Human contribution to the European heatwave of 2003

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1 Abstract

The summer of 2003 was probably the hottest in Europe since at latest AD 1500 (Luterbacher et al. 2004; Schär et al. 2004; Beniston 31; Black et al. 2004), and unusually large numbers of heat related deaths were reported in France, Germany, and Italy (Institut de veille sanitaire 2003). It is an illposed question whether the 2003 heatwave was caused, in a simple deterministic sense, by a modification of the external influences on climate, for example increasing concentrations of greenhouse gases in the atmosphere, because almost any such weather event might have occurred by chance in an unmodified climate. However, it is possible to estimate by how much human activities may have increased the risk of the occurrence of such a heatwave (Palmer and Räisänen 2002; Allen 2003; Stone and Allen 2005). Here we use this conceptual framework to estimate the contribution of human-induced increases in atmospheric concentrations of greenhouse gases and other pollutants to the risk of the occurrence of unusually high mean summer temperatures throughout a large region of continental Europe. Using a threshold for mean summer temperature that was exceeded in 2003, but in no other year since the start of the instrumental record in 1851, we estimate it is very likely (confidence level >90%) that human influence has at least doubled the risk of a heatwave exceeding this threshold magnitude.

2 The summer of 2003 in Europe

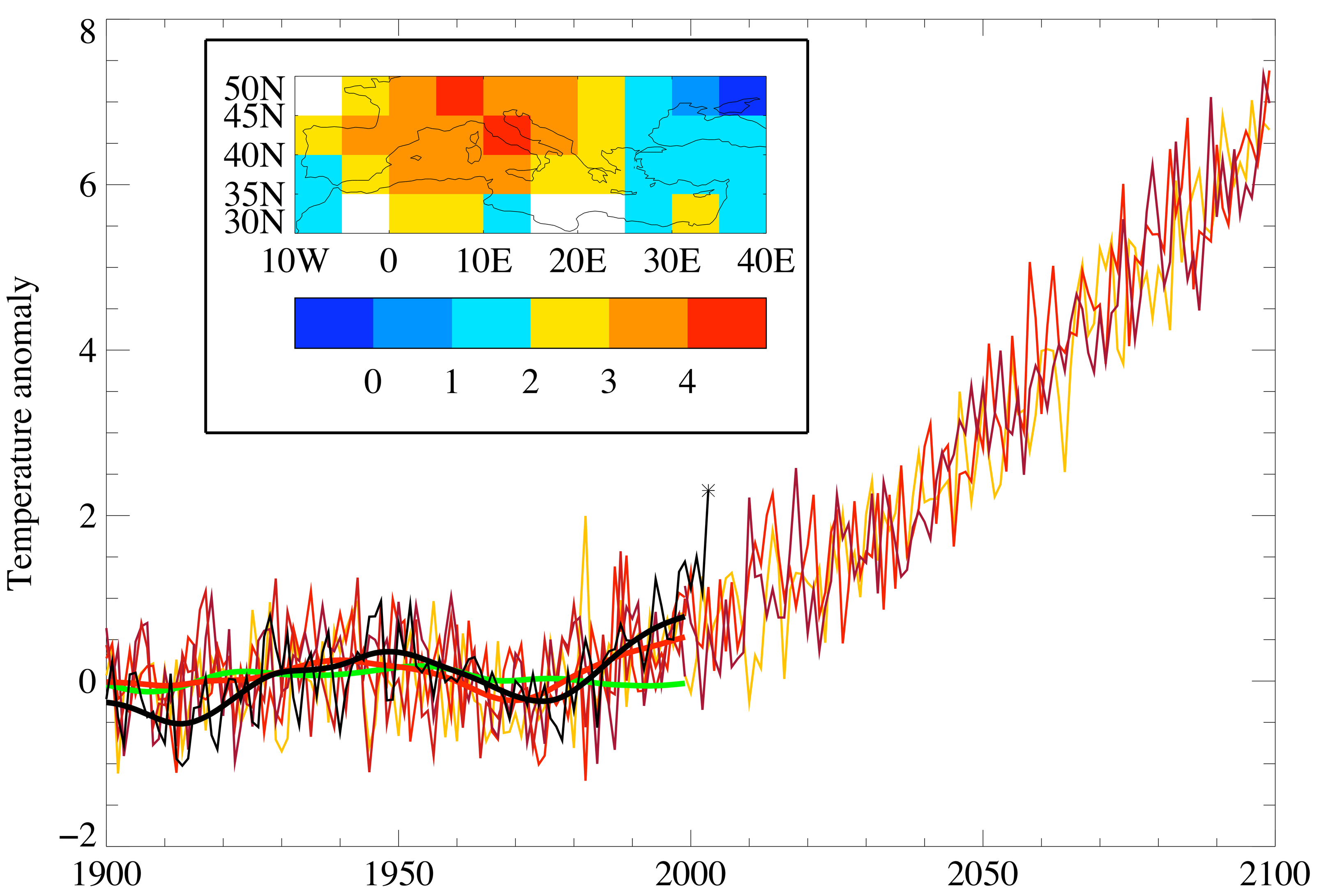

Figure 1 June-August 2003 temperature anomalies (relative to 1961-90 mean, in K) over the region shown in inset. Shown are observed temperatures (thin black line, with low-pass filtered temperatures in thick black line), modelled temperatures from four HadCM3 simulations including both anthropogenic and natural forcings (ALL) to 2000 (thin red-yellow lines, ensemble average in thick red line), and average of four HadCM3 simulations including natural forcings only (NAT) (thick green line). Also shown (thin red-yellow lines) are three simulations (initialized 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.

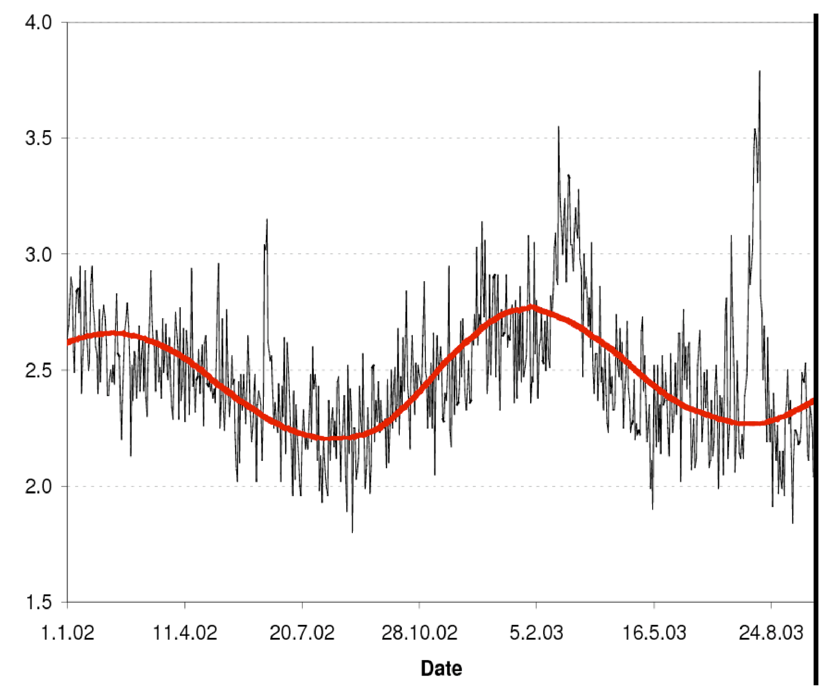

Figure 2 The daily mortality rate in Baden-Württemberg, Germany, preceding and during the summer 2003. Total daily mortality data are in black, with the mean seasonal evolution in red. Note the peak in August 2003, due to the heatwave, which caused 900-1300 extra deaths in a population of 10.7 million people. From Koppe, C. & Jendritzky, G. in *Gesundheitliche Auswirkungen der Hitzewelle im August 2003* (Sozialministerium Baden-Württemberg, Stuttgart, 2004); www.gesundheit-bw.de/download/bericht_gesundh_auswirkungen.pdf.

