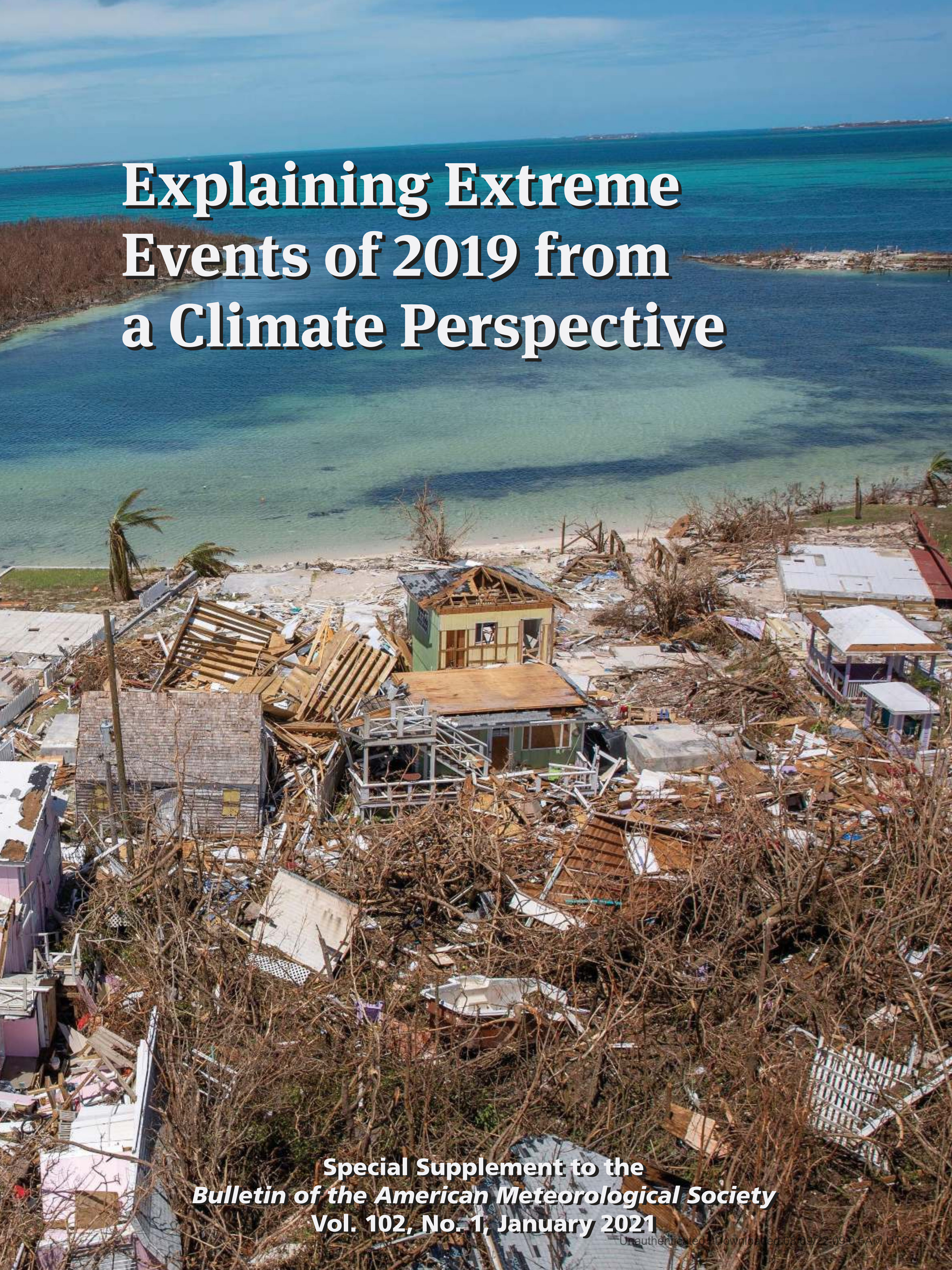

Explaining Extreme Events of 2019 from a Climate Perspective

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EXPLAINING EXTREME EVENTS OF 2019 FROM A CLIMATE PERSPECTIVE

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Cover: Ruins and rubble are all that are left of homes destroyed by Hurricane Dorian viewed from a U.S. Customs and Border Protection rescue helicopter 5 September 2019 in Marsh Harbour, Abaco, Bahamas. Dorian struck the small island nation as a Category 5 storm with winds of 185 mph. (credit: Planetpix/Alamy Stock Photo)

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Anthropogenic Influences on the Extreme Cold Surge of Early Spring 2019 over the Southeastern Tibetan Plateau

Jianping Duan, Liang Chen, Lun Li, Peili Wu, Nikolaos Christidis, Zhuguo Ma, Fraser C. Lott, Andrew Ciavarella, and Peter A. Stott

HadGEM3 and CMIP6 ensemble simulations suggest that anthropogenic forcing has reduced the likelihood of extreme early-spring cold surge over the southeast Tibetan Plateau similar to 2019 by ~80%.

