Understanding of the roles of global warming and natural variability on monsoon rainfall

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Extended Abstract

A number of studies have investigated the mechanisms that determine changes in precipitation, including how a wet region gets wetter. However, not all monsoon areas get wetter – there is a need to understand the major factors behind changes in regional monsoon precipitation, in terms of external forcing and internal variabilities in the last six decades by a combination of different observed datasets and model runs. We have found that emerging times of anthropogenic signals are detected in the northern African and Southeast Asian monsoons from the 1990s with the use of CESM Large Ensemble Project. From CMIP5 model runs and three reanalysis datasets, the results are found that the change in monsoon rainfall over African is mainly due to anthropogenic forcing and that over Asian is affected by internal variability. Moreover, the cause of American monsoon rainfall change cannot be known due to a discrepancy among observed datasets.

Monsoon precipitation is the largest component of the global water and energy cycles and a major driver of general atmospheric circulation [*C P Chang and World Meteorological Organization.*, 2011; *C P Chang et al.*, 2018]. The increasing intensity and frequency of heavy rainfall events, heat waves, and severe droughts over the globe have affected the lives of people around the globe and caused huge loss of life, material damages, and associated social costs [*Min et al.*, 2011; *Qiu*, 2013]. As our climate rapidly changes, we need to improve our understanding of the effect of climate change on monsoons, including on their changes in rainfall and circulation over regionally and geologically different monsoons.

Climate modeling studies [*Chou and Neelin*, 2004; *Chou et al.*, 2013; *Min et al.*, 2011] predict changes in global precipitation in response to increases in the mean global surface temperature of the Earth. A prevailing theory of precipitation change in a warming world is that wet areas will get wetter [*Chou et al.*, 2009; *Held and Soden*, 2006]. Under the global warming scenario in phase five of the Coupled Model Intercomparison Project (CMIP5), the Northern Hemisphere (NH) monsoon precipitation will be increased by the increased temperature difference between the NH and Southern Hemisphere (SH) and the enhanced atmospheric moistening [*Lee and Wang*, 2014]. However, on a basin scale, this is not always the case [*Hsu and Li*, 2012]. In model simulations, a swing in the South Pacific convergence zone due to global warming (GW) has been predicted that might cause catastrophic droughts and food shortages in the region [*Cai et al.*, 2012], and the increasing global surface temperature induces a decrease in soil moisture due to increased evaporation [*Dai*, 2013].

As well as GW, natural variability, especially El Niño-Southern Oscillation (ENSO) effect, is also mentioned as the cause of drought [*Trenberth et al.*, 2014]. On the other hand, past variability in rainfall in the Sahel which depends strongly on the West African monsoon is closely linked to the global sea surface temperature (SST) distributions in both observations and models [*Cook*, 2008]. These differences are likely manifestations of the different roles played by natural variability and GW in different regions [*Kim and Ha*, 2015 and 2018; Chung et al., 2019]. Multidecadal Pacific SST anomalies have been shown to contribute significantly to severe droughts over both the western U.S. and the Great Plains [*Meehl and Hu*, 2006]. In addition to the influence of the north-south hemispheric thermal contrast in the Atlantic-Indian Ocean, an east-west thermal contrast in the Pacific Ocean, which is measured by the Interdecadal Pacific Oscillation (IPO) index, is also predicted to increase the decadal variability of NH land monsoon rainfall [*Wang et al.*, 2018].

However, the key factors of monsoon rainfall change are not clearly defined due to the uncertainty of climate models and the inconsistency of observed datasets despite many studies on climate change. The urgency of this question is further complicated by the facts that the observed trends lie outside the range of natural variability simulated in climate models [*Hoerling et al.*, 2010], but at the same time oppose the simulated response to GW. This conundrum requires an in-depth re-evaluation of the changes in global and regional monsoons and causes and drivers of recent global and regional monsoons. The purpose of this study is, therefore, twofold: 1) to identify long-term climatic change by analyzing robust changes in precipitation over monsoons from 1958 to 2015 using various reanalysis datasets based on observations, specifically focusing on different monsoon regions; and 2) impacts of external forcings in driving these precipitation changes over the individual monsoon region using model simulations from Community Earth System Model (CESM) and CMIP5.

