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Thermal Variability in the Lublin Region During the Frost Wave in January 2017

Zróżnicowanie termiczne na Lubelszczyźnie podczas fali mrozów w styczniu 2017 r.

Abstrakt: Fale mrozów należą do ekstremalnych zjawisk pogodowych stanowiących – podobnie jak inne tego typu zjawiska – zagrożenie dla zdrowia i życia człowieka oraz wpływających niekorzystnie na środowisko przyrodnicze. Za falę mrozów przyjmuje się ciąg przynajmniej trzech kolejnych dni, podczas których minimalna dobowa temperatura powietrza była równa lub niższa od –15°C (Wibig i in. 2009). Celem niniejszej pracy jest zbadanie warunków termicznych na Lubelszczyźnie podczas szczególnie mroźnego stycznia 2017 r. Jako materiał źródłowy wykorzystano wyniki pomiarów minimalnych i maksymalnych dobowych wartości temperatury powietrza oraz terminowe wartości temperatury powietrza o kroku czasowym 1 godziny, z terenowych stacji meteorologicznych Katedry Hydrologii i Klimatologii UMCS, zlokalizowanych na obszarze Lubelszczyzny (Celejów, Leśniowice, Rybczewice, Wola Wereszczyńska, Guciów) oraz stacji meteorologicznych IMGW-PIB (Siedlce, Terespol, Lublin-Radawiec, Włodawa, Sandomierz, Zamość, Kozienice). Fala mrozów na Lubelszczyźnie wystąpiła w dniach od 5 do 11 stycznia 2017 r., przy czym na większości stacji (z wyjątkiem stacji w Terespolu) 9 stycznia minimalna dobowa temperatura powietrza była wyższa od –15°C. Podczas analizowanego okresu najniższą temperaturę powietrza zanotowano 7 stycznia na stacji w Guciowie (–25,3°C). Przyczyną tej fali mrozów był napływ powietrza arktycznego z północy.

Słowa kluczowe: Lubelszczyzna; Lublin; warunki termiczne; fale mrozu

Abstract: Frost waves are included to extreme weather phenomena – similarly as other phenomena of the type – constituting a threat for human health and life, as well as negatively affecting the natural environment. Frost wave is defined as a sequence of at least three consecutive days with minimum daily air temperature equal or lower than –15°C (Wibig et al. 2009). The aim of this paper is to examine the thermal conditions in the Lublin Region during particularly cold January of 2017. The adopted source materials were results of measurements of minimum and maximum daily air temperature and term values of air temperatures with a 1-hour time step from field meteorological stations of the Department of Hydrology and Climatology of the University of Maria Curie-Skłodowska (UMCS) located in the Lublin Region (Celejów, Leśniowice, Rybczewice, Wola Wereszczyńska, Guciów), as well as meteorological stations of the Institute of Meteorology and Water Management – National Research Institute IMGW-PIB (Siedlce, Terespol, Lublin-Radawiec, Włodawa, Sandomierz, Zamość, Kozienice). Frost wave in the Lublin Region was from 5 to 11 January. However, at the majority of stations (excluding the station in Terespol) on 9 January, the minimum daily air temperature was higher than –15°C. During this phenomenon, the lowest air temperature was recorded on 7 January in Guciów, and its value reached –25.3°C. The cause of this frost wave was the inflow of Arctic air from the north.

Keywords: Lublin Region; Lublin; thermal conditions; cold spells

INTRODUCTION

Frost waves are considered as extreme weather phenomena being a threat for human health and life, as well as negatively affecting the natural environment.

Although, according to the IPCC report (2014), the number of frost days and frost waves is expected to decrease, they will still occur. Some cases of cold waves are known to be caused by the weakening of the polar vortex, negative AO index, and rapid flow of cold air to the south (Li et al. 2017). In Poland, cold waves or frost waves occur with anticyclonic circulation and are usually caused by the inflow of air from the north or east (Wibig et al. 2009).

