Evaluation of East Asian Summer Climate Prediction from the CESM Large-ensemble Initialized Decadal Prediction Project

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ABSTRACT

Based on surface air temperature and precipitation observation data and NCEP/NCAR atmospheric reanalysis data, this study evaluates the prediction of East Asian summer climate during 1959–2016 undertaken by the CESM (Community Earth System Model) large-ensemble initialized decadal prediction (CESM-DPLE) project. The results demonstrate that CESM-DPLE can reasonably capture the basic features of the East Asian summer climate and associated main atmospheric circulation patterns. In general, the prediction skill is quite high for surface air temperature, but less so for precipitation, on the interannual timescale. CESM-DPLE reproduces the anomalies of mid- and high-latitude atmospheric circulation and the East Asian monsoon and climate reasonably well, all of which are attributed to the teleconnection wave train driven by the Atlantic Multidecadal Oscillation (AMO). A transition into the warm phase of the AMO after the late 1990s decreased the geopotential height and enhanced the strength of the monsoon in East Asia via the teleconnection wave train during summer, leading to excessive precipitation and warming over East Asia. Altogether, CESM-DPLE is capable of predicting the summer temperature in East Asia on the interannual timescale, as well as the interdecadal variations of East Asian summer climate associated with the transition of AMO phases in the late 1990s, albeit with certain inadequacies remaining. The CESM-DPLE project provides an important resource for investigating and predicting the East Asian climate on the interannual and decadal timescales.

Key words: Community Earth System Model (CESM), large-ensemble initialized decadal prediction (DPLE), climate prediction, East Asian summer climate, decadal variation

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1. Introduction

Near-term climate prediction usually refers to the numerical prediction on timescales from 1 to 10 yr or even 30 yr in advance using globally coupled atmosphere–ocean general circulation models (Hurrell et al., 2009). Research on near-term climate prediction has grown rapidly in recent decades. Disentangling the impact of initialization versus external forcing on decadal and interdecadal climate prediction by conducting an extensive set of numerical experiments is among the most imperative tasks in phase 5 of the Coupled Model Intercomparison Project (CMIP5). The CMIP5 multimodel decadal experiments indicate that decadal and interdecadal climate prediction is sensitive to both the initialization and external forcing. Examination of CMIP5 decadal prediction experiments indicates a wide range in skill for different prediction systems and for different variables. Although the potential for useful applications has been affirmed, the CMIP5 experiments have also emphasized many outstanding issues, such as developing more accurate and efficient initialization schemes, which needs to be solved to improve the skill levels of decadal prediction (Smith et al., 2007; Keenlyside et al., 2008; Meehl et al., 2009,...

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The Word Climate Research Programme has recognized near-term prediction as one of the major challenges of the international climate research community, and the latest phase (Phase 6) of CMIP (CMIP6) designates a coordinated set of decadal prediction experiments in order to advance decadal climate prediction skill and capacities (Boer et al., 2016).

Previous studies suggest that decadal prediction with observation-based initialization increases in prediction skill compared to uninitialized simulations based on the same models. For example, ocean initialization can enhance model skill in terms of predicting observed surface air temperature (SAT) variations; indeed, as reported by Smith et al. (2007), the thus predicted globally averaged SAT from 1983 to 2002 and that during the late-1990s warming hiatus, are closer to observations. Furthermore, such an initialization improves the predictive skill of sea surface temperature (SST) in the North Atlantic and tropical Pacific oceans, and captures well the weakening of Atlantic Meridional Overturning Circulation in recent decades (Keenlyside et al., 2008; Pohlmann et al., 2009). Moreover, initialization leads to retrospective SST prediction skill over the Pacific and other oceans to an extent that is significantly better than reference skill levels from uninitialized prediction (Meehl et al., 2009, 2014; Karspeck et al., 2015).

