RAINFALL PATTERN ASSESSMENT FROM GLOBAL CLIMATE MODELS BASED ON SATELLITE-DERIVED ESTIMATES OVER THE INDIAN REGION

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ABSTRACT: The objective of this study is to evaluate the rainfall pattern from Coupled Model Inter-comparison Project Phase 5 (CMIP5) based on satellite-derived rainfall products Tropical Rainfall Measuring Mission 3B43V7 (TRMM 3B43v7) over the Indian region, with special focus on monsoon season (JJJAS) rainfall at daily scale. To serve that purpose, JJAS daily rainfall data from five best defined CMIP5 models along with its multi-model mean (MMM) have been utilized to find out the rainfall pattern in terms of contour map and time series under the Representative Concentration Pathway 4.5 (RCP 4.5) and Representative Concentration Pathway 8.5 (RCP 8.5) during 2006 to 2018. On the other hand, we have downloaded TRMM 3B43v7 rainfall data in terms of contour map and time series during the same time period to evaluate the rainfall pattern with the CMIP5 models; Whether the CMIP5 models will be able to capture rainfall pattern compared to satellite-derived estimates under the climate change scenarios over that region. Based on the assessment, it is noted that some CMIP5 models are able to capture mean daily monsoon season rainfall during JJAS but it underestimate the rainfall intensity at daily scale. The outcomes presented here might be useful for the researcher, how much the model data can be relied on to predict the rainfall pattern under climate change scenarios over the Indian region.

1. INTRODUCTION

Indian region is primarily distinguished by typical monsoon climate according to its climatic viewpoint. The main characteristics of monsoon climate over the Indian region are wet summer season and dry winter season. India receives more than 80 % of rainfall by the influence of south-westerly monsoon during the summer monsoon which starts from 1st June to 30th September (Lunine & Lunine, 2017; Singh & Mal, 2014). The Himalayan plays an important role by defending rain-bearing south-westerly monsoon to give up maximum precipitation in the Indian subcontinent (Ray et al., 2011). Rainfall is one of the major climatic parameter of the hydrological cycle where it dominates the environment both directly and indirectly. In the country like India, monsoon rainfall has a great impact over its socio-economic aspects especially in the industrial and agricultural sectors (Menon et al., 2013). According to the Fifth Assessment Report (AR5) of Intergovernmental Panel on Climate Change (IPCC), earth's surface temperature will be increased due to the effect of global warming (Sharmila et al., 2015). So, there is a possibility of anticipation in the monsoon rainfall over the Indian region under the different future warming scenarios. The accuracy in the rainfall data is highly needed for the better implications in agriculture and drought monitoring, hydrological modelling and climate studies. Climate models could be the useful medium to predict future climate variability in terms of rainfall pattern as well as monsoon in changing climate (Sharmila et al., 2015). According to Wu et al., (2017), Global climate models (GCMs) namely CMIP5 can be treated as primary tools to project future climate under the different future warming scenarios compared to the reference historical period. But Climate projections using models are more uncertain for mountain regions compared to plains mainly due to complex orographic dependent climatic regime. In addition, important climatic variables such as rainfall are inadequately reproduced by model experiments than any other parameters such as temperature (Choudhary & Dimri, 2017). In this regards, the evaluation of climate models are very significant. The CMIP5 models like MIROC5, MPI-ESM-LR, IPSLCM5A-LR, GFDL-CM3, and CMCC-CM may be used to study the monsoon season rainfall under the different warming scenarios (which start from the year 2006) due to their ability to simulate the reasonable boreal summer intra-seasonal oscillation (BSISO) characteristics over the Indian subcontinent (Sabeerali et al., 2013). To acquire the rainfall estimates, satellite-derived rainfall product appears as a more promising approach at regional and global scale. The satellite-derived rainfall product is very useful for those regions where ground-based rain gauges or ground-based radar are not able to provide faithful output (Xu et al., 2017). Among the various satellite-derived rainfall products, the latest version TRMM is able to provide very higher resolution (both spatial and temporal) rainfall data than any other space-borne rainfall product over the tropics and subtropics since December 1997. The recent studies about satellite-derived rainfall products especially TRMM have evaluated the issues only about the errors in rainfall estimation with ground validation mostly. Considering the recently reported studies regarding TRMM rainfall estimation, the present study is an attempt to evaluate the rainfall pattern from CMIP5 models based on TRMM 3B43v7 under the future warming scenarios namely RCP 4.5 and RCP 8.5 (up to 2018) over the Indian region.

