Temperature Extremes, the Past and the Future.

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Abstract

The summer of 2003 was very likely the hottest in Europe since 1500 (Luterbacheret al. 2004, Schar et al. 2004, Beniston 2004, Black 2004) with large numbers of excess deaths reported in France, Germany and Italy (Sanitaire 2003). For such obvious reasons there is great concern as to whether human activities has changed the likelihood and nature of extreme events and whether they will do so in the future. We present recent developments on the detection of changes in extreme daily temperature over the last 50 years and the attribution of such changes to causes. We focus on the European summer of 2003 and look to see how these extreme temperature events might change in the future as predicted from a perturbed physics ensemble allowing some degree of quantification of uncertainty.

The Past

Europe had a very hot Summer in 2003. Was this because climate is becoming more extreme? To answer this we assess a recently developed gridded daily temperature dataset (Caeser et al 2005) for changes in temperature extremes since 1950. We use an extension of extreme value theory to allow time dependant extreme value distributions to be fitted to this new data. For large areas we find statistically significant increases in extremes of daily temperature for minimum and maximum Tmax and Tmin. Some smaller areas show decreases. Anomalously warm days are found to have increased typically by 1 to 2 ˚C over the last 50 years.

But was the 2003 heatwave itself caused by climate change? The question of whether any external driver of climate change, such as increased atmospheric greenhouse gas concentrations, "caused", in a simple deterministic way, any individual event is ill-posed. This is because weather is unpredictable, and almost any weather event might have occurred by chance in an unmodified climate. Instead, we can estimate how much human activities may have increased the risk of such a heat-wave occurring, since changes in weather risk may be predictable even though weather itself is not (Palmer and Räisänen 2002, Allen 2003, Stone submitted}.

To determine the changed risk of a heatwave such as occurred in 2003 over Europe we compare observed temperatures averaged over the European region (black line figure 1) with temperatures simulated by the HadCM3 climate model forced with both anthropogenic and natural forcings (coloured lines) and with simulations with just natural forcings (yellow line). An optimal detection analysis shows that an anthropogenic influence on decadal mean European summer temperature is detected at the 5\% significance level (i.e. the possibility that there is no positive anthropogenic influence can be rejected at the 5\% level) from which we conclude that it is very likely that past anthropogenic forcing is responsible for a significant fraction of the observed European summer warming.

We then calculate the implications of this mean summer warming on the risk of experiencing a very hot summer. Figure 2a shows estimated probabilities of the risk (likelihood) of exceedance of a 1.6K threshold (the only year in the instrumental record that this temperature was exceeded was 2003) in the presence of anthropogenic climate change (red line) and in the absence of anthropogenic change (green line), expressed both as a frequency (number of occurrences per thousand years, top axis) and as a return period (bottom axis). The clear shift from the green to the red distribution implies that a predictable fraction of the risk of such hot summers can be attributed to human influence on climate. Even in the presence of anthropogenic warming, we conclude the estimated probability of exceeding 1.6K appears to be low (best estimate of a 1 in 250 year event) but this risk may be increasing rapidly Figure 2a (red curve).

The fraction attributable risk expresses the fraction of risk that can be attributed to anthropogenic forcing and is expressed as $(P_1-P_0)/P_1$ where P_0 is the probability of the 1.6K threshold being exceeded without anthropogenic climate change (shown by green curve in Fig. 2a expressed as return period, bottom axis, and number of occurrences per 1000 years, top axis) and P_1 is the probability of exceedance with anthropogenic climate change (red curve in Fig. 2a). The fraction attributable risk (FAR) is estimated in Fig. 2b. According to our calculation, there is a greater than 90\% chance that over half the risk of European summer temperatures exceeding a threshold of 1.6K is attributable to human influence on climate. Although there is a large spread, reflecting the remaining uncertainties in the effects of climate change on this spatial scale, the anthropogenic FAR could be substantially greater than 0.5. Also marked on Fig. 2b is a vertical line representing an overall “best estimate” of the human contribution to the increased risk of these very hot European summers ~\cite{art:allen.03.nat}, given the information we have available at present. On this basis, human influence is to blame for 75\% of the increased risk of such a heat-wave.

