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Anthropogenic influences on the persistent night-time heat wave in summer 2018 over North-East China

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Capsule summary

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

Introduction

In the summer of 2018, North-East 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 14th July to 15th August in 2018. Record-breaking hot minimum temperatures were observed in a large area of North-East China (34°N-55°N, 105°E-135°E) with a stable spatial pattern on timescales of 20-40 days (Fig. 1a, S1). Further, minimum temperatures were more extreme, with a much larger record-breaking area than maximum temperatures (Fig. S1). On the 30th 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 RMB (https://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 (CMA 2018).

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 et al., 2016). Previous heat event attribution studies in China usually considered seasonal mean and maximum temperature covering a fixed period (e.g., Sun et al., 2016; 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 et al. 2005) and is a strong predictor for human morbidity and mortality (Laaidi et al. 2012; Madrigano et al. 2015; Murage et al. 2017). Previous studies show that anthropogenic 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. 2014; 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 2400 meteorological stations over China for the period 1961-2018. These were quality-controled 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, 2010), including geopotential height, horizontal wind and specific humidity.

Model

Simulations from the atmosphere model HadGEM3-A-N216 at a horizontal resolution of 0.56°×0.83° 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 preindustrial atmospheric forcing and the anthropogenic contribution removed from SST and SIC (HistoricalNatExt. See SI for details).

- A second 525-member ensemble of simulations (factual world), driven with the same as “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 (Tmin) anomalies relative to the daily 1961-2013 climatology were computed in each calendar day. We then gridded these anomalies to the 0.56°×0.83° model resolution by averaging all station anomalies in each grid box. The gridded Tmin anomalies were then area averaged over North-East China (34°N-55°N, 105°E-135°E), and finally used to calculate the hottest 30-day running mean Tmin 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-side Kolmogorov-Smirnoff 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 North-East China, the risk ratio (National Academies of Sciences, Engineering, and Medicine 2016) defined as P(HistoricalExt)/P(HistoricalNatExt) was calculated, where P(HistoricalExt) and P(HistoricalNatExt) are the probability of the event in factual and counterfactual world, respectively. We bootstrapped with replacement 1000 times to generate PDFs, and then computed 1000 risk ratios and then used that to compute uncertainties in risk ratios.

3. Results

3.1 Observed events and model performance

In summer 2018, the regional average of TNx30 over North-East China was 3 standard deviations of inter-annual 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 (850hPa), anomalous northwestward moisture transportation from the warm Bohai Sea resulted in increased specific humidity (Fig. 1c) and consequently contributed to significant night-time 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 explains 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 K-S test (p=0.80, Fig. 2b). Such good performance of the HadGEM3-A-N216 simulations provides the basis for further attribution analysis.

3.2 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 5^{th}-95^{th} 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(HistoricalExt) = 0.17) than the counterfactual world (P(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, 5^{th}-95^{th}) in the factual world, and 0.8 °C (0.8-0.9 5^{th}-95^{th}) in the counterfactual world (Fig. 2d). For a one-in-50-year event, the estimated magnitude of a heat event is 2.1°C (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 20 day or 40 day moving average and find similar risk ratio, suggesting the robustness of the results.

4. Conclusions and discussion

North-East China experienced a record-breaking night-time heat wave in 2018 summer. This kind of 30-day night-time 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 night-time 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 at 500-hPa over Northeast Asia during this heat event was reproduced with the six hottest simulations in study region (Fig S2), confirming the role of abnormal high-pressure system in this heat wave event. As increased occurrence of anticyclonic circulations in the mid-latitude 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), this leaves further questions whether anthropogenic warming has contributed to the heat waves like 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 period greater than 50 years (e.g., Sparrow et al. 2018), and more work is necessary to better understand this uncertainty.