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In early 2019, anomalously low air temperature hit the southeastern Tibetan Plateau (TP) and had disastrous influence in some areas. A few local meteorological administrations issued warnings for the cold event (http://www.cma.gov.cn/2011xwzx/2011xqxxw/2011xqxyw/201902/t20190220_515063.html). Reports show that the daily life of more than 158,000 people and forage supplies of 1.19 million livestock were affected by the cold event, which resulted in economic losses totaling 100 million Yuan (http://www.tibet.cn/cn/news/zcdt/201903/t20190321_6530435.html). This event prompted an emergency rescue from the local governments.

Observed records show that early spring air temperature in 2019 (averaged during 25 February to 11 March) over the TP was obviously lower compared to the 1981–2010 climatology and was largely confined to 28°–35°N, 90°–100.3°E (Figs. 1a,b; see Fig. ES1 in the online supplemental material). In particular, the regionally averaged daily maximum air temperature (Tmax) during 25 February to 11 March of 2019 is record-breaking since 1966 (Figs. 1c,d).

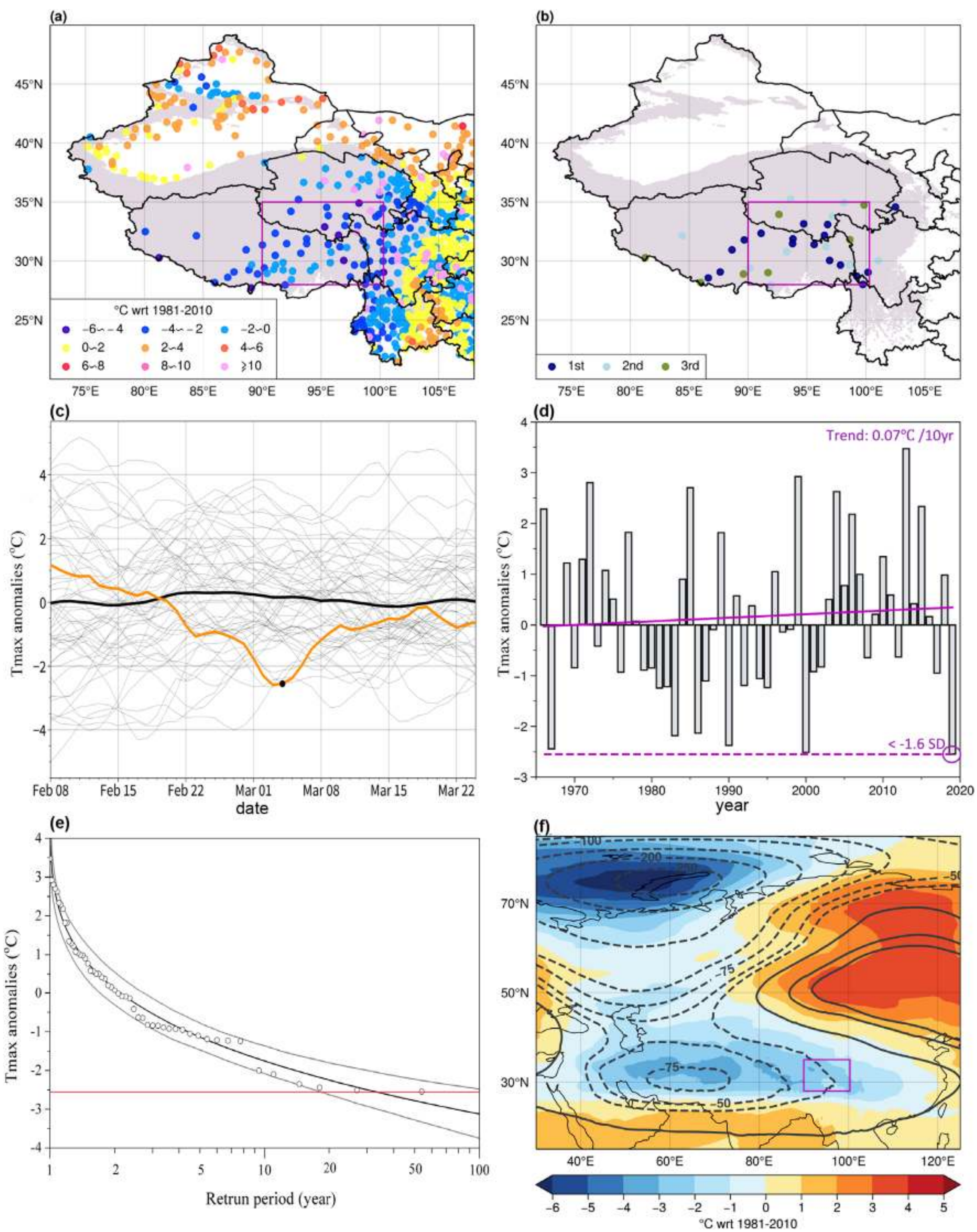

Fig. 1. (a) Observed anomalies of early spring (25 Feb to 11 Mar) Tmax (°C) over the TP and the surrounding area. (b) Meteorological stations with Tmax anomaly of early spring 2019 ranked among the three coldest since 1966. (c) The 15-day moving average of regional daily Tmax from February to March during 1966–2019. The orange, thin gray, and thick gray lines are for 2019, 1966–2018, and the period mean of 1966–2019, respectively. The black dot indicates the regional Tmax anomaly during 25 Feb to 11 Mar 2019. (d) Time series of early spring Tmax during 1966–2019 in the study area. (e) Return periods and 95% confidence intervals for early spring Tmax (°C), where the red line denotes the year 2019. (f) Anomalies of 500-hPa geopotential height field (gpm) and early spring Tmax (°C) of 2019 derived from ERA-5 dataset. Dots and the light gray shaded areas in (a) and (b) indicate the locations of meteorological stations and the TP scope with an elevation more than 2,000 m above mean sea level, respectively. The magenta box in (a), (b), and (f) indicates the range of the study area. All the anomalies are with respect to the 1981–2010 climatology.

