Chapter 23

Moisture recycling over the Indian monsoon core region in response to global warming from CMIP5 models

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Abstract

In the present work, we studied the changes in moisture recycling over the monsoon core region of India (MCI) by using Coupled Model Intercomparison Project (CMIP5) multimodel mean (MMM) datasets during the southwest monsoon season (June to September) in the present and future climate, in particular during the future El Nino years. Our results show that the advection contributes much more to the rainfall than evaporation in some parts of Indo-Gangetic Plains (IGP). Moisture recycling is about 50–60% over the eastern parts of IGP and about 10% over the rest of the MCI. The overall trend of local evaporation contribution has shown a decreasing trend with less than 21% of the normal by the end of the twenty-first century under the RCP4.5 and RCP8.5 (medium and very high) emission scenarios during future strong and very strong El Nino years.

Keywords: CMIP5; Local evaporation; Monsoon Core Region; Moisture recycling

23.1 Introduction

Rainfall over a region is the resultant contribution of local evaporation recycled and the amount of advected water vapor into that region (Trenberth, 1999). The precipitated water component emerged from the evaporated moisture in the same region of the specified control volume is called as the moisture recycling (Brubaker et al, 1993). It is also reported that the precipitation recycling/moisture recycling ratio is a degree of measure of the land surface forcing (via evaporation) on the climate interactions (Brubakar et al., 1993).

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Moisture recycling plays an important role in explaining the land-atmosphere interactions (Savenije, 1995). It provides a key understanding of water resource engineering, hydrology, etc. by enhancing the knowledge on the coupling of land and atmospheric variables contributing to rainfall. Global moisture/precipitation recycling estimates infer less than 20% of the precipitation originates from evaporation for a mean space scale of 1000 km (Trenberth, 1999). Recent studies on precipitation recycling provided a deep understanding of its variability, sources, sinks of precipitation, the interaction between soil and precipitation, etc. The length scale of moisture recycling over tropical regions, temperate climates, and desert regions are found to be 500–2000 km, 3000–5000 km, and above 7000 km, respectively (van der Ent and Savenije, 2011). Except in desert areas, the time scales of moisture recycling are reported as 3–20 days. Studies of Keys et al., 2016 showed the percentage of precipitation triggered by land evaporation globally (Fig. 23.1) using the coupled land surface (STEAM) and atmospheric moisture budget (WAM) model. It can be seen from Fig. 23.1 that the contribution of evaporation over the Indian monsoon region in contributing the rainfall is about less than 40%.

Humans' role in modifying water vapor that enters the atmosphere through evaporation (Gordon et al. 2005) is a great concern. Deforestation and irrigation have significantly decreased and increased the water vapor flow of about 3000 km^3/year and 2600 km^3/year, respectively, in the atmosphere, leading to large spatiotemporal variations that affect the earth's hydrological cycle (Gordon et al. 2005). These changes, particularly concerning land around the Indian Ocean, will alter the Asian monsoon system behavior. As it is already witnessed that the increasing temperatures due to climate change cause the increased moisture-holding capacity of the atmosphere that increases the atmospheric moisture together with the enhanced evapotranspiration, this will have large implications on the increasing risks of droughts and floods. Under these

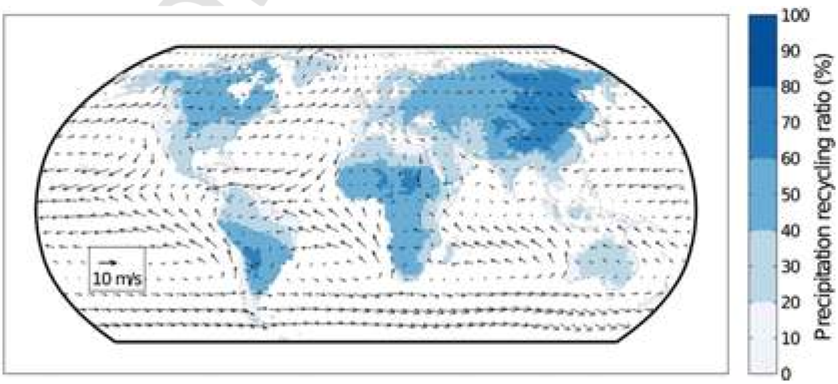

FIG. 23.1 Percentage of precipitation coming from the land evaporation (*Source:*Keys et al., 2016).

