THE CHANGE AND VARIABILITY OF SNOW COVER IN KRAKÓW IN A 100-YEAR OBSERVATION SERIES

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Abstract: This article presents the results of research on the changes and variability of snow cover in Kraków in the 100-year period 1921/22–2020/21 and in its two sub-periods covering the years of the slow and rapid territorial, urban and industrial development of Kraków (respectively, 1921/22–1960/61 and 1961/62–2020/21). The long-term variability of the number of days with snow cover, the maximum depth of the snow layer, the dates of the beginning and end of snow cover duration in the winter season, the potential snow cover duration and the index of snow cover stability were analysed. The directions of changes in the snow cover in the last 100 winter seasons in Kraków correspond to the global changes in air temperature presented in the latest IPCC reports: until the end of the 1950s there were no significant trends, or only small trends were observed, whereas from the beginning of the 1960s faster changes in the snow cover duration and maximum seasonal snow depth have been visible. In the last 60 years (1961/62–2020/21), the impact of global changes in Kraków has been joined by the impact of territorial, demographic and industrial development of the city, causing significant negative trends in snow cover with relative values of less than $-9\% \cdot 10\ \mathrm{years}^{-1}$, both in the case of snow cover duration and its maximum depth in the winter season; these changes are statistically significant. Throughout the whole 100-year period (1921/22–2020/21) and in its second part (1961/62–2020/21), a decrease in snow cover stability has also been observed.

Key words: snow cover change, climate change, winter, Kraków

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Introduction

Snow cover plays a very important role in the Earth's climate system, mainly owing to its high albedo, which significantly affects the components of the radiation balance. It is also considered a very good indicator of climate change in the winter, as it reflects the simultaneous impact of thermal, precipitation, solar and actinometric conditions, and, indirectly, also the conditions of atmospheric circulation. Hence, there is a great interest in researching this element of climate, both on a global and hemispheric scale (e.g. Choi et al. 2010, Brown, Robinson 2011), and that of continents (Henderson, Leathers 2010, Fontrodona et al. 2018), countries (Falarz 2004, 2008, 2013, Czarnecka 2012, Dyrrdal et al. 2013, Falarz et al. 2018, Viru, Jaagus 2020, Falarz, Bednorz 2021) and regions (e.g. Bednorz 2004, Bulygina et al. 2009, Rimkus et al. 2018, Dong, Menzel 2019), as well as in relation to individual measurement points (Piotrowicz 1996, Falarz 2002, 2007a). Decreases

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in maximum and mean snow cover depth have been found over Europe, except in the coldest climates (Fontrodona et al. 2018). The average decrease has been –12.2% · 10 years^{-1} for mean snow depth and −11.4% · 10 years^{-1} for maximum snow depth since 1951. These trends have accelerated since the 1980s. Small European snow extent is associated with positive 850 hPa zonal wind anomalies, positive European 1000–500 hPa thickness anomalies and generally negative Northern European precipitation anomalies (Henderson, Leathers 2010). There are strong associations between small snow cover extent and the positive phase of the North Atlantic Oscillation (NAO). In the study of snow cover in northern Eurasia, based on data from 820 weather stations for the years 1966–2007, Bulygina et al. (2009) found a decrease in the duration of snow cover in the northern regions of European Russia and in the mountainous regions of southern Siberia, whereas an increase was found in Yakutia and in the Far East.

The first measurements of snow cover at the meteorological station in Kraków were made in the autumn of 1897. In the following years, however, they were carried out irregularly and were limited only to determining the possible snow cover duration, without specifying its depth. It is only from January 1921 that measurements have been carried out systematically, providing a continuous 100-year series of the number of days with snow cover and its depth. This series is uninterrupted, covering also the years of World War II. The measuring station is located in the Botanical Garden in Kraków. It was not moved during its existence, but was subject to the influence of the developing city. This is the only such a long series of snow cover measurements in Poland carried out without interruptions or changing the location of the observation point. The study of the snow cover in Kraków concerned, among other things, the probability of its occurrence (Trepińska 1973), comparisons of snow conditions in the city and in extra-urban areas (Falarz 1998, Pajek 2000–2001), reconstruction of the snow cover (Falarz 2002), and above all, the directions of changes and long-term variability of various characteristics of snow cover (Piotrowicz 1996, Falarz 2002, 2007a). These studies focussed on the snow conditions in the 20th century, not covering the next two decades.