This cold event resulted from the invasion of cold air from the northern high latitudes centered basically at Novaya Zemlya where the cold air originated (Fig. 1f). Anomalies of geopotential height at 500 hPa (Z500) during 25 February to 11 March 2019 show a large-scale cyclonic circulation west of the TP, transporting cold air from the northern high latitudes across the TP. This induced the persistent and anomalous low daily Tmax in early spring of 2019 over the southeastern TP. Attribution and atmospheric circulation analysis of extreme events on the TP (Yin et al. 2019; Dong et al. 2001, Huang et al. 2018, Li and He 2019) and cold events in other midlatitude areas (Sun et al. 2018; Francis and Vavrus 2015; Kug et al. 2015; Mori et al. 2014) have drawn great attention. However, it is unclear how anthropogenic forcing has influenced the likelihood of 2019-like cold events on the TP, especially under a rapid warming background. In this study, we concentrate on such cold events and quantify the anthropogenic contribution to the likelihood of cold events as instances when the early spring Tmax is lower than the one observed in 2019 using daily observations and model simulations.

Data and methods.

Observations of daily temperature derived from 48 stations located in the study area (available at http://data.cma.cn/) were used in this study (for detailed information please see the supplemental information). The HadGEM3-A-N216 model simulations at a horizontal resolution of 0.83° × 0.56° (Christidis et al. 2013; Ciavarella et al. 2018) and available simulations from 10 CMIP6 models (Table ES1) with (Historical/ALL) and without (HistoricalNat/NAT) anthropogenic forcing are used in this study. Fifteen ensemble members are available for Historical and HistoricalNat simulations during the period of 1960–2013 and are extended to 525 members for 2019 conditions (HistoricalExt and HistoricalNatExt). The HistoricalExt run was driven with observed SSTs, sea ice concentrations, and corresponding anthropogenic forcing (Rayner et al. 2003; Christidis et al. 2013). The HistoricalNatExt run was driven by SSTs and sea ice concentrations where a multimodel estimate of anthropogenic climate change has been removed from the observations. All other forcings are set to preindustrial levels. Both the ALL and NAT simulations from CMIP6 include 39 members (Table ES1). Moreover, daily Tmax and daily geopotential height field data at 500 hPa from ERA5 (the fifth generation of ECMWF atmospheric reanalyses of the global climate; Hersbach et al. 2020) were used to analyze the atmospheric circulation related to the 2019 early spring cold event over the TP.

