Rainfall Pattern inferred from CORDEX-SA Domain Models for Future Warming Scenarios over Northwest Himalayan Region

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ABSTRACT

Indian economy is predominantly dependent on cultivation and further India receives more or less 80% of its annual rainfall in the summer monsoon season. Therefore, summer monsoon plays an important role from the economic point of view. Based on the recent study, it is said that the rainfall pattern under the global warming scenarios has undergone changes. The rainfall pattern over the North West Himalayan (NWH) region has become more unpredictable as there is a difference in the amount of rainfall and duration of monsoon; rainfall becomes more intense with shorter duration. The extreme weather condition such as cloud burst, heavy precipitation, flash floods, landslides etc. are happening frequently over that region. It has become very difficult to project rainfall pattern under the different warming scenarios over the mountainous NWH region. However, the rainfall pattern over that region can be projected by utilizing finer resolution Coordinated Regional Climate Downscaling Experiment (CORDEX) models. The present study has been planned to investigate the rainfall pattern from the CORDEX South Asia (CORDEX-SA) domain in a consistent framework for the period 2076 to 2100 under different future warming scenarios compared to the historical period from 1976 to 2000. CORDEX-SA domain simulated fields forced by four well known global models (i.e., MIROC5, MPI-ESM-LR, GFDL-ESM2M and IPSL-CM5A-LR) have been examined in the context of spatio-temporal distribution of rainfall over the NWH region in the rainy season. The downscaled rainfall have been validated against the ground-based IMD gridded rainfall data set. It is inferred from the analysis that models like MIROC5 and MPI-ESM-LR provide the best spatial distribution of downscaled rainfall, although CORDEX domain models are unable to simulate the intensity of rainfall at daily scale compared to IMD data over the NWH region.

Keywords: *Rainfall, CORDEX, Future warming scenarios, MIROC5, MPI-ESM-LR and NWH.*

1. Introduction

The Himalayas play important role by influencing the climatic conditions in the Indian subcontinent. It defends chill continental air from the north into India in winter and rain-bearing south-westerly monsoon to capitulate maximum precipitation in that area in the monsoon season (Chatterjee & Bishop, 2019). Now-a-days, the extreme weather conditions like heavy precipitation, cloud burst, flash flood, landslide, and extreme avalanches are happening frequently in the North West Himalayas due to overall changing rainfall pattern (Kumar et al., 2016). As per the report of the Intergovernmental Panel on Climate Change (IPCC), the frequency and intensity of rainfall are predicted to increase in the Asian monsoon region. The recent study also suggests that the rainfall over that region becomes more intense with shorter duration. It has been observed in the last century that rainfall has increased in some places like Nainital, Dehradun, Almora whereas decreased in Shimla, Mussoorie, Srinagar, Joshimath etc. (Ray et al., 2011). As the climate is becoming unstable in some areas of the Himalayan region, it is very crucial to investigate the rainfall pattern over that region. The present study is based on the modelled data from CORDEX-SA domain. In the global warming scenario, the changes in the monsoon rainfall pattern are anticipated due to the increase in the global temperature (Sharmila et al., 2015). After considering the recently reported research (Choudhary & Dimri, 2017; Umakanth & Kesarkar, 2017) on the pattern of rainfall during the recent decades over the NWH region, the present work focuses on the changing rainfall pattern under different future warming scenarios. Here two representative concentration pathways (RCP) have been considered to predict the future rainfall pattern namely RCP4.5 and RCP8.5 in terms of spatio-temporal analysis of rainfall compared to the historical data.

2. Study Area

The study area North-West Himalayan region consists of Jammu & Kashmir (J&K), Himachal Pradesh (HP) and Uttarakhand states of India (Figure 1). It extends from 28°N to 37°N and 72°E to 82°E and the Altitude ranges from 170 m to 7861 m.