The vast majority of snow cover research results in the world indicate negative, sometimes statistically significant, trends in the duration and depth of the snow layer, the cause of which is seen in changes in circulation (e.g. Falarz 2007b), thermal conditions (e.g. Ye, Lau 2017, Rimkus et al. 2018) and the increasing trend of rain-on-snow events (Dong, Menzel 2019).

The present research aims to assess the changes and variability of various snow cover characteristics in Kraków in the 100-year period of 1921/22–2020/21 and its sub-periods, considering the impact of the developing city.

Study methods

A day with snow cover was a day when, in the morning observation, the depth of the snow layer was at least 1 cm. During the 100-year period, snow cover measurements were made at the meteorological station in the same way (manually), and in the same place.

The long-term variability of the number of days with snow cover, the dates of the beginning and end of snow cover duration in the winter season, the potential snow cover duration, the index of snow cover stability and the maximum depth of the snow layer were analysed. The potential snow cover duration was considered to be the time (number of days) from the first to the last occurrence of snow cover in a given winter season. The index of snow cover stability was calculated according to Leśniak (1981) method as the quotient of snow cover duration and its potential occurrence, expressed as a percentage. This index can reach values from close to 0%, to 100%. Regression analysis was used and the coefficient of variation was calculated (as a percentage of the standard deviation and the arithmetic mean of a given characteristic), and so were the absolute and relative changes of individual snow cover characteristics for 10 years. The statistical significance of trends was determined for the significance level of 0.05.

The analysis of changes and variability of snow cover was carried out both for the entire 100-year period and in its two sub-periods covering the years of the slow and rapid territorial, urban and industrial development of Kraków (respectively, 1921/22–1960/61 and 1961/62–2020/21). The

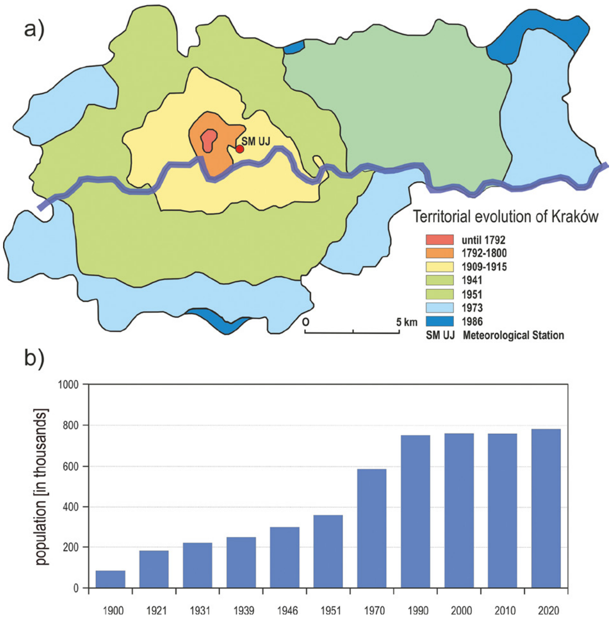

Fig. 1. Territorial evolution – A and number of populations of Kraków – B (based on Mydel [1994], Jelonek [1956] and GUS [2022]).