Frost waves are defined in different ways by different authors (Krzyżewska 2014). In the English-language literature, a frost wave is also called a "cold wave" or "cold spell". The Polish term *fala chłodu* (cold wave) is more general than *fala mrozów* (frost wave; the former can occur in summer, and the latter is "reserved" for the cold season of the year). A cold wave is "an evident decrease in temperature lasting several weeks resulting from the advection of very cold air over a large area, repeating more or less regularly, alternately with warmer periods" (Niedźwiedź (ed.) 2003). According to the World Meteorological Organization, a cold wave is considerable cooling of air, or invasion (advection) of very cold air over a very large area (www.wmo.int). The dictionary of American Meteorological Society designates a cold wave in the case of a rapid decrease in temperature within 24 hours requiring protection of agriculture, industry, services, and activities of society (http://glossary.ametsoc.org).

In the case of frost waves, there is no uniform definition. It is usually defined as a sequence of characteristic days, e.g. frost days with $t_{max} < 0°C$, very frost days with $t_{max} < -10°C$, frost nights with $t_{min} \leq -15°C$, or very frost nights with $t_{min} \leq -20°C$ (Wibig et al. 2009).

Effects of frost waves have a negative impact on living organisms – from higher than average mortality and morbidity in humans to higher than average demand for more caloric food in animals. During low air temperature, more energy is used for heating. Weather conditions occurring during a frost wave, related to lack of cloudiness, low wind speed, and occurrence of stable aerostatic equilibrium, may cause the persistence of pollutants at the earth surface, and reduced ventilation of cities. Negative effects are also observed in energy engineering, economy, and road and railway infrastructure (Smoyer-Tomic et al. 2003).

The Lublin Region is a historical-geographic region located between the Vistula and Bug Rivers (Nowak, Nowak 1996). It is, however, often associated with the area of the Lubelskie Voivodship with the last change of boundaries dated 1 January 1999 (Kaszewski 2008). The northern and eastern part of the region is occupied by lowlands (Podlasie Lowland, Mazovian Lowland and Lublin Polesie). The central and southern part is mostly upland with variable heights (the Lublin Upland and Roztocze).

The Lublin Region is characterised by variable climatic conditions. According to Kaszewski (2008), despite the small longitudinal extent, the area is characterised by high thermal variability. This part of Poland has eight climatic regions: Mazovian Lowland Region (I), Polesie Region (II), Vistula Region (III), West Lublin Upland Region (IV), Central Lublin Upland Region (V), East Lublin Upland Region and Pobuże (VI), Roztocze Region (VII), and Sandomierz Lowland Region (VIII). Despite numerous publications concerning the issues of climatic conditions in the area, further research is required, especially in the context of the currently observed climate change.

The objective of this paper is the analysis of the variability of thermal conditions during the frost wave of January 2017 in the Lublin Region characterised by variable land relief.

DATA AND METHODS

In this paper, frost waves are defined as at least three consecutive days with a minimum temperature of ≤–15°C. The threshold value of –15°C was adopted from Wibig et al. (2009). For the analysis of thermal conditions during the frost wave in January 2017 as well as a 5-year thermal background (2013–2017), we used data obtained from the following meteorological stations:

