

SUMMER HEAT EPISODES IN CENTRAL AND EASTERN EUROPE: CZECH REPUBLIC AND REPUBLIC OF MOLDOVA CASE

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Introduction

The impact of extreme events is more serious when the extreme weather conditions prevail over extended periods. Moreover, unusually warm summers, observed increasingly frequently in various regions of the world in recent years. The 2006 European heat wave was also a period of exceptionally hot weather that arrived at the end of June 2006 in certain European countries. Regions such as northern France, Germany, Belgium, and the Czech Republic, which were strongly affected by the 2003 heat wave, were affected by an even more extreme heat wave in July 2006, in terms of absolute mean monthly values. Much less studied is summer heat of 2007 in South-Eastern Europe that have affected a lot of countries, including Italy, Greece, Hungary, Romania, Bulgaria, Moldova and others.

In this paper, we present the results of two research goals: (1) comparative assessment of the extremely hot summer of 2006 in the Czech Republic (CR) and 2007 in the Republic of Moldova (RM) and (2) identification of heat episodes (tropical days and heat waves) in these countries during 1961-2009.

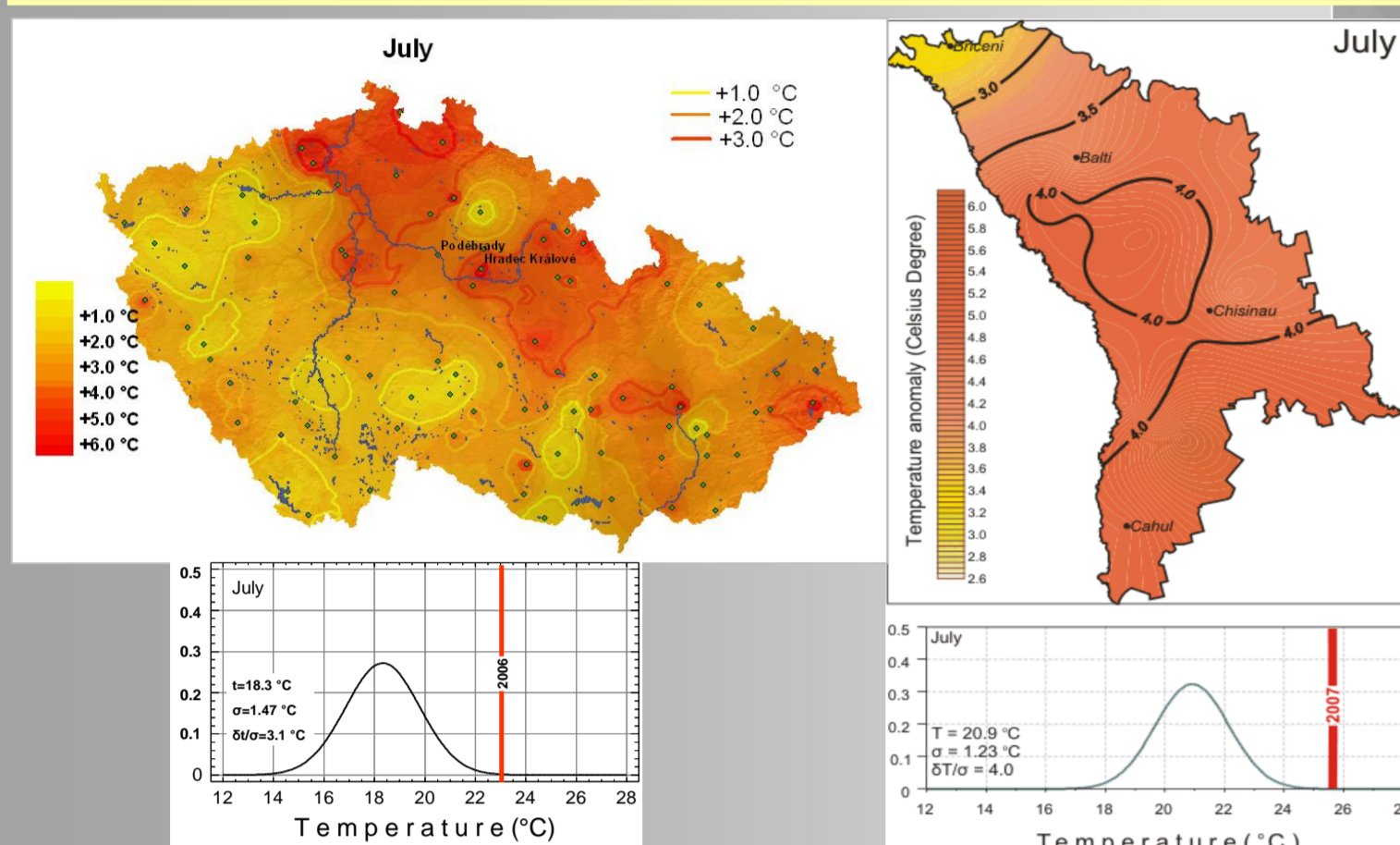


Fig. 1
Anomalies of averaged July temperatures in Moldova (map) and Czechia in 2007 and 2006 on the background of baseline (1961-1990) temperatures approximated by a normal distribution curve. T - the average July temperature; σ - standard deviation of the reference period; $\delta T/\sigma$ - the normalized deviation

Methods and materials

This paper analyses a 49-yr (1961-2009) time series of daily temperatures (maximum, minimum and mean daily temperature) in the Republic of Moldova (Eastern Europe) and the Czech Republic (Central Europe). The data series of daily air temperature in summer season (June-July-August) were available for Czech Republic from Czech Hydrometeorological Institute and for Moldova from Hydrometeorology data service. There are no missing values in the datasets over the period of June to August. Available datasets consist of measurements at two stations in the Czech Republic