first analysed sub-period (1921/22–1960/61) is the time when the impact of the city on the measurement results was very small. At that time, the weather station was located on the outskirts of Kraków, surrounded by loose, single-family housing, and it can be considered that it represented a large area of almost natural environmental conditions. Changes in the snow cover during that period can, therefore, be considered changes typical of a natural area, also subject to the influence of global changes. In the second sub-period (1961/62–2020/21), there was significant territorial development of Kraków, which was expressed primarily in the incorporation of the new Nowa Huta district (located east of the city centre) into Kraków in 1951, the expansion of which lasted for several decades. In the 1970s–1980s, the southern districts of Kraków were intensively developed and incorporated into the city (Fig. 1). This resulted in a rapid increase in the population of Kraków. In the early 1960s, the city's population exceeded 500,000. The 1950s were also the beginning of the rapid industrial development of the city. East of Kraków, a metallurgical plant was established at that time, expanding its activities for the next two decades. In 1954, an aluminium smelter was set up with its location in Skawina, southwest of Kraków. Smaller electromechanical and metal industry plants were also established in Kraków itself and in its vicinity (e.g. in Zabierzów, Niepołomice, Olkusz). It can be assumed that the described multidirectional development of Kraków could have had a stronger impact on weather conditions since the 1960s. The qualification of the location of the weather station in the Botanical Garden in Kraków changed in that period from a location on the outskirts of the city to a location in the city centre.

Results

Snow cover duration

On average, of the 100-year period in question, there were 59 days in Kraków with a snow cover of at least 1 cm depth. The winter of 1995/96 was the snowiest in this respect, as there were as many as 133 snow days recorded that season (Fig. 2). At the turn of 2019/20, there was only 1 day with snow cover, and thus it was the smallest number of days since the beginning of regular measurements, i.e. since the winter of 1921/22. In the last 100 years, there has never been a case where the snow cover did not occur in Kraków for at least 1 day.

In the long-term course, however, there is a clear downward trend in the occurrence of days with snow cover, both in the entire 100-year period (trend −2.0 days · 10 years^{-1}) and in the last 60 years (1961/62–2020/21; −5.2 days · 10 years^{-1}) (Table 1). These changes are statistically significant. The relative trend throughout the entire 100-year period is −3.3% · 10 years^{-1}, and in the second

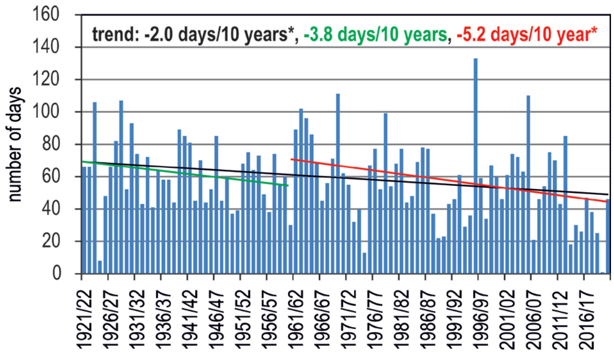

Fig. 2. Number of days with snow cover and trends of its changes in the period 1921/22–2020/21, 1921/22–1960/61 and 1961/62–2020/21 (*statistically significant changes at a level of 0.05). The trend value for the entire analysed 100-year period is shown in black font, in green font for the first sub-period and in red for the second sub-period.

analysed sub-period it is −9.1% · 10 years^{-1}. The variability of the number of examined days in the last 60 years has also clearly increased, compared to the years 1921/22–1960/61 (33% and 46%, respectively) (Table 2). The pace of changes has slightly accelerated since the second half of the 1990s (i.e. since the winter of 1996/97), when 56% of the seasons were characterised by the number of days with snow cover smaller than the long-term average, whereas in the 21st century (2001/02–2020/21) it was already 60% of winters. However, it should also be noted that years with a very large number of days with snow cover (>100 days in a season) occurred not only in the 1920s (1923/24 and 1928/29) and in the 1960s (1962/63 and 1969/70) but also in 1995/96 and 2005/06 (Fig. 2). Therefore, despite a clear decrease in the number of days with snow cover, an increase in the impact of anthropogenic factors, and climate warming, it is still very probable that there will be single winters in which snow cover may last longer than the average in the 100-year period (Brown 2019, Annella et al. 2023).

