 | 4.2 | 4.4 | 12.3 | 2.9 | 3.6 | 5.0 | 12.2 | 17.9 | 6.0 | 1.2 | 3.8 |

A - western cyclonic circulation; $D_2C$ - south-western and south cyclonic circulation;
CB - north-western cyclonic circulation; G - central anticyclonic circulation;
D - south-western cyclonic circulation; $E_2C$ - north-western anticyclonic circulation;
B - southern cyclonic circulation; $E_0$ - north-eastern and eastern cyclonic circulation;
F - south-eastern cyclonic circulation; E - north-eastern anticyclonic circulation;
$C_2D$ - western anticyclonic circulatio; $E_1$ - south-eastern and eastern anticyclonic circulation; BE - southern circulation - transitional between cyclonic and anticyclonic;
X - unclassified circulation

(BE) – 1.2%, southern and south-eastern air advection in anticyclonic conditions ($D_2C$) – 2.9%, as well as central anticyclonic situation (G) – 3.6%.

The results were then compared with the frequency of days with thunderstorm in each circulation type. The two patterns had a high degree of similarity. The majority of thunderstorms occurred under cyclonic conditions (62.5% excluding types X and BE) and taking under consideration particular circulation types most thunderstorms occurred during CB (17.1%), E (13.9%) and $E_0$ (12.1%). At the other side of the spectrum were circulation types with the lowest thunderstorm occurrence, i.e. BE (1.0%), G (1.7%) and $D_2C$ (2.3%). This would indicate a lesser influence of certain circulation types on the occurrence of thunderstorms than might otherwise have been expected. This was further confirmed by the values of conditional probability for the occurrence of days with thunderstorm as related to the type of atmospheric circulation. The values of the probability, apart from indeterminate cases, stayed within 20% (Tab. 2). Of all circulation types selected, thunderstorms should be expected most

Tab. 2. Conditional probability [%] of the days with thunderstorm's occurrence in particular circulation types in Poland in the period 1949-1998.

| circulation types | A | CB | D | B | F | $C_2D$ | $D_2C$ | G | $E_2C$ | $E_0$ | E | $E_1$ | BE | X |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| conditional probability [%] | 15.7 | 15.0 | 17.7 | 18.0 | 19.5 | 8.7 | 9.9 | 6.0 | 7.3 | 12.9 | 10.2 | 11.9 | 10.9 | 21.5 |

often under a circulation characterised by the advection air masses from the southern sector related to cyclonic air pressure pattern (F – 19.5%, D - 17.7% and B - 18.0%). Generally, one in five such days should yield a thunderstorm. The lowest probability of a thunderstorm is under the central anticyclonic situation (G - 6.0%), as well as in an anticyclonic situation with air advection from the west or north west ($C_2D$ - 8.7% and $E_2C$ - 7.3%).

In the following step, the author checked whether the correlation presented also took place at the meteorological stations concerned. It turned out that the results presented did not much differ from the Poland's average pattern; larger discrepancies were only discovered during the station-to-station comparisons, which provided the basis for grouping stations featuring similar pattern types. Thus, a proposition was developed to divide Poland into five regions with similar frequency of thunderstorms under particular circulation types (Fig. 1). Of all regions one stood out most, i.e. region A1 that spanned almost the entire length of the Polish Baltic coast. Here, more than anywhere else, the proportion of days with thunderstorm under cyclonic circulation with advection from the western sector (A, CB and D) is the highest, accounting for 40.6% of all cases. Eastern and southern regions, on the other hand, were typified by a high proportion of days with thunderstorm during advection from the eastern and south-eastern sectors ($E_0$ and E). In region A5, days with thunderstorm

Fig. 1. Thunderstorm regions determined according to the frequency of the days with thunderstorm in particular circulation types in Poland in the period 1949-1998.

that occurred under the mentioned circumstances accounted for more than 30% of all cases.

## 3. Probability of the Occurrence of the Days with Thunderstorm in Particular Circulation Types

More significant differences between regions were found in case of conditional probability than for frequency of days with thunderstorm in particular circulation types (Tab. 3). Generally speaking, in all regions the probability of a day with a

Tab. 3. Conditional probability [%] of the days with thunderstorm's occurrence in particular circulation types for the thunderstorm regions in Poland in the period 1949-1998.

| region | circulation types | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | CB | D | B | F | $C_2D$ | $D_2C$ | G | $E_2C$ | $E_0$ | E | $E_1$ | BE | X |
| A1 | 16.2 | 14.2 | **21.1** | 15.9 | 14.2 | 6.3 | 11.0 | 5.9 | **4.5** | 7.2 | 4.8 | 13.7 | 11.0 | 17.4 |
| A2 | 15.1 | 10.8 | **18.7** | 14.5 | 18.6 | 6.4 | 13.3 | 6.7 | **4.9** | 8.9 | 7.4 | 12.8 | 11.9 | 21.0 |
| A3 | 16.7 | 15.2 | 17.1 | **21.3** | 18.8 | 8.1 | 8.2 | **4.8** | 5.9 | 14.1 | 8.7 | 9.4 | 8.3 | 20.2 |
| A4 | 14.7 | 13.4 | 19.4 | 16.8 | **23.4** | 8.7 | 12.7 | **7.1** | 8.0 | 11.9 | 12.0 | 14.3 | 14.6 | 24.6 |
| A5 | 15.7 | 17.5 | 15.3 | 18.7 | **20.3** | 11.0 | 7.7 | **6.0** | 9.7 | 16.6 | 13.6 | 10.9 | 10.2 | 22.6 |

thunderstorm is the highest during cyclonic circulation with air advection from the western, southern and south-eastern sectors (A, CB, D, B, F and $E_1$). It is the lowest under central anticyclonic situation (G) and the north-western anticyclonic circulation ($E_2C$). Additionally, it was noted that the highest probability values for the northern (A1) and north-western regions (A2) related to days with south-western air advection (D). In the north-eastern (A3) region this was southern air advection (B), whilst in southern Poland (regions A4 and A5) it was south-eastern (F). In the first two regions the lowest probability of thunderstorm occurrence was under advection from the north-west linked with an anticyclonic situations ($E_2C$). The remaining regions recorded the lowest probability of thunderstorms under central anticyclonic situation (G). It should also be mentioned that in the southern regions the probability of a day with thunderstorm during advection from the eastern sector ($E_0$, E and $E_1$) is higher than in the remaining part of the country.