circumstances, studies on the quantification of rainfall from local evaporation and advection look essential. Kao et al. (2018) used the Coupled Model Intercomparison (CMIP5) models to study the moisture recycling phenomena and found that these models could capture the temporal variations of moisture recycling at long-term scales. It is also found that the models are capable of simulating water vapor than precipitation and reported that the recycling rate of atmospheric moisture is a better indicator of climate change. Laine et al. (2014) concluded that evaporation changes to the global precipitation will vary from 11% to 16 % during the period 2080–2099 under the CMIP5 intermediate greenhouse gas emission scenario of RCP 4.5 with more contribution from continents (32–35%) than oceans (8–13%). It is also worth noting the impact of global teleconnections on the regional moisture recycling ratios. The El Nino conditions could cause major fluctuations in atmospheric water vapor, particularly in the troposphere (Trenberth et al. 2005, 2011). Moisture recycling estimated based on Chahine (1992) over India is found to be less than the normal during the ENSO years (Lakshmi Kumar et al. 2014). Sujith et al. (2017) found that the advection/local evaporative components are strong and weak during the global teleconnections of ENSO over the Indian region. Pathak et al. (2014) also discussed the changes in local evaporation's contributions to rainfall during El Nino and La Nina years during the study period 1980–2010 and reported the lower recycling ratios during El Nino years. As it is known that the extreme El Nino events are responsible for disastrous events worldwide (Cai et al. 2014), These extreme El Nino events will be doubled in the future (Wang et al. 2017) which will have large bearing on the changes in the recycling ratios.

Taking into consideration of the above, the present work mainly focused on understanding the role of evapotranspiration in contributing to the regional rainfall over the monsoon core region of India (MCI) during the southwest monsoon season. This objective has been studied using a moisture recycling method that accounts for the advected and evaporated components in the rainfall occurrence. Also, we focus on presenting the anomalies of recycling during the future El Nino conditions under two emission scenarios (RCP 4.5 and RCP 8.5). The changes in local evaporation contribution to rainfall over MCI spatially and temporally will provide a general understanding to the policymakers to identify the moisture sources and sinks over this region.

23.2 Data and methodology

To study the long-term variations of moisture recycling (calculated by using rainfall, evaporation, and water vapor), monthly simulations of 18 General Circulation Models (GCMs) data from a suite of the CMIP5 (Taylor et al. 2012) have been used. The models have been selected based on the availability of rainfall, evaporation, and water vapor data for the historical and future emission scenarios. We estimated the moisture recycling in the historical period of 1976–2005 and also for the three future epochs 2011–2040, 2041–2070, and 2071–2100, which are treated as near-, mid-, and long-term (IPCC, 2013) under the two emission scenarios of RCP 4.5 and RCP 8.5. The recycling ratios of local evaporation (η) and advection (Ω) have been estimated for the historical period and for future under RCP4.5 and 8.5 emission scenarios. All the models used in the study are brought to a uniform spatial resolution of 0.25° × 0.25° using the bilinear interpolation method (Mishra et al. 2018;Matthes et al. 2016) for obtaining the multimodel mean (MMM) (mean of the all models) which will help to study the explicit diagnosis of moisture recycling on space and time scale. The list of models used and the details with grid resolutions are provided in Table 23.1.

To compare the MMM of rainfall and evaporation with the observed data, we have used IMD and European Centre for Medium range Weather Forecasting Reanalysis (ERA) data of rainfall and evaporation, respectively, for the historical period 1976–2005. The space scale resolutions of IMD rainfall and ERA evaporation are available at 0.25 × 0.25. The details of these datasets can be found in Pai et al, 2014 and Purnadurga et al, 2019.

We identified the future El Nino years by using the CMIP5 outputs of Sea Surface Temperatures over the Nino 3.4 region. The average SSTs of December–January–February have been obtained, and based on the anomalies of the same (> 1.5°C), the future El Nino years have been recognized. Rao et al. (2019) has proposed this analysis, and this approach was able to reproduce the previous El Nino years, such as 1982–1983, 1987–1988, etc. The detailed approach of inferring the strength of El Nino based on the quantification of anomalies can be found in ggweather.com/enso/oni.htm. In the present work, we did consider the strong and very strong El Nino years for the different epochs and examined the spatiotemporal variations of moisture recycling.

The MCI is considered as the focused study region in the present study (Fig. 23.2). The MCI covers the major portions of central India and the Indo-Gangetic plains. The low heat characterizes the MCI before the arrival of the SW monsoon. Thereafter, a tropical convergence zone will be established, which produces the rains (Gadgil, 2007; Lakshmi Kumar et al. 2019). The boundary between the lows of northwestern regions and the moist convective regimes of the northeastern parts decides the core region of the Indian monsoon,

Moisture recycling is defined as the amount of moisture that has been recycled by the local evaporation before it precipitates (Brubaker et al. 1993). Moisture recycling provides a diagnostic measure to understand the role of local evaporation and advection in turning the moisture into rainfall over the region (Burde 2006; Fitzmaurice, 2007). Brubaker et al. (1993) proposed a methodology to estimate the rainfall components contributed by the local evaporation and advection, and the same is adopted in the present study.

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TABLE 23.1 Description of the CMIP5 18 global climate models (Taylor et al. 2012).

