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The maximum temperatures and heat waves in Serbia during the summer of 2007

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Abstract An extraordinary heat wave occurred in Serbia from July 14 to July 24 in 2007. Record values of the maximum temperatures were observed over almost the whole territory of Serbia and in Smederevska Palanka, a temperature of 44.9°C was registered, which was the absolute maximum value ever recorded. The highest increase over the previous absolute maximum temperature, dating back to 1888, of 3.1°C was registered in Belgrade. The Warm Spell Duration Indicator, from which the duration and severity of the heat waves are estimated, was applied to the series of the daily maximum temperatures in Smederevska Palanka. An analysis of the daily maximum temperatures and heat waves during the summer of 2007 revealed significant changes in the trends of anomalies and extreme (90%) quantiles. In addition, the main characteristics of the heat wave and the circulation conditions which caused the heat wave in Serbia during the summer 2007 were analyzed.

1 Introduction

In light of recent climate trends and current predictions for the twenty-first century, climatic change is becoming a major concern for scientists and society in general. There is an increasing interest in different parts of the world in research on extreme temperatures and their variation, with the purpose of building models which predict climatic change and modifications introduced by human activities.

Temperature extremes are an important aspect of any climate change because ecosystems and societal responses are most sensitive to them. Moreover, changes in

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temperature extremes are often sensitive to inhomogeneous temperature monitoring practices, making the assessment of change more difficult than assessing a change in the mean. Mearns et al. (1984) and Hansen et al. (1988) concluded that relatively small changes in the mean temperature could produce substantial changes in the frequency of temperature extremes.

The last decade of the twentieth century was globally the hottest since the beginning of worldwide temperature measurement during the nineteenth century. Alexander et al. (2006) showed that annual trends in the lowest and highest daily minimum and maximum temperatures in the latter half of the twentieth century increased at many locations throughout the world. Further global warming ranging between 1.4°C and 5.8°C is expected by the end of the twenty-first century (IPCC 2007). This could also lead to an increase in temperature extremes.

A number of recent studies have indicated that European summer temperatures as well as heat waves are sensitive to global warming (Schär et al. 2004; Founda et al. 2004; Della-Marta et al. 2007). Klein Tank and Können (2003) found that the pronounced warming between 1976 and 1999 was primarily associated with an increase in warm extremes rather than with a decrease in cold extremes. During the period from June to August 2003, high temperatures were reported across Europe (Luterbacher et al. 2007; Schär et al. 2004), including Serbia. In many European countries, particularly in France, the heat wave was associated with an increase in mortality (Hemon and Jougla 2003; Beniston and Diaz 2004).

During July and August 2007, record values of temperatures were also observed in southeastern (SE) Europe. Serbia, Bulgaria and Greece were the European countries most affected by the heat wave (Unkašević and Tošić 2009; Founda and Giannakopoulos 2009). According to the National Meteorological Service of Serbia, the summer of 2007 was the warmest in Serbia during the last 120 years. It has been mentioned that heat waves can be detrimental to human health and, combined with an absence of precipitation, can cause severe forest fires (which were recorded in the eastern parts of Serbia during July 2007).

The initial results of an analysis of the mean summer and daily maximum temperatures in Serbia and the heat waves in Smederevska Palanka (SP) during the summer of 2007 are presented herein. The mean summer and daily maximum temperature extremes in Serbia are analyzed in Section 2. Analysis of the maximum temperatures and trends of the mean maximum temperature anomalies with 90% quantiles during the summer from 1949 to 2007 in Smederevska Palanka are presented (Section 3). Also, the duration and severity of the heat waves in Smederevska Palanka were estimated by applying the Warm Spell Duration Indicator. In Section 4, the main features of the July 2007 heat wave in Smederevska Palanka and of the circulation conditions which caused the heat wave in Serbia during the summer 2007 are presented. Some conclusions are given in Section 5.

2 The mean summer and daily maximum temperature extremes in Serbia

In this study, the mean summer (June, July and August, JJA) temperatures measured at 18 meteorological stations in Serbia from 1951 to 2007 (Table 1), and the daily maximum temperature extremes were analyzed.

Table 1 Number (No), abbrevation (Abbr) and location (ϕ, λ, h) of meteorological stations with the previous absolute maximum temperature until 2007 (AT_{max}), and during the summer of 2007

No	Abbr	Station	ϕ	λ	h (m)	AT_{max} (°C)	T_{max} (°C) 2007
1	PA	Palić	46°06′	19°46′	102	39.2	38.2
2	SO	Sombor	45°47′	19°05′	88	39.6	40.3
3	KI	Kikinda	45°51′	20°28′	81	39.0	40.0
4	ZR	Zrenjanin	45°24′	20°21′	80	39.8	42.9
5	NS	Novi Sad	45°20′	19°51′	84	39.8	41.6
6	SM	Sremska Mitrovica	44°58′	19°38′	81	40.8	40.7
7	BG	Belgrade	44°48′	20°28′	132	40.5	**43.6**
8	VG	Veliko Gradište	44°45′	21°31′	82	40.9	43.6
9	LO	Loznica	44°33′	19°14′	121	40.1	42.3
10	SP	Smederevska Palanka	44°22′	20°57′	122	43.0	**44.9**
11	NE	Negotin	44°14′	22°33′	42	42.0	42.6
12	KG	Kragujevac	44°02′	20°56′	185	41.7	43.9
13	ĆU	Ćuprija	43°56′	21°23′	123	42.4	44.6
14	ZA	Zaječar	43°53′	22°17′	144	42.7	44.7
15	KR	Kraljevo	43°44′	20°41′	215	44.3	43.6
16	Ni	Niš	43°20′	21°54′	201	42.5	44.2
17	DI	Dimitrovgrad	43°01′	22°45′	450	39.6	41.4
18	VR	Vranje	42°29′	21°54′	432	40.7	41.6

The homogeneity of the summer temperatures were tested according to Alexandersson (1986). Applying the Alexandersson test (1986), Tošić (2005) indicated that all 18 temperature series were homogenous.