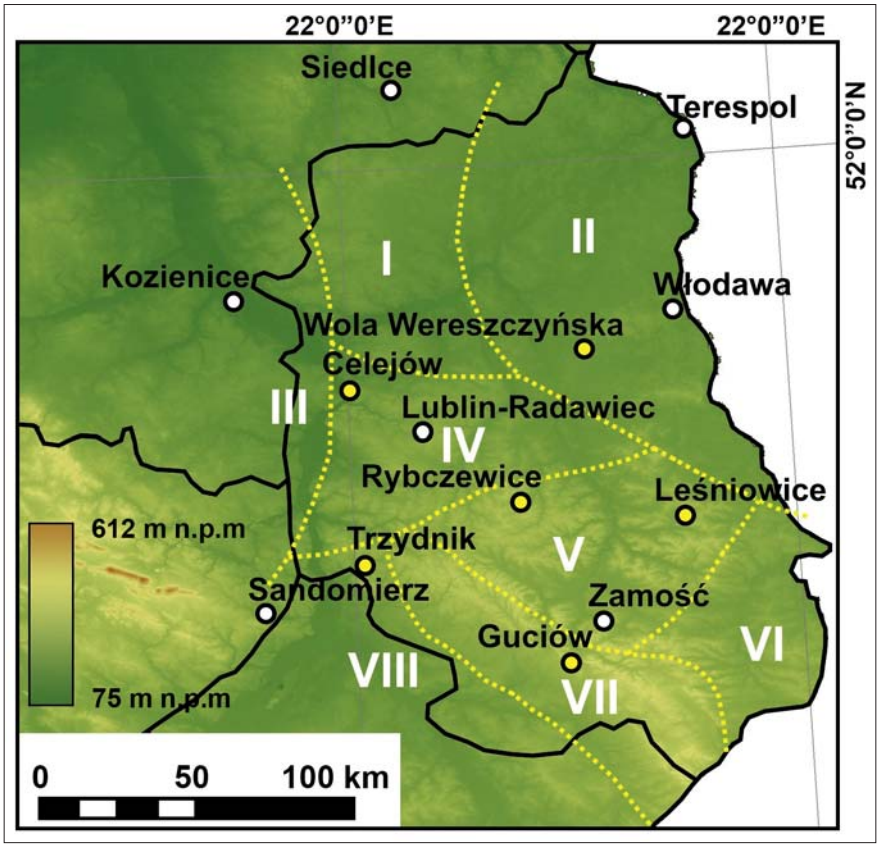

Fig. l. Location of meteorological stations in the Lublin Region on the background of climatic regions following Kaszewski (2008). Yellow colour signifies field stations of UMCS, white colour – stations of IMGW.

– Celejów, Guciów, Leśniowice, Rybczewice, and Wola Wereszczyńska from the Department of Hydrology and Climatology of UMCS in Lublin,

– Kozienice, Lublin-Radawiec, Sandomierz, Siedlce, Terespol, Włodawa, and Zamość from the Institute of Meteorology and Water Management – National Research Institute (Fig. 1).

Data from stations in Terespol, Siedlce, and Lublin-Radawiec provide a complete measurement series for the years 2013–2017. For the remaining stations, the completeness of thermal data was as follows: Włodawa (99.9%), Sandomierz (98.7%), Guciów (97.6%), Rybczewice (95.1%), Wola Wereszczyńska (93.8%), and Celejów (88.0%). Those data are thermal background for our analysis. Mean, minimum and maximum daily temperature values are according to IMGW standards. The missing data were supplemented as described by

Krzyżewska et al. (2018). The data from Kaunas, Vilnius and Grodno needed to determine the gradient of temperature during the frost wave was downloaded from the www.ogimet.com website.

SELECTED ASPECTS OF THERMAL CONDITIONS IN THE LUBLIN REGION

According to Ewert (1998), the Lublin Region stands out among other regions of Poland due to the highest thermal continentalism and lower cloudiness except for winter months. Mean annual air temperature in the region in the years 1951–1960 varied from 7.0 to 7.9°C (Zinkiewicz, Zinkiewicz 1973). For the period 1951–2000, Kaszewski (2008) provides a broader range of variability of the component – from 6.8–6.9°C in higher parts of Roztocze to 8.0°C in the Vistula Region. In the Lublin Region, a decrease in the mean air temperature is observed from the west to the east, and the central and eastern part of the region is characterised by thermal monotony (Kaszewski 2008).

Mean annual air temperature at the analysed meteorological stations calculated for the years 2013–2017 varied from 7.9°C in Guciów to 9.3°C in Sandomierz. The differences between the remaining stations did not exceed 0.5°C (8.4–8.9°C). Mean temperature of 2017 at all stations was lower than the value in the analysed 5-year period, from 0.1°C in Guciów to 0.3°C in Terespol, Lublin-Radawiec, and Sandomierz. Mean 5-year temperature in January varied from –3.6°C in Wola Wereszczyńska and Guciów to –2.6°C in Sandomierz. In the years 2013–2017, in the Lublin Region, January 2017 was the coldest month. The mean from the month was lower than multi-annual values at all the analysed stations. The greatest differences, reaching up to 3.3°C, were recorded in Guciów, and the smallest differences of 1.7°C – in Siedlce and Terespol (Tab. 1). The annual course of mean monthly air temperatures is presented by Krzyżewska et al. (2018).