Based on the observations (Fig. 1), regionally averaged anomalies of Tmax (simple average of station data) during 25 February to 11 March (early spring hereafter) from 48 meteorological stations located within 28°–35°N, 90°–100.3°E are used to define the extreme cold event over the southeastern TP. The value in 2019 (the lowest one, –2.55°C with respect to 1981–2010 climatology) was chosen as the threshold for observations. For HadGEM/CMIP6 model simulations, area-averaged anomalies of early spring Tmax over the study region (28°–35°N, 90°–100.3°E) were calculated for both the historical period of 1966–2013/1966–2019 and the event year 2019. The generalized extreme value (GEV) distributions were used to fit the distributions of both simulated and observed data. A two-sided Kolmogorov–Smirnoff (K-S) test was applied to test if the distributions of the observations and historical simulations are from the same population. To make simulations and observations comparable, we construct GEV distributions using the samples from simulations and derive the thresholds for the event in HadGEM3-A-N216 and CMIP6 with the same return period as the year 2019 in observation. The risk ratio (RR) (National Academies of Sciences, Engineering, and Medicine 2016) was used to quantify anthropogenic influences on the likelihood of frequency of the 2019-like event. The RR is defined as P1/P0, where P1 is the probability of the event in ensembles with anthropogenic forcing and P0 is that for ensembles without anthropogenic forcing. Bootstrapping with 1,000 resamples was employed to calculate the confidence intervals for the return period using empirical data.

Results.

The Tmax of early spring on the southeastern TP has a warming trend during 1966–2019 (0.07°C decade^{-1}) (Fig. 1). Anomalies of the averaged early spring Tmax in 2019 at some stations reached −6° to −4°C with respect to the 1981–2010 climatology, and ranked in the lowest three since 1966. The return period of the 2019 cold event in observations is about once in 34 years (Fig. 1e). Although comparisons of time series and spatial pattern between the observed and simulated anomalies of early spring Tmax show some differences (HadGEM simulations are better than CMIP6 simulations) (not shown), the probability density function (PDF) indicates a relatively good similarity between the simulated and observed early spring Tmax distributions (Figs. 2a,b). The Kolmogorov–Smirnoff test indicates that there is no significant difference between the distributions derived from HadGEM/CMIP6 model simulations and observations in the historical period (p = 0.15/0.34). These results indicate that a formal attribution analysis for the Tmax in early spring of 2019 can be reasonably conducted using the model simulations.

The 2019 GEV distributions show that the early spring Tmax is generally greater from the PDFs derived from the Historical/ALL forcing than the PDFs derived from the HistoricalNat/NAT forcing (Figs. 2c,d). The thresholds at −3.0°C (−2.42°C) with the same return periods as observations are derived from simulations of HadGEM3-A-N216 (CMIP6) for attribution (Figs. 2e,f). The likelihood of a 2019-like cold event over the southeastern TP in HadGEM (CMIP6) model simulations with anthropogenic influence is 0.0295 (0.0294) [P1 = 0.0295 (0.0294)], while without anthropogenic influence is 0.2797 (0.152) [P0 = 0.2797 (0.152)]; therefore, the RR is 0.11 (0.19). This suggests that anthropogenic forcing has reduced the likelihood of extreme early spring cold surges over the southeastern TP similar to the 2019 event by 89% (81%). Like previous studies (Mori et al. 2014; Francis and Vavrus 2015; Kug et al. 2015), our study also shows an influence of the Arctic cold air on the 2019 cold event over the midlatitude TP (Fig. 1f). However, further attribution analysis indicates that climate warming (i.e., anthropogenic warming) has not induced an increase of the frequency of such cold events, but rather has reduced its likelihood in the midlatitude TP. Of course, our analyses are only based on one case of cold events and cannot conclude that whether or not the southward movement of the Arctic cold air under climate warming has induced more frequent cold events in other seasons or other time windows on the TP. Both observed SSTs (used to drive HistoricalExt) (Figs. ES2a,c,e) and the anthropogenic climate change of SSTs (removed from the HistoricalExt run SSTs to generate the HistoricalNatExt boundary forcing) (Figs. ES2b,d,f) show warming conditions in the early spring 2019. Anthropogenic climate change of SSTs contributed to warming both in the land and ocean (Fig. ES2). Based on these estimates, anthropogenic warming over the TP during February to March of 2019 was about 1.9°C. This means that the Tmax of early spring 2019 would be 1.9°C lower than the actual without anthropogenic forcing. The uncertainty depends on the multimodel estimate used for simulations of HistoricalExt (Christidis et al. 2013; Ciavarella et al. 2018).

Conclusions.

The southeastern TP experienced the coldest early spring in 2019 since 1966. This cold event originated from the invasion of cold air from the northern high latitudes transported by an anomalous strong cyclonic circulation west of the TP. Analyses based on HadGEM3 and CMIP6 ensemble simulations indicate that anthropogenic forcing has reduced the likelihood of extreme cold event of early spring with an intensity equal to or stronger than the record of 2019 over the southeastern TP by ~80%.

