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FUTURE CLIMATE PROJECTIONS OF NORTHEAST MONSOON OVER SOUTH INDIA

*P Suneetha, P Latha, S Ramalingeswara Rao, K Nagalakshmi, D Melchi Zedek
and Bhanu Kumar, O S R U
Department of Meteorology and Oceanography, College of Science and Technology
Andhra University, Visakhapatanm-530 003 India

ABSTRACT

Northeast monsoon (NEM) season plays an important role in producing the rainfall over south India through intense heavy rainfall events, tropical cyclones and easterly waves. This study aims to understand climate change phenomenon for the past century (20th century) over south India during northeast monsoon season in terms of rainfall and temperature projected for 21st century using IPCC AR4 model outputs. Historical study of surface-air-temperature and rainfall were made using 22 IPCC AOGCMs. Of them GFDL_CM2.0, GFDL_CM2.1, CNRM, CGCM-T63 and MPI model projections show the signature of the rainfall and temperature reasonably good by validating with available datasets CMAP and CRU respectively. The future climate projection scenarios are based on SRES A1B scenarios over south Indian region in three time-slices viz. short (2020s), medium (2050s) and long (2080s) periods. The rainfall exhibits increasing trend in 2020s (4 mm/day) and 2080s (7mm/day) when compared with the 2050s (2mm/day). It is striking to note that the spatial distribution of NEM rainfall is shifting towards the western part of south India in 2020s and 2080s. Next, the temperature projections also represent 3.5°C rise in temperature over south India in 2080s when compared with the baseline period. Thus, the IPCC AR4 model SRES A1B scenarios representing the rise in temperature and rainfall during NEM season over south India for 21st century.

Keywords: IPCC, SRES, projections, baseline period, South India.

INTRODUCTION

The Northeast monsoon season from October through December is the period of major rainfall activity over south peninsular India, particularly over Coastal Andhra Pradesh, Rayalaseema, Tamil Nadu, Coastal Karnataka, South Interior Karnataka, North Interior Karnataka and Kerala (Fig. 1). This season is also known as the winter monsoon and post-monsoon season (Singh and Sontakke, 1999; Nageswara Rao, 1999). During southwest monsoon, there is not much rain over this region due to rain shadow region of the Western Ghats along the west coast of India. When the southwest monsoon retreats, pressure and wind distribution reverses at the beginning of October, a trough of low pressure becomes established in the south Bay of Bengal and this is treated as onset of NEM season. The passage of easterly low pressure waves occasionally intensifies this trough. Depressions and cyclonic storms form in the trough of low pressure over the south Bay of Bengal. Due to this type of situations, equatorial maritime air moves towards South India, and causes widespread rainfall (Kripalani and Kumar, 2004). The rainfall during this period is of immense societal significance to 150 million people as it supports the main cultivation season known as Maha in Sri Lanka and Rabi in southern India (Zubair, 2002).

For predicting southwest monsoon rainfall over India, many statistical/empirical forecasting models (Thapliyal, 1981; Gowariker *et al*., 1991; Sahai *et al*., 2003; Rajeevan *et al*., 2006) have been developed and used. But there are no such studies about the prediction of NEM season. Even though interannual variation and prediction of the southwest monsoon has been widely studied, the NEM season over south peninsular India has received much less attention, with a limited number of studies (Doraiswamy, 1946; Rao and Jagannathan, 1953; Rao, 1963; Ramaswamy, 1972; Srinivasan and Ramamurthy, 1973; Dhar and Rakecha, 1983; Krishnan 1984; Raj and Jamadar, 1990; Sridharan and Muthusamy, 1990; Singh and Sontakke, 1999; Kripalani *et al*., 2004; Zubair and Ropelewski, 2006; Kumar *et al*., 2007; Nayagam *et al*., 2009). Some of the studies have discussed about global teleconnection patterns related to NEM over South India. Studies have shown that the rainfall over the southern part of India, during the NEM season increases with El Ni˜no events (Dhar and Rakecha, 1983; Singh and Sontakke, 1999).

