

The Relationship between Extreme Precipitation and Surface Air Temperature in Bangladesh

Bangladeshにおける極端降雨と
 地表面気温との関係

By

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the degree of

Master of Engineering

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...dedicated
to
HUMANITY

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ABSTRACT

First and foremost, Precipitation plays a crucial role in global hydrological cycle. Extreme precipitation has a huge influence on society. They are associated with flood disaster, erosion, water damage, and may have serious impacts on transport and safety. In fact, extreme hydro meteorological events' intensified by climate change due to nature and anthropogenic activity is a great concern for present society. According to IPCC (Intergovernmental Panel on Climate Change) 2007 report it is expected that the intensity of extreme precipitation will increase as the climate warms. The primary reason for this expectation is the fact that the maximum moisture content of the atmosphere increases with approximately 7% per degree temperature rise, which follows from the Clausius-Clapeyron relation. The increase in the atmospheric water holding capacity associated with a temperature increase considerably influences the changes in the extreme precipitation intensity under warmer climates.

Besides, Bangladesh is very prone to flooding due to its location at the confluence of the Ganges, Brahmaputra and Meghna (GBM) rivers and because of the hydro-meteorological and topographical characteristics of the basins in which it is situated. 80 Percent of the annual rainfall occurs in the monsoon (June–September) across the river basins. It was observed that extreme flood events occurred due to excessive rainfall in the catchments. When WLS (Water Levels) in the three major rivers systems rises simultaneously and crosses the danger marks extreme flood situation usually occurs all over the country. This was observed during the three flood events occurred in 1987, 1988 and 1998. Water Levels crossing the danger marks start occurring from mid-July and continue till mid-September. Inundated area during 1987, 1988 and 1998 are 66%, 68% and 70% respectively. Duration of the extreme flood events usually extends from 15 days to 45 days, the longest one occurred during 1998. So, Extreme precipitation has its influence in flood disaster in Bangladesh. Hence study on extreme precipitation can result in better understanding of rainfall characteristics and contribution to society.

This study aims exploring the characteristics of extreme precipitation due to surface air temperature change in Bangladesh using In-Situ data set. In-situ data set is obtained from Bangladesh Meteorological Department (BMD). Analysis for each seven division of Bangladesh has been accomplished separately. Afterward, analyses for each four season are performed here.

In the next step, validation of historical extreme precipitation from GCM model MIROC simulation has been performed by comparing with observation. Model simulated data set is obtained from scenario of RCP8.5 of MIROC5. From the comparison of Temperature Distribution Curve between surface air temperature data set obtained from MIROC and In Situ, it is found that there is bias error in model MIROC simulated data set. Analysis is done considering bias error correction.

Finally, model simulation is applied to analyze projection of future changes of extreme precipitation in the targeted region. Result shows that MIROC is a good simulation model as the analysis result of observation and MIROC present simulation has well agreement despite of some minor deviations. Also MIROC present simulation and future simulation has good agreement. So for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation in tropical region like Bangladesh, though future climate is too much unpredictable. Yet, preliminary we can adopt MIROC as an assessment tool, indeed.

List of Acronyms & Abbreviations

AIM	Asian Pacific Integrated Model
Avg.	Average
BMD	Bangladesh Meteorological Department
C-C	Clausius-Clapeyron
CCSR	Center for Climate System Research
FRCGC	Frontier Research Center for Global Change
GCM	General Circulation Model
GCAM	General Campaign Analysis Model
IIASA	International Institute for Applied Systems Analysis
IMAGE	Integrated Model to Assess the Global Environment
IPCC	Intergovernmental Panel on Climate Change
JGCRI	Joint Global Change Research Institute
MESSAGE	Model for Energy Supply Strategy Alternatives and their General Environmental Impact
MIROC	Model for Interdisciplinary Research On Climate
NIES	National Institute for Environmental Studies, Japan
Obs.	Observation
p99	99 th percentile precipitation
PBL	The PBL Netherlands Environmental Assessment Agency (PBL)
RCP	Representative Concentration Pathways
TDC	Temperature Distribution Curve

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Chapter 1

1. Introduction

1.1 Background

Precipitation plays a crucial role in global hydrological cycle. Extreme precipitation has a huge influence on society. They are associated with flood disaster, erosion, water damage, and may have serious impacts on transport and safety. In fact, extreme hydro meteorological events' intensified by climate change due to nature and anthropogenic activity is a great concern for present society [Oki and Kanae (2006); Pall et al. (2011); Min et al. (2011); Utsumi et al. (2011)]. It is expected that the intensity of extreme precipitation will increase as the climate warms (IPCC, 2007). Precipitation intensity is projected to increase in most regions under warmer climates, and the increase in precipitation extremes will be larger than that in the mean precipitation [Meehl et al. (2007); Utsumi et al. (2011)]. The primary reason for this expectation is the fact that the maximum moisture content of the atmosphere increases with approximately 7% per degree temperature rise, which follows from the Clausius-Clapeyron relation [Lenderink et al. (2011)]. The increase in the atmospheric water holding capacity associated with a temperature increase (described by the C-C relation) considerably influences the changes in the extreme precipitation intensity under warmer climates [Trenberth et al. (2003) ; Utsumi et al. (2011); Lenderink et al. (2011)]. A plot of the vapor pressure of water versus the water's temperature explains it more clearly (Figure 1.1).

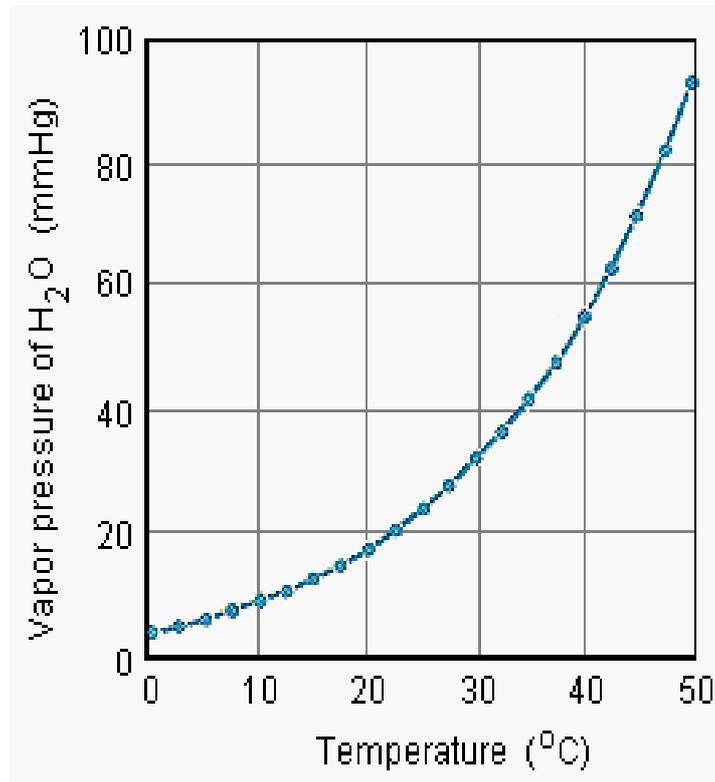
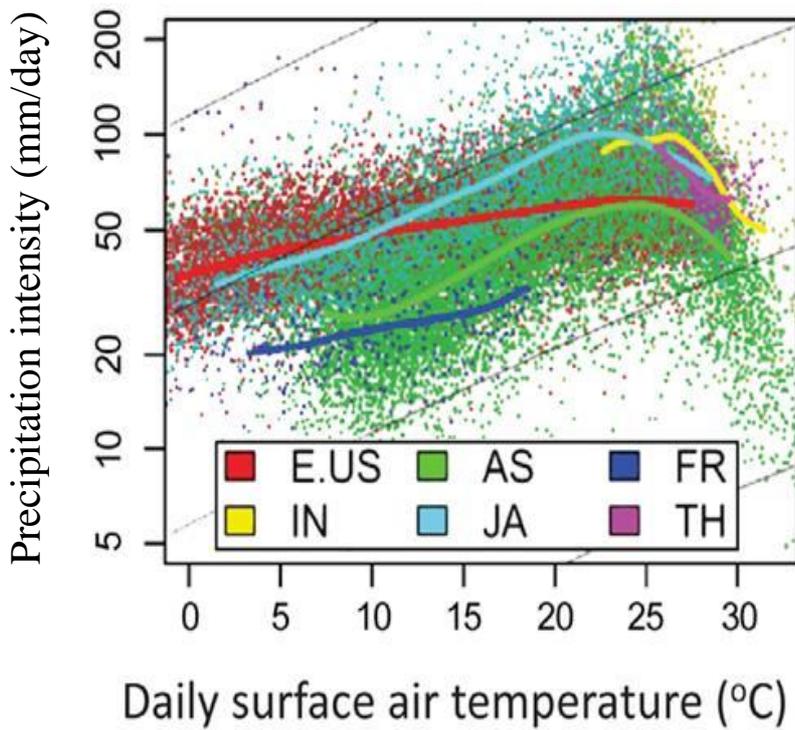


Figure 1.1: A plot of the vapor pressure of water versus the water's temperature

Source: <http://chemed.chem.purdue.edu/genchem/topicreview/bp/ch14/tvsvp.html>

Allen and Ingram (2002) and Pall et al. (2007) found the increase of daily precipitation extremes at rate predicted by the C-C relation in their studies with global climate model results. It is still not clear that why changes in precipitation extremes should follow a C-C scaling. However, changes in the atmospheric large scale motions [Emori and Brown (2005); Lenderink et al. (2011)], the moist-adiabatic lapse rate [O’Gorman and Schneider (2009); Lenderink et al. (2011)], the dynamics of the clouds [Trenberth et al. (2003); Lenderink et al. (2011)] and limitations in moisture increase due to soil water depletion [Berg et al. (2009); Lenderink et al. (2011)] may result in deviations from a C-C scaling. Later on, Utsumi et al. (2011) focus on the global relationship between the extreme precipitation intensity and surface air temperature and compare it with Clausius–Clapeyron scaling. They studied behaviour of 99th percentile for six countries namely Eastern United States, Australia, France, India, Japan and Thailand (as shown in Figure 1.2).



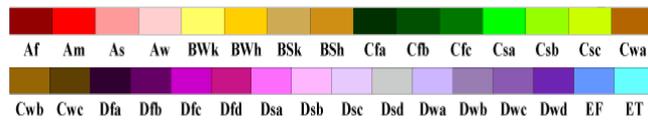
E.US: Eastern United States
 AS: Australia
 FR: France
 IN: India
 JA: Japan
 TH: Thailand
 Each plot shows P99_d for each Ta bin at each station.
 Thick lines denote the LOWESS (Locally weighted Regression Smoothing) lines for the six countries.
 CC scaling is illustrated by thin black lines for reference.

Figure 1.2: Behavior of p99 of six countries namely Eastern United States, Australia, France, India, Japan and Thailand [Adopted from Utsumi et al (2011)]

Now what about sub-tropical region like Bangladesh? According to Koppen-Geiger Climate Classification System (Figure 1.3), Bangladesh falls in sub-tropical monsoon region.

World Map of Köppen–Geiger Climate Classification

updated with CRU TS 2.1 temperature and VASCLimO v1.1 precipitation data 1951 to 2000



Main climates

A: equatorial
B: arid
C: warm temperate
D: snow
E: polar

Precipitation

W: desert
S: steppe
f: fully humid
s: summer dry
w: winter dry
m: monsoonal

Temperature

h: hot arid
k: cold arid
a: hot summer
b: warm summer
c: cool summer
d: extremely continental
F: polar frost
T: polar tundra

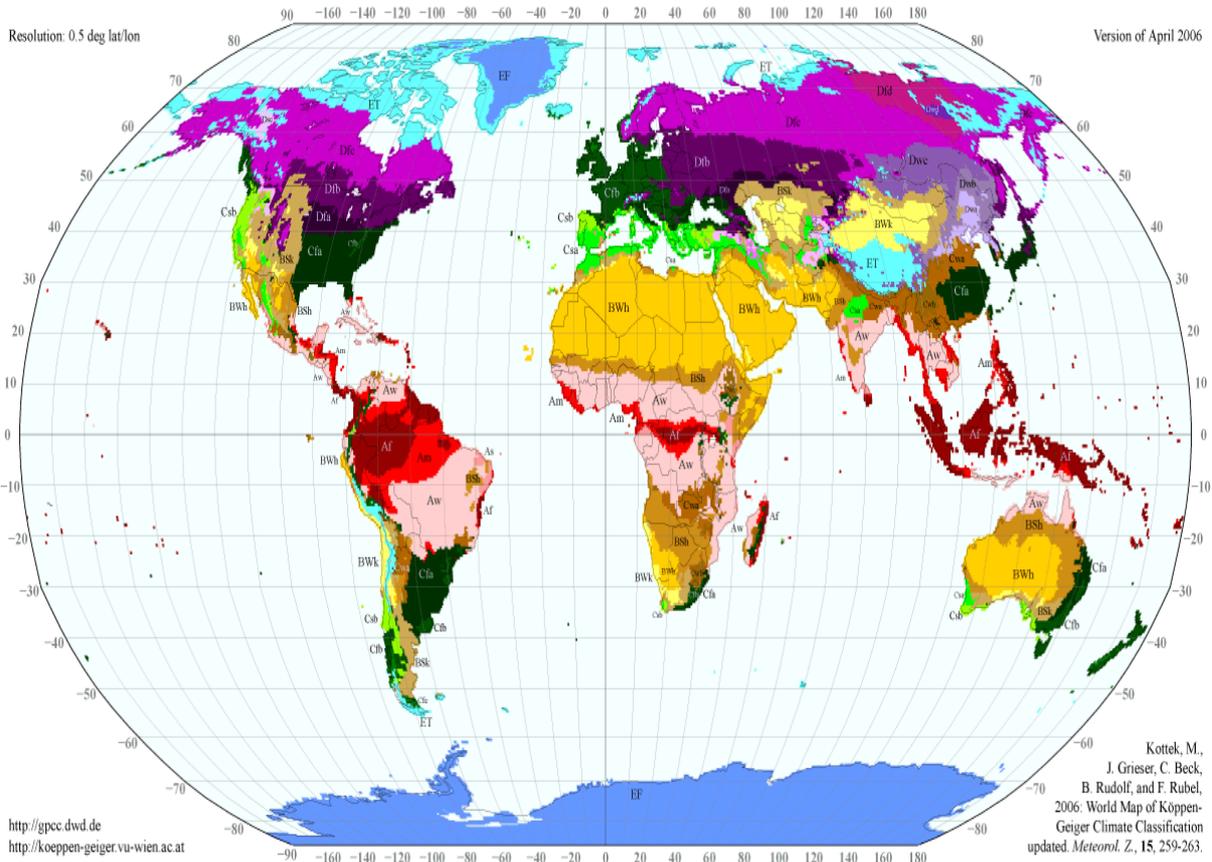


Figure 1.2: World map of Köppen-Geiger Climate Classification

(Source: <http://koeppen-geiger.vu-wien.ac.at/present.htm>)

1.1.1 Climate of Bangladesh

Bangladesh is a subtropical monsoon climate characterized by wide seasonal variations in rainfall, moderately warm temperatures, and high humidity. It has mainly four seasons, e.g. Pre-monsoon (March to May), Monsoon (June to September), Postmonsoon (October to November), Dry (December to February). Its climate is influenced by the Indian monsoon. Average rainfall is 2200-2500 mm but the range of which is between 1200 to 6500 mm. 80% of the rainfall occurs during monsoon i.e. from June to September. Average temperature is around 30 C except during the dry season [Hossain, (2003)].

In fact, based on the analysis of pressure, rainfall and temperature, the climate of this country can be described under the following four seasons (Figure 1.3) [Agrawala, (2003); Hossain, (2003); Habib (2011)]:

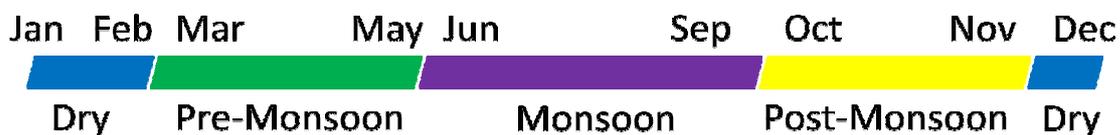


Figure 1.3: Four Seasons of Bangladesh

- a. **Dry or Winter Season:** This season comprises of December, January and February; mean temperature is 18-21°C and average rainfall is about 1.5% of the total annual rainfall [Agrawala, (2003); Habib, (2011)].
- b. **Pre-Monsoon:** This season consists of March, April and May; mean temperature is 23-30°C and average rainfall is 17% [Habib (2011)].
- c. **Monsoon:** This season consists of June, July, August and September; mean temperature is 27-30°C [Rahman, (2012)] and average rain fall of this season is about 72.5% of the total annual rainfall [Habib (2011)].
- d. **Post-Monsoon:** This season consists of October and November; mean temperature is 23-28°C [Rahman, (2012)] and average rainfall receives in this season is about 9% [Habib (2011)].

Bangladesh is very prone to flooding due to its location at the confluence of the Ganges, Brahmaputra and Meghna (GBM) rivers and because of the hydro-meteorological and topographical characteristics of the basins in which it is situated. 80 Percent of the annual rainfall occurs in the monsoon (June–September) across the river basins. The extensive low-lying flat flood plain of the three principal rivers and their numerous tributaries and distributaries is the main physiographic feature of the country [Mirza (2002)]. About 60 percent of the country is lower than 6m above the sea level, with an average river gradient of 6 cm/km in the delta [USAID (1988); GOB (1992); Mirza (2002)]. As a result of the flat topography of the floodplain about 20.5 per cent of Bangladesh (3.03 million ha) is flooded annually by many types of floods [Mirza et al. (2002); Chowdhury et al (1996)]. The area

flooded in Bangladesh during the period 1954–1999 is presented in Figure 1.4 [Adopted from Mirza (2002)].

It was observed that extreme flood events occurred due to excessive rainfall in the catchments [Hossain, (2003)]. When WLs (Water Levels) in the three major rivers systems rises simultaneously and crosses the danger marks extreme flood situation usually occurs all over the country. This was observed during the three flood events occurred in 1987, 1988 and 1998 [Hossain, (2003)]. Water Levels crossing the danger marks start occurring from mid-July and continue till mid-September. Inundated area during 1987, 1988 and 1998 are 66%, 68% and 70% respectively [Hossain, (2003)]. Duration of the extreme flood events usually extends from 15 days to 45 days, the longest one occurred during 1998 [Hossain, (2003)]. So, Extreme precipitation has its influence in flood disaster in Bangladesh. Hence study on extreme precipitation can result in better understanding of rainfall characteristics and contribution to society.

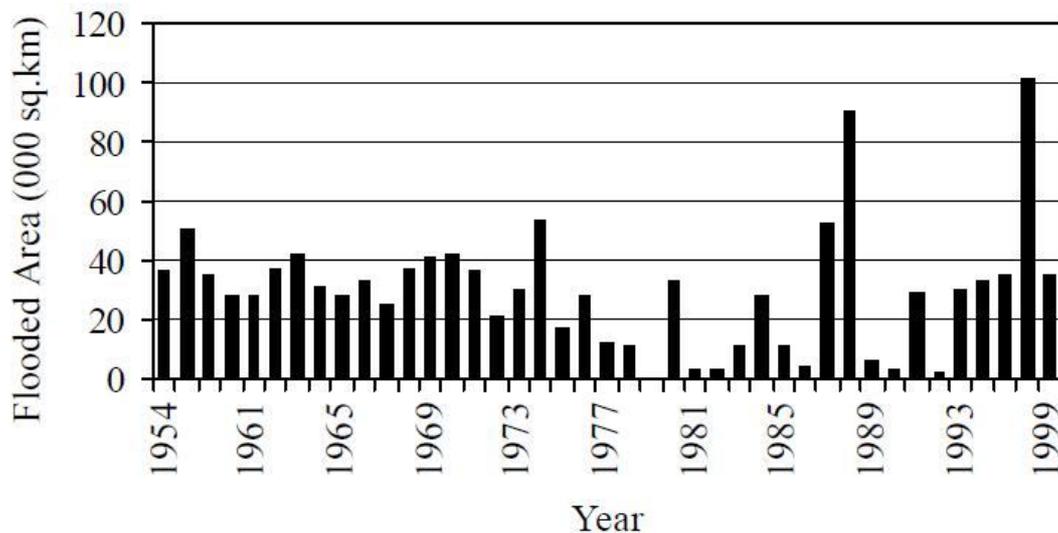


Figure 1.4: Flooded area in Bangladesh during 1954–1998 [Mirza (2002)]

1.2 Motivation and Contribution to Society

To prevent the heavy rain disasters, it is necessary to know the characteristics of heavy rain in a better way. Also, it is a good idea to know something about the impact of global warming on heavy rain which is likely expected off, is an important theme in social science. Hence, relationship between extreme precipitation and global warming are under discussion.

1.3 Objectives

To achieve the final goal of the thesis following objectives are set:

- To explore the characteristics of extreme precipitation due to surface air temperature change in Bangladesh using in situ data set.
- To assess the seasonal impact of extreme precipitation.
- Evaluation of model MIROC simulation with in situ or observation data set.
- Correction of bias error of daily surface air temperature generated by model MIROC simulation with respect to In Situ daily surface air temperature.
- Projection of model simulation for future forecasting of extreme precipitation in the targeted region.

1.4 Possible Outcome and Implications

From this thesis work, it is expected to have the following outcomes as well as implications:

- Establishment of relationship between extreme precipitation and surface air temperature in tropical region like Bangladesh using in situ data set covering Bangladesh region.
- Validation of historical extreme precipitation from MIROC using in situ observation.
- Apply model simulation to analyze future changes in extreme precipitation in Bangladesh.
- Reason of descending trend of extreme precipitation after a certain limit of surface air temperature rise.
- Implications of impact on flood disaster.

1.5 Thesis Outline

This thesis paper has been subdivided into 5 chapters.

Chapter 2: Data Set

This chapter discusses the details of data set for analyzing characteristics of extreme precipitation.

Chapter 3: Methodology

Methodology has been described in this chapter for performing desired work.

Chapter 4: Result and Consideration

Result and consideration are discussed in this chapter.