S. no	Modeling center (or group)	Model name	Grid size
1.	Commonwealth Scientific and Industrial Research Organization (CSIRO)	ACCESS1.0	192 × 145
2.	Beijing Climate Center	BCC-CSM1-1	128 × 64
3.	Beijing Climate Center	BCC-CSM1-1-M	320 × 160
4.	College of Global Change and Earth System Science, Beijing, Normal University.	BNU-ESM	128 × 64
5.	Canadian Centre for Climate Modeling and Analysis	CanESM2	128 × 64
6.	Centre National de Recherches Météorologiques	CNRM-CM5	128 × 256
7.	Commonwealth Scientific and Industrial Research Organization.	CSIRO-Mk3.6.0	192 × 96
8.	NOAA Geophysical Fluid Dynamics Laboratory	GFDL-ESM2M	144 × 90
9.	Met Office Hadley Centre	HadGEM2-CC	192 × 144
10.	Met Office Hadley Centre	HadGEM2-ES	192 × 144
11.	Institute for Numerical Mathematics	INM-CM4	180 × 120
12.	Institut Pierre-Simon Laplace	IPSL-CM5A-LR	96 × 96
13.	Institut Pierre-Simon Laplace	IPSL-CM5A-MR	144 × 143
14.	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo)	MIROC-ESM	128 × 64

S. no	Modeling center (or group)	Model name	Grid size
15.	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo)	MIROC-ESM-CHEM	128 × 64
16.	International Centre for Earth Simulation	MIROC5	256 × 128
17.	Meteorological Research Institute	MRI-CGCM3	320 × 160
18.	Norwegian Climate Centre	NorESM1-M	144 × 96

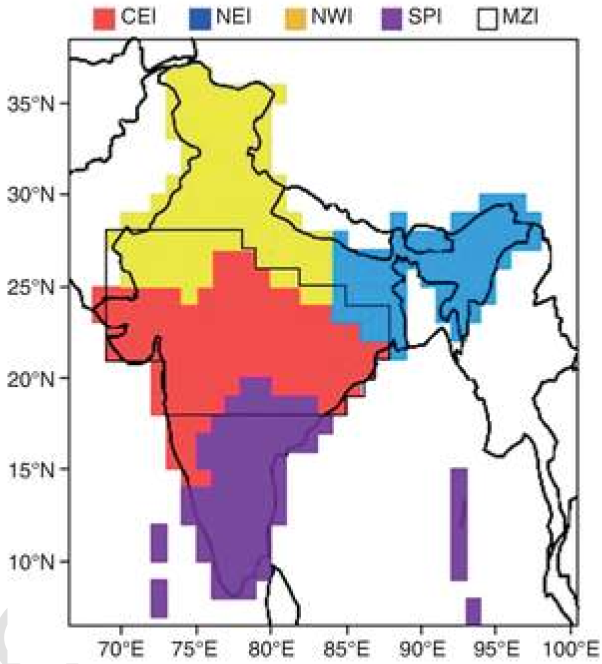
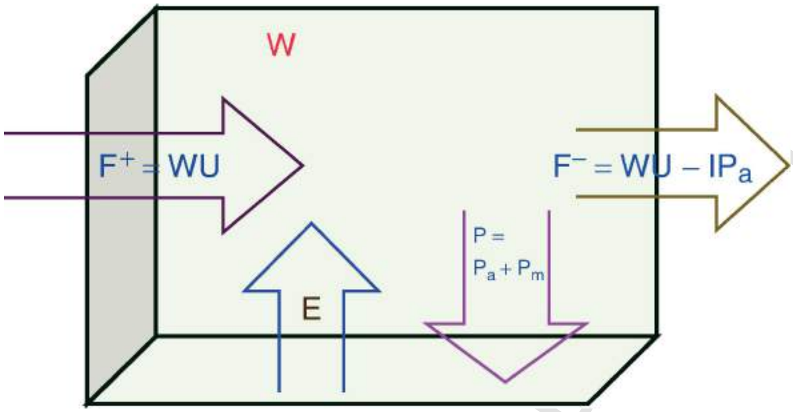


FIG. 23.2 Monsoon core region of India (MCI)—Solid black line drawn over India. (*Source:*https://nwp.imd.gov.in/ERF_Report_2017.pdf).



Total precipitation over a box region $P = P_a$ (rainfall due to advection) + P_m (rainfall due to local evaporation)

Average horizontal flux of advected moisture: $Q_a = wu - \left(\frac{lP_a}{2}\right)$

Average horizontal flux of locally exported moisture: $Q_m = \left(\frac{1}{2(E-P_m)}\right)$ and

Contribution from local evaporation: Eta (η) $= 1 + \left(2\left(\frac{wu}{Pl}\right) \times \left(\frac{P}{E}\right)\right)^{-1}$

Contribution from advection: Omega (Ω) $= 1 + \left(\frac{El}{2wu}\right)^{-1}$ where E is evapotranspiration in mm