*Corresponding author e-mail: sunitha.pmet@gmail.com

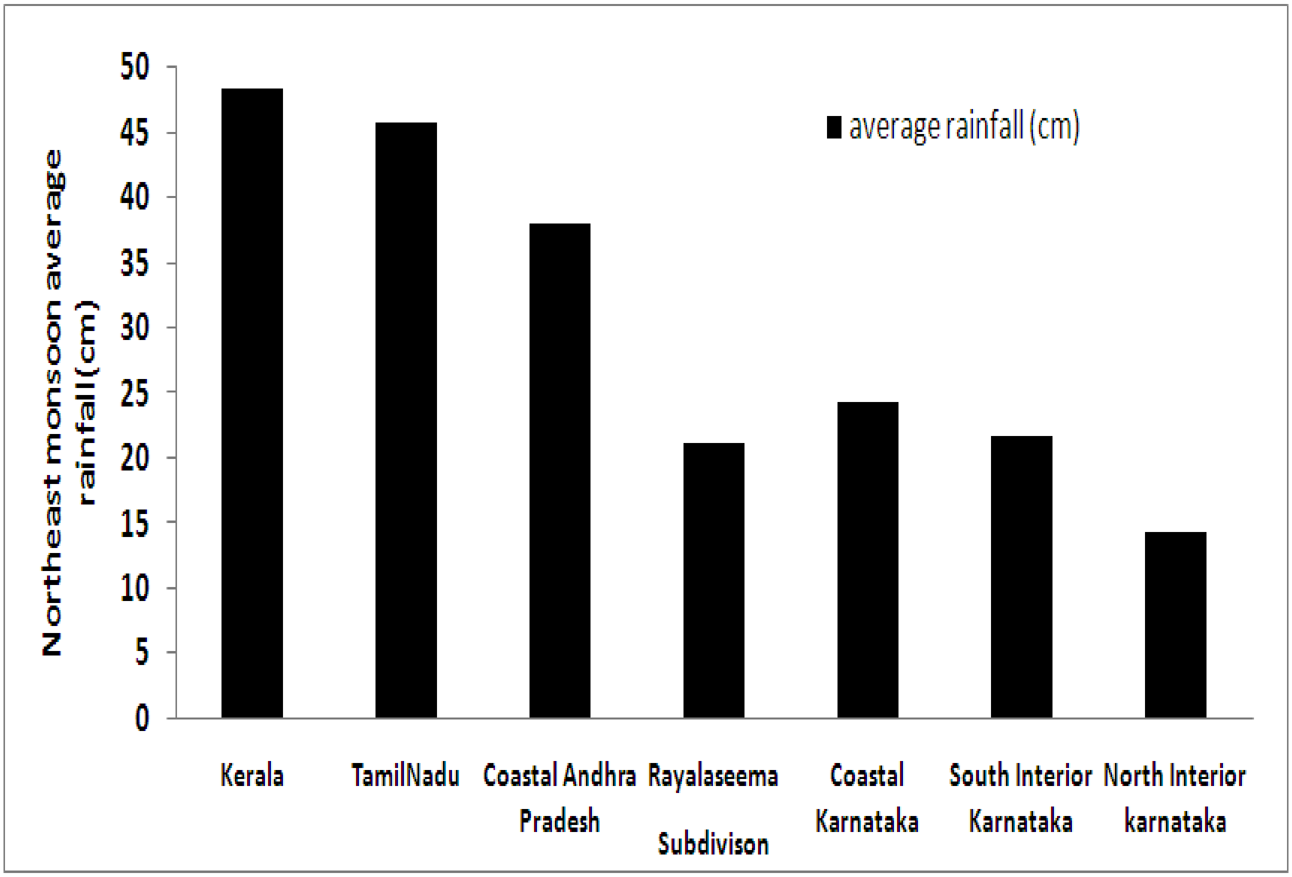


Fig. 1. Average area-weighted rainfall (cm) distribution over different subdivisions of south India during Northeast Monsoon Season from 1871-2014.

Similarly Kripalani and Kumar (2004) found a direct relationship between Indian Ocean Dipole (IOD) and NEM rainfall, suggesting that the positive (negative) phase enhances (suppresses) the northeast monsoon activity. Zubair and Ropelewski (2006) have explained the relationship between El-Niño Southern Oscillation (ENSO) and NEM over South India and Sri Lanka and concluded that if South India is considered as a single entity, there has been a remarkable rise in the correlation of the NEM rainfall and ENSO. Balachandran *et al*. (2006) defined a zonal temperature anomaly gradient index between eastern equatorial Pacific and western equatorial Pacific and found a stable significant inverse relationship with NEM rainfall. Subsequently the spatial and temporal variability of rainfall over South India during the NEM season has been discussed by Nayagam *et al*. (2009). This regional rise may be attributed to a slight enhancement of the low-level circulation in recent decades during the northeast monsoon that leads to relative increase in the orographic component of rainfall. The intensification of the circulation is consistent with the warming of surface temperatures over the tropical Indian Ocean in recent decades. Kumar *et al*. (2007) reveals that the NEM season contributes to about 50% of annual rainfall in the east coast of India.

