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DAILY MINIMUM AND MAXIMUM AIR TEMPERATURE IN POLAND IN THE YEARS 1951–2005

Abstract: In this study grid data of daily maximum and minimum air temperatures taken from the NCEP/NCAR reanalysis for the territory of Poland for the years 1951–2005 have been used as a basis for an analysis of the spatial distribution of daily maximum and minimum air temperature, the frequency of characteristic days and the variability of these parameters in the period analysed. The results obtained were then compared to the variability in atmospheric circulation in Europe, described by the North Atlantic Oscillation (NAO) index.

Key words: air temperature, NAO, climate changes, Poland

Introduction

In the years 1906–2005 global air temperature increased by an average of 0.74°C (IPCC 4th Assessment Report 2007). However, within this general tendency there are substantial regional differences. In the second half of the 20th century the air temperature in Poland rose by 0.8°C (cf. Fortuniak et al. 2001; Kożuchowski and Żmudzka 2001). Changes were also observed in the courses of daily maximum (T_{max}) and minimum (T_{min}) air temperature and the frequency of characteristic days (cf. Niedźwiedź and Ustrnul 1994; Wibig 2000a,b, 2000/2001; Głowicki 2003; Trepińska 2003; Wyszkowski 2006a; Bielec-Bąkowska and Łupikasza 2007; Durło et al. 2007; Kaszewski et al. 2007). Extreme values of air temperature reveal a considerable regional diversity, partially connected with the influence of local factors (Miętus and Filipiak 2003; Cebulak and Limanówka 2007).

Even slight changes in the mean air temperature lead to an escalation in the occurrence of extreme weather phenomena (Heino et al. 1999). The intensity of extreme phenomena in Poland is growing, although the trends observed are not yet statistically significant (Przybylak et al. 2007). These phenomena have an enormous impact on the environment and the economy (Easterling et al. 2000). Hence another aim of this article is to analyse the spatial distribution and temporal variability of T_{max} and T_{min} and the frequency of characteristic days in Poland during a period of progressive warming. The results obtained were compared to the pattern of the NAO, which considerably affects weather conditions throughout Europe (Hurrell 1995), including Poland (cf. Marsz and Styszyńska 2001; Olszewski 2007; Ustrnul and Czekierda 2007).

Methodology

The study used daily values of T_{min} and T_{max} from reanalyses for the period 1951–2005, made available by NCEP/NCAR (www.cdc.noaa.gov). The reanalyses include data collected from standard measuring stations, ships, floating buoys, planes, balloons, satellites, radars etc. (Kalnay et al. 1996). Grid data are generally accurate as far as the actual distribution of air temperature is concerned, both for mean and extreme values (Wyszkowski 2006a,b). Reanalyses may be even better in comparison to the data from stations because of the control procedures applied which eliminate measurement errors (Ustrnul 2001). One should not forget that grid data represent mean values for areas of approx. 2 by 2^{o} longitude and latitude, whereas measurement data come from individual sites where local factors may have a substantial influence.

The grid data were used in the spatial variability studies of different meteorological components for the whole of the globe and for individual regions (cf. Jones et al. 1999), including Poland (cf. Ustrnul 2001; Wyszkowski 2006b; Przybylak et al. 2007). The present study uses 28 grids in Poland or near its borders (Fig. 1). The grids are identified by 4-digit numbers describing longitude (first two digits) and latitude (next two digits).

A number of indices are used to determine extreme weather states. For instance, the Expert Team on Climate Change Detection Monitoring and

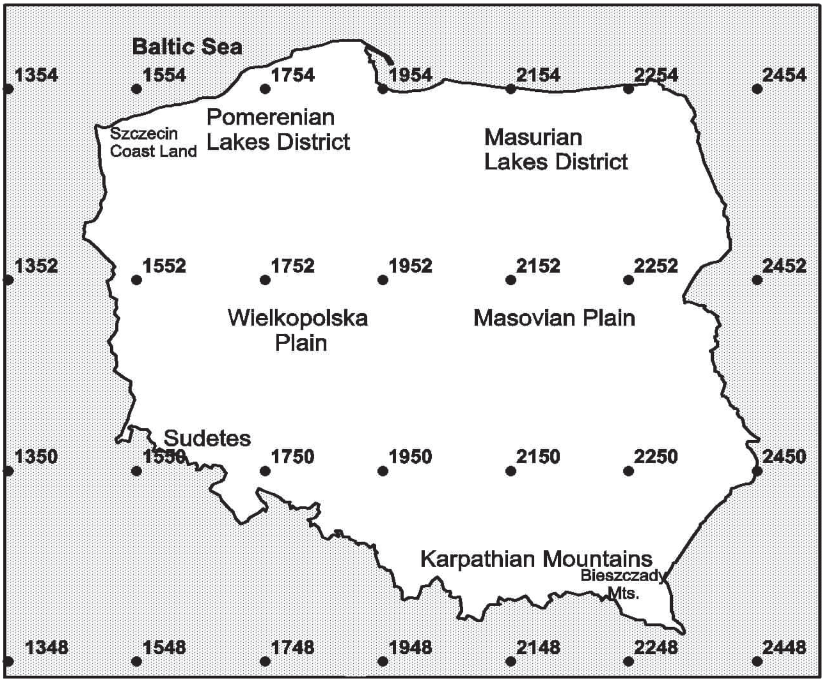

Fig. 1. Study area and location of grids points

Indices (ETCCDMI) at the World Meteorological Organization (WMO) proposed 27 indices for temperature and atmospheric precipitation (Sillman and Roeckner 2008). Similarly, the *Climate Atlas of Poland* published in 2005 (H. Lorenc, ed.) contains a spatial distribution of numerous climate indices, while a team composed of T. Niedźwiedź, Z. Michalczyk, L. Starkel and Z. Ustrnul defined a number of threshold values of extreme weather events as a requirement of the grant "Extreme Meteorological and Hydrological Events in Poland (Assessment and Forecasting their Impact on Human Environment)." The above-mentioned lists provided a basis for the determination of the following statistics for each grid:

- monthly and annual mean T_{min},
- frequency of occurrence of days with T_{min} <0°C,
- frequency of occurrence of days with T_{min} <-10°C,
- frequency of occurrence of days with T_{min} <-20°C,

– frequency of occurrence of days with T_{min} <-30°C,
– monthly and annual mean T_{max},
– frequency of occurrence of days with T_{max} >25°C,
– frequency of occurrence of days with T_{max} >30°C,
– frequency of occurrence of days with T_{max} >35°C.

