Future Changes in Monsoon Precipitation and Their Uncertainty Projected by Global Climate Models

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気候モデルを用いたモンスーン地域の降水の将来変化と予測不確実性に関する研究

Name: Hirokazu Endo (Student ID No: 201730304)

Doctor Program in Sustainable Environmental Studies
Graduate School of Life and Environmental Sciences

Abstract

Abundant precipitation brought by monsoon provides rich water resources to support agriculture, industry, and a population of billions in monsoon regions worldwide. It is desirable to provide a reliable future projection of monsoon precipitation on regional scales in a warmer climate. Global climate models used in a global warming projection have been extensively developed and improved for the past several decades. However, a projection of regional precipitation change still faces challenges because of its large spatial variation and large uncertainty. Therefore, it is necessary to quantify projected changes and their uncertainty on regional scales as well as to understand their mechanisms. In addition, a use of high-resolution models is essential for projecting changes in extreme precipitation which has large impact on society.

This study investigates future changes in monsoon precipitation with global warming and their uncertainty in various monsoon regions worldwide, focusing on understanding regional variations of the monsoon responses, based on simulations by various global climate models, including atmosphere-ocean coupled general circulation models (AOGCMs) of the Coupled Model Intercomparison Project phase 5 (CMIP5) and a high-resolution atmospheric general circulation model (AGCM).

Model performances of present-day climate simulations are evaluated. The CMIP5 AOGCMs reproduce the observed distribution and intensity of monsoon precipitation reasonably well. The high resolution AGCM shows generally high performance in simulating monsoon precipitation including extremes, not only on a global scale but also on regional scales.

Both CMIP5 AOGCMs and the high-resolution AGCM project that summer precipitation will increase in most monsoon regions in a warmer climate, but with large regional variations in

terms of the magnitudes. A moisture budget analysis based on CMIP5 multi-AOGCMs reveals that an increase in atmospheric moisture (thermodynamic component) contributes positively to the precipitation changes, while a general weakening of the monsoon circulation (dynamic component) contribute negatively to those. In many monsoon regions, the thermodynamic component is larger than the dynamic component, with a large cancellation between the two components. Interestingly, in the Asian monsoon regions, the negative dynamical component is much less than in other monsoons, resulting in larger increases in precipitation.

To understand the unique feature of the Asian monsoon response to global warming, idealized multi-model experiments in CMIP5 are analyzed. On the AOGCM response to increased CO_2, monsoon westerlies in the lower troposphere are shifted poleward and slightly strengthened over land, while the tropical easterly jet in the upper troposphere are broadly weakened. The different circulation responses between the lower and upper troposphere could be attributed to vertically opposite changes in the meridional temperature gradient (MTG) between the Eurasian continent and the tropical Indian Ocean, with a strengthening (weakening) in the lower (upper) troposphere. AGCM experiments to separate the effects of CO_2 increase and sea surface temperature (SST) warming reveal that the strengthened MTG in the lower troposphere is explained by the effect of CO_2 increase. On a global perspective, the CO_2 effect-induced enhancement of the land-sea thermal contrast and associated circulation changes are the most influential in precipitation in South Asia. These suggest an important role of the increased land-sea thermal contrast on the Asian monsoon response to global warming.

Ensemble projections with the high-resolution AGCM, which are perturbed by different convective parameterization schemes, SST warming patterns, and atmospheric initial conditions, reveal that extreme precipitation increases more than mean precipitation in most monsoon regions, except in some regions around the western tropical Pacific. Decomposition of inter-member variability reveals that large regional variations exist in the relative importance of sources of uncertainty in the projections, especially between land and ocean. In the land monsoon regions, different types of convection schemes cause a large difference in the precipitation change, suggesting that the use of a realistic convection scheme is necessary for a reliable projection of land monsoon precipitation.