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RESEARCH

Cold spells in the city of Poznań and their circulation conditions

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Abstract

This study analyzed the occurrence of cold days, very cold days and cold spells in Poznań in the years 2008/09-2022/23. A cold day was defined as a day with Tmax < 0.0 °C and ≥-10.0 °C, whereas a very cold day was defined as a day with Tmax <-10.0 °C. In the next step, cold spells were determined, which are sequences of at least 5 days with Tmax < 0.0 °C. Circulation conditions were determined based on daily values of sea-level pressure, the height of the 500 hPa isobaric surface, as well as their anomalies and air temperature anomalies at the 850 hPa isobaric level. The conducted research showed a decrease in the number of cold and very cold days in Poznań in the years 2008/09-2022/23. A variation in the number of cold and very cold days and cold spells was noted across the city area, which is a consequence of the form of land use. The occurrence of cold spells in Poznań was associated with higher than average sea-level pressure.

1 Introduction

Since the beginning of the 21st century, new thermal extremes have been recorded in subsequent years. As indicated by NOAA (2023), 10 of the warmest years in Europe after 1910 occurred in the 21st century, with the warmest being 2023. Similar conditions were observed on a global scale. In the years 1850–2023, the 10 warmest years occurred in the last 10 years (2014–2023). The above data, indicate evident intensification of progressing warming in Europe and worldwide. The contemporary warming manifested most resoundingly in the warmer half of the year by the occurrence of exceptionally extreme heatwaves, but also in winter by an increasing frequency in exceptionally mild winters and diminishing frequency of cold episodes, which also become less extreme relative to winters of the past decades (Cattiaux et al. 2010; Guirguis et al. 2011; Twardosz and Kossowska-Cezak 2016). According to McCabe and Wolock (2010) an increase in mean winter Norther Hemisphere temperature is associated with a substantial decrease in snow cover extent since about 1970.Similar directions of change were also indicated in numerous studies from the territory of Poland (Kejna and Rudzki 2021; Marosz et al. 2023). As pointed out in studies based on long measurement series, a clear increase in the rate of air temperature rise has been noted since the end of the 1980s (Migała et al. 2016; Kolendowicz et al. 2019; Pospieszyńska and Przybylak 2019). The most intense warming was recorded in winter and spring (or spring and winter) (Kolendowicz et al. 2019; Pospieszyńska and Przybylak 2019). Similar results were obtained by Ustrnul et al. (2021) analysing changes in thermal conditions in Poland between 1951 and 2018. As demonstrated by Kejna and Rudzki (2021), the increase in the average annual air temperature in Poland between 1961 and 2018 was 0.3 °C/10 years. The most significant changes were recorded on the Silesian, Wielkopolska, and Mazovian lowlands, and in the central part of the Baltic coast.

The results presented above were obtained based on research conducted using synoptic stations located in the outskirts of cities. Such a location does not fully reflect the conditions prevailing in the urban area, which are varied and are the result of specific physical properties of materials covering the ground in the city, absorbing more solar radiation than they reflect (Oke 1982; Lopes et al. 2001; Błażejczyk

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et al. 2014). The beginnings of urban climate research in Poland date back to the early 20th century (Merecki 1915; Błażejczyk et al. 2014). In recent years, research on the climate of cities in Poland has included both aspects of changes and variability of selected meteorological elements as well as biometeorological conditions and air quality (Bokwa 2019; Filipiak and Miętus 2019; Fortuniak et al. 2019; Kaszewski 2019; Kuchcik et al. 2019; Półrolniczak et al. 2019a; Przybylak and Uscka-Kowalkowska 2019; Szymanowski et al. 2019; Żmudzka 2019).

Contemporary research on the climate of the city of Poznań began in the first decade of the 21st century with the development of a measurement network operating within the Department of Meteorology and Climatology (previously the Department of Climatology). The first group of studies consists of research on urban heat islands (UHI) conducted based on measurement data (Busiakiewicz 2011; Półrolniczak et al. 2017) and using satellite data (Majkowska et al. 2017). The second group consists of studies on air quality in the city and its circulatory conditions (Czernecki et al. 2017; Pilguj et al. 2018). The third group includes studies on biometeorological conditions and their impact on the perception of the landscape (Półrolniczak et al. 2019b; Półrolniczak and Kolendowicz 2021, 2023), as well as the occurrence of hot and cold weather (Półrolniczak et al. 2018; Tomczyk et al. 2018).

The present study refers to the last of the groups presented above and constitutes a continuation of research on thermal extremes in the winter season. The research has a strong biometeorological aspect, concerning human activity and functioning in the city space during the persisting periods of low temperature.

Although, the general patterns of winter temperature changes and the related changes in the frequency cold days and cold spells are well-known, there is lack of studies on the low-scale spatial diversity in frequency of the characteristic days within the city, despite of well-recognized regularities of spatial temperature changes in urbanized areas.

The objectives of the research were set as follows:

- recognizing the spatial diversity in the occurrence of cold and very cold days, as well as cold spells within the city of Poznań,
- identification of circulation conditions conducive to the occurrence of cold spells in Poznań.

