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VARIABILITY OF AIR TEMPERATURE IN SKIERNIEWICE, POLAND, OVER THE PERIOD 1923–2022

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ABSTRACT

The study aimed to determine the magnitude of changes in air temperature in Skierniewice, Poland, over the last 100 years, with particular emphasis on multi-year variability. The source material for the analyses were air temperature measurements from 1923 to 2022 obtained from the meteorological station in the Experimental Field of the Warsaw University of Life Sciences and the station in the Experimental Orchard of the National Institute of Horticultural Research. The study presents average annual, minimum, and maximum air temperatures along with an assessment of the trend of their multi-year variability. The features of changes in the average air temperature in Skierniewice presented in the study based on a 100-year series of meteorological measurements are characterized by high temporal variability with a clear upward trend. The average warming rate over 100 years was 0.17°C per 10 years, but in the last 60 years it has already reached 0.38°C per 10 years. In the case of the average annual air temperature since 1981, there has been a sequence of years warmer than average throughout the measurement period. The number of summer days (>25°C) and hot days, when the maximum temperature exceeds 30°C, is also increasing. In the analyzed period, the decade 2013–2022 was the warmest.

Key words: agroclimate changes, warming rate, temperature variability, weather forecasting

INTRODUCTION

Climate and its variability significantly affect various areas of human life, from economic activity through living conditions to food security. For many years, there has been a view in the scientific literature that the observed climate changes are, among others, significantly influenced by humans (Manabe & Wetherald 1975; Wu et al. 2013; Herrero et al. 2016; James et al. 2017). This applies in particular to the impact of human activity on the increase in the concentration of greenhouse gases and dust in the atmosphere (He & Silliman 2019). However, air temperature on Earth changes naturally over time. Boryczka (2001) states that cyclical climate changes are caused by the Earth's rotation, the Earth's movement around the Sun, and changes in solar activity. Time series of air temperatures in Europe over recent centuries indicate that contemporary climate warming may be largely due to natural causes (Boryczka & Stopa-Boryczka 2004). Based on reconstruction analyses, Burroughs (2007) states that the climate has also been subject to significant temperature fluctuations in past eras. However, these changes were slow, and the increase in average annual temperature was at most a few tenths of a degree Celsius per 100 years. The recently observed constant and rapid increase in air temperature is probably related to the anthropogenic factor (Michalska 2011). The temperature increase recorded in the second half of the 20th century (1951–2000) had a clear linear trend, reaching an unprecedented value of 0.2°C per 10 years (Kożuchowski & Żmudzka 2001).

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According to Gumiński (1998), heat, water, and light are the three fundamental factors related to plant development; therefore, the global increase in air temperature has and will significantly impact agricultural production around the world. According to Karaczun and Kozyra (2020), Poland is already experiencing the negative consequences of climate change. It is necessary to point out that Poland's food security is and will be affected not only by changes that will occur in our country, but also by those that will influence food production on a global scale. The adverse effects of climate warming observed in many regions affect crops that are the basis of global agri-food trade (e.g., beverage and spice crops) (Adhikari et al. 2015; Jayasinghe & Kumar 2019). A reduction in their yields may limit the availability of their products on the world market, and therefore also in Poland.

Climate change trends can only be assessed based on long-term measurement data. The analysis of a multi-year series of meteorological measurements allows us to learn about the range of fluctuations in climatic conditions and determine the direction and rate of their changes. This study aimed to determine changes in air temperature in Skierniewice over the last 100 years (1923–2022), with particular emphasis on multi-year variability. As mentioned above, ongoing climate change may threaten human health, food and water security, and socioeconomic development in many regions. Therefore, the work aimed to verify the occurrence of climate change (warming) in Poland. This was made possible by access to a long series of meteorological data dating back to the 1920s. According to the Doboszyńskis (1963), the location of Skierniewice is such that the data can be considered characteristic of a larger area of central Poland.

MATERIALS AND METHODS

The source material included air temperature measurements for the period 1923–2022 from the meteorological station located at the Warsaw University of Life Sciences – SGGW (WULS-SGGW) Experimental Field (manual measurements, taken until 2010) and from the automatic station (Metos, Pessl Instruments, Austria) located in the Pomological Orchard of the National Institute of Horticultural Research (51.96 N, 20.16 E, 125 m above sea level). The distance between the two stations is approximately 500 m.

The study presents annual average, minimum, and maximum air temperatures along with an assessment of the multi-year trend of their variability by determining a linear trend line and 30-year moving average. The direction and rate of changes in air temperature were determined using a linear trend at the significance level of $\alpha = 0.05$. Forecasting the course of changes in these parameters for the next decade (2023–2032) was carried out using basic exponential smoothing of time series of data from the last 100 years. Based on the analysis of air temperature data, the number of characteristic days in successive years was determined:

– number of frosty days per year (maximum temperature <0°C);
– number of very frosty days per year (maximum temperature <−10°C);
– number of summer days (maximum temperature >25°C);
– number of hot days (maximum temperature >30°C).

The determinations were carried out according to the thresholds proposed by Gumiński (1998).

Analyses were performed using an Excel spreadsheet (Microsoft, USA) and Statistica 13.1 (StatSoft, Poland).

RESULTS AND DISCUSSION

The average air temperature in Skierniewice over the last 100 years (1923–2022) was 8.3°C and ranged from 6.1°C in 1956 to 10.6°C in 2019. The range of fluctuations in the average annual air temperature during this period was as much as 4.6°C. The statistical coefficient of variation of average annual air temperatures was 12.5%.