We attempted to draw what drives the linear trend of global monsoon rainfall. According to Figure 1 and 2, which are representing the linear trends of reanalysis rainfall and CMIP5 model rainfall, the results demonstrate many important points as follows: Major factors of regional monsoon rainfall changes are investigated by combinations of multi-ensemble, external forcing runs, and observed datasets. The effects of external forcings on the rainfall are detected from the 1990s over northern Africa and Southeast Asia and spread to other regions. The African and Asian monsoon rainfall changes, respectively, are caused by the anthropogenic forcing and internal variability

The present study intends to investigate the reliability of available precipitation data and the trends in rainfall over regional monsoons in order to project the future of monsoons. The CESM does not accurately simulate the changes seen in global rainfall during the past 60 years (1958-2015) and there is a significant need to improve our understanding of such changes and the driving factors behind them. By studying the time of emergence of the effects of human activities on the global rainfall change using the CESM simulation, we find that changes in precipitation by the anthropogenic forcing is detected over the northern African and Southeast Asian monsoons from the 1990s. The GHG forcing drives a meridional dipole in trends over the western Pacific, while natural variabilities such as IPO and NAID induce a horizontal dipole over the western-central Pacific. This study also suggests that the AMM has a broader gap in observed land rainfall dataset compared to other monsoons, a distinctive decreasing trend in only land rainfall can be found in the AFM, and an increasing trend is seen in the southern AAM(i.e. Australian monsoon).

In terms of regional monsoon land rainfall changes, the main forcing is different depending on the region. The decreasing trend in rainfall over the AFM can be seen to come from aerosol and GHG forcings in northern and southern parts, respectively. The change in Asian monsoon rainfall may be primarily due to the internal variability rather than external forcings, while the Australian monsoon rainfall has the potential to be increased by the aerosol forcing. The cause of an increasing trend of the AMM, especially in the northern part, cannot be known through the response of monsoon rainfall by the external forcings because the GHG and anthropogenic forcings induce a decreasing rainfall trend. In addition, it is difficult to understand the observed change in land rainfall over the AMM due to a discrepancy between reanalysis datasets based on observations.

The discussion on quantification of external forcings or internal variability on the individual monsoon rainfall change still remains unexplored in this study. However, this study shows that a major factor of rainfall change over the individual monsoon region is distinguishable, which is provided through combinations of results from different observed datasets and model runs. These results are expected to provide an improvement in the predictability of individual monsoon rainfall in future climate change.

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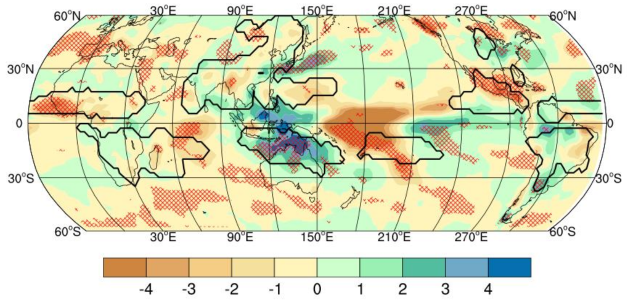
(a) PREC



(b) CESM

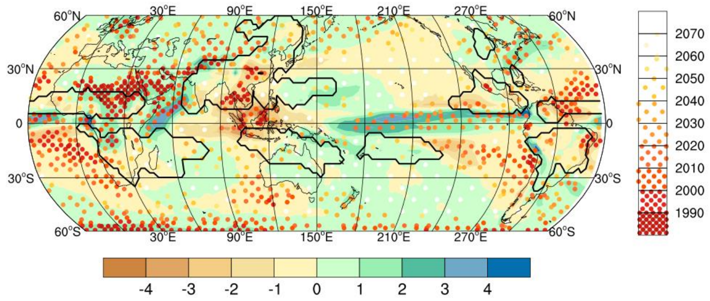
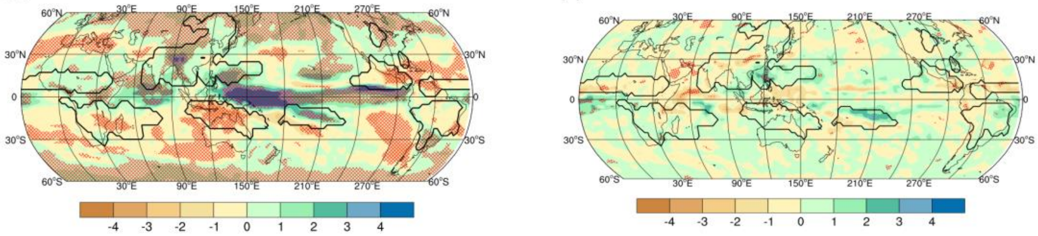


