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ICE PHENOMENA IN RIVERS OF THE COASTAL ZONE (SOUTHERN BALTIC) IN THE YEARS 1956-2015

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Abstract

The paper presents a description of the course of ice phenomena in three rivers (Rega, Parsęta, Łupawa) in the coastal zone (Southern Baltic) in the territory of Poland. An evident acceleration of the term of decline of ice phenomena has been observed over the period of the last 60 years, varying from 3 to 5 days·dec^{-1}. The situation caused shortening of the ice season in a range from 3 to 7 days dec^{-1}. The observed transformation of the ice regime of rivers should be associated with climatic changes. The analysis of air temperature in the same period for two meteorological stations (Kołobrzeg, Łeba) suggests a considerable increase in the mean annual air temperature, amounting to 0.3 and 0.2ºC·dec^{-1}, respectively. In the monthly distribution, temperature growth was the highest in April, where an increase in air temperature of 0.5ºC·dec^{-1} and 0.4ºC·dec^{-1} was recorded, respectively.

Key words: ice phenomena, river, coastal, Baltic

INTRODUCTION

Modern climatic changes are reflected in the course of many processes and hydrological phenomena. A very extensive collection of papers in the discipline suggests the multidimensional character of the relationship between climate and water (Hellmann and Vermaat 2012, Latkovska et al. 2012, Bednorz et al. 2013, Salamat et al. 2014, Yan and Zheng 2015, Choiński et al. 2015, Ejankowski and Lenard 2015, Arnell and Gosling 2016, Varela-Ortega et al. 2016). The characteristic feature of moderate latitudes is the occurrence of ice phenomena on rivers and lakes in the winter season. In the case of rivers, the occurrence of ice affects their functioning in the hydrologic context (Prowse and Carter 2002, Ma et al. 2005, Turcotte et al. 2011, Kalinowski et al. 2012), although it is also important in terms of economic aspects and safety of the population (Nazarenko and Sakharova 1982, Matousek 1990, Starosolszky 1990, Beltaos and Burrell 2002).

In reference to the territory of Poland, the most complex study concerning the occurrence of ice on rivers was performed by Gołek (1964). The paper includes data on the parameters of ice phenomena in several tens of rivers in the years 1946-1960. The current knowledge in the scope has a point character, referring to particular rivers (Grześ 1999, Ciupa 2006, Pawłowski and Sobota 2012, Gorączko and Pawłowski 2014, Kornaś 2014, Trubalski 2014).

The issues discussed in this paper refer to this type of studies. Its objective is to determine long-term changes in the occurrence of ice phenomena on selected coastal rivers in the context of climatic changes. No analysis of ice phenomena for such a long observation term exists so far.

STUDY AREA, MATERIALS AND METHODS

Due to the vicinity of the Baltic Sea, the northern area of Poland is a specific region. According to Cieśliński (2006), the coastal zone of the southern Baltic Sea is a place valuable in economic terms, but also due to the unique character of the natural environment. Such unique character is expressed among others in climatic conditions, as evidenced by the continentalism index. In Poland, it varies from 38 to 52%, and the lowest values concern the coastal zone (Atlas… 1994). Świątek (2014) also emphasised the specificity of the area in terms of distribution of atmospheric precipitation.

In terms of hydrographic division, the boundary of the coastal zone is the watershed of the I order (Fig. 1) separating two large catchments in Poland (Vistula and Odra rivers), and designating so-called coastal rivers. The paper presents an analysis of changes in ice conditions for three of them, namely the Rega (profile Trzebiatów), Parsęta (profile Bardy), and Łupawa Rivers (profile Smołdzino).