The Future

Under all emission scenarios proposed by the IPCC, atmospheric concentrations of CO2 rise markedly. A number of studies (e.g. Meehl et al. 2004, Zwiers and Kharin 1998, Kharin and Zwiers 2000) have shown that under such conditions extremes in temperature increase. However there are substantial differences in the patterns and magnitudes of changes between climate models. To investigate the robustness of these results we have analysed the perturbed physics ensemble of Murphy et al. (2004) where the response to doubled atmospheric CO2 is simulated in an ensemble of 53 versions of HadSM3, consisting of the HadAM3 atmospheric general circulation model (GCM) coupled to a mixed layer ocean. By virtue of its size and design, the ensemble, samples uncertainty arising from the parameterisation of atmospheric physical processes and the effects of natural variability. This ensemble provides the opportunity to quantify the robustness of predictions of changes in extremes obtained from GCM simulations.

We see large changes in distributions of daily maximum June, July and August temperatures with increases in ‘once a summer’ event intensities of the order of several degrees Celsius for most of the globe as a result of doubling global atmospheric concentrations of Carbon Dioxide (Figure 3). For large areas these changes are significantly larger than changes in the mean value. The intensity, duration and frequency of summer heat waves are expected to be substantially greater over all continents (Figure 4). The largest changes are expected over Europe and North America where severe consequences for health, agriculture, society and ecosystems are likely. Prolonged heat waves of 1 in 100 year intensity and duration, as defined by pre-industrial climate, are expected to become up to 10 times more frequent in parts of Europe.

There is large uncertainty (up to 50%) associated with the magnitude of the modeled changes as a result of imperfect model representation of atmospheric processes and feedbacks, but this does not question the sign or nature of the projected changes. Even with the most benign ensemble members, hot extreme events are still expected to substantially increase in intensity, duration and frequency. This ensemble, however, does not represent the full range of uncertainty in future projections and the coarse resolution of the global model may inaccurately represent local processes which may be significant for extreme temperatures. This being said, it is not envisaged at this stage that the nature of these results will change substantially. Should atmospheric concentrations of CO_2 not be stabilised at levels significantly below twice pre-industrial levels adaptation to such changes and the mitigation of their impacts will be a considerable challenge.

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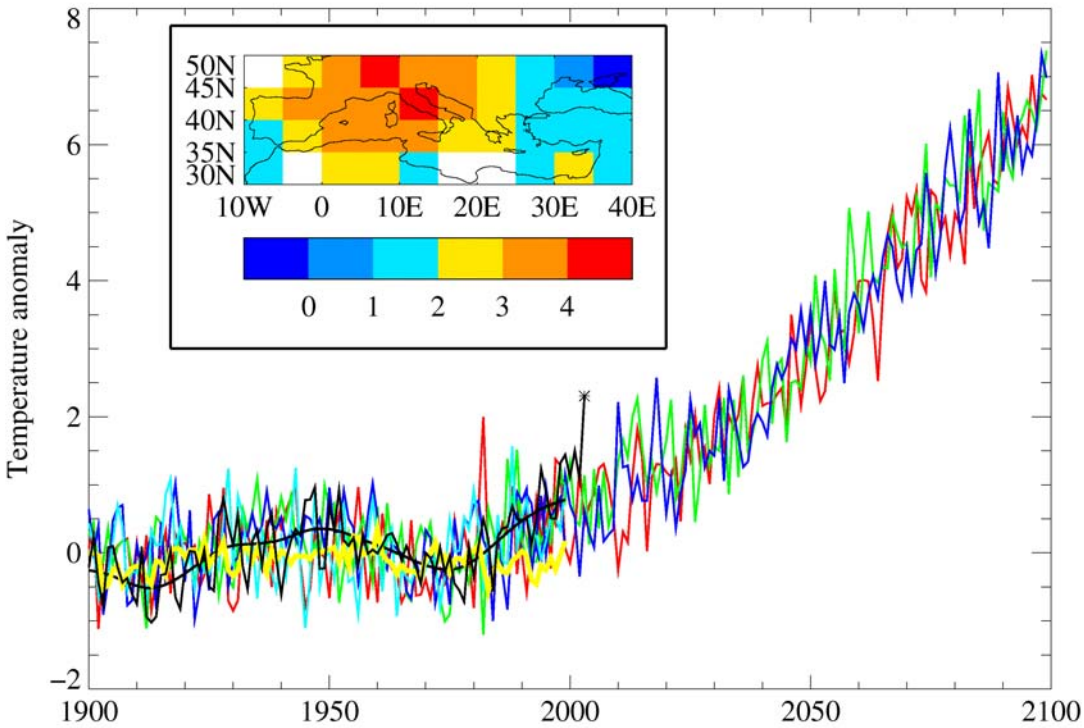

