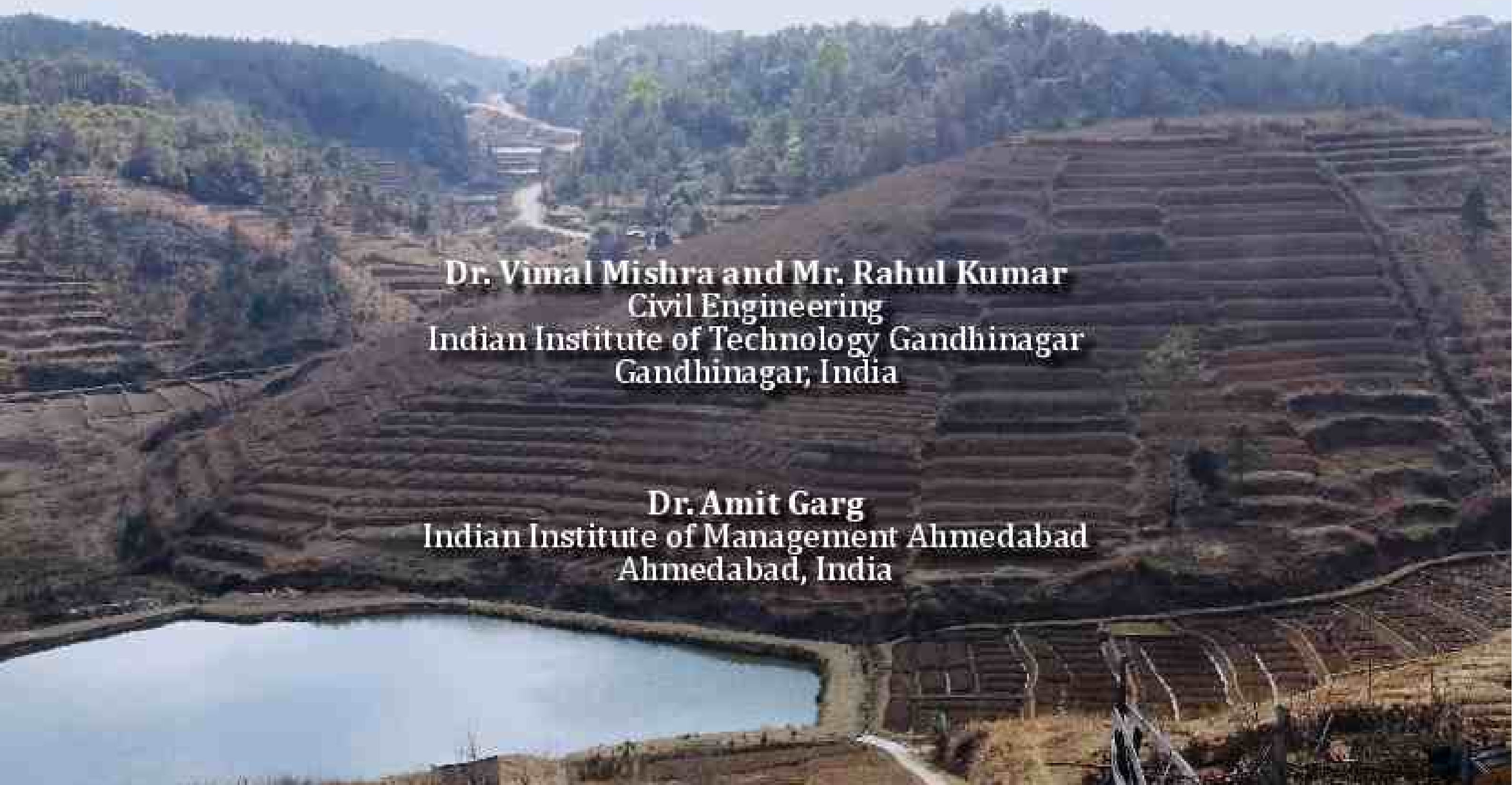
सत्यमेव जयते

Identification of climate vulnerability hot-spots in Meghalaya using high-resolution climate projections



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Civil Engineering
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Gandhinagar, India

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Ahmedabad, India

Study done for
The Government of Meghalaya

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MESSAGE

Climate change has emerged as the greatest threat to the survival of life on the planet earth. The Paris climate accord has been an important step and the agreement on making effort for containing the global rise in temperature to 1.5° C by 2050 is significant but the initial trend in the last two years have defied the expectations on this count. Against this back drop, the recent study for Meghalaya indicating that the per capita emission from the State is amongst the lowest not only in the country but possibly amongst the lowest as compared to any region in the world is very heartening for us.

Meghalaya is blessed with rich biodiversity, high rainfall and diverse landscapes. People in the State have lived in symbiotic relationship with the ecosystems and derived their livelihoods from the natural resources, sustainably, since ages. But the sustainability of our natural ecosystems could be under serious threat on account of climate change. Consequences of climate change have potential to disrupt livelihoods of lakhs of our people in the villages and also to diminish productivity of our natural ecosystems beyond critical levels. We need to take cognizance of this emerging reality with a sense of urgency and also need to take appropriate measures for reorienting our policies, programmes and adaptation actions on the ground to the extent necessary.

Scientific and analytical approaches are always helpful in sound decision taking. I am happy to see that an effort has been made by Meghalaya Basin Development Authority for mapping vulnerable areas of the State from the climate change point of view by using latest computer models in collaboration with a premier institution of the country. I hope that findings of this study would lead to a better understanding of climate change phenomenon in the State and would help in prioritizing of our actions for adaptation to climate change. I compliment the scientists of IIT Gandhinagar and officials of Meghalaya Climate Change Center, MBDA for bringing out this useful report.

(Dr Mukul Sangma)

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Dated Shillong, the 27th April, 2017

FOREWORD

Meghalaya's diversity of biological resources and landscapes is well known. Mountainous terrain and high rainfall are the other distinguishing features which define the contours of bio-physical conditions and livelihood pattern in the State. Amidst the bountiful nature and endowments such as high rainfall and high density of water streams and springs, there are concerns of fast changing land use and land cover in the State marked by shifting cultivation and mining activities. Climate change, which is a global reality, has already started to show its signs in several ways such as warming, climate variability, extreme events in the State. Changes of anthropogenic nature and climate change are perceived as the greatest challenges to the sustainability of natural resources and livelihood of the people in the State.

Meghalaya has reasons to be concerned about the impacts of climate change as its large segment of population depends on climate sensitive sectors such as agriculture, water, livestock and forestry for their livelihoods. Studies have shown that climate change and its impacts are more pronounced in the mountains. Therefore other sectors such as health, urban habitats, infrastructure and economy of the State as a whole are threatened with dire consequences of climate change.

While we prepare ourselves to face the impacts of climate change and take actions to adapt to it, our planning and strategies should be based on all possible scientific data and studies. In this context, I am happy to see that, at the initiation of Meghalaya Climate Change Centre under MBDA, a study titled "**Identification of climate vulnerability hotspots in Meghalaya using high resolution climate projections**" has been done by the Water and Climate Laboratory, Indian Institute of Technology Gandhinagar, for the Government of Meghalaya. I am sure findings of this study will be of immense use not only in effective planning of our adaptation actions to climate change but also provide important inputs in development planning to almost every Department.

I compliment Head of the Water and Climate Laboratory of Indian Institute of Technology Gandhinagar and his team for accomplishing this important study for Meghalaya. I also congratulate officials and Scientists of Meghalaya Climate Change Centre and Meghalaya Basin Development Authority, Shillong for their initiatives towards science based climate change actions in the State.

(K. S. Kropha)

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Development Commissioner
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PREFACE

Climate change has emerged as one of the most serious threats to the sustainability of natural ecosystems on the planet earth. It is now established beyond doubt that the climate change is real and happening with even greater intensity than what was visualized under the previous scientific projections.

Cascading impacts of climate change on natural resources and livelihood of millions of people dependent on them have potential to disrupt socio-economic and socio-cultural fabric of the society and thus pose a serious challenge before the governance.

Meghalaya is bestowed with high forest cover, rich biodiversity, high rainfall and network of large number of meandering streams. People in the State are largely dependent on natural resources for their livelihood activities such as agriculture, horticulture, forestry and live stock rearing and are in turn inherently vulnerable to climate change. Actions towards adaptation to climate change are therefore of utmost importance for policy, planning and action by different sectoral Departments. State Action Plan on Climate Change (SAPCC) addresses concerns on account of climate change in the State and helps convergence of related initiatives.

Effective implementation of adaptation actions on the ground can happen only if the planning and implementation strategies are based on scientific data including climate change projections at an appropriate scale. It is a matter of great satisfaction that the study "**Identification *of climate vulnerability hotspots in Meghalaya using high resolution climate projections***" which has been done by the Water and Climate Group of IIT Gandhi Nagar will equip us with the desired scientific information. It is further encouraging to note that the high resolution at which this Study has been done makes the data usable for even sub district level planning. I congratulate Dr Vimal Mishra and his team at IIT Gandhinagar for successfully completing the study.

I compliment Dr Subhash Ashutosh, IFS Addl PCCF & Dy CEO MBDA the Nodal Officer for Climate Change Management in Meghalaya for his initiatives in relation to Climate Change Adaptation. The efforts of the team of Scientists of Meghalaya Climate Change Centre, MBDA (Shri L Shabong, OSD) are also highly appreciated.

Shillong
24th April, 2017

Ram Mohan Mishra
Development Commissioner
Government of Meghalaya

Acknowledgements

"Identification of climate vulnerability hot-spots in Meghalaya using high-resolution climate projections" was prepared to identify the regions which are likely to face climatic stresses in the future. This work was possible due to the support and inputs of several people.

The authors acknowledge data availability from the CMIP5 models. The authors acknowledge officials of Government of Meghalaya, especially Dr. Subhash Ashutosh for providing inputs for improvement of the report.

While numerous researchers and officials provided their support and encouragement to the research leading to this report, the responsibility for the content solely rests with the authors.

Authors

Summary

Both observations and climate change projections show significant changes in mean and extreme climate in the State of Meghalaya, which can have tremendous implications on agriculture, water resources, forests, and biodiversity of the State. High resolution (~ 5km) gridded observations of precipitation and air temperatures (maximum and minimum) were obtained and bias corrected to estimate observed changes in Meghalaya. The State has a complex topography, which requires high resolution observations and climate change projections. We used high resolution precipitation and temperature data to statistically downscale and bias correct climate change projections (~ 5 km), which otherwise are too coarse to resolve the topographic variability in Meghalaya. The five best global climate models (GCMs) were selected from the 40 models that participated in the Coupled Model Intercomparion Project 5 (CMIP5). These five best models were selected based on their skills to simulate the observed climate and other features related to the Indian summer monsoon rainfall. Finally, for these five models, high resolution (~ 5km) climate projections were developed for the entire State and analysis was performed to understand the changes under the projected future climate. Both observations and future projections suggest an increase in precipitation and air temperature in the State of Meghalaya. Moreover, under the future climate mean and extreme temperatures are projected to increase in the majority of the State. The State is projected to experience a significant rise in the frequency of extreme precipitation and temperature (hot days, hot nights, and heatwaves) events under all the selected representative concentration pathways (RCPs 2.6, 4.5, 6.0, and 8.5). Moreover, the frequency of cold days and cold nights is projected to significantly decline in the future climate in the Near (2013-2040), Mid (2041-2070), and End (2071-2100) term periods. These projected changes may have implications for the agriculture, water resources, forests, and public health sectors. For instance, a significant rise in air temperature and heat waves can affect crop production and water storage in lakes and reservoirs. The projected changes under the future climate are estimated at block level using the high resolution data, which can be used for policy and decision making for adaptation. While more in-depth analysis to using the high resolution data developed in this study for sectorial impacts assessment is needed, uncertainty in the projections for the Near, Mid, and Long term climate should be incorporated in the framework of the adaptation policies at local level.

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Abbreviations

BCSD	Bias Corrected and Statistically Downscaled
CBDR	Common But Differentiated Responsibilities
CCSM	Community Climate System Model
CHIRPS	Climate Hazards Group Infrared Precipitation with Station data
CMIP	Coupled Model Intercomparison Project
CORDEX	Coordinated Regional Climate Downscaling Experiment
ESM	Earth System Models
FMD	Foot and Mouth Disease
GCM	General Circulation Model
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gases
IMD	India Meteorological Department
IPCC	Intergovernmental Panel on Climate Change
LULC	Land Use and Land Cover
MIROC	Model for Interdisciplinary Research on Climate
MODONER	Ministry of Development of North Eastern Region
NESAC	North Eastern Space Application Centre
NorESM	Norwegian Earth System Model
PPR	Pestis des Petis Ruminants
PBVI	Precipitation Based Vulnerability Index
RCM	Regional Climate Model
RCP	Representative Concentration Pathways
SPEI	Standardized Precipitation and Evapotranspiration Index
SPI	Standardized Precipitation Index
SRTM	Shuttle Radar Topography Mission
TBVI	Temperature Based Vulnerability Index

1. Introduction

Global and regional air temperature increased in the 20th century with the largest warming experienced during the recent decades [*WMO*, 2005]. Moreover, 2016, 2015 and 2014 were recorded as the top three warmest years in the entire record for which measurements are available. Diurnal temperature range (difference between maximum and minimum temperature) is reducing, which may pose negative impacts on agriculture [*Easterling et al.*, 1997]. Significant changes in precipitation and air temperature are noticed across India between1950 and2008 [*Mishra et al.*, 2014a, 2014b]. Observed precipitation during the monsoon season has declined in many parts in India (*Mishra et al.* [2012, 2016]), which are linked with the warming in the Indian Ocean [*Alory et al.*, 2007; *Brown and Funk*, 2008]. Global mean air temperature has increased significantly [*Karl et al.*, 1996], which is consistent with the trends observed in India [*Kumar et al.*, 1994]. At the regional scale, *Mishra et al.* [2014a]reported that monsoon season precipitation has declined and air temperature has increased over the majority of India in the recent past, which has resulted in an increased frequency of droughts.

Some of the observed trends in precipitation and air temperature are projected to remain the same under the future climate [*Easterling et al.*, 2000; *Shefield and Wood*, 2008; *Mishra et al.*, 2014b]. For instance, *Kumar et al.* [2011] found that annual air temperatures are projected to increase under the future climate. *RupaKumar et al.* [2006] reported that both precipitation and temperature are projected to increase in India under the climate warming. Moreover, *Chaturvedi et al.* [2012] using the CMIP5 dataset reported a large uncertainty in precipitation projections. Moreover, temperature is projected to increase 3-4^{0}C under the representative concentration pathways (RCP) 8.5 by the end of 21st century in India as reported in Chaturvedi et al [2012]. Similar to previous studies, *Mishra* [2015] reported that there is a large uncertainty in projections of the monsoon season precipitation under the future climate, while the temperature projections are relatively robust. Moreover, *Mishra et al.*[2014a] showed that the selection of climate models that show skills against observed data is important to understand the projected changes under the future climate. Since the global climate models (GCMs) use coarser spatial resolution (150-200km), use the regional climate models (RCMs) that simulate climate variables at higher spatial (50km) resolutions is required for the climate impact studies.