The variation in East Asian climate is complex, with a myriad of influential factors, and its prediction on multiple timescales has always been recognized as one of the major challenges in the field of climate research (Wang et al., 2015). Since the 1990s, the following prediction experiments have been carried out in China: seasonal climate prediction experiments with atmospheric general circulation models (Zeng et al., 1990, 1997; Wang, 1997; Lang et al., 2004); short-term predictions of El Niño–Southern Oscillation (ENSO) based on coupled general circulation models (Zhou and Zeng, 2001); and short-term East Asian climate prediction experiments by use of a dynamical East Asian climate prediction system based on the Community Climate System Model version 4 (CCSM4) (Ma et al., 2015). At the same time, the first generation of a national short-term climate prediction system was set up in China (Ding et al., 2004; Li Q. Q. et al., 2004; Li W. J. et al., 2005). In addition, the statistical and dynamical downscaling prediction has been widely applied and shown good performance in the climate prediction community (Zhu et al., 2008; Lang and Wang, 2010; Lang, 2011; Lang and Zheng, 2011; Li, 2011; Liu and Fan, 2013; Ren et al., 2014, 2019; Xu et al., 2018). In general, however, climate prediction in China has focused mainly on the seasonal timescale, with very few studies being conducted on longer timescales. A set of decadal experiments performed by using the BCC_CSM1.1 (Beijing Climate Center Climate System Model version 1.1) suggested that ocean initialization can increase the level of skill in predicting mid- and low-latitude SST and global land SAT (Gao et al., 2012). Moreover, near-term climate prediction performed by the Institute of Atmospheric Physics of the Chinese Academy of Sciences has indicated that ocean initialization schemes exert a notable influence on the predictive skill of global SST (Wu et al., 2017).

To perform decadal and interdecadal climate prediction experiments carries an enormous cost in terms of computational resource, and therefore the tier-1 set of hindcasts in the Decadal Climate Prediction Project of CMIP6 only requires a set of 10-member-ensemble initialized hindcast experiments. The experiments initialized each year from 1960 to 2019 for 60 yr and integrated for 5 yr for each member cost 3000 modeling years (Boer et al., 2016), and the resource demand will double to 6000 modeling years if the length of integration is extended to 10 yr in order to assess the decadal-scale skill. Furthermore, the ensemble members should be large enough so that the ensemble mean method can strictly extract the shared information within the individual members (Boer et al., 2013). In reality, the standard 10-member ensemble is generally selected, owing to computational resource limitations (Sienz et al., 2015), although it is arguably inadequate.

Recently, a set of large-ensemble initialized decadal prediction simulations using the Community Earth System Model (CESM-DPLE) has been completed. The CESM-DPLE project includes 40 ensemble members, each initialized from 1 November 1954 to 2015 (62 yr in total) and integrated forward for 122 months. Since 2018, the project has provided publicly available climate data ranging from the six-hourly to annual scale from four CESM component models, including atmosphere, ocean, sea ice, and land. The use of large ensembles provides more accurate measures of sample statistics via the probability distribution function (PDF) method. Actually, one of the motivations for the CESM-DPLE experiments is to examine whether the numerical model can capture the PDF shifts in extreme weather and climate events, such as floods, cold surges, and heat waves. Meanwhile, the large ensemble size of CESM-DPLE will increase the sampling accuracy of weather and climate processes, thus facilitating a deeper understanding of the key mechanisms involved in near-term prediction. The large ensemble size will also enable CESM-DPLE to distinguish
between the influences of external forcing and internal variability on decadal climate prediction. The predictive skill of CESM-DPLE with respect to global SST and tropical zonal wind has been assessed recently by Yeager et al. (2018). However, the performance of the CESM-DPLE experiment in terms of East Asian summer climate remains unclear, and it is necessary to evaluate and quantify its predictive skill in this regard to provide a reference for climate prediction research and operational applications.

The rest of this paper is organized as follows. Section 2 details the model (i.e., CESM1.1), the CESM-DPLE simulations, and the observational datasets employed. Section 3 evaluates the simulations of East Asian summer climatologies by CESM-DPLE. Section 4 assesses the predictive skill of CESM-DPLE in terms of the interannual variation of East Asian summer climate. Section 5 analyzes the change in East Asian summer climate associated with the phase transition of the Atlantic Multidecadal Oscillation (AMO) in the late 1990s and its simulation by CESM-DPLE. Finally, Section 6 summarizes the key findings of the present study.

2. Model, experiment, and data

2.1 CESM1.1

The CESM-DPLE simulations use the Community Earth System Model version 1.1 (CESM1.1), which consists of four component models (atmosphere, ocean, sea ice, and land) exchanged via a central coupler (Hurrell et al., 2013). The atmosphere model uses CAM5.2 (the Community Atmosphere Model, version 5.2) at a horizontal resolution of approximately 1°, with 30 levels in the vertical. The ocean model uses POP2 (the Parallel Ocean Program, version 2) at a horizontal resolution of approximately 1°, with 60 levels in the vertical. The sea-ice model uses CICE4 (the Community sea Ice CodE, version 4) and is run on the same horizontal grid as the ocean model. The land model uses CLM4 (the Community Land Model, version 4) and is run on the same horizontal grid as the atmosphere model. Previous investigations have shown that the CESM1.1 and CCSM4 (Community Climate System Model, version 4) exhibit a certain level of skill in simulating the climatology and annual variability (Tian et al., 2012; Tian and Jiang, 2013; Zhang et al., 2015) as well as interdecadal change (Zhao and Cong, 2018; Wang and Li, 2019) of the East Asian climate.

