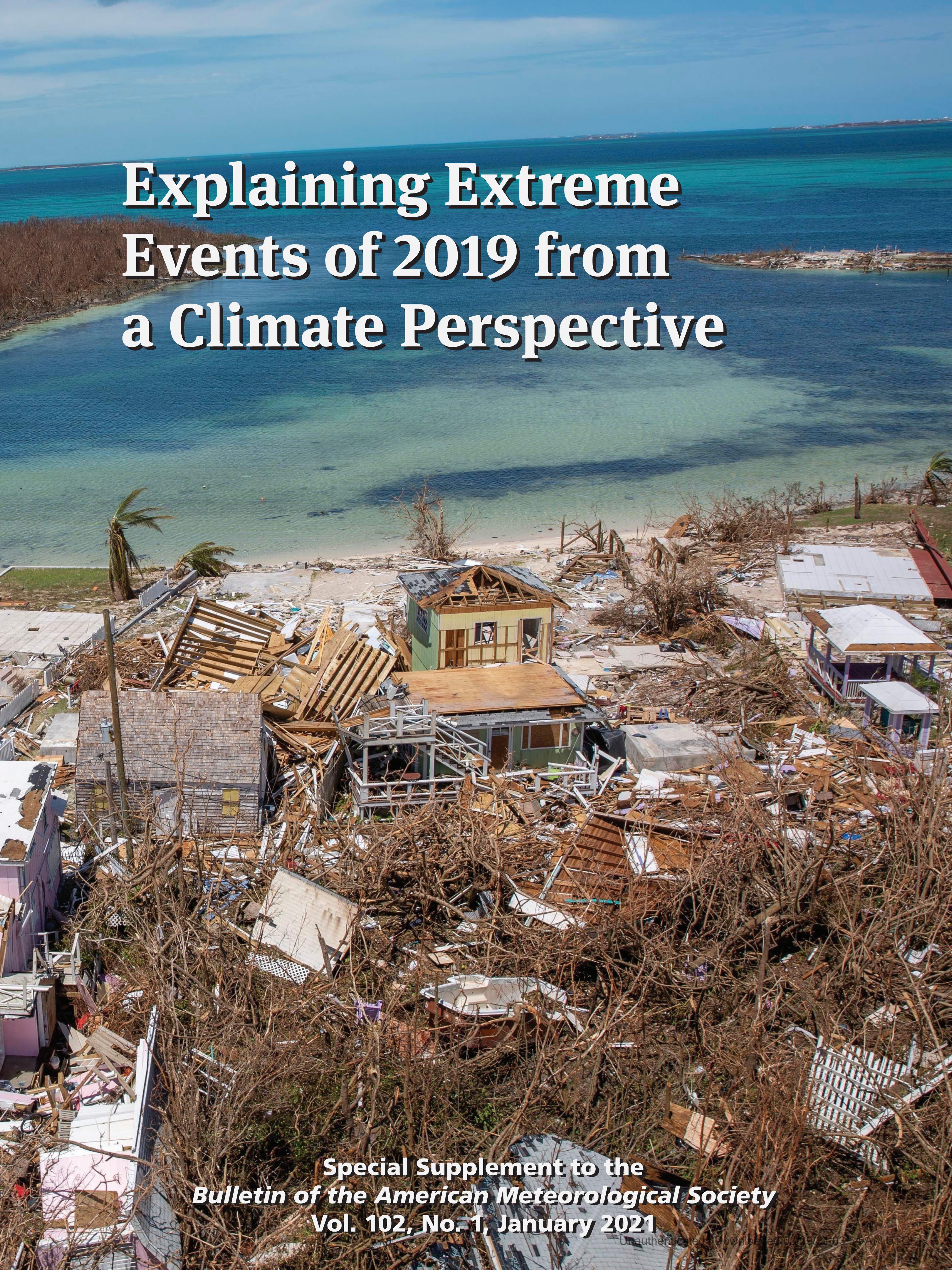
Explaining Extreme Events of 2019 from a Climate Perspective



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EXPLAINING EXTREME EVENTS OF 2019 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

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Corresponding Editor:

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

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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Attribution of 2019 Extreme Spring–Early Summer Hot Drought over Yunnan in Southwestern China

Shanshan Wang, Jianping Huang, and Xing Yuan

Anthropogenic influence has increased the risk of 2019 March–June hot and dry extremes over Yunnan province in southwestern China by 123%–157% and 13%–23%, respectively.

