IMPACT OF CLIMATE CHANGE ON PRECIPITATION CHARACTERISTICS OF BRAHMAPUTRA BASIN

A Study Report

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ABSTRACT

The climate of North-Eastern region of India is depicted by its extreme humidity. Its most distinguishing feature being the abundant rainfall between March and May at a time when rain in other India is at its minimum. Along with ample precipitation in this part of the country is the associated water induced disasters. These problems may worsen because of impacts of global climate change. Changing climate may have significant impacts on the quality and quantity of water that is available and accessible. The consequent social, economic, livelihood and environmental implications in the Himalayan region are of immediate concern.

The present study has been taken up to quantify the impact of the climate change on the precipitation characteristics of Brahmaputra Basin. Considering the variation of precipitation in the entire basin, two stations have been selected based on their contrasting features and also on the availability of data. One of the sites is Gerukamukh rainfall station in the Subansiri river basin at Arunachal Pradesh which is located on the upper reach of the basin in India. The other site is the rainfall station at Guwahati which is situated at the lower reach of the basin having considerable flatter terrain.

In this study the Large-scale predictor variables obtained from the National Centre for Environmental Prediction (NCEP) reanalysis data and observed meteorological station data are used to develop and validate a Statistical downscaling model for establishing a statistical relationship between the data. Using this downscaling model the possible future scenarios of temperature and precipitation variations are generated using large-scale predictor variables obtained from the Global Climate Model (GCM) outputs. Downscaling has been carried out by statistical approaches using ASD (Automated Statistical Downscaling) model. The statistical model uses the HadCM3 daily weather data under A2 scenario to determine the precipitation and temperature variations at a specific site.

The result shows decrease in precipitation in the early monsoon period and marginal increase in precipitation in the late monsoon period in the future. The future series generated by temperature model has produced up to 1.8^0C rise in the maximum temperature averaged over month. In the process of model development, it was experienced that the selection of predictors plays an important role in future series generation through downscaling of GCM.

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CHAPTER 1 : INTRODUCTION

Climate change has been defined by the United Nations Framework Convention on Climate Change 2007 as, "a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods".

Climate change is caused by greenhouse gases which trap the outgoing radiations and leads to increasing of the earth's temperature. Carbon Dioxide and Water Vapour are mainly responsible for increasing the temperature. The artificial gases responsible for greenhouse effect are Carbon dioxide (CO_2), Methane (CH_4), Chlorofluorocarbons (CFC), Nitrous Oxide (NO_2) and others. After Industrialization CO_2 has been significantly increasing and is the major greenhouse gas. The artificial greenhouse gases that are causing global warming are produced from the burning of fossil fuels. Paddy fields, swamps and marshes are the sources of emission of Methane. Gases such as CFCs, HFCs and PFCs enter the atmosphere through their use in air conditioning, refrigeration, propellants etc.

The world wide emission of greenhouse gases has been rising since industrialization. The increase of CO_2 since 1940 follows exponential growth. With such a rate of emission, amount of CO_2 in the atmosphere is likely to be doubled in the near future. The developing countries like India and China is also adding to the amount of CO_2 as the demand for energy has increased.

1.1 THE IMPACTS OF CLIMATE CHANGE

The Intergovernmental Panel on Climate Change has identified five key areas to be influenced from increasing temperature. They are Water, Agriculture, Ecosystems, Health and Coastlines. The rising temperature will lead to intensification of the hydrological cycle. The result may be in dryer dry seasons and wetter rainy seasons.

The Changing climate will lead to decline in the Agricultural yield as many of the varieties of crop would not be able to survive such a climate. However, some colder region of the world may become better for sustaining crops.

Increasing temperature will also have significant impacts on the availability of water as well as the quality and quantity of water. The global warming causes melting of glaciers which will increase flood risk during the rainy season, and strongly reduce dry-season water supplies. Higher temperatures expand the range of some dangerous vector-borne diseases, such as malaria. The rising of sea levels resulting from melting ice will also lead to salt water contamination of groundwater supplies, thus threatening the quality and quantity of freshwater.

1.2 IMPACT OF CLIMATE CHANGE ON WATER RESOURCES

In the future, water is the resource that will have a profound effect of climate change. Global warming will alter the water distribution, thus there will become more water, but not everywhere. Climate change is expected to increase the severity and frequency of weather-related natural hazards such as storms, heavy rainfall, floods, and droughts.

The increasing global warming will accelerate the hydrologic cycle, altering the rainfall and eventually the runoff. The rainfall pattern will be considerably changed. Warm air can hold more moisture and increases the evaporation of surface moisture which tends to increase the precipitation. Monsoon rainfall can vary leading to flood as well as drought.

Developing countries like India has already understood the impact of climate change which will be induced as a result of maintaining economic growth and requirement of energy to sustain such a growth.

The future impacts of climate change, identified by the Government of India's National Communications (NATCOM) in 2004 include:

- Decreased snow cover, affecting snow-fed and glacial systems such as the Ganges and Brahmaputra. 70% of the summer flow of the Ganges comes from meltwater
- Erratic monsoon with serious effects on rain-fed agriculture, peninsular rivers, water and power supply
- Drop in wheat production by 4-5 million tones, with even a 1ºC rise in temperature
- Rising sea levels causing displacement along one of the most densely populated coastlines in the world, threatened freshwater sources and mangrove ecosystems
- Increased frequency and intensity of floods. Increased vulnerability of people in coastal, arid and semi-arid zones of the country
- Over 50% of India's forests are likely to experience shift in forest types, adversely impacting associated biodiversity, regional climate dynamics as well as livelihoods based on forest products.

1.3 BRAHMAPUTRA RIVER SYSTEM

The Brahmaputra is one of the largest rivers of the world. Its sources are near Mansarovar in a great glacier mass in the Kailash range of Himalayas. The river flows through a length of 1600 km in Tibet, over 160 km in Arunachal Pradesh, 720 km in Assam and rest in Bangladesh. It has a length of 2880 km and width as high as 18 km.

The Himalayas acts as a climate divide. In winter, it serves as a barrier to the intense cold continental air flowing southwards and in monsoon months, the moist rain bearing winds are forced up the mountains to deposit their moisture. The South West Monsoon, which enters Assam and adjoining area around the end of May and beginning of June establishes firmly over the entire North East India by June end. During the monsoon season a low pressure region develop and extends from the seasonal low over Rajasthan to the Bay of Bengal. This monsoon axis oscillates about its normal position to the north and south during this season. When it moves north, towards the foothill of Himalayas, the rainfall over Assam increases.

1.4 ORGANISATION OF THE REPORT

The entire work presented in this report has been divided into chapters and presented in a sequential manner for easy understanding of the readers. The present chapter is an introduction to the subject.

Chapter 2 provides some insight into the Climate modeling aspects. It explains the different types of climate model which have originated in the past and its evolution in the form of GCMs.

Chapter 3 is the Survey of Literature. The purpose of this survey is to focus on strategies and policies for downscaling large scale predictor variables to obtain meteorological variables under future climatic variation at a specific site.

Chapter 4 present the methodology applied in this project work. It defines the study area, models used and techniques applied to arrive at future predictand.

The study of precipitation characteristic in the Brahmaputra basin has been carried out both at the upper and lower reach of the basin. Chapter 5 provides the study undertaken at the upper reach while lower reach has been dealt with in Chapter 6.

Chapter 7 present an attempt made to examine whether there is any change in the observed rainfall of Guwahati station under consideration due to climatic impact. This has been done by trend analysis of the available rainfall series.

A conclusion on the whole work with the findings of the project and limitation of the study has been presented at Chapter 8 along with the scope of future work.

CHAPTER 2: CLIMATE MODELLING

The climate models take account of incoming energy as short wave electromagnetic radiation, chiefly visible and short-wave infrared, as well as outgoing energy as long wave infrared electromagnetic radiation from the earth. Any imbalance results in a change in temperature.

2.1 Types of Climate model

Four basic types of model are described below [10] [17].

Zero-dimensional models

They predict the surface temperature as a function of the energy balance of the earth. A very simple model of the radiative equilibrium of the Earth is

$$(1 - a)S\pi r^2 = 4\pi r^2 \varepsilon\sigma T^4$$

where

- the left hand side represents the incoming energy from the Sun
- the right hand side represents the outgoing energy from the Earth, calculated from the Stefan-Boltzmann law assuming a constant radiative temperature, T, that is to be found,

and

- S is the solar constant - the incoming solar radiation per unit area—about 1367 $W \cdot m^{-2}$
- a is the Earth's average albedo, measured to be 0.3.
- r is Earth's radius—approximately 6.371×10^6m
- π is the mathematical constant (3.141...)
- σ is the Stefan-Boltzmann constant—approximately $5.67\times10^{-8}\ J\cdot K^{-4}\cdot m^{-2}\cdot s^{-1}$
- ε is the effective emissivity of earth, about 0.612

Radiative-Convective Models

One dimensional models such as radiative-convective models focuses on the processes in the vertical. They compute the temperature profile by explicit modeling of radiative processes and a convective adjustment which reestablishes a predetermined lapse rate. The radiative-convective models have advantages over the simple model. They can determine the effects of varying greenhouse gas concentrations on effective emissivity and therefore the surface temperature. But added parameters are needed to determine local emissivity and albedo and address the factors that move energy about the earth.

Dimensionally constrained climate models

Dimensionally constrained climate models typically represent two horizontal dimensions or the vertical plus one horizontal dimension. These models also tended to include a more realistic parameterization of the latitudinal energy transport. In such models, the general circulation is assumed to be composed mainly of a cellular flow between latitudes, which is characterized using a combination of empirical and theoretical formulations. A set of statistics summarizes the wind speeds and directions while an eddy diffusion coefficient of the type used in EBMs governs energy transport. As a consequence of this approach, these models are called 'statistical dynamical' (SD) models. These 2D SDs can be considered as the first attempts at Earth modelling with intermediate complexity – the EMICs. Models of intermediate complexity bridge the gap between the conceptual, more inductive models and general circulation models operating at the highest spatial and temporal resolution. One example of EMIC is the Climber-3 model. Its atmosphere is a 2.5-dimensional statistical-dynamical model with 7.5° × 22.5° resolution and time step of 1/2 a day; the ocean is MOM-3 (Modular Ocean Model) with a 3.75° × 3.75° grid and 24 vertical levels.

GCMs (Global Climate Models or General circulation models)

Numerical models (General Circulation Models or GCMs), representing physical processes in the atmosphere, ocean, cryosphere and land surface, are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentrations.

The solution of a series of equations that describe the movement of energy, momentum and various tracers (e.g. water vapour in the atmosphere and salt in the oceans) and the conservation of mass is therefore required. Generally the equations are solved to give the mass movement (i.e. wind field or ocean currents) at the next time step, but models must also include processes such as cloud and sea ice formation and heat, moisture and salt transport. The first step in obtaining a solution is to specify the atmospheric and oceanic conditions at a number of 'grid points', obtained by dividing the Earth's surface into a series of rectangles, so that a traditionally regular grid results. Conditions are specified at each grid point for the surface and several layers in the atmosphere and ocean. The resulting set of coupled non-linear equations is then solved at each grid point using numerical techniques. Various techniques are available, but all use a time step approach. GCMs depict the climate using a three dimensional grid over the globe, typically having a horizontal resolution of between 250 and 600 km, 10 to 20 vertical layers in the atmosphere and sometimes as many as 30 layers in the oceans.

2.2 Downscaling

Downscaling refers to techniques that take output from the model and add information at scales smaller than the grid spacing. General circulation models (GCMs) used in assessing the climate change impact are run on a coarse scale and thus the simulation results obtained from GCMs are not particularly useful in a comparatively smaller river basin scale hydrology. Global climate models (GCMs) are run at coarse spatial resolution and are unable to resolve important sub-grid scale features such as clouds and topography. As a result GCMs can't be used for local impact studies. To overcome this problem downscaling methods are developed to obtain local-scale surface weather from regional-scale atmospheric variables that are provided by GCMs. Broadly downscaling is divided into four categories: regression methods, weather pattern-based approaches, stochastic weather generators and limited-area modeling. Among this approaches regression methods are preferred because of its ease of implementation and low computation requirements.

CHAPTER 3 : LITERATURE SURVEY

The purpose of this literature survey is to focus on strategies and policies for downscaling large scale predictor variables to obtain meteorological variables under future climatic variation at a specific site. A selective presentation is made below of the literature survey carried out.

3.1. Global Climate Change

Climate change is typically discussed in global terms, yet its effects vary quite dramatically among different regions of the earth. What we do know for certain is that over the last 100 years the earth has experienced an approximate 0.6°C (1.1°F) increase in global mean annual temperature (IPCC, 2001) [1]. This warming trend is expected to continue, increasing at alarming rates.

The leading scientific research authority on global climate change, the Intergovernmental Panel on Climate Change (IPCC), produced its Third Assessment Report in 2001. In this report, it was projected that there will be a 1.4 to 5.8°C (2.5 to 10.4°F) increase in globally averaged surface temperature between 1990 and 2100. In order to put this number in perspective, the IPCC states that this amount of warming exceeds that of the 20th century by two to ten times, and this rate of warming is faster than any rate within the last 10,000 years.

3.2. Climate change and water resources

The Climate Change study carried out by Gulay Onusluel Gul *et al.* (2010) [5] employs a technical reasoning to set up a model for analysing the variable impacts of potential changes in regional climatic conditions on the lowland catchment of the Havelse river system in Denmark. Although the simulation results from different global circulation models (GCMs) indicate different responses in flows to the climate change, there are obvious deviations of the river flows and environmental flow potentials computed for all the scenario cases from the averages of the base period with current conditions.

Se-Yeun Lee *et al.* (2009) [16] carried out a study especially for large, multi-objective water systems to adapt to the hydrologic changes, refill timing and evacuation requirements for flood control need owing to climate change. An existing optimization/ simulation procedure is refined for rebalancing flood control and refill objectives for the Columbia River Basin for anticipated global warming. To calibrate the optimization model for the 20th century flow, the objective function is tuned to reproduce the current reliability of reservoir refill, while providing comparable levels of flood control to those produced by current flood control practices. After the optimization model is calibrated using the 20th century flow the same objective function is used to develop flood control curves for a global warming scenario which assumes an approximately 2°C increase in air temperature. Robust decreases in system storage deficits are simulated for the climate change scenario when optimized flood rule curves replace the current flood control curves, without increasing monthly flood risks.

Minville *et al.* (2008) [13] evaluated the impact of climate change on the hydrology of the Chute-du-Diable watershed (Quebec, Canada) by comparing statistics on current and projected future discharge resulting from a wide range of climate change scenarios. Results indicate a 1–14 _C increase in seasonal temperature and a _9 to +55% change in seasonal precipitation. The largest increases in both temperature and precipitation are observed in the winter and spring seasons. The main hydrologic impact observed is a spring flood appearing 1–5 weeks earlier than usual and a modification of its amplitude from _40 to +25%. Most scenarios suggest increases in the winter, spring and fall discharge, whereas summer is expected to see a decrease in discharge. While there is still a large scatter in projected values, the uncertainty analysis projects a better view of the most probable future hydrologic behaviour of the watershed.