2.2 The CESM-DPLE experiment

The CESM-DPLE used a forced ocean–sea ice (FOSI) simulation to provide initial ocean and sea-ice conditions. The FOSI simulation was driven by the Coordinated Ocean–Ice Reference Experiment (CORE) forcing data, and it produced ocean and sea-ice fields from 1954 to 2015 to serve as the initial condition for CESM-DPLE. Examination of the first generation CORE forcing data indicated a spurious weakening trend in the zonal SST gradient along the equatorial Pacific Ocean compared to the observation, which resulted in a systematic bias in equatorial Pacific air–sea circulation produced by the FOSI simulation. To eliminate this bias, CESM-DPLE used the second generation CORE forcing dataset. This new CORE-forced FOSI simulation successfully eliminated the spurious weakening trend in the equatorial Pacific Ocean (Yeager et al., 2018). The atmospheric and land initial conditions were taken from the corresponding year of the historical and projection simulations from CESM1.1. These simulations were started from 1850 to 2015 with time-evolving observed external forcings, such as CO₂, CH₄, solar radiation, and volcanoes from 1850 to 2005, but under the Representative Concentration Pathway 8.5 (RCP8.5) scenario from 2006 to 2015.

The CESM-DPLE simulations were initialized every year on 1 November from 1954 to 2015 and integrated forward for 122 months with 40 ensemble members. These ensemble members were generated by adding random round-off level perturbations into the atmospheric initial fields. In the current study, the predicted quantity was represented as the average of years 3–7 for year 5 in each hindcast simulation, e.g., the prediction for 1959 was the average over 1957–1961 in the prediction initialized on 1 November 1954 (Meeth and Teng, 2014), and the prediction was compared with the corresponding observation. The predicted data during 1959–2016 are analyzed in this paper.

2.3 Observational and reanalysis data

The observational and reanalysis data used in this study include: the NOAA Precipitation Reconstruction over Land dataset; the University of Delaware global SAT dataset; and the NCEP–NCAR atmospheric reanalysis dataset, including the 500-hPa geopotential height, 850-hPa zonal and meridional wind components, and 850-hPa specific humidity.

3. Mean states of East Asian summer climate simulated by CESM-DPLE

Figure 1 shows the climatological distributions of the observed and simulated summer SAT in East Asia. In the observation, the SAT in East Asia generally exhibits a
decreasing trend from south to north. An extensive area of low SAT is observed over the Tibetan Plateau because of its high altitude, with a climatological value lower than 12°C. Moreover, the climatological summer SAT in western Mongolia and northern Xinjiang is also lower than 12°C, while it is higher than 24°C in Southeast China and the southern part of Xinjiang (Fig. 1a). CESM-DPLE simulates well the decreasing pattern in SAT from south to north, and the high SAT centers over Southeast China and southern Xinjiang, as well as the low SAT centers over the Tibetan Plateau, western Mongolia, and northern Xinjiang (Fig. 1b). Inspection of the difference between the simulation and observation reveals a notable cold bias in most parts of East Asia. The simulated SAT over Southeast China, Northeast China, the Korean Peninsula, and southern Japan is 0–3°C lower than observed, and 3–5°C lower than observed over North China, Southwest China, and southern Xinjiang. Meanwhile, the simulated SAT is 3–5°C higher than observed over most of Xinjiang (Fig. 1c). Here, root-mean-square error (RMSE) and pattern correlation coefficient (PCC) are used to quantify the errors of the simulation. Table 1 shows that the RMSE and PCC for summertime East Asian SAT are 3.24°C and 0.88 respectively, suggesting that CESM-DPLE simulates well the spatial distribution of summer SAT in East Asia.

