How exceptional was the early August 2003 heatwave in France?

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[1] The summer of 2003 was characterised by exceptionally warm weather in Europe with the average temperature exceeding that of any previous summer over the last 500 years. The seasonal 2003 summer temperature for central Europe was beyond the historical distribution range and could bear a closer resemblance with climate change scenarios for late XXI century. Nevertheless, it was the heatwave that occurred between the 1st and the 15th of August 2003 that had a major impact in excessive mortality rates throughout Europe, with catastrophic amplitude in France. Here we show, on a daily basis, when and where the magnitude and spatial extent of this heatwave episode has surpassed previous historical maxima, and that this episode is associated with an equally maximum blocking pattern over western Europe. Finally we show that surface and low troposphere air temperature anomalies are particularly well associated with the increased mortality rates in France. **Citation:** Trigo, R. M., R. García-Herrera, J. Díaz, I. F. Trigo, and M. A. Valente (2005), How exceptional was the early August 2003 heatwave in France?, *Geophys. Res. Lett.*, *32*, L10701, doi:10.1029/2005GL022410.

1. Introduction

[2] The summer of 2003 has been recently classified as the warmest summer in Europe over the last 500 years [*Luterbacher et al.*, 2004]. In particular, monthly and seasonal average temperatures for central Europe reached values beyond the historical distribution range [*Schär et al.*, 2004] and could bear a closer resemblance with climate change scenarios for late XXI century [*Stott et al.*, 2004]. However, it was the relatively short-lived heatwave that occurred during the first fortnight of August 2003 that had a major impact on excessive mortality rates throughout western Europe, particularly over certain regions of France [*Grynszpan*, 2004; *Valleron and Boumendil*, 2004]. Therefore, unlike most previous works, we will focus on the European summer 2003 heatwave (hereafter EH03) from a sub-monthly perspective.

[3] Reports by the World Health Organization [*World Health Organization* (*WHO*), 2004], based on national health authorities inquests, suggest that an additional 30,000 deaths can be associated to the unrelenting heat registered in the EH03. France has suffered the largest burden of this public health catastrophe with approximately an additional 15.000 deaths, but Germany (~5.000), Italy (~3.000), Spain (~6.000), Holland (~1.500), Portugal (~2.000) and the United Kingdom (~2.000) have also contributed decisively to the total figure [*Grynszpan*, 2004; *WHO*, 2004; *Institut de Veille Sanitaire* (*InVS*), 2003]. There is not a unique definition of what can be regarded as a heatwave episode, although these events cannot be considered a rare phenomena. In particular, Europe has suffered, in recent decades, intense heatwave episodes such as those occurred in France in 1976, Portugal in 1981, Greece in 1987 and the UK in 1995, and readers looking for a more complete review are referred to *InVS* [2003].

[4] The vast majority of deaths in France correspond to elderly people with people older than 75 years accounting for more than 80% of the total excessive mortality [*InVS*, 2003; *Valleron and Boumendil*, 2004]. Previous studies for South-western Europe show that, under these circumstances, mortality is mostly due to maximum daily temperature, with minimum temperature and air pollutants such as ozone playing a minor role [*Díaz et al.*, 2002; *García-Herrera et al.*, 2005]. However, in the case of EH03 the very high values of night time minimum temperatures have probably amplified the impact of the EH03 on mortality, particularly in the Metropolitan area of Paris [*Valleron and Boumendil*, 2004]. Additionally, the impact of extreme summer temperatures occurs almost immediately, being maximum after 1–2 days [*Díaz et al.*, 2002; *García-Herrera et al.*, 2005], a pattern also observed in France during the EH03 event [*InVS*, 2003].

[5] Here we analyze the temporal and spatial evolution of the EH03 at the sub-monthly scale. We then assess those periods and regions when this heatwave episode has surpassed previous historical maxima stressing the link with the excessive mortality rates in France.

2. Associated Synoptic Patterns

[6] Meteorological large-scale variables used here were extracted from NCEP/NCAR Reanalyses [*Kistler et al.*, 2001] for the 1958–2003 period. In order to characterize the thermal structure of EH03 we used the 850 hPa temperature field, since it is sufficiently near the surface to be representative of the low troposphere state, and it does not suffer some of the problems that affect reanalysis variables near surface [*Ogi et al.*, 2005; *García-Herrera et al.*, 2005]. The composites of the 850 hPa temperature and 500 hPa geopotential height for the 1–15 August period show the usual pattern of summer heatwaves for south-

