nature climate change

SUPPLEMENTARY INFORMATION

DOI: 10.1038/NCLIMATE2468

Dramatically increasing chance of extremely hot summers since the 2003 European heatwave

Model simulations

To estimate the anthropogenic and natural components of the summer temperature change, our analysis requires data from model experiments that simulate a) the effect of all the main historical natural and anthropogenic forcings (ALL) and b) the effect of the natural historical forcings only (NAT). We also require simulations that are extended to year 2012 (i.e. the most recent year in CMIP5 model experiments with historical forcings), to estimate the forced change relevant to present-day. In addition, each model needs to provide multiple ALL and NAT simulations, as well as at least 500 years of a control climate simulation. The models that meet the above criteria and are employed in the optimal fingerprinting analyses are listed in Table S1.

Table S1. The 7 CMIP5 models used in the optimal fingerprinting analyses.

Model	**ALL ensemble size**	**NAT ensemble size**	**Control length (years)**
HadGEM2-ES	4	4	1400
CanESM2	5	5	995
CNRM-CM5	10	6	850
CSIRO-Mk3.6.0	10	5	500
GISS-E2-H	5	5	240, 540
GISS-E2-R	5	5	300, 550
IPSL-CM5A-LR	4	3	1000
	43	33	6375

DOI: 10.1038/NCLIMATE2468

construct Gaussian distributions for each RCP and every decade from the 2020s to the 2090s (Fig. 3). The CMIP5 models used to produce the future temperature distributions are listed in Table S2.

Table S2. The CMIP5 models that provided simulations with different RCPs.

Model	RCP26	RCP45	RCP60	RCP85
ACCESS1-0	-	1	-	1
ACCESS1-3	-	1	-	1
BNU-ESM	1	1	-	1
CCSM4	6	6	6	6
CESM1-BGC	-	1	-	1
CESM1-CAM5	3	3	3	3
CESM1-WACCM	-	1	-	1
CMCC-CM	-	1	-	1
CMCC-CMS	-	1	-	1
CNRM-CM5	1	1	-	5
CSIRO-Mk3.6.0	10	10	10	10
CanESM2	5	5	-	5
EC-EARTH	2	6	-	6
FIO-ESM	3	3	3	3
GFDL-CM3	1	1	1	1
GFDL-ESM2G	1	1	1	1
GFDL-ESM2M	1	1	1	1
GISS-E2-H	1	5	1	2
GISS-E2-H-CC	-	1	-	-
GISS-E2-R	1	6	1	2
GISS-E2-R-CC	-	1	-	-
HadGEM2-AO	1	1	1	1
HadGEM2-CC	-	1	-	1
HadGEM2-ES	4	4	4	4
IPSL-CM5A-LR	4	4	1	4
IPSL-CM5A-MR	1	1	1	1
IPSL-CM5B-LR	-	1	-	1
MIROC-ESM	1	1	1	1
MIROC-ESM-CHEM	1	1	1	1
MIROC5	3	3	3	3
MPI-ESM-LR	3	3	-	3
MPI-ESM-MR	1	3	-	1
MRI-CGCM3	1	1	-	1
NorESM1-M	1	1	1	1
NorESM1-ME	1	1	1	1
bcc-csm1-1	1	1	1	1
bcc-csm1-1-m	1	1	1	1
inmc4	-	1	-	1
	60	86	43	79

Base period of temperature anomalies

We repeated our analyses using temperature anomalies relative to the 1901-1930 period, which provides a measure of climatic changes against the preindustrial climate (or an approximation of it) rather than the climate of 1961-1990. The anomalies in the observations were produced simply by subtracting the average of the 10 regional mean temperature records for years 1901-1930 from the CRUTEM4 temperature timeseries shown in Fig. 1. This 10-year average is only an approximation of the 1901-1930 climate, which is based on a poorer observational coverage compared to more recent years (30% coverage as opposed to 60% in 1961-1990). Consequently, there is uncertainty introduced into the resulting timeseries compared to the timeseries used in our original analysis, which in turn leads to an increase in the uncertainty in the scaling factors and in the estimates of the return times (Fig. S1).