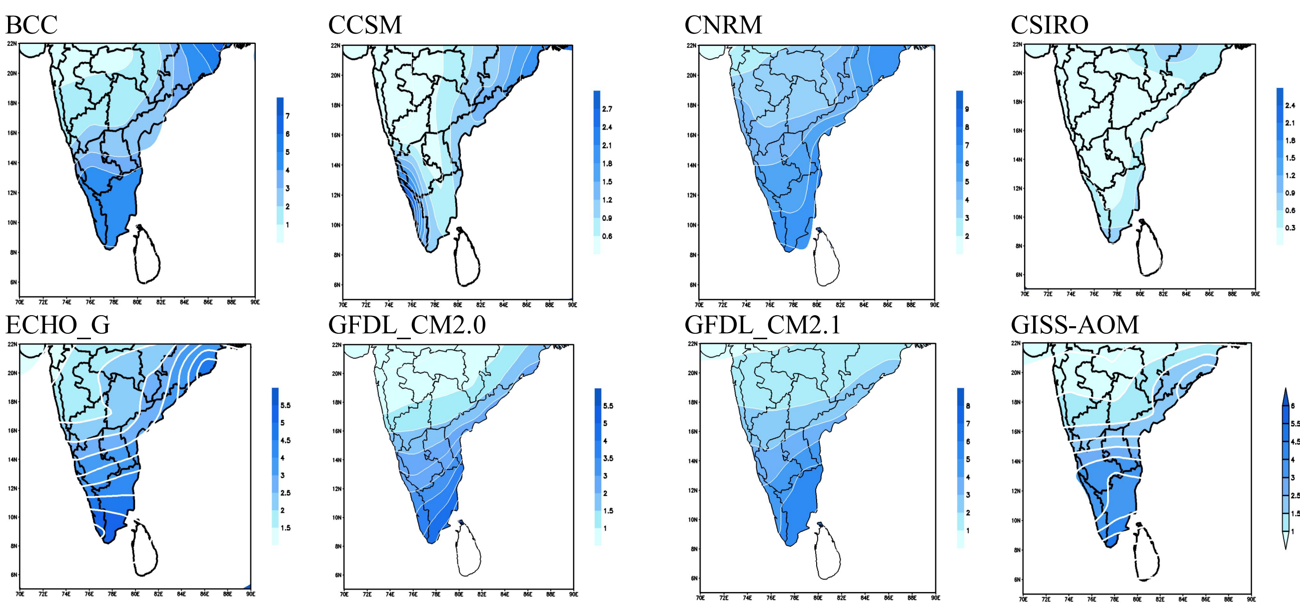
Global warming in the recent decades refers to a rise in land and ocean temperatures that leads to changes in circulation, rainfall and pressure patterns (Suneetha, 2012). The abnormal warming of the equatorial waters of the central and eastern Pacific has often been associated with failure of the southwest monsoon (Bhalme and Mooley, 1980; Bhalme *et al*., 1986; Bhanu Kumar and Ramalingeswara Rao, 2009; Bhanu Kumar *et al*., 2011). However, the same phenomenon appears to have just the opposite effect on the NEM, leading to more bountiful rain (Jayanthi and Govindhachari, 1999; Bhanu Kumar *et al*., 2004, 2007). Next, Bhanu Kumar and Suryanarayana (2016) studied the detailed NEM activity using PRECIS model output. Recently Suneetha *et al*. (2017) studied the impact of western Pacific high and Siberian high on NEM rainfall over South India and concluded that intensity of spatial variation of those regions has profound impact on NEM rainfall over South India. With the above said information, an attempt is made in the present study for future projections of NEM season over South India with IPCC AR4 model outputs.

MATERIALS AND METHODS
DATA MATERIALS AND METHODOLOGY

The WCRP/CLIVAR Working Group on Coupled Models (WGCM) organized an international project to run a co-ordinate set of 20th and 21st century climate simulations, as well as several climate change commitment experiments, for assessment in the IPCC AR4 (Meehl *et al*., 2007). The IPCC climate model data were collected, archived and made available to the international climate science community by the Program for Climate Model Diagnosis and Inter-comparison (PCMDI) at the Lawrence Livermore National Laboratory, USA. 25 atmosphere-ocean general circulation modeling (AOGCMs) groups have participated in IPCC AR4 coordinated experiments. There is a fairly large range in the horizontal resolution of the models varying from 1.125^0 long / lat to 5^0 long by 4^0 lat. In this paper, author analyzed the data of monthly precipitation flux and surface-air-temperature available for the 22 models under the 20th century climate simulations (20c3m) scenario. Future projections of precipitation flux and surface-air-temperature over south India are downloaded in three twenty-first century climate change simulations SRES A1B from 2000 to 2100. The projected changes in precipitation are examined in three time slices; 2020s, 2050s and 2080s. The total precipitation consists of convection and large-scale or stratiform precipitation. Climate Prediction Center Merged Analysis Precipitation (CMAP; Xie and Arkin 1997). The CMAP precipitation analysis (obtained from the website ftp://ftpprd.ncep.noaa.gov), which has a resolution of 2.5^0 lat by 2.5^0 long, was formed by combining rain gauge measurements with several types of satellite data.

RESULTS AND DISCUSSION
Historical rainfall and temperature from IPCC AR4 model outputs

The simulation of the NEM rainfall patterns over study region is extremely a difficult task due to its spatial distribution and large precipitation gradients. This may pose difficulties in replicating the exact pattern with the correct amplitude. Since the model resolutions vary substantially the areas of maximum/minimum precipitation and their amplitudes may show some shifts in these areas. The NEM rainfall over south India is associated with Intertropical Convergence Zone in southward direction with more moisture, convergence over Indian Ocean. During this season November month is the peak month to receive highest amount of rainfall over south India due to tropical cyclogenesis by ITCZ and easterly waves. The Indian Ocean contributing more amount of moisture through tropical cyclones and induced intense heavy rainfall events especially over Tamil Nadu, Coastal Andhra Pradesh. Figure 2 reveals IPCC AR4 coupled model simulations of NEM rainfall for the 20th century over south India. These model results are compared with the available satellite, in-situ measurements of CMAP and IMD. The observed rainfall varies from 2-9 mm/day over south India with a peak intensity of 5 mm/day at Tamil Nadu region. The IPCC AR4 simulations show a realistic pattern of rainfall with varying intensities from one model to another. Out of 22 models only eight models (GFDL_CM2.0, GFDL_CM2.1, UKMO-HadCM3, BCC, CNRM, MPI, CGCM-T47 and CGCM-T63) are able to produce the NEM rainfall. Of them, some of the models like CCSM, CSIRO, PCM, IPSL and GISS-ER are underestimate the rainfall, while models like GISS-EH, UKMO-HadGem1, IAP and INMCM3 overestimated over south India.



