TEMPORAL VARIABILITY OF DAILY CLIMATE EXTREMES OF TEMPERATURE AND PRECIPITATION IN THE MIDDLE POLABÍ (*ELBELAND*) LOWLAND REGION*

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This paper analyses a 49 year (1961–2009) average 10th and 90th percentile values of daily temperatures and precipitation in a region of the middle Polabi lowland region in order to predict extreme dry-wet and cold-warm spells risk. The extremes are described by 11 indices based on temperature and precipitation. For the temperature indices based on relative thresholds are include cold days (TX10p) for lower extremes and warm days (TX90p) for higher extremes. To examine durational characteristics of extreme temperature events, such as cold spell (CSDI), warm spell (WSDI) and heat wave duration index (HWDI). Index using fixed threshold includes frost days (t ≤ –0.1°C). In the same way for the precipitation indices based on relative thresholds, upper fifth (R95p) and first (R99p) percentile values are used to calculate the accumulation of very wet day or extremely wet day precipitation. Very heavy or intense rainfall is measured using the RX1day index. To examine durational characteristics of extreme precipitation events, as consecutive dry (CDD) and wet (CWD) days are used. The Poisson process was successfully applied in the study of extreme climatic variable values. The probability of risk assessment (λ, 1/year) of the occurrences of extreme climate events was classificated: **λ**. > 0.2 (frequent), 0.1 < **λ** < 0.2 (probable) and 0.01< **λ** < 0.1 (rare). The results showed statistically relatively significant variability in frequency, duration and severity of heat waves and number of tropical days. The annual occurrence of frost days are decreases, while the annual warm and tropical days are increased. However, the trend in warm and tropical days is greater in magnitude and is related to rise in these events since early 1990s.

heat and cold waves; wet spell; dry spell

INTRODUCTION

Extreme events come in many different forms and sizes. Events occurring over short time scales, between less than 1 day and 6–10 days, are often referred to as extreme weather events. Statistically, extreme events are defined as possessing a low probability of occurrence. From agricultural point of view, extreme events are those events that agriculture is susceptible to or unable to cope with. Extreme weather events are events that are rare within its statistical reference distribution at a particular place. The Intergovernmental Panel on Climate Change (IPCC) defined extreme events of meteorological conditions as: "an extreme weather event would normally be as rare or rare than the 10th or 90th percentile of the observed probability density function" (IPCC, 2001). However, anomalies in different variables are typical of individual weather extremes (e.g. heavy precipitation, heat episodes) and even of individual events. Moreover, the value of a variable can be extreme in one region while it can be normal in another (e.g. Lana, Burgueno, 1998; Blazejczyk et al., 1998; Vicente-Serrano, Beguería-Portugués, 2003; Rebetez et al., 2009). Extreme climate events are the average of a number of weather events over a certain period, which is itself extreme (e.g. *drought* or heavy rainfall over a season). While this definition distinguishes between events at a specific time and events that persist over some time such as a season (e.g. wet and dry spells), respectively called extreme weather events and extreme climatic events, the IPCC WGII 2007 report provides a definition where both types of events are called extreme weather events. Extreme climate events are very severe, rare, magnitude and determined by their spatial scale (waste or local, e.g. heat wave, drought), temporal scale (frequency, onset and duration, e.g. days, weeks) and complexity (1 or more variables). Thus, the following three criteria are often used in classify events as extreme (WMO, 2003):

- Rarity – how rare they are, which contains information of frequency of occurrence (frequent or rare).
- Intense – events characterized by relatively small or large values (i.e. events that have large magnitude deviations from the standard).
- Severe – events that result in large socio-economic losses or the impacts they exert on environmental or economic sectors (in terms of costs or damage).

For identification climate extreme events are used several categories of indices: a) percentile-based indices: sample the extreme end of a reference period distribution e.g. 10th or 90th percentile of min/max temperature; b) absolute indices: represent maximum or minimum values within a season/year e.g. maximum 5 day precipitation;

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c) threshold indices: number of days on which temperature/precipitation falls above or below a fixed threshold e.g. frost days (minimum temperature < 0 °C), days with precipitation > 10 mm; d) duration indices: define periods of excessive warmth, cold, wetness or dryness, e.g. heat wave duration, number of consecutive dry days.

With respect to the studies of the heat waves, dry pattern in the Czech Republic, over the past decade many climatologists have studied the frequency and severity of this event (e.g. Huth et al., 2000; Kyselý et al., 2000; Brazdil et al., 2009; Potop et al., 2010). Since 1961, the warmest summer seasons occurred in the Czech Republic in 1983, 1992, 1994, 2003 and 2006 (Kyselý, Kalvova, 1998; Kyselý, 2010). The absolute air temperature maximum on the territory of the Czech Republic was observed on July 27, 1983 (40.2 °C) at Prague-Uhříněves (Krska, Munzar, 1984). At the same time, at the Poděbrady weather station maximum temperature 37.7 °C was reached. The result of temporal analysis of the heat waves records from Prague-Klementinum by Kyselý et al. (2000) shows that extreme heat waves occurrence (warmest summer seasons) were observed in 1947, 1952, 1992 and 1994. For the majority weather stations in Polabí lowland, the year 1994 is distinguished particularly in the much higher cumulative temperature excess of heat waves.