Podstawczyńska (2010) states that the average temperature for a period of 103 years (1904–2006) for Łódź, which is located 53 km in a straight line southwest of Skierniewice, was 7.8°C. During the period under study, the annual air temperature in Łódź varied from 5.5°C in 1940 to 9.6°C in 1989 and 2000. Due to war activities, the data for 1940 in Skierniewice are incomplete, so they cannot be referred to; however, the average air temperatures in 1989 and 2000 were also high, reaching 9.9°C. In turn, according to Kozłowska-Szczęsna et al. (1993), the average annual air temperature for Warsaw (66 km northeast of Skierniewice) during a period of 200 years (1781–1980) was 7.5°C, with an even higher temperature difference between the coldest and warmest years for that period under study (4.9°C). Wójcik and Miętus (2014), who analyzed temperature data in Poland from 1951 to 2010, also found an increase in the average annual temperature throughout the country.

Since the 1980s, a clear increase in the average air temperature in Skierniewice has been observed (Figs. 1–4), which is confirmed not only by the linear model describing the course of changes in average annual temperatures in successive years (r = 0.48), but also by the 30-year moving average. The straight line representing the linear relationship between the deviations in average annual air temperatures and the multi-year average intersects the time axis strictly in 1974 (Fig. 2). After that year, most average annual temperatures were higher than the multi-year average.

The average annual air temperature over the last ten years (2013–2022) was 9.7°C, whereas in the first ten years of measurements (1923–1932) it was 8°C (Fig. 3). The average value of the annual temperature for the 30 years 1983–2012 is higher than the corresponding values for the previous two 30-year periods. However, it is lower than the average over the last ten years (Fig. 4). There is a high probability that in the next ten years the average annual temperature in Skierniewice may exceed 10°C (Fig. 1).

Kozłowska-Szczęsna et al. (1993) report that in Warsaw, in the years 1781–1980 they assessed, there was a "slight upward trend in the average annual air temperature", which the authors describe with the linear regression equation $y = 0.0074\,x + 6.7$, with the correlation coefficient r = 0.39, where y is the average air temperature in year x, and x varies from 1 (in 1781) to 200 (in 1980). In the case of our 100-year observations (x ranging from 1 to 100), the formula is $y = 0.0173\,x + 7.5$ (r = 0.48). Both models differ significantly in the value of the slope coefficient (a). For the years 1781–1980 (Warsaw), the temperature increase in each successive year was 0.0074°C, which for 200 years gives a value of 1.48°C. In the case of Skierniewice, a = 0.0173 means that over 100 years of observations, the temperature increased by as much as 1.73°C.

Wójcik and Miętus (2014) describe the annual values of air temperature increase in Poland by multiplying the value of the slope coefficient of the linear regression model by 10 (°C per 10 years). The authors showed that in the years 1951–2010 (60 years), the trend coefficient of increase in average annual air temperature in central Poland was 0.22°C per 10 years. In the case of data from Skierniewice, the trend coefficient of temperature increase over the last 60 years was much higher, reaching the value of 0.38°C per 10 years ($y = 0.0381\,x - 67.243$, r = 0.65). Bielec-Bąkowska and Piotrowicz (2013), analyzing the course of temperature changes throughout Poland, report that the greatest increase in annual air temperatures, both in maximum, minimum, and average values, was observed in the central and western parts of Poland. The cited data confirm the information about climate warming and its high temporal variability.

Ghazi et al. (2023) projected changes in climatic conditions in Central Poland. The results show that temperatures (and precipitation) will increase in this region by the end of the twenty-first century. The authors expect that the increase in average annual temperature will amount to 1–4.8°C, with an increase in the number of hot days and a decrease in the number of frosty days.

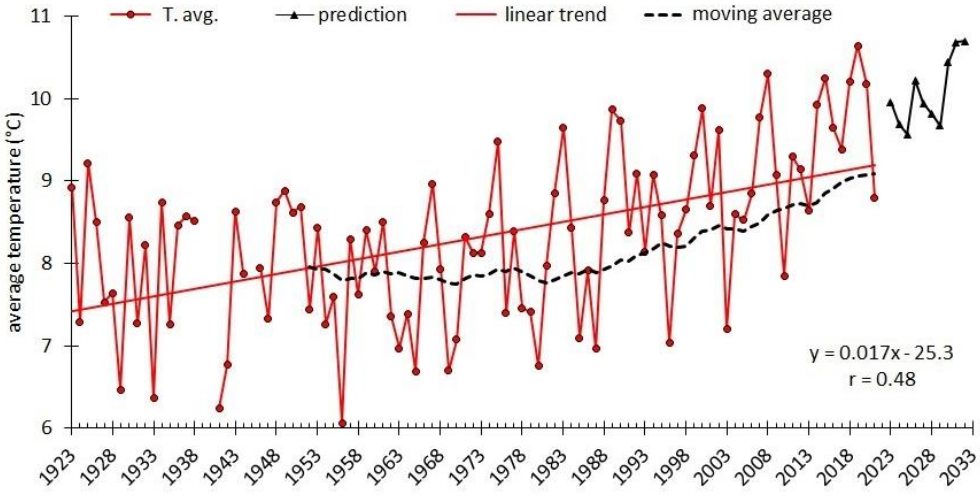


Figure 1. Variability of average annual air temperatures (Skierniewice 1923–2022)