2. STUDY REGION

The chosen study region for the present study is Indian region (fig. 1) which is extended in between 8° north to 38° north latitude and 68° east to 98° east longitude. For the time series analysis between the CMIP5 models and TRMM 3B42v7, we have considered Kerala region (only land) which is extended in between 8° N to 12° N latitude and 74° E to 78° E longitude (Chakraborty & Agrawal, 2017). The onset of Indian summer monsoon (ISM) heats that region first of all and it also receives heavy rainfall during JJAS. It has been denoted a by black box in fig. 1.

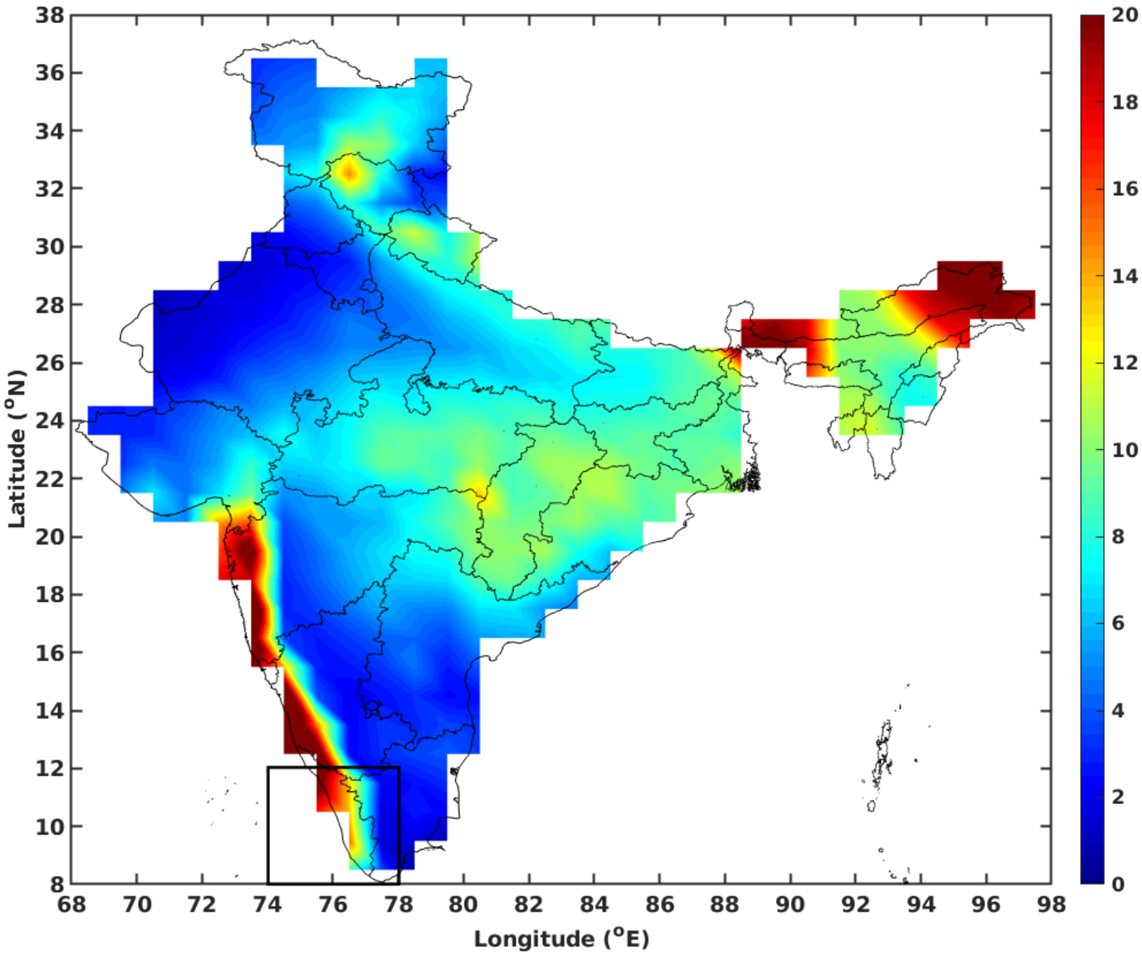

Figure 1: *Location map of Indian region showing the daily mean JJAS rainfall using IMD rainfall data during 1901 to 2015*