Declining monsoon season precipitation and increasing air temperatures can lead to persistent drought conditions that can hamper agricultural production in various parts of India. Frequent droughts during the monsoon season under the current and projected climate may pose challenges for food grain production and may affect food and fresh water security in India[*Mishra et al.*, 2014b]. Projected future climate with substantial rise in mean and extreme air temperature can result in an increased frequency of heat waves, number of hot days and hot nights. The impacts of drought and increased warming may pose adverse impacts on agricultural production [*Lobell and Asner*, 2003; *Lobell and Field*, 2007; *Mishra and Cherkauer*, 2010; *Mishra et al.*,2014b].Studies based on climate models showed that food grain yield might decline by 2.5% to 16% for every increase of 1 °C in seasonal air temperature in the sub-tropics and tropical regions [*Lobell et al.*, 2008; *Battisti and Naylor*, 2009]. Moreover, *Fischer et al.*, [2005] reported that in warming climate, the gap between crop production and consumption may rise especially in the developing countries. *Schmidhuber and Tubiello* [2007] reported that the impacts of climate change on food production and food security can be more than previously thought.

The north-eastern region of India can face implications of climate variability and climate change. Climate change can put severe pressure on water resources and agriculture in the northeastern India. Increased climate warming will lead to more losses through evaporation and evapotranspiration, which will increase irrigation frequency and irrigation water demands [*Barnett et al.*, 2005; *Schlenker et al.*, 2007]. During the recent years, the summer monsoon has become erratic leading to frequent droughts and posing challenges for water availability [*Ramanathan et al.*, 2005; *Mishra et al.*, 2010]. Surface water storage in reservoirs will experience more evaporation under enhanced hydrologic cycle [*Barnett et al.*, 2005; *Tanaka et al.*, 2006]. Climate change impacts and the vulnerability of certain regions in terms of its effect can be quantified using precipitation and temperature as variables. Both the variables are interdependent and are the major driving factors of short term weather and long term climate systems. Thus, the hazards associated with each variable can provide insight to the existing and probable projected future. This report provides an assessment for the observed and projected future climate in the State of Meghalaya using high resolution (~ 5km) datasets. The high resolution climate projections were downscaled and bias corrected using the data from the CMIP5 models and observations. The high resolution climate projections can better resolve topographic variability that is present in the State of Meghalaya.

1.1 Hydrometeorological hazards

Hydrometeorological hazards can be considered based on precipitation and air temperature. The events may not be exclusive regarding the two variables, as these variables may be interdependent. However, for simplification, the hazards affected by the two variables are categorized into precipitation based and temperature based events. Precipitation-based events are droughts and floods, while temperature based events are heatwaves, extreme hot and cold days and nights.

1.1.1 Precipitation-based hazards

Droughts are classified as meteorological, agricultural, hydrological, and socioeconomic droughts. Droughts are not only sector specific but time-based too. Droughts are observed on the scale of months (1, 3, or 5) or years (1 or 2), comparing the observations for the climatological period. The short-term (1-6) droughts months can affect agricultural production while long-term (more than 12 months) droughts can affect streamflow, groundwater, and water storage in reservoirs. In this study, the reference period considered is 1981 - 2012.

Some indices such as Standardised Precipitation Index (SPI) and Standardised Precipitation-Evapotranspiration Index (SPEI) are used to quantify the intensity and duration of droughts. Not only agriculture, groundwater, surface water storage as well as water availability in dams and reservoirs are dependent on precipitation. These indices can be used to quantify precipitation deficit (and available water) for multiple timescales. These timescales reflect the impacts of drought on different sectors and provide information needed by various decision-makers and stakeholders. Meteorological and soil moisture conditions (agriculture) respond to precipitation anomalies on relatively short timescales, for example, 1 - 6 months, whereas streamflow, reservoirs, and groundwater respond to longer term precipitation anomalies of the order of 6 months up to 24 months or longer. These indices also indicate the condition of surplus precipitation events in the same context.

1.1.2 Temperature based hazards

Heatwaves have different definitions, and one or more definitions may not relate to the discomfort felt by humans. One of the definitions which is considered in this study is based on extreme temperature events and its persistence through several days. In technical terms, heatwave may be defined as the event wherein the daily maximum temperatures (T_{max}) are higher than 95th percentile of daily maximum temperature of the hottest three months in a year, and maximum temperatures remains higher than the 95th percentile threshold for more than size consecutive days. This period of excess maximum temperature is known as heatwave spell. In simpler terms, the heatwave is a period of prolonged hot weather.

Extreme hot or cold day/night events are those days/nights which records rare hot or cold temperatures in the region for the observation period. The rarity of such events is defined by temperatures below or exceeding a threshold value, which is based on the distribution of values for the period of observation. The threshold temperatures are not absolute for the whole area, rather it is determined by pixel-by-pixel order (or grid). In other words, a day may be considered hot if the maximum temperature (T_{max}) at a place (or pixel) is higher than the 95th percentile value of T_{max} for the temperature distribution of that place (or pixel). However, the same temperature may not be considered as hot at another place (or pixel), since the threshold temperature for that place may be higher or lower than that of the other place (or pixel). Similarly, a cold night can be identified if minimum temperature is less than 5th percentile of the coldest three months ina year.

2. Study Area: State of Meghalaya

Meghalaya State is one of the seven sister States of northeastern India. The State has mainly three climate zones, i.e., Tropical Monsoon (West Garo Hills, East Garo Hills and South Garo Hills), Hot humid subtropical (West Khasi Hills and Ri-Bhoi) and Warm humid subtropical (East Khasi Hills) as per modified Koppen-Geiger climate classification [*Peel et al.*, 2007].

The average annual rainfall in Meghalaya State is about 4100 mm for the period of 1981-2012. However, there is a very high spatial variability in rainfall in the region. For instance, the southern West Khasi Hills and East Khasi Hills receives more than 8000 mm rainfall while the rest of the State receives an average value of 3200 mm in a year. The precipitation intensities also have very large spatial variability in the State. Mawsynram, the wettest place on the earth is also located in Meghalaya.

As per 2011 census, 80% of the total population of the State lives in rural areas and almost same percentage of population is dependent on agriculture and allied activities for their livelihoods. Despite the heavy dependence on agriculture, the State has only 37% of cultivated land and significantly depends on imports from other States of the country. Meghalaya produces mainly rice, which is approximately 80% of the total crop production. Other than rice, the agriculture produce includes maize and some cash crops and fruits. Out of the 37% cultivated land, only 47% area is irrigated and the rest is rainfed. Even with multiple projects promoting irrigation schemes, nearly half of the cultivated land will remain rainfed. Rainfall dependent agriculture in itself is risk prone and complex, as well as has low productivity.

Meghalaya also faces multiple flash floods as a result of deforestation, and slash-burn type of agricultural practices. A huge amount of hill sand, stones, logs and trees are washed up in the floods, which damages the crops in the downstream.

The problems associated with changing climate may aggravate the current situation in the State in terms of intensity and frequency of floods, changes in precipitation and temperature. To better manage climate change implications, more robust understanding of the current and projected future conditions are required.

Figure 2 to **Figure 4** shows forest cover, Land Use Land Cover (LULC) and elevation map for the State. The forest cover and the LULC maps were derived from data obtained from North Eastern Space Applications Centre (NESAC) and was supplied by the funding agency. The elevation map of the region was developed from Shuttle Radar Tropical Mission (SRTM) available at a spatial resolution of 30 m. **Figure 5** shows grid coverage used in the study. All the analysis are based on these grids. **Figure 6** shows the climate system of India and Meghalaya. These major classes of climatic systems were derived from Köppen-Geiger climate classification system [Peel et al., 2007].

Figure 1. District map of Meghalaya

Figure 7 to Figure 20 shows precipitation and temperature variations for the State for different time periods. These plots shows indicative values of changes happened or are projected to happen in the State with respect to the climatological variables. Figure 7 shows spatial variation of monsoon precipitation in the year 2012. Figure 8 shows average monsoon precipitation in the period 1981-2012 and Figure 9 shows average change in monsoon precipitation for the same period of time. Figure 10 to Figure 13 shows multimodel ensemble average change in monsoon season precipitation for the period 2020-2050 for different Representative Concentration Pathways (RCPs; RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5). Figure 14 shows average daily mean temperature for the year 2012. Figure 15 shows average daily mean temperature for the period 1981-2012. Figure 16 shows the average change in daily mean temperature for the period 1981-2012. Figure 17 to Figure 20 shows multimodel ensemble average of projected changes of daily mean temperatures for the period 2020-2050 for above mentioned RCPs. An elaborated study is presented in subsequent sections.

To get an understanding of the general hydrometeorological variablity in the study region, variables such as precipitation and temperature are plotted for different periods. In **Figure 7** to **Figure 9** precipitation variability and its change is shown and in **Figure 14** to **Figure 16** variability in temperature is shown. For projected climate, a simple overview as plots is provided in **Figure 10** to **Figure 13** for precipitation and in **Figure 17** to **Figure 20** for temperature. The projected period is considered from 2020 to 2050. A further detailed analysis of the variables is done in subsequent sections.

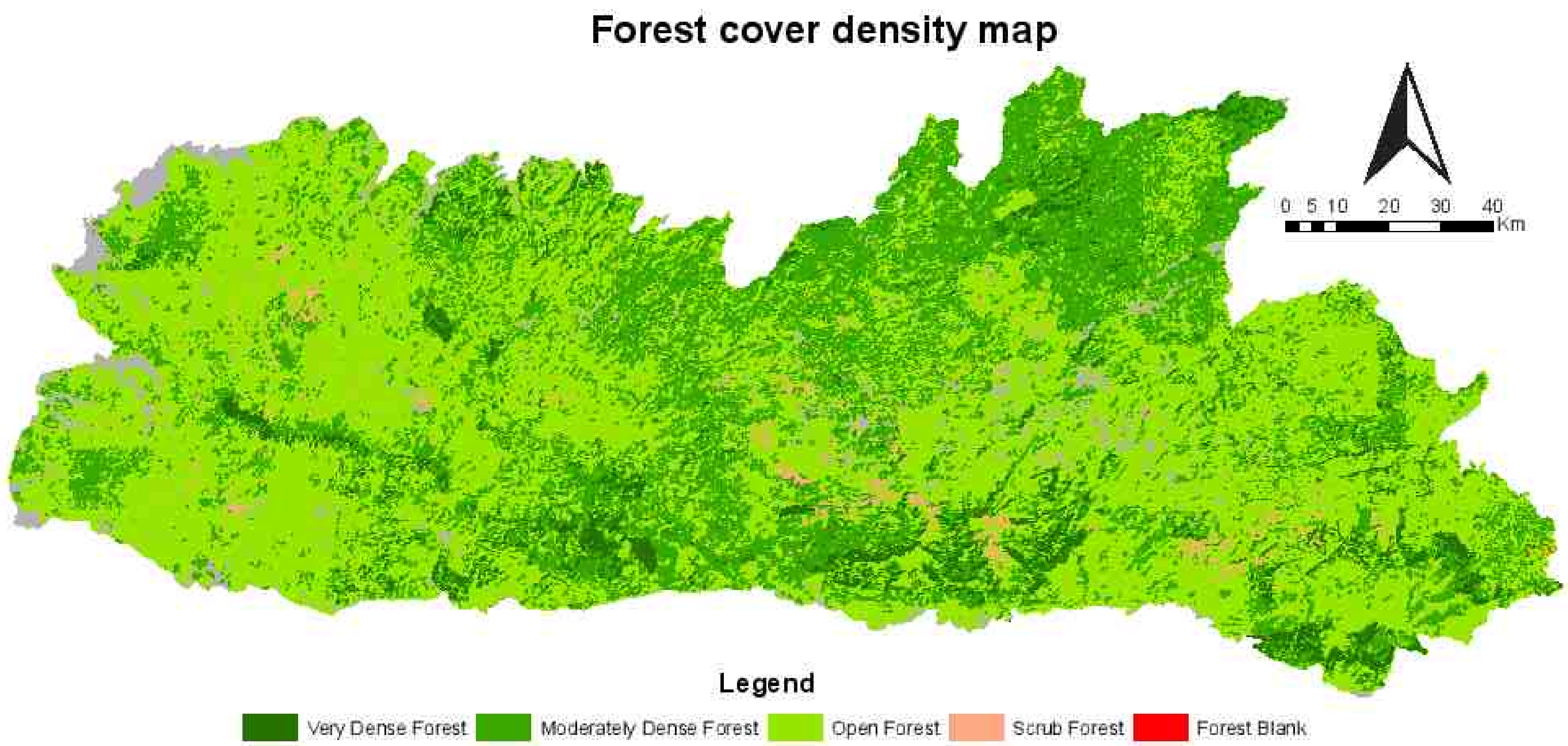

Figure 2. Meghalaya forest density cover. Derived from NESAC Land Use and Land Cover (LULC) map.