Maximum of seasonal snow cover depth

Another important criterion for the characteristics of snow cover, especially its long-term variability and change tendencies, is the maximum depth of the snow layer in individual winter seasons. The values presented in Figure 3 show that the maximum depth of snow cover, at 65 cm, occurred in the winter of 1962/63. From the 1970s, it was less than or equal to 40 cm, and from 2010/11, even less than 25 cm (Fig. 3). Although such a small maximum depth of snow cover also occurred in the first half of the 20th century, such winters, in which maximum snow cover was only a dozen or so centimetres, were rare at that time. In the last 60 years (1961/92–2020/21), and especially in the 21st century,

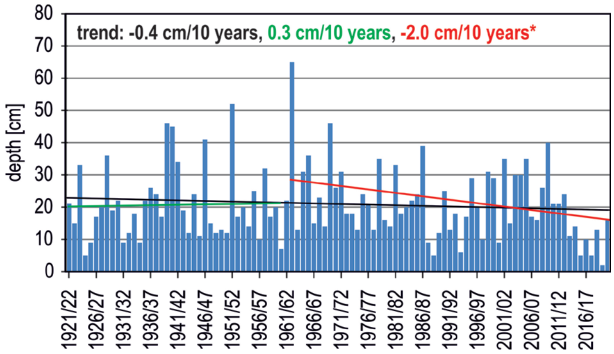

Fig. 3. Maximum depth of snow cover and trends of its changes in the periods 1921/22–2020/21, 1921/22–1960/61 and 1961/62–2020/21 (explanations as in Fig. 2).

Table 1. Absolute and relative trends of basic snow cover characteristics in the periods 1921/22–2020/22, 1921/22–1960/61 and 1961/62–2020/21.

Snow cover characteristics	Units	Absolute trend			Relative trend [% · 10 years^{-1}]		
		1921/22–2020/21	1921/22–1960/61	1961/62–2020/21	1921/22–2020/21	1921/22–1960/61	1961/62–2020/21
Number of days	[days · 10 years^{-1}]	−2.0*	−3.8	−5.2*	−3.3*	−6.0	−9.1*
Maximum seasonal depth	[cm · 10 years^{-1}]	−0.4	0.3	−2.0*	−1.5	1.4	−9.5*
First day	[days · 10 years^{-1}]	0.6	5.7*	1.9	0.2	1.7*	0.6
Last day		−0.7	−4.0	−0.6	−0.9	−5.0	−0.8
Potential duration		−1.3	−9.7*	−2.5	−1.2	−8.5*	−2.2
Stability index	[% · 10 years^{-1}]	−0.9	1.7*	−2.3	−1.7	3.1*	−0.6

*Statistically significant changes at a level of 0.05.

Table 2. Variation coefficient of selected snow cover characteristics in the period 1921/22–2020/22 and in its two sub-periods (1921/22–1960/61 and 1961/62–2020/21).

Snow cover characteristics	Variation coefficient [%]		
	1921/22–2020/21	1921/22–1960/61	1961/62–2020/21
Number of days	40.8	33.1	45.5
Maximum seasonal depth	53.5	53.6	53.4
First day	6.7	6.1	7.1
Last day	24.9	20.4	27.6
Potential duration	26.4	24.8	27.4
Stability index	35.6	30.0	39.1

there has already been a statistically significant downward trend in the maximum depth of snow cover of −2.0 cm · 10 years^{-1} (absolute trend −9.5% · 10 years^{-1}) (Table 1). It can, therefore, be concluded that, especially in the 21st century, changes in the snow cover in Kraków are most noticeable in the decrease in its number of days and in maximum depth. The maximum depth of snow cover in the winter season is also characterised by the greatest variability from year to year compared to other analysed characteristics; the coefficient of variation exceeds 50% throughout the entire 100-year period and both its sub-periods, and is quite stable over time (Table 2).

The dates of the first and last days with snow cover

In the analysed 100-year period, the first day with snow cover occurred on average on 25 November, and the last day on 19 March. Snow cover with a depth of 31 cm in Kraków appears between 15 October and 27 April (Fig. 4). The first day with snow cover occurred the earliest in the winter of 2009/2010, on 15 October, whereas the latest only on 30 March, in the winter of 2019/2020. It is worth noting that during that winter there was only 1 day with snow cover (the smallest number in the entire analysed multi-year period) and only on 30 March. The second latest date for the occurrence of the first day with snow cover was 6 January in 1952 (i.e. in the winter season of 1951/52). It is the latest start date for the snow cover season. For the end of the season, the extreme dates were, respectively, 9 January (1988/89) and 27 April (1981/82) (Fig. 4).