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Reference

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., N. Christidis, M. Andrews, M. Groenendijk, J. Rostron, M. Elkington, C. Burke, F. C. Lott, and P. A. Stott, 2018: Upgrade of the HadGEM3-A based attribution system to high resolution and a new validation framework for probabilistic event attribution, Weather and Climate Extremes, 20, 9-32, doi: 15110.1016/j.wace.2018.03.003.

Dee, D. P., and Coauthors, 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system J. Roy.Meteor. Soc. 137 553–97

Habeeb D, Vargo J, Stone B., 2015: Rising heat wave trends in large US cities, Natural Hazards, 2015, 76(3): 1651-1665.

Hansen, J., M. Sato, and R. Ruedy, 2012: Perception of climate change, Proc. Natl. Acad. Sci. U. S. A., 109(37), E2415–E2423, doi:10.1073/ PNAS.1205276109.

Horton, D. E., Johnson, N. C., Singh, D., Swain, D. L., Rajaratnam, B., & Diffenbaugh, N. S.,2015: Contribution of changes in atmospheric circulation patterns to extreme temperature trends. Nature, 522(7557), 465.

Laaidi K, Zeghnoun A, Dousset B, Bretin P, Vandentorren S, Giraudet E, Beaudeau P , 2012: The impact of heat islands on mortality in Paris during the August 2003 heat wave. Environ Health Perspect 120:254–259

Lewis, S. C., Karoly, D. J, 2013: Anthropogenic contributions to Australia's record summer temperatures of 2013. Geophysical Research Letters, 40(14), 3705-3709.

Liu, B., Zhu, C., Su, J., Ma, S., Xu, K., 2019: Record-Breaking Northward Shift of the Western North Pacific Subtropical High in July 2018. Journal of the Meteorological Society of Japan. Ser. II., 10.2151/jmsj.2019-047

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). Environmental health perspectives, 123(7), 672-678. 11(11): 114009, doi:210 10.1088/1748-9326/11/11/114009.mate Change, 6(7), 706.

Ma, S., Zhou, T., Stone, D.A., Angelil, O., Shiogama, H., 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/aa69d

Murage, P., Hajat, S., & Kovats, R. S., 2017: Effect of night-time temperatures on cause and age-specific mortality in London. Environmental Epidemiology, 1(2), e005.

National Academies of Sciences, Engineering, and Medicine 2016 Attribution of Extreme Weather Events in the Context of Climate Change (Washington,DC: The National Academies Press) (https://doi.org/10.17226/21852)

Ren, Z., Yu, Y., Zou, F., Xu, Y., 2012: Quality Detection of Surface Historical Basic Meteorological Data. Journal of Applied Meteorological Science, 23(6), 739-747.

Schwartz J., 2005: Who is sensitive to extremes of temperature? A case-only analysis. Epidemiology 16:67–72.

Sparrow S., Q. Su, F. Tian, S. Li, Y. Chen, W. Chen, F. Luo, N. Freychet, F. Lott, B. Dong, S. F. B. Tett, D. Wallom, 2018: Attributing human influence on the July 2017 Chinese heatwave: the influence of sea-surface temperatures. Environmental Research Letters, 13(11), 114004.

Sun, Y., Zhang, X., Ren, G., Zwiers, F. W., Hu, T., 2016: Contribution of urbanization to warming in China. Nature Climate Change, 6(7), 706.

Sun, Y., Song, L., Yin, H., Zhou, B., Hu, T., Zhang, X., Stott, P. A., Zhou B., Hu T., 2016: Human influence on the 2015 extreme high temperature events in western china. Bulletin of the American Meteorological Society, 97(12), S102–S106.

Vautard, R., P. Yiou, F. Otto, P. Stott, N. Christidis, G. J. van Oldenborgh, and N.Schaller, 2016: Attribution of human-induced dynamical and thermodynamical contributions in extreme weather events. Environ. Res. Lett, **11(11)**: 114009, doi:210 10.1088/1748-9326/11/11/114009.

Wang, J., Yan, Z., Quan, X. W., Feng, J., 2017: Urban warming in the 2013 summer heat wave in eastern China. Climate dynamics, 48(9-10), 3015-3033.