Figure 1. Linear trend of annual global (60°S-60°N, 0°-360°) rainfall. Plots are made using precipitation data from (a) PREC dataset (1958-2015) and (b) the present run which is merged historical run (1958-2005) and RCP8.5 run (2006-2015) of CESM Large Ensemble Project (1958-2015). Color shading shows linear temporal trends (mm yr^{-1}). In (a), the diagonal cross-hatching (red) denotes the statistically significant region above the 95% confidence level, as determined using the Mann-Kendall test. The red stippled areas in (b) denote the end year of a period starting in 1958 for which the linear temporal trend predicts that the signal-to-noise (SNR) ratio exceeds 1 for the first time. The global monsoon domains (black solid) are defined according to Wang and Ding (2006) using PREC data.

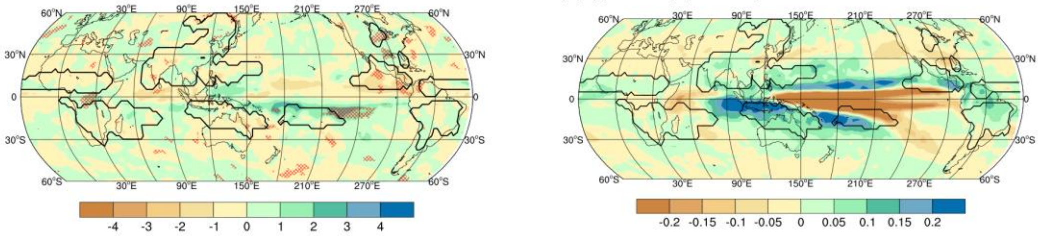
(a) GHG

(d) Pre-industrial



(b) NAT

(e) (-)IPO – (+)IPO in pre-industrial



(c) Aerosol

(f) (+)NAID – (-)NAID in pre-industrial

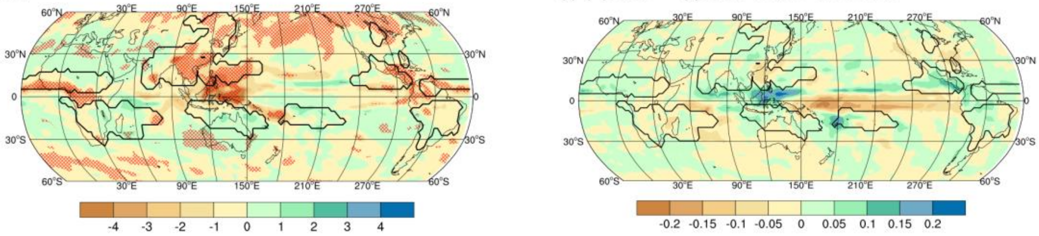


Figure 2. Linear trend of annual global (60°S-60°N, 0°-360°) rainfall. Plots are made using precipitation data from (a) GHG run (1958-2005), (b) NAT run (1958-2005), (c) Aerosol run (only anthropogenic aerosol forcing, 1958-2005), and (d) pre-industrial run (1-59) from multi-model mean (MMM) in CMIP5. Composite difference of annual precipitation based on (e) -IPO minus +IPO, and (f) +NAID and -NAID in pre-industrial run of CMIP5. Color shading shows linear temporal trends (mm yr^{-1}). In (a-d), the diagonal cross-hatching (red) denotes the statistically significant region above the 95% confidence level, as determined using the Mann-Kendall test. The global monsoon domains (black solid lines) are defined according to Wang and Ding (2006) using PREC data.