Chapter 2
Exceptionally Hot Summers Months in Central and Eastern Europe During the Years 1951–2010

Robert Twardosz and Urszula Kossowska-Cezak

Abstract This chapter reports a study of extremely hot months (EHMs) during the period 1951–2010. Input data includes average, maximum and minimum monthly air temperatures, the number of days with t_{max} >25, 30, 35 °C and the number of days with t_{min} >20 °C, as recorded during three summer months (June–August) at 59 weather stations in Central and Eastern Europe. This body of data was used to identify and characterise EHMs, which were defined as months with an average monthly temperature exceeding the long-term average by two or more standard deviations ($t \geq t_{av.} + 2\sigma$). The frequency and geographical coverage of EHMs were also identified.

Over the 60-year study period a total of 47 EHMs of various sizes and location were identified of which 15 occurred at only 1–2 stations and another 15 at 3–6 stations. The remaining 17 EHMs, which occurred at more than 6 stations (i.e. more than 10 % of all stations), were selected for an in depth analysis. Their distribution during the study period was found to be uneven with just 6 EHMs during the first 50 years and 11 during the final decade. The EHMs with the greatest geographical extent occurred in Russia in June (36 stations) and August (34) 2010, in August 2007 (25), August 1972 (19), June 1999 (19) and August 1992 (17). The average temperature in a typical EHM was 3–5 °C greater than the long-term average (scale of anomaly), but sometimes it reached 5–6 °C greater.

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I. Dincer et al. (eds.), *Causes, Impacts and Solutions to Global Warming*,
DOI 10.1007/978-1-4614-7588-0_2,

2.1 Introduction

An increased frequency of extreme meteorological phenomena and exceptional weather conditions, including exceptionally hot summers and summer heat waves, is often quoted as a symptom of contemporary climate change. Considerable fluctuation of thermal conditions from year to year is particularly characteristic of the temperate geographical zone covering much of the European continent. Nonetheless, the last decade of the twentieth century and the first decade of the twenty-first century stand out with particularly frequent occurrences of hot summer months and even entire summer seasons. Examples of this phenomenon include extremely hot summer seasons of 2003 in Western Europe and of 2010 in the European part of Russia characterised by an enormous extent of both the scale of thermal anomalies and their spatial coverage [1].

Such intensive and persistent heat waves are classified as extreme climatic phenomena and are known to have multiple adverse consequences. Overheating has severely adverse effects on the human health and well-being and may increase the risk of death [2–7]. Droughts that accompany heat spells damage the agriculture and increase the risk of wide spread forest fires. High air temperatures cause the melting of mountain glaciers, which cannot recover during the subsequent winter. Modelling research shows that the tendency for such adverse weather conditions to increase in frequency is likely to continue leading to more frequent, lasting and intense hot spells [8–12]. The exceptional heat waves of 2003 and 2010 constitute particularly strong manifestations of the contemporary warming of the European climate and abound in proofs of the effects mentioned before. Sources of such anomalies are still to be fully understood. In the temperate zone of Europe the direct causes include stationary high-pressure systems, which normally involve tropical advection and, additionally, strong insolation on long summer days due to the lack of cloud cover typical of high-pressure systems. Various scholars pointed to different primary causes of these anomalies, including ocean thermal conditions [13], especially their surface temperature [14–17], but also a growing concentration of greenhouse gases in the atmosphere [18–20].

This chapter focuses primarily on the frequency of exceptionally hot summer months in Central and Eastern Europe, their spatial extent and the thermal characteristic of the months. Most of the study area is relatively flat and only the south-western part features uplands and two large mountain ranges, i.e. the Carpathian Mts. and Sudety Mts., running predominantly along an east–west axis. This morphology contributes to a great variation in the frequency, intensity, duration and timing of hot spells within a relatively small area [21–23].

This chapter builds on the authors' earlier research on whole summer seasons [1].

2.2 Data and Method

The input to the study involved monthly average, maximum and minimum air temperatures; the number of days with t_{max} >25, 30 and 35 °C (defined respectively as summer days, hot and very hot days); and days with t_{min} >20 °C (tropical nights), as recorded in the summer months (June–August) at 59 weather stations in Central and Eastern Europe in 1951–2010 (Table 2.1). The study area spans 45–60°N and 15–65°E, excluding the Scandinavian Peninsula. The weather records were sourced from an on-line database *European Climate Assessment & Dataset* (ECA&D).

An EHM was defined as a month, in which the average air temperature was higher by at least two standard deviations ($t \geq t_{av.} + 2\sigma$) than the long-term average (1951–2010). The same definition had been applied for extremely hot summers [1, 22].

The study area is predominantly lowland. Indeed, 49 of the 59 weather stations are located below 200 m a.s.l., 7 stations are between 200 and 300 m and only 3 stations are above 300 m a.s.l. (L'viv at 323 m, Praha at 365 m and Cluj at 413 m). Astrachan' lies in a depression at −23 m.

The central and eastern sections of the area, which form the majority, have a moderate continental climate, while a transitional maritime to continental climate

Table 2.1 List of weather stations included in the study (station names after CLINO) [24]

Station			Station			Station		
No.	Name	WMO no.	No.	Name	WMO no.	No.	Name	WMO no.
1	Vaasa	02911	21	Ekaterinburg	28440	41	Orenburg	35121
2	Jyväskyla	02935	22	Berlin	10381	42	Ufa	28722
3	Petrozavodsk	22820	23	Praha	11518	43	Aktobe	35229
4	Arhangel'sk	22550	24	Poznan	12330	44	Zagreb	14236
5	Kotlas	22887	25	Krakow	12566	45	Wien	11035
6	Syktyvar	23804	26	Kaliningrad	26702	46	Budapest	12843
7	Pecora	23418	27	Warszawa	12375	47	Beograd	12840
8	Ivdel'	23921	28	Brest	33008	48	Debrecen	12882
9	Riga	26422	29	Kaunas	26629	49	Cluj	15120
10	Tallinn	26038	30	Minsk	26850	50	L'viv	33393
11	Daugavpils	26544	31	Vasilevici	33038	51	Chernivtsi	33658
12	Tartu	26242	32	Kyiv	33345	52	Bucuresti	15420
13	St. Petersburg	26063	33	Smolensk	26781	53	Chrisinau	33815
14	Moskva	27612	34	Kursk	34009	54	Sulina	15360
15	Vologda	27037	35	Voronez	34122	55	Odesa	33837
16	Kostroma	27333	36	Tambov	27947	56	Kharkiv	34300
17	Niznij Novgorod	27553	37	Saratov	34172	57	Luhans'k	34523
18	Kazan'	27595	38	Aleksandrov-Gaj	34391	58	Astrachan'	34880
19	Kirov	27199	39	Samara	27995	59	Atyrau	35700
20	Perm	28224	40	Ural'sk	35108			

prevails over the western part. The average long-term temperature of the warmest month, i.e. July, ranges from ca. 15 °C in the extreme north of the area to 25 °C and more in the southeast. This is evidence of a wide range of thermal characteristics within the study area. In this context it is important to note that the definition of an EHM is relative, which means that in each case it is related to the average long-term temperature in a given month at a given station. The adoption of this method has two specific consequences:

1. The average air temperature of an EHM ranges widely. For example, in July it may even fall short of 20 °C in the north-east, while in the southeast it must be 10 °C higher to meet the criterion ($t \geq t_{av.} + 2\sigma$). This means that an EHM may mean very different thermal conditions in different sections of the same climatic zone.
2. Subsequent summer months with similar average temperatures may or may not qualify as EHMs. For example, in 1972 in Moscow, the average temperature of July was 22.4 °C and 20.6 °C in August, but only the cooler August cleared the threshold ($t \geq t_{av.} + 2\sigma$).