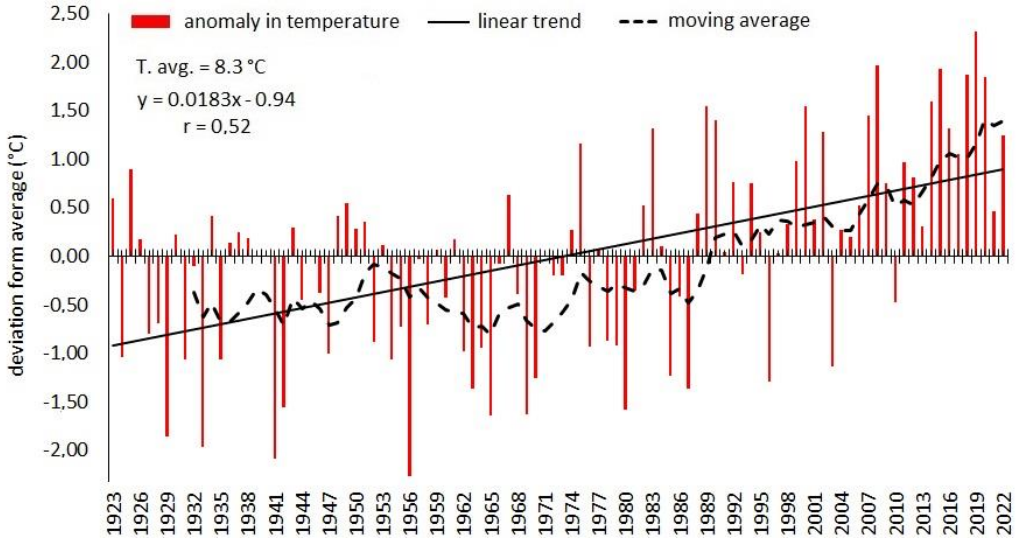


Figure 2. Long-term course of average annual air temperature anomalies in Skierniewice (1923–2022)

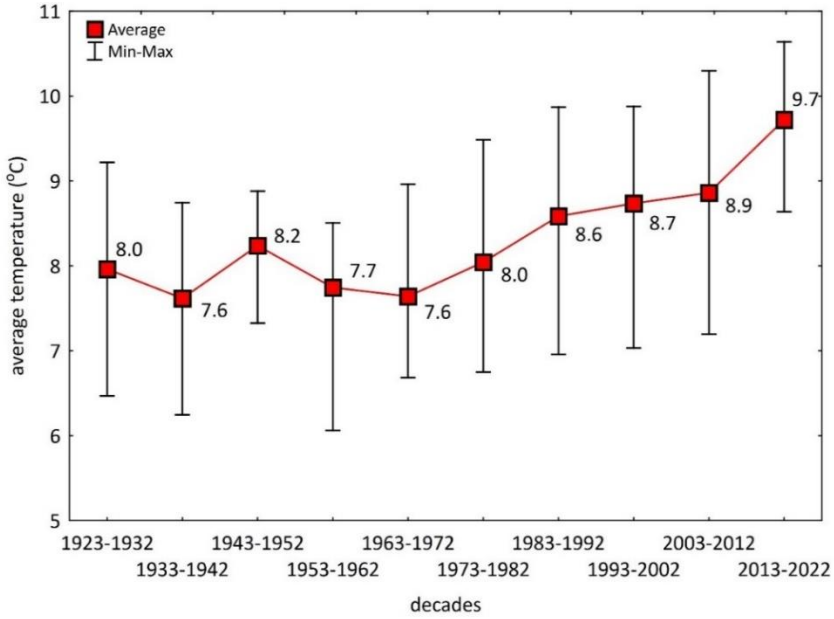


Figure 3. Variability of average air temperatures in individual 10-year periods (Skierniewice 1923–2022)

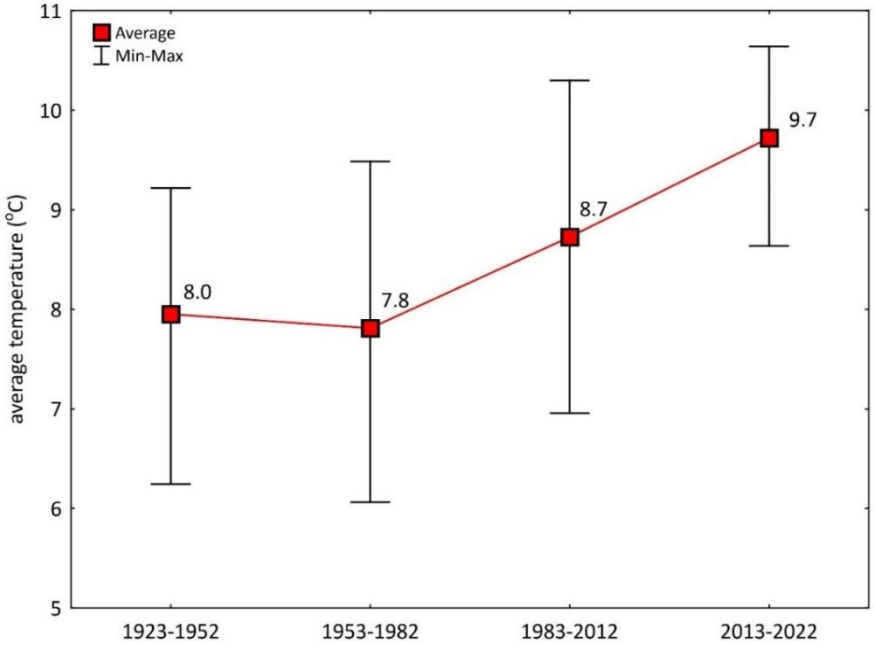


Figure 4. Variability of average temperatures for 30-year periods compared to 2013–2022 (10-year period) (Skierniewice 1923–2022)

