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THERMAL VARIABILITY IN THE LUBLIN REGION DURING AN EXCEPTIONALLY SEVERE HEAT WAVE IN AUGUST 2015

Introduction

Heat waves have a number of negative effects, as exemplified by the European heat wave from 2003, causing death of even 70 000 people in West Europe (Robine et al. 2008). Moreover, the heat wave caused huge losses in the agriculture, economy, transport, and services (De Bono et al. 2004). This event was just one from the series of particularly strong events, which have been occurring in Europe since the beginning of the 21st century (Twardosz 2009). The last one occurred in August 2015 in Central Europe, covering the area from France to western Russia (Sippel et al. 2016). The model experiments show that changes in sea surface temperature and sea ice extent together with anthropogenic forcing are responsible for its extreme character (Dong et al. 2016). Although the research papers regarding the consequences of this event are just beginning to appear in scientific journals, it seems to be the one of the most deadly heat wave in Central Europe – for example in the Czech Republic the mortality from the 2015 event exceeded the mortality from 1994 event (Urban et al. 2017).

In Poland, the strongest heat waves occurred in 1963, 1994, and 2015 (Krzyżewska, Dyer 2018). Significant events were also noted in years 1959, 1968, 1992, 2006, 2010 (Wibig 2018). The 2015 event was particularly harmful for farmers. The severe draught and high precipitation deficit caused a decrease in harvest yields by 11.2% in comparison to the preceding year. The greatest losses were incurred in the Lublin, kujawsko-pomorskie, and

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partly mazowieckie voivodeships (GUS 2016). As a result of a long series of hot days and the hydrological situation in the main rivers (excessive temperature and insufficient water stage), the conditions of functioning of production facilities and electricity networks deteriorated. This caused the necessity of limiting electricity supply to industrial recipients (Rączka, Maćkowiak-Pandera 2015).

The Lublin Region is located in the eastern part of Poland, between the Vistula and Bug Rivers (Nowak, Nowak 1996). In the northern part, the relief is of lowland character, and the middle and southern part is characterised by greater height differences. Kaszewski (2008) designates eight climatic regions here, namely: Region of the Mazowiecka Lowland (I), Polesie Region (II), Nadwiślański Region (III), Region of the western part of the Lublin Upland (IV), Region of the middle part of the Lublin Upland (V), Region of the eastern part of the Lublin Upland with Pobuże (VI), Roztocze Region (VII), and Region of the Sandomierz Lowland (VIII).

The objective of this paper is the analysis of the variability of thermal conditions during a heat wave from August 2015 in the Lublin Region, characterised by variable land relief. According to the state of knowledge to date, in spite of extending in latitudinal direction, the region is distinguished by high thermal variability (Kaszewski 2008).

Material and methods

A heat wave was adopted as at least three subsequent days with maximum temperature >30°C (Krzyżewska, Wereski 2011). The analysis of thermal conditions during the heat wave in August 2015 was based on data obtained from the following meteorological stations (fig. 1):

- automatic stations of the Department of Meteorology and Climatology of UMCS in Lublin: Celejów, Rybczewice, Trzydnik, Wola Wereszczyńska, Guciów;
- stations of IMGW-PIB: Włodawa, Terespol, Siedlce, Sandomierz, Lublin-Radawiec.

In Guciów, on 5-7 August, a break occurred in recording meteorological measurements.

Mean daily temperature was calculated from the following formula:

$$T_{śr.} = \frac{T_{max} + T_{min} + T_{06} + T_{12}}{4}$$

where: T_{max} – maximum daily temperature; T_{min} – minimum daily temperature; T_{06} – temperature at 6.00 UTC; T_{12} – temperature at 12.00 UTC