2.3 General Characteristic of EHM Occurrence in the Summer Season

During the 60-year period, 326 months met the condition $t \geq t_{av.} + 2\sigma$ (3.1 % of all months in the period) at 59 weather stations. These EHMs occurred in 47 calendar months in 33 years of the study period, as shown in Table 2.2. The table also specifies the number of stations where a given EHM occurred and offers the calendar of extremely hot summer seasons (EHS). Interestingly, for statistical purposes there were several EHSs without a single EHM.

The study revealed that EHMs varied very widely in terms of their geographical extent, ranging from one or two stations (13 and 2 EHMs) to more than a half of all stations (one EHM each at 36 and 34 stations).

The EHM count at all stations ranged from 3 to 10, but at a clear majority (41) it was 4–6. There was no clear spatial pattern, as even neighbouring stations differed greatly in the number of occurrences, e.g. Chernivtsi 3, Kyiv 8. Generally, however, they were less numerous (3–4) in the west of the area (from Lithuania to Poland, the Czech Republic, Slovakia to Romania) and at some stations in Russia within the belt 50–55°N, than in Belarus, north-eastern Ukraine and Russia between the Black and Caspian Seas and on the Caspian coast of Kazakhstan (7–10). They were also surprisingly frequent (8) in Pecora, the farthest station to the north-east.

The likelihood of an EHM in June, July and August is virtually identical (15, 16 and 16 cases), but the geographical extent of EHMs clearly increases as the summer progresses from 87 station-months in June to 98 in July and 141 in August (Table 2.2). This would suggest that the gradually warming ground plays a role as a factor in levels of air temperature.

Table 2.2 Calendar of exceptionally hot months (EHM) and summers (EHS) and number of station at which EHM and EHS occurred in Central and Eastern Europe

	EHM			EHS		EHM			EHS		EHM			EHS
Year	Jun	Jul	Aug	Jun–Aug	Year	Jun	Jul	Aug	Jun–Aug	Year	Jun	Jul	Aug	Jun–Aug
1951			2		1971					1991	5			
1952			3		1972		4	19	16	1992	1		17	7
1953			4		1973					1993	1			
1954	2	4		1	1974		1		1	1994		3		
1955					1975	3				1995	1			
1956					1976					1996				
1957			1		1977					1997			3	3
1958					1978					1998	7			3
1959					1979	4				1999	19	1		3
1960		1			1980					2000			1	1
1961					1981			5	8	2001		15		
1962					1982					2002		9	9	10
1963					1983		1			2003	7	3	9	7
1964	11				1984		1			2004				
1965					1985			1		2005				
1966					1986					2006	1	9	5	3
1967					1987					2007	9	3	25	8
1968			3		1988		6		5	2008				
1969					1989	9	1			2009				
1970					1990					2010	7	36	34	39
Totals											87	98	141	115
											326			

Table 2.3 Years, months and occurrences with EHMs in individual decades of the period 1951–2010 in Central and Eastern Europe

10-years	No. of years	No. of months	No. of occurrences	EHM with the highest extend (number of stations)
1951–1960	6	7	17	4 each in Aug 53 and Jul 54
1961–1970	2	2	14	11 in Jun 64
1971–1980	4	5	31	19 in Aug 72
1981–1990	6	7	24	9 in Jun 89
1991–2000	9	11	59	19 in Jun 99, 17 in Aug 92
2001–2010	6	15	181	34 and 36 in Jul and Aug 10, 25 in Aug 07
1951–2010	33	47	326	36 in Aug 10; 34 in Jul 10

EHMs were distributed highly unevenly during the study period, and increased in frequency after 1990 (Tables 2.2 and 2.3). Until that year, their occurrence was similar at 5–7 per decade, with an exception of just 2 EHMs during the period 1961–1970. In the last decade of the twentieth century, this number increased to 11 EHMs (including 5 at a single station), which trend continued in the first decade of the twenty-first century with 15 EHMs. These latter EHMs occurred simultaneously over large areas, the record of which was in 2010. Also EHMs in the twenty-first century tended to be more concentrated in the same year at 2–3 each.

Individual EHMs spanned different parts of the study area and while they showed no temporal pattern, there was a general increase in their occurrence in European Russia.

2.4 Location, Extent and Thermal Characteristic of Extremely Hot Months

As has already been mentioned, 15 of the 47 EHMs occurred in areas with just 1 or 2 meteorological stations (Table 2.2). Some of these represent an interesting case of EHMs around the edges of the study area (Berlin, Bucuresti, Astrachan'), which may suggest that the EHMs recorded there could have covered a wider territory that fell outside the study area boundaries. These 15 cases will be omitted from an examination of the detailed thermal characteristics of EHMs that follows, as will 15 other EHMs which occurred at only 3–6 stations.

Indeed, only the 17 remaining EHMs which occurred at more than 6 stations (more than 10 % of all stations) are included in the discussion, as they represent the greatest geographical extent and/or greatest temperature increase. All 47 EHMs, however, are included in Table 2.3 and in a summary of all EHMs (Table 2.4).