Figure 2 shows the observed and simulated climatological mean summer precipitation over China. CESM-DPLE simulates well the observed large-scale pattern of “southeast coast wet–northwest inland dry” and the heavy precipitation above 540 mm over the southeastern Tibetan Plateau, southern part of South China, middle and lower reaches of the Yangtze River, North China, southern part of Northeast China, and the Korean Peninsula (Fig. 2b). The differences between the simulated and observed precipitation in East China indicate that the simulated rainbelt extends too far northward compared to the observation, and the simulated precipitation is lower than observed to the south of the Yangtze River valley and over the Korean Peninsula and southern Japan, but higher than observed to the north of the Yangtze River and over Northeast China. In addition, CESM-DPLE simulates excessive precipitation over the eastern Tibetan Plateau and the Sichuan basin (Fig. 2c). This bias has also been found to exist in previous climate model studies (Jiang et al., 2004, 2016; Zhang et al., 2008; Si et al., 2009). As for this spurious high precipitation center, it may be due to the low horizontal resolution of the clim...
mate model (Jiang et al., 2005; Gao et al., 2006; Xu et al., 2010). As Table 1 reveals, the RMSE and PCC for the simulated summertime East Asian precipitation are 284.82 mm and 0.67 respectively, and therefore the skill of CESM-DPLE with respect to the precipitation distribution is generally lower than that for the SAT.

Since the simulated precipitation and SAT are dynamically related to the large-scale atmospheric circulation, we assess the simulation skill of CESM-DPLE with respect to the summertime atmospheric circulation in East Asia. At 500 hPa, a “one trough and one ridge” geopotential height pattern dominates the mid–high latitudes of Asia, featuring a trough over Lake Balkash and a ridge over East Siberia (Fig. 3a). Meanwhile, a “two high and one low” geopotential height pattern emerges over the mid–low latitudes of Asia. The western North Pacific subtropical high (WPSH) generally situates between 20° and 30°N, and its westernmost ridge point lies around 140°E. The other high pressure locates over the Arabian Peninsula. Between the two high pressures, there is an inverted Ω-like trough over India. Generally, CESM-DPLE simulates well the “one trough and one ridge” and “two high and one low” geopotential height patterns over the
mid–high latitudes and mid–low latitudes in Asia, respectively (Fig. 3b). However, it simulates a stronger trough over Lake Balkash and a stronger ridge over East Siberia compared with observation. The simulated WPSH is stronger and larger than observed, and extends to the west of its observational position (Fig. 3b). The geopotential height values are higher in the CESM-DPLE simulation than observed in most parts of Asia, except the Tibetan Plateau where the simulated geopotential height is lower than observed. The simulated low geopotential height over the Tibetan Plateau, together with the simulated stronger WPSH, intensifies the pressure gradient between the Tibetan Plateau and WPSH (Fig. 3c), in the region where the East Asian summer monsoon prevails, thus causing a northward advance of the East Asian summer monsoon rainbelt (Si et al., 2009; Tian et al., 2012).

Next, we examine the simulation of the low-level summer monsoon circulation in East Asia. On the one hand, the simulated southwesterly winds from the Indian Ocean are weaker than observed (Fig. 4), which is largely a result of the weak simulation of the India–Burma trough (Fig. 3); whilst on the other hand, the simulated southeasterly winds from the western North Pacific are stronger than observed, possibly because of the simulated stronger and more westward extended WPSH. Inspection of the difference between the simulation and observation reveals strong southerly winds prevailing over East China, the Korean Peninsula, and Japan, which converge with the northerly winds along Southwest China, North China, and Northeast China (Fig. 4c), leading to a northward advance of the major rainbelt and excessive precipitation over the eastern Tibetan Plateau.

Table 1 shows that the RMSE for the summer 500-hPa geopotential height, 850-hPa meridional wind, and 850-hPa zonal wind over East Asia is 16.99 gpm, 1.94 m s$^{-1}$, and 1.11 m s$^{-1}$, respectively. The PCC for these variables is 0.99, 0.72, and 0.67, respectively, all of which exceed the 99% confidence level.