Chapter 5: Conclusion

Thesis is concluded by the detail discussion of thesis outcome and implications.

Chapter 2

2. Data Set

Two kinds of data set is used in this work namely In Situ data set of Bangladesh and MIROC data set. Section 2.1 discusses about the study area and its geography; Section 2.2 explains about In Situ data set and Section 2.3 explains about MIROC data set respectively.

2.1 Study Area

Study area in this thesis work covers whole Bangladesh. Bangladesh is located between $20^{\circ}34'$ to $26^{\circ}38'$ North latitude and $88^{\circ}01'$ to $92^{\circ}42'$ East longitude. It is a low-lying and riverine south Asian country bordered on the west, north and east by India, on the south-east by Myanmar (Burma) and on the south by the Bay of Bengal. The country occupies an area of 147,570 sq. km [Raven, (2005); Ahmed, (2006)].

Geologically it is a part of the Bengal Basin which has been filled by sediments washed down from the highlands on three sides of it, especially from the Himalayas. A network of rivers originated in the Himalayas flow over the country, that carry sediments – the building blocks of the landmass of the delta. The major river systems of the eastern Himalaya – the Ganges, the Brahmaputra, and the Meghna (GBM) – their tributaries and distributaries crisscross the floodplains [Ahmed (2006); Hossain, (2003)]. Figure 2.1 shows the location (map) of Bangladesh in South Asia sub-continent and River System of Bangladesh [Hossain, (2003)]. There are seven major administrative division in Bangladesh namely Dhaka –The Capital, Barisal, Chittagong, Khulna, Rajshahi, Rangpur and Sylhet (Figure 2.2).

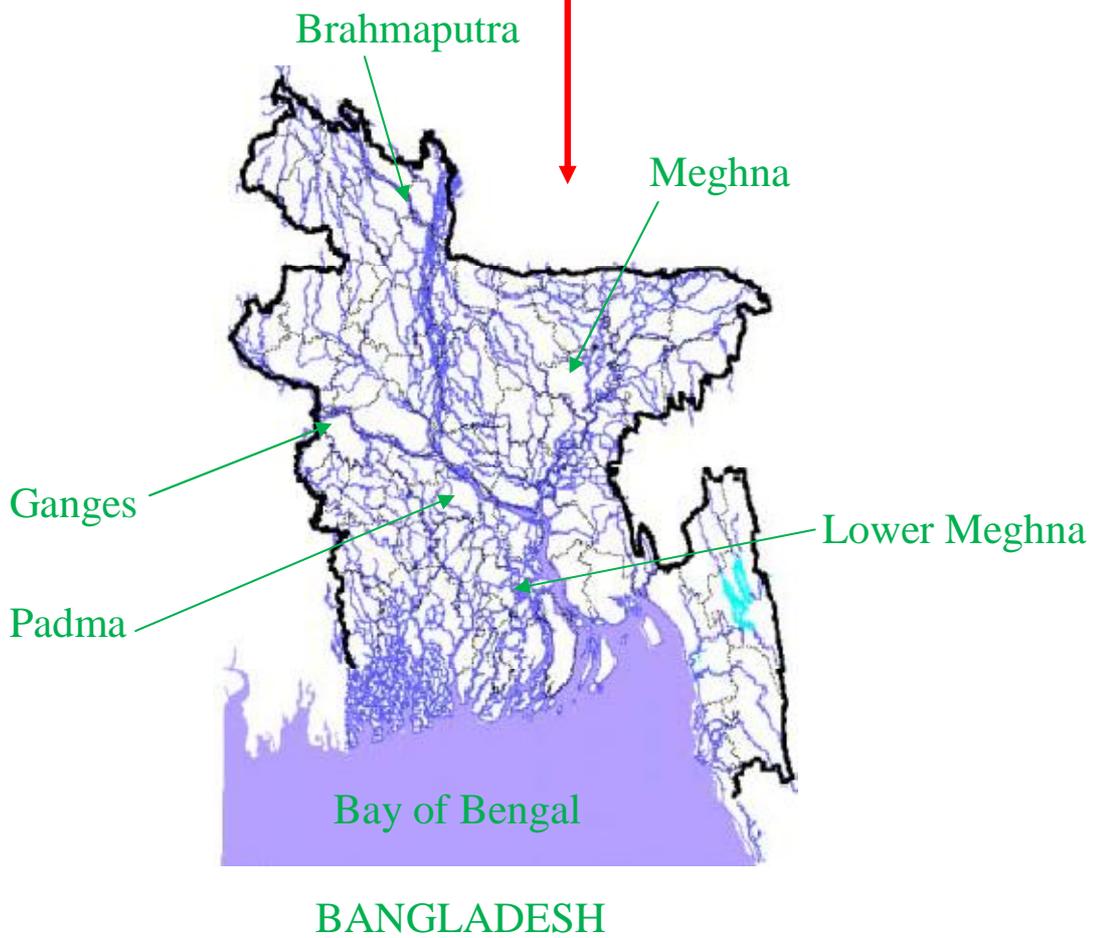
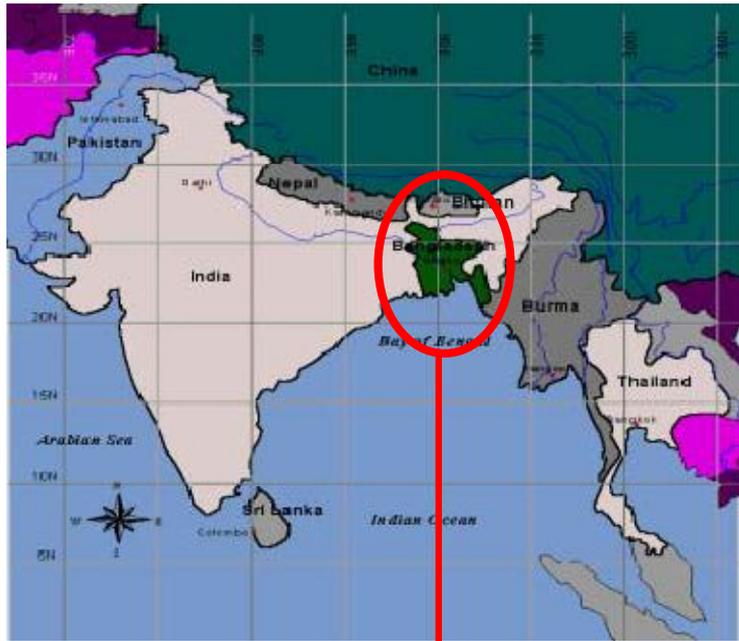


Figure 2.1: Study Area – Bangladesh [Source: Hossain, (2003)]

2.2 In Situ Data Set

In situ data set as an observation data set, collected from Bangladesh Meteorological Department (BMD), has been used for analyzing extreme precipitation.

2.2.1 Bangladesh Meteorological Department (BMD)

Bangladesh Meteorological Department is governmental organization of the People's Republic of Bangladesh, observe and monitor the weather and climate systems and issue of forecasts and warnings for all sorts of operations pertaining to Aviation, Maritime, Inland Water Ways and advisories to the Disaster Management Bureau (DMB) and Relief Ministry in managing all types of natural disasters and its application in social and economic planning. The Department has its Headquarters in Dhaka with two regional centres i.e. Storm Warning Centre (SWC), Dhaka and Meteorological & Geo-Physical Centre (M & GC), Chittagong.

In a word, BMD (<http://www.bmd.gov.bd/>) is the authorized Government organization for all meteorological activities like maintaining a network of surface and upper air observatories, radar and satellite stations, agro-meteorological observatories, geomagnetic and seismological observatories and meteorological telecommunication system.

2.2.2 Location of In Situ Rain Gauge Stations

There are 34 Rain gauge stations in Bangladesh namely Dinajpur, Rangpur, Rajshahi, Bogra, Mymensing, Sylhet, Srimangal, Ishardi, Dhaka, Comilla, Chandpur, Jessore, Faridpur, Madaripur, Khulna, Satkhira, Barisal, Bhola, Feni, Maijdi, Hatia, Sitakunda, Sandwip, Chittagong, Kutubdia, CoxsBazar, Teknaf, Rangamati, Patuakhali, Khepupara, Sayedpur, Tangail, Chuadanga and Mongla. Table 2.1 describes the station name, station Identification (ID) Number and their global locations. Red color indicates that station is excluded to analysis due to data missing.

Table 2.1 Rain gauge stations of Bangladesh (Red color indicates data missing)

Division	Station Name	Station ID	Coordinates	
			Longitude (East)	Latitude (North)
Barisal	Barisal	11704	90.4	22.667
Barisal	Bhola	11706	90.667	22.333
Barisal	Patuakhali	12103	90.366	22.333
Barisal	Khepupara	12110	90.233	21.933
Chittagong	Comilla	11313	91.2	23.45
Chittagong	Chandpur	11316	90.666	23.2
Chittagong	Feni	11805	91.4	23
Chittagong	Maijdi	11809	91.133	22.833
Chittagong	Hatia	11814	91.075	22.307
Chittagong	Sitakunda	11912	91.583	22.533
Chittagong	Sandwip	11916	91.416	22.416
Chittagong	Chittagong	11921	91.866	22.316
Chittagong	Kutubdia	11925	91.833	21.833
Chittagong	CoxsBazar	11927	92.033	21.417
Chittagong	Teknaf	11929	92.333	20.833
Chittagong	Rangamati	12007	92.216	22.583
Dhaka	Mymensing	10609	90.416	24.766
Dhaka	Dhaka	11111	90.4	23.683
Dhaka	Faridpur	11505	89.866	23.583
Dhaka	Madaripur	11513	90.216	23.183
Dhaka	Tangail	41909	89.833	24.166
Khulna	Jessore	11407	89.233	23.166
Khulna	Khulna	11604	89.583	22.833
Khulna	Satkhira	11610	89.166	22.683
Khulna	Chuadanga	41926	88.866	23.666
Khulna	Mongla	41958	89.666	22.417
Rajshahi	Ishardi	10910	89.166	24.166
Rajshahi	Bogra	10408	89.416	24.833

Division	Station Name	Station ID	Coordinates	
			Longitude (East)	Latitude (North)
Rajshahi	Rajshahi	10320	88.583	24.333
Rangpur	Dinajpur	10120	88.616	25.583
Rangpur	Rangpur	10208	89.3	25.7
Rangpur	Sayedpur	41858	88.833	25.766
Sylhet	Sylhet	10705	91.833	24.9
Sylhet	Srimangal	10724	91.666	24.3

2.2.3 Use of BMD Data Set

The data set obtained from BMD has been used here as an observation data set for analyzing present extreme precipitation condition and after that it has compared with the MIROC model simulated data set as a validation. Bangladesh has seven major administrative division namely Dhaka (The Capital), Rajshahi, Rangpur, Sylhet, Chittagong, Barisal and Khulna. Figure 2.2 shows the demarcation of seven divisions of Bangladesh. Analysis for each division has been performed separately in this study. Figure 2.3 show the rain gauge stations that are considered for analysis in this work.



Figure 2.2 Administrative Divisions of Bangladesh
(Source: <http://www.loc.gov/item/2011588372>)

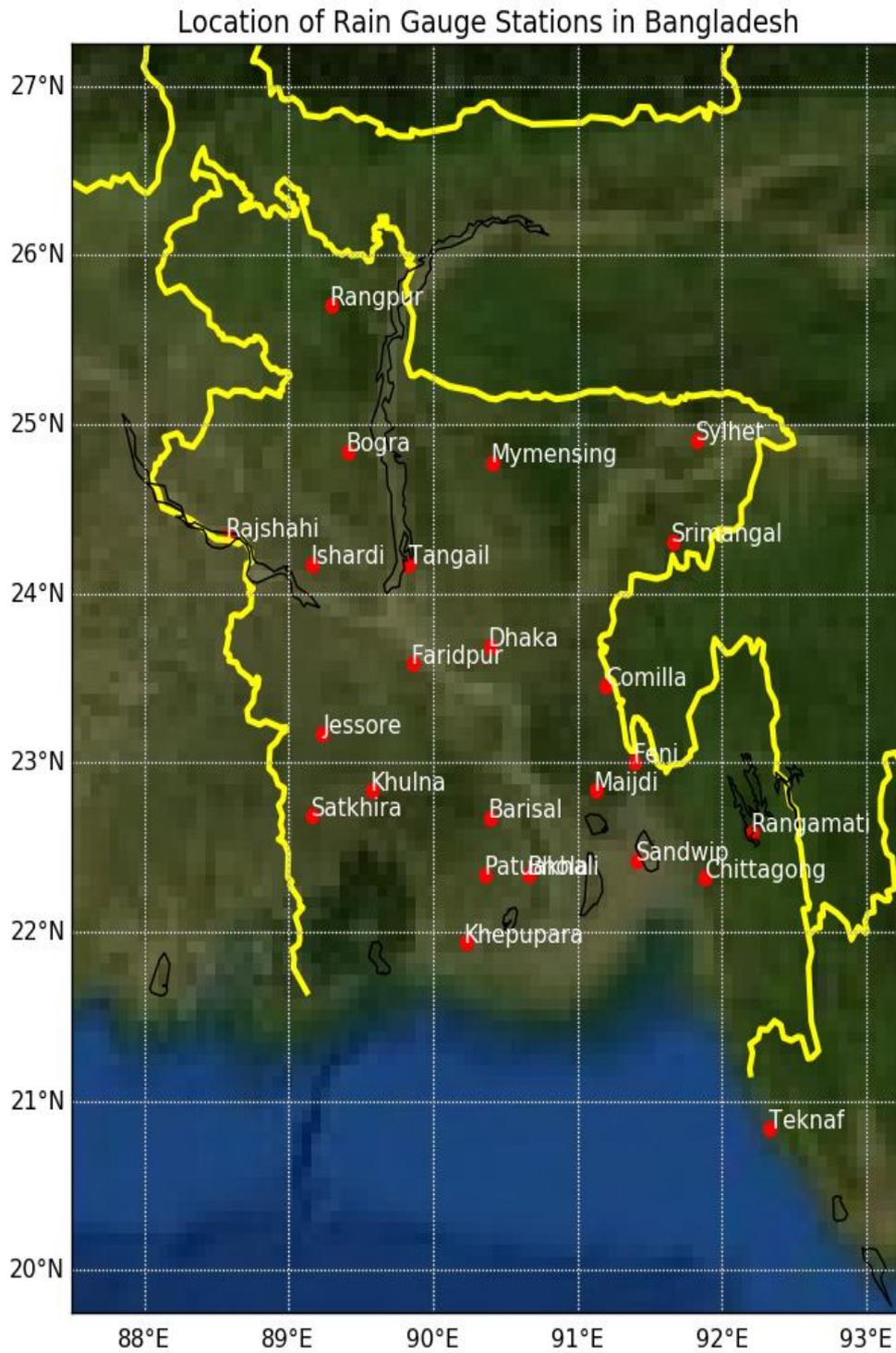


Figure 2.3: Position of rain gauge stations considered for analysis

2.3 MIROC Data Set

MIROC data set is obtained from the simulation of MIROC5 GCM model. In this study scenario RCP8.5 has been considered.

2.3.1 About MIROC

MIROC stands for the Model for Interdisciplinary Research On Climate (MIROC), which is the coupled general circulation model used in the K-1 project, consists of five components models: atmosphere, land, river, sea ice, and ocean. The K-1 project, formally the subject No. 1 of the Kyousei project, is a part of the Human-Nature-Earth Symbiosis Project. It is supported by the Research Revolution 2002 Program of the Ministry of Education, Culture, Sports, Science, and Technology of Japan. K-1 model developers are Center for Climate System Research (CCSR), University of Tokyo; National Institute for Environmental Studies (NIES); Frontier Research Center for Global Change (FRCGC).

The atmospheric component interacts with the land and sea ice components. The air-sea exchange is realized exclusively between the atmosphere and sea ice components, not directly between the atmosphere and ocean components, and the ocean component interacts only with the sea ice component. That is, air-sea flux at ice-free grids is consequently passed to the ocean component without modification, but it is first passed to the sea ice component. The river component receives ground runoff water from the land component and drains river runoff water into the sea ice component. Lakes are dealt with by the sea ice and ocean components [Hasumi and Emori (2004)]. About the scenario RCP are being discussed in section 2.3.1.1.

2.3.1.1 Representative Concentration Pathways (RCP)

The Representative Concentration Pathways (RCPs) form a set of greenhouse gas concentration and emissions pathways designed to support research on impacts and potential policy responses to climate change [Moss et al., (2010); van Vuuren et al., (2011); Riahi et al. (2011)]. There are four scenarios namely RCP2.6, RCP 4.5, RCP6 and RCP8.5. Table 4.2 shows the main characteristics of four RCP as described by van Vuuren et al. (2011).

Table 2.2: Main Characteristics of each RCP [Adopted from van Vuuren et al., (2011a)]

Scenario Component	RCP2.6	RCP4.5	RCP6	RCP8.5
Greenhouse gas emissions	Very low	Medium-low mitigation Very low baseline	Medium baseline; high mitigation	High baseline
Agricultural area	Medium for cropland and pasture	Very low for both cropland and pasture	Medium for cropland but very low for pasture (total low)	Medium for both cropland and pasture
Air pollution	Medium-Low	Medium	Medium	Medium-high

The RCP 8.5 was developed using the MESSAGE (Model for Energy Supply Strategy Alternatives and their General Environmental Impact) model and the IIASA (International Institute for Applied Systems Analysis) Integrated Assessment Framework by the International Institute for Applied Systems Analysis (IIASA), Austria. This RCP is characterized by increasing greenhouse gas emissions over time, representative of scenarios in the literature that lead to high greenhouse gas concentration levels [Riahi et al., 2007]; van Vuuren et al., (2011)].

The RCP6 was developed by the AIM (Asian Pacific Integrated Model) modeling team at the National Institute for Environmental Studies (NIES) in Japan. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshoot, by the application of a range of technologies and strategies for reducing greenhouse gas emissions [Fujino et al., (2006); Hijioka et al., (2008); van Vuuren et al., (2011)].

The RCP 4.5 was developed by the GCAM modeling team at the Pacific Northwest National Laboratory's Joint Global Change Research Institute (JGCRI) in the United States. It is a stabilization scenario in which total radiative forcing is stabilized shortly after 2100, without overshooting the long-run radiative forcing target level [Clarke et al., (2007); Smith and Wigley, (2006); Wise et al., (2009); van Vuuren et al., (2011)].

The RCP2.6 was developed by the IMAGE (Integrated Model to Assess the Global Environment) modeling team of the PBL Netherlands Environmental Assessment Agency. The emission pathway is representative of scenarios in the literature that lead to very low greenhouse gas concentration levels [van Vuuren et al., (2011)].

2.3.2 Use of MIROC Data Set

In this thesis work MIROC5 GCM data set is used for validation with in situ data set as well as for forecasting. Why MIROC5 is being used here? There are a few reasons behind using MIROC5 instead of MIROC3.2

A few aspects of the mean fields in MIROC5 are similar to or slightly worse than MIROC3.2, but otherwise the climatological features are considerably better. In particular, improvements are found in precipitation, zonal mean atmospheric fields, equatorial ocean subsurface fields, and the simulation of El Nino–Southern Oscillation. The difference between MIROC5 and the previous model is larger than that between the two MIROC3.2 versions, indicating a greater effect of updating parameterization schemes on the model climate than increasing the model resolution. The mean cloud property obtained from the sophisticated prognostic schemes in MIROC5 shows good agreement with satellite measurements [Watanabe et al (2011)].

For analysis RCP8.5 scenario data set has been adopted here. Spatial resolution for T85 MIROC5 data is about 150 Km. RCP8.5 has been chosen among the 4 future scenarios for future projection. In this study, the time period 1950 – 1999 is used for validation and 2006 - 2100 is for future projection. The location and grid positions of seven Divisions of Bangladesh are shown in figure 2.4.

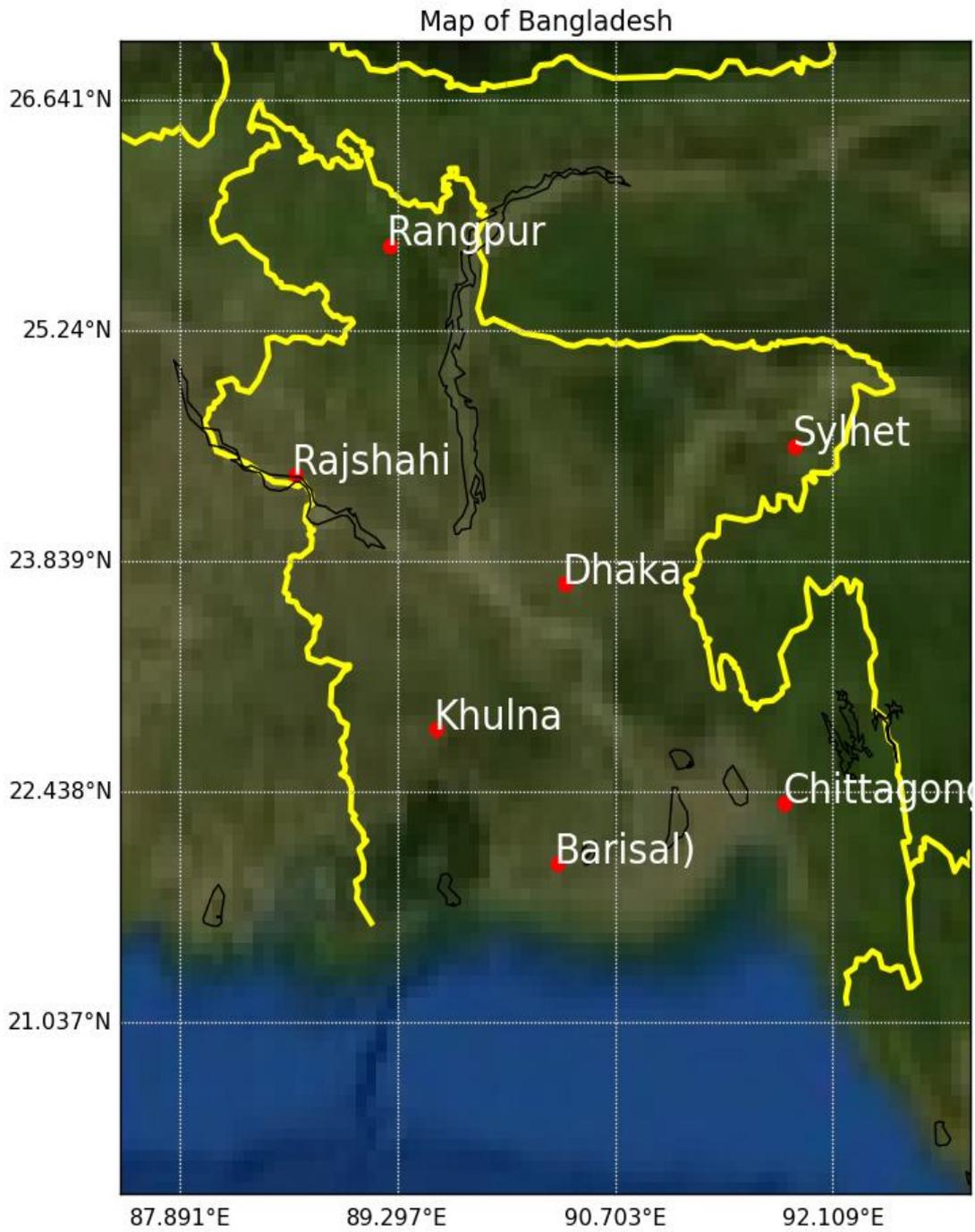


Figure 2.4: Grid of MIROC over Bangladesh and position of seven major divisions.