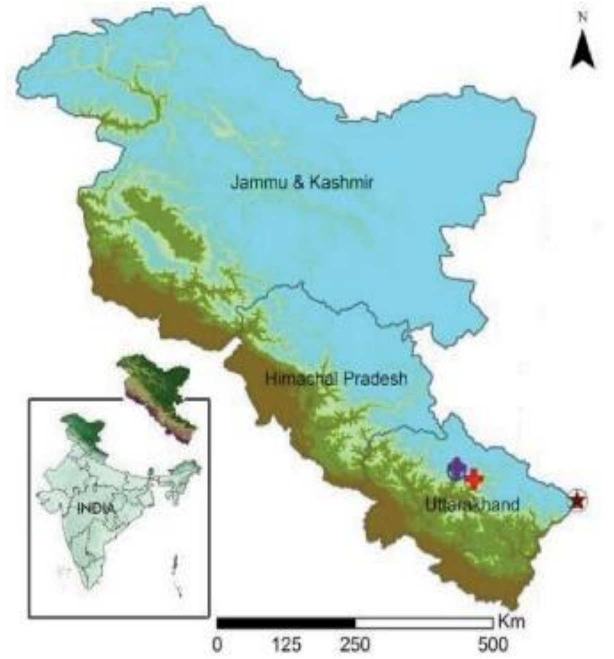

Figure 1: Study area. Source: Rai et al. (2016).

3. Datasets and Methodology

The following data sets have been utilized to undertake the present study.

CORDEX domain models: CORDEX is a strategic approach to understand the regional climate change and the fidelity of climate models. It provides a common modelling framework, where different groups from all over the world are participating. CORDEX is a WCRP-sponsored international coordinated framework to improve regional climate change projections globally. These projections consist of the output of the regional models which are forced by the boundary conditions from global models (Christensen et al., 2014). The world has been divided into 14 CORDEX domains and India falls under the Region 6: South Asia (WCRP-CORDEX, 2013). The output of models from CORDEX-SA domain used in this study are given in Table 1.

IMD Gridded Data: National Climate Centre (NCC), India Meteorological Department (IMD), Pune provides CD ROMs which contain high resolution daily gridded rainfall and temperature data sets for the Indian region. These CD ROMs are only available for research community in academic and research institutes and not for commercial use and applications. The 0.5°×0.5° IMD gridded rainfall data have been used for the validation purpose.

To analyse rainfall pattern in the future warming scenarios, the spatial map over NWH region has been prepared for RCP4.5 and RCP8.5 scenarios. At first, data have been extracted from the CORDEX-SA domain models and these are validated against the IMD rainfall data for the historical period (1976-2000). After that, the spatial maps have been generated for the two future warming scenarios (2076-2100) over this region. The difference plots have also been introduced to understand the increasing or decreasing patterns of rainfall under the future warming scenarios. The methods followed have been schematically shown in Figure 2.

4. Results and Discussion

The spatial map of rainfall over NWH region has been prepared for the historical period (1976-2000) and compared with the IMD gridded rainfall data for the validation purpose. The time series plots have also been generated over the states Uttarakhand and HP for the validation purpose. To investigate the future rainfall patterns over that region, RCP4.5 and RCP8.5 scenario fields have been utilized in terms of spatial plot. Thereafter, the difference plots between RCPs and historical period have also been prepared to investigate the increasing or decreasing tendencies of rainfall over that region.

4.1 Spatial distribution of rainfall during historical (1976-2000) period and comparison with IMD data

The spatial plots for the four CORDEX-SA domain models such as GFDL-ESM2M, IPSL-CM5A-LR, MIROC5 and MPI-ESM-LR have been prepared to find out the suitable model(s) which can capture the

Table 1. Details of CORDEX-SA domain models.

Driving models	Contributing Institute	Extension		Resolution (Lon × Lat)
		Longitude (Lon)	Latitude (Lat)	
GFDL-ESM2M	CCCR, IITM, Pune, India	1.90 to 138.10 & 20.79 to119.21	-25.23 to 42.43 & -25.23 to 42.43	0.54˚×0.46˚
IPSL-CM5A	CCCR, IITM, Pune, India	1.90 to 138.10 & 20.79 to 119.21	-25.23 to 42.43 & -25.23 to 42.43	0.54˚×0.46˚
MIROC5	Rossby Centre, Swedish Meteorological and Hydrological Institute (SMHI), Sweden	19.86to 115.53 & 26.17 to 106.41	-12.97 to 43.50 & -15.23 to 40.89	0.50˚×0.47˚
MPI-ESM-LR	Rossby Centre, Swedish Meteorological and Hydrological Institute (SMHI), Sweden	19.86 to 115.53 & 26.17 to 106.41	-12.97 to 43.50 & -15.23 to 40.89	0.50˚×0.47˚