P is precipitation in mm

w is precipitable water vapor in mm/day

u zonal wind speed in m/s

l is the length of the region

23.3 Results and discussion

23.3.1 Space scale variations of rainfall, evaporation, omega, and eta for the historical period

The spatial variations of the seasonal mean rainfall (mm/day) (Fig. 23.3A) and evaporation (mm/day) (Fig. 23.3C) from CMIP5 MMM for the summer monsoon season for the historical period 1976–2005 are shown in Fig. 23.3. Also the space scale variations of observed datasets of rainfall (IMD4) and evaporation (ERA) for the same study period are provided as Fig. 23.3B and D, respectively. The preponderant features of rainfall and evaporation are captured over India by the MMM datasets during the historical period when compared with the observed ones. Higher/lower rainfall associated with higher/lower evaporation features over Western Ghats/Northwest portions has been observed over India. It is worth noting that several studies reported the agreement over the CMIP5 rainfall and the observational records (IMD) in depicting the large-scale features of the southwest monsoon (Jena et al. 2016;

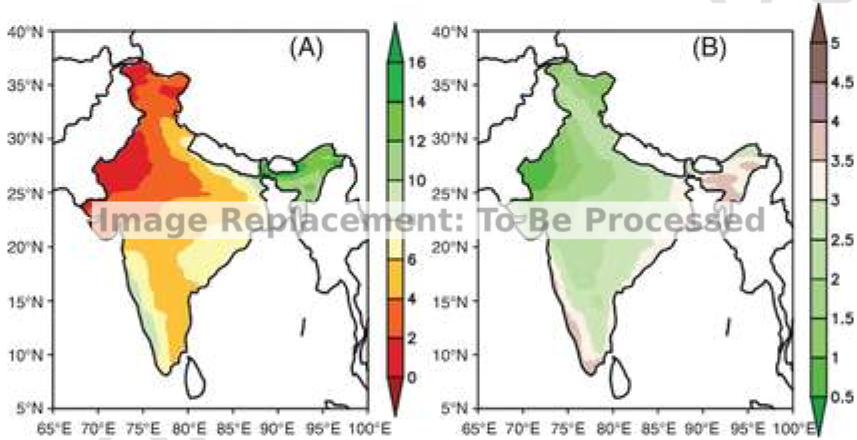


FIG. 23.3 Spatial variation of seasonal mean (A) rainfall (mm/day) from CMIP5 MMM and (B) rainfall (mm/day) from IMD , (C) evaporation (mm/day) from CMIP5 MMM, and (D) evaporation (mm/day) from ERA for the historical period 1976–2005.

Mishra et al. 2018). The discrepancies in the quantification of rainfall/evaporation magnitudes do exist in the CMIP5 datasets from the IMD and ERA datasets. The spatial variations of CMIP5 MMM evaporation are analogous to the same obtained from the ERA datasets over India (Purnadurga et al. 2019). Time series analysis of seasonal rainfall and mean evaporation from the observed and MMM showed the increasing trends for the period 1976–2005 with a statistical significance at 0.05 level (figure not shown here). The seasonal mean daily all-India rainfall from IMD/CMIP5 are 6.9 mm/5.4 mm and the seasonal mean daily all-India evaporation from ERA/CMIP5 are 6.7 mm/2.4 mm for the study period 1976–2005. The standard deviations of MMM rainfall and evaporation are 1.11 mm and 0.08 mm, indicating more interannual variability in rainfall than evaporation. The increase in evaporation due to increase in temperature causes an increase in the atmospheric moisture-holding capacity that modulates the rainfall pattern (Trenberth, 1998). Hence, in the present study, the increase in evaporation contributes to an increase in the amount of precipitable water vapor, which has a large bearing on the rainfall amounts. However, the increasing rainfall trends and evaporation do not explicitly infer the evaporation's role in contributing to rainfall. For this purpose, we estimated the moisture recycling and found the changes in the local evaporative ($\boldsymbol{\eta}$) and advective ($\boldsymbol{\Omega}$) components' contribution. The spatial variations of Omega ($\boldsymbol{\Omega}$) and Eta ($\boldsymbol{\eta}$) (in %) estimated on a local scale over India are shown in Fig. 23.4A and B for the historical period. It is observed that the Omega values vary spatially from 70% to 90% over most of the regions of India, with an exception to the parts of Northeast, Indo-Gangetic Plains, and Western Himalayan region (Fig. 23.4A). The contribution of the evaporative component, $\boldsymbol{\eta}$, has also shown variations quite opposite of $\boldsymbol{\Omega}$. The $\boldsymbol{\eta}$ values are high (up to 60%) over the NE parts and parts of the Ganges river basin, which show the contribution of evaporation in the rainfall is high over these regions (Fig. 23.4B). These results are similar to Pathak et al. (2014), where they reported that the recycled precipitation is high over Northeastern parts due to more vegetation, which triggers more recycling. They also reported that recycled rainfall estimated from the dynamic recycling model using NCEP Climate Forecast System Reanalysis data had shown a decreasing trend for the period 1980–2010 over northeastern regions of India. Also, studies of Tuineburg et al. (2012) pointed out the contribution of moisture recycling is up to 5% over the Ganges River basin when studied with European Centre for Medium range Weather Forecasting (ECMWF) reanalysis datasets for the period 1990–2009. A similar type of study over the Australian monsoon also stressed that the land surface processes that drive the moisture recycling plays a significant role in the precipitation patterns and further can change the atmospheric circulation patterns (Xue et al. 2010). The inference of Fig. 23.4 provides a dominance of the advected component over the MCI except over the regions of northeastern parts during the southwest monsoon season. When recycling is estimated at a local scale, as expected, the contribution of advection dominates

