An attribution study of the UK mean temperature in year 2022.

Technical summary. Details of the attribution system in Christidis (2021).

Nikolaos Christidis, Peter A Stott, Mark McCarthy

January 2023.

An attribution study was conducted to examine how human influence on the climate increases the likelihood of seeing a new record of the annual mean temperature in the UK in year 2022. The analysis was produced with a system developed in Hadley Centre for the attribution of extremes in near-real time (Christidis, 2021). It employs an unconditional attribution framing, which estimates the changing risk of critical temperature threshold crossings under any possible conditions. The system also adopts the well-established and peer-reviewed risk-based methodology that infers probabilities of extreme events with and without the effect of human influence from large multi-model ensembles of climate model simulations. The new analysis employed coupled model temperature data drawn from large multi-model ensembles of the Coupled Model Intercomparison Project phase 6 (CMIP6, Eyring et al., 2016). In total, the study uses data from 14 models that provide the necessary experiments for event attribution, namely historical simulations extended to the end of the 21st century with the medium emissions scenario SSP2-4.5 (ALL; Riahi et al., 2017) and simulations with natural forcings only (NAT) to year 2020. Each model provides several simulations for each experiment and there are in total 87 ALL and 72 NAT model runs as listed in Table 1.

Table 1. The CMIP6 models used in the attribution analysis. The table gives the number of simulations per experiment and the total mutli-model ensemble size (last row).

MODEL	**ALL hist + ssp245**	**NAT**
ACCESS-CM2	3	3
ACCESS-ESM1-5	18	3
BCC-CSM2-MR	1	3
CESM2	3	3
CNRM-CM6-1	6	10
CanESM5	25	15
FGOALS-g3	4	3
GFDL-ESM4	3	3
GISS-E2-1-G	3	5
HadGEM3-GC31-LL	5	5
IPSL-CM6A-LR	9	10
MIROC6	3	3
MRI-ESM2-0	1	3
NorESM2-LM	3	3
Total	**87**	**72**

The study aims to a) estimate the likelihood of the annual mean temperature in the UK (land areas only) exceeding 10 ^{0}C for the first time, or reaching a new record in year 2022, and b) assess the role of anthropogenic forcings in the changing likelihood of extreme annual mean temperatures. Extreme events are defined as exceedances of 10 ^{0}C (or an anomaly of 1.88 ^{0}C relative to 1901-1930), or exceedances of the previous record of 9.88 ^{0}C observed in year 2014 (or an anomaly of 1.76 ^{0}C relative to 1901-1930). Temperature observations come from the HadUK-Grid dataset (Hollis et al., 2019) and cover the period 1884-2021. The model simulations start at year 1850. The likelihood of extreme temperatures is calculated under three different climatic conditions:

- the natural climate, represented by all annual mean temperature anomalies extracted from the NAT experiment.
- the present climate, represented by the temperature anomalies in years 2013-2032 extracted from the ALL experiment.
- the climate of the late 21st century, represented by temperature anomalies in years 2081-2100 extracted from the ALL experiment (ALL simulations extended with SSP2 4.5).

Observed and modelled timeseries of the UK temperature anomalies are illustrated in Fig. 1. Both HadUK-Grid and the ALL experiment suggest an increase in temperature since the late 20th century that continues throughout the 21st century, expected to steadily increase the likelihood of extremely hot years. Such long-term warming is not seen in the NAT climate, suggesting it is of anthropogenic origin.