The absolute minimum annual air temperatures in Skierniewice ranged from −35.8°C in 1929 to −8.7°C in 1990 (Fig. 5). After 2007, temperatures lower than −30°C were no longer recorded. Although minimum air temperatures have not reached such low values in recent years, no significant impact of the passing years on the recorded minimum temperatures has been confirmed (r = 0.13). Over the last ten years (2013–2022), the average annual minimum temperatures reached the highest value (−15.4°C), with the smallest range in values compared to all assessed 10-year periods of the last 100 years (Fig. 6). In three successive 30-year periods, we observe similar values of average annual minimum temperatures (from −20.6 to −20.1) and a wide spread of these values (Fig. 7). Over the last ten years, the range of these temperatures has been much smaller, and the average value of annual minimum temperatures has increased by almost 5°C. In the winter of 1928/1929, very low air temperatures prevailed throughout Poland. Kuziemska (1983), whose research covered the period until 1975, determined the temperature drop in Żywiec to −40.6°C in February 1929 as the largest in the last 100 years. An even lower value of the minimum temperature that winter (−49°C) is given by Różański (1951). Other authors (Tomczyk et al. 2021) noted an increase in both minimum and maximum temperatures during winter seasons in Poland, with the most intense changes recorded in the northern regions. According to these authors, warmer winters with shorter snow seasons have become more and more frequent in recent years, which is part of global warming trends, especially noticeable in land regions of the Northern Hemisphere.

The number of very frosty days in Skierniewice (maximum temperature <−10°C) has varied significantly over the last 100 years, from their complete absence to as many as 15 days a year in 1942 and 1963 (Fig. 8). The average annual number of very frosty days during the entire monitoring period was 2 per year. Large fluctuations in this parameter in individual years resulted in a very low value of the correlation coefficient (r = 0.18) between the number of very frosty days and successive years of measurements. However, the 30-year moving average shown in the graph has a clear downward trend.

Analyzing the averages for successive 10-year periods, it can be concluded that the lowest average annual number of very frosty days (0.3) occurred in the years 1973–1982 (Fig. 9). This is a very low value compared to the average (5 days a year) observed in 1933–1942. Also over the last ten years we have had on average several very frosty days a year (0.9). Analyzing the first three 30-year periods, a downward trend in the average number of very frosty days can be observed, from 3 days a year in 1923–1952 to 2.3 days in 1953–1982, and only two days in the 30 years 1983–2012.

The annual number of frosty days also shows a decreasing trend for the assessed period of 100 years (r = 0.30, Fig. 10). Over the last 100 years, we have had an average of 35.7 frosty days in Skierniewice. According to Podstawczyńska (2010), in the years 1904–2006 in the Łódź region, frosty days occurred on average 39 times. The decline in the number of frosty days is particularly visible in the last decade, when on average there were only 23 frosty days a year, which is less than the average for all analyzed 100-year periods (Fig. 11).

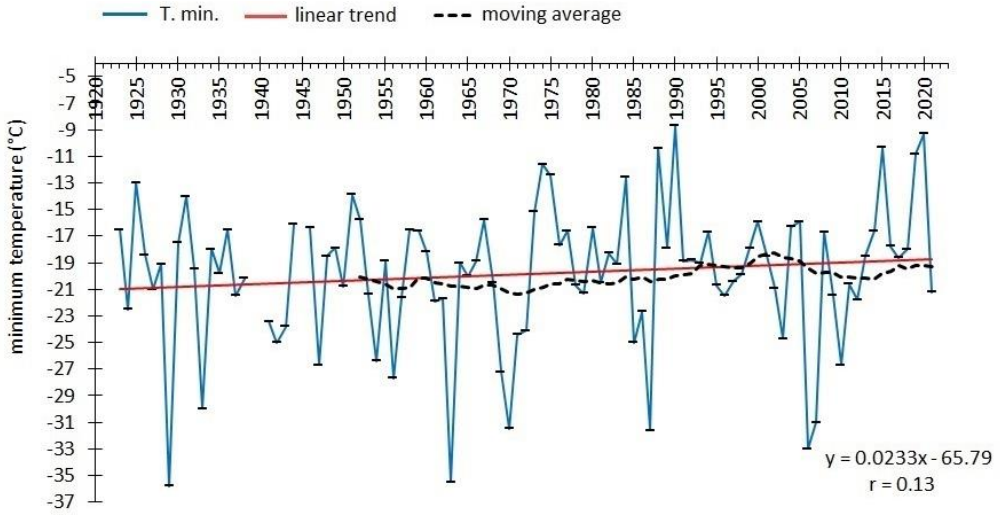


Figure 5. Variability of absolute annual minimum air temperatures (Skierniewice 1923–2022)