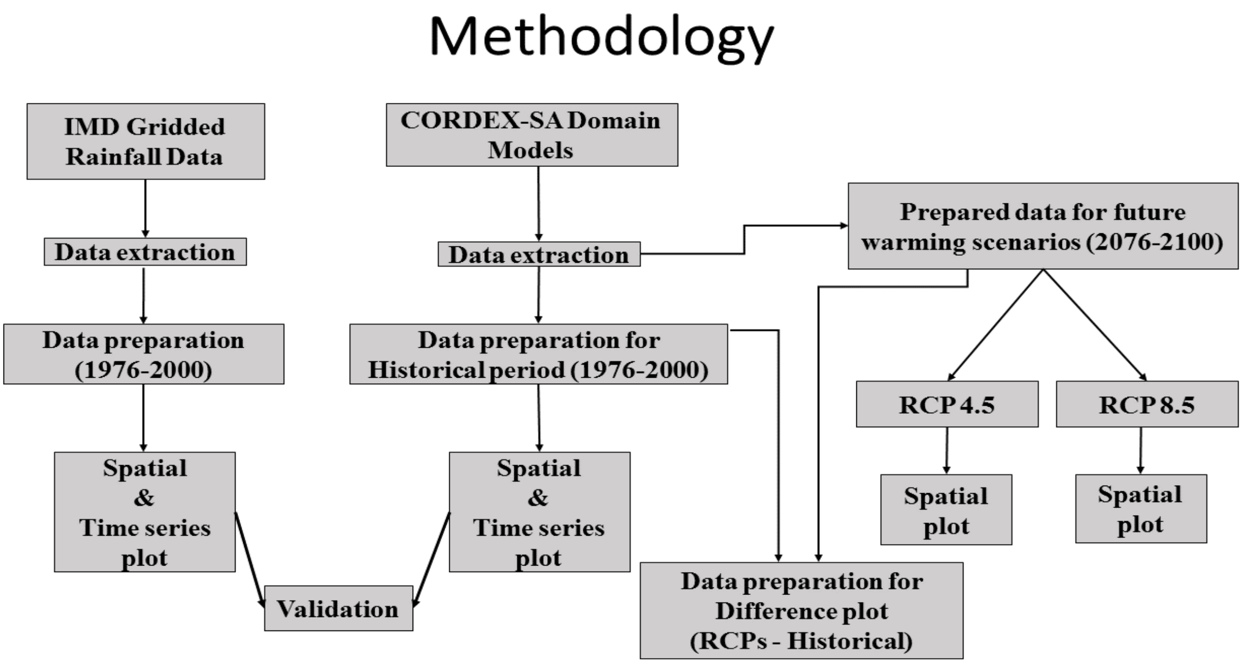

Figure 2: Schematic diagram of the methods followed.

best rainfall pattern as compared to IMD observations (Figure 3). As per IMD gridded rainfall data, it can be said that the western most part of eastern Uttarakhand has received the maximum rainfall during the period 1976 to 2000. The western part of HP also received maximum rainfall compared to the rest of the region. On the other hand, the northern part of Uttarakhand, north-eastern part of HP and a greater portion of J&K received minimum rainfall. Apart from that, rest of the NWH region received average rainfall. The model GFDL-ESM2M captured unusually greater rainfall over NWH region whereas IPSL-CM5A-LR simulated lesser over Uttarakhand and HP but greater over J&K. Rest of the two models MIROC5 and MPI-ESM-LR simulated rainfall similar to

