An analysis of the July 2006 heatwave extent in Europe compared to the record year of 2003

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With 3 Figures

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Summary

Recent analyses have identified summer warming trends in Europe in recent decades, culminating in 2003, when mean summer temperatures were exceptionally hot over much of Europe. Mean monthly temperatures were very high in July 2003 and reached record levels in both June and August. In 2006, the mean monthly temperature for July reached a record high. Our analysis of temperature observations shows that in July 2006, as in summer 2003, maximum temperatures were more abnormal than minimum values. The 2006 heatwave was located more to the north than in 2003, and particularly affected the Netherlands, Belgium, Germany, Poland, France and Switzerland. The July 2006 anomalies were similar in magnitude to those of June and August 2003, but the discrepancy between minimum and maximum temperature anomalies was larger in 2006 compared to both June and August 2003. For maximum temperature, the affected land area by anomalies higher than 4–6K was largest in July 2006, although the anomalies were higher in June and August 2003 at the most anomalous sites. In the north of Europe, the absolute monthly temperature values were higher in July 2006 compared to both June (also on the Iberian Peninsula) and August 2003.

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1. Introduction

More hot days and high-temperature events are expected over nearly all land areas as a consequence of anthropogenic climate change (e.g., Easterling et al. 2000a, b, c; Barnett 2001; IPCC 2001; Sparks et al. 2002; Bell et al. 2004; Rebetez 2004; Schaer et al. 2004; Stott et al. 2004; IPCC 2007). Extreme events could potentially have an enormous impact on the economy, on human health, and on environmental sustainability. Abrupt changes in the frequency, location or intensity of extreme meteorological events (floods, drought and storms, etc.) have direct and severe effects on ecosystems and society, resulting in social and economic costs (e.g., Meehl et al. 2000; Parmesan et al. 2000; Murnane 2004; Vescovi et al. 2005). The need to plan for the effects of climate change is becoming urgent for decision-makers (Smoyer 1998; Kunkel et al. 1999; IPCC 2002; Schnur 2002; Menne et al. 2003; De et al. 2004; Haines and Patz 2004; McMichael and Woodruff 2004; McMichel et al. 2004; Stephenson 2004; Kovats and Haines 2005; IPCC 2007). Climate synopses and analyses of recent events could provide us with valuable knowledge about climate change directly relevant to decision-makers.

An unprecedented heatwave affected large parts of the European continent in summer 2003 (Fink et al. 2004; Luterbacher et al. 2004; Rebetez 2004; Schaer et al. 2004; Trigo et al.2005; Rebetez et al. 2006; Della-Marta et al. 2007b). Summer 2003 was the hottest since at least 1500 in Switzerland (Luterbacher et al. 2004) and at least 1761 in Germany (Schönwiese et al. 2004). More generally, recent analyses show that over the period 1880–2005, the frequency of hot days has almost tripled over western Europe (Della-Marta et al. 2007a). Analyses of the temperatures in summer 2003 have shown that the record-breaking values were mainly due to extremely hot maximum temperatures in June and August (Rebetez et al. 2006). The heatwave was centred over France, Germany and Switzerland. In July 2003, contrary to June and August, temperatures were above normal, but not record-breaking, even at the most anomalous sites (Schaer et al. 2004; Rebetez et al. 2006). As mean July temperatures were extremely high in 2006, we analyzed maximum, minimum and mean monthly anomalies over Europe. We compared our results with monthly data from June and August 2003 in order to better understand the heatwave of July 2006. We compared the spatial extent of the anomalies above three temperature thresholds in order to show the differences between June 2003, August 2003 and July 2006 on one hand and the differences between the anomalies for mean, minimum and maximum temperature on the other. We expect the results to contribute to a better understanding of these heatwaves in the context of climate change.

2. Data and methods

We used mean, minimum and maximum monthly surface air temperature data over Europe provided by Meteo-France and MeteoSwiss. We elaborated anomaly data based on a 1961–1990 reference period. We mapped monthly mean, minimum and maximum air temperature anomalies and compared the continental areas concerned by anomalies reaching three thresholds (4/5/6 K) in June 2003, August 2003 and July 2006. We also mapped the absolute temperature differences between July 2006 on one hand, and June and August 2003 on the other.

