

# Heat waves in Central Europe during the period 1991-2006

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**Abstract** — The paper concerns the occurrence of heat waves in Central Europe. Data was collected from five regional weather stations in Budapest, Krakow, Lvov, Prague and Vienna and included records of the average, maximum and minimum daily air temperatures during the period 1991-2006. The authors defined a heat wave as an unbroken period of at least three days with a maximum temperature of more than 30°C. The study demonstrates that the greatest intensity of heat stress is observed during short heat waves that lasted typically for three to four days and whose timing did not coincide at the different stations involved. Indeed, even longer heat waves, characterised by lower temperature values, were not always recorded at all the stations. This was due to the division of the region by mountain ranges, which impeded the flow of hot tropical air into southern Poland and western Ukraine.

**Keywords** — Central Europe, heat waves, maximum temperature, minimum temperature, tropical nights

## 1 INTRODUCTION

Heat waves, just as other extreme weather events, have recently become increasingly frequent [1]. They not only result from a trend towards a rise in Earth surface temperature [2], but also from the variability in atmospheric circulation [3]. Longer spells of high temperatures may have an adverse impact on human health. Staying out in the sun during a heat wave is a known cause of an increased risk of stroke and heart attack and, as a consequence, of death. In 2003, an extreme heat wave that affected Southern and Western Europe contributed to the death of more than 35 thousand people in large metropolitan areas, primarily in France [4]. This type of extreme phenomena was recorded particularly frequently in the late 20<sup>th</sup> and early 21<sup>st</sup> century [1], [3]. Climatologists have been forecasting that frequency to grow [5], [6]. It seems therefore useful to investigate the topic to better understand this interesting, albeit dangerous phenomenon.

The objective of this paper is to describe the occurrence of heat waves in Central Europe during the period 1991-2006.

## 2 DATA AND METHODS

The paper employs daily average, maximum and minimum air temperatures recorded at five Central European stations in Budapest, Krakow, Lvov, Prague and Vienna during the period 1991-2006. The stations were selected on both sides of the Sudety and Carpathian Mountains, which should help assess the impact of this orographic barrier on

the occurrence of heat waves (Fig. 1). Of all the stations Prague is the furthest north, Budapest is the furthest south, Lvov is the highest (323 m) and Budapest the lowest (139 m).



Fig. 1. Location of the five weather stations included in the study

The meteorological data were downloaded from databases available at the websites of the American National Climatic Data Center (NCDC) [www.ncdc.noaa.gov](http://www.ncdc.noaa.gov) and of the European Climate Assessment & Dataset (ECA&D) [www.eca.knmi.nl](http://www.eca.knmi.nl) [10].

From a number of definitions of a heat wave available, e. g. [1], [7], the authors chose one which defines it as a period of at least three days during which the maximum air temperature is higher than 30°C. Similar criteria are used in many Central

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European countries [1], [7], [8]. Heat waves were identified at each of the weather stations and the study focused on characteristics associated with the frequency and thermal patterns, the latter based on the average maximum temperature. Average minimum and average temperatures are also available as additional characteristics [9].

### 3 RESULTS

The current trend in air temperature variability includes the unprecedented growth in recent years [10]. The growth rate is particularly strong in Western and Central Europe where the average increase in summer temperature is rated at 0.6°C per ten years (Fig. 2). In the late 20<sup>th</sup> and early 21<sup>st</sup> centuries, Europe experienced a number of anomalously hot summers. During the particularly hot summer of 1992, the temperatures over much of the continent were higher than the 1961-1990 average. An extremely high positive deviation was recorded in August, which reached 6°C in Central Europe (Fig. 3). That particular summer was also the warmest on record, i.e. since 1792, in Krakow [3].

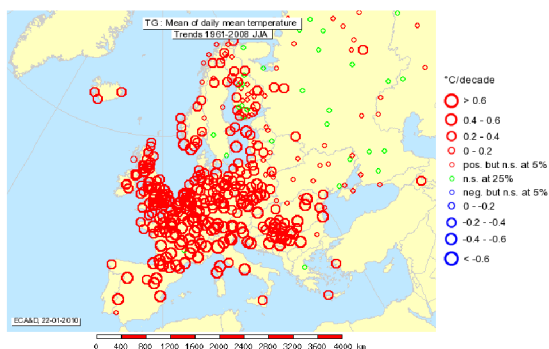


Fig. 2. Trends of mean summer temperature in the years 1961-2008 ([www.knmi.nl](http://www.knmi.nl))

