An Attribution Study of the UK mean temperature in summer 2025

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1. Introduction

Summer 2025 was the hottest on record for the UK, driven by persistent high-pressure conditions resulting in a season punctuated by four notable heatwave periods, and extended periods of clear skies resulting in a season that was also drier and sunnier than average. The peak maximum temperature (35.8°C at Faversham (Kent) on 1st July) was not as high as in some recent heatwaves, but the persistence of high temperatures through much of the summer means that 2025, with a mean temperature of 16.10°C, replaces 2018 (15.76°C) as the hottest summer on record.

A rapid attribution analysis was conducted to quantify the human-influence on the likelihood of reaching or exceeding the 2025 summer mean temperature. The approach provides estimates of the exceedance probability of similar events in the climate of a 'natural' world, the climate of the present day, and that of the end of the 21st Century.

The analysis was conducted using a system developed by the Met Office for rapid studies and described in Christidis (2021). This uses climate models from the Coupled Model Intercomparison Project Phase 6 (CMIP6, Eyring et al., 2016).
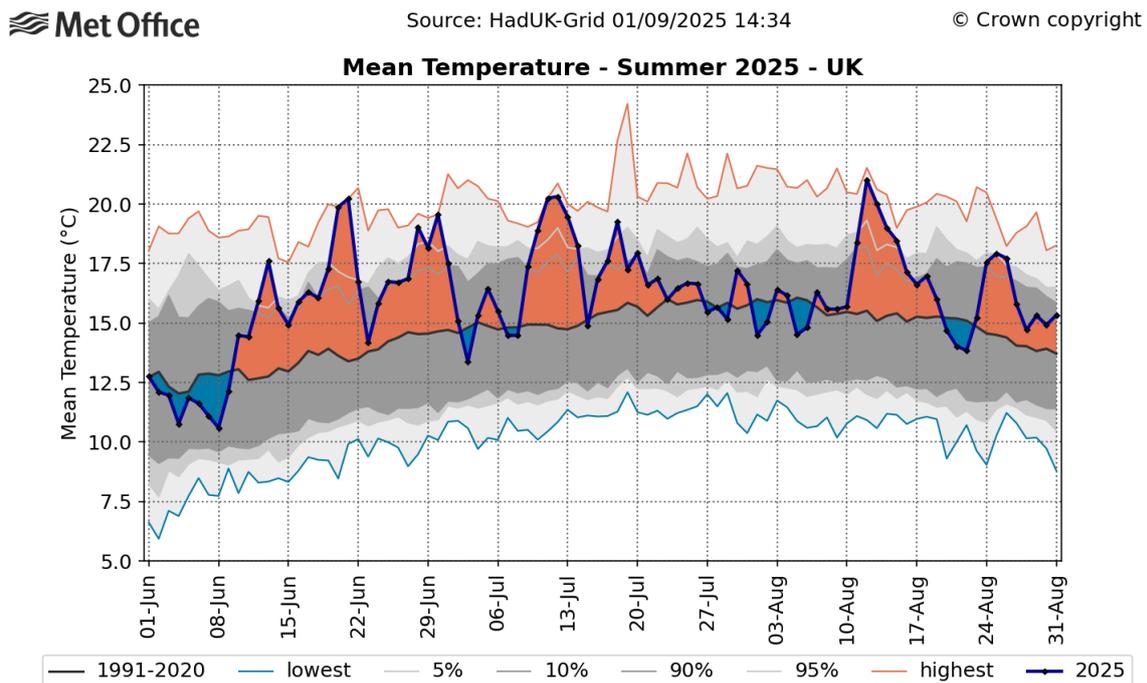

