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• News & Views •

Will the Globe Encounter the Warmest Winter after the Hottest Summer in 2023?

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ABSTRACT

In the boreal summer and autumn of 2023, the globe experienced an extremely hot period across both oceans and continents. The consecutive record-breaking mean surface temperature has caused many to speculate upon how the global temperature will evolve in the coming 2023/24 boreal winter. In this report, as shown in the multi-model ensemble mean (MME) prediction released by the Institute of Atmospheric Physics at the Chinese Academy of Sciences, a medium-to-strong eastern Pacific El Niño event will reach its mature phase in the following 2–3 months, which tends to excite an anomalous anticyclone over the western North Pacific and the Pacific-North American teleconnection, thus serving to modulate the winter climate in East Asia and North America. Despite some uncertainty due to unpredictable internal atmospheric variability, the global mean surface temperature (GMST) in the 2023/24 winter will likely be the warmest in recorded history as a consequence of both the El Niño event and the long-term global warming trend. Specifically, the middle and low latitudes of Eurasia are expected to experience an anomalously warm winter, and the surface air temperature anomaly in China will likely exceed 2.4 standard deviations above climatology and subsequently be recorded as the warmest winter since 1991. Moreover, the necessary early warnings are still reliable in the timely updated medium-term numerical weather forecasts and sub-seasonal-to-seasonal prediction.

Key words: winter climate, El Niño, seasonal forecast, GMST

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1. Addressing the general concern on how the global temperature will change in the 2023/24 boreal winter

Since June 2023, the global mean surface temperature (GMST) has continued to increase, repeatedly breaking records. The GMST reached record warmth in September, 1.82°C warmer than the 1850 to 1900 baseline temperature, an anomaly that exceeded any other month by an astonishingly large margin (https://berkeleyearth.org/september-2023-temperature-update/), further noting the unprecedented high temperatures were dually sourced from both ocean and land

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(https://public.wmo.int/en/media/press-release/earth-had-hottest-three-month-period-record-unprecedented-sea-surface) as reported by the World Meteorological Organization. Over the ocean, significant warm anomalies are mainly located in the North Pacific, North Atlantic, and tropical Pacific in 2023, where an El Niño event formed in June and has further developed in the past few months. Over the land, long-term warmer-than-normal temperatures occurred, as several heatwaves hit North America, southern Europe, and Asia during boreal summer (https://bnn.network/world/the-year-of-the-heatwave-2023s-global-climate-crisis/), increasing the likelihood for wildfires and human deaths (Ruffault et al., 2020; Lüthi et al., 2023).

According to both dynamic and statistical forecasts, the current El Niño event may continue to strengthen and is expected to become a strong (Niño-3.4 index ⩾ 1.5°C) El Niño for the remainder of 2023 (https://iri.columbia.edu/our-expertise/climate/forecasts/enso/current/), which will have the effect of consistently releasing plentiful heat into the atmosphere (Cheng et al., 2019), thus enhancing the warming of the GMST (Su et al., 2017; Li et al., 2022). Considering these predictions and the fact that the GMST rose beyond expectations during June to September 2023, should the GMST warming continue into boreal winter, 2023 will be the warmest year on record, possibly exceeding the 1.5°C global warming threshold (Li et al., 2023). This could accelerate sea-level rise and sea ice loss (Zhang et al., 2022), severely impacting the global ecosystem (Walther, 2010) and food security; such effects may persist into 2024 (Singh et al., 2023). In light of the general concern regarding the nature of the temperature change and climate conditions, we will present the climate predictions in global temperature for the 2023/24 boreal winter, focusing on the potential climate impacts in Eurasia, with a particular emphasis on China.

2. Prediction of the global climate in 2023/24 boreal winter

Multi-member seasonal climate predictions were carried out for the boreal winter (December–January–February, DJF) of 2023/24 using three global climate models (FGOALS-f2, FGOALS-f3_L, and NZC-PSM) developed by the Institute of Atmospheric Physics (IAP) at the Chinese Academy of Sciences. These models are initialized by assimilating various observational data through different assimilation schemes (Table 1; Ma and Wang, 2014; Wu et al., 2018; Bao and Li, 2020). Multi-member ensemble means were conducted for each model, and then the multi-model ensemble mean (MME) was calculated as the mean of the single-model ensemble means (i.e., the so-called one-model-one-vote approach; Borchert et al., 2021). The MME shows that a medium-strong eastern Pacific (EP) El Niño will reach its mature phase during the boreal winter of 2023/24, with positive SST anomalies in the equatorial central-eastern Pacific reaching around 1.7°C (Fig. 1a), consistent with recently published El Niño predictions (Li et al., 2023).