In spring to early summer of 2019, Yunnan province in southwestern China was dominated by persistently and extensively hot and dry weather, especially during May. The mean rainfall deficit during March–June in 2019 was ranked first since 1961, with the hottest temperature on record over Yunnan. According to the statistics reported by the Chinese government, this severe drought together with high temperature caused water scarcity that affected nearly 7 million residents and resulted in crop failure over at least 1.35×10^4 km^2 cropland (Fig. 1). More than 94% of the total area in the province was drought-stricken and around 2 million people faced drinking water shortages, with direct economic loss of about 6.56 billion RMB (Fig. 1f; https://www.kunming.cn/news/c/2019-08-19/12704597.shtml).

AFFILIATIONS: Wang and Huang—Key Laboratory for Semi-Arid Climate Change of the Ministry of Education, College of Atmospheric Sciences, Lanzhou University, Lanzhou, China; **Yuan**—School of Hydrology and Water Resources, Nanjing University of Information Science and Technology, Nanjing, Jiangsu, China

CORRESPONDING AUTHOR: Jianping Huang, jhuang@lzu.edu.cn

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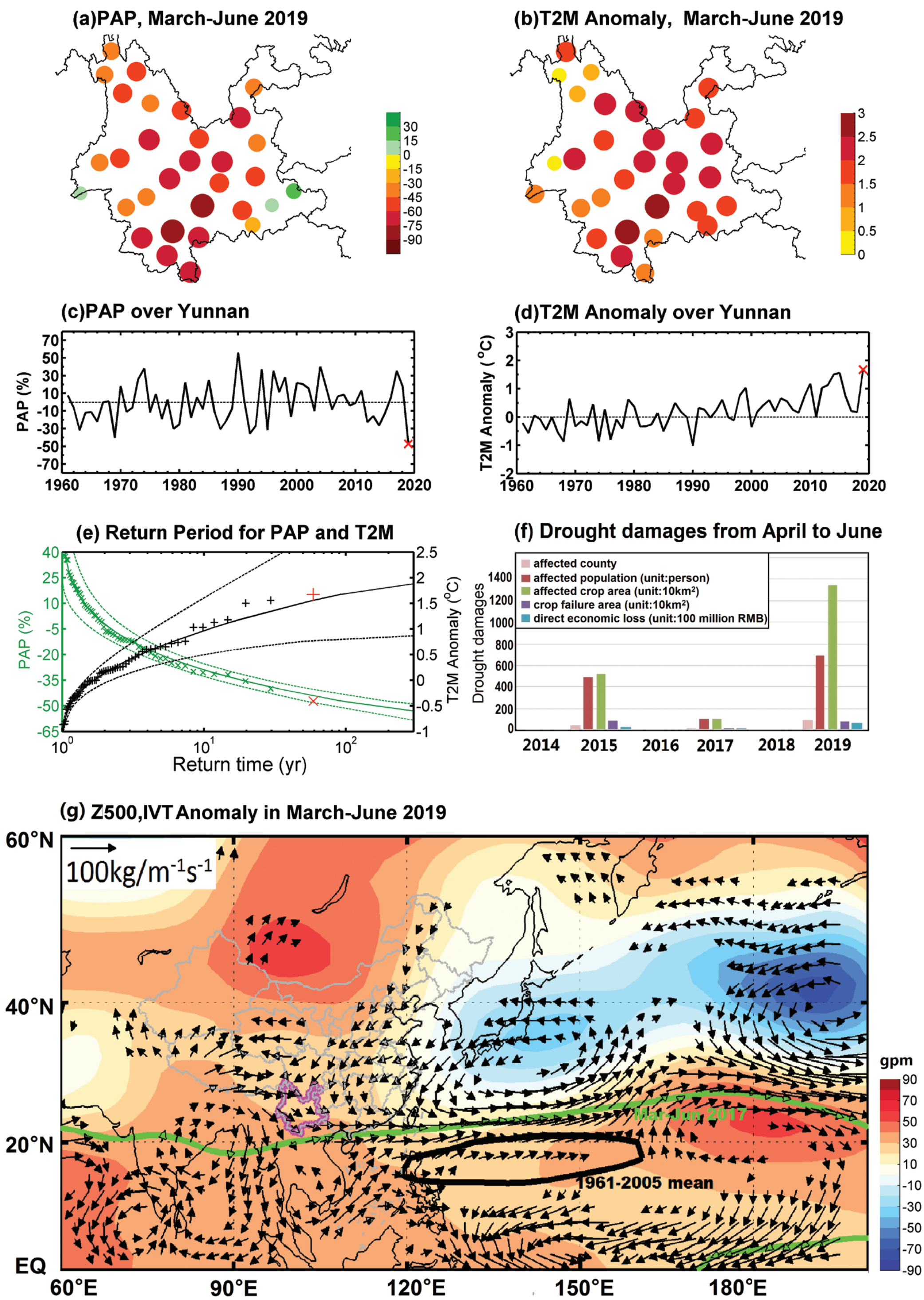