The aim of this study was to analyze local temporal variability of daily climate extremes of temperature and precipitation based on the datasets at the Poděbrady weather station (φ = 50°08'N, λ = 15°06'E, h = 196 m a.s.l.). This station is representative for lowland of Polabí, where is one of the largest farmed in especially in growing marketing vegetable crops.

MATERIAL AND METHODS

A set of climate extreme indices derived from daily temperature and precipitation data, with a primary focus on extreme events, were computed and analyzed. The biggest problem in assessment variability of extreme events is in exact definition, data availability and inhomogeneities. To fill the gaps in daily data of Poděbrady was used the dataset of the Hradec Králové station (φ = 50°10'N, λ = 15°50'E, h = 278 m) as reference time-series. For this purpose the ProClimDB software was used (Štěpánek, 2004). In this study, we use some of these temperature and precipitation extreme indices developed by the Expert Team on Climate Change Detection, Monitoring and Indices. Indices used in the analysis are given in Table 1. The observed indices are calculated based on daily maximum temperature, daily minimum temperature, and daily total precipitation during the period 1961–2009. The observations were taken at Poděbrady weather station. In addition, to examine spatial distribution of temperature and rainfall events was based on 90 weather stations over 1989–2009. The time series daily and monthly data resolution for individual meteorological elements is reported by Czech Hydrometeorological Institute. All statistical analyses were carried out with Statistica 8.0 and for mapping the ArcGis Software 9.1 was used.

Mainly task was identifying annual frequency of extreme events. The second ways applied to identify occurrence of ten-day period extreme, focuses on wet and dry, hot and cold extremes. The long-term average percentile-based indices include cold days (TX10p) for lower extremes and warm days (TX90p) for higher extremes. Cold spell (CSDI), warm spell (WSDI), and heat wave duration index (HWDI) consider the events of long lasting runs of warm or cool days based on the percentile values. Index using fixed threshold includes frost days (t ≤ –0.1 °C) and tropical days (tmax ≥ 30 °C). In the same way for the precipitation indices based on relative thresholds, upper fifth (R95p) and first (R99p) percentile values are used to calculate the accumulation of very wet day or extremely wet day precipitation. Very heavy or intense rainfall is measured using the RX1day index. To examine durational characteristics of extreme precipitation events, as consecutive dry (CDD) and wet (CWD) days are used. Those indices reflect time-series variations that can lead to dry-

Table 1. Definitions of the indices of cold and warm temperature extremes and the indices of precipitation extremes used in this study

Index		Indicator name	Definitions
Temperature	TX10p	Cold days	Percentage of days TX < 10^{th} percentile
	TX90p	Warm days	Percentage of days TX > 90^{th} percentile
	WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90^{th} percentile
	CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TX < 10^{th} percentile
	HWDI	Heat wave duration index	Maximum period > 5 consecutive days with *T*max > 5 °C above the 1961–1990 daily *T*max normal
	FDO	Frost days	Annual count when daily minimum temperature ≤ –0.1 °C
Rainfall	CDD	Consecutive dry days	Maximum number of consecutive days with RR < 0.1 mm
	CWD	Consecutive wet days	Maximum number of consecutive days with RR ≥ 1 mm
	Rx1day	Max 1-day precipitation amount	Monthly maximum 1-day precipitation
	R95p	Very wet days	Annual total PRCP when RR > 95^{th} percentile
	R99p	Extremely wet days	Annual total PRCP when RR > 99^{th} percentile

ness and wetter conditions. For the temperature indices based on relative thresholds, the 49-year average 10th and 90th percentile values of daily temperatures are calculated for each of the 365 days of the year (The February 29 value is excluded). In the present study, the values of the heat wave duration (HWDI) were determined empirically from the observed station series in the climatological standard-normal period 1961–90. The definitions for extreme events are generally based on a frequency distribution. Variability in the occurrence of extreme events are defined by conditions, which are found to be infrequent the control period or constitute a condition with potentially detrimental effect to the environment. Thereby, number of extreme events and its probability was estimated in accordance Poisson's generalized distribution:

$$P\,[(N\,(t+\tau) - N\,(t)) = \mathrm{k}] = \frac{e^{-e\lambda\tau}\,(\lambda\tau)^{k}}{k!} \quad \mathrm{k} = 0,1,\ldots..$$

where $N\,(t+\tau) - N\,(t)$ describes the number of climate extreme events in time interval $(t, t+\tau)$. Poisson process (*Pp*) is characterized by a rate parameter λ, such that the average of the number of events observed in year $(t, t+\tau)$ with associated parameter $\lambda\tau > 0$. The exponential parameter λ is estimated to minimize the difference between the actual extreme events and its value predicted by exponential distribution. The observed extreme events frequency comes from random sampling from the relevant *Pp*. The estimate of λ is: λ = 1/avg (k). The probability of risk assessment (λ, 1/year) of the occurrences of extreme climate events was classified: $\boldsymbol{\lambda} > 0.2$ (frequent), $0.1 < \boldsymbol{\lambda} < 0.2$ (probable) and $0.01 < \boldsymbol{\lambda} < 0.1$ (rare).