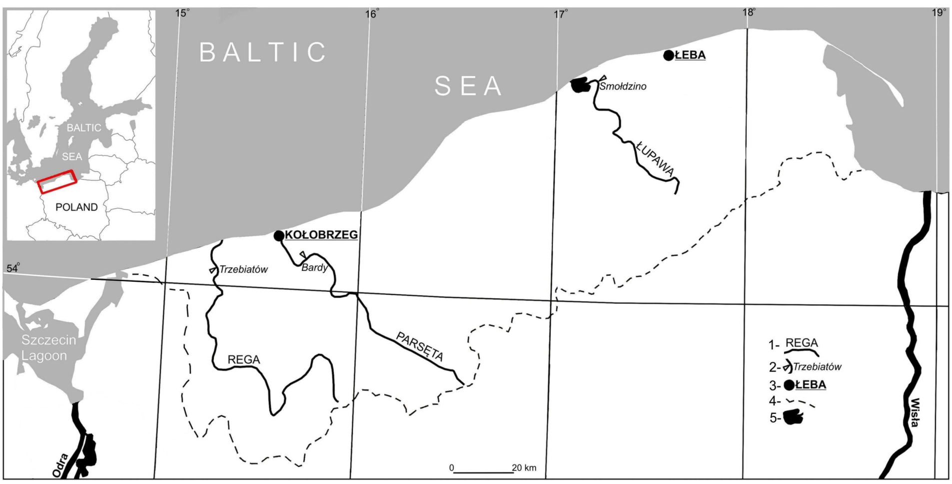

Fig. 1. Location of study objects. 1– rivers, 2 – observation site, 3 – meteorological station, 4 – watershed of the first order, 5 – lake Gardno

The Rega River is the longest (168 km), followed by the Parsęta (139 km) and Łupawa rivers (98.7 km). All of the rivers analysed in the paper and their catchments are subject to numerous studies concerning among others climatic, biological, geomorphological, and hydrological factors, human impact, etc. (Zwoliński 1989, Kolendowicz 1995, Obolewski et al. 2009, Mazurek 2010, Radtke et al. 2010, Lampart-Kałużniacka et al. 2012, Major and Pawlyta 2012, Szpikowski and Domańska 2014). The determination of the course of ice phenomena is aimed at expanding the already rich knowledge on the subject.

The paper is based on data of the Institute of Meteorology and Water Management (IMGW) concerning observation of ice phenomena on three rivers analysed in the paper in the years 1956-2015 (Rocznik…, Centralna…). The observations covered the determination of the date of the commencement and end of occurrence of ice phenomena. An ice phenomenon is defined as any form of ice on water (stranded ice, frazil ice, ice cover, etc.). The difference between the extreme terms of occurrence of ice in water provides information on the duration of ice phenomena. The analysis of ice phenomena was presented in the course of the hydrological year adopted for Poland (1 November - 31 October).

Moreover, the paper uses information concerning changes in air temperature in the analogical period for stations Kołobrzeg and Łeba, also collected by IMGW. Air temperatures were considered over the hydrological year.

The analysis of trends of changes in the ice conditions of the discussed rivers and air temperature in the analysed period was conducted by means of linear regression in Microsoft Excel software, adopting the significance level $p = 0.05$.

RESULTS AND DISCUSSION

Figure 2 presents the course and tendencies of changes in the commencement and end of ice phenomena on the analysed rivers.

The average term of commencement and end of ice phenomena for the Rega River in the above period was 27 December and 12 February, respectively. The commencement of ice phenomena was usually recorded on 1 December. The latest term of the decline of ice phenomena occurred on 19 March. The average term of commencement and end of ice phenomena for the Parsęta River was 27 December and 15 February. The commencement of ice phenomena was recorded the earliest on 2 December. The latest term of the end of ice phenomena occurred on 17 March. The average term of commencement and end of ice phenomena for the Łupawa River was 27 December and 8 February. The commencement of ice phenomena was recorded the earliest on 1 December. The latest term of the decline of ice phenomena also occurred on 19 March. In the case of the Rega River, no tendency was recorded in terms of development of ice phenomena. For the two remaining rivers, the tendency was positive. This means their increasingly delayed commencement. In both of the cases, the tendencies were statistically insignificant. A more coherent situation was recorded in the case of tendencies of the decline of ice phenomena. It was negative and statistically significant in all of the cases. The acceleration of the decline of ice phenomena amounted to 3 days·dec^{-1} in the case of the Rega and Parsęta rivers, and 5 days·dec^{-1} in the case of the Łupawa River.

