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

Editors

Stephanie C. Herring, Nikolaos Christidis, Andrew Hoell,
Martin P. Hoerling, and Peter A. Stott

BAMS Special Editors for Climate

Andrew King, Thomas Knutson,
John Nielsen-Gammon, and Friederike Otto

Special Supplement to the

Bulletin of the American Meteorological Society

Vol. 101, No. 1, January 2020

AMERICAN METEOROLOGICAL SOCIETY

CORRESPONDING EDITOR:

Stephanie C. Herring, PhD
NOAA National Centers for Environmental Information
325 Broadway, E/CC23, Rm 1B-131
Boulder, CO, 80305-3328
E-mail: stephanie.herring@noaa.gov

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.

TABLE OF CONTENTS

1. The Extreme 2018 Northern California Fire Season	1
2. Anthropogenic Impacts on the Exceptional Precipitation of 2018 in the Mid-Atlantic United States	5
3. Quantifying Human-Induced Temperature Impacts on the 2018 United States Four Corners Hydrologic and Agro-Pastoral Drought	11
4. Extreme Hail Storms and Climate Change: Foretelling the Future in Tiny, Turbulent Crystal Balls?	17
5. The Extremely Cold Start of the Spring of 2018 in the United Kingdom.....	23
6. The Exceptional Iberian Heatwave of Summer 2018	29
7. Analyses of the Northern European Summer Heatwave of 2018.....	35
8. Anthropogenic Influence on the 2018 Summer Warm Spell in Europe: The Impact of Different Spatio-Temporal Scales	41
9. On High Precipitation in Mozambique, Zimbabwe and Zambia in February 2018.....	47
10. The Record Low Bering Sea Ice Extent in 2018: Context, Impacts, and an Assessment of the Role of Anthropogenic Climate Change	53
11. The Late Spring Drought of 2018 in South China.	59
12. Anthropogenic Influence on 2018 Summer Persistent Heavy Rainfall in Central Western China	65
13. Conditional Attribution of the 2018 Summer Extreme Heat over Northeast China: Roles of Urbanization, Global Warming, and Warming-Induced Circulation Changes	71
14. Effects of Anthropogenic Forcing and Natural Variability on the 2018 Heatwave in Northeast Asia.	77
15. Anthropogenic Influences on the Persistent Night-Time Heat Wave in Summer 2018 over Northeast China	83
16. Anthropogenic Contributions to the 2018 Extreme Flooding over the Upper Yellow River Basin in China	89
17. Attribution of the Record-Breaking Consecutive Dry Days in Winter 2017/18 in Beijing	95
18. Quantifying Human Impact on the 2018 Summer Longest Heat Wave in South Korea	103
19. The Heavy Rain Event of July 2018 in Japan Enhanced by Historical Warming.	109
20. Deconstructing Factors Contributing to the 2018 Fire Weather in Queensland, Australia	115
21. A 1-Day Extreme Rainfall Event in Tasmania: Process Evaluation and Long Tail Attribution	123

ANTHROPOGENIC INFLUENCES ON THE PERSISTENT NIGHT-TIME HEAT WAVE IN SUMMER 2018 OVER NORTHEAST CHINA

LIWEN REN, DONGQIAN WANG, NING AN, SHUOYI DING, KAI YANG, RONG YU,
NICOLAS FREYCHET, SIMON F. B. TETT, BUWEN DONG, AND FRASER C. LOTT

Persistent night-time heat waves like the event of summer 2018 in Northeast China are extremely rare (about a one-in-a-500-year event) in the natural world, but now have become about a one-in-60-year event with anthropogenic warming.

In the summer of 2018, Northeast China was affected by an unprecedentedly long and intense heat wave. The China Meteorological Administration issued 33 days of consecutive “high temperature-alert” warnings from 14 July to 15 August in 2018. Record-breaking hot minimum temperatures were observed in a large area of Northeast China (34°–55°N, 105°–135°E) with a stable spatial pattern on time scales of 20–40 days (Fig. 1a; see also Fig. ES1 in the online supplemental material). Further, minimum temperatures were more extreme, with a much larger record-breaking area than maximum temperatures (Fig. ES1). On 30 July, the number of heat-related hospitalization admissions broke the historical record in Shenyang, a large city in Northeast China (<http://news.lnd.com.cn/system/2018/08/01/000008645.shtml>). The aquaculture industry in Liaoning Province suffered from economic loss of 6.87 billion renminbi (RMB) (www.zhonghongwang.com/show-256-103674-1.html).