3. DATASETS AND METHODOLOGY

3.1 Used datasets

The present study is based on the daily rainfall data both from selected CMIP5 models (details are discussed in table 1) and TRMM 3B43v7 during 2006 to 2018 over the Indian region. CMIP5 is a newly set up coordinated climate model experiments produced by the Working Group on Coupled Modelling (WGCM) of World Climate Research Programme (WCRP) which was agreed in the September 2008 meeting which involved 20 climate modelling groups. It has been aimed to better understanding of climate and also to estimate future climate change (Taylor et al., 2007). It evaluates climate "predictability" to find out the predictive ability of forecast system for the decadal time scale (Emori et al., 2016). CMIP5 dataset has been examined by the scientific community worldwide for processing which underlay the IPCC's AR5 and also available for further analysis. CMIP5 contained more metadata describing model simulations than the previous phases. The TRMM 3B42v7, one of the latest satellite-derived rainfall products has been utilised to evaluate the rainfall pattern obtained from CMIP5 models. TRMM is a joint mission between the Japan Aerospace Exploration Agency (JAXA) and the

National Aeronautics and Space Administration (NASA), routinely since December, 1997 with very fine spatial and temporal resolutions of 0.25° × 0.25° and 3 hours respectively.

Table 1: Details of five CMIP5 models utilized in the present study

Models	Contributing Institutes	Resolution	
		Longitude in degree	Latitude in degree
MPI-ESM-LR	Max Planck Institute for Meteorology (MPI-M), Germany	1.86	1.87
MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	1.41	1.40
IPSL-CM5A-LR	Institut Pierre-Simon Laplace, France	3.75	1.875
GFDL-CM3	Geophysical Fluid Dynamics Laboratory, US	2.5	2
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici, Italy	0.75	0.75

3.2 Methodology

Here, the rainfall pattern from some selected CMIP5 models (both RCP 4.5 and RCP 8.5) have been evaluated based on and TRMM 3B43v7 during 2006 to 2018 over the Indian region (fig. 2). To serve that purpose, the rainfall pattern has been analysed based on contour map and time series (only for Kerala region). First of all, we have analysed the rainfall rate (mm/day) for the four monsoon months namely June, July, August and September individually during 2006 to 2018 and make four composite maps. Thereafter, a composite map of rainfall rate for June, July, and August (JJA) has also been prepared during the same time period. To analysis the time series over the Kerala region, the area average map has been prepared for the months June, July, August, and September during 2006 to 2018 from both CMIP5 models and satellite data.