Chapter 3

3. Methodology

We use daily average surface air temperature and daily precipitation (rainfall) for analyzing behavior of extreme precipitation. Dependencies of daily precipitation intensity on the surface air temperature are computed using a binning technique following Lenderink and van Meijgaard (2008, 2010). Binning is done in classes of 1 degree Celsius width. From the binned data different percentiles are computed from the distribution of wet events. As stated in data set chapter analysis is subdivided into seven parts that means for each division analysis will be accomplished. First the observational extreme precipitation will be analyzed. Besides, the MIROC model output data set will be analyzed. After that the observation and Model result will be compared to evaluate the performance of model MIROC. If there any bias error in MIROC model, an attempt to overcome that error will be accomplished. After validation of MIROC present and observation data set, an attempt to forecast for extreme precipitation in Bangladesh will be done.

3.1 Index of Extreme Precipitation

99th percentile precipitation is used as an index of extreme precipitation in this study. Statistically, the 99th percentile is the smallest number that is greater than 99% of the numbers in a given set. So the highest 1% precipitation among a precipitation data set can be considered as 99th percentile precipitation.

3.2 Computing 99th Percentile

Step1. Rainfall for specific or corresponding temperature is separated. Rainfall for that specific temperature is called bin as illustrated in schematic diagram (Figure 3.1). After separating rainfalls, each bin of surface air temperature has all rainfall events for corresponding surface air temperature.

Step2. From each bin, rainfall events are sorted in ascending order for calculation of 99th or 90th percentile for daily Rainfall.

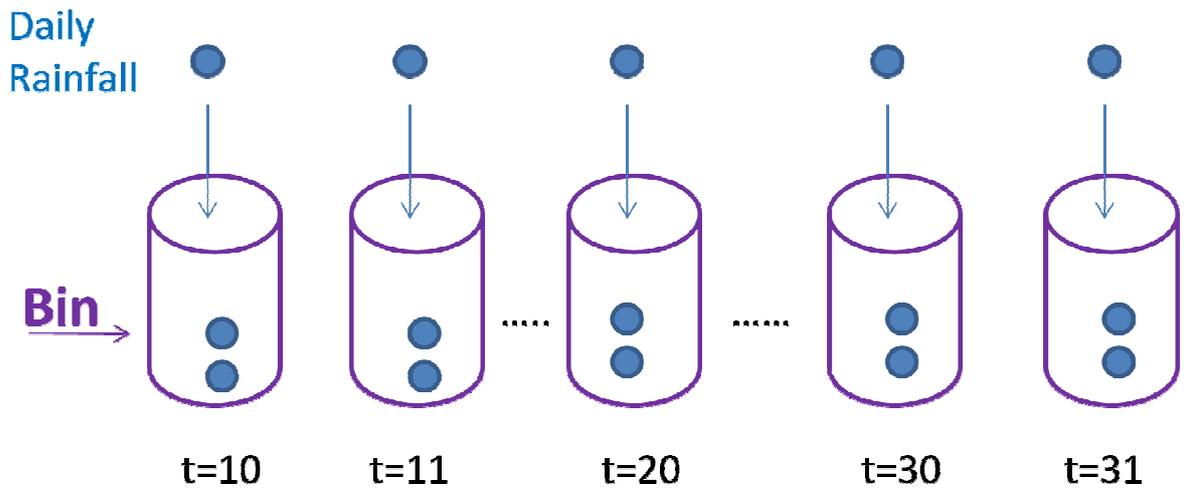


Figure 3.1: Schematic Diagram for Calculating 99th percentile precipitation.

Step3. 99th percentiles of daily rainfall are calculated from each bin. These obtained all 99th percentile precipitation are plotted against daily average surface air temperature.

3.3 Computation of Bias Correction

Temperature Distribution Curve (TDC) is the curve that represents relation between temperature (T) and no. of days (N) of that specific temperature over a period of time. Here temperature means daily average surface air temperature. By comparing TDC of In-situ and MIROC, if we get some deviation of MIROC simulated data over In-situ data. This deviation is called Bias Error in Model MIROC simulated data set. To get the actual Bias Error is the difference of mean temperature of MIROC and In-situ. Mean can be calculated as the summation of N and T over Total N. That means

$$T(\text{mean}) = (\sum(N*T)) / N(\text{Total}) \dots\dots\dots\text{equation (1)}$$

$$\text{Bias Error} = T(\text{mean MIROC}) - T(\text{mean Observation}) \dots\dots\dots\text{equation (2)}$$

Chapter 4

4. Result and Consideration

Based on the methodology described in chapter 3, here the characteristics of extreme precipitation with respect to surface air temperature will be illustrated in this chapter here. In all figures Surface Air Temperature stands for Average Daily Surface Air Temperature.

4.1 Result of In-Situ Data Set

In this section results obtained from using in-situ data set are shown.

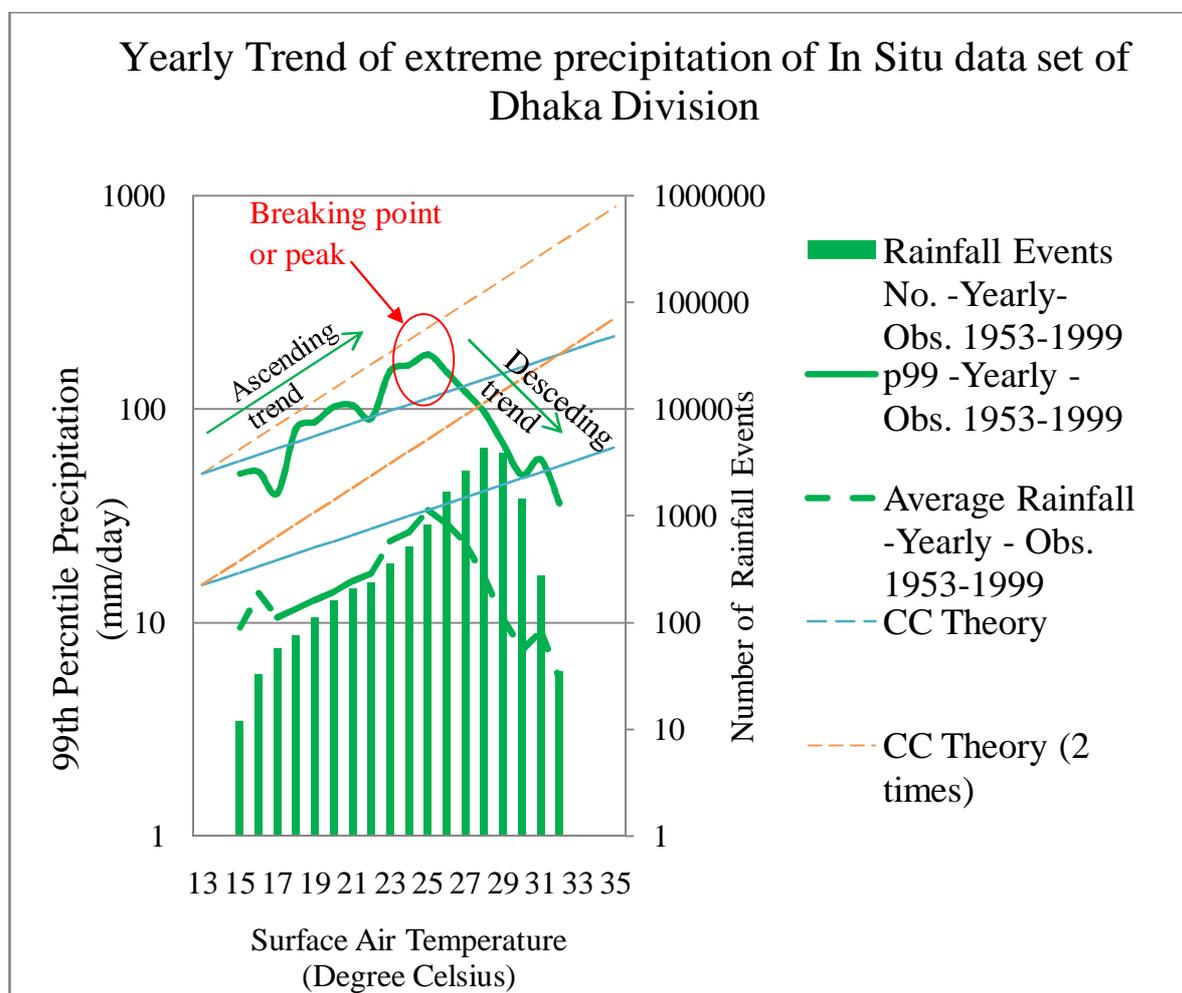


Figure 4.1(a): Yearly trend of extreme precipitation of In Situ data set of Dhaka Division

Figure 4.1(a) represents the relationship between daily extreme precipitation and daily average surface air temperature obtained by analyzing the data set of **Dhaka Division** (Dhaka is the capital of Bangladesh). This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

In this figure 4.1(a), the result shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

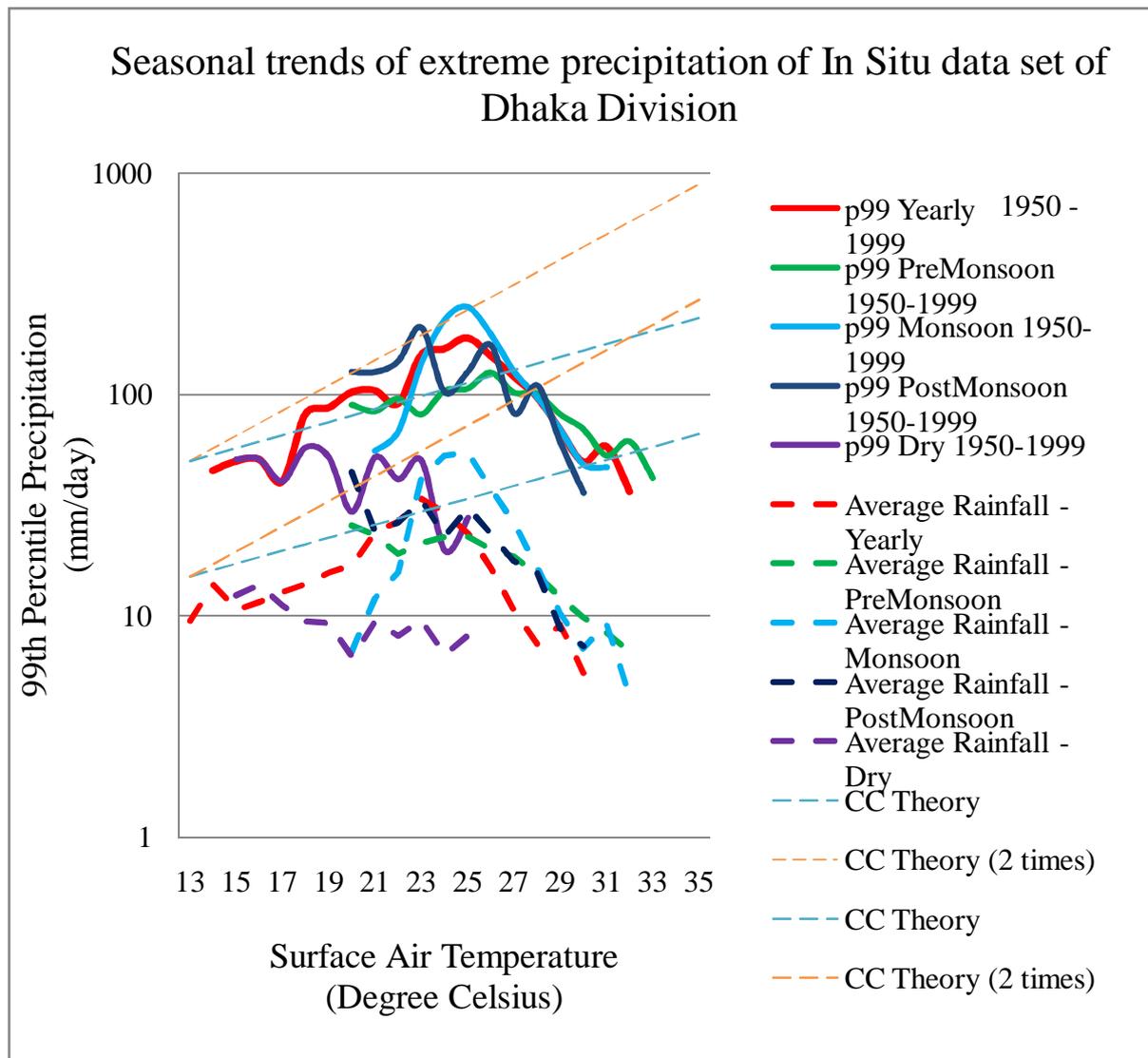


Figure 4.1(b): Comparison of seasonal trends of extreme precipitation of In Situ data set of Dhaka Division

Here in figure 4.1(b), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Dhaka Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(b) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Dhaka Division** (Dhaka is the Capital of Bangladesh). Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season.

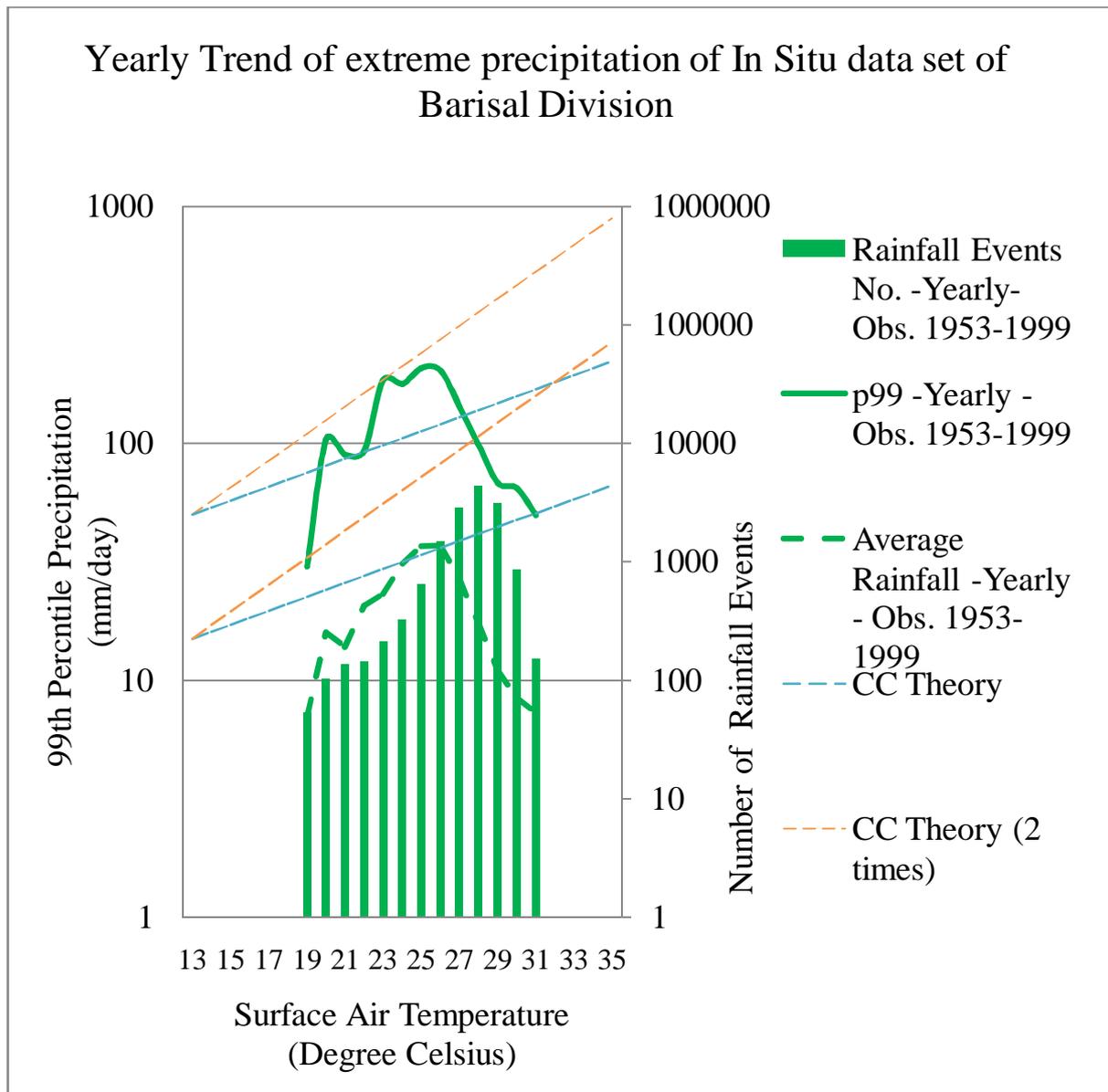


Figure 4.1(c): Yearly trend of extreme precipitation of In Situ data set of Barisal Division

Figure 4.1(c) also represents the relationship between daily extreme precipitation and daily average surface air temperature but data set is of **Barisal Division**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(c), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

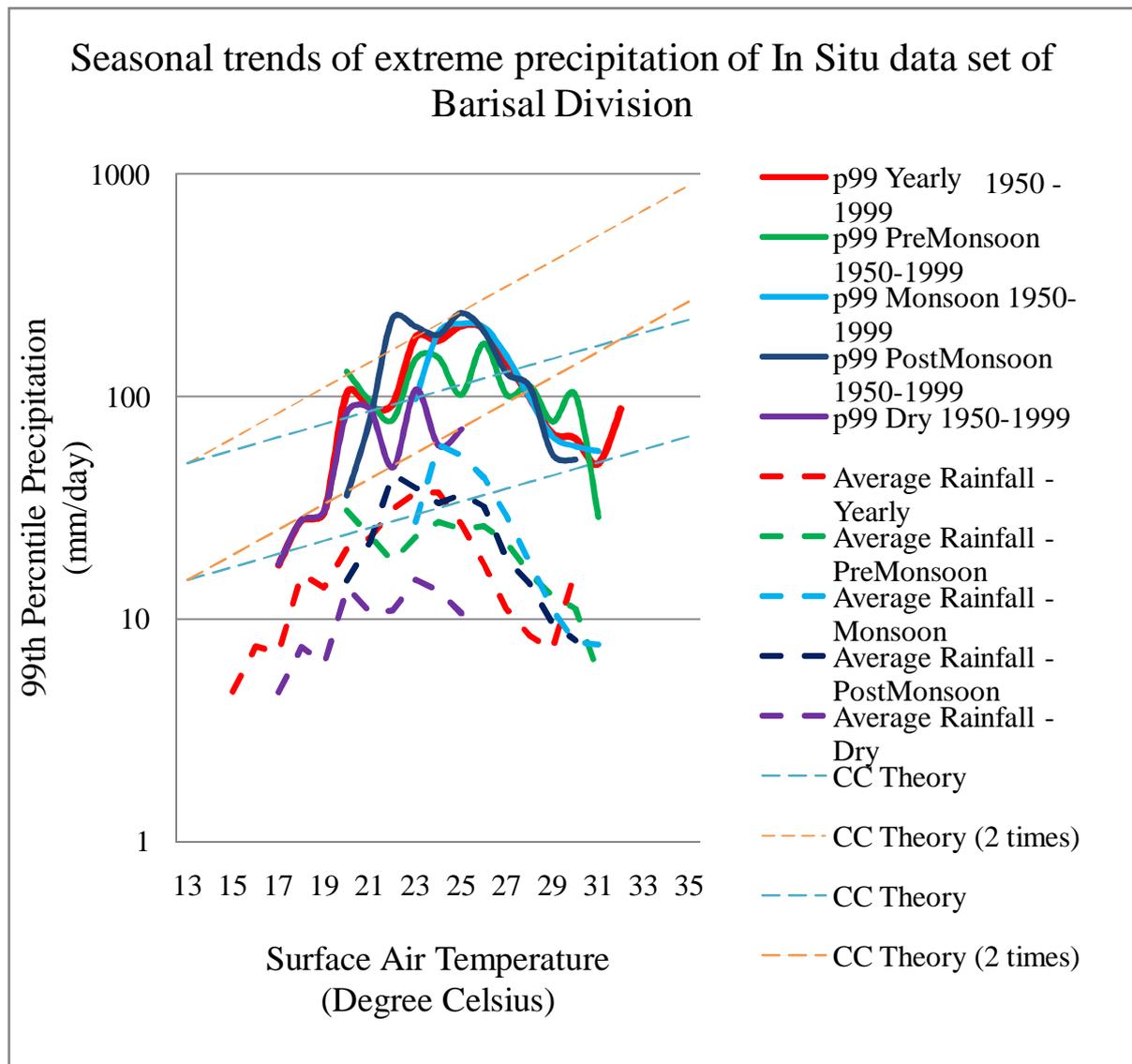


Figure 4.1(d): Comparison of seasonal trends of extreme precipitation of In Situ data set of Barisal Division

Also in figure 4.1(d), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Barisal Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(d) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Barisal Division**. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season.