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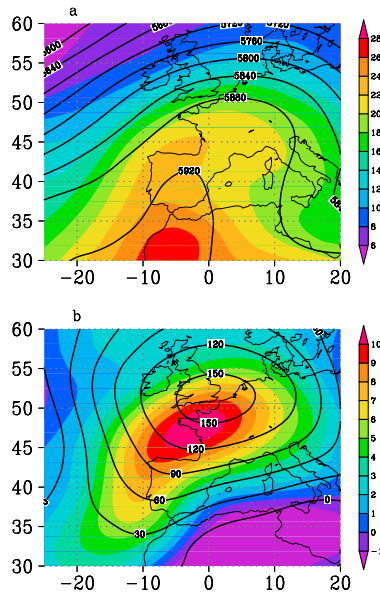[5]Instituto de Meteorologia, Lisbon, Portugal.

Figure 1. (a) Air temperature (shaded, °C) at 850 hPa height and 500 hPa geopotential height (contour, gpm), for the period 1–15 August 2003 composite and (b) respective anomalies. Anomalies have been computed with respect to the daily average values of the 1958–2002 period.

western Europe (Figure 1a). These are usually characterized by the appearance of strong ridges over the Iberian Peninsula and France [*García-Herrera et al.*, 2005]. These two variables are commonly employed to characterize blocking events [*Ogi et al.*, 2005]. The temperature and geopotential anomalies with respect to the corresponding 15-day climatology (Figure 1b) further emphasize the amplitude of this extreme event. It should be stressed that we have computed anomalies using a daily climatology, *i.e.* the average for the 1st of June is obtained by averaging the 45 fields corresponding to all 1st of June observed between 1958 and 2002. All anomalies presented in Figures 1b and 2 were computed removing only the corresponding 15-day climatology (not the entire summer). The anomalous atmospheric

circulation is dominated by an intense blocking pattern in the mid-troposphere, with strong meridional air-flow components. Blocking episodes are known to induce important climate anomalies on the week-to-month time scale in both winter and summer [*Xoplaki et al.*, 2003]. The corresponding low-tropospheric air temperature anomaly field (Figure 1b) shows a maximum located over north-western France (>10°C), but with high anomaly values (>7°C) extending well into northern Spain and Portugal, southern England, Belgium, Holland, Germany and Switzerland.

[7] The 500 hPa geopotential height anomaly field is dominated by a conspicuous positive anomaly maximum (>150 gpm) centered between northern France and southern England (Figure 1b). This large-scale feature not only impedes the natural eastward progression of low pressure systems that frequently cross northern European countries in the summer but contributes to the advection of warm air masses in its southern branch. Exceptionally strong anticyclonic blocking patterns can typically induce subsiding movements that can further heat the surface layers through enhanced adiabatic heating [*Xoplaki et al.*, 2003]. Furthermore, the long clear sky periods associated with the blocking condition described above contribute to enhanced solar radiative heating over the region [*García-Herrera et al.*, 2005]. Some authors have stressed the decisive role played by this type of blocking pattern to attain the observed high temperature values, nevertheless this was done on a monthly scale [e.g., *Beniston and Diaz*, 2004].

3. Historical Maxima

[8] To analyse the EH03 spatial and temporal evolution 1) we compute 15 day (15d) averages for the entire available period of 45 summers (1958–2002) allowing superposition, i.e. first for the period 1–15 of June of 1958, then 2–16 of June and so on, until the last period 16–30 of September 1958, 2) thus we obtain 5310 (118×45) cases for the entire 45 year period, 3) the maximum 15d average is computed for each grid-point. It should be stressed that for each individual grid-point the
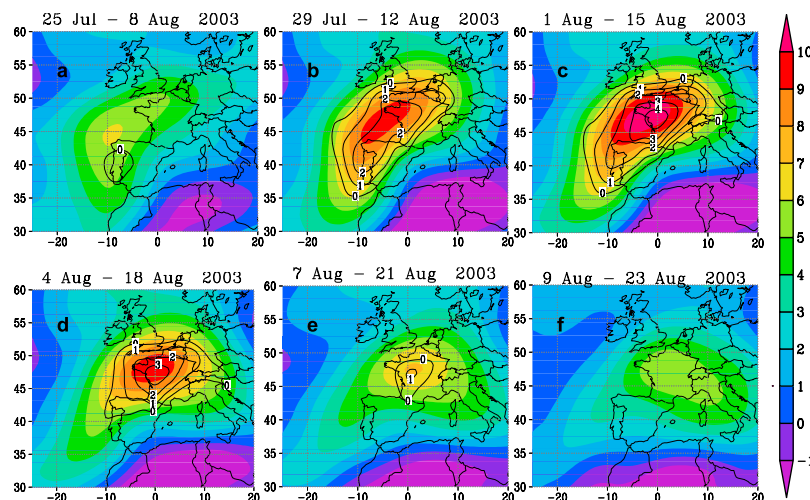