2 Study area, data and study methods

Poznań is located in western Poland within the Wielkopolskie Lake District (Richling et al. 2021). The city is the capital of the Wielkopolskie Voivodeship. As of 31 December 2020, the city's area was 262 km², inhabited by 532,048 people (GUS 2023). The population density was 2,031 people per 1 km². In terms of population, Poznań is the fifth-largest city in Poland. Approximately 4.3% of the city's area comprised areas of special natural value under legal protection, including the largest share of ecological sites, followed by protected landscape areas and nature reserves. The forest cover of the city was 13.7% (GUS 2023).

According to the Köppen-Geiger climate classification (Kottek et al. 2006), Poznań is located in the Cfb type, which is a warm temperate moist climate. The average annual air temperature was 9.4 °C for the period 1991–2020 (Tomczyk 2022). The average monthly air temperature in winter ranged from -0.4 °C (January) to 0.9 °C (December). In the said multiannual period, the absolute minimum air temperature was -26.4 °C, recorded on 23 January 2006 (Tomczyk 2022). The average annual total precipitation was 538,2 mm (Bednorz 2022a). Meanwhile, the average monthly total precipitation varied from 30,1 mm in February to 84,4 mm in July. In the said multiannual period, snow cover typically lasted for 36 days (Bednorz 2022b).

The continual expansion of urban areas and its impact on urban residents has necessitated the development of a methodology to standardize research on urban climate. This study used the Local Climate Zones (LCZ) classification devised by Stewart and Oke (2012). This classification system delves into the various local climates within a city, accounting for the distinct manifestations of climate patterns influenced by specific land use and land cover (LULC) characteristics. With 17 typological units based on the height and density of surface structures and cover, the LCZ classification incorporates factors such as building surface fraction, aspect ratio, sky view factor, impervious/pervious surface factor, the geometric mean height of roughness elements, and terrain roughness class (Stewart and Oke 2012). In this study, there utilized the LCZ classification product for Poznań obtained from WUDAPT (The World Urban Database and Access Portal Tools) (Demuzere et al. 2021; Zwolska et al. 2022).

The research was conducted based on hourly air temperature values obtained for nine measurement points located in the area of Poznań. The measurement points (Fig. 1) strategically cover both the city center and varying distances from it, each indicative of distinct types within the local climate. Piekary (No 4) and Collegium Minus (No 5), positioned in the city's oldest segment, exhibit midrise compact urban structures at the center (LCZ 2). Moving eastward