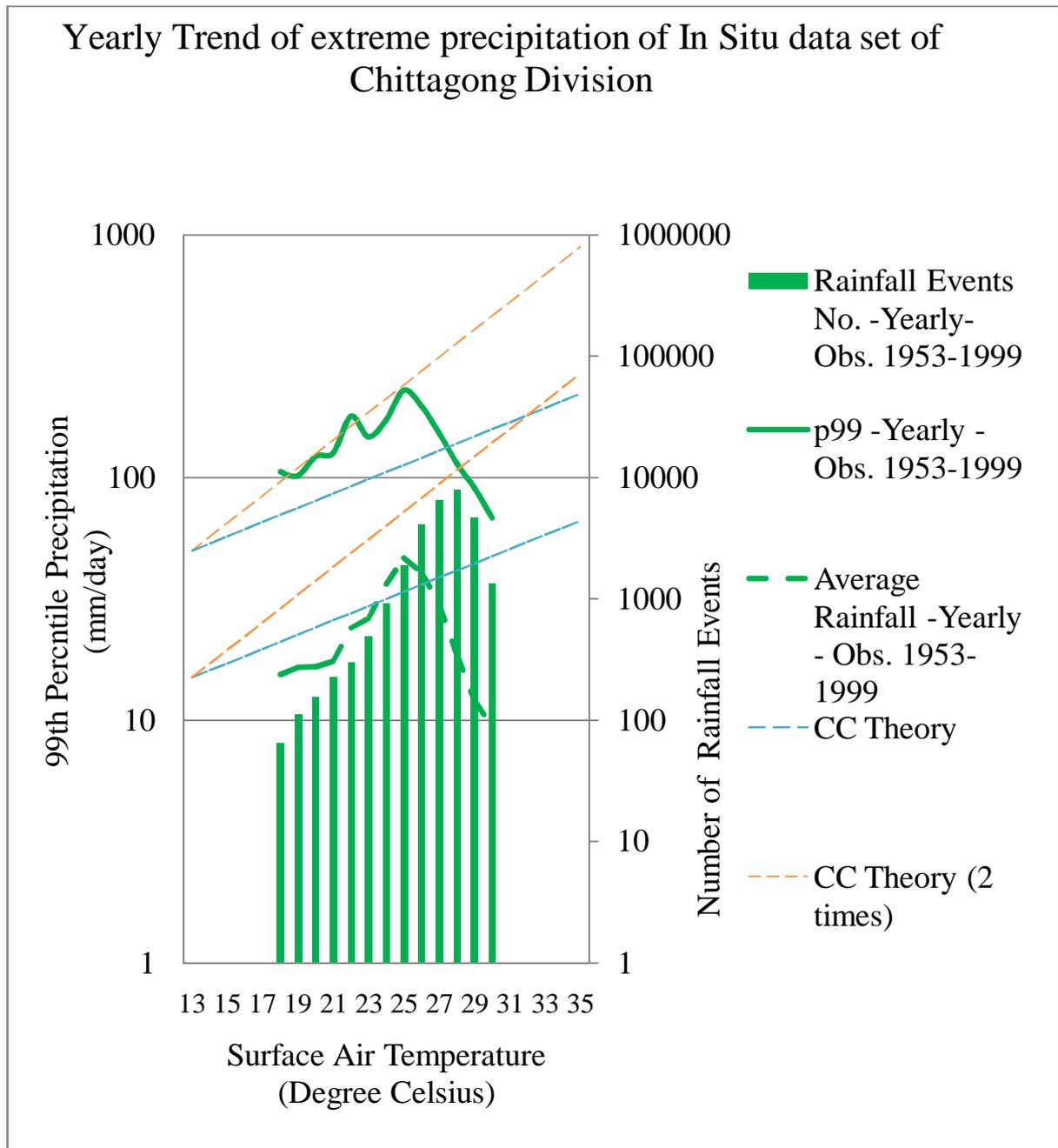


Figure 4.1(e): Yearly trend of extreme precipitation of In Situ data set of Chittagong Division

Figure 4.1(e) also represents the relationship between daily extreme precipitation and daily average surface air temperature but data set is of **Chittagong Division**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(e), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

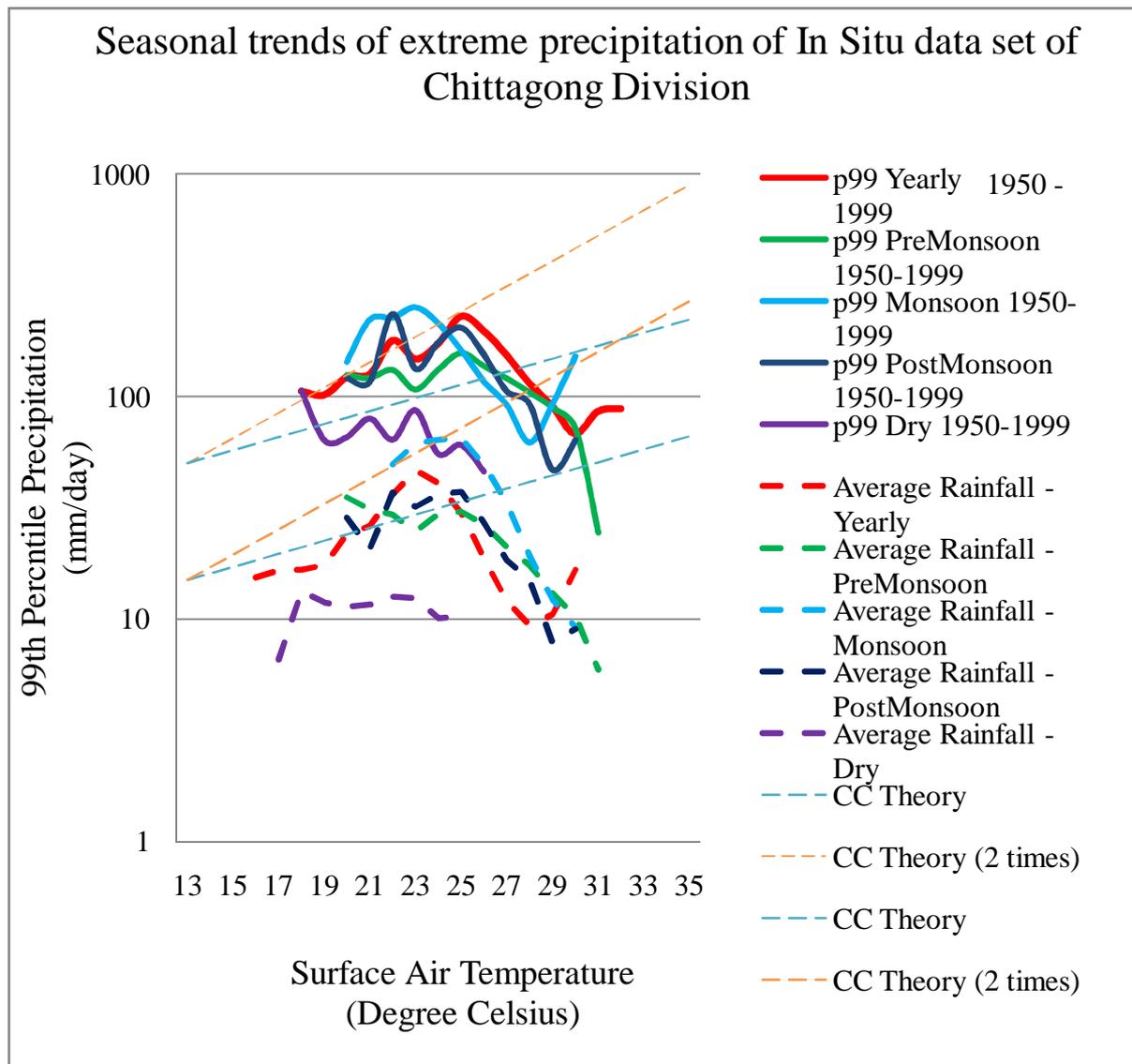


Figure 4.1(f): Comparison of seasonal trends of extreme precipitation of In Situ data set of Chittagong Division

Also in figure 4.1(f), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Chittagong Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(f) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Chittagong Division**. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season.

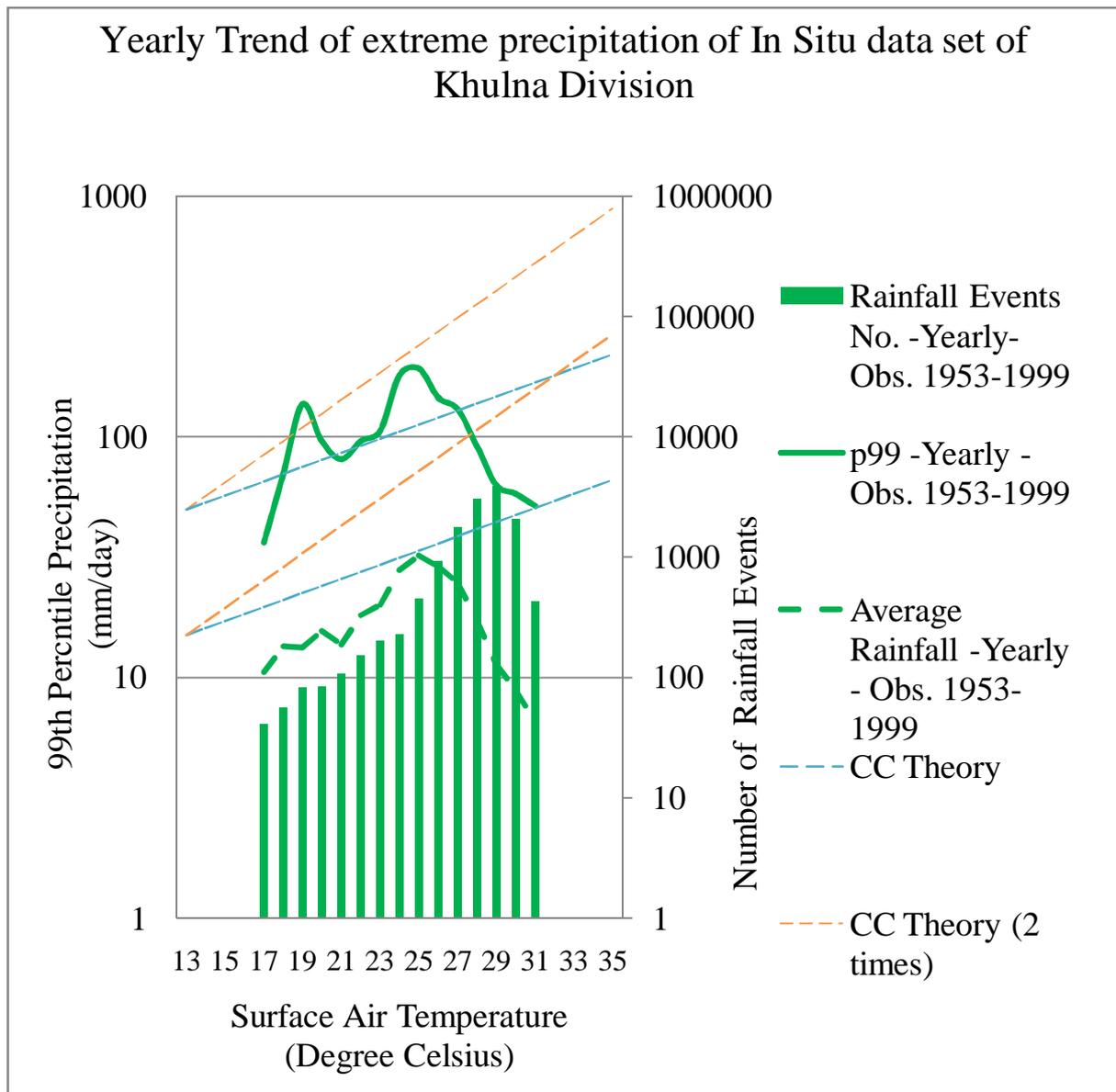


Figure 4.1(g): Yearly trend of extreme precipitation of In Situ data set of Khulna Division

Figure 4.1(g) also represents the relationship between daily extreme precipitation and daily average surface air temperature but data set is of **Khulna Division**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(g), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

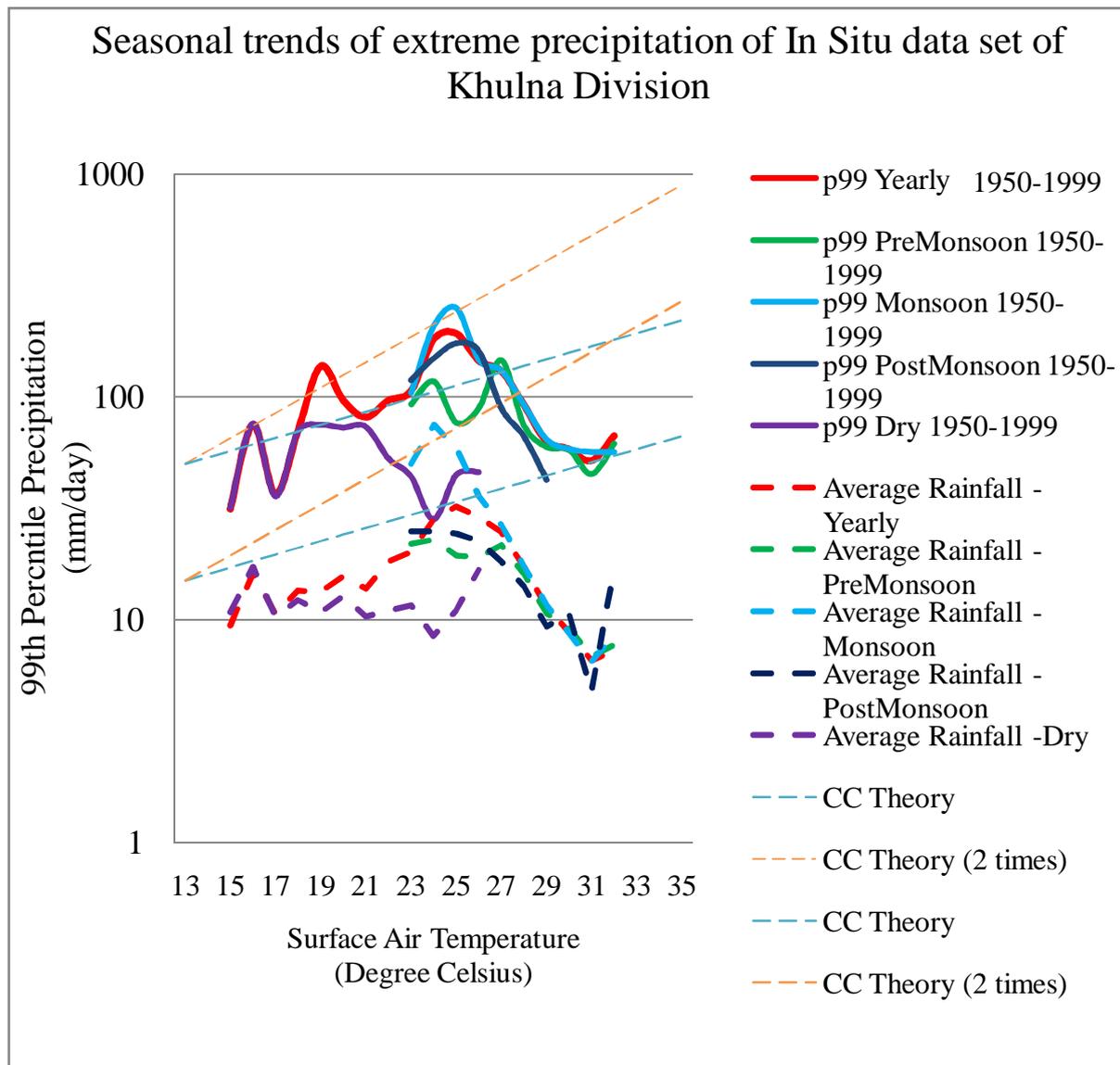


Figure 4.1(h): Comparison of seasonal trends of extreme precipitation of In Situ data set of Khulna Division

Also in figure 4.1(h), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Khulna Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(h) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Khulna Division**. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season.

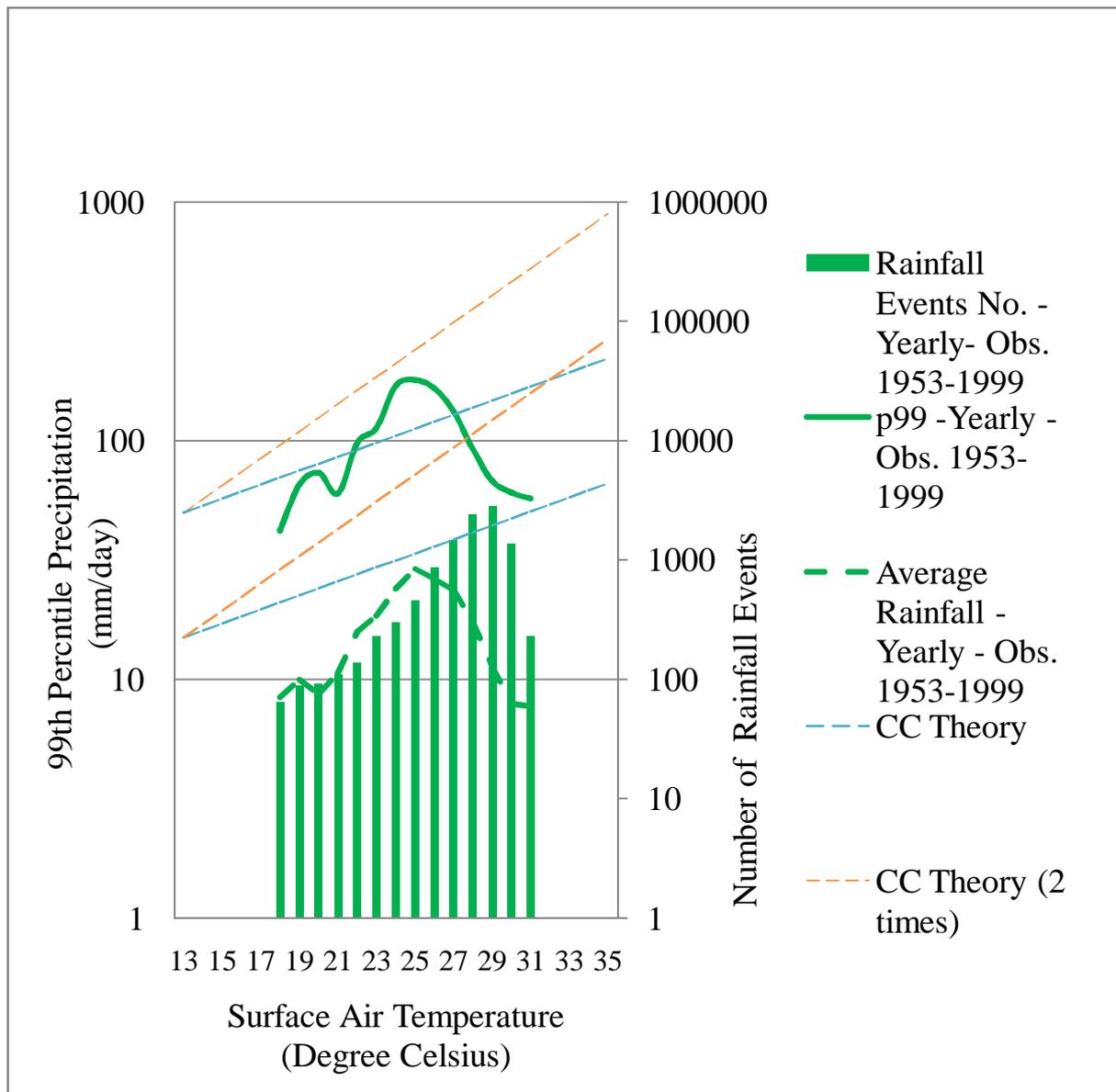


Figure 4.1(i): Yearly trend of extreme precipitation of In Situ data set of Rajshahi Division

Figure 4.1(i) also represents the relationship between daily extreme precipitation and daily average surface air temperature but data set is of **Rajshahi Division**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(i), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