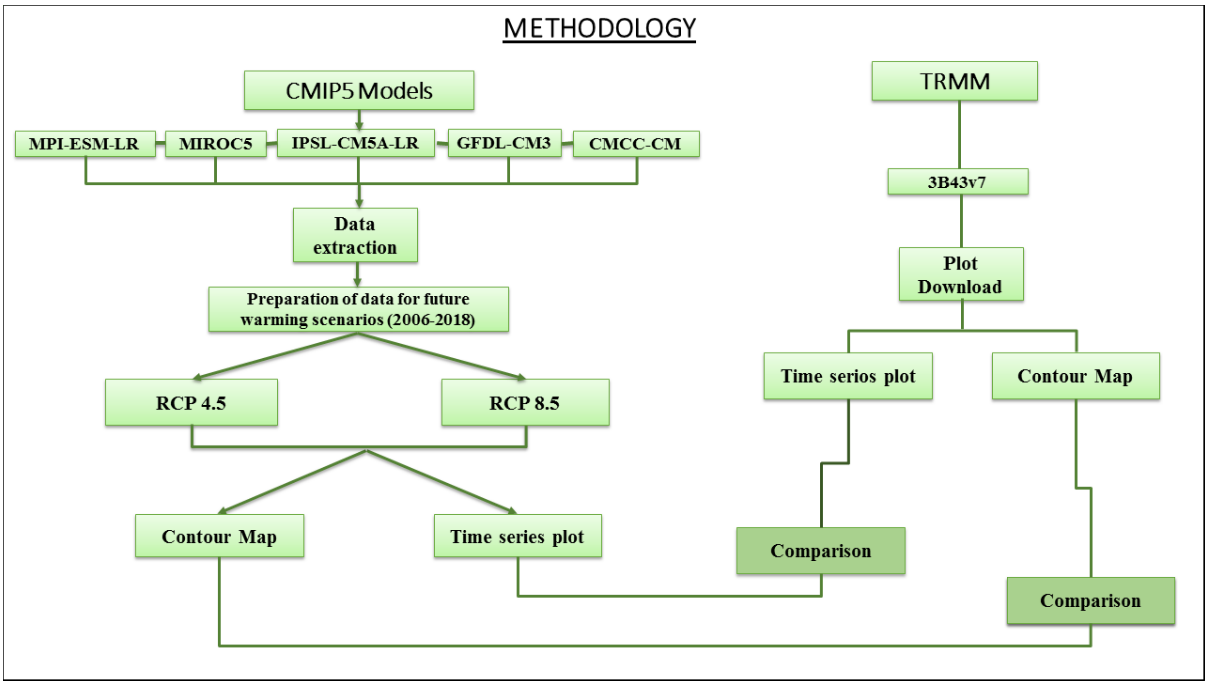

Figure 2: *Flow chart for methodology of the present study*

4. RESULTS AND DISCUSSIONS

The daily rainfall data (mm/day) has been extracted and plotted from the selected CMIP5 models along with their MMM for the month June, July, August, and September separately under the both warming scenarios RCP 4.5 and RCP 8.5 during 2006 to 2018. The composite maps and time series of rainfall at daily scale (precipitation rate) have also been downloaded from satellite-derived TRMM 3B43v7 rainfall data for the JJAS months separately during the same time period. As the main motto of the present study is to evaluate the CMIP5 models based on satellite-derived estimates, we compare both composite maps and time series between the selected CMIP5 models and TRMM 3B43v7.

4.1 Contour map analysis

The composite maps of TRMM 3B43v7 rainfall product (fig. 3) for the months June (1st row), July (2nd row), August (3rd row), and September (4th row) during 2006 to 2018 capture maximum rainfall along the west coast of India (Kerala region) and north-east India. Only in the months of July and August, the TRMM 3B43v7 satellite product capture heavy rainfall over the western Himalayan region and central India along with west coast and north-east India. The CMIP5 models like MPI-ESM-LR, MIROC5 and CMCC-CM including MMM are able to simulate mean spatial pattern of rainfall during 2006 to 2018 under both the RCPs. The regions like west coast and north-east India are captured more rainfall by the CMIP5 models like TRMM 3B43v7 but the highest warming scenarios RCP 8.5 simulate the same with higher magnitude. The MMM also simulate more heavy rainfall during the monsoon months July and August like TRMM 3B43v7 over the western Himalayan region and central India. The models IPSL-CM5A-LR and GFDL-CM3 both underestimate the rainfall over the Indian region compare to satellite derived estimates.