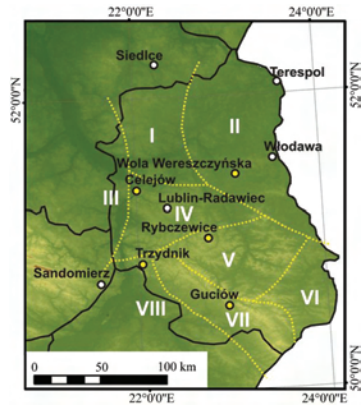

Fig. 1. Location of meteorological stations on the background of climatic regions of the Lublin Region according to Kaszewski (2008)

Among the analysed stations, Terespol, Siedlce, and Lublin-Radawiec are characterised by 100% completeness of mean daily air temperature data in the period from 2013 to 2016. High level of completeness also concerns data from Włodawa (99.9%) and Sandomierz (98.8%). Based on field observations, it was possible to calculate mean daily temperature in reference to the following percentage of days: 97.3% (Guciów), 94.6% (Trzydnik), 94.0% (Rybczewice), 93.0% (Wola Wereszczyńska), and 85.3% (Celejów).

The supplementation of data applied the difference method (Pruchnicki 1987). For the majority of sites, the base/reference station was adopted to be Lublin-Radawiec. Only in reference to Wola Wereszczyńska, Włodawa was adopted. The selection of the reference station depended on the correlation coefficient between mean values of daily air temperature in the stations for which supplementation is required, and in the nearest stations with complete data. Correlation coefficients were calculated between mean daily temperatures in potential base stations and in the analysed stations. Lublin-Radawiec (for Trzydnik) and Włodawa (for Wola Wereszczyńska) were selected due to the higher value of the said correlation coefficient.

Calculations by the difference method were performed in two ways. If the number of missing data in a month amounted to 8 or less, that month remained the base month. If the gap in material was larger, mean difference was calculated between air temperature in stations for the entire season in a period of four years.

Thermal conditions in the Lublin Region

The Lublin Region is distinguished among other regions of Poland with the highest thermal continentalism, primarily related to high temperatures in sum-

mer. Lower cloudiness is also observed here, particularly in the warm half year (Ewert 1998). Zinkiewicz and Zinkiewicz (1973) provide a range of variability of mean annual air temperature for the period 1951-1960 from 7.0 to 7.9°C. For the longest measurement period (1951-2000), the variability of the characteristic varies from 6.8-6.9°C in the higher parts of Roztocze to 8.0°C in Puławy (Kaszewski 2008). The greatest thermal uniformity concerns the middle and eastern part of the region, while a decrease in mean air temperature is observed from west to east (Kaszewski 2008).

The coldest site among the analysed stations (2013-2016) is Guciów with mean annual temperature of 8.0°C, and the warmest one is Sandomierz, where the value of the component amounts to 9.4°C. In the remaining stations of the region, the temperatures vary from 8.4°C in Wola Wereszczyńska to 8.9°C in Terespol and Włodawa. In all of the stations, January was the coldest month. The mean monthly value of the component varied from –3.0°C in Wola Wereszczyńska to –1.9°C in Sandomierz. Mean monthly temperature from July, the warmest month in a year (with the exception of Sandomierz) varied from 18.2°C in Guciów to 19.7°C in Włodawa (table 1).

Values calculated from the years 2013-2016 are higher than those cited in the literature. This is determined by the short measurement period (4 years) and an increasing tendency of air temperature in the Lublin Region, observed by Kaszewski (2006).

At 5 selected stations the measurements have been conducted as early as 1976 year. Basic characteristics of the mean air temperature in August in the years 1976-2015 are presented in table 2. It is noteworthy that in the years

Table 1. Mean monthly and annual air temperature values in selected stations of the Lublin Region (2013-2016)

