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# Interannual variability of western North Pacific subtropical high, East Asian jet and East Asian summer precipitation: CMIP5 simulation and projection

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ABSTRACT

Based on the Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations, this paper evaluated the performance of the state-of-the-art climate models in simulating the interannual variability of the western North Pacific subtropical high (WNPSH), East Asian jet (EAJ) and East Asian summer rainfall (EASR), and further projected their potential changes in a future warmer world. The results show that the multimodel ensemble mean (MME) simulation has good ability to model the interannual variability of the WNPSH, EAJ and EASR, although some discrepancy exists among the individual models. The MME simulation can also reasonably capture the observed relationship of the EASR with the WNPSH and the EAJ. Under the RCP4.5 and the RCP8.5 scenarios, the interannual variability in WNPSH, EAJ and EASR is projected by the MME to increase in the 21st century. In addition, the WNPSH and EAJ would still be the dominant systems influencing the East Asian summer precipitation under global warming scenarios. But the linkage of the EASR to the WNPSH may be slightly weaker and that to the EAJ may be slightly stronger in the 21st century as compared to the present.



## 1. Introduction

The East Asian summer monsoon (EASM) plays an important role in the occurrence of summer precipitation over Asia, thereby exerting significant impacts on the economic and social development of East Asian countries. The observations indicate that the EASM has experienced a significant weakening during the second half of the 20th century (Wang, 2001; Yu et al., 2004; Wang and Ding, 2006; Xu et al., 2006; Wang et al., 2015), which may be a response to anthropogenic forcing (Ueda et al., 2006; Zhu et al., 2012; Wang et al., 2013) and natural variability (Yang and Lau, 2004; Lei et al., 2014). The weakening of the EASM and resultant change of precipitation have large impacts on agriculture, water resources and society, particularly in eastern China with a dense population and concentrated industries and agricultures (Piao et al., 2010). Therefore, how the EASM system and its related precipitation will change in the future is a key issue concerned to both science community and policy makers. Researches on it not only provide useful information for science community but also serve as the important scientific basis for policy-making in disaster prevention and mitigation.

With better understanding of climate system and continuous improvement of climate models, the CMIP provides a great opportunity for projecting changes of the EASM and associated precipitation systematically. Many studies (e.g., Min et al., 2004; Kimoto, 2005; Sun and Ding, 2010; IPCC, 2013) have projected an increase in both East Asian monsoon circulation and precipitation under global warming scenarios. However, these studies mainly concentrated on the climate mean status and paid less attention to the interannual variability. As is known, besides changes in climate mean state, changes in variance that is used to represent interannual variability is another important indicator to measure climate change. In recent years, some researches have started to study future change of the interannual variability in East Asian summer

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rainfall (EASR). For example, Kripalani et al. (2007) revealed a significant increase of the interannual variability of the EASR in response to doubled atmospheric $CO_2$. Lu and Fu (2010) projected that the interannual variability of the EASR will be intensified by 12% and 19% during the 21st century under the A1B and A2 scenarios, respectively, with two abrupt changes occurring in the 2030s and the 2070s (Fu, 2012). The projected intensification of the interannual variability is much more prominent in comparison with the mean East Asian summer precipitation itself (Lu and Fu, 2010).

In addition, the interannual variability of the EASR is closely associated with the western North Pacific subtropical high (WNPSH) and the East Asian westerly jet (EAJ), which are two key elements of the EASM system. The WNPSH and the EAJ affect the EASR respectively from the south in the lower troposphere and from the north in the upper troposphere. If the WNPSH extends westward (retreats eastward), more (less) precipitation tends to occur in East Asia (Chen and Wu, 1998; Lu, 2001). The summer EAJ, especially its location, plays a strong dynamical role on the precipitation variation. When the EAJ is located in the south (north) of the normal position, above-normal (below-normal) precipitation is inclined to appear in East Asia (Liang and Wang, 1998; Lau et al., 2000; Lu, 2004). Therefore, it is also crucial to project the interannual variability in WNPSH and EAJ and their relationships with the EASR under global warming scenarios. The results of Lu and Fu (2010) indicated that the relationships of the EASR with the WNPSH and the EAJ do not exhibit clear changes in the 21st century under the A1B and A2 scenarios, and there are great discrepancies among the individual CMIP3 models.