RESULTS AND DISCUSSION

Time distribution of the average (N) and maximum number (Nmax) of wet, dry, cold and hot climate events in a year to a Poisson distribution are included in Table 2. Given that parameter λ is estimated from the empirical data as the average number of events per year, with the maximum number of events in a year (Nmax). The daily extreme temperature events occurred in the following years: 1963 (75 – maximum cold days), 2003 (62 – maximum warm days), 1994 (22 – length of warm spell), 1985 (30 – length of cold spell), 1994 (17 days of heat wave duration) and 1997 (149 – annual frost days). The extreme rainfall events occurred in the following years: 1985 (52 – maximum length of dry spell), 1974 (18 – maximum length of wet spell), 1979 (82 mm/day – heavy rainfall), 1977 (13 very wet days) and 1981 (5 extremely wet days) (see Table 2). Fig. 1 shows Poisson distribution of annual wet and dry weather events, while in Fig. 2 are included cold, warm and hot climate events. Fig. 3 illustrates relative frequency of severity CSDI, WSDI, HWDI indices and peak temperature in cold and heat waves.

According to the length of extreme temperature and rainfall events there are 3 classes: medium length, long length and very long length. A good strategy could be that proposed by the mentioned author, who tested several percentiles ranging from 50th to 99.75th and assumed as the best parameters the average derived from the different percentiles. Given that the goal is the optimal sample of long extreme temperature and rainfall spells, the 50th the percentile was a mean length of spells not classified as extremes. Opposite to that, it is very likely that percentiles close to the 99th percentile only include maximum lengths (Nmax) in all cases. For example, daily precipitation dry-spell series are commonly used in the stochastic analysis of drought occurrence. Extreme values correspond to very long spells of consecutive days without precipitation that generate episodes of extreme drought. To date, the frequency analysis of these extreme values has been carried out using the Poisson distribution (Table 3).

The annual number of dry days (11 days/year) is higher than wet days (5 days/year), with a non-uniform seasonal distribution. Higher dry days are in spring (predominantly in April) and autumn (especially in October-November) but wet days are in summer. Analyses of the length of temperature and rainfall events are included in Figs 1–2. As the results of dry events may occur 9 dry spells per year with mean 22 consecutive dry days. Wet

Table 2. Parameter λ, in years-1, of the Poisson distribution for a number (N) of extreme weather events. For the day-count indices, the corresponding mean return period (in days) and RX1day is in mm

Index		Return period, average number and length of event per year, λ	Return period, maximum number of event in a year, Nmax	Probability λ, 1/year
Temperature	TX10p	38	75 (1963)	0.022
	TX90p	37	62 (2003)	0.021
	WSDI	10	22 (1994)	0.016
	CSDI	10	30 (1985)	0.011
	HWDI	7	17 (1994)	0.019
	FDO	92	149 (1997)	0.021
Rainfall	CDD	22	52 (1985)	0.020
	CWD	5	18 (1974)	0.010
	Rx1day	36	82 (1979)	0.021
	R95p	5	13 (1977)	0.010
	R99p	1	5 (1981)	0.021