Station	Region	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Year
Siedlce	I	–2.8	0.9	2.9	8.6	14.0	16.8	19.3	18.7	13.5	7.8	4.0	1.4	8.8
Terespol	II	–2.9	0.9	3.1	8.9	14.5	17.4	19.6	19.0	13.7	7.8	4.0	1.1	8.9
Włodawa	II	–2.9	0.9	3.0	8.8	14.3	17.4	19.7	19.3	13.8	7.9	4.0	1.0	8.9
Wola Wereszczyńska	II	–3.0	0.4	1.9	8.3	13.9	17.3	19.4	18.5	13.1	7.3	3.7	0.7	8.4
Celejów	IV	–2.5	0.8	2.6	8.4	13.7	17.1	19.2	18.4	13.0	7.3	4.0	1.2	8.6
Lublin-Radawiec	IV	–2.7	0.8	2.9	8.6	13.8	17.1	19.3	19.0	13.9	8.1	4.1	1.1	8.8
Rybczewice	V	–2.7	0.7	2.4	8.3	13.7	17.2	19.4	18.4	13.1	7.4	4.1	1.0	8.6
Guciów	VII	–2.8	0.4	1.9	7.9	12.8	16.6	18.2	17.1	12.4	7.0	3.7	0.4	8.0
Sandomierz	VIII	–1.9	1.4	3.7	9.4	14.3	17.8	19.3	19.5	14.6	8.6	4.5	1.4	9.4
Trzydnik	VIII	–2.6	0.7	2.8	8.5	13.7	17.3	19.3	18.6	13.4	7.8	3.9	0.7	8.7

Table 2. August mean monthly temperature and number of standard deviations [*s*] between 2015 temperature and mean 1976-2016 in some of selected stations of the Lublin Region

Station	Region	1976-2016					Number of *s* between 2015 temperature and mean 1976-2016
		Min of means	Year of min	Mean	Max of means	Year of max	
Siedlce	I	14.9	1976	17.6	21.0	2015	2.5
Włodawa	II	14.9	1987	17.8	21.9		2.9
Terespol	II	14.9	1987	17.7	21.5		2.7
Lublin-Radawiec	IV	14.6	1987	17.5	21.8		2.8
Sandomierz	VIII	15.2	1987	18.1	22.3		2.8

2013-2016 the mean monthly value in August was higher than in the period of 1976-2016 (from 1.2°C in Sandomierz to 1.9°C in Terespol and Włodawa). All these 5 stations recorded the highest mean August temperature exactly in 2015. It exceeded the long-term average by 2.5 (Siedlce) to 2.9 (Włodawa) standard deviation. According to Kossowska-Cezak (1993) the months with means exceeding multiannual mean value by just 2 standard deviations are described as 'very warm'. For this difference exceeding 2.5 standard deviation, we suggest using the term 'exceptionally warm'.

Synoptic conditions

Conditions favouring the occurrence of a heat wave in August 2015 occurred after the development of a high east of Poland, causing advection of tropical air masses from the south over Poland (fig. 2). Based on the data from 1971-2010, such conditions are frequent causes of heat waves over Poland (Tomczyk, Bednorz 2015). The inflow was intensified by the low pressure system which at the beginning of the heat wave was still over the British Isles, and then slowly moved towards the west. The hottest day of the heat wave in the Lublin Region was 9 August. On this day, a cool front reached the south-western boundary of the region (fig. 3). It was part of a weak low pressure system. The front caused a slight decrease in temperature in the following days, without disturbing the continuity of the heat wave. Eventually, the high developing over the Scandinavia with polar continental air masses caused air cooling, pushing tropical air masses southwards (fig. 4).