In Serbia, the mean summer temperature of 2007 exceeded the 1961–1990 mean by 3°C (3.1°C in SP), corresponding to an excess of up to four standard deviations (Fig. 1a). Also, the mean July temperature in 2007 exceeded the 1961–1990 mean by 3.3°C, corresponding to an excess of up to three standard deviations (Fig. 1b). The mean summer and July temperatures during 2007 in SP (indicated by an arrow) are outside the scale in Fig. 1a, and at the end of the last bin of the histogram in Fig. 1b, respectively. This was caused by an increase of the daily mean temperatures in the summer of 2007.

The sensitivity of extremes to the width of the statistical distribution has led to the opinion that variability is more important than averages (Katz and Brown 1992). Thus, an increase in variability is a plausible hypothesis to explain the extreme July 2007 conditions. Such a hypothesis would also be compatible with the occurrence of drastically different European summers, such as in 1992–1994 and 2003 (Kyselý 2002; Schär et al. 2004; Beniston and Diaz 2004).

Record values of the maximum temperatures affected the territory of Serbia during the summer of 2007 and, indeed, the previous absolute maximum temperature records dating back to the middle of the twentieth century were exceeded at almost all meteorological stations (Table 1). The absolute temperature record for Serbia was reached on July 24 in Smederevska Palanka with a reading of 44.9°C, thus exceeding the previous all-time high temperature record of 44.3°C, held since July 1939 by Kraljevo. It is interesting that in Belgrade, the previous absolute maximum temperature record, dating back to 1888, was exceeded by 3.1°C (bold in Table 1).

The summer of 2007 was characterized by atmospheric circulation anomalies at several pressure levels. The 850-hPa temperature anomalies of the summer and July

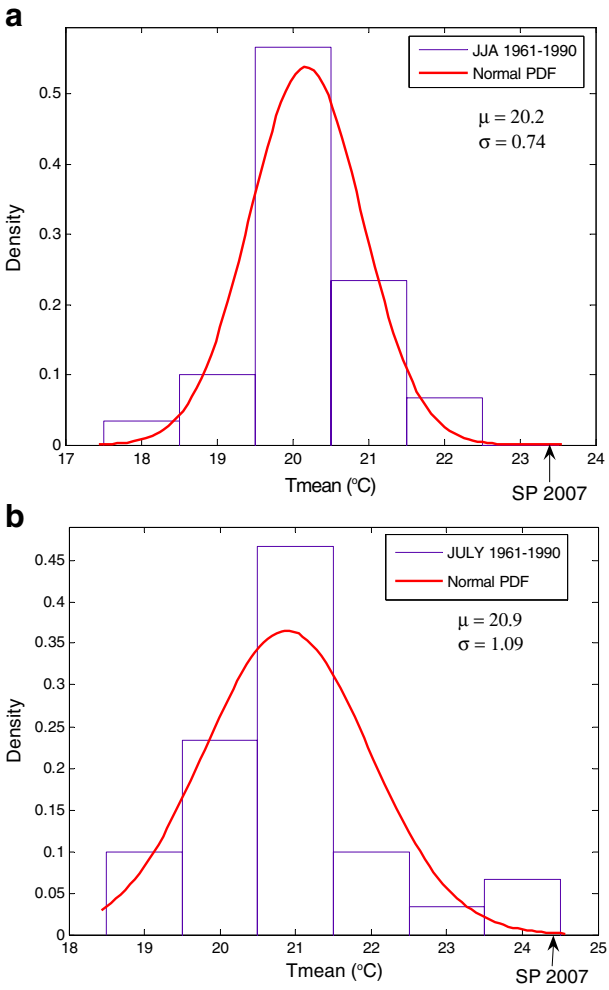

Fig. 1 Distribution of: **a** the mean summer and **b** the mean July temperatures in Serbia during the period 1961–1990 (Table 1). The fitted Gaussian distribution is indicated in bold. The mean summer and July temperatures in 2007 in Smederevska Palanka are assigned by *arrows*

2007 over SE Europe with respect to the 1961–1990 reference period are presented in Fig. 2, from which it can be seen that the JJA and July temperature anomalies were between 3°C and 3.5°C and 3.5°C and 4°C over Serbia, respectively.

3 The daily maximum temperatures and heat waves in Smederevska Palanka

In this Section, the daily maximum temperatures (T_{max}) and heat waves in Smederevska Palanka during the period 1949–2007 are analyzed.

3.1 The daily maximum temperatures in Smederevska Palanka

The meteorological station in SP (a small town in central Serbia with a population of 56,000) remained at the same locality during the study period and the data sets have