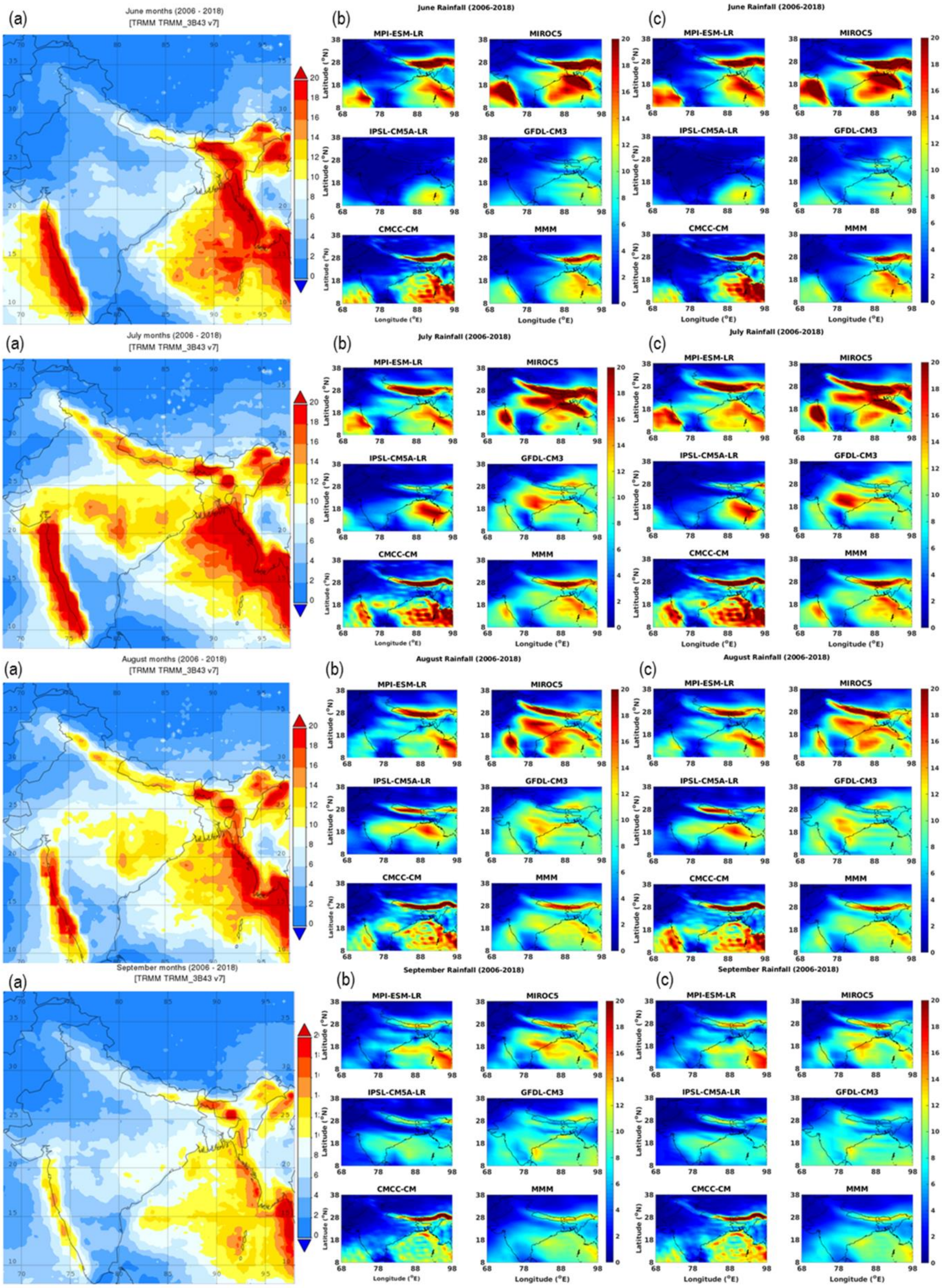

Figure 3.a *Composite rainfall map from TRMM 3B43v7,* ***3.b*** *Composite rainfall map from some selected CMIP5 models under RCP 4.5,* ***3.c*** *Composite rainfall map from some selected CMIP5 models under RCP 8.5 using daily mean rainfall during the monsoon months June, July, August, and September individually (row-wise, 1st to 4th row respectively) for the period 2006 to 2018 over the Indian region*

During 2006 to 2018, the composite map (fig. 4) of daily mean rainfall for the months June, July and August months (JJA) have been prepared. The satellite-derived product TRMM 3B43v7 capture most rainfall over the north-east India and west coast of India which are perfectly simulate by the MMM of selected CMIP5 models too under both the RCPs. Similarly, the CMIP5 models MPI-ESM-LR, MIROC5, and CMCC-CM are able to simulate the daily mean rainfall during JJA, where rest two models IPSL-CM5A-LR and GFDL-CM3 underestimate the same.