The results, averaged for the whole period, have been presented on maps of Poland using the optimal interpolation method (kriging). Linear trends were also calculated and their statistical significance was proved with the t-Student test. Then the correlations between the thermal indices and the NAO index (NAO_{DJFM}) after Hurrell (1995) were analysed.

Results

Daily minimum of air temperature (T_{min})

Mean annual values of T_{min} in Poland are highest on the Baltic coast, where they exceed 5°C. The lowest values of $T_{min\ avg}$ occur in the east of the country, where they are below 2.5°C (Fig. 2a). The meridional pattern of $T_{min\ avg}$ isotherms is disturbed by thermal influences of the Baltic Sea, the elevation above sea level and orography in the south of the country.

The values of T_{min} reveal a statistically significant (of the 0.05 level) increase in NW Poland (from 0.2 to 0.3°C/10 years). In the rest of the area the changes are not significant. The biggest rise of T_{min} took place in grid 1754, where it reached 0.28°C/10 years (Fig. 3). The course of T_{min} varies substantially from year to year. In the period under investigation there were years with exceptionally low T_{min}, e.g. 1963, 1970, 1980, 1987 and 1996. On the other hand, the years 1975, 1983, 1989, 1990, 2000 and 2005 were among the warmest.

Days with T_{min} <0°C

In Poland, according to the grid data, there are less than 100 days with T_{min}<0°C on the Baltic coast, 110 to 120 days with slight frost in the west of the country and over 140 such days in the east (Fig. 4). The warming influence of the Atlantic and the Baltic Sea are evident there, along with the eastward rise in continentality of the climate, characterised by a long and freezing winter.

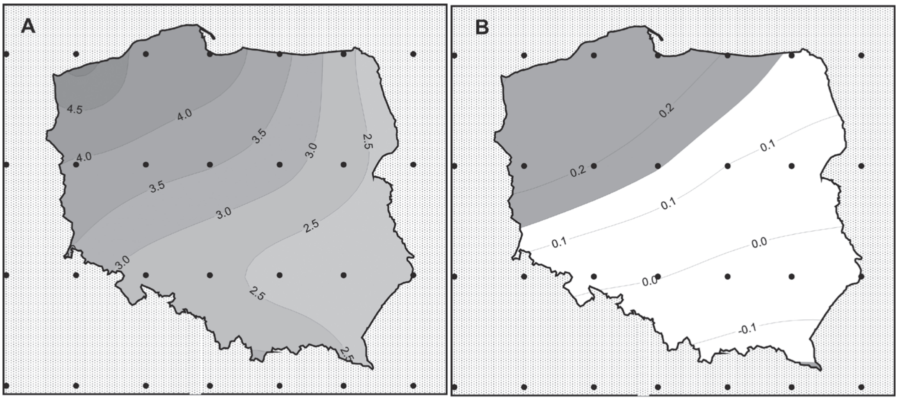

Fig. 2. Annual mean T_{min} in Poland (A) and its trend in °C/10 years (B) in the period 1951–2005 (grey – area with significant positive trend to the level of 0.05)

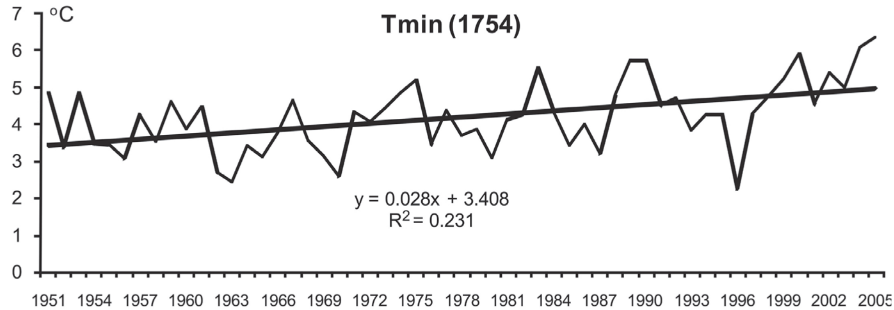

Fig. 3. Year-to-year course of annual T_{min} at the grid 1754 in the period 1951–2005

In NW Poland the annual mean number of days with $T_{min} < 0^oC$ shows a declining trend (Fig. 4a). The biggest changes took place in grid 1754, where from 1951 the number of days with $T_{min} < 0^oC$ dropped by as much as 21.5 (-4.3 days/10 years) – Fig. 5. In the rest of Poland no significant changes were observed (except for the Bieszczady Mountains, where a slight increase in the frequency of cold days occurred).