Table 2.4 Exceptionally hot months (EHM) in Central and Eastern Europe (1951–2010)

Year	Month	No. of stations	Stations (no. according to Table 2.1)
1951	Aug	2	4, 5
1952	Aug	3	47, 49, 52
1953	Aug	4	7, 8, 20, 42
1954	Jun	2	56, 57
	Jul	4	4, 38, 40, 58
1957	Aug	1	7
1960	Jul	1	4
1964	Jun	11	25, 27, 28, 30, 31, 32, 48, 49, **50**, 51, 53
1967	Aug	3	4, 5, 6
1972	Jul	4	2, 13, 15, 16
	Aug	19	3, 4, 5, 6, 13, 14, **15**, **16**, **17**, **18**, 19, 34, **35**, **36**, 37, 38, 39, 56, 57
1974	Jul	1	7
1975	Jun	3	56, 57, 59
1979	Jun	4	26, 27, 28, 48
1981	Aug	5	7, 8, 19, 20, 21
1983	Jul	1	45
1984	Jul	1	43
1985	Aug	1	15
1988	Jul	6	5, 6, 8, 18, 19, 20
1989	Jun	9	4, 5, 6, 7, 8, 16, 19, 20, 21
	Jul	1	21
1991	Jun	5	6, 7, 8, 20, 21
1992	Jun	1	22
	Aug	17	23, 24, **25**, 27, 28, 30, 31, 32, 44, **45**, **46**, 47, **48**, 49, 50, 51, 53
1993	Jun	1	7
1994	Jul	3	22, 23, 45
1995	Jun	1	12
1997	Aug	3	9, 10, 22
1998	Jun	7	38, 39, 40, 41, 43, 58, 59
1999	Jun	19	1, 2, 3, 9, 10, 11, 12, 13, 14, 15, 16, 28, 29, 30, 31, 32, 33, 54, 55
	Jul	1	56
2000	Aug	1	47
2001	Jul	15	3, 9, 11, 12, 14, 30, 31, 32, 33, 34, 35, 54, 55, 56, 57
2002	Jul	9	14, 30, 31, 32, 33, 50, 54, 55, 56
	Aug	9	1, 2, 9, 22, 24, 26, 27, 28, 29
2003	Jun	7	23, 25, **44**, **45**, 46, 47, 49
	Jul	3	1, 2, 9
	Aug	9	7, 8, 21, 22, 23, 44, 45, 46, 47
2006	Jun	1	58
	Jul	9	22, 23, 24, 25, 26, 27, 28, 44, 45
	Aug	5	1, 2, 57, 58, 59

(continued)

Table 2.4 (continued)

Year	Month	No. of stations	Stations (no. according to Table 2.1)
2007	Jun	9	44, 45, 46, 47, 48, 52, 53, 54, 55
	Jul	3	47, **52**, 53
	Aug	25	3, 10, 12, 13, 14, 15, 16, 17, 18, 19, 30, 34, 35, 36, 37, 38, 39, 40, 41, 42, 55, 56, 57, 58, 59
2010	Jun	7	32, 34, 35, 43, 56, 58, 59
	Jul	36	1, **2**, **3**, 9, **10**, 11, **12**, **13**, **14**, **15**, **16**, **17**, 18, 19, 22, 24, 26, 28, 29, 30, 31, 32, **33**, **34**, **35**, **36**, 37, 38, **39**, 40, 41, 44, 56, 57, 58, 59
	Aug	34	11, 12, 13, **14**, 15, 16, 17, 18, 21, 28, 29, 30, **31**, **32**, **33**, **34**, **35**, **36**, **37**, 38, **39**, 40, 41, 42, 43, 50, 51, 53, 54, **55**, **56**, 57, 58, 59

Notes: Station numbers printed in bold mean that the average temperature met the formula $t \geq t_{av.}+3\sigma$

2.5 EHMs During 1951–2000

During the first 50 years of the study period, only six EHMs extended to more than 10 % of the stations (Table 2.2).

June 1964 (Fig. 2.1, Table 2.5) was an EHM in the south-western part of the area covering sections of Poland, Belarus, Slovakia, Hungary, western Ukraine and northern Romania (Fig. 2.1). The EHM centred on L'viv where the temperature reached $t \geq t_{av.}+3\sigma$ (the anomaly, or Δt, in L'viv was 4.2 °C, and outside L'viv it ranged from 2.5 to 4.0 °C). At most of the stations this was the hottest June in the study period. Hot days were recorded across the area.

August 1972 (Fig. 2.1, Table 2.5) was the first EHM of the period, which covered nearly all of the European part of Russia (Δt from 3.0 to 6.5 °C). In its central section the anomaly reached three standard deviations from the long-term average, or more than 5 °C, including 6.1 °C in Voronez and 6.5 °C in Tambov. (There were only 13 cases where the long-term average temperature was exceeded by more than 6.0 °C). At some of the stations this was the hottest August of the study period. Hot days were recorded across the area (e.g. 7 in St. Petersburg compared to an average of once in 3 years and ca. 20 in the south compared with ca. 5 on average). In the southern half of the EHM area there were cases of the very rare tropical nights (e.g. 8 in Kharkiv, 1–2 on average). The summer of 1972 proved an EHS and the month was the hottest in Finland and northern Russia and the second most expansive EHS during the study period [28].

June 1989 (Table 2.5). The EHM covered the entire north-eastern part of the European Russia (Δt from 4.2 to 5.5 °C). At a majority of the stations it was the warmest EHM of the study period. Hot days were observed at all stations.

August 1992 (Fig. 2.2, Table 2.5) The EHM covered a south-western part of the area, including the larger part of Poland in the south. In most of the area the average

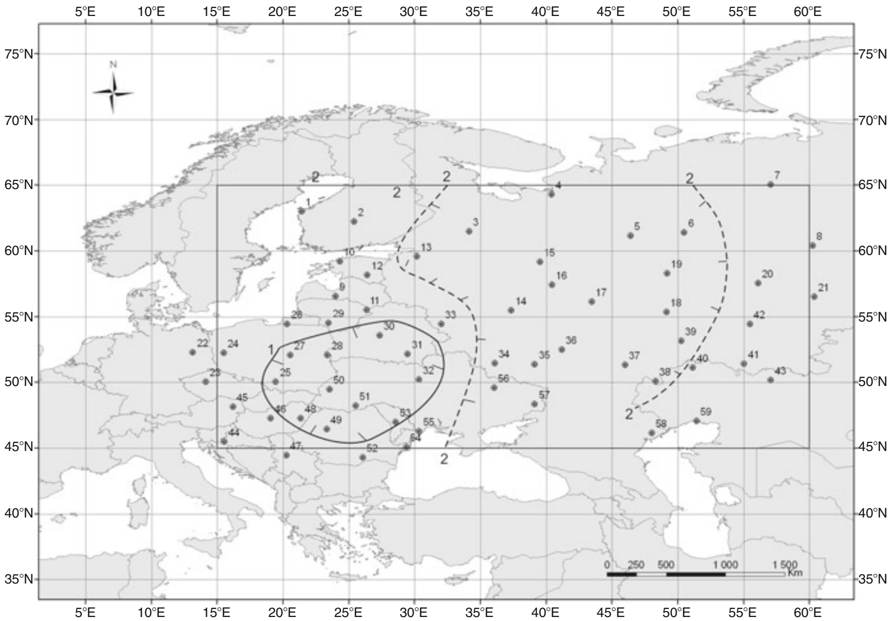

Fig. 2.1 Geographic coverage of the exceptionally hot month of June 1964 (1) and August 1972 (2)

temperature exceeded the long-term average by more than 3 °C (Δt from 2.9 °C in Poznan to 5.0 °C in Wien; in Wien, Budapest, Debrecen and Krakow the anomaly exceeded three standard deviations). At nearly all stations (excluding those located at the edge of the area) this was the hottest August of the period. The maximum temperatures were very high, hot days were recorded at all stations and there were also some very hot days. Krakow had the highest frequency of very hot days (t_{max}>35 °C; 13 cf an average of 1 day every 2 years). These exceptionally high temperatures in Krakow could be explained both by the foehn effect and a vast forest fire at Kuźnia Raciborska 120 km to the west [25]. In the south of the area there were many instances of tropical nights (t_{min}>20 °C = ca. 20, cf an average of ca. 4).