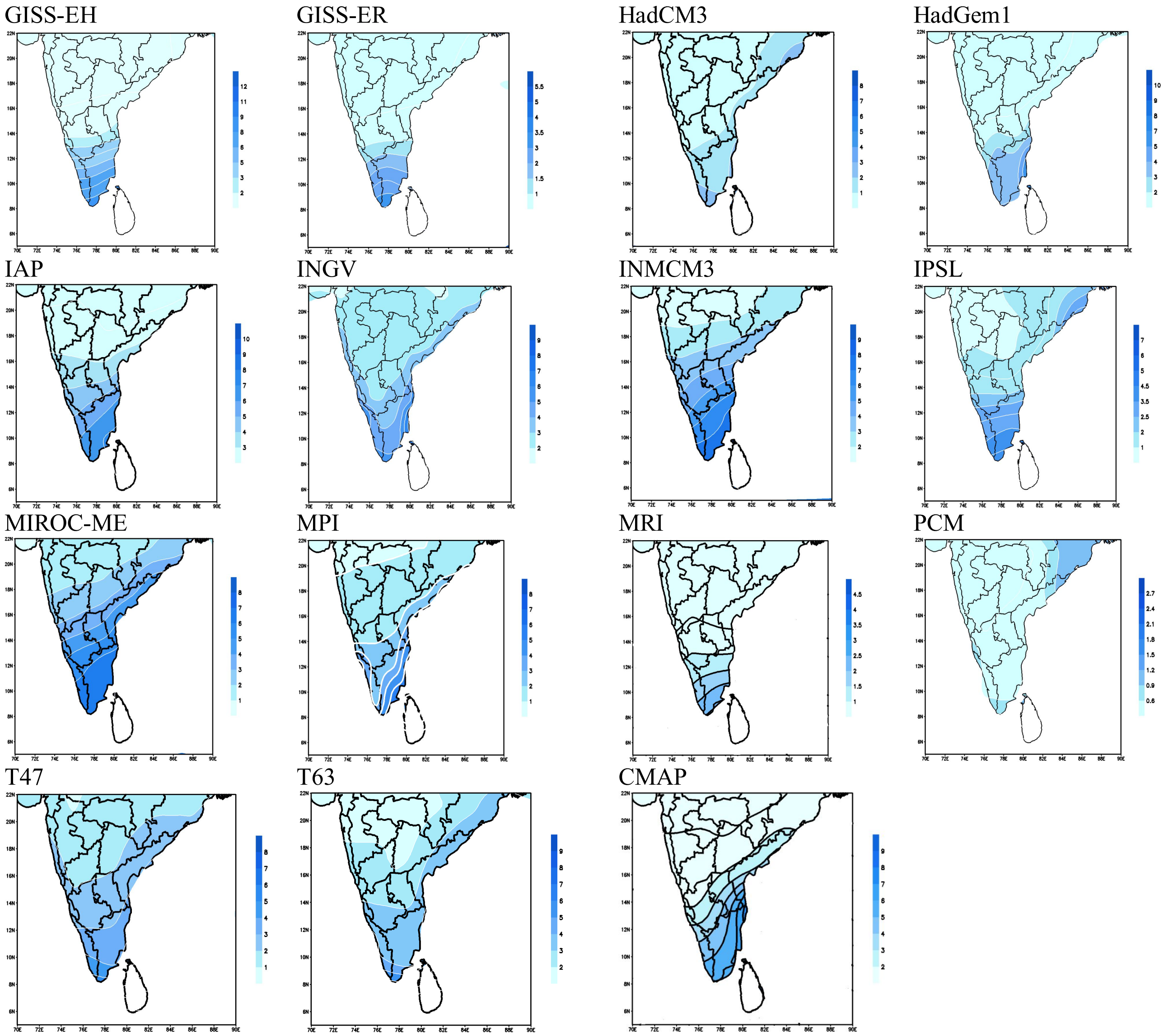


Fig. 2. Average northeast monsoon rainfall (mm/day) over south India for the 20th Century using IPCC AR4 coupled models along with observed data.

Most general circulation models are unable to reproduce the seasonal migration of the ITCZ precipitation (Hack *et al*., 1998; Gates *et al*., 1999; Wu *et al*., 2003). Using 20-year GCM simulations with observed SSTs, Wu *et al.* (2003) identified that the secondary meridional circulation induced by convective momentum transport is the missing dynamical mechanism that causes the common failure in GCMs in simulating the seasonal migration of ITCZ precipitation across the equator. Lin (2007) addressed the issue of double-ITCZ problem in the 20th century simulation of the IPCC AR4 coupled models.

