International Journal of Applied Research 2016; 2(3): 399-405

ISSN Print: 2394-7500
ISSN Online: 2394-5869
Impact Factor: 5.2
IJAR 2016; 2(3): 399-405
www.allresearchjournal.com
Received: 15-01-2016
Accepted: 16-02-2016

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Projections of rainfall and surface temperature over Nabarangpur district using multiple CMIP5 models in RCP 4.5 and 8.5 scenarios

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Abstract
In India, district level climate change information is still a challenging task for the meteorologist. Thus an attempt has been made to project the temporal variations of rainfall and surface temperature over Nabarangpur district using fifth phase of the Climate Model Inter-comparison Project (CMIP5) models under Representative Concentration Pathways (RCP) 4.5 and 8.5 emission scenarios for the twenty first century. For this purpose, six CMIP5 models have been chosen. The study period has been considered from 1901 to 2100. From this period, initial 105 years i.e. 1901 to 2005 is historical period and 2006 to 2100 is future period. The climatological annual mean rainfall and surface temperature has been obtained from the CRU observations over the period 1901 to 2012. The rate of increase or decrease in rainfall and temperature are relatively more in RCP8.5 than RCP4.5 over the district. The rainfall in the summer monsoon months may increase in future periods and it might be even higher in the RCP8.5 scenarios towards the end of the 21st century. The surface temperature in all the months might get increases in both the scenarios but it will be higher in the RCP8.5 than that in the RCP4.5. Thus our model projections indicate that the coming years may be hotter and wetter than the present years.

Keywords: CMIP5, Climate Change, Representative Concentration Pathways, Climate Projections, Rainfall, Surface Temperature, Nabarangpur District.

1. Introduction
India is a land of diverse topographies and climates. In order to plan for suitable adaptation policies for the future, it is very essential to estimate the magnitudes of climate changes and their uncertainties in the regional scale. Most of the studies have been carried out at broader scale to say country scale or up to the state scale. District level climate change information is still a challenging task for the meteorologist in the country. In this study, one of the districts in Odisha state has been chosen for studying the climate change information. Nabarangpur District is one among 30 districts of Odisha State, India having population of about 1.2 millions have been chosen for this study. The tribal population mostly inhabits the district and so 80 % of the population depends on Agriculture. Thus the economical progress of this region is mostly dependent on the behavior and changes in summer monsoon rainfall. The variability of the monsoon rainfall from year to year results in extreme hydrological events like droughts and floods; as a consequence it affects the economy.

Many researchers have examined the long-term trend of rainfall over Odisha (Rupa Kumar *et al*. 1992; Dash *et al*. 2007; Kumar *et al*. 2010; Jain and Kumar 2012; Pattnayak *et al*. 2013 and 2015) [14, 2, 19, 7, 11, 12]. Rupa Kumar *et al*. (1992) [14] found that the rainfall shows a decreasing trend over Orissa during 1871 to 1990. Dash *et al*. (2007) [2] also agrees with the Rupa Kumar *et al*. (1992) [14]. Further Dash *et al*. (2007) [2] showed that the extreme temperature events over Odisha have increased in the recent past. The stations in Odisha broke their 100 years record in maximum temperatures. Kumar *et al*. (2010) also showed that the annual rainfall has been decreasing at the order of -0.31 mm/year and -0.45 mm/year during monsoon season rainfall over Orissa. Orissa have experienced a decreasing trend of about 2% of mean per 100 years annual rainfall. Jain and Kumar (2012) [7] examined the annual rainfall over the river basin in the south Odisha. They found –1.231mm/day decrease in rainfall and rainy days –0.190 days/year over this basin during last 100 years. Pattnayak *et al*. (2013, 2015) [11, 12] showed that the regional climate model can simulates the Indian summer monsoon characteristics closely to the observations, especially over the central northeast India, which includes Odisha.