In Poland, Slovakia, Czech Republic and Hungary the summer of 1992 was classified as an EHS. It was also the hottest summer of the period in southern Poland and Krakow's only EHS [28].

June 1998 (Table 2.5) was the first EHM to cover the southeast of the study area starting from the latitude of Samara to the Caspian Sea. It was the hottest June in this territory in the study period (Δt from 3.5 to 4.7 °C). Both the maximum and minimum temperatures were very high and all stations recorded both hot and very hot days (e.g. 20 hot and 9 very hot days at Orenburg, cf 9 and 2 on average; 26 and 12 at Atyrau, cf 17 and 5 on average) and tropical nights (e.g. 8 in Orenburg, cf 1 on average and 19 at Atyrau, cf 8 on average).

Table 2.5 Thermal characteristic of the EHM: June 1964, August 1972

Station		Temperature (°C)			Number of days with temperature			
					T_{max}		T_{min}	
No.	Name	Average	Max	Min	>25 °C	>30 °C	>35 °C	>20 °C
June 1964								
27	Warszawa	20.0	25.7	13.6	17	6	–	–
32	Kyiv	22.3	28.1[a]	16.9	26[a]	9	–	1
50	L'viv	**20,6**[a]	**26,6**[a]	14.1	21[a]	3[a]	–	–
August 1972								
4	Arhangel'sk	17.1	23.3[a]	11.9	12[a]	1	–	–
13	St. Petersburg	19.9[a]	24.7[a]	15.8	16[a]	7[a]	–	4
14	Moskva	20.6	**27.6**[a]	14.1	21[a]	13	–	–
17	Niznij Novgorod	**22.7**[a]	27.1	17.2[a]	20	10	–	8
35	Voronez	**25.0**	**31.9**	**18.1**[a]	27[a]	22[a]	8	8
56	Kharkiv	23.9	30.2	17.6	26[a]	19	3	8
June 1989								
4	Arhangel'sk	17.6[a]	24.0[a]	11.5	16[a]	1	–	–
7	Pecora	17.2	24.6[a]	10.7	17[a]	4	–	1
20	Perm	21.0[a]	27.2[a]	14.5[a]	23[a]	5	–	–
21	Ekaterinburg	23.1[a]	28.0[a]	15.3[a]	27[a]	6	–	–
August 1992								
25	Krakow	**22.0**[a]	**30.2**[a]	15.4	27[a]	16[a]	13[a]	1
32	Kyiv	22.9	30.0	17.4	27	12	–	2
45	Wien	**25.1**[a]	**31.5**[a]	**18.7**[a]	30[a]	21[a]	3[a]	9[a]
47	Beograd	26.8[a]	33.6[a]	20.6[a]	31[a]	28[a]	11[a]	20[a]
June 1998								
41	Orenburg	24.8[a]	31.9	16.8[a]	27[a]	20[a]	9	8
58	Astrachan'	26.6[a]	33.3[a]	20.2[a]	30[a]	23	10[a]	16[a]
June 1999								
2	Jyväskyla	17.7[a]	23.5[a]	11.8[a]	10	–	–	–
13	St. Petersburg	20.5[a]	25.9[a]	15.7[a]	18[a]	4	–	3[a]
14	Moskva	21.4[a]	27.2[a]	14.4	22[a]	6	–	–
30	Minsk	21.1[a]	26.9[a]	15.4[a]	22[a]	5[a]	–	–
32	Kyiv	22.6[a]	28.1[a]	17.1[a]	23	11[a]	–	3
55	Odesa	22.8	27.6[a]	18.4	24	5	–	7

Notes: a value in bold means that the temperature meets the criterion $t \geq t_{av.}+3\sigma$
[a]Highest in 60 years

June 1999 (Fig. 2.2, Table 2.5) was one of the most extensive EHMs, ranging from Finland to north-western Russia, the Baltic states (but not Poland), Belarus, and central Ukraine to the Black Sea. Across its territory it was the hottest June in the study period (Δt from 2.4 to 3.0 °C in the south, to 4.3–5.0 °C in the centre to 3.3–3.9 °C in the far north). The maximum temperatures were particularly high with hot days at all stations, especially in Kyiv (11, cf. 2 on average), but no very hot days.

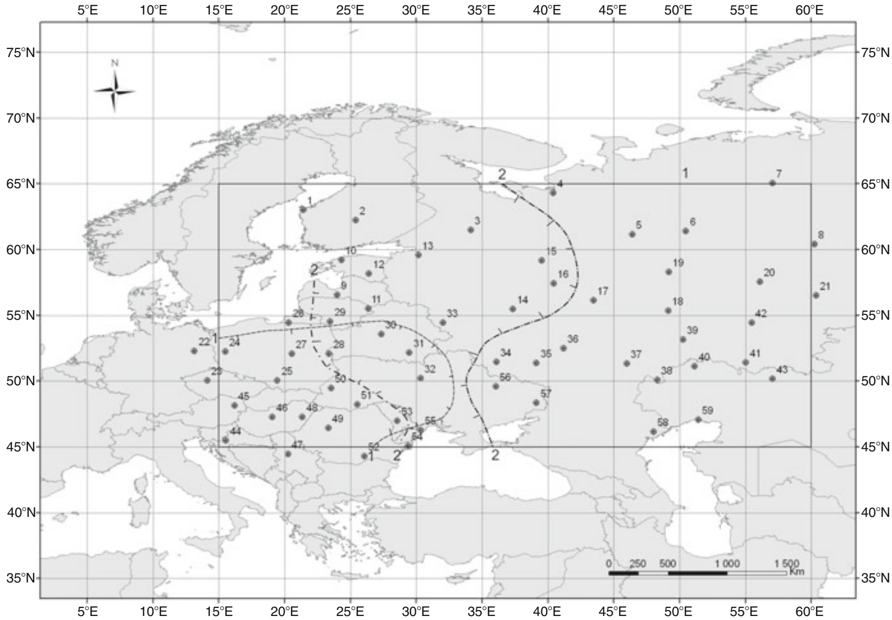

Fig. 2.2 Geographic coverage of the exceptionally hot month of August 1992 (1) and June 1999 (2)

2.5.1 EHMs During 2000–2010

There were nearly twice as many EHMs (11) during the last decade of the study period, which were observed at more than 10 % of the stations than during the previous 50 years (Table 2.2).