R. K. Mall *et al.* (2006) [14] examined the potential for sustainable development of surface water and groundwater resources within the constraints imposed by climate change and future research needs in India. The paper present an assessment of the availability of water resources in the context of future national requirements and expected impacts of climate change and its variability is critical for relevant National and regional long-term development strategies and sustainable development.

3.3. Statistical downscaling approaches

Statistical downscaling is based on the use of statistical tools and rules to develop local scale hydro-meteorological data using the GCM outputs. Statistical downscaling approaches can be classified into three broad categories, namely (1) weather typing (2) weather generators and (3) regression-based downscaling.

Ricardo M. Trigo *et al.* (2001) [15] carried out Comparison between Direct GCM Output and Different Downscaling Techniques to study the Precipitation Scenarios over Iberia. In this work, linear and nonlinear downscaling transfer functions are developed based on artificial neural networks (ANNs), to downscale monthly precipitation to nine grid boxes over the Iberian Peninsula. It was found that the precipitation characteristics (mean, variance, and empirical distribution) were better reproduced by the downscaled results than by the GCM direct output. Precipitation scenarios constructed for the future (2041–90) reveal an increase of precipitation in winter and small decreases in most sectors of Iberia for the spring and autumn seasons. Such scenarios are in good agreement with those obtained by other researchers using different downscaling techniques with HadCM2 data.

Dibike and Coulibaly, (2005) [2] used Weather generators for filling missing data and interpolating or extrapolating the data to indefinite length by using the statistical properties of the available observed data.

Subimal Ghosh and P. P. Mujumdar (2006) [3] presented a methodology for examining future rainfall scenario using fuzzy clustering technique from GCM projections. In another study Ghosh S and Mujumdar P P (2008) [4] presented a methodology of statistical downscaling based on sparse Bayesian learning and Relevance Vector Machine (RVM) to model streamflow at river basin scale for monsoon period (June, July, August, September) using GCM simulated climatic variables. NCEP/NCAR reanalysis data have been used for training the model to establish a statistical relationship between streamflow and climatic variables. The relationship thus obtained is used to project the future streamflow from GCM simulations. The statistical methodology involves principal component analysis, fuzzy clustering and RVM. Different kernel functions are used for comparison purpose. The model is applied to Mahanadi river basin in India.

3.4. Dynamical downscaling approaches

The regional climate models (RCM) are of higher resolution as compared to the General Circulation Models. They can be used to model the atmospheric process within a particular area with input of the boundary conditions from the GCM. They are used as an alternative to the Statistical downscaling approaches.

Manoj Jha *et al.* (2003) [12] evaluated the impact of climate change on stream flow in the Upper Mississippi River Basin (UMRB) by using a regional climate model (RCM) coupled with a hydrologic model the Soil and Water Assessment Tool (SWAT). They found that a 21 percent increase in future precipitation simulated by the RCM produced an 18 percent increase in snowfall, a 51 percent increase in surface runoff, and a 43 percent increase in groundwater recharge, resulting in a 50 percent net increase in total water yield in the UMRB on an annual basis.

3.5. Conclusion

From the extensive search of literature, it can be concluded that the awareness of possible impacts of climate change has already evolved worldwide. Attentions are being focused on studying the sensitivity of climate to enhanced levels of greenhouse gases. However, limited studies are made towards quantification of the impacts of climate change on precipitation in the Indian region. Hardly any literature could be found to address the change in precipitation brought about by climatic variations in the Brahmaputra Basin. Thus the study of climate change in this part of the world seems to be essential and also challenging due to its most distinguishing feature being the abundance of rainfall between March and May at a time when rain in other parts of India is at its minimum. Along with ample precipitation in this part of the country is the associated water induced disasters. These problems may worsen because of impacts of global climate change. These facts motivated me to take up this work of addressing climate change impact in the Brahmaputra basin.

CHAPTER 4 : METHODOLOGY

In this study the Large-scale predictor variables obtained from the National Centre for Environmental Prediction (NCEP) reanalysis data and observed meteorological station data are used to develop and validate a Statistical downscaling model for establishing a statistical relationship between the data. Using this downscaling model the possible future scenarios of temperature and precipitation variations are generated using large-scale predictor variables obtained from the Global Climate Model (GCM) outputs.

4.1 STUDY AREA

This present work aims to study the future precipitation variation in the Brahmaputra basin. Brahmaputra is the biggest river in India with as many as 48 important tributaries of which 31 are on the north bank and 17 on the south bank. The north bank tributaries have steep slopes, shallow braided channels and catchment area having intense rainfall. The unique hydro-meteorological, geo-morphological and topographical conditions of the catchment and the valley combines to create a condition of high potential on the one hand and large scale devastation and destruction on the other hand.

It is intended to utilize specific rainfall station data to study the possible climatic variations in the future and its impact on precipitation characteristics. Considering the variation of precipitation and topography in the entire basin, two stations have been selected based on their contrasting features and also on the availability of data. One of the sites is Gerukamukh rainfall station in the Subansiri river basin at Arunachal Pradesh which is located on the upper reach of the basin. The other site is the rainfall station at Guwahati which is situated at a lower reach with considerable flatter terrain and to the south west of the Brahmaputra basin. The study for both the station has been individually carried out and placed at chapter 5 & 6.

4.2 GENERAL CIRCULATION MODEL USED

Atmospheric variables from A2 scenario simulation run of a GCM named HadCM3 has been used for the study considering its better resolution than the others. HadCM3 (abbreviation for Hadley Centre Coupled Model, version 3) is a coupled atmosphere-ocean general circulation model (AOGCM) developed at the Hadley Centre in the United Kingdom has been used as the GCM model to obtain large scale predictors. Unlike earlier AOGCMs at the Hadley Centre and elsewhere, HadCM3 does not need flux adjustment (additional "artificial" heat and freshwater fluxes at the ocean surface) to produce a good simulation [18].

HadCM3 is composed of two components: the atmospheric model HadAM3 and the ocean model (which includes a sea ice model). Simulations often use a 360-day calendar, where each month is 30 days.

HadAM3 is a grid point model and has a horizontal resolution of 3.75×2.5 degrees in longitude × latitude. This gives 96×73 grid points on the scalar (pressure, temperature and moisture) grid; the vector (wind velocity) grid is offset by 1/2 a grid box. This gives a resolution of approximately 300 km. There are 19 levels in the vertical.

The ocean model has a resolution of 1.25×1.25 degrees, 20 levels. Thus there are 6 ocean grid points for every atmospheric one. The atmospheric model is run for a day, and the fluxes (of heat, moisture and momentum) at the atmos-ocean interface are accumulated. Then the ocean model is run for a day, with the reverse fluxes accumulated. This then repeats through the length of the run.

4.3 DOWNSCALING TECHNIQUE USED

In this study statistical downscaling technique has been applied for downscaling and future weather generation. The Automated Statistical Downscaling (ASD) tool is used for the statistical downscaling of GCM outputs to regional or local variables. This tool has been developed by the team of the Canada Research Chair on the Estimation of Hydrometeorological variables (Pr. T. Ouarda), in collaboration with the Adaptation and Impacts Research Division[6]. The development team includes also Pr. M. Hessami from Shahid Bahonar University of Kerman (Iran) and A. St-Hilaire from INRS-ÉTÉ. ASD runs on all platforms that support MATLAB.

ASD is a hybrid of a stochastic weather generator and regression-based downscaling methods and facilitates the rapid development of multiple, low-cost, single-site scenarios of daily surface weather variables under current and future climate forcing. ASD is designed to help the user identify those large-scale climate variables (the predictors) which explain most of the variability in the climate (the predictand) at a particular site and statistical models are then built based on this information. Statistical models are built using daily observed data – local climate data for a specific location for the predictand and larger-scale NCEP data for the predictors – and these models are then used with GCM-derived predictors to obtain daily weather data at the site in question for a future time period.

The advantage of using Statistical downscaling includes that it is computationally inexpensive, and thus can be easily applied to the output of different GCM experiments. The following three inherited assumptions are involved in the statistical downscaling:

- predictors are variables of relevance and are realistically modeled by the GCMs
- the employed predictors fully represent the climate change signal
- these observed empirical relationships are valid also under altered climate change conditions

CHAPTER 5 : PRECIPITATION & TEMPARATURE MODEL FOR STATION AT UPPER REACH OF BRAHMAPUTRA BASIN

The four main tributaries of Brahmaputra namely Dehang, Debang, Lohit and Subansiri contribute as much as 60% of the total flow of the entire Brahmaputra River at Guwahati. Of this, the contribution of Subansiri is 11%. The Subansiri river basin is one of the largest sub basins in the Brahmaputra Valley. The Subansiri River and its tributaries drain an area of more than 37000 sq km upto the confluence of river Brahmaputra. The catchment includes mountainous terrain ranging in height from 5591 m in the Himalayas to about 152 m near the foot hills. A considerable part of the catchment is snow fed. This catchment is extremely important from the view of hydropower generation. Considering the features of the catchment a site named Gerukamukh is selected for study of impact of climate change on precipitation characteristics in the upper reaches of Brahmaputra basin. The Gerukamukh station is located in the Subansiri basin at a latitude-longitude of about 27.5^0N -94^0E.

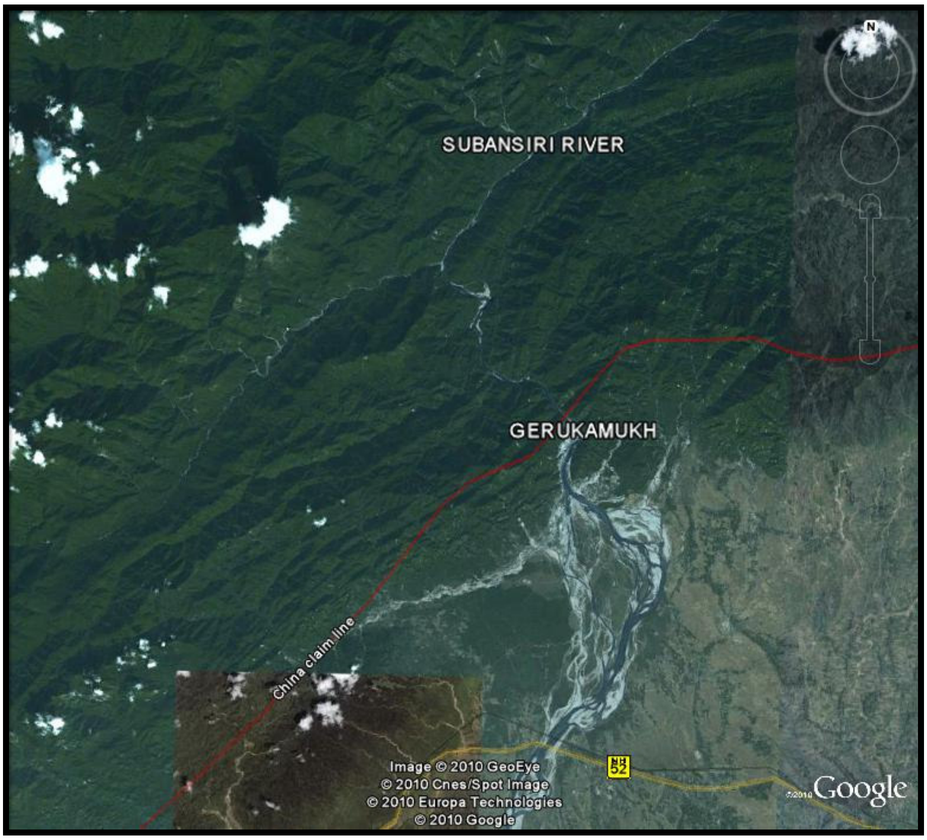


Fig 5.1: Gerukamukh site in the Subansiri river basin (source: Google)

5.1 Data used and Selection of predictors

The data used for this station includes

- NCEP_1961-2001: This contains 41 years of daily predictor data, derived from the NCEP reanalyses. These data were interpolated to the same grid as HadCM3.
- HadCM3A2_1961-2099: This contains daily GCM predictor data, derived from the HadCM3 GCM following the SRES A2 scenario. The data is accessed from web-site: www.cics.uvic.ca.
- Precipitation Data: Observed precipitation at the Gerukamukh site for the period 1976-1984 and 1992 – 1998. However few month of rainfall are considered as average of corresponding months due to unavailability.
- Temperature Data : Observed temperature data at the Gerukamukh site for the period 1995-1998

The selection of the most relevant predictor variables is the first task for setting the precipitation and temperature model. A general way is to carry out correlation between the predictors and the predictand. However, after many trial simulations run with different predictors it is learnt that the predictors of the NCEP & GCM which have similarity in the variance ultimately leads to better validation of the model. Hence, in this study an effort has been made to analyse the similarity of distribution (e.g. variance) using Ansari-Bradley test to arrive at the relevant predictors. Table 5.1 & 5.2 gives the values of the Ansari-Bradley test between the NCEP and GCM predictors and Correlation between the NCEP predictors and predictand. In the Ansari Bradley test '0' indicates that there is no reason to reject the null hypothesis, that the two series have come from the same distribution, whereas '1' indicates that the alternative that they come from distributions that have the same median and shape but different dispersions (e.g. variances).

NCEP Predictors	Homogeneity of NCEP with GCM Variable		Correlation of NCEP with observed Temperature
	Ansari-Bradley test		
	Null hypothesis	Probability	
ncepmslpas	0	0.899	-0.594
ncepp5_fas	0	0.2612	-0.686
ncep5_uas	0	0.8168	-0.689
ncep5_vas	0	0.4835	0.252
ncepp5_zas	1	0	-0.475
ncepp5thas	1	0.2291	0.273
ncepp5zhas	0	0.1904	-0.268
ncepp8_fas	1	0	-0.213
ncepp8_uas	1	0.0002	0.152
ncepp8_vas	0	0.0784	0.201
ncepp8_zas	1	0	0.066
ncepp8_thas	1	0.0689	-0.051
ncepp8zhas	0	0.0584	-0.284
ncepp500as	0	0.0067	0.758
ncepp850as	0	0.6993	-0.453
ncepp_fas	1	0.0037	-0.031
ncepp_uas	1	0	-0.061
ncepp_vas	1	0	-0.352
ncepp_zas	0	0.9633	0.297
ncepp_thas	0	0	0.034
ncepp_zhas	1	0	-0.390
ncepr500as	0	0.2213	0.453
ncepr850as	0	0.0088	0.474
ncephumas	1	0	0.468
ncepshumas	0	0.1898	0.765
nceptempas	0	0.0009	0.733

Table 5.1 : Ansari Bradley test and Correlation for Temperature model

NCEP Predictors	Homogeneity of NCEP with GCM Variable		Correlation of NCEP with observed rainfall
	Ansari-Bradley test		
	Null hypothesis	Probability	
ncepmslpas	0	0.899	-0.423
ncepp5_fas	0	0.2612	-0.315
ncep5_uas	0	0.8168	-0.294
ncep5_vas	0	0.4835	0.148
ncepp5_zas	1	0	-0.196
ncepp5thas	1	0.2291	0.062
ncepp5zhas	0	0.1904	-0.155
ncepp8_fas	1	0	-0.122
ncepp8_uas	1	0.0002	0.261
ncepp8_vas	0	0.0784	0.204
ncepp8_zas	1	0	0.052
ncepp8_thas	1	0.0689	-0.239
ncepp8zhas	0	0.0584	-0.239
ncepp500as	0	0.0067	0.307
ncepp850as	0	0.6993	-0.408
ncepp_fas	1	0.0037	-0.240
ncepp_uas	1	0	0.146
ncepp_vas	1	0	-0.071
ncepp_zas	0	0.9633	0.192
ncepp_thas	0	0	0.058
ncepp_zhas	1	0	-0.245
ncepr500as	0	0.2213	0.352
ncepr850as	0	0.0088	0.282
nceprhumas	1	0	0.239
ncepshumas	0	0.1898	0.432
nceptempas	0	0.0009	0.389

Table 5.2 : Ansari Bradley test and Correlation for precipitation model

A few numbers of predictors are initially chosen based on the above test of variance and correlation. Among the chosen predictors, the table below shows the predictors which are finally retained after calibration and validation of the models.