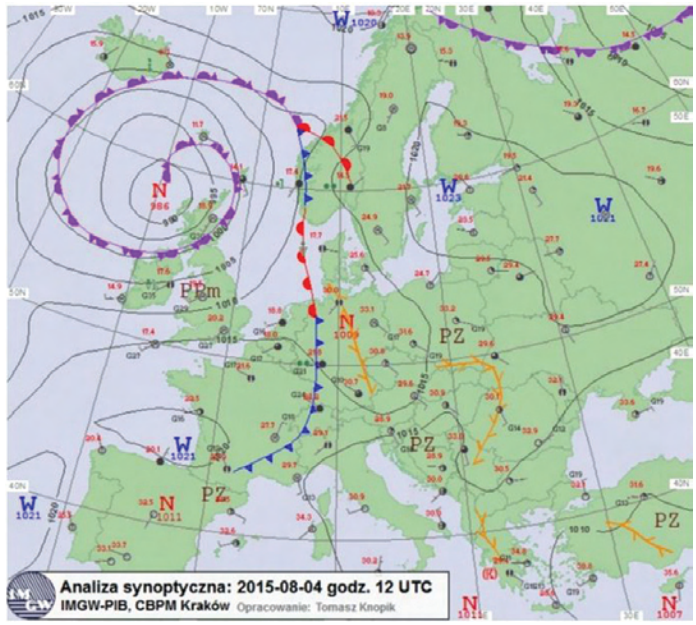

Fig. 2. Synoptic situation over Europe on 4 August 2015 at 12.00 UTC (source: pogodynka.pl)

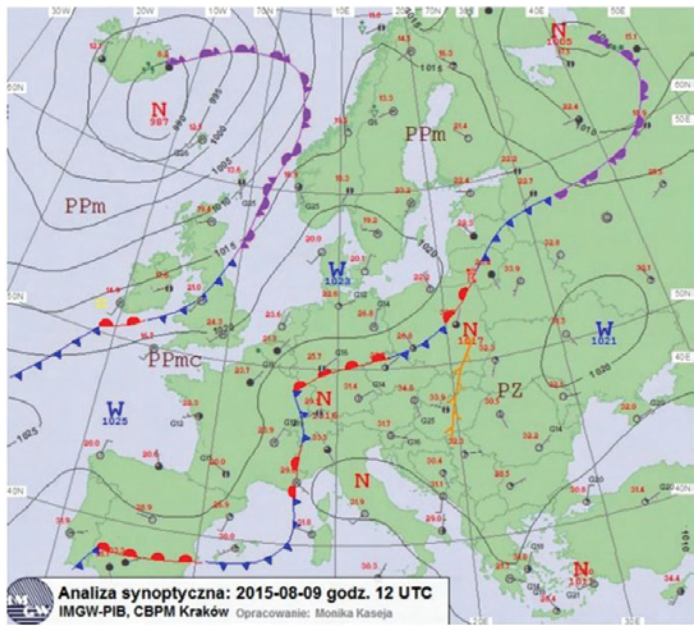

Fig. 3. Synoptic situation over Europe on 9 August 2015 at 12.00 UTC (source: pogodynka.pl)

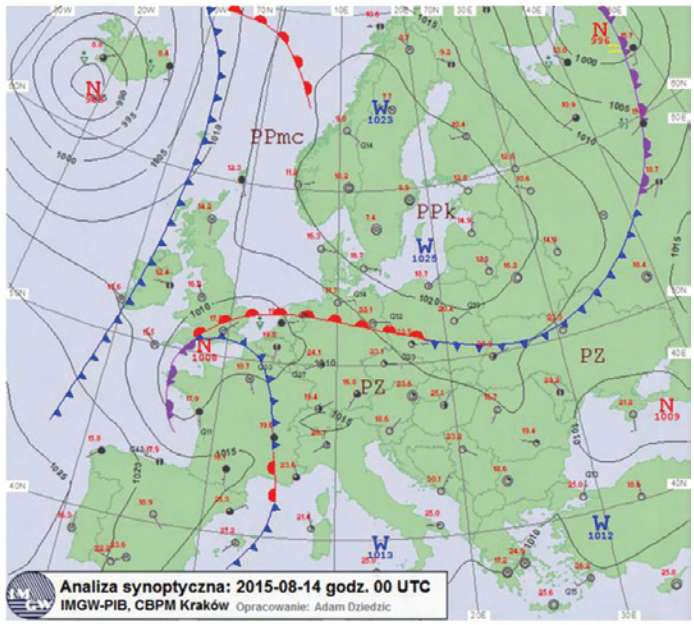

Fig. 4. Synoptic situation over Europe on 14 August 2015 at 00.00 UTC (source: pogodynka.pl)