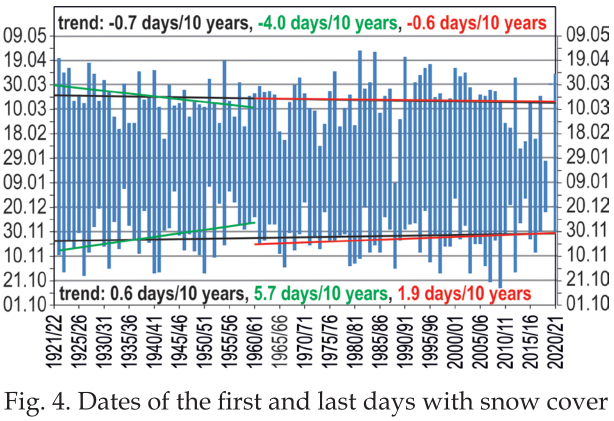

Fig. 4. Dates of the first and last days with snow cover and trends of its changes in the periods 1921/22–2020/21, 1921/22–1960/61 and 1961/62–2020/21 (explanations as in Fig. 2; at the bottom the date of the first day, at the top the date of the last day).

In the long-term course, there is a tendency for a slightly later start of the season with snow cover and its earlier end, but these changes, both for the entire 100-year period and for the last 60 years (1961/62–2021/22), are not statistically significant at a level of 0.05. In the case of the first of the analysed periods (1921/22–1960/61), the only exception is the trend of changes in start dates, which amounted to 5.7 days · 10 years^{-1} (absolute trend 1.7% · 10 years^{-1}) and was statistically significant ($p < 0.05$) (Table 1). It follows from this that despite the occurrence of very mild winters in recent years, with a small amount and depth of snow cover, the dates of its beginning and end do not show a clear tendency to change. It is still very likely that both very early and very late first and last days with snow cover will occur, with the beginning rather than the end of this season being more variable (Table 2). Therefore, the territorial and population development of Kraków did not significantly affect the analysed dates.

Potential snow cover duration

Considering the time from the first to the last day with snow cover at the turn of each year, i.e. the potential period of occurrence of this meteorological element, it was found that in the years 1921/22–2020/21 its average duration was 113 days, and the longest was in the winter of 1981/82 with 170 days, whereas the shortest was only 1 day (30 March 2020) (Fig. 5). Again, in this case, taking into account the long-term course of the potential snow cover duration, no statistically significant tendency to shorten

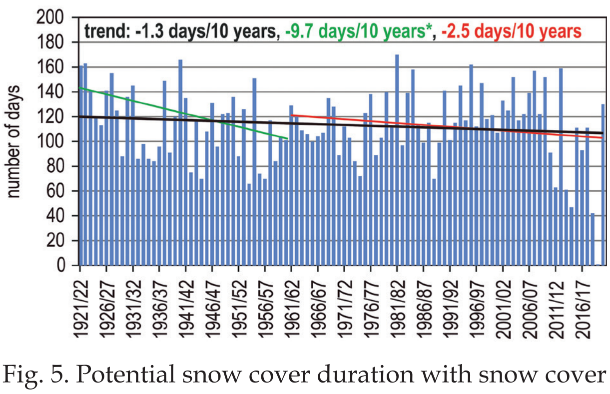

Fig. 5. Potential snow cover duration with snow cover and trends of its changes in the periods 1921/22–2020/21, 1921/22–1960/61 and 1961/62–2020/21 (explanations as in Fig. 2).

that period in the 100-year period and the years 1961/62–2020/21 was found, except in the first of the distinguished periods, namely 1921/22–1960/61 (−9.7 days · 10 years^{-1}) (Table 1). The potential period of snow cover duration in the years 1961/62–2020/21 was characterised by the greatest variability (27.4%), whereas the year-to-year variability of that period was slightly lower in the first 40 years of the studied 100-year period (24.8%). Weak and statistically insignificant trends in changes in the dates of the beginning and end of the season with snow cover did not affect the long-term variability of its potential duration either.

