The projected temporal evolution in the interannual variability of East Asian summer rainfall by CMIP3 coupled models

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The projected temporal evolution in the interannual variability of East Asian summer rainfall in the 21st century is investigated here, by analyzing the simulated results of 18 coupled models under the 20th century climate experiment and scenario A1B. The multi-model ensemble (MME) mean projects two prominent changes in the interannual variability of East Asian summer rainfall in the 21st century under scenario A1B. The first change occurs around the 2030s, with a small change before and a large increase afterward. The intensity of the interannual variability increases up to approximately 0.53 mm/d in the 2070s, representing an increase of approximately 30% relative to the early 21st century. The second change happens around the 2070s, with a decrease afterward. By the end of the 21st century, the increase is approximately 12% relative to the early 21st century.

The interannual variability of two circulation factors, the western North Pacific subtropical high (WNPSH) and the East Asian upper-tropospheric jet (EAJ), are also projected to exhibit two prominent changes around the 2030s and 2070 under scenario A1B, with consistent increases and decreases afterward, respectively. The MME result also projects two prominent changes in the interannual variability of water vapor transported to East Asia at 850 hPa, which occurs separately around the 2040s and 2070s, with a persistent increase and decrease afterward. Meanwhile, the precipitable water interannual variability over East Asia and the western North Pacific is projected to exhibit two prominent enhancements around the 2030s and 2060s and an increase from 0.1 kg/m$^2$ in the early 21st century to 0.5 kg/m$^2$ at the end of the 21st century, implying a continuous intensification in the interannual variability of the potential precipitation. Otherwise, the intensities of the three factors’ (except EAJ) interannual variability are all projected to be stronger at the end of the 21st century than that in the early period. These studies indicate that the change of interannual variability of the East Asian summer rainfall is caused by the variability of both the dynamic and thermodynamic variables under scenario A1B. In the early and middle 21st century, both factors lead to an intensified interannual variability of rainfall, whereas the dynamic factors weaken the interannual variability, and the thermodynamic factor intensifies the interannual variability in the late period.

interannual variability, East Asian summer rainfall, future projection, climate change, climate model


Awareness of global warming and its influence on the Earth’s environment is one of the most important advancements of meteorology in the 20th century. Climatic disasters and extreme climate events, such as droughts and floods, occur frequently in East Asia under global warming, resulting in enormous damages to society and economies. Therefore, making projections of future climate change in East Asia has been a key goal of climate change research.

The change of interannual variability is one of the important measurements of climate change and is closely related to the potential occurrence of droughts and floods. An intensified (weakened) change of interannual variability.
indicates the increased (decreased) occurrence of climatic disasters. The East Asian summer precipitation exhibits a clear interannual variability, with the interannual standard deviation being approximately 6%–7% of the climatological mean [1]. Therefore, droughts and floods are the most serious disasters happening during the summer in East Asia, and they cause enormous damages.

Many studies have shown that summer precipitation increases in East Asia under global warming scenarios [2–10]. For example, Bueh [3] showed that the summer precipitation may significantly increase over the Yangtze (Changjiang) River valley and North China in the future. Sun and Ding [8] stated that summer precipitation may increase in East Asia and experience a prominent change around the 2040s with a large increase afterward. Li et al. [9] also suggested an intensified precipitation over most of China.

There are few studies on the possible change in the interannual variability of East Asian summer rainfall in the future. Recently, Kripalani et al. [1] showed that out of the 19 CMIP3 models, 13 depict significant increases in the interannual variability of the East Asian summer rainfall, but the multi-model ensemble (MME) mean showed no obvious change. By analyzing the simulation results of 12 CMIP3 models under scenarios A1B and A2, Lu and Fu [11] found that most of the selected models project an enhanced interannual variability of the East Asian summer rainfall in the 21st century, and the increased ratios of interannual variability of approximately 10% and 17% under scenarios A1B and A2, respectively, which are much stronger than those of the summer climatological precipitation.

Although the projected change in the interannual variability of East Asian summer rainfall in the future has been investigated, few studies have been performed on the temporal evolution of the interannual variability. We still have a paucity of knowledge for some important questions, such as whether the temporal evolution of the East Asian summer rainfall interannual variability experiences prominent change, how the change evolves in response to global warming, how the spatial pattern of precipitation variability changes, and what the roles of key dynamic and thermodynamic factors play in the process.

Unfortunately, numerical simulations for precipitation based on coupled models remain uncertain [12, 13], especially in East Asia, where there is a strong interaction between the lower and higher latitudes. Meanwhile, great uncertainties exist among models in simulating future climatological mean precipitation changes in East Asia [14, 15], and the MME results are even weaker than the dispersion among the models. For instance, Kitoh et al. [6] noticed a decreased precipitation in North China in summer, contrary to the results of Bueh [3] and Min et al. [4]. Therefore, we should also examine the changes in the interannual variability of dominant dynamic and thermodynamic components of the East Asian summer monsoon system, which are most closely related to the changes of East Asian summer precipitation interannual variability, to prove the changes of precipitation variability.

The interannual variation of East Asian summer precipitation is found to be closely related to local circulation anomalies as well as those in the western North Pacific [16]. The interannual variability of East Asian summer precipitation is closely related to anomalies of the western North Pacific subtropical high (WNPSH) in the lower troposphere and to the East Asian westerly jet (EAJ) in the upper troposphere. On the one hand, the WNPSH affects East Asian summer rainfall from south in the lower troposphere through zonal displacement. East Asia experiences flood (drought) when the WNPSH extends westward (retreats eastward) [17]. On the other hand, the EAJ affects East Asian summer rainfall from north in the upper troposphere through meridional displacement. A southward (northward) displaced EAJ favors above-normal (below-normal) precipitation in East Asia [18]. The relationships of East Asian summer rainfall with the WNPSH and EAJ remain robust in the 21st century [11].

Therefore, by analyzing the simulated results of 18 coupled models under the 20th century climate experiment (20C3M) and scenario A1B, we investigate the projected temporal evolution of the interannual variability of East Asian summer precipitation as well as the key dynamic components (the WNPSH, EAJ and water vapor transport) and thermodynamic component (precipitable water) of the East Asian summer monsoon system. In so doing, we attempt to obtain somewhat reliable projected changes of interannual rainfall variability in East Asia.

1 Models, data and methodology

We analyzed the results of 18 CMIP3 models for the 20C3M and scenario A1B. For both experiments, 100-year simulations (1901–2000 for 20C3M and 2001–2100 for A1B) are used to represent the 20th and 21st century climates. Table 1 lists the basic features of the selected models, and more detailed descriptions about the models can be found at http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php.

The method of MME mean is used to analyze the projected change in interannual variability of the East Asian summer climate. The MME results are obtained by simply averaging over the available models with equivalent weight because uncertainty exists among the different models even under the same greenhouse gases and aerosol forcing and because there is no scientific way to evaluate the models. This method has been widely accepted and adopted in the climate change projection [8, 11, 19]. Many studies also suggest that the MME method has a better performance than individual models in reproducing the present climate in East Asia [13, 20–22].

Because the experiment number differs from model to