Thermal variability in the Lublin Region during the heat wave in August 2015

The heat wave commenced the earliest on 3 August at 10:00 UTC in stations in Rybczewice and in Guciów. Three further stations in which temperature exceeding 30°C was recorded are Celejów, Włodawa, and Wola Wereszczyńska. The latest, on 5 August at 12:00 UTC, the heat wave commenced in Sandomierz. The end of the heat wave occurred the earliest in Terespol on 12 August at 17:00 UTC. The latest, the heat wave ended on 16 August on 9:00 UTC in Celejów. In the remaining stations, the end of the heat wave occurred on 15 August between 14:00 and 16:00 UTC (table 3).

The heat wave was the longest and continuous in Celejów – 14 days, and the shortest in Terespol – 9 days. With the exception of Siedlce, where two breaks of 3 days in total were recorded during the heat wave, a one-day break occurred in the remaining stations covered by the analysis on 14 August.

During the heat wave on 3-16 August, the warmest station was Sandomierz with a mean value of air temperature of 25.0°C, as well as Lublin-Radawiec (24.9°) and Włodawa (24.8°C). The lowest mean value for the heat wave was determined for Guciów (23.1°C). The temperature was by almost one degree higher in Celejów (24.0°C), as well as in Siedlce and Rybczewice (24.1°C).

Table 3. Minimum, mean, and maximum air temperature values in the Lublin Region, and dates of the commencement and end of the heat wave on 3-16 August 2015

Station	Region	Temperature			Commencement		End	
		Min	Mean	Max	Date	UTC	Date	UTC
Siedlce	I	10.6	24.1	35.2	4.08	10:00	15.08	14:00
Włodawa	II	12.1	24.8	36.0	3.08	12:00	15.08	14:00
Wola Wereszczyńska	II	12.6	24.4	36.5	3.08	12:00	15.08	14:00
Terespol	II	12.5	24.4	36.2	4.08	09:00	12.08	17:00
Celejów	IV	13.1	24.0	35.7	3.08	11:00	16.08	09:00
Lublin--Radawiec	IV	14.8	24.9	35.2	4.08	10:00	15.08	15:00
Rybczewice	V	12.1	24.1	36.0	3.08	10:00	15.08	15:00
Guciów*	VII	11.7	23.1	35.5	3.08	10:00	15.08	15:00
Sandomierz	VIII	16.5	25.0	35.0	5.08	12:00	15.08	16:00
Trzydnik	VIII	14.4	24.2	34.8	4.03	12:00	15.08	15:00

* no data in the period from 5.06 16:00 UTC to 7.08 14:00 UTC

The highest maximum temperature during the heat wave occurred in Wola Wereszczyńska (36.5°C). Approximate values were also recorded in Terespol (36.2°C) and in Włodawa and Rybczewice (36.0°C). The lowest maximum temperature occurred in Trzydnik (34.8°C). The range of variability of minimum temperature was from 10.6°C in Siedlce to 16.5°C in Sandomierz.

The highest temperatures during the heat wave occurred on 7-9 August. In that period, low thermal variability in a day was observed between particular stations, amounting to approximately 2-3°C (fig. 5). By night, the differences

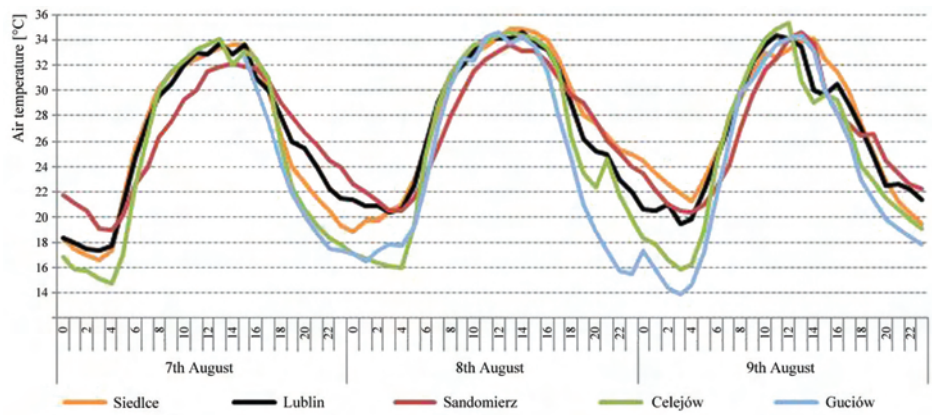

Fig. 5. Course of air temperature in selected stations of the Lublin Region and its vicinity/neighbouring areas on 7-9 August 2015

