An attribution study of the UK mean temperature in year 2023.

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Document history

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Introduction

A rapid attribution study was conducted to examine the effect of human influence on the occurrence of UK annual mean temperatures exceeding those observed in 2023. While 2023 did not exceed the record set in 2022 (Christidis et al., 2023) it came very close. We provide estimates for the exceedance probability of similar events in the climate of the natural world, the climate of the present day and that of the end of the century as well as the associated probability ratios.

The analysis was produced using a system developed in the Met Office Hadley Centre for near real-time attribution (Christidis, 2021) making use of a multi-model ensemble of latest generation coupled models. The framing of the study is unconditional so we examine the possibility of exceeding observed temperatures under any physical circumstances generated by the models. The analysis deploys well established and peer-reviewed methodologies.

The following sections present the observational and model data used, the attribution method, evaluation of the multi-model ensemble and finally the attribution results.

Data

Observed values of the UK annual mean temperature are obtained from the HadUK-Grid dataset v1.2.0.0 (Hollis et al., 2019, Met Office, 2023). The time series spans 1884 – 2023, with the 2023 values being provisional as of 2nd January 2024. Model data is taken from 14 CMIP6 models (Eyering et al., 2016) that provide ensemble members for each of the natural (hist-nat) and historical climate (historical) experiments as well as projections from the SSP2-4.5 scenario (ssp245, Riahi et al., 2017). The names of models and the number of ensemble members used from each are tabulated in Table 1.

Observed and modelled timeseries of UK annual mean temperature anomalies are illustrated in Fig. 1. Both HadUK-Grid and the historical simulations suggest an increase in temperature since the late 20th century and the model projections show that this is expected to continue throughout the 21st century, steadily increasing the likelihood of higher temperatures being observed in the UK. Such long-term warming is not seen in the hist-nat climate (green), suggesting it is of anthropogenic origin.

The value of the UK annual mean temperature anomaly relative to a baseline period of 1901-1930 in 2023 was +1.83°C, just 0.05°C below the record set in 2022 of +1.88°C and making 2023 the second warmest year for the UK in HadUK-Grid going back to 1884. It is already clear from the time series in Figure 1 that considerably higher temperatures are possible in the current climate.

Table 1. CMIP6 models and corresponding number of ensemble members used from each experiment in the attribution analysis.

Model	**historical**	**ssp245**	**hist-nat**
ACCESS-CM2	3	3	3
ACCESS-ESM1-5	18	18	3
BCC-CSM2-MR	3	1	3
CESM2	11	6	3
CNRM-CM6-1	30	6	10
CanESM5	25	25	15
FGOALS-g3	4	4	3
GFDL-ESM4	3	3	3
GISS-E2-1-G	6	3	5
HadGEM3-GC31-LL	5	5	5
IPSL-CM6A-LR	32	11	10
MIROC6	10	3	10
MRI-ESM2-0	5	1	5
NorESM2-LM	3	3	3
Total	**158**	**81**	**92**

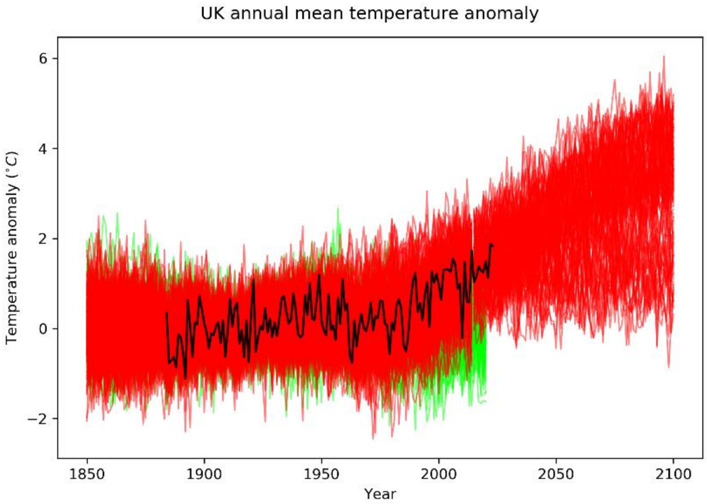

Figure 1. Timeseries of the UK annual mean temperature anomaly (w.r.t. 1901-1930) computed with observational data from HadUK-Grid (black line) and simulations from the CMIP6 historical and ssp245 experiments (red lines) and hist-nat experiment (green lines). Observed data runs from 1884 – 2023.