STATION	PREDICTANDS	PREDICTORS
Gerukamukh	Temperature	Mean sea level pressure Surface Vorticity 500hpa geo-potential height
	Precipitation	Surface Vorticity 500hpa zonal velocity

Table 5.3: List of Predictors finally adopted for Gerukamukh

5.2 MODEL CALIBRATION AND VALIDATION

The calibration and validation of the temperature and precipitation model is explained below with the graphical plot of outputs. As stated earlier, the predictors finally arrived after the calibrations are shown in the table 5.3 above.

5.2.1 Temperature model

The Temperature model uses the large predictor from NCEP data and observed data at Gerukamukh from 1995 to 1997 during calibrating the model. The validation was carried out using the data from 1996 to 1998 which is overlapping with the calibration period. It may be revisited here that the temperature data is only available for a period of four years.

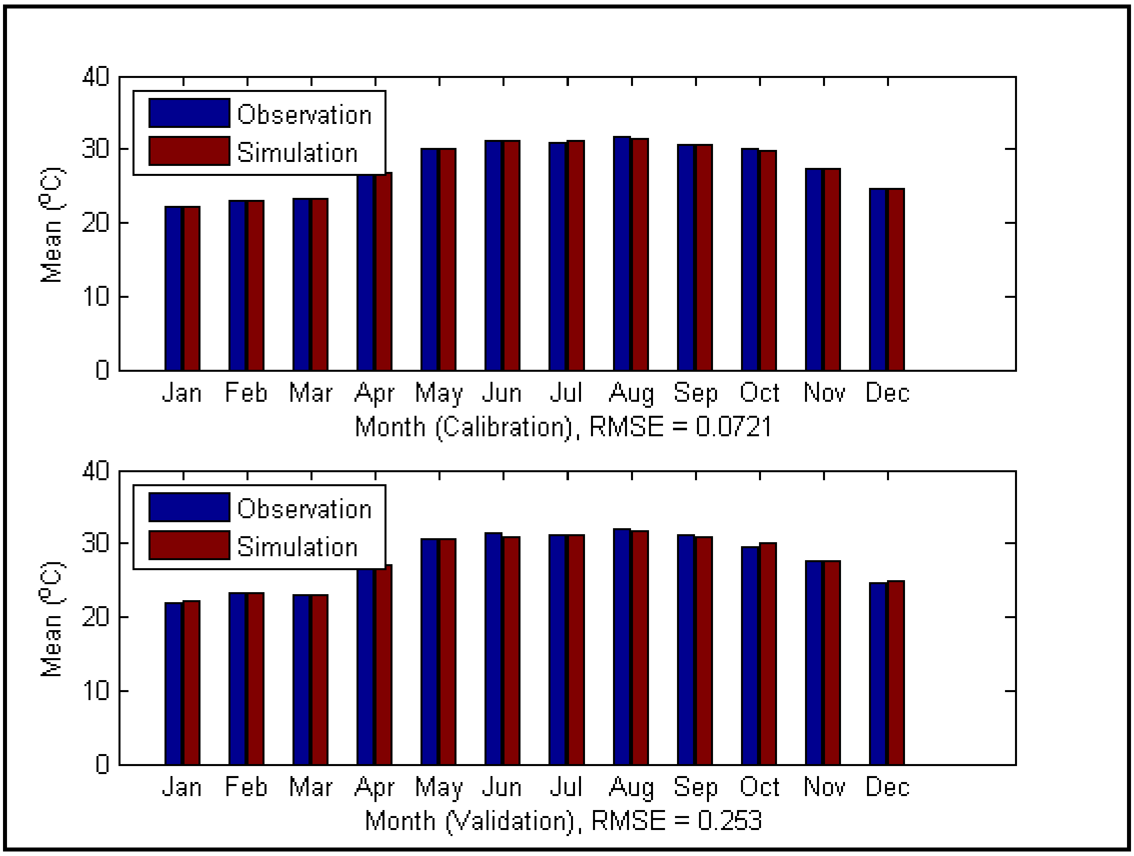


Fig 5.2 : Calibration and validation of Temperature model using NCEP data

Again the model has been validated by GCM data for the calibration (1995-1997) period and validation (1996-1998) period.

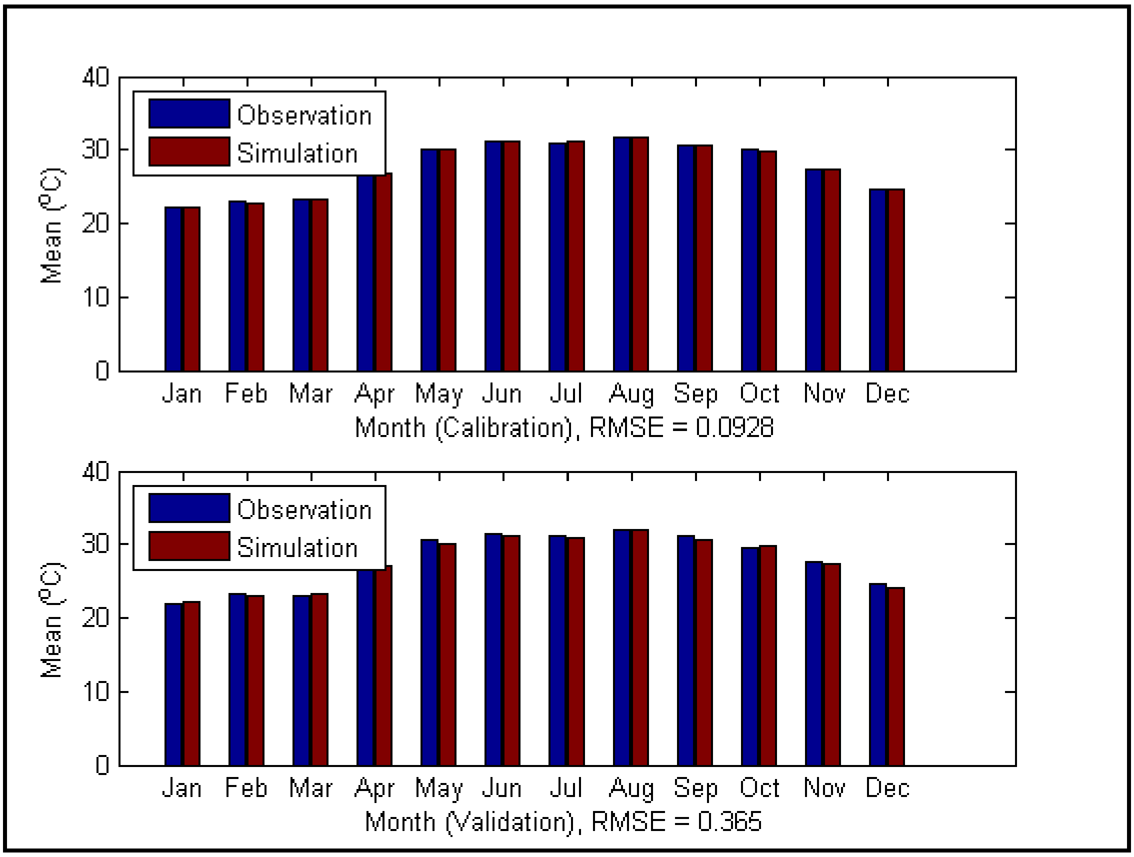


Fig 5.3 : Validation of Temperature model using GCM data

5.2.2 Precipitation model

For calibrating the precipitation model, observed precipitation data at Gerukamukh is used for the period 1975 to 1984. The model has been validated using NCEP data set for the period 1992 to 1998. Fig 5.4 shows the calibration and validation with NCEP data. The validation with GCM data has been placed at Fig 5.5.

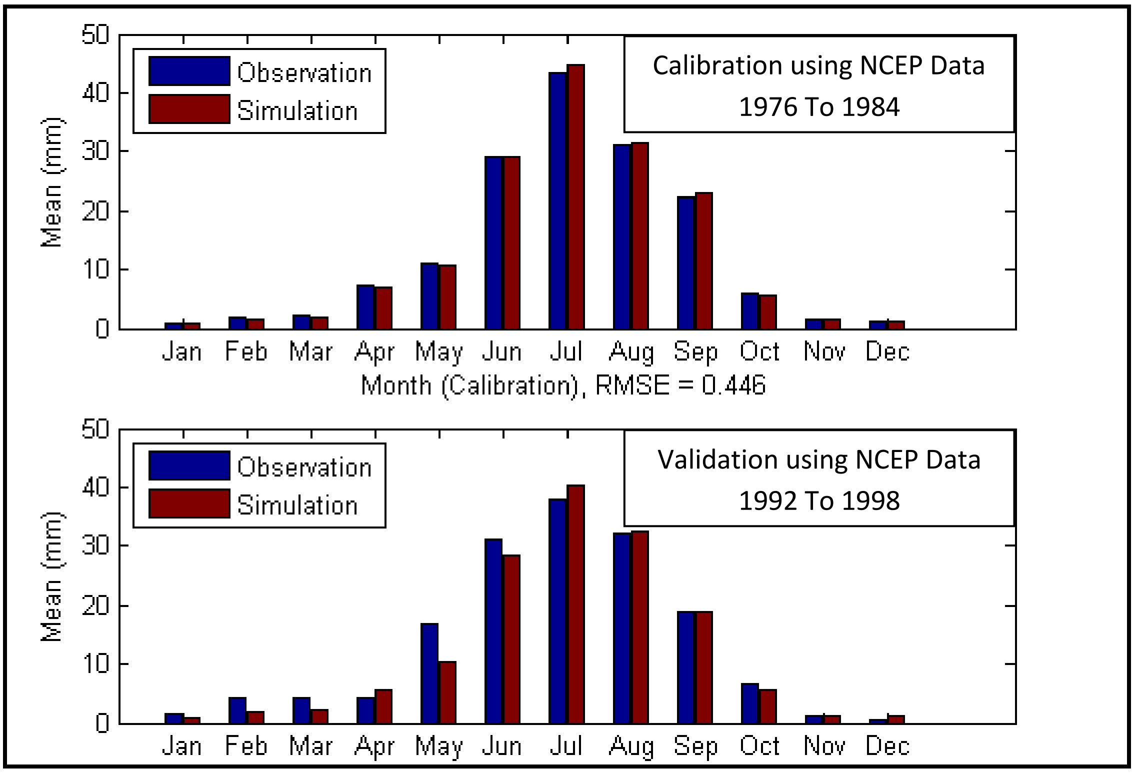


Fig 5.4 : Calibration and validation of Precipitation model using NCEP data

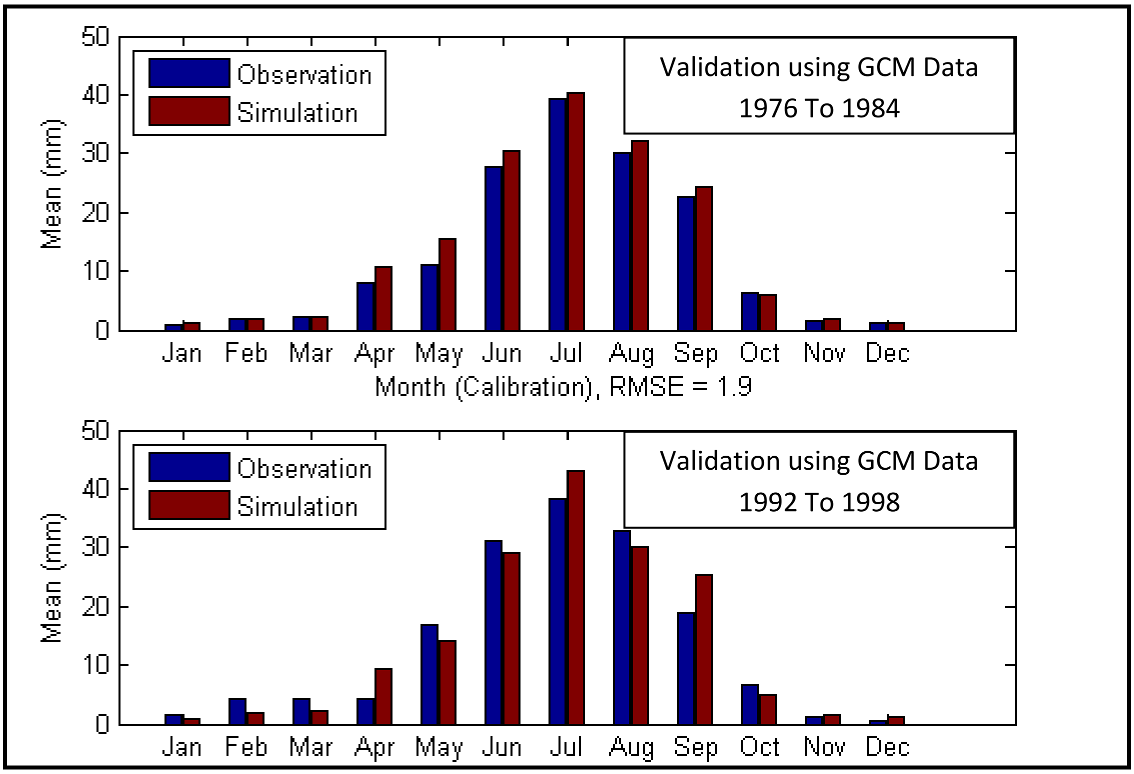


Fig 5.5 : Validation of Precipitation model using GCM data

5.3 FUTURE DATA GENERATION

Using the Temperature model, future data set of 2011 to 2040 and 2041-2070 has been generated for climate change SRES A2 scenario using HadCM3 predictors. The daily Maximum temperature averaged over corresponding months of the data period is shown below where the future data set is compared with the observed.

