Extremely Warm Days in the United Kingdom in Winter 2018/19

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Extremely warm winter days in central England, as in 2018/19, are still very rare, but human influence is estimated to have made them about 300 times more likely.

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In stark contrast to the frigid close of the 2017/18 winter in the United Kingdom (Christidis and Stott 2020), daytime winter temperatures above 20°C were recorded for the first time in the country only a year later, with a maximum of 21.2°C at Kew Gardens on 26 February 2019.[1] Strong anticyclonic conditions at the end of the winter season steered exceptionally mild tropical maritime air over western Europe and were identified by Kendon et al. (2020) as a key driver of the extreme U.K. temperatures. Their study suggests that the atmospheric state alone would be sufficient to raise U.K. temperatures above 20°C, even without the effect of human influence on the climate. Here, we carry out a complementary attribution study to investigate extremes in the warmest day in winter, described by the maximum daytime temperature (Tmax) in

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[1] See https://www.metoffice.gov.uk/about-us/press-office/news/weather-and-climate/2019/february-and-winter-statistics.

central England, and we quantify the anthropogenic effect on their present and future probabilities. Central England Tmax observations are available since 1878 (CET dataset; Parker et al. 1992) and manifest a record of 18.1°C on 26 February 2019 (i.e., the same date as the U.K. national record).

Observations and atmospheric circulation.

Time series of the daily Tmax plotted for every winter (December to February) in the CET dataset (Fig. 1a) show a steep increase at the end of winter 2018/19 with temperatures rising well above previous records. The year also stands out as a striking extreme in the observational time series of the warmest winter day in central England (Fig. 1b), reaching an anomaly that is approximately 5 times the standard deviation of the detrended observations. The observed anomaly of +5.2°C relative to the base period 1901–30 sets the threshold for the definition of extreme events in this study: the warmest day anomalies above this threshold are counted as extremes. The anomaly is 1.5 times higher than the previous record (+3.5°C) and 6 times higher than the 1900–2018 warming (+0.87°C) estimated by fitting a linear trend to the CET data. 500-hPa geopotential height (Z500) data from the NCEP–NCAR reanalysis (Kalnay et al. 1996) illustrate the deep anticyclonic anomaly over northwestern Europe present on the day