Index of snow cover stability

In the temperate climate zone, a very characteristic feature of the winter period is the presence of snow cover, which, however, does not occur throughout the entire season, from the first to the last day of its occurrence, and repeatedly occurs and melts. In order to better characterise such cases, it is possible to analyse the so-called index of snow cover stability, which tells us what percentage of days, from the first to the last day with snow cover in a given winter season, were those in which snow occurred on the surface. The higher the value of this index, expressed as a percentage (%), the more coherent a given winter can be considered in terms of snow cover. However, high values of the index do not always mean a very snowy winter. This is evidenced, for example, by the value of the index in the winter of 2019/20, which is equal to 100%, because as stated earlier, in that season there was only 1 day with snow cover, i.e. it was both the first and the last day with snow duration.

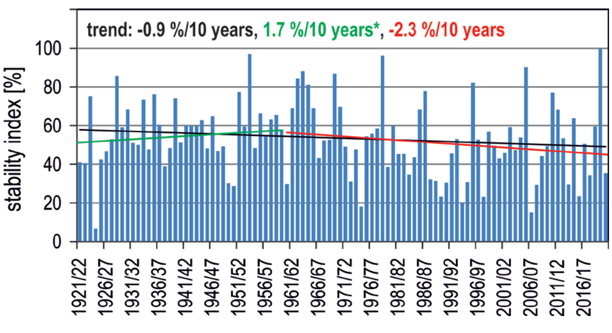

Fig. 6. Index of snow cover stability and trends of its changes in the periods 1921/22–2020/21, 1921/22–1960/61 and 1961/62–2020/21 (explanations as in Fig. 2).

In the studied 100-year period, the average value of the index of snow cover stability was 53.4% and ranged from 5.7% in the winter of 1924/25 to the already mentioned 100% at the turn of 2019/2020 (Fig. 6). In the long-term course, again as in many previous characteristics, there is no clear trend of changes in this index. The trend is statistically significant only for the first of the distinguished periods (1921/22–1960/61), indicating a slight increase in snow cover stability (1.7 percentage points per 10 years) (Table 1). In the other cases, the trend values were negative, indicating a slight decrease in stability (−2.3 percentage points per 10 years in the second examined sub-period), but statistically insignificant at a level of 0.05 (Table 1). The year-to-year variability of the index significantly increased in the second sub-period: it amounted to 39% against 30% in the period 1921/22–1960/61 (Table 2).

Discussion

The results of the research are similar to the results published earlier for Kraków, based on shorter observation sequences (Piotrowicz 1996, Falarz 1998, 2002, 2007a), which proves a certain constancy of negative trends in snow cover in Kraków. In some cases, these trends were intensified: in the study periods 1930–1995 (Piotrowicz 1996), 1948–1998 (Falarz 2004) and 1921–2000 (Falarz 2007a), only a slight downward trend in the number of days with snow cover was observed, whereas in the entire 100-year period analysed here, we are dealing with a statistically significant trend.

Negative trends in snow cover also apply to large areas of the Northern Hemisphere, especially mid-latitudes. The average Northern Hemisphere full snow season duration has decreased at a rate of 5.3 days · 10 years^{-1} in 1972/73–2007/08 (Choi et al. 2010). This value is very similar to the trend in snow cover duration in Kraków in the period 1961/62–2020/21. Many researchers draw attention to the special importance of the conditions of the spring period (March, April; Brown, Robinson 2011, Viru, Jaagus 2020). According to Choi et al. (2010), spring snowmelt is an indicator of hemispheric climate variability and change. There are observed significant reductions of spring snow cover extent in the Northern Hemisphere over 1922–2010 (Brown, Robinson 2011). The authors indicate the 1970s as the period of the beginning of the acceleration of negative trends.