Days with T_{min} <-10°C

On the coast of Poland days with $T_{min}<-10^oC$ are very infrequent (less than 10 days per year). However, in the west of the country the frequency

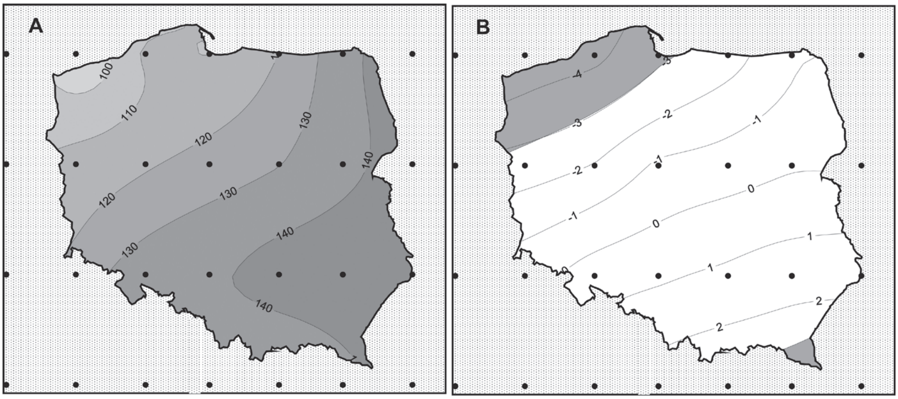

Fig. 4. Mean annual number of days with $T_{min} < 0^oC$ in Poland (A) and their trend in days/10 years (B) in the period 1951–2005 (grey – area with significant trend to the level of 0.05)

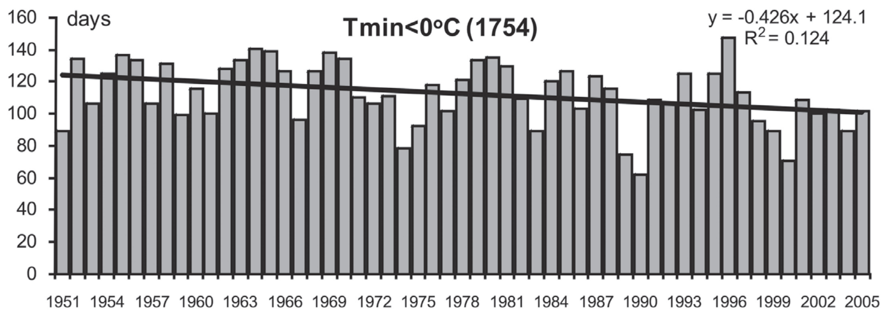

Fig. 5. Year-to-year course of mean annual number of days with $T_{min} < 0^oC$ at the grid 1754 in the period 1951–2005

increases from 10–20 days, in contrast with over 40 days at the eastern border (Fig. 6a). The frequency of days with T_{min} <-10°C does not show any statistically significant changes and an increase of 2–3 days/10 years is only noticeable in the south of the country (Fig. 6b). For example, in grid 2150 between 1951 and 2005 the gain was more than 11 days with T_{min} <-10°C. The course of this category of days shows a substantial variability from year to year – from just a few days (e.g. in 1951) to 70–80 days (e.g. in 1963 and 1996) – Fig. 7.

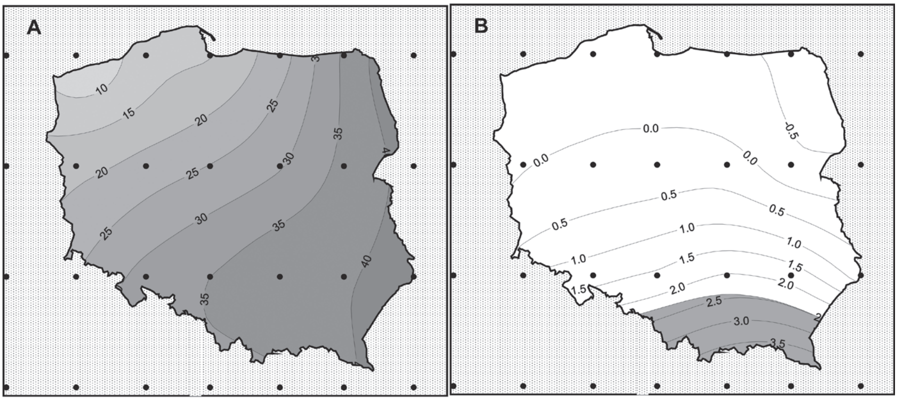

Fig. 6. Mean annual number of days with T_{min} <-10°C in Poland (A) and their trend in days/10 years (B) in the period 1951–2005 (grey – area with significant trend to the level of 0.05)

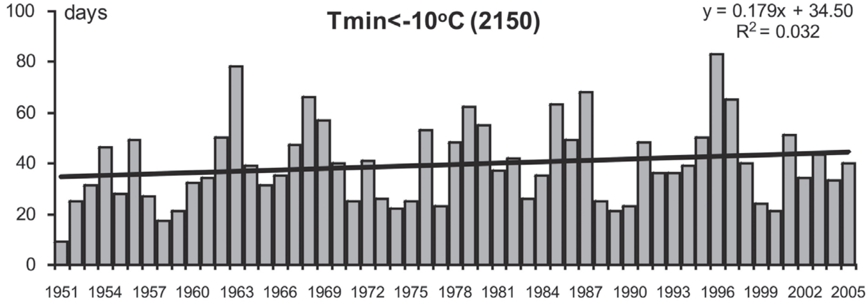

Fig. 7. Year-to-year course of mean annual number of days with T_{min} <-10°C at the grid 2150 in the period 1951–2005

Days with T_{min} <-20°C

In Poland, days with T_{min}<-20°C are sporadic. On the Baltic coast their mean frequency does not exceed 1 day per year. Days with such temperature drops are more frequent in the east of Poland (7–8 days) – Fig. 8a. In most of the country the number of days with T_{min}<-20°C is not statistically significant (Fig. 8b). Only in south-east of Poland is an increase observed, with a frequency of 1.2 days/10 years in grid 2152 (Fig. 9).