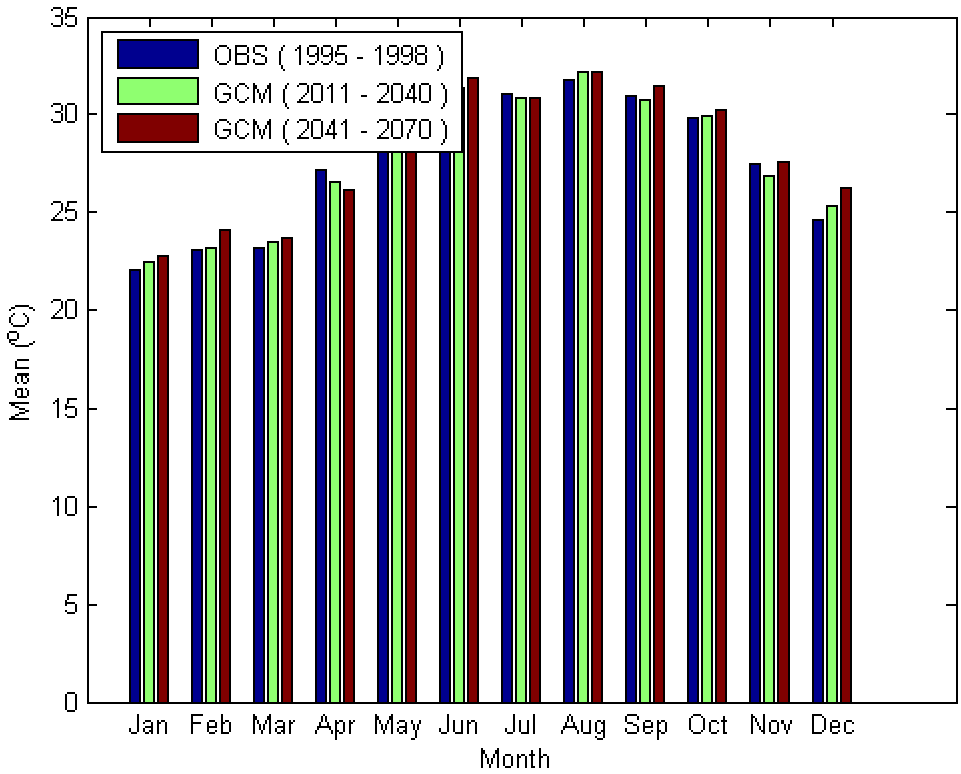


Fig 5.6 : Comparison of present and future (generated) Temperature

It is seen that the temperature is substantially increasing in the period from 2041 to 2070. A rise upto 1.8 degree celcius in the daily Maximum Temperature averaged in months can be observed from the generated data.

Now, the calibrated and validated precipitation model has been used to generate future Precipitation data set of 2011 to 2040 and 2041-2070 using HadCM3 predictors for SRES A2 scenario. The comparision of precipitation (mm/day) averaged over month is plotted between the observed and generated future data and placed at Fig 5.7.

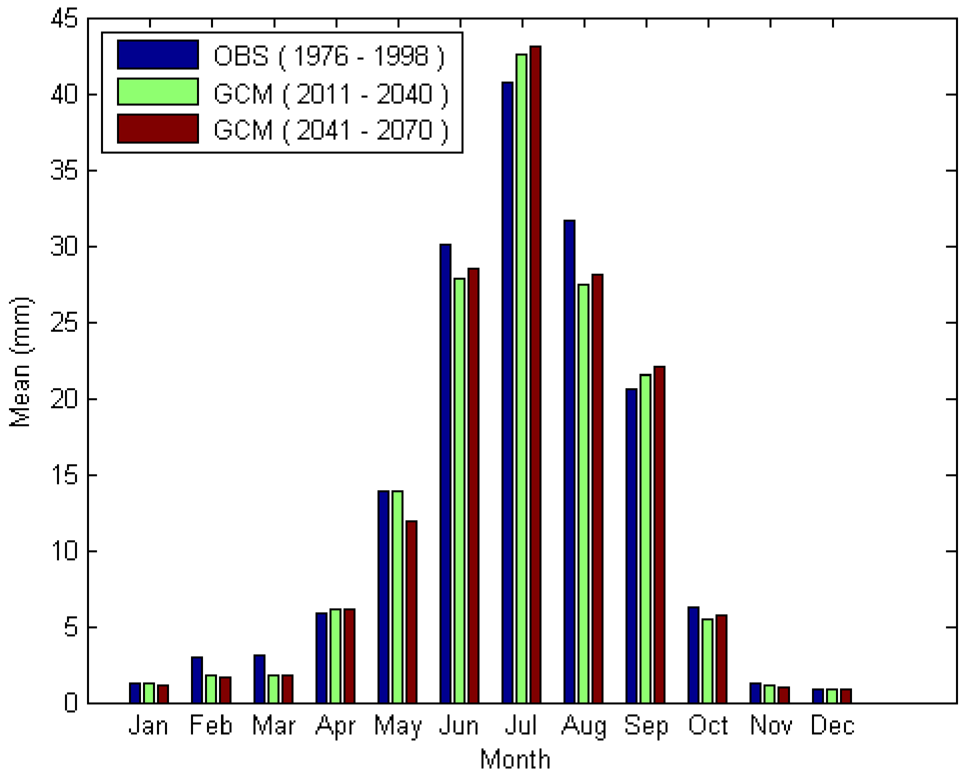


Fig 5.7 : Comparison of present and future (generated) Precipitation

The validation of the precipitation model with GCM data was not very encouraging during the validation period of 1992-1998. Hence the generated future precipitation series cannot be accepted for all months. The generated precipitation series does not provide any indication of significant trend in change in the precipitation volumes in future, although the precipitation in particular month like May & June seems to be decreasing.

CHAPTER 6: PRECIPITATION MODEL FOR STATION AT LOWER REACH OF BRAHMAPUTRA BASIN

In order to ascertain the impact of climate change on precipitation characteristics at the lower reach of Brahmaputra Basin on Indian soil, the precipitation station at Guwahati has been selected for the study based on availability of data. The rainfall station at Guwahati along with the nearest grid points at which GCM data of HadCM3 are available are shown in the figure below.

Fig 6.1: Guwahati station along with four neighbouring grid points (Source: Google)

It can be seen that the grid points of HadCM3 are not available exactly over the station at Guwahati (26^0 N – 91.35^0E). Hence four case studies have been taken up for formulating precipitation model of the observed data with predictors at each of the four available GCM points individually. Also, another case study has been incorporated by linearly interpolating the available GCM variables to the coordinates at Guwahati. Hence five different case study of future precipitation projections are attempted using GCM data of HadCM3 as listed below:-

CASE 1 : Lat-Long : 25^0 N – 90^0E
CASE 2 : Lat-Long : 25^0 N– 93.75^0E
CASE 3 : Lat-Long : 27.5^0 N – 90^0E
CASE 4 : Lat-Long : 27.5^0 N – 93.75^0E
CASE 5 : Interpolated to Guwahati station at Lat-Long : 26^0 N– 91.35^0E

The data used as input includes

- NCEP_1961-2001: This contains 41 years of daily predictor data, derived from the NCEP reanalyses. These data were interpolated to the same grid as HadCM3.
- HadCM3A2_1961-2099: This contains daily GCM predictor data, derived from the HadCM3 GCM following the SRES A2 scenario. The data is accessed at web-site: www.cics.uvic.ca.
- Precipitation Data : Observed precipitation at the Guwahati rainfall station for the period 1980-2001. However few month of rainfall are considered as average of corresponding months due to unavailability.

6.1 SELECTION OF PREDICTORS

The selection of the most relevant predictor variables was carried out through correlation analysis between the predictors and the predictand variables. Also the homogeneity of distribution between the NCEP and GCM variables are checked. The tables below from 6.1 to 6.5 give the test statistics for the five precipitation model at the different GCM points mentioned above. In the Ansari Bradley test '0' indicates that there is no reason to reject the null hypothesis, that the two series have identical distribution (e.g. variance), whereas '1' indicates that the null hypothesis is not valid.

Among the predictors selected by the above correlation and Ansari-Bradley tests, the predictors finally retained which produce proper calibration and validation of the precipitation model are appended to their corresponding tables.

NCEP Predictors	Homogeneity of NCEP with GCM Variable Ansari-Bradley test		Correlation of NCEP with observed rainfall
	Null hypothesis	Probability	
ncepmslpas	0	0.2078	-0.301
ncepp5_fas	0	0.3144	-0.193
ncep5_uas	0	0.8961	-0.193
ncep5_vas	0	0.7926	0.084
ncepp5_zas	1	0.0000	-0.008
ncepp5thas	1	0.7827	0.091
ncepp5zhas	0	0.3804	-0.089
ncepp8_fas	1	0	0.175
ncepp8_uas	0	0	0.135
ncepp8_vas	0	0	0.304
ncepp8_zas	0	0.0063	-0.059
ncepp8_thas	0	0.0000	-0.093
ncepp8zhas	0	0.0010	-0.290
ncepp500as	1	0.0257	0.155
ncepp850as	0	0.4553	-0.284
ncepp_fas	1	0.0000	0.060
ncepp_uas	1	0.3371	-0.070
ncepp_vas	1	0.0000	0.298
ncepp_zas	1	0.0003	0.140
ncepp_thas	0	0.0000	0.211
ncepp_zhas	0	0.0875	-0.191
ncepr500as	0	0.1701	0.232
ncepr850as	0	0.4858	0.239
ncephumas	1	0.0000	0.212
ncepshumas	1	0.2722	0.305
nceptempas	0	0.0542	0.258

STATION	PREDICTANDS	PREDICTORS
Guwahati	Precipitation	500hpa Zonal velocity 500hpa Meridional Velocity

Table 6.1 : Correlation and Ansari-Bradley test result at Lat-Long : 25^0 N – 90^0E

(CASE1)

NCEP Predictors	Homogeneity of NCEP with GCM Variable		Correlation of NCEP with observed rainfall
	Ansari-Bradley test		
	Null hypothesis	Probability	
ncepmslpas	0	0.7062	-0.279
ncepp5_fas	0	0.3935	-0.200
ncep5_uas	0	0.8253	-0.198
ncep5_vas	1	0.0008	0.129
ncepp5_zas	0	0.9443	-0.056
ncepp5thas	1	0.0681	0.060
ncepp5zhas	1	0.0003	-0.133
ncepp8_fas	1	0.0004	0.169
ncepp8_uas	0	0.1017	0.235
ncepp8_vas	0	0.0495	0.295
ncepp8_zas	1	0	-0.158
ncepp8_thas	0	0.4152	-0.201
ncepp8zhas	1	0.0002	-0.288
ncepp500as	1	0.0011	0.171
ncepp850as	0	0.067	-0.249
ncepp_fas	1	0	-0.160
ncepp_uas	0	0.8025	0.260
ncepp_vas	0	0.0617	0.286
ncepp_zas	0	0.8743	0.088
ncepp_thas	0	0	0.010
ncepp_zhas	1	0	-0.265
ncepr500as	0	0.2399	0.257
ncepr850as	0	0.2444	0.249
nceprhumas	1	0	0.213
ncepshumas	0	0.0273	0.288
nceptempas	0	0.0553	0.240

STATION	PREDICTANDS	PREDICTORS
Guwahati	Precipitation	Mean sea level pressure 500hpa zonal velocity

Table 6.2 : Correlation and Ansari-Bradley test result for Lat-Long : 25^0 N – 93.75^0E

(CASE 2)

NCEP Predictors	Homogeneity of NCEP with GCM Variable		Correlation of NCEP with observed rainfall
	Ansari-Bradley test		
	Null hypothesis	Probability	
ncepmslpas	0	0.480	-0.299
ncepp5_fas	0	0.106	-0.201
ncep5_uas	0	0.589	-0.201
ncep5_vas	1	0.089	0.073
ncepp5_zas	1	0.001	-0.061
ncepp5thas	1	0.004	0.099
ncepp5zhas	0	0.213	-0.076
ncepp8_fas	0	0.141	-0.103
ncepp8_uas	1	0.000	0.126
ncepp8_vas	1	0.000	0.137
ncepp8_zas	1	0.000	0.013
ncepp8_thas	0	0.000	-0.037
ncepp8zhas	1	0.000	-0.159
ncepp500as	1	0.021	0.179
ncepp850as	1	0.071	-0.293
ncepp_fas	0	0.111	-0.097
ncepp_uas	1	0.000	0.047
ncepp_vas	0	0.825	-0.088
ncepp_zas	1	0.000	-0.206
ncepp_thas	0	0.000	-0.007
ncepp_zhas	0	0.239	-0.145
ncepr500as	1	0.082	0.286
ncepr850as	1	0.000	0.267
nceprhumas	1	0.000	0.267
ncepshumas	0	0.223	0.310
nceptempas	0	0.099	0.277

STATION	PREDICTANDS	PREDICTORS
Guwahati	Precipitation	Mean sea level pressure 500hpa Zonal velocity

Table 6.3 : Correlation and Ansari-Bradley test result at Lat-Long : 27.5^0 N – 90^0E

(CASE3)

NCEP Predictors	Homogeneity of NCEP with GCM Variable		Correlation of NCEP with observed rainfall
	Ansari-Bradley test		
	Null hypothesis	Probability	
ncepmslpas	0	0.899	-0.294
ncepp5_fas	0	0.2612	-0.203
ncep5_uas	0	0.8168	-0.198
ncep5_vas	0	0.4835	0.145
ncepp5_zas	1	0	-0.093
ncepp5thas	1	0.2291	0.028
ncepp5zhas	0	0.1904	-0.142
ncepp8_fas	1	0	-0.090
ncepp8_uas	1	0.0002	0.189
ncepp8_vas	0	0.0784	0.189
ncepp8_zas	1	0	0.013
ncepp8_thas	1	0.0689	-0.159
ncepp8zhas	0	0.0584	-0.210
ncepp500as	0	0.0067	0.190
ncepp850as	0	0.6993	-0.278
ncepp_fas	1	0.0037	-0.136
ncepp_uas	1	0	0.091
ncepp_vas	1	0	-0.009
ncepp_zas	0	0.9633	0.106
ncepp_thas	0	0	0.040
ncepp_zhas	1	0	-0.205
ncepr500as	0	0.2213	0.290
ncepr850as	0	0.0088	0.213
nceprhumas	1	0	0.198
ncepshumas	0	0.1898	0.296
nceptempas	0	0.0009	0.271

STATION	PREDICTANDS	PREDICTORS
Guwahati	Precipitation	Mean sea level pressure 500hpa zonal velocity

Table 6.4 : Correlation and Ansari-Bradley test result for Lat-Long : 27.5^0 N – 93.75^0E

(CASE4)

NCEP Predictors	Homogeneity of NCEP with GCM Variable		Correlation of NCEP with observed rainfall
	Ansari-Bradley test		
	Null hypothesis	Probability	
ncepmslpas	0	0.5661	-0.300
ncepp5_fas	0	0.2227	-0.202
ncep5_uas	0	0.794	-0.200
ncep5_vas	0	0.1176	0.106
ncepp5_zas	1	0	-0.049
ncepp5thas	1	0.1447	0.089
ncepp5zhas	0	0.0553	-0.110
ncepp8_fas	1	0.0001	0.075
ncepp8_uas	1	0	0.180
ncepp8_vas	1	0	0.298
ncepp8_zas	0	0.4721	-0.064
ncepp8_thas	1	0	-0.145
ncepp8zhas	0	0.2341	-0.286
ncepp500as	1	0.0019	0.171
ncepp850as	0	0.6817	-0.282
ncepp_fas	0	0.0485	-0.071
ncepp_uas	1	0.0087	0.074
ncepp_vas	0	0.6027	0.220
ncepp_zas	0	0.0859	0.073
ncepp_thas	0	0	0.151
ncepp_zhas	1	0.0377	-0.246
ncepr500as	0	0.4824	0.277
ncepr850as	1	0.0572	0.280
nceprhumas	1	0	0.249
ncepshumas	1	0.0875	0.308
nceptempas	0	0.0076	0.275

STATION	PREDICTANDS	PREDICTORS
Guwahati	Precipitation	Mean sea level pressure 500hpa zonal velocity

Table 6.5: Correlation and Ansari-Bradley test result at 26^0 N–91.35^0E **(CASE5)**

6.2 CALIBRATION AND VALIDATION OF PRECIPITATION MODEL

For calibrating the precipitation model observed precipitation data at Guwahati is used for the period 1980 to 1994. Further, the model has been validated using NCEP data set and GCM data set for the period as shown in the following figures, Fig 6.2 to Fig 6.6, for all the five considered cases.