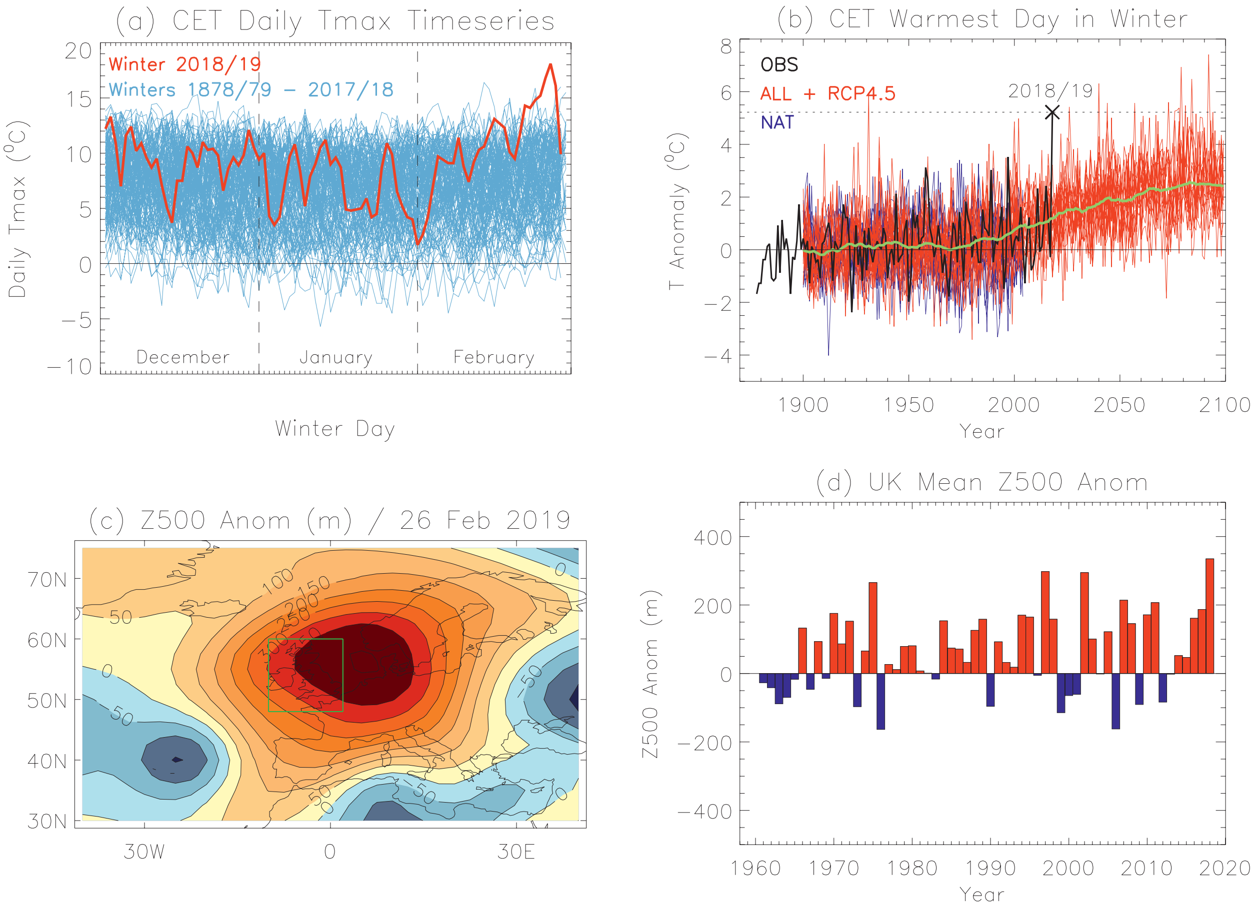


Fig. 1. (a) Time series of the observed daily Tmax in central England during winter months. 2018/19 is shown in red and all other winters in blue. (b) Time series of the warmest day in winter in central England. Anomalies are relative to 1901/02–1930/31. Observations are plotted in black and bias-corrected CMIP5 data from ALL and NAT simulations in red and blue respectively. 2018/19 is marked by the cross and the horizontal dotted line. The yellow line represents the forced response (mean of the ALL simulations). (c) NCEP–NCAR Z500 anomalies on 26 Feb 2019. Anomalies are relative to the winter mean Z500 during 1961/62–90/91. (d) Time series of Z500 anomalies over the United Kingdom [green box in (c)] for the warmest day in winter.

of the Tmax record (Fig. 1c). Positive Z500 anomalies are usually associated with the warmest day in winter in most years, as illustrated in Fig. 1d, which shows the mean Z500 anomaly over the United Kingdom on the days of the CET winter maxima since the 1960s.

CMIP5 data.

The change in the likelihood of extreme events is assessed with a risk-based attribution methodology (Stott et al. 2016), by comparing their probability in the real world with all external forcings acting on the climate (ALL), and a hypothetical "natural" world without the anthropogenic effect (NAT). We use data from 16 models that contributed to the phase 5 of the Coupled Model Intercomparison Project (CMIP5; see the online supplemental material). Although the models typically generate several simulations of the ALL and NAT climate, here we employ one simulation per model per experiment and estimate for each simulation the warmest winter's day Tmax anomaly over central England in all years since 1900 (Fig. 1b). The ALL simulations were extended to the end of the twenty-first century with the RCP4.5 scenario. The forced response is estimated by the mean of the ALL simulations (yellow line in Fig. 1b).

Evaluating the models against CET observations (see the supplemental material) shows that although they yield trends consistent with the observations, their variability is smaller. A simple bias correction is thus applied that inflates their standard deviation to match it to the observations. Once the models are corrected, their variability and distribution of the warmest day in winter agree well with the CET dataset. The variability correction is pointed out as a major caveat of the analysis that could adversely affect the probability estimates, especially if there are future changes in variability that are not correctly captured by the models. However, neither the observations nor the models indicate a notable temporal change in the variability of the warmest day in winter during the observational period, so the effect is likely to be minor.

Our analysis compares the likelihood of extreme events under different climatic conditions. The NAT climate is assumed stationary and we therefore utilize a sample of all simulated years (16 NAT simulations × 105 years in the period 1900/01–2004/05). Since the ALL climate has a warming trend, we first remove an estimate of the response to external forcings from each model's time series and subsequently adjust them to the mean forced response in (a) years 1900–20 (early twentieth century), (b) 2008–28 (present climate), and (c) 2080–2100 (late twenty-first century). This produces samples of 3200 simulated events (16 simulations × 200 years in the period 1900/01–2099/2100).

