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Climate Change Scenarios for South Asia and Central Himalayan region Based on GCM Ensemble

Jagadishwor Karmacharya, Archana Shrestha, Madan L. Shrestha

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Department of Hydrology and Meteorology
Kathmandu - Nepal

Preface

This report has been completed as part of APN CAPaBLE project:” Enhancement of National Capacities in the Application of Simulation Models for Climate Change and its Impacts on Water Resources and Agricultural Production” awarded to Global Change Impact Studies Centre (GCISC) and Pakistan Metrological Department by Asia Pacific Network for Global Change (APN) in 2005 for three years.

The analysis reported here makes use of the outputs of eleven GCMs obtained from (IPCC data distributed centre) and ICTP PWC group which are greatly acknowledged. These data covered the historical periods (1961-1990) and projection to the year 2100 corresponding to the IPCC SRES scenarios B1, A1B and A2 .These models were compared for their ability to reproduce historical climatic data for the period 1990-1961 over the South Asia region. The output of these models were then used to develop climate change scenarios corresponding to three IPCC scenarios for South Asia as a whole as well as for Central Himalayan region.

Table of Contents

List of Figures

List of Tables

1 Introduction

The awareness of global warming caused by the enhanced greenhouse effect period has increased the demand of climate change scenarios. Climate scenarios are plausible representations of the future that are consistent with assumptions about future emissions of greenhouse gases and with our understanding of the effect of increased atmospheric concentrations of these gases on global climate. A range of scenarios can be used to identify the sensitivity of an exposure unit to climate change and to help policy makers decide on appropriate policy responses. It is important to emphasize that climate scenarios are not predictions, like weather forecasts. Weather forecasts make use of enormous quantities of information on the observed state of the atmosphere and calculate, using the laws of physics, how this state will evolve during the next few days, producing a prediction of the future - a forecast. In contrast, a climate scenario is a plausible indication of what the future could be like over decades or centuries, given a specific set of assumptions. These assumptions include future trends in energy demand, emissions of greenhouse gases, land use change as well as assumptions about the behavior of the climate system over long time scales. It is largely the uncertainty surrounding these assumptions which determines the range of possible scenarios[1].

The Intergovernmental Panel on Climate Change (IPCC) Special Report on Emission Scenarios (SRES) provides 40 different scenarios. The choice of climate scenarios and related non-climatic scenarios is important because it can determine the outcome of a climate impact assessment. Extreme scenarios can produce extreme impacts; moderate scenarios may produce more modest effects. It follows that the selection of scenarios can also be controversial, unless the fundamental uncertainties inherent in future projections are properly addressed in the impact analysis.

1.1 Global Climate Models (GCMs)

The most common and widely accepted method of scenario construction involves the use of the output of Global Climate Models (GCMs), also known as General Circulation Models. These models are the most complex of climate models, since they attempt to represent the main components of the climate system in three dimensions. GCMs are the tools used to perform climate change experiments from which climate change scenarios (possible representations of how the climate will evolve) can be constructed. The design and structure of an individual GCM determines the climate change experiments that can be performed. These characteristics are limited by our scientific understanding of the climate system and by the available computing resources. GCMs are able to simulate fairly well the most important mean variables. Among surface climate variables, large-scale sea level pressure (SLP) is usually better simulated, while for the others, such as temperature and precipitation, GCMs have much smaller skill. Because of some uncertainty in the modeling, it is first important to asses how well a GCM simulates the present-day climatology at various spatial and temporal scales over some particular domain. Nowadays coupled atmosphere-ocean general circulation models (AOGCMs) are the most complex models in use, consisting of an AGCM coupled to an OGCM.

There are two factors that must be borne in mind in comparing the modeled present-day climate with observations. Firstly, there is natural interdecadal variability both in the models and in the real world. This variability is stronger for precipitation than for temperature, and may partly explain the model vs. observed differences. Secondly, due to the low horizontal resolution of the models, orography is represented fairly crudely. Thus the area-mean elevation in a model may deviate from the real elevation, biasing the temperature. Precipitation is sensitive to small-scale orographic features, which are poorly represented in present-day models.

The criteria commonly applied in selecting a GCM to be used in constructing regional climate scenarios for impact assessment, is the performance of the GCM in simulating the present-day climate in the region. To evaluate this we have compared the GCMs output with observed climate (CRU data) in the target region, and have determined the ability of the models to simulate large scale circulation patterns over South Asia. This report describes validation of different GCMs output and construction of future climate scenarios over South Asia. The purpose is to estimate how well GCMs evaluate the precipitation and temperature in the selected regions and how much change occurs in these two variables for future. We have analyzed the output of eleven different AOGCMs which were selected from the IPCC Data Distribution Centre (DDC) [2] and Program for Climate Model Diagnosis and Intercomparison (PCMDI) site [3].

1.2 Description of Selected IPCC AOGCMs

In this study, we analyzed SRES B1, A1B and A2 scenario runs performed with eleven coupled atmosphere-ocean GCMs, the data is available from IPCC – DDC and PCMDI. All of the AOGCM datasets analyzed included monthly mean surface air temperatures and precipitation for the period beginning in 1960 or 1961 and ending in 2099.

Brief discussion of selected AOGCMs is given below: Details on the model configuration is available on IPCC Data Distribution Centre (DDC) and Program for Climate Model Diagnosis and Intercomparison (PCMDI) site

a) CNRM_CM3 (Centre National de Researches Meteorologiques), France

b) CSIRO_MK3 (Commonwealth Scientific and Industrial Research Organization), Australia

The CSIRO climate model has been used for a number of more sophisticated climate change simulations. The model has 9 levels in the vertical and horizontal resolution of approximately 5.6 by 3.2 degrees. The ocean model has the same horizontal resolution with 21 levels.

c) GFDL_CM2 (Geophysical Fluid Dynamics Laboratory), USA

d) GISS_E_R (Goddard Institute for Space Studies), USA
e) INMCM3 (Institute for Numerical Mathematics) ,Russia
f) MIROC3_2_M (Center for Climate System Research, The University of Tokyo; National Institute for Environmental Studies, and Frontier Research Center for Global Change, JAMSTEC), Japan
g) MPI_ECHAM5 (Max-Planck-Institute for Meteorology), Germany
h) MRI_CGCM2 (Meteorological Research Institute), Japan
I) NCAR_CCSM (National Center for Atmospheric Physics), USA
j) NCAR_PCM1 (National Center for Atmospheric Physics), USA
k) UKMO_HADCM3 (Hadley Centre for Climate Prediction and Research), UK
HadCM3 is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre. The higher ocean resolution of HadCM3 is a major factor in this. HadCM3 has been run for over a thousand years. The atmospheric component of HadCM3 has 19 levels with a horizontal resolution of 2.75° of latitude by 3.75° of longitude, which produces a global grid of 96 x 73 grid cells. The oceanic component of HadCM3 has 20 levels with a horizontal resolution of 1.25 x 1.25°. At this resolution it is possible to represent important details in oceanic current structures.

1.3 Observed CRU data

The Climatic Research Unit (CRU) is widely recognized as one of the world's leading institutions concerned with the study of natural and anthropogenic climate change.

The CRU Global Climate Dataset, available through the IPCC DDC, consists of a 1ºx1º resolution mean monthly climatology for global land areas, excluding Antarctica. The CRU Global Climate Dataset can be used to examine climate variability over the twentieth century, to evaluate the simulations of various GCMs over the period 1961-1990 and to combine observed data with GCM projections.

2 Methodology

To evaluate the performance of different GCMs, we have compared GCMs simulated climatology against observational data set for two variables precipitation and temperature. Observational data set (CRU Global Climate

Dataset) is available through the IPCC DDC. These data corresponding to different grid size are outlined below.

MODEL	GRID SIZE (Atmosphere)
CNRM_CM3	2.8 °
CSIRO_MK3	T63, L18
GFDL_CM2	2.5° x 2.0° long lat, 24 levels
GISS_E_R	5° x 4° long lat
INMCM3	5° x 4° long lat, 21 vertical levels
MIROC3_2_M	T42 L20
MPI_ECHAM5	NA
MRI_CGCM2	T42 (approx. 2.8°)
NCAR_CCSM	NA
NCAR_PCM1	NA
UKMO_HADCM3	3.75° x 2.75° long lat

All the data sets are regridded to common resolution of 1°x1° grid to facilitate comparisons against observations. Since it is deemed ensemble average gives better representation of state of climate ensemble average values we have concentrated more on analysis of ensemble average than individual model. Ensemble average are computed by Arithmetic averaging the corresponding values for all the models over each grid point at each time step.