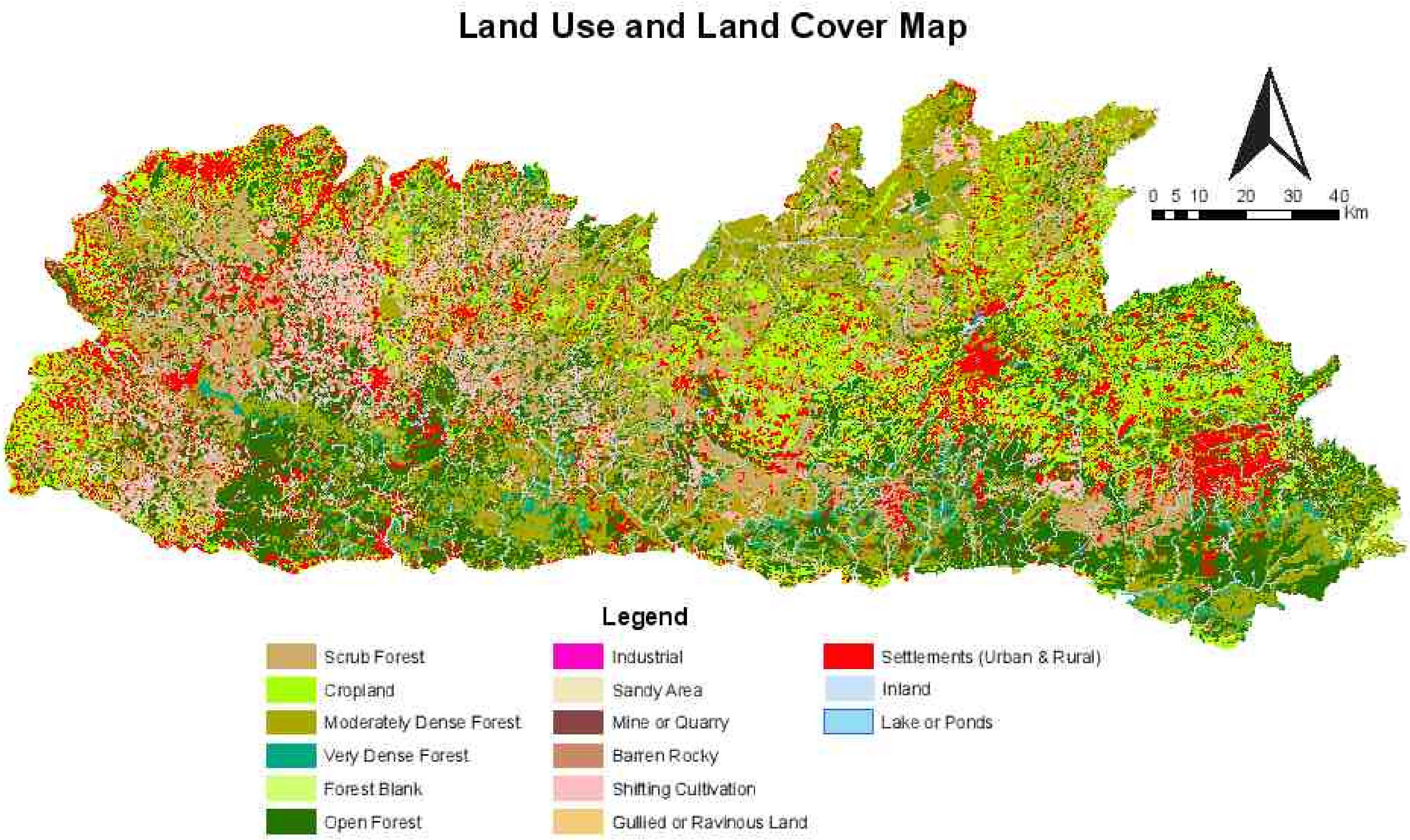

Figure 3. Meghalaya Land Use and Land Cover (LULC) map. Derived from NESAC LULC map.

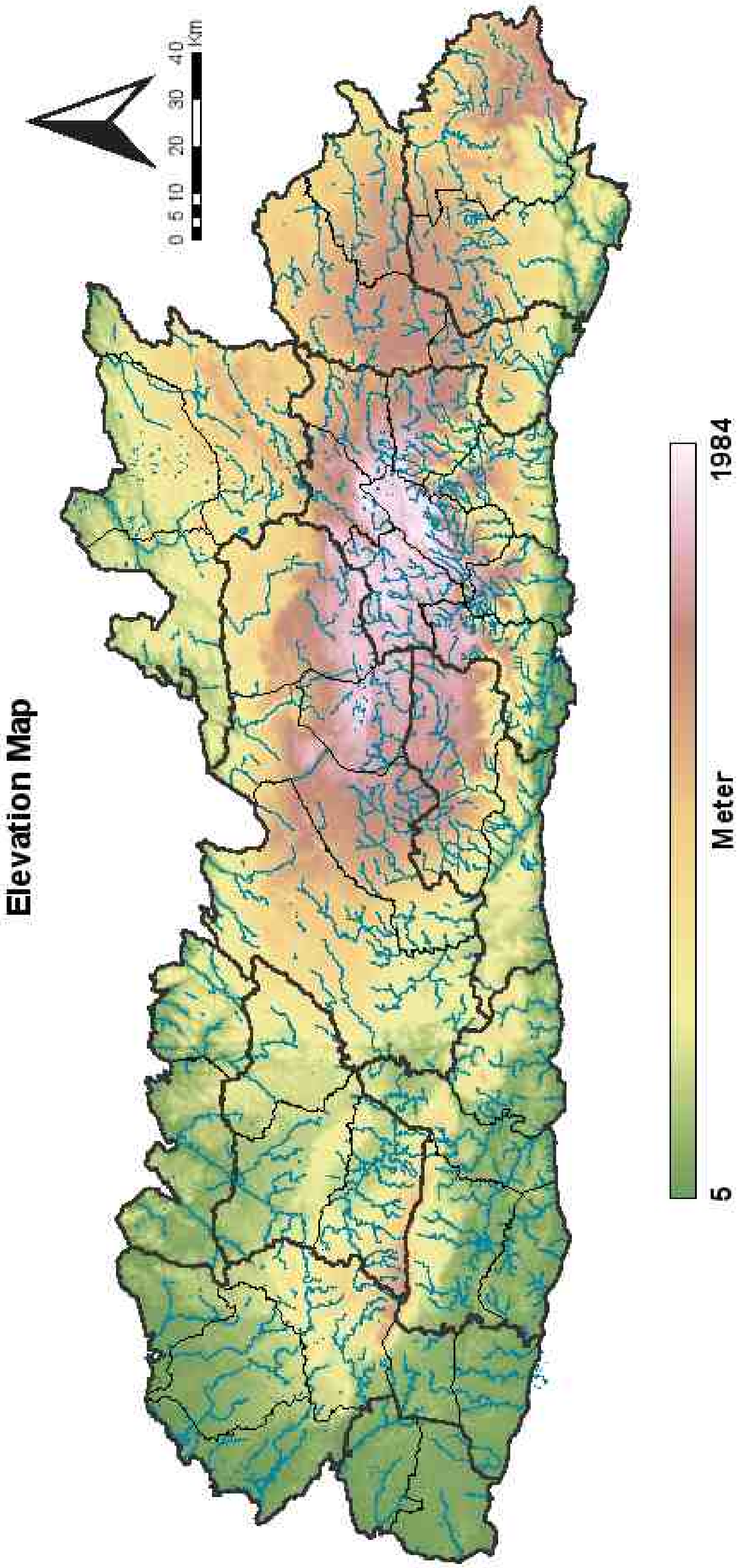

Figure 4. Meghalaya topographical elevation. Derived from SRTM DEM at 30 m resolution.

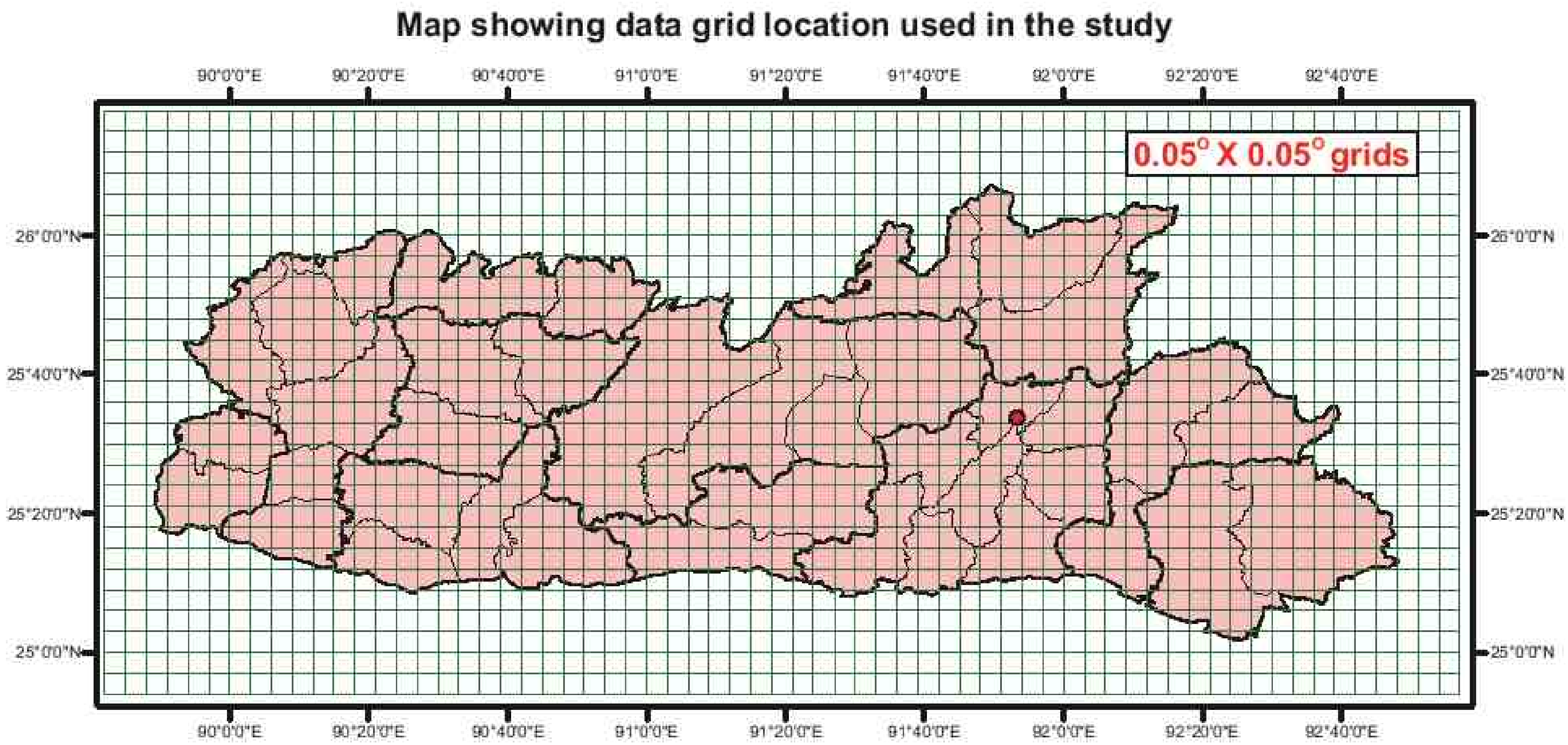

Figure 5. Map showing grid coverage used in the study. Each grid has 30.8 m² area.

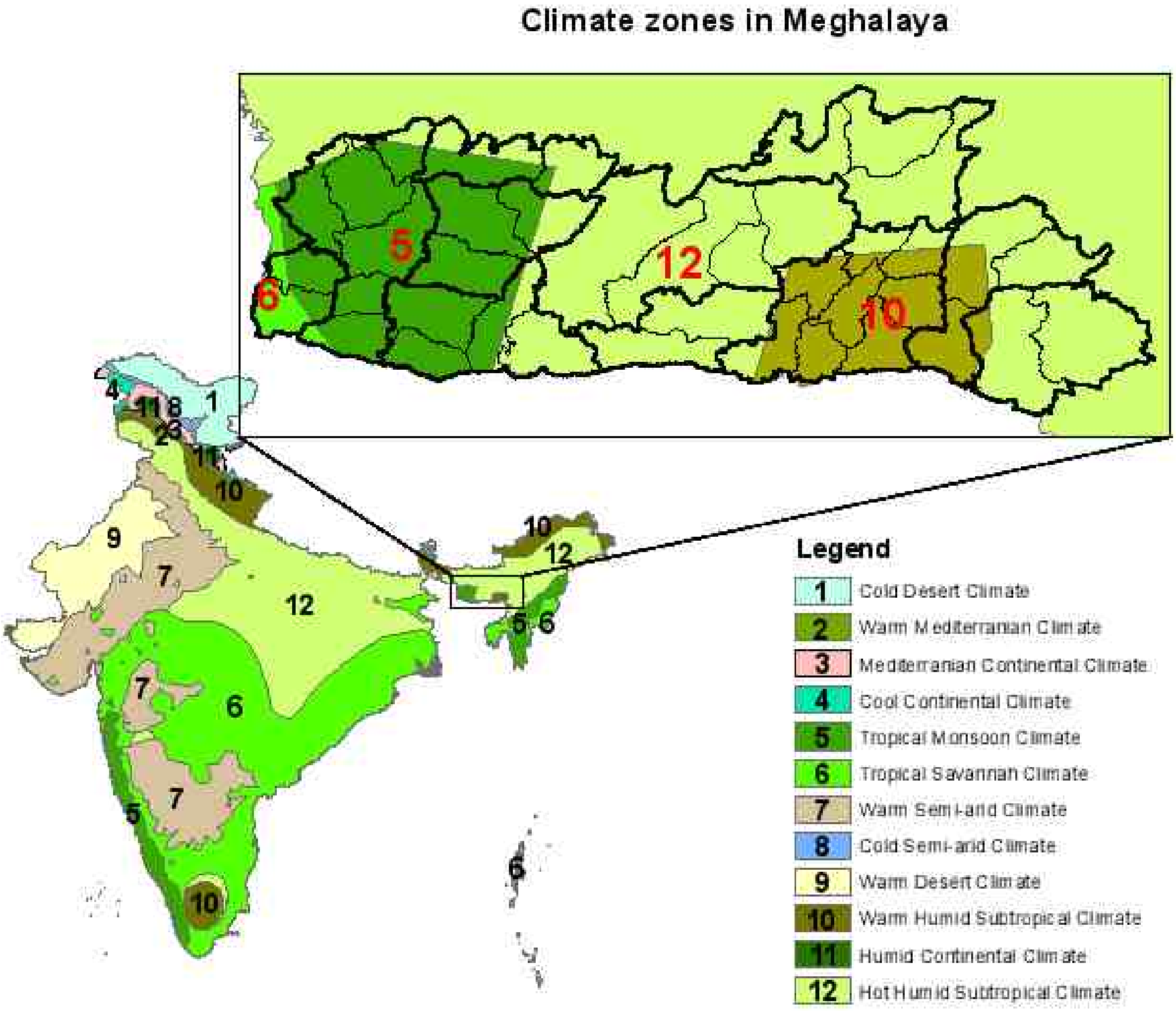

Figure 6. Map showing climate map of India derived from Köppen-Geiger climate classification system [Peel et al., 2007]. The inset shows climate systems in the State of Meghalaya.