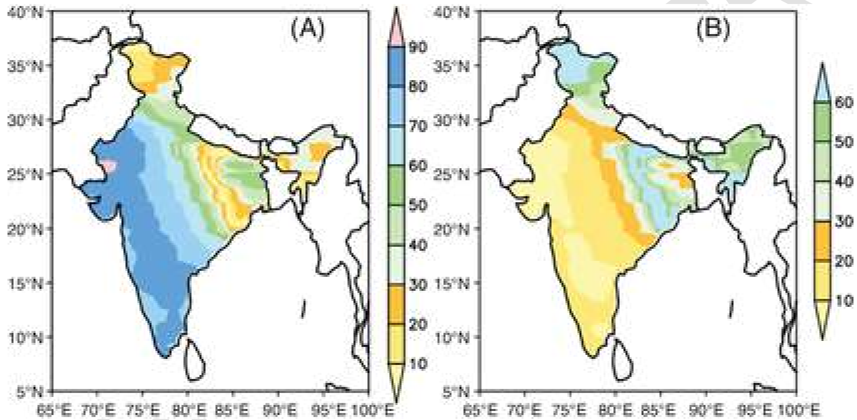


FIG. 23.4 Percentage seasonal mean of (A) omega (advected component) and (B) eta (evaporative component) for the historical period 1976–2005.

the contribution of evaporation, and the same is reflected in the present analysis. We may expect a considerable difference in these contributions when averaged for a region.

Fig. 23.5 shows the time series anomalies of mean daily evaporation, rainfall, Eta, and Omega for the MCI for the historical period 1976–2005 obtained from the CMIP5 MMM datasets. The lines plotted in Fig. 23C and D are obtained from the IMD4 and ERA data sources for the respective variables. The agreement between the anomalies of observed and MMM datasets of rainfall and evaporation were found to be varied from year to year during the study period. It is worth recalling the results reported by Goswami et al. (2006) that rainfall over Central India has no particular trend over the study period of 1951–2000. However, there are an increasing number of heavy rainfall events. Goswami et al. (2006) pointed out the decrease in the number of moderate rainfall days offset the increasing number of heavy rain days, thus leading to a steady state in the rainfall trend. However, observations show a declining trend of Indian summer monsoon rainfall from 1950 to 1999 due to global warming, aerosol loading, and deforestation and are recovered further (Huang et al. 2020)**.** The estimated omega and eta also have shown the increasing and decreasing trends, respectively, during the study period. The increasing role of advection (denoted by omega) infers the increasing westerlies from the Ara-

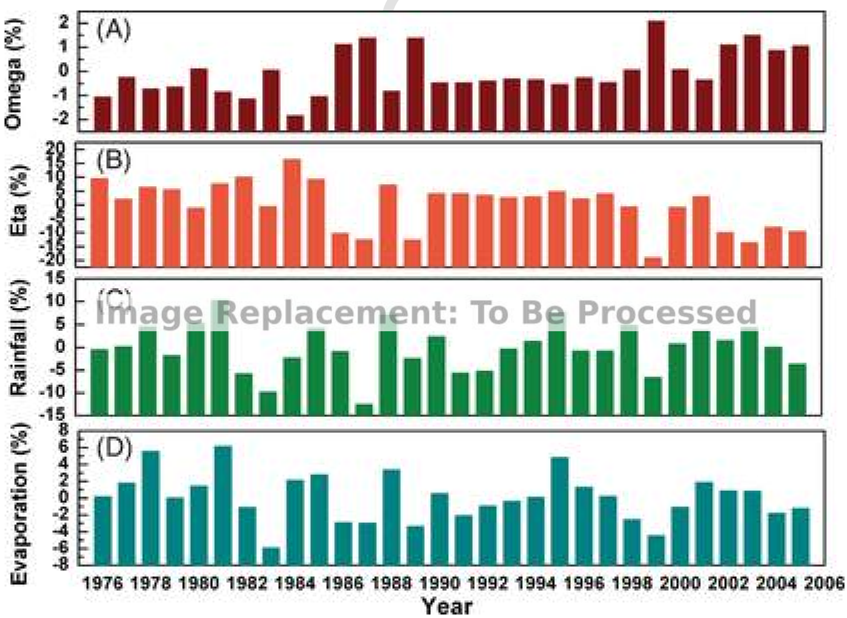


FIG. 23.5 Time series anomalies of (A) omega, (B) eta, (C) rainfall, and (D) evaporation for the historical period 1976–2005 during SW monsoon season.