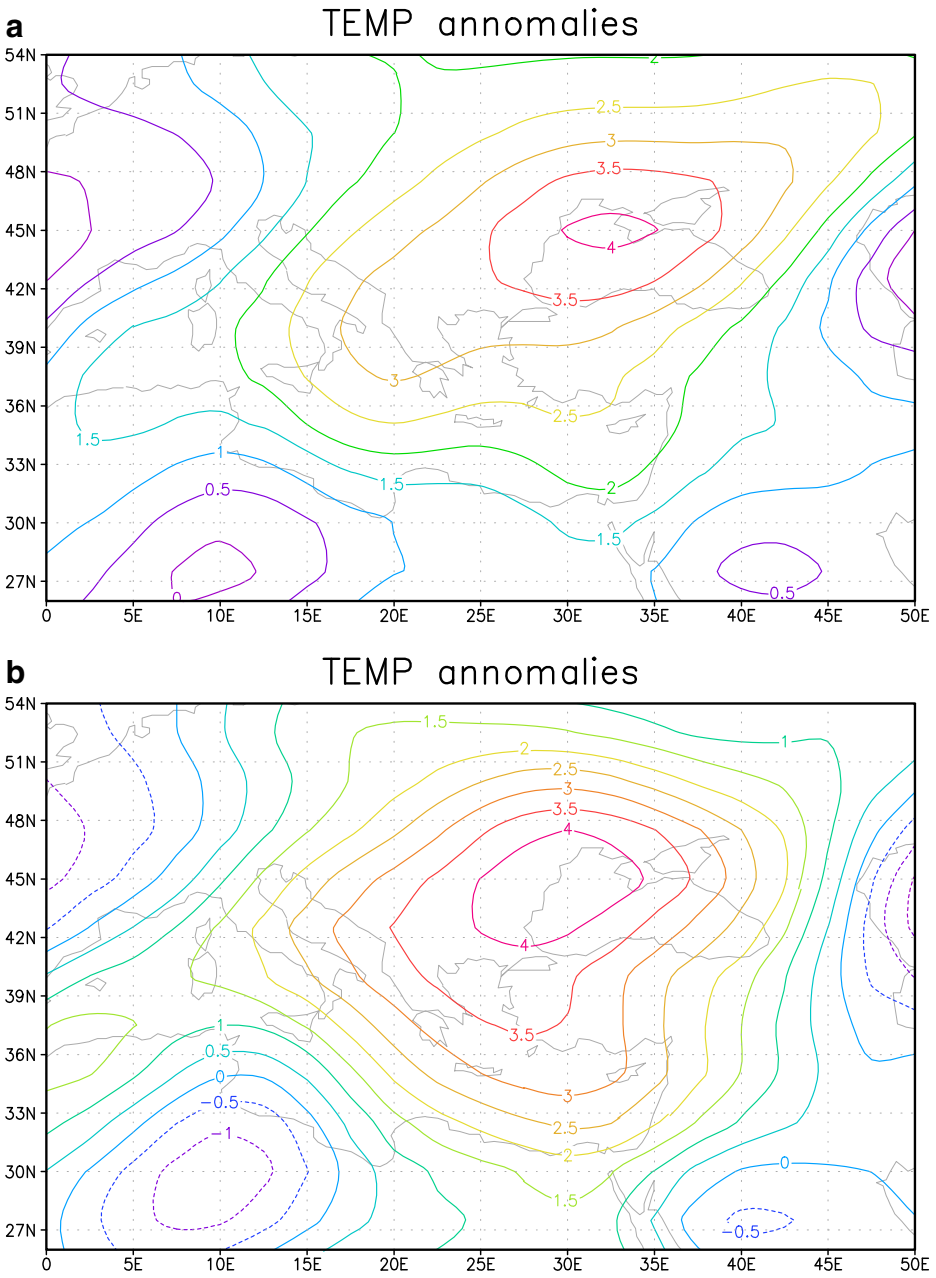

Fig. 2 Seasonal (**a**) and July (**b**) 850-hPa temperature anomalies of summer (JJA) and July 2007 over SE Europe, based on the 1961–1990 reference period

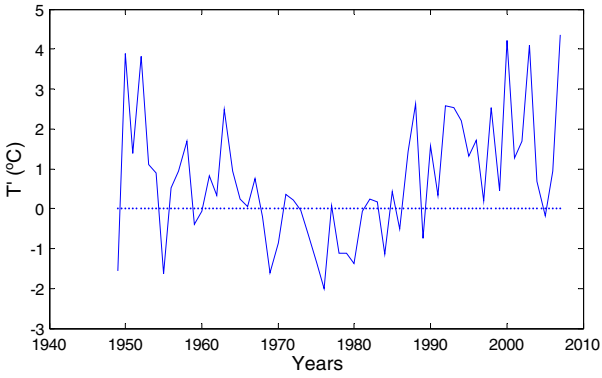

Fig. 3 Anomalies of mean summer T_{max} (T′) from the 1961–1990 mean in Smederevska Palanka (1949–2007)

no missing records. The climate in SP is moderate-continental with the maximum temperatures observed during July or August and highest precipitation during the summer months. The mean summer maximum temperature is 26.5°C, while the mean summer precipitation is 196.5 mm.

The anomalies of the maximum daily temperatures averaged over the three summer months (JJA) in SP from 1949 to 2007 are shown in Fig. 3. It is evident that positive anomalies of the summer T_{max} prevailed after 1990. The departure of the mean summer maximum temperature from the 1961–1990 mean in SP was the highest (4.4°C) in 2007.

The evolution of the mean summer maximum temperatures and their 90% quantile values for the periods 1961–1990 and 1991–2007 in SP are compared in Fig. 4. While for the 30 years period (1961–1990), the mean summer T_{max} was only twice above the mean value, during the period 1991–2007 (28.3°C), this value was

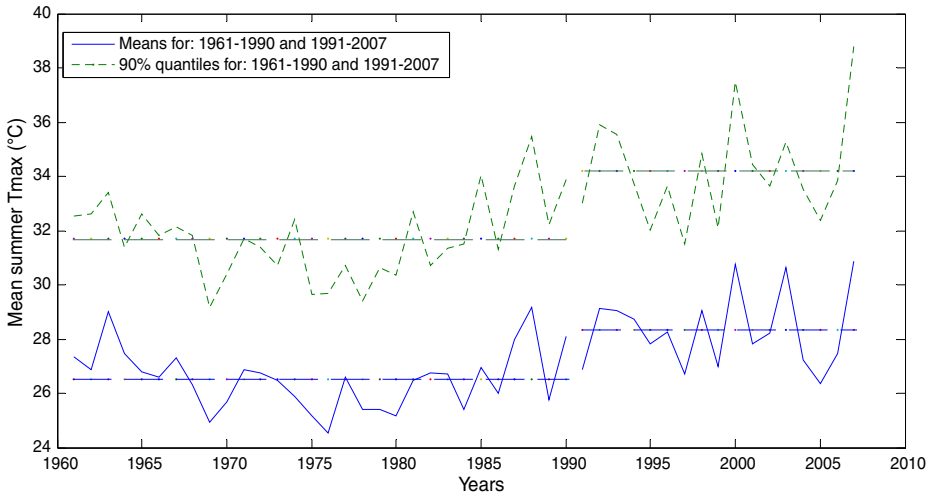

Fig. 4 Comparisons of the mean summer maximum temperatures and the 90% quantile for the 1961–1990 reference period, and the period 1991–2007 in Smederevska Palanka. The *dashed horizontal lines* represent the mean values during the 1961–1990 and 1991–2007 periods

Table 2 The number of the heat waves per decade with peak of T_{max} (°C) and duration (days) in Smederevska Palanka, 1949–2007

Decade	Number of heat waves	Peak of T_{max} (°C)	Duration (days)
1949–1958	4	39.6	7–9
1959–1968	5	37.9	6–9
1969–1978	1	34.2	6
1979–1988	4	39.2	6–13
1989–1998	7	41.7	6–10
1999–2007	8	44.9	6–11

exceeded on several occasions in the last period. Also, the mean summer maximum temperature from 1991 to 2007 was 1.8°C higher than that from the period 1961–1990. Similarly, an analysis of the behaviour of the 90% quantile shows that between 1961 and 1990, the upper extreme of the maximum temperature was confined in the range 29–35.5°C, whereas for the 1991–2007 period, the range was between 31.5–38.8°C, with a peak of 38.8°C in 2007.