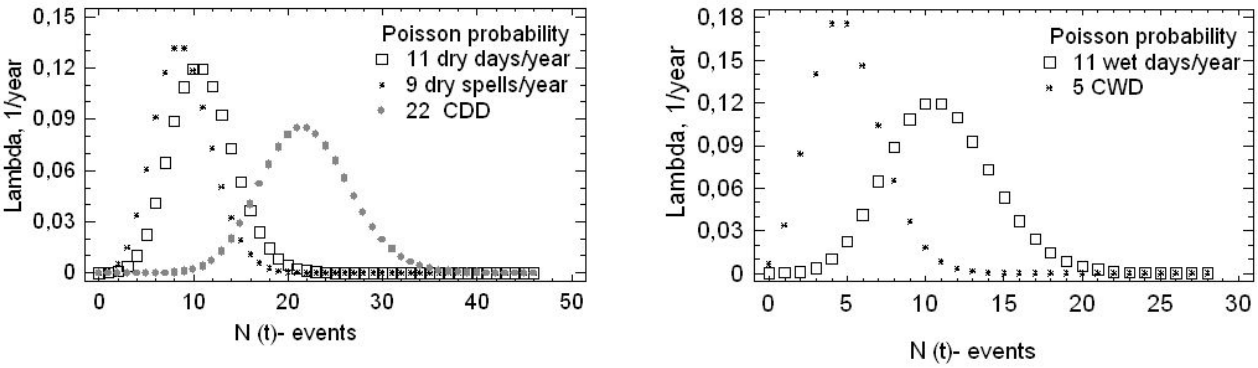


Fig. 1. Poisson distribution of wet and dry events

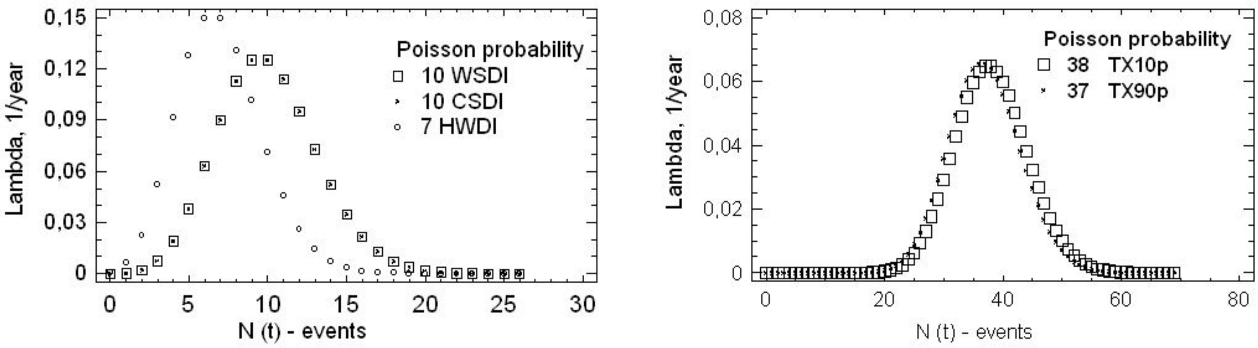


Fig. 2. Poisson distribution of cold, warm and heat events

events may occur 5 wet spells per year with mean 11 consecutive wet days. Thus, according to Poisson's law an increased frequency and length of the dry spells. Thereby, mean length of dry and wet spells can be expected once every 2 years, long length (above 33 consecutive dry days) once in 10 years and very long length (< 50 days) once in 50 year. Long and very long length of extreme temperature events are between 20 and 30 consecutive cold days, consecutive warm days from 28 to 36 and 14–17 heat wave duration (Table 3).

In order to detect the trend pattern of warm days, dry days, tropical days, very wet days and extremely wet days in the second half of the twentieth century were estimated according to 2nd polynomial trend (Fig. 4). The annual occurrence of frost days are decreases, while the annual warm and tropical days are increased. However, the trend in warm and tropical days is greater in magnitude and is related to rise in these events since early 1990s. The higher number of cold days was found in the 70's and 80's of the 20th century. The frequency of these days in the investigated period has decreasing character. There are increased trends in rainfall on extreme precipitation days, but is not statistically significant.

Long-lasting extreme temperature and rainfall events may do harm in any season of the year and can bring damage plants e.g. summer drought combined with hot spell, summer extreme warm events coupled with wet spell. Fig. 5 illustrates the result of the time distribution on ten-day period of average number of very wet and extremely wet days (a); number of dry spells and average interval between dry spells per year (b); warm days per year (c) during 1961–2009. The high concentrations of maximum dry spells are on April, September and August. The maximum values reaching 2nd ten-day of April and September (23–26 days). The number of wet days decline was most obvious in April and September what has been accompanied by increased dry days during this period (Fig. 5). Extremely wet and very wet days are frequent on third ten-day period of June and July and first ten-day period of August. This causes precipitation to be concentrated in a small number of days and summer maxima events represent a high percentage of the total annual. Concerning

Table 3. Predicted length of dry, wet, hot, cold and warm spells using the Poisson distribution

Length spells	50th – mean length	95th – long length	≥ 99th – very long length
Consecutive dry days within spell (CDD)	22	33	52
Consecutive wet days within spell (CWD)	5	12	18
Consecutive cold days within spell (CSDI)	9	20	30
Consecutive warm days within spell (WSDI)	13	28	36
Consecutive days in heat wave (HWDI)	6	14	17