Figure 1: UK daily mean temperature for summer 2025. Periods of above average temperature are highlighted orange, and periods below average are blue. The 1991-2020 average temperature is shown in black. The (light) grey shaded regions show the (5%-95%) 10%-90% of all summers, and the thin orange and blue outer lines show the daily record temperatures.
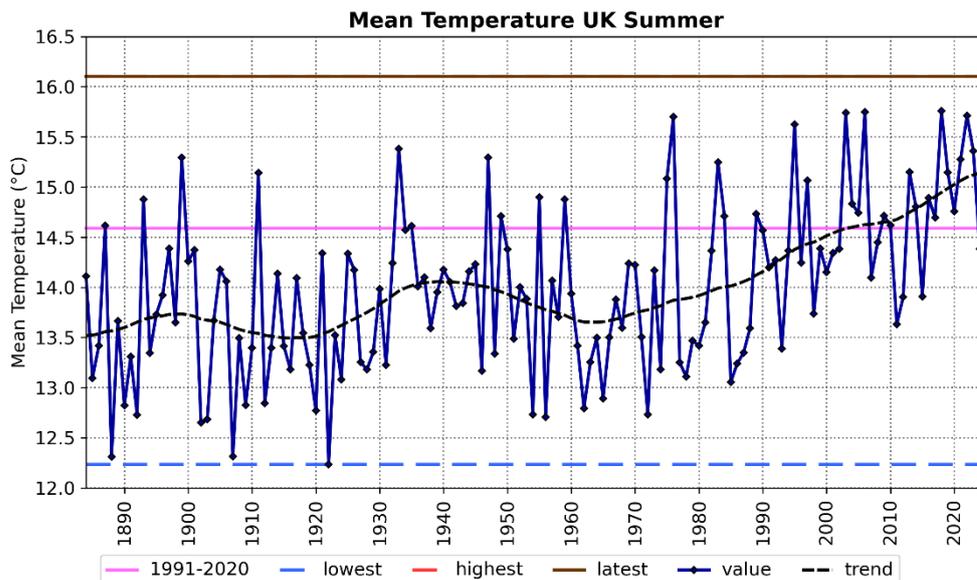
Figure 2: UK summer mean temperature from 1884 to 2025. The smoothed trend is shown as a black dashed curve. The 1991-2020 summer average is shown as a pink line.

2. Data

Observed values of the UK summer mean temperature are obtained from the HadUK-Grid dataset v1.3.1.0 (Hollis et al., 2019; Met Office, 2025). The time series contains UK monthly means spanning January 1884 – August 2025, with the 2025 values being provisional at the time of writing. Summer mean values are obtained by averaging this monthly data over summer months of June, July and August, appropriately weighted by the number of days in each month.

Model data is taken from 14 CMIP6 models that provide ensemble members for each of the natural (hist-nat) and historical (historical) climate experiments as well as projections from the SSP2-4.5 scenario (ssp245, Riahi et al., 2017). The hist-nat experiment provides simulations of the pre-industrial climate and the historical experiment provides simulations of the changing climate under observed climate forcings. The SSP2-4.5 projections are valid from 2015 onwards and are chosen as a "middle of the road" scenario for mitigation and adaptation to climate change. These projections see moderate global population growth and uneven development, that may remain a close analogue of the real world. The names of models and the number of ensemble members used from each are shown in Table 1.

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

Model Name	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**	**92**	**81**

Time series of the observed and modelled UK summer mean temperature anomalies are shown in Fig. 3. Increasing summer temperatures are shown in both observations and the historical and ssp245 simulations, with further increases projected through the rest of the 21st Century. This shows a steadily increasing likelihood of higher than average summer temperatures being experienced in the UK. The historical and hist-nat ensembles start to diverge from around the 1980s suggesting that climate forcings arising from human influence are the dominant factor in the observed warming trend.

The value of the UK summer mean temperature anomaly in 2025, relative to a baseline period of 1901 – 1930, was 2.61°C, 0.35°C above the record set in 2018 of 2.26°C. The median summer model anomaly for ssp245 data rises by 0.26°C from 2018 to 2025. It is clear just from the time series in Figure 3 that this new summer record is not particularly extreme in the current climate, and that considerably higher summer mean temperatures are already possible.
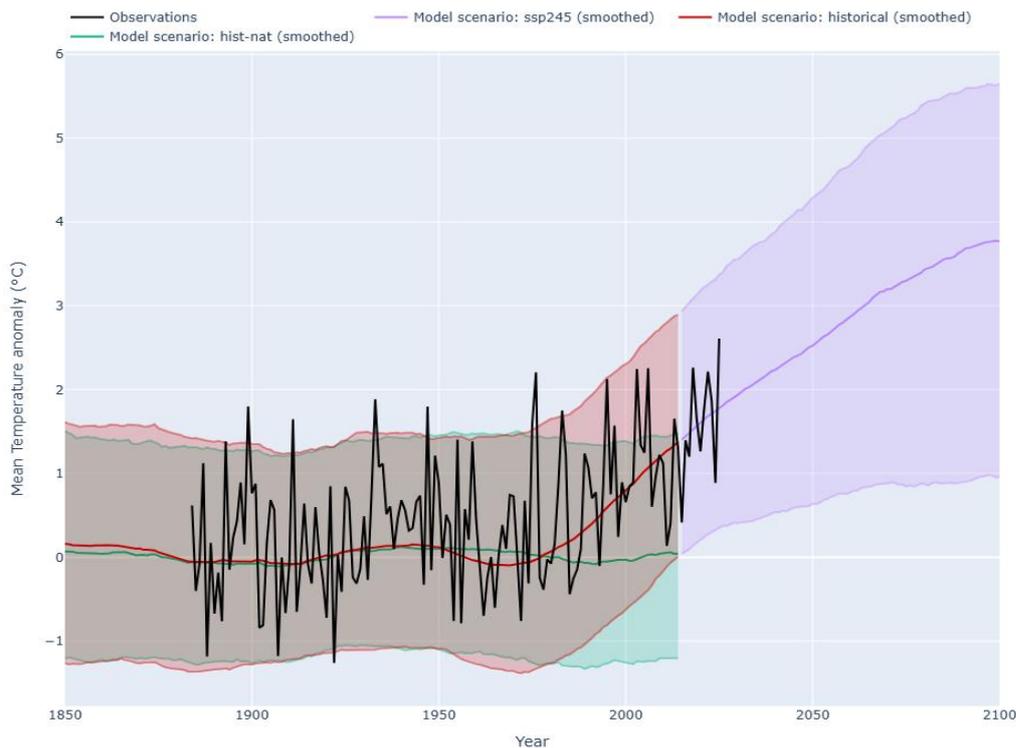
Figure 3: Time series of the UK summer mean temperature anomaly (w.r.t. 1901 – 1930). Observational data from HadUK-Grid (black). Simulations from the CMIP6 historical (red), ssp245 (purple) and hist-nat (green) experiments. Simulation data is represented as median values and filled 5th – 95th percentile ranges explored by members of the multi-model ensemble. Simulation data is smoothed with a rolling window of 20 years, with historical and ssp245 combined into one continuous series. Observed data runs from 1884 – 2025.