Temperature data originated from CLIMAT codes except for France and Switzerland. CLIMAT codes are part of the basic data sets and products supporting WMO programs and which members exchange free of charge and free of rights. French and Swiss data originated from synoptic surface stations, so that extra data were available compared to CLIMAT codes only. Quality control issues were applied systematically.

Data were selected from a domain 5° larger on every side than the final mapped area in order to keep a high spatial quality on the map edges. The monthly data was systematically checked for significance over the investigated area.

Temperature data were gridded for the whole data selection zone using Point Kriging. A 25-class isotropic experimental variogram was created, then a linear variogram model was chosen and fitted to the experimental variogram curve. The grid spacing value was set to 0.1°. Duplicate data were defined by setting an X and Y tolerance to 0.02°. Only the point with the median Z value was kept for each set of duplicates.

Original monthly data and mean monthly values computed from minimum and maximum temperature data were first mapped and analyzed separately to detect visibly aberrant data. This led us to eliminate a few rare meteorological stations showing doubtful measurement quality. The final maps were established by again kriging monthly and mean monthly temperatures separately, this time only considering the stations accepted for the analysis.

3. Results

Compared to 2003, the heatwave of July 2006 was centred more to the north, over Germany, Belgium and the Netherlands (Fig. 1). The most extreme anomalies were lower in July 2006 compared to June (minimum and maximum temperature) and August (maximum temperature) 2003. Maximum temperature anomaly values above 8 K were measured in France in August 2003 and in France, Switzerland, Southern Germany and central Italy in June 2003. Mean temperature anomaly values above 6 K were measured in France and Switzerland in June 2003 and in Germany in July 2006. Minimum temperature anomaly values above 6 K were measured in France, Switzerland and Italy in June 2003.

Comparing the extent of the areas with anomalies above 3 different thresholds reveals that in July 2006, the mean monthly maximum temperatures were more than 6 K above longterm average values over 686,000 km2 and an area of 2,210,000 km2 was affected by maximum temperature anomalies higher than 4 K (Table 1). For the same temperature thresholds, the anomalies concerned smaller areas for minimum and mean temperature. The areas affected by the three threshold anomalies for maximum temperatures were largest in July 2006 compared to June or August 2003 (Table 1 and Fig. 1). For minimum temperatures, the areas affected were