In the second half of the 20th century, a considerable increase in the mean annual air temperature was observed, particularly related to an increase in the air temperature in spring and winter (Kaszewski 2006). Due to this fact, and a short 5-year period of analysis, the calculated annual temperatures are considerably higher than those presented in the literature.

The average air temperature in January with regard to the 1931–1960 period was between –5°C and –4°C. In the particular years of that period this value was from between –14°C and –13°C (1942) to about +2°C (Wiszniewski 1973, p. 96). The average daily minimum values in that period in January were from –6°C to –7°C (Wiszniewski 1973, p. 102). The lowest daily minimum air temperature

Tab. 1. Mean monthly temperature of January and the year 2017 in comparison to the 5-year period of 2013–2017 at selected stations of the Lublin Region (authors' study)

Station	Region	Mean temp. 2013–2017 (in °C)		Mean temp. 2017 (in °C)	
		January	Year	January	Year
Siedlce	I	–3.2	8.7	–4.9	8.5
Terespol	II	–3.4	8.9	–5.1	8.6
Włodawa	II	–3.5	8.8	–5.6	8.6
Wola Wereszczyńska	II	–3.6	8.4	–6.0	8.2
Celejów	IV	–3.1	8.6	–5.5	8.4
Lublin-Radawiec	IV	–3.3	8.7	–5.9	8.4
Leśniowice	V	–4.0	8.4	–6.7	8.2
Rybczewice	V	–3.4	8.5	–6.2	8.3
Guciów	VII	–3.6	7.9	–6.9	7.8
Sandomierz	VIII	–2.6	9.3	–5.4	9.0

in January was between –25°C and –27°C (26 January 1954) (Wiszniewski 1973, p. 104). Very frost days ($t_{max} \leq -10°C$) did not occur every year[1] in the Lublin Region. The highest number of frost days occurred in 1940 (about 30 days) (Wiszniewski 1973, p. 111). Considering the "milder" definition of "frost day" ($t_{min} < -10.0°C$), its seasonal average in the Lublin Region with regard to the 1950/1951–1974/1975 periods was 22–28 days (Paczos 1982, p. 64).

In the years 1951–1985, at the Lublin-Felin station, the lowest minimum air temperature was –29.2°C (January of 1963, [Kołodziej et al. 1987/1988, p. 144]). The average air temperature in January in Zamość in the period 1951–1990 was from –6°C (1963) to +4.7°C (1990) (Paczos 1990, p. 88).

The average number of days with $t_{min} \leq -15°C$ in Siedlce with regard to the years 1951–2006 was almost 10, and the average cold wave lasted 2.7 days (Wibig et al. 2009, p. 49).

In the city of Lublin, in the years 1981–2015, there were 64 frost waves (defined as 3 consecutive days with $t_{min} < -10°C$), but they did not appear every year. The highest number of frost wave days were recorded in 1985 (41 days during 2 frost waves) and in 1987 (38 days during 5 frost waves) (Kaszewski et al. 2018).

It is hard to compare the results presented in this paper with the results obtained by other authors due to different criteria of defining frost days and frost

[1] In our opinion, the number of frost days should be related to the winter season (DJF). Wiszniewski (1973, p. 111), however, referred to calendar years.

waves. For example, Krzyżewska and Wereski (2011) and Tomczyk et al. (2019) use the $t_{max} \leq -10°C$ criterion, while Porębska and Zdunek (2013) use the $t_{max} \leq -5°C$ criterion, or Tomczyk (2015) defines frost wave as a period of 5 days below 5th annual percentile.