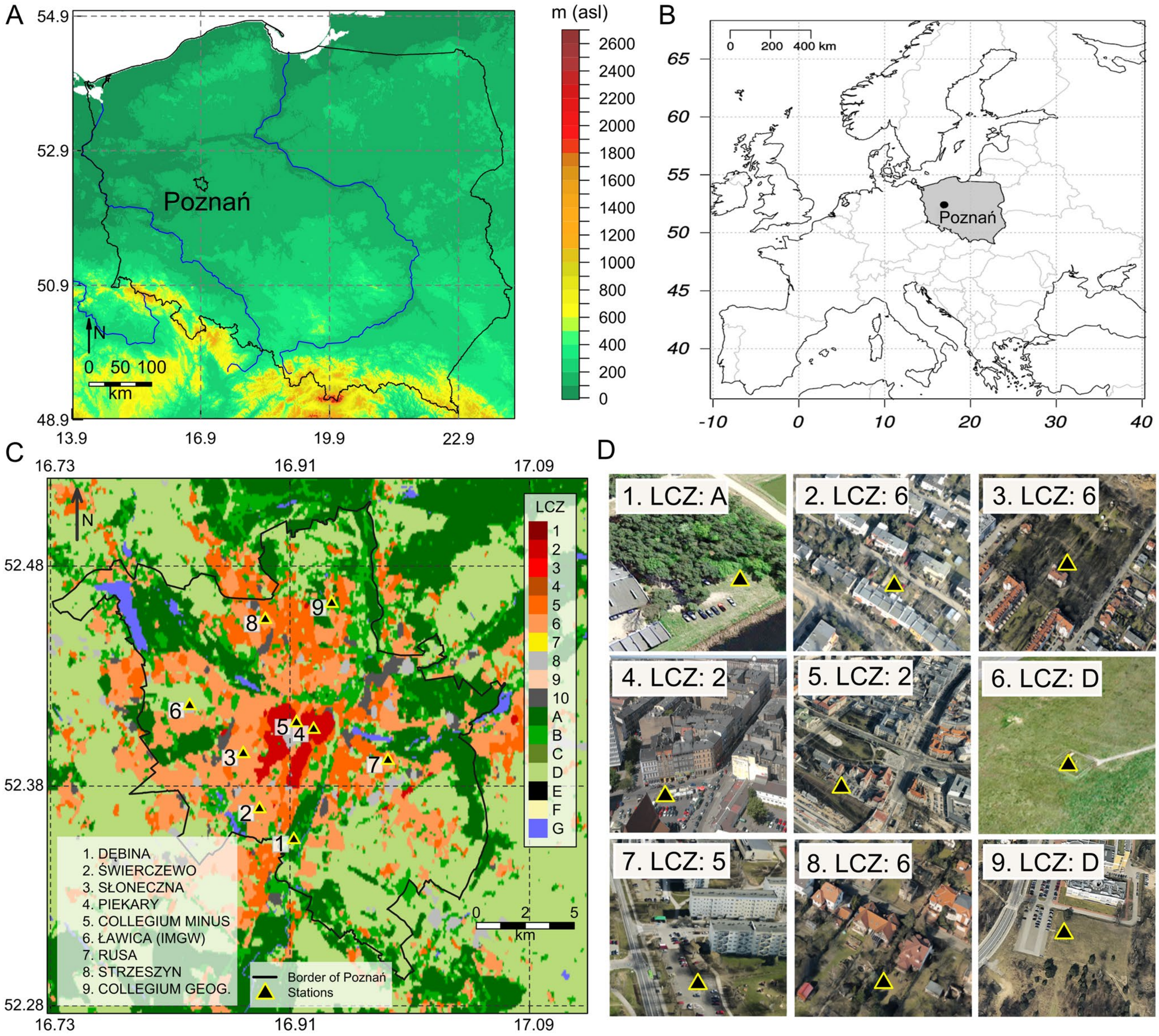

Fig. 1 Location of Poznań (**A**, **B**) and measuring points (1–9) on the map of Poznań (**C**) as well as its aerial visualization (**D**, https://www.google.com/maps). The type of Local Climate Zone class (full LCZ colour scale legend): (1) Compact high-rise, (2) Compact midrise, (3) Compact low-rise, (4) Open high-rise, (5) Open midrise, (6) Open low-rise, (7) Lightweight low-rise, (8) Large low-rise, (9) Sparsely build, (10) Heavy industry, (**A**) Dense trees, (**B**) Scattered trees, (**C**) Bush, scrub, (**D**) Low plants, (**E**) Bare rock or paved, (**F**) Bare soil or sand, (**G**) Water

from the central core, Rusa (No 7) characterizes open areas with midrise building height (LCZ 5). Słoneczna (No 3), Strzeszyn (No 8), and Świerczewo (No 2) share a common classification featuring low buildings set in open structures with a significant presence of greenery (LCZ 6). Notably, these locations are situated in different sectors of the city – to the west, north, and south of the city center. Ławica (No 6) and Collegium Geographicum (No 9) typify areas with low vegetation, positioned to the west and relatively close to the center (Ławica), and to the north, significantly farther from the city centre (Collegium Geographicum). Dębina (No 1) epitomizes an area of the local climate associated with forested regions (LCZ A), characterized by the highest proportion of greenery, located southward and distant from the city centre. Data for eight measurement points were obtained from the resources of the Department of Meteorology and Climatology of the Adam Mickiewicz University in Poznań. Air temperature and humidity measurements are conducted at a height of 2 m above ground level using HOBO U23-001 A recorders positioned within a solar radiation shield (M-RSA) with a temporal resolution of one hour. The equipment parameters adhere to attainable measurement uncertainty standards (WMO 2021). Meteorological data for Poznań-Ławica (WMO id 12330 synoptic station) were acquired from the resources of the Institute of Meteorology and Water Management – National Research Institute (IMGW-PIB). The meteorological data, integral to the operation of the measurement network in the Poznań area, undergoes meticulous scrutiny before integration into the historical database. This scrutiny encompasses an initial quantitative assessment, followed by subsequent qualitative checks involving statistical testing and a comparison with values obtained from the official IMGW-PIB network. Additionally, the standard normal homogeneity test (SNHT) is applied to discern change points in normal variables. The research covered winter season (December-February) for the period 2008–2023. The choice of the multi-year period was conditioned by the availability of data from the city area.

Based on the above data, the maximum daily air temperature (Tmax) was determined at each measurement point. Subsequently, based on Tmax, cold and very cold days were identified. A cold day was defined as a day with Tmax < 0.0 °C and ≥-10.0 °C, whereas a very cold day was defined as a day with Tmax <-10.0 °C. These definitions have been commonly used in Poland to date (Wibig et al. 2009a, b; Kossowska-Cezak 2014). Then, for the designated days, the direction of changes and the statistical significance of these changes (0.05) were determined using the non-parametric Mann-Kendall test. Moreover, the same test was used to estimate the differences in medians for the number of these days across individual locations within the city.

In the next step, cold spells were determined, which are sequences of at least 5 days with Tmax < 0.0 °C. Cold spells do not have one universal definition, and various criteria have been adopted in previous studies, such as at least 3 days with a maximum daily air temperature <-10.0 °C (Jarzyna 2016; Tomczyk and Bednorz 2023), at least 3 days with a minimum daily air temperature <-20 °C (Jarzyna 2016), at least 3 days with a maximum daily air temperature <-5.0 °C, at least 6 days with a minimum daily air temperature and average daily air temperature below the 5th annual percentile, and initially a drop of 2 °C compared to the previous day (a 1-day break with a higher air temperature is possible, but not exceeding the 10th percentile) (Kozłowska-Szczęsna et al. 2004), at least 5 days with Tmax < 5th annual percentile (Tomczyk et al. 2018). After determining the cold spells, their number and duration in individual seasons and the entire multi-year period were defined.