Fig. 1. (a) Precipitation anomaly percentage (PAP; %) and (b) temperature (T2M) anomaly (°C) during March–June of 2019 relative to the 1961–2005 climatology based on CMA/NMIC station observations. (c),(d) Observed regional PAP and mean T2M anomaly over Yunnan for the period of 1961–2019. (e) Return periods and 95% confidence intervals for regional mean March–June T2M anomaly and PAP, where the red markers represent year 2019. (f) Drought damages in the second quarter (April–June) during 2014 to 2019 from the Emergency Management Office of Yunnan Province. (g) 200-hPa geopotential height anomalies (gpm; shading) and the 587-dagpm contours (in green) during March–June of 2019, superimposed with corresponding vertically integrated atmospheric water vapor transport between 300 and 1000 hPa (IVT; vectors). The thick black contour is the climatological March–June mean 587-dagpm contour for 1961–2005.

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In recent decades, Yunnan province has suffered from frequent and severe droughts, especially since 2006 (Qiu 2010; Wang et al. 2015b; Ren et al. 2017). Numerous research has explored the causes of drought in Yunnan and its neighboring zones, and the results indicate that the persistently abnormal sea surface temperature (SST) over the tropical Pacific and Indian Oceans (Yang et al. 2011; Feng et al. 2014; Wang et al. 2015a), anomalous snow cover in Northern Hemisphere (He et al. 2013) and the abnormality of the high-latitude Arctic Oscillation (AO; Barriopedro et al. 2012; Yang et al. 2012) and low-latitude Madden–Julian oscillation (MJO; Lü et al. 2012) contribute greatly to the Yunnan drought (Wang et al. 2015b; Ren et al. 2017). However, it is still unclear and even disputable as to what extent the above SST anomalies and circulation patterns affect Yunnan drought because of the complexity of drought and the presence of strong nonlinearity. Particularly, the effect of anthropogenic forcing on the hot droughts (concurrent hot and dry conditions) over Yunnan remains unclear.

Therefore, in addition to assessing the contribution of anthropogenic climate change on Yunnan spring–early summer hot drought in 2019, we also briefly discussed the cause of this persistent hot drought from the perspective of anomalous circulations. This case study is timely for developing appropriate strategies and plans for mitigating the threats of drought over Yunnan.

Data and methods.

Daily surface air temperature (T2M) and precipitation observations for the period 1961–2019 at 839 stations are collected from China Meteorological Administration (CMA) National Meteorological Information Center (NMIC; available http://data.cma.cn/), and converted into monthly means. The precipitation anomaly percentage (PAP) is used to represent drought severity relative to the 1961–2005 climatology. The generalized extreme value (GEV) distribution is used here to fit the observed and modeled March–June mean and extreme T2M and PAP distribution.