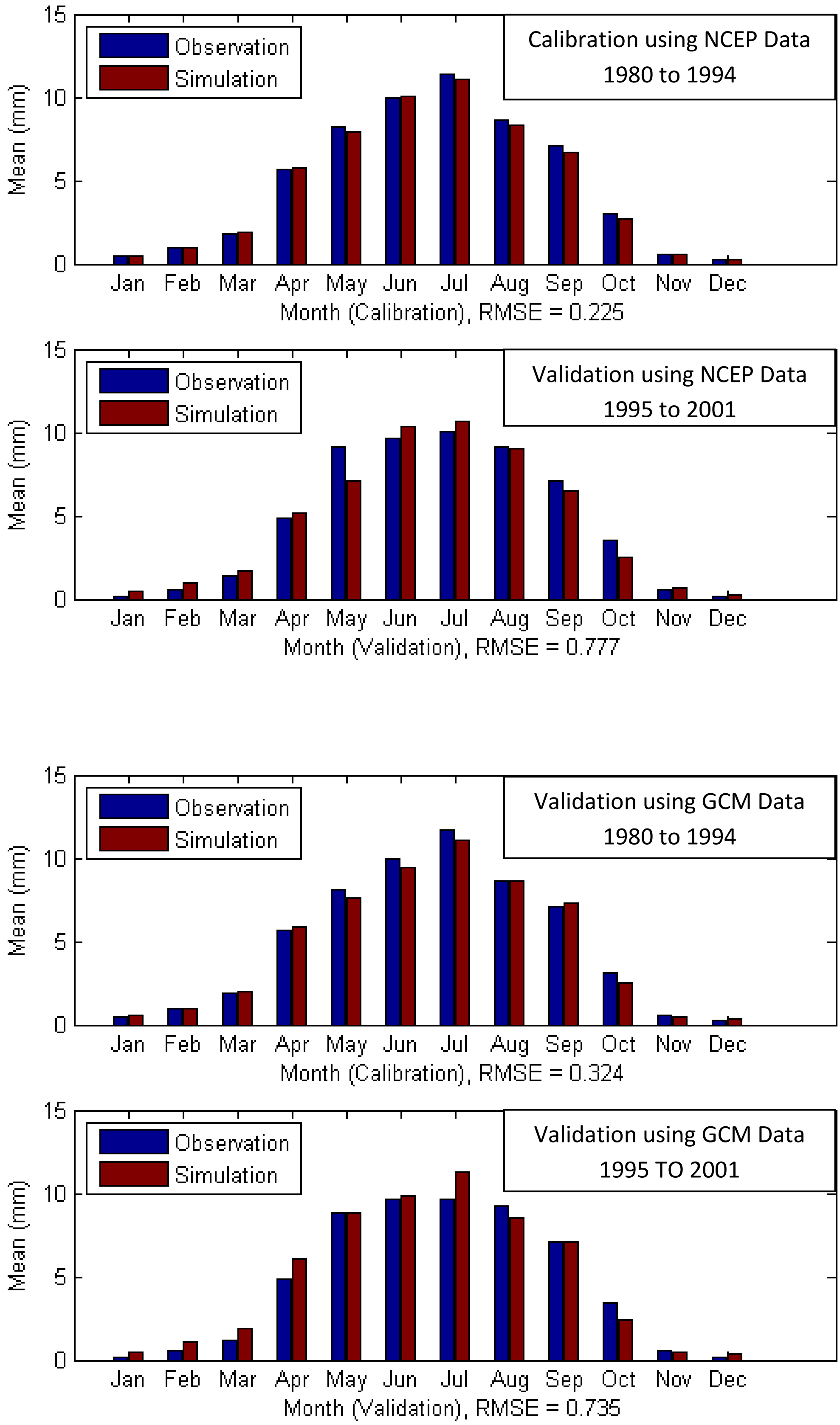


Fig 6.2 : Calibration and validation of precipitation model for **CASE 1** : 25^0 N – 90^0E

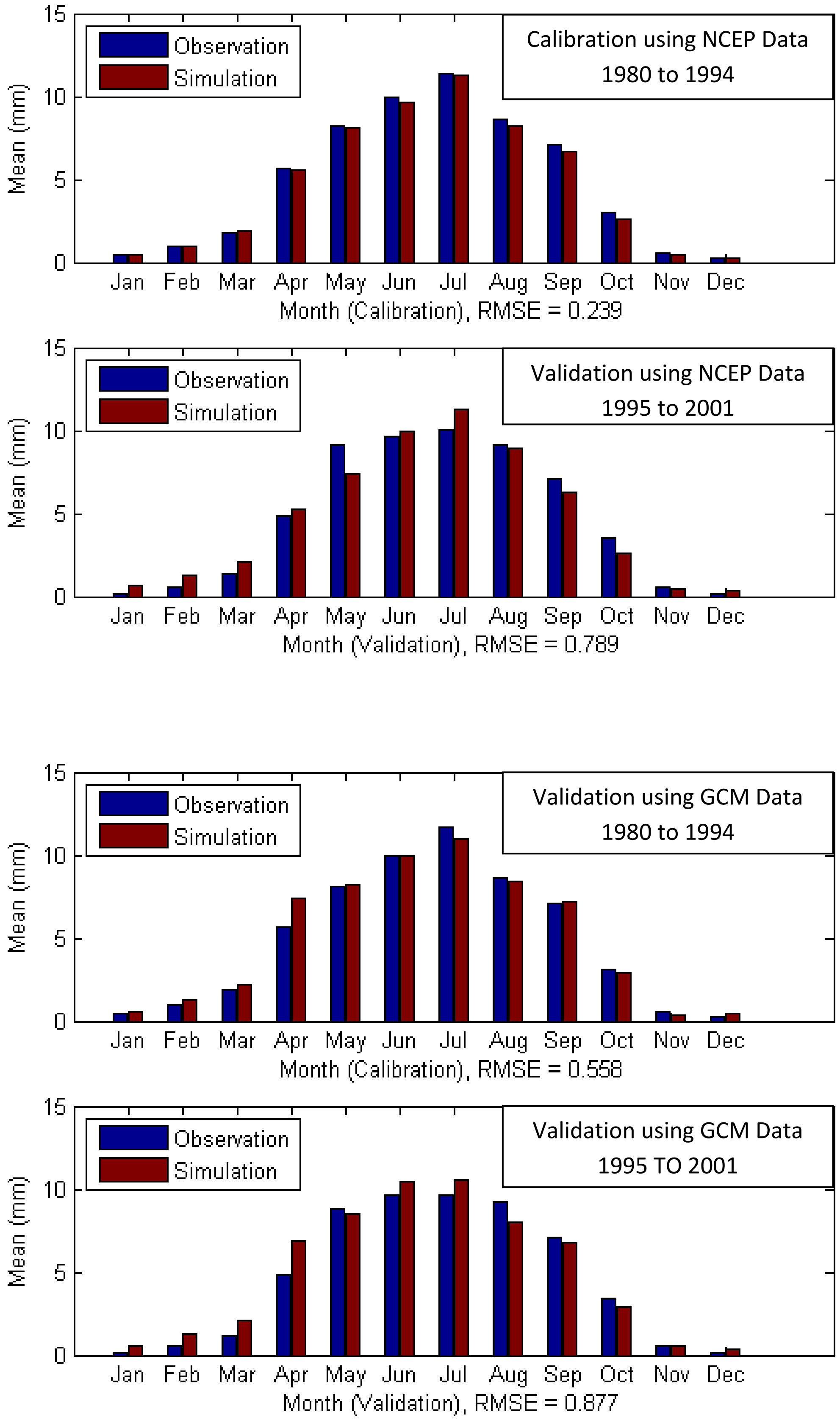


Fig 6.3: Calibration and validation of precipitation model for **CASE 2** : 25^0 N – 93.75^0E

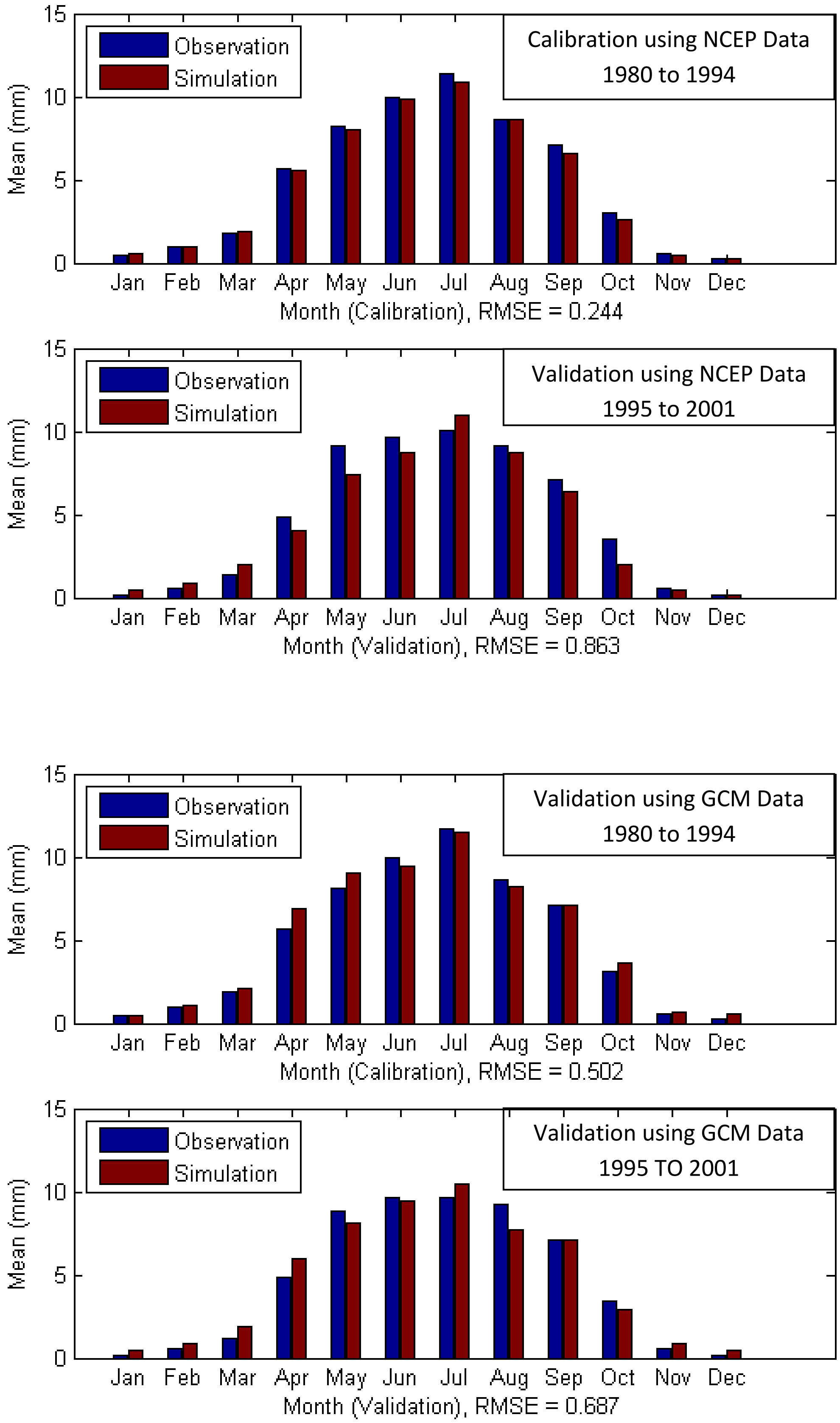


Fig 6.4: Calibration and validation of precipitation model for **CASE 3**: 27.5^0N–90^0E