4. Interannual variation of East Asian summer climate predicted by CESM-DPLE

Similarly, we employ the RMSE and temporal correlation coefficient (TCC) to quantify the predictive skill with respect to the interannual variation of summer SAT and precipitation over East Asia. In general, the RMSE for SAT variability increases with latitude in East Asia, with low values from 0 to 0.3°C in South China and Southwest China, values from 0.4 to 0.7°C over the middle and lower reaches of the Yangtze River and southern Japan, values above 0.7°C over Inner Mongolia and the Korean Peninsula, and the highest values exceeding 0.9°C over Mongolia (Fig. 5a). The high RMSE values at high latitudes might be attributable to cold-air activity in East Asia. Although it is summer, cold-air activity is still frequent at high latitudes in East Asia, which results in a high amplitude of SAT variability at high latitudes. A previous study found that it is a common defect for climate models to reproduce SAT variability in East Asia (Jiang et al., 2016). As seen in Fig. 5b, CESM-DPLE has a high predictive skill with respect to the summer SAT over East Asia. The TCC for summer SAT is high in the CESM-DPLE prediction in most parts of East Asia, except over the middle reaches of the Yangtze River, southern part of the Yellow–Huai River valley, southern part of the Korean Peninsula, and south-
ern Japan. The TCC over southern South China, Southwest China, the Tibetan Plateau, and the region to the north of 35°N reaches 0.6 and locally exceeds 0.9.

Figure 6a shows the RMSE for the interannual variation of summer precipitation in East Asia. The RMSE ranges from 200 to 400 mm over the southern part of South China, lower reaches of the Yangtze River, North China, Korean Peninsula, and southern Japan, with the highest value exceeding 400 mm over the eastern Tibetan Plateau. As described above, this large bias in climate models worldwide is a result of excessive precipitation simulated over there. Although CESM-DPLE shows a certain level of skill with respect to summer precipitation over parts of East Asia, such as South China, the southeastern part of Southwest China, the middle and lower reaches of the Yellow River, the eastern part of North China, and the western part of Northeast China, CESM-DPLE has little predictive skill in terms of the interannual variation of summer precipitation over East Asia during 1959–2016 overall. Especially, over the regions south of the Yangtze River, Sichuan basin, Northwest China, and the northern part of the Korean Peninsula, the simulated precipitation varies out-of-phase with the observation (Fig. 6b).
In order to assess the influence of RCP8.5 forcing on the predictive skill of CESM-DPLE, we further analyze the change in predictive skill with and without the RCP8.5 forcing (figure omitted). For SAT, without the RCP8.5 forcing for 1959–2005, the RMSE generally decreases but not obviously; the RMSE decreases in Southwest China, Inner Mongolia, and Mongolia, while it increases in the eastern part of the region south of the Yangtze River, North China, Korean Peninsula, and Lake Baikal. Correlation analysis indicates that the TCC decreases slightly without the RCP8.5 forcing, especially over Southwest China and the Tibetan Plateau. For precipitation, without the RCP8.5 forcing for 1959–2005, the RMSE slightly decreases in the northern part of East Asia but increases in the southern part. In the meantime, the TCC slightly increases, especially over the northern part of China and Southwest China, but decreases over the eastern Tibetan Plateau.

5. CESM-DPLE-simulated interdecadal change in East Asian summer climate associated with the phase transition of the AMO

The East Asian climate is not only influenced by the local atmospheric circulation, but also modulated by the large-scale circulation in Eurasia and even the whole of the Northern Hemisphere. More specifically, the interannual and interdecadal variations of the Asian monsoon are affected by both the northern mid- and high-latitude tropospheric atmospheric circulation anomalies (Wu and Zhang, 2011; Huang and Wang, 2012; Yang et al., 2018) and the stratospheric circumpolar zonal circulation in the Northern Hemisphere (Liu and Qu, 1991). Moreover, mid- and high-latitude atmospheric circulation anomalies in Eurasia exert an important impact on the interdecadal change in summer SAT and precipitation in East Asia (Cai et al., 2011; Tian et al., 2017).

Observational and modeling investigations suggest that the Atlantic SST anomalies modulate winter atmospheric circulation at middle and high latitudes in Eurasia (Yang et al., 1992; Qu et al., 2006) and affect climate effect of the Tibetan Plateau (Lu et al., 2019). A warm AMO phase gives rise to increased SAT over most parts of China in all four seasons (Li et al., 2009). The AMO also modulates the East Asian summer monsoon (Yang et al., 2017) and Afro-Asian summer monsoon (Li et al., 2017). The AMO can act as a driver of interdecadal precipitation variation in not only East Asia but also almost the entire Northern Hemisphere from the North Atlantic through Eurasia and extending to North America by exciting a circumglobal stationary baroclinic wave train (Si and Ding, 2016).

In the late 1990s, the AMO transited from a cold phase to a warm phase. Next, we analyze the associated change in summer climate over East Asia and its simulation by CESM-DPLE. As seen in Fig. 7a, since the late 1990s, the SAT has generally increased over East Asia, especially over the middle and lower reaches of the Yangtze River, the Tibetan Plateau, Xinjiang, the Korean Peninsula, and Mongolia. Qualitatively, CESM-DPLE simulates the high SAT in East Asia since the late 1990s, although there are still quantitative inadequacies (Fig. 7b).