Figure 2. (a–f) Sequential presentation of 850 hPa air temperature anomalies (°C) for the 15d periods indicated on the top of each panel. Regions with 15d average above the historical 15d maximum are represented by solid contours (°C).

historical 15d maximum average could have happened during a different heatwave than the maximum observed for neighboring grid-points. Finally, we have obtained 118 anomaly fields of all 15d periods for the summer 2003, however, only a representative subset of six 15d anomalies is shown in Figure 2. Again, T850 anomalies (color) were computed between the 15d averages for 2003 and the corresponding 15d climatology. If the 15d average for a particular region falls above the historical 15d maximum average, then the exceeding temperature difference above that 45-year historical maximum is also plotted (contour). This sequential presentation allows for a proper evaluation of the time evolution of the low troposphere temperature anomalies, and more important, to flag those regions where 15d historical maxima were broken. Between the beginning of June and mid-July the highest 15d anomalies were observed over the Mediterranean basin (not shown). Before the 15d period starting on the 24th of July 2003 no 15d field showed averaged T850 above the historical maximum over Europe. The first time such condition is fulfilled is over western Iberia (Portugal) for the 15d period between the 25th of July and the 8th of August (region inside the zero contour line in Figure 2a). The maximum anomalies for that period (>6°C), located over the north-western corner of Iberia, are not found to be above the historical maximum. Four days later (15d period between the 29th July and 12th August) the T850 anomaly deepens considerably, with a core sector (>9°C) stretching between north-western Spain and north-western France; the anomalies above the historical maximum extend further between southern Portugal and western Germany (Figure 2b). Three days later (between the 1st and the 15th of August) the area with new historical maxima is very similar (Figure 2c). However, the amplitude of the T850 anomaly reaches the summer 2003 maximum value over northern France (>10°C), where the historical maximum is exceeded by more than 4°C. The spatial extent and the magnitude of this new 15d historical maximum temperature reflects the exceptional amplitude of this event, and it also confirms that the peak of the heatwave occurred during the first two weeks of August. Then, gradually, the intensity of the heatwave diminishes (Figures 2d and 2e) and, after the 9th of August, no 15d period presents any grid-points with average temperatures above the historical maximum (Figure 2f). The same methodology was applied to shorter time windows (e.g. 7days, 10days) with similar results (not shown), *i.e.* historical maximum values are firstly surpassed over Iberia and then move gradually into northern France where they attain the largest amplitude.

[9] This temperature pattern can also be seen when analyzing surface anomalies, those with an actual impact on human health. Maximum temperature data for 228 stations covering the entire continental French territory were obtained from Météo-France. These correspond to daily values between the 1st and 15th of August 2003 and to monthly (August) averages for the 1971–2000 period. If we analyze the spatial distribution of excessive deaths in France, between the 1st and 15th of August 2003 (by comparison with the average 2000–2002), there is a remarkable concentration of higher values in the northern half of the country, with the maximum axis presenting a SW-NE orientation, that includes the larger Parisian region (Figure 3a). Although not
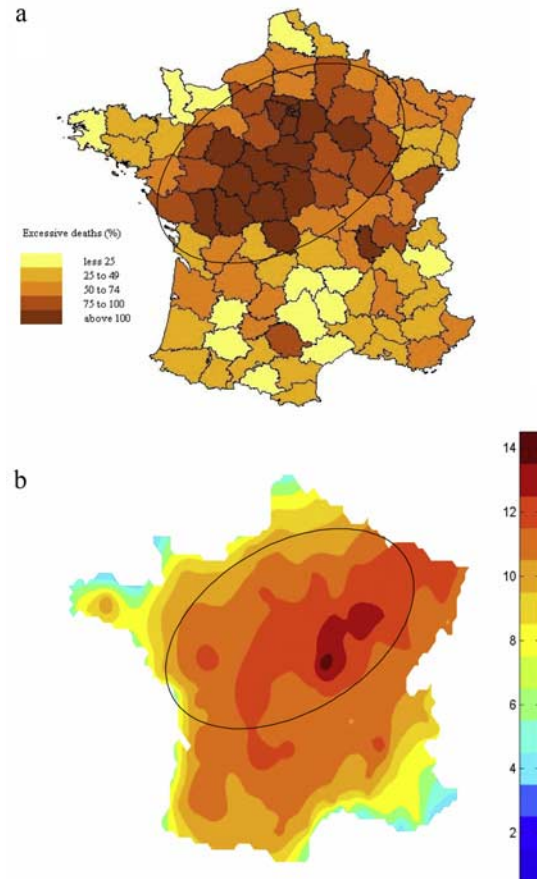