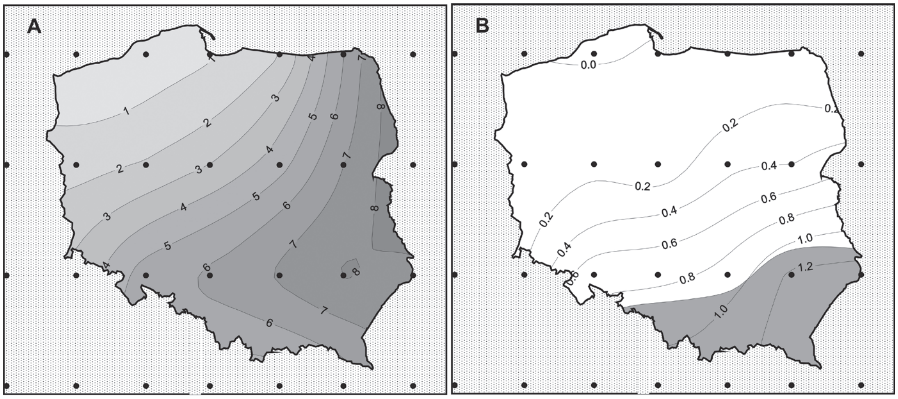

Fig. 8. Mean annual number of the days with T_{min} <-20°C in Poland (A) and their trend in days/10 years (B) in the period 1951–2005 (grey – area with significant trend to the level of 0.05)

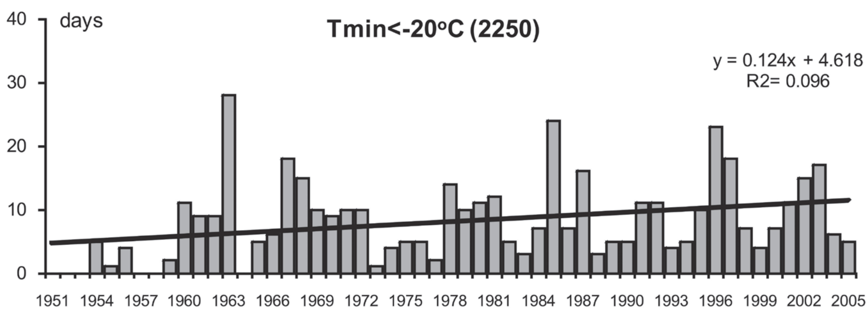

Fig. 9. Year-to-year course of mean annual number of days with T_{min} <-20°C at the grid 2250 in the period 1951–2005

Days with T_{min} <-30°C

Days with T_{min} below -30°C are very exceptional in Poland. They hardly ever occur on the coast or in the west. In the east and south-east of the country the coldest days average at 0.5–0.7 days per year, e.g. in grid 2250 (0.71 day/year). In the study period the winters of 1996 (6 days in grid 2250), 1963 and 1987 (5 days), and 1960 and 2003 (4 days) were particularly frosty. Days like these are noted once every few years, often in series of a several days in the year. Data collected from 19 measurement locations shows that in the period analysed there were only 7 days with T_{min}<-30°C in

Poland (Cebulak and Limanówka 2007). Days with T_{min}<-30°C do not have a statistically significant trend.

Daily maximum of air temperature (T_{max})

Annual values of T_{max} are highest in the western part of Poland (above 11.5°C) and decrease eastwards (to below 10.5°C) – Fig. 10. A distinct fall in T_{max} can be seen on the Baltic coast (especially in the coastal area around Szczecin). In the rest of the country T_{max} increases, except for in the south and – particularly – the south-east of Poland. Between 1951 and 2005 T_{max} grew by 1.4°C (0.26°C/10 years) in grid 1754 (Fig. 11).

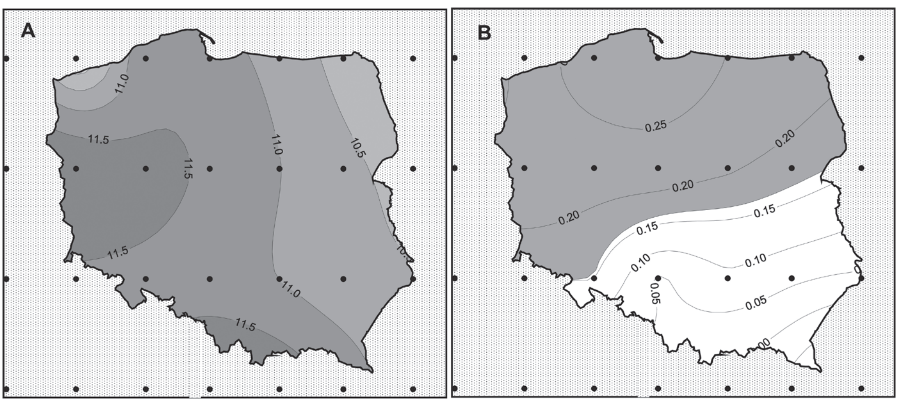

Fig. 10. Annual mean T_{max} in Poland (A) and its trend in °C/10 years (B) in the period 1951–2005 (grey – area with significant trend to the level of 0.05)

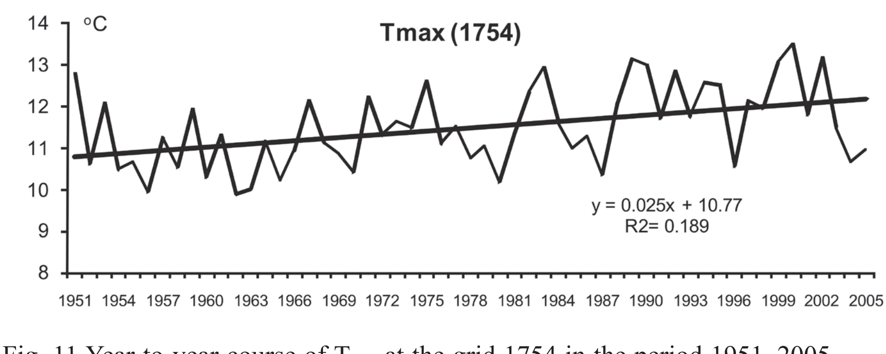

Fig. 11. Year-to-year course of T_{max} at the grid 1754 in the period 1951–2005

Days with T_{max} >25°C

Most of the hot days (i.e. with T_{max}>25°C) occur in central Poland (more than 30 days per year), whereas the Baltic coast and southern Poland seldom witness such temperatures (less than 15–20 days per year and less than 25 days per year, respectively) – Fig. 12. Throughout the country a statistically significant increase in the number of hot days has been observed. The biggest changes have taken place in the central regions of Poland. In grid 1750 there are as many as 4.6 more hot days per decade. The biggest increase occurred in the 1990s and at the beginning of the 21st century (Fig. 13).