and one station in the Republic of Moldova. The observations for Moldova were taken at Chisinau weather station ($\varphi=46^{\circ}58'03''N$, $\lambda=28^{\circ}51'23''E$, $h=173$ m). Because of the small size of Moldova (33,846 km²), the relatively homogeneous terrain, and the location of Chisinau near its geographic centre, the research results could be considered as representative of the whole country. The methodology for Czech Republic were applied on the Czech study area located in the middle part of Polabí (*Elbeland*) lowland, where one of the largest farmed especially in growing marketing vegetable crops. The observations were taken at Hradec Králové ($\varphi=50^{\circ}10'N$, $\lambda=15^{\circ}50'E$, $h=278$ m) and Poděbrady ($\varphi=50^{\circ}08'N$, $\lambda=15^{\circ}06'E$, $h=196$ m) weather stations. In addition, to examine spatial distribution of temperatures anomalies data records of 90 weather stations over the Czech Republic and 15 weather stations over Moldova were used.

Assessment of the extremely hot summer both in the Czech Republic and Moldova is based on long-term series' analysis, considering the criterion of extreme, adopted by IPCC. We have chosen to define a heat wave by applying heat wave duration index (HWDI) as the maximum period greater than five consecutive days with maximum air temperature (T_{max}) >5 °C above 1961-1990 daily T_{max} normal. To characterize the heat waves severity the cumulative T_{max} excess above 30.0 °C ($\Sigma\Delta T_{max}>30$) and the peak temperature during heatwaves are used (Kyselý, 2010). Tropical days refer to days with T_{max} reaching or exceeding 30.0 °C.

Results

□ In July 2006, as in June and August 2003, deviation of the mean temperature from norm was more than $+4.7$ °C over the Czech Republic, so this month was the warmest in summer 2006 in the Czech Republic (Fig. 1). The highest above normal temperature deviation occurred at Milesovka mountain station (833 m.a.s.l), where it was $+6.0$ °C. Also, the chart from Fig. 1 shows that averaged temperatures were exceeded 4 standard deviations ($\delta T/\sigma = 4.2$) in the case of normal distribution with respect to the reference period.

