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Projected Change in Seasonal Monsoon Precipitation over Southeast Asia under CMIP6 Climate Model

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ABSTRACT

The present study applies the statistical bias-correction to analyze the changes in mean temperature and precipitation of the latest 18 Couple Model Intercomparison Project phase 6 (CMIP6) models simulation over Southeast Asia (SEA). The models are employed to assess future mean precipitation change for 3 periods (Near-future: 2015-2039, Mid-future: 2040-2069, and far-future: 2070-2099) derived from the climate projections under the medium-emission (SSP2-4.5) and high-emission (SSP5-8.5) scenarios. The bias-correction is employed by using the “Variance scaling” method for the temperature and the “Empirical quantile mapping” method for the precipitation. Higher annual-mean precipitation is observed over the Maritime Continent than the mainland SEA. The MME model gives wet bias during the boreal summer (JJAS) while dry bias during the boreal winter (NDJF). Overall, there are robust increases in Southwest and Northeast monsoon rainfall (SWMR and NEMR) along the timeline of the 21st century with larger values found under SSP5-8.5 than SSP2-4.5. For SSP2-4.5, SWMR (NEMR) increases 7.79 %, 12.10 %, and 14.54 % (-4.09 %, -0.79 %, and 1.68 %) for the near-future, mid-future, and far-future, respectively. For SSP5-8.5, SWMR (NEMR) increases 8.1 %, 13.24 %, and 19.69 % (-3.29 %, 1.19 %, and 6.61 %) for the near-future, mid-future, and far-future, respectively. Both SSP2-4.5 and SSP5-8.5 scenarios display greater increases during the boreal summer than boreal winter.

Keywords— CMIP6; Shared socioeconomic pathway; Monsoon precipitation

1 INTRODUCTION

Southeast Asia (SEA) is considered to be most vulnerable to climate extremes as a result of its high population density, long coastline with exposure to tropical cyclones, low-lying area, more than 20,000 islands and significant rainfall variability. Manton et al. 2001 analysed climate extreme indices for historical period over the SEA and South Pacific. Regional studies across the Asia–Pacific (Griffiths et al. 2005) have shown significant increases in occurrences of annual number of hot days and warm nights and decreases in incidences of annual number of cool days and cold nights over the past few decades. The projected changes in precipitation characteristics during the east Asian summer rainy season was investigated by Kitoh et al. (2009). They found an increase in the frequency of heavy precipitation in the near future and by the end of 21st century. Caesar et al. (2011) made an assessment of the changing climate extremes in the Indo-Pacific region using available data from 13 countries between 1971-2005. They discovered that the warm extremes are increasing and cold extremes are decreasing. Trends in precipitation extremes are less spatially consistent across the region.

Studies investigating the consequences of climate change over SEA are limited. The majority of SEA is influenced by the Asian–Australian monsoon and several regions within it are affected by extreme weather events, particularly tropical cyclones, droughts, and floods (Chang et al., 2005). The warm extremes increased while the cold extremes decreased over the Indo-Pacific region during 1971–2005 (Caesar et al., 2011). Most studies of the projected changes in SEA climate are embedded in global-scale domain carried out using global climate models (GCM) (Chadwick et al., 2016). The projected changes in mean and extreme precipitation (using the NASA Earth Exchange Global Daily Downscaled

Projection, NEX- GDDP dataset) over several parts of SEA show substantial increases in the 21st century (Mandapaka and Lo, 2018). Suppari et al. (2020) found significant changes in consecutive dry day (CDD) and a decrease in total wet day precipitation (PRCPTOT) over most regions in SEA by using eight ensemble members of CORDEX-SEA simulations for RCP4.5 and RCP8.5 scenarios. A marked amplification in extreme precipitation over the Indochina Peninsula and the Maritime Continent were found under 1.5 °C and 2 °C global warming levels (Ge et al., 2019). Recently, Tangang et al. (2020) examined the projected rainfall changes in Southeast Asia in the 21st century based on seven regional climate models (RCMs) members of archived CORDEX-SEA simulations.