3 Variability in observed and simulated summer temperature

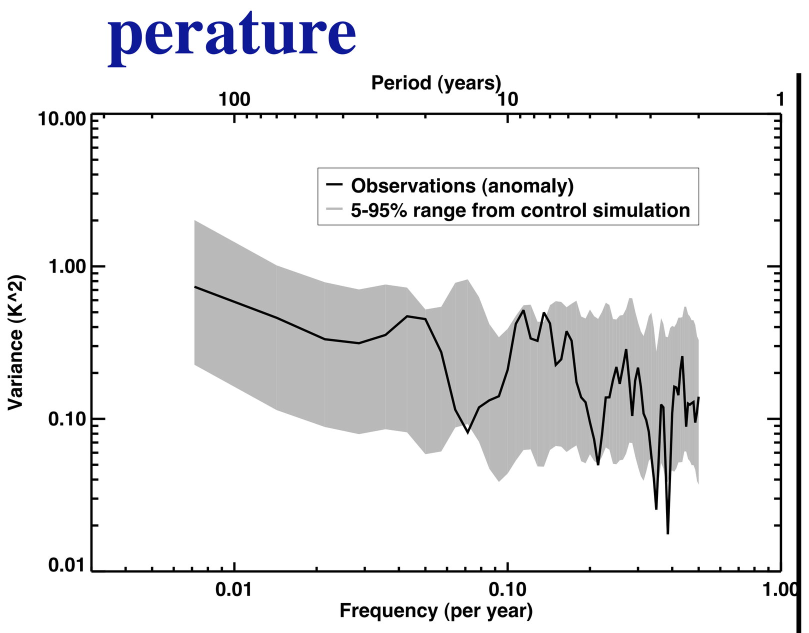

Figure 3 Power spectra of European mean summer temperature. Solid line, observed spectrum after removing an independent estimate of the externally forced response provided by the ensemble mean of the HadCM3 ALL simulations. Shaded region, 5 to 95 percentile region of the estimated range of spectra of natural internal variability estimated from comparable segments taken from the HadCM3 control run. Model spectral densities have been inflated by a factor of 1.25 to allow for sampling uncertainty in the ALL ensemble mean.

4 Contribution of forcings to observed warming

Construct observed summer temperature changes with a regression model (Allen and Stott 2003):

$$\vec{T}_{obs} = \sum_{i=1}^{m} \beta_i (\vec{T}_i + \vec{\nu}_i) + \vec{\nu}_0$$

Here β_i is the scaling factor corresponding to forcing i that is to be estimated in the regression. Uncertainty in the estimation arises from uncertainty in the observed changes ($\vec{\nu}_0$) and model responses ($\vec{\nu}_i$).