The historical run of 20th Century surface-air-temperature from the 22 AOGCMs represented its variability during NEM season in Figure 3. From the figure it is clearly evident that the inland regions like South Interior Karnataka, North Interior Karnataka, Rayalaseema is under the influence of less temperature (20.5°-23.5°C). Whereas the coastal regions of south India, Coastal Andhra Pradesh, Tamil Nadu, Kerala and Coastal Karnataka are under the influence of higher temperature (24°-26.5°C). The temperature gradients in between the inland and coastal regions are of 6°C. Out of 23 models, only 8 models represents the base period very well; they are BCC, GFDL_CM2.0, GFDL_CM2.1,CGCM_T63, MPI, ECHO_G and CNRM. The above models show the magnitude also very well over south India.

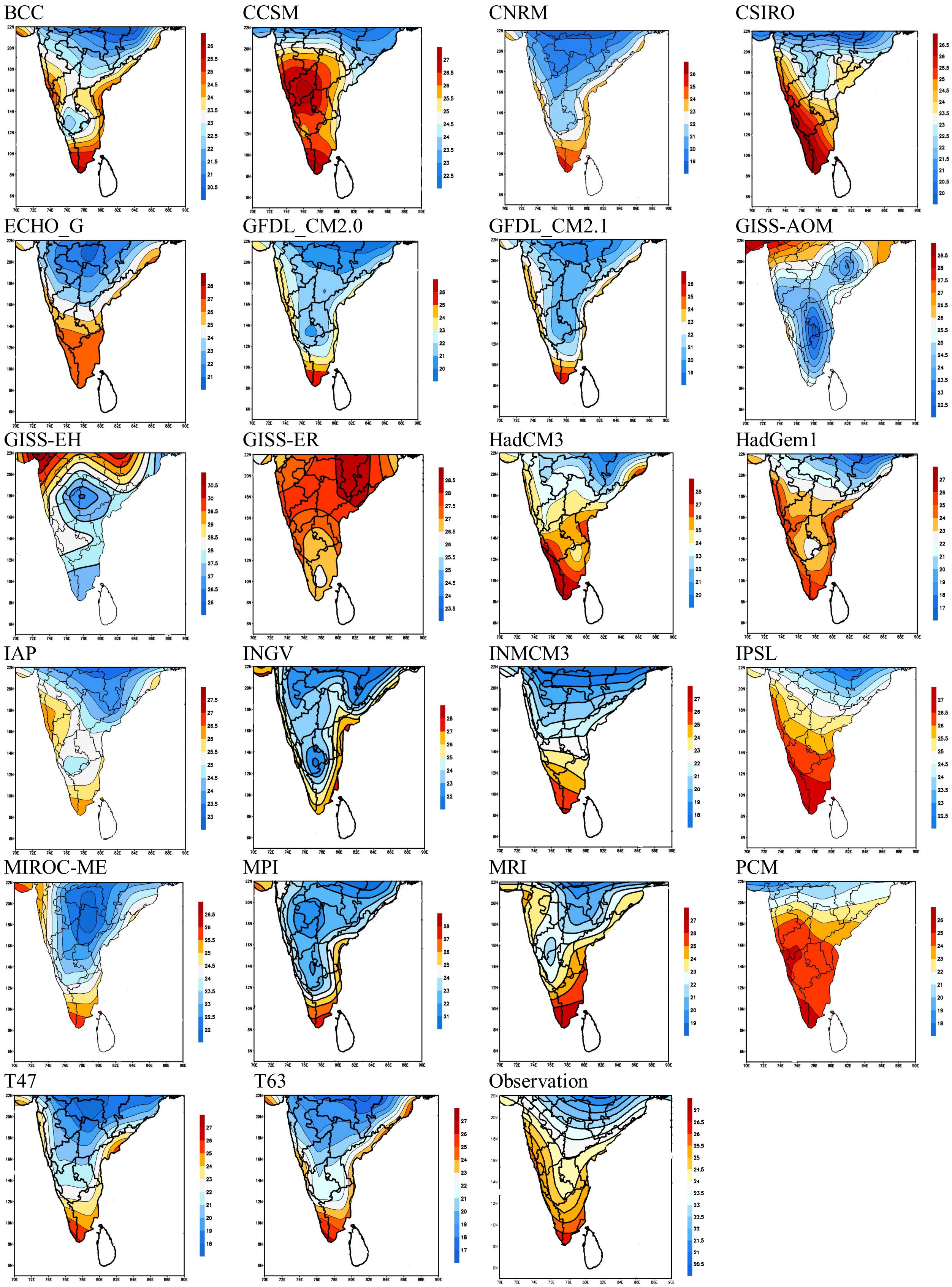
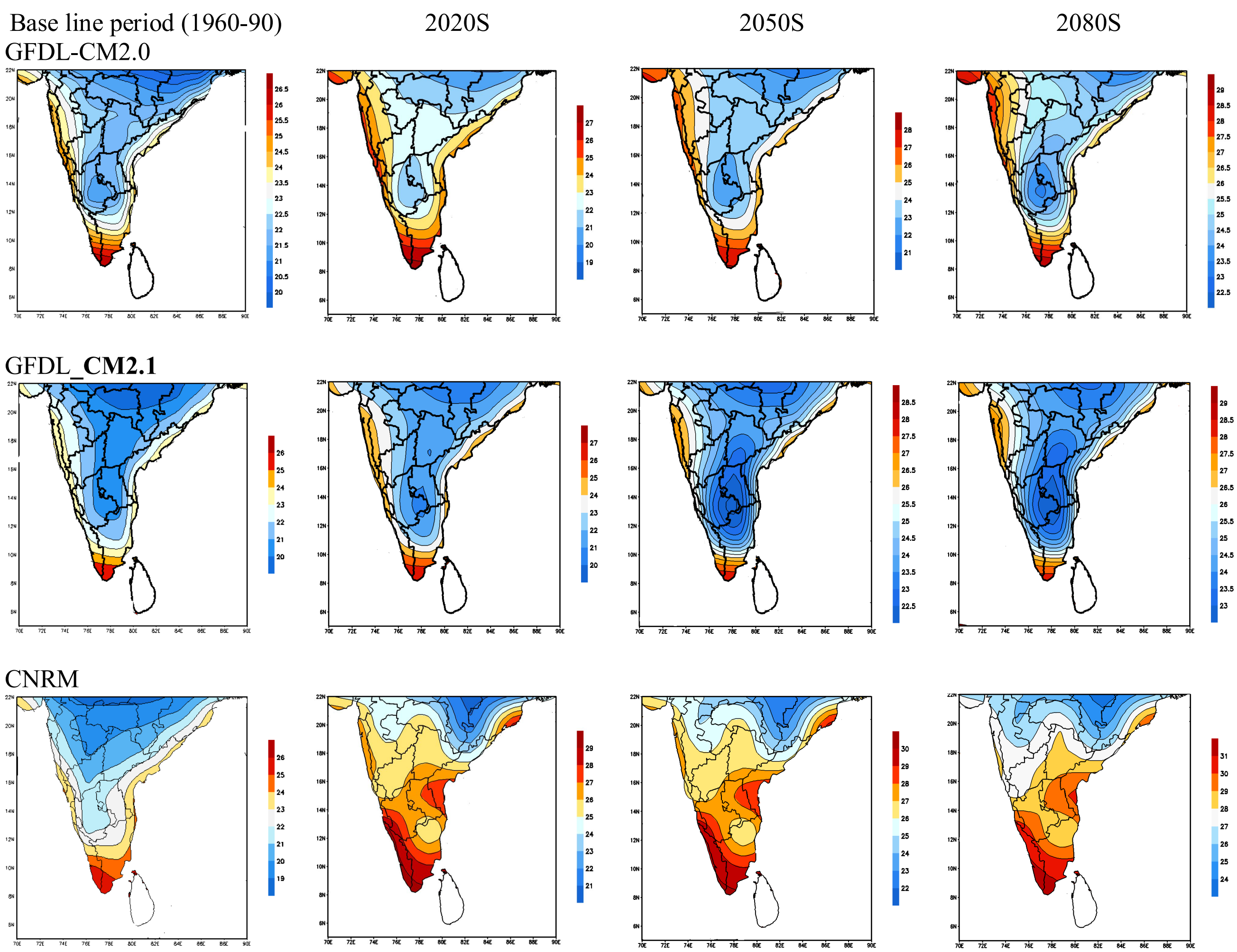