We have taken the area that extends from 65°- 97°E and 5°-33°N as South Asia Region. All the calculations are done only over the land grid points within that region. We have taken a irregular box over the Central Himalayan region that extends from 78°- 89°E and 24°-32°N to represent Nepal and neighboring regions.

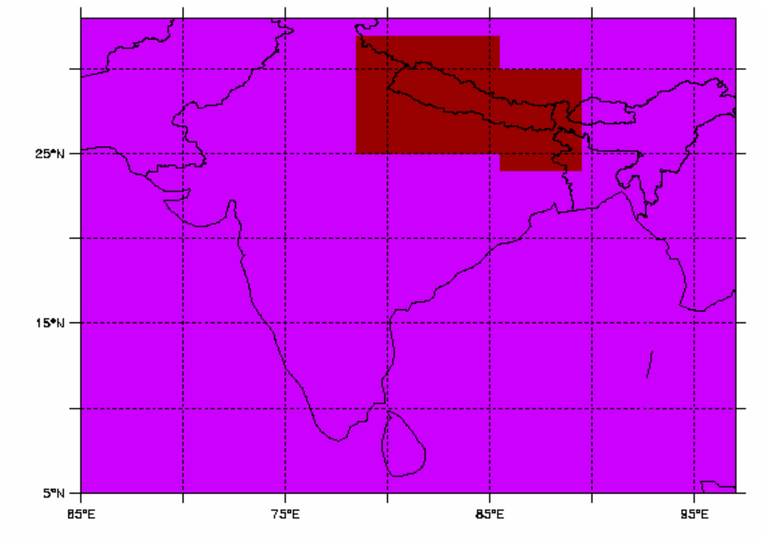

Figure 1: South Asia and Central Himalayan region (Nepal and vicinity) used in model validation and preliminary projections

2.1 Methodology used for models validation

Models output and CRU data sets were truncated into the 30 years baseline period (1961-1990). A popular climatological baseline period is a 30-year "normal" period as defined by the World Meteorological Organization (WMO).

In validation process, we have analyzed the spatial pattern of precipitation and temperature for annual averages for GCMs and CRU data over South Asia. The differences of annual for each model and ensemble mean with the observed i.e. CRU averages were analyzed to observe the bias in each GCM.

2.2 Methodology used for scenario formulation

For future projections, GCMs output data information is used to define the change in climate between the present-day and future over South Asia region.
Three time slices each of thirty years period centered around 2020s, 2050s and 2080s were selected to gain some insight into the range of future changes of temperature and precipitation. Annual average are calculated for each 30 year time slice in the future compared to the 1961–1990 baseline period to compute climate changes.

3 Validation effort

In this section we briefly discuss the results of validation of GCMs output. Spatial patterns of ensemble composite temperature and precipitation over South Asia are compared with observed CRU data. The pattern of mean annual temperature and precipitation is well captured by GCMs as depicted in GCM composite however the model composite lacks the fine scale features due to its course resolution. For example observed tight gradient of temperature over the Himalayan range is missing in the model composite map like wise High precipitation over East India and neighboring region and over Western Ghats is also not captured by the model.

Observed and model simulated annual cycle of temperature and precipitation averaged over the South Asia domain are in good agreement. Seasonal stride of temperature and monsoon burst of precipitation is well captured by all the models however most of the model are cold biased and under estimates the precipitation

3.1 Precipitation

The annual precipitation for the period 1961-1990 of Model composite and CRU data set is shown in Figure 2. Annual pattern of participation is determined primarily by the monsoon precipitation. Observation shows Northeast to Southwest gradient of precipitation over North Indian and neighboring regions with high pocket of precipitation over Northeast India centered over Cherapungi which has highest annual precipitation in the world. Model Composite map captures the Northeast to Southwest gradient of precipitation over North Indian and neighboring regions with indication of high rainfall pocket over Northeast India; however it fail to capture the fine scale details and underestimate the precipitation by large margin over that region. Models also fails to capture the high rainfall over the Western Ghats of the Western coastal India, probably due to its coarse resolution.

Figure 4 (b) shows annual cycle of precipitation averaged over South Asia

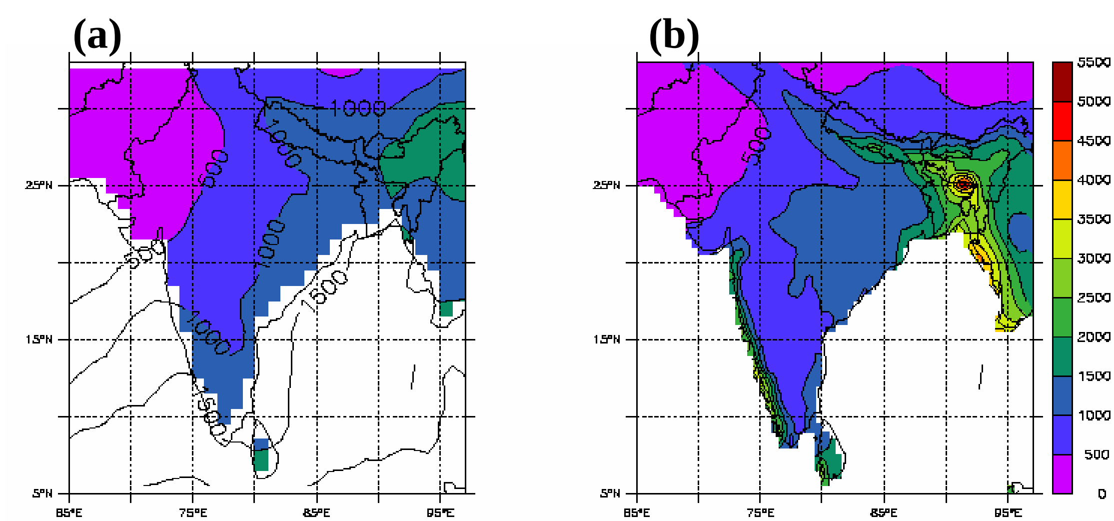

Figure 2: Reference Period Annual Mean Precipitation (in millimeter)

(a) GCM Composite 30 years mean precipitation average for the period (1961-1990)

(b) CRU 30 years mean precipitation average for the period (1961-1990)

domain during the 30 year period from 1961 to 1990 for CRU data set, individual models and model composite. All the models capture the monsoon dominate feature of precipitation over South Asia however all but one model underestimates the monsoon precipitation with few models showing large dry bias during monsoon. Biases are narrow during other seasons with some models showing wet bias during winter seasons.

3.2 Temperature

Spatial patterns of simulated temperature from model composite is compared with observed temperature i.e. CRU. The models response in simulating temperature is always better than precipitation. In Figure 3, annual temperature of model composite and CRU data is shown over South Asia. In CRU observation the major part of India and Pakistan shows a mean annual temperature ranging between 20°C to 30°C while over the Himalayan range there is step gradient of temperature that goes down to –5°C over Tibetan Plateau. Model composite capture the North South gradient of temperature quite well with fair degree of match in magnitude over most part thought with some cold bias. Moreover the model composite fails to capture step decline of temperature over the Himalayan range from South to North which may be due to under estimate of elevation in model topography as well as its coarse resolution.