RESULTS

Synoptic conditions

On 5 January 2017, when conditions for the occurrence of a frost wave over the Lublin Region were favourable, Poland was under the influence of an atmospheric high with a centre over the Scandinavian Peninsula. The synoptic situation caused the inflow of Arctic air from the north over the territory of Poland (Fig. 2). The greatest decreases in temperature were recorded on 7 January.

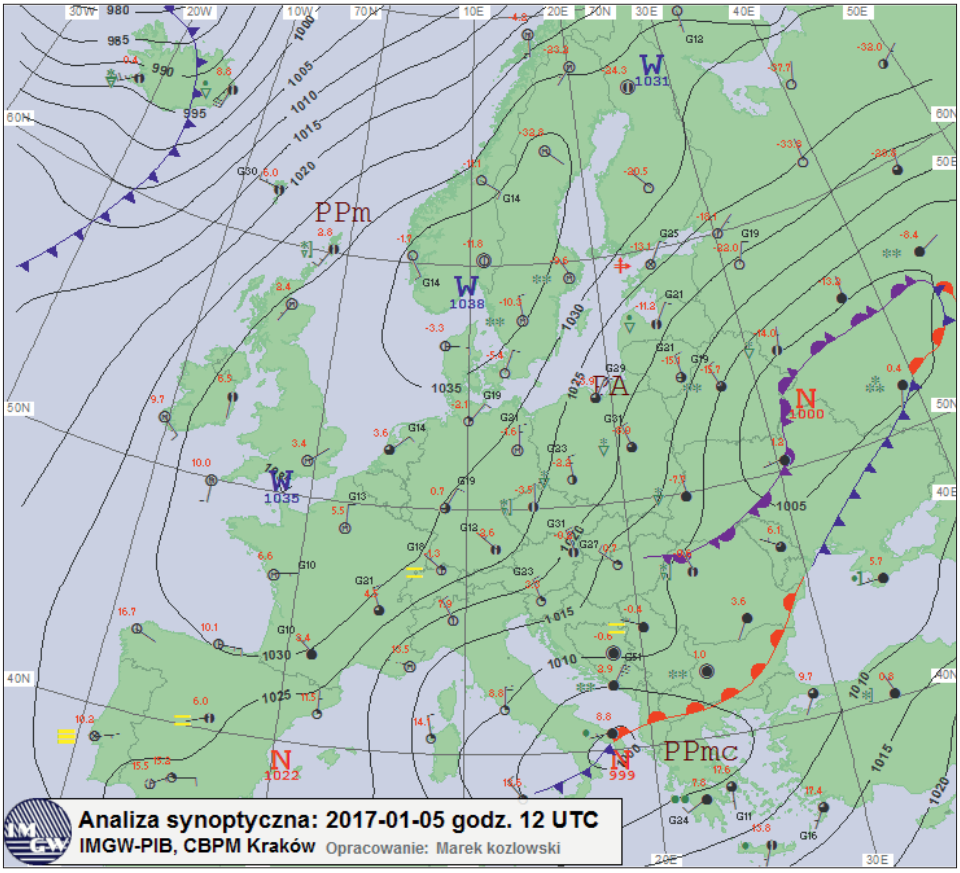

Fig. 2. Synoptic situation over Europe on 5 January 2017 at 12.00 UTC (www.pogodynka.pl)