It is worth noting that those results are based on the CMIP3 simulations. Compared with the CMIP3, the CMIP5 features substantial model improvements (Taylor et al., 2012) and adopts a new set of emission scenarios Representative Concentration Pathways (RCPs) (Moss et al., 2010) for future climate simulations. Then, how well do the CMIP5 models simulate the interannual variability of the WNPSH, EAJ and EASR? Can they capture the observed relationships of the EASR with the WNPSH and the EAJ? What about their future changes under the RCP scenarios? This is the main motivation of the present study.

The remainder of this paper is organized as follows. The data and methods used in this study are described in Section 2. Section 3 evaluates the performance of the CMIP5 models in simulating the interannual variability of the WNPSH, EAJ and EASR as well as the relationships of the EASR with the WNPSH and the EAJ. Their future changes under the RCP4.5 and RCP8.5 scenarios are projected in Section 4, followed by conclusions in Section 5.

## 2. Data and methods

The results of 19 CMIP5 models (Table 1) for historical, RCP4.5 and RCP8.5 simulations are employed in this study. The historical experiment represents the simulations of the twentieth century climate. The RCP4.5 and RCP8.5, which have the radiative forcing peaking at 4.5 W/m$^2$ and 8.5 W/m$^2$ by 2100, represent a medium-low and high radiative forcing scenario respectively. More details on the models and the forcings can be found at the CMIP5 website (http://cmippcmdi.llnl.gov/cmip5/availability.html). The time periods used for analysis are 1900–2005 for the historical simulation and 2006–2100 for the RCP scenarios. To validate the performance of the CMIP5 models, the monthly mean geopotential height and zonal wind for 1948–2010 from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP/NCAR) (Kalnay et al., 1996) and the precipitation data for 1979–2010 from Global Precipitation Climatology Project (GPCP) (Huffman et al., 1995) are exploited and identified as the observation (OBS). The horizontal resolution for both the NCEP/NCAR reanalysis and the GPCP precipitation data are 2.5° longitude by 2.5° latitude. These data can be downloaded from the website http://www.esrl.noaa.gov/psd/data/gridded/tables/monthly.html. Since the CMIP5 models have different spatial resolutions (see Table 1), data from the different models are all converted to the 2.5° × 2.5° grid using a bilinear interpolation scheme before analysis.

**Table 1**
Information of the 19 CMIP5 models used in the present analysis.

| Name | Modeling group | Atm. Resolution (lon × lat) |
|---|---|---|
| ACCESS1-0 | Common wealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia | 192 × 145 |
| ACCESS1-3 | Common wealth Scientific and Industrial Research Organization (CSIRO) and Bureau of Meteorology (BOM), Australia | 192 × 145 |
| BCC-CSM1-1-m | Beijing Climate Center, China Meteorological Administration, China | 320 × 160 |
| BNU-ESM | Beijing Normal University/China | 128 × 64 |
| CanESM2 | Canadian Centre for Climate Modeling and Analysis, Canada | 128 × 64 |
| CCSM4 | National Center for Atmosphere Research, United States | 288 × 192 |
| CMCC-CMS | Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy | 192 × 96 |
| CNRM-CM5 | Centre National de Recherches Meteorologiques and Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique, France | 256 × 128 |
| FGOALS-g2 | State Key Laboratory of Numerical Modeling for Atmospheric Sciences and Geophysical Fluid Dynamics (LASG), Institute of Atmospheric Physics, Chinese Academy of Sciences, China | 128 × 60 |
| FIO-ESM | First Institute of Oceanography, China | 128 × 64 |
| GFDL-CM3 | NOAA Geophysical Fluid Dynamics Laboratory, United States | 144 × 90 |
| GFDL-ESM2G | NOAA Geophysical Fluid Dynamics Laboratory, United States | 144 × 90 |
| GFDL-ESM2M | NOAA Geophysical Fluid Dynamics Laboratory, United States | 144 × 90 |
| HadGEM2-AO | Met Office Hadley Centre, United Kingdom | 192 × 144 |
| HadGEM2-CC | Met Office Hadley Centre, United Kingdom | 192 × 144 |
| HadGEM2-ES | Met Office Hadley Centre, United Kingdom | 192 × 144 |
| IPSL-CM5A-MR | Institute Pierre-Simon Laplace, France | 144 × 143 |
| MIROC-ESM | Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan | 128 × 64 |
| NorESM1-M | Norwegian Climate Centre/Norway | 144 × 96 |

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