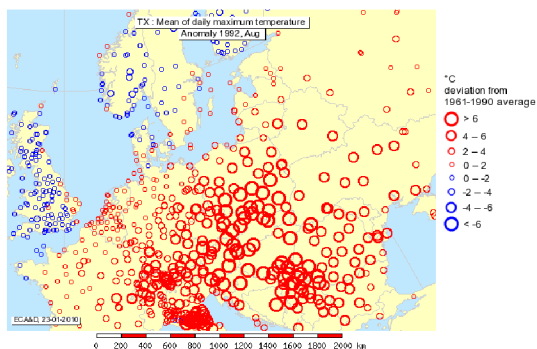


Fig. 3. Anomalous air temperatures in August 1992 as compared to the average of 1961-1990 ([www.knmi.nl](http://www.knmi.nl))

The number of heat waves during the study period, 1991-2006, varied considerably from station to station with the largest number of 59 occurring in

Budapest and the lowest number of 8 in Lvov (Tab. 1). This would suggest that their frequency diminished northwards: Vienna had two per year on average, Prague had 1.5 and Krakow - only one. Lvov had just one every two years.

The monthly number of heat waves is illustrated in Figure 4. Relevant events that straddled two months were included in the month when most of that spell took place. The heat wave season began in May and ended in August except in Lvov where it was limited to July and August. Prague was the only city where the largest number of heat waves was recorded in August (47% and 10 out of 21). In Budapest and Krakow they were most frequent in July, while in Lvov and Vienna the frequencies were equal in July and August.

Table 1. Number of heat waves at the five weather stations in Central Europe in 1991-2006

Years	Prague	Krakow	Lvov	Vienna	Budapest
1991	-	-	-	-	2
1992	2	3	2	4	4
1993	1	1	-	3	4
1994	3	1	2	2	3
1995	1	-	-	2	6
1996	-	1	-	1	1
1997	-	1	-	-	2
1998	1	1	1	3	4
1999	1	1	-	1	1
2000	1	1	1	3	5
2001	-	1	1	2	4
2002	-	-	-	1	4
2003	4	-	-	4	10
2004	2	-	-	2	2
2005	2	2	1	2	2
2006	3	2	-	4	5
Σ	21	15	8	34	59

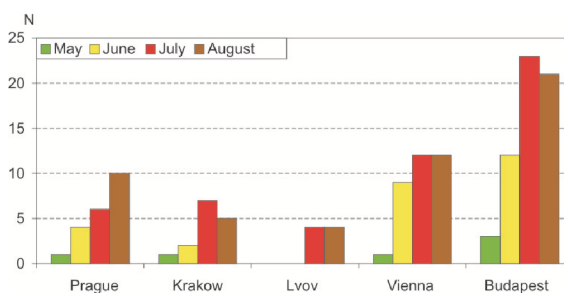


Fig. 4. Numbers of heat waves (N) in each month during the period 1991-2006

The earliest beginning of a heat wave season was recorded in Budapest, starting with heat waves lasting from 6<sup>th</sup> to 9<sup>th</sup> May in 2003. This year also saw the earliest onset of heat waves in Vienna (27

May) and in Krakow and Prague (28 May). In Lvov the earliest beginning of the season was 15-17 July (in 2001). The conclusion of the heat wave season showed more coincidence across the weather stations, as the dates fell on 30<sup>th</sup> and 31<sup>st</sup> August.

Budapest experienced heat waves in every year of the study period and the number peaked in 2003 with ten such spells (Tab. 1). Elsewhere there were years with more than one heat wave, as well as years without any. The year 2003 was particularly remarkable in this respect in Europe south of the Sudety and Carpathian Mountain orographic barrier and in nearly all of Western Europe [3]. In Prague heat waves were short in duration, between 3 and 4 days long. In Budapest and Vienna, in addition to several short hot spells, a longer heat wave occurred that lasted for more than ten days in mid-August. The year 1992 also had a large number of heat waves, 15 in total, and each station recorded at least two such periods, mostly in August. Most of the periods lasted between three and five days, but there was also an 11-day heat wave in Budapest. Lvov had the largest number of years without a heat wave [10]

The average duration of heat waves in the study area was 4.9 days. Prague had the shortest average of 4 days, while Budapest had the longest average of 5.3 days (Tab. 2).

Table 2. Number of heat waves of certain duration at the five weather stations in Central Europe in 1991-2006

Duration (in days)	Prague	Krakow	Lvov	Vienna	Budapest
3	13	7	4	13	26
4	5	5	3	9	8
5	1	0	-	5	6
6	-	1	-	3	5
7	-	-	-	-	4
8	-	-	-	-	2
9	-	1	1	-	-
10	1	-	-	-	2
11	1	1	-	2	3
12	-	-	-	-	1
13	-	-	-	1	-
14	-	-	-	-	-
15	-	-	-	-	1
16	-	-	-	-	-
17	-	-	-	1	-
18	-	-	-	-	1
Av.	4.0	4.5	4.4	5.0	5.3

The shortest heat waves, defined at three days long, were the most frequent and accounted for 45% of all heat waves. The next most frequent category of heat wave was four days, a category that constituted only 22% of the total events. Heat waves occurred the earliest in Vienna and Budapest, one day ahead of Prague. Krakow and Lvov came only

two to three days later. The end of the heat wave season followed a similar sequence.