Few researchers are interested in the trends in the dates of the first and last occurrences of snow cover. Over North America, the last date of snow cover remained stable during the period 1980–2006, whereas over Eurasia the trend varies between −2.6 days · 10 years^{-1} and −5.6 days · 10 years^{-1} (Peng et al. 2013). Earlier snow cover termination is systematically correlated with a positive temperature anomaly during the snowmelt month (Peng et al. 2013). The research by Choi et al. (2010) for the Northern Hemisphere shows the consistency of the changes with the changes observed in southern Poland: changes in the snow season duration are attributed primarily to a progressively earlier offset, which is at a rate of 5.5 days · 10 years^{-1}. Earlier offsets are observed in Western Europe, Central and East Asia, and in the mountainous Western United States. Also, detailed studies in Estonia show that the negative trend in snow cover duration there is related to the earlier snow melting in the spring at the majority of stations (Viru, Jaagus 2020). However, in a Fennoscandian fell area, the date of the first snow cover, as well as the onset and ending dates of permanent snow cover, reveals no significant change in the period 1978–2012 (Kivinen, Rasmus 2015). Snow depth trends in Estonia are also comparable to those presented in this paper: snow depth has decreased by 0.5–1.5 cm · 10 years^{-1} (Viru and Jaagus 2020). In the area of the Baltic States (Lithuania, Latvia and Estonia), for the period 1961–2015, a decrease in the number of days with snow cover was determined, statistically significant in 35% of the investigated area, mostly in the southern part of the region (Rimkus et al. 2018).

The main and direct cause of the negative trends in snow cover in southern Poland is the change in thermal conditions, which show a statistically significant positive trend in the winter and spring. In Kraków, in over 200 years of measurements, the change in winter temperature reached 3.4°C (Ustrnul et al. 2021), and in the period 1966/67–2019/20 the change in maximum temperature was 0.44°C · 10 years^{-1} (Tomczyk et al. 2021). In addition, the average winter temperature in Kraków is increasingly often above zero. The winter circulation of the atmosphere is of great importance, and especially western circulation bringing relatively warm air from the Atlantic to southern Poland. In the period 1986–2005, the advection from the western sector in winters was particularly intense, whereas after 2005 its frequency decreased (Niedźwiedź, Ustrnul 2021). Similar reasons for the negative trends in snow cover are indicated by researchers analysing its changes throughout the Northern Hemisphere and in Europe. The air temperature of the mid-latitude Northern Hemisphere explains ~50% of the variance in spring snow cover (Brown, Robinson 2011). European winter snow cover is closely correlated with surface air temperature (Ye, Lau 2017).

An indirect, but very important, cause of changes in snow cover are changes in the circulation of the atmosphere. Variations in the atmospheric circulation in the North Atlantic/European sector are accompanied by changes in horizontal heat advection over Europe modulating the water vapour transport and leading to fluctuations in downward longwave irradiance and cloud cover (Ye, Lau 2017). Changes in the North Atlantic Oscillation and Scandinavian pattern around 1980 have contributed to reductions in March snow cover extent over Eurasia (Brown, Robinson 2011). Similar results were obtained by Capozzi et al. (2022) for the snowfall trends in the Apennine Mountains (Italy). The strong reduction in snowfall frequency and amounts between the 1970s and 1990s can mainly be the consequence of the strong positive trend of North Atlantic Oscillation and Arctic Oscillation indices. Popova (2007) reported the decrease of snow accumulation over northern Eurasia caused by the eastward shift of cyclone tracks related to the positive NAO phase. According to the conclusions of Brown (2019) and Annella et al. (2023), future changes of the snow cover duration will depend on dominant annual/decadal large-scale atmospheric circulation in addition to long-term decrease due to climate warming, and occasional periods of longer snow cover duration might be expected. That is in line with the results of the present work.