The El Niño event will dominate the global climate variations in the 2023/24 boreal winter. In the tropics, it will enhance convection over the equatorial central-eastern Pacific and further cause an eastward shift of the Walker circulation, a pattern that corresponds with negative precipitation anomalies over the Indo-Pacific warm pool. An anomalous anticyclone will establish itself over the western North Pacific (WNPAC, Fig. 1c) through a Rossby wave response (Zhang et al., 1996; Wang et al., 2000). The southwesterly wind anomalies on the northwestern flank of the WNPAC tend to weaken the northeasterly associated with East Asian winter monsoon (Zhang et al., 1996; Chen et al., 2000; Kim et al., 2017). In the extratropics, the enhanced convective heating over the equatorial central-eastern Pacific will excite the poleward propagation of the Pacific-North American (PNA) teleconnection (Horel and Wallace, 1981). Meanwhile, heating anomalies associated with zonal dipole precipitation anomalies over the tropical Indian Ocean will tend to excite a poleward propagating wave train (Doi et al., 2020), which will contribute to a weakening of the East Asian trough.

El Niño-Southern Oscillation (ENSO) is the most important internal mode that modulates the interannual variations of the GMST (Yin et al., 2018; Hsu and Yin, 2019). The retrospectively predicted GMST by the MME for the past 30 years shows a high temporal correlation with observations (r=0.89). However, the variance of the simulated GMST is underestimated compared with observations. This suggests that the MME simulations have the problem of a signal-to-noise paradox. That is, the MME can capture the temporal evolution signal but underestimate its strength (Scaife and Smith, 2018). To address this issue, we corrected the simulated GMST by amplifying its variance to a magnitude consistent with that in the observation (Eade et al., 2014). After the correction, the predicted GMST in the 2023/24 boreal winter will break the historical record (Fig. 1b), in accordance with the superposition of the El Niño event and long-term global warming.

Meanwhile, the IAP GMST statistical ensemble prediction model is also adopted to predict the annual GMST in 2023

Table 1. Seasonal prediction experiments used in this report.

Model	Ensemble size	Assimilated observational/reanalysis data	Reference
NZC-PSM	12	FNL, CFSR, CFSR	Ma and Wang (2014)
FGOALS-f2	60	CRA40, FNL/GFS, OSTIA	Bao and Li (2020); Li et al. (2021)
FGOALS-f3_L	10	EN4, HadISST	Wu et al. (2018); Hu et al. (2020, 2023)