Thus, this unprecedented persistent and extreme heat wave event led to severe impacts, including increased human morbidity and mortality, reduced agriculture productivity, and increased strain on power systems and water supplies.

Anthropogenic warming has been shown to drive recent record-breaking heat and summer extremes in different regions of the world (Hansen et al. 2012; Lewis and Karoly 2013). Previous heat event attribution studies in China usually considered seasonal mean and maximum temperature covering a fixed period (e.g., Sun et al. 2016a; Ma et al. 2017), with few studies focusing on consecutive minimum temperatures when there is the strongest signal in summer. Daily minimum temperature allows people and ecosystems to recover from thermal stresses experienced during the previous day (Schwartz 2005) and is a strong predictor for human morbidity and mortality (Laaïdi et al. 2012; Madrigano et al. 2015; Murage et al. 2017). Previous studies show that anthropo-

AFFILIATIONS: REN—State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, and University of Chinese Academy of Sciences, Beijing, China; WANG—National Climate Center, China Meteorological Administration, Beijing, China; AN AND YU—State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing, China; DING—Department of Atmospheric and Oceanic Sciences, Institute of Atmospheric Sciences, Fudan University, Shanghai, China; YANG—State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, and Key Laboratory of Meteorological Disaster (KLME), Ministry of Education and Collaborative Innovation Center on Forecast and Evaluation of Meteorological Disasters (CIC-FEMD), Nanjing

University of Information Science and Technology, Nanjing, China; FREYCHET AND TETT—School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom; DONG—National Centre for Atmospheric Science, Department of Meteorology, University of Reading, Reading, United Kingdom; LOTT—Met Office Hadley Centre, Exeter, United Kingdom

CORRESPONDING AUTHOR: Dr. Dongqian Wang, wangdq@cma.gov.cn

DOI:10.1175/BAMS-D-19-0152.1

A supplement to this article is available online (10.1175/BAMS-D-19-0152.2)

© 2020 American Meteorological Society

For information regarding reuse of this content and general copyright information, consult the [AMS Copyright Policy](#).

genic influences, including anthropogenic emission of greenhouse gases and urbanization leading to the expansion of urban heat islands, has contributed to higher summer minimum temperatures in Eastern China (Sun et al. 2016b; Wang et al. 2017). Hence, this study aims to investigate whether anthropogenic influences have increased the frequency of the monthly time scale heat waves like the summer 2018 event over Northeast China.

DATA AND METHODS. *Observations.* We used observed daily minimum temperatures at about 2,400 meteorological stations over China for the period 1961–2018. These were quality-controlled and homogenized by National Meteorological Information

Center of China (Ren et al. 2012). We also used daily atmospheric circulation field data from ERA-Interim (Dee et al. 2011), including geopotential height, horizontal wind, and specific humidity.

Model. Simulations from the atmosphere model HadGEM3-A-N216 at a horizontal resolution of $0.56^\circ \times 0.83^\circ$ were used in this study (Christidis et al. 2013; Ciavarella et al. 2018). Three ensembles were used:

- An 15-member ensemble of simulations for period 1960–2013, in which the model is forced by observed sea surface temperatures (SST) and sea ice concentrations (SIC) from HadISST (Rayner et al. 2003), and a comprehensive package of historical anthropogenic atmospheric forcing (Historical).
- A 525-member ensemble of simulations for 2018 only (counterfactual world), driven with pre-industrial atmospheric forcing and the anthropogenic contribution removed from SST and SIC (HistoricalNatExt; see the online line supplemental information for details).
- A second 525-member ensemble of simulations (factual world), driven as for “Historical” but for 2018 only (HistoricalExt).