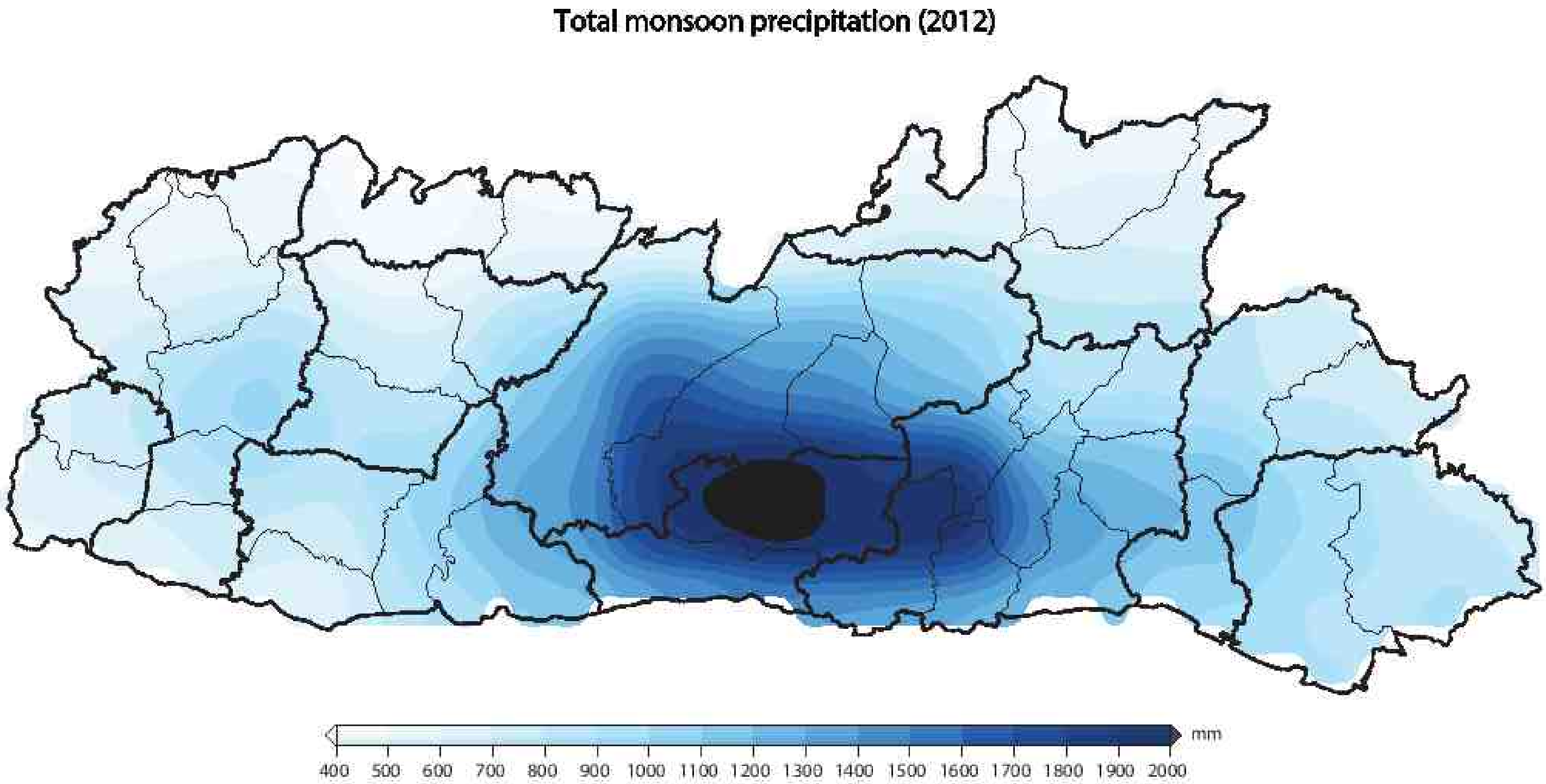

Figure 7. Total monsoon season precipitation (mm) in 2012. Based on corrected CHIRPS precipitation data.

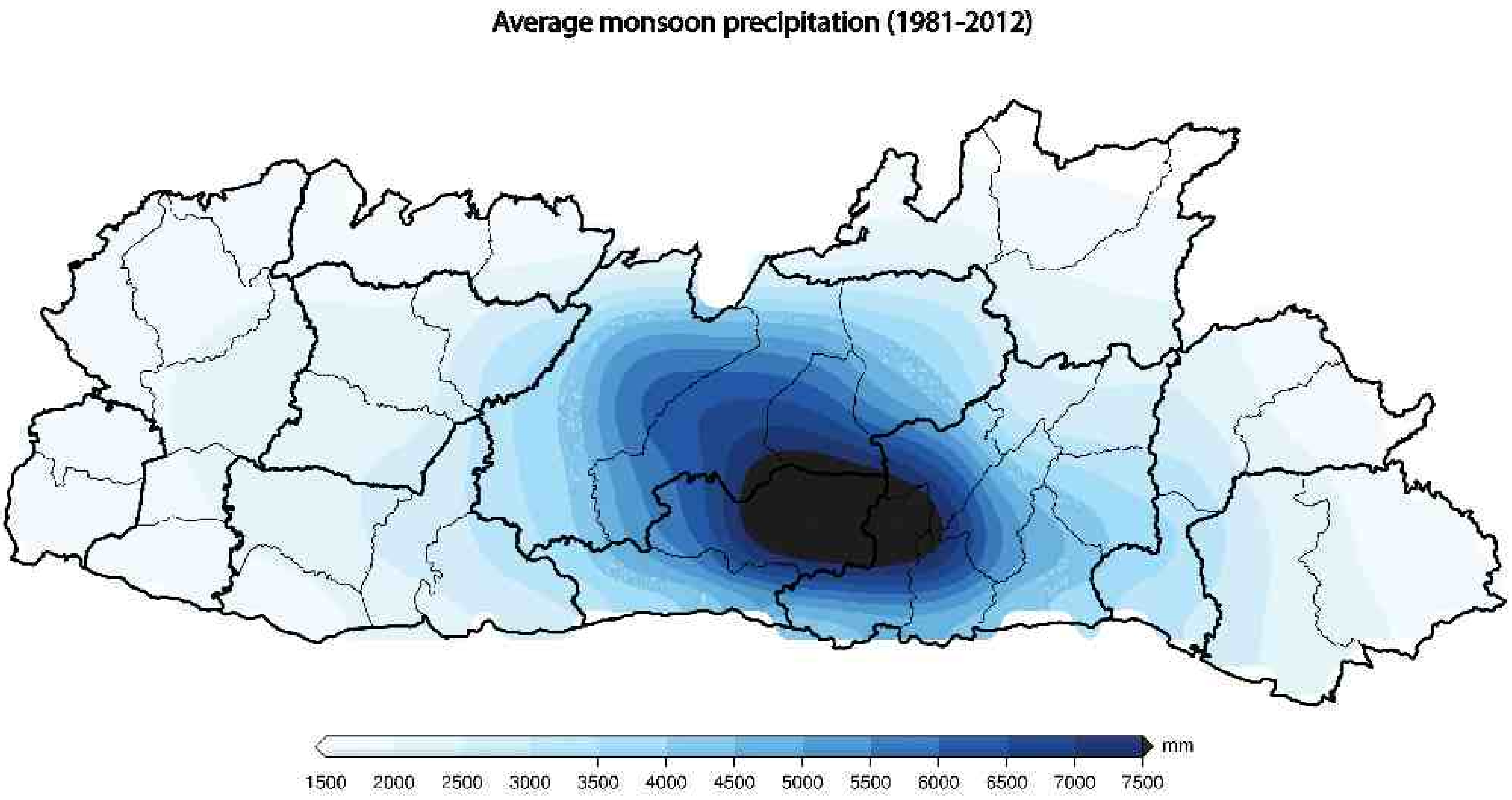

Figure 8. Average monsoon season precipitation (mm) in 1981-2012. Based on corrected CHIRPS precipitation data.

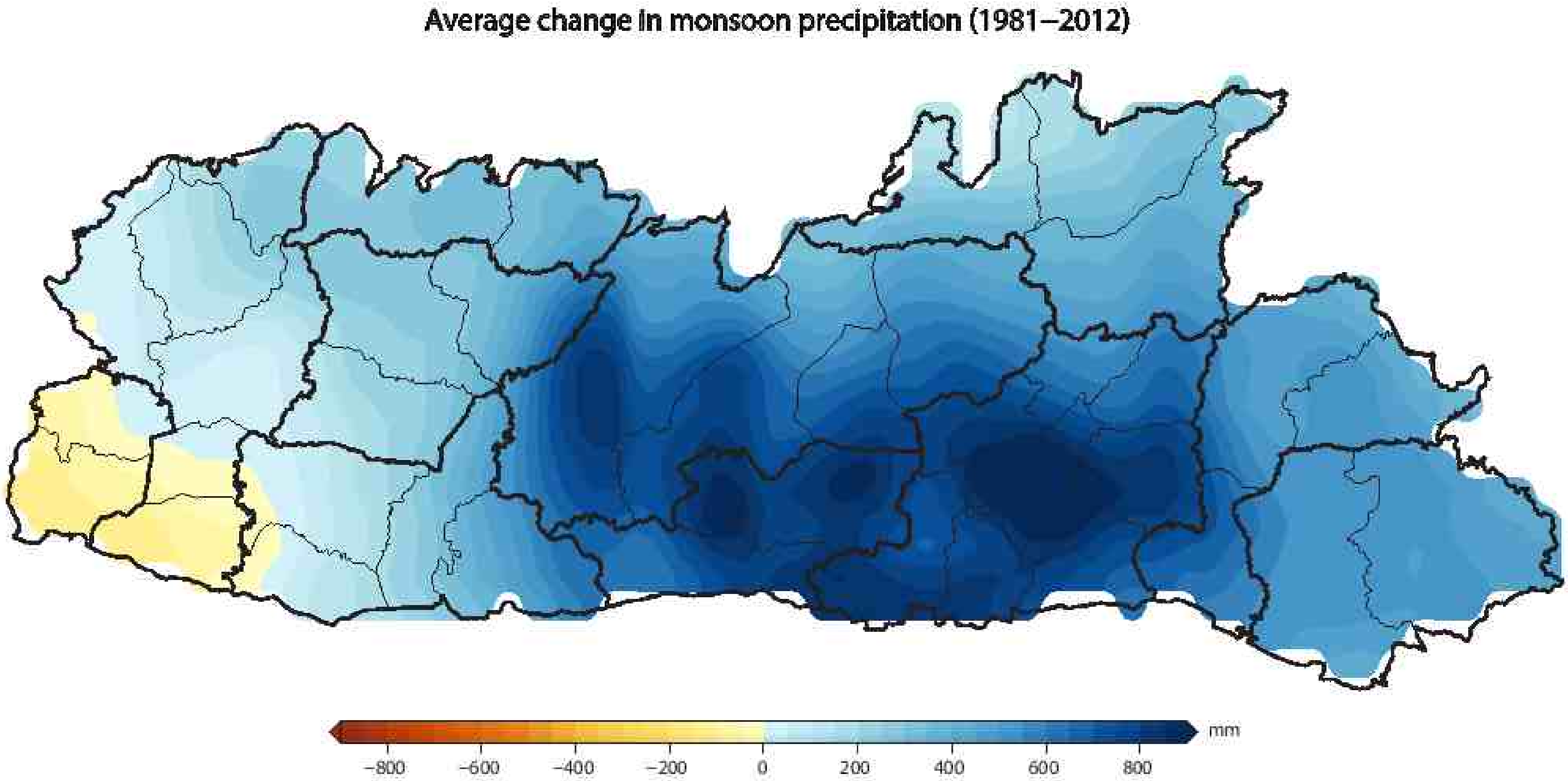

Figure 9. Average change in monsoon season precipitation (mm) in 1981-2012. Based on corrected CHIRPS precipitation data.

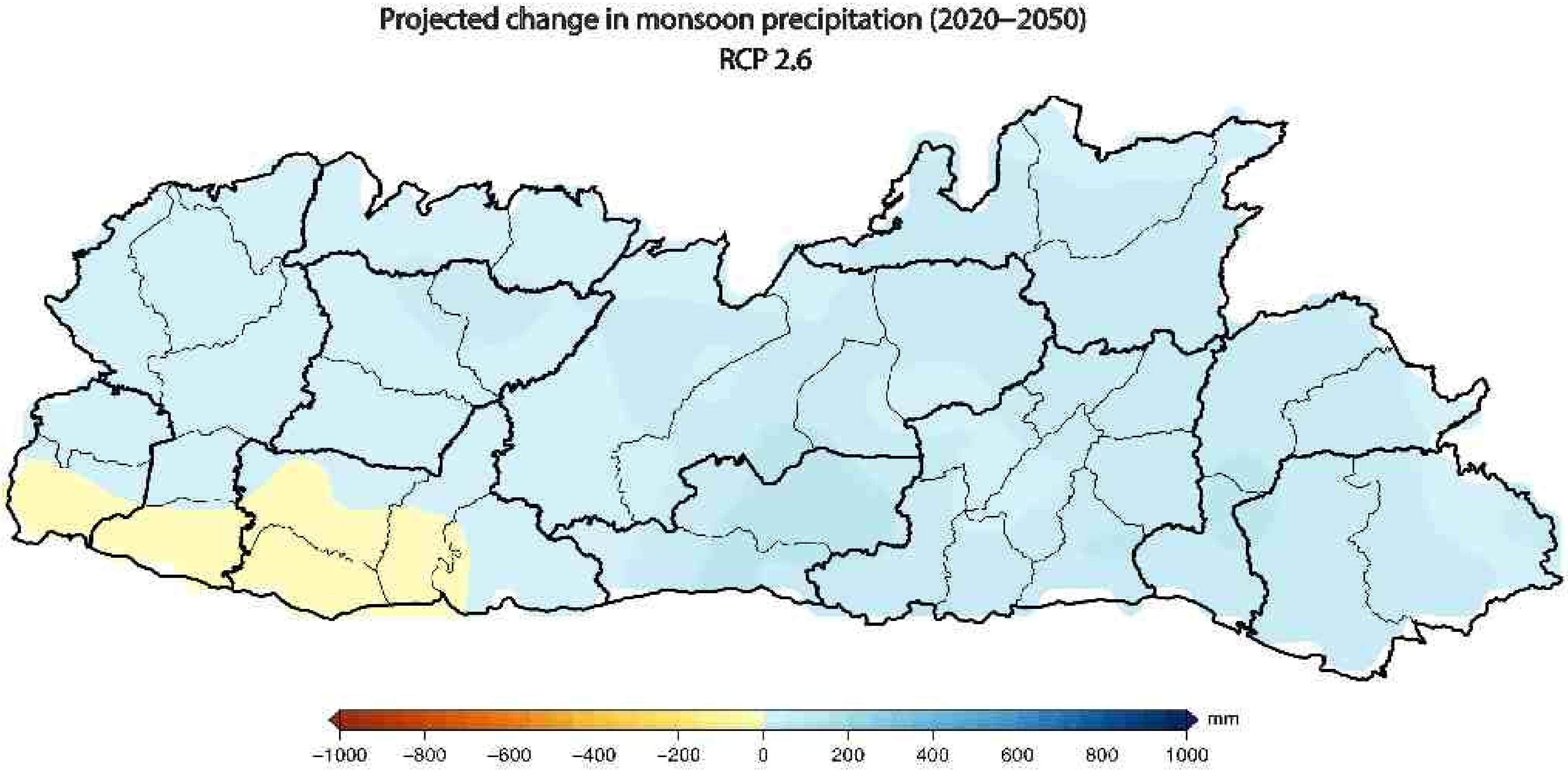

Figure 10. Multimodel ensemble projected change in monsoon season precipitation (mm) for the period 2020-2050 based on RCP 2.6.