Pressure conditions were determined based on daily values of sea-level pressure (SLP), the height of the 500 hPa isobaric surface (z500 hPa), as well as their anomalies and air temperature anomalies at the 850 hPa isobaric level (T850). Anomalies were calculated as the difference between the average value on a specific day of sea-level pressure, 500 hPa isobaric surface heights, and 850 hPa level air temperatures, and the average value of the above elements on the same day in the studied multi-year period. Up to this stage of the research, Reanalysis 2 data were used, derived from the NCEP-DOE (National Centers for Environmental Prediction – Department of Energy) archives (Kanamitsu et al. 2002). Based on the above data, maps of average SLP, z500 hPa, and anomalies of SLP, z500 hPa, and T850 were plotted for all analysed cold spells and for the designated types of circulation. The designation of circulation types was carried out based on daily SLP values using Ward's method (Ward 1963; Wilks 1995). The description of the designation of circulation types was detailed in earlier research (Tomczyk et al. 2022; Tomczyk and Mendel 2023). All analyses covered days that occurred at all measurement points.

In the next stage, the presence of air masses over Poland on the days included in the analysis of pressure conditions was analysed. For this purpose, information about air masses was obtained from daily synoptic maps available in the Daily Meteorological Bulletin of the Institute of Meteorology and Water Management and on the website with archival data of the Institute of Meteorology and Water Management – National Research Institute (danepubliczne.imgw.pl).

3 Results

3.1 Cold and very cold days as cold spells in Poznań in the period 2008/09-2022/23

The average number of cold days in Poznań in the years 2008/09-2022/23 was about 19 days per season. On average, the number of cold days ranged from 18 days at Piekary and Collegium Minus (compact midrise) to 21 days at Strzeszyn (open low-rise) (Fig. 2). Cold days occurred in every winter season, except for the 2019/20 season, in which no cold days were recorded in Poznań (the exception is point Strzeszyn – 1 day). In the 2010/11 season, at 66% (6 points) of the measurement points, the maximum number of cold days was recorded, with a maximum at Collegium Geographicum – 49 days, and Ławica (low plants) and Strzeszyn (open low-rise) – 47 days. Very cold days occurred much less frequently, averaging once a season and were present in only 40% of the seasons. The winter season of 2009/10 was characterised by the highest frequency of very cold days, with seven out of nine measurement points recording 6 very cold days. Meanwhile, at the remaining two points (compact midrise – Piekary and Collegium Minus), there were 5 days. Differences in the occurrence of these

