Climatological study on long-term changes in the interannual variation of the Asian summer monsoon precipitation

Nozomi KAMIZAWA

Department of Geography

Graduate School of Urban Environmental Sciences

Tokyo Metropolitan University

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② Summary

The precipitation that the Asian summer monsoon (ASM) brings in accounts for a large portion of the annual precipitation. It is an important water source for the daily lives and socioeconomic activities for the region that includes densely populated areas. The ASM region is often worst affected by floods and droughts in the wet and dry extreme years of the interannual variation. Hence it is required to understand the behavior of the ASM precipitation in the past and to obtain a reliable view of the future ASM precipitation under global warming.

This dissertation investigated the long-term changes in the interannual variation of the past and future ASM precipitation. Two primary questions were addressed and restated here as follows.

1. How did the relationship between the ASM precipitation and its related interannual timescale phenomena change in the past?
2. How will the interannual variation of the ASM precipitation and its wet and dry extremes change in the future under global warming?

For the first question, we examined the interdecadal changes in the relationship between the ASM precipitation and the El Niño–Southern Oscillation (ENSO) for the period 1950 onwards by using observational data. ENSO is a phenomenon that directly and/or indirectly affects the climate worldwide in interannual timescale. It is well known that the summer seasonal precipitation over India is relatively low during El Niño year. Observational data were analyzed to investigate how the relationship with ENSO changed for regional precipitation inside and outside India. The negatively correlated relationship between the Indian summer monsoon and the Niño-3.4 index weakened after the 1970s, which was consistent with previous studies. The correlation maps of the relationship between the June–September (JJAS) precipitation and the Niño-3.4 index showed that the negatively correlated relationship remained over peninsular India throughout the researching period, whereas it broke down over northwest India and the Indochina Peninsula after the 1970s. The spatial patterns of the sea

surface temperature (SST), 200-hPa velocity potential, and 850-hPa streamfunction related to the precipitation over northwest India and the Indochina Peninsula showed that their ENSO-related pattern which appeared in the third quarter of the twentieth century faded in the final quarter of the twentieth century. Further investigations are required to understand whether these changes in the ASM–ENSO relationship is due to global warming or a phase of the internal variation.

For the second question, we used two global warming experiments simulated from climate models to understand the future projections for the ASM precipitation under global warming. One was phase 5 of the Coupled Model Intercomparison Project (CMIP5), which was a dataset consist of multi-coupled atmosphere–ocean general circulation models (multi-CGCMs). The other was database for Policy Decision making for Future climate change (d4PDF), which was a dataset consist of large ensemble members by a high-resolution atmospheric general circulation model (AGCM). We were able to consider model uncertainty in CMIP5, and partially the uncertainty of the internal climate variability (a land–atmosphere system) under the same SST forcing and the uncertainties from the climatological SST warming patterns (ΔSSTs) in d4PDF.

In the CMIP5 analyses, we examined the representative concentration pathway 4.5 (RCP4.5) experiment for 22 CGCMs. We evaluated the projection for the fluctuation of the interannual variation of the JJA precipitation and its extremes among the 22 CGCMs by counting the numbers of CGCMs. This approach equalized the effect on the multi-model projection from each CGCM and removed the risk for the multi-model projection being heavily impacted by a CGCM that projected an exceptionally large value. The CMIP5 models projected the fluctuation of the interannual variation of the June–August (JJA) precipitation to increase over the ASM region. Based on the result that the CMIP5 multi-model ensemble (MME) projected a wet-gets-wetter pattern for the long-term changes in the mean JJA precipitation, we investigated whether the long-term changes in the wet and dry extremes of the JJA precipitation anomalies have such characteristics. The wet and dry extremes had asymmetric features.

CMIP5 models projected that the dry extreme tended to extend where the long-term changes in the mean JJA precipitation were large, but such tendency was not projected in the wet extreme. Moreover, we assumed that the interannual variation of the JJA precipitation over the Indochina Peninsula increased due to the long-term changes in frequency and/or intensity of the physical phenomena that influence its interannual variation from the results from the composite analysis.

The multi-model analyses from CMIP5 revealed that the fluctuation of the interannual variation of the ASM precipitation tended to increase and the wet and dry extremes of the JJA precipitation anomalies tended to extend. However, the amount of changes was not discussed for these results due to large inter-model variance. Moreover, the wettest and driest years are generally statistically unstable, but the number of samples was limited for CMIP5. Thus, we analyzed d4PDF for further understanding. d4PDF enabled us to discuss the amount of changes in the ASM precipitation because it was a dataset consist of large ensemble members by a single climate model.

In the d4PDF analyses, we examined the historical and +4-K experiments, which had 90 and 100 ensemble members. The +4-K experiment simulates a future climate that the global-mean surface air temperature becomes 4 K warmer than the pre-industrial climate. Moreover, six ΔSSTs were used to prescribe the SST in the +4-K experiment, in which each had 15 ensemble members. The projection based on each ΔSSTs agreed to one another that the ASM precipitation overall increases and its interannual variation amplifies. However, their spatial patterns differed among the ΔSSTs. The inter-ΔSST spread of the long-term changes in the mean ASM precipitation was larger than its inter-ensemble spread of each ΔSST. The inter-ΔSST spread was large over the high-precipitation areas. The spatial patterns of the inter-ensemble spread of each ΔSST were similar to each other. It was large over central India. We also investigate the amount of change for the mean JJA precipitation and the wettest and driest JJA anomalies over high precipitation areas near the convection heat source of the ASM; the Indochina Peninsula, the Bay of Bengal, and Bangladesh. The ensemble members were clustered according to ΔSST in the distribution of the mean JJA precipitation in the +4-K experiment, implying that the amount of the mean JJA precipitation was ΔSST dependent. The ΔSST dependent tendency was also recognized in the distributions for the wet and dry extremes, and their relative positions in the distributions corresponded with the long-term changes in the mean precipitation. From the above results, we concluded the uncertainty in the spatial pattern of the SST affected the changes in the spatial pattern of the ASM precipitation for the mean, interannual variation, and wet and dry extremes, at least for these three areas.

The projections from CMIP5 and d4PDF agreed that the mean ASM precipitation and its fluctuation of the interannual variation increase under global warming. These results imply the growing risks of floods and droughts in the future. However, the spatial patterns of these long-term changes differed between the two datasets. These differences indicate the uncertainty of the future ASM precipitation is large. The mean ASM precipitation in the CMIP5 MME increased over the whole ASM region, particularly over the monsoon trough. On the other hand, the JJA precipitation along the monsoon trough decreased in d4PDF.