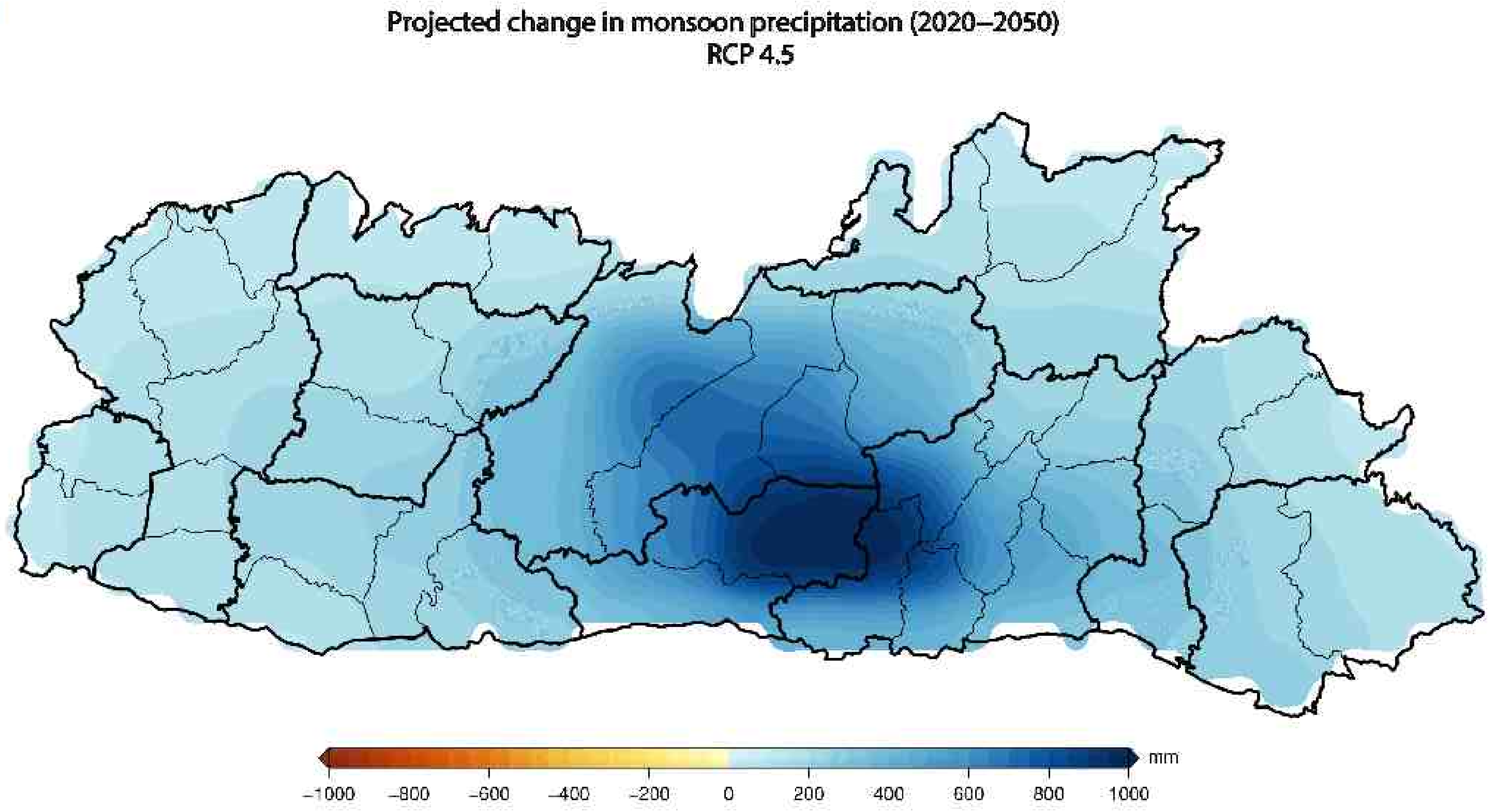

Figure 11. Multimodel ensemble projected change in monsoon season precipitation (mm) for the period 2020-2050 based on RCP 4.5.

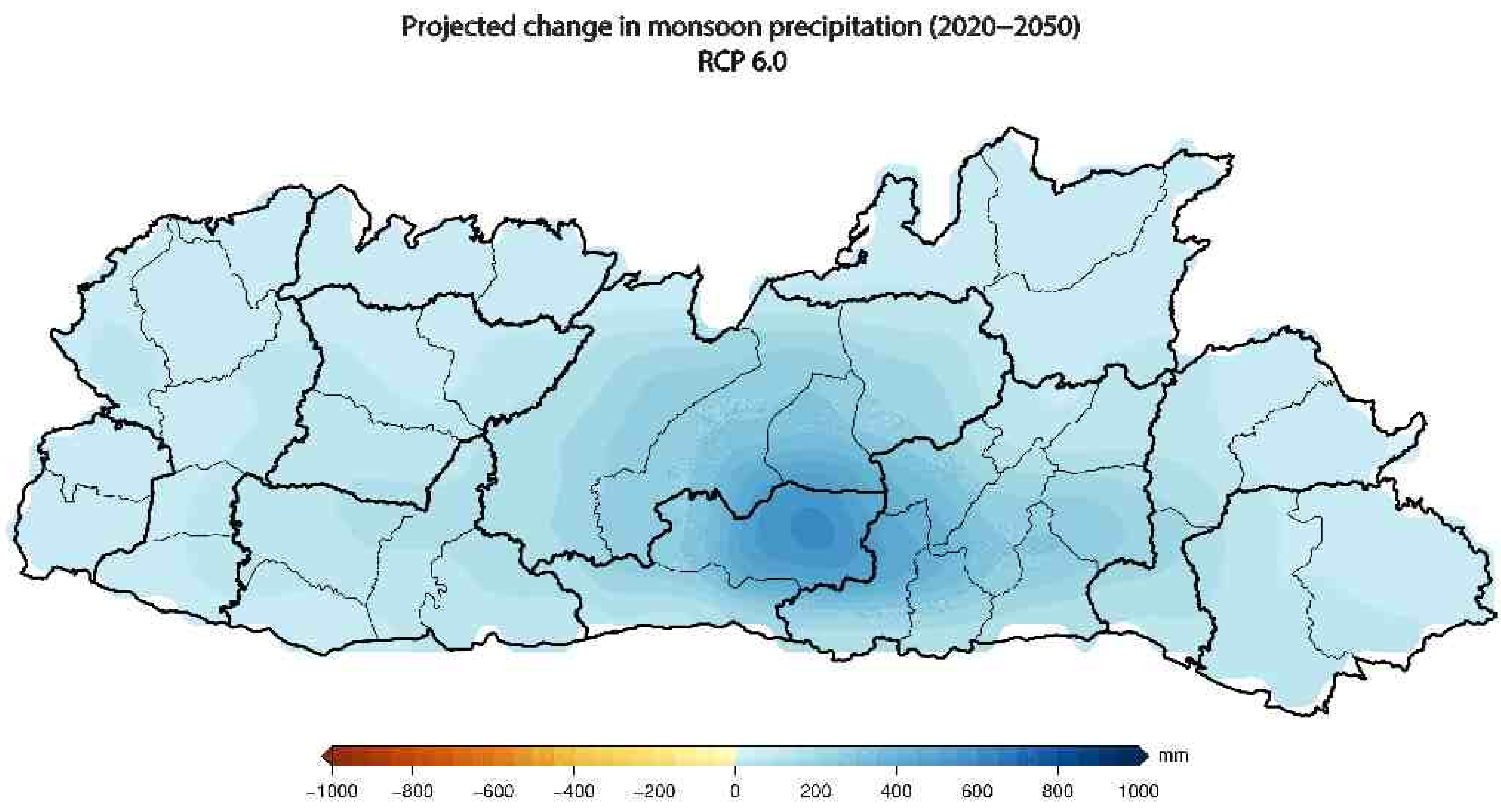

Figure 12. Multimodel ensemble projected change in monsoon season precipitation (mm) for the period 2020-2050 based on RCP 6.0.

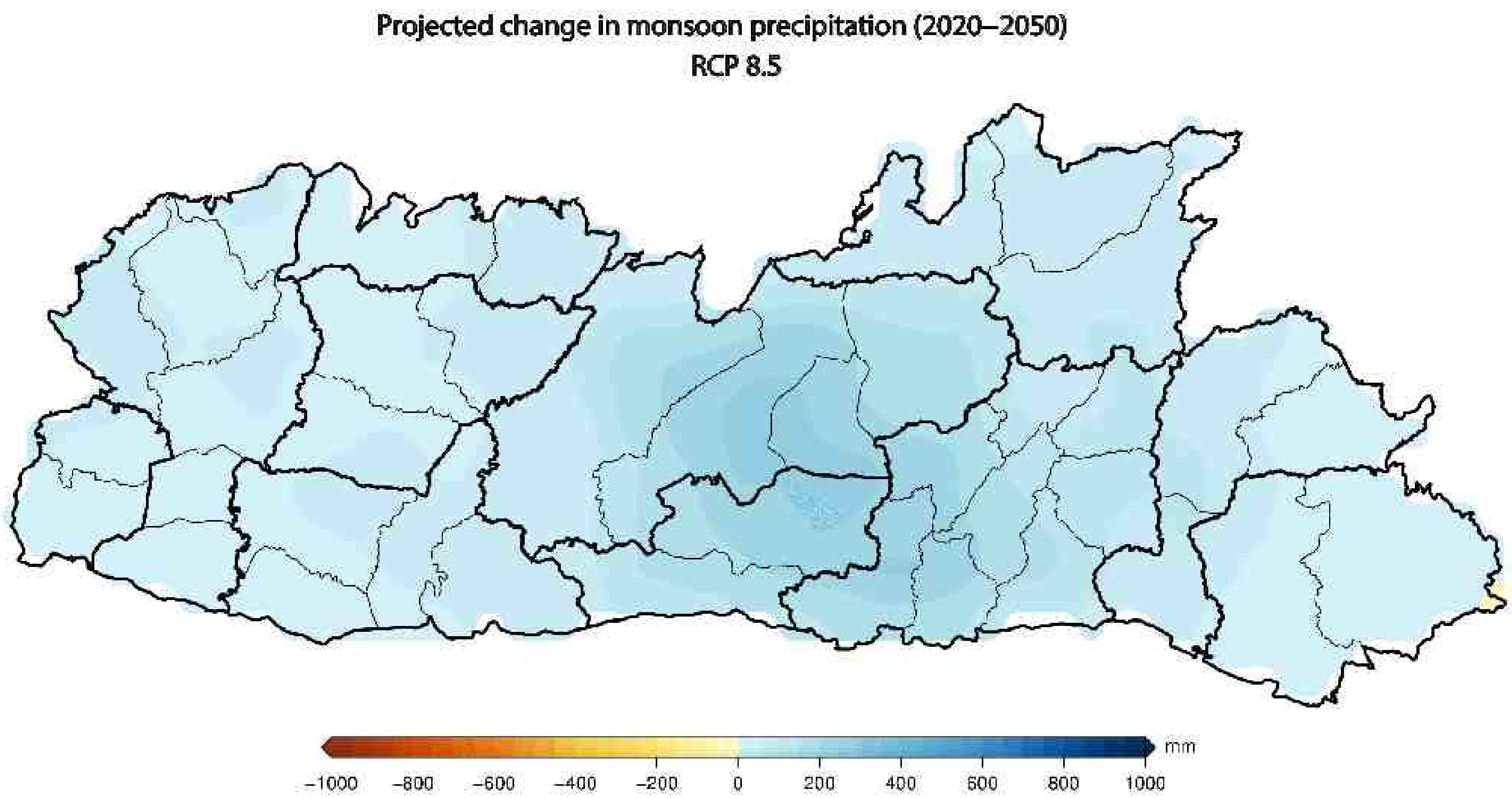

Figure 13. Multimodel ensemble projected change in monsoon season precipitation (mm) for the period 2020-2050 based on RCP 8.5.

Average daily mean temperature (2012)

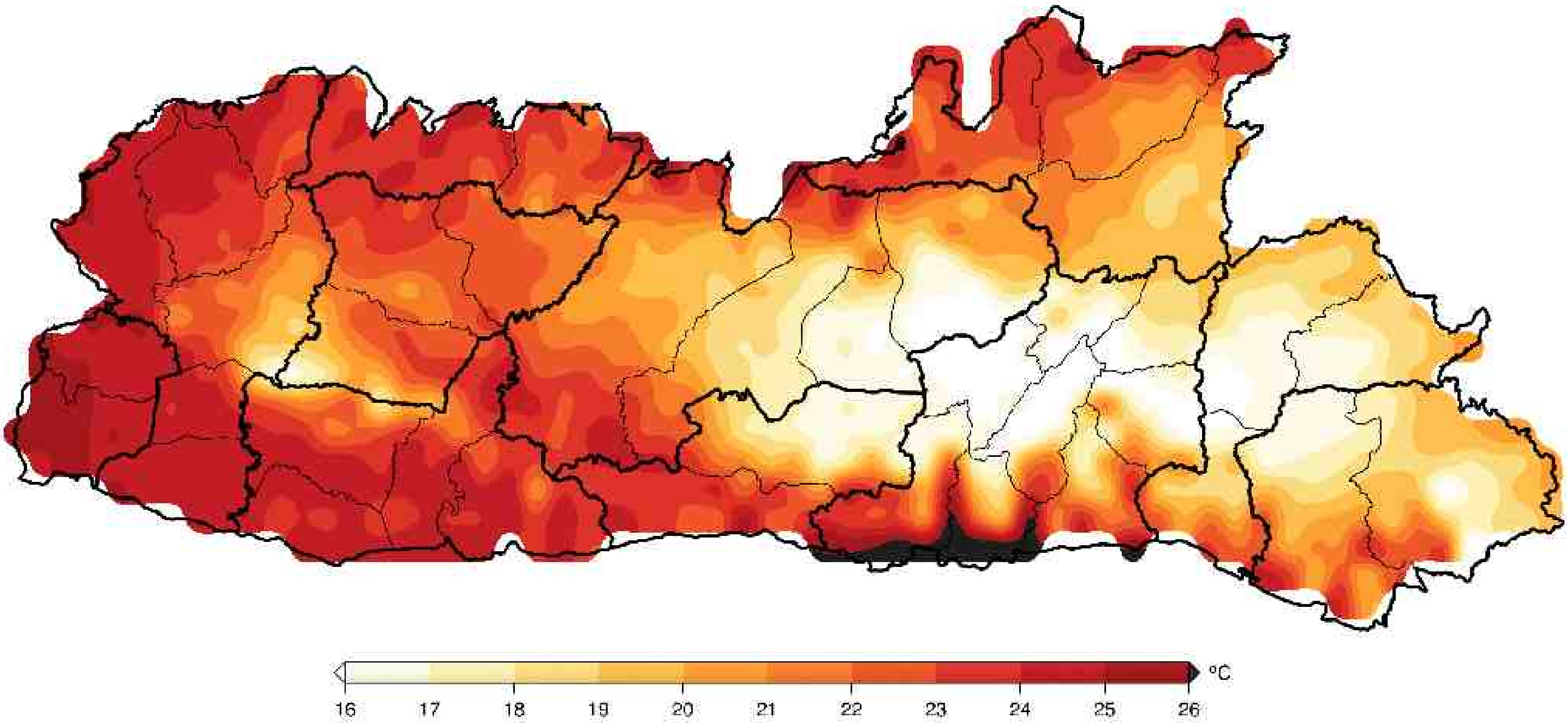

Figure 14. Average daily mean temperature (°C) in 2012. Based on the data from Sheffield et al., 2006 version 2.