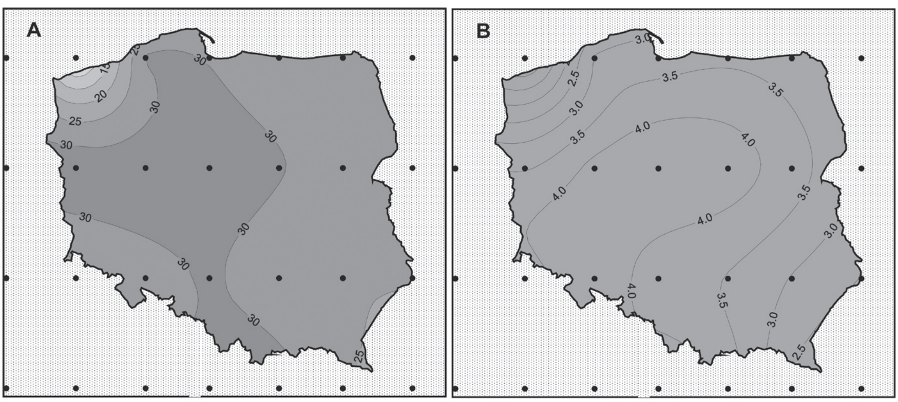

Fig. 12. Mean annual number of days with T_{max} >25°C in Poland (A) and their trend in days/10 years (B) in the period 1951–2005 (grey – area with significant trend to the level of 0.05)

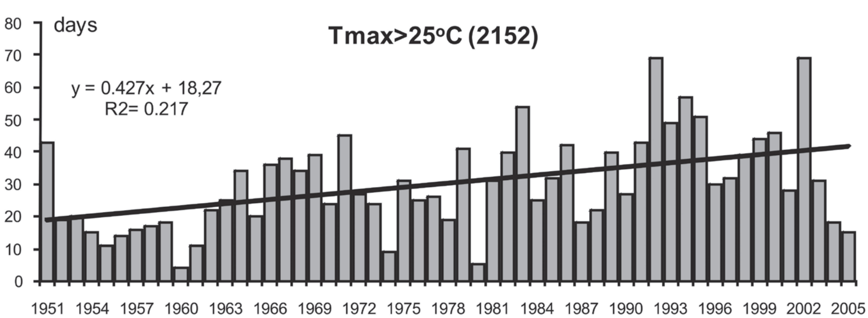

Fig. 13. Year-to-year course of mean annual number of days with T_{max}>25°C at the grid 2152 in the period 1951–2005

Days with T_{max} >30°C

Very hot days (with T_{max}>30°C) are very rare in Poland, occurring only 2–6 days per year (Fig. 14). They are most frequent in central Poland and least frequent at the seaside and in the mountains. Over the last two decades of the 20th century the frequency of days with T_{max}>30°C increased, as evidenced in the data from measurement stations (Cebulak and Limanówka 2007). The increase in very hot days ranges from 0.8 to 1.2 days per 10 years. The greatest change was noted in the Pomeranian Lake District, where in grid 1754 the trend reached 1.4 days/10 years (Fig. 15).

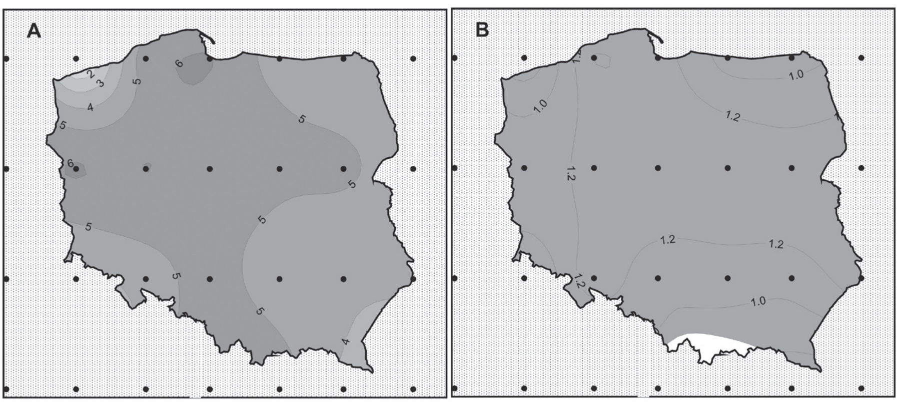

Fig. 14. Mean annual number of days with T_{max} >30°C in Poland (A) and its trend in days/10 years (B) in the period 1951–2005 (grey – area with significant trend to the level of 0.05)

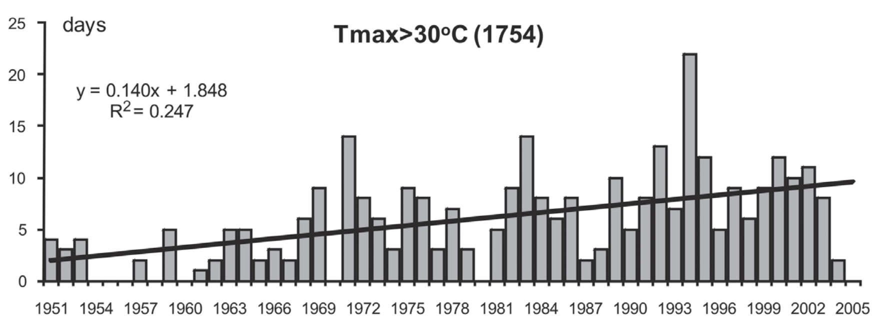

Fig. 15. Year-to-year course of mean annual number of days with T_{max} >30°C at the grid 1754 in the period 1951–2005

Days with T_{max} >35°C

Extremely hot days (with T_{max} >35°C) are sporadic in Poland (on average 0.2–0.6 days per year) and they do not occur every year. In the study period there were just 14 days (according to the data from 19 locations) with T_{max} >35°C (Cebulak and Limanówka 2007). In central Poland (grid 2152) extremely hot days occurred in 1994 (9 days), in 1992 (6 days) and in 1959 (3 days). Nevertheless, this shows that the frequency of extremely hot days increased in the period analysed, particularly in central parts of the country.