3.2 Heat waves in Smederevska Palanka

Many definitions quantifying the duration and/or intensity of either the night-time minima or daytime maxima could be applied to heat waves (Karl and Knight 1997; Huth et al. 2000; Palecki et al. 2001; Meehl and Tebaldi 2004). In this study, it was decided to define a heat wave on the concept of exceeding various thresholds, thus allowing the analyses of the heat wave duration and frequency.

According to Alexander et al. (2006), the Warm Spell Duration Indicator (WSDI) was used. WSDI is defined as follows. Let Tx_{ij} be the daily maximum temperature on day i in period j and let Tx_{in} 90 be the calendar day 90th percentile on a 5-day window (Zhang et al. 2005). Then the number of days per period is summed in intervals of at least six consecutive days ($Tx_{ij} > Tx_{in}$ 90).

In the present study, the values of the percentile thresholds were determined empirically from he observed SP maximum temperature series in the climatological standard–normal period 1961–1990. As the percentiles were calculated from 5-day windows centred on each calendar day, this yields a total sample size of 30 years × 5 day = 150 for a calendar day. The procedure ensures that extreme temperature events, in terms of crossing of percentile thresholds, can occur with equal probability throughout the year (Klein Tank and Können 2003).

The number of the heat waves was summed for six decades (Table 2). It was calculated that the number of the heat waves was the greatest in the last decade (eight times). Then follows the number of the heat waves during the decades 1989–1998 (7)

Table 3 The longest heat waves with their severity (as measured by cumulative T_{max} excess above the various threshold) in Smederevska Palanka, 1949–2007

The maximum value is highlighted in bold

Beginning, end, and year	Duration (days)	$\Sigma\Delta T_{max}$ > thresholds	Peak T_{max} (°C)
14.7.–26.7.1987	13	56.0	39.0
14.7.–24.7.2007	11	**88.4**	**44.9**
19.7.–28.7.1998	10	30.6	37.5
29.6.–07.7.1950	9	47.4	38.8
24.6.–02.7.1963	9	26.2	37.0
19.7.–27.7.2006	9	27.6	34.4

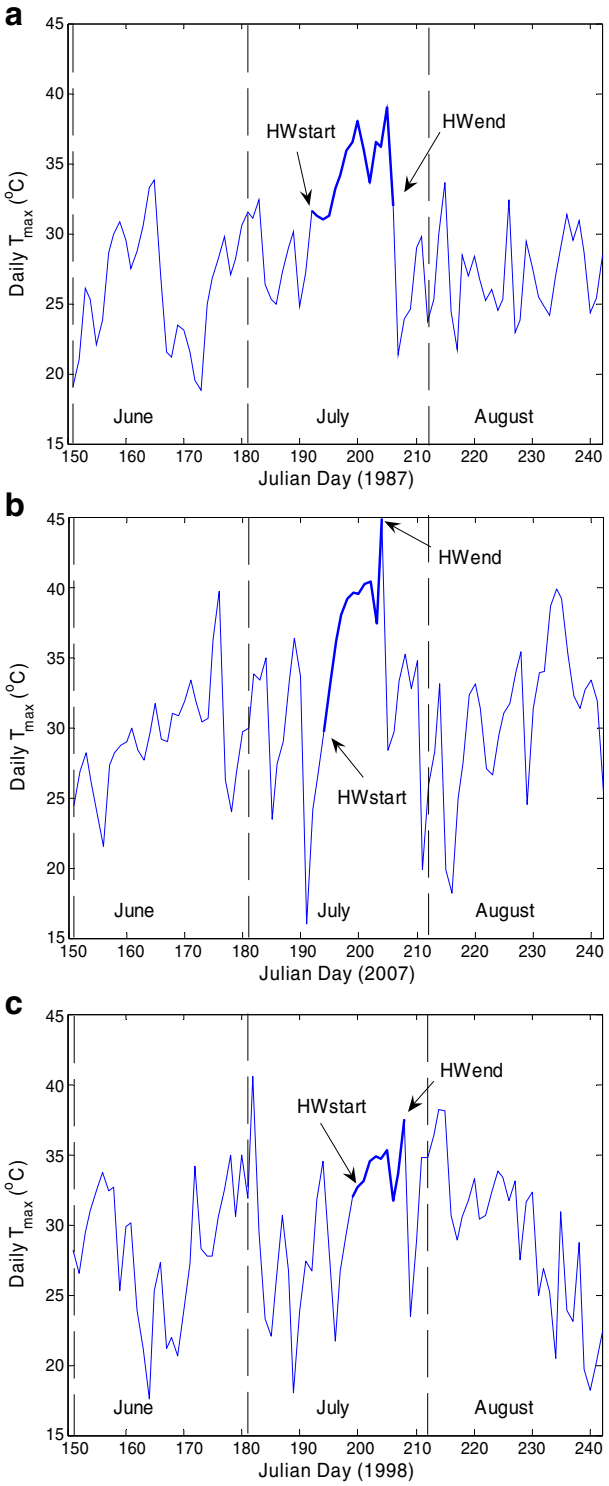

Fig. 5 The longest and most severe heat waves in Smederevska Palanka (1949–2007)

and 1959–1968 (5). Also, the peak of T_{max} was observed during the last decade (in 2007). A heat wave duration longer than 8 days was recorded only once in the first, second, fourth and fifth decade, while in the last decade it was registered three times. It can be concluded that the frequency of the occurrence of heat waves as well as their duration exhibited a sudden increase during the last decade.