To our knowledge, few studies have analyzed the CMIP6 datasets to examine the future climate, especially in SEA. Grose et al (2020) evaluated CMIP6 models and its future climate projects over Australia compared to CMIP5 models. Almazroui et al (2020) examined the projected changes in temperature and precipitation over 6 South Asian countries during the 21st century using the latest Coupled Model Intercomparison Project phase 6 (CMIP6) dataset. They found an increase in annual-mean precipitation under all scenarios with considerable variations among countries. Ukkola et al (2020) revealed larger projected drought changes and more consistent in CMIP6 compared to CMIP5 models. Very recently Supharatid et al (2021) assessed changes in climate variables (mean temperature and precipitation) over SEA by using 18 CMIP6 models. They found robust increases in rainfall during the Southwest Monsoon.

The present study analyses the changes in mean temperature and precipitation using the latest Couple Model Intercomparison Project phase 6 (CMIP6; Eyring et al. 2015) model simulation dataset over SEA. It has yet to be thoroughly understood how the latest CMIP6 models can effectively simulate the climate response to anthropogenic forcing over SEA. The goal of this work is to assess the long-term changes of the temperature and precipitation in different areas of SEA, especially, the seasonal monsoon precipitation in the near-future, mid-future, and far-future periods. This is an initial step required to find appropriate level of adaptation measures in response to the impacts of projected climate extreme events.

2 Data and methodology

2.1 Study region

Our region of interest is the Southeast Asia domain as display in Fig. 1. The climate of SEA is mainly tropical–hot and humid most part of the year and is characterized by two distinct sub-monsoon seasons: wet and dry. The southwest monsoon (SWM) typically begins from early June to late September, causing heavy rainfall over the mainland SEA between May to October. The northeast monsoon (NEM) is characterized by cold air from the Himalayas, causing heavy rain from December to early March over the southern parts of SEA while the northern parts experience drier weather. Majority of the Southeast Asia region is affected by extreme weather events, particularly tropical cyclones, droughts and floods.

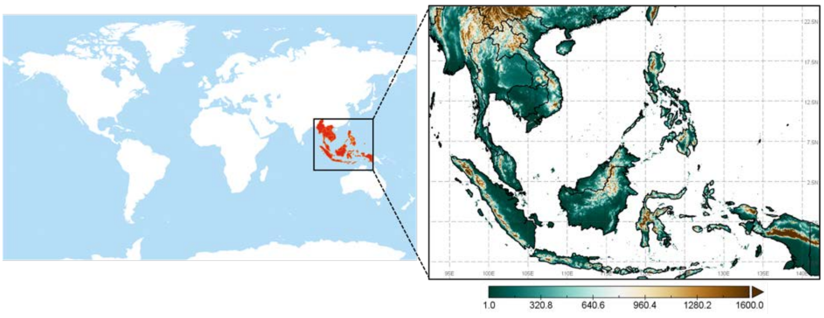

Fig. 1 Study area SEA (Southeast Asia)

2.2 Observation and model datasets

In this study, we use SA-OBS as observation dataset. SA-OBS is a daily high-resolution land-gridded observational dataset for the minimum, mean and maximum temperature and precipitation covering SEA region. This data set is delivered in 0.25° by 0.25° and a 0.5° by 0.5° regular latitude-longitude grid during the period of 1981– 2016 (Van Den Besselaar et al., 2016).

For model datasets, we examine 18 CMIP6 models (see Table 1) obtained from the CMIP6 database website (https://esgf-node.llnl.gov/search/cmip6) . The new generation of CMIP6 models differs from those of CMIP5 in a new set of specifications for concentration, emission, and land-use scenarios (Gidden et al. 2019) as well as a new start year for the future scenarios. The CMIP6 is based on community scenarios (Van Vuuren et al., 2014) by integrating across different research disciplines including societal development, known as Shared Socioeconomic Pathways (SSPs). The SSPs are based on 5 narratives that describe different levels of socioeconomic development (Riahi et al. 2017): sustainable development (SSP1), middle-of-the-road development (SSP2), regional rivalry (SSP3), inequality (SSP4), and fossil fuel-driven development (SSP5). Detailed descriptions of the SSPs are available in O'Neill et al. (2016).