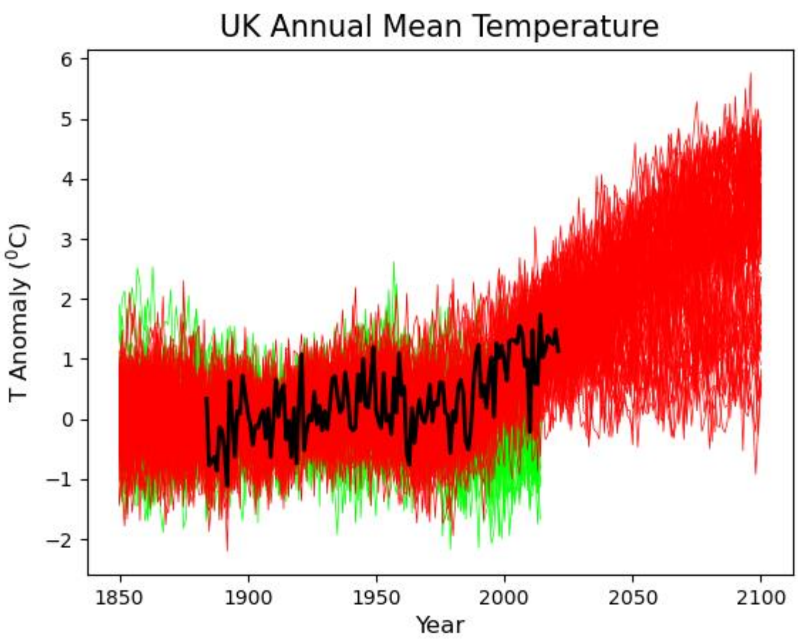

Figure 1. Timeseries of the annual temperature anomaly (relative to 1901-1930) in the UK computed with observational data from HadUK-Grid (black line) and the CMIP6 ALL (red lines) and NAT (green lines) simulations.

The models were evaluated against the observations (Fig. 2) by applying a number of evaluation tests commonly employed in event attribution studies (Christidis et al., 2013). The observed temperature trend is within the range of the ALL simulations and close to the ensemble mean (Fig. 2, top panel). Power spectra also indicate good consistency between the models and HadUK-Grid (middle panel). The Q-Q plot produced for each simulation separately shows lines that lie close to the diagonal, which indicates that the modelled distribution compares well with the observed one. Hence, on the basis of this assessments, the models are deemed suitable for an attribution analysis of extreme heatwaves in the reference region.