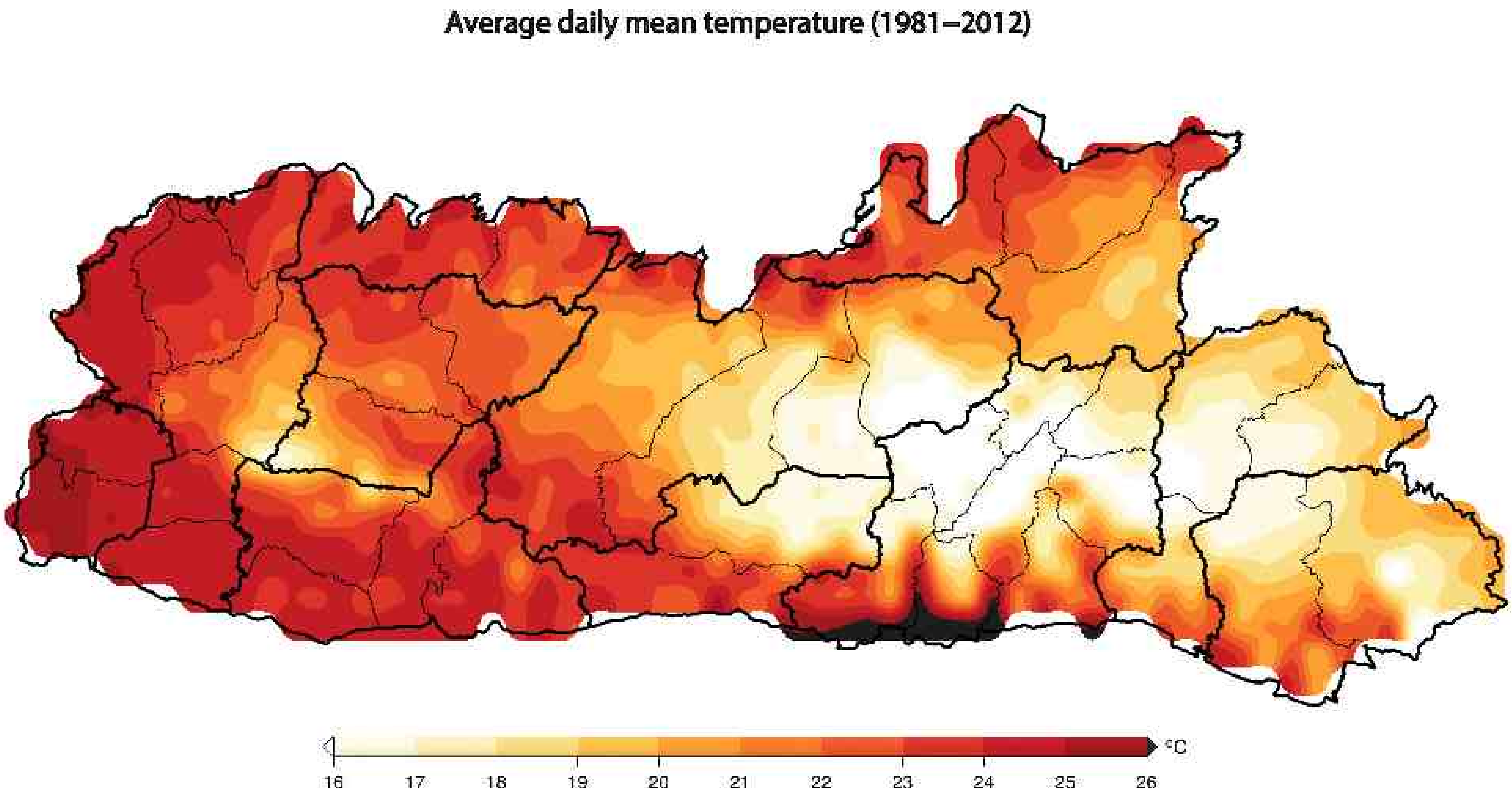

Figure 15. Average daily mean temperature (°C) in 1981-2012. Based on the data from Sheffield et al., 2006 version 2.

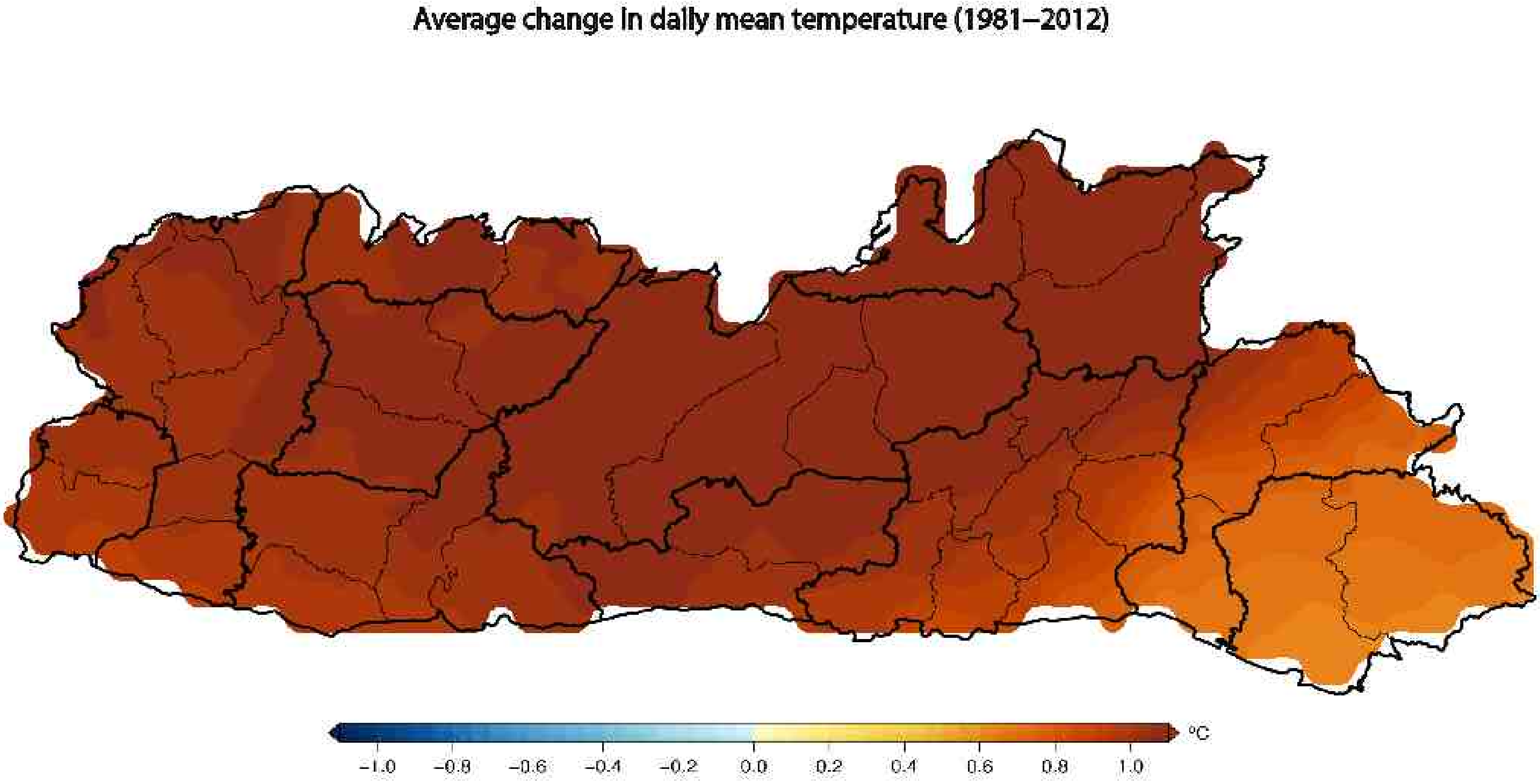

Figure 16. Average change in daily mean temperature (°C) in 1981-2012. Based on the data from Sheffield et al., 2006 version 2.

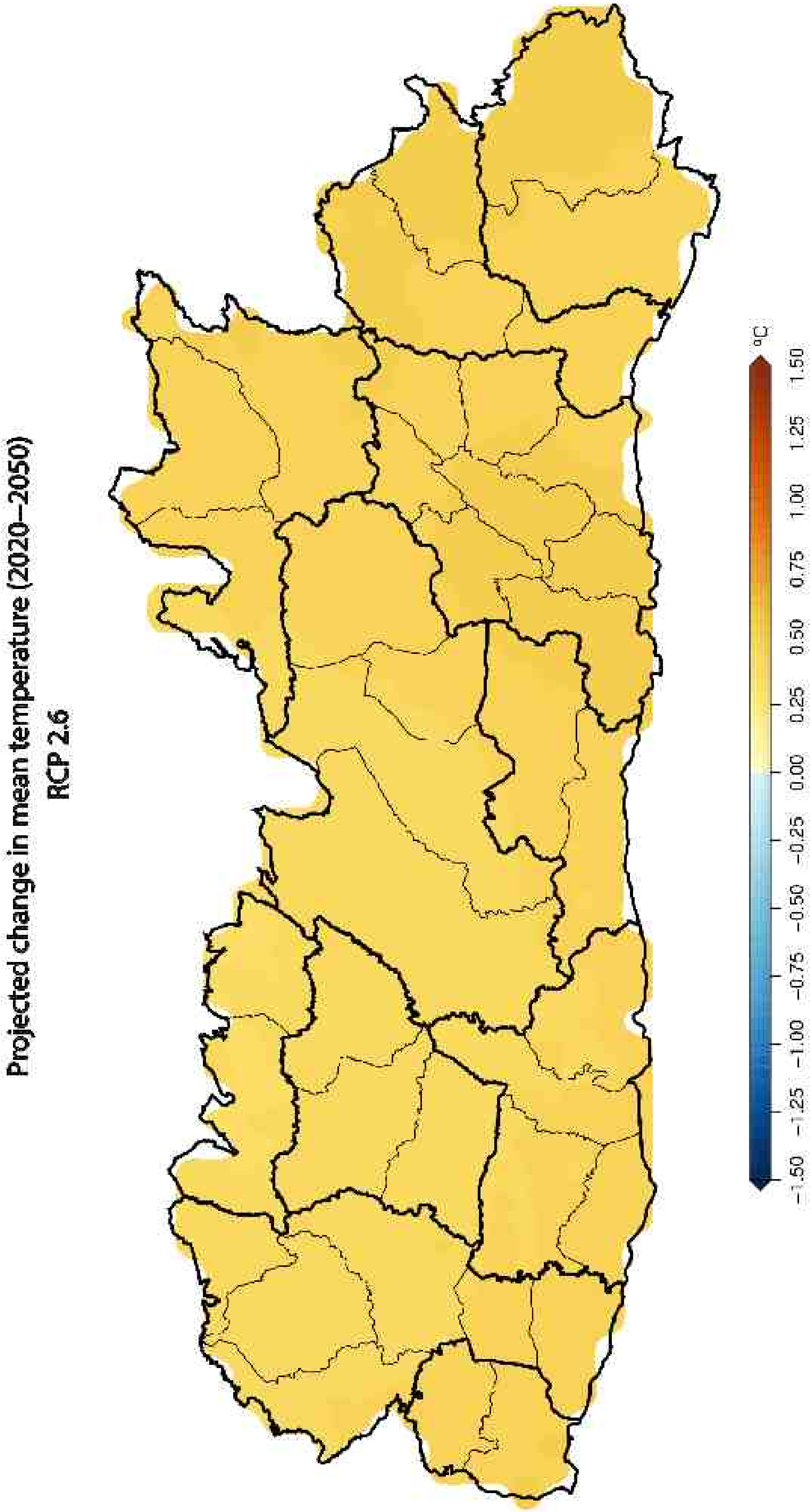

Figure 17. Multimodel ensemble projected change in mean temperature (°C) for the period 2020-2050 based on RCP 2.6.