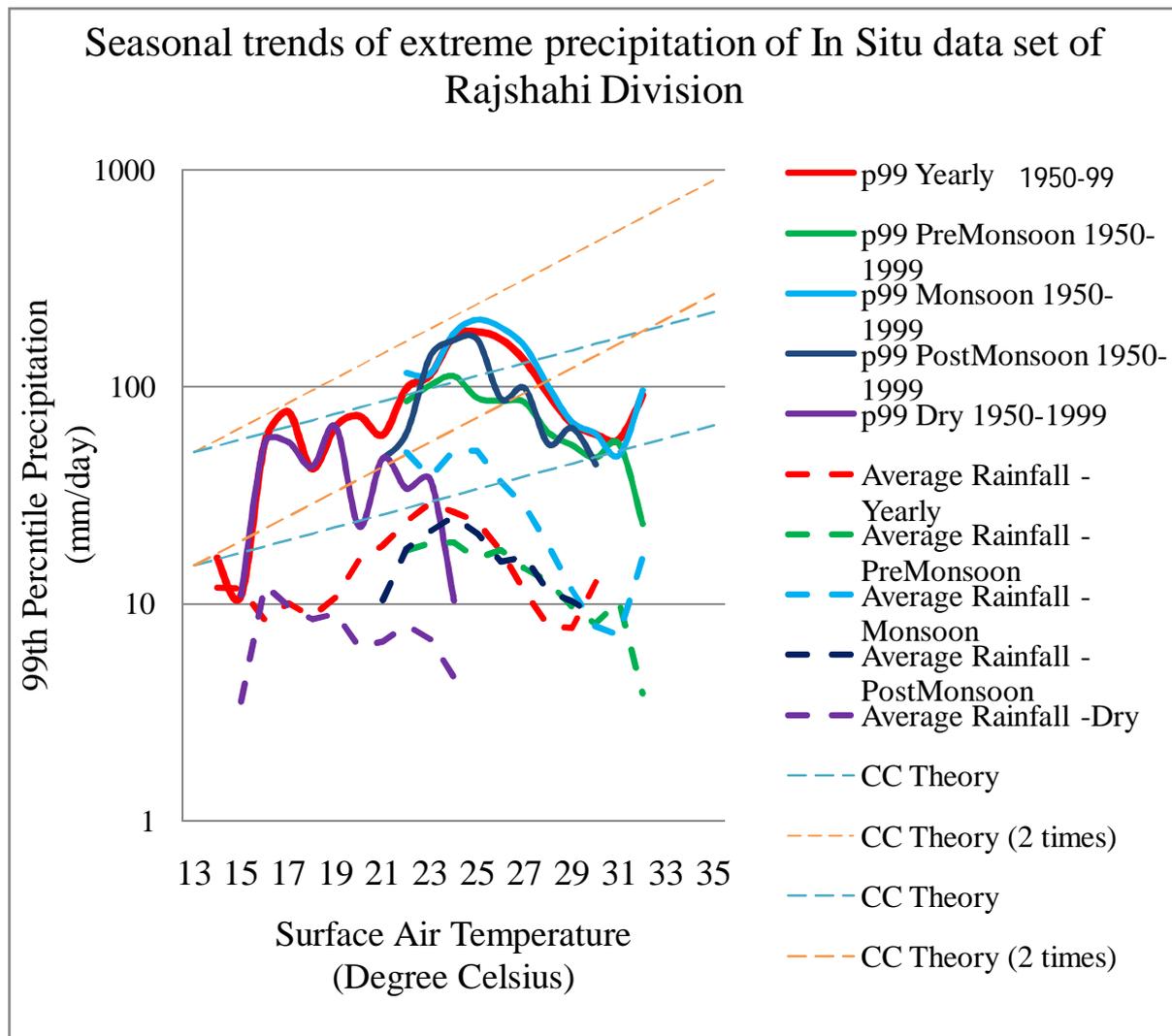


Figure 4.1(j): Comparison of seasonal trends of extreme precipitation of In Situ data set of Rajshahi Division

Also in figure 4.1(j), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Rajshahi Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(j) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Rajshahi Division**. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season

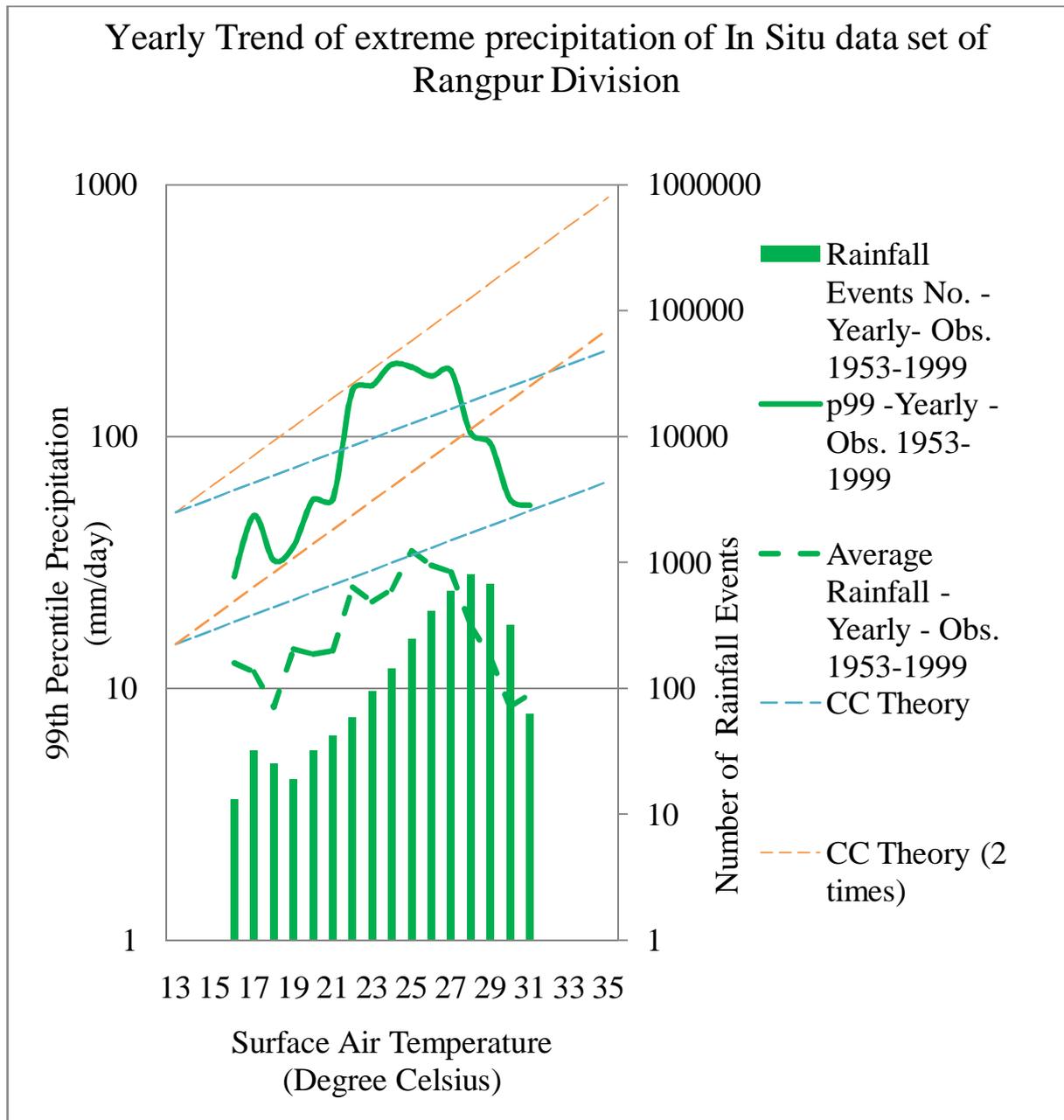


Figure 4.1(k): Yearly trend of extreme precipitation of In Situ data set of Rangpur Division

Figure 4.1(k) also represents the relationship between daily extreme precipitation and daily average surface air temperature but data set is of **Rangpur Division**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(k), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

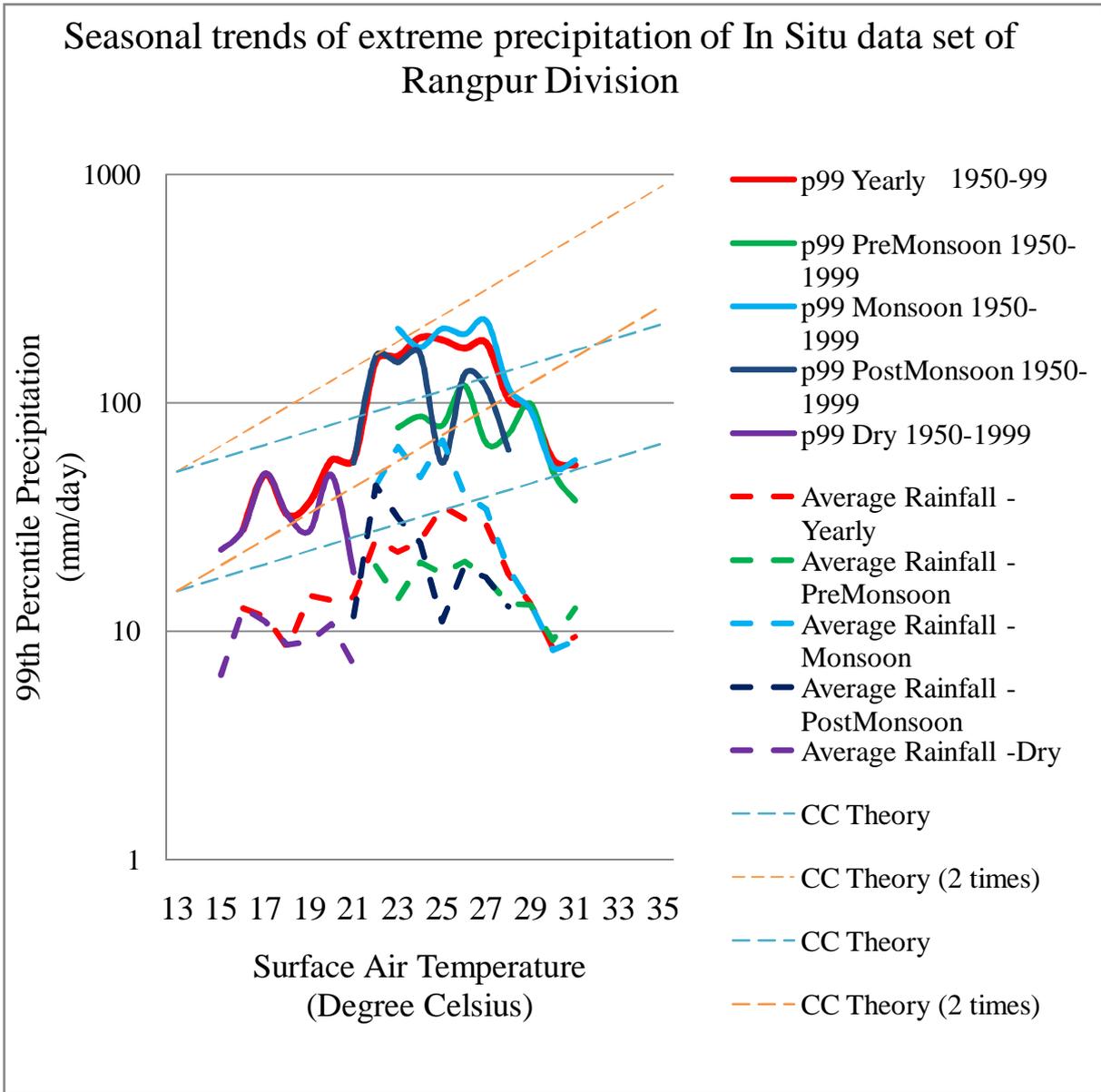


Figure 4.1(l): Comparison of seasonal trends of extreme precipitation of In Situ data set of Rangpur Division

Also in figure 4.1(l), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Rangpur Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(l) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Rangpur Division**. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season.

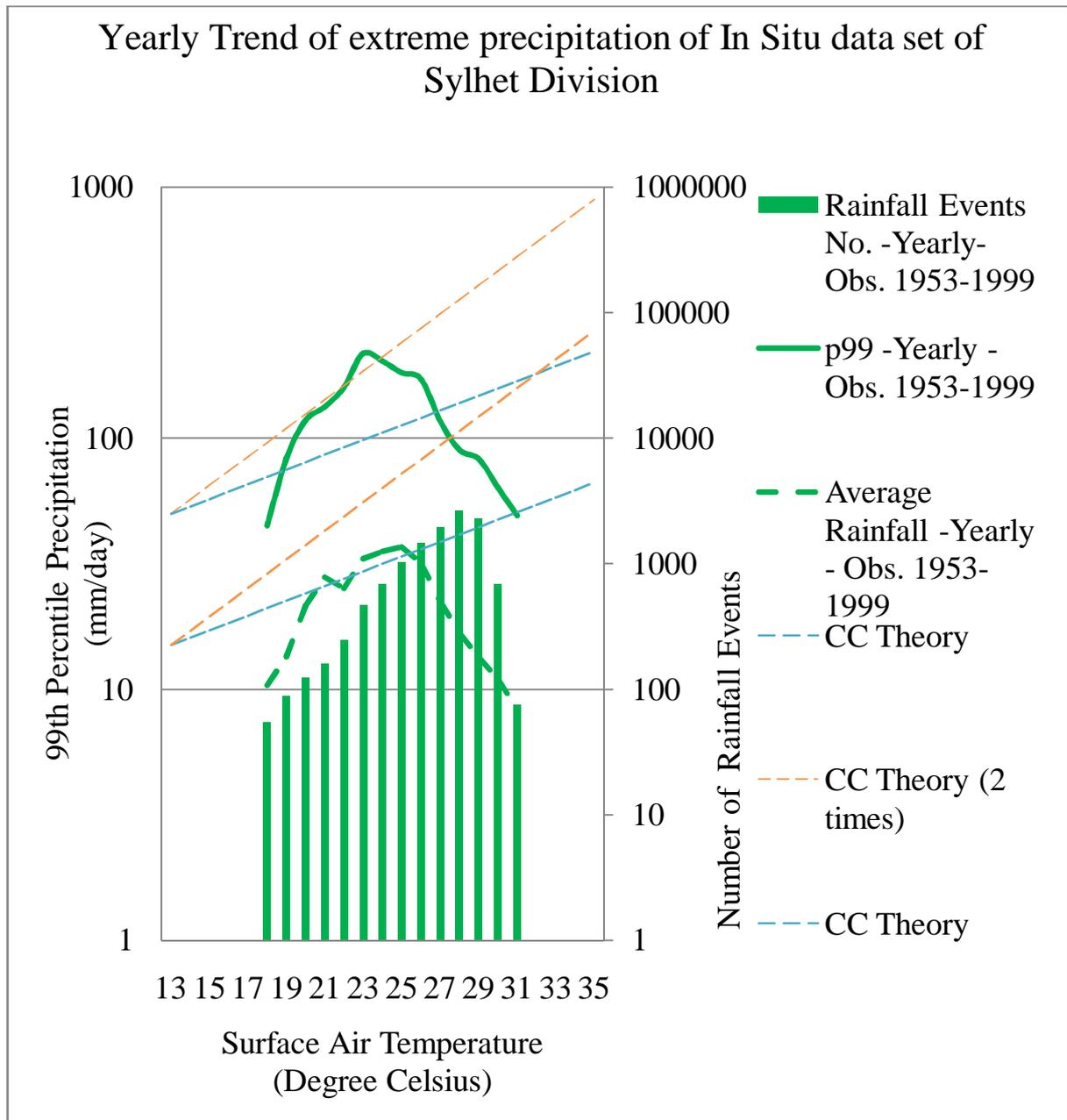


Figure 4.1(m): Yearly trend of extreme precipitation of In Situ data set of Sylhet Division

Figure 4.1(m) also represents the relationship between daily extreme precipitation and daily average surface air temperature but data set is of **Sylhet Division**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(m), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

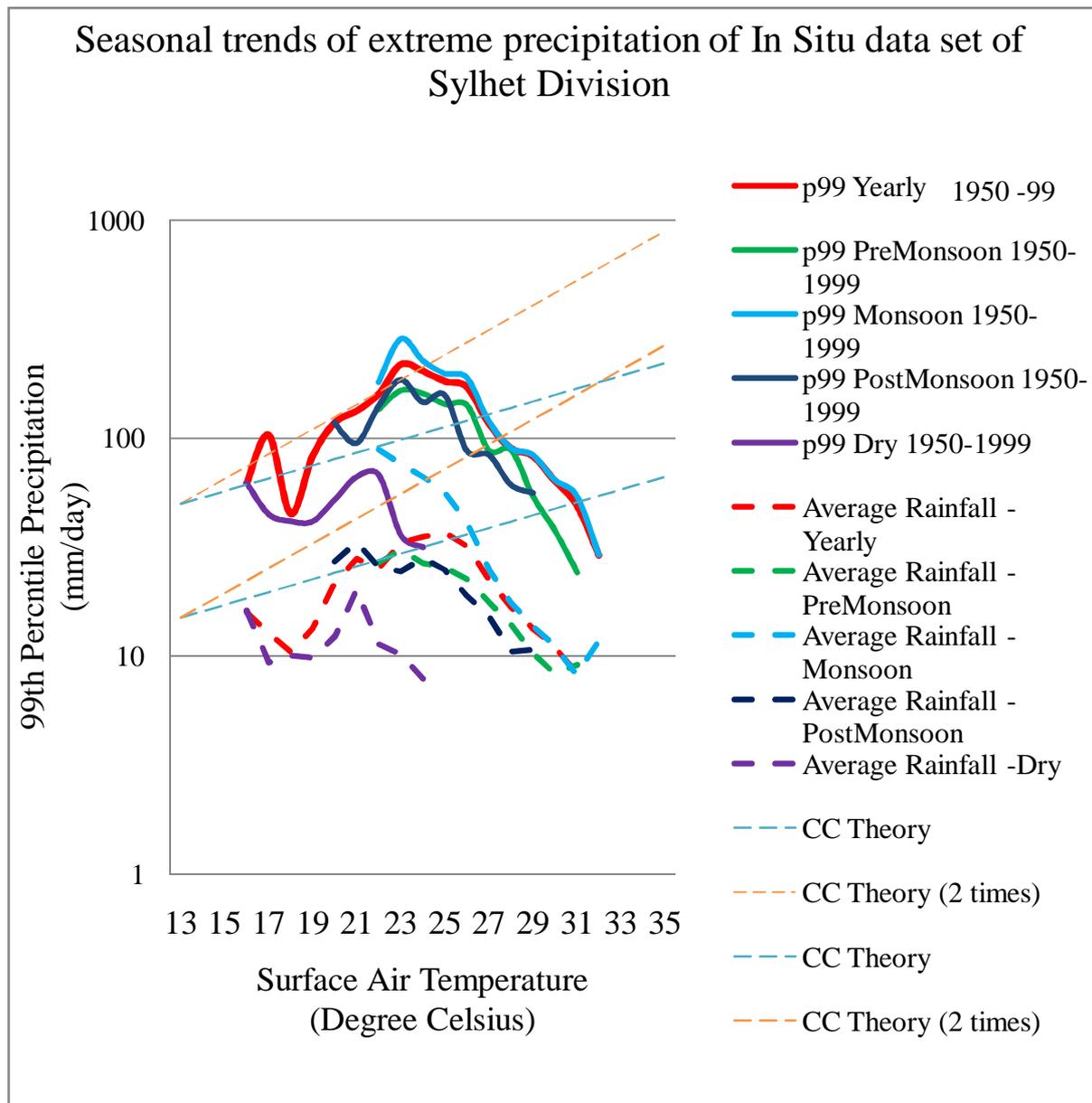


Figure 4.1(n): Comparison of seasonal trends of extreme precipitation of In Situ data set of Sylhet Division

Also in figure 4.1(n), extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Sylhet Division**. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(n) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of **Sylhet Division**. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend is similar to yearly trend except dry season

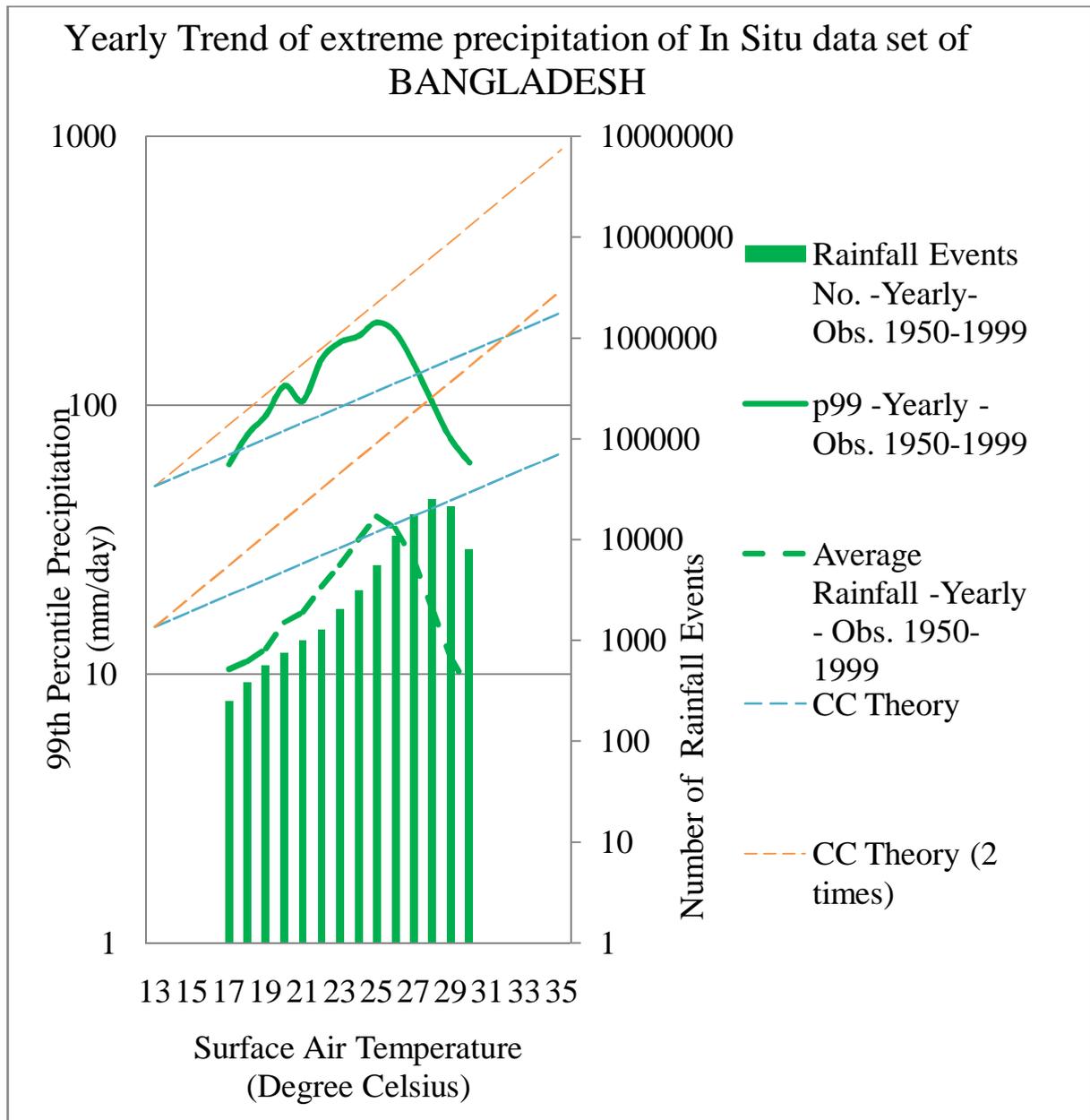


Figure 4.1(o): Yearly trend of extreme precipitation of In Situ data set of Bangladesh combining seven Divisions.

