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TEMPERATURE-RELATED CLIMATE EXTREMES IN THE POTSDAM OBSERVATION RECORD

Z. W. Kundzewicz, D. Józefczyk: *Temperature-related climate extremes in the Potsdam observation record.* – Geografie–Sborník ČGS, 113, 4, pp. 372–382 (2008). – This paper examines temperature-related climate extremes in the unique long-term gap-free record at the Secular Meteorological Station in Potsdam. Increasing tendencies in daily minimum temperature in winter and daily maximum temperature in summer, as well as monthly means of daily minimum temperatures in winter months and of daily maximum temperatures in summer months are illustrated. Also the numbers of hot days and of summer days (with maximum daily temperature exceeding 30 °C and 25 °C, respectively) have been increasing. In agreement with warming of winter minimum temperatures, the numbers of frost days (with minimum daily temperature below 0 °C) and of ice days (with maximum daily temperature below 0 °C) have been decreasing. However, low correlation coefficient and huge scatter illustrate strong natural variability, so that the occurrence of extremes departs from the general underlying tendency.
KEY WORDS: climate extremes – climate variability – climate change – temperature – trend.

Introduction

As noted in IPCC (2007), warming of the global climate system is unequivocal. This is now evident from observations of increases in air temperatures, which show clear trends at a range of scales, from local, via regional, to continental, hemispheric, and global. Most of the observed increase in global mean air temperature since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations. The updated 100-year linear trend (1906 to 2005) shows a 0.74 °C (0.56 °C to 0.92 °C) global mean temperature increase, while the linear warming trend over the last 50 years (0.65 °C) is nearly twice as strong as that for the last 100 years (IPCC 2007). Global temperature changes are accompanied by changes in other climatic variables.

However, besides conducting the trend detection studies, the research community has been carefully watching temperature-related records of climate extremes in different categories, such as maximum and minimum daily, monthly, seasonal, and annual temperatures. Absolute record values of maximum or minimum temperature do not necessarily match the tendencies present in the long-term time series. Even if a clear rising trend of global mean annual temperature is unabated, the highest global mean annual temperature on record occurred already nine years ago, in 1998 (related to a strong El Niño phase). This is so, despite the fact that among 13 globally warmest calendar years in the global instrumental observation record, available since 1850, there are 12 years from the last 13 years. Each of the

years 2001–2007 belongs to the set of second-warmest to eighth-warmest years (Brohan et al. 2006, Kundzewicz 2008).

Beside the data at larger scales, it is of much interest to examine long time series of good-quality observation records, wherever available, looking for changes at regional and local scales.

The secular meteorological station in Potsdam

The data set used in the present paper stems from the Secular Meteorological Station in Potsdam (Germany), located at the south-west of the town (co-ordinates: 52°23'N, 13°04'E, elevation 81 m a.s.l.), approximately 600 m away from the built-up area. It is a notable station, world-wide, with an uninterrupted observation programme carried out since January 1, 1893. The station was established with the purpose to serve for a longer time (for ages, since the word saeculum means age in Latin). Comprehensive information about the station, as well as a wealth of long-term observation records can be found in public domain at the web portal: http://www.klima-potsdam.de/. Open access to the long time series of good-quality climatic observations at the Potsdam observatory encourages scientists to analyze these data holdings. This is true not only for Germany, but also for the neighbour country, Poland, where no hydrometeorological data are in public domain and the prohibitively high cost charged by the national hydrometeorological service is not affordable to most scientists (cf. Kundzewicz et al. 2007).

Among the many variables that have been measured at the station are: air and ground temperature, air pressure, global radiation, relative humidity, water vapour pressure, wind speed, precipitation, cloudiness, snow cover, frost depth, sunshine hours, such weather events as haze and storm. Considerable efforts have been made to keep the observation conditions homogeneous, by maintaining the station location, conditions of the environment, methods and principles of instrumental observation.

In the present contribution, valuable long gap-free records at Potsdam are examined in the context of temperature-related climate extremes, understood here as the maximum or minimum values of selected climate indices at a pre-defined time interval (e.g. 12 consecutive months, year, season, month, day). Among the variables tackled are temperature (minimum, maximum); the number of frost days (with minimum daily temperature below 0 °C) and ice days (with maximum daily temperature below 0 °C); the number of hot days (with maximum daily temperature exceeding 30 °C) and summer days (with maximum daily temperature exceeding 25 °C).