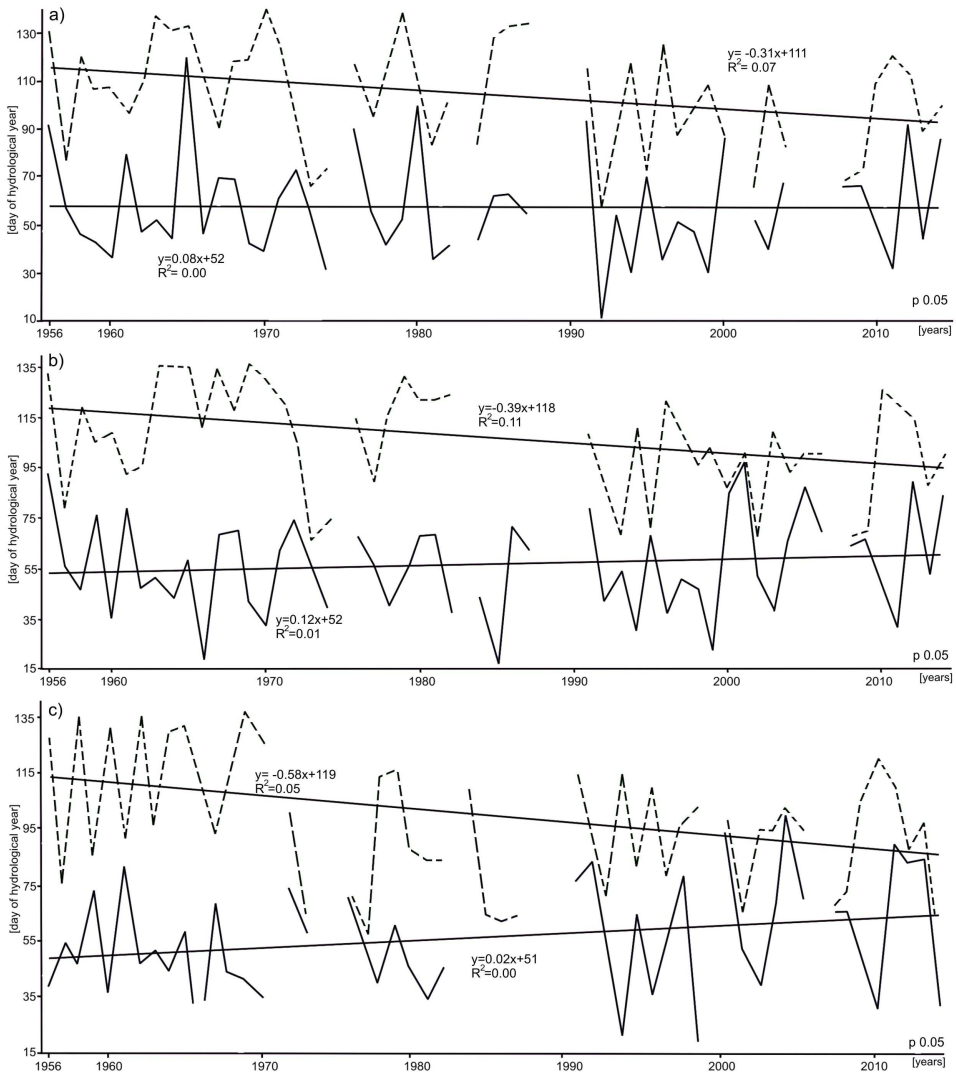

Fig. 2. Commencement and end of ice phenomena; a) Rega, b) Parsęta, c) Łupawa; continuous line – commencement of ice phenomena, dotted line – end of ice phenomena, discontinued line – no data

The above situation contributed to a reduction in the persisience of ice phenomena (Fig. 3).

The mean persistence of ice phenomena in the case of the Rega River amounted to 49 days, Parsęta 51 days, and Łupawa 44 days. The longest persistence of ice phenomena equalled 101 days for the Rega and Parsęta rivers, and 97 days for the Łupawa River.

In the analysed multiannual, they were shorter by: 3 days·dec^{-1} for the Rega River, 5 days·dec^{-1} for Parsęta, and by 7 days·dec^{-1} for Łupawa. In the first of the cases, the changes are not statistically significant.