Event definition. An index of 30-day moving average of daily minimum temperature anomalies (TNx30) over the study area was defined. First, to remove the seasonal cycle at each station, daily minimum temperature ($T_{\min}$) anomalies relative to the daily 1961–2013 climatology were computed in each calendar day. We then gridded these anomalies to the $0.56^\circ \times 0.83^\circ$ model resolution by averaging all station anomalies in each grid box. The gridded $T_{\min}$ anomalies were then area averaged over Northeast China (34° – 55° N,

FIG. 1. Observed characteristics of the heat wave in Northeast China during 12 Jul–10 Aug 2018, with maximum consecutive 30-day $T_{\min}$ anomalies in summer 2018 (TNx30). (a) Spatial pattern of TNx30 (shading; unit: $^\circ\text{C}$) relative to 1961–2013. Locations with record-breaking and second highest values since 1961 are shown with black and blue dots, respectively. (b) Time series of TNx30 anomalies over Northeast China (black rectangle shown in Fig. 1a) from 1961 to 2018. (c) Circulation field from ERA-Interim with specific humidity anomalies (shading; unit: g kg^{-1}) and 850-hPa moisture flux anomalies (vectors). The light black contours denote the 500-hPa geopotential height anomalies. The 12 Jul–10 Aug 2018 mean geopotential height (blue lines) and climatology (red lines) are also shown.

105°–135°E), and finally used to calculate the hottest 30-day running mean $T_{\min}$ in summer (June–August) for each year. For model datasets, the same process was followed except rather than gridding the simulations, grid points were used only if they were land and there were observations in the grid box. The anomaly of the index TNx30 in summer was used in this study and the value of 2018 event (2.15°C) was chosen as the threshold.

To estimate probabilities, generalized extreme value (GEV) distributions were fitted to both simulated and observed data. A two-sided Kolmogorov–Smirnov (K-S) test was then applied to test if the distributions of the observations and historical simulations from 1961 to 2013 are from the same population. To estimate the anthropogenic contribution to the heat wave event like 2018 summer in Northeast China, the risk ratio (National Academies of Sciences, Engineering, and Medicine 2016) defined as $P(\text{HistoricalExt})/P(\text{HistoricalNatExt})$ was calculated, where $P(\text{HistoricalExt})$ and $P(\text{HistoricalNatExt})$ are the probability of the event in factual and counterfactual world, respectively. We bootstrapped with replacement 1,000 times to generate PDFs, and then computed 1,000 risk ratios and then used that to compute uncertainties in risk ratios.

RESULTS. Observed events and model performance.

In summer 2018, the regional average of TNx30 over Northeast China was 3 standard deviations of interannual variability above the 1961–2013 climatology and the highest on record since at least 1961 (Fig. 1b). This heat wave was accompanied by positive geopotential height anomalies over Northeast Asia, induced by the unprecedented northward shift of the western Pacific subtropical high (Fig. 1c; Liu et al. 2019). At low levels (850 hPa), anomalous northwestward moisture transportation from the warm Bohai Sea resulted in increased specific humidity (Fig. 1c) and consequently contributed to significant nighttime warming.

Model performance was evaluated using the ensemble mean of the historical ensemble, which reasonably reproduced the time series of TNx30 anomalies, with a correlation coefficient of 0.70 (Fig. 2a). This means that forcing, SST, and SIC variations explain about half of the observed variance in TNx30. The distributions of observed and simulated TNx30 for summers during 1961–2013 are also statistically indistinguishable based on the K-S test ($p = 0.80$; Fig. 2b). Such good performance of the HadGEM3-A-N216 simulations provides the basis for further attribution analysis.

Anthropogenic impact on the risk of heat waves. There is a shift of the PDF to warm anomalies from HistoricalNatExt to HistoricalExt (Fig. 2c), indicating that anthropogenic influences have increased the probability of heat wave events. Since the magnitude of this event lies at the far warm-end tail of PDF, events like 2018 are very rare in the counterfactual world. Only one member in 525-member HistoricalNatExt ensemble exceeds the 2018 threshold. By contrast, the estimated probability is 0.02 in factual world. These indicate that the 2018-like night-time heat event is extremely rare without anthropogenic warming. The estimated return period of heat wave events hotter than 2018 is about one-in-60-years with anthropogenic warming, with 5th–95th percentile uncertainty ranges of 43–116 years (Fig. 2d). A second threshold was also selected, defined as the second-most extreme year (2017, with an anomaly of 1.55°C). For this threshold, the heatwave is 57 times more frequent in the factual world ($P(\text{HistoricalExt}) = 0.17$) than the counterfactual world [$P(\text{HistoricalNatExt}) = 0.003$], which confirms the role of anthropogenic warming in these heat events. In terms of return period, for a one-in-10-year event, the magnitude of TNx30 in 2018 is estimated to be 1.7°C (1.7°–1.8°; 5th–95th) in the factual world, and 0.8°C (0.8°–0.9°; 5th–95th) in the counterfactual world (Fig. 2d). For a one-in-50-year event, the estimated magnitude of a heat event is 2.1° (2.0°–2.2°) and 1.2°C (1.1°–1.3°) in the counterfactual and factual worlds (Fig. 2d). The change in return level (0.9°C) between counterfactual and factual simulations is generally consistent with mean warming, as the shift in mean state between with (0.95°C) and without (–0.04°C) anthropogenic influence was 0.99°C (Fig. 2c). Besides, the uncertainty range of return periods increases with the rarity of events. We repeat our analyses by using different durations of either a 20-day or 40-day moving average and find similar risk ratio, suggesting the robustness of the results.