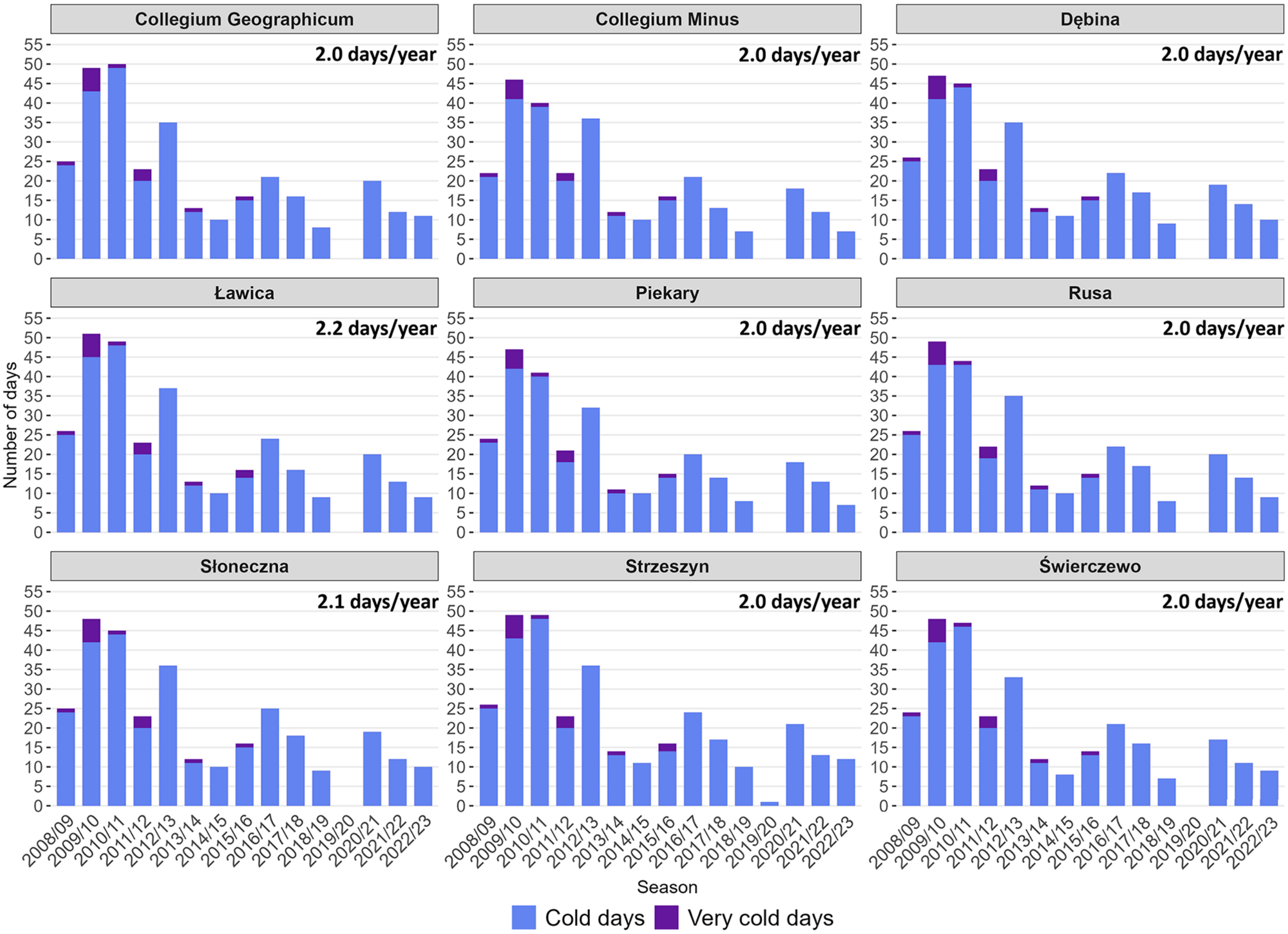

Fig. 2 Course of cold and very cold days in winter in Poznań in the years 2008/09-2022/23

days in individual places in the city are statistically insignificant. During the studied period, a decrease in the number of cold and very cold days was observed, ranging from 2.0 days/year at six stations (Collegium Minus, Dębina, Piekary, Rusa, Słoneczna and Strzeszyn) to 2.2 days/year at Ławica. Changes at all measurement points were statistically significant.

The occurrence of cold spells in the area of Poznań varied spatially. On average, 22 cold spells were recorded, which an average lasted a total of 204 days. At individual points, the number of cold spells ranged from 20 at Rusa (open midrise) to 24 at Strzeszyn (open low-rise) (Fig. 3; Table 1). A greater difference was observed in the total duration of the cold spells. They lasted the shortest at Collegium Minus (compact midrise), i.e., 190 days, and the longest at Strzeszyn (open low-rise), i.e., 221 days. The longest cold spell was recorded at the turn of 2009 and 2010, starting on 30 December 2009 and lasting until 27 January 2010, thus lasting a total of 29 days. This spell was recorded at the Rusa (open midrise) and Collegium Geographicum (low plants) measurement points. In the other points this spell was split into two spells by one or two warmer days. In these points, the longest cold spell occurred in 2012 and lasted 20–21 days. The overwhelming majority of cold spells were the shortest, lasting from 5 to 7 days – 55%. Next were spells of 8–12 days – 27%, while spells lasting 13–18 days and 19 days and more lasted for 9% of the time, respectively. In the studied period, 19 cold spells were found to be simultaneously recorded at all measurement points, although in many cases, they differed in duration. The designated cold spells differed in thermal conditions. The average Tmax during the cold spells ranged from -4.7 °C at Słoneczna (open low-rise) to -4.3 °C at Collegium Minus (compact midrise). The spell with the lowest Tmax was recorded at Dębina (-9.0 °C; 20-27.01.2010).

3.2 Pressure conditions of cold spells in Poznań in the period 2008/09-2022/23

156 cold days were selected for the analysis of synoptic conditions causing persistent winter cold in Poznań. The occurrence of cold spells was caused by the presence