July 2001 (Fig. 2.3, Table 2.6). The EHM covered an area stretching from Estonia, Latvia, eastern Lithuania, Belarus and the Ukraine without its western part and the western edge of Russia. In the centre of the area, the average temperature was more than 4 °C higher than the long-term average (Δ*t* across the area from 3.1 to 4.9 °C). Hot days were recorded at all the stations, very hot days in the south (e.g. 16 hot and 4 very hot days in Kharkiv, on average every 4 and 5 years) and also tropical nights at nearly all stations, especially on the Black Sea coast (13 in Kharkiv, 26 in Odesa; cf averages of 2 and 7 respectively).

July 2002 (Table 2.6). The EHM covered more or less the same area as the year before, apart from the far north, but including the whole of the Ukraine (Δt from 3.0 to 3.9 °C). Just as in the previous year, hot days were recorded across the board, but very hot days only in the far south. Tropical nights occurred everywhere.

August 2002 (Table 2.6). This was the second consecutive EHM that year, but this time only at the north-western end of the study area stretching from Finland to the northern half of Poland (Δt from 2.7 to 4.0 °C). At certain stations (Jyvaskyla,

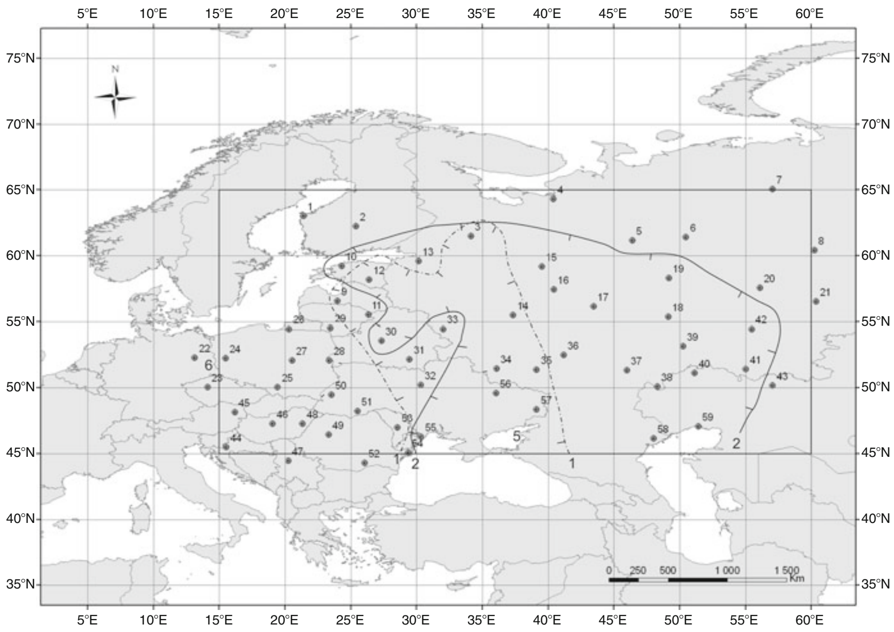

Fig. 2.3 Geographic coverage of the EHM of July 2001 (1) and August 2007 (2)

Riga, Kaliningrad, Poznan) this was the hottest August of the study period. There were isolated hot days.

In addition the entire summer season of 2002 was classified as an EHS at a few stations in the western part of the study area.

In 2003, all summer the months qualified as EHMs, but only in June and August were more than 10 % of the stations involved (Table 2.2). In these months, the EHM area covered a south-western section of the study area (Δt from 2.3 to 3.3 °C), which was on the periphery of an EHS observed throughout Western Europe. There the exceptional heat wave contributed to higher death rates and to an increased rate of melting of Alpine glaciers noted in several studies [e.g. 4, 18, 19, 23, 26–29].

June 2003 (Table 2.6) was an EHM in Western Europe, which only covered the south-western edge of the study area from Praha and Krakow to Beograd (Δt from 2.8 to 4.6 °C). At nearly all of the stations it was the hottest June of the study period. In Wien and Zagreb the average temperature climbed to $t \geq t_{av.}+3\sigma$. Hot days were recorded at all stations, but there were only sporadic cases of very hot days.

August 2003 (Table 2.6) was the second case, 49 years after July 1954, of a dual-area EHM: one in the foreland of the Ural Mountains to the east of the area (Δt from 4.2 to 5.1 °C, the hottest August of the study period) and the other in the far south-west stretching from Berlin to Beograd (Δt from 2.7 to 4.6 °C). Again, like in June, this latter area was on the periphery of a powerful EHM that covered Western Europe and featured the greatest temperature increase rate during the study period. The single largest temperature anomaly was recorded in the south-western

Table 2.6 Thermal characteristics of the EHM: July 2001, July and August 2002

Station		Temperature (°C)			Number of days with temperature			
					T_{max}		T_{min}	
No.	Name	Average	Max	Min	>25 °C	>30 °C	>35 °C	>20 °C
July 2001								
9	Riga	21.7	26.8	13.0?	20	5	–	–
14	Moskva	23.0	28.4	17.8	27	10	–	5
30	Minsk	22.1	27.5	17.5	24	7	–	6
32	Kyiv	24.6	30.3[a]	19.5	31[a]	16	–	10
35	Voronez	24.1	30.6	18.2	31[a]	15	3	6
55	Odesa	26.0[a]	30.6[a]	21.7[a]	31[a]	20[a]	1	26[a]
July 2002								
14	Moskva	22.6	28.3	16.3	26	8	–	2
30	Minsk	22.0	27.9[a]	16.5	25[a]	7	–	2
32	Kyiv	23.9	29.7	18.7	28	20[a]	–	11
50	L'viv	21.0[a]	26.6	15.8[a]	20	5	–	1[a]
55	Odesa	25.6	30.4	21.1	30	17	3[a]	20
August 2002								
2	Jyväskyla	17.0[a]	23.5[a]	10.3	11[a]	–	–	–
9	Riga	20.9[a]	26.1[a]	13.6	28[a]	2	–	–
22	Berlin	20.6	26.2	15.9[a]	25[a]	1	–	–
27	Waszawa	20.7	26.8	15.0	25	2	–	–
June 2003								
25	Krakow	19.1[a]	25.9[a]	14.3	17	3	–	–
45	Wien	**22.6**[a]	**28.1**[a]	**17.0**[a]	25[a]	9	–	3
47	Beograd	25.0[a]	30.8[a]	**19.2**[a]	28[a]	18[a]	2	12[a]
August 2003								
7	Pecora	17.4[a]	22.5	13.5[a]	9	2[a]	–	–
21	Ekaterinburg	20.4[a]	26.1	15.7[a]	20	6	–	1
22	Berlin	20.5	26.9	14.3	19	9[a]	–	–
45	Wien	24.4	**30.8**	17.9	30[a]	18	2	5
47	Beograd	25.6	32.2	19.3	31[a]	24	4	9
July 2006								
22	Berlin	23.2[a]	29.8[a]	16.3[a]	29[a]	15[a]	1	2[a]
25	Krakow	21.3[a]	29.7[a]	15.7	26	18[a]	3	–
27	Warszawa	23.1[a]	30.0[a]	16.2	29[a]	18[a]	1	2
45	Wien	24.1[a]	29.8[a]	18.3[a]	26	17[a]	–	6[a]
June 2007								
45	Wien	21.5	27.0	15.8	22	3	–	–
52	Bucuresti	23.3[a]	31.4[a]	15.0	29	20[a]	1	1
55	Odesa	23.4[a]	27.0	18.9[a]	28[a]	7	–	8
August 2007								
13	St. Petersburg	19.7	24.1	15.4	16[a]	3	–	1
14	Moskva	20.2	25.7	14.7	18	9	–	1
34	Kursk	21.8	27.6	16.1	21	12	1	2
39	Samara	24.0	28.9	17.5[a]	28[a]	14	–	10[a]
41	Orenburg	24.3	32.0[a]	16.1	29[a]	25[a]	6	5