□ The year 2007 was extremely hot across south-eastern Europe, and the warmest in the history of instrumental observations in Moldova. Practically all air temperature records were broken in winter, spring and especially in summer, with numerous heat waves and an extreme shortage of precipitation. July was the warmest month for all observation period with mean air temperature deviation more than $+3.7$ - $+4.8$ °C from the normal. Duration of heat days ($T_{max}\geq 30$ °C) during summer season was 45-60 (3-4 times higher than norm); days with $T_{max}\geq 35$ °C - 15-22 against one; $T_{max}\geq 40$ °C - 5 days (for the first time).

□ As seen, all temperature anomalies have exceeded its baseline in July on $3-4\sigma$ and in summer up to 5σ (Tab.1). If to mention that in the case of normal distribution, which is characteristic of the averaged temperatures, anomaly $\geq 2\sigma$ can occur with a probability of 5%, and $\geq 3\sigma$ - 0.3% (i.e. with respect to our analysis, respectively, 5 times in 100 years and 3 once in 1000 years), it is easy to imagine, even while speculative, how rare was summer of 2007 in Moldova. In the Czech Republic such exceptional period was July - anomalies of all temperature variables are more than 4σ .

□ Such anomalies of monthly temperatures were the result of extremely hot days over the summer (Fig. 2). With few exceptions, the mean, maximum and minimum temperatures in almost all days and especially in July and August were significantly higher (up to 10 °C and higher) than their baseline norms at Chişinău weather station. The 2006 June and July mean, maximum and minimum temperatures in the Czech Republic were constantly above the normal temperatures with exception of August (Fig. 2).

□ Moldova's summer is hotter - the highest number of TD were recorded in 2007 (44 days), 2009 (38 days), and in 1999-2001 (34-32 days) with the average number of tropical days - 18 per year. 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 has increased (Table 2).

□ In the Czech Republic summer of 1994 (33 days), 2003 (31 days) and 2006 (28 days) were characterized with the highest number of tropical days (Fig. 3).

□ Regarding the analysis of heatwaves in the middle part of Polabí (CR), we can mention, that the absolute maximum temperatures were recorded in Poděbrady on August 1, 1994 ($T_{max} = 39.2$ °C) and in Hradec Králové on July 30, 1994 ($T_{max} = 37.8$ °C), i.e. in that summer when the longest and most severe heat wave was recorded since 1961 (Tab. 3a)

□ In Moldova the longest cumulative heat wave duration (lasting in total 24 days with very short break of 1-2 days) as well as the highest number of heatwaves (three) was recorded in 2007 (Table 3b). This was followed by heat waves recorded in 1992 (13 days) and in 2002 and 1999 with a total heat wave duration of 12 days. The most severe heatwave in Chişinău (as measured in terms of the cumulative T_{max} excess above 30 °C) was in 2007 (127.2 °C) and more than 2.5 times less severe than heat waves in 2008 and 2002 (-47 °C). In Moldova the frequency of heat waves has increased in 4 times, with simultaneous increasing their duration and severity (in 5 and 10 times respectively). An overwhelming percentage (76.2%) of the heat waves in RM during the whole period was made by the last two decades.