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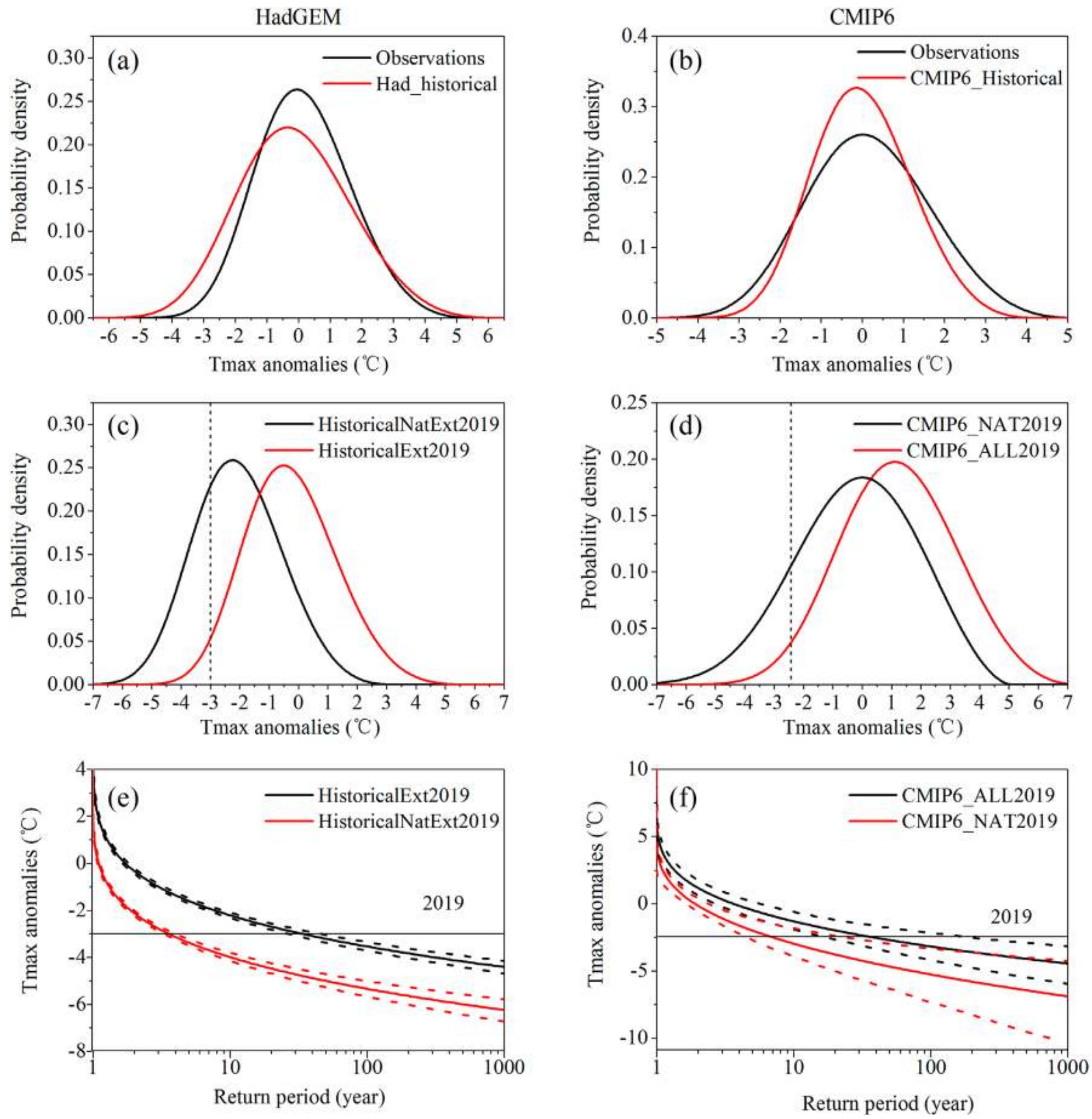

Fig. 2. (a),(b) Probability density functions (PDFs) based on GEV fit for the observed and simulated early spring Tmax during 1966–2013/2019. (c),(d) PDFs of fitted GEV distributions for early spring Tmax in 2019 from HistoricalExt/ALL and HistoricalNatExt/NAT simulations. The dotted line indicates the threshold used. (e),(f) Return period (years) of early spring Tmax in HistoricalExt/ALL and HistoricalNatExt/NAT simulations. Dotted lines show the bootstrapped 5%–95% uncertainty range. Results are for simulations from the HadGEM model in (a), (c), and (e) and the CMIP6 models in (b), (d), and (f).

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