No climate change studies using climate models have been performed over the Nabarangpur district. This is the first attempt to project the temporal variations of precipitation and temperature over Nabarangpur district using CMIP5 models under the RCP 4.5 and 8.5 emission scenarios for the twenty first century. A brief discussion of the data and methodology used for this study are described in Section 2. Section 3 discusses the geographical information of Nabarangpur district. Observed climate of the district has been given in Section 4. Section 5 provides the rainfall and surface temperature projections in RCP 4.5 and 8.5 scenarios. The last Section 6 summarizes the conclusions.

2. Data and Methodology

For examining the climate (history and future) of Nabarangpur district, two sets of data have been used in this study. The first one is from Climatic Research Unit (CRU) observations for studying the historical and present day climate of the district and second one from CMIP5 model for examining the climate projections in the future in different emission scenarios. The Climatic Research Unit (CRU) observed gridded rainfall and temperature (TS3.21; Harris at al. 2014) with 0.5x0.5° grid horizontal resolution available only at land points have been downloaded from http://iridl.ldeo.columbia.edu/SOURCES/.UEA/.CRU/.TS3p 21/.monthly/index.html?Set-Language=en for the period 1901 to 2012. For the future projections, the model output from the Fifth Coupled Model Inter-comparison Project (CMIP5, Taylor *et al*. 2012) for Inter-governmental Panel on Climate Change (IPCC) Fifth Assessment Report (AR5) over the Nabarangpur district (figure 1) have been used for this study. Among all the available CMIP5 model simulations, six models have been chosen to analyze for historical and climate projection in RCP 4.5 and 8.5. These six models used have been listed in Table 1, together with their host institutions, and their abbreviations. The model simulations are available from 1860 up to 2100 but for this study 1901 to 2100 have been considered. This period of simulation has been divided in to two periods, historical or present day climate (1901 to 2005) and projected climate (2006 to 2100). The historical simulations has been forced by observed atmospheric composition changes (including Green House Gas (GHG), natural and anthropogenic aerosols and volcanic forcing), solar variations and time-evolving land cover in a bid to simulate the observed climate of the recent historical period. The projected climate simulations have been forced by radiative forcing of 4.5 and 8.5 W/m2 in RCP 4.5 and 8.5 respectively, and while GHGs, solar constant, ozone and aerosol are kept changing with time. An overview of all the RCPs has been given in Table 2. The rainfall and surface temperature data from CRU and the CMIP5 models have been averaged over region of Nabarangpur district i.e. 81**.**5 to 82.5 °E and 19.5 to 20**.**5 °N for the entire period of study.

Table 1: List of CMIP5 climate models and ensemble outputs used in this study, their resolution, and research groups responsible for their development

Models	Modelling Centre/Group	Resolution (Lat) -deg	Resolution (Lon) -deg
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory	2.00	2.50
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	2.00	2.50
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory	2.00	2.50
HadGEM2-AO	Met Office, Hadley Centre, UK	1.25	1.875
HadGEM2-CC	Met Office, Hadley Centre, UK	1.25	1.875
HadGEM2-ES	Met Office, Hadley Centre, UK	1.25	1.875

Table 2: Overview of Representative Concentration Pathways (RCPs)

RCP Scenarios	Description	CO_2 Equivalent	Publication
RCP8.5	Rising radiative forcing pathway leading to 8.5 W/m^2 in 2100.	1370 ppm	Riahi *et al*. 2007
RCP6.0	Stabilization without overshoot pathway to 6 W/m^2 at 2100	850 ppm	Fujino *et al*. 2006; Hijioka *et al*. 2008
RCP4.5	Stabilization without overshoot pathway to 4.5 W/m^2 2100	650 ppm	Clarke *et al*. 2007; Smith and Wigley 2006; Wise *et al*. 2009
RCP2.6	Peak in radiative forcing at about 3 W/m2 before 2100 and decline	490 ppm	van Vuuren *et al*., 2007