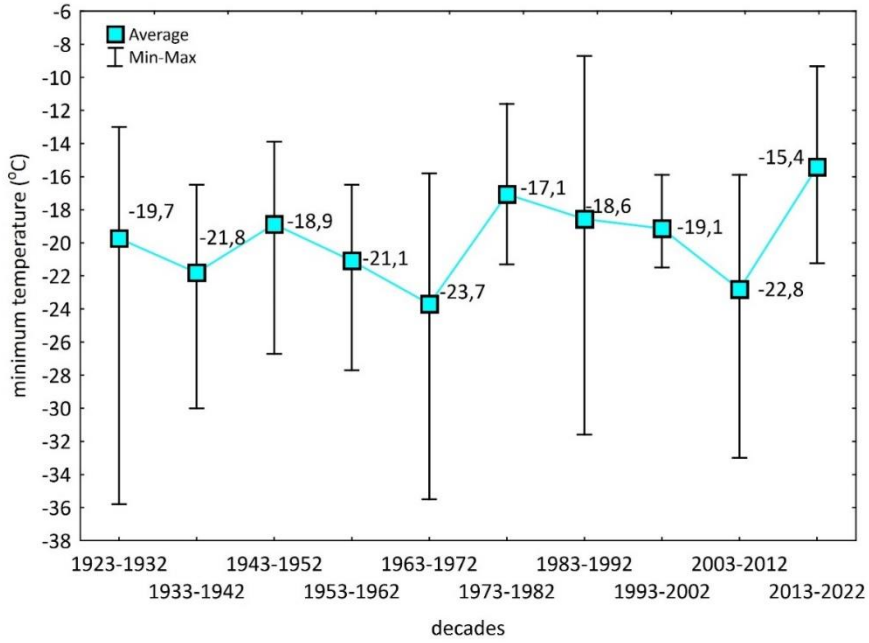


Figure 6. Variability of average absolute minimum temperatures for individual 10-year periods (Skierniewice 1923–2022)

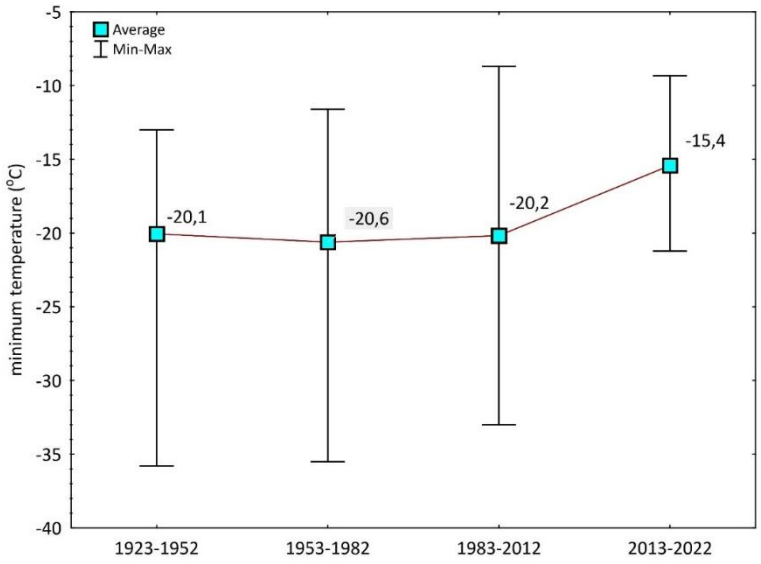


Figure 7. Variability of average absolute minimum temperatures for 30-year periods in relation to the years 2013–2022 (10-year period) (Skierniewice 1923–2022)

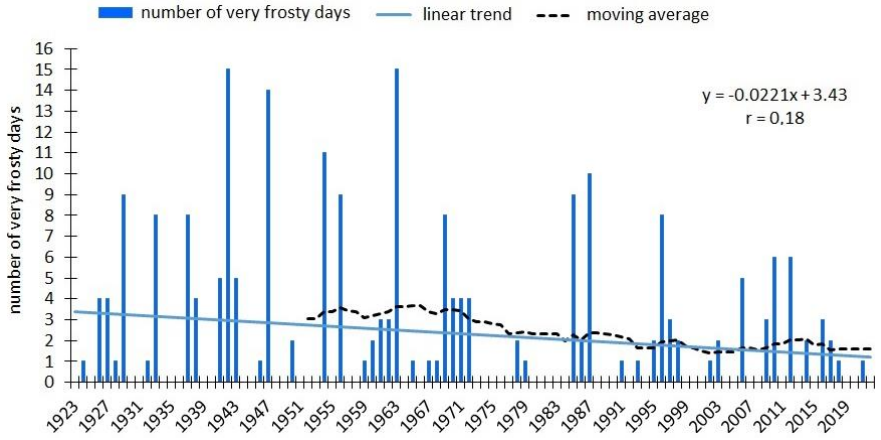


Figure 8. Number of very frosty days (maximum temperature <−10°C) (Skierniewice 1923–2022)