Since the largest number of days with thunderstorm occur during a period of four months (May through August), it was interesting to check whether the probability of days with thunderstorm determined for this period was significantly different to that calculated for the maximum thunderstorm activity period. It turned out that the most important difference concerned a higher probability, while the general classification of conditions that to a larger or lesser extent were conductive to the development of thunderstorms, remained unchanged. The highest increase of days with thunderstorm probability occurred on days with advection from the western sector under cyclonic conditions (D, B and F), which in region A3 went up to 29.1% (B) and in region A4 as high as 31.5% (F).

## 4. The Relation between Long-Term Variability of Circulation Types and the Number of Days with Thunderstorm

The results of the analysis of the relationship between the number of days with thunderstorms and accompanying synoptic situations did not provide answers to the

Fig. 2. Thunderstorm regions determined according to the long-term variability of the days with thunderstorm in Poland in the period 1949-1998.

question as to whether synoptic conditions do influence the analysed ratio in time, and if so – in what way. In order to ascertain this, the author compared the long-term variability of the number of days with thunderstorm with the variability of days with a particular circulation type during the maximum thunderstorm activity period. This analysis was carried out for the average number of days with thunderstorm in Poland and by regions identified after an analysis of similarities between stations in the long-term course of days with thunderstorm (Fig. 2).

Just an initial comparison of long-term variability in the occurrence of days with thunderstorm to circulation types showed that their correlation was weak. This was

Tab. 4. Correlation between number of days with thunderstorm and number of days with particular circulation types in Poland in the period 1949-1998.

| region | circulation types | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A | CB | D | B | F | $C_2D$ | $D_2C$ | G | $E_2C$ | $E_0$ | E | $E_1$ | BE | X |
| B1 | 0.10 | -0.13 | 0.23 | -0.10 | -0.26 | 0.22 | -0.01 | -0.24 | 0.07 | -0.09 | -0.08 | ***0.28*** | -0.12 | 0.01 |
| B2 | 0.10 | -0.11 | 0.10 | -0.02 | -0.18 | 0.09 | 0.00 | -0.11 | 0.06 | -0.14 | -0.05 | 0.21 | -0.02 | 0.05 |
| B3 | -0.03 | -0.09 | 0.13 | 0.06 | -0.04 | 0.03 | -0.07 | -0.05 | 0.00 | 0.05 | -0.02 | 0.09 | 0.00 | -0.01 |
| B4 | 0.22 | -0.21 | -0.13 | 0.09 | ***-0.33*** | 0.24 | -0.17 | -0.16 | 0.00 | ***-0.46*** | 0.04 | ***0.31*** | -0.15 | 0.22 |
| B5 | -0.24 | 0.03 | -0.14 | 0.17 | -0.08 | -0.19 | -0.21 | 0.08 | 0.07 | 0.05 | 0.12 | 0.08 | 0.13 | 0.07 |
| B6 | ***-0.32*** | -0.12 | -0.21 | 0.13 | -0.04 | 0.06 | -0.13 | -0.02 | -0.15 | 0.10 | ***0.35*** | 0.22 | -0.12 | -0.24 |
| Poland | -0.06 | -0.09 | 0.02 | 0.06 | -0.20 | 0.07 | -0.14 | -0.09 | 0.02 | -0.08 | 0.06 | 0.23 | -0.02 | 0.02 |

***0.28*** – correlation coefficient statistically significant on the 0.05 confidence level

true both for the average variability of days with thunderstorm for Poland and for each region, as was confirmed by correlation coefficients (Tab. 4). There were only few cases where the coefficients indicated a weak impact of circulation types on the number of days with thunderstorms in certain regions. It should also be added that the above statement was true mostly for the Baltic coast (region B1) and the Sudety Mountains (region B4) and Carpathian-Zamość region (B6 region), i.e. the areas that stood out so far as the number of days with thunderstorm was concerned. Advection from the eastern sector was the chief air circulation condition that influenced the number of days with thunderstorm in those regions. When this sector advection accompanied a cyclonic situation, the number of days with thunderstorm would be lower, while the air coming from the east accompanied by anticyclonic condition resulted in an increase. Out of the remaining circulation types, only the western cyclonic circulation, and just in the Carpathian-Zamość region (B6), influenced the number of days with a thunderstorm; the number of days dropped with the increase in the number of days with this circulation type in any given year.

## 5. Conclusions

In summary it may be stated that the influence of circulation types on the number of days with thunderstorm was not so high as might have had been expected. In Poland, the circulation type that should be regarded as the most conductive to the formation of thunderstorms is the cyclonic circulation, particularly when it is accompanied by the advection from the southern sector. In the southern regions the eastern sector should be added to that. No significant impact of changes to the frequency of specific circulation types on the long-term variability of days with thunderstorm was found. This is why it seems justifiable that future research into the

reasons of annual days with thunderstorm variability are not just concerned with the types of synoptic conditions, but also with the related atmospheric fronts, air masses and the variability of other indicators.

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