EXPLAINING EXTREME EVENTS OF 2018

From a Climate Perspective

Special Supplement to the
Bulletin of the American Meteorological Society
Vol. 101, No. 1, January 2020

EXPLAINING EXTREME EVENTS OF 2018 FROM A CLIMATE PERSPECTIVE

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Bulletin of the American Meteorological Society

Vol. 101, No. 1, January 2020

AMERICAN METEOROLOGICAL SOCIETY

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COVER CREDIT: iStock.com/Alena Kravchenko—River Thames receded during a heatwave in summer 2018 in London, United Kingdom.

HOW TO CITE THIS DOCUMENT

Citing the complete report:

Herring, S. C., N. Christidis, A. Hoell, M. P. Hoerling, and P. A. Stott, Eds., 2020: Explaining Extreme Events of 2018 from a Climate Perspective. *Bull. Amer. Meteor. Soc.*, **101** (1), S1–S128, doi:10.1175/BAMS-ExplainingExtremeEvents2018.1.

Citing a section (example):

Mahoney, K., 2020: Extreme Hail Storms and Climate Change: Foretelling the Future in Tiny, Turbulent Crystal Balls? [in “Explaining Extremes of 2018 from a Climate Perspective”]. *Bull. Amer. Meteor. Soc.*, **101** (1), S17–S22, doi:10.1175/BAMS-D-19-0233.1.

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THE EXTREMELY COLD START OF THE SPRING OF 2018 IN THE UNITED KINGDOM

NIKOLAOS CHRISTIDIS AND PETER A. STOTT

Observational and model analyses suggest a 6- and 12-fold increase in the likelihood of extremely cold days in March in central England, as in year 2018, without anthropogenic climate change.

Red warnings, the U.K. Met Office's most severe and rare alerts, signaled the arrival of an anticipated deadly cold spell in the country in early March 2018.¹ Extremely cold conditions developed as a persistent easterly circulation, associated with a sudden stratospheric warming (Karpechko et al. 2018), steered a massive Arctic airmass toward the British Isles at the end of February 2018, where it collided with winter storm Emma in the first days of March. The combination of the storm with the frigid Siberian weather system, dubbed "the Beast from the East," led to freezing temperatures, blizzards, and heavy snow in excess of 50 cm on high ground. U.K. media widely reported on the substantial impacts of the extreme weather, including loss of life, business and travel disruptions, cancellation of hospital operations, food shortages, and several thousand car accidents with insurance costs of over £10 million.² Daily mean temperature time series from the Central England Temperature (CET) instrumental record (Parker et al. 1992) show a prominent dip at the start

of spring (Fig. 1a), making the first day of March markedly colder than all days in the preceding winter season. Sub-zero temperatures (in °C) were also observed later in the month during a less intense cold snap nicknamed the "Mini Beast from the East." Despite these extremely cold days, the month of March as a whole was not extreme, but had a mean temperature within the middle tercile of the post-1659 distribution based on the CET data. On the other hand, observational time series of the coldest day in March since 1772 have their fourth coldest value in 2018 (Fig. 1b). This study concentrates mainly on such low daily temperatures and defines extremely cold events as instances when the coldest day in March has a temperature lower than the one observed in 2018. Although heavy snowfall was another interesting aspect of the 2018 cold wave, the lack of long and reliable observations hinders a snowfall analysis, although this aspect will also be briefly considered using modeled data only. It should be noted that the time series shown in Fig. 1b have a positive long-term trend of 0.07°C decade⁻¹, suggesting that cold events are becoming rarer. Synoptic conditions over Europe in March 2018 are illustrated in Fig. 1c. The 500-hPa geopotential height (Z500) field from the NCEP–NCAR reanalysis (Kalnay et al. 1996) displays a large-scale cyclonic circulation southwest of the United Kingdom, transporting cold air from eastern Europe across the northern parts of the continent. Moreover, CRUTEM4 observations (Jones et al. 2012) reveal large cold anomalies over Russia where the cold air originated. This state of the atmosphere combined with the development of storm Emma and the influence of anthropogenic climate change are factors that made the event unique. Here, while the focus remains on the role of climate change, the contribution of the easterly circulation to cold events will also be assessed with modeled data, to help establish a link between circulation and extremes and compare it with the

¹ See <https://www.metoffice.gov.uk/climate/uk/interesting/february2018-snow>.