Annual and 12-month temperature records

The mean annual temperature observed at Potsdam shows a clearly increasing trend (Kundzewicz et al. 2007). There have been seven calendar years on record with mean annual temperature in excess of 10 °C (Table 1). In 2007, the mean annual temperature record of 2000 (10.47 °C) was not exceeded, but the value recorded for 2007 was only marginally lower (10.46 °C).

Even if the instantaneous temperature value is measured with 0.1 °C accuracy, Table 1, presenting mean annual temperature, calculated from

Table 1 – Warmest years at the Potsdam secular meteorological station

Rank	Year	Mean annual temperature (°C)
1	2000	10.47
2	2007	10.46
3	1934	10.44
4–5	1989, 1999	10.26
6–7	1990, 2006	10.17

daily mean temperatures, contains values with 0.01 °C resolution. This allows, for instance, ordering of the years 2000 and 2007. Leaving 0.1 °C resolution one would not distinguish between the mean annual temperature in 2000 and 2007.

There is a strong random component in climate extremes that illustrates natural variability and weather vagaries. Occurrence of a record high mean monthly temperature does not necessarily mean that the highest daily maximum temperature in this month is record high. For example, July 2006 was the warmest July on record, as far as the monthly mean temperature is concerned (23.69 °C). However, the highest daily maximum temperature during this month was 35.9 °C, that is below the highest daily maximum temperature of 36.8 °C, observed during a much less warm July 2007, with mean monthly temperature being 18.05 °C only.

Even if a record of a mean temperature during a calendar year dates back to 2000 and has not been exceeded since, looking at the mean temperature of any consecutive 12-month period, that commences on the 1st of any month (rather than on January 1), one can find a new record. Until 2007, the warmest 12 consecutive months in the history of observations at the Potsdam Secular Meteorological Station were recorded from July 1999 to June 2000, with a mean temperature of 10.70 °C. On 31 January 2007, this record went up to 10.83 °C, on February 28, 2007 – to 11.16 °C. On March 31, 2007 the

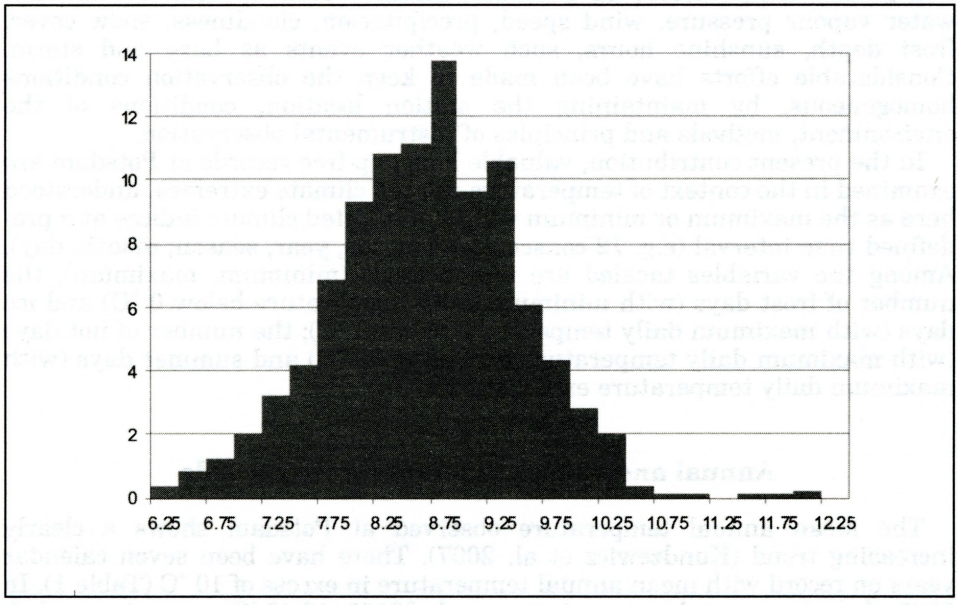

Fig. 1 – Proportion (in %) of mean temperature (°C) of 12 consecutive months in Potsdam (after Kundzewicz et al., 2007). All 12-month periods from 1 January 1893 to 30 June 2007 were considered. Value of 2 corresponding to the interval 7.0–7.25 means that 2 % of all values of 12-month mean temperature belong to this interval.