bian Sea due to its warming reaching the MCI and causing rainfall (Satyaban et al. 2014). Particularly the winds from the western Arabian Sea are reported to carry more moisture. The same is converged over the MCI, which acts as the sink of the moisture transported by the Arabian Sea (Pathak et al. 2014). The decreasing tendency in the evaporative component also complements the increasing role of advection. However, we also observed the interannual variability in $\boldsymbol{\Omega}$ and $\boldsymbol{\eta}$, as is observed in rainfall and evaporation. As mentioned by Trenberth (1999) that the advection dominates in some regions of Amazon, whereas the local evaporation shows dominance in southern parts of Amazon. However, during the annual cycle, it is reported that 34% of the moisture is recycled. Evaporation contributes to 1% of its total rainfall over the Mississippi basin (Benton and Estoque, 1954). The summer daytime rainfall over central North America was completely from local evaporation (Zangvil et al. 1993). The extent of recycling of moisture mainly depends on the study domain (Brubaker et al. 1993). If the selected domain is small, then a little amount of moisture gets recycled. Solander et al. (2020) reported that the El Nino conditions could cause a consistent decrease in soil moisture over the Amazon region due to less amplification of land–atmospheric interactions. Similarly, during El Nino years over the MCI, less moisture has been recycled due to low land-atmospheric interactions. The interannual variability of $\boldsymbol{\eta}$ shows that $\boldsymbol{\eta}$ is low during the El Nino years 1983, 1987, and 2002 compared to the previous years, which infer a low feedback mechanism between the land surface processes and the atmosphere. However, it is understood that external influences such as El Nino can impact regional feedback, such as the drier than the normal conditions (Ropelewski and Halpert, 1987), decreasing the soil moisture (Solander et al. 2020). The lower values of recycling also depend on the rainfall pattern during the initial months of monsoon. If the monsoon is weak, there will be less moisture source for the recycling. Similarly, when the monsoon is strong during the initial conditions, the El Nino offsets moisture recycling by showing the lesser values (Pathak et al. 2014).

23.4 Analysis of time and space scale moisture recycling—future El Nino events

Fig. 23.6 shows the epochal trends of rainfall, evaporation, and $\boldsymbol{\eta}$ for RCP4.5 and RCP 8.5 scenarios. This analysis has been conducted mainly to examine the role of evaporation in contributing to the rainfall over the MCI. It is difficult to explain the role of evaporation in the rainfall just by seeing the trends and magnitudes of evaporation estimates as the locally evaporated water may transport and fall as rain in other regions. In such cases, the region of locally evaporative fluxes acts as the source, and the region where the fluxes converge are treated as the sinks of the moisture. However, as the study region is very active during the southwest monsoon, where the cloud cover influences the local evaporation, quantifying evaporation’s role is difficult, as reported by Hua