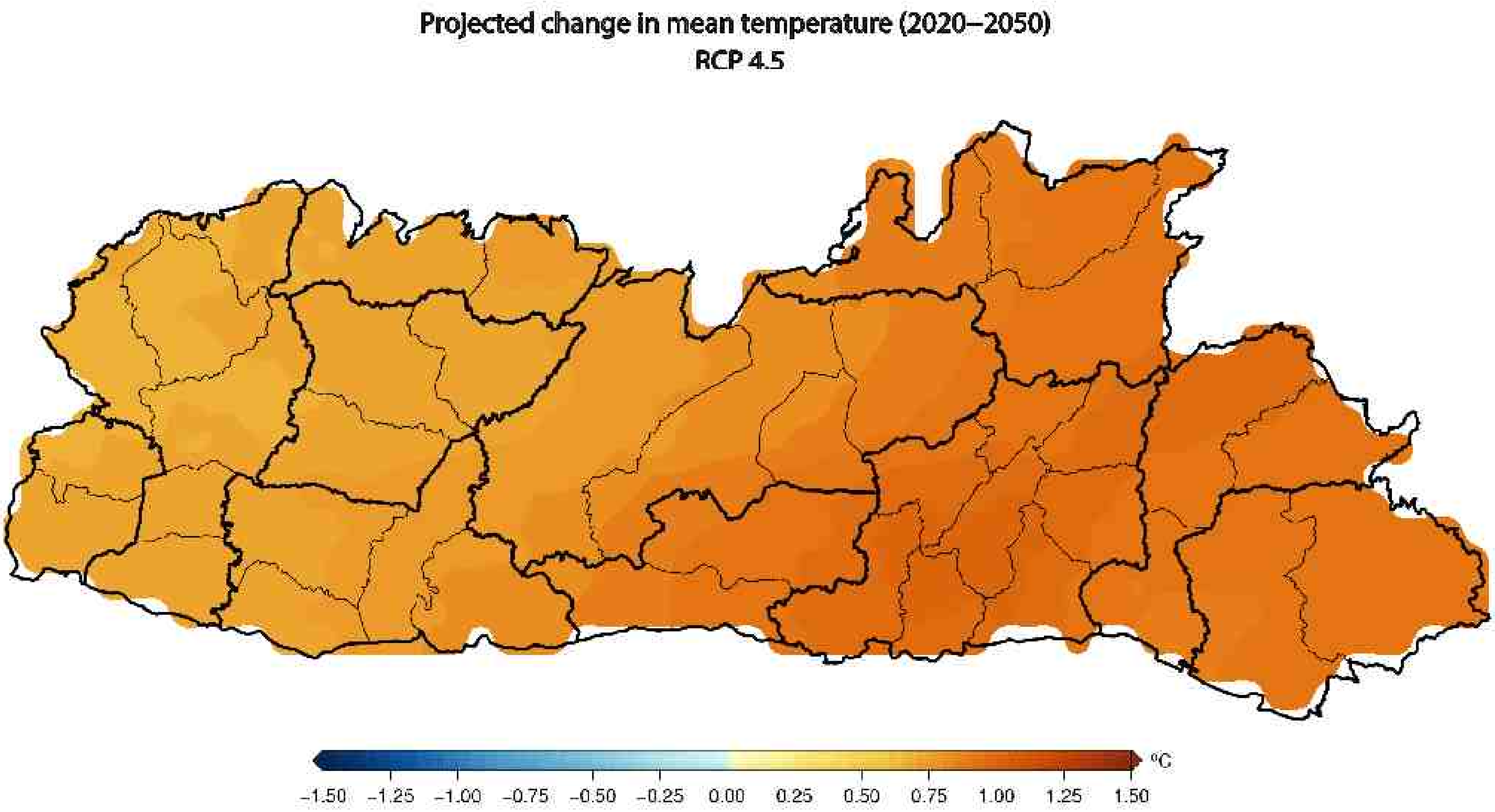

Figure 18.Multimodel ensemble projected change in mean temperature (°C) for the period 2020-2050 based on RCP 4.5.

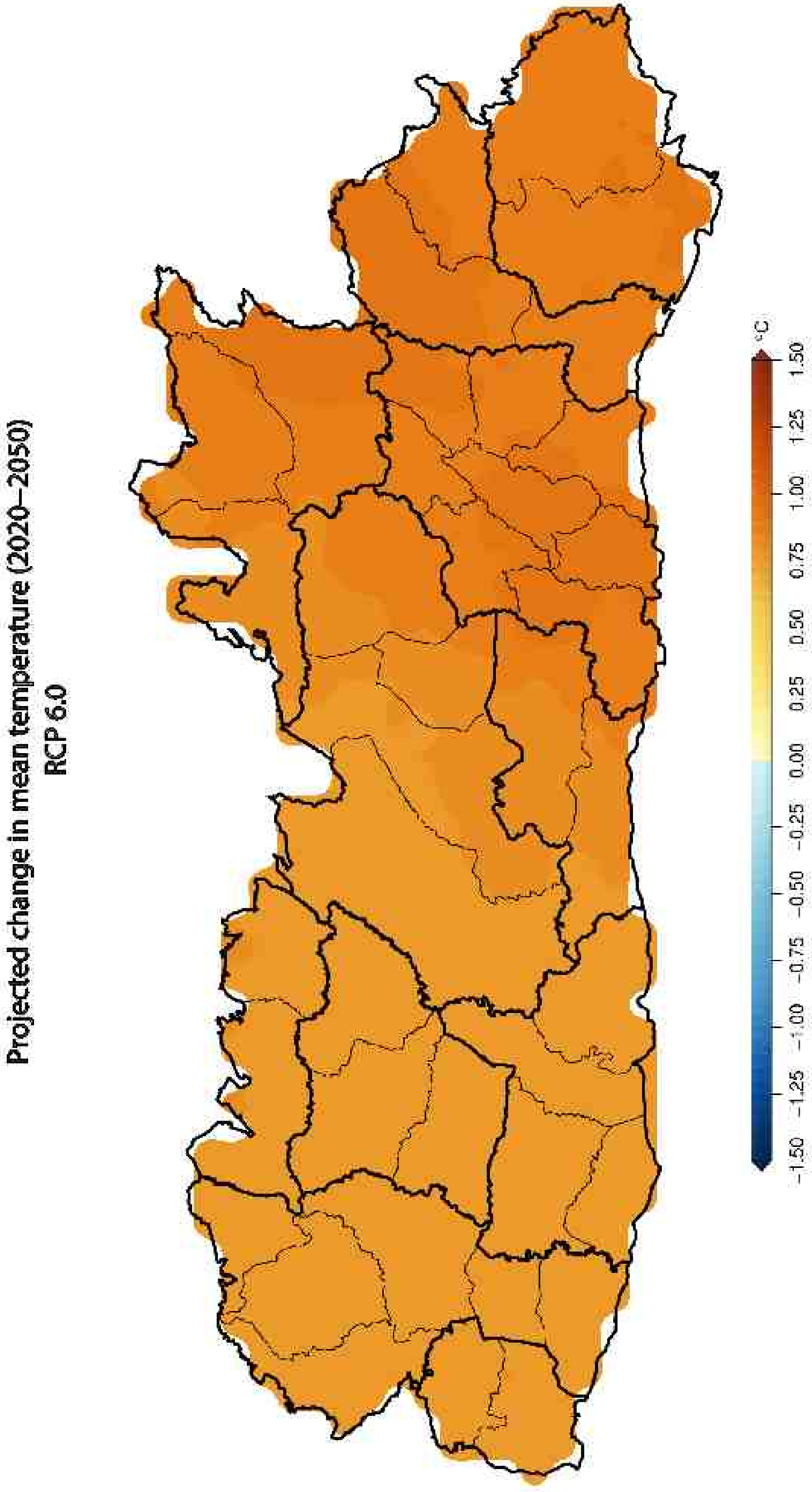

Figure 19. Multimodel ensemble projected change in mean temperature (°C) for the period 2020-2050 based on RCP 6.0.

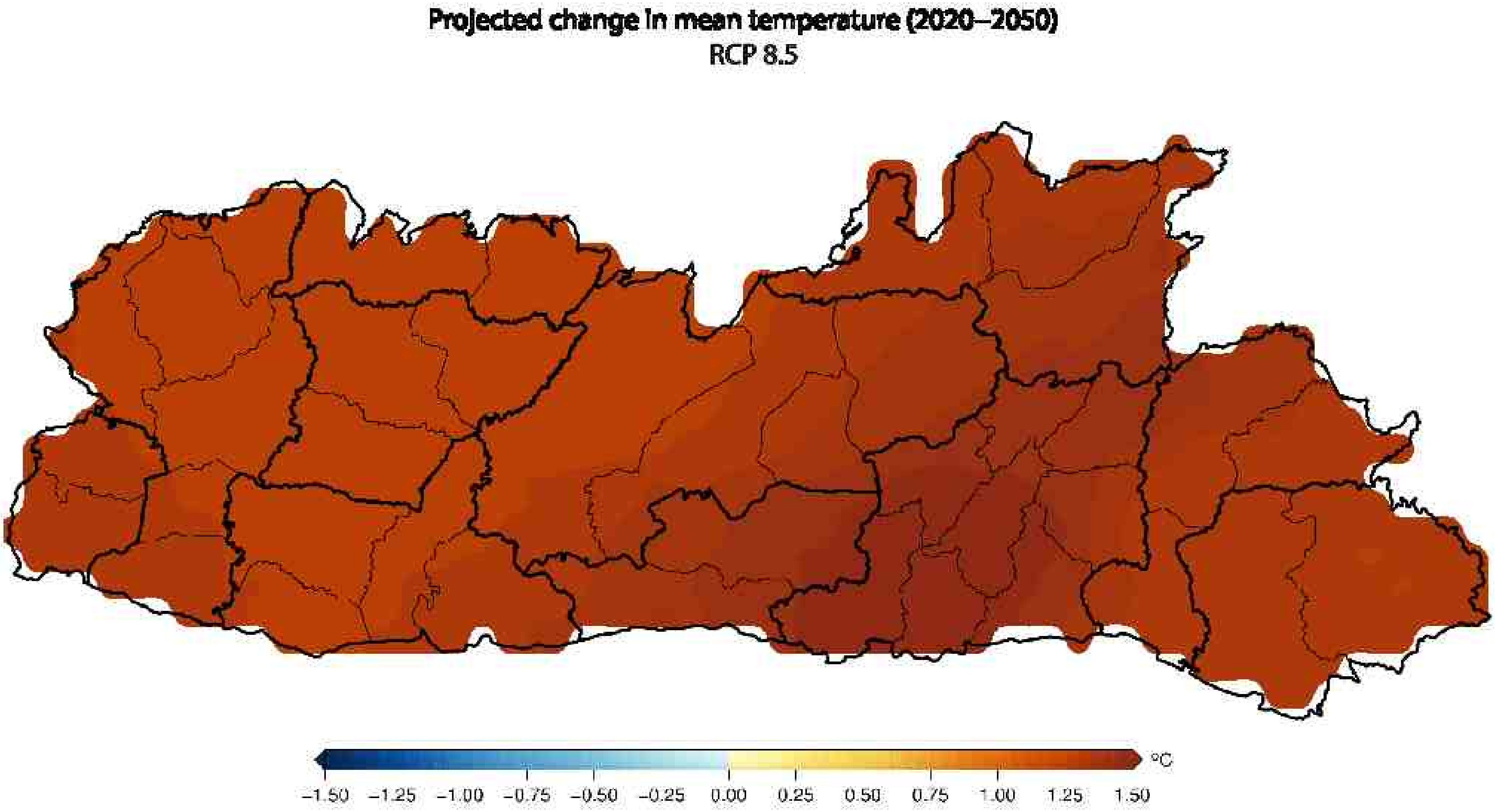

Figure 20. Multimodel ensemble projected change in mean temperature (°C) for the period 2020-2050 based on RCP 8.5.

3.
Data and Methods

The study required observed datasets and climate model projections at high spatial resolution to resolve topographic variability in the State of Meghalaya. Precipitation and air temperature (maximum and minimum) at high spatial resolution and daily temporal resolution are needed to estimate change in the observed and projected future climate. In the purview of this study, precipitation and rainfall were used interchangeably.

3.1 Observed data

Observed precipitation and temperature (maximum and minimum) data from India Meteorological Department (IMD) were not suitable for high resolution analysis as the spatial coverage near the international borders were not consistent. Moreover, number of raingauge stations is fairly limited in the State of Meghalaya, which may not capture the observed variability due to complex topography of the State. Precipitation data from Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS, Funk et al., 2015) at 0.05° (~5x5 km) resolution at daily scale and temperature data from Sheffield et al. (2006) version 2 at 0.25° (~25x25 km) resolution was used for the analysis and statistical downscaling and bias correction of climate projections to high resolution. The temperature data was further regridded to 0.05° resolution using the SYMAP algorithm, which considers the effect of lapse rate on air temperature based on elevation data as described in Maurer et al. (2002). The high resolution CHIRPS data (Funk et al., 2015) were also bias corrected using the APHRODITE (Yatagai et al., 2012) precipitation that is available for the entire monsoon Asia. More details on the bias correction of CHIRPS precipitation can be obtained from Aadhar and Mishra (2017). The observation period, based on the available data, is 1981-2012.

3.2 Future Climate Projections

Data for the projected future climate were obtained from the CMIP5 models. To understand the variability in the considered variables, the uncertainty attributed to selection of multiple models needed to be reduced. Out of 40 CMIP5 models, the five best models, which showed better skills to simulate observed climate and features of the Indian summer monsoon rainfall (based on bias, temporal and spatial correlations), were selected. The models which were finally selected were CCSM4, GFDL-ESM2M, MIROC5, NorESM1-M and NorESM1-ME of ensemble number r1i1p1 (see Taylor et al, 2012 for details).

Table 1. CMIP5 models primarily considered in the study.

IPSL-CM5B-LR	IPSL-CM5A-LR	CanESM2	CESM1-CAM5
MRI-CGCM3	FGOALS-g2	MPI-ESM-LR	NorESM1-M
MRI-ESM1	IPSL-CM5A-MR	MPI-ESM-MR	NorESM1-ME
GISS-E2-R-CC	bcc-csm1-1-m	ACCESS1-0	CESM1-CAM5-1-FV2
GISS-E2-R	HadGEM2-CC	CNRM-CM5	GFDL-CM3
GISS-E2-H-CC	HadGEM2-ES	inmcm4	CESM1-BGC
CSIRO-Mk3-6-0	CMCC-CM	CMCC-CESM	CESM1-FASTCHEM
GISS-E2-H	CMCC-CMS	FIO-ESM	CCSM4
ACCESS1-3	HadGEM2-AO	GFDL-ESM2M	MIROC5
bcc-csm1-1	MPI-ESM-P	GFDL-ESM2G	CESM1-WACCM

When comparing model simulations and observed data, there are some differences in the two and these differences are known as bias, which suggests that the models are over/under estimating a variable or are positively/negatively biased. The selected models showed less than 1°C bias (i.e., the models deviated from actual temperatures or are biased by less than 1°C) in annual mean air temperature and less than 100 mm bias (i.e., the models deviated from actual precipitation values or are biased by less than 100 mm) in mean monsoon season precipitation.

These CMIP5 model outputs are too coarse and may not be appropriate for regional scale climate change impacts assessments and may have biases against the observed data, therefore, needed to be converted to a finer spatial resolution (statistical downscaling) and corrected for the bias (bias correction). Statistical downscaling is a method to compute higher resolution data (here, 5 x 5 km) from coarse resolution (here, 50 x 50 km) data using statistical corrections based on the observed high resolution data (here, 5 x 5 km CHIRPS precipitation & Sheffield temperature). Thus, bias correction and statistical downscaling were performed using the precipitation and temperature from the selected CMIP5 models. Originally, the Bias Correction and Spatial Disaggregation (BCSD) approach was proposed by Wood et al. (2002, 2004) and was further modified by Thrasher et al (2013). We employed quantile-quantile modified BCSD approach to develop downscaled and bias corrected data at high resolution.