3. Geographical Information of Nabarangpur District

The Nabarangpur district is located at 81°52’ to 82°53’ E Longitude and 19°9’ to 20°5’ N Latitude and stretches over an area of approximately 5294 sq kms (figure 1). It shares its border with Bastar District to the west, Kalahandi District to the North and Koraput District to the South. Also shares its state boundary with Chhattisgarh State to the North. It’s in the 662 meters to 241 meters elevation range. This District belongs to Eastern India. It is 17^{th} largest district in the state by population. The entire district falls under Eastern Ghat High Lands. According to Koppen's classification (Oliver and Wilson, 1987) [8], the climate experienced over this district is sub-tropical to temperate and is characterized by hot and dry summer, cool and humid monsoon and dry winter. The district experiences the first arrival of monsoon about ten days before the rest of Odisha. Unlike the rest of the state, where the monsoon arrives from the Bay of Bengal, it receives the monsoon from the southwest, off the Arabian Sea. It enjoys generous rainfall and droughts are extremely rare. The district gets most of its precipitation during boreal summer (June to September) while the winter (December to February) is mostly dry over this region. Due to massive deforestation in the district during last 30 years particularly the Raigarh, Umerkote and Jharigaon blocks, the microclimate is affected (Odisha District Gazetteers). The frequency and quantity of pre monsoon rainfall in the district has been coming down since last decade. Periodic dry spell are observed in the district. In drought years block like Chandahandi, Dabugam, Jharigam, Raigarh and Tentulikhunti are most affected as limited irrigation scope exist in these blocks. The contingency plan for the entire district is developed to mitigate the drought, flood and other emergency situation in the district. During the hot summer, the maximum temperature reaches up to 42 °C and in cold winter the minimum temperature touches 12 °C.

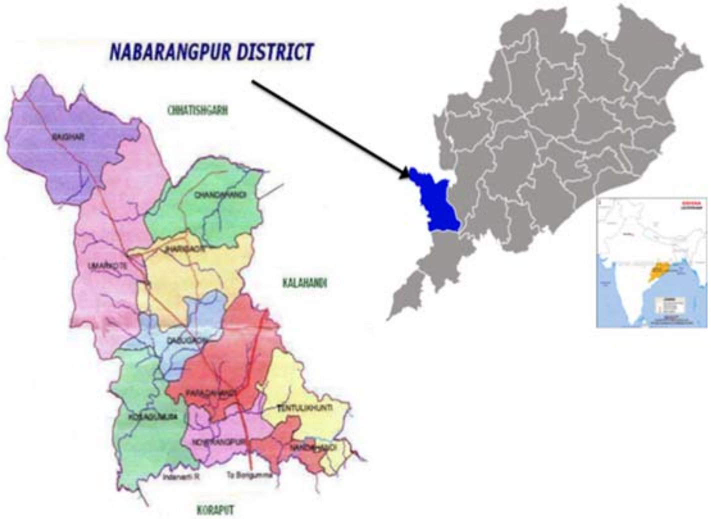

Fig 1: Map of Nabarangpur district, which is the area of interest over which the study has been carried out. The India map along with the Odisha state has been downloaded from http://www.mapsofindia.com/maps/orissa/orissalocation.htm. And the Odisha map along with its all districts (highlighting Nabarangpur district) has been downloaded from Wikipedia (https://en.wikipedia.org/wiki/Nabarangpur_district).

4. Observed Climate of Nabarangpur District

The climatology of rainfall and surface temperature over the Nabarangpur district has been studied using CRU observations. Figure 2 shows the inter-annual variations of area-weighted rainfall by CRU over the district in the period 1901 to 2012. From the figure it can be noticed that the annual mean precipitation values observed are showing slightly decreasing trend in the district. The annual rainfall in the region is received mainly from the southwest monsoon starting from second week of June to September end. Based on the observed values obtained from the CRU dataset, the mean annual rainfall for NEI over a period of 112 years (1971–2005) is 3.77mm/day (~1376mm). The annual mean rainfall has decreased slightly in last 50 years. The annual mean rainfall during 1901 to 1950 and 1950 to 2012 were 3.89 mm/day (~1419mm) and 3.67mm/day (~1340mm) respectively. The most deficit rainfall was in 1923 in which annual rainfall was about 2.51mm/day (~916mm), while the most excess annual rainfall was 5.59mm/day (~2040mm) in the year 1936. Figure 3 shows the time series of annual mean surface temperature over the Nabarangpur district from CRU during the period 1901 to 2012. Climatological annual mean temperature for the period 1901 to 2012 as observed by CRU over the district is 25.24 ºC. Figure 3 indicates that the observed annual mean surface air temperature from CRU over the Nabarangpur district little increasing trends. The surface temperature has increased at higher rate in the recent two decades than the others. The average temperature during 1901 to 1950 and 1951 to 2012 were 24.7 and 25.5 ºC respectively.1918 and 2009 were the coldest (24.3 ºC) and hottest (26.7 ºC) years during last 112 years period.