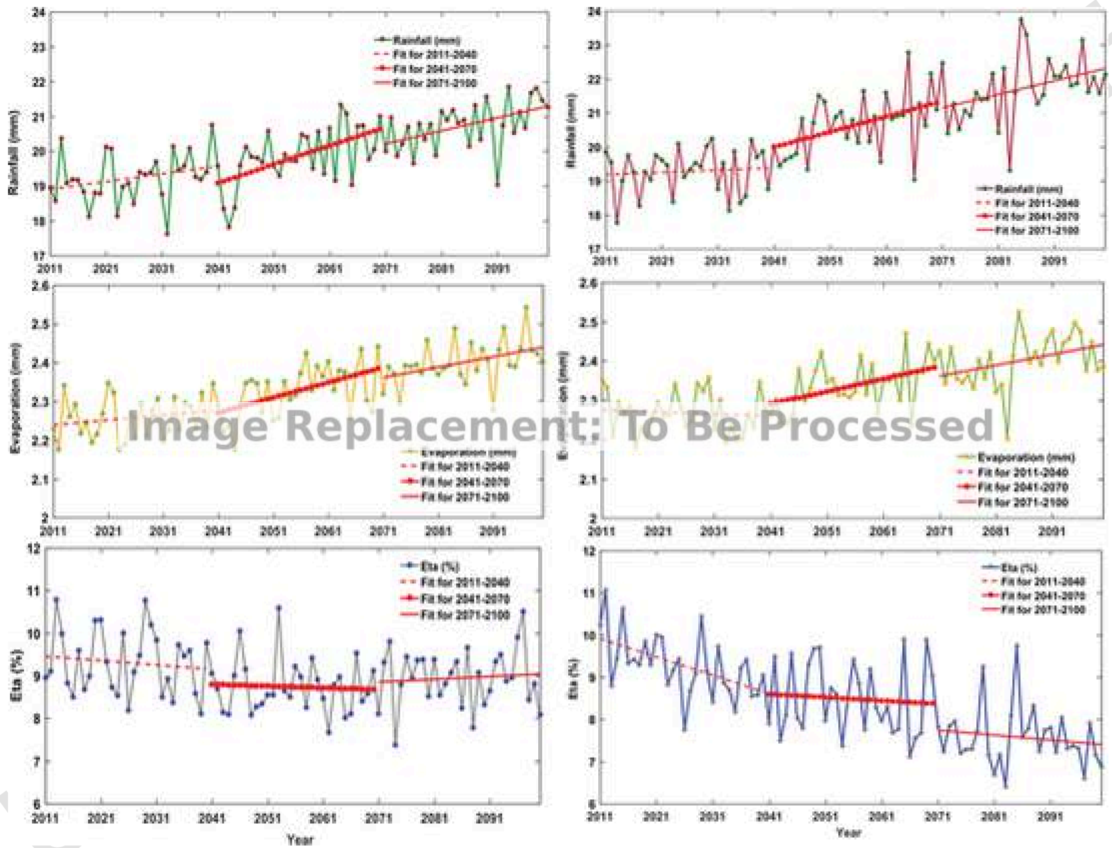


FIG. 23.6 Break trend analysis of rainfall, evaporation, and **η** for the period 2011–2100 under RCP4.5 (left panel) and RCP 8.5 (right) scenarios.

et al. (2017). It is found from Fig. 23.6 that rainfall and evaporation have shown statistically significant increasing trends (see Table 23.2 for significance levels) during all the epochs of RCP 4.5 and 8.5 scenarios. The trends of **η** have yielded decreasing trends during these epochs. The trends of the three variables are shown in Table 23.2, along with their statistical significance levels.

The MCI is characterized by more advection during the SW monsoon being proxy to the Arabian Sea. In such cases, one may expect the rainfall mainly contributed by the advection as the MCI falls under the humid seasonal climate category during the SW monsoon season. On the contrary, the advection is very low over the arid regions, and the local moisture will be recycled more, as reported by Li et al. (2016). In all three epochs, rainfall and evaporation have shown increasing trends with distinctive slopes. Rainfall variations are mimicked by the evaporation, which shows that the precipitation over MCI controls the local evaporation trends. The trends of **η** are exciting and not completely followed in either rainfall or evaporation. The trend of **η** during the epochs 2011–2040 and 2041–2070 yielded slightly decreasing trends, and thereafter, it has shown the increasing trend during the RCP4.5 scenario. But in the case of the RCP8.5 scenario, though the rainfall and evaporation have shown increasing trends during all the epochs, the trends of **η** have undergone the decreasing trends during all the epochs. The overall analysis shows that though the evaporation is increasing over the MCI, the local evaporation contribution in converting the moisture into rainfall decreases from 2011 to 2100 but changing when examined for different epochs. The analysis of recycling ratio estimated over Southeast China from 1979 to 2010 discloses that local evaporation influence will be less but significant over the regions where the monsoon winds take major part (Hua et al. 2017). An increase in moisture recycling over Tibetan Plateau has been attributed to land-use changes and land cover associated with evapotranspiration, which intensifies moisture recycling. The extreme moisture recycling values are due to the large-scale atmospheric circulation and extreme weather events (An et al. 2017).

Spatiotemporal anomalies of **η** for the composite strong and very strong El Nino years over India, particularly in MCI, infer the changing role of evaporation in contributing to the MCI's rainfall during different epochs (Fig. 23.7). The anomalies of **η** during the composite El Nino years are decreased from the epoch 2011–2040 to 2041–2070 in the RCP4.5 scenario. But, during the epoch 2071–2100, the anomalies are slightly improved, indicating the lesser role of evaporation over the western parts of MCI than the western part of MCI, which includes the Indo-Gangetic Plains. The anomalies of η are varied from 9% to 21% below normal during all the epochs in the RCP8.5 scenario, which infers the diminishing role of evaporation over the MCI in contributing to rainfall. Contribution of local evaporation has shown a considerable negative shift (more than 20% below normal) during the epoch 2071–2100 of the RCP8.5 scenario. A reduction of 6–12% (2011–2040) and 9–21% (2041–2070 and

Table 232

TABLE 23.2 Trends in rainfall, evaporation, and eta for different epochs of RCP4.5 and RCP8.5 future scenarios.

Slopes/Mean		Eta (%)	RF (mm)	ET (mm)	Eta (%)	RF (mm)	ET (mm)
RCP4.5	2011–2040	–0.0103***	0.0222**	0.0013**	9.31	19.13	2.25
	2041–2070	–0.0041**	0.0532*	0.0039*	8.74	19.86	2.33
	2071–2100	0.0065**	0.0372*	0.0027*	8.95	20.75	2.40
RCP8.5	2011–2040	–0.0435*	0.0067***	–0.0005***	9.28	19.28	2.27
	2041–2070	–0.0078**	0.0452*	0.0032*	8.49	20.64	2.34
	2071–2100	–0.0116***	0.0398*	0.0028*	7.58	21.73	2.40

*, **, and *** indicate 0.01, 0.05, and 0.10 levels of significance.