Figure 4 (a) shows annual cycle of mean temperature averaged over South Asia domain during the 30 year period from 1961 to 1990 for CRU data set, individual models and model composite. All the models well capture the seasonal march of temperature over South Asia however most of the models underestimate the mean temperature most of the season with few models showing large cold bias throughout the year. In comparison Model composite is in better agreement with

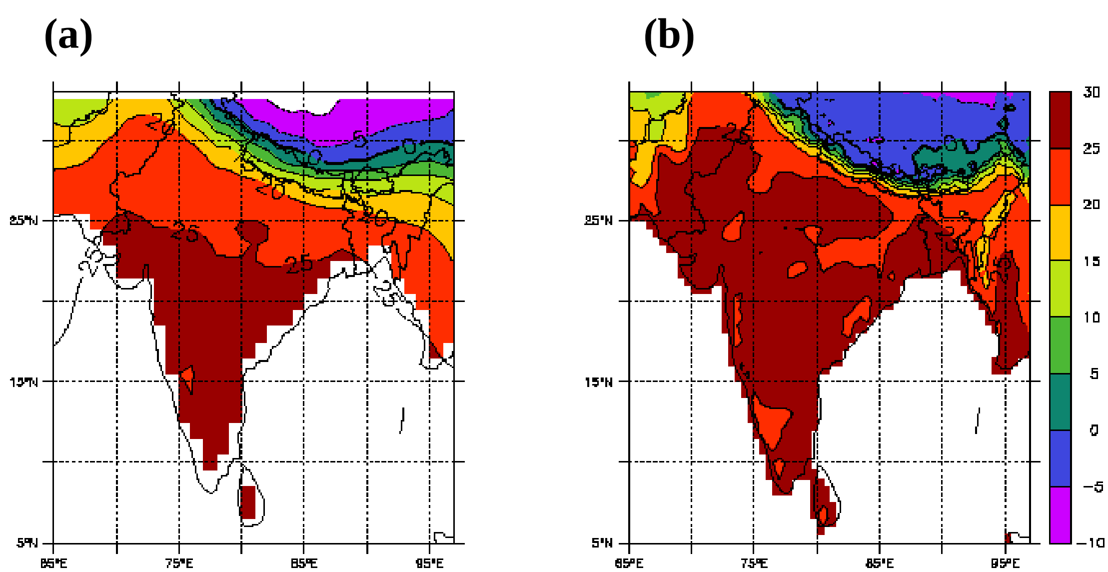

Figure 3: **Reference Period Annual Mean Temperature (in °C)**
(a) GCM Composite 30 years mean temperature average for the period (1961-1990)
(b) CRU 30 years mean temperature average for the period (1961-1990)

observation but slightly cold biased.

In Table 1, area average values of mean temperature and precipitation over South Asia and Central Himalayan region. Observed mean value of temperature and precipitation are 19.8°C and 1083 mm over South Asia while respective model composite values are 17.9°C and 911.2 mm. The biases are 1.9°C and 171.8 mm respectively. Underestimation of temperature and precipitation by the models are reflected in these figures. Likewise Model composite mean value of temperature and precipitation over Central Himalayan region are 10.9°C and 1017 mm respectively.

	South Asia			Central Himalayan region		
	CRU	Ensemble Mean	Bias	CRU	Ensemble Mean	Bias
Temperature (°C)	19.8	17.9	1.9	-	10.9	-
Precipitation (millimeter)	1083	911.2	171.8	-	1017	-

Table 1: Reference period annual climatology over South Asia and Central Himalayan region

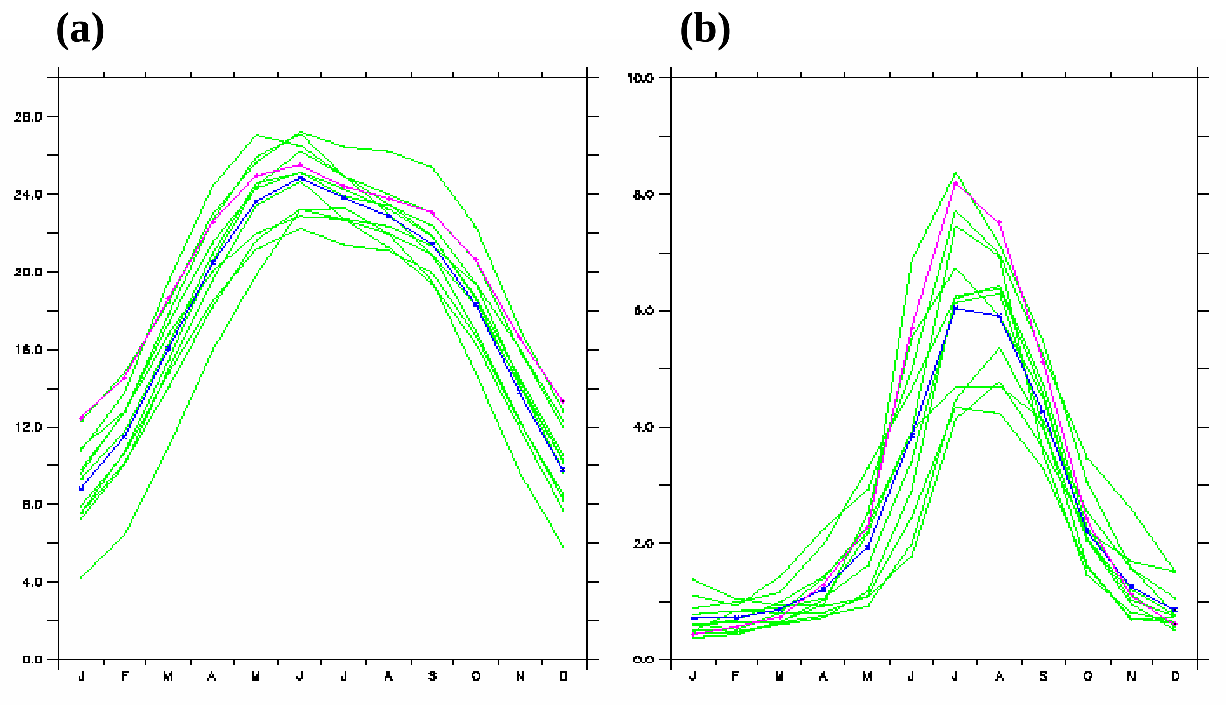

Figure 4: Reference Period Annual Cycle of Temperature and rainfall
(a) temperature (in °C) and (b) Precipitation (in millimeter/day)
CRU observation in purple, Model composite in blue and Model members in Green

4 Climate change projections

Three time slices incorporating 30-year centered on 2020s, 2050s and 2080s were examined to gain some insight into the range of future prediction of temperature and precipitation for A2, A1B and B1 scenarios estimated from the AOGCMs. Spatial patterns of precipitation and temperature for all three futures are discussed on annual basis. Never the less this work is giving good initial idea about the future climate changes in temperature and precipitation over South Asia and Central Himalayan region.

4.1 South Asia

4.1.1 Precipitation and Temperature

Future change in the amount of precipitation over South Asia is observed by taking difference plots to examine spatial changes between AOGCMs estimates and baseline (1961-1990) period. Percentage change in precipitation under three different scenario for three different futures is discussed below for the model composite.

4.1.2 B1 Scenario

For this scenario, the ensemble averaged precipitation change shows more or less consistent pattern for all three future periods. Precipitation is projected to increase in the entire domain except for small area in East Central India during 20's and small part of Pakistan and Western Himalayan range during 50's and 80's. Larger increase in precipitation is projected over North East India and Western Ghats with up to 250 mm increase per annum projected over North East India during 80's and 80 mm increase per annum increase over Western Ghats during 50's and 80's.(see figure 5) Since these are the areas with high precipitation any significant increase in precipitation as projected over these areas will increase the likelihood of flood and other related hazards.