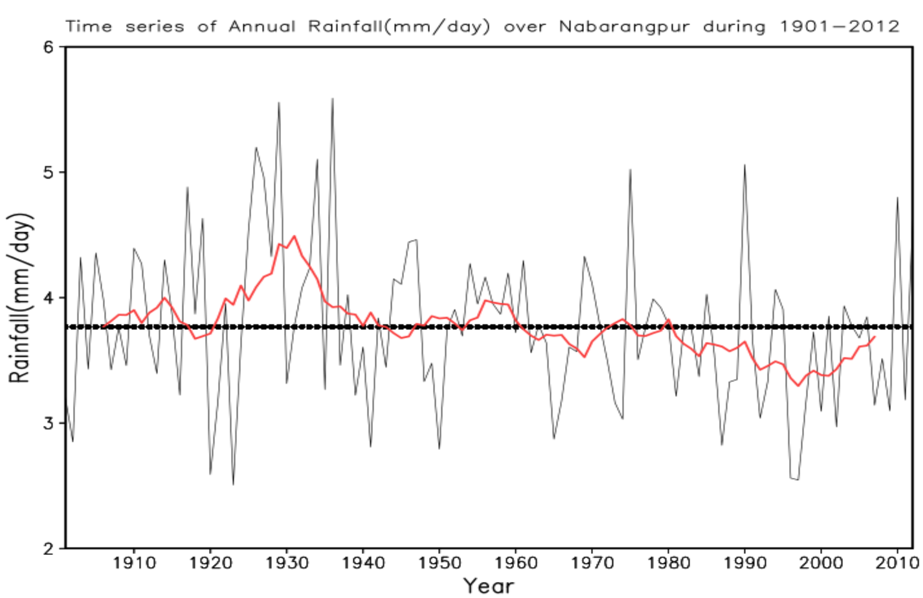

Fig 2: Time series of annual mean rainfall (mm/day) over Nabarangpur district from CRU during the period 1901 to 2012. Black and red curves represent the annual mean and 11 years running mean rainfall respectively. Climatology of annual mean rainfall has been represented as black dotted line.