Table 2 – Review of records of temperature-related climate extremes. Data from www.klima-potsdam.de.

Variable	Date of record	Value of record	Other recent entries in the list of 5
Maximum daily temperature	9.8.1992	39.1 °C	Rank 4 reached in 1994
Minimum daily temperature	11.2.1929	–26.8 °C	Most recent entry (rank 4) in 1969
Longest hot[1] period	23.7. to 6.8.1969	15 days	Rank 2 reached in 1994
Longest cold[2] period	21.1. to 26.2.1947	37 days	Rank 4 reached in 1996
First hot day in year	22.4.1968	31.8 °C	Ranks 2 and 3 reached in 2000 and 1996, respectively
Last hot day in year	20.9.1947	32.9 °C	No entries after 1975 in top 5
First frost[3] day in year	2.10.1957	–0.1 °C	This is the most recent entry in top 5
Last frost day in year	20.5.1952	–0.8 °C	This is the most recent entry in top 5
First summer[4] day in year	30.3.1968	25.7 °C	Among entries in top 5: 1985 and 1989
Last summer day in year	10.10.1995	25.3 °C	Rank 3 in 1985. Attention – rank 2 was observed in 1893!
Daily maximum sum of precipitation	8.8.1978	105.7 mm	Rank 2 in 2002
Longest dry spell	19.9.–20.10.1949	32 days	Rank 4 in 1996 (winter)
Longest wet spell	2.2.–6.3.1970	33 days	This was the most recent entry in top 5
Maximum snow depth	6.3.1970	70 cm	All five entries in the top 5 refer to the same month (March 1970)
Longest period with closed snow cover	1 December 1969 to 23 March 1970	113 days	Rank 5 refers to Dec 1978 – March 1979

Notes: [1] Hot day is understood as a day with $T_{max} \geq 30$ °C; [2] Cold (ice) day is understood as a day with $T_{max} < 0$ °C; [3] Frost day is understood as a day with $T_{min} < 0$ °C; 4 Summer day is understood as a day with $T_{max} \geq 25$ °C.

record increased vigorously (by 0.48 °C) to 11.64 °C, because the cold March 2006 did not count any more in calculations, and on April 30, 2007 it rose strongly again (by 0.27 °C) to 11.91 °C, as April 2007 – warmest on record – replaced less warm April 2006. Further, on May 31, 2007 the record went up to 12.04 °C, and on June 30, 2007 – to 12.09 °C (Kundzewicz et al. 2007). This latter figure is higher than the record before 2007 (see Fig. 1) by a very large increment (1.39 °C). All six outlier-like values (between 10.75 and 12.25) in the tail of the distribution of the 12-month mean temperature presented in Figure 1 occurred in 2006–2007.

It was shown in Kundzewicz et al. (2008) that in 2006-2007, the records of mean temperature over consecutive 12 months have been exceeded also at the national, continental, and hemispheric scales.