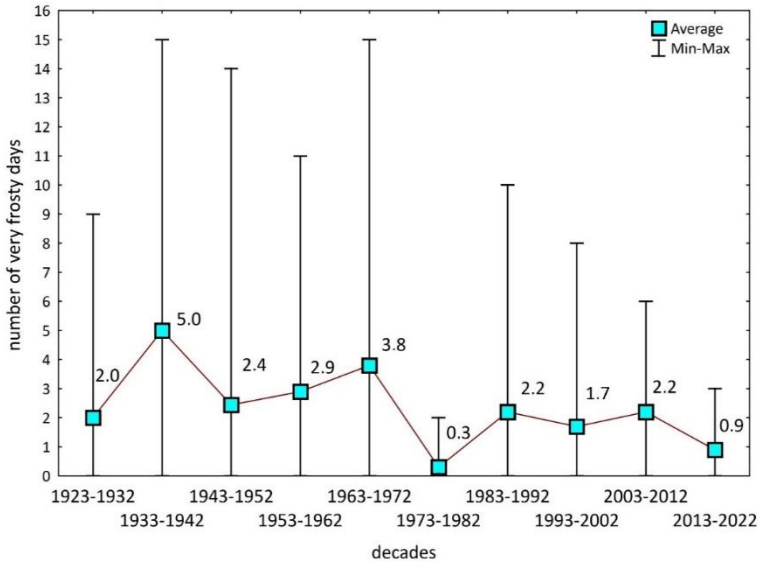


Figure 9. Number of very frosty days in successive 10-year periods (Skierniewice 1923–2022)

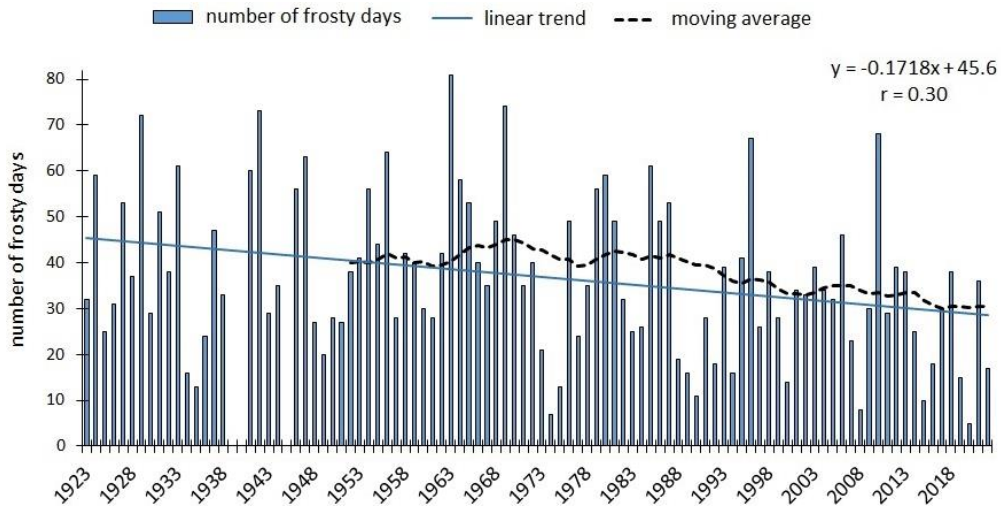


Figure 10. Number of frosty days (maximum temperature <0 °C) (Skierniewice 1923–2022)

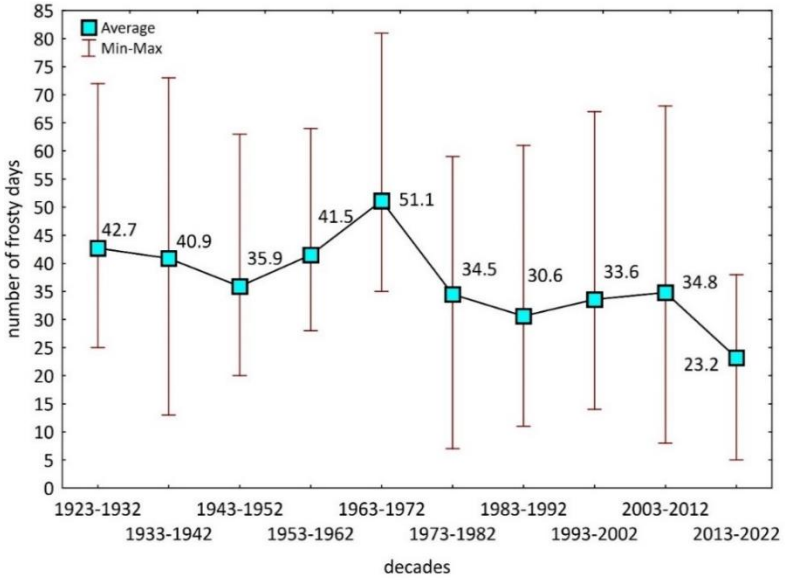


Figure 11. Number of frosty days in successive 10-year periods (Skierniewice 1923–2022)

Absolute maximum annual temperatures ranged from 26.7 °C in 1980 to 38.9 °C in 1943 (Fig. 12). Such high temperatures have not been recorded in Skierniewice. Bielec-Bąkowska and Piotrowicz (2013) report that the highest air temperature in Poland (40.2 °C) was recorded in Prószków near Opole in the previous century (July 29, 1921). Kuziemska (1983), analyzing the range of variability of air temperatures in Poland until 1975, reports that in Warsaw the highest temperatures close to 39 °C occurred in 1892 and 1921, and in the following years no such temperatures were recorded, except for 1959, when the maximum temperature reached 38.3 °C. In 1994, 2013, and 2015, maximum temperatures in Skierniewice slightly exceeded 37 °C. Also, the forecast for the next ten years, based on the analysis of time series, does not predict that the maximum annual air temperature in Skierniewice will exceed 37 °C. The curve representing the 30-year moving average of annual maximum temperatures is decreasing until 1982, and then shows a clear upward trend.