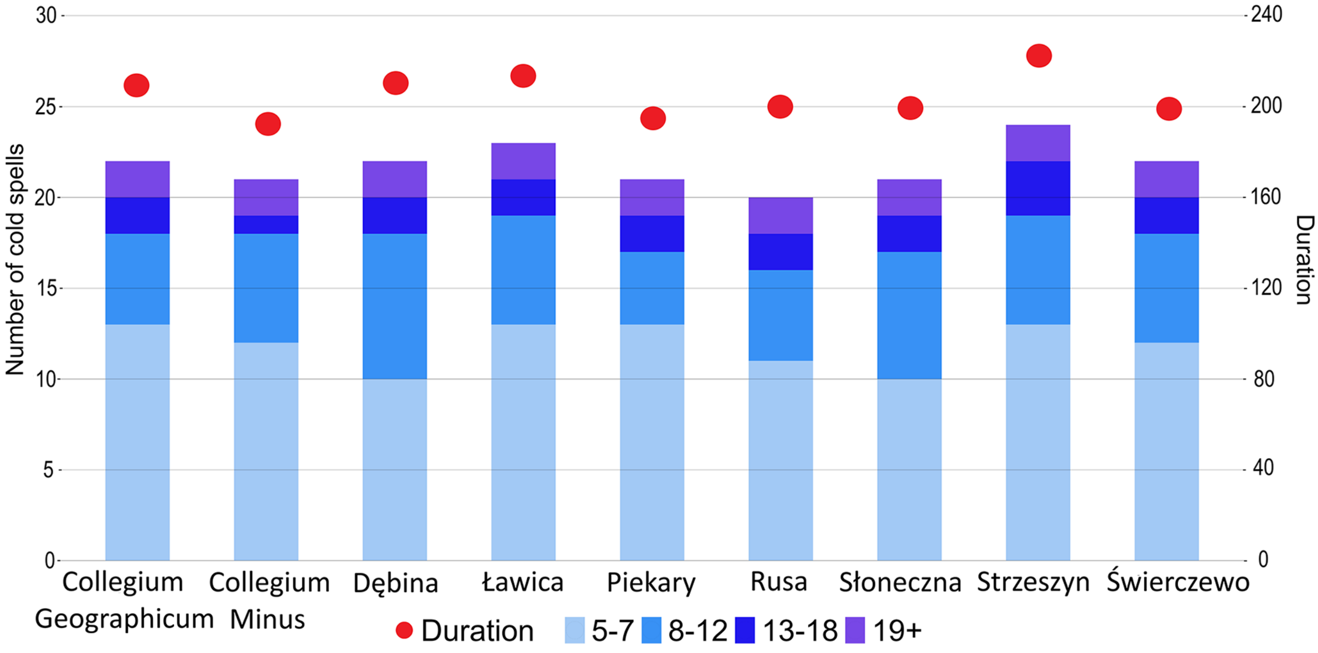

Fig. 3 Number of cold spells and their duration and number of cold spells by duration in Poznań in the years 2008/09-2022/23

Table 1 Characteristics of the occurrence of cold spells in Poznań in the years 2008/09-2022/23

Location	Cold spells		Longest cold spells	
	number	total number of days	duration	date
Collegium Geographicum	22	210	29	30.12.2009–27.01.2010
Collegium Minus	21	190	20	26.01–14.02.2012
Dębina	22	210	21	25.01–14.02.2012
Ławica	23	214	21	25.01–14.02.2012
Piekary	21	193	20	26.01–14.02.2012
Rusa	20	200	29	30.12.2009–27.01.2010
Słoneczna	21	199	21	25.01–14.02.2012
Strzeszyn	24	221	21	25.01–14.02.2012
Świerczewo	22	200	21	25.01–14.02.2012

of a high-pressure wedge associated with an anticyclone with a center over the border of Russia and Kazakhstan (> 1028 hPa) (Fig. 4). This system primarily covered northern, eastern, and central Europe. On the analysed days, in the indicated regions, the sea-level pressure (SLP) was higher than average, and the maximum anomaly was located over northern Europe (> 12 hPa). In the Euro-Atlantic sector, another high was located over the Atlantic – the Azores High (> 1020 hPa). This system, however, was weaker than average, and anomalies in the center were <-4 hPa. Additionally, a low with its center over the Apennine Peninsula (< 1010 hPa) lingered over southern Europe. In this area, the SLP was lower than average (in the center by over 4 hPa). Meanwhile, over the North Atlantic, a shallower than average low – the Icelandic Low – prevailed. The described pressure situation in the Euro-Atlantic sector favoured the advection of cold continental air masses from the east. The most significant deviations from average thermal conditions were noted over central Europe, including Poland (over 5 °C). The presence of cold air masses is also indicated by the course of the 500 hPa isohypse. Over the majority of the area, they were bent towards the southwest. On the days considered, negative anomalies of z500 hPa were recorded over the predominant area of the sector, and their center was located over the Apennine Peninsula (-75 gpm).

Detailed analyses allowed for the identification of two types of pressure conditions conducive to the occurrence of cold spells in Poznań. Type 1 (T1) was the most numerous, with 110 days classified. This type referred to the general conditions described above, meaning northern, central, and eastern Europe were under the influence of a high-pressure wedge associated with an anticyclone with its center over Russia (> 1030 hPa) (Fig. 4). This system was stronger than in the general conditions, as confirmed by the SLP anomalies. The highest values were noted over northern regions with the center over the Scandinavian Peninsula (> 18 hPa). The Azores High, weaker than average for this period, prevailed over the Atlantic. Southern Europe was under the