(continued)

Table 2.6 (continued)

Station		Temperature (°C)			Number of days with temperature			
					T_{max}		T_{min}	
No.	Name	Average	Max	Min	>25 °C	>30 °C	>35 °C	>20 °C
55	Odesa	24.7	28.7	20.6[a]	28	10	3	17
58	Astrachan'	27.4	35.1	20.4[a]	31[a]	30[a]	19[a]	16

Notes: a value in bold means that the temperature meets the criterion $t \geq t_{av.}+3\sigma$
[a]Highest in 60 years

part of the Massif Central, France (Gordon weather station) [12]. In the western part of the study area the summer of 2003 also qualified as an EHS.

July 2006 (Table 2.6) was an EHM in the west and stretched from Poland to western Hungary and Croatia and, just as in 2003, it was part of an EHM centred on Western Europe. Throughout the area affected it was the hottest July in the study period (Δt from 2.8° in Zagreb to 5.2 °C in Poznan). Hot days occurred very frequently at all stations (e.g. 18 each in Warszawa and Krakow, cf 3–4 on average), while very hot days were sporadic.

The summer of 2007 again involved three EHMs, even if July only covered 5 % of the stations. In the south-western part of the area the season qualified as EHS.

June 2007 (Table 2.6). The EHM covered a small area in the south-west to the south of the line Vienna-Odessa and was part of a larger EHM in the Balkan Peninsula. In the east of the affected area, Bucuresti to Odesa, this was the hottest June during the study period (Δt from 2.7 to 3.7 °C, except Sulina 2.2 °C). Throughout the area hot days and tropical nights were commonly recorded, but very hot days were only recorded sporadically.

August 2007 (Fig. 2.3, Table 2.6) covered the largest area to that date, including a larger south-eastern part of European Russia, parts of Estonia, Latvia and Belarus, eastern Ukraine and western Kazakhstan. The long-term average was exceeded by ca. 3 °C in the north, by 3.5–4.5 °C in the south and by ca. 5 °C in the centre (Δt from 2.8 to 5.3 °C). Hot days were recorded throughout the area, from 2 to 3 in the north (cf an average of once every few years) to 30–31 on the Caspian coast (cf an average of 18–20), where very hot days peaked in frequency (19–22, cf an average of 3–6). Tropical nights were also observed throughout the area with the record numbers on the Black Sea and Caspian coasts (Odesa 17, cf an average of 7; Atyrau 25, cf an average of 10).

The most intense heat wave of 2007 was recorded in the Balkan Peninsula [30].

All three summer months of 2010 qualified as EHMs, but for the first time their coverage was similar, especially in July and August (Fig. 2.4). The latter two were also the EHMs with the largest territorial extent during the study period. Both had a similar coverage to August 2007, including a western part of the European Russia, Belarus, the Ukraine and western Kazakhstan. In an earlier study the authors [28]

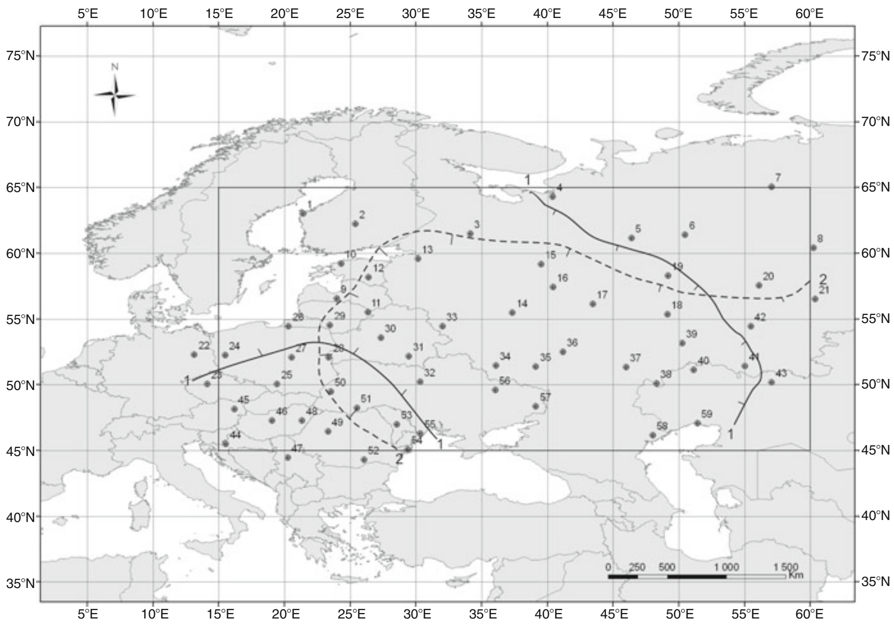

Fig. 2.4 Geographic coverage of the EHM of July (1) and August (2) 2010

found that the average temperature at certain Russian stations exceeded the long-term averages by up to 4σ.

June 2010 (Table 2.7). The EHM was split into two relatively small areas: one from Kyiv to Voronez along the border between Russia and the Ukraine (Δt from 3.4 to 4.0 °C) and the other in the southeast from Astrachan' to Aktobe (Δt from 3.1 to 4.9 °C). At most of these stations this was the hottest June during the study period. Tropical nights were recorded at all stations and very hot days at nearly all of them.