Fig. 3. Same as above figure 2, but for surface-air temperatures (^oC).

Projected temperature and rainfall under IPCC AR4 SRES A1B Scenarios

Projected temperature scenarios over south India

From the previous analysis, five best models (MPI-ECHAM5, CNRM-CM3, GFDL and MRI) are considered on the basis of availability of data to understand annual temperature and Indian southwest monsoon rainfall under SRES A1B future scenarios 2031-2050 and 2081-2100 with relative to industrial period (1981-2000). NCEP/NCAR reanalysis surface temperature and CMAP rainfall data are utilized to compare the industrial base line period (1981-2000). Figure 4a shows the CMIP3 best models annual temperature (°C) projected for 2031-2050, and 2081-2100 relative to the industrial baseline (1981-2000). All India annual mean temperature increases by 1.7°C–2.02°C under 2031-2050 scenarios and by about 2°C–4.3°C by 2080s, relative to the pre-industrial period from the observations. The three models (CNRM, MPI and MRI) shows that annual temperature varies in between -15°C to 30°C in 1981-2000, while there is an increment of temperature in 2081-2100 (-10°C to -30°C) period. Among the five models, MPI is showing high amplitude of temperatures in 2081-2100 when compare with the industrial period (Table 1). The following figures clearly depicts the lowest temperatures at Tibetan Plateau (-15°C to -10°C) and highest temperatures over Indian land mass and partly over Indian Ocean. In future there is a consistent warming over Indian land mass especially in northern part of India compared to south India. Later the study is extended for the intercomparison of CMIP5 and CMIP3 best models to understand the quantitative variation of past, present and future scenarios in terms of surface air temperature and southwest monsoon rainfall.