² See <https://www.theguardian.com/uk-news/2018/mar/01/beast-from-east-storm-emma-uk-worst-weather-years>.

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DOI:10.1175/BAMS-D-19-0084.1

A supplement to this article is available online (10.1175/BAMS-D-19-0084.2)

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FIG. 1. (a) Time series of the observed daily mean temperature in central England. (b) Time series of the coldest day in March in central England from observations. Temperatures are expressed as anomalies relative to the 1901–30 mean. The 2018 anomaly is marked by the red dotted line. The orange line represents the forced response derived from CMIP5 simulations. (c) NCEP–NCAR Z500 anomalies (contours) and CRUTEM4 monthly mean temperature anomalies (colored grid boxes) in March 2018. Anomalies are relative to the period 1961–90. (d) Normalized distributions of the return time of extremely cold events estimated from CET observations for the present-day (red histogram) and natural (blue histogram) climate. The best estimate (50th percentile) is marked by the vertical lines.

anthropogenic impact. The attribution study follows the popular risk-based approach (Stott et al. 2016), whereby the likelihood of extreme events is estimated in the present-day climate and in a hypothetical “natural” world without any human influence on the climate. The risk ratio measuring the anthropogenic effect is subsequently computed as the ratio of the two likelihood estimates. Two analyses are carried out, one with the CET observational data and one using simulations with 18 models that contributed data to the phase 5 of the Coupled Model Intercomparison Project (CMIP5; see the supplemental material).

OBSERVATIONAL ANALYSIS. Empirical event attribution assessments can be derived from observational data (van Oldenborgh 2007). The main assumption

of this methodology is that the non-stationarity in long records is primarily driven by anthropogenic influence and needs to be accounted for, such as by allowing the position parameter of an extreme distribution to vary with the global mean temperature (Kew et al. 2019). CET temperature anomalies of the coldest day in March since 1900 are used here. The anthropogenic component is represented independently by the mean of 39 CMIP5 simulations of the historical climate extended to future years with the RCP4.5 scenario (orange line in Fig. 1b). The anthropogenic component is then removed from the observations and the remaining time series represent the natural climate. The accuracy of this approximation depends on how well the CMIP5 models simulate the forced response. A Kolmogorov–Smirnov test indicates

that the distribution of the coldest day in March in our representation of the natural climate is not significantly different (p value: 0.3) from the one based on a multimodel ensemble of CMIP5 simulations without anthropogenic forcings (see Table ES1 in the supplemental material).

To get a representation of the present-day climate, the natural time series are adjusted to the mean anthropogenic response in period 2008–28. The GEV distribution is then applied to the two time series data and the likelihoods of cold events with anomalies below the one in 2018 (-5°C) are estimated for the present day and the natural world, while a Monte Carlo bootstrap procedure (Christidis et al. 2013) is employed to estimate the uncertainties. Distributions of the return time (inverse probability) of cold events are illustrated in Fig. 1d. Human influence is estimated to increase the return time from 77 (37–478)³ years to 432 (109 to >103) years. The probability of cold events without the effect of human influence increases by 5.84 (best estimate). However, as the observational sample is relatively small to provide the estimate the low present-day probability of cold extremes, the associated uncertainty in the risk ratio is large (Fig. 2a).

CMIP5 ANALYSIS. Ensembles of 39 and 49 simulations with and without the effect of human influence generated by the 18 CMIP5 models (see the supplemental material) are used next

to estimate the change in the risk of cold events. Temperature anomalies of the coldest day in March in central England (0° – 3°E , 51° – 54°N) are computed for each simulated year. Common model evaluation assessments against the observations (Christidis

FIG. 2. (a) Risk ratio estimates measuring the change in the likelihood of cold extremes without anthropogenic forcings estimated with observations (left) and CMIP5 models (middle). The change in the likelihood under easterly circulation is shown on the right. The best estimates are represented by crosses and the 5%–95% range by whiskers. Also shown are normalized distributions of (b) the coldest day in March and (c) the total snow amount in central England constructed with CMIP5 data for the present climate (solid line; colored distribution), the early twentieth century (dashed line), and the end of the twenty-first century (dotted line). The 2018 event is marked in (b) and a 1-in-50-yr event in the natural climate is marked in (c). Anomalies are relative to 1901–30.