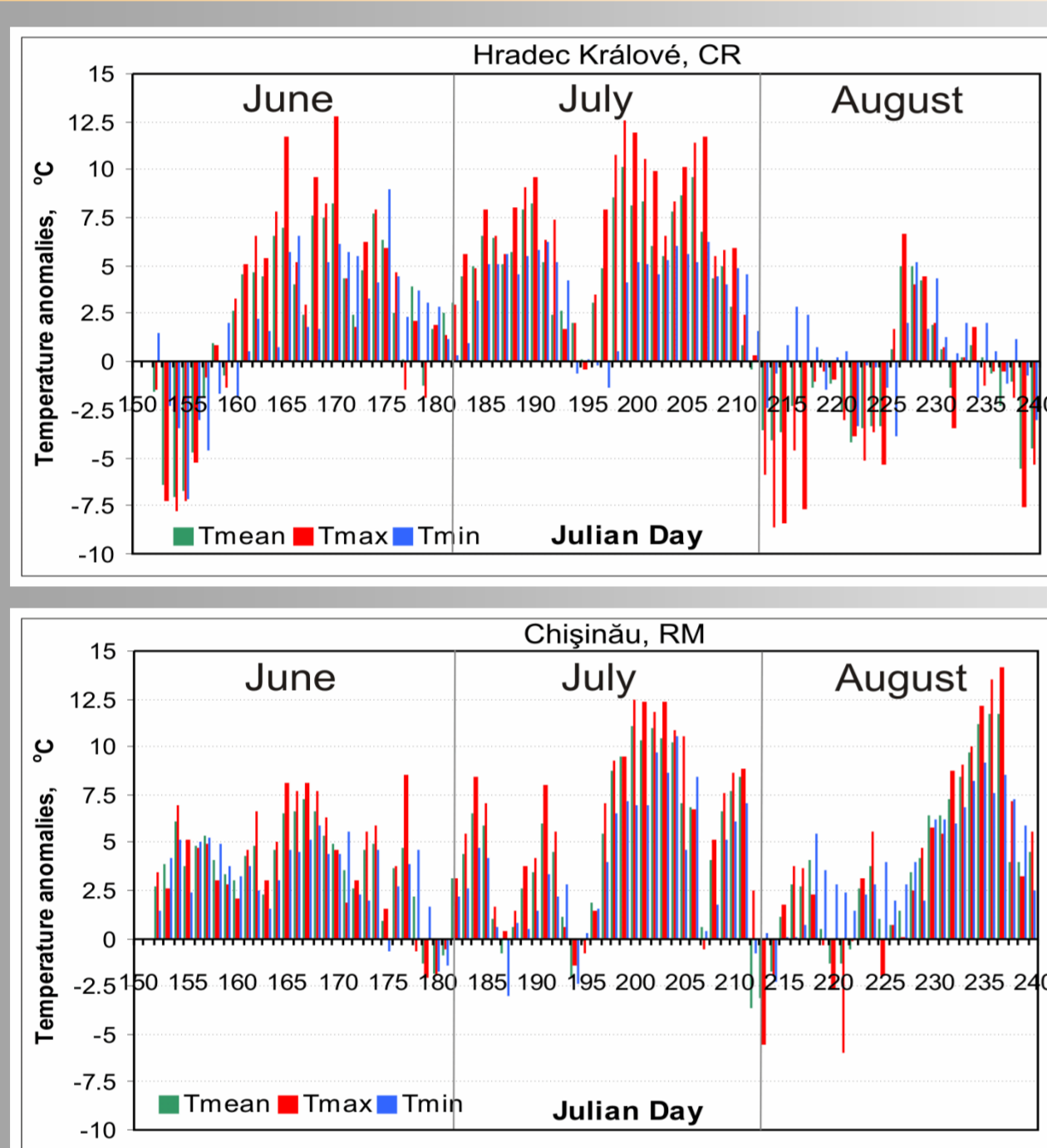


Fig. 2
Deviations of summer daily air temperatures in Hradec Králové, CR, 2006 and in Chişinău, RM, 2007 from their baseline values (horizontal null line)