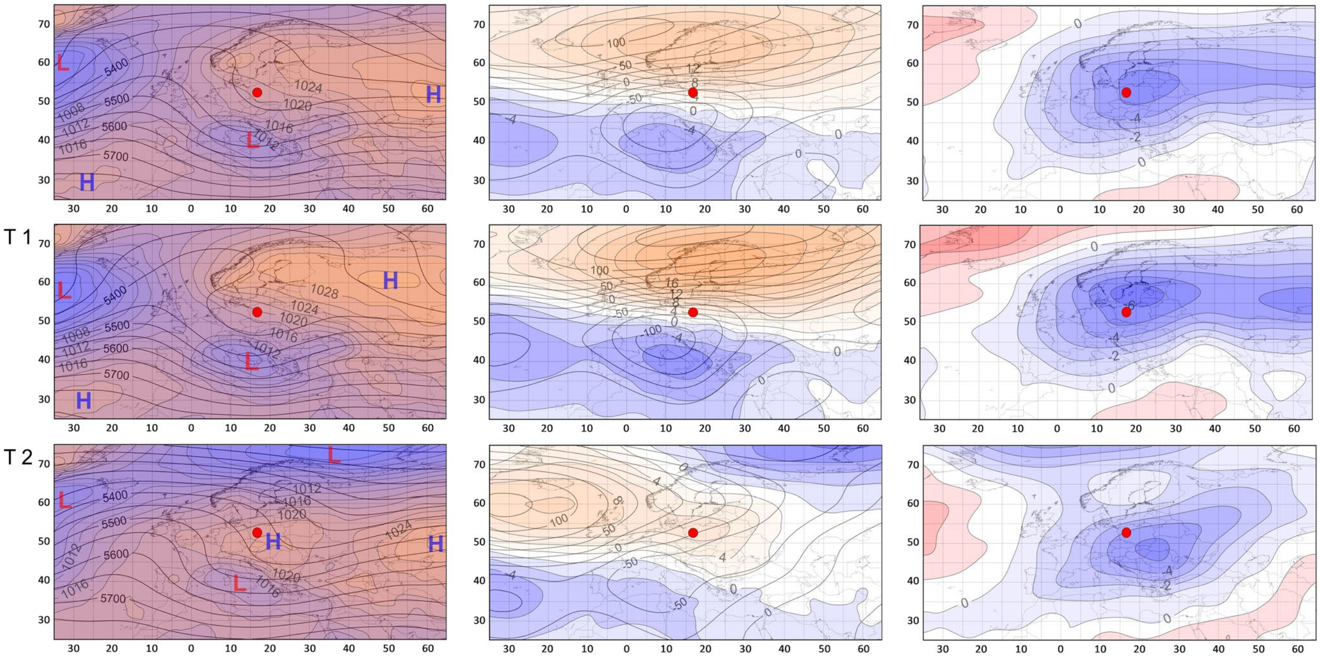

Fig. 4 Mean SLP and z500 hPa (left column), anomalies of SLP and z500 hPa (middle column), and anomalies of T850 (right column) during all cold spells (top row) and circulation types (T1 and T2). Red dot – Poznań

influence of a low from the Apennine Peninsula, which was deeper than in the general conditions. Anomalies in the center of the system were <-6 hPa. Meanwhile, a shallower than average Icelandic Low was located over the northern part of the ocean in the considered period. The described pressure situation favoured the advection of cold continental air masses from the east. The majority of the Euro-Atlantic sector was within the negative T850 anomalies. The most significant deviations from average conditions were mainly noted over central Europe, with their center located over the southern Baltic (over 6 °C). On the indicated days, the z500 hPa was lower than average, and the most significant deviations from average conditions were observed over southern Europe (in the center, over 100 m lower).

In Type 2 (T2), 46 days were classified. The pressure situation in the Euro-Atlantic sector in this type differed from the conditions in Type 1. On the analysed days, a distinct high with its center over, among other areas, southern Poland (> 1024 hPa) prevailed over central Europe (Fig. 4). This system was associated with an extensive high-pressure wedge linked to the anticyclone over Asia. The SLP was then higher than average, and the center of the anomaly was located over the ocean, south of Iceland (> 10 hPa). Similar to the general conditions and in Type 1, a low was situated over southern Europe, although it was noticeably shallower. The anomaly field indicates that on the considered days, the Icelandic Low was also shallower than average for that time of the year. Northern regions of the continent were also under the influence of the low-pressure system. The center of the low lay over the Arctic Ocean (< 1000 hPa). The SLP in this part of the analysed sector was even over 8 hPa lower. The described pressure situation caused advection of cold air masses from the northeast. As in Type 1, over a significant area of the continent, the z500 hPa lay lower than average, and the most significant deviations in its height were noted over southern Europe (in the center, over 50 m lower). Meanwhile, over the North Atlantic, a center of positive z500 hPa anomalies was recorded (in the center, over 130 higher), resulting from the presence of warmer air masses (area of positive T850 anomalies).

The pressure situations described above generated the inflow of air masses from the east and northeast, namely arctic (A) and continental polar (cP) air masses (Fig. 5). These air masses were recorded during 63.2% and 29.0% of all the considered days, respectively. The maritime polar air masses (mP), which was present in only 7.7% of the days, was noted much less frequently.

4 Summary and discussion

The conducted research showed a decrease in the number of cold and very cold days in Poznań in the years 2008/09-2022/23. The most intense changes were observed at Ławica (LCZ D: low plants), amounting to 2.2 days/year. It should be noted that the magnitude of changes across the entire city was similar. The decline in the analysed days was a consequence of the progressing warming of the