³ The 5%–95% uncertainty range in return time estimates is reported in parentheses.

et al. 2013; Vautard et al. 2019) show that the models represent well the observed variability and long-term trend in the coldest day in March. More specifically a trend analysis, power spectra, and a quantile–quantile (Q-Q) plot are employed and provide strong evidence that the simulated trends, variability, and distribution of the coldest day in March are consistent with the CET observations (supplemental material). The likelihood of cold extremes in the natural world is estimated from all the simulated years provided by the ensemble without the effect of anthropogenic forcings. The present-day likelihood is estimated from simulations with all forcings, which are processed the same way as the CET data in the observational analysis. In this approach, the estimate of the forced response is removed from each simulation and the remaining time series are adjusted to the 2008–28 mean response. As before, probability estimates are calculated with the generalized extreme value (GEV) distribution and uncertainties with the Monte Carlo bootstrapping procedure (resampling with replacement 1000 times). Cold extremes are found to be 12.33 times more likely without human influence (Fig. 2a) and human influence is estimated to increase the return time from 108 (92–133) years to 1307 (1039–2815) years. Compared to the observational analysis, the CMIP5 methodology yields smaller uncertainties in the estimated probabilities and risk ratio, as it relies on larger samples. Temporal changes in the distribution of the coldest day in March are illustrated in Fig. 2b. Using data from simulations with all forcings, the distributions are constructed for three different periods: the early twentieth century (1900–20), the present climate (2008–28), and the end of the twenty-first century (2080–2100). As the climate warms, the 2018 anomaly moves farther into the cold tail and becomes extremely unlikely by the end of the century. To test the effect of the persistent easterly circulation on cold extremes, simulated data of the present-day climate were sub-sampled (Christidis et al. 2018) to represent years when the circulation in March matches the one in 2018 (Fig. 1c) and years when it does not. Correlations with the Z500 pattern in March 2018 above 0.6 indicate a similar easterly circulation. In total, there are 289 events with high-correlation patterns and 2363 events with low-correlation patterns. The persistence of the circulation pattern following a sudden stratospheric warming justifies the use of the monthly mean Z500 pattern, instead of the circulation pattern during the actual coldest days, as in the work by Cattiaux et al. (2010). Therefore, the attribution question asked here is what is the change in the likelihood of cold events in months with persistent

flow from the European continent over the United Kingdom. By computing the likelihood of cold events in months with high and low correlation patterns, it is estimated that the presence of this circulation pattern increases the chance of cold extremes by a factor of 11.80 (Fig. 2a), although the uncertainty range is larger than the one estimated for the anthropogenic effect, because the sample size is reduced by sub-sampling. Finally, modeled distributions of the total snow (Fig. 2c) are found to shift to smaller amounts as the climate warms and tend to form a second peak at lower values, as snow-free years increase. The models suggest that snow events that occurred once every 50 years in the natural climate have almost zero probability by the end of the century. An accelerated decrease in snow over Europe in recent decades has been seen in observations (Fontrodona Bach et al. 2018), while differences between changes in mean and extreme snowfall have also been suggested (O’Gorman 2014).

CONCLUSIONS. Extremely cold daily temperatures in England, as in March 2018, are found to have become less frequent. The observational analysis gives a smaller present-day probability of cold extremes than the CMIP5 models, but as it relies on a smaller data sample, the probability estimate is more uncertain. Although changes in the circulation are expected to be less influenced by anthropogenic forcings than changes in the thermodynamic state (Trenberth et al. 2015), stratospheric warming events, like the one that triggered the 2018 cold wave, have been suggested to become more common in a warmer world (Kang and Tziperman 2017). However, U.K. seasons are still projected to become warmer during the course of the century (Murphy et al. 2018).

ACKNOWLEDGMENTS. This work was supported by the Met Office Hadley Centre Climate Programme funded by BEIS and Defra and the EUPHEME project, which is part of ERA4CS, an ERA-NET initiated by JPI Climate and co-funded by the European Union (Grant 690462).

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