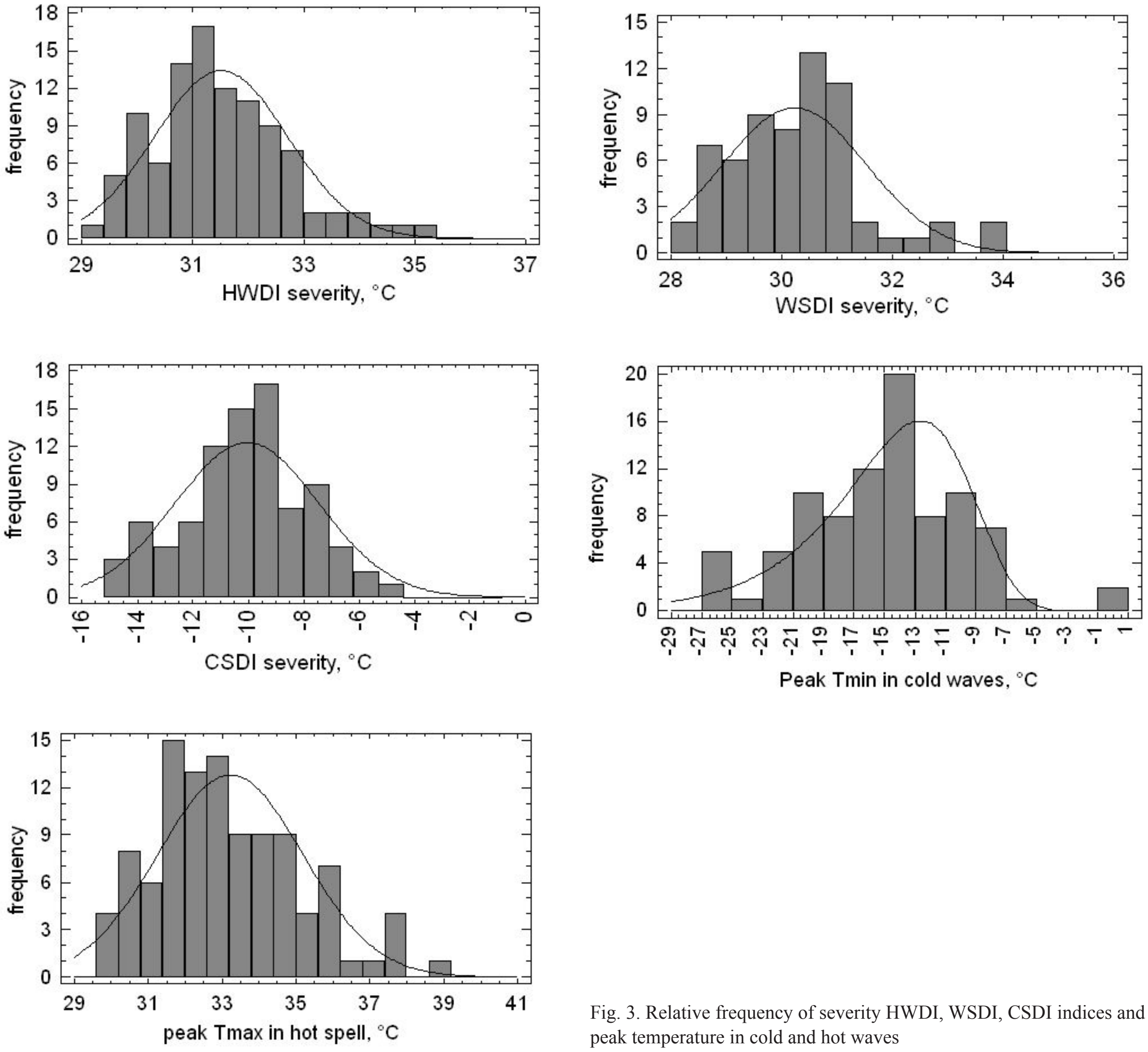


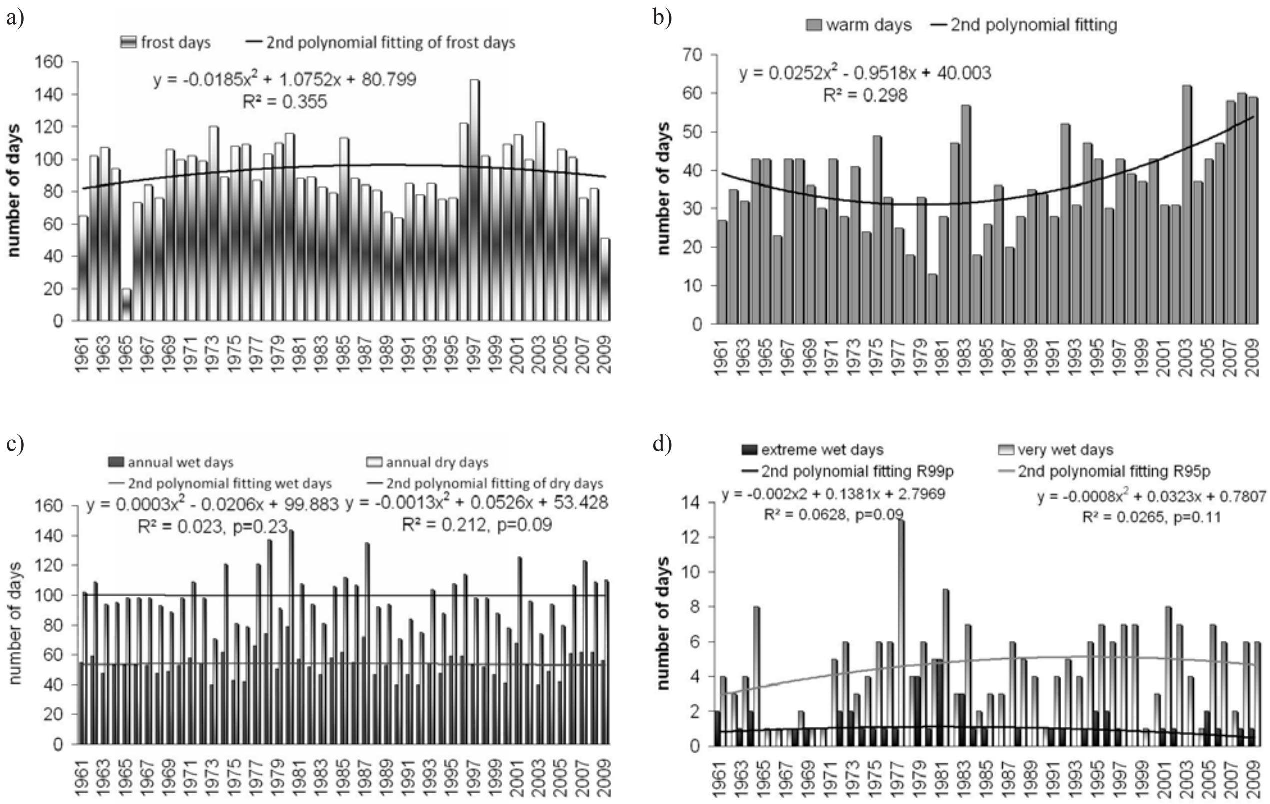
Fig. 3. Relative frequency of severity HWDI, WSDI, CSDI indices and peak temperature in cold and hot waves

time distribution on ten-day period of warm days is observed that maximum in first ten-day of August and third ten-day of July. Thereby, the warmest ten-day period is 1st ten-day period of August, the driest ten-day period is 2nd ten-day period of April and the wetness is 2nd ten-day period of June.