Figure 1. June-August temperature anomalies (relative to 1961-1990 mean, in K) over the region shown in inset. Shown are observed temperatures (black line, with low-pass-filtered temperature as heavy black line), modelled temperature from four HadCM3 simulations including both anthropogenic and natural forcings to 2000 (red, green, blue and turquoise lines), and estimated HadCM3 response to purely natural forcings (yellow line). The observed 2003 temperature is shown as a star. Also shown (red, green and blue lines) are three simulations (initialised in 1989) including changes in greenhouse gas and sulphur emissions according to the SRES A2 scenario to 2100. The inset shows observed summer 2003 temperature anomalies, in K.

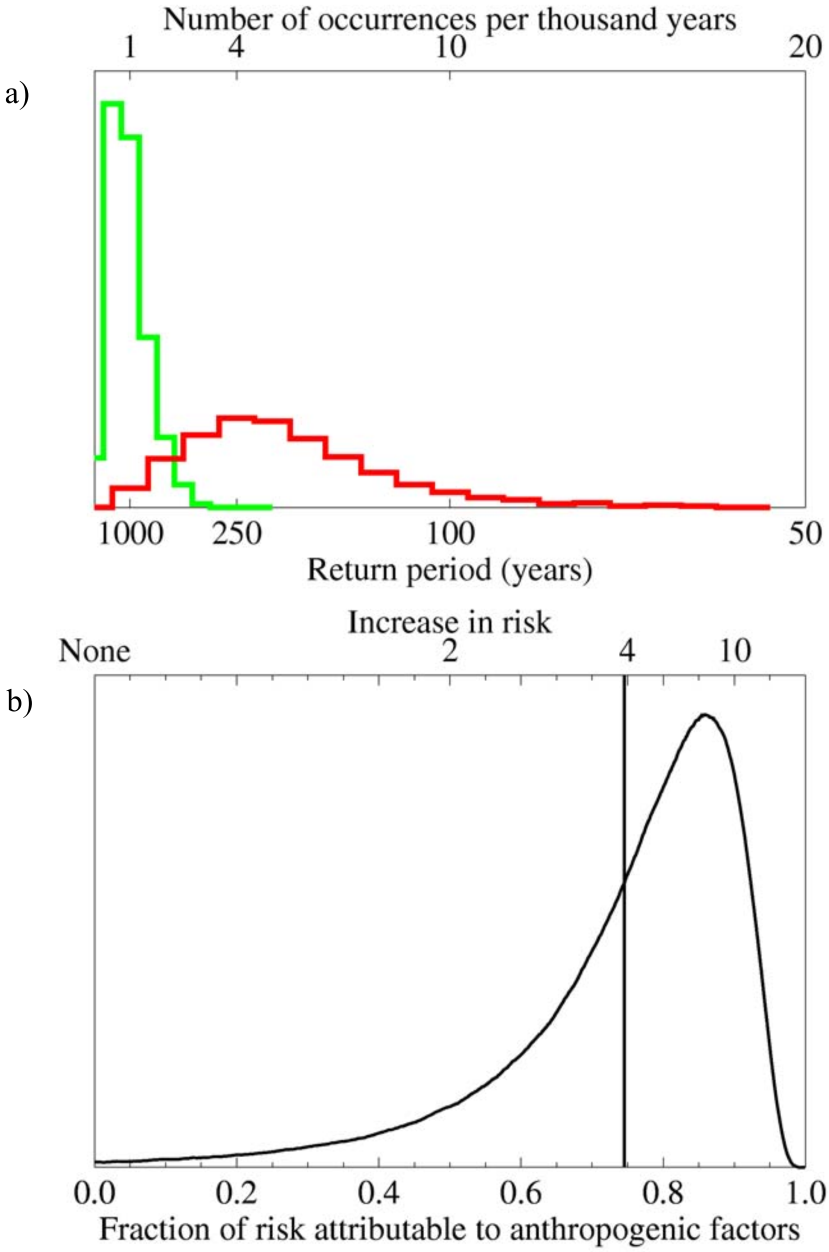

Figure 2. Change in risk of mean European summer temperature exceeding the 1.6 K threshold. a) Histograms of instantaneous return periods under late-twentieth-century conditions in the absence of anthropogenic climate change (green line) and with anthropogenic climate change (red line), b) fraction attributable risk (FAR). Also shown, as the vertical line, is the "best estimate" FAR, the mean risk attributable to anthropogenic factors averaged over the distribution. Vertical ordinates are normalised estimated likelihood.