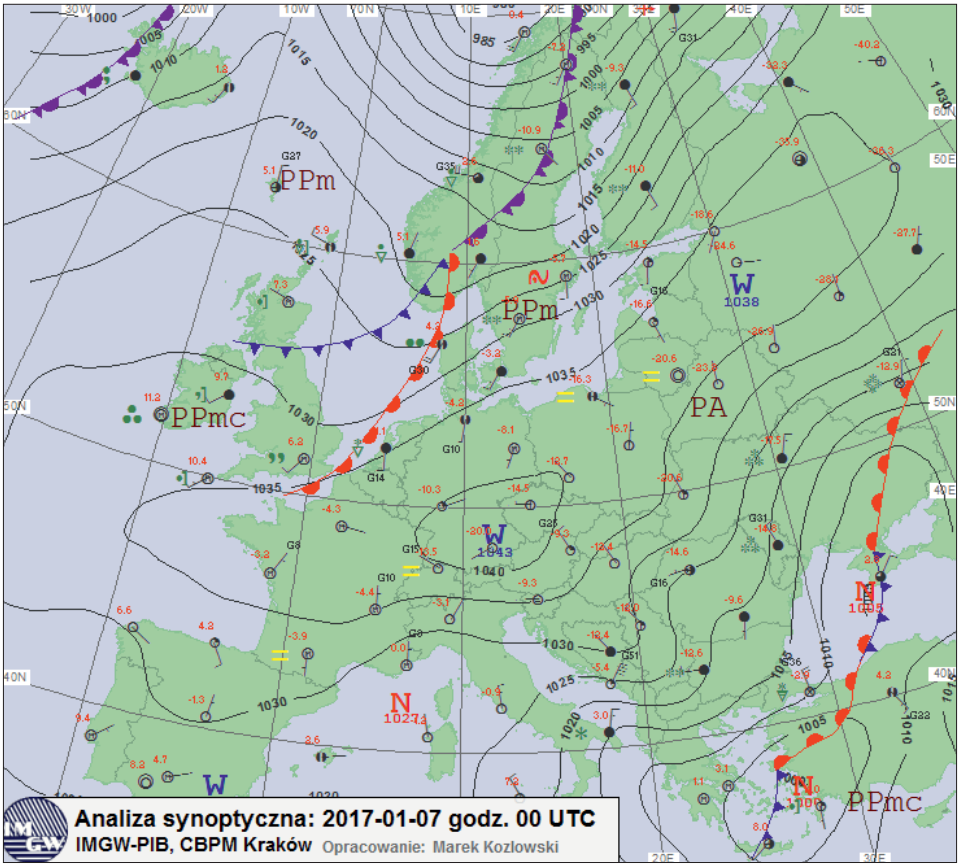

Fig. 3. Synoptic situation over Europe on 7 January 2017 at 00.00 UTC (www.pogodynka.pl)

A high pressure system developed over Europe, extending from France to Russia (Fig. 3). In the Lublin Region (as well as in the remaining part of the country), an Arctic air mass persisted (PA). Moreover, a decrease in air temperature below –20°C, recorded on that day at stations of the Lublin Region, was caused by intensive long-wave radiation related to low cloudiness.

Thermal variability in the Lublin Region during the frost wave in January 2017

On 4 January, at 22.00 UTC, the air temperature in the Lublin Region was between 0 and –1°C. The inflow of the air from the north during forthcoming hours caused a quick drop in temperature. Between 00:00 and 7:00 UTC (5 January), this drop in the northern and middle part of the Lublin Region was about 8–9°C (on average more than 1°C/hour). In the southern part of the Region this drop was about 5°C. During 1:00–3:00 UTC, the temperature gradient between

the stations localized in the middle part of Lublin Region and stations localized in north-eastern part of Poland (Białystok, Olsztyn, Suwałki), in Lithuania (Kaunas, Vilnius) and in western part of Belarus (Grodno) was the largest and it was 2–4°C/100 km. On 5 January, the temperature was still dropping, but it was much slower than at the beginning of the frost wave (about 0.3°C/hour).

The earliest occurrence of the frost wave, i.e. a decrease in air temperature to –15°C, was observed in Terespol on 5 January at 21:00 UTC, and at stations in Sandomierz and Kozienice it only occurred on 6 January at 17:00 UTC (Tab. 2). In case of 4 analyzed stations (out of 12), the beginning of the frost wave occurred on 5 January, and in case of the remaining stations – on the following day. It should be mentioned that in the analysis full-time measurements were used, and in case of 5 stations, the phenomenon started at midnight (0:00 UTC), which means that the actual decrease in temperature to the threshold value could occur somewhat earlier.