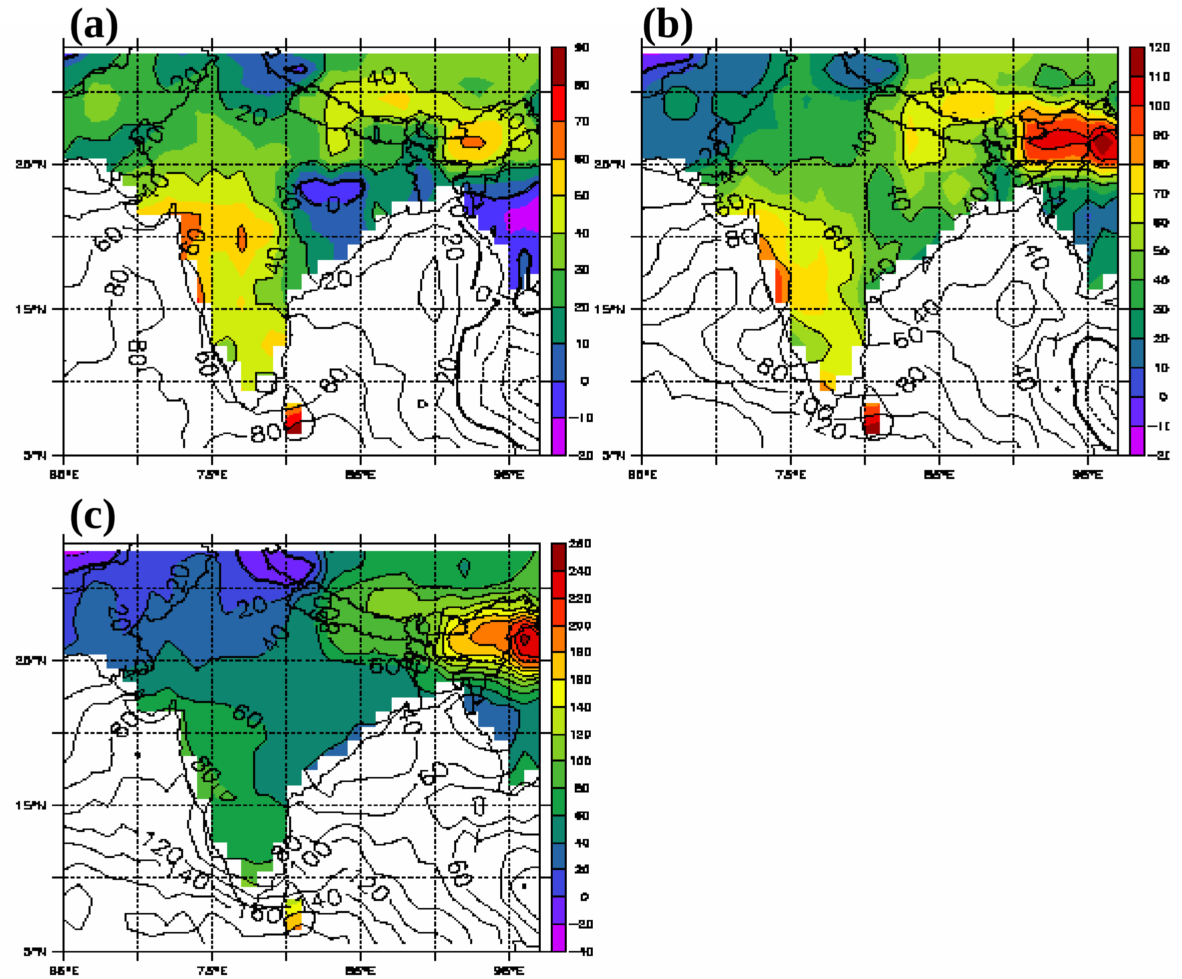

Figure 5: Mean annual Change in precipitation (in millimeter) for B1 scenario (a) 2020's (b) 2050's (c) 2080's

The ensemble annual temperature changes shows consistent pattern over all the scenario and period with higher increase over interior and Northern longitudes than coastal regions, larger warming in distance future than near future and higher rate of warming for higher GHG concentration scenario. Under B1 scenario the projected increase in temperature is as low as 0.8°C over coastal area and goes up to 1.5°C over Tibetan platue for 20's; Similarly for 50's the values lies between 1.2°C 2.4°C and for 80's 1.6°C to 3.2°C with consistent spatial pattern. (see figure 6)

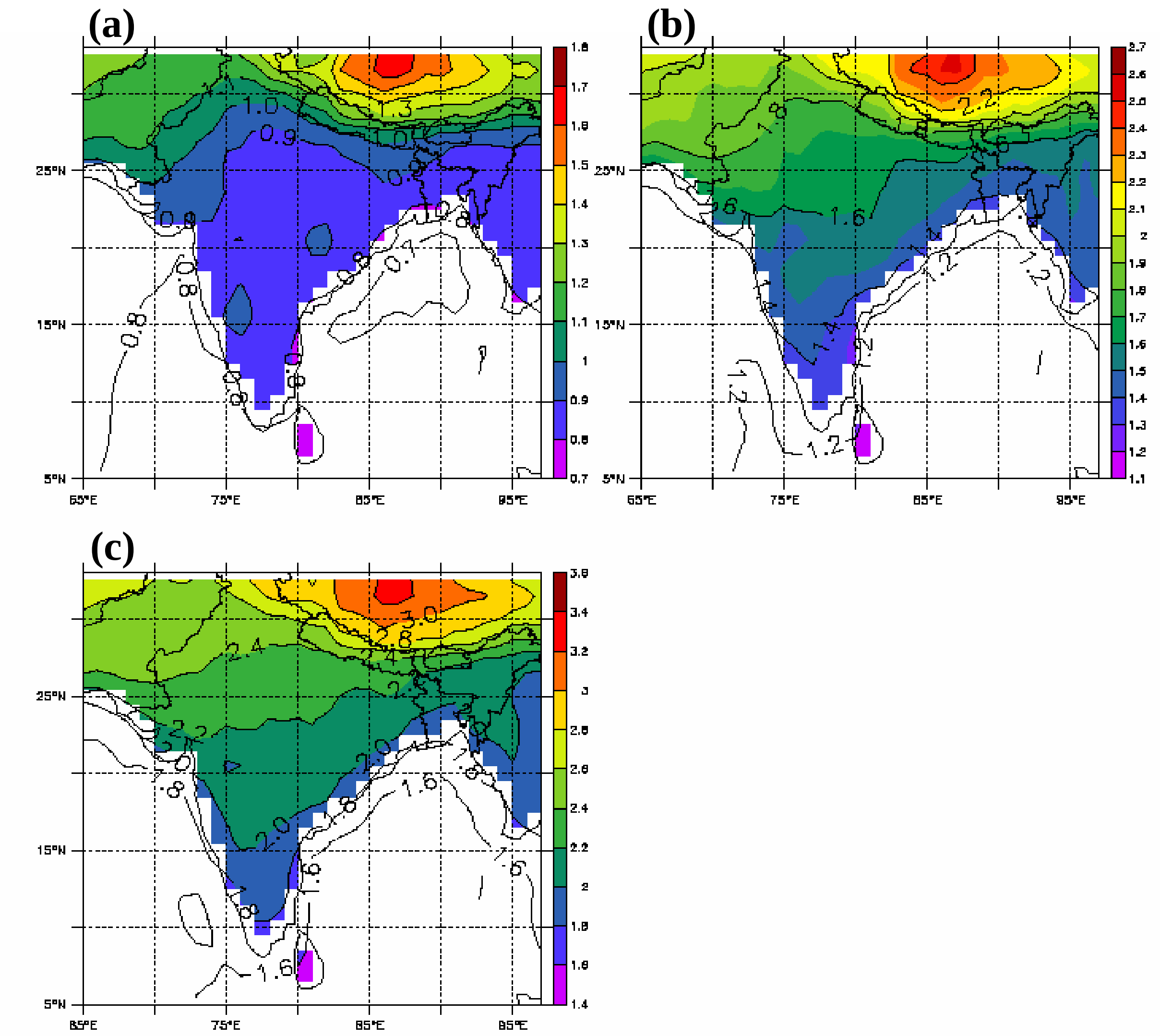

Figure 6: Mean Change in temperature (in °C) for B1 scenario (a) 2020's (b) 2050's (c) 2080's

4.1.3 A1B Scenario

The ensemble averaged precipitation change shows more or less consistent pattern compared to B1 scenario for all three future periods.