To characterize the heat waves in SP (1949–2007), the duration, the cumulative T_{max} excess above various thresholds during heat waves ($\Sigma\Delta T_{max}$ > various thresholds) and the peak temperature were employed. According to Kyselý (2000), the cumulative T_{max} excess is probably the most appropriate variable to characterize the severity of heat waves.

The longest and most severe heat waves in SP during the summer in the second half of the twentieth century are presented in Table 3 and Fig. 5. According to Table 3, 1987, 2007 and 1998 were the 3 years with the longest heat waves from the beginning of measurements, having a duration of 13, 11 and 10 days, respectively. Then follows the heat waves during the summers of 1950, 1963 and 2006, with a duration of 9 days.

4 Analysis of July 2007 heat wave

4.1 Main features of the heat wave in Smederevska Palanka

An extreme heat wave affected SE Europe including Serbia in July 2007, breaking previous records with the daily maximum temperatures between 40°C and 45°C (see Table 1). According to Founda and Giannakopoulos (2009), this wave also occurred in Athens (Greece).

The most severe heat wave (as measured in term of the cumulative T_{max} excess above various thresholds) was recorded from July 14 to July 24 at the SP meteorological station, with a value of 88.4°C (Table 3). The longest heat wave observed in 1987 (Fig. 5a) did not reach the severity of the heat wave in July 2007 (Fig. 5b), i.e., the $\Sigma\Delta T_{max}$ > various thresholds was 56.0°C. It was mentioned that during the summer of 1998, a heat wave was also recorded with a duration of 10 days (from July 19 to July 28), with a heat wave severity of 30.6°C and a peak temperature of 37.5°C (Fig. 5c). In addition, the record value of the maximum temperature in Serbia during 2007 of 44.9°C (July 24) was recorded in SP (Fig. 5b).

It is interesting that the night-time temperatures during the July 2007 heat wave were also high. The mean night-time temperature was about 5°C higher than the mean value obtained for the 1961–1990 reference period. In addition, the anomalies of the highest night-time temperatures during the July 2007 heat wave were positive and the highest values of about 8°C and 10°C were recorded on July 20 and 24, respectively.

It should be noted that during the summer of 2007, low amounts of precipitation (17.8 mm in July in SP, i.e., 28% of the 1961–1990 norm of 63.0 mm) were recorded in most parts of Serbia. The JJA precipitation sum for SP in 2007 was 113.5 mm compared to the long-term average value of 199.0 mm. Bartholy and Pongrácz (2007) found that precipitation occurred less frequently in the Carpathian Basin during the period 1946–2001. Also, they found a negative decadal tendency in days with daily precipitation exceeding 1 mm, and positive tendency of fraction of total

annual rainfall due to very wet days in Belgrade. Christensen and Christensen (2003) analyzed the A2 global scenario for the European continent, and concluded that the number of very wet days is very likely to increase in many European regions, despite a possible reduction in the summer mean precipitation amount over a substantial part of the continent.

The preceding winter in Serbia was also warm and dry, as in many parts of SE Europe (Luterbacher et al. 2007; Founda and Giannakopoulos 2009). The anomalies of the daily maximum temperatures in SP during the winter of 2007 (from December 2006 to February 2007) according to the 1961–1990 reference period are presented in Fig. 6, from which it can seen that significant positive anomalies were observed in SP during this winter. The highest value of the anomalies, reaching the record of 18°C, was registered during January 2007.

4.2 Circulation conditions during the summer of 2007

Domonkos et al. (2003) analyzed the variability of summer extreme high-temperature events using daily temperature series (1901–1998) from 11 sites in central and southern Europe, including two sites in Serbia. They found that southerlies and persistent anticyclonic situations are favourable for the occurrence of summer extreme warm events. In addition, Unkašević and Tošić (2009) examining heat waves for Belgrade and Niš, indicated that the longest heat wave days in Serbia occurred under prevailing anticyclonic and southerlies major types of the Hess-Brezowsky catalogue. There are typical synoptic situations that cause the highest daily maximum temperatures and severe heat waves. Namely, there was a low pressure system with its centre east of Britain and a weak gradient pressure field over central and SE Europe on July 24, 2007 (Fig. 7a). This synoptic situation allowed the flow of warmer and drier air from North Africa across the Mediterranean towards the Balkans (Fig. 7b). Fine particles of dust were carried high into the atmosphere making the sun appear red at sunset (author's observation).

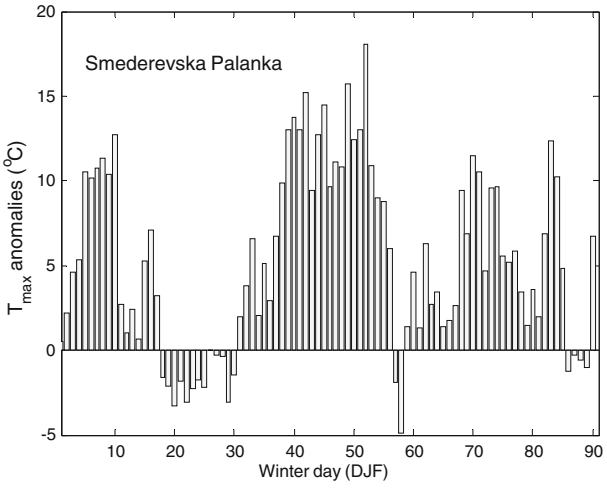

Fig. 6 The daily maximum temperature anomalies (according to the 1961–1990 reference period) in Smederevska Palanka during the winter (from December 2006 to February 2007)