The influence of NAO on T_{max} and T_{min} and the number of characteristic days

Atmospheric circulation has a particular impact on the climate of Poland with the variability of thermal conditions being determined by the type of inflowing air masses. The atmospheric circulation over Europe is controlled by permanent barometric centres: the Azores High and the Icelandic Low, and seasonal centres. The relationship between the Azores High and the Icelandic Low is described by the NAO index (Hurrell 1995; Jones et al. 1997). The circulation oscillation influences thermal conditions in Poland, especially in the cool half of the year (cf. Marsz and Styszyńska 2001; Kożuchowski and Degirmendžić 2002; Przybylak et al. 2003). Therefore, further analysis makes use of Hurrell's NAO winter index (1995), which is the difference in standardised atmospheric pressure between Lisbon (Portugal) and Stykkisholmur/Reykjavik (Iceland) in the months from December to March (NAO_{DJFM}). For high values of NAO_{DJFM} there are major differences in pressure between the regions, and this results in an increased frequency of maritime air advection in central Europe and thus higher air temperature and greater precipitation. On the other hand, for negative values of NAO_{DJFM} the western circulation lessens, which supports the build-up of the high over eastern Europe and the advection of cooler, continental air masses.

In the NAO_{DJFM} pattern winters with very low values of the index can be seen: e.g. in 1963 (-3.60), 1969 (-4.89), 1996 (-3.78), or with high values: e.g. the years 1988–1995 with the highest NAO_{DJFM} of 5.08 in 1989 – Fig. 16. At high values of NAO_{DJFM} abnormally warm winters occurred, whereas at its low values the winters were very frosty. This is also evident in the significant values of T_{min} and T_{max}. The most visible relationships were

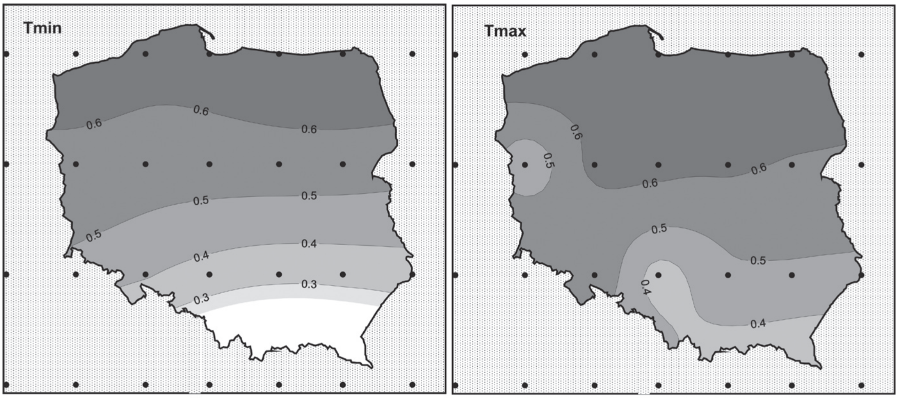

Fig. 16. Pearson linear regression coefficient between NAO_{DJFM} and daily minimum (T_{min}) and daily maximum (T_{max}) air temperatures in Poland in the period 1951–2005 (white area – no significant correlation to the level of 0.05)

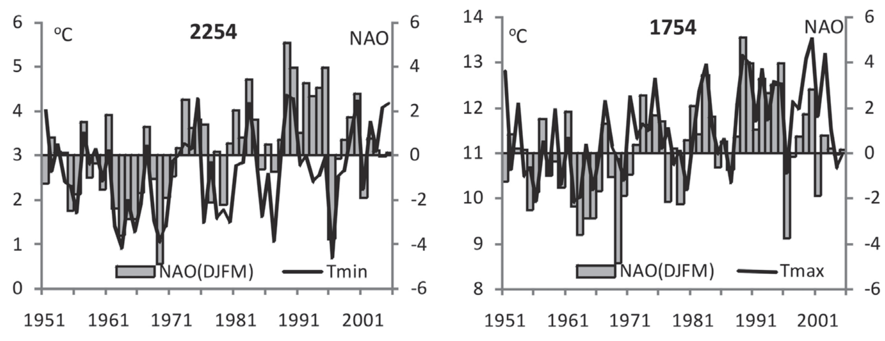

Fig. 17. Year-to-year course of NAO_{DJFM} and daily minimum air temperature (T_{min}) at the grid 2254 and daily maximum air temperature (T_{max}) at the grid 1754 in the period 1951–2005

observed for the north of Poland (grid 2254), where the linear correlation coefficient for T_{min} and T_{max} reaches 0.67 – Figs. 16 and 17. In the south of the country the correlation is less visible and for T_{min} it is not statistically significant.

Also the number of days with $T_{min}<0°C$ shows a substantial dependence on NAO_{DJFM}. In northern Poland (grid 2154) the linear correlation coefficient reaches -0.65. However, for the number of days with $T_{min}<-10°C$ and

T_{min}<-20°C the highest correlation with NAO_{DJFM} was found in the north-eastern part of the country (grid 2254: -0.62 and -0.49, respectively). An increase of NAO_{DJFM} results in a lower frequency of occurrence of such days and vice versa. In southern Poland the correlation was found not to be statistically significant. Days with T_{min}<-30°C are not frequent enough to permit a spatial analysis. However, for days with T_{max}>25 and T_{max}>30°C no statistically significant dependence was observed, except for a positive correlation between NAO_{DJFM} and T_{max}>35°C (r = 0.45 in grid 1354).