To analyze the possible causes for this concurrent hot and dry extreme event, monthly atmospheric circulation data during 1961–2019 at 2.5° resolution from NCEP–NCAR reanalysis (Kalnay et al. 1996) is also used in this study.

Monthly T2M and precipitation simulations from multiple the Coupled Model Intercomparison Project Phase 5 (CMIP5; Taylor et al. 2012) models driven by all (ALL) and natural only (NAT) forcings since 1961 are used in this study (see Table ES1 in the supplemental information for the model list and information). Due to the data availability, only one pair of realizations (r1i1p1) is used to assure an equal weight for different CMIP5 models. All simulations are bilinearly regridded into 0.5° resolution and matched well with the observed distribution via a Kolmogorov–Smirnov test ($p < 0.05$; see Figs. ES1a,b). We further evaluate the relationship of March–June mean temperature and precipitation in Yunnan, and results show that the CMIP5 models capture the inverse correlation between temperature and precipitation that is evident in the observations (Fig. ES1c). To quantitatively assess the contributions of anthropogenic influence on 2019 extreme hot drought in Yunnan, the fraction of attributable risk (FAR; Stott et al. 2004) and the probability ratio (PR; Fischer and Knutti 2015) are both calculated with definition of $FAR = 1 - P_{NAT}/P_{ALL}$ and $PR = P_{ALL}/P_{NAT}$. Here, P_{NAT} denotes the probability of exceeding the 2019 high temperature and drought conditions in the natural-forcing scenarios and P_{ALL} denotes the equivalent for the all-forcings scenarios. Bootstrapping is performed 1000 times to estimate the FAR and PR uncertainty by resampling (Yuan et al. 2018; Wang et al. 2019). To identify the significance level of the difference between ALL and NAT forcings for a given period, p values are calculated with a right-tailed test at the 1% significance level.

In this paper, the highest (lowest) 15% of the regional mean T2M anomalies (PAP) on all months during March–June are considered as the extreme hot (dry) events, which ensure there are enough samples to examine the tails of the distribution of climate variables (Wang et al. 2019). If both extremes occur in the same year (e.g., 2019), it is considered as a hot drought event (Diffenbaugh et al. 2015; Chen and Sun 2017). This

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is similar to the concurrent hot and dry extremes investigated by Wang et al. (2016), but at a longer time scale.

Results.

Combined with the spatial distribution of March–June mean PAP during 2019 and the corresponding time series of area-averaged values during 1961–2019, it is found that Yunnan was much drier than normal, with a widespread rainfall deficit over most of the province and particularly in the southern region, which received only 10% of its expected precipitation over that period (Fig. 1a). The area-averaged rainfall in March–June 2019 was unprecedentedly low (Fig. 1c), and a GEV fit denotes the 2019 extreme drought is a 1-in-94-yr event (>11 years at 95% confidence level) in Yunnan province (Fig. 1e). In addition, Yunnan suffered the hottest season from spring to early summer since records began in 1961 (Fig. 1b). Taking Yuanjiang county in the south central region as an example, there were 15 days exceeding 40°C in May. The area-averaged T2M anomaly in March–June 2019 is ranked highest since 1961 (Fig. 1d), with a return period of 93 years (>52 years at 95% confidence level; Fig. 1e).

Generally, the maintenance of drought over the region is often regulated by persistently abnormal SST and the resulting anomalous atmospheric conditions. These concurrent hot and dry extremes over Yunnan province in 2019 occurred during weak El Niño and in the context of a warmer Indian Ocean. During March–June in 2019, the low-latitude region was dominated by the high pressure anomalies, and the western Pacific subtropical high (WPSH) was strengthened with its ridge line shifting northward and extending westward (Fig. 1g). The intensification and westward shift of the WPSH further weakened the southern branch trough (SBT) and enhanced the local downward motion over southwestern China (Yang et al. 2012; Ding and Gao 2020). The vertically integrated atmospheric water vapor transport fields show that there was an anomalous anticyclone over the Bay of Bengal and the Indochina Peninsula impeding the water vapor transport from the Bay of Bengal and Indian Ocean into the Yunnan region (Wang et al. 2015b; Ren et al. 2017; Ding and Gao 2020). Meanwhile, there were both a high pressure anomaly around Lake Baikal and a low pressure anomaly around Japan over the Eurasian midlatitudes. This circulation pattern resulted in a deepened and eastward East Asian trough, where the northerly cold air invaded into the eastern part of China rather than the southwestern region, which is unbeneficial for water vapor convergence in Yunnan. Therefore, the spring and early summer in Yunnan were characterized by high temperature and severe drought in 2019 (Wang et al. 2015b; Ren et al. 2017).