Precipitation is projected to increase in the entire domain except for small area in East Central India during 20's and small part of Pakistan and Western Himalayan range during 50's and 80's. Larger increase in precipitation is projected over North East India and Western Ghats with up to 300 mm increase per annum projected over North East India during 80's and 120 mm increase per annum increase over Western Ghats during 50's and 80's.(see figure 7)

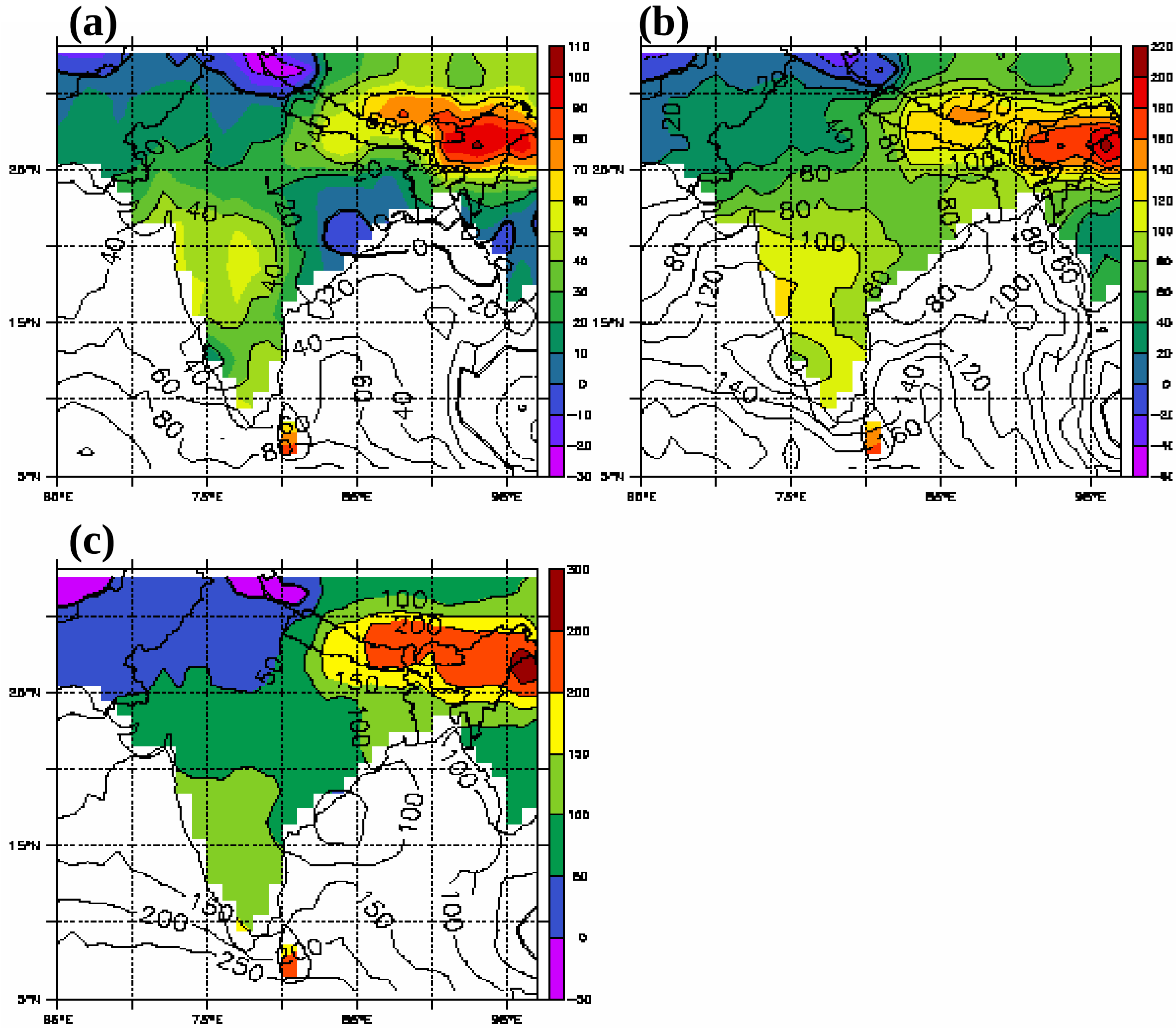

Figure 7: Mean annual Change in precipitation (in millimeter) for A1B scenario (a) 2020's (b) 2050's (c) 2080's

Like in B1 scenario The ensemble annual temperature changes show consistent amplified warmer pattern over all future period with higher increase over interior and Northern longitudes than coastal regions, larger warming in distance future than near future. Under A1B scenario the projected increase in temperature is as low as 0.6°C over coastal area and goes up to 2°C over Tibetan platue for 20's; Similarly for 50's the values lies between 1.6°C to 3.2°C and for 80's 2.6°C to 4.6°C with consistent spatial pattern. (see figure 8)

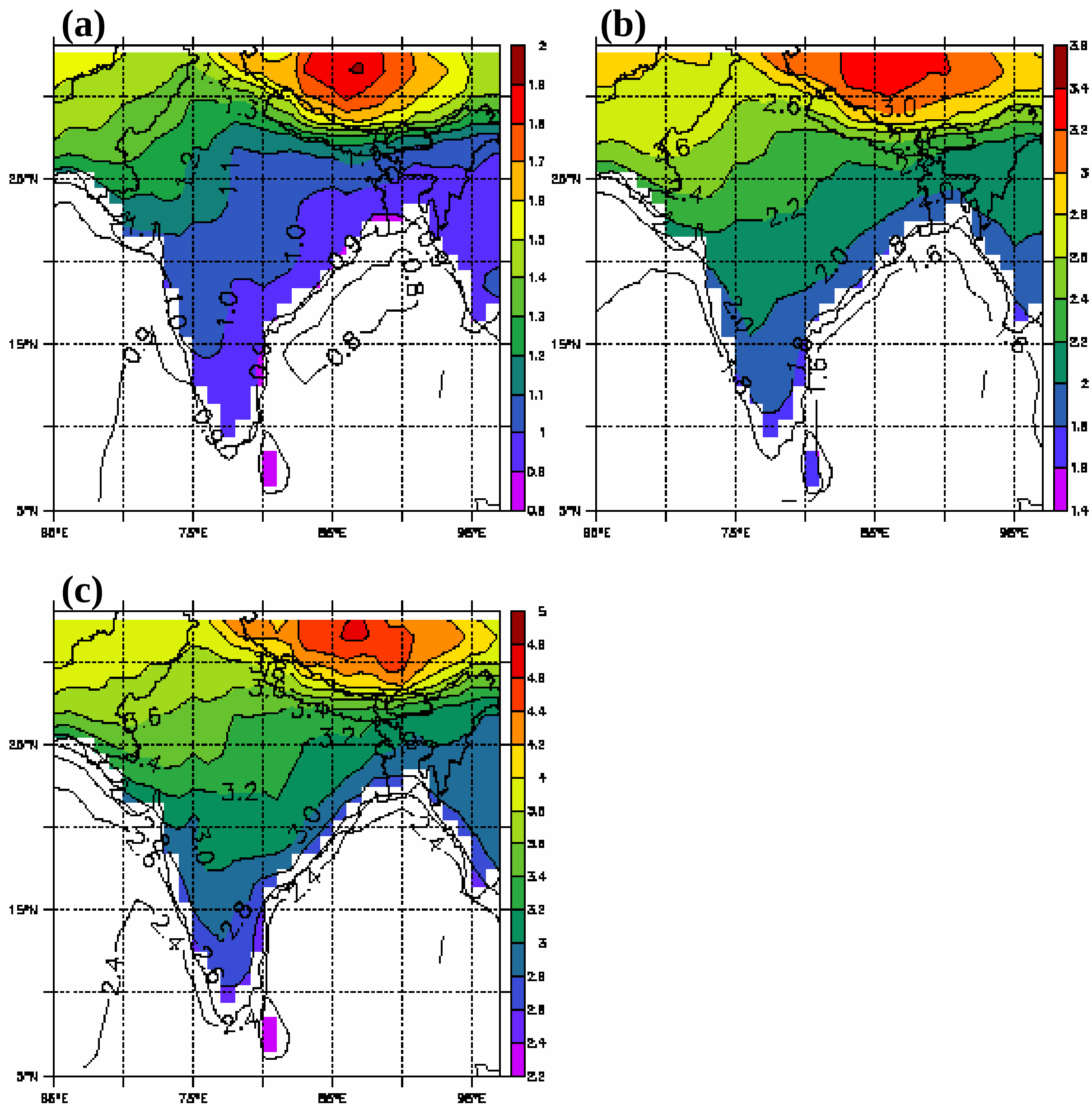

Figure 8: Mean Change in temperature (in °C) for A1B scenario (a) 2020's (b) 2050's (c) 2080's