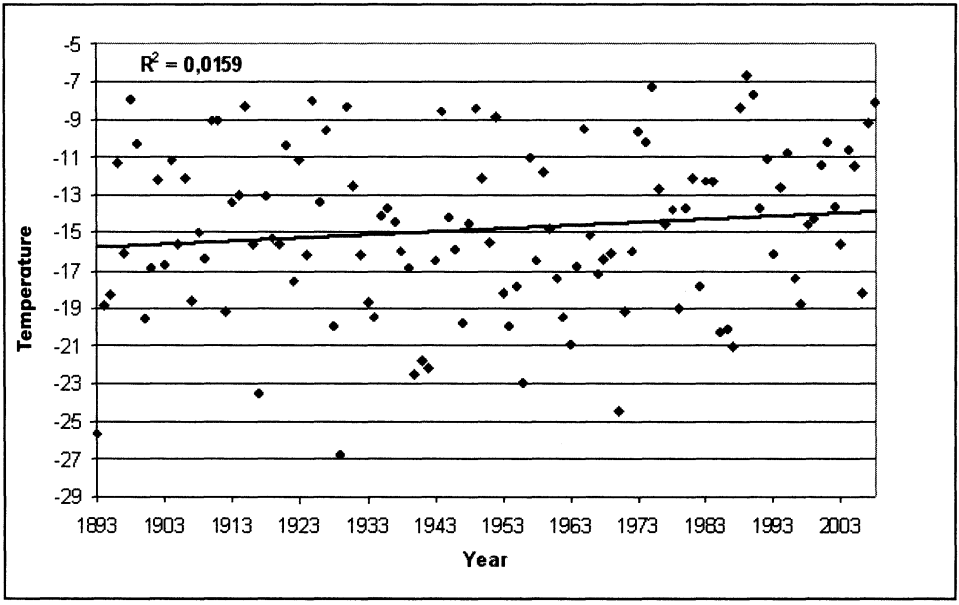

Fig. 2 – Lowest minimum daily temperature (°C) for winters from 1893 to 2008

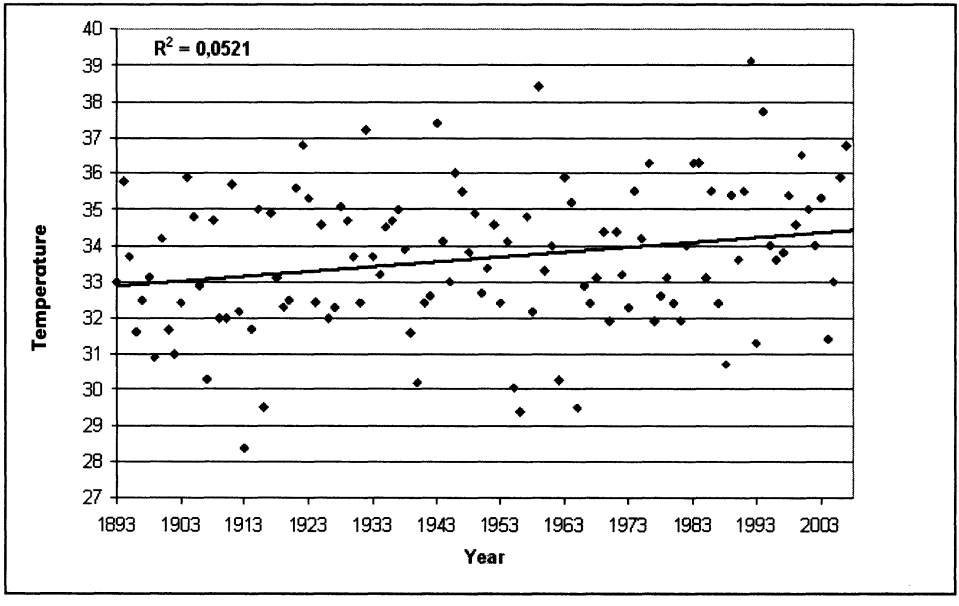

Fig. 3 – Highest maximum daily temperature (°C) for summers from 1893 to 2007

Review of records

Careful look at the table of records from Potsdam (Table 2; data from www.klima-potsdam.de) allows to conclude that cold extremes have been rare