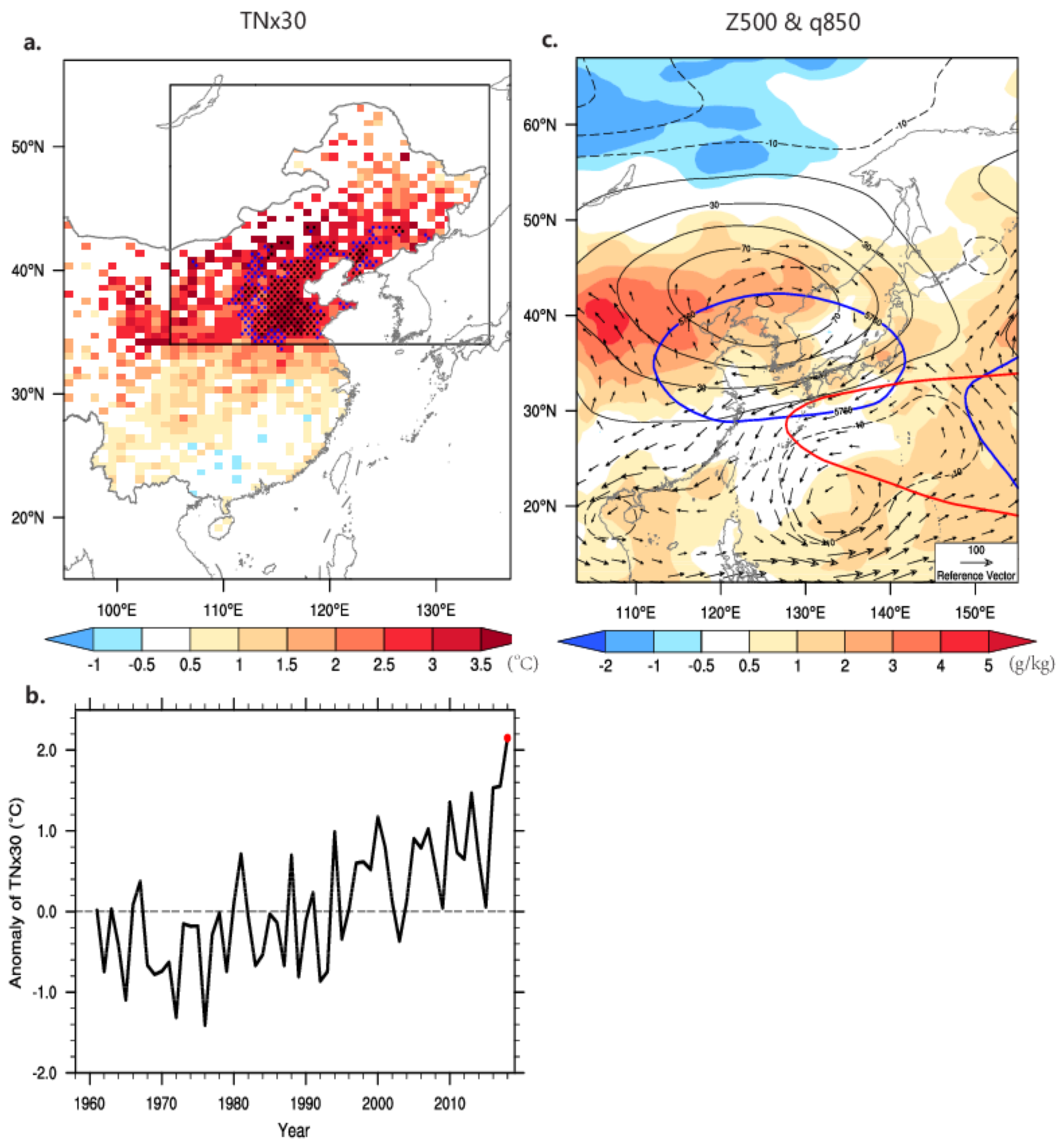

Fig1. Observed characteristics of the heat wave in Northeast China during 12th July – 10th August, with maximum consecutive 30-day Tmin anomalies in summer 2018 (TNx30). (a) Spatial pattern of TNx30 (shading, unit:°C) relative to 1961-2013. Locations with record-breaking and second highest values since 1961 are shown with black and blue dots, respectively. (b) Time series of TNx30 anomalies over Northeast China (black rectangle shown in Fig1 a) from 1961-2018. (c) Circulation field from ERA-interim with specific humidity anomalies (shading, unit: g/kg) and 850-hPa moisture flux anomalies (vectors). The light black contours denote the 500-hPa geopotential height anomalies. 12th July – 10th August mean geopotential height (blue lines) and climatology (red lines) are also shown.