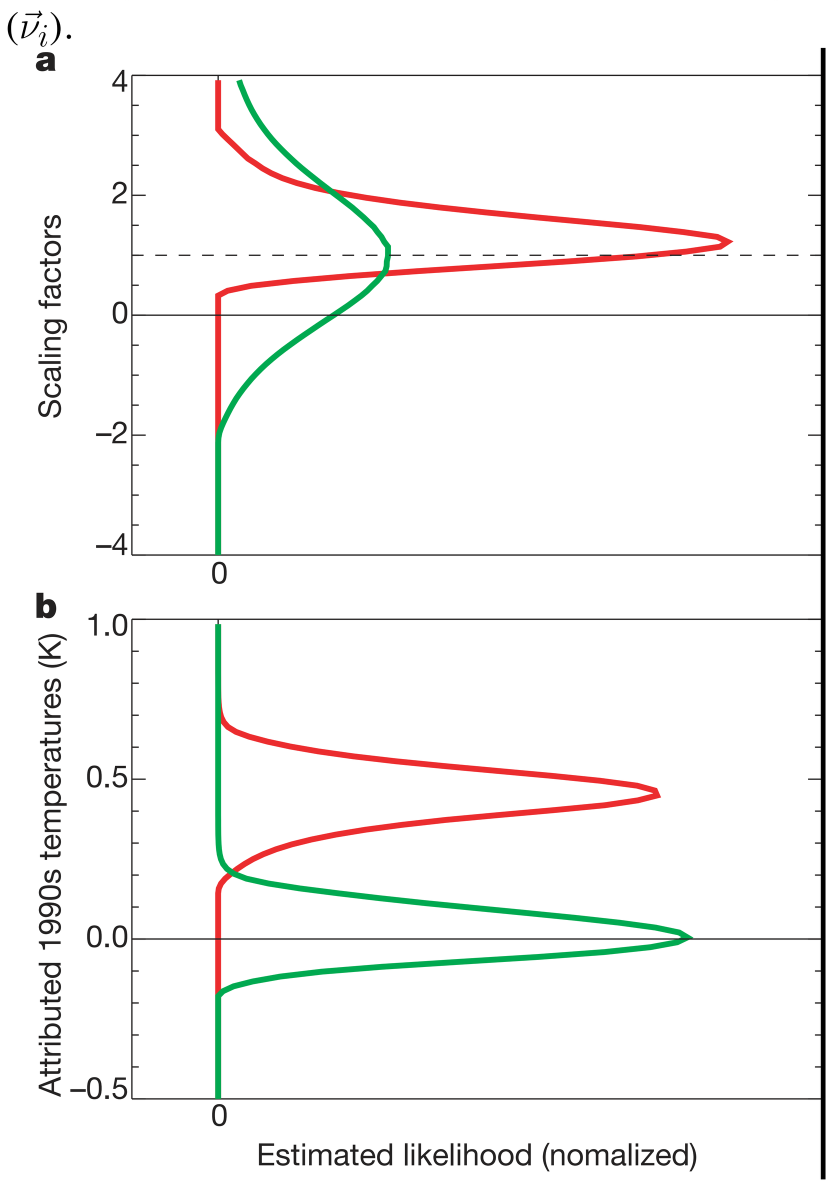

Figure 4 Estimated likelihood functions for anthropogenic and natural contributions to European summer temperature changes.
a) The curves show estimated distributions of anthropogenic (red) and natural (green) scaling factors (β_i) on model simulated responses.
b) 1990s summer temperatures (relative to pre-industrial climate) including all external drivers of climate change (red) and with anthropogenic drivers removed (green).

A scaling factor of zero (horizontal solid line in a)) implies no contribution to observed 1990s temperatures from this driver, while unity (horizontal dashed line in a) implies no systematic under- or over-estimate by the model of the observed response to this driver. The width of these distributions reflects the uncertainties for these probabilities.

5 Change in risk of record hot summer

We can scale the model responses by the scaling factors above and add variability to get estimates of the likelihood of a record hot summer (1.6 K, i.e. hotter than 2001).