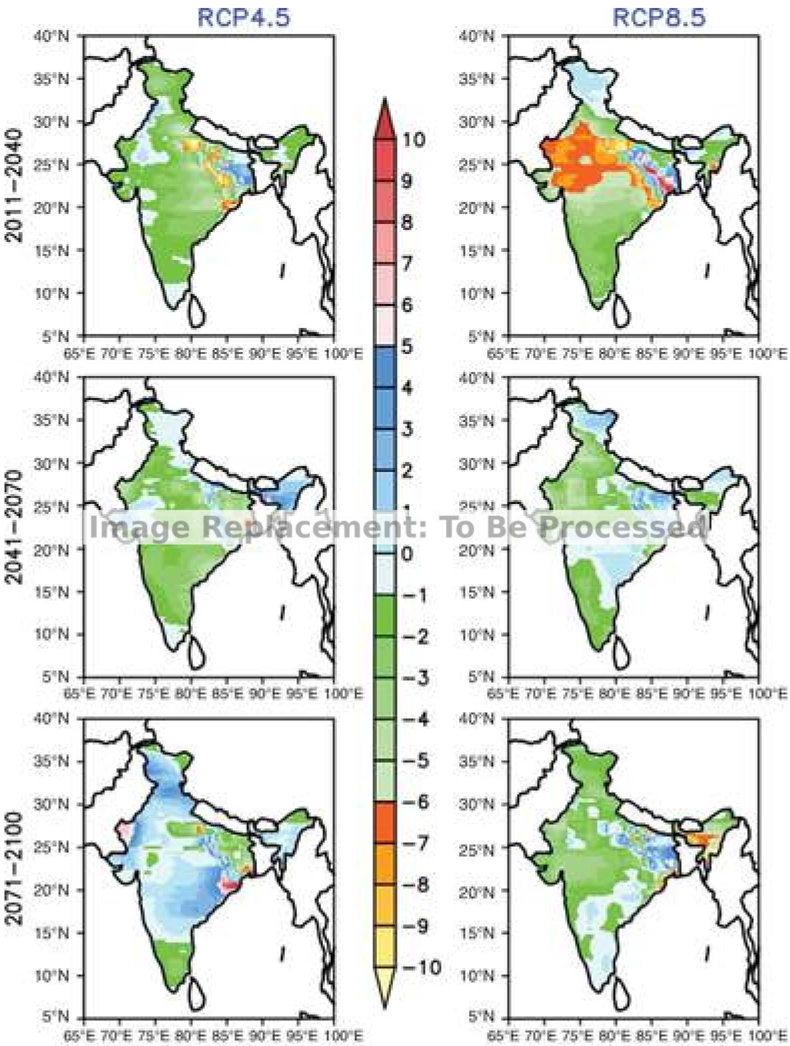


FIG. 23.7 Spatiotemporal composite anomalies of **η** for the strong and very strong El Nino years for the epochs 2011–2040, 2041–2070, and 2071–2100 for RCP 4.5 (left pane) and RCP 8.5 (right panel) emission scenarios.

2071–2100) has been observed on local evaporation's contribution over most parts of the MCI in RCP8.5 scenario. The overall changes may be attributed to soil moisture interactions via evaporation with the circulation and associated surface heating mechanisms. Hence, further studies such as future land–atmospheric interactions and land surface feedback associated with LULC changes are required to understand the changing contributions of local evaporation in contributing to rainfall. With the increasing irrigation, changing vegetation, and anthropogenic activities, the changes in LULC may affect the regional feedback mechanisms (Gogoi et al. 2019). The moisture recycling needs to be revisited by taking into account these changes (Keys et al. 2017).

23.5 Conclusions

In the present study, an attempt has been made to understand the role of local evaporation and advection in contributing to the MCI rainfall using the CMIP5 MMM model datasets. The necessity of using the CMIP5 for this purpose is to examine the future changes in response to global warming. Knowing the changes in moisture recycling in future El Nino events allows policymakers to enact the framework for water resource management. Our study reports that moisture recycling plays a key role in the eastern parts of MCI by contributing 50–60% of the rainfall than in the other parts during the southwest monsoon season. During the El Nino years, moisture recycling is much less than normal. A gradual decrease in local evaporation contribution was observed in the two emission scenarios by the end of the century. The anomalies of moisture recycling during RCP8.5 scenario are declined by up to 21% below normal from 2011–2100, which infers the diminishing role of evaporation over the MCI in contributing to rainfall. The spatiotemporal variations of moisture recycling during the future strong and very strong El Nino years suggest the changing land-atmospheric interactions, which will have a great bearing on future LULC changes and moisture sources and sinks.

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