The results showed statistically relatively significant variability in frequency, duration and severity of heat episodes (expressed by heat waves and number of tropical days). These days are considered as very hot, and they particularly are of great importance for vegetable crops which are sensitive in the heat-stress. To characterize heat waves at Poděbrady weather stations, the duration, the cumulative *Tmax* excess above certain threshold ($\Sigma\Delta T$max > 30) during heat waves and the peak temperature are used. The mean numbers of tropical days per year are 14. If to compare the total number of tropical days in summer season for two research periods (1961–1990 and 1991–2009), it is evident that over the past 20 years, the average number of tropical days increased in the summer season (Table 4). In the summer of 1994 (33 days), 2003 (31 days) and 2006 (28 days) were characterized with the highest

Table 4. Heat waves and tropical days (June-August) summary characteristics at Poděbrady station

Periods	Heat waves				Tropical days			
	frequency of heat waves	mean duration of heat waves, days	the longest heat waves, days	year	mean number of tropical days	highest number of tropical days	year	highest tmax ºC
1961–1990	0.9	7.5	9	1983	10	22	1967	35.4
1991–2000	1.2	9.5	17	1994	15	33	1994	39.2
2001–2009	0.9	7.1	11	2003	18	31	2003	37.5



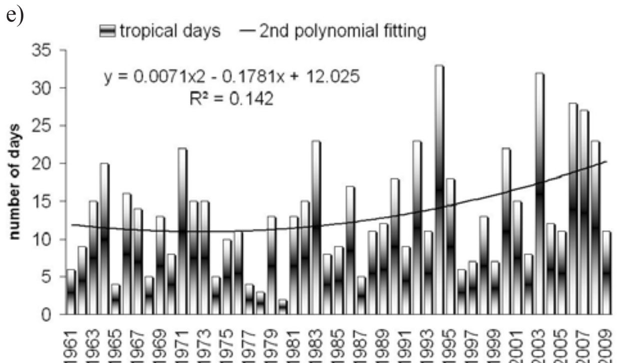


Fig. 4a–e. Tendency of number of annual frost days, warm days, dry days, wet days, extreme wet days, very wet days and tropical days in summer during 1961–2009

number of tropical days. Moreover, the form of a polynomial curve has a clear bottom-up character (Fig. 4). Regarding the analysis of heat waves at the Poděbrady, it can mentioned, the absolute maxima was recorded on August 1, 1994 (tmax = 39.2 °C), i.e. in summer when was recorded the longest and most severe heat wave since 1961 (Table 4). A more recent study (K y s e l ý , 2010) showed that the July 2006 heat wave, lasting 33 days, was the longest and most severe heat wave in Prague since 1775. At the Poděbrady, the heat wave in summer 2006 was the one with largest number of tropical days with peak of maximum temperature in heat wave reach 35.2 °C (27th July). The July of 2006 was the warmest month in summer of 2006 in the Czech Republic. In July 2006, as in June and August 2003, departure of the mean temperature was more than +4.7 °C over the Czech Republic (Fig. 6a–b). Such anomalies of monthly temperatures were the result of extremely hot days over the summer. In the majority stations beginning with 5th July maximum temperature was from 27.0 to 33.0 °C, it isolated until 37.0 °C. The highest above normal temperature departure occurred at Milešovka mountain meteorological station (833 m a.s.l.), where it was +6.0 °C. So, the highest positive deviation from the normal average temperature (+4.7 °C) was recorded in July, following by autumn months +2.6 °C was reached in September, +2.1 °C in October, +3.0 °C in November, and +2.7 °C in December. These abnormal temperature distributions are continued till July 2007. Moreover, an unusual warm of weather in winter 2006/2007, when this period with mean air temperature deviation was more than +3.9 °C from the normal, accentuated the severe drought event in the spring season (Fig. 7). The anomalies of temperature distribution from the June 2006 to July 2007 years were quite rare. Moreover, recent research also showed that while the summer of 2006 was unusual for the current climate, its temperature regime is very similar to what is projected for the late 21st century (H u t h et al., 2000; K y s e l ý , 2010).