4.1.4 A2 Scenario

The ensemble averaged precipitation change shows more or less consistent pattern compared to previous two scenarios for all three future periods but there are subtle variation for 20's. Precipitation is projected to decrease by up to 20 mm over East Central India and Western Himalaya and adjacent regions during 20's and over the rest of domain increase ranges from 20 mm up to 80 mm. Pattern for 50's and 80's quite consistent for A2 scenario in comparison to B1 and A1B scenario with increase up to 100 mm over Western Ghats and 300 mm over North Western India during 80's.(see figure 9)

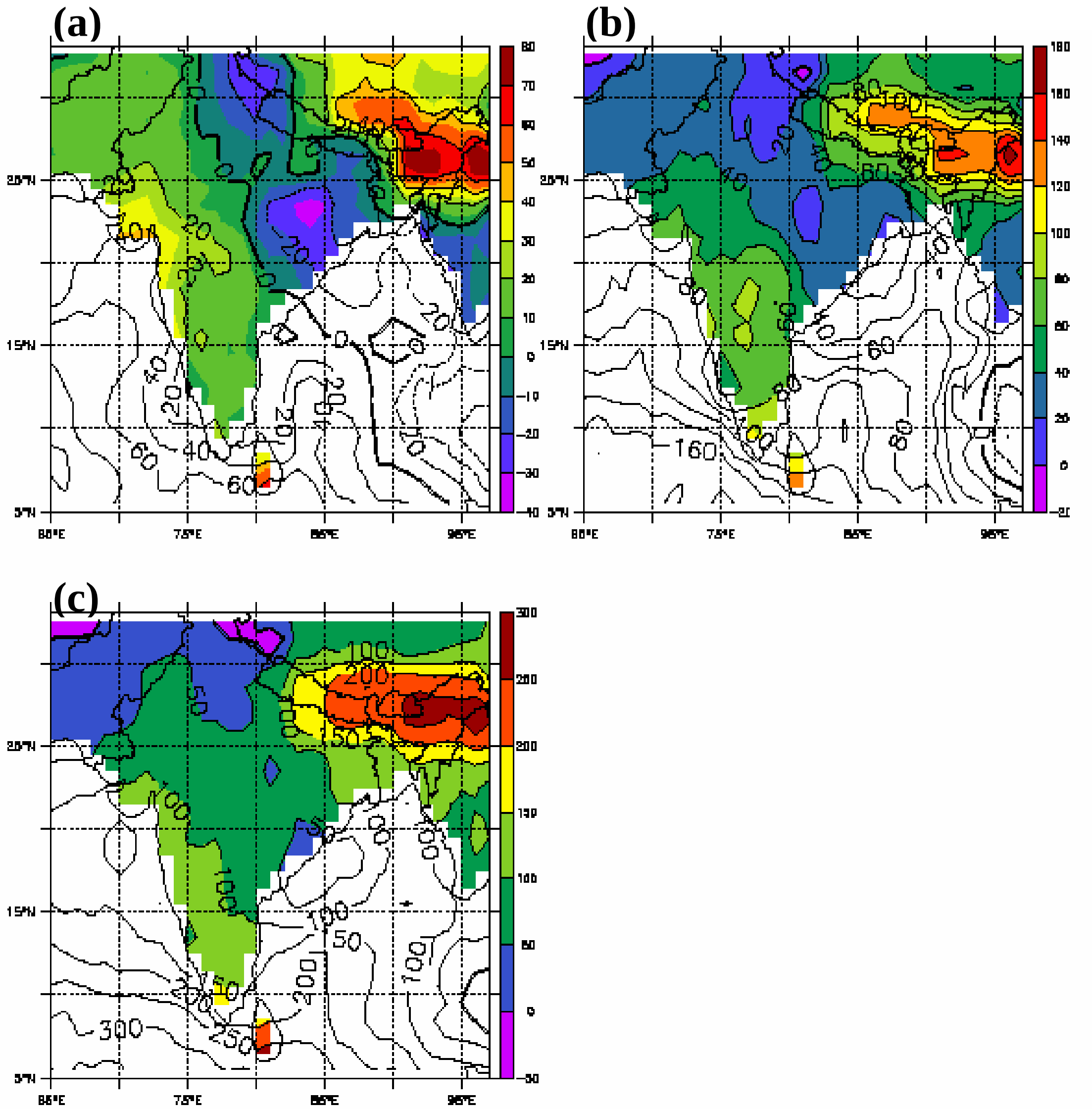

Figure 9: Mean annual Change in precipitation (in millimeter) for A2 scenario (a) 2020's (b) 2050's (c) 2080's

The ensemble average annual temperature change show consistent but amplified warmer pattern over all future period with higher increase over interior and Northern longitudes than coastal regions, larger warming in distance future than near future. Also the projected increase in temperature is largest under A2 for 2080's among the three scenarios. For this scenario the projected increase in temperature range from 0.8°C over coastal area and goes up to 1.9°C over Tibetan platue for 20's; Similarly for 50's the values lies between 1.6°C to 3.6°C and for 80's 3°C to 5.4°C with consistent spatial pattern. (see figure 10)

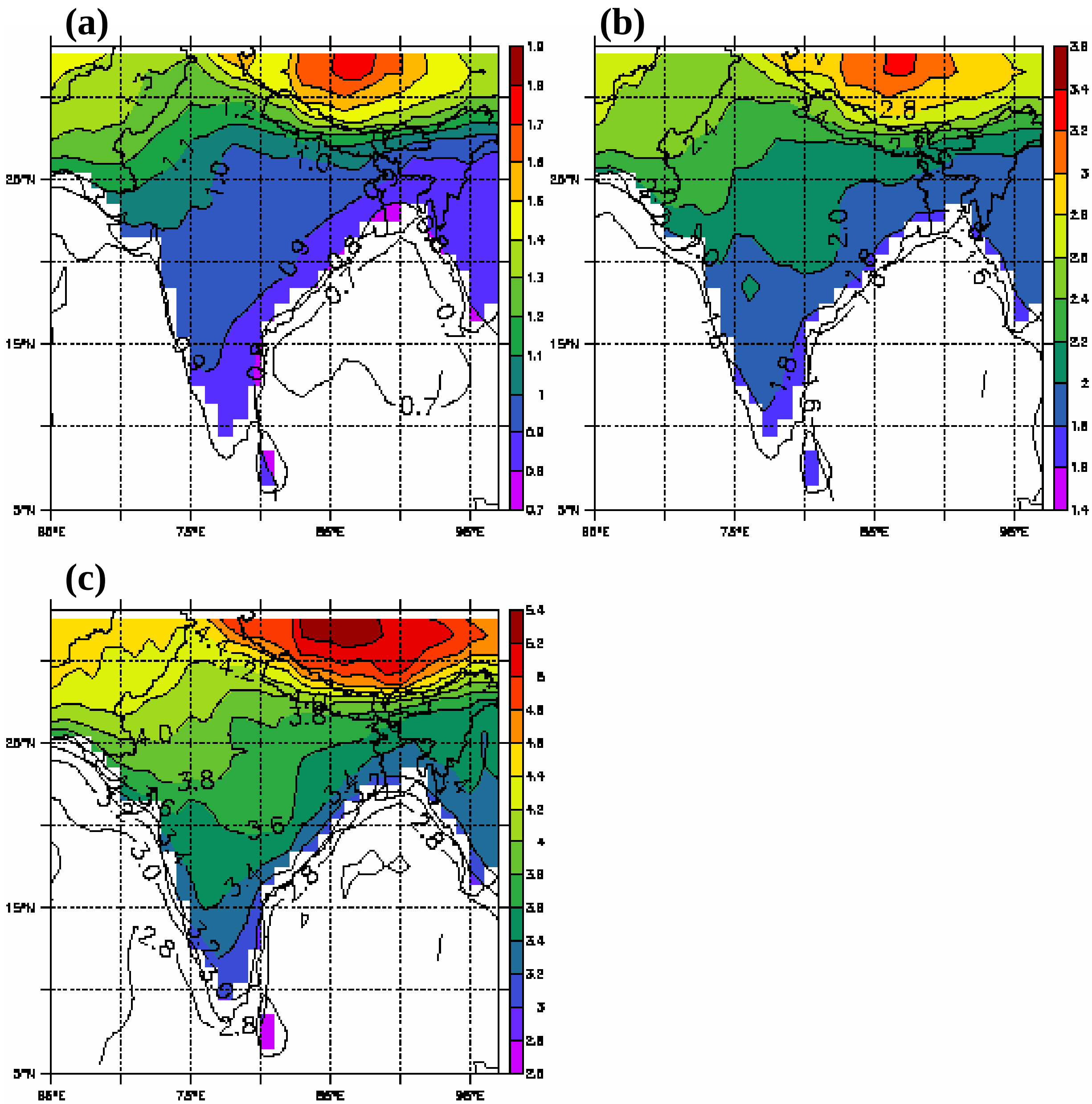

Figure 10: Mean Change in temperature (in °C) for A2 scenario (a) 2020's (b) 2050's (c) 2080's