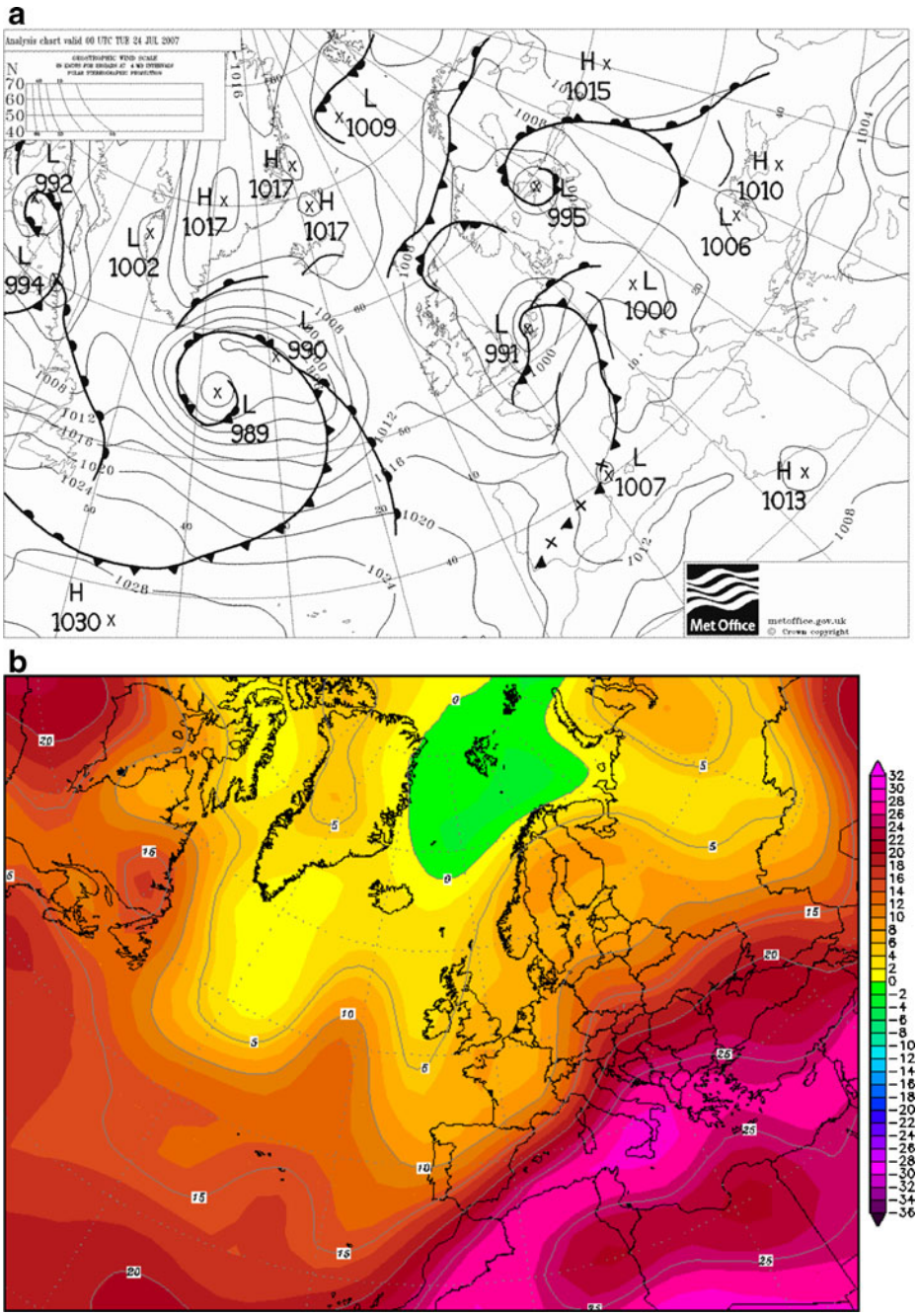

Fig. 7 Synoptic situation at 00UTC in Europe on July 24, 2007: **a** sea level pressure http://www.wetterzentrale.de/topkarten/tkfaxbraar.htm, **b** 850-hPa temperature http://www.wetterzentrale.de/topkarten/fsreaeur.html