CMIP5 attribution.

Probabilities of extreme events (i.e., instances of threshold exceedance) are computed from the CMIP5 data with the generalized extreme value (GEV) distribution and their uncertainty is estimated with a simple Monte Carlo bootstrap procedure (Christidis et al. 2013). Return time (inverse probability) and risk ratio estimates are reported in Table 1. Extreme years like 2018/19 are currently highly rare with return times of the order of a thousand years, but they become increasingly common, expected to occur once or twice a century by 2100. Their likelihood in the natural climate is too small to be estimated with the limited sample size from the NAT simulations, but is approximated with the larger ALL sample for the early twentieth century and found to be near-zero (Table 1). The temporal shift in the distribution of the warmest day is depicted in Fig. 2a. The intensity of extremes is also on the rise: events as rare as 2018/19 presently correspond to a + 5.2°C anomaly, which would only be +4.4°C in the early twentieth century, increasing to +7°C by 2100.

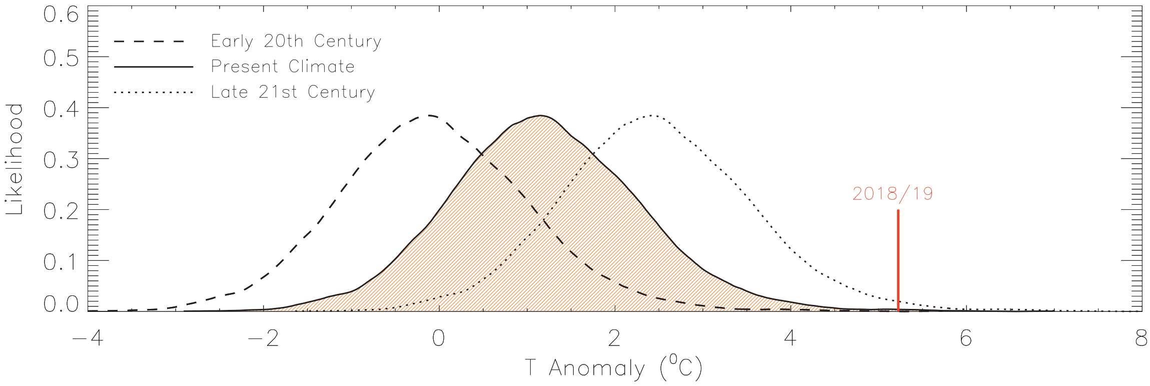
As an independent check of the model results, empirical return time estimates are also derived from the observations. As in Christidis and Stott (2020), nonstationarity is accounted for by removing the modeled forced response from the observa-

Table 1. Return time and risk ratio estimates from the CMIP5 analysis. Extremes in the warmest day in winter in central England have temperature anomalies above the +5.2°C threshold observed in winter 2018/19. Reported best estimates correspond to the 50th percentile and the 5%–95% uncertainty range is given in parentheses.

	Return time (yr)
Present day (2008–28)	1161 (740 to 5020)
Early twentieth century (1900–1920)	3.4×10^5 (5.7×10^4 to infinity)
Risk Ratio: Prob (present)/Prob (past)	282 (26 to infinity)
	Return time (yr)
Late twenty-first century (2080–2100)	64 (54 to 90)
Risk ratio: Prob (future)/Prob (past)	5136 (806 to infinity)

tional time series and then adjusting them to the mean forced response in different periods. Using the GEV distribution, it is estimated that the return time increases from ~10^5 years in the early twentieth century to 1400 years at present and 78.5 years by 2100. The observationally based estimates are hence in good agreement with the CMIP5 results.