Research by Tomczyk et al. (2022) showed an increase in maximum air temperatures in summer seasons (analyses were conducted from 1966 to 2020). The authors observed that the most intense temperature changes occurred in the last two decades (after 2000) and predicted a further increase in maximum temperature, which is consistent with our observations.

Since the 1980s, along with the increase in the average air temperature in Skierniewice, we have observed an increase in the number of summer days (T_{max} > 25°C), which is illustrated not only by the linear trend model (r = 0.44), but also by the 30-year moving average (Fig. 13). In the last 10-year period, we have observed a significant increase in the annual number of summer days, which has already reached an average value of 58.9 (Fig. 14). In 2018, there were as many as 85 such days, which is the highest value in this period. Over the last 100 years, Skierniewice has had an average of 41.4 summer days per year. The lower average value (37) of this type of days for Łódź in the period 1904–2006 is provided by Podstawczyńska (2010).

The number of hot days with maximum temperatures exceeding 30°C is also increasing (Fig. 15). The most such days were recorded in 2015 (24 days). The average number of summer days over the last 10 years was as much as 13.7 and was much higher than the corresponding values for the previous 10 years and the average value (6.6) for the entire period under study (Fig. 16). The average frequency of hot days in Łódź in the years 1904–2006 was 5 (Podstawczyńska 2010). The trend of increasing the number of summer and hot days is also confirmed by previous works of many authors, including Cebulak and Limanówka (2007), Kaszewski et al. (2007), Bielec-Bąkowska and Piotrowicz (2013), and Tomczyk et al. (2022).

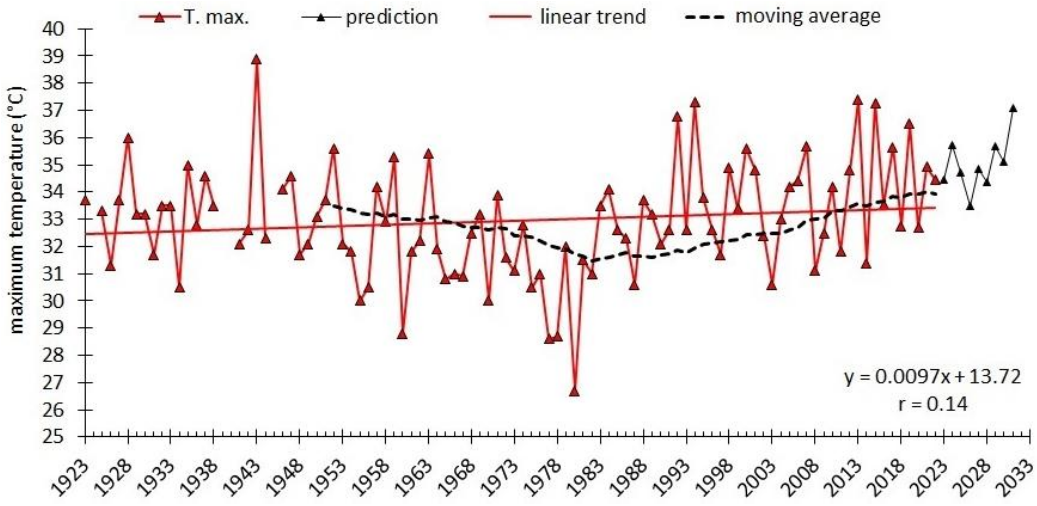


Figure 12. Variability of absolute annual maximum air temperatures (Skierniewice 1923–2022)

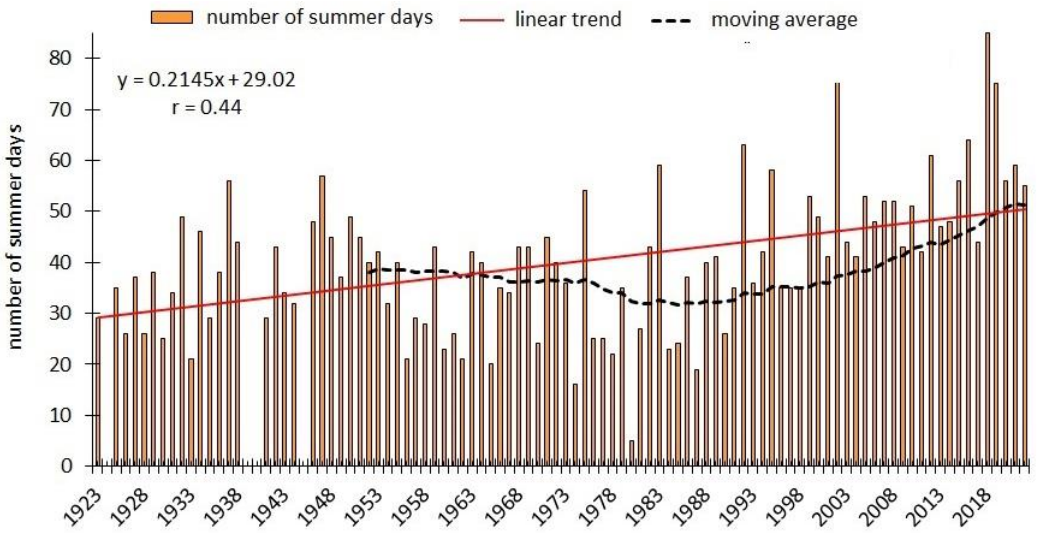


Figure 13. Number of summer days (Skierniewice 1923–2022)