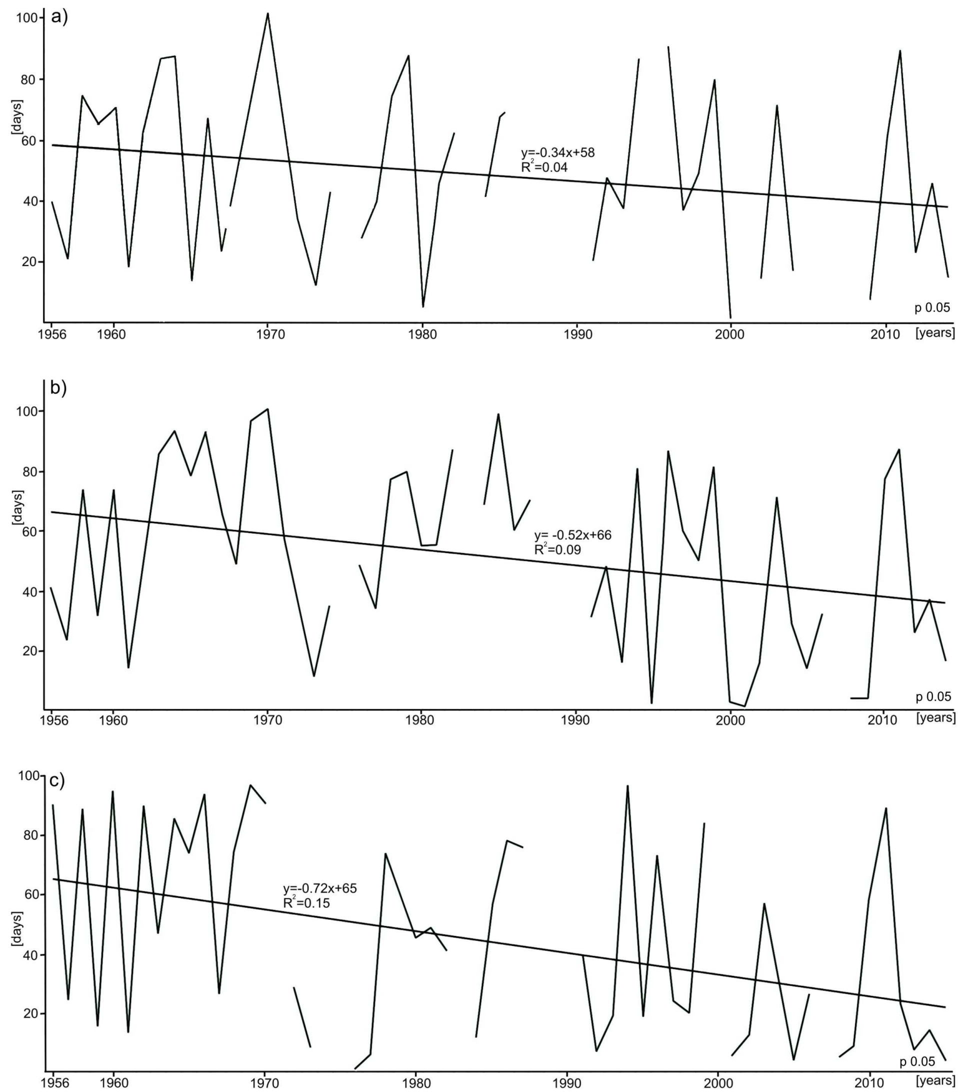

Fig. 3. Persistence of ice phenomena; a) Rega, b) Parsęta, c) Łupawa, discontinued line – no data

The obtained results suggest evident changes in the ice regime of all of the analysed rivers over the last 60 years. The situation corresponds with the observed climatic changes. The analysis of air temperature for stations Kołobrzeg and Łeba (Fig. 4) directly suggests warming.

In the case of station Kołobrzeg, an increase in temperature by $0.3°C·dec^{-1}$ was recorded, and for station Łeba, the increase amounted to $0.2°C·dec^{-1}$. The changes were statistically significant. In the monthly course, the highest increase in temperature was recorded in April ($0.5°C·dec^{-1}$ and $0.4°C·dec^{-1}$, respectively). A decreasing tendency was only recorded in October for Łeba, but it was not statistically significant.