Figure 4.1(o) shows the Yearly trend of extreme precipitation with respect to daily surface air temperature of In Situ data set of whole **Bangladesh combining seven Divisions**. This trend is yearly trend of extreme precipitation. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation with respect to temperature. Green dash line is for average yearly rainfall. Green solid column represent Number of rainfall events for that specific temperature. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line. Observation data set ranges from the year of 1953 to 1999.

Figure 4.1(o), shows that Extreme precipitation (daily) trend start with ascending trend similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall. The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.

The pattern of Extreme precipitation trend of seven divisions and whole Bangladesh is similar.

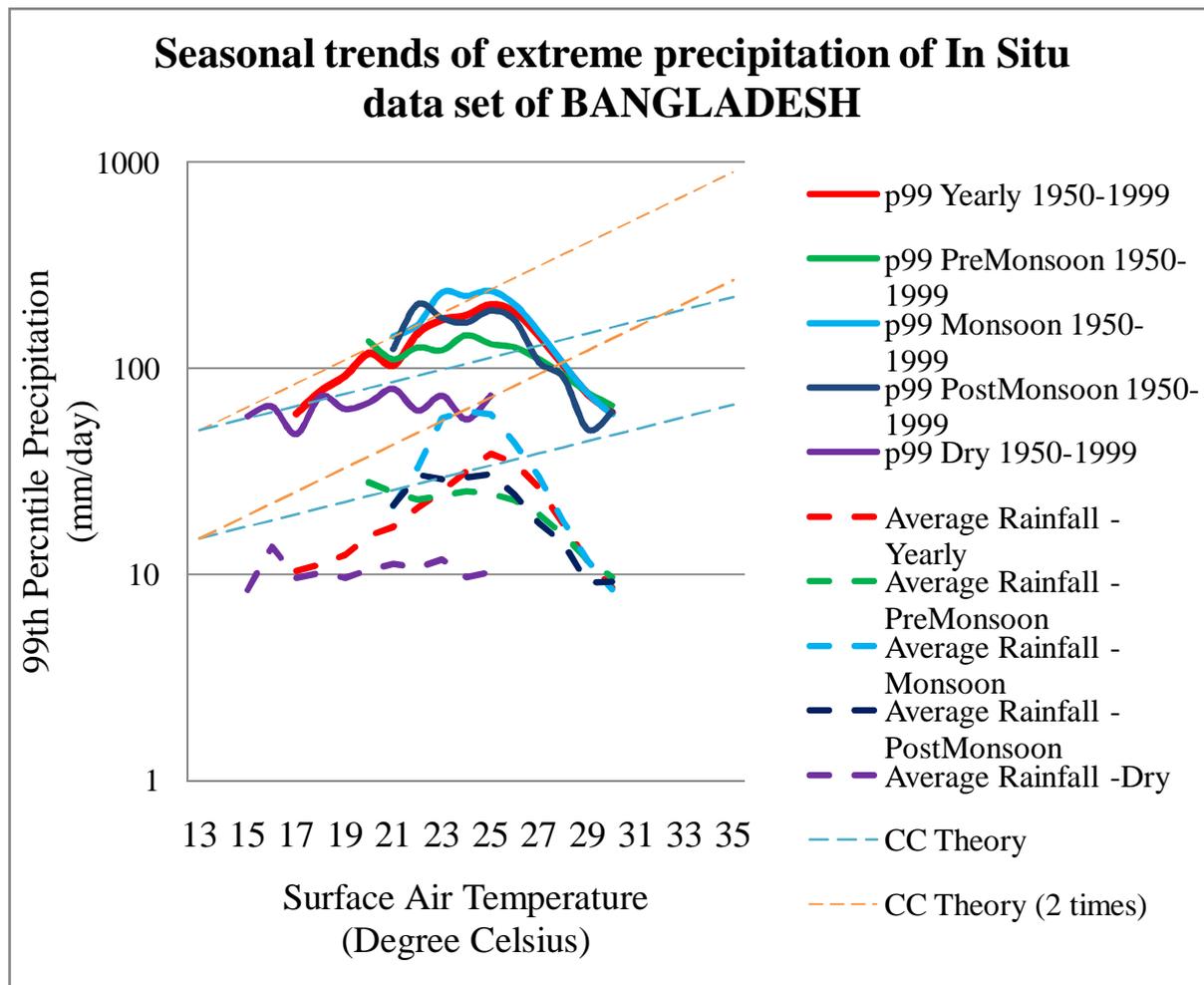


Figure 4.1(n): Comparison of seasonal trends of extreme precipitation of In Situ data set of Bangladesh combining seven Divisions.

Figure 4.1(n) represent extreme precipitation trend of each four seasons Pre-monsoon (March to May), Monsoon (June to September), Post-monsoon (October to November), Dry (December to February) has been shown for the data set of **Bangladesh** combining seven divisions. The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

Figure 4.1(n) shows the comparison of seasonal trends of extreme precipitation of In Situ data set of whole Bangladesh combining seven divisions. Green legend is for Pre-monsoon, Light Blue for Monsoon, Dark Blue for Post-monsoon, Purple color for dry season and Red legend is for yearly trend. Solid line represent 99th percentile precipitation (p99) in mm/day and corresponding dash line represents Average rainfall for that particular trend. The pattern of seasonal (Pre-monsoon, Monsoon and Post-monsoon) trend of Bangladesh is also similar like other seven divisions to yearly trend except dry season.

4.2 MIROC Data Set

In this section bias correction of model simulated data set for each seven division of Bangladesh has been given.

4.2.1 Bias Correction

From figure 4.2(a) to 4.2(g) shows the temperature distribution curve of daily average surface air temperature of model simulated data set and in-situ data set. Table 4.1 shows the calculated bias error for each division.

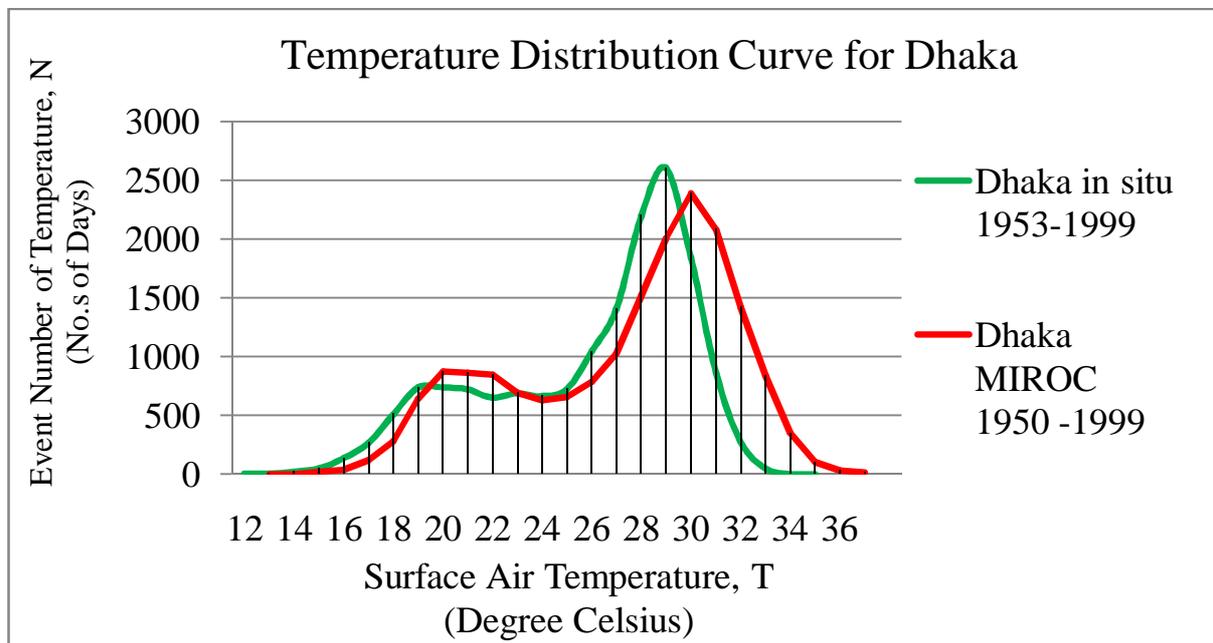


Figure 4.2(a): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Dhaka region.

Temperature Distribution Curve (TDC) is the curve that represents relation between temperature and no. of days of that specific temperature over a period of time. Here temperature means daily average surface air temperature. Figure 4.2(a) shows the TDCs of In-situ data set of Dhaka region (Green curve) and that of MIROC simulated data set over Dhaka region (Red curve). By comparing TDC of In-situ and MIROC we find that there is deviation of MIROC simulated data set about 1 Degree Celsius from In-situ data. This deviation is called Bias Error in Model MIROC. To get the actual Bias Error is the difference of mean temperature of MIROC and In-situ. Mean can be calculated as the summation of N and T over Total N. That means

$$T(\text{mean}) = (\sum(N*T))/N(\text{Total}) \dots\dots\dots\text{equation (1)}$$

$$\text{Bias Error} = T(\text{mean MIROC}) - T(\text{mean observation}) \dots\dots\dots\text{equation (2)}$$

Using above stated relation the calculated actual Bias Error for Dhaka = 1.36 Degree Celsius
 It means that we should consider 1.36 degree Celsius warmer when we use MIROC simulated data set.

Actual Bias Error for Barisal = 0.88 Degree Celsius

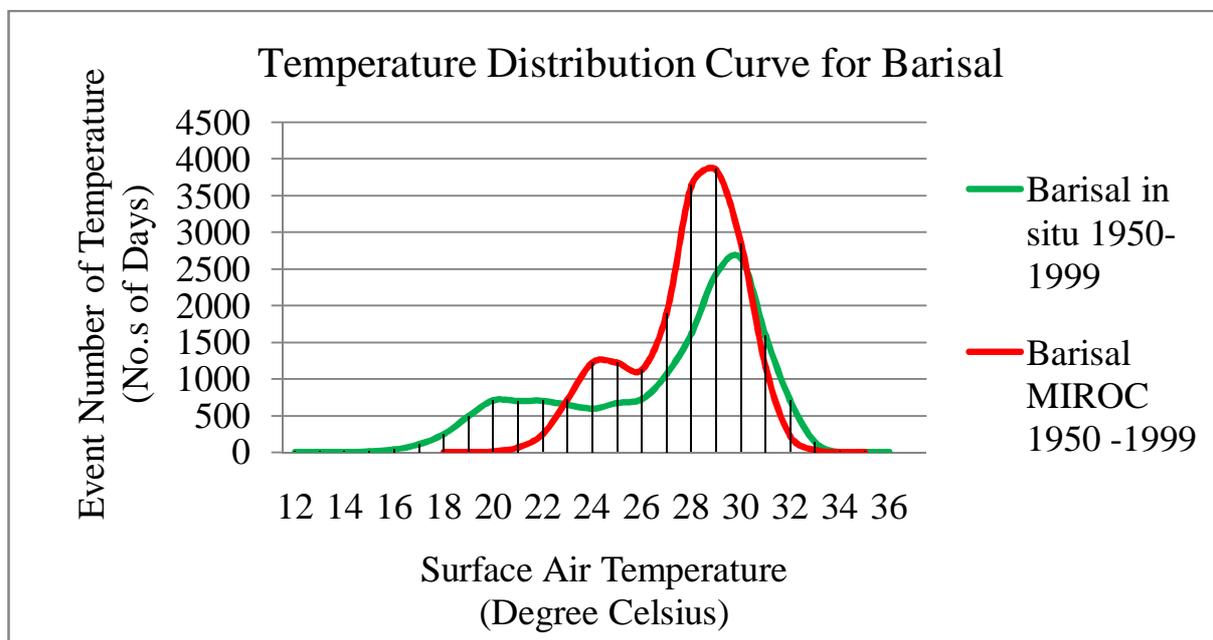


Figure 4.2(b): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Barisal region.

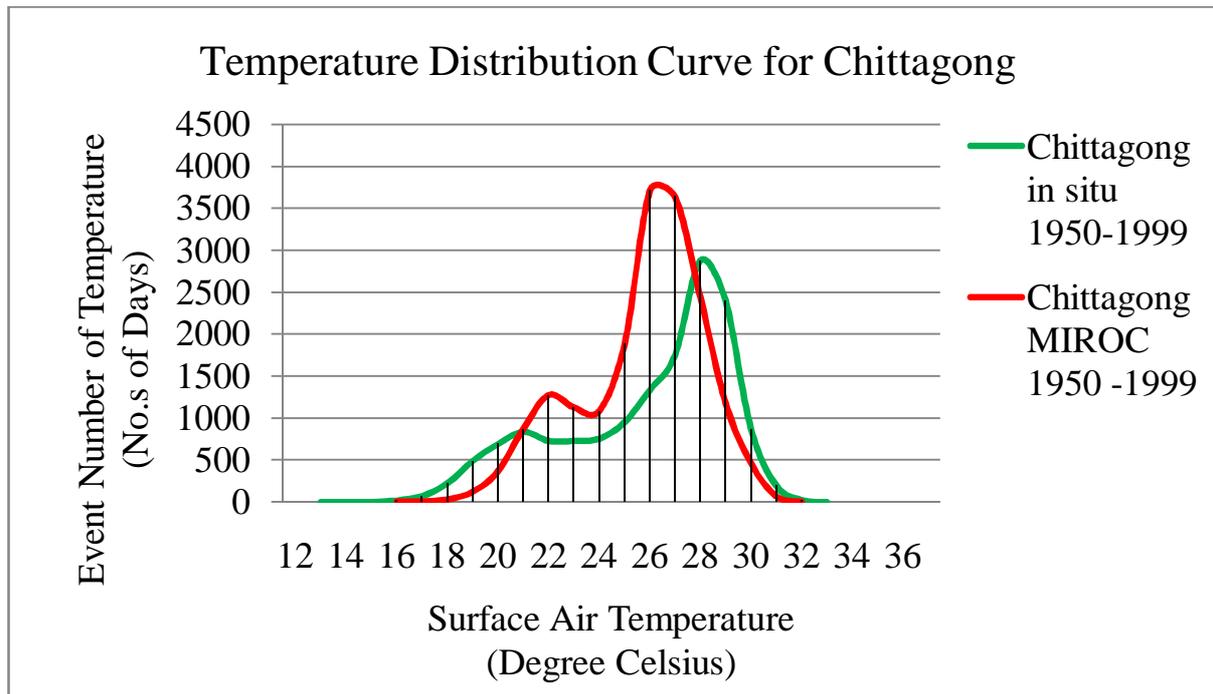


Figure 4.2(c): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Chittagong region.

From figure 4.2 (c), MIROC TDC is lagging behind the TDC of In-situ.

Using equation (1) and (2), calculated actual Bias Error for Chittagong region = -0.15 Degree Celsius.

Negative value indicates that Temperature data set from MIROC simulation is less warm than that of observation data set.

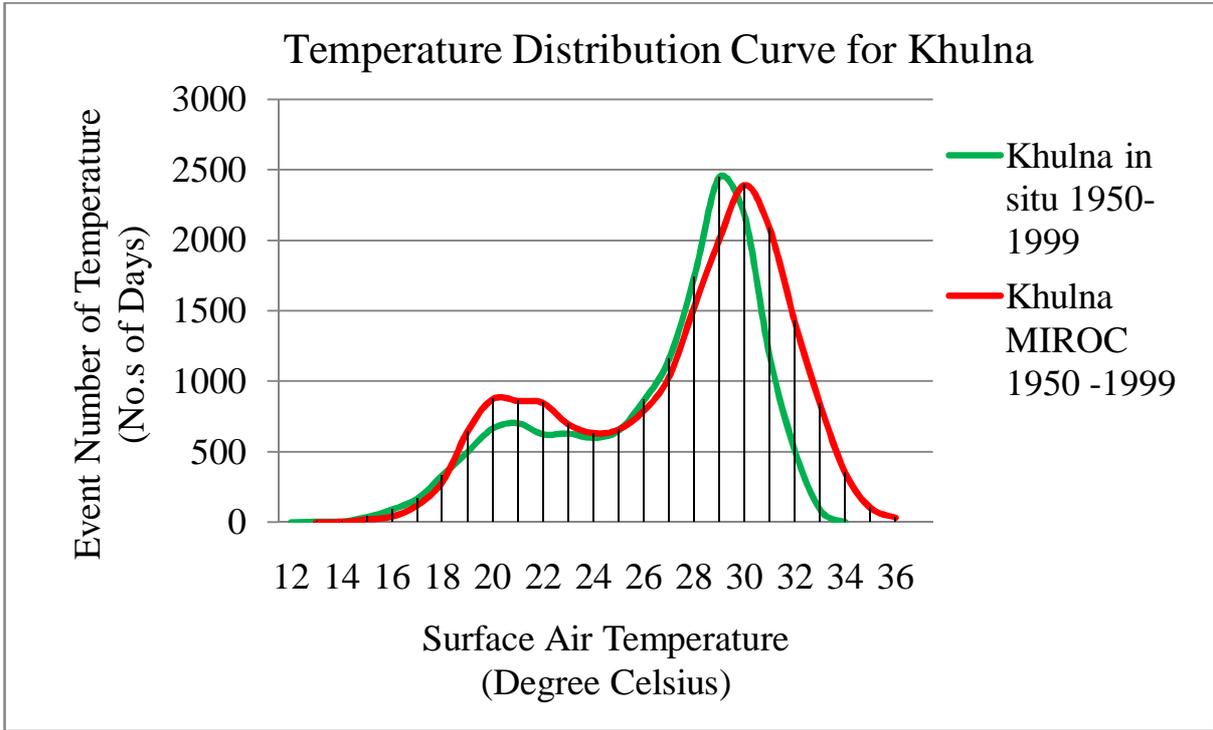


Figure 4.2(d): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Khulna region.

From figure 4.2 (c), TDC of in-situ is lagging behind the TDC of MIROC.

Using equation (1) and (2), calculated actual Bias Error for Khulna region = 0.78 Degree Celsius.

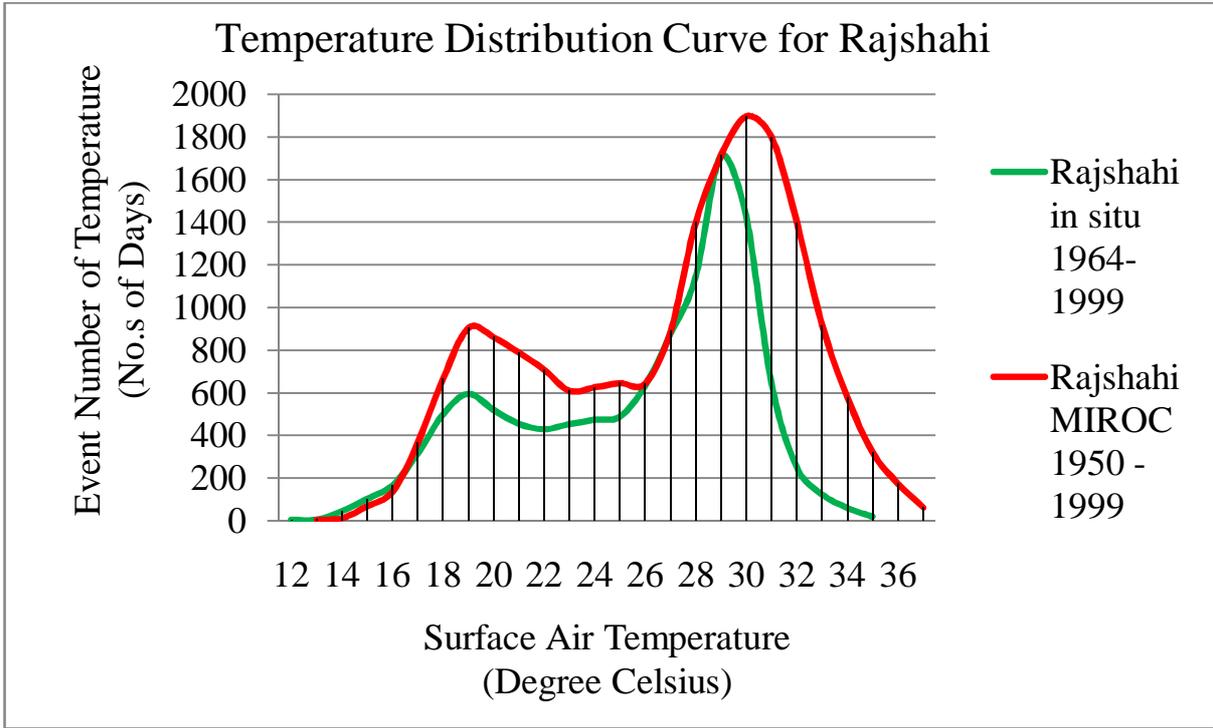


Figure 4.2(e): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Rajshahi region.

From figure 4.2 (c), TDC of in-situ is lagging behind the TDC of MIROC.

Using equation (1) and (2), calculated actual Bias Error for Rajshahi region = 1.29 Degree Celsius

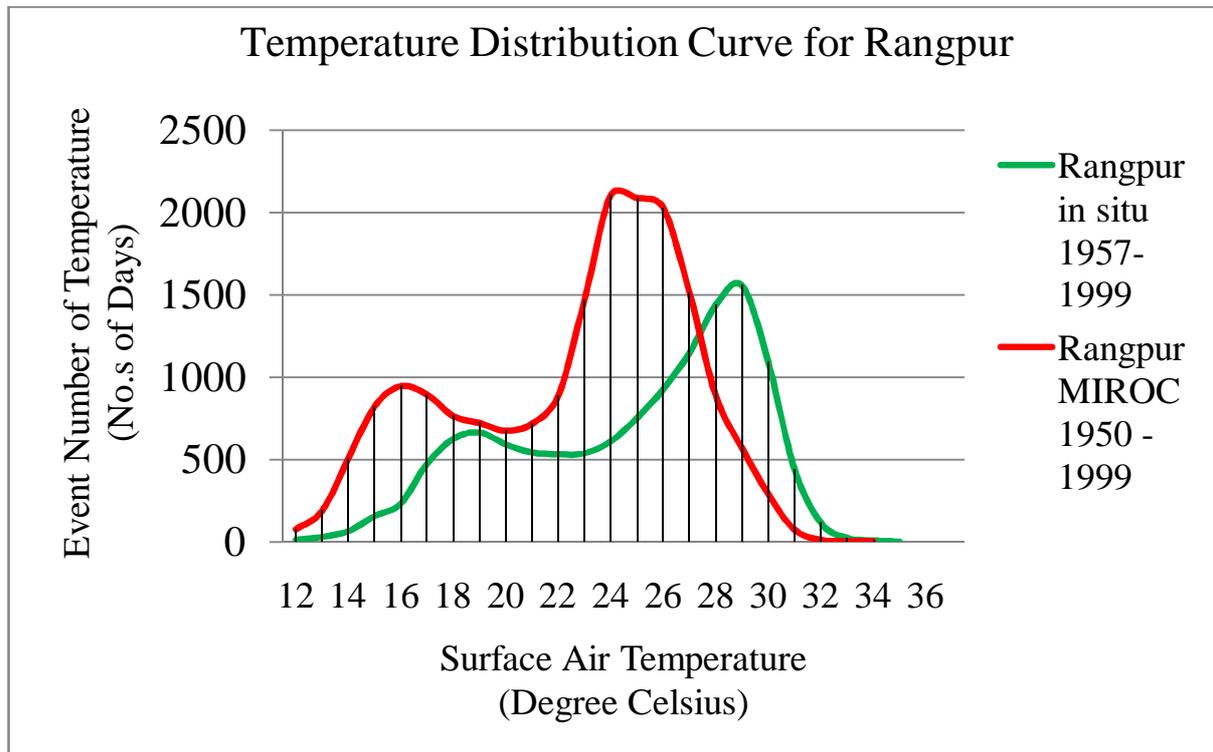


Figure 4.2(f): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Rangpur region.