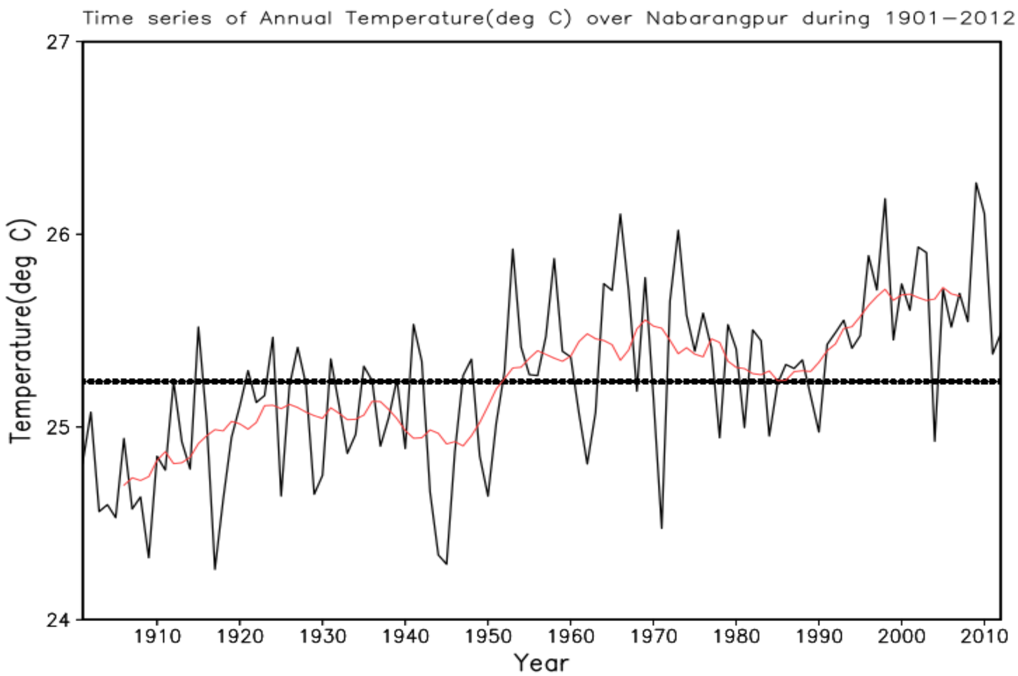

Fig 3: Same as figure 2 but for surface temperature (ºC).

5. Projection of Rainfall and Temperature in CMIP5 Models

This section deals with the projections of annual rainfall and temperature in ensemble mean of six CMIP5 models in RCP4.5 and 8.5 over the Nabarangpur district. Ensembles of up to 6 Global Climate Models (GCMs) were used to generate the future scenarios, by providing the range of ensemble member values per variable. Figure 4 depicts the time series of annual mean rainfall from the ensemble mean for the period 1901 to 2100 over the district. The model ensemble shows a slight increasing trend of annual rainfall over Nabarangpur in both the RCP scenarios. Up to the year 2050 both the RCP scenarios may behave similar but the rainfall might increase at higher rate in RCP8.5 than that in RCP4.5. The rate of increase in annual rainfall in RCP4.5 may be up to 0.55 mm/year with respect to 1901 while the rate in RCP8.5 may reach up to 0.91mm/year with respect to 1901. In RCP4.5 the rainfall might decrease for two decades from 2050 but it may start increasing from 2070 onwards. The time series of annual mean surface temperature from the ensemble mean over the Nabarangpur district has been shown in figure 5 for the period 1901 to 2100. From the figure 5 it clear that the surface temperature may increase in both the RCP scenarios at higher rate than in the historical period. Again in RCP8.5 the rate of increase of temperature is way higher than in the RCP4.5. The rate of increase in RCP8.5 might be similar to RCP4.5 up to 2050, but then it may increases more rapidly. The reason behind the slower rate beyond 2050 might be stabilization character of the radiative forcings in RCP4.5. The annual mean surface temperature may reach up to 28.5 ºC and 31 ºC in RCP4.5 and 8.5 respectively.

To investigate, how the annual cycle may behave in the future, the study period has been divided in to three 30 years time slice periods, one period from the historical period (1976 to 2005 aka reference period) and two from the future period. The future periods with a time slice of 30 years are 2020–2049 (near future) and 2071–2099 (far future). Figure 6 represents the annual cycles of rainfall from the ensemble mean in reference period, near future and far future in RCP4.5 and 8.5 scenarios. It can be noticed that the rainfall in the future (both near and far) may increase as compared to the reference period. The rainfall might not change in the other seasons except summer monsoon season (June to September) in any of the period or scenarios. But during the summer monsoon months in all the future period, the rainfall may increase with respect to the reference period. However, the increase of summer monsoon month's rainfall may be higher in far future than in the near future. The rainfall in the near future is same in both the scenarios. But it is more in RCP8.5 in the far future. The annual cycles of surface temperature from ensemble mean have been illustrated in figure 7. The surface temperature in all the months may increase in the future in both the scenarios. But it might be highest in RCP8.5 far future than those in the other periods. In RCP8.5 far future, the surface temperature of the district might get increased by 4 – 5 ºC in all the months as compared to the reference period. And in RCP4.5 far future, the increase of temperature might be up to 2 – 3 ºC. During the near future, the temperature might be similar in both the scenarios