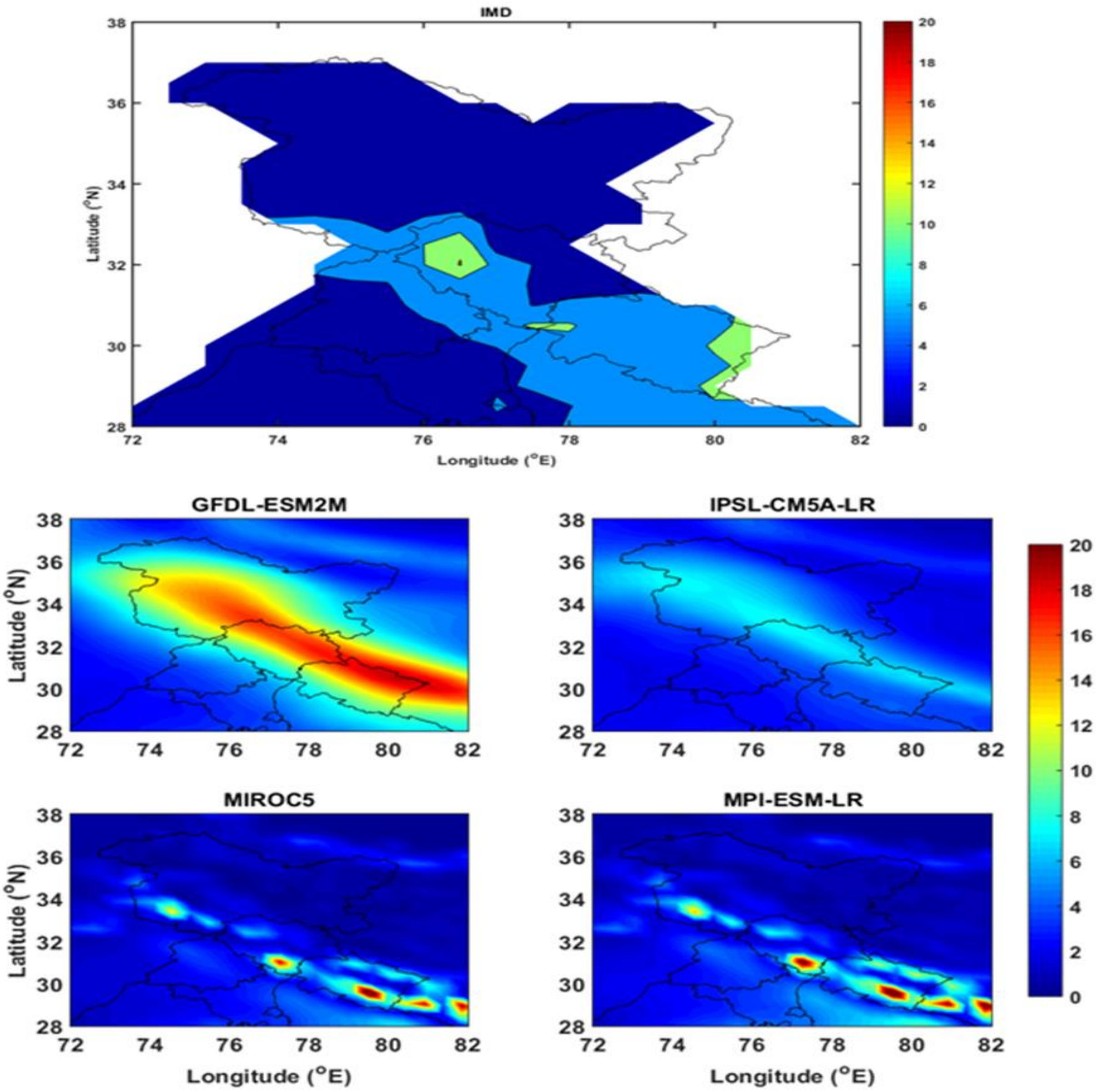

Figure 3: Spatial distribution of JJAS mean precipitation during the Historical period (1976-2000) over NWH region using IMD gridded rainfall and selected CORDEX-SA experiments.

IMD as the regions such as parts of Uttarakhand and HP received greater rainfall and J&K captured minimum rainfall.

4.2 Time series of rainfall during historical (1976-2000) period and comparison with IMD data

The time series of seasonal mean rainfall have been generated using IMD data and CORDEX-SA domain models outputs. Figure 4 shows the time series of rainfall for HP. MPI-ESM-LR model output and IMD gridded rainfall data show increasing trends in rainfall for the period 1976 to 2000 whereas other three models indicate not much change in rainfall. The CORDEX-SA domain models are unable to simulate daily rainfall intensity compared to IMD data over the HP. Similar results are obtained for Uttarakhand region.

4.3 Spatial distribution of rainfall under the warming scenarios RCP 4.5 and RCP 8.5

The future rainfall patterns over the NWH region have been examined for the years 2076 to 2100 under the warming scenarios RCP4.5 (Figure 5) and RCP8.5 (Figure 6).