Table 1 List of CMIP6 models used in this study

GCM	Research Center	Resolution
ACCESS-CM2	Australian Community Climate and Earth System Simulator	1.88×1.25
ACCESS-ESM1-5	Australian Community Climate and Earth System Simulator	1.88×1.25
BCC-CSM2-MR	Beijing Climate Center, China Meteorological Administration, Beijing, China	1.12×1.11
CanESM5	Canadian Centre for Climate Modelling and Analysis, Environment and Climate Change Canada, Canada	2.81×2.77
CNRM-CM6-1	National Center for Meteorological Research, France	1.41×1.39
CNRM-ESM2-1	National Center for Meteorological Research, France	1.41×1.39
EC-Earth3	EC-Earth Consortium (EC-Earth)	0.70×0.70
FGOALS-g3	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, 100029, China	0.70×0.70
GFDL-ESM4	NOAA Geophysical Fluid Dynamics Laboratory, USA	1.25×1.00
INM-CM4-8	Institute for Numerical Mathematics, Russia	2.00×1.50
INM-CM5-0	Institute for Numerical Mathematics, Russia	2.00×1.50
IPSL-CM6A-LR	The Institut Pierre Simon Laplace, France	2.50×1.27
MIROC6	JAMSTEC (Japan Agency for Marine-Earth Science and Technology, Japan), AORI (Atmosphere and Ocean Research Institute, The University of Tokyo), NIES (National Institute for Environmental Studies), and R-CCS (RIKEN Center for Computational Science), Japan	1.41×1.39
MIROC-ES2L	JAMSTEC, AORI, NIES, and R-CCS, Japan	2.81×2.77
MPI-ESM1-2-LR	Max Planck Institute for Meteorology, Germany	1.88×1.85
MRI-ESM2-0	Meteorological Research Institute, Japan	1.12×1.11
NESM3	Nanjing University of Information Science and Technology, China	1.88×1.85
NorESM2-LM	NorESM Climate modeling Consortium consisting of CICERO (Center for International Climate and Environmental Research), MET-Norway (Norwegian Meteorological Institute), NERSC (Nansen Environmental and Remote Sensing Center, Bergen), NILU (Norwegian Institute for Air Research), UiB (University of Bergen, Bergen), UiO (University of Oslo) and UNI (Uni Research), Norway	2.50×1.89

2.3 Bias correction

Bias correction is widely used in climate impact modelling. The aim is to adjust selected statistics (mean, variance and/or quantile) of a climate model simulation to better match observed statistics during a reference period. Many bias correction methods have been employed in previous studies (Teutschbein and Seibert, 2012; Chen et al. 2013; Supharatid, 2016; Navarro-Racines et al. 2020) with a critical review by Maraun (2016). In this study, we use the "Variance scaling" method for the temperature and the "Empirical quantile mapping" method for the precipitation.

3 Results and Discussion

3.1 Model performance

The CMIP6 model performance was evaluated in terms of correlation coefficient (R), center root mean-square difference (RMSD) and standard deviations (SD) by the Taylor Diagram (Taylor 2001) during the reference period (see Fig. 2). The center root mean-square difference and the standard deviation are normalized by their corresponding observations of SA-OBS. The observation datasets are represented by black symbol and the CMIP6 models are represented by other colors. Most temperature datasets show high R (> 0.9) to SA-OBS. Most CMIP6 models give R in a range 0.8-0.9 and more spread SD are found than R and RMSD. For precipitation, all datasets are found to give also high R (> 0.8) but lower than ones of temperature. We observe distinctly different magnitudes of SD but similar RMSD. The CMIP6 models display more widespread with lower R compared to Tmean. Most CMIP6 model correlation coefficients lie between 0.4 to 0.7 by which MIROC-ES2L gives the highest R and smallest RMSD. NorESM2 shows highest SD and also RMSD. The MME model is found to give best results (Highest R and lowest RMSD) among CMIP6 models.

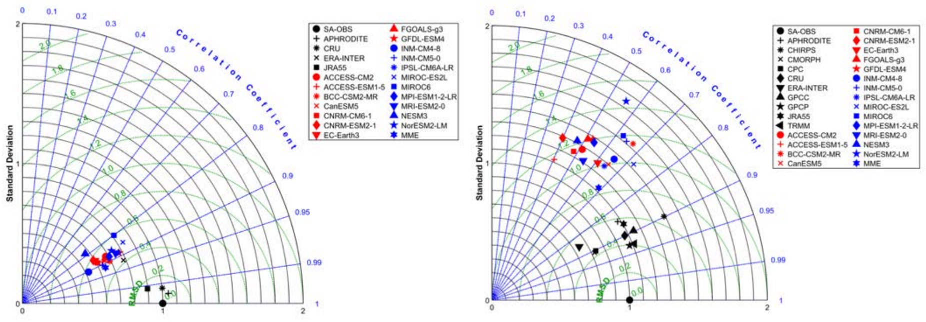

Fig. 2 Taylor diagram of temperature and precipitation for CMIP6 models during the reference period