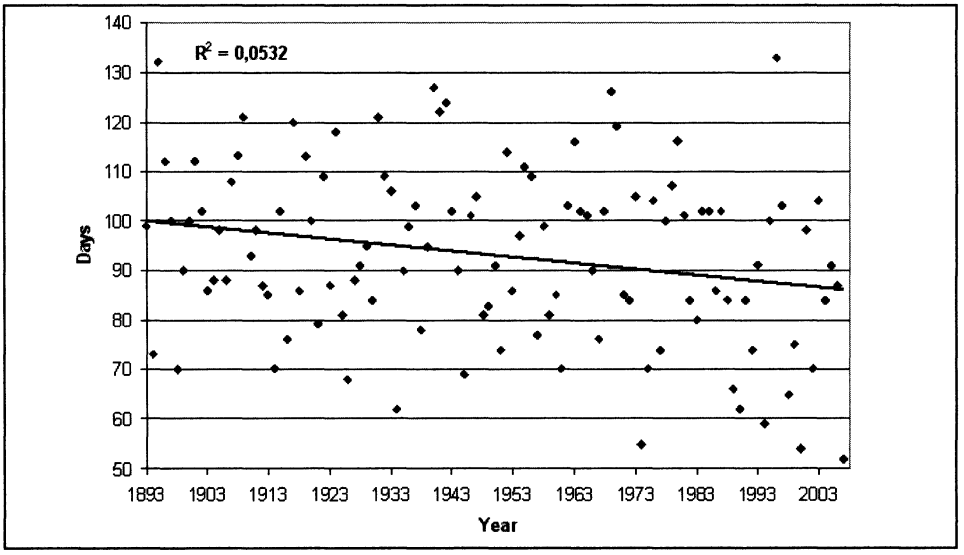

Fig. 4 – Number of frost days in individual winters from 1893 to 2008

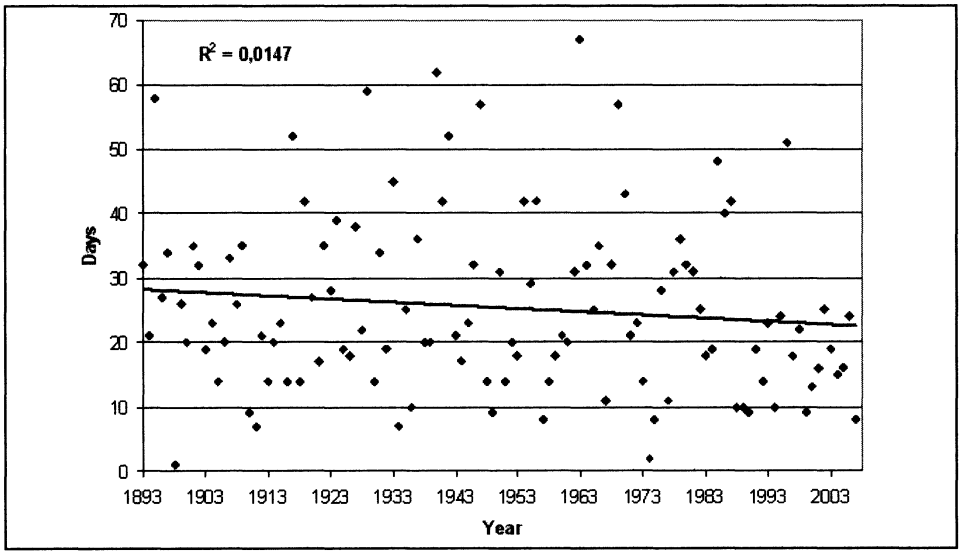

Fig. 5 – Number of ice days in individual winters from 1893 to 2008

in recent decades, while warm extremes occur more often. For example, the most recent entry in the list of five lowest values of minimum daily temperature dates back to 1969 (rank 4), while two entries in the list of five highest values of maximum daily temperature occurred after 1990 (ranks 1 and 4).