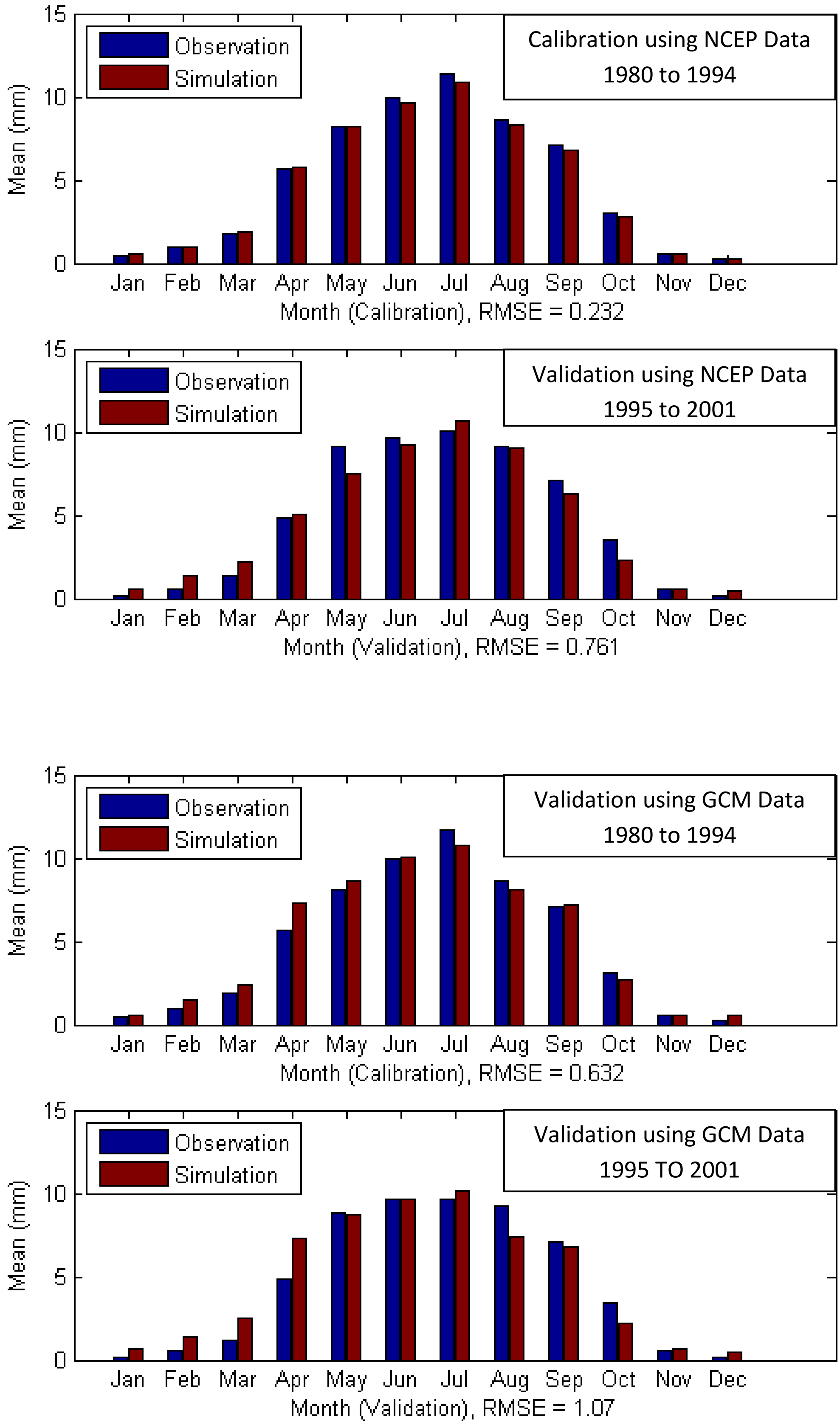


Fig 6.5: Calibration and validation of precipitation model for **CASE 4**: 27.5^{0}N–93.75^{0}E

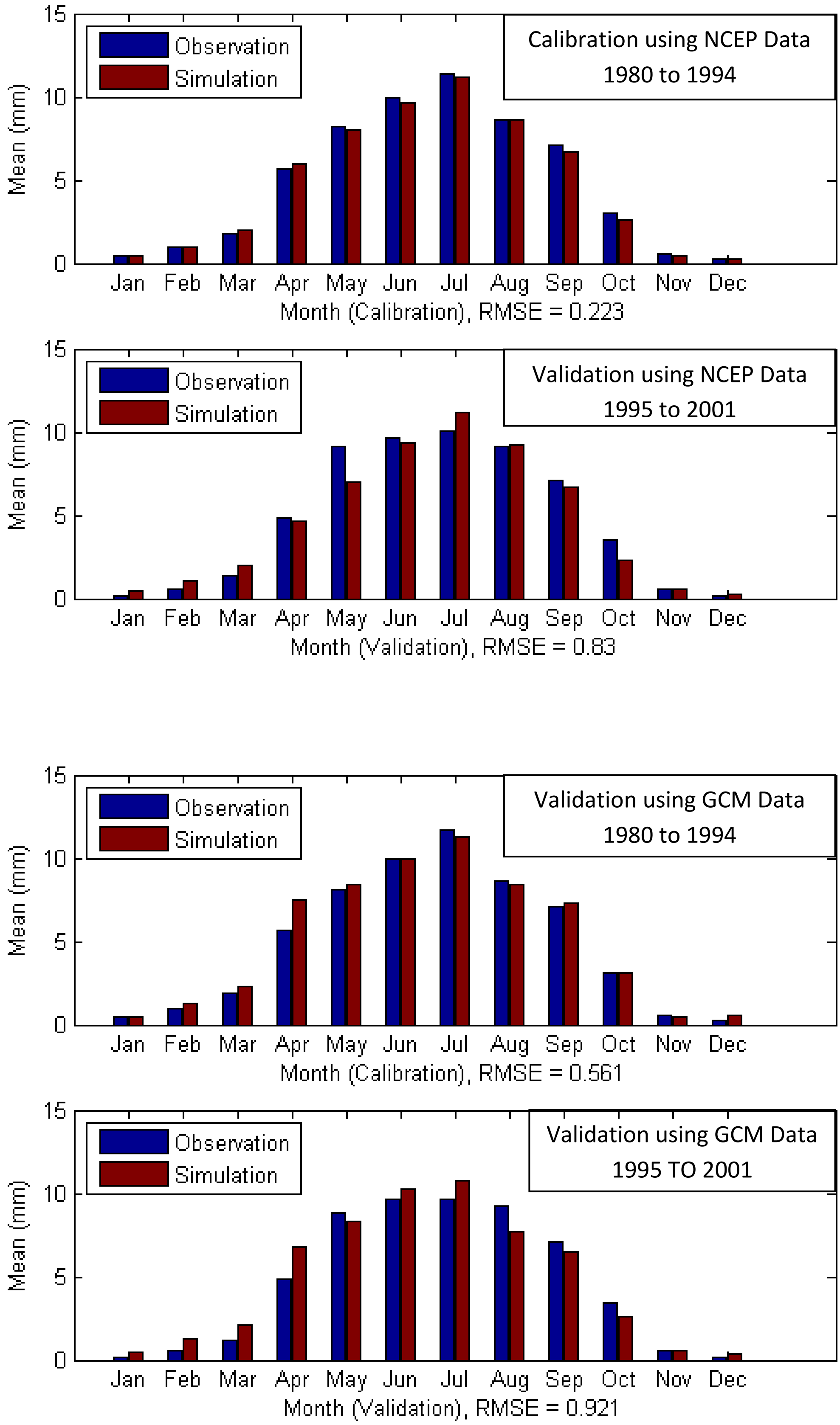


Fig 6.6: Calibration and validation of precipitation model for **CASE 5** : 26^0N–91.35^0E

The calibration and validation of the precipitation model for five different case of input predictor variables has been shown in the figures from Fig 6.2 to Fig 6.6. It can be clearly seen from the figure that for few months the precipitation models does not produce a proper validation.

6.3 FUTURE DATA GENERATION

Future Precipitation data set (2011-2040, 2041-2070) has been generated using the calibrated and validated precipitation model for the above five cases. The data set from HadCM3 for SRES A2 scenario has been used as the climate change scenario. The comparision of precipitation (mm/day) averaged monthly has been placed at Fig 6.7 to Fig 6.11 showing observed and generated future data.

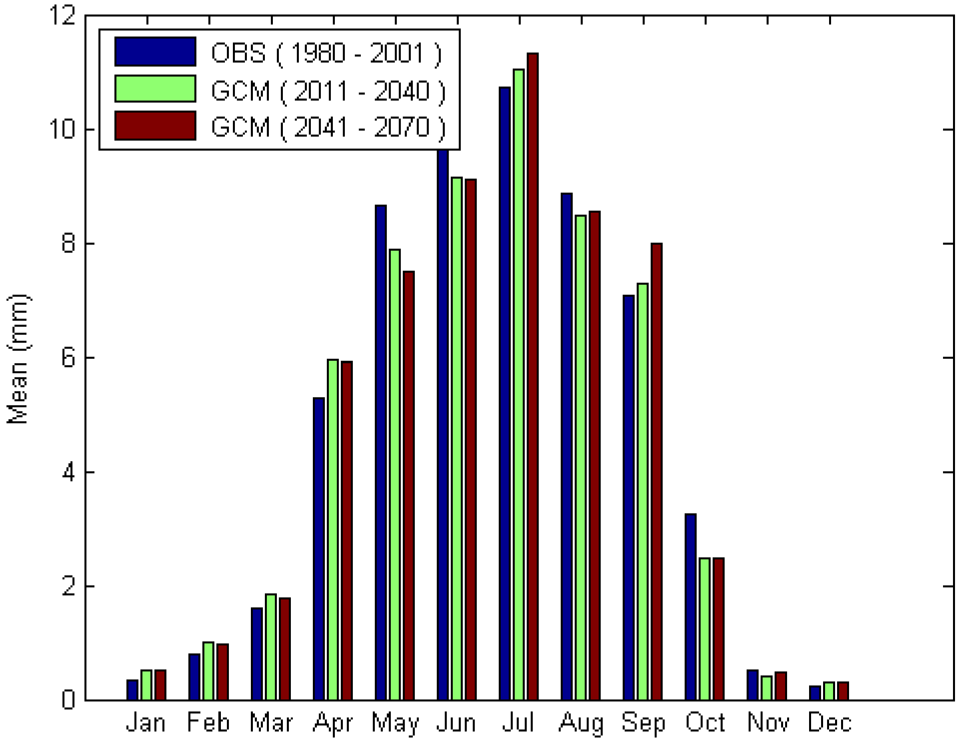


Fig 6.7: Comparison of observed and future (generated) precipitation **CASE1**: 25^0N–90^0E

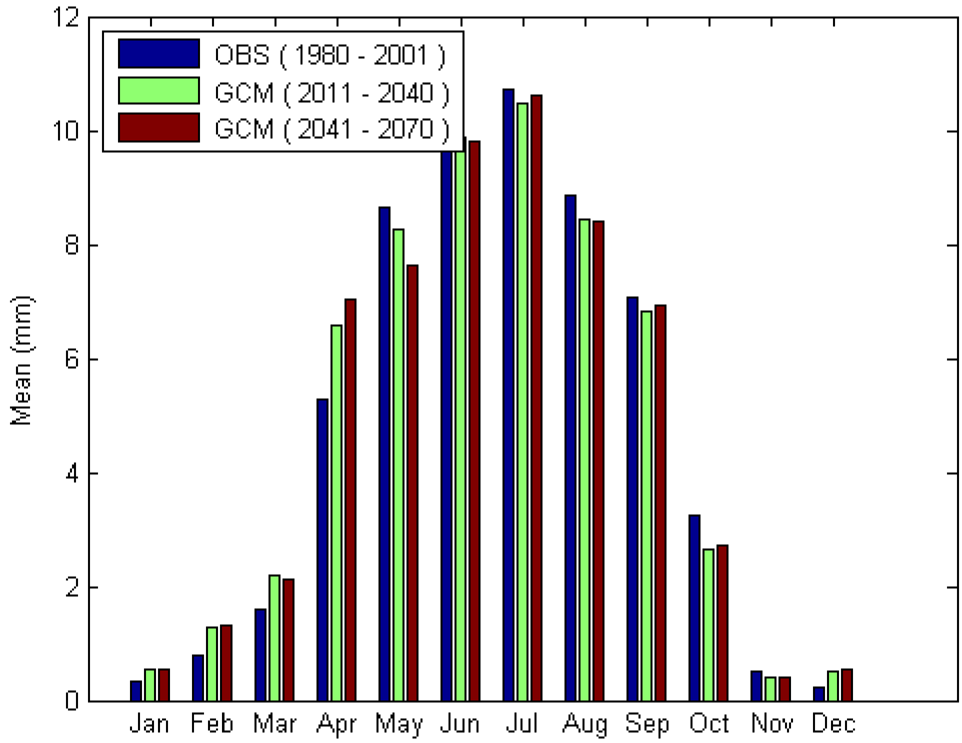


Fig 6.8: Comparison of observed & future (generated) precipitation **CASE2**: 25^0N–93.75^0E

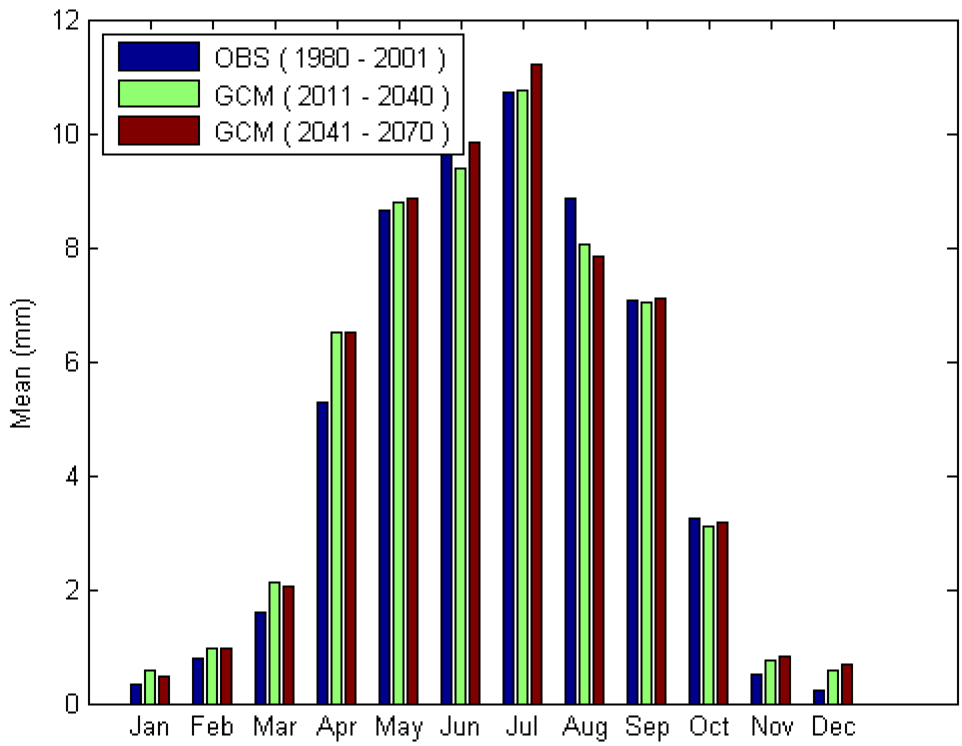


Fig 6.9: Comparison of observed & future (generated) precipitation **CASE3**: 27.5^0N–90^0E