3.2 Projected Changes in annual-mean precipitation

The annual-mean precipitation changes show significant regional difference (see Fig. 3). Overall, the projected annual-mean precipitation shows small reductions (< 10%) over northern SEA and Indonesia (Java) for the near-future period and, then increases towards the far-future periods. For the near-future period, the projected precipitation shows an increase of 3.04 % and 3.64 % under SSP2-4.5 and SSP5-8.5, respectively as compared to the present climate. For the mid-future period, the projected precipitation shows an increase of 7.10 % and 8.51 % under SSP2-4.5 and SSP5-8.5, respectively. And for the far-future period, precipitation is projected to increase by 9.62 % and 15.19 % under SSP2-4.5 and SSP5-8.5, respectively. Under the high-emission SSP5-8.5 scenario, most areas in SEA exhibits a significant and robust increase in precipitation (except in Java) relative to the present climate. Mandapaka and Lo (2018) also found similar results from the NEX-GDDP dataset under RCP4.5 and RCP8.5 scenarios. The larger increases in precipitation are projected over northern and central Vietnam, northern Thailand, northern Myanmar, northern Laos, Cambodia, Kalimantan, Sulawesi, and east Papua. These findings are generally consistent with Tangang et al. (2019, 2020) who used 7 RCMs in CORDEX-SEA domain and 11 driving CMIP5 GCMs and found robust increases in the 21st century over northern Vietnam, Cambodia, Laos, and northern Thailand.

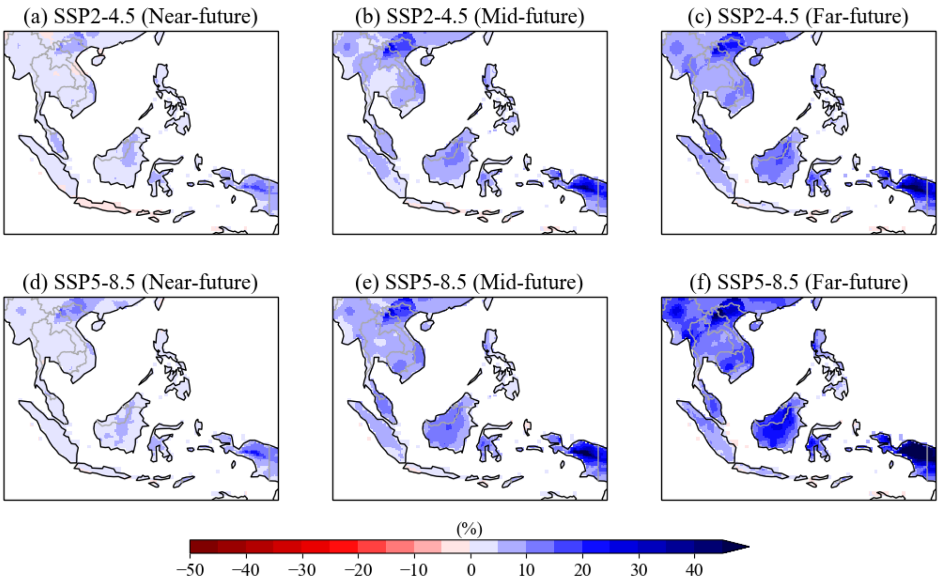

Fig. 3 Spatial distribution of future changes in mean Precipitation

3.3 Projected Changes in seasonal monsoon rainfall

The area-averaged mean seasonal monsoon precipitation over SEA is shown for MME model in Fig. 4. The 1st, 2nd, 3rd, and 4th columns represent values for the historical, near-future, mid-future, and far-future periods, respectively. The projection in each column is displayed under both SSP2-4.5 and SSP5-8.5 scenarios. The MME model gives wet bias during the boreal summer (JJAS) while dry bias during the boreal winter (NDJF). Overall, there are robust increasing of SWMR, NEMR along the timeline to the 21st century with larger increases are found under SSP5-8.5 than SSP2-4.5. For SSP2-4.5, SWMR (NEMR) increases 7.79 %, 12.10 %, and 14.54 % (-4.09 %, -0.79 %, and 1.68 %) for the near-future, mid-future, and far-future, respectively. For SSP5-8.5, SWMR (NEMR) increases 8.1 %, 13.24 %, and 19.69 % (-3.29 %, 1.19 %, and 6.61 %) for the near-future, mid-future, and far-future, respectively. Both SSP2-4.5 and SSP5-8.5 scenarios display larger increases during the boreal summer than boreal winter.