Figure 3. (a) Excessive mortality (%) per French *Department* for the period 1–15 August 2003 by comparison with the average 2000–2002 (adapted from *Institut de Veille Sanitaire* [2003]). (b) T_max anomaly (°C) for the same period, after subtracting the 1971–2000 mean from the 2003 values.

shown, the corresponding average T_{max} distribution reveals a different pattern, with higher values in the southern ends, near the Mediterranean coast and the Pyrenees, i.e. a spatial distribution not consistent with those areas where excessive deaths have increased by more than 100%. However, the corresponding T_{max} anomaly pattern (after subtracting the August average) exhibits a much closer picture, with the highest T_{max} anomalies and excessive mortality rates enclosed by the SW-NE oriented ellipsoid (Figure 3b). This is attributable to the preeminent role played by T_{max} anomaly on mortality, instead of the absolute T_{max} values. As expected, the spatial distribution of the observed surface T_{max} anomaly pattern presented in Figure 3b is in good agreement with the corresponding low-troposphere temperature anomaly field (Figure 1b).

[10] The exceptionality of the synoptic pattern can also be seen in Figure 4, where we evaluate the full amplitude of the atmospheric blocking pattern shown in Figure 2. A similar methodology to that followed for 850 hPa temperature anomaly field is now applied to the 500 hPa geopotential height. The anomaly field for the 15d average (1–15 August) reaches its maximum over the English Channel (>160 gpm), however it is over western France and Germany that the historical maximum was exceeded (>30 gpm). In fact, the
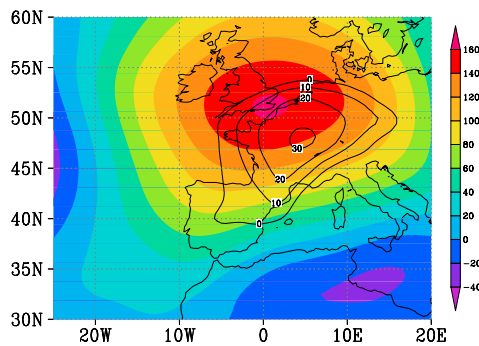
Figure 4. 500 hPa height anomalies (shaded; gpm) and regions with 15d average above the historical 15d maximum (contours; gpm).

sequence for the entire summer was obtained (not shown here) and proves that this is the only 15d period for which the historical maximum is broken by more than 30 gpm over any specific region.

4. Discussion and Conclusions

[11] The summer 2003 was exceptional from a seasonal perspective [*Luterbacher et al.*, 2004; *Schär et al.*, 2004]. However, from a health impact perspective, it was the short-lived heatwave of early August that lead to the vast majority of excess mortality rates throughout Europe. This work shows the spatial evolution of the EH03 at sub-monthly scales, highlighting the periods and location where the temperature and geopotential fields reached maximum values, with respect to analyses from the last 45 years. It should be stressed that the seasonal anomaly pattern is considerably different (in magnitude and spatial extent) from the specific heatwave event described here (e.g., compare our Figure 1 with Figure 1 of *Schär et al.* [2004] and Figure 2 of *Luterbacher et al.* [2004]). Finally it is shown that low troposphere and surface temperature anomaly fields, for the 1st fortnight of August 2003, present good spatial coherence with the excessive mortality rates observed for France.

[12] Different papers analyse the contribution of large-scale forcing mechanisms, which could help to achieve a persistent anomaly through a long period. Monthly SST averaged over the entire Mediterranean Sea for May, June, July and August 2003, were consistently above the corresponding monthly maximum value observed during the previous 45 years [*Grazzini and Viterbo*, 2003]. Although the persistent SST warm values and the amplitude of the blocking event over Europe are likely to be closely linked, the exact role of high SST values within the sub-monthly or seasonal heatwave is not clear [*Beniston and Diaz*, 2004] and needs further investigation. Another forcing mechanism is associated with the soil moisture content.

The prevalence of Anticyclonic weather in spring and summer of 2003 caused widespread drought conditions in Europe. This situation led to a continuous reduction of the soil moisture content and the greenness of vegetation, surface conditions that favour high temperatures as they enhance large values of surface sensible heat flux [*Fink et al.*, 2004].

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