Method

The method is to find exceedance probabilities of the 2023 UK annual mean temperature anomaly (w.r.t the period 1901 - 1930) in the natural world climate without human influence (NAT), the current day climate (ALL-present) and that of the end of the century (ALL-future). The NAT climate is represented by combining all available years from the hist-nat simulations (1850 - 2020). The ALL-present climate is represented by taking all data from a 20 year period centred on 2023 from the historical simulations continued by ssp245. The ALL-future climate is represented by all data taken from the final 20 years of the ssp245 experiment (2080 - 2099).

Time series of both observations and model members are produced as the UK regional mean of anomalies of gridded annual mean temperatures. For the models land fraction masks are applied for each model individually to obtain land-only temperatures comparable to those of the HadUK-Grid observations. All available members from the 14 CMIP6 models are combined into a single multi-model ensemble and samples taken from the appropriate time periods, as just discussed, from which distributions may be estimated.

Exceedance probabilities are then calculated in one of two ways. If the observed value of the UK annual mean temperature anomaly is less than a chosen threshold percentile (example 80%) of the model distribution then the exceedance probability is the empirical fraction of model values lying above the observed threshold. If the observed value of the UK annual mean temperature anomaly is higher than the threshold percentile then a Generalised Pareto Distribution (GPD) is fit to the model data above this threshold and an exceedance probability found from this continuous approximation to the tail of the model distribution.

Uncertainty ranges are calculated by performing a 10,000 member bootstrap (90% with replacement) from which the 5% and 95% values of the exceedance probabilities and probability ratios are found. For each bootstrap resampling of the data we re-count or re-fit the GPD to find the new exceedance probability.

Model Evaluation

The models were evaluated against the HadUK-Grid observations, as presented in Figure 2. A number of evaluation tests commonly employed in event attribution studies (Christidis et al., 2013, Christidis, 2021) are conducted on the full multi-model ensemble of historical simulations over the evaluation period 1884 – 2014, defined as the overlap of the historical experiment with availability of the observations. This provides over 20,000 years of model data.

The observed temperature trend is well within the range of the simulations and close to the ensemble mean (Figure. 2, top panel). A small number of simulations exhibit a negative trend over the evaluation period but we do not exclude these members. Examining each model separately, all models have a positive trend when extended further into the 21st with the SSP2-4.5 scenario.

Estimates of the power spectra also indicate good consistency between the ensemble and HadUK-Grid (middle panel), both at short and long periods. The Quantile-Quantile plot produced for each simulation separately shows curves that mostly lie close to the 1:1 line, indicating that the multi-model ensemble distribution compares well with the observed one. We do not exclude any members or models based on these assessments. The ensemble is deemed suitable for an attribution analysis of extreme UK annual mean temperatures.