Meanwhile, summer precipitation has increased in East Asia since the late 1990s, especially over South China, the regions north of the Yangtze River, the Korean Peninsula, and southern Japan, while it has decreased over the middle and lower reaches of the Yangtze River (Fig. 8a). In general, CESM-DPLE captures reasonably this interdecadal change in East Asian summer precipitation (Fig. 8b), including the wet tend-
ency in the Yangtze–Huaihe River valley north of the Yangtze River, Yellow–Huaihe River valley, southern part of Northeast China, South China, and northern part of the Korean Peninsula, as well as the dry tendency (to a degree) over the middle reaches of the Yangtze River.

Since the late 1990s, a wave train has extended from East Europe, through Asia, to the western North Pacific, in the middle troposphere (Fig. 9a). An anomalous low in geopotential height is located over East Asia, resulting in a positive precipitation anomaly in the region. A previous study revealed that the geopotential height pattern associated with the AMO displays a prominent global zonal wave train, with a wavenumber of approximately 5 at midlatitudes over the Northern Hemisphere; and 8 centers of action are located over the Atlantic Ocean, West Europe, East Europe, central Asia, the area near Lake Baikal, East Asia, North Pacific, and North America (Si and Ding, 2016). Figure 9a indicates that the wave train has 5 centers of action over East Europe, central Asia, Lake Baikal, East Asia, and North Pacific, which is consistent with the wave train driven by the AMO (Si and Ding, 2016). Additionally, the phase of this wave train corresponds to the phase of the wave train associated with a warm AMO. Given that the AMO shifted from a cold to a warm phase in the late 1990s, this feature suggests that the wave train could be linked to the AMO. CESM-DPLE reproduces the wave train extending from East Europe to the western North Pacific, including the low pressure in East Asia (Fig. 9b). However, the simulated amplitude of the wave train is weaker than observed. On the one hand, we discuss only the ensemble mean results, and the amplitudes decrease significantly for the ensemble mean because it largely eliminates the internal climate variability. On the other hand, the weak amplitude may be related to the ability of CESM.

In the 850-hPa wind field, the wave train can still be observed as extending from East Europe to the western North Pacific. Since the late 1990s, the wave train has
enhanced the southerly winds in East Asia and led to a stronger East Asian summer monsoon (Fig. 10a), which eventually resulted in a high SAT (Fig. 7a) and northward shift of the rainbelt in East Asia (Fig. 8a). In the large-scale circulation field, CESM-DPLE reproduces the wave train in the lower troposphere, and captures the enhancement of the East Asian summer monsoon since the late 1990s (Fig. 10b).

6. Summary

This study evaluates the skill of CESM-DPLE in simulating the mean basic states of East Asian summer climate and in predicting its interannual variation as well as its interdecadal change associated with the phase transition of the AMO. Main conclusions are summarized as follows.

(1) CESM-DPLE captures well the basic features of the East Asian summer climate and associated main atmospheric circulation patterns. In general, the predictive skill is quite high for the interannual variation of summer SAT in East Asia with RMSE lower than 1°C. Meanwhile, despite isolated and localized high predictive skill, CESM-DPLE generally exhibits almost no skill in terms of the interannual variation of summer precipitation over East Asia.

(2) The AMO underwent a phase transition in the late 1990s, and the summer SAT, precipitation, and major atmospheric circulation over East Asia changed accordingly. Specifically, since the late 1990s, the AMO has shifted to a warm phase, which has enhanced the East Asian summer monsoon and increased the summer precipitation and SAT in East Asia through a teleconnection wave train. In general, CESM-DPLE reproduces reasonably the interdecadal change in East Asian summer climate associated with this phase transition of the AMO.

In summary, CESM-DPLE is capable of predicting the East Asian summer temperature on the interannual timescale and the interdecadal change in East Asian summer climate associated with the transition of AMO phases in the late 1990s. The CESM-DPLE Project is an important resource for investigating and predicting the East Asian climate in subsequent studies. It is also worthwhile noting that, different from previous initialized decadal prediction experiments, CESM-DPLE is an initialized large ensemble experiment composed of 40 members, and thus it provides more accurate measures of sample statistics and is able to distinguish between the influences of external forcings and internal variability in decadal climate predictions.

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