4.1.5 Area average projection

Figure 11 shows model composite annual cycle of temperature and precipitation averaged over South Asia domain for the 30 year time slice each for reference period, 2020's, 2050's and 2080's for reference dataset, A2, A1B and B1 scenario. The figure give the snapshot of the model projection over south Asia under different scenario for various time slice. Model projection shows that seasonal cycle under different time period and scenario remain the same however temperature is projected to increase throughout the year for all scenario and time period. As discussed earlier this increase is higher for the distance future than near future for a given scenario and for a given time period Its is higher for higher emission scenario. Figure 12(a) shows that increase in temperature is higher for winter months compared to summer, which is consistent across the scenarios and time frame. In case of precipitation, it is projected to increase mainly during the summer months. Figure 12(b) shows precipitation is projected to decrease during winter months marginally, while the increase during the summer months specially monsoon. Projected increase is highest under A2 scenario during 2080's. Interestingly, this increase is higher for the distance future than near future for a given scenario i.e. precipitation is projected to increase with passage of time.

Table 2 shows the projected change for temperature and precipitation under different scenario averaged over South Asia. As discussed earlier, projected increase in temperature is lowest under B1 scenario (1°C in 2020's up to 2.3°C in 2050's) and highest for A1B scenario during 2020's and 2050's and A2 scenario

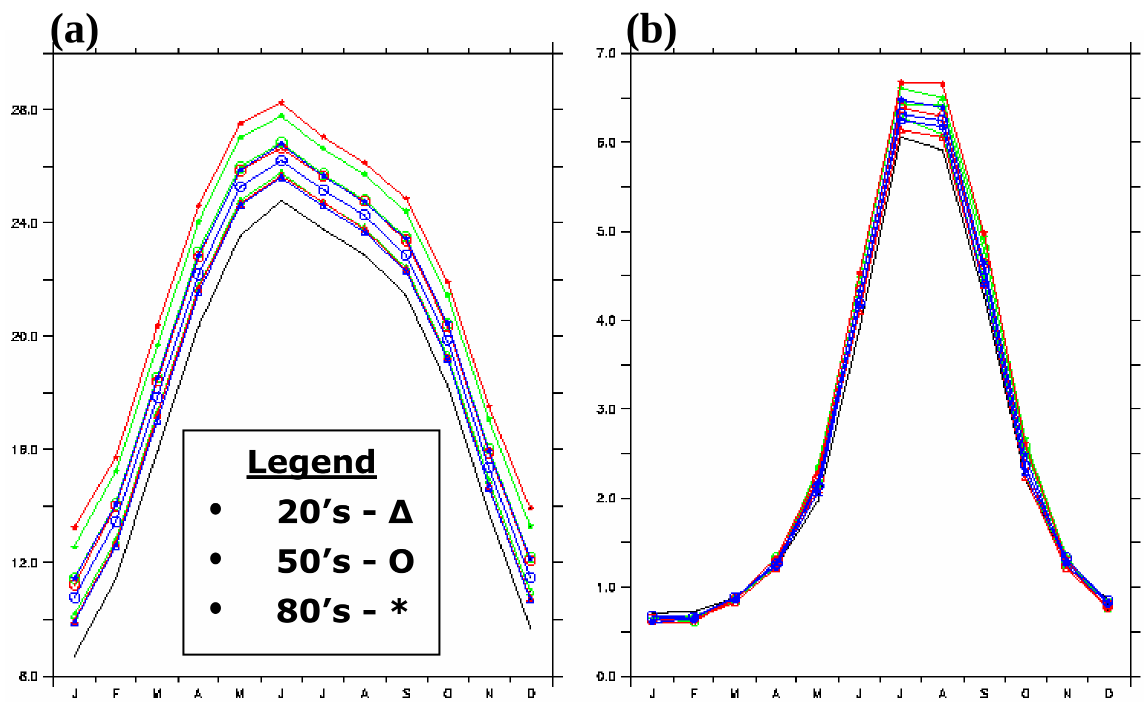

Figure 11 : Ensemble mean Annual cycle of (a) Temperature (in °C) and (b) precipitation (in millimeter/day)

A2 scenario in red, A1B scenario in green, B1 scenario in blue and reference period in Black during 2080's. Also as expected, temperature increase steady in future. Its interesting to note that projected increase in temperature is higher under A1B than A2 scenario during 2020's and 2050's and only during 2080's it is highest in A2 scenario among the three scenario under consideration which is consistent with the IPCC emission and concentration scenario. Regarding precipitation there is steady increase from near future to distance future though the increase is small compared to present day climatology.

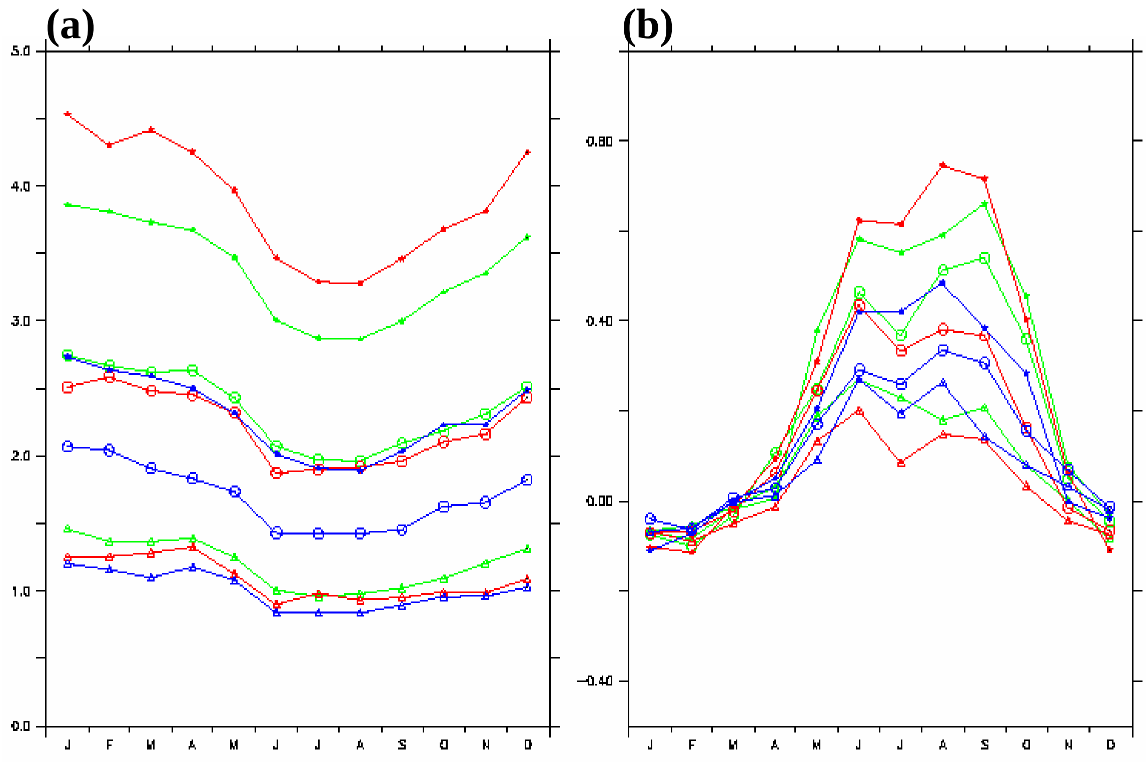

Figure 12: Ensemble mean Change from reference period for (a) Temperature (in °C) and (b) precipitation (in millimeter/day)

A2 scenario in red, A1B scenario in green and B1 scenario in blue

	Temperature Change (°C)			Precipitation Change (millimeter)		
Scenario	2020's	2050's	2080's	2020's	2050's	2080's
B1	1.0	1.7	2.3	28.5	45.8	61.5
A1B	1.2	2.4	3.4	29.4	73.0	94.3
A2	1.1	2.2	3.9	12.1	53.0	98.2

Table 2: Projected Change in temperature and precipitation over South Asia

4.2 Central Himalayan region

Table 3 shows the projected change for temperature and precipitation under different scenario averaged over Central Himalayan region that covers Nepal and adjacent areas. In case of temperature the projected increase is slightly higher than that averaged over South Asia. It ranges from 1.1C to 1.3C in 2020's, 1.8C to 2.5C in 2050's and 2.5C to 4.2C in 2080's among the three scenario. In case of precipitation the projected changes are in line with that average over South Asia.