Discussion

The study demonstrated the possibility of applying grid data for analyses of contemporary climate changes in Poland. Admittedly, there are certain differences between the maps drawn on the basis of grid data and those based on measurements taken at stations (Lorenc 2005), yet the general pattern of isotherms is similar. The biggest differences were noted around the Baltic Sea, and their impact – according to the data taken from measurement stations – is limited to a narrow strip of coastline (especially for T_{min}), and in the mountains. The influence of orography on temperature values in grids was not sufficiently taken into consideration. The differences between the grid data and the measurements reach 0.5–1.5°C (the values of T_{min} and T_{max} on the grid maps are lower), and this is partially due to different periods analysed. *The Climate Atlas of Poland* (Lorenc 2005) uses data from 1971–2000, i.e. a very warm period, whereas this study also makes use of the much cooler decades of the 1950s and 1960s. Nevertheless, there are differences, for example in Lublin during the years 1951–2004 (Kaszewski et al. 2007). Mean annual T_{min} was 4.5°C, while in the nearest grid 2250 it was only 2.2°C. The respective values of the mean annual T_{max} in that period are 12.0°C and 10.6°C. The numbers of characteristic days also differ from the data contained in the *Climate Atlas of Poland*. The grid data show higher frequency and the differences reach e.g. 10–20 days for T_{min}<0°C and 5–10 days for T_{max}>25°C.

Generally, the global daily minimum and maximum air temperature values (T_{min} and T_{max}) increase, though the minima increase three times faster: in the years 1951–1990 they increase by 0.84°C and 0.28°C, respectively (Karl et al. 1993). In the same period the changes in central Europe reached 0.60°C for T_{min} and 0.52°C for T_{max} (Brázdil et al. 1996). Similar changes occur in

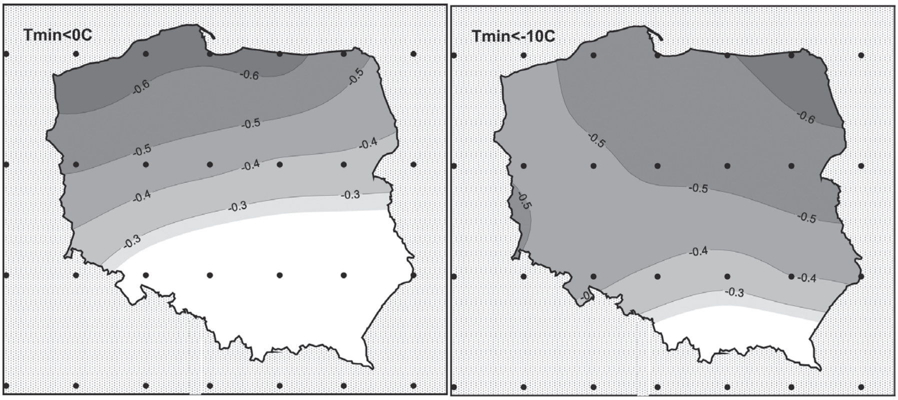

Fig. 18. Pearson linear regression coefficient between NAO_{DJFM} and number of days with T_{min}<0°C and T_{min}<-10°C in Poland in the period 1951–2005 (white area – no significant correlation to the level of 0.05)

Poland (Wibig and Głowicki 2002). The study validated the considerable increase of T_{min} and T_{max}, though only for northern Poland. In grid 1754 T_{min} increased by 0.28°C/10 years, and T_{max} by 0.26°C. In southern Poland, on the other hand, the changes of T_{max} and T_{min} in individual grids are not statistically significant. Yet this conclusion is not confirmed by the data from measurement stations: in the years 1951–2000 T_{min} increased in Aleksandrowice, Kasprowy Wierch, Kraków, Nowy Sącz, Tarnów and Zakopane. For T_{max} the changes are not so ambiguous, as only in Aleksandrowice, Nowy Sącz and Tarnów was the increase statistically significant (Bielec-Bąkowska and Łupikasza 2007). A lack of any significant increase of T_{max} in the years 1976–1990 was confirmed in the research by Wibig (2000/2001) and Wyszkowski (2006a). In mountain regions temperature changes are more variable. For instance, no significant trend of T_{max} and T_{min} was observed in Beskid Sądecki for the years 1971–2000 (Durło et al. 2007), whereas at the summit of Mt. Śnieżka the trends of T_{min} and T_{max} were 1.38°C/100 years and 0.72°C/100 years, respectively, in the period 1901–2000 (Głowicki 2003).

A bigger increase of T_{min}, as compared to $T_{max,}$ leads to a lower daily temperature range (DTR) (Easterling et al. 2000). However, this phenomenon varies in territorial distribution throughout Europe (Heino et al. 1999). In central Europe the DTR decreases (Brázdil et al. 1996). Similarly, in Finland since the 1950s the DTR has dropped by 0.5°C (Heino et al. 1999). No significant changes in the DTR have been observed in the grid data for Poland. In some grids, especially in the north of the country, there was a decrease, while in the south there was an increase. Nevertheless, the trends are not statistically significant, which confirms the results of previous studies (e.g. Niedźwiedź and Ustrnul 1994; Miętus and Filipiak 2003).

In central and northern Europe the number of days with slight frost ($T_{min} < 0^{o}C$) has fallen. In Prague (Czech Republic) in the years 1931–1995 the trend reached -3.1 days/10 years (Heino et al. 2000). Also in Poland the frequency of slight frost days has significantly changed. On the basis of the grid data it was found that in the period 1951–2005 days with ground frost were becoming less and less frequent, particularly in north-west Poland (-4.3 days/10 years). This is connected with the general increase in air temperature in winter and spring (Fortuniak et al. 2001; Kożuchowski and Żmudzka 2001). On the other hand, despite the overall warming, there are more and more days with T_{min} <-10°C and -20°C in the south of the country. The number of hot days, with T_{max} >25°C, is increasing, especially in the centre of Poland (4.6 days/10 years), and the same applies to very hot days (increase of 1.2 days/10 years).