From figure 4.2 (c), MIROC TDC is lagging behind the TDC of In-situ.

Using equation (1) and (2), calculated actual Bias Error for Rangpur region = -2.23 Degree Celsius.

Negative value indicates that Temperature data set from MIROC simulation is less warm than that of observation data set.

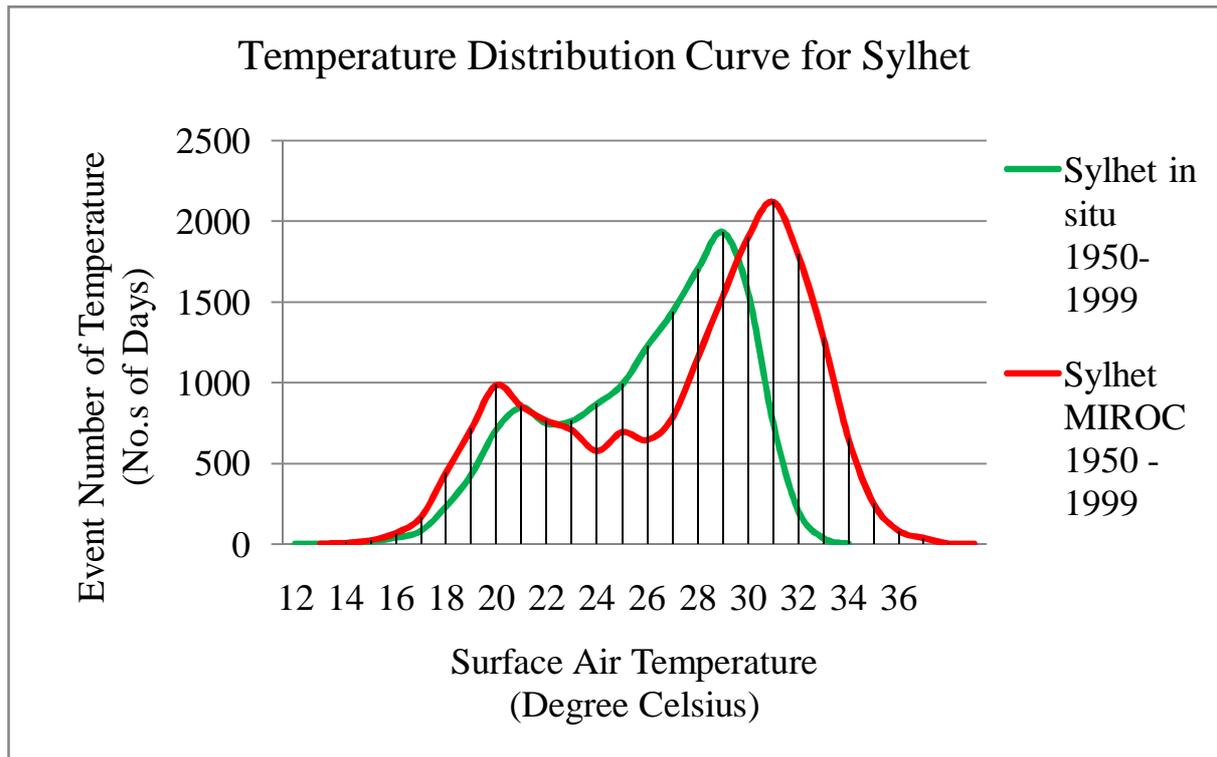


Figure 4.2(g): Temperature Distribution Curve for estimating bias error of MIROC simulation with respect to In-Situ surface air temperature in Sylhet region.

From figure 4.2 (c), TDC of in-situ is lagging behind the TDC of MIROC.

Using equation (1) and (2), calculated actual Bias Error for Sylhet region = 1.48 Degree Celsius

Table 4.1 shows the summary of estimated actual Bias Error for all seven divisional regions.

Table 4.1: Bias correction for each division

Division	Bias Error (Degree Celsius)
Barisal	0.88
Chittagong	-0.15
Dhaka	1.36
Khulna	0.78
Rajshahi	1.29
Rangpur	-2.23
Sylhet	1.48

4.3 Evaluation of MIROC and In Situ Result and Future Projection

In this section results for validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation are given. Besides, results of application of model simulation in projection of future changes of extreme precipitation in the targeted region are shown. Figures 4.3(a) to 4.3(g) shows the result for each seven divisions. A summary of result discussion has been given in conclusion chapter.

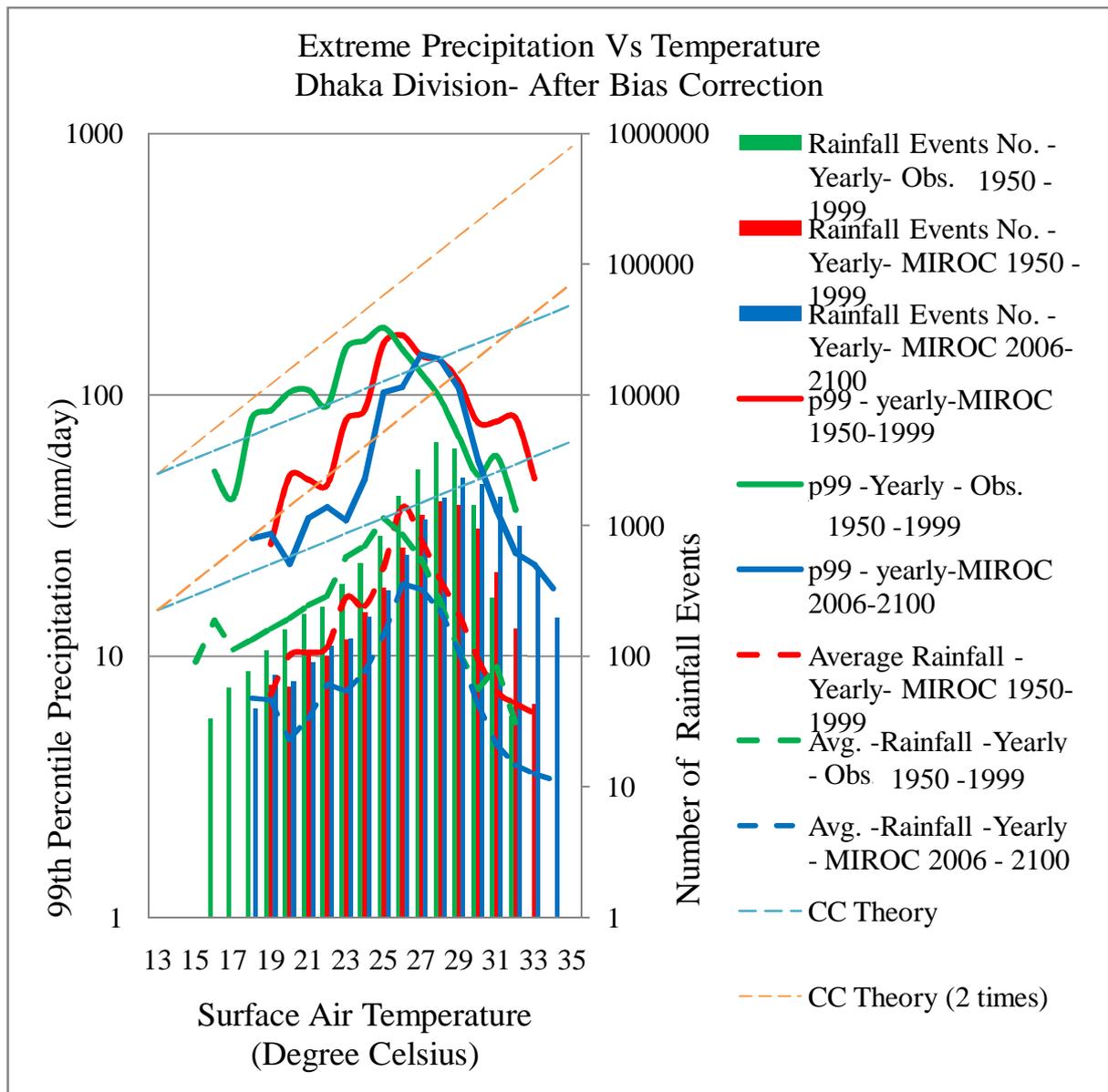


Figure 4.3(a): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for Dhaka Division after considering bias error correction.

In figure 4.3(a), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis is for Number of rainfall events. Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Dhaka Division* for the time period year of 1950 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Dhaka Division* for the time period year of 1950 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Dhaka Division* for the time period year of 1950 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Dhaka Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Dhaka Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Dhaka Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Dhaka Divisional Region* for the time period year of **2006 to 2100**. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Dhaka Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Dhaka Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

From the figure 4.3(a), the peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent for Observation, MIROC present and MIROC projection. Even, while the trend is decline downward but No. of Rainfall Events is still increasing for all three trends. So, the trends of extreme precipitation cannot be explained by the corresponding rainfall event numbers. For future projection of MIROC, rainfall event numbers are projected in higher temperature than in-situ. It indicates that in future in higher temperature rainfall may occur more compared to present observation rainfall.

From MIROC and In Situ observations, results of peak of p99 show somewhat low magnitude of MIROC compare to In Situ extreme precipitation.

Result shows that the peak of p99 of MIROC and In Situ differ to some marginal extent in daily temperature. But still they have similarities in the pattern of p99 of Observation, MIROC present and MIROC projection. So, present analysis of p99 of observation and that of MIROC present simulation has good agreement. Also MIROC present simulation and MIROC future simulation has good agreement. Hence for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation for *Dhaka* region.

So, Figure 4.3(a) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Dhaka Division*.

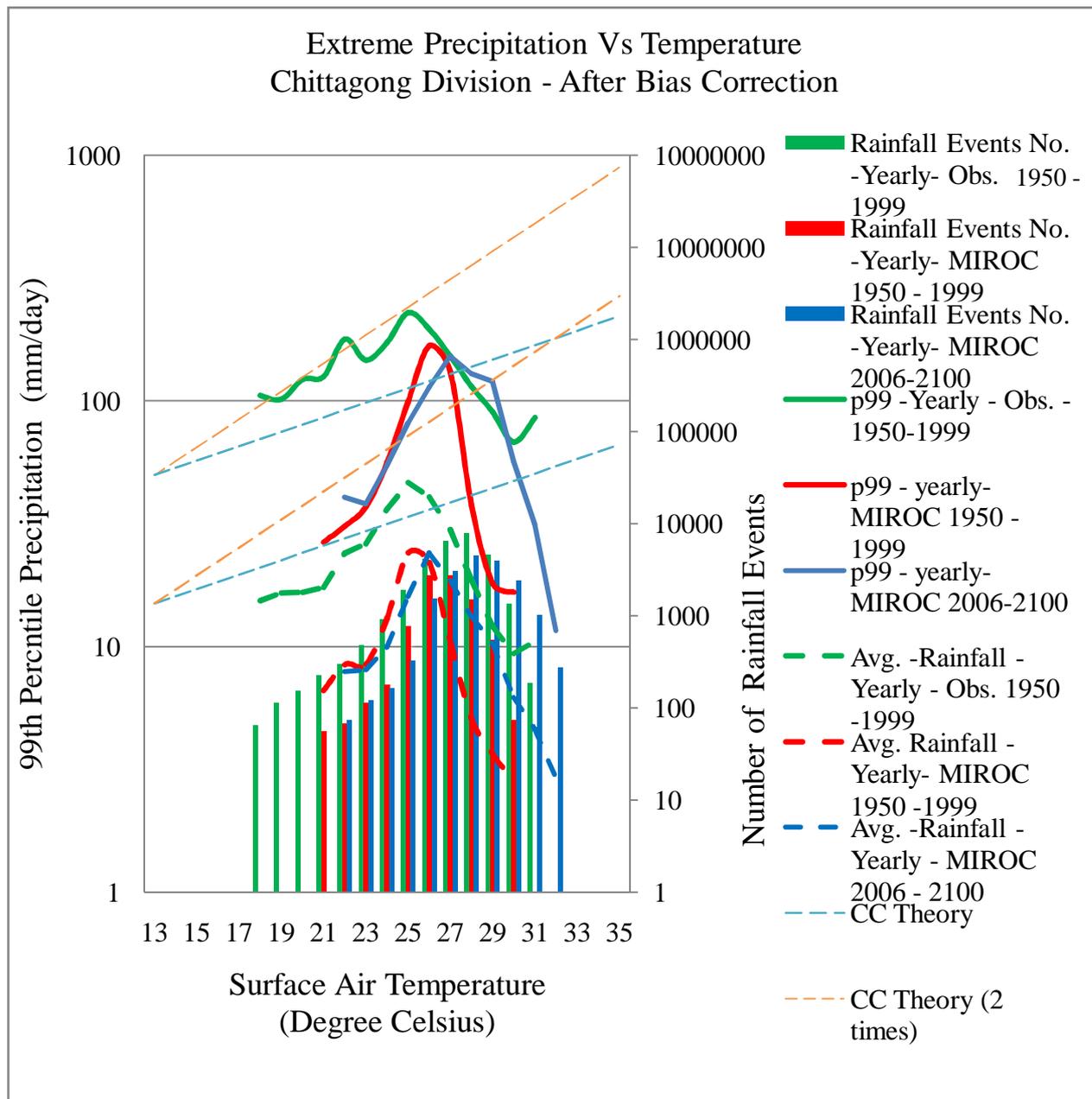


Figure 4.3(b): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for **Chittagong Division** after considering bias error correction.

In figure 4.3(b), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis (Right) is for Number of rainfall events.

Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Chittagong Division* for the time period year of 1950 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Chittagong Division* for the time period year of 1950 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Chittagong Division* for the time period year of 1950 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Chittagong Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Chittagong Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Chittagong Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Chittagong Divisional Region* for the time period year of **2006 to 2100**. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Chittagong Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Chittagong Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

From the figure 4.3(b), the peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent for Observation, MIROC present and MIROC projection. Even, while the trend is decline downward but No. of Rainfall Events is still increasing for all three trends. So, the trends of extreme precipitation cannot be explained by the corresponding rainfall event numbers. For future projection of MIROC, rainfall event numbers are projected in higher temperature than in-situ. It indicates that in future in higher temperature rainfall may occur more compared to present observation rainfall.

From MIROC and In Situ observations, results of peak of p99 show somewhat low magnitude of MIROC compare to In Situ extreme precipitation.

Result shows that the peak of p99 of MIROC and In Situ differ to some marginal extent in daily temperature. But still they have similarities in the pattern of p99 of Observation, MIROC present and MIROC projection but rate of ascending trend of MIROC is much higher than that of Observation. So, present analysis of p99 of observation and that of MIROC present simulation has somewhat good agreement. Also MIROC present simulation and MIROC future simulation has good agreement. Hence for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation for *Chittagong* region.

So, Figure 4.3(b) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Chittagong Division*.

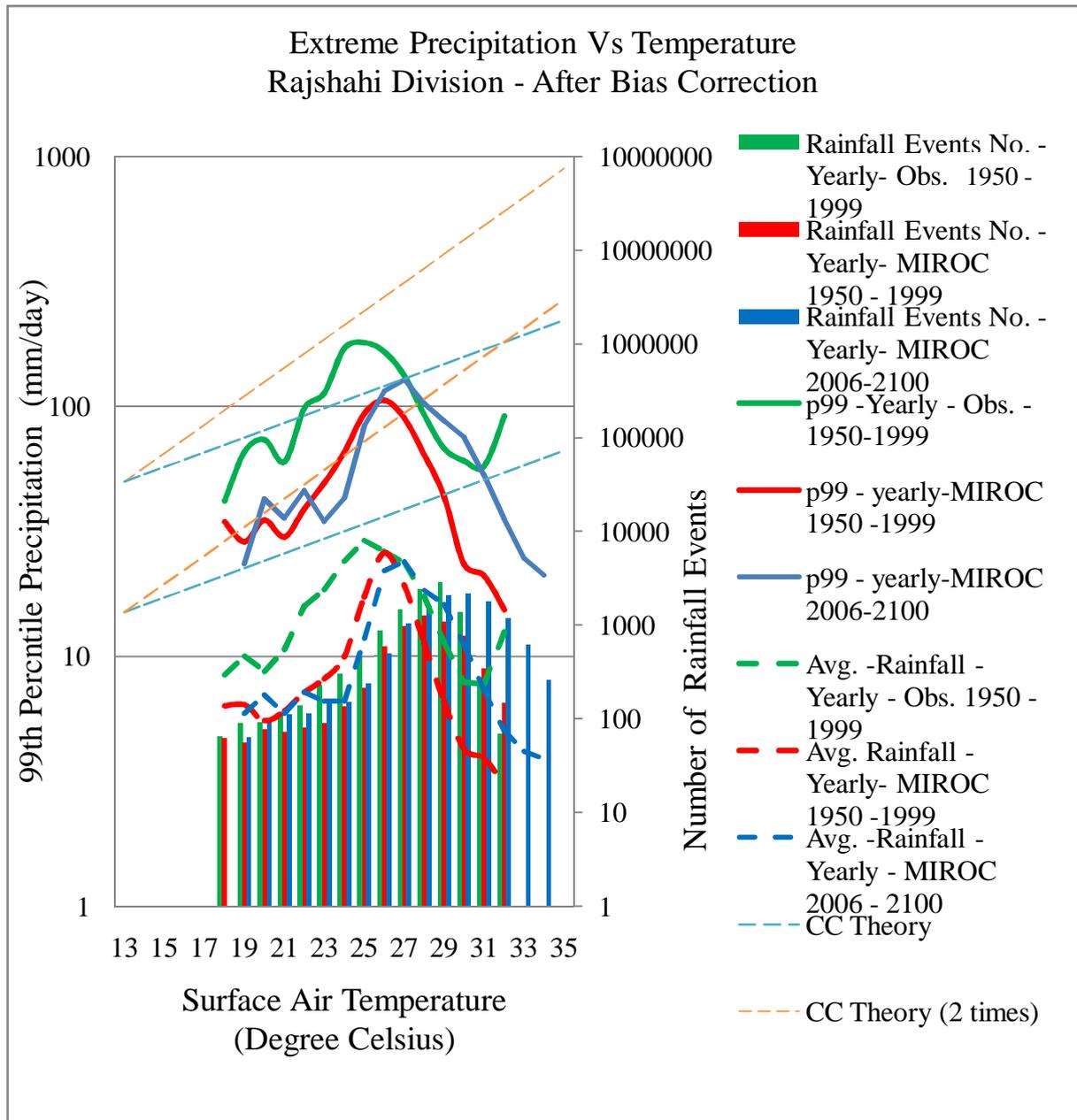


Figure 4.3(c): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for Rajshahi Division after considering bias error correction

In figure 4.3(c), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis (Right) is for Number of rainfall events.

Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Rajshahi Division* for the time period year of 1950 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Rajshahi Division* for the time period year of 1950 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Rajshahi Division* for the time period year of 1950 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Rajshahi Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Rajshahi Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Rajshahi Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Rajshahi Divisional Region* for the time period year of **2006 to 2100**. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Rajshahi Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Rajshahi Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

From the figure 4.3(c), the peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent for Observation, MIROC present and MIROC projection. Even, while the trend is decline downward but No. of Rainfall Events is still increasing for all three trends. So, the trends of extreme precipitation cannot be explained by the corresponding rainfall event numbers. For future projection of MIROC, rainfall event numbers are projected in higher temperature than in-situ. It indicates that in future in higher temperature rainfall may occur more compared to present observation rainfall.

From MIROC and In Situ observations, results of peak of p99 show somewhat low magnitude of MIROC compare to In Situ extreme precipitation.

Result shows that the peak of p99 of MIROC and In Situ differ to some marginal extent in daily temperature. But still they have similarities in the pattern of p99 of Observation, MIROC present and MIROC projection. So, present analysis of p99 of observation and that of MIROC present simulation has good agreement. Also MIROC present simulation and MIROC future simulation has good agreement. Hence for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation for *Rajshahi* region.

So, Figure 4.3(c) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Rajshahi Division*.