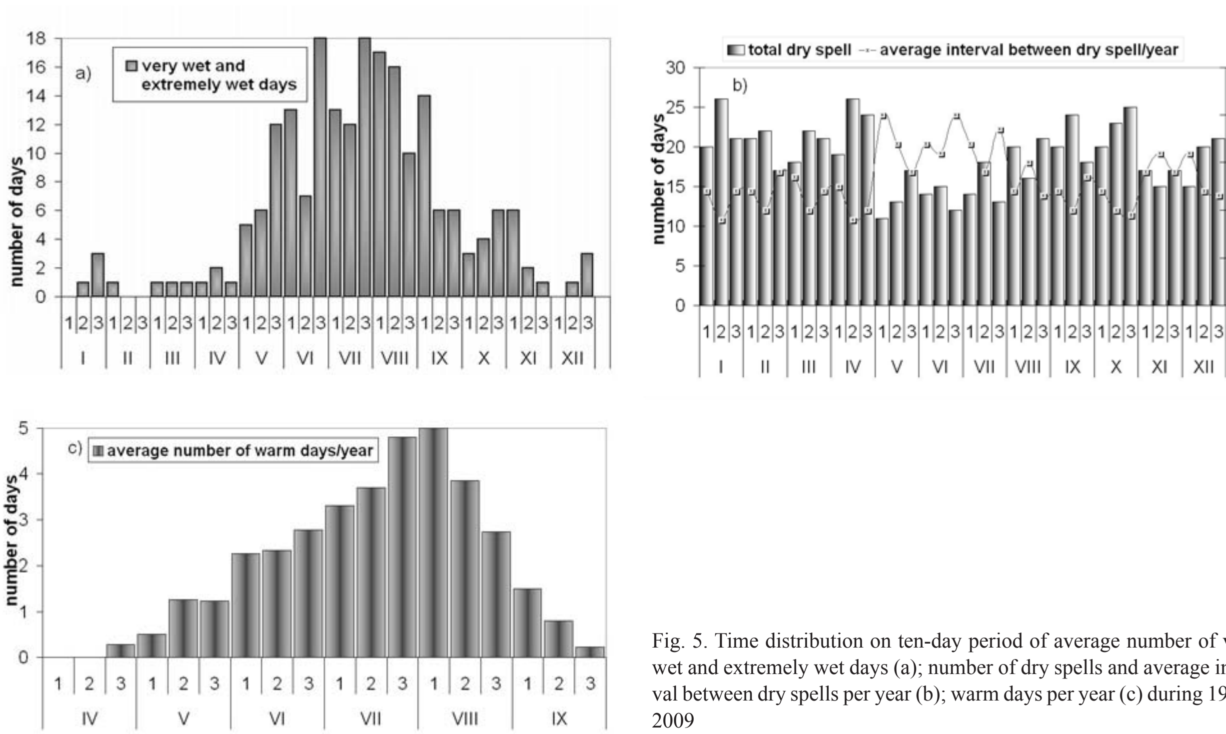


Fig. 5. Time distribution on ten-day period of average number of very wet and extremely wet days (a); number of dry spells and average interval between dry spells per year (b); warm days per year (c) during 1961–2009

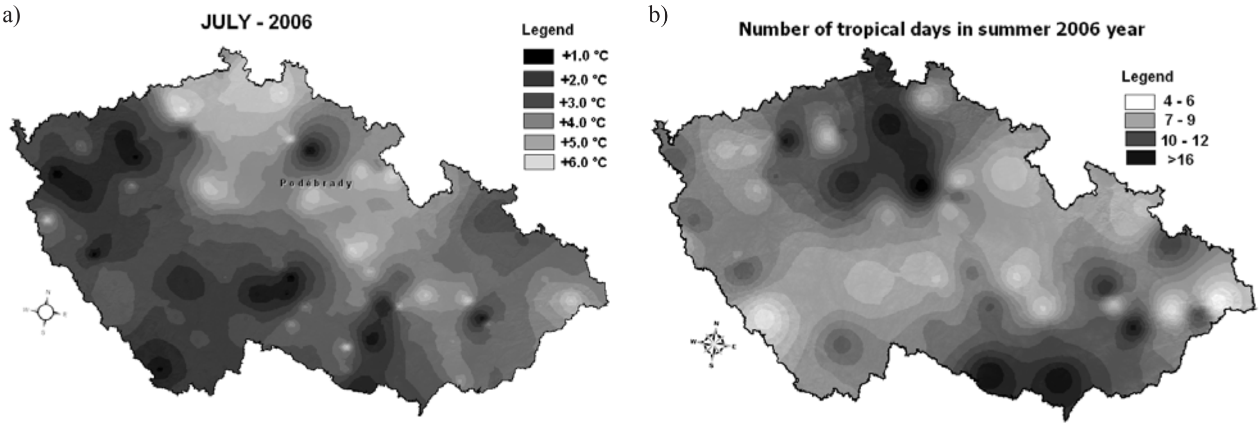


Fig. 6. Anomalies of July temperatures (a) and spatial variability of tropical days (b) in summer of 2006 in the Czech Republic

CONCLUSION

Eleven key indices for daily precipitation and temperature extreme events are chosen for the present analysis. The analysis covered the period 1961–2009. Extremes in temperature, particularly through occurrences of prolonged hot and cold events, can have significant agricultural impacts. In Polabí, examples are the hot dry summers of 1976, 1994 and 2003 which were associated with substantial economic costs and recently, a very cold spell on January 2006 and very hot spell on July 2006. From the analysis of temporal variability of daily weather extremes of temperature and precipitation in Poděbrady, it can be concluded that: (1) minimum extremes occurred during the 1970s, while maximum extremes occurred during 1990s; (2) there are increased tendency in dry spell length and annual 1-day maximum rainfall (CDD and Rx-1day), but trend is not statistically significant; (3) the warmest summers with regards to heat wave duration and severity occurred in 1994 year; (4) the average number of tropical days in summer season over the past 20 years increased and in the summer of 1994, 2003 and 2006 were characterized with the highest number of tropical days; (5) mean length of annual dry spells can be expected once every 2 years, long length once in 10 years and very long length once in 50 year.

Obtained results are a major starting point for a more precise estimation of extreme drought and heat risks in Polabí region. The method should also be of benefit in drawing of risk maps of vegetable crops for the mitigation of the effects of temperature-rainfall extreme events.