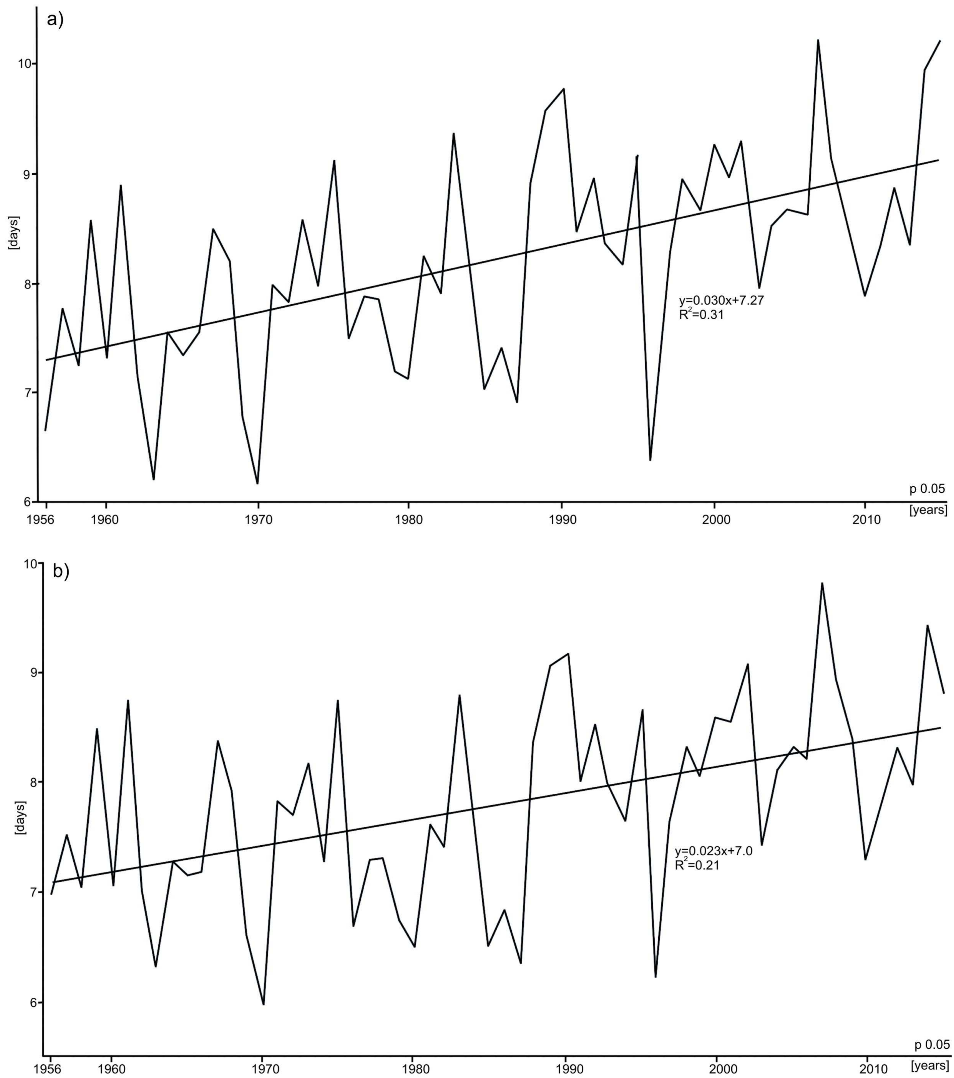

Fig. 4. Mean annual air temperatures; a) Kołobrzeg, b) Łeba

The results of the conducted analyses directly suggest the occurrence of considerable changes in the ice regime of coastal rivers over the last several decades. Delayed appearance of ice, its earlier decline, and consequently shorter persistence of ice phenomena is a situation corresponding with many similar studies in the world. Analysing ice phenomena on the Yellow River, Jiang et al. (2008) observed a reduction of their persistence – the period, depending on the observation station amounts to even 38 days. In the case of the Drava River, constituting a right tributary of the Danube River, delayed appearance of ice was observed, and its earlier decline, by 9 and 10 days, respectively (Takács and Kern 2015). An increasingly shorter ice season was recorded for among others rivers in Russia (Soldatova 1993).

Earlier decline of the ice cover was also recorded in North America (Zhang et al. 2001).

A description of the ice phenomena on rivers in the region of the Baltic Sea was presented by Klavins et al. (2009), analysing the area of the Baltic republics (and Belarus). According to the study, the persistence of the ice cover was reduced in a range from 2.8 to 6.3 days·dec^{-1} over the last 30 years.