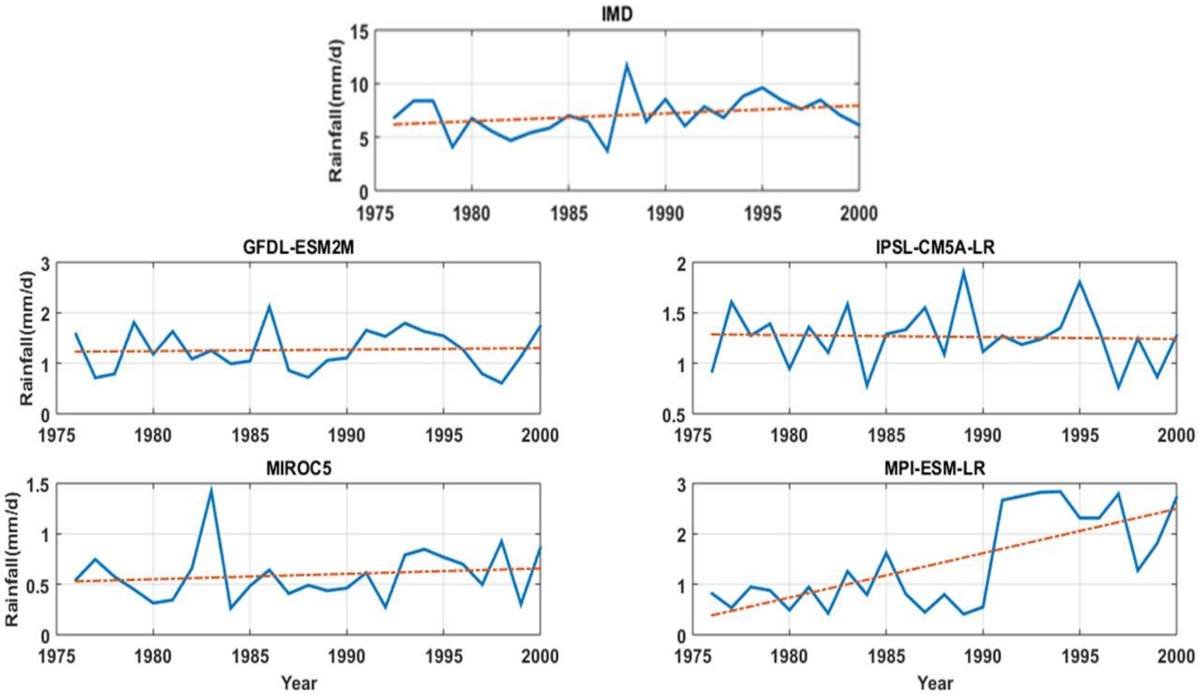

Figure 4: Time series of JJAS mean precipitation during Historical period (1976-2000) using IMD rainfall data and different CORDEX-SA experiments over the state of HP.

4.3.1 RCP4.5

The model GFDL-ESM2M simulated maximum rainfall (Figure 5) in northern part of Uttarakhand, north-eastern part of HP and even in J&K. IPSL-CM5A-LR captured comparatively higher rainfall over J&K region as compared to Uttarakhand and HP. The other two models MIROC5 and MPI-ESM-LR captured almost same rainfall distribution over NWH, Uttarakhand and HP.

4.3.2 RCP8.5

The spatial distribution of rainfall under RCP8.5 scenario also indicate approximately similar results as compared to the RCP4.5. But as compared to Figure 5, Figure 6 captures more rainfall in the specific regions with expanding spatial dimension.

4.4 Difference between RCPs and Historical Simulations

The difference plots between RCPs and historical simulations have also been prepared to investigate the increasing or decreasing rainfall patterns over the study region.

In case of RCP4.5 (Figure 7), there is an overall increase in rainfall in most of the region of NWH although MIROC5 shows higher increase in rainfall in northern and southern parts of Uttarakhand, western and southern parts of HP and south-western part of J&K. On the other hand, MPI-ESM-LR shows decreasing pattern of rainfall in the same area where MIROC5 shows increasing pattern. Other two models, GFDL-ESM2M and IPSL-CMA5A indicate the same patterns of rainfall. There is increase in rainfall over eastern part of Uttarakhand and J&K and decrease in the western and southern parts of J&K. Rest of the study region experience very little increase in the amount of rainfall compared to historical data. When similar analysis has been made on RCP 8.5 (Figure 8) the models represent almost similar patterns but with more rainfall in the previously defined high rainfall regions and less rainfall in the previously defined low rainfall region.