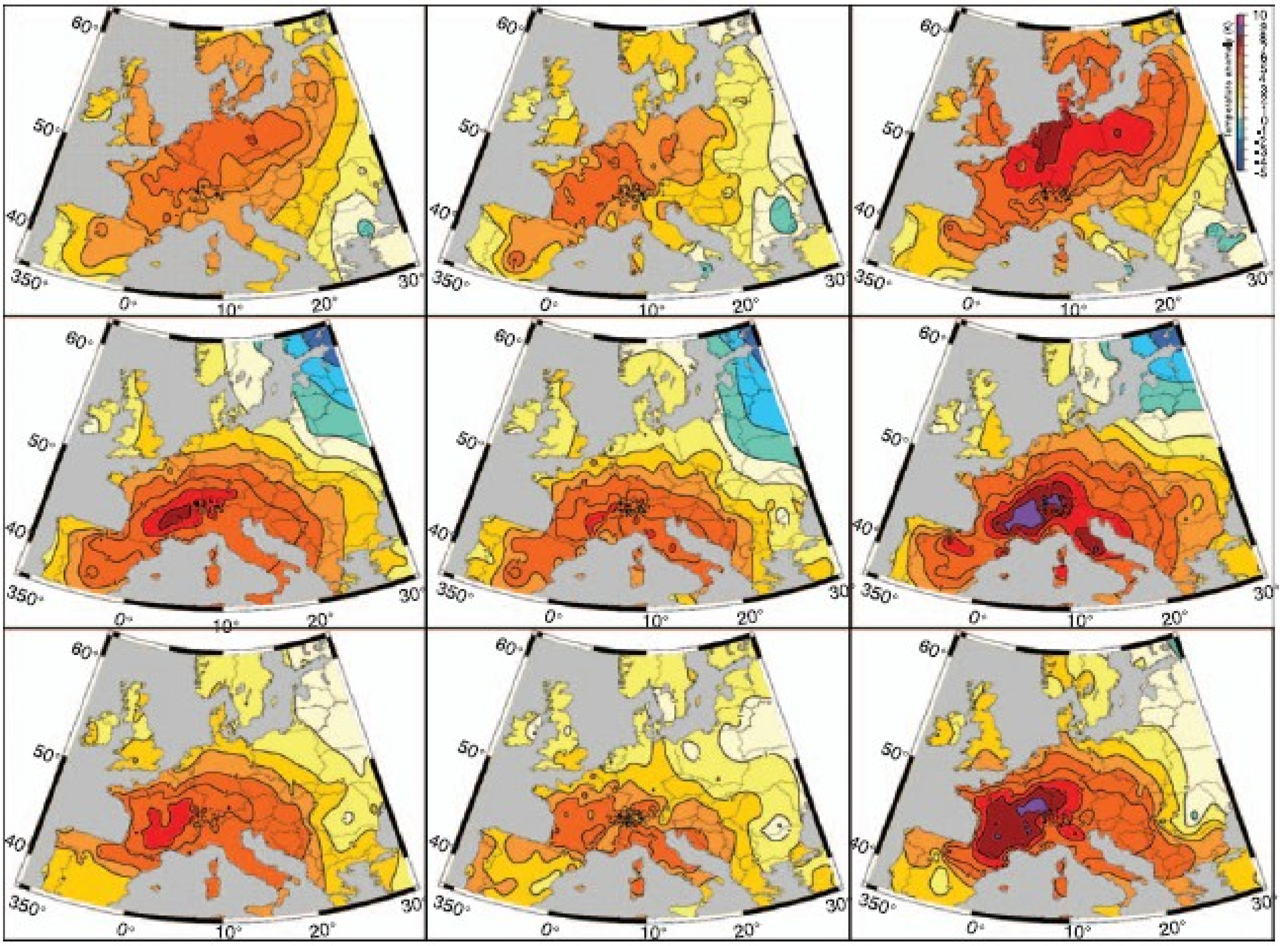

Fig. 1. Surface air temperature anomalies in July 2006 (top), June 2003 (middle) and August 2003 (bottom): mean (left), minimum (middle) and maximum (right) surface air temperature

largest in June 2003 and second largest in August 2003. For mean temperatures, the areas were largest in June 2003, second largest in July 2006 for the 5 K threshold and in August 2003 for the 6 K and 4 K thresholds.

Table 1. European continental areas [km^2] where the specified temperature anomaly thresholds (compared to the 1961–1990 CLINO values) are exceeded in selected summer months

Maximum temperature	>4 K	>5 K	>6 K
July 06	2.21×10^6	1.37×10^6	6.86×10^5
June 03	1.95×10^6	1.28×10^6	6.41×10^5
August 03	1.77×10^6	1.20×10^6	5.89×10^5
Minimum temperature	>4 K	>5 K	>6 K
July 06	4.66×10^5	9.27×10^3	0.00
June 03	1.14×10^6	4.04×10^5	4.67×10^4
August 03	5.52×10^5	6.18×10^4	0.00
Mean temperature	>4 K	>5 K	>6 K
July 06	1.36×10^6	6.45×10^5	5.38×10^3
June 03	1.63×10^6	8.95×10^5	2.32×10^5
August 03	1.37×10^6	5.29×10^5	1.46×10^5

Comparing minimum and maximum temperatures for each month shows that the greatest anomalies were always reached for maximum temperatures, with lesser anomalies occurring for minimum temperature values (Fig. 1 and Table 1). The discrepancy between minimum and maximum temperature anomalies was larger in 2006 compared to both June and August 2003 (Table 1).

Considering the absolute air temperature values, July 2006 was hotter than June 2003 north of 45 N, as well as on the Iberian Peninsula and Western France (Fig. 2). This feature was more pronounced for maximum than for minimum temperature. July 2006 was also hotter than August 2003 over North-European lands north of 50 N. Differences were stronger for June than for August, and for maximum than for minimum temperature. The 2006 heatwave was clearly located more to the north than in summer 2003. Regions such as Northern France, Germany, Belgium, and the Czech Republic, which were strongly affected by the 2003 heatwave, were affected by an even more extreme heatwave in July 2006, in terms of absolute mean monthly values.