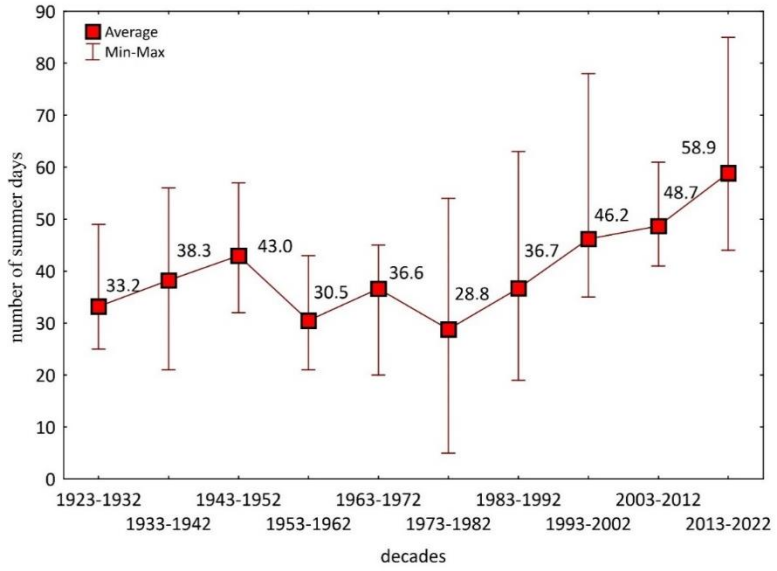


Figure 14. Number of summer days in successive 10-year periods (Skierniewice 1923–2022)

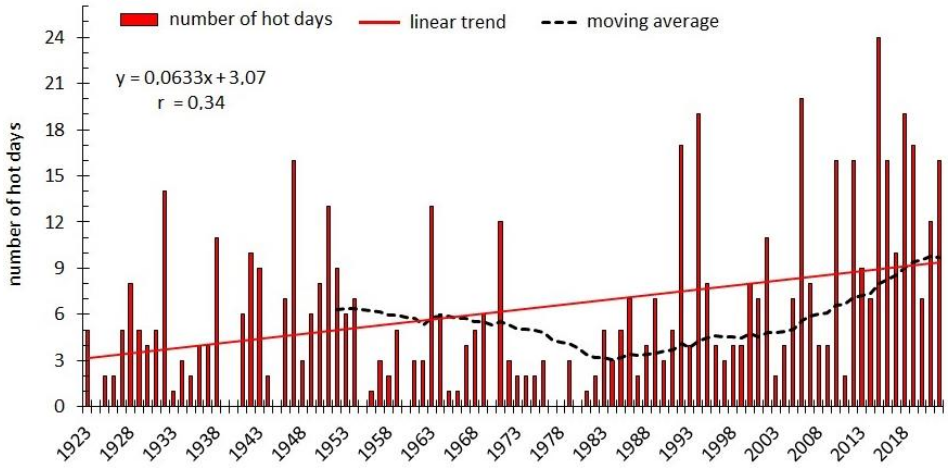


Figure 15. Number of hot days (Skierniewice 1923–2022)

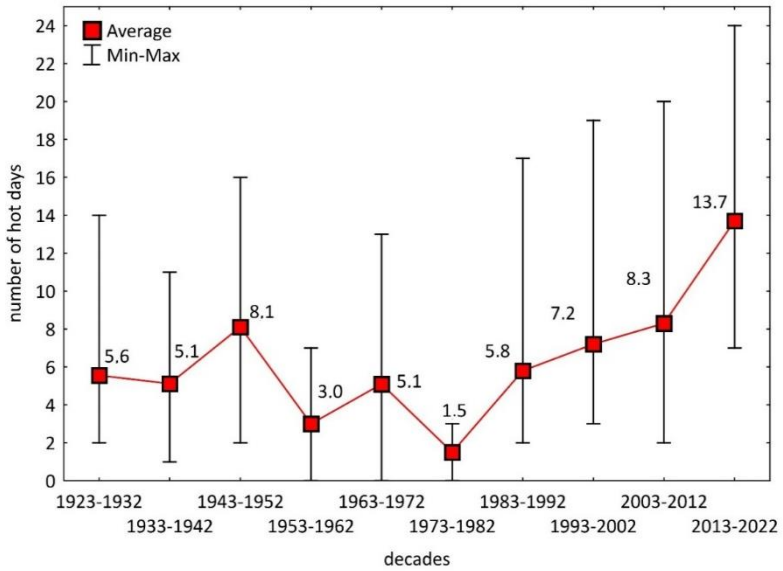


Figure 16. Number of hot days in successive 10-year periods (Skierniewice 1923–2022)

CONCLUSIONS

The characteristics of changes in the average air temperature in Skierniewice, presented in this study based on a 100-year series of meteorological measurements, show high temporal variability with a clear upward trend. High variability over time means that warm and cooler years often alternate. The average warming rate over 100 years was 0.17°C per 10 years, but for the last 60 years it has already reached 0.38°C per 10 years. As for the average annual air temperature, since 1981 there has been a series of warmer years than the average over the entire measurement period. The number of hot and summer days also increased, and the number of very frosty and frosty days decreased. In the analyzed 100-year period, the warmest was the 10-year period 2013–2022.

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