The comparison of the obtained results with earlier studies provides information on the ice phenomena of the Rega River in the years 1946-1960, and the Łupawa River in the years 1947-1960 (Gołek 1964). The average term of commencement and end of ice phenomena for the Rega River in the above period was 1 January and 21 February, respectively. The commencement of ice phenomena was recorded the earliest on 24 November. The latest term of decline of ice phenomena was 22 March. The average term of commencement and end of ice phenomena for the Łupawa River was 5 January and 28 February, respectively. The commencement of ice phenomena was recorded the earliest on 7 December. The latest term of decline of ice phenomena also occurred on 22 March. The average persistence of ice phenomena in the case of the Rega River amounted to 30 days, and for Łupawa 28 days. The longest persistence amounted to 93 days in both of the cases.

According to Okulanis and Szukalski (1960), analysing ice phenomena in rivers of the Kaszubskie Lakeland in northern Poland (including the Łupawa River in the years 1947-1958), they persisted the longest in the central part of the area (45-59 days), and persisted for an average of 39-45 days in the remaining area.

The comparison of the results of the conducted analysis to other studies regarding ice phenomena in Polish rivers suggests that coastal rivers are characterised by similar parameters. This concerns among others the Warta River. According to Kornaś (2014), describing ice phenomena on the river in the years 1961-2010 based on observations conducted in Poznań, the longest persistence of ice phenomena amounted to 118 days. In the case of the Vistula River (observation station Toruń), Pawłowski (2015) determined that in comparison to the end of the 19th century, a reduction of the persistence of ice phenomena occurred from 88 to 53 days. In the case of the Brda River (station Tuchola), the average persistence of ice phenomena in the years 1955-2009 amounted to 41 days, the shortest period (except for years where no occurrence of ice phenomena was recorded) 2 days, and the longest 104 days (Choiński and Ptak 2016).

Changes in the ice regime will have their consequences in the functioning of fluvial ecosystems. In addition to biotic conditions (Engström et al. 2011, Prowse et al. 2011), they will also affect the economic aspect, including issues related to e.g. energy production (Agafonova and Frolova 2009, Bajkowski and Olifirowicz 2014, Timalsina et al. 2015). The latter issue is important in the case of coastal rivers on which hydroelectric power plants are located. Such a situation was favoured by natural environmental conditions. Coastal rivers are among those with the highest inclinations among lowland rivers. In their upper courses, the inclinations reach 7‰ (Florek 2008).

CONCLUSIONS

The climatic changes observed at a global scale result in a number of consequences in the functioning of various components of the natural environment. Particular elements of the hydrosphere are among the most sensitive to the aforementioned changes. The close climate-water relation is evidenced by a number of studies. The results obtained in the paper are in accordance with the trend. The ice season is subject to an evident reduction in duration in the analysed rivers (up to 7 days·dec^{-1}). The situation should be associated with climatic changes. This is confirmed by the course of air temperature in the analysed multiannual. Its recorded increase amounted to 0.25°C·dec^{-1} on average. In the above case, the analysis of data for small rivers also suggests the effect of global warming. Therefore, not only rivers with large catchments, but also small rivers suggest the existence of the phenomenon.

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ZLODZENIE RZEK STREFY PRZYMORSKIEJ (POŁUDNIOWY BAŁTYK) W LATACH 1956-2015

Streszczenie

W pracy przedstawiono charakterystykę zlodzenia trzech rzek (Rega, Parsęta, Łupawa) w strefie przymorskiej (Południowy Bałtyk) na terenie Polski. Ustalono, że w okresie ostatnich 60 lat wyraźnie widoczne jest przyspieszenie terminu zakończenia zjawisk lodowych wynoszące od 3 do 5 dni·dec^{-1}. Sytuacja ta spowodowała skrócenie sezonu lodowego w przedziale od 3 do 7 dni·dec^{-1}. Obserwowaną transformację reżimu lodowego rzek należy wiązać ze zmianami klimatycznymi. Analiza temperatury powietrza w tym samym okresie dla dwóch stacji meteorologicznych (Kołobrzeg, Łeba) pozwala stwierdzić, że nastąpił znaczny wzrost średniej rocznej temperatury powietrza, który wynosił odpowiednio 0,3 i 0,2°C·dec^{-1}. W układzie miesięcznym ocieplenie było najwyższe w kwietniu, kiedy odnotowano wzrost temperatury powietrza odpowiednio rzędu 0,5°C·dec^{-1} i 0,4°C·dec^{-1}.