3. Method

The method employed is to find exceedance probabilities of the 2025 UK summer mean temperature in the natural world climate without human influence (nat), the current day climate (now) and that of the end of the century (end). The nat climate is represented by collating all available years from the hist-nat simulations (1850 - 2020). The now climate is represented by taking all data from the 20-year period 2015 – 2034 that is centred on 2025, from the historical simulations up to 2014 and continued by ssp245. The end climate is represented by all data taken from the final 20 years of the ssp245 experiment (2081 - 2100).

Time series of both observations and model members are produced for the UK regional mean of anomalies of gridded summer mean temperatures. In all cases the anomalies are calculated relative to a 1901 – 1930 baseline. Land fraction masks are applied for each model individually to obtain land-only temperatures comparable to 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, from which

distributions may be estimated.

Exceedance probabilities are then calculated in one of two ways.
If the observed value of the UK summer mean temperature anomaly is not an extreme value (i.e. it does not sit within the tail of the distribution), then the exceedance probability is the empirical fraction of model values lying above the observed threshold.
If the observed value of the UK summer mean temperature anomaly can be treated as an extreme value, then a Generalised Pareto Distribution (GPD) is fit to the model tail data and an exceedance probability is found from the continuous approximation of the tail of the model distribution.

Probability ratios are used to express changes in probability between the current climate and that of the natural world, and between the climate of the end of the century and the natural world. The probability ratio in each case is the exceedance probability in the climate of interest divided by that in the pre-industrial climate.

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, return times 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.

4. Model Evaluation

The models were evaluated against the HadUK-Grid observations, as presented in Figure 4. Several 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, which is 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 very close to the ensemble mean (Figure 4, top panel, observed and model mean trend indistinguishable). 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 Century with the SSP2-4.5 scenario.

Estimates of the power spectra as seen in the periodogram (Figure 4, middle panel) also indicate good consistency of the variability in summer mean temperature between the model ensemble and HadUK-Grid, both at short and long periods.

The Quantile-Quantile plot (Figure 4, lower panel) produced for each simulation separately shows curves that mostly lie close to the 1:1 line, indicating that the shapes of member distributions compare well with that observed. Model values cooler than observed below anomalies of 0°C expresses the fact that the observed world explored cooler variations during the anomaly period 1901 – 1930 (Figure 3.). Model members examined separately

exhibit consistent variability at multi-decadal time scales (see the periodograms, Figure 4, middle panel). As the observed quantiles still remain within the range of members over these values, and both trend and periodogram show consistency, we accept the multi-model ensemble representation of the shape of the distribution of anomalies.