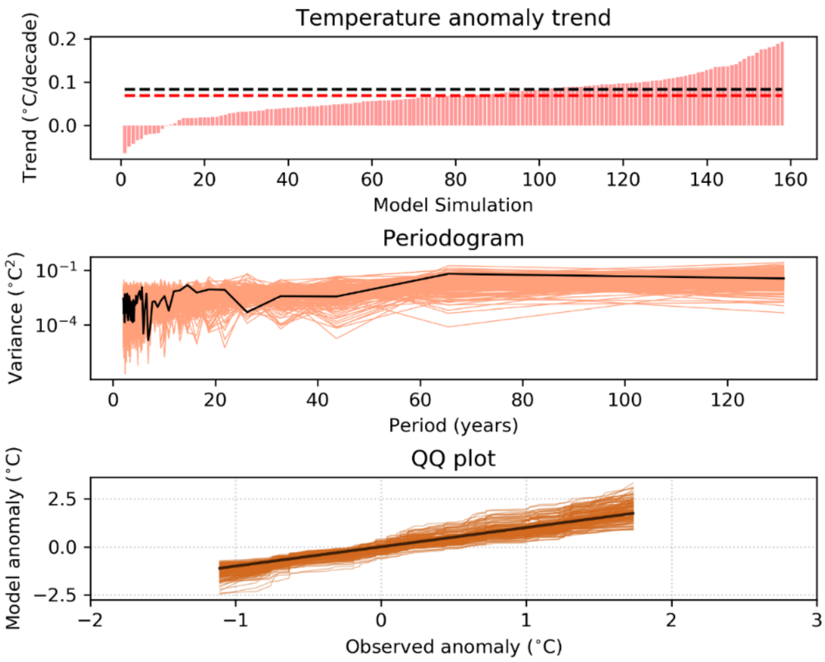

Figure 2. Evaluation of CMIP6 multi-model ensemble used in the attribution analysis. Top panel: temperature trends over the historical evaluation period (1884 – 2014) computed with HadUK-Grid (black dashed line) and individual ALL simulations (vertical bars). The red dashed line marks the ensemble mean. Middle panel: Power spectra estimates (periodogram) from HadUK-Grid (black) and the ALL simulations (orange). Bottom panel: Quantile-Quantile plot for each of the ALL simulations.

Climate Attribution

The results of the analysis are presented as the probability of exceeding the 2023 observed temperature along with associated probability ratios in Table 2. Probability ratios are a commonly reported statistic in attribution studies and are calculated as the estimated probability of observing the event in one time period, divided by the estimated probability of observing the event in the natural climate, where these probabilities are calculated over a set time period (e.g. 1 year). UK annual mean temperatures exceeding those observed in 2023 are only expected to occur with a probability of 0.2% (range 0.17% to 1.2%) in the natural world climate but human influence has increased the exceedance probability by over 150 times (best estimate 153, range 27.1 to 196) to 33% (range 32% to 35%) showing that while these temperatures are extreme in the record since 1884 they are not so in the present day climate. Further warming to the end of the century could see the temperatures of 2023 being exceeded more frequently than every other year.

Table 2. Exceedance probabilities and risk ratio estimates for exceeding the observed 2023 UK annual mean temperature anomaly (w.r.t. 1901 - 1930). 5-95% uncertainty ranges found by a 10,000 member bootstrap follow in brackets.

	Exceedance probability
	2023 (provisional 2nd Jan '24) (+1.83°C)
NAT	2.18×10^{-3} (1.70×10^{-3}, 1.22×10^{-2})
ALL-present	3.33×10^{-1} (3.15×10^{-1}, 3.50×10^{-1})
ALL-future	7.86×10^{-1} (7.70×10^{-1}, 8.02×10^{-1})
	Probability Ratio
Pr(ALL-present)/Pr(NAT)	153 (27.1, 196)
Pr(ALL-future)/Pr(NAT)	361 (64.6, 462)

The UK annual mean temperature anomaly for 2023 was only a fraction of a degree below the record breaking 2022 value and so we should expect the exceedance probabilities to be correspondingly very similar. This is indeed the case when we compare the values found in Christidis et al., 2023, where the only statistically significant difference is in the ALL-present probability that is slightly lower (best estimate 29% in 2022 compared to 33% in 2023). Based on these present day probabilities we should not be surprised by two consecutive years reaching these values that are extreme in the historical context. The ALL-future projections from this multi-model ensemble are broadly consistent with probabilistic projections from the UK Climate Projections (UKCP, for example Fig. 58 from Kendon et al., 2023), although a comprehensive quantitative comparison with UKCP accounting for differences in model ensembles, method and emissions scenarios is beyond the scope of this report.

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