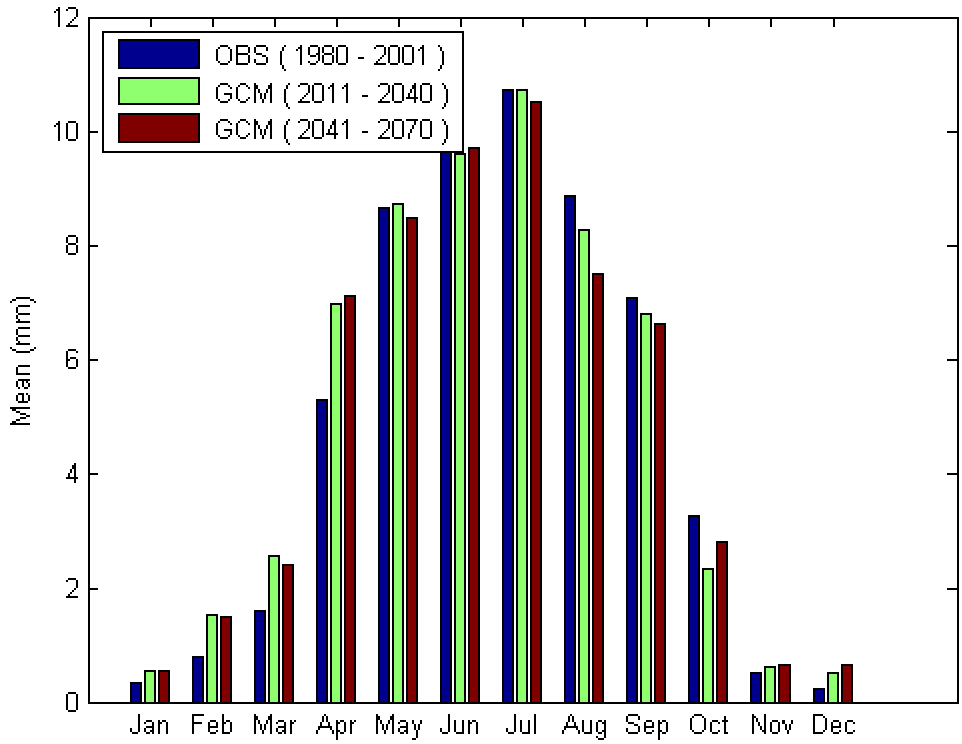


Fig 6.10: Comparison of observed & future precipitation **CASE4**: 27.5^{0}N–93.75^{0}E

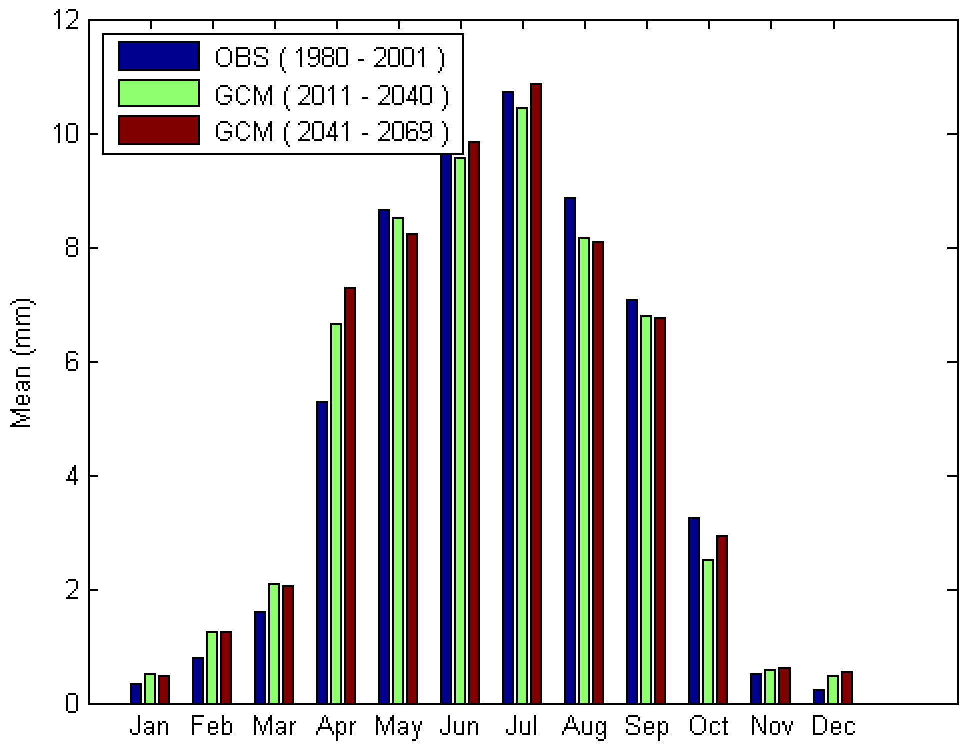


Fig 6.11: Comparison of observed & future precipitation **CASE5**: 26^{0}N–91.35^{0}E

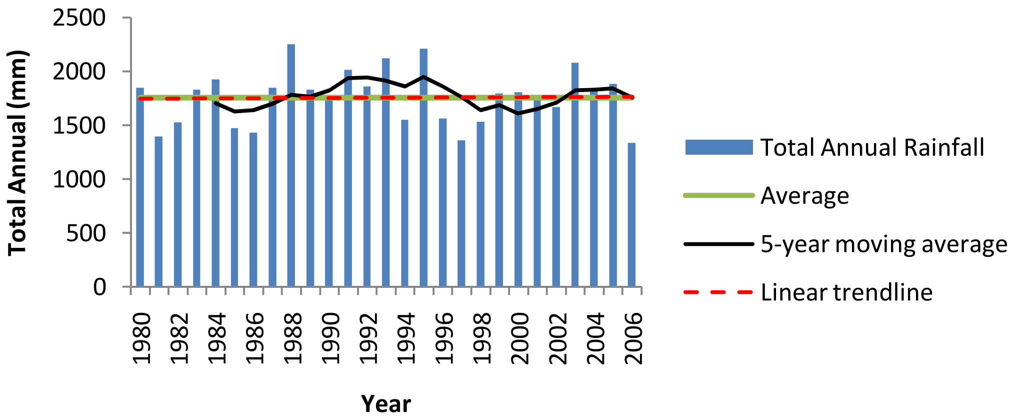
It can be seen from the comparision that all the cases suggest near similar indication of climate change in this station. A particular trend of increse or decrease is absent in the average annual precipitation of the future. A major change noticed in the comparision of observed and future precipitation series is the disproportion between the observed and generated monsoon rainfall. The monsoon season is likely to be delayed or it can also be inferred that the volume of monsoon rainfall will decrease. Due to scanty rainfall in the non-monsoon period (many months having zero rainfall) the output of the model produce lesser confidence in its acceptance. Particularly, the prediction in the month of April is totally unaccepted due to improper validation of the model.

CHAPTER 7 : ANALYSING DATA TRENDS

In this section an attempt has been made to examine whether there is any change in the observed rainfall of station under consideration due to climatic impact. This can be done by trend analysis of the available rainfall series. However the Gerukamukh station does not have any recent rainfall records. Hence the trend analysis has been done only for the Guwahati rainfall data series, where rainfall records are available upto 2006.

Fig 7.1 shows the plot of the Total annual observed rainfall at Guwahati from 1980 to 2006. The figure also displays the 5-year moving average, average(1980 to 2006) and a linear trendline fitting the data. As seen, no obvious trend can be identified from the annual rainfall.

Fig 7.1 Trend in Annual observed Rainfall



In the event of absense of any trend in the total annual rainfall of the Guwahati rainfall station, the monthly data has been exanined and plotted below to identify trends in the monthly rainfall at the station. Fig 7.2 to Fig 7.13 shows the plot of total monthly rainfall vs time for January to December from 1980-2006.

Fig 7.2 : Trend in January observed Rainfall

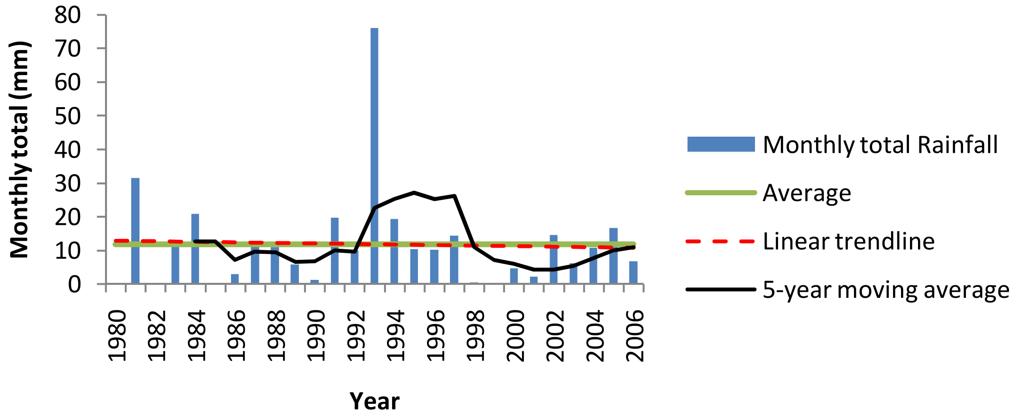
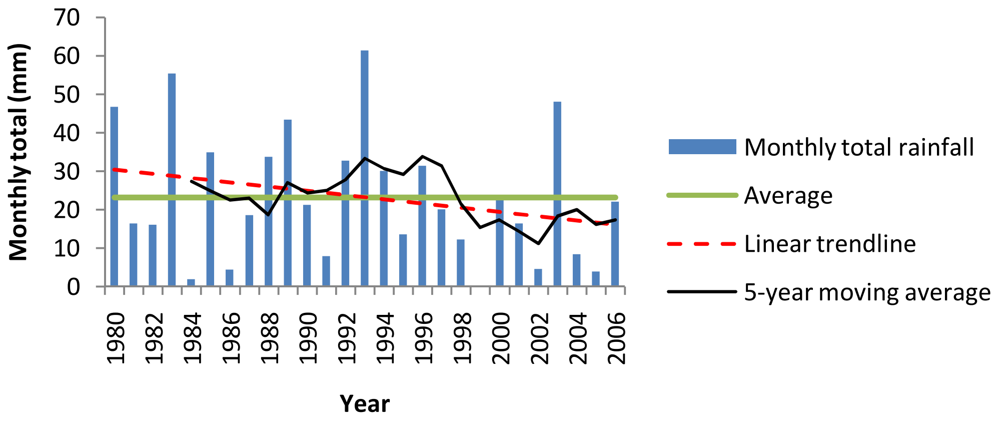


Fig 7.3 : Trend in February observed Rainfall



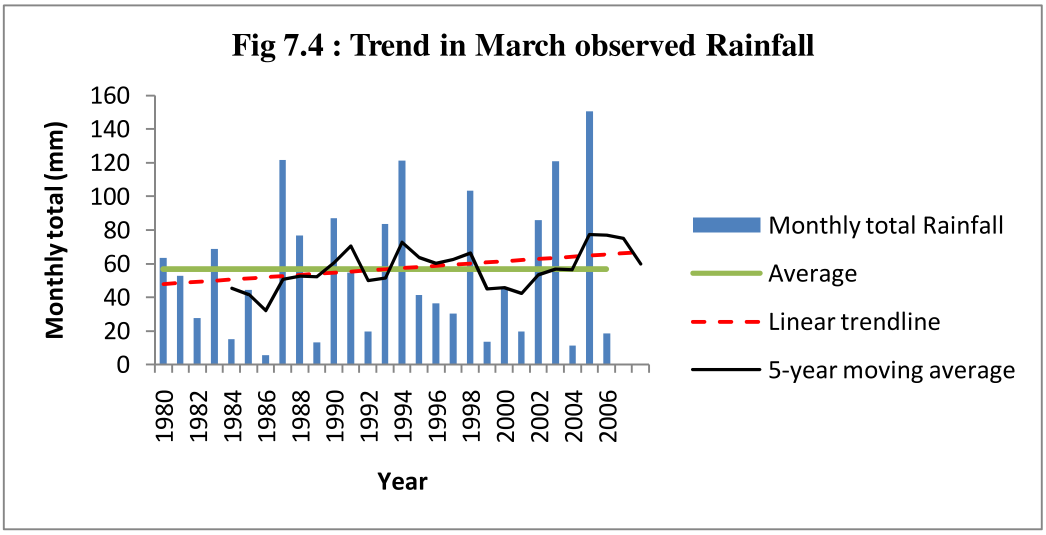


Fig 7.4 : Trend in March observed Rainfall
Monthly total (mm)
160
140
120
100
80
60
40
20
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Monthly total Rainfall
Average
Linear trendline
5-year moving average

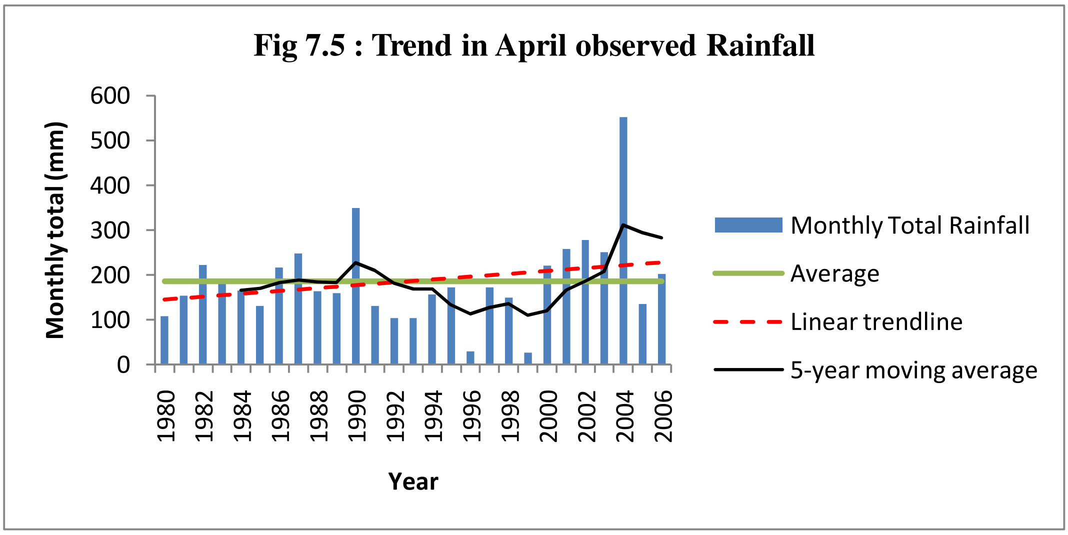


Fig 7.5 : Trend in April observed Rainfall
Monthly total (mm)
600
500
400
300
200
100
0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Monthly Total Rainfall
Average
Linear trendline
5-year moving average

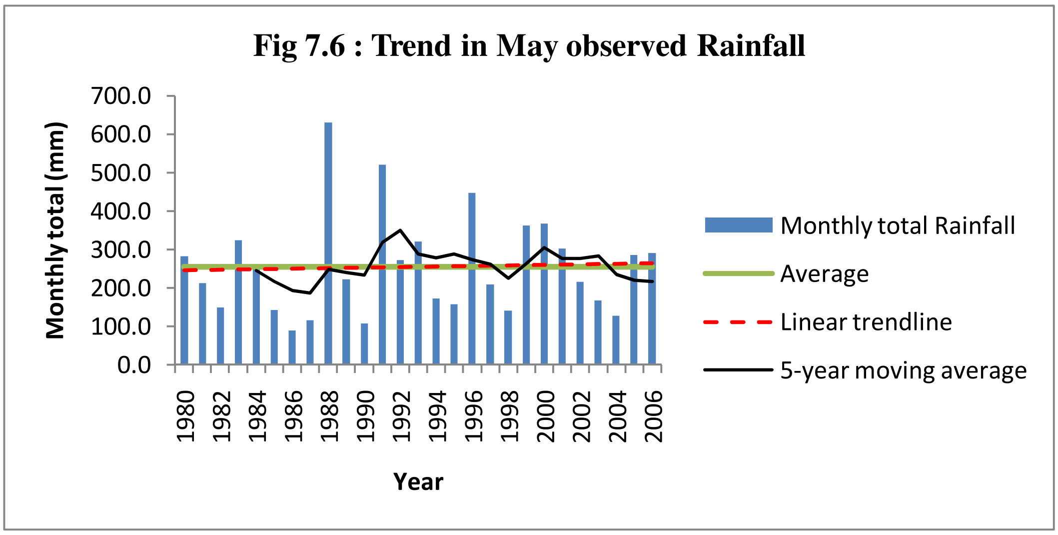


Fig 7.6 : Trend in May observed Rainfall
Monthly total (mm)
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
Year
Monthly total Rainfall
Average
Linear trendline
5-year moving average