5. Conclusions

The future projections of rainfall in the Himalayan region is a very difficult task as it is mostly dependent on the complex orographic regime (Meher et al., 2017). Although the CORDEX-SA domain downscaled mean seasonal rainfall of 25 years show better spatial distribution with respect to

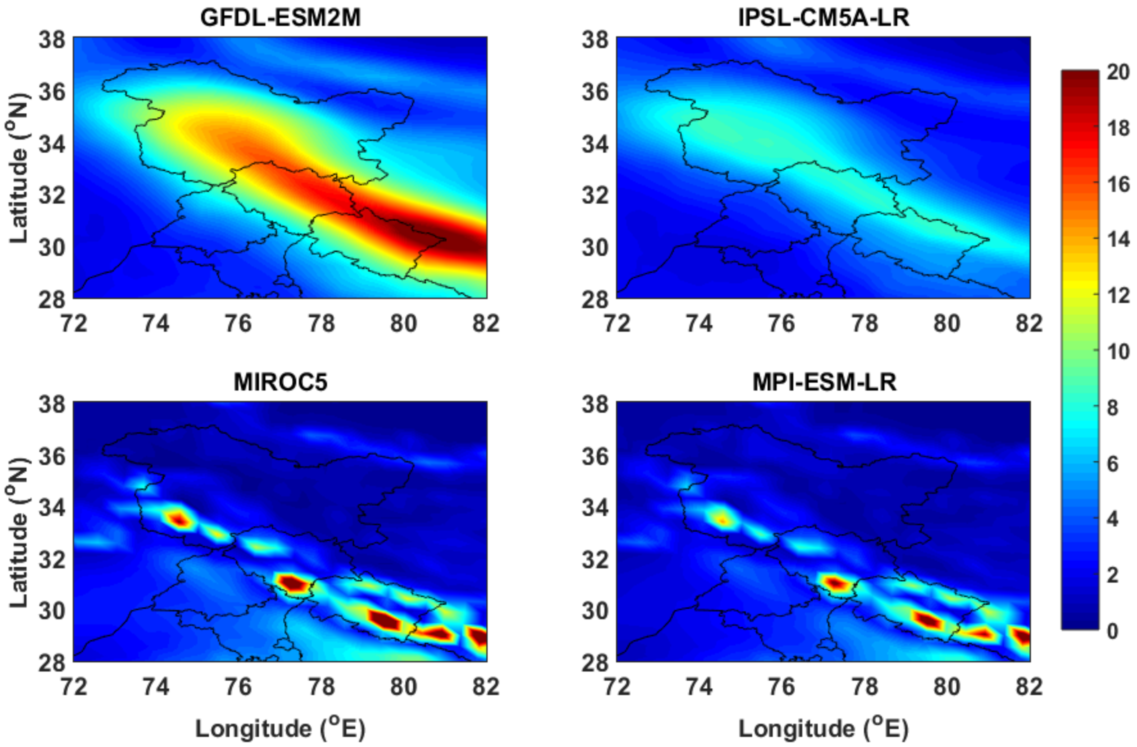

Figure 5: Spatial plot for the warming Scenarios RCP 4.5 (2076-2100) in JJAS mean precipitation over NWH region using different CORDEX-SA experiments.