July 2010 (Fig. 2.4, Table 2.7). The EHM covered an area of record size stretching from the Baltic coast to the eastern part of the Black Sea and the Caspian Sea. At all stations, except Berlin and Poznan, it was the hottest July during the study period. Everywhere the average long-term temperature was exceeded by more than 3.5 °C and in the central part of the area affected by more than 5 °C, including by more than 6 °C at 8 stations (record Δt values: 6.9 °C at Kursk and 6.8 °C in Moscow and Tambov). At 14 stations from Jyvaskyla to Samara the average monthly temperature equalled $t \geq t_{av.}+3\sigma$. Hot days were observed throughout the area; from 5 at Jyvaskyla (an average of once in 3 years), 14 at St. Petersburg (on average 1) to 23–25 at Kursk and Voronez (on average 3–6) and 31 (on all days of the month) on the Caspian Sea (on average 21–24). In the central and south-eastern part of the area there were also very hot days (e.g. 7–9 at Kursk and Voronez, on average once in a few years; 24 at Atyrau, on average 9). Tropical nights were also recorded at all stations and at most of them at record levels,

Table 2.7 Thermal characteristics of the EHM in 2010

Station					Number of days with temperature			
		Temperature (°C)			T_{max}			T_{min}
No.	Name	Average	Max	Min	>25 °C	>30 °C	>35 °C	>20 °C
June 2010								
32	Kyiv	22.0	27.3	16.6	22	8	–	3
34	Kursk	21.9[a]	27.4	16.5	21	8	1	1
58	Astrachan'	26.2	32.5	19.0	30[a]	25	7	14
July 2010								
2	Jyväskyla	**20.9**[a]	26.8[a]	14.9[a]	22[a]	5[a]	–	1
9	Riga	22.1[a]	27.3[a]	12.7?	21[a]	11[a]	–	3
13	St. Petersburg	**24.5**[a]	**28.9**[a]	**20.1**[a]	26[a]	14[a]	1[a]	16[a]
14	Moskva	**25.6**[a]	**32.1**[a]	**19.1**[a]	31[a]	22[a]	9[a]	16[a]
22	Berlin	22.2	28.4	15.4	22	11	3[a]	2[a]
32	Kyiv	25.0[a]	30.3[a]	19.6	31[a]	17	1[a]	13[a]
34	Kursk	**26.1**[a]	**32.1**[a]	20.3[a]	31[a]	23[a]	7[a]	17[a]
39	Samara	**26.8**[a]	**33.2**[a]	17.5	30[a]	25[a]	15[a]	6
41	Orenburg	25.9[a]	33.4	18.4[a]	30	25[a]	15[a]	11[a]
58	Astrachan'	29.1[a]	36.1[a]	21.5[a]	31[a]	31[a]	20[a]	26[a]
August 2010								
13	St. Petersburg	19.8	23.6	16.1[a]	14	5	1[a]	6[a]
14	Moskva	**21.5**[a]	27.4	**15.6**[a]	19	16	7[a]	8[a]
21	Ekaterinburg	19.5	24.5	14.4	15	10[a]	2[a]	8[a]
32	Kyiv	**25.2**[a]	**31.2**[a]	**19.1**[a]	23	19[a]	13[a]	18[a]
34	Kursk	**25.2**[a]	**31.2**[a]	**19.3**[a]	23	20[a]	13[a]	19[a]
39	Samara	**25.0**[a]	30.2[a]	14.6?	25	17	12[a]	9?
41	Orenburg	24.7[a]	32.0[a]	17.0[a]	26	21	14[a]	6
55	Odesa	**26.4**[a]	31.1[a]	20.5	28	17[a]	7[a]	21[a]
58	Astrachan'	27.7[a]	35.5[a]	19.0?	30	27	16	16

Notes: a value in bold means that the temperature meets the criterion $t \geq t_{av.}+3\sigma$
[a]Highest in 60 years

including the only occurrence during the study period at Jyvaskyla, 16 each in St. Petersburg and Moscow (less than one on average) and 26–27 at Astrachan' and Atyrau (on average 13–14).

August 2010 (Fig. 2.4, Table 2.7) This EHM by-and-large overlapped with the territory of the July EHM, but included a shift to the east into the southern Ural Mts., at the cost of northern and western coverage (Δt from 2.7 to 7.0 °C). In its central section it was the hottest August during the study period. Here, in the central part of European Russia and the neighbouring part of Ukraine, the average monthly temperature reached $t \geq t_{av.}+3\sigma$, which in absolute terms typically meant 5 °C. In the town of Kursk, which recorded the greatest anomaly at $t \geq t_{av.}+3.9\sigma$, or 7.0 °C, as well as in Kiev, Kharkiv and Voronez, this was the third consecutive EHM, a sole event of the type during the study period. All the stations within the EHM area recorded hot days, ranging from 5 in St. Petersburg (on average once in

3 years), to 16 in Moscow (on average 1), 20 at Kursk (on average 2) to 27 at Astrachan' (on average 18). Very hot days were also recorded by most stations where they typically reached the highest frequency during the study period. Moscow with its 7 very hot days (after 9 such days in July) stood out particularly, as they included the sole case of a maximum temperature above 35 °C during the study period. On the Caspian coast the incidence of very hot days, common in the area, was 3–5 times greater than the average. Tropical nights were noted almost at all stations, including 19 at Kursk (on average less than 1) and 8 in Moscow (on average once in 5 years), while in the far south of the territory affected they were 2–3 times more frequent than on average.

The final year of the study period was unique within its decade with two consecutive EHMs with the greatest spatial scale and greatest temperature increase. This long spell of exceptionally high temperatures caused a considerable deterioration in living conditions and highly adverse economic effects as it contributed to the development of vast wildfires, which, in turn, caused the levels of air pollution in Moscow to rise by 2–3 times [31]. The wildfires may have also made a considerable contribution to the scale of the temperature increase [1]. This proposition is supported by a study on an EHS of 1992 in Poland [25].

2.6 Conclusions

During the period 1951–1960, 47 exceptionally hot summer months (EHMs) of varying territorial extent occurred in Central and Eastern Europe. In total 22 EHMs covered areas represented by 1–3 out of the total 59 stations (5 %), 30 EHM were recorded by 6 stations (10 %) and only 7 EHMs occurred in areas with more than 15 stations (more than 25 %).

The EHMs with small station coverage must be seen in the context of the boundaries of the study area, beyond which many EHMs might indeed have continued.

A vast majority of the EHMs occurred in a single area and there were only three EHMs, which had two separate locations during the study period (July 1954, August 2003 and August 2006).

EHMs did not display any specific spatial or temporal patterns of occurrence, although there were temporary trends when they concentrated in a similar area, including 4 EHMs in the far north-west (1981–1991), 5 EHMs in the far south-west (twenty-first century), and a series of EHMs in European Russia (2007 and 2010). During the study period, the frequency of EHMs increased after 1990 and further still after 2000.