Using an earlier base period does not notably change the relative position of the heatwave thresholds relative to the distribution with ALL forcings, as they both shift by the same amount. The best estimates of the return times of events at present day are similar to the original estimates, but their uncertainty is larger for reasons already explained (Table S3). The use of a colder base period increases the separation between the ALL and NAT distributions as well as the distance between the NAT distribution and the heatwave thresholds. As a result, the probabilities of hot summers without the anthropogenic effect are even smaller than in our original analysis and cannot be accurately estimated given the size of our sample. In conclusion, consistent with the original analysis, we find more than an order of magnitude increase in the chances of hot summers in the region over the last decade and estimate the return time of events as severe as in 2003 to be about a century (best estimate). Because of the uncertainty introduced in the observations when we compute anomalies relative to 1901-1930, we suggest that our original results obtained with the base period of 1961-1990 are more robust.

DOI: 10.1038/NCLIMATE2468

Table S3. Return times of hot summers in the reference region estimated with the effect of human influence and their 5-95% uncertainty range (in brackets). Results are shown from analyses that use temperature anomalies relative to different base periods.

	Return time (years) Base period 1901-1930	**Return time (years)** Base period 1961-1990
Decade 1990-1999 / 1.6 K	298 (39 – 52,000)	52 (14 – 444)
Decade 2003-2012 / 1.6 K	4.3 (2 – 15)	5 (2.7 – 11)
Decade 2003-2012 / 2.3 K	94 (17 – 2630)	127 (34 – 999)

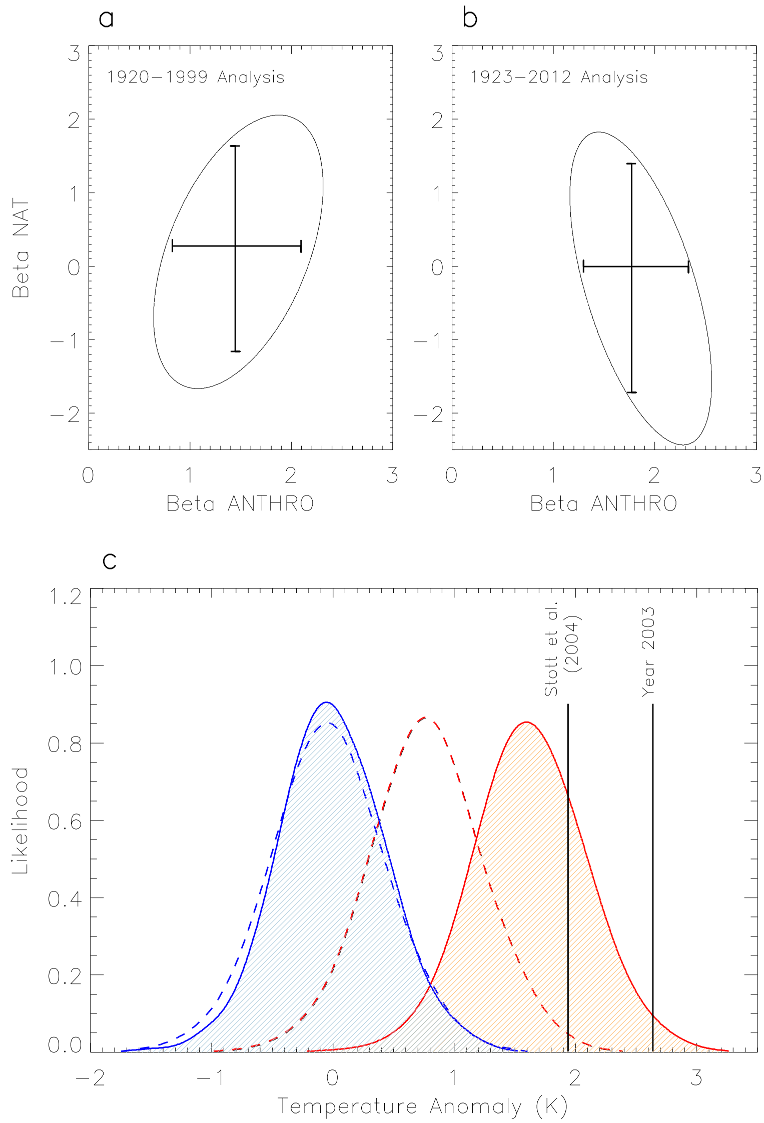

Figure S1. The same as Fig. 2, but for analyses with temperature anomalies relative to 1901-1930.