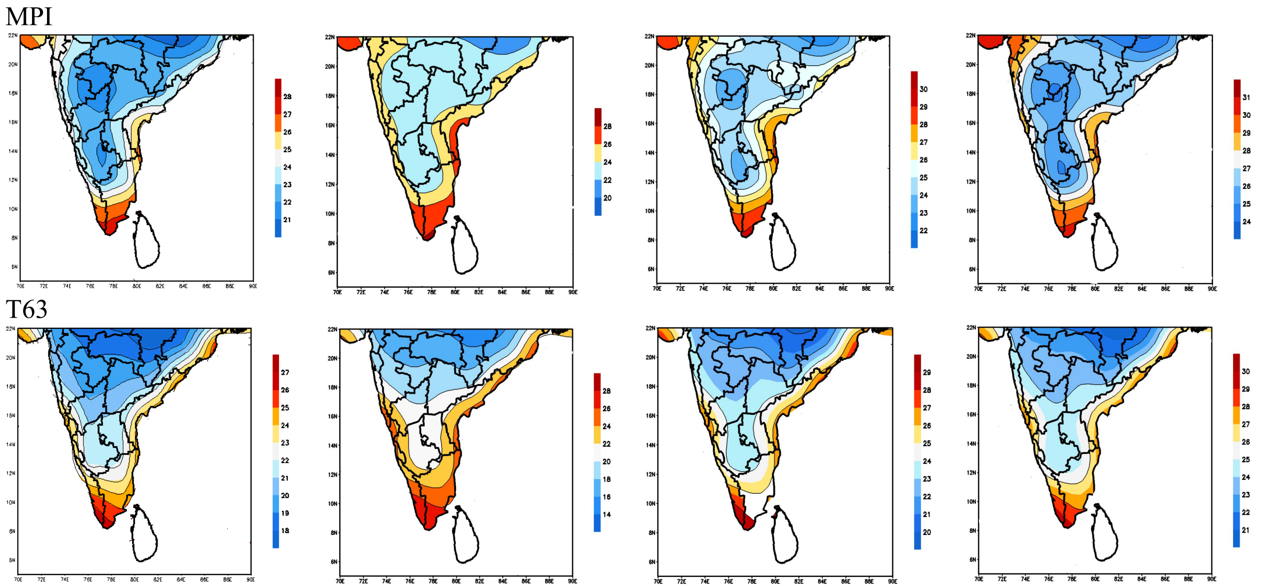


Fig. 4a. Projected surface-air-temperature (°C) for 2020s, 2050s and 2080s from the best IPCC AR4 models.

Table 1. NEM surface-air-temperature (°C) variation during 2020s, 2050s and 2080s over south India from the best subset of models.

Model Name	2020s	2050s	2080s
GFDL_CM2.0	21-27	21-28	22.5-29
GFDL_CM2.1	20-27	22.5-28.5	23-29
CNRM	24-29	25-30	27-31
MPI	23-28	22-30	24-31
CGCM-T63	18-28	21-29	22-30

Future projection scenarios of NEM rainfall over south India

From the above discussion, it is interesting to note that surface temperature of both land and ocean are significantly increasing and creates very low temperature gradient. This temperature gradient plays an important role for getting monsoon over Indian subcontinent. In this connection, it is very essential to examine the seasonal monsoon rainfall variation under different time slices. By basing on warming climate 1981-2000, the Indian southwest monsoon rainfall is in between 2 to 16 mm/day from the CMAP observations. Figure 4b represent the IPCC AR4 best simulated southwest monsoon rainfall for two time slices 2031-2050 and 2081-2100 and compared with industrial period 1981-2000. The southwest monsoon rainfall varies in between 2-20 mm/day in three models (Table 2). CNRM and MPI models represent that the amount of rainfall is decreased in 2031-2050 compared to 1981-2000 and 2081-2100, while GISS AOM showing there is no significant variation in all three time slices. The rainfall increases substantially over certain regions and the significance of the difference has been identified. Under SRES A1B scenario, area with significant increase expands and at the end of the 21st century the rainfall shows significant increase over entire Indian land region and decrease in northwest part of India.