The course of the analysed frost wave was different at particular stations. Only in Terespol, the continuous character of the phenomenon was observed in the period from 5 to 11 January. This means that each day, there were met the conditions provided in the criterion applied by the authors ($t_{min} \leq -15°C$). At stations in Celejów, Rybczewice, Wola Wereszczyńska, Leśniowice, Guciów, and Zamość, a one-day break in the frost wave occurred (9 January), whereas

Tab. 2. Minimum, mean, and maximum values of air temperature in the Lublin Region, and dates of the beginning and end of the frost wave of 5–11 January 2017 (authors' study)

Station	Region	Temperature			Beginning		End	
		Min	Mean	Max	Date	Time (UTC)	Date	Time (UTC)
Siedlce	I	–21.5	–12.6	0.5	6.01	3:00	11.01	6:00
Włodawa	II	–22.7	–13.0	1.2	5.01	22:00	11.01	8:00
Wola Wereszczyńska	II	–24.5	–12.8	0.8	5.01	23:00	11.01	8:00
Terespol	II	–22.2	–13.1	1.4	5.01	21:00	11.01	6:00
Kozienice	III	–21.6	–11.6	1.3	6.01	17:00	11.01	7:00
Celejów	IV	–24.5	–12.8	0.8	5.01	23:00	11.01	8:00
Lublin-Radawiec	IV	–22.1	–12.2	1.1	6.01	0:00	11.01	7:00
Leśniowice	V	–21.5	–12.5	0.0	6.01	0:00	11.01	7:00
Rybczewice	V	–24.4	–12.8	0.4	6.01	0:00	11.01	8:00
Zamość	V	–21.6	–12.6	1.1	6.01	0:00	11.01	9:00
Guciów	VII	–25.3	–13.6	–0.4	6.01	0:00	11.01	19:00
Sandomierz	VIII	–20.2	–11.5	1.1	6.01	17:00	11.01	8:00

in Siedlce, Lublin-Radawiec, Włodawa, Sandomierz, and Kozienice, the break lasted for two days (9–10 January). Thermal conditions for the frost wave at all analysed stations were recorded in the period from 6 to 8 January, and on 11 January which was the last day of the wave. With the exception of the station in Guciów, where at 19:00 UTC the air temperature was still –15.7°C, the end of the frost wave occurred in the morning hours from 6:00 to 9:00 UTC (Tab. 2).

The lowest mean temperature during the frost wave in the period from 7 to 11 January 2017 occurred in Guciów (–13.6°C). Similar values were recorded in Terespol (–13.3°C) and Włodawa (–13.0°C). The highest mean temperature occurred in Sandomierz (–11.5°C) and in Kozienice (–11.6°C).

Among the analysed stations of the Lublin Region, the lowest minimum temperature was observed in Guciów (–25.3°C). About 1°C higher values of air temperature were observed in Wola Wereszczyńska and Celejów (–24.5°C) as well as in Rybczewice (–24.4°C). The highest value of the minimum temperature occurred in Sandomierz (–20.2°C). The maximum air temperature during the analysed frost wave varied from –0.4°C in Guciów to 1.4°C in Terespol.

During 9 and 10 January, the minimum air temperature has risen above the –15°C threshold. On 9 January, the minimum temperature was from –8.1°C in Rybczewice to –13.1°C in Kozienice. Only in Terespol, the minimum temperature was –16.1°C. On 10 January, the minimum temperature was >–15°C only at 5 out of 12 stations (Siedlce, Lublin, Włodawa, Sandomierz, and Kozienice), where it was between –12.4°C in Siedlce and –15°C in Lublin.

The analysis of the temperature observed during the frost wave at selected stations of the Lublin Region showed the greatest thermal variability by night from 16:00 UTC to 8:00 UTC. Such a situation occurred, among others, during two coldest days of the wave, i.e. 7 and 8 January 2017 (Fig. 4). On 7 January, until 16:00 UTC, the course of air temperature at the analysed stations was similar. The differences were small with the exception of the station in Kozienice, warmer by about 2°C. In later hours, the differences between particular stations increased, and exceeded 7°C. The lowest temperature values were recorded at the stations in Guciów, Rybczewice, and Wola Wereszczyńska, and the highest – in Lublin-Radawiec, Siedlce, Kozienice, and Zamość. It is noteworthy that in Guciów and Zamość, located at a distance of approximately 25 km from each other, differences in temperature exceeded 5°C. It means that local conditions are of particular importance in the development of thermal conditions. Around 9:00 UTC, differences in thermal conditions between all stations in the region decreased, and did not exceed 3°C.