CONCLUSIONS AND DISCUSSION. Northeast China experienced a record-breaking nighttime heat wave in 2018 summer. This kind of 30-day nighttime heatwave was a one-in-500-year (or less) event in the counterfactual world. Forced by anthropogenic forcing and the observed 2018 SSTs, it became a one-in-60-year event.

This unprecedentedly long-lasting nighttime heat wave was also related to the northwestward shift of west Pacific subtropical high and the anomalous moisture transportation from the warm ocean. Additionally, the configuration of anomalous anticyclone

FIG. 2. (a) Time series of observed (black) and simulated ensemble mean (red) of TNx30 anomalies, with 15-member spread shown as light pink shading. (b) Histograms and GEV-fit probability density function of TNx30 anomalies in observations (black line and gray bars) and historical simulations (red line and light pink bars) from 1961 to 2013. (c) Histograms and GEV-fit probability density function (PDF) of TNx30 anomalies in 2018 summer with 525-member HistoricalExt (red) and HistoricalNatExt (blue) simulations. The black lines indicate the TNx30 thresholds of 2018 and 2017. (d) As in (c), but for return periods. Dash-dotted lines indicate the 5th–95th uncertainty range based on 1,000 bootstrap resamples for all-forcing (red) and natural-forcing (blue).

at 500 hPa over Northeast Asia during this heat event was reproduced with the six hottest simulations in study region (Fig. ES2), confirming the role of abnormal high pressure system in this heat wave event. As increased occurrence of anticyclonic circulations in the midlatitudes has made a substantial contribution (one-third to one-half) to the increased summertime temperature extremes over portions of Eurasia since 1979 (Horton et al. 2015), which leaves further questions as to whether anthropogenic warming has contributed to the heat waves like that in summer 2018 through affecting the background circulation. This study used an atmospheric model conditioned on the observed SSTs. Results are inevitably affected by uncertainty in the representation on the SSTs in the counterfactual world, especially for severe events

with return periods greater than 50 years (e.g., Sparrow et al. 2018), and more work is necessary to better understand this uncertainty.

ACKNOWLEDGMENTS. This study was largely carried out during a workshop on Operational Attribution at the National Climate Centre sponsored by the U.K.–China Research and Innovation Partnership Fund through the Met Office Climate Science for Service Partnership (CSSP) China as part of the Newton Fund and the National Key Research and Development Program (2018YFC1507702). LR, NA, SD, and KY were supported by the National Key Research and Development Program (2018YFC1507701), the National Natural Science Foundation of China (41822503, 41730959, 41790472), National Key Basic Research Project of China (2015CB453200), and Open Research Fund

Program of Key Laboratory of Meteorological Disaster of Ministry of Education (Nanjing University of Information Science and Technology) Grant KLME201806. NF, SFBT, BD (through the RICHES project), and FCL were supported by the U.K.–China Research and Innovation Partnership Fund through the Met Office Climate Science for Service Partnership (CSSP) China as part of the Newton Fund.