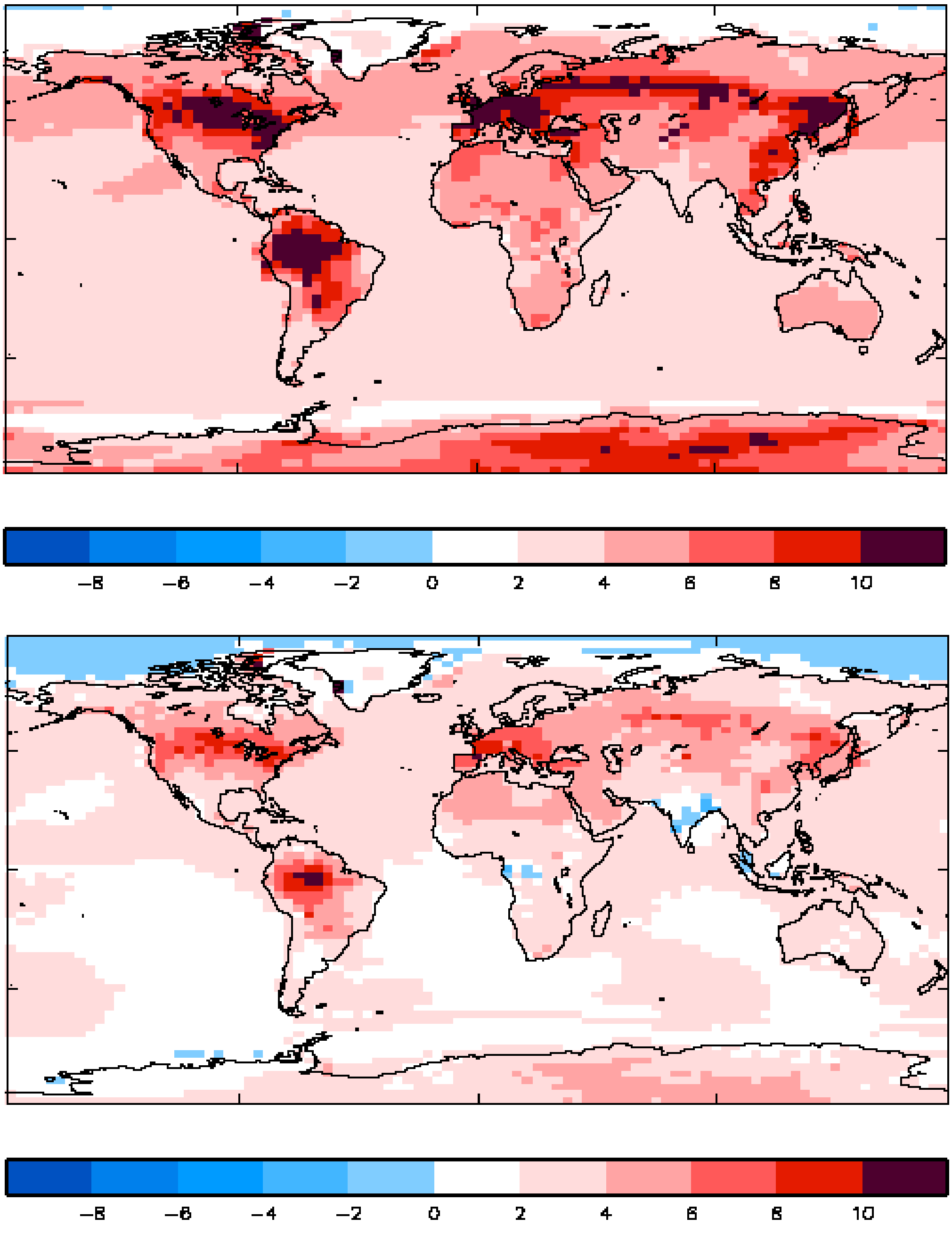

Figure 3. Magnitude and uncertainty in changes of 99th percentile threshold of June, July and August daily maximum surface temperature between pre-industrial and double CO_2 conditions. Uncertainty is shown here as 90th (top) and the 10th (bottom) quantile of the ensemble spread of the 99th percentile changes. Units are ˚C.