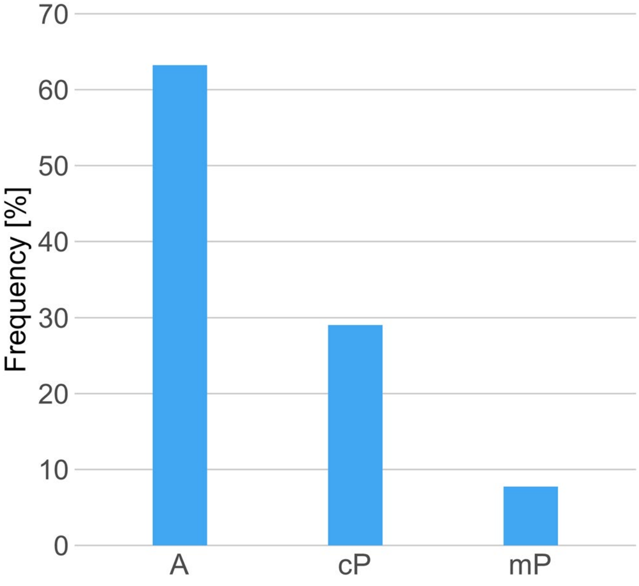

Fig. 5 Frequency of air masses during cold spells in Poznań in 2008/09-2022/23

climate, intensified at the end of the 1980s (Migała et al. 2016; Kolendowicz et al. 2019; Pospieszyńska and Przybylak 2019; Twardosz et al. 2021). As demonstrated in earlier research, winter is one of the seasons in which changes occur most rapidly (Kolendowicz et al. 2019; Pospieszyńska and Przybylak 2019). The highest number of cold and very cold days was recorded in the 2009/10 season. A variation in the occurrence of the analysed days was noted across the city area. The fewest were recorded in compact midrise type of local climate (LCZ 2: Collegium Minus and Piekary), and the most at Strzeszyn (LCZ 6: open low-rise), Ławica and Collegium Geographicum (LCZ D: low plants). A similar spatial variability was found in occurrence of winter cold spells within the city of Poznań, both in terms of their number and duration. The fewest cold spells were recorded in the Rusa housing estate (LCZ 5: open midrise), and the shortest duration of cold spells was observed in Collegium Minus (LCZ 2: compact midrise). In contrast, the most cold spells and the longest duration were noted in Strzeszyn (LCZ 6: open low-rise). In all measurement points, the most frequent occurrence was of the shortest spells, i.e., lasting 5–7 days. The above variation in the occurrence of the designated characteristic days resulted from the thermal conditions in the city and is independent of the adopted methods and criteria for the selection of the characteristic days. As shown in earlier studies (Majkowska et al. 2017; Półrolniczak et al. 2018; Tomczyk et al. 2018), the direct city center – an area with compact midrise buildings – was characterised by the highest air temperature, while areas outside the city center – with a large share of natural surfaces – had the lowest air temperature.

The differences in air temperature between different parts of the city depend on weather conditions. During clear and windless weather, natural surfaces cool faster than artificial ones which leads to large thermal contrasts between urbanized and rural areas. In such conditions, record values of the urban heat island are usually recorded (Błażejczyk et al. 2014). The winter of 2009/10 stood out in terms of conditions not only in Poznań. This season in Poland (Tomczyk et al. 2021; Ustrnul et al. 2021), but also in other regions of the Northern Hemisphere (Cattiaux et al. 2010; Wang et al. 2010), was one of the coldest seasons since the beginning of the 21st century. Twardosz and Kossowska-Cezak (2016), analysing the occurrence of exceptionally cold and mild winters in Europe, found that it was the only exceptionally cold winter in the 21st century. This particularly affected Northwestern Europe, and in the Bergen station, it was the coldest winter in 60 years. In Great Britain, it was reported to be the coldest winter in over 30 years (Prior and Kendon 2011).

Throughout the city, not a single cold or very cold day (except for the Strzeszyn, LCZ 6: open low-rise) was recorded in the winter of 2019/20. This season was the warmest in the last several decades in Poland (Tomczyk et al. 2021; Tomczyk 2022). Referring to research based on over a century-long measurement series, it can be concluded that it was the warmest season since at least the second half of the 19th century (Kolendowicz et al. 2019; Pospieszyńska and Przybylak 2019). As a consequence of such weather conditions, there was a lack of snow cover throughout the season in many stations in western and southwestern Poland (Bednorz 2022b; Szyga-Pluta 2022).

The occurrence of cold spells in Poznań was associated with higher than average pressure over the western Poland. They most frequently occurred during an expanded high-pressure wedge associated with the anticyclone over Russia. The second pressure situation was related to a high over central Europe. The designated types of circulation favoured the advection of cold air masses from the east and northeast. During the analysed cold spells, Arctic and Continental Polar air were most commonly recorded. Similar pressure conditions were demonstrated when analysing the conditions for the occurrence of cold spells in Central Europe in recent decades (Tomczyk et al. 2019a). In the cited studies, the authors showed that maximum anomalies of isobaric surface heights occurred in the upper troposphere and appeared several days in advance. Generally, the presence of high-pressure systems, blocking zonal circulation, favours the occurrence of air temperature anomalies – in winter, these are negative anomalies, and in summer, positive (Porębska and Zdunek 2013; Piotrowicz et al. 2016). Additionally, a characteristic feature of anticyclonic weather is little or no cloud cover, which favours intense radiation of heat from the ground. This was demonstrated in other research concerning cold spells both in Europe (Tomczyk et al. 2019a, b) and China (Qian et al. 2016). The authors of the cited studies proved that the maximum of negative air temperature anomalies occurred closest to the ground surface.

5 Conclusions

The conducted research showed that the progressing warming has led to increasingly rare occurrences of cold and very cold days in Poznań in the years 2008/09-2022/23. The indicated days occurred most frequently at the beginning of the analysis period, i.e., in the 2009/10 and 2010/11 seasons. The temporal distribution of cold spells was similar. A variation in the number of cold and very cold days and cold spells was noted across the city area, which is a consequence of the form of land use and land cover. In heavily modified areas, with compact midrise buildings – the analysed days and spells were noted least frequently, while most commonly in areas with a large share of natural terrains – forests, grassy surfaces, and near rivers and water bodies, which is a consequence of the different thermal capacity of artificial and natural surfaces. The research showed that weather conditions shaped by atmospheric circulation on a macroscale are modified by local factors such as forms of land use.

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Data availability The obtained data can be made available on reqeuest of interested parties under the condition of approval of the request by the authors of the article..

Declarations

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