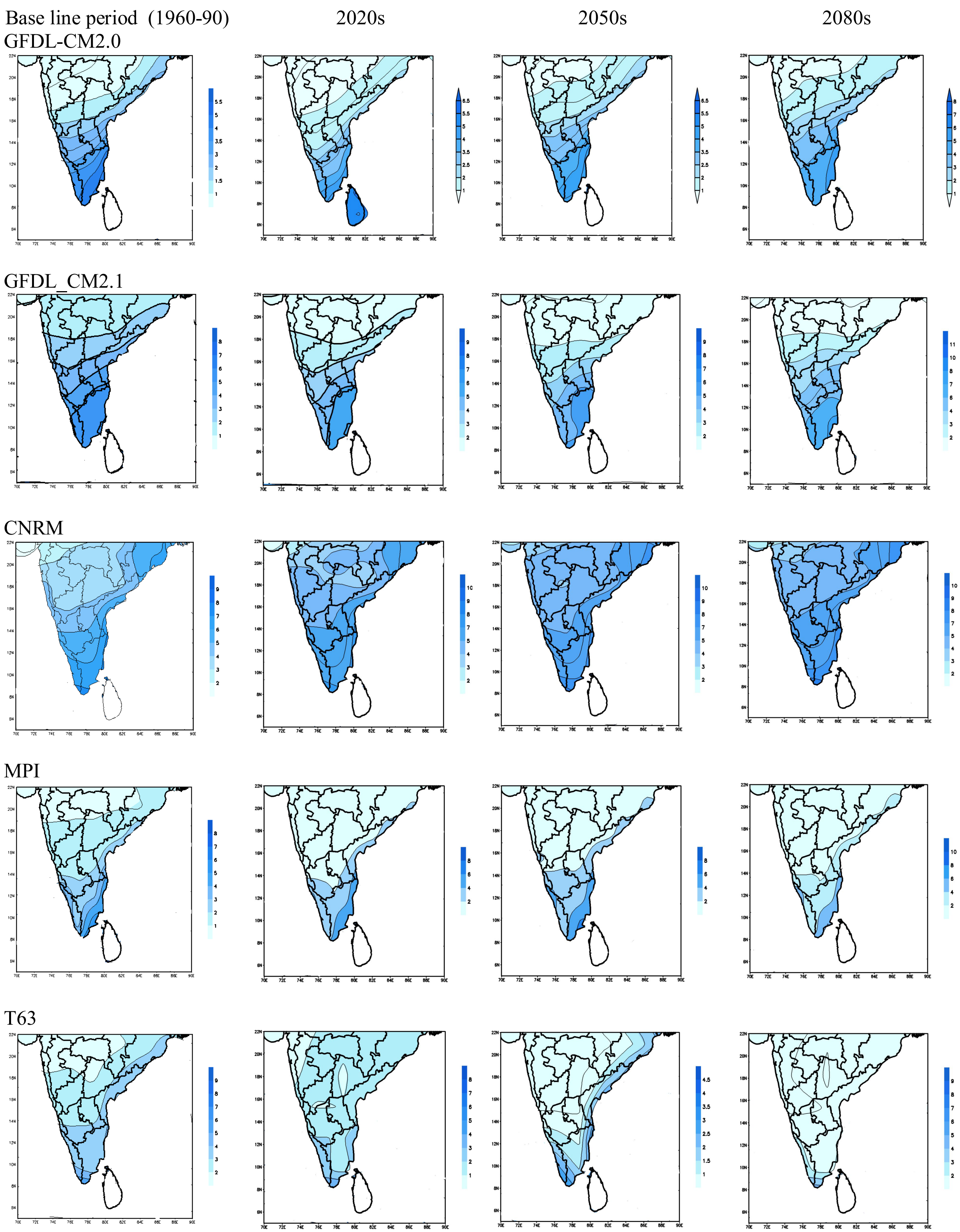


Fig. 4b. Same as above figure 4a but for NEM rainfall.

Table 2. NEM rainfall (mm) variation during 2020s, 2050s and 2080s over south India from the best subset of models.

Model Name	2020s	2050s	2080s
GFDL_CM2.0	1-6.5	2-5.5	2-7
GFDL_CM2.1	4-6	4-6	2-11
CNRM	7-8	5-9	7-10
MPI	2-6	2-6	2-8
CGCM-T63	2-4	1-4.5	2

To examine the nature of annual cycle in warming climate, the monthly average rainfall over south Asian domain under the three scenarios is examined. The monthly average of multi model ensemble (MME) constructed for 20th century (1981-2000) and the three climate change experiments (2081-2100). The annual cycle does not change much in the middle of the century i.e. from 2031-2050 (figure not shown). It is observed that the overall shape of annual cycle and the seasonal march would not change in future scenarios implying that the monsoon season (June through September) will remain the same with peak rainfall in July and August. Under scenario A1B the increase is 0.5 mm/day only, while under B1 scenario it is approximately 1mm/day and A2 scenarios show the maximum increase of about 1.5 mm/day. The MME projects a decrease of rainfall during winter and early spring (January through May) and increase in summer (June through August) and the following autumn (September through November), possibly indicating the extension /lengthening of summer monsoon rainfall period.

CONCLUSION

Based on the recommendations of the Intergovernmental Panel on Climate Change (IPCC) the authors of the present study have analyzed a comprehensive, systematic and well designed and well coordinated two sets of 20th and 21st century climate change experiment model outputs. The 20th century simulated NEM precipitation over the south Indian domain (5^{o}– 22^{o}N, 70^{o}–90^{o} E) for all available models and runs are analyzed with respect to the baseline period with spatial characteristics. These simulated features are compared with observed and they are in very good agreement. Based on the performance of the models in simulating the 20th century precipitation variability over south India, 5 models were selected to examine future precipitation projections under three climate change experiments. In the present study it is found that five of the twenty two climate models simulate the maximum precipitation during NEM period, but with some deviations in the magnitude. Next five models (CGCM-T63, CNRM, MPI-ECHAM5, GFDL_CM2.0 and GFDL_CM2.1) simulate NEM variability reasonably well. The five models are examined for projections of NEM rainfall under SRES A1B three time slices in the 21st century, 2020s, 2050s and 2080s. It is observed that the seasonal precipitation over South Indian domain is projected to increase in 21st century and the surface-air-temperature during NEM season is also revealed from the models and there is an increasing trend over south India and its rise is of 3.4°C for 21st century.

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