The longest heat wave during the study period occurred in Budapest and lasted for 18 days between 22<sup>th</sup> July and 8<sup>th</sup> August 1994. This coincided with the longest hot spells in Vienna (17 days between 23<sup>th</sup> July and 8<sup>th</sup> August) and Lvov (nine days between 26<sup>th</sup> July and 3<sup>th</sup> August). Krakow and Prague experienced their longest heat waves of 11 days in July 2006.

An analysis of maximum temperatures recorded during each heat wave has shown that the highest maximum temperatures occurred typically during short spells, but the average temperatures were similar both for different durations and at all stations (Tab. 3).

Table 3. Average maximum temperatures of heat waves of varied durations at the five weather stations in Central Europe in 1991-2006

Duration (in days)	Prague	Krakow	Lvov	Vienna	Budapest
3	32.3	32.1	31.9	32.2	32.1
4	32.3	32.8	31.7	32.4	32.1
5	33.0	-	-	33.5	32.7
6	-	30.5	-	31.9	33.8
7	-	-	-	-	33.2
8	-	-	-	-	32.2
9	-	32.7	31.9	-	-
10	34.2	-	-	-	32.2
11	33.3	32.3	-	33.4	33.2
12	-	-	-	-	34.3
13	-	-	-	33.1	-
14	-	-	-	-	-
15	-	-	-	-	33.4
16	-	-	-	-	-
17	-	-	-	33.3	-
18	-	-	-	-	33.5
Av.	32.5	32.3	31.8	32.5	32.5

There were a number of heat waves during the study period that were recorded at all five weather stations. An example of these was a hot spell that started in late July and ended in early August 1994 and was one of the longest in the study period (Fig. 5). It began in Budapest (on 22<sup>nd</sup>), swept to Prague and Vienna one day later before it reached Krakow (25<sup>th</sup>) and Lvov (26<sup>th</sup>). In Budapest and Vienna the heat wave lasted until 8<sup>th</sup> August. While this was one of the longest heat waves experienced in Central Europe, it did not reach the highest average maximum temperatures (Tab. 3). The worst biothermic conditions were recorded in Vienna as the heat stress was exacerbated by very high night-time (minimum) temperatures of more than 20°C. Nights with minimum temperatures this high are classified as tropical nights.

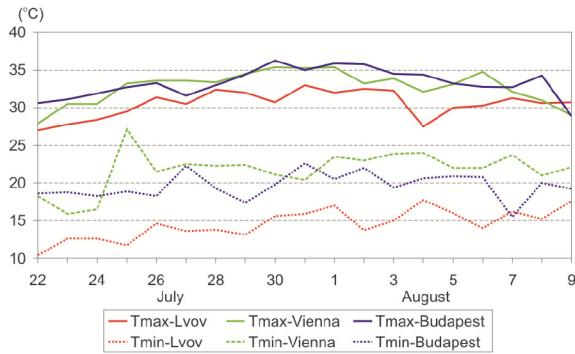


Fig. 5. Variation of maximum and minimum air temperatures between 22<sup>th</sup> July and 9<sup>th</sup> August 1994 in Lvov, Vienna and Budapest

In Krakow and Prague the longest heat spells were also recorded in the second half of July 2006. In Krakow the heat wave lasted from 18<sup>th</sup> to 28<sup>th</sup> July and in Prague it started and ended one day later. Both were among the hottest periods with average maximum temperatures of 32.3°C in Krakow and 33.3°C in Prague (Tab. 3). The levels of heat stress were mostly limited to daytime, as night-time temperatures remained below 20°C (Fig. 6).