These latest EHMs grew in size and frequency to 2 or even 3 in the same year, sometimes in the same area. The persistence of exceptionally hot spells increased while the deviation of the average temperature from the long-term average was often greater than ever before. This constitutes an unquestionable example of the contemporary global warming.

The most intense and vast EHMs in the area included: August 1972 (Russia), August 1992 (the south-west), June 1999 (broad belt from Finland to the Black Sea), August 2007 (Russia) and July and August 2010 (Russia). The persistence of exceptionally hot spells increased while the deviation of the average temperature from the long-term average was often greater than ever before. This constitutes an unquestionable example of the contemporary global warming.

References

1. Twardosz R, Kossowska-Cezak U (2012) Exceptionally hot summers in central and eastern Europe (1951–2010), Theor Appl Climatol 112:617–628. doi:10.1007/s00704-012-0757-0
2. Błażejczyk K, McGregor G (2007) Warunki biotermiczne a umieralność w wybranych aglomeracjach europejskich. Przegląd Geograficzny 3–4:401–423
3. Hutter HP, Moshammer H, Wallner P, Leitner B, Kundi M (2007) Heatwaves in Vienna: effects on mortality. Wien Klin Wochenschr 119(7–8):223–227
4. Twardosz R (2009) Fale niezwykłych upałów w Europie na początku XXI wieku. Przegląd Geofizyczny 3–4:193–204
5. Muthers S, Matzarakis A, Koch E (2010) Climate change and mortality in Vienna—a human biometeorological analysis based on regional climate modeling. Int J Environ Res Public Health 7:2965–2977
6. Barriopedro D, Fischer EM, Luterbacher J, Trigo RM, García-Herrera R (2011) The Hot summer of 2010: redrawing the temperature record map of Europe. Science 332 (6026):220–224
7. Revich BA, Shaposhnikov DA (2012) Climate change, heat waves, and cold spells as risk factors for increased mortality in some regions of Russia. Stud Russ Econ Dev 23(2):195–207
8. Meehl GA, Tebaldi C (2004) More intense, more frequent, and longer lasting heat waves in the 21st century. Science 305:994–997
9. Révész A (2008) Stochastic behaviour of heat waves and temperature in Hungary. Appl Ecol Environ Res 6(4):85–100
10. Kürbis K, Mudelsee M, Tetzlaff G, Brázdil R (2009) Trends in extremes of temperature, dew point, and precipitation from long instrumental series from central Europe. Theor Appl Climatol 98:187–195
11. Bardin MY (2011) Scenary forecasts of air temperature variations for the regions of the Russian Federation up to 2030 using the empirical stochastic climate models. Russ Meteorol Hydrol 36(4):217–228
12. Fischer EM, Schär C (2010) Consistent geographical patterns of changes in high-impact European heat waves. Nat Geosci 3:398–403
13. Black E, Sutton R (2007) The influence of oceanic conditions on the hot European summer of 2003. Clim Dyn 28:53–66
14. Della-Marta PM, Luterbacher J, von Weissenfluh H, Xoplaki E, Brunet M, Wanner H (2007) Summer heat waves over western Europe 1880–2003, their relationship to large-scale forcings and predictability. Clim Dyn 29:251–275
15. Feudale L, Shukla J (2011) Influence of sea surface temperature on the European heat wave of 2003 summer. Part I: an observational study. Clim Dyn 36(9–10):1691–1703
16. Dole R, Hoerling M, Perlwitz J, Eischeid J, Pegion P, Zhang T, Quan XW, Xu T, Murray D (2011) Was there a basis for anticipating the 2010 Russian heat wave? Geophys Res Lett 38, L06702. doi:10.1029/2010GL046582

17. Zveryaev I, Zyulyaeva Yu, Gulev S, Koltermann P (2012) Intercomparison of the Russian Summer HeatWaves of 2010 and 1972. Geophysical Research Abstracts, 14: EGU2012-9714, 2012, EGU General Assembly 2012
18. Schär C, Vidale PL, Lüthi D, Frei C, Häberli C, Liniger MA, Appenzeller C (2004) The role of increasing temperature variability in European summer heatwaves. Nature 427:332–336
19. Stott DA, Stone DA, Allen MR (2004) Human contribution to the European heatwave of 2003. Nature 432:610–614
20. Gruza GV, Ran'kova EYA (2011) Estimation of probable contribution of global warming to the genesis of abnormally hot summers in the European part of Russia. Izvestiya, Atmospheric Oceanic Physics 47(6):661–664
21. Gerstengarbe FW, Werner PC (1992) The time structure of extreme summers in central Europe between 1901 and 1980. Meteorol Zeitschrift NF 1:285–289
22. Filipiuk E, Kaszewski BM (2000) Hot and cold summer in Central Europe (1871–1990). Prace Geograficzne 108:149–154
23. Twardosz R, Batko A (2012) Heat waves in Central Europe (1991–2006). Int J Global Warming 4:261–272, Nos 3/4
24. WMO (1996) Climatological normals (CLINO) for the period 1961–1990. WMO, Geneva
25. Kossowska-Cezak U (1993) Lato roku 1992 w Polsce na tle sezonów letnich ostatnich 120 lat. Przegląd Geofizyczny 1:67–74
26. Auswirkungen des Hitzesommer 2003 auf die Gewässer. Dokumentation. 2004, Schriftenreiche Umwelt, Nr 369. Gewässerschutz, Bern
27. Fink AH, Brücher T, Krüger A, Leckebusch GC, Pinto JG, Ulbrich U (2004) The 2003 European summer heatwaves and drought—synoptic diagnosis and impacts. Weather 59 (8):209–216
28. Chase TN, Wolter RA, Pielke SR, Rasool I (2006) Was the 2003 European summer heat wave unusual in a global context? Geophys Res Lett 33:L23709
29. D'Ippoliti D, Michelozzi P, Marino C, de'Donato F, Menne B, Katsouyanni K, Kirchmayer U, Analitis A, Medina-Ramón M, Paldy A, Atkinson R, Kovats S, Bisanti L, Schneider A, Lefranc A, Ińiguez C, Peruccilet CA (2010) The impact of heat waves on mortality in 9 European cities: results from the EuroHEAT project. Environ Health 9(37):1–9
30. Founda D, Giannakopoulos C (2009) The exceptionally hot summer of 2007 in Athens, Greece—A typical summer in the future climate? Global Planet Change 67(3–4):227–236
31. Zvyagintsev AM, Blum OB, Glazkova AA, Kotel'nikov SN, Kuznetsova IN, Lapchenko VA, Lezina EA, Miller EA, Milyaev VA, Popikov AP (2011) Air pollution over European Russia and ukraine under the hot summer conditions of 2010. Izvestiya, Atmospheric Oceanic Physics 47(6):699–707