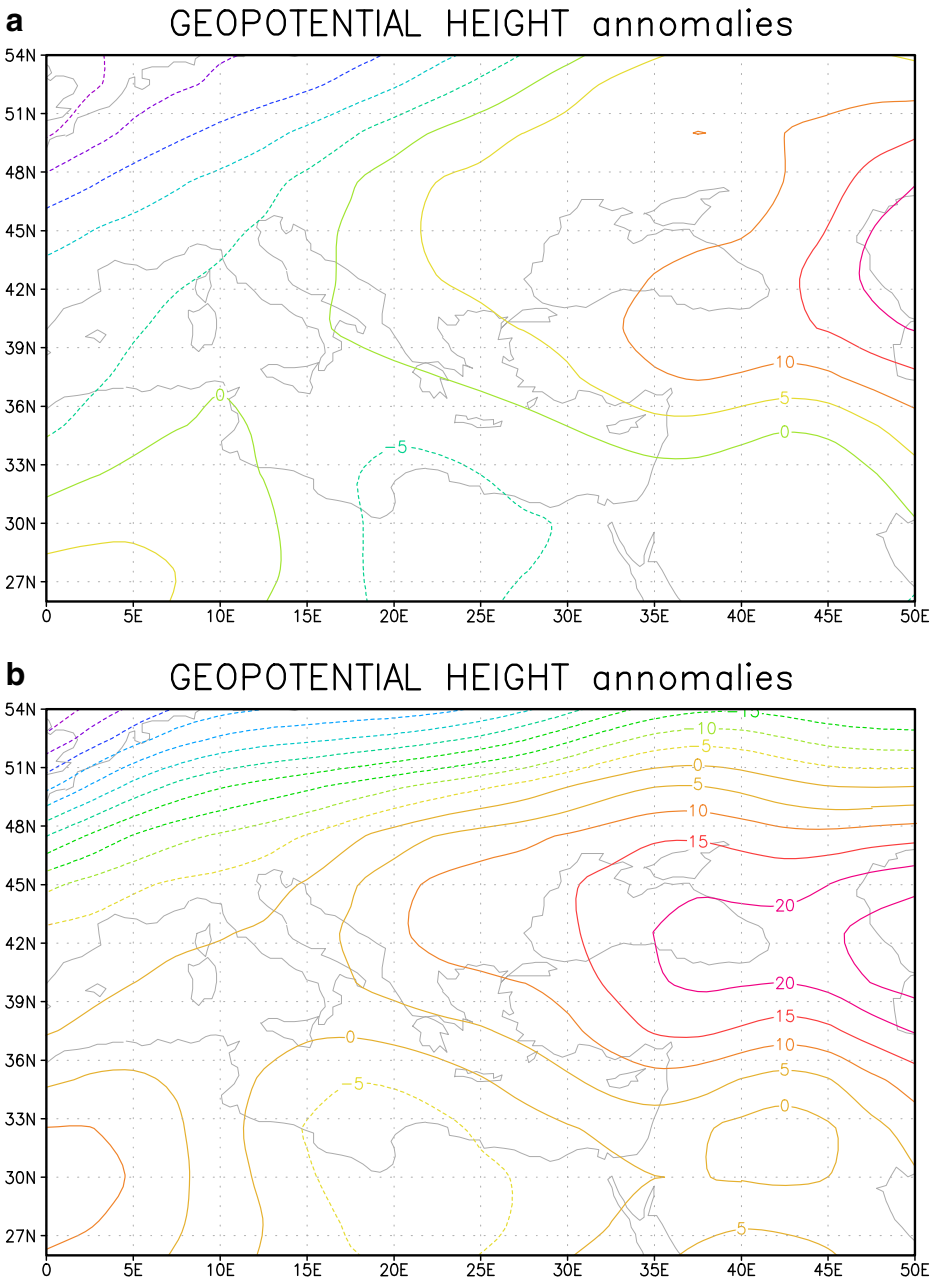

Fig. 8 Seasonal (**a**) and July (**b**) 850-hPa geopotential anomalies of summer (JJA) and July 2007 over SE Europe based on the 1961–1990 reference period