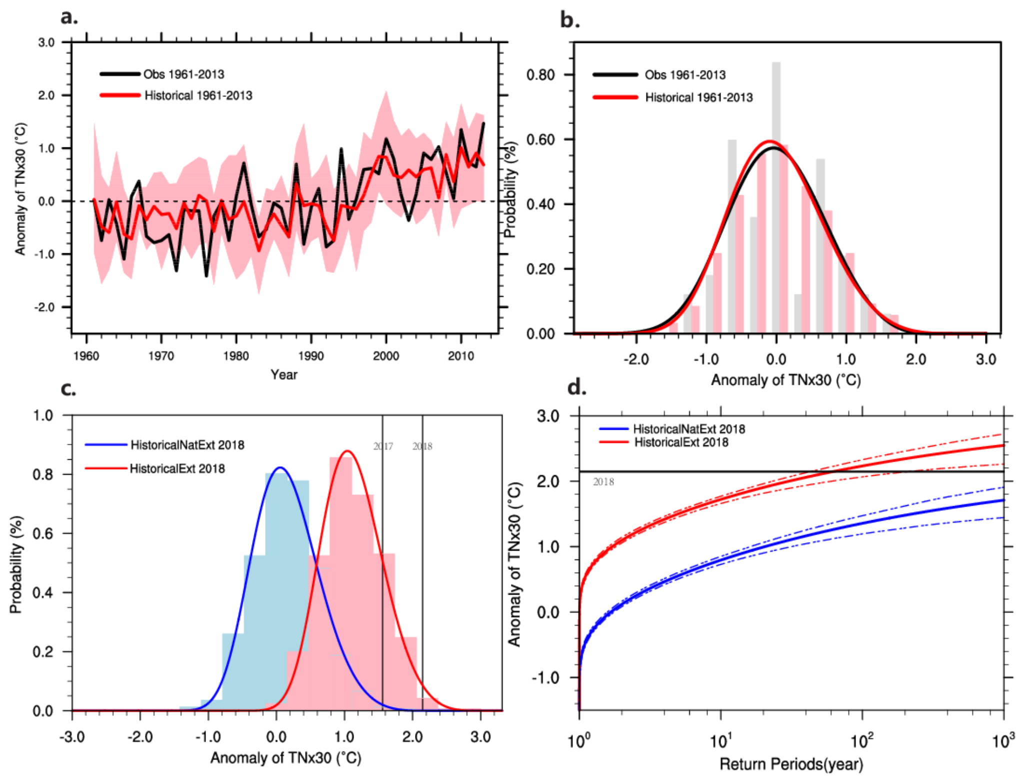

Fig2. (a) Time series of observed (black) and simulated ensemble mean (red) of TNx30 anomalies, with 15-member spread shown as light pink shading. (b) Histograms and GEV-fit probability density function of TNx30 anomalies in observations (black line and grey bars) and historical simulations (red line and light pink bars) from 1961-2013. (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) same as (c) but for return periods. Dash-dot lines indicate the 5^{th}-95^{th} uncertainty range based on 1000 bootstrap resamples for All-forcing (red) and natural-forcing (blue).