To compare the likelihood of occurrence of such extreme spring–early summer hot drought events over Yunnan like 2019 due to anthropogenic climate change, CMIP5 model simulations with all and with natural only forcings are used. Results show an overall mean shift of T2M and PAP toward a hotter and drier condition due to the anthropogenic forcing by fitting GEV distributions, with FAR values of 0.43 (±0.04) and 0.12 (±0.04) (Figs. 2a,b). Furthermore, the attribution of anthropogenic influences on high temperature and low rainfall extremes are also carried out as indicated in Figs. 2c and 2d, and results show that the extreme events are more sensitive to anthropogenic climate change than the monthly mean. The likelihood of the extreme hot events like 2019 increases from 21% to 49% due to the anthropogenic climate change, with FAR of 0.58 (±0.03) and PR of 2.40 (±0.17). In other words, anthropogenic influence has increased the risk of 2019 Yunnan persistent high temperature extremes by 123%–157%. The extreme low rainfall occurs more frequently in Yunnan under the influence of the anthropogenic climate change, with FAR of 0.15 (±0.03) and PR of 1.18 (±0.05). Moreover, the concurrent extreme high temperature and low precipitation shows a tendency to increase in ALL simulations for the study period, particularly entering into the twenty-first century, with a FAR value of up to 0.42 compared with NAT simulations for the recent decade. Between the first and last decades, CMIP5 simulated ensembles show shifts toward warmer and slightly drier conditions in Yunnan (Fig. 2f).

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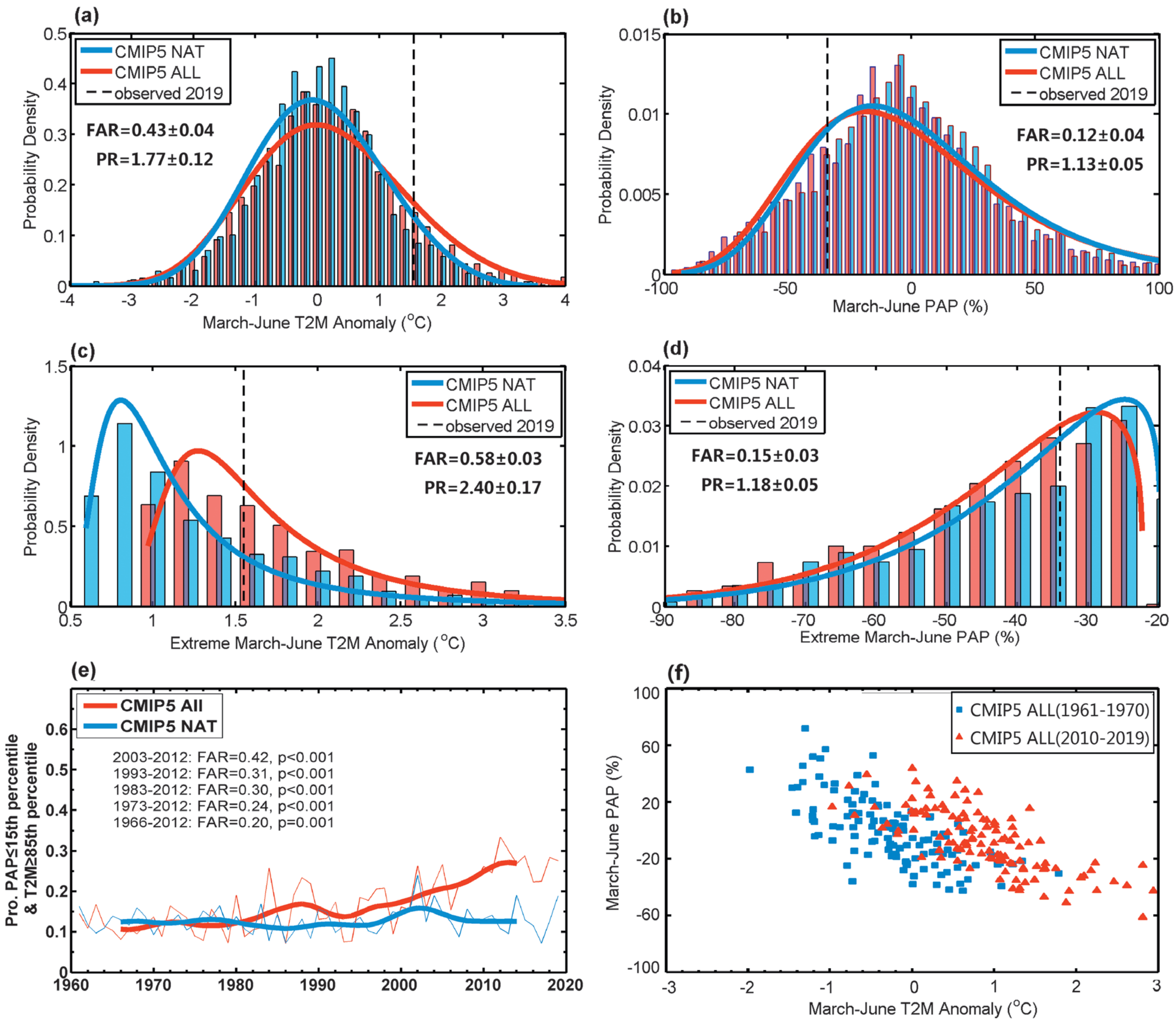