Fig 7.7 : Trend in June observed Rainfall

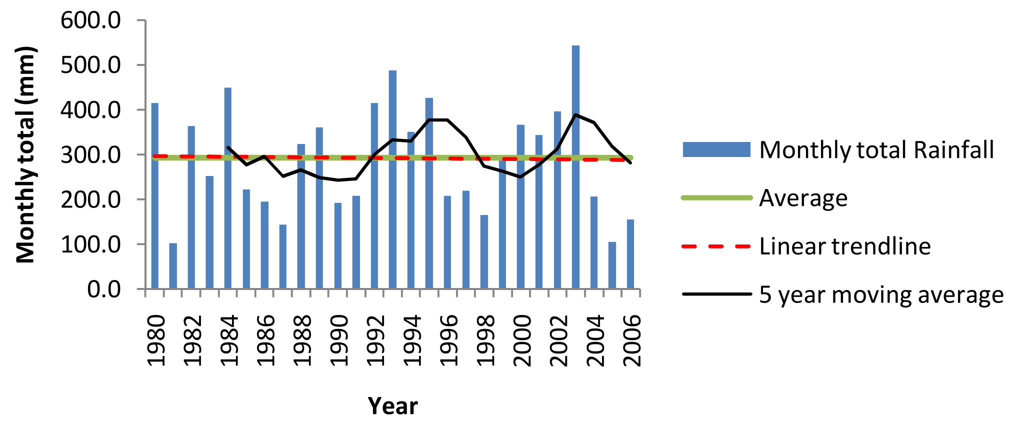


Fig 7.8 : Trend in July observed Rainfall

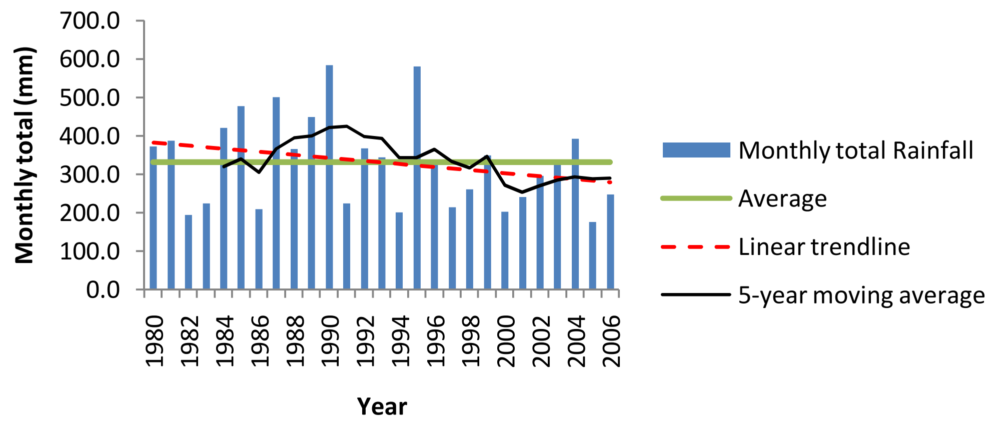


Fig 7.9 : Trend in August observed Rainfall

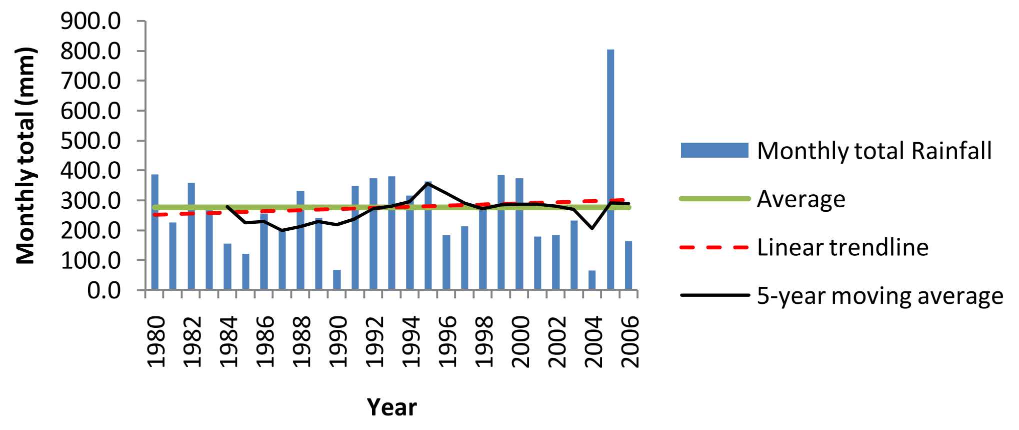


Fig 7.10 : Trend in September observed Rainfall

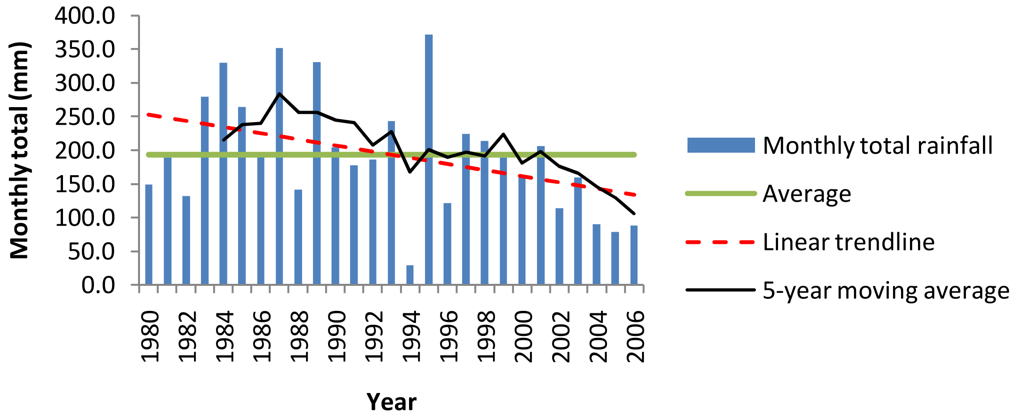


Fig 7.11 : Trend in October observed Rainfall

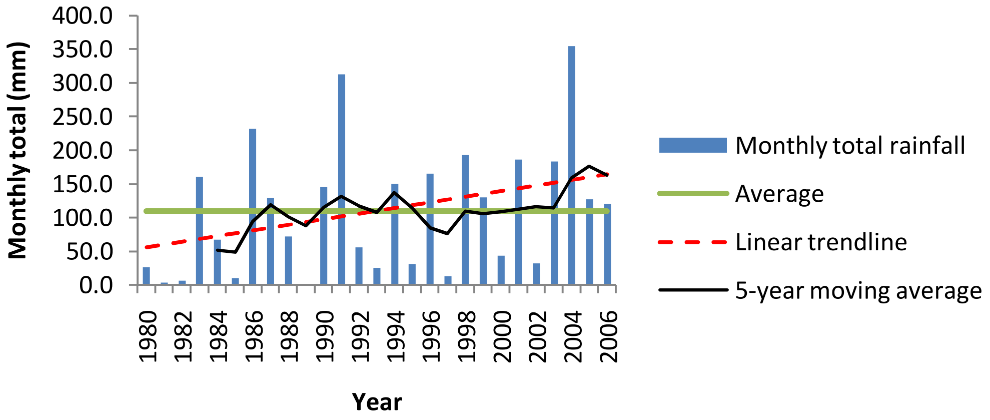
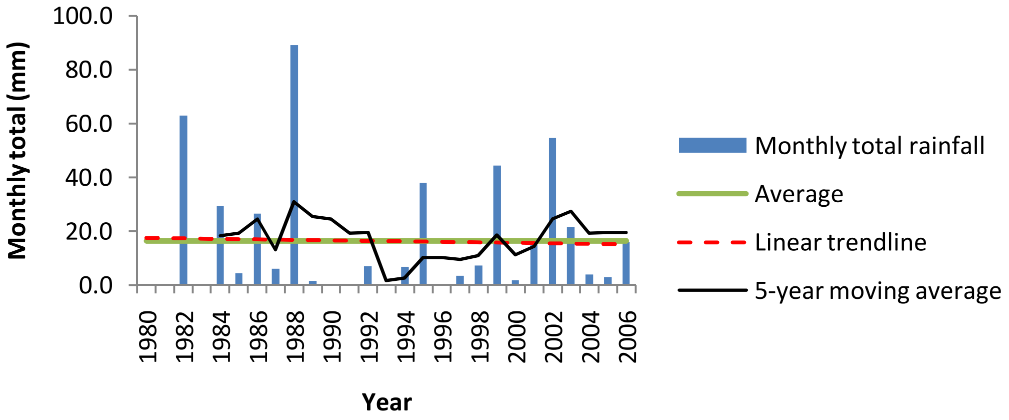
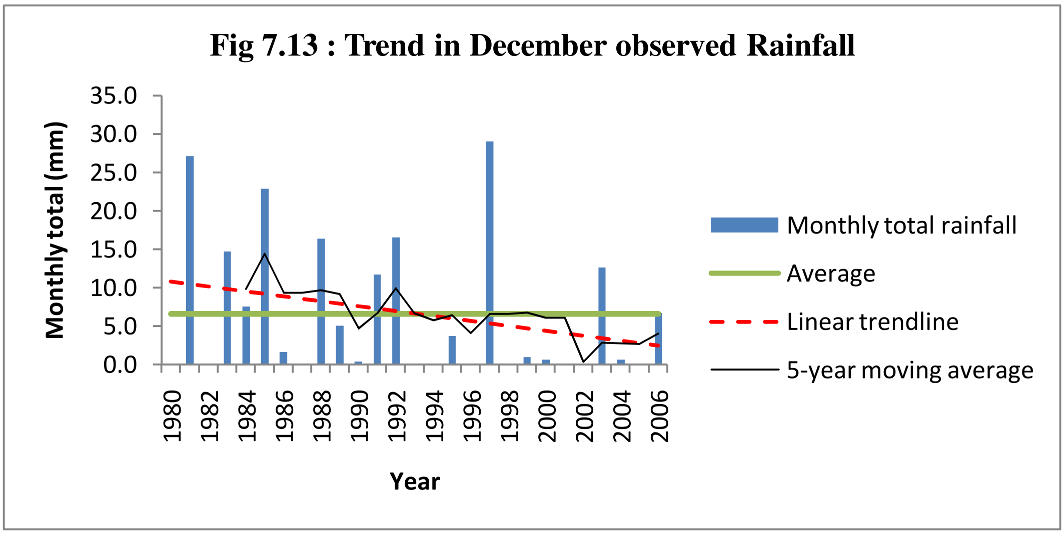


Fig 7.12 : Trend in November observed Rainfall





From the figures above a incresing trend can be seen in the month of March, April and October. Decreasing trend can be identified for the month of February, July, September and December. Although some months does show trends in the rainfall records but it is premature to draw conclusion of any climatic trend. With further collection of observed rainfall records and inclusion of more rainfall stations in the trend anaysis study, reflection of climatic change can be identified with more confident.

CHAPTER 8 : CONCLUSION AND FUTURE WORK

CONCLUSION

Brahmaputra basin is unique in its hydro-meteorological, geo-morphological and topographical conditions of the catchment. The river has high potential on the one hand and large scale devastation and destruction on the other hand. It receives a heavy precipitation for large part of the year which is unevenly distributed in the entire catchment. To determine the change in precipitation characteristics, longer period of data series is required and also more precipitation stations needs to be incorporated in the study to suitably represent the entire basin.

From the study in the upper and lower reach of Brahmaputra basin to analyse the impact of climate change in the precipitation characteristics, the following are the findings below.

1) The generated precipitation series does not suggest a particular trend in the average annual precipitation.
2) It has been identified from the study that the volume of rainfall will be decreasing in the month of May-June. In some of the cases computed precipitation was observed to give higher value in the month of July and September. As such the monsoon in the future seems to be arriving later than the present observed condition and retreating monsoon may produce higher precipitation. Thus, further analyses are required to ascertain the future pattern of monsoon and are being taken up at IIT Guwahati.
3) A distinguishing characteristic in the region is the rainfall during pre monsoon period. However, the precipitation characteristics in the month of April could not be perfectly represented in the model.
4) From the study it can be concluded that the predictors - Mean sea level pressure and wind velocity (500 hp zonal) are two important factors for climatic study in this region.

5) From the future Temperature data generated at Gerukamukh it has been established that the maximum temperature averaged monthly is likely to increase upto 1.8 degree Celsius under the considered forcing.

6) The precipitation model could not be well validated for the Gerukamukh station with the HadCM3 predictor for A2 scenario. Hence the applicability of the same to this station needs to be reevaluated with addition of more observed data. However the generated series does not provide any significant change in the precipitation volumes in future. Although the precipitation in monsoon months seems to be decreasing.

7) In the study at Guwahati station, GCM data has been used from each of the four neighbouring grid points individually to develop 5 different cases of precipitation model. The GCM data at the lower latitude (25^0N) validate the model better than the data at the higher latitude.

8) The NCEP data represents the historical atmospheric variables while the GCM data gives both the simulation of past and future atmospheric variables. Hence, a similarity in the distribution of the corresponding variables for a particular grid point is essential for validation of the model. In this study it is suggested to carry out a test for analyzing similarity in dispersion between the NCEP and GCM predictors. Such an analysis leads to faster and better identification of the relevant predictors. During the process of model development it was observed that correct selection of predictors is extremely important as different predictors can lead to significantly different model results.

FUTURE WORK

From this study it can be concluded that climate change in the future will induce variation in the hydrologic phenomenon and subsequently in the precipitation characteristics. As such the planning and management of the water resources should be done taking into account the climate variations in the future.

As the climate variation at a particular station can be of importance for the hydrologic changes, hence its impact on water resource and its management needs to be studied further. For the study of climatic variation in this basin different GCMs can be incorporated to validate the applicability of a GCM to this region.

In this study a statistical approach has been used to select the predictors. As observed in this study, as different predictors can lead to different future precipitation scenario, more emphasis should be given on physical relationship of the predictors with the process of precipitation generation in a particular region. Further study in this regards is going on in IIT Guwahati.

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