We do not exclude any members or models based on these assessments. The ensemble is deemed suitable for an attribution analysis of extreme UK summer mean temperatures.
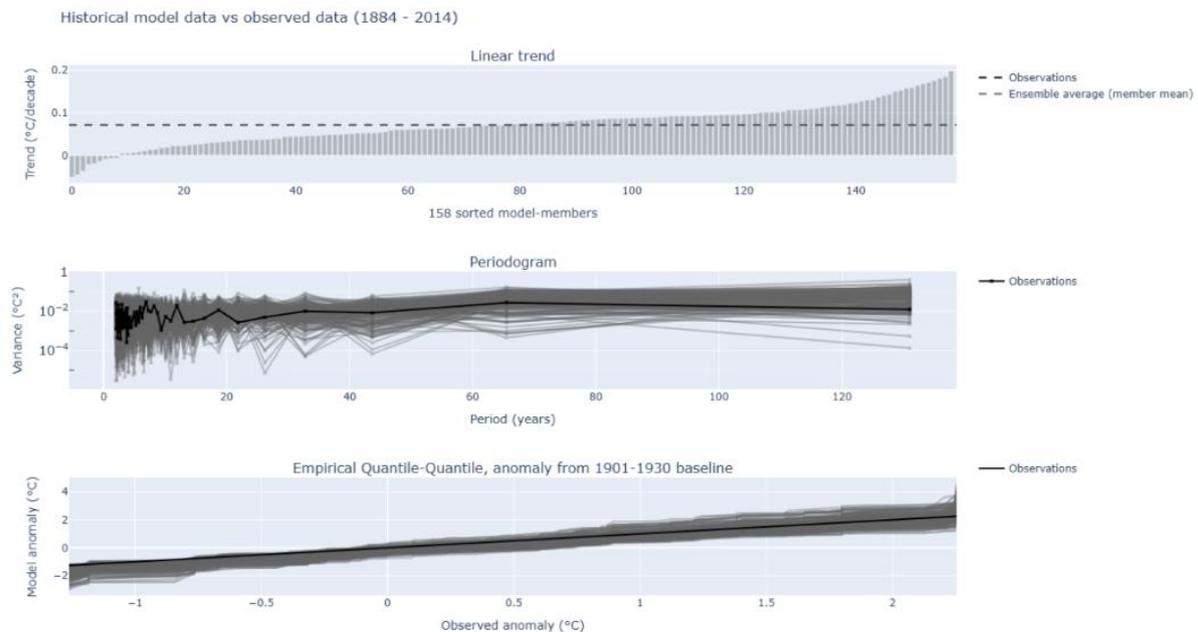

Figure 4: Evaluation of CMIP6 multi-model ensemble used in the attribution analysis, for the historical experiment, evaluated over 1884 – 2014 by comparison with observational HadUK-Grid data. Top panel: temperature trends over the evaluation period. Middle panel: power spectra estimates (periodogram) from the HadUK-Grid data and historical simulations. Bottom panel: quantile-quantile plot for each of the historical simulations.

5. Climate Attribution

The results of the analysis are presented as the probability and equivalent return period of exceeding the 2025 observed summer mean temperature anomaly, along with associated probability ratios in Table 2. UK summer mean temperatures exceeding those observed in 2025 are expected to occur with a best estimate return time of approximately 5 years (5% to 95% range 4.6 to 5.4 years) in the current climate, human influence having increased the probability of occurrence by around 70 times from an equivalent return time estimate of just below 340 years (5% to 95% range 270 to 430 years) in the climate of the pre-industrial period.

Individual model projections (not shown) diverge by the end of the century (apparent from Figure 3) but further warming to the end of the century could see the temperatures of 2025

being exceeded as frequently as every other year. The multi-model best estimate return time is approximately 1.4 years at the end of the century, but this includes a range of projections and is shorter in some individual model projections and longer in others.

Table 2. Exceedance probabilities and risk ratio estimates for exceeding the observed 2025 UK summer mean temperature anomaly (w.r.t. 1901 - 1930). 5-95% uncertainty ranges found by a 10,000-member bootstrap.

Experiment	Exceedance Probability (5%, 95%)	Return time / years (5%, 95)	Probability Ratio (5%, 95%)
nat: hist-nat all data	0.00297 (0.0023, 0.0037)	337 (270, 430)	N/A
now: historical and ssp245 2015-2034	0.204 (0.19, 0.22)	4.92 (4.6, 5.4)	68.6 (53, 88)
end: ssp245 2081-2100	0.727 (0.71, 0.74)	1.38 (1.3, 1.4)	245 (190, 310)

Other attribution studies have evaluated UK summer mean temperature extremes using essentially the same method as used here. McCarthy et al. (2019) conducted an attribution study of the, at the time, record 2018 summer. This study estimated a return time of reaching or exceeding 2018 summer mean temperature of 8 to 9 years, for a climate centred on 2018. In Kendon et al. (2024) a corresponding analysis but for just England, rather than the UK, and for the summer of 1976 found a return time in the current climate of 4.25 years.

UK summer mean temperatures are warming rapidly. The change between 2018 and 2025 in the CMIP6 ensemble mean is a quarter of a degree in 7 years (0.26°C, equivalent to 0.38°C in 10 years). Consequently, as the 2018 record was broken by 0.3°C, most of this difference could potentially be explained by the rapid background warming in UK summers arising from human-induced climate change.

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