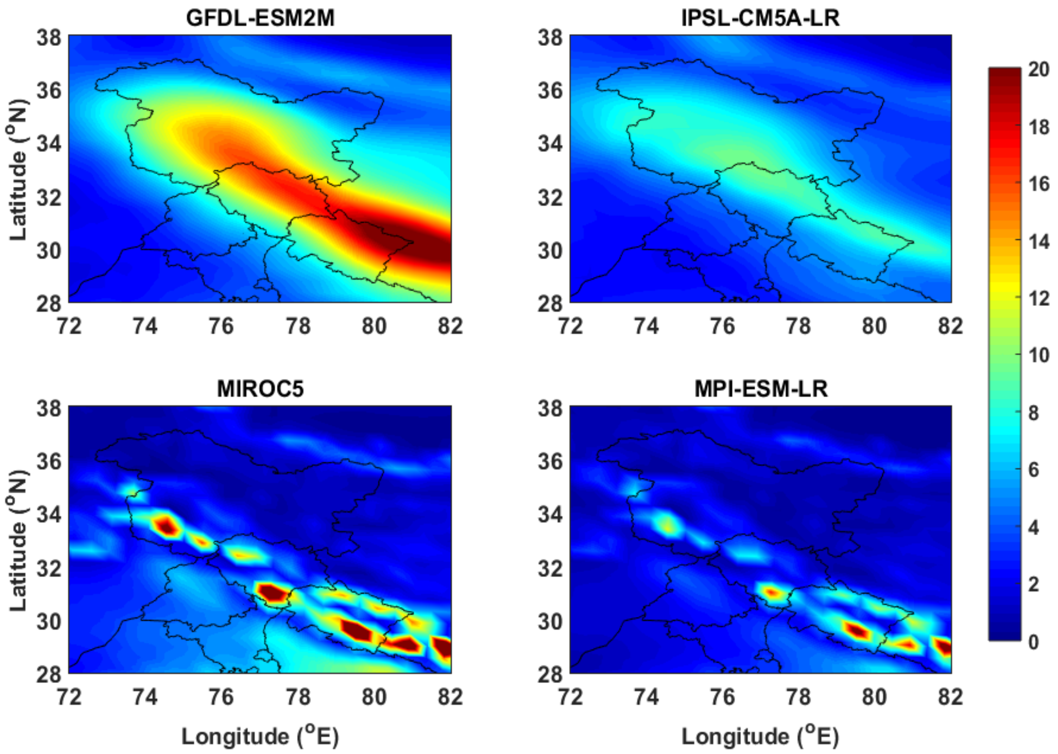

Figure 6: Spatial distribution of JJAS mean precipitation for the warming Scenario RCP 8.5 (2076-2100) over NWH region using different CORDEX-SA experiments.