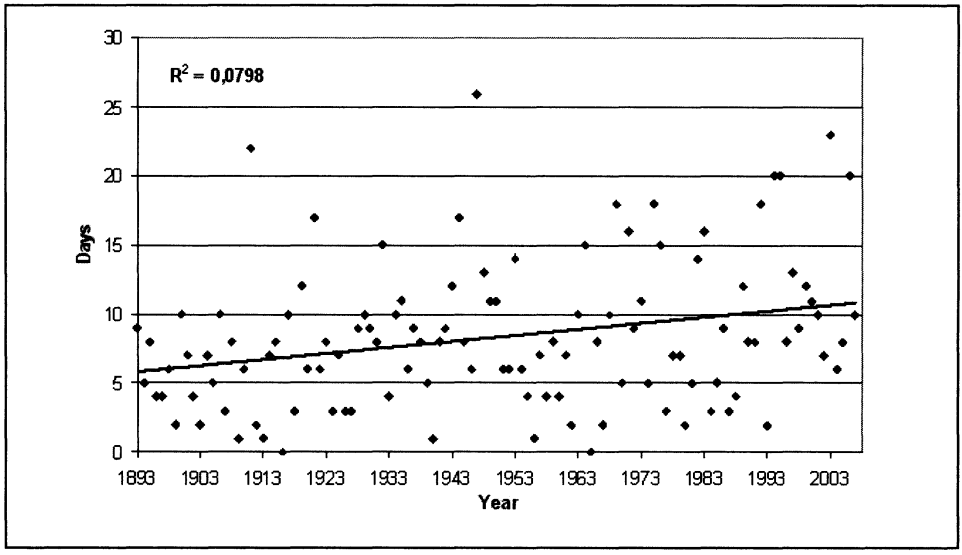

Fig. 6 – Number of hot days in individual years from 1893 to 2007

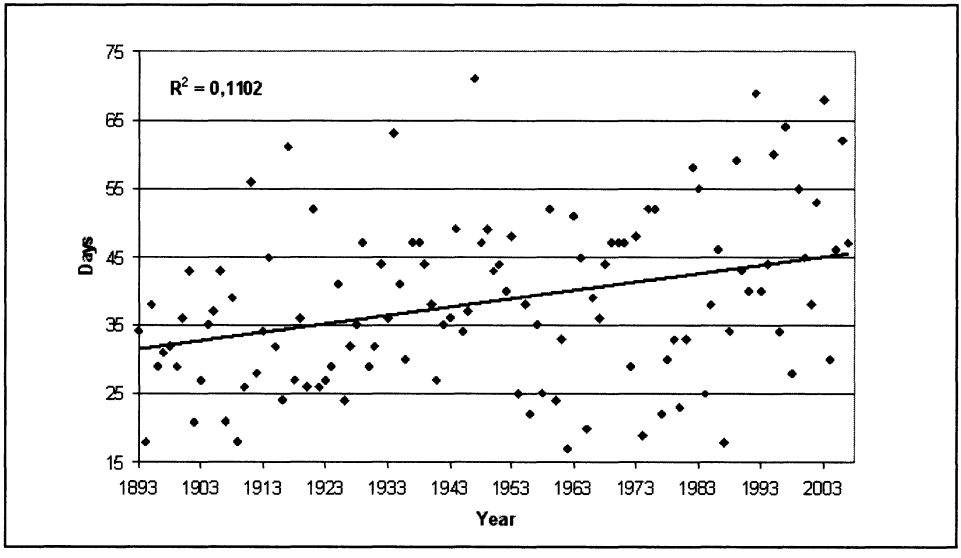

Fig. 7 – Number of summer days in individual years from 1893 to 2007

Indices of temperature-related climate extremes

Trends in daily minimum temperature in winter (December, January, February) and daily maximum temperature in summer (June, July, August), as well as monthly means of daily minimum temperatures in winter and monthly means of daily maximum temperatures in summer are examined next.

Table 3 – Monthly means of daily maximum temperature in summer

	June		July		August	
	Year	Temperature (°C)	Year	Temperature (°C)	Year	Temperature (°C)
Warmest	1917	27.15	2006	30.3	1997	28.09
2nd warmest	1992	26.59	1994	29.26	1944	27.97
2nd coldest	1984	18.39	1954	19.55	1941	19.79
Coldest	1923	15.62	1898	19.33	1902	19.54

Table 4 – Monthly means of daily minimum temperature in winter

	December		January		February	
	Year	Temperature (°C)	Year	Temperature (°C)	Year	Temperature (°C)
Warmest	2006	2.80	2007	2.24	1998	2.41
2nd warmest	1974	2.49	1975	2.13	1990	2.15
2nd coldest	1933	–6.85	1893	–12.76	1956	–13.35
Coldest	1969	–8.99	1940	–13.52	1929	–15.43

Figures 2 and 3 illustrate variations of the lowest minimum daily temperature in winter and of the highest maximum daily temperature in summer, for each of the years 1893–2008. Although the rising trend is visible, the scatter is very strong and overshadows the signal. The correlation coefficient attains low values. For lowest minimum daily temperature in winter the correlation coefficient takes considerably lower values than for highest maximum daily temperatures in summer.

The warming trend for the minimum temperature in winter is stronger than for the maximum temperature in summer (attention: the temperature scales in Figs. 2 and 3 are different). The number of frost days (defined as days with minimum temperature below 0 °C) and ice days (defined as days with maximum temperature below 0 °C) have been decreasing with time (Figs. 4 and 5), but in individual years, departures from the overall decreasing trend are very strong. For example, within the last 15 years both the highest value (133 frost days in 1996) and the lowest value (52 frost days in 2007) on record have been observed.

Figures 6 and 7 illustrate, respectively, the numbers of hot days, defined as days with maximum daily temperature exceeding 30 °C and the numbers of summer days (with maximum daily temperature exceeding 25 °C), for individual years. Increasing tendency is clearly seen in both figures and the values of correlation coefficient are significantly higher than in all the time series of indices considered earlier in this paper.