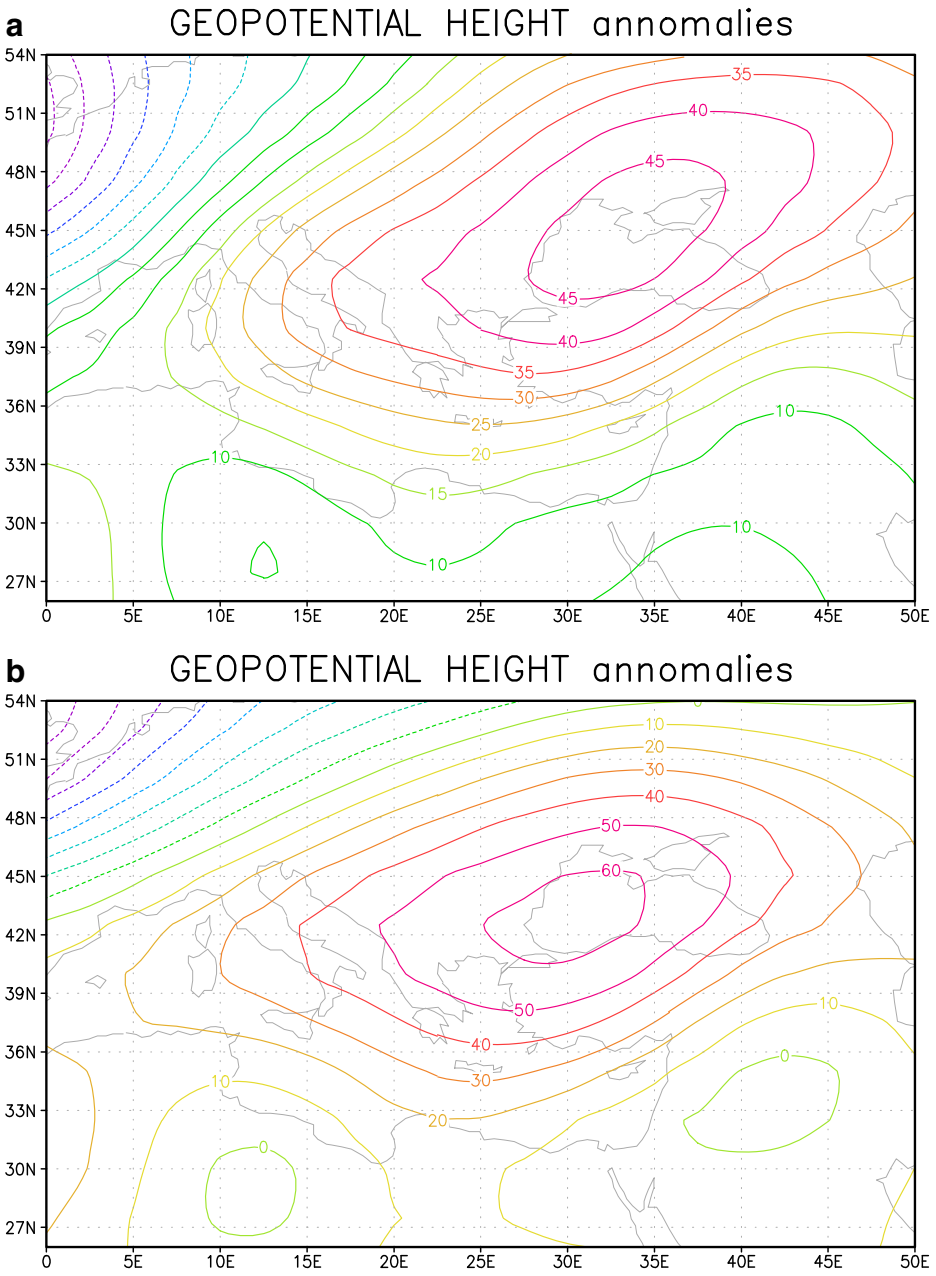

Fig. 9 As in Fig. 8 but for the level of 500-hPa

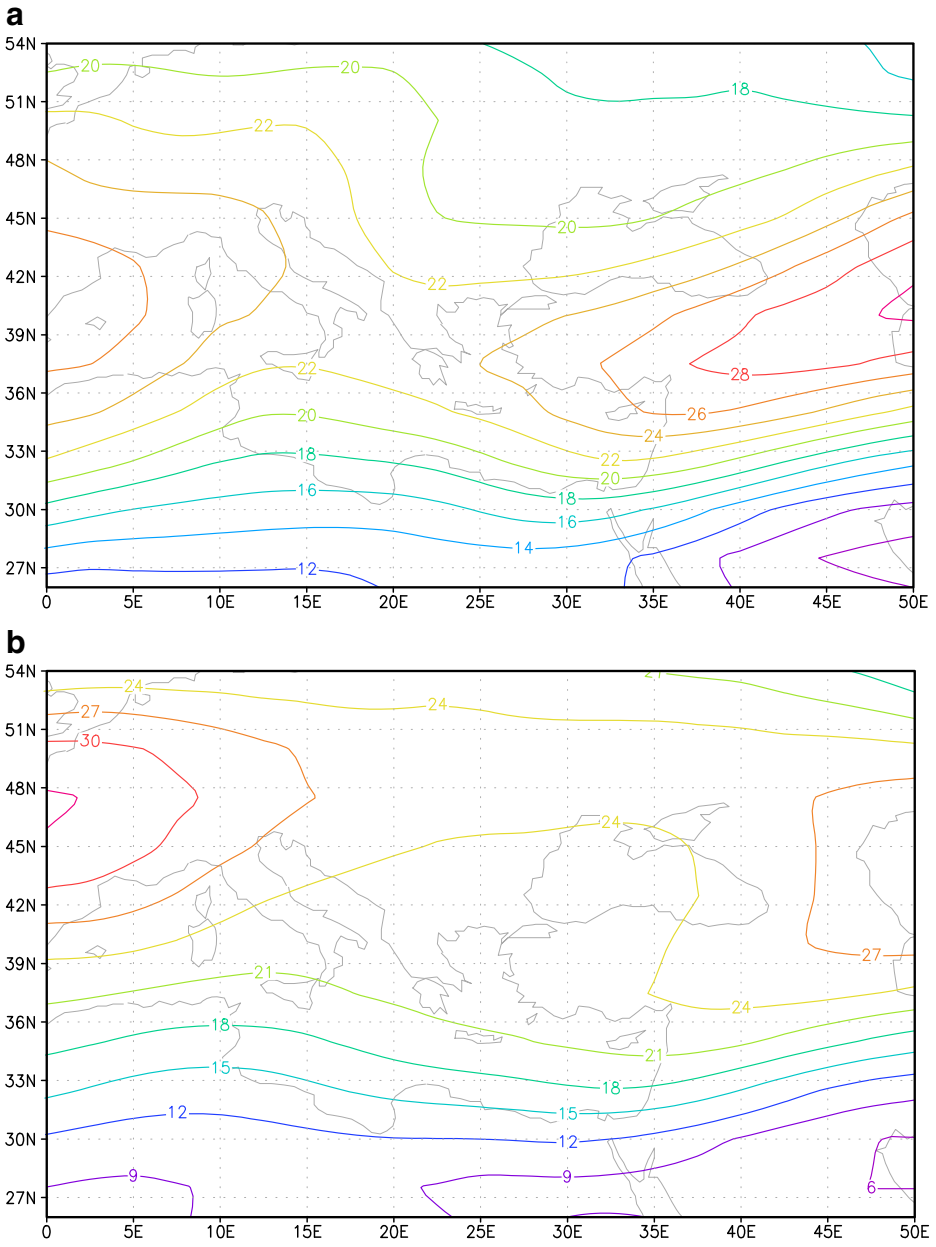

Fig. 10 Seasonal (**a**) and July (**b**) 200-hP wind anomalies of summer (JJA) and July 2007 over SE Europe based on the 1961–1990 reference period

The seasonal (a) and July (b) 850-hPa geopotential anomalies of the summer (JJA) and July 2007 over SE Europe based on the 1961–1990 reference period are presented in Fig. 8. These anomalies reached 5 and 10 gpm over Serbia during the summer and July 2007, respectively.

The atmospheric circulation at 500-hPa (not shown) resulted in the horizontal advection of warm air masses from northern Africa across central and eastern Mediterranean towards the Balkans. The 500-hPa geopotential anomalies (according to the 1961–1990 reference period) of the summer and July 2007 exceeded 35 and 40 gpm over Serbia, respectively (Fig. 9). The warm advection was manifested in temperature anomalies over Serbia, reaching up to 3.5°C and 4.0°C for the summer and July 2007, respectively (see Fig. 2).

The 200-hPa wind anomalies of summer and July 2007 over SE Europe are presented in Fig. 10. During the summer 2007, the 200-hPa wind anomaly over Serbia reached 22 m/s, while it was greater (24 m/s) in July 2007.

Founda and Giannakopoulos (2009) analyzed the circulation at the level of 200-hPa and determined the location of the south jet (SJ) stream during the heat wave of 2007 north of Greece (i.e., north of Serbia). The SJ location in heat waves is related to the inducement or enhancement of the subsidence of air into the troposphere south of the SJ. Downward velocities of up to 6.0 hPa/h (at the level 700-hPa) were found to occur over Greece on July 24, 2007 (when the records of the maximum temperature were observed in Serbia). This downward motion which increased the air temperature at lower levels through adiabatic heating, caused the most intense heat wave over Serbia.

Also, Baldi et al. (2006) showed that warm episodes during the extended summers from 1951 to 2003 in the Mediterranean were associated with the presence of a SJ located to the north of the Alps and an anticyclonic vortex over the Mediterranean. With such a configuration, there was a strong subsidence and an adiabatic warming of the troposphere.

5 Conclusions

The most severe heat wave ever recorded in Serbia occurred from July 14 to July 24 2007, with record values of the maximum temperature (44.9°C in Smederevska Palanka). The present analysis of the mean summer maximum temperatures measured from 1949 to 2007 and the heat waves in Smederevska Palanka revealed that:

- the greatest changes of the mean summer maximum temperatures emerged after the year 1990;
- the frequency of the occurrence of heat waves as well as their duration showed a sudden increase during the last decade;
- the highest anomaly of the mean summer maximum temperature according to the 1961–1990 reference period was evident in 2007;
- the most intense heat wave was recorded during July 2007;
- a synoptic situation which enabled the flow of warm and dry air from North Africa towards SE Europe and strong subsidence in the atmosphere with an adiabatic warming were responsible for the extra severe heat wave with high maximum temperatures during July of 2007 in Serbia;

It is supposed that a regime with an increased anomaly of the mean summer maximum temperature may account for the summer of 2007.

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