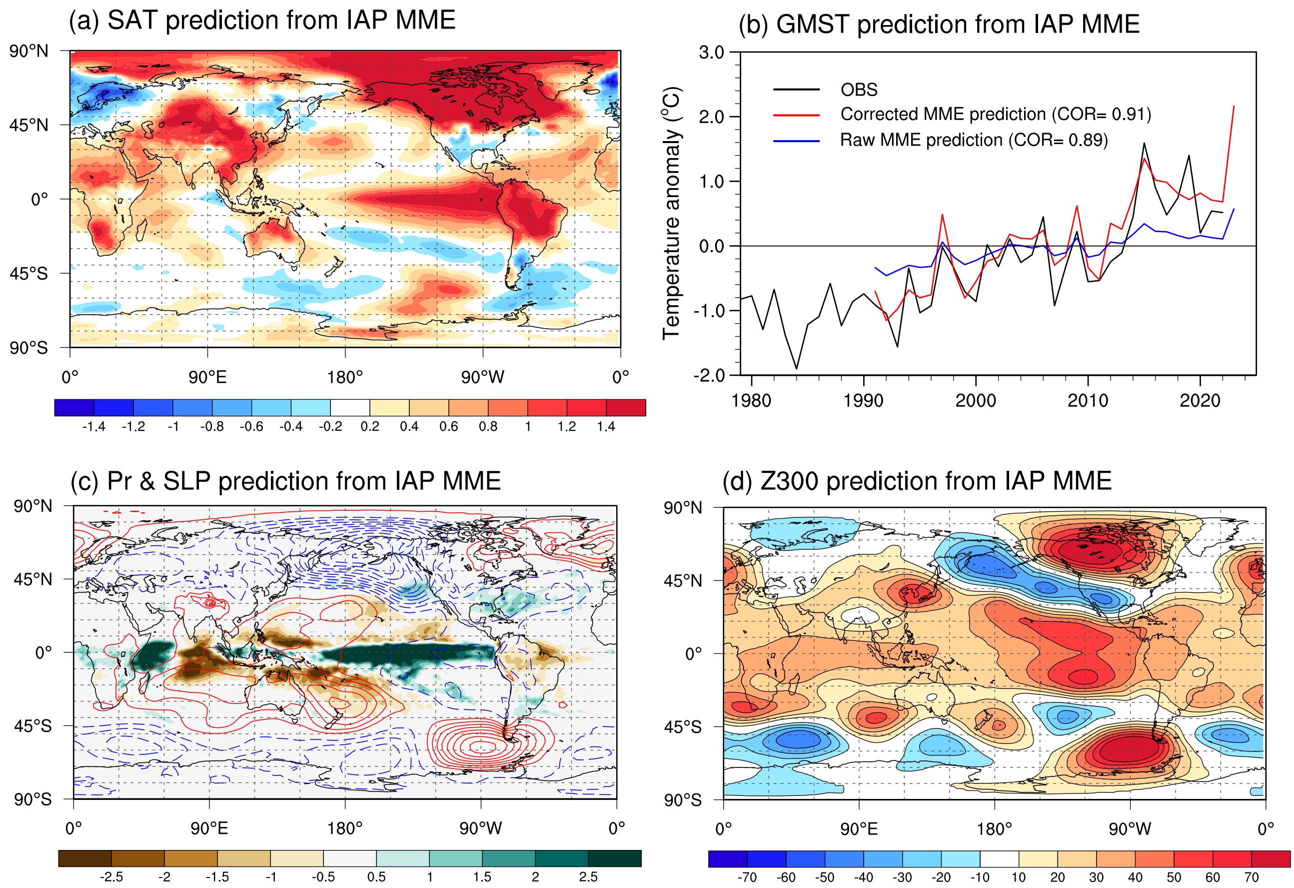

Fig. 1. The multi-model ensemble mean (MME) prediction of the 2023/24 boreal winter (December–January–February, DJF) climate based on the three global climate models (FGOALS-f2, IAP-DecPreS, and NZC-PSM) developed by IAP. (a) The predicted DJF surface air temperature (SAT) anomalies in 2023/24, units: °C. (b) The predicted time series of the DJF global mean SAT (GMST) for the period 1979–2023, unit: °C. The black, red, and blue lines represent the observation, corrected MME prediction, and raw MME prediction, respectively. The correlation coefficients between the observation and the prediction are shown in parentheses. (c) The predicted DJF precipitation (shading, units: mm d^{-1}) and sea level pressure (SLP) anomalies in 2023/24 (contour, units: Pa; the red solid lines are positive, the blue dashed lines are negative, and the interval is 50 Pa). (d) The predicted DJF geopotential anomalies at 300 hPa in 2023/24, units: gpm. The anomalies are relative to the climatology of 1999–2018.

based on three datasets [HadCRUT5, NOAAGlobal-Temp5, and BEST (Rohde and Hausfather, 2020; Morice et al., 2021; Vose et al., 2021)]. The prediction model contains various statistical methods that are generated by using historical observations to predict the subseasonal-to-interannual GMST signals at a lead of 3–4 months, which have demonstrated good predictive skill during the evaluation period of 1980–2022. According to the latest forecast initiated in September 2023 (Fig. 2), the GMST in 2023 should be 1.38°C±0.09°C higher than that during 1850–1900, indicating that the GMST in 2023 will certainly exceed that in 2016 (1.29°C) and go on to become the record high since 1850 (~95% chance).

3. Warmer-than-normal winter climate in Eurasia and China

Strong positive 500-hPa geopotential height anomalies are predicted by the ensemble results in low and middle latitudes across Eurasia. Positive height anomalies at both 500 and 300 hPa are beneficial for weakening the East Asian trough, especially over Northeast Asia (figure not shown). In addition, the negative (positive) anomalies of sea level pressure over the mid-high (low) latitudes are unfavorable for a strong Siberian high (figure not shown). Such responses in atmospheric circulation are consistent with the impact of an EP El Niño on the East Asian winter monsoon, as shown in previous studies (Tao and Zhang, 1998; Mu and Li, 1999; Chen et al., 2000; Wang et al., 2000; Chen, 2002; Jia et al., 2015; Yu and Sun, 2018). Weak cold advection over East Asia is supported by the atmospheric circulation anomalies for the DJF mean (Ding, 1994; Wang et al., 2009; Wang and Lu, 2017).