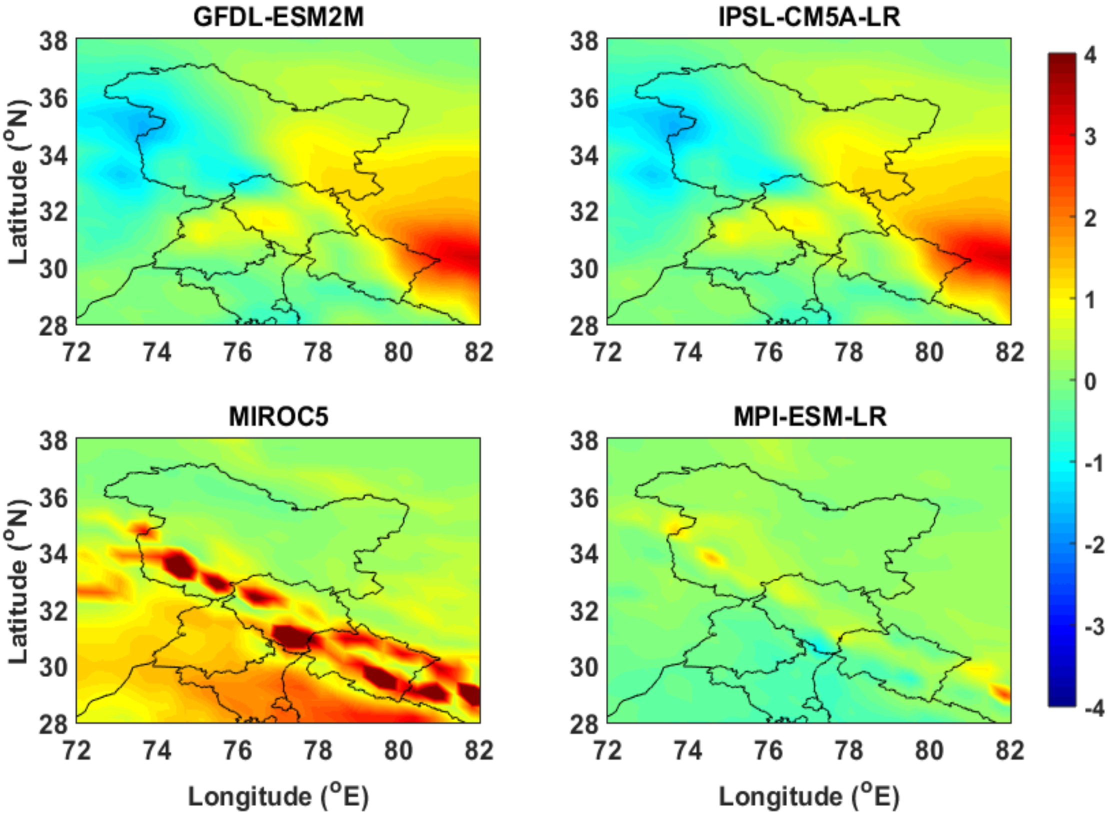

Figure 7: Differences in JJAS mean precipitation obtained under the warming Scenario RCP 4.5 (2076-2100) and historical period (1976-2000) over NWH region using different CORDEX-SA experiments.

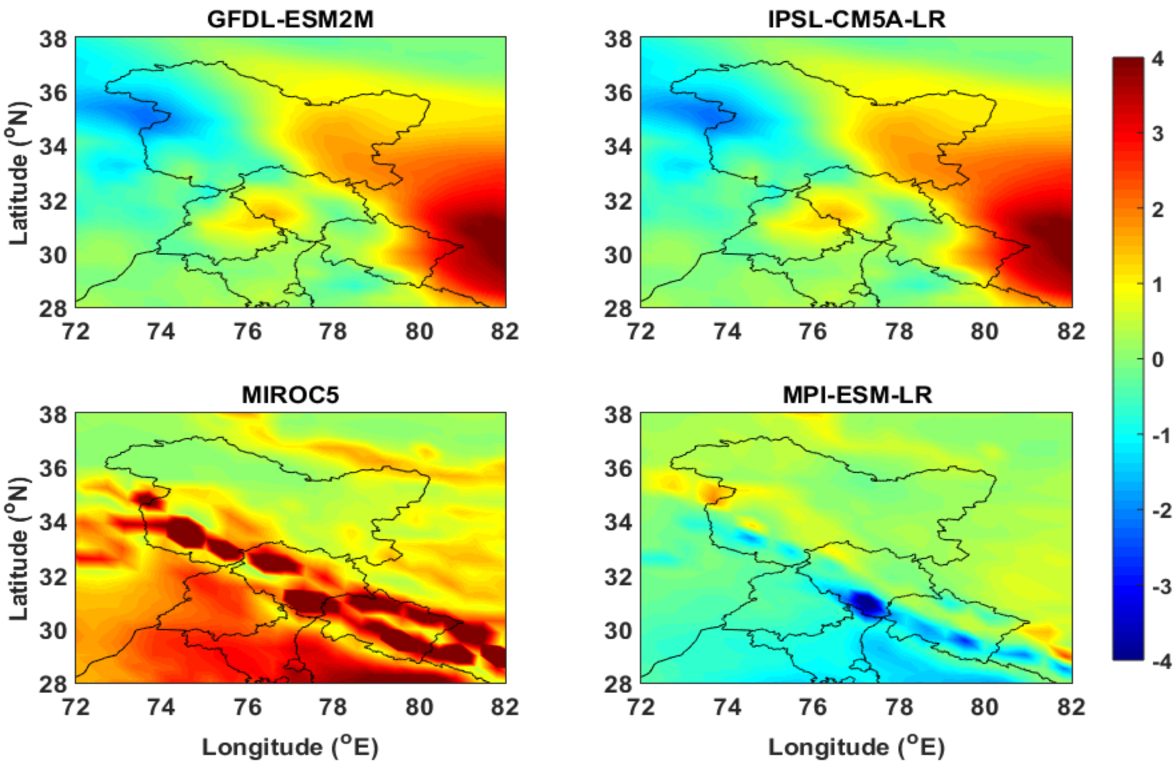

Figure 8: Differences in JJAS mean precipitation obtained under warming Scenario RCP 8.5 (2076-2100) and historical period (1976-2000) over NWH region using different CORDEX-SA experiments.

IMD gridded rainfall, the CORDEX results fail to capture the daily rainfall intensity properly. There is an average increasing pattern of rainfall over the NWH region similar to the research documented by Lee & Wang (2014) and Choudhary & Dimri (2017). However, an overall increase in the amount of rainfall over the NWH region is noted from the present study. Finally, it can be concluded that under the global warming scenarios, the wet region will become wetter and drier region will become drier in future.

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