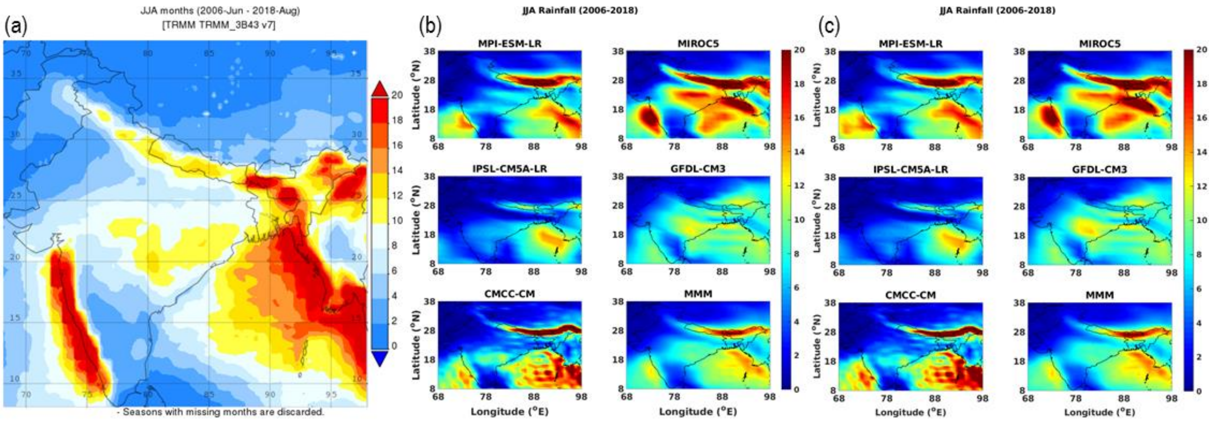

Figure 4.a *Composite rainfall map from TRMM 3B43v7,* ***4.b*** *Composite rainfall map from some selected CMIP5 models under RCP 4.5,* ***4.c*** *Composite rainfall map from some selected CMIP5 models under RCP 8.5 using daily mean rainfall during JJA for the period 2006 to 2018 over the Indian region*

4.2 Time series analysis

The daily mean rainfall (precipitation rate for TRMM 3B43v7) derived from TRMM 3B43v7 are greater than 5 mm/day for all the JJAS months (except September) from 2006 to 2018 over the Kerala region which is slightly higher than the CMIP5 simulations (fig. 5). The MMM of those selected CMIP5 models capture daily mean rainfall ranges from 3 to 5 mm/day under both the warming scenarios (RCP 8.5 captures slightly higher magnitude than RCP 4.5) for all the JJAS months during 2006 to 2018 over that region. Most significantly, the TRMM 3B43v7 and CMIP5 models (both RCPs) both capture high pick of daily mean rainfall during July 2007. The most similarity is found in the time series of September month for the satellite-derived estimates and MMM simulations under RCP 4.5. Unlikely, under the scenarios RCP 8.5, it irrelevantly captures higher rainfall in September for most of the years than any other months compare to TRMM 3B43v7 (where it is lower than any other month).

Figure 5.a *Time series from TRMM 3B43v7,* ***5.b*** *Time series from MMM of some selected CMIP5 models under RCP 4.5 and* ***5.c*** *Time series from MMM of some selected CMIP5 models under RCP 8.5 using daily mean rainfall for the monsoon months June, July, August, and September individually during 2006 to 2018 over the Kerala region*

5. CONCLUSIONS

Climate models have been treated as the primary tools to investigate the response of the climate system for various forcing and make predictions of future climate on the seasonal and decadal time scales for upcoming century and the beyond (Flato et al., 2013). According to AR5 of IPCC, the simulations from CMIP5 will become high precedence for most of the major climate modelling centres on the field of research agendas. The present study deals with the assessment of rainfall pattern from CMIP5 models based on satellite-derived estimates TRMM 3B43v7 rainfall products. Climate models are built on well-established physical principles but it has a better prediction power on the temperature pattern than the precipitations and can project globally well (Farber, 2007). The present study noticed that, the MMM of five selected CMIP5 models are able to simulate spatial pattern of mean daily monsoon season rainfall for the months June, July, August, and September individually over the India region during 2006 to 2018. The MMM are also able to capture spatial pattern of mean daily monsoon season rainfall during JJA. But the CMIP5 models underestimate rainfall intensity at daily scale compare to TRMM 3B43v7 during monsoon months over the Kerala region. So, the MMM of five selected CMIP5 models have better ability to capture daily mean monsoon season rainfall than any other individual CMIP5 models over the Indian region during 2006 to 2018. Therefore, the CMIP5 models may not be the correct impression of reality and these particulars need to be addressed. As per author's knowledge, no such work regarding the evaluation of CMIP5 models based on TRMM 3B43v7 has been done over the study region. The obtained result from the present study may also be helpful in research regarding rainfall prediction from climate models and for policy makers.

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