An equally important reason for changes in snow cover in the last 100-year period in Kraków is the development of the city itself and the intensification of the urban heat island (UHI). UHI intensity exceeds 3.0 K during 7.9% winter nights in the street canyon (Bokwa 2011). The increase in air temperature in Kraków caused by the supply of a large amount of 'anthropogenic heat' to the atmosphere leads to a greater number of mid-winter thaws (Piotrowicz 2003), faster melting of snow cover both in the winter and spring, which in turn affects a significant decrease in the albedo of the Earth's surface, and an increase in the absorption of short-wave solar radiation. The research completed over 20 years ago shows that the magnitude of the negative trend in the depth of snow cover after 1960 is smaller in the suburban and extra-urban areas of Kraków compared to its centre (Falarz 1998). Comparative research will be a continuation of this work.

Conclusion

The directions of changes in snow cover in the last 100 winter seasons in Kraków correspond to the global changes in air temperature presented in the latest IPCC reports (2018, 2021): until the end of the 1950s there were no significant trends or only small trends were observed, and from the beginning of the 1960s faster changes in the snow cover duration and maximum snow cover depth have been observable. In the last 60 years (1961/62–2020/21), the impact of global changes in Kraków has been joined by the impact of the territorial, demographic and industrial development of the city, causing significant negative trends in snow cover with relative values of less than $-9\% \cdot 10\ \text{years}^{-1}$, both in the case of snow cover duration and its maximum depth in the winter season; these changes are statistically significant. Throughout the entire 100-year period (1921/22–2020/21) and in its second part (1961/62–2020/21), a decrease in snow cover stability is also observed. The first day with snow cover appears in Kraków later and later, and the last earlier and earlier, which results in the shortening of the potential duration of snow cover. It is significant that the variability of almost all snow cover characteristics increases from year to year: the variation coefficient is the highest in the second sub-period of the studied 100-year period and has the highest values (>50%) for the maximum depth of snow cover.

It should be emphasised, however, that the growing pace of negative trends in snow cover in Kraków at the turn of the 20th and 21st centuries is not a rule. In the case of some characteristics (i.e. the dates of the first and last occurrences of snow cover in the winter season and the potential duration of snow cover) in the first analysed sub-period, a faster rate of change was noted than in the second one. Moreover, the resulting trend value for snow cover duration in the period 1961/62–2020/21 may have been influenced by quite high values in the first few years of this period.

Regular measurements of snow cover in Kraków cover a period of 100 years. We can only conclude about earlier snow conditions indirectly, i.e. on the basis of temperature and precipitation values (Falarz 2002), as well as verbal chronicle records from the Poland area. Low snow and almost snowless winters also occurred in earlier centuries. For example, Wiktoryn Kuczyński writes about it, describing the winter of 1724 in the region of Podlasie:

> *The year 1724 followed, and the winter was strange, because it was warm, there was no snow until the end of March for a few days. The water was low, until on May 1 there was huge rain, which made rivers flood* (Wiktoryn Kuczyński, after: Maroszek 1999, Girguś 2022).
>
> Original spelling in Polish: [Nastąpił rok 1724, którego zima dziwna była, bo ciepła nad to była, śniegu nie było, aż w końcu marca kilka dni. Woda mała, aż 1 maja deszcz wielki spadł, który uczynił wylew rzek (Wiktoryn Kuczyński, za: Maroszek 1999, Girguś 2022).]

There were also exceptionally snowy winters. Wierzbowski describes the winter of 1651 as follows:

> *That year the winter was hard, not so cold as with long-lasting snow. – After St. Adalbert's Day* [23rd April – authors' footnote], *sleighs were still being driven* (Wierzbowski 1858, after: Girguś 2022).
>
> Original spelling in Polish: [Tego roku była zima ciężka nie tak w zimno, jak śnieg długo trwający. – Po ś. Wojciechu na saniach jeżdżono (Wierzbowski 1858, za: Girguś 2022).]

Anthropopressure is, therefore, only one of many factors shaping snow conditions. An attempt to assess the magnitude of this impact will be the subject of further research.

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Authors' Contribution

Introduction: MF; Methodology: MF, KP; Results: KP; Graphics: KP; Discussion: MF; Conclusion: MF.

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