Fig. 2. Histogram (bars) and probability density functions (PDFs; curve) for Yunnan province in southwest China March–June (a) T2M anomaly and (b) PAP from CMIP5 simulations under all (ALL; in red) and natural only (NAT; in blue) forcings. (c),(d) As in (a) and (b), but for the high temperature and low precipitation extremes. (e) The probability of concurrent extremely low precipitation and high temperature where both the PAP is less than the 15th percentile and T2M anomaly is greater than the 85th percentile. The bold curves show 11-yr running mean of the annual time series. The p values indicate the difference between the ALL and NAT forcings for the most recent 10- (2003–12), 20- (1993–2012), 30- (1983–2012), and 40-yr (1973–2012) periods of the CMIP5 protocol. The p values are calculated using the block bootstrap resampling approach. (f) The scatters of PAP against T2M anomalies in CMIP5 ALL simulations. The blue denotes the first decade (1961–70) and the red denotes the last decade (2010–19).

Conclusions.

In March–June 2019, an unprecedented rainfall deficit combined with record-breaking high temperature hit Yunnan province in southwestern China. Observational analysis shows that the persistent strengthening WPSH and anomalous anticyclone over the Bay of Bengal–India region played a crucial role on this extreme event, via reducing the water vapor transportation to Yunnan and enhancing the local downward motion over southwestern China (Yang et al. 2012; Feng et al. 2014; Wang et al. 2015b; Ren et al. 2017; Ding and Gao 2020). Attribution analysis based on the CMIP5 simulations with and without anthropogenic forcings indicates that the likelihood of extremely high temperature in Yunnan like the year of 2019 increased by about 140% (123%–157%)

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due to anthropogenic climate change, and the extremely low precipitation increased by about 18% (13%–23%). Furthermore, the concurrence of such hot and dry extremes exhibited an increasing risk of 43% in the recent 30-yr period due to anthropogenic climate change. Recently, research by Yuan et al. (2019) warned that southern China, including Yunnan, faces a higher flash drought risk during the growing seasons in a warming future climate. This increase in drought risk over Yunnan, a southern nontraditional drought region (humid region) of China, poses serious challenges for decision makers in water resource management and economic development.

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