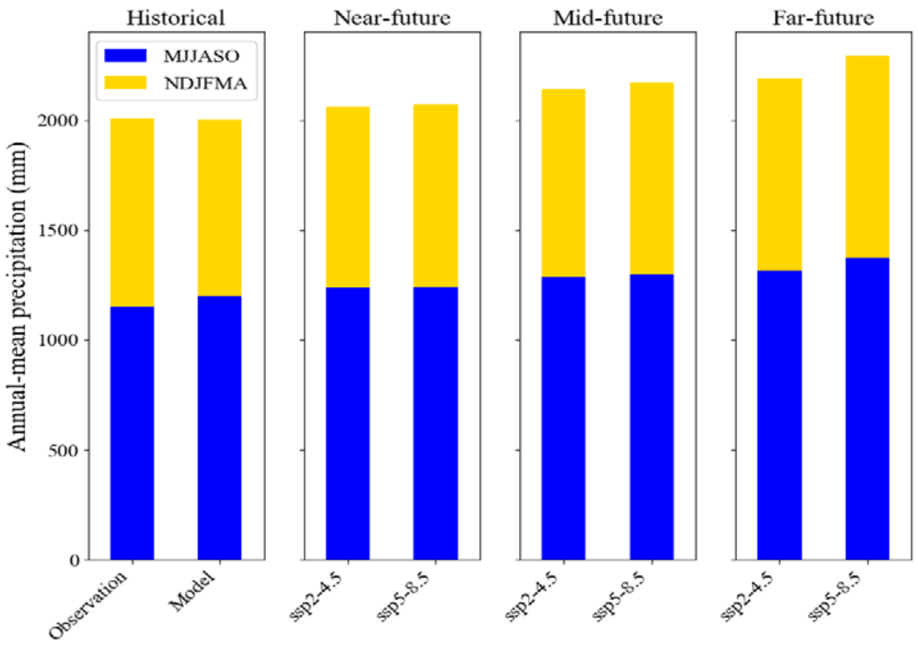

Fig. 4 Mean seasonal monsoon precipitation

4 Conclusions

The present study applies the statistical bias-correction ("Variance scaling" method for the temperature and the "Empirical quantile mapping" method for the precipitation) to analyze the changes in mean temperature and precipitation of the latest Couple Model Intercomparison Project phase 6 (CMIP6) model simulation over SEA. The CMIP6 is based on community scenarios known as Shared Socioeconomic Pathways which differ from CMIP3 and CMIP5 in a different start year of the future scenarios, as well as a new set of specifications on emission and land-use scenarios. In this study, Eighteen CMIP6 models are employed to assess future mean climate change for 3 periods (Near-future: 2015-2039, Mid-future: 2040-2069, and far-future: 2070-2099) derived from the climate projections under the medium-emission (SSP2-4.5) and high-emission (SSP5- 8.5) scenarios.

The spatial distributions in annual-mean temperature and precipitation of CMIP6 models generally produce similar pattern to SA-OBS. Higher annual-mean precipitation is observed over the Maritime Continent than the mainland SEA. The annual-mean temperature under SSP2-4.5 (SSP5-8.5) is projected to increase by 1.1 ° C (1.41° C) in 2050 and 1.99 °C (4.29° C) in 2100. The annual-mean precipitation is projected to increase by 6.21 % (8.11 %) in 2050 and 9.62 % (18.43 %) in 2100 under SSP2-4.5 (SSP5-8.5).

The MME model gives wet bias during the boreal summer (JJAS) while dry bias during the boreal winter (NDJF). Overall, there are robust increases in Southwest and Northeast monsoon rainfall (SWMR and NEMR) along the timeline of the 21st century with larger values found under SSP5-8.5 than SSP2-4.5. For SSP2-4.5, SWMR (NEMR) increases 7.79 %, 12.10 %, and 14.54 % (-4.09 %, -0.79 %, and 1.68 %) for the near-future, mid-future, and far-future, respectively. For SSP5-8.5, SWMR (NEMR) increases 8.1 %, 13.24 %, and 19.69 % (-3.29 %, 1.19 %, and 6.61 %) for the near-future, mid-future, and far-future, respectively. Both SSP2-4.5 and SSP5-8.5 scenarios display greater increases during the boreal summer than boreal winter.

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