The records of monthly means of daily maximum temperature in summer and of daily minimum temperature in winter are presented in Tables 3 and 4, respectively. These tables, containing the two highest and the two lowest values on record, agree with the warming tendency, as expected. Warm extremes get gradually more frequent and cold extremes – less frequent. Among the two warmest temperature values for each summer and winter months, there are 8 (out of 12) entries since 1990 and only two before 1950. However, variability of monthly means is very high, so that high or low values occur throughout the time period analyzed, independently on the general

tendency. For instance, in 1917, the highest monthly mean of daily maximum temperature of June (27.15 °C) was observed, even if the climate was clearly colder than now. Only six years later, in 1923, the lowest monthly mean of daily maximum temperature of June (15.62 °C) was observed. Tables 3 and 4 show that individual outliers-like lowest values may be very much below the second lowest values. For instance, the two coldest Decembers had mean daily minima of –8.99 °C in 1969 and –6.85 °C in 1933 (difference of 2.14 °C). The two coldest Februaries with mean daily minima of –15.43 °C (1929) and –13.35 °C (1956), show a difference of 2.08 °C. The two Junes with lowest daily maxima of 15.62 °C (1923) and 18.39 °C in 1984 manifest an even larger difference of 2.77 °C.

Conclusions

Climatic time series show strong natural variability (irregular oscillations), which is superimposed on a gradual trend accompanying the warming signal. Extremes get more extreme – says the IPCC report. Such tendency refers to both observations and even more so to projections, but there is a strong random component, so that heat records are not broken every year. Indeed, hot extremes occurred in old times, while cold extremes occur also now (albeit less frequently).

As reported by Trenberth et al. (2007), in the last 50 years there has been a significant decrease in the annual occurrence of cold nights (falling below the 10th percentile from the control reference period) in winter. The distributions of minimum and maximum temperatures have not only shifted to higher values, consistent with overall warming, but the cold extremes have warmed more than the warm extremes. More warm extremes imply an increased frequency of heat waves. There has been a global trend towards fewer frost days associated with the warming.

The present paper indicates that these global and general findings also hold for a specific, long-term, high-quality observation record. However, it shows that the natural variability is very strong and that extremes in individual year may largely differ from the dominating tendency. It can be clearly seen that an extreme value of such temperature-related indicators as maximum temperature in summer, minimum temperature in winter, number of hot days, and number of summer days may have occurred in the remote past, when the level of warming (as indicated by the linear regression) was much lower than now. Similarly, despite the warming, high values of the number of frost days and ice days may occur recently, largely exceeding the low value resulting from the decreasing tendency.

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Shrnutí

TEPLOTNÍ KLIMATICKÉ EXTRÉMY ZAZNAMENANÉ PŘI POZOROVÁNÍCH V POSTUPIMI

Pozorované teploty vzduchu, které vykazují na všech úrovních vzestupný trend, svědčí o nesporném oteplování globálního klimatického systému. Globální lineární teplotní trend je v posledních padesáti letech silný (0,65 °C). Pozorované vzestupy průměrné teploty vzduchu od poloviny 20. století jsou většinou pravděpodobně důsledkem pozorovaného vzestupu koncentrace skleníkových plynů, produkovaných člověkem.

Příspěvek doplňuje rozsáhlé souhrnné výsledky uvedením tendencí dlouhodobých záznamů velmi kvalitních pozorování. Zkoumá klimatické extrémy teploty vzduchu v jedinečném, dlouhodobém a souvislém pozorování na meteorologické stanici v Postupimi, prováděném od ledna 1893 do února 2008. Průměrná roční teplota vzduchu zaznamenaná v Postupimi vykazuje zřetelný vzestupný trend. I když rekordní průměrná teplota v kalendářním roce byla dosažena v roce 2000 a nebyla od té doby překonána, průměrná teplota jakéhokoliv následujícího dvanáctiměsíčního období začínajícího prvním dnem kteréhokoliv měsíce (spíše než 1. lednem) je vždy rekordní. Rekordní dvanáctiměsíční průměrná teplota před rokem 2007 byla 10,70 °C, ale na konci června 2007 dosáhla 12,09 °C a výrazně překonala předchozí hodnotu (o 1,39 °C).