The statistical distribution of monthly July temperature values in France (Fig. 3) shows that July 2006 was by far the hottest month of July for both minimum and maximum temperature. The variability is higher for maximum than for minimum temperature. In Switzerland, July 2006 was also by far the hottest month of July ever measured. Both minimum and maximum temperature distributions have a positive asymmetry coefficient.

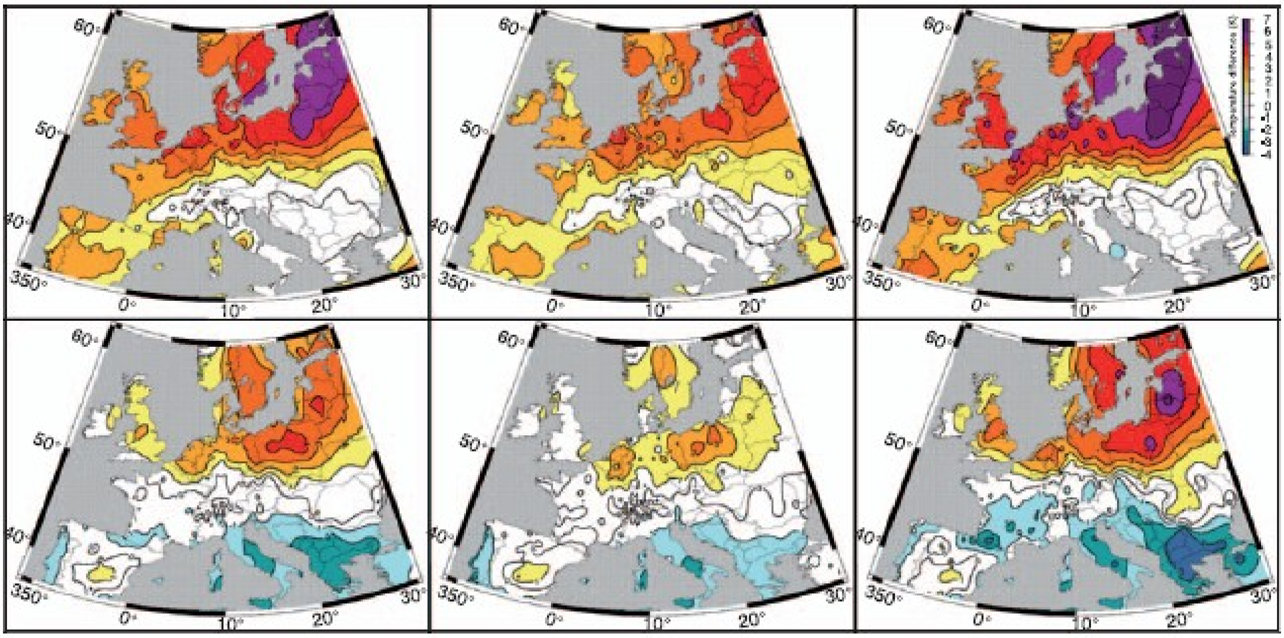

Fig. 2. Differences between July 2006 and June 2003 (top)/August 2003 (bottom) average (left), minimum (middle) and maximum (right) surface air temperature