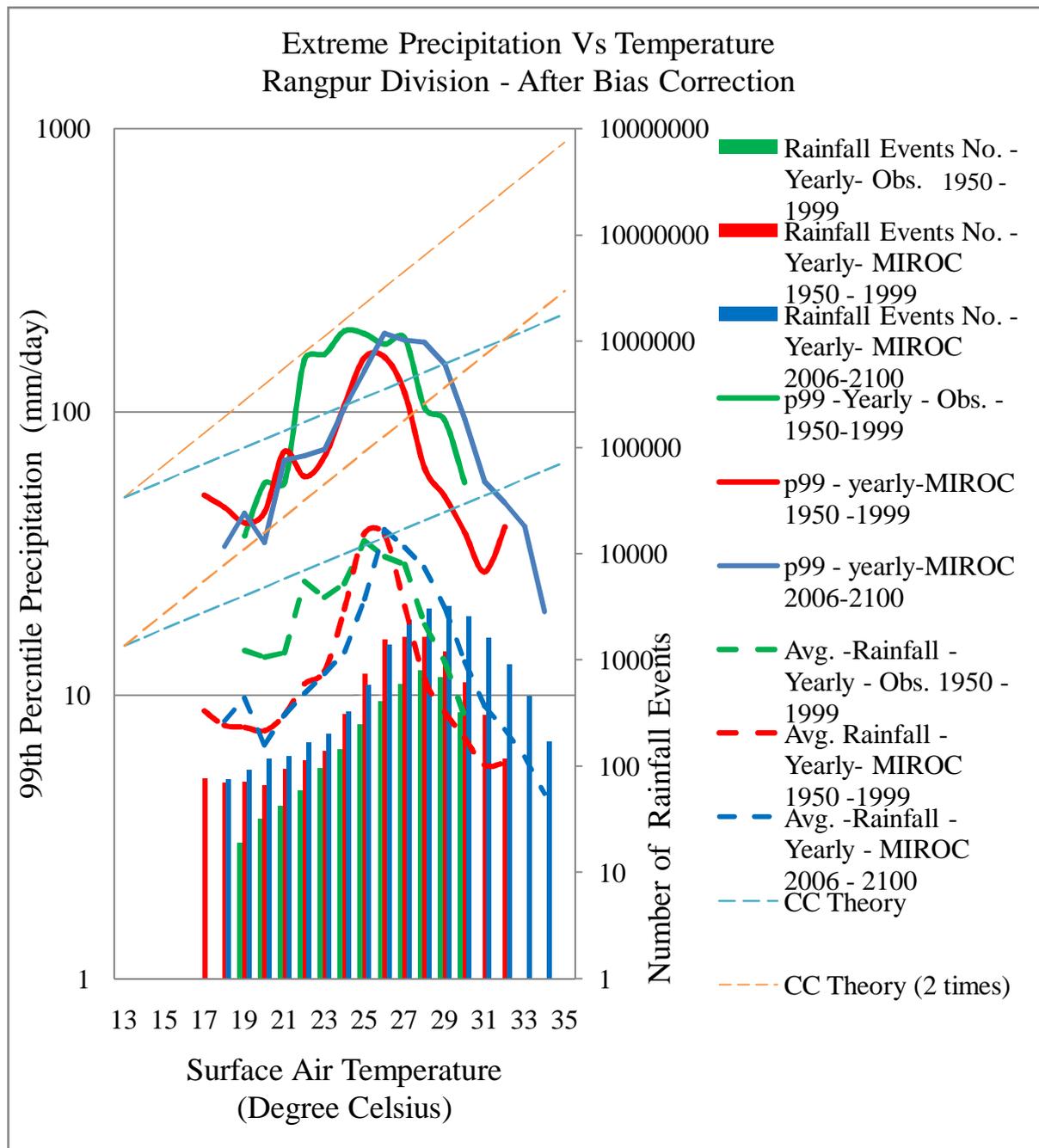


Figure 4.3(d): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for Rangpur Division after considering bias error correction

In figure 4.3(d), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis (Right) is for Number of rainfall events.

Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Rangpur Division* for the time period year of 1950 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Rangpur Division* for the time period year of 1950 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Rangpur Division* for the time period year of 1950 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Rangpur Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Rangpur Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Rangpur Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Rangpur Divisional Region* for the time period year of **2006 to 2100**. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Rangpur Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Rangpur Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

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So, Figure 4.3(d) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Rangpur Division*.

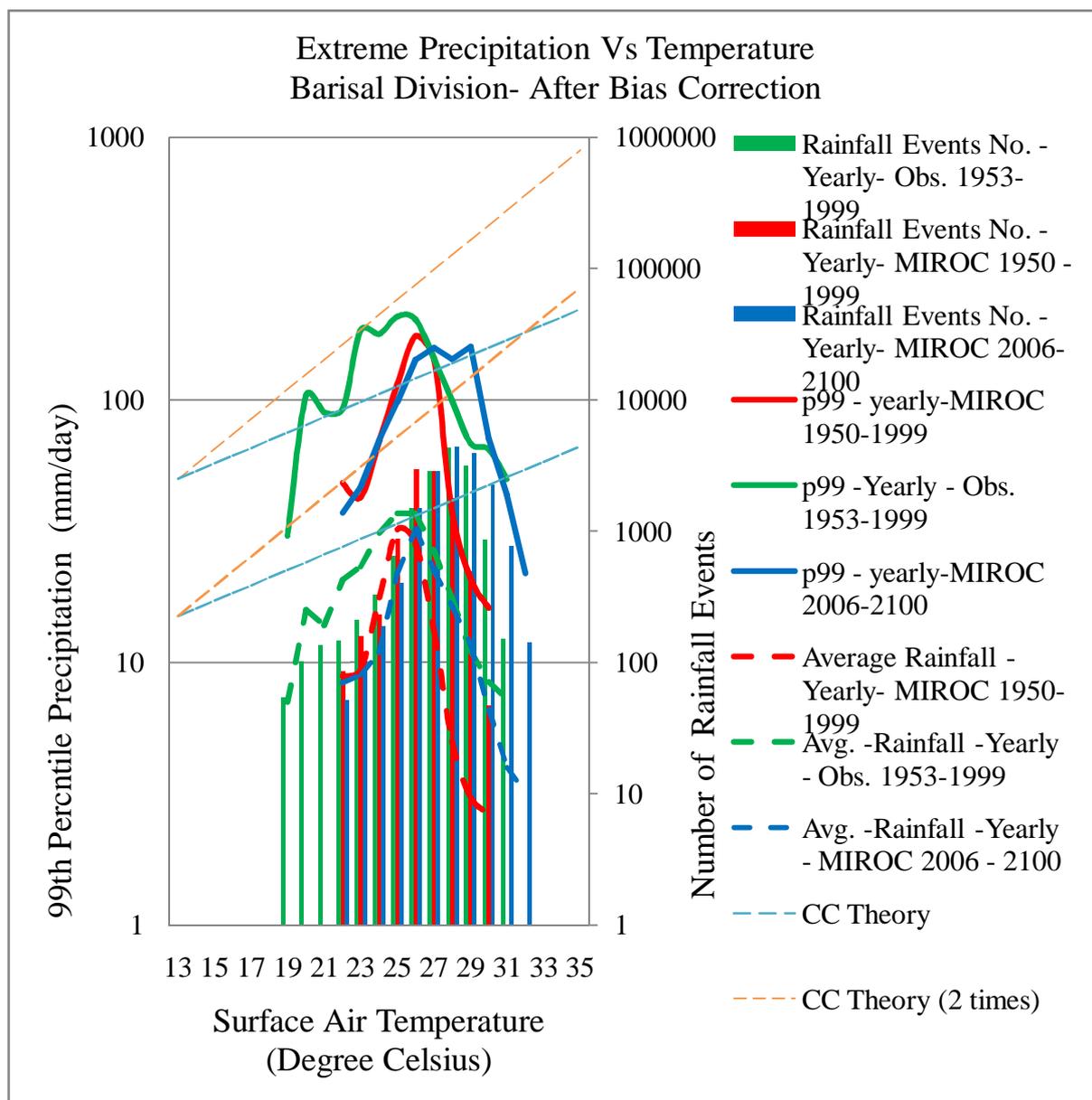


Figure 4.3(e): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for Barisal Division after considering bias error correction

In figure 4.3(e), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis (Right) is for Number of rainfall events.

Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Barisal Division* for the time period

year of 1953 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Barisal Division* for the time period year of 1953 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Barisal Division* for the time period year of 1953 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Barisal Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Barisal Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Barisal Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Barisal Divisional Region* for the time period year of 2006 to 2100. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Barisal Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Barisal Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

From the figure 4.3(e), the peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent for Observation, MIROC present and MIROC projection. Even, while the trend is decline downward but No. of Rainfall Events is still increasing for all three trends. So, the trends of extreme precipitation cannot be explained by the corresponding rainfall event numbers. For future projection of MIROC, rainfall event numbers are projected in higher temperature than in-situ. It indicates that in future in higher temperature rainfall may occur more compared to present observation rainfall.

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So, Figure 4.3(e) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Barisal Division*.

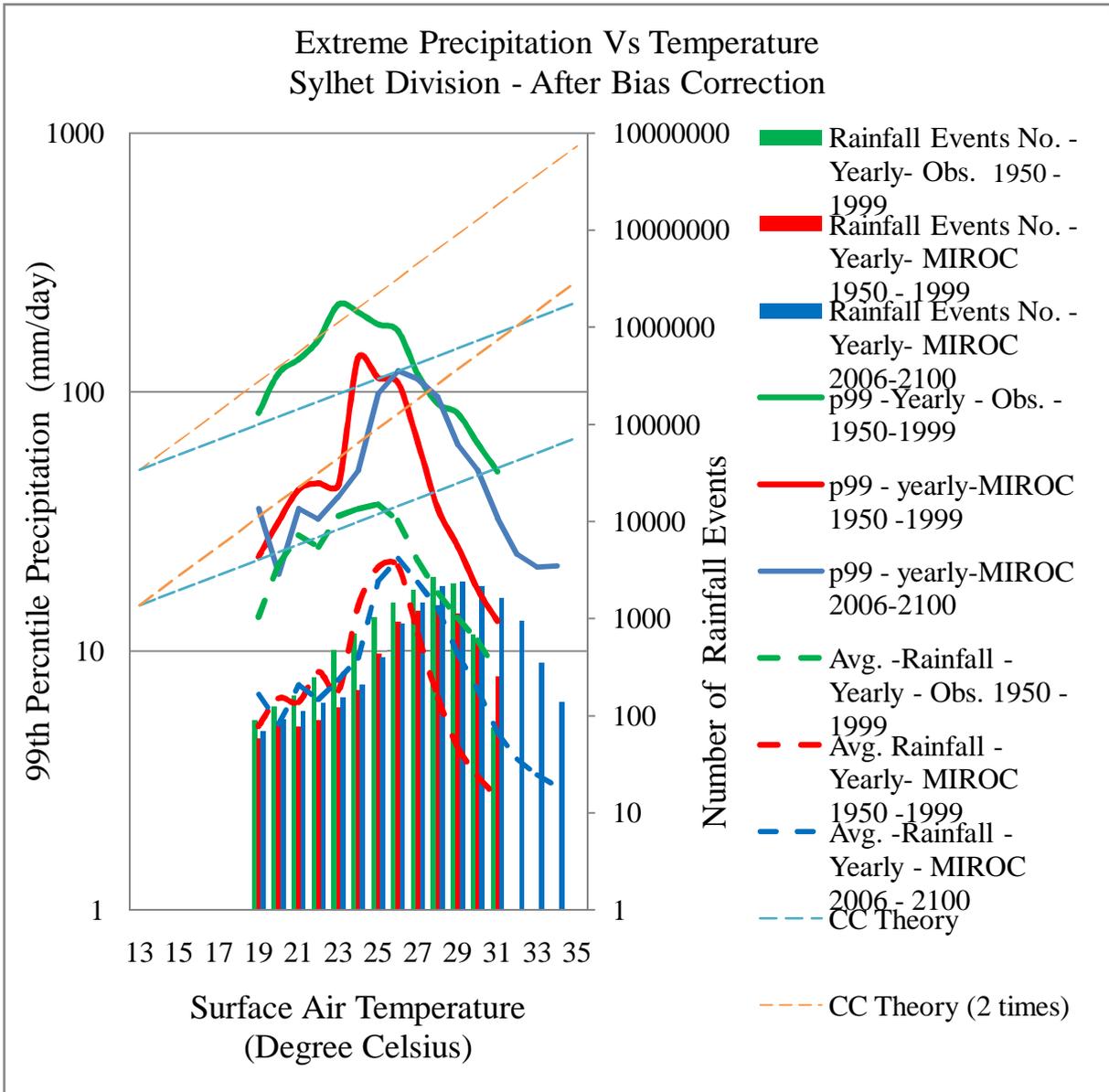


Figure 4.3(f): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for Sylhet Division after considering bias error correction

In figure 4.3(f), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis (Right) is for Number of rainfall events.

Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Sylhet Division* for the time period year of 1950 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Sylhet Division* for the time period year of 1950 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Sylhet Division* for the time period year of 1950 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Sylhet Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Sylhet Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Sylhet Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Sylhet Divisional Region* for the time period year of **2006 to 2100**. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Sylhet Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Sylhet Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

From the figure 4.3(f), the peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent for Observation, MIROC present and MIROC projection. Even, while the trend is decline downward but No. of Rainfall Events is still increasing for all three trends. So, the trends of extreme precipitation cannot be explained by the corresponding rainfall event numbers. For future projection of MIROC, rainfall event numbers are projected in higher temperature than in-situ. It indicates that in future in higher temperature rainfall may occur more compared to present observation rainfall.

From MIROC and In Situ observations, results of peak of p99 show somewhat low magnitude of MIROC compare to In Situ extreme precipitation.

Result shows that the peak of p99 of MIROC and In Situ differ to some marginal extent in daily temperature. But still they have similarities in the pattern of p99 of Observation, MIROC present and MIROC projection but rate of ascending trend of MIROC is much higher than that of Observation. So, present analysis of p99 of observation and that of MIROC present simulation has somewhat good agreement. Also MIROC present simulation and MIROC future simulation has good agreement. Hence for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation for *Sylhet* region.

So, Figure 4.3(f) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Sylhet Division*.

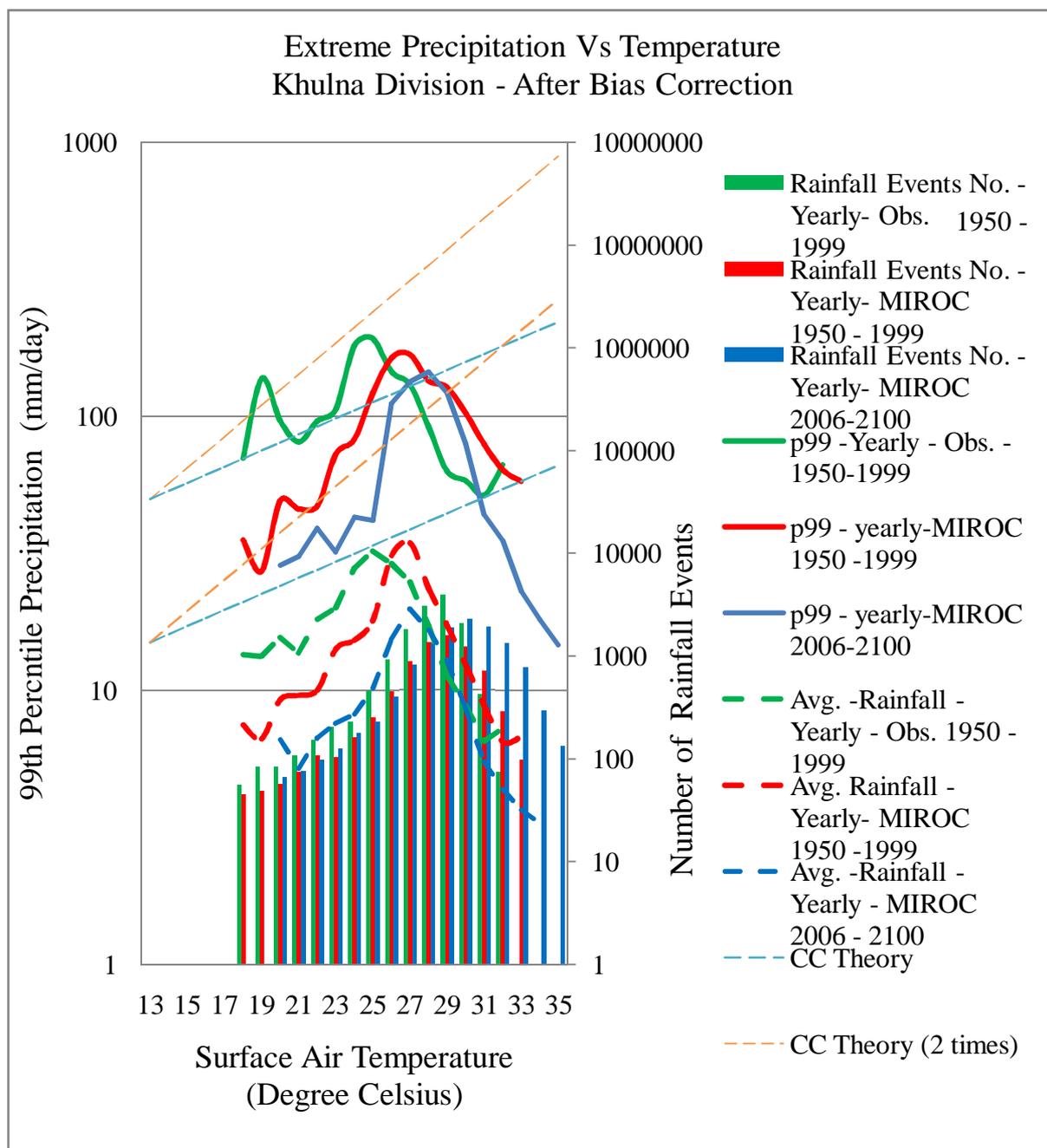


Figure 4.3(g): Comparison between MIROC & Observation, and Future projection of MIROC Simulation for Khulna Division after considering bias error correction

In figure 4.3(g), The Horizontal axis is daily average surface air temperature in Degree Celsius. Vertical primary (Left) axis is 99th percentile precipitation in mm/day. In vertical primary axis, scale is in logarithmic scale. Vertical secondary axis (Right) is for Number of rainfall events.

Green solid line represent trend of 99th percentile precipitation (p99) with respect to daily average surface air temperature of observed data set of *Khulna Division* for the time period year of 1950 to 1999. Green dash line is for average yearly rainfall for in-situ data set of *Khulna Division* for the time period year of 1950 to 1999. Green solid column represent corresponding Number of rainfall events of p99 for in-situ data set of *Khulna Division* for the time period year of 1950 to 1999.

Red solid line represent trend of 99th percentile precipitation (p99 MIROC present) with respect to daily average surface air temperature of model MIROC simulated data set of *Khulna Divisional Region* for the time period year of 1950 to 1999. Red dash line is for average yearly rainfall for MIROC simulated data set of *Khulna Divisional Region* for the time period year of 1950 to 1999. Red solid column represent corresponding Number of rainfall events of p99 for MIROC simulated data set of *Khulna Divisional Region* for the time period year of 1950 to 1999.

Blue solid line represent projection trend of 99th percentile precipitation (p99 MIROC projection) with respect to daily average surface air temperature of model MIROC simulated data set of *Khulna Divisional Region* for the time period year of **2006 to 2100**. Blue dash line is for average yearly rainfall for MIROC simulated data set of *Khulna Divisional Region* for the time period year of 2006 to 2100. Blue solid column represent corresponding Number of rainfall events of projected p99 for MIROC simulated data set of *Khulna Divisional Region* for the time period year of 2006 to 2100.

Blue thin dash line is used as reference of C-C relation. Orange thin dash line is 2 times C-C theory line.

From the figure 4.3(g), the peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent for Observation, MIROC present and MIROC projection. Even, while the trend is decline downward but No. of Rainfall Events is still increasing for all three trends. So, the trends of extreme precipitation cannot be explained by the corresponding rainfall event numbers. For future projection of MIROC, rainfall event numbers are projected in higher temperature than in-situ. It indicates that in future in higher temperature rainfall may occur more compared to present observation rainfall.

From MIROC and In Situ observations, results of peak of p99 show somewhat low magnitude of MIROC compare to In Situ extreme precipitation.

Result shows that the peak of p99 of MIROC and In Situ differ to some marginal extent in daily temperature. But still they have similarities in the pattern of p99 of Observation, MIROC present and MIROC projection. So, present analysis of p99 of observation and that of MIROC present simulation has somewhat good agreement. Also MIROC present simulation and MIROC future simulation has good agreement. Hence for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation for *Khulna* region.

So, Figure 4.3(g) represents Validation of historical extreme precipitation from GCM model MIROC5 simulation by comparing with In-situ observation, and Projection of model simulation for future changes of extreme precipitation in the targeted region of *Khulna Division*.

Chapter 5

5. Conclusion

5.1 Conclusion and Discussion

From the present study, it may come to conclusion as follows -

- Extreme precipitation (daily) trend is similar to C-C (Clausius–Clapeyron) relation up to certain limit (around 25 degree Celsius) but the rate of increase of ascending trend of extreme precipitation is higher (about 2 to 3 times) than C-C relation before breaking point. After the breaking point precipitation trend declines downward for the daily observed rainfall.
- Why the decreasing trend after a certain limit, still it is not clear. From the result of our analysis, we cannot explain clearly why this decline trend. Some researchers think that changes in the atmospheric large scale motions and limitations in moisture increase due to soil water depletion may result in deviations from a C-C scaling.
- Pattern of seasonal trends are almost same as yearly trend except dry season.
- The peak of trend of extreme precipitation and that of the No. of rainfall event is differing to some extent. Even, while the trend is decline downward but No. of Rainfall Events is still increasing. So, the trends of extreme precipitation cannot be explained by the rainfall event numbers.
- From MIROC and In Situ observations, there are some results that show the low magnitude of MIROC compare to In Situ extreme precipitation. There may have several reasons behind that. One of them could be the difference in spatial resolution of MIROC RCP8.5 (about 150 km) and Cumulus cloud (<10km). Hence, the projection of MIROC for 21th century may produce lower value of extreme precipitation than that of in practical field.

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- Some result show that the peak of rainfall events of MIROC and In Situ differ by 1 or 2 degree Celsius in daily temperature . So there may some bias error in MIROC. From the comparison of Temperature Distribution Curve between MIROC and In Situ, it can be concluded that there is bias error in model MIROC.

Finally, despite of some minor deviations, MIROC is a good simulation model as we find from the present analysis result of observation and MIROC present simulation. Also MIROC present simulation and future simulation has good agreement. So for future projection MIROC data set can be applied for the assessment of characteristics of extreme precipitation in tropical region like Bangladesh, though future climate is too much unpredictable. Yet, preliminary we can adopt MIROC as an assessment tool, indeed.

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