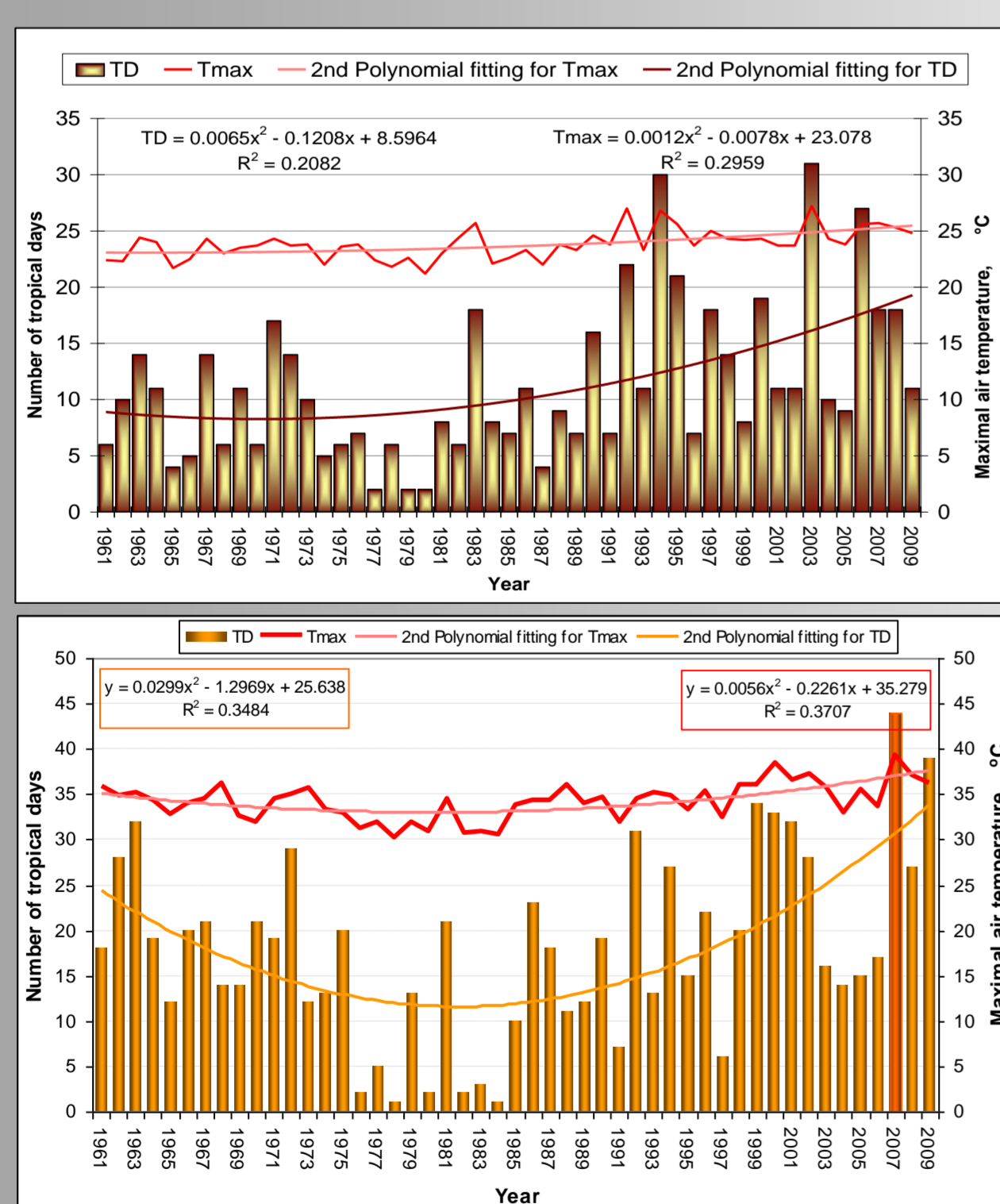


Fig. 3
Tendency of number of tropical days in summer during 1961-2009 in the Czech Republic (upper) and the Republic of Moldova (lower)

Table 2. Mean number of tropical days in Czechia (Hradec Králové) and Moldova (Chişinău) for two research periods.

Period	Czechia			Moldova		
	1961-1990	1991-2009	Excess ratio	1961-1990	1991-2009	Excess ratio
June	1.7	3.0	1.76	3.1	4.7	1.52
July	3.4	6.2	1.82	5.3	8.6	1.62
August	3.0	5.9	1.96	5.6	8.9	1.59
Summer	8.2	15.2	1.85	14.5	23.4	1.61

Conclusion

In this study for the first time a comparative analysis of heat episodes, including heat waves and tropical days, between Moldova and the Czech Republic was performed. Use of unified methodology for both countries has permitted to conclude the follows:

➤ The summer of 2006 in the Czech Republic was recorded as very hot; however, temperatures in June and July did not break record. But in the Republic of Moldova during summer 2007 the absolute temperature records for different parameters were registered for all observation period (since 1887).