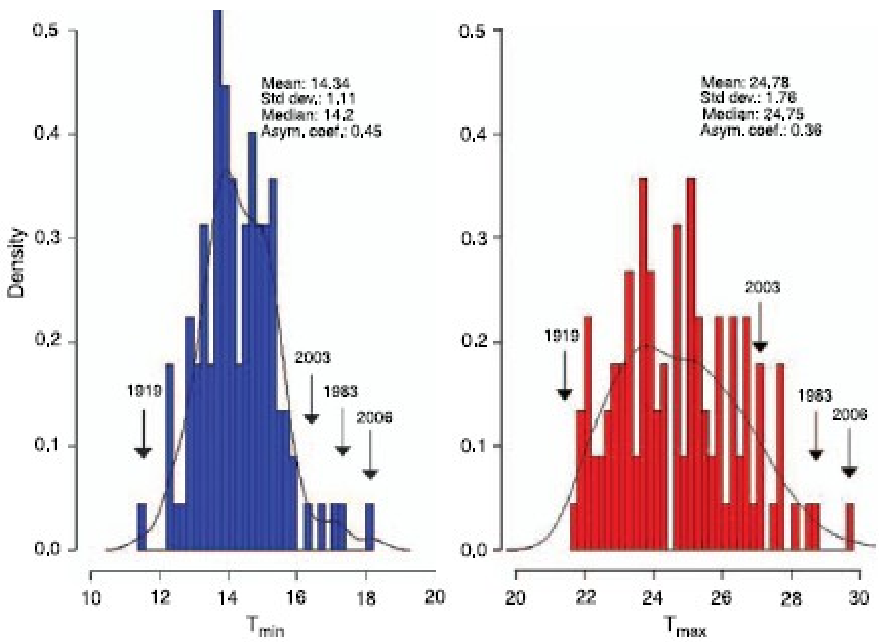

Fig. 3. Statistical distribution of minimum (left) and maximum (right) July monthly surface air temperatures 1895–2006 in France (60–68 stations). Only stations below 500 m asl were used

4. Discussion

In July 2006, the heat was linked to persistent anticyclonic situations favouring the advection of dry air masses. A ridge extended at the 500 hPa level, from Spain to Denmark, during most of the month (1st–5th July, 10th–27th July) causing an Omega blocking situation (15th–27th July), which forced the jet-stream to flow well north of Scotland. On July 27th, the westerlies resumed, bringing a frontal zone across Western Europe.

In summer 2003, anticyclonic weather types also dominated over Central Europe, especially in spring and summer (Black et al. 2004; Fink et al. 2004; Schaer et al. 2004). A large-scale anticyclonic forcing cannot alone explain extreme surface air temperature values as several factors such as heat advection, radiation, cloud cover, moist convection and other processes can vary between different periods of the same anticyclonic weather type. However the prevalence of anticyclonic weather leads to a lack of soil moisture, which generally favours high temperatures by enhancing the surface sensible heat flux and substantially reducing the surface latent heat flux. This process may be amplified by a positive feedback between soil moisture and precipitation during heatwaves (Seneviratne et al. 2006; Della-Marta et al. 2007B; Fischer et al. 2007). In conjunction with these drought conditions, a high level of radiation is expected to increase maximum temperatures. North-Eastern France, for example, experienced record-breaking sunshine hours in June 2003, was very sunny, although not record-breaking, in July 2003, and had the largest record-breaking number of sunshine hours in August 2003 (Rebetez et al. 2006). In July 2006, new recordbreaking sunshine durations were measured at all stations located in North-Eastern France. For the three months studied here, the anomalies are clearly larger for maximum than for minimum temperature. The discrepancy between minimum and maximum temperature anomalies was even larger in 2006 compared to both June and August 2003. For the future, results of climate models suggest that temperature variability should be increasing for summer temperatures in a warmer climate due to the impact of lower soil humidity (Schaer et al. 2004; Seneviratne et al. 2006).

The statistical distribution of monthly July temperatures (Fig. 2) shows that although only the north-eastern part of the French territory was most affected by the 2006 anomalies, July 2006 was by far the hottest month for both minimum and maximum temperature. The variability is clearly higher for maximum temperature than for minimum temperature, but the positive asymmetry coefficient of the distribution shows that the variability of the warmer part of the series is higher than that of the colder part for both minimum and maximum temperature.

5. Conclusions

In July 2006, as in June and August 2003, mean temperature anomalies reached more than 6K over large parts of Europe. Most anomalous for all 3 months were maximum temperatures, based on the affected areas, as well as on the absolute values of the anomalies. Considering the areas affected by the maximum temperature anomalies, July 2006 was the most anomalously hot summer month ever measured in Europe: 686,000 km2 were affected by a maximum temperature anomaly above 6 K and 2.21 million km^2 by an anomaly above 4 K. Considering the monthly anomalies, June and August 2003 were more extreme, but based on monthly absolute temperature values, our results show that for the regions affected by the 2003 and 2006 heatwaves, more severe temperature conditions occurred in July 2006 in the north of Europe.

It is likely that the higher anomalies measured in our three case studies for maximum temperature as compared to minimum temperature were due to particularly low values in soil humidity, hampering a cooling of the ground by evaporation. The extremely high values reached in 2006 after the exceptional summer 2003 should be understood as one more sign indicating that an increase in temperature variability could lead to particularly hot summer temperatures, as maximum temperatures during heatwaves will tend to be hotter than expected. In a warmer climate, heatwaves will probably be more extreme than expected, particularly during daytime, due to increasing summer temperature variability.

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