Corresponding to the anomalous atmospheric circulation, it is predicted that most of China will experience a warm winter, except for northeastern China (Fig. 1a). The regions that are expected to experience abnormal warming of more than 1°C span from Northwest China to Central and Eastern China. The magnitude of the average warming predicted over mainland

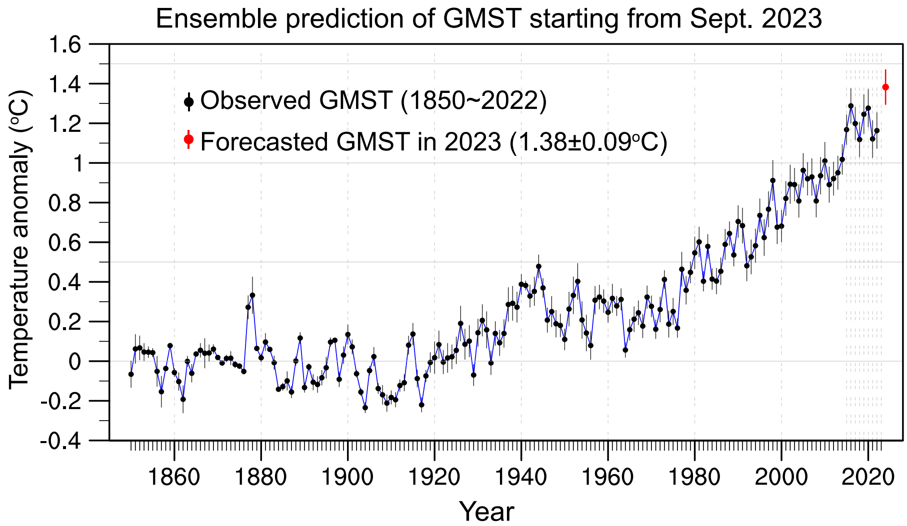

Fig. 2. The 2023 GMST prediction (relative to 1850–1900), starting in September 2023, by the IAP GMST statistical ensemble prediction model. The red dot and red bar represent the ensemble mean and ensemble spread of the forecasted results, respectively. The black dots and black bars represent the historical observed GMST during 1850–2022 and their uncertainties between three different datasets (HadCRUT5, NOAAGlobal-Temp5, and BEST).

China is up to 2.4 standard deviations above climatology, surpassing that of the 2015/16 winter. Consistent with the predicted GMST, this winter will be the warmest winter since 1991, according to the MME prediction, further noting that the warming in China is 1.84 times higher than the global average.

It should be noted that the results shown in this report are for the overall DJF mean. Nonetheless, given the significant sub-seasonal variability of the East Asian winter climate (Wu, 2016; Geng et al., 2017; Dai et al., 2019), it cannot be ruled out that severe cooling processes caused by the cold air activities may occur in stages.

4. Uncertainties in seasonal climate prediction

The uncertainties in seasonal climate prediction arise not only from the capability of the prediction system itself, but also from climate noise that often originates from internal atmospheric dynamics that are loosely coupled to the slow-varying components of the climate system, such as SST, sea ice, or soil moisture (Zheng et al., 2023a). These uncertainties pose challenges in predicting the status of the upcoming winter with a lead time of two months. Taking the 2022/23 winter as an example, a combination of the objective predictions from dynamical models and the empirical predictions based on La Niña and Arctic sea ice (Zheng et al., 2022a) generally captured the pattern of surface air temperature in China, but the observations and predictions still showed discrepancies in the coverage and amplitude of temperature anomalies because of frequent mid- and high-latitude synoptic disturbances from the resultant extreme cold weather (Yao et al., 2023; Zheng et al., 2023b).

In contrast to the La Niña condition of the 2021/22 winter, the 2023−24 winter will very likely experience an El Niño condition, with the Arctic remaining warmer than normal. This configuration of the climatic background does not facilitate the occurrence of persistent Ural blocking because of the intensified meridional potential vorticity gradient (Luo et al., 2019; Zheng et al., 2022b; Yao et al., 2023). As such, the primary internal variability of influential concern is the East Asian winter monsoon (Wang and Lu, 2017; Wang et al., 2019) which will tend to be inactive. This will likely reduce the potential uncertainty of the wintertime prediction and increase the fidelity of seasonal prediction from dynamic models. However, this report mainly explored the anomalous climate variations over the northern hemisphere (NH) that are primarily based on the effects of El Niño and atmospheric circulations in the NH mid- and high-latitudes, further noting that the influence of the southern hemisphere on the winter climate over NH is less considered. This is an issue that will be further examined through diagnostic analysis and sensitivity experiments.

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