➤ Exceptionality of summer season in 2006 in Hradec Králové and Poděbrady, Czech Republic, and in 2007 in Chisinau, Moldova, was confirmed by (1) normalized standard deviation - in both countries temperature anomalies have exceeded more than 4σ ; (2) by 90th and 95th quantiles - in Chişinău all three indicators of 2007 summer temperatures were significantly higher than extremely possible in the baseline climate, and for Czech Republic such exceedance in 2006 was observed only in June and July.

➤ Over past 20 years the average number of tropical days in the summer season has increased in more than 1.5 times both in Moldova and in the middle part of Polabí (CR) with the highest excess ratio in CR in August, but in Moldova - in July (more than 2-fold). The growing number of tropical days is accompanied by increase of maximum temperatures during the whole period (coefficient of determination in Moldova is 0.39, in Czech Republic - 0.30 at 95% probability level).

➤ In the Czech Republic, the last two decades (1990s and 2000s) were characterized by prolonged periods of severe heat waves, whereas the 1970s and 1980s were characterized by diminishing or completely missing heat waves number. The hottest summer as regards heat wave duration and severity have occurred in the CR in 1994 (the longest heatwave lasting 17 days and cumulative T_{max} excess of 72.8 °C in Hradec Králové weather station) and in Moldova in 2007 (24 days and 127.2 °C respectively in Chişinău weather station).

Table 1. Summer 2006 (Hradec Králové, CR, a) and 2007 (Chişinău, MD, b) anomalies in comparison with the baseline (monthly values)

a - Hradec Králové, CR												
Period	TMean				TMax				TMin			
	Mean	σ	2006	$\delta T/\sigma$	Mean	σ	2006	$\delta T/\sigma$	Mean	σ	2006	$\delta T/\sigma$
June	16.7	1.0	18.5	1.8	22.3	1.1	24.4	1.9	10.9	0.8	12.4	1.9
July	18.1	1.3	23.5	4.2	23.8	1.7	30.7	4.1	12.3	0.9	16.0	4.1
August	17.6	1.0	16.5	-1.1	23.6	1.2	21.2	-2.0	12.1	0.6	12.5	0.7
Summer	17.5	0.6	19.5	3.3	23.2	0.9	25.4	2.4	11.8	0.4	13.6	4.5

b - Chişinău, RM												
Period	TMean				TMax				TMin			
	Mean	σ	2007	$\delta T/\sigma$	Mean	σ	2007	$\delta T/\sigma$	Mean	σ	2007	$\delta T/\sigma$
June	19.4	1.3	23.2	2.9	24.5	2.0	28.9	2.2	14.4	1.2	17.7	2.8
July	20.9	1.2	25.8	4.1	26.2	1.7	32.3	3.6	16.0	1.2	19.7	3.1
August	20.5	1.3	23.9	2.6	26.1	1.9	29.3	1.7	15.5	1.1	19.1	3.3
Summer	20.3	0.8	24.3	5.0	25.6	1.2	30.2	3.8	15.3	0.7	18.8	5.0

Table 3. The most severe heat waves in Hradec Králové (Czech Republic) and Chişinău (the Republic of Moldova) from 1961 to 2009

Year	Tropical Days	Heat waves number	Heat wave Duration, days in total	Severity of heat waves ($\Sigma\Delta T_{max}>30$), °C	Highest T_{max} during heat waves, °C	Highest T_{max} for summer season, °C
a - Hradec Králové, CR						
1994	30	1	17	72.8	37.8	37.8
2006	27	2	14	14.1	36.1	36.1
b - Chişinău, RM						
2007	44	3	24	127.2	39.4	39.4
2008	27	2	11	47.5	37.1	37.1

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