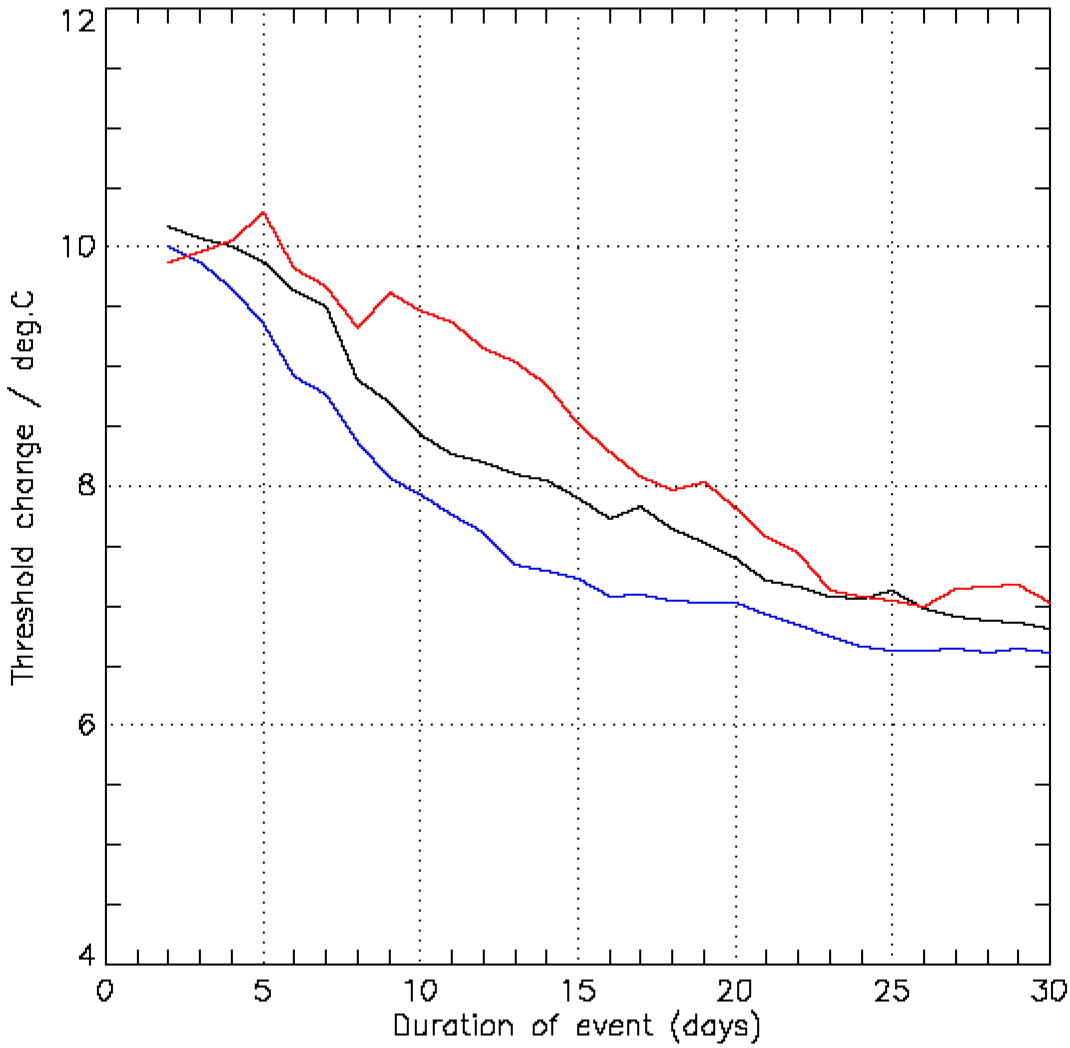

Figure 4. Change in intensity of 5, 10 and 20 year (blue, black and red respectively) heatwave return periods of varying duration (in days) for the global model grid box containing Chicago due to doubling atmospheric CO2 concentrations.