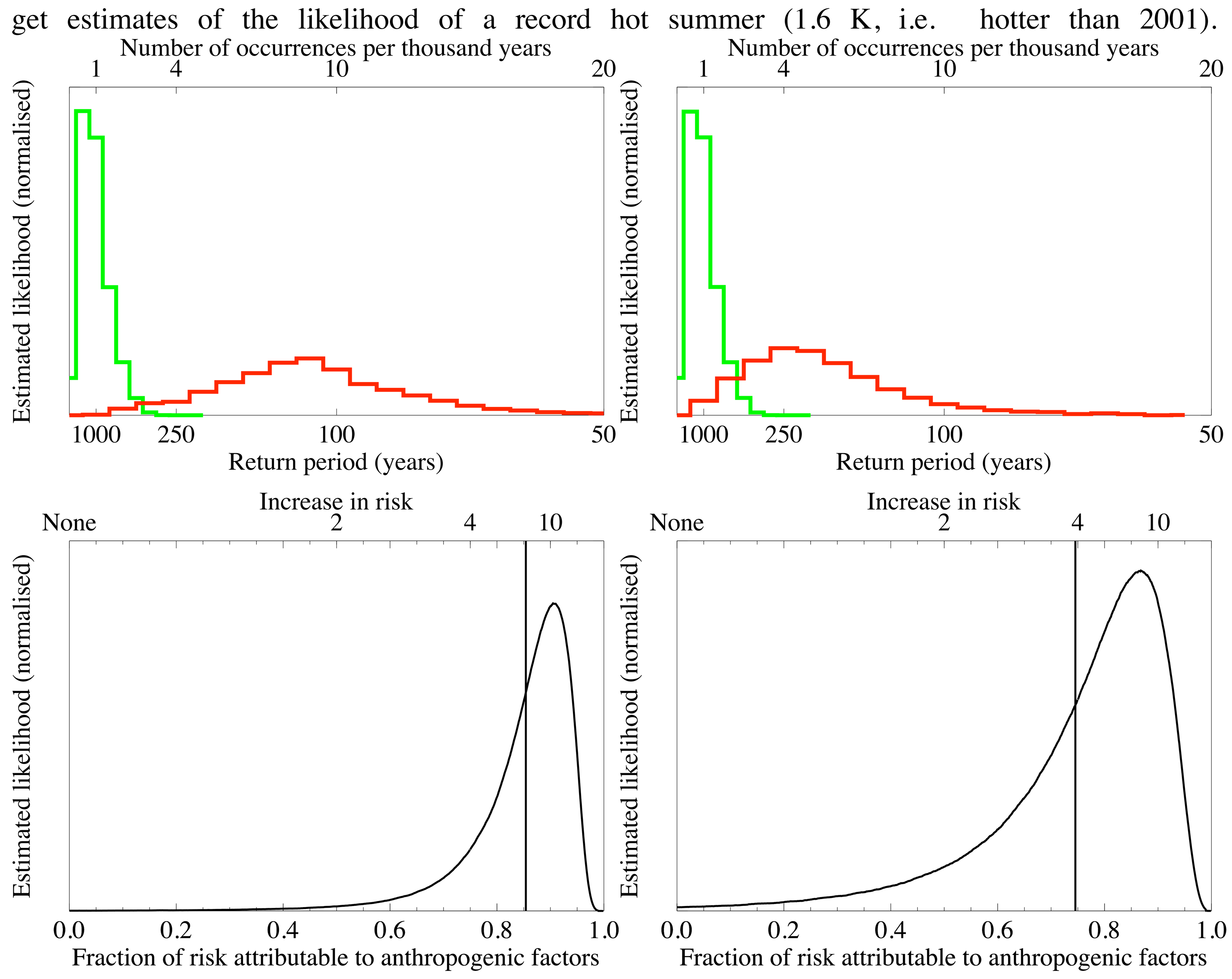

Figure 5 Change in risk of mean European summer temperatures exceeding the 1.6 K threshold.
a) Histograms of instantaneous return periods under late 20th century conditions in the absence of anthropogenic climate change (p_0, green line) and with anthropogenic climate change (p_1, red line).
b) Fraction attributable risk ($FAR = \frac{p_1 - p_0}{p_1}$). A value of $FAR = 1$ implies that the event occurs in the presence of anthropogenic climate change but not in it's absence, a value of $FAR = 0$ implies no change in the likelihood, a value of $FAR = 0.5$ implies a doubling of the likelihood. Also shown, as the vertical line, is the best estimate of FAR, the mean risk attributable to anthropogenic factors averaged over the distribution.
The left hand plots show the result if an extreme value distribution is used to estimate the likelihood for both the industrial and non-industrial cases, while the right plots show the result if a Gaussian distribution is used for the industrial case.

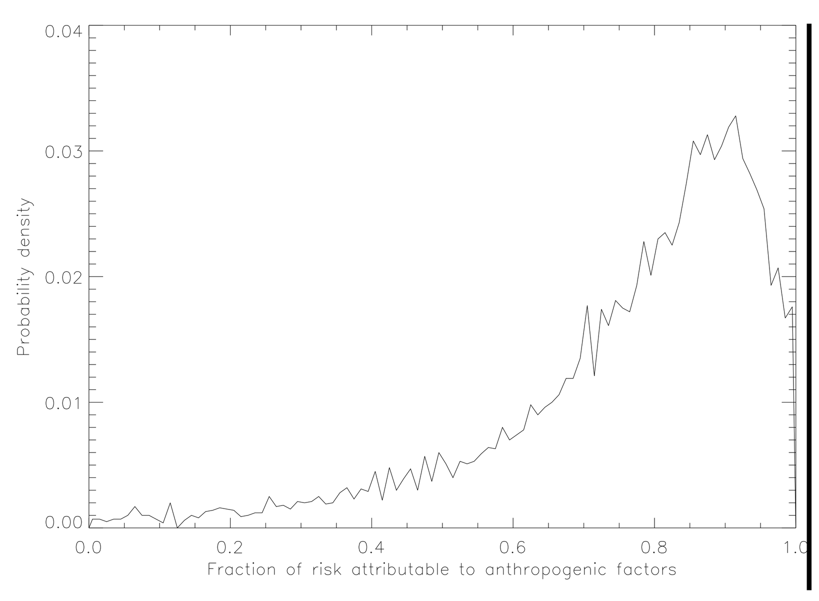

Figure 6 As in Figure 5b, but using simulation from the Challenge ensemble (Selten et al. 2003) of 62 simulations with the NCAR CCSM1.4 model and a slightly different methodology.

6 Discussion

Quantitatively, the result does appear to depend on the climate model used as well as on the statistical models used. However, qualitatively the results appear fairly robust to these points. In particular, the conclusion that it is very likely (confidence level >90%) that human influence has at least doubled the risk of a record hot summer appears unaffected.

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