REFERENCES

- Christidis, N., P. A. Stott, A. 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. Climate*, **26**, 2756–2783, <https://doi.org/10.1175/JCLI-D-12-00169.1>.
- Ciavarella, A., and Coauthors, 2018: Upgrade of the HadGEM3-A based attribution system to high resolution and a new validation framework for probabilistic event attribution. *Wea. Climate Extremes*, **20**, 9–32, <https://doi.org/10.1016/J.WACE.2018.03.003>.
- Dee, D. P., and Coauthors, 2011: The ERA-Interim reanalysis: Configuration and performance of the data assimilation system. *Quart. J. Roy. Meteor. Soc.*, **137**, 553–597, <https://doi.org/10.1002/qj.828>.
- Hansen, J., M. Sato, and R. Ruedy, 2012: Perception of climate change. *Proc. Natl. Acad. Sci. USA*, **109**, E2415–E2423, <https://doi.org/10.1073/PNAS.1205276109>.
- Horton, D. E., N. C. Johnson, D. Singh, D. L. Swain, B. Rajaratnam, and N. S. Diffenbaugh, 2015: Contribution of changes in atmospheric circulation patterns to extreme temperature trends. *Nature*, **522**, 465–469, <https://doi.org/10.1038/nature14550>.
- Laaidi, K., A. Zeghnoun, B. Dousset, P. Bretin, S. Vandentorren, E. Giraudet, and P. Beaudeau, 2012: The impact of heat islands on mortality in Paris during the August 2003 heat wave. *Environ. Health Perspect.*, **120**, 254–259, <https://doi.org/10.1289/ehp.1103532>.
- Lewis, S. C., and D. J. Karoly, 2013: Anthropogenic contributions to Australia's record summer temperatures of 2013. *Geophys. Res. Lett.*, **40**, 3705–3709, <https://doi.org/10.1002/grl.50673>.
- Liu, B., C. Zhu, J. Su, S. Ma, and K. Xu, 2019: Record-breaking northward shift of the western North Pacific subtropical high in July 2018. *J. Meteor. Soc. Japan*, **97**, 913–925, <https://doi.org/10.2151/JMSJ.2019-047>.
- Ma, S., T. Zhou, D. A. Stone, O. Angelil, and H. Shiogama, 2017: Attribution of the July–August 2013 heat event in Central and Eastern China to anthropogenic greenhouse gas emissions. *Environ. Res. Lett.*, **12**, 054020, <https://doi.org/10.1088/1748-9326/aa69d2>.
- Madrigano, J., Ito, K., Johnson, S., Kinney, P. L., Matte, T., 2015: A case-only study of vulnerability to heat wave–related mortality in New York City (2000–2011). *Environ. Health Perspect.*, **123**, 672–678, <https://doi.org/10.1289/EHP.1408178>.
- Murage, P., S. Hajat, and R. S. Kovats, 2017: Effect of night-time temperatures on cause and age-specific mortality in London. *Environ. Epidemiol.*, **1**, e005, <https://doi.org/10.1097/EE9.0000000000000005>.
- National Academies of Sciences, Engineering, and Medicine, 2016: Attribution of Extreme Weather Events in the Context of Climate Change. National Academies Press, 186 pp., <https://doi.org/10.17226/21852>.
- Rayner, N. A., D. E. Parker, E. B. Horton, C. K. Folland, L. V. Alexander, D. P. Rowell, E. C. Kent, and A. Kaplan, 2003: Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J. Geophys. Res.*, **108**, 4407, <https://doi.org/10.1029/2002JD002670>.
- Ren, Z., Y. Yu, F. Zou, and Y. Xu, 2012: Quality detection of surface historical basic meteorological data (in Chinese). *J. Appl. Meteor. Sci.*, **23**, 739–747.
- Schwartz, J., 2005: Who is sensitive to extremes of temperature? A case-only analysis. *Epidemiology*, **16**, 67–72, <https://doi.org/10.1097/01.ede.0000147114.25957.71>.
- Sparrow, S., and Coauthors, 2018: Attributing human influence on the July 2017 Chinese heatwave: the influence of sea-surface temperatures. *Environ. Res. Lett.*, **13**, 114004, <https://doi.org/10.1088/1748-9326/aae356>.
- Sun, Y., L. Song, H. Yin, B. Zhou, T. Hu, X. Zhang, and P. A. Stott, 2016a: Human influence on the 2015 extreme high temperature events in western China [in “Explaining Extreme Events of 2015 from a Climate Perspective”]. *Bull. Amer. Meteor. Soc.*, **97** (12), S102–S106, <https://doi.org/10.1175/BAMS-D-16-0158.1>.
- Sun, Y., X. Zhang, G. Ren, F. W. Zwiers, and T. Hu, 2016b: Contribution of urbanization to warming in China. *Nat. Climate Change*, **6**, 706–709, <https://doi.org/10.1038/nclimate2956>.
- Wang, J., Z. Yan, X. W. Quan, and J. Feng, 2017: Urban warming in the 2013 summer heat wave in eastern China. *Climate Dyn.*, **48**, 3015–3033, <https://doi.org/10.1007/s00382-016-3248-7>.