	Temperature Change (°C)			Precipitation Change (millimeter)		
Scenario	2020's	2050's	2080's	2020's	2050's	2080's
B1	1.1	1.9	2.5	28.4	49.3	64.1
A1B	1.3	2.6	3.7	33.7	84.9	121.0
A2	1.2	2.4	4.2	1.6	58.4	124.6

Table 3: Projected Change in temperature and precipitation over Central Himalayan region

Figure 13 and 14 show comparison of area averaged projected change for South Asia and Central Himalayan region. As stated above change in temperature is slightly higher for Central Himalayan region than South Asia for all scenario and time period. In case of precipitation change the values are close to each other though it is marginally higher for Central Himalayan region in most cases.

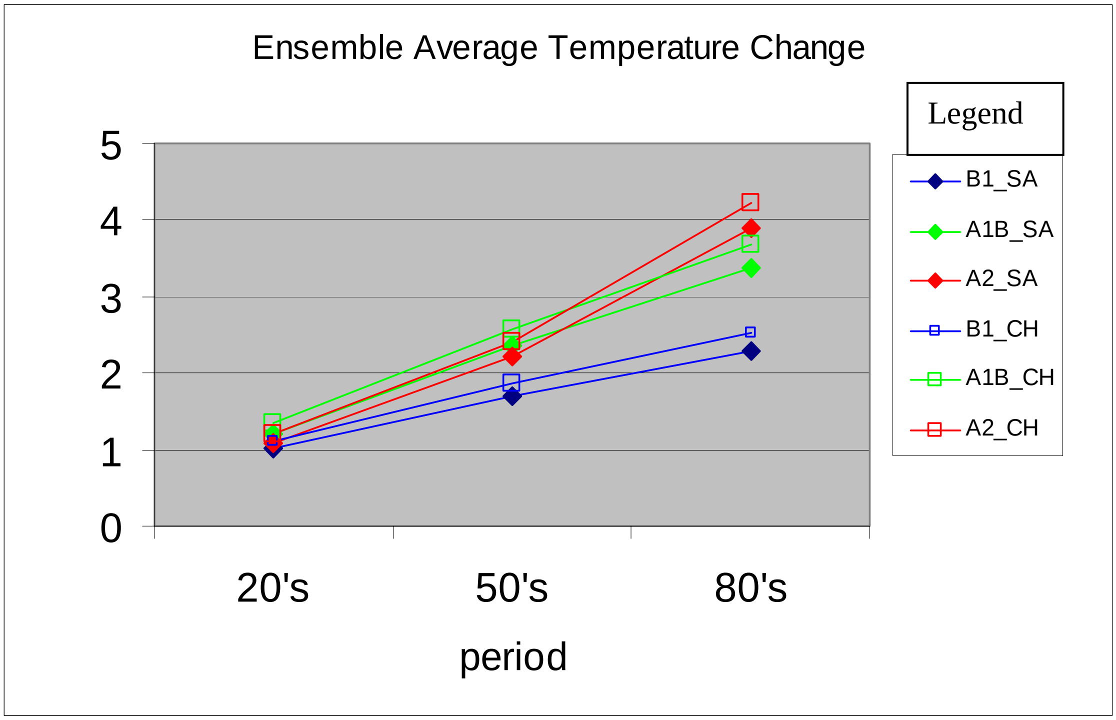

Figure 13 : Ensemble mean Change in temperature (in °C) for South Asia (SA) and Central Himalayan region (CH)

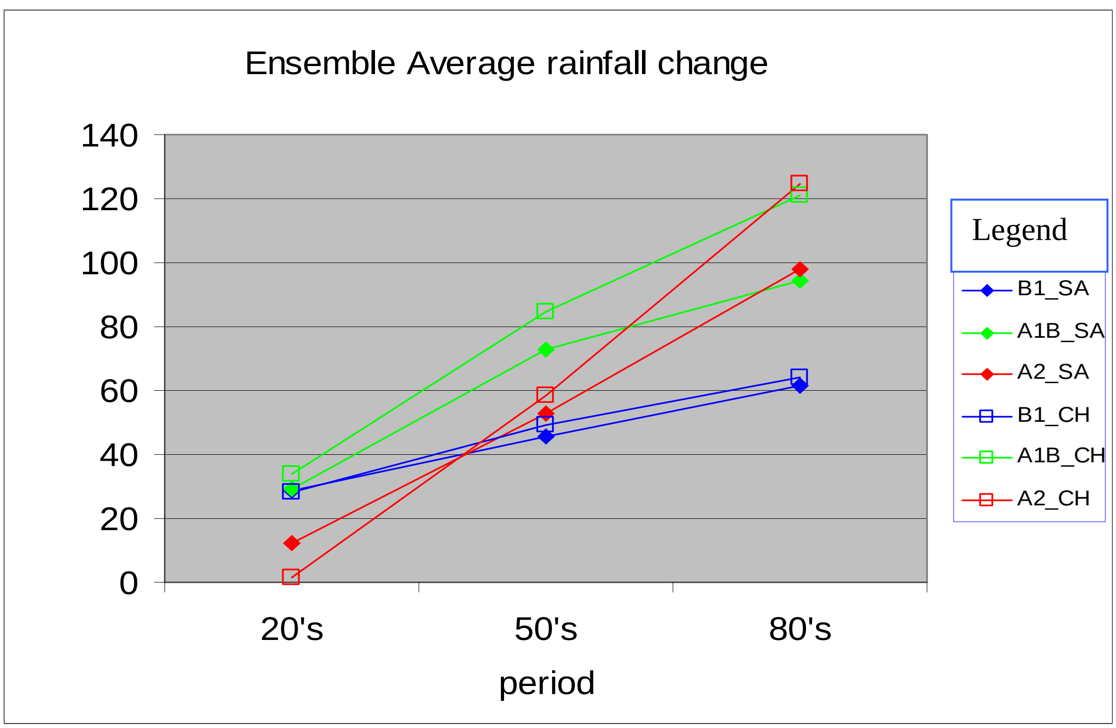

Figure 14 : Ensemble mean Change in Precipitation (in millimeter) for South Asia (SA) and Central Himalayan region (CH)

5 Conclusion and Summary

Analysis of GCM composite output for precipitation and temperature from eleven GCMs shows that they are able to simulate different aspect of the observed climatology over the South Asia fairly well. The main model systematic bias is a tendency to underestimate winter temperature and summer monsoon precipitation. Climate change projection for three future period under three different emission scenario Viz. B1, A1B and A2 projects consistent spatial and temporal pattern of change specially for temperature. This indicates the robustness of the signal and increases confidence in the projection.

Main features in future projection over South Asia are as follows:

- Climatological annual cycle will not alter e.g. no change in monsoon regime.
- Warming with the passage of time with rapid warming over Tibet and Northern Latitude .
- Warming rate higher in Winter than in Summer
- Indication of wetter summer monsoon with largest increase in precipitation over North East India and drier winter.

- In null set GCM composite projects a tendency for wetter and warmer summer and drier and enhanced warmer winter

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References

[1] IPCC-TGCIA, 1999: Guidelines on the use of scenario data for climate impact and adaptation assessment, Version 1.

[2] IPCC Data Distribution Center (http://ipcc-ddc.cruuea.ac.uk)

[3] Program for Climate Model Diagnosis and Intercomparison PCMDI site (http://www-pcmdi.llnl.gov)