The observed changes, especially those happening in the most recent years, are caused by intensified zonal circulation with the increasing western component of the geostrophic wind over Europe (Marsz and Styszyńska 2001). A substantial growth in T_{max} and T_{min} has taken place in the last 20 years as a result of intensified western circulation (Niedźwiedź 2003; Ustrnul 2007). In Lublin the increase of positive air temperature anomalies has been evident since 1989 (Kaszewski et al. 2007). Marsz (2007) argues that a change in the circulation regime took place as early as 1976–1978, following a shift of the Icelandic Low to the north-west and the decrease of pressure by 8 hPa north of Norway (Lofoten Low). Similarly, the Azores High moved eastwards, which caused an intensified transfer of maritime air masses over Europe and an increase in the NAO (Hilmer, Jung 2000). The changes are particularly apparent in winter, when the highest increase in temperature took place (Ustrnul 2007). Research confirms the exceptional role played by the NAO in shaping the climate of Europe, including Poland, in winter months (e.g. Hurrell 1995; Wibig 2000a; Marsz and Styszyńska 2001; Przybylak et al. 2003; Ustrnul 2007). The strongest correlations between the patterns of T_{max} and T_{min} have been observed in NW Poland (r = 0.67), decreasing towards the south, as has been shown elsewhere (e.g. Ustrnul and Czekierda 2007). Nevertheless, the linear correlation coefficient between the air temperature and the NAO index at Święty Krzyż reaches 0.73 in January (Olszewski et al. 2007).

The correlation with days of $T_{min} < 0^{o}C$, $T_{min} < -10^{o}C$ and $T_{min} < -20^{o}C$ is negative (r = -0.65, -0.62 and -0.49, respectively), especially in the north of Poland. In the south the correlation is weaker, though in Kraków the correlation between NAO and days with $T_{min} < -15^{o}C$ and T_{min} $-30^{o}C$ reaches -0.5 and -0.7 (Cebulak and Limanówka 2007).

During periods of low NAO index values the Icelandic Low and the Azores High become weaker and the zonal atmospheric circulation becomes limited. In circumstances like these, Poland often finds itself in the area of influence of eastern European highs, carrying cold continental air masses in winter. Therefore, the lowest T_{min} in Kraków occur during anticyclone types of circulation (Ca and Ka) – Michniewski (2007).

The impact of the NAO on the number of hot and very hot days occurring in the warm half of the year is not statistically significant, as proved by Walsh et al. (2001). Only the number of days with $T_{max} > 35^{o}C$ shows a positive correlation. The extension of the Azores High in summer (a higher NAO index) results in more frequent heat waves over Europe (Marsz 2007). This phenomenon has been increasing in recent years. In the Czech Republic the series of heats of 1994 and 1995 had been unprecedented since 1775 (Kysely 2002). According to weather scenarios for the years until 2100 the absolute minimum of air temperature in central Europe may increase by 4–7^{o}C, whereas the absolute maximum of air temperature may reach 42–44^{o}C (Sillman and Roeckner 2008).

Concluding remarks

The daily T_{max} and T_{min} data used in NCEP/NCAR reanalyses for the years 1951–2005 make it possible to analyse the spatial distribution of those temperatures in Poland, as well as the frequency of characteristic days. The thermal parameters reveal statistically significant trends in spite of great year-to-year variability.

The distribution of T_{min} is meridional, with high values in the west and on the Baltic coast (4–5^{o}C), and lowest in the east (2.5^{o}C). In the period analysed a statistically significant increase of T_{min} occurred in north-west Poland, reaching 0.2–0.3^{o}C per 10 years.

The highest mean T_{max} are in the west of Poland (up to 12°C) and they decrease eastwards and on the coast (10.5°C). In most of the country they increase (up to 0.26°C/10 years), though the changes in south-east Poland are not significant.

No statistically significant increases or decreases in DTRs were observed, as the T_{max} and T_{min} trends are similar.

The number of days with T_{min}<0°C varied from less than 100 days on the Baltic coast to over 140 days in the east of Poland. Their frequency drops almost throughout the country, and by as much as 4.3 days per 10 years in the north. The frequency of days with T_{min}<-10°C in Poland oscillated between 10 on the coast to 40 in the east, showing a significant growth only in the south (by 2–3 days/10 years). Days with T_{min}<-20°C are sporadic (1–8) and their frequency grows in south-east Poland (by 1.2 days/10 years). Days with T_{min}<-30°C are very rare (less than 1).

Hot days (T_{max}>25°C) occur from 15–20 times a year on the coast and 25 in the south to over 30 times in the centre of the Poland. Throughout country the number of hot days increases by up to 4.6 days/10 years. Similarly, the number of very hot days (T_{max}>30°C) have increased to 1.4 days in the Pomeranian Lake District. Their frequency ranges from 2 to 6 days per year. Extremely hot days (T_{max} >35°C) are very sporadic in Poland (less than 1 day per year) and their frequency has also slightly increased.

Thermal conditions in Poland are particularly influenced by atmospheric circulation. The NAO_{DJFM} was seen to exert a substantial impact, especially in winter. At high values of the $NAO_{DJFM,}$ winters were abnormally warm, while at its low values they were very cold and frosty. The greatest relations were found in the north of Poland, where the linear correlation coefficient between NAO_{DJFM} and T_{min} and T_{max} reached 0.67. In the south the relationship is weaker, and for T_{min} it is even statistically significant. The number of days with T_{min}<0°C also revealed some dependence on NAO_{DJFM} in the north of Poland (r = -0.65). For days with T_{min}<-10°C, r was -0.62, and for T_{min}< -20°C it was -0.49. In the south of Poland the correlation is not statistically significant. For days with T_{max}>25 and T_{max}>30°C, occurring in the warm half of the year, no statistically significant correlation was found, except for T_{max}>35°C (r = 0.45).

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