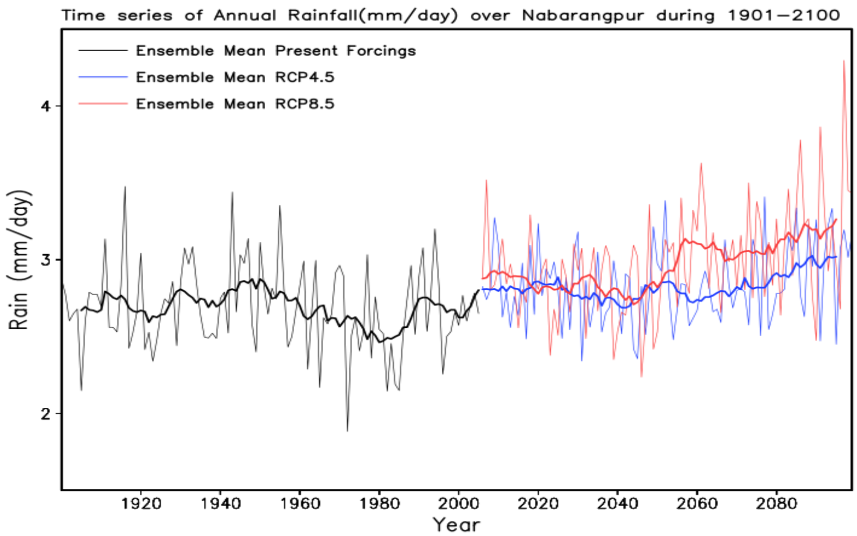

Fig 4: Time series of annual mean rainfall (mm/day) during the period 1901 to 2100. Black curve represents ensemble mean of six CMIP5 model simulated rainfall for the historical period (1901 to 2005). Blue and red curve represents the annual mean rainfall in RCP4.5 and RCP8.5 respectively. Thick curves (black, blue and red) represent the 11 years running mean of annual rainfall for corresponding periods.

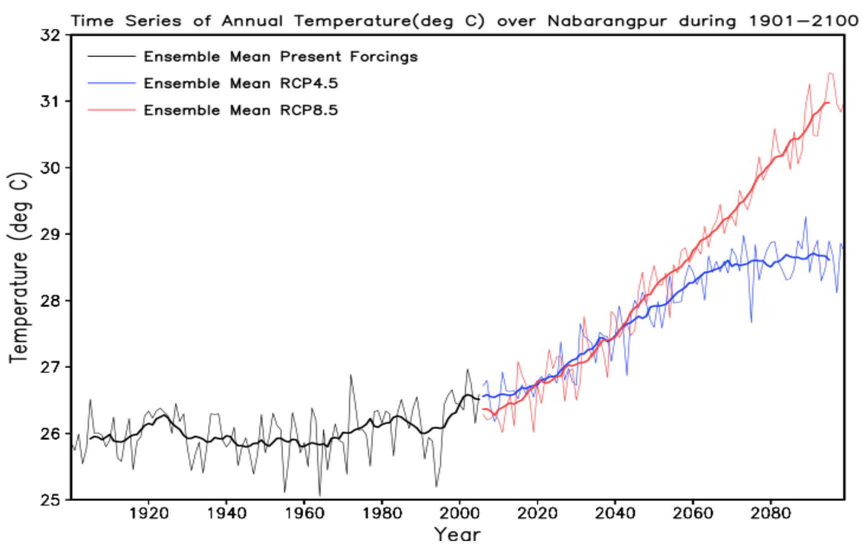

Fig 5: Same as figure 4 but for surface temperature (ºC).