(a) CMIP5 Attribution Analysis



(b) Different framing in attribution studies

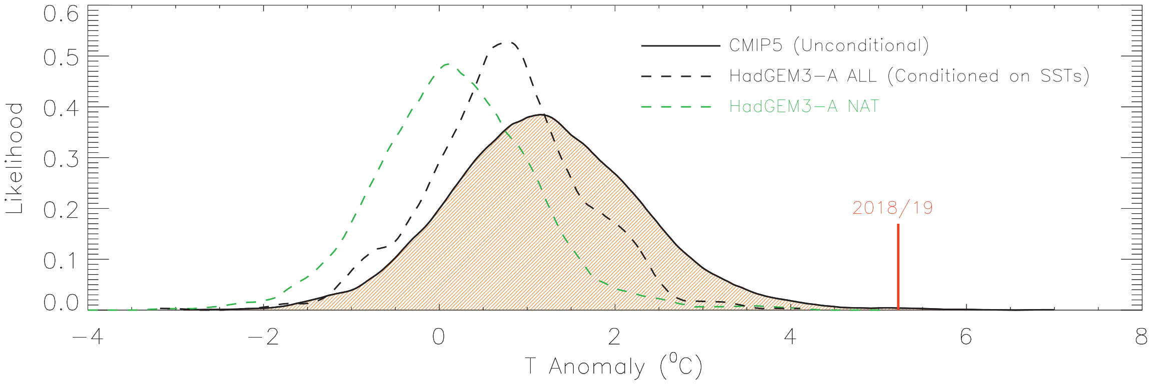


Fig. 2. (a) Normalized distributions of the warmest day in winter in central England constructed with CMIP5 data from the ALL simulations for the present climate (years 2008–28; solid line, filled curve), the climate of the early twentieth century (years 1900–1920; dashed line), and the climate of the late twenty-first century (years 2080–2100; dotted line). (b) The same CMIP5 distribution as in (a) is shown for the present climate (solid line, filled curve), together with the distribution constructed with HadGEM3-A data from the ALL (black dashed line) and NAT (green dashed line) simulations for the same period. The 2018/19 anomaly is marked by the red vertical line.

HadGEM3-A attribution.

A complementary analysis with ALL and NAT simulations of the winter 2018/19 produced by the HadGEM3-A attribution system of the Hadley Centre (Ciavarella et al. 2018) is also carried out. HadGEM3-A provides 525 simulations for each experiment and as it is an atmosphere-only model, it prescribes the oceanic state using HadISST observations (Rayner et al. 2003; also, see the online supplemental material). Like the CMIP5 ensemble, the model variance is also small and is corrected as described earlier. The sample size of simulated events is too small to compute the near-zero likelihood in the NAT climate. Unlike the CMIP5 analysis, it is also not feasible to estimate the probability in the ALL climate of 2018/19, since the HadGEM3-A distribution is narrower and thus the event lies farther into the warm tail (Fig. 2b). The use of a single model (HadGEM3-A) rather than a multimodel ensemble with a mixture of climate change sensitivities as well as the conditioning on the observed oceanic state may both contribute to the smaller spread of the distribution. As atmosphere–ocean coupled models sample the range of all possible states of the ocean, they may indeed yield a broader distribution than atmospheric models, providing a general probability estimate irrespective of the oceanic conditions.

Discussion.

Our study employs two methodologies that frame the attribution question in two different ways. The question in the multimodel CMIP5 analysis is “What is the likelihood of extremes with and without human influence in the general case (i.e. under any possible conditions)?”. On the other hand, the single-model HadGEM3-A analysis asks: “What is the likelihood, given the oceanic conditions at the time of the 2018/19 event?”. Both questions are valid and useful, but the two approaches can lead to different answers, as demonstrated in Fig. 2b. While a recent report by the United States National Academies of Sciences, Engineering, and Medicine (NASEM 2016) encouraged multimethod approaches in studies of extreme events, one should also be careful not to interpret apparent inconsistencies as limitations, when different methods may simply attempt to answer different questions. A more detailed assessment of the framing effect in event attribution is given in Christidis et al. (2018) and Fischer et al. (2018).

The CMIP5 analysis reveals that winter CET extremes like in 2018/19 are rare even in today’s warmer climate, but still about 300 times more likely because of human influence. Moreover, they are shown to become decidedly more common in the future, expected to occur at least once a century by 2100, and probably more frequently under higher emissions scenarios than RCP4.5. While the effect of the atmospheric circulation was key for the reference event, here we only consider an unconditional framing without explicitly assessing the effect of dynamics. Previous work has suggested that Arctic warming may impact U.K. extremes via dynamical changes (Hanna et al. 2017), although this link has not been robustly established (Blackport and Screen 2020). A possible strengthening of the Atlantic jet (Lee et al. 2019) may constitute another dynamical driver of winter changes. Taking the overall effect of anthropogenic climate change into account, milder winters are expected in the United Kingdom (Murphy et al. 2018), with less frequent cold extremes and new high temperature records.

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