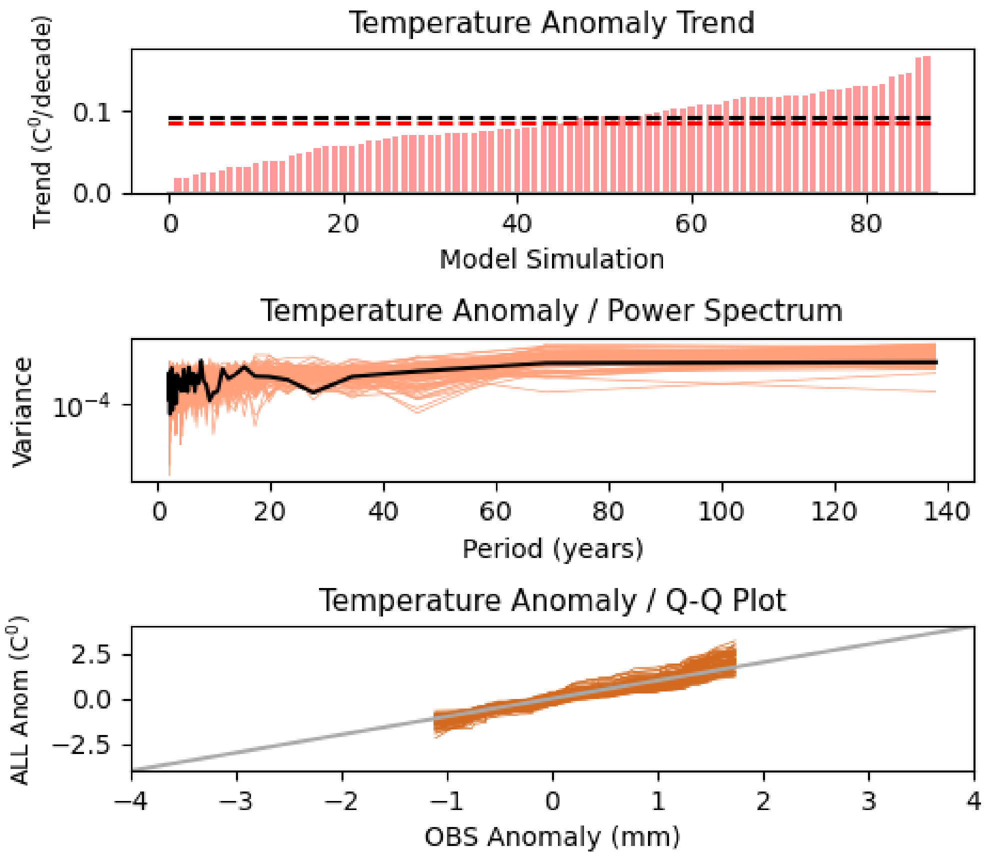

Figure 2. Evaluation of the CMIP6 models. Top panel: temperature trends over the observational period computed with HadUK-Grid (black dashed line) and individual ALL simulations (vertical bars). The dashed red line marks the ensemble mean. Middle panel: Power spectra from HadUK-Grid (black) and the ALL simulations (orange). Bottom panel: Quantile-Quantile plot for each of the ALL simulations.

Probabilities of extreme annual mean temperatures are computed next. The likelihood of exceeding 10 ^{0}C is estimated first. Return time estimates (inverse probabilities) and their associated uncertainty are reported in Table 2. The table also shows the change in the likelihood (risk ratio) relative to the NAT world. It is found that temperatures above 10 ^{0}C would occur one in hundreds of years in the NAT climate, but such events are now common (return time of 3-4 years) and, under SSP2-4.5, the threshold is set to be crossed almost every year by the end of the century. The event in the present climate has a return time of 3.41 years (best estimate) and is estimated to be about 160 times more likely than in the NAT climate. The likelihood of exceeding the record seen in year 2014 is calculated next and results are summarised in Table 3. A similar increase in the likelihood of a new record is found.

Table 2. Return times for extremely warm years with temperatures above 10 ^{0}C and risk ratio estimates. The 5-95% uncertainty range is given in brackets.

	Return Time (Years)
NAT	528 (118 to 733)
ALL-present	3.41 (3.22 to 3.64)
ALL-future	1.26 (1.24 to 1.29)
	Risk Ratio
Pr(ALL-present)/Pr(NAT)	157 (33.6 to 216)
Pr(ALL-future)/Pr(NAT)	426 (92.1 to 574)

Table 3. Return times for extremely warm years with temperatures above the 2014 record and risk ratio estimates. The 5-95% uncertainty range is given in brackets.

	Return Time (Years)
NAT	338 (101 to 437)
ALL-present	2.82 (2.69 to 2.99)
ALL-future	1.24 (1.22 to 1.27)
	Risk Ratio
Pr(ALL-present)/Pr(NAT)	122 (34.4 to 153)
Pr(ALL-future)/Pr(NAT)	276 (79.8 to 351)

References

Christidis, N., 2021: Using CMIP6 multi-model ensembles for near real-time attribution of extreme events, Hadley Centre Technical Note 107, Available from https://www.metoffice.gov.uk/research/library-and-archive/publications/science/climate-science-technical-notes

Christidis, N., P. A. Stott, A. Scaife, A. Arribas, G. S. Jones, D. Copsey, J. R. Knight, and W. J. Tennant, 2013: A new HadGEM3-A based system for attribution of weather and climate-related extreme events, *J. Clim*., **26**, 2756-2783, https://doi.org/10.1175/JCLI-D-12-00169.1.

Eyring, V., S. Bony, G. A. Meehl, C. A. Senior, B. Stevens, R. J. Stouffer, and K. E. Taylor, 2016: Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization, *Geosci. Mod. Dev*., **9**, 1937–1958, https://doi.org/10.5194/gmd-9-1937-2016.

Hollis, D., M. McCarthy, M. Kendon, T. Legg, and I. Simpson, 2019: HadUK-Grid—A new UK dataset of gridded climate observations, *Geosci. Data. J.*, **6**, 151-159, https://doi.org/10.1002/gdj3.78.

Riahi, K., and co-Authors, 2017: The shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview, *Global Env. Change*, **42**, 153– 168, https://doi.org/10.1016/j.gloenvcha.2016.05.009.