were considerably higher, and reached approximately 10°C. The lowest temperature by night was recorded in Guciów and Celejów. In Sandomierz and Siedlce, temperature did not fall below 20°C, which is defined as a tropical night. It is worth emphasising that the analysed stations are located in non-urbanised areas, where such nights occur sporadically. During the analysed period, as many as six such nights occurred in the station located in the centre of Lublin (Krzyżewska et al. 2016). Thermal variability in afternoon hours on 9 August was related to the transition of the atmospheric front presented in figure 4.

Conclusions

In the Lublin Region in the period 2013-2016, the variability of mean air temperature between the analysed stations equalled up to 1.4°C (from 8.0°C in Guciów to 9.4°C in Sandomierz), and in the remaining stations, the variability was low and did not exceed 0.5°C. The values are higher than those presented by the authors of earlier publications concerning thermal variability of the region, as resulting from a different period of observation and higher air temperature values observed in the recent years.

The heat wave that occurred on 3-16 August 2015 was caused by the inflow of tropical air masses from the south. The longest and continuous heat wave occurred in Celejów – 14 days, and the shortest in Terespol – 9 days. The earliest, on 3 August, the heat wave commenced in Rybczewice and Guciów, and in Sandomierz it commenced two days later. The heat wave ended the earliest in Terespol, on 12 August, and the latest on 16 August in Celejów.

Auring the heat wave on 3-16 August, Sandomierz was the warmest with a mean value of air temperature of 25.0°C, and Guciów was the coldest (23.1°C). The highest maximum temperature during the heat wave occurred in Wola Wereszczyńska (36.5°C). The lowest maximum temperature of the heat wave occurred in Trzydnik (34.8°C). The range of minimum temperature variability was from 10.6°C in Siedlce to 16.5°C in Sandomierz.

The highest temperatures during the heat wave occurred on 7-9 August. In the Lublin Region during the time, by night, higher thermal variability was observed than during the day. By night, differences between particular stations reached up to 10°C, and by day they amounted to only approximately 2-3°C. The lowest temperature by night (approximately 14-17°C) were recorded in Celejów and Guciów. In Sandomierz and Siedlce, the phenomenon of tropical nights occurred on those days. It is worth emphasising that during the same heat wave, in the station located in the centre of Lublin, on 8-13 August, six subsequent tropical nights occurred, negatively affecting human health (Krzyżewska et al. 2016).

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S u m m a r y

Heat waves are defined as at least 3 consecutive days with maximum temperature >30°C (Krzyżewska, Wereski 2011). Their course largely depends on the circulation conditions, but local conditions related to the geographic location and surroundings of the station also play an important role.

According to the International Panel for Climate Change, heat waves are treated as extreme events (IPCC 2014) that will be longer and more intensive in the future (Meehl, Tebaldi 2004). One of the longest and most intensive heat waves in Central-East Europe occurred in the first half of August 2015. In the Lublin Region, it commenced on 3 August 2015, and lasted continuously for almost two weeks.

The objective of the paper is to present the variability of the thermal conditions that occurred in the Lublin Region during an exceptionally strong heat wave in August 2015. The analysis was performed based on data obtained from six stations of the Institute of Meteorology and Water Management (IMGW) and seven automatic field stations of the Maria Curie-Skłodowska University (UMCS).

Key words: Lublin Region, air temperature, heat wave, synoptic conditions, exceptionally warm month.