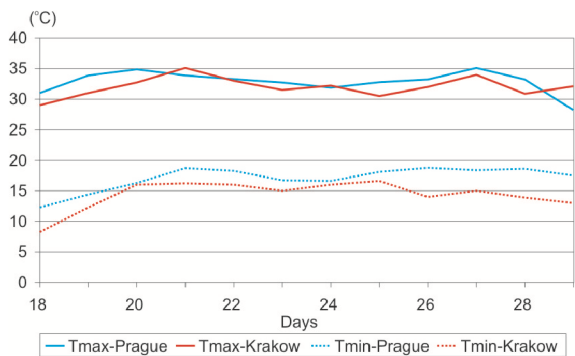


Fig. 6. Variation of maximum and minimum air temperatures between 18<sup>th</sup> and 29<sup>th</sup> July 2006 in Prague and Krakow

A sizeable body of research is available about the enormous heat wave that engulfed Western Europe in August 2003 and contributed to the death of thousands of people in France and the UK [2], [3], [12]. It is therefore interesting to see what temperatures were experienced in Central Europe at the same time. Was the deadly heat wave equally as intense? An answer can be obtained by analysing the maximum temperature data depicted on Figure 7. The August heat wave reached three of the five weather stations in the study. In Budapest, Prague and Vienna the hot air masses persisted throughout the first half of August and the maximum temperatures typically exceeded 30°C. There were particularly high temperatures on 13<sup>th</sup> and 14<sup>th</sup> August 2003 when the maximum temperature reached 40°C. This coincided with the peak maximum temperature in many Western European cities [3]. The following two days brought a

temporary respite, as the maximum temperature dropped to 25-28°C. After that, the hot spell in Budapest and Vienna continued into the second half of August, but it eased up in Prague, where the maximum temperature exceeded 30°C only once. Krakow and Lvov recorded no heat waves during that time. This means that the hot air masses that advanced from the south stopped at the arc of the Carpathian Mountains sparing Poland and the Ukraine. Indeed, there were only three days when the maximum temperature exceeded 30°C in Krakow and one day in Lvov (29 August). In Central Europe the impact of the heat wave on human health was significantly weaker than in Western Europe where the overall heat stress levels were exacerbated by very high night-time temperatures [3], which resulted in a particularly high increase of mortality.

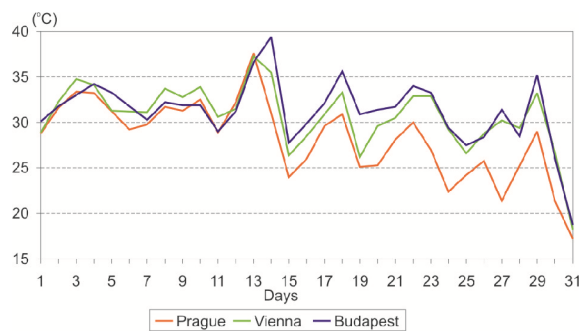


Fig. 7. Variation of maximum air temperatures in August 2003 in Prague, Vienna and Budapest

#### 4 DISCUSSION

Heat waves are among those adverse biothermic situations during which sickness and mortality rates seem to be increasing, particularly in big cities. In such large metropolitan areas the overall impact of heat stress is exacerbated by air pollution, including growing concentrations of tropospheric ozone and falling concentrations of oxygen.

Heat wave research in Central Europe shows that while the temperatures can be very high, their duration tends to be relatively short. For this reason the scale of catastrophic biometeorological effects known from the Western European metropolises in August 2003 have not been confirmed in this region so far. Indeed, while the number of deaths in Paris on 13<sup>th</sup> August 2003 exceeded the daily average by a factor of six [3]. Central European records show no more than two times the average mortality rates in large cities according to [7]. It can be said that a direct threat to life due to high air temperatures is in general more likely in the south of Europe, while in Central Europe adverse biometeorological effects tend to be linked to extreme cold rather than heat [13]. The winter of 2009/2010 can serve as an example when dozens of people died due to very low temperatures reaching -30°C.

The Sudety and Carpathian mountain ranges

influence the spatial distribution and intensity of heat waves in Central Europe. There have been many instances when these mountains have constituted an effective barrier to the spread of hot air masses arriving from the south. The heat wave of August 2003 provides an example of this effect.

## 5 CONCLUSIONS

In Central Europe there is great variability in the number of heat waves per year, in their duration, timing and intensity, all of which are influenced by land relief and the pattern of mountain ranges.

The most intense heat waves tend to be short, typically three or four days long, and to occur in July or August. They also mostly do not coincide with those recorded at other weather stations. Only Krakow and Vienna had their respective most intense heat waves at the same time (end of August 1992). At the other stations the most intense heat waves occurred at different times. (In Budapest in mid August 2003, in Lvov in August 2000 and in Prague in late July 2005.)

Long hot spells can last up to 18 days, but typically feature lower levels of thermal stress than short spells and are not always recorded at all the stations. Heat waves of such duration tend to be linked to tropical air masses moving from the south and encountering the longitudinal mountain ranges that in most cases prevent them from reaching Poland and western Ukraine.

There is a greater variability in the onset of heat waves than in the timing of their conclusion. No dependence has been found between the duration and the average maximum temperature during a heat wave.

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