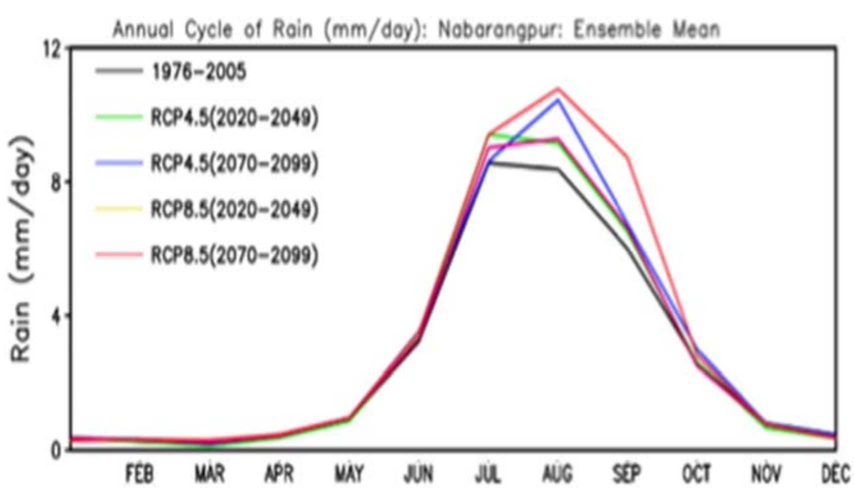

Fig 6: Annual cycle of rainfall (mm/day) from the ensemble mean for the reference period, near future and far future periods. Black curve represents reference period (1976 to 2005). Green and blue curves represent near future (2020 to 2049) and far future (2070 to 2099) periods in RCP4.5 respectively. Yellow and red curves represent near future (2020 to 2049) and far future (2070 to 2099) periods in RCP8.5 respectively.

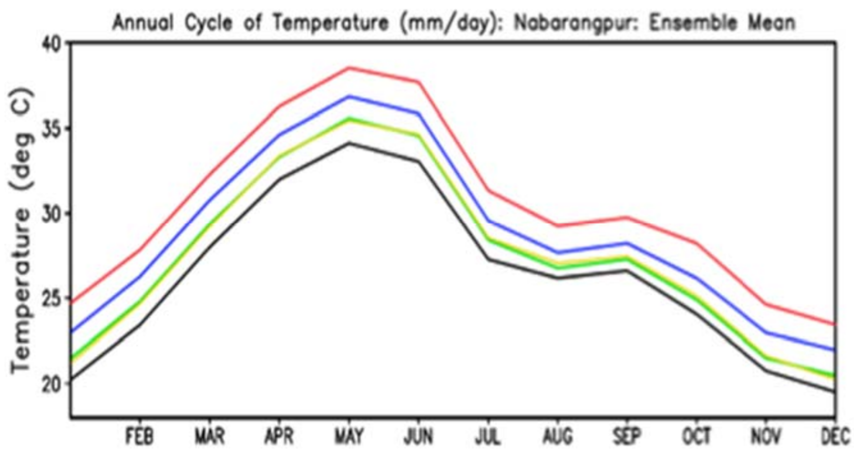

Fig 7: Same as figure 6 but for surface temperature (ºC).

6. Conclusions

In this study, future changes in annual rainfall and surface temperature projected by the six state-of-the-art IPCC AR5 CMIP5 models are analyzed to derive robust signals of projected changes and its variability over the Nabarangpur district. During the historical period, the CRU observations reveal that the rainfall and the surface temperature have been increasing in the last century but the rate is more in the last two three decades. In the future, the model ensemble shows that the annual rainfall might increase slightly over the district in both the RCP scenarios. However the rate might be higher in the RCP8.5 than in the RCP4.5. The surface temperature also might increase in both the scenarios. Annual cycle of rainfall reveals that the rainfall during the summer monsoon months might get increase in all the future periods whereas there may not be any changes in the other months. But in case of surface temperature, it may increase in all the months during the future periods. However, the temperature may be stronger by 2 – 3 ºC and 4 – 5 ºC in the far future of RCP4.5 and 8.5 respectively. The main limitation of this study is that we used GCMs, which is of coarser resolution. A finer resolution modelling system is needed to provide more robustness to this result. So regional climate model of finer resolutions would be better tool for the district level climate projections. Many more such kind of studies with regional climate models are required to help the scientists and policy makers to develop suitable strategies to cope with and take advantage of possible future changes.

Acknowledgments

The authors are thankful to the organizations from which datasets are obtained for conducting this study. We are thankful to CRU for providing the observed rainfall and surface temperature data and also thankful to all the sources of the CMIP5 model data used in this study. Thanks are also due to the Odisha district gazetteers for providing details about the Nabarangpur district.

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