Jsou prokázány rostoucí minimální denní teploty v zimě (prosinec, leden, únor) a maximální denní teploty v létě (červen, červenec, srpen), jakož i rostoucí měsíční průměry minimálních denních teplot v zimních měsících a maximálních denních teplot v letních měsících. Rostou také ukazatele extrémního tepla, jako počet horkých dní (s maximálními denními teplotami překračujícími 30 °C) a letních dní (s maximálními denními teplotami nad 25 °C). V souvislosti se zvyšováním minimálních zimních teplot se snižují indikátory extrémního chladu, jako je počet mrazových dní (s minimálními denními teplotami pod bodem mrazu) a ledových dní (s maximálními denními teplotami pod bodem mrazu). V určitých letech se však objevují značné odchylky od tohoto obecně poklesového trendu. Například během posledních 15 let byly pozorovány jak nejvyšší hodnoty (133 mrazových dní v roce 1996), tak nejnižší hodnoty (52 mrazových dní v roce 2007). Nízké hodnoty korelačního koeficientu a široký rozptyl, který zastiňuje tento signál, svědčí o silné přirozené variabilitě a o existenci extrémních odchylek od obecné tendence.

Pro nejnižší minimální denní teploty v zimě dosahuje korelační koeficient výrazně nižší hodnoty než pro nejvyšší maximální denní teploty v létě. Tendence růstu minimálních teplot v zimě je silnější než tendence zvyšování maximálních teplot v létě. Nejen to, že se rozložení minimálních a maximálních teplot posunulo k vyšším hodnotám, což svědčí o globálním oteplování, ale i teplota extrémních chladen vzrostla více než teplota extrémního tepla. Více teplotních extrémů znamená vyšší frekvenci vlivů horkých vln.

Klimatické řady svědčí o silné přirozené variabilitě (nepravidelné výkyvy), které se přidávají k postupnému trendu oteplování. Jak konstatuje zpráva Mezivládního panelu pro klimatické změny (IPCC), extrémy se stávají ještě extrémnějšími. I v minulosti

samozřejmě docházelo k extrémnímu horku, ale extrémní chladna jsou nyní výrazně méně častá, i když se samozřejmě mohou objevovat i dnes. Vzhledem k silné náhodné komponentě nejsou teplotní rekordy překonávány každým rokem.

Předložená práce uvádí, že tyto globální a obecné poznatky platí také pro konkrétní dlouhodobá a vysoce kvalitní pozorování. Ukazuje se však, že přirozená variabilita je velice silná a že extrémy se mohou v jednotlivých letech velmi odchylovat od převládajícího trendu. Je jasně vidět, že velice vysoké hodnoty takovýchto extrémů spojených s teplotou, jako jsou maximální teploty v létě, minimální teploty v zimě, počet horkých dní a počet letních dní, se mohly objevovat i v dávné minulosti, kdy úroveň oteplování (indikovaného lineární regresí) byla výrazně nižší než dnes. Podobně i navzdory oteplování se i dnes (i když ne příliš často) může objevit vysoký počet mrazových a ledových dní, který vysoce přesahuje nízké hodnoty, které plynou z uvedené poklesové tendence.

Obr. 1 – Podíl (%) průměrné teploty vzduchu (°C) ve dvanácti po sobě následujících měsících v Postupimi (podle Kundzewicze et al., 2007). Zkoumána byla všechna dvanáctiměsíční období od 1. ledna 1893 do 30. června 2007. Hodnota 2 odpovídající intervalu 7,0–7,25 znamená, že 2 % všech hodnot dvanáctiměsíčních průměrných teplot náleží do tohoto intervalu.
Obr. 2 – Nejnižší minimální denní teploty vzduchu v zimě od roku 1893 do roku 2008.
Obr. 3 – Nejvyšší maximální denní teploty vzduchu v létě od roku 1893 do roku 2007.
Obr. 4 – Počet mrazových dní během jednotlivých zim v období 1893–2008.
Obr. 5 – Počet ledových dní během jednotlivých zim v období 1893–2008.
Obr. 6 – Počet horkých dní během jednotlivých let v období 1893–2007.
Obr. 7 – Počet letních dní během jednotlivých let v období 1893–2007.

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