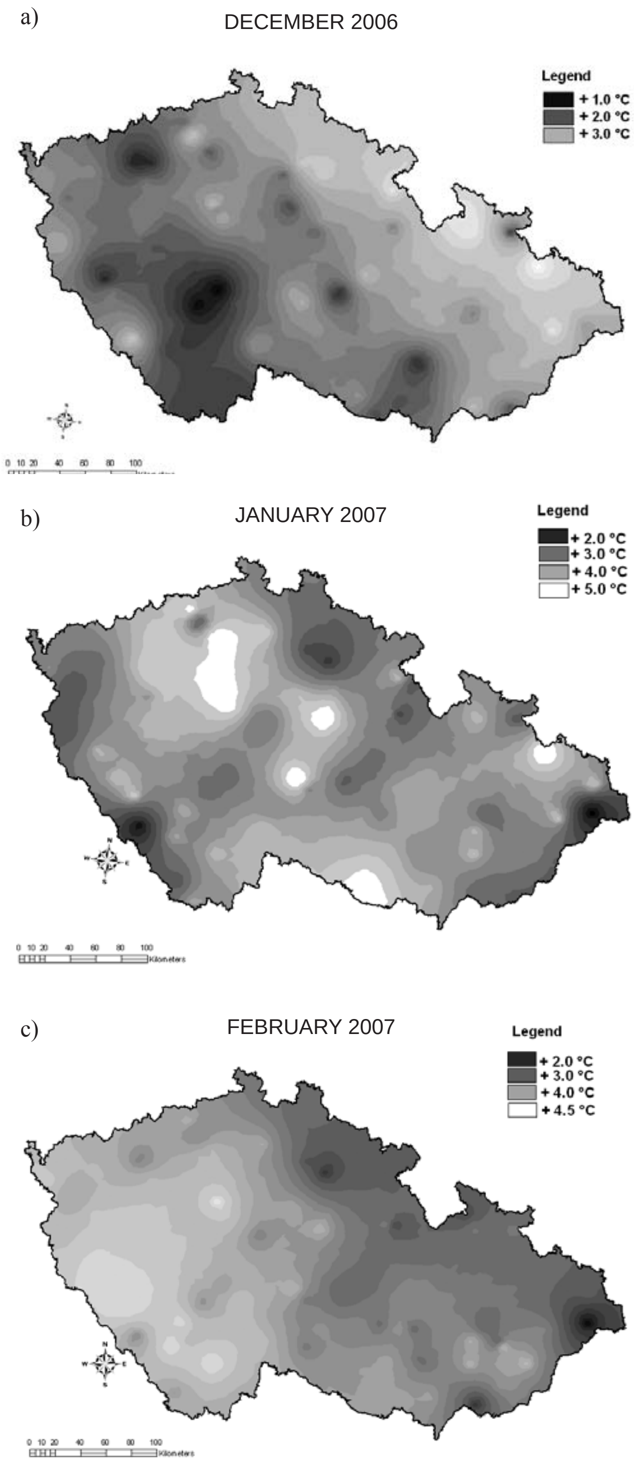


Fig. 7a–c. Anomalies of temperatures in extreme warm winter of 2006–2007 in the Czech Republic

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Časová variabilita denních klimatických extrémů teploty a srážek ve středním Polabí.

Scientia Agric. Bohem., *41*, 2010: 140–148.

Příspěvek uvádí výsledky studie časových variabilit denních klimatických extrémů teploty a srážek ve středním Polabí jako rizikových jevů v zemědělství. Byly použity údaje pro analýzu četnosti teplotních a srážkových extrémních jevů pro vybranou stanici Poděbrady za období 1961–2009. Řady obsahovaly denní teploty (maximum, minimum a denní průměr) a denní srážkový úhrn. Klimatické extrémní jevy jsou popsány podle 11 indexů na základě teplotních a srážkových charakteristik: TX10p, TX90p, WSDI, CSDI, HWDI, FDO, CDD, CWD, RX1day, R95p a R99p. Četnost výskytu extrémních jevů a pravděpodobnost jejich opakování byla stanovena podle Poissonova modelu: $\lambda. > 0{,}2$ (frekventní), $0{,}1 < \lambda < 0{,}2$ (pravděpodobný) a $0{,}01 < \lambda < 0{,}1$ (zřídkavý).

Během posledních 20 let se průměrný počet tropických dnů v letní sezoně zvýšil více než 1,5krát. Rostoucí počet tropických dnů je doprovázen zvýšením maximálních denních teplot v průběhu sledovaného období ($r = 0{,}20$ s pravděpodobností 95 %). V období 1991–2009 se délka letních horkých vln v Poděbradech zvýšila 1,3krát. Nejteplejší léto, pokud jde o délku trvání a závažnost horké vlny, se v Polabí vyskytlo v roce 1994. V posledním desetiletí bylo zaznamenáno méně mrazivých dnů. Analýza četností výskytu bezesrážkových a srážkových období v letech 1961–2009 neukazuje na průkazné změny (nevýznamný trend). V 90. letech byla výrazně zvýšena četnost extrémně suchých měsíců duben, květen, srpen a září. Je zřejmé, že v průběhu posledních dvou desetiletí se celkový počet meteorologických extrémních jevů výrazně zvýšil v důsledku proměnlivosti klimatu.

horké a studené vlny; vlhká období; suchá období

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