After the end of the frost wave, on 11 January 2017, there was further increase in temperature, leading to thaw on the next day. The fastest increase

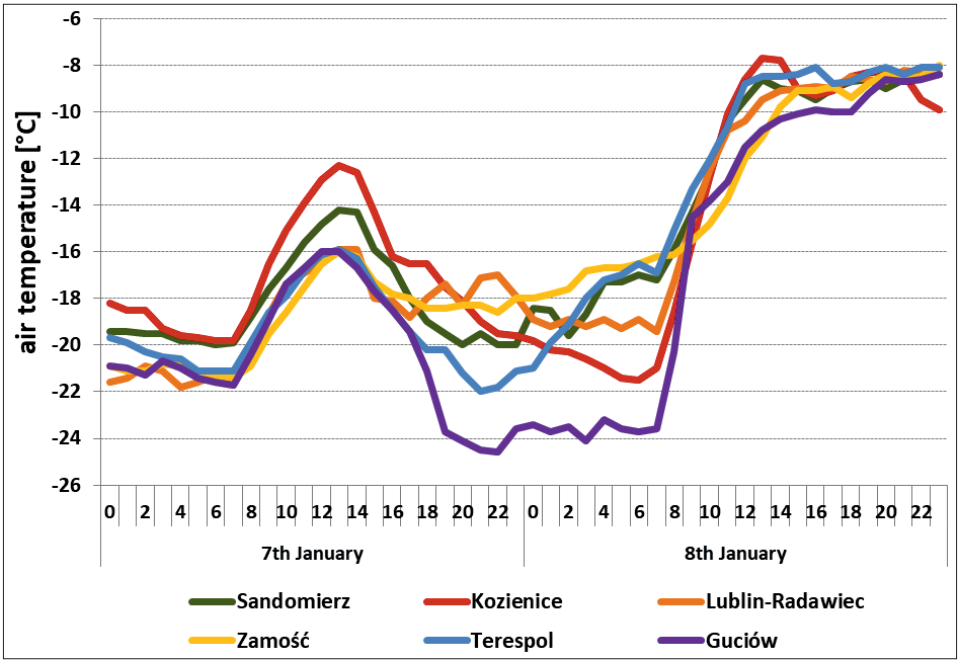

Fig. 4. Air temperature in the Lublin Region on 7 and 8 January 2017 (authors' study)

of air temperature was on 11 January, from 6:00–13:00 UTC. It was 7 to 14°C (on average 1–2°C/hour).

CONCLUSIONS

The mean temperature in January 2017 (from –6.9°C in Guciów to –4.9 in Siedlce) was significantly lower than the mean 2013–2017 January temperature in the Lublin Region.

The occurrence of the frost wave of 5–11 January 2017 was connected with the high pressure system with the centre over Scandinavia, and the inflow of Arctic air. The longest frost wave was in Terespol and lasted 7 days. In Siedlce, Lublin-Radawiec, Sandomierz, and Kozienice, it began one day later, and its main part was separated from the last frost day by two warmer days ($t_{min} > -15$°C).

The lowest mean, maximum, and minimum temperature values during the frost wave occurred in Guciów (–13.6°C, –0.4°C, –25.3°C, respectively). The highest mean and minimum temperature values occurred in Sandomierz (–11.5°C and –20.2°C, respectively), and the highest maximum temperature was observed in Terespol (1.4°C).

During the frost wave, the highest thermal variability between the stations occurred at night from 7 to 8 January 2017, when the thermal differences reached 7°C. The highest decreases in temperature were observed at the stations of Roztocze and Lublin Polesie, and the lowest – at the stations of the northwestern part of the Lublin Region and those near the largest cities, namely Lublin and Zamość. It seems, however, that local conditions are of greater importance than geographic location of stations in particular climatic regions of the Lublin Region.

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