The high resolution dataset for the projected future climate were developed for the period of 2013-2100. Precipitation and air temperature (maximum and minimum) from the five best CMIP5 models were bias-corrected for four Representative Concentration Pathways (RCPs), RCP 2.6, 4.5, 6.0 and 8.5. These RCPs represent alternative scenarios based on economy, scientific advancement, and mitigation efforts. For instance, RCP 8.5 considers the most pessimistic scenario for future, while the RCP 2.6 takes relatively optimistic future scenario. RCP 4.5 and RCP 6.0 fall between the other two extreme scenarios. Based on the radiative forcing warming equivalent (2.6, 4.5, 6.0 & 8.5 W/m^2) of the warming produced by increasing greenhouse gases, different climatic variables (precipitation and temperature) can be derived using climate model simulations. The final BCSD and temporally disaggregated product of the models were at a spatial resolution of 0.05 degree (5 x 5 km) and at daily timescale, consistent with the observed datasets.

Technical terms

Climate models: These are mathematical, computational and physics based models which can simulate climate conditions based on the past changes in Earth's climate. These models are provided by several agencies and are different from each other in terms of assumptions and conditions being simulated. Due to these variations, several models needed to be considered for the analysis so as to reduce the uncertainty associated with each of them. These are also termed as GCM (General Circulation Models) or RCM (Regional - Climate Models). The latter being high resolution and captures local scale variability, while the former takes into consideration global aspects of climatic variability.

Representative Concentration Pathways (RCPs): Future global warming contribution towards climate change is difficult to quantify in general terms. There are numerous factors that affect the future climate systems such as technological development, changes in energy generation and land-use, global and regional economic circumstances, and population growth. The earlier second generation SRES (Special Report on Emissions Scenarios) scenarios were complex and ambiguous in terms of applicability and realisation (viz. scenarios A1B, A2B1, B1, etc). To standardise these research and findings, a set of third generation scenarios were suggested to keep the initial conditions, historical data and projections consistent across the various branches of climate science.

RCPs are climate pathways for approximate greenhouse gas concentration and anthropogenic heat, and which represents an equivalent earth system dynamics at certain radiative flux or forcings from the Sun in year 2100 relative to year 1750. There are four indicative pathways (RCP 2.6, RCP 4.5, RCP 6.0 and RCP 8.5), which represents mitigation scenarios with very low forcings (RCP 2.6), two stabilization scenarios (RCP 4.5 and RCP 6.0), and one scenario with very high greenhouse gas emissions (RCP 8.5). In simpler terms, RCP 8.5 represents climatic scenario of the Earth, equivalent to the condition when an added +8.5 W/m^2 of radiative flux is provided by the Sun in the year 2100 in comparison to pre-industrial period or year 1750.

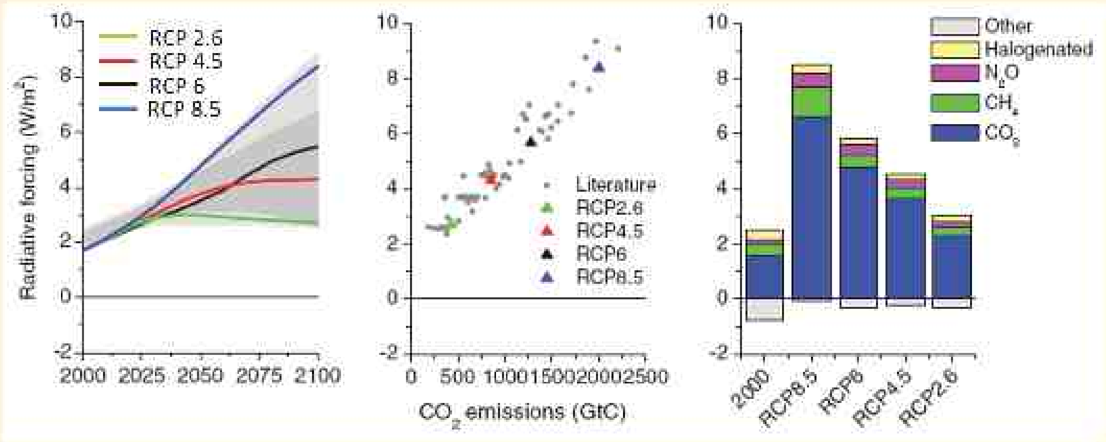

Figure 21. The above figure shows trends in radiative forcing (left), cumulative 21st century CO_2 emissions versus 2100 radiative forcing (middle) and 2100 forcing level per category (right). Grey area indicates the 98th and 90th percentiles (light/dark grey). The dots in the middle graph also represent a large number of studies. Forcing is relative to pre-industrial values and does not include land use (albedo), dust, or nitrate aerosol forcing [Source: van Vuuren, 2011].

Each RCP provides spatially resolved data sets of land use change and sector-based emissions of air pollutants, and it specifies annual greenhouse gas concentrations and anthropogenic emissions up to 2100. RCPs are based on a combination of integrated assessment models, simple climate models, atmospheric chemistry and global carbon cycle models. While the RCPs span a wide range of total forcing value, they do not cover the full range of emissions in the literature, particularly for aerosols. (Source: https://skepticalscience.com/rcp.php; IPCC Climate Change Report 2013, Summary for Policymakers (SPM)).

3.3 Analysis Approach

To determine hydrometeorological variations in the State of Meghalaya, indicators such as SPEI and SPI were used. Historical analysis is done using the bias corrected Climate Hazards Group Infrared Precipitation with Station (CHIRPS) precipitation data, which is based on satellite observations merged with station data (Funk et al., 2015). For future projections, bias corrected and downscaled projections from the five best CMIP5 models were used. Observed temperature data were obtained from Sheffield et al., 2006 at 0.25 degree resolution which were spatially disaggregated to 0.05 degree (5 x 5 km) resolution considering the lapse rate of temperature for different elevations. All spatial variations were determined by analysing the data on pixel-by-pixel basis whereas block/district/State averages were calculated based on spatial average of the attributes associated only in the pixels covering the State. The seasons considered for the analysis are winter (December - March), pre-monsoon (April - May), monsoon (June - September) and post-monsoon (October - November).

The precipitation analysis, changes in cumulative monsoon season precipitation and intensities were considered. Extreme precipitation events frequency shows how a region is likely to face extreme wet rainy events. SPI and SPEI values show how the monsoon seasons are faring with time, that is, to know if a region is likely to experience unusually wet or deficit precipitation in the monsoon season.

Analysis using temperatures (maximum and minimum) considers changes in maximum, mean, and minimum air temperatures. Extreme events such as hot days/nights, cold days/nights and heatwaves show the vulnerability of a region in terms of such rare temperatures events.

The extreme events are identified using percentile values. An x percentile value represents that x % of records or data are below this value. For instance, a 75 percentile value represents that 75% of all records or data have magnitudes less than this value.

3.3.1 Observed period analysis

a) Precipitation

Observed precipitation were obtained from CHIRPS at 0.05° spatial resolution. State averaged monthly precipitation shows that most (72% of total) of the rainfall occurs in the monsoon season (June - September) **(Figure 22)**. Changes in precipitation were thus, computed for monsoon season over the period of 1981 - 2012. Seasonal variation of the precipitation received in the State through the observed period is shown in **Figure 23**. Changes in mean monsoon precipitation were computed based on Mann-Kendall non-parametric trend analysis and Sen's slope method (Sen et al, 1968). Changes (mm) were estimated by multiplying the trend slope to the number of years in the observed period **(Figure 24b & 24d)**. Statistical significance in the trend analysis was estimated at 5% significance level. Extreme precipitation events are the number of rainy days which resulted in more than 95th percentile level of daily precipitation (95th percentile value represents the events below which 95% of the observation lies). Similarly, 5th percentile value may also be defined). Rainy days are those days which receives at least 1 mm of rainfall. The general trend of spatially averaged precipitation received in a year is determined on annual basis which shows a mildly increasing trend in annual average rainfall **(Figure 25)**.

b) Extreme precipitation during the monsoon season

To determine surplus or deficit extreme event frequencies, Standardised Precipitation Index (SPI) and Standardised Precipitation and Evapotranspiration Index (SPEI) were used. Values of SPI or SPEI less than -1.3 indicates at least a mild drought event, which worsens (severe to extreme droughts) as the value deviates towards more negative values. Similarly, if the SPI or SPEI values are greater than 1.3, that indicates mild to severe surplus rainfall event. The frequency of occurrence of such events indicates us the vulnerability of that area considering rainfall and temperature as variables **(Figure 26)**.

c) Air Temperature

Air temperature plays a vital role in the evaluation of hydrometeorological hazards. This has a prominent effect on surface and groundwater water availability. The effect can be very well noticed on SPI and SPEI, as the latter is affected by the average temperature, which is further an indicator for deficit or surplus of water availability. The annual average of maximum, mean, and minimum temperatures were computed for each 0.05° grid. Changes for the observed period were computed using Mann-Kendall trend method and Sen's slope method **(Figure 27)**, similar to estimation of change in precipitation **(Figure 24)**. The general trend of change in average temperature was determined by spatial average of annual daily mean temperature **(Figure 28)**.

d) Extreme temperature events

Frequencies of days and nights which were exceptionally cool or hot, with respect to the normal temperatures in that area, points about the vulnerability of that area against such severe events related to temperature **(Figure 30** and **Figure 31)**. Hot days and nights are those days and nights on which the maximum temperature was greater than 95th percentile of usual day's maximum temperature and greater than 95th percentile of usual night's minimum temperature, respectively **(Figure 30)**. Cold days and cold nights were considered on the days and nights when the maximum temperature and minimum temperature were less than the 5th percentile value for the same variable, respectively **(Figure 31)**. These also indicate the effect on growing degree days on crop growth. One of the most severe events related to health and mortality in extreme temperatures is heatwave. The observations related to heatwaves were calculated based on number of spells in which at least 6 continuous hot days were observed. The frequency of such spells shows the affected portion of an area and its severity **(Figure 32)**.

3.3.2 Analysis for the projected future climate

Projected period data were obtained by selecting the five best CMIP5 models in Indian context for Representative Concentration Pathways (RCPs) 2.6, 4.5, 6.0 and 8.5. The model projection data were bias-corrected and spatially disaggregated (BCSD) (Thrasher et. al, 2013) at 0.05 degree spatial resolution. The projected period considered was from 2016 - 2090, which was subdivided for the analysis in near-term (2016 - 2040), mid-term (2041 - 2065) and long term (2066 - 2090). The period 1981 - 2012 from historical period of the model output is designated as the reference historical period. Changes in the selected variables and indices were computed based on the difference in the value of attributes in consideration with respect to that obtained for the historical reference period (1981 - 2012). To reduce intermodel variability, the inferences were obtained on the basis of multimodel ensemble mean of the attribute in consideration for each concentration pathway.

Mean projected changes in precipitation were computed by taking the difference in the same variable obtained for the reference period for near-term, mid-term, and long-term projected ensemble means for the different RCP scenarios **(Figure 33)**. Changes in extreme precipitation events were determined with reference to that obtained in the historical reference period (1981 - 2012). The 95th percentile threshold for considering a rainy event as extreme was obtained from the distribution of rainy days available in the historical reference period. Thus, the precipitation events, when rainfall was greater than these thresholds, were considered as an extreme precipitation events **(Figure 34)**.

Similarly, changes in maximum, mean, and minimum temperatures in near-term, mid-term, and long-term were computed based on the difference in respective temperatures from historical reference period **(Figure 37, Figure 38** and **Figure 39)**. The threshold for considering extreme events related to temperature were obtained from that computed from historical reference period. That is, the 95th percentile of respective temperature variable in the historical reference period (1981 - 2012) were considered for calculation of frequency of extreme hot and cold days or nights. The hot days and cold days were computed with 95th and 5th percentiles thresholds, respectively, of maximum temperature in the historical reference period. Whereas, hot nights and cold nights frequencies were obtained based on 95th and 5th percentile of minimum temperature in the historical reference period **(Figure 40** to **Figure 41)**. Projected heatwaves frequencies were determined based on number of spells per year, having at least 3 continuous hot days **(Figure 44)**.

4. Results

4.1 Changes in the Observed Period (1981-2012)

4.1.1 Precipitation

Precipitation data for the observation period of 1981-2012 were analysed for the State of Meghalaya to understand the seasonal contribution towards total annual precipitation received by the State. This data do not tell us the contribution towards the streamflows as the study is not concerned with flow accumulations resulting from rainfall.

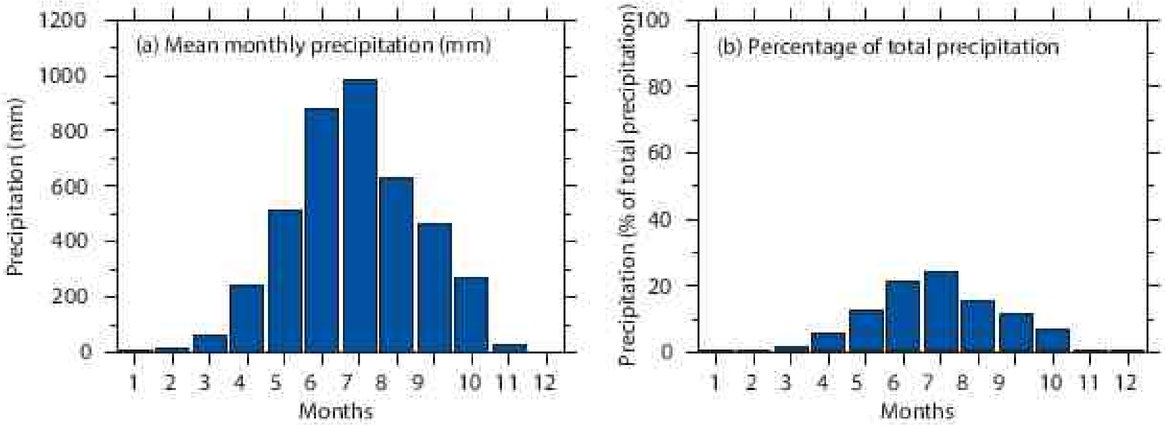

Figure 22. (a) Mean monthly average precipitation received, and (b) percentage of total precipitation in each month for the period of 1981-2012.

Long term State wide spatial average precipitation was found to be 4085 mm and most of the precipitation occurred in the monsoon season during the observed period. Figure 22 shows that the largest portion, around 2950 mm, of annual spatial average rainfall occurs in June-September which is 72% of total annual average precipitation.

Temporal analysis of seasonal precipitation received in the State shows consistent precipitation events in monsoon seasons through 1981-2012 with an average value of 2955 mm (Figure 23). There were some non-monsoon season extremes in comparison to the usual rainfall levels if those particular seasons. The State received the post monsoon extremes in 1988 (1082 mm), 1991 (976 mm), 1993 (902 mm), 2000 (949 mm) and 2010 (1119 mm) in the recent past (Figure 23b). Winter season showers were usually very light with an average of 75 mm (Figure 23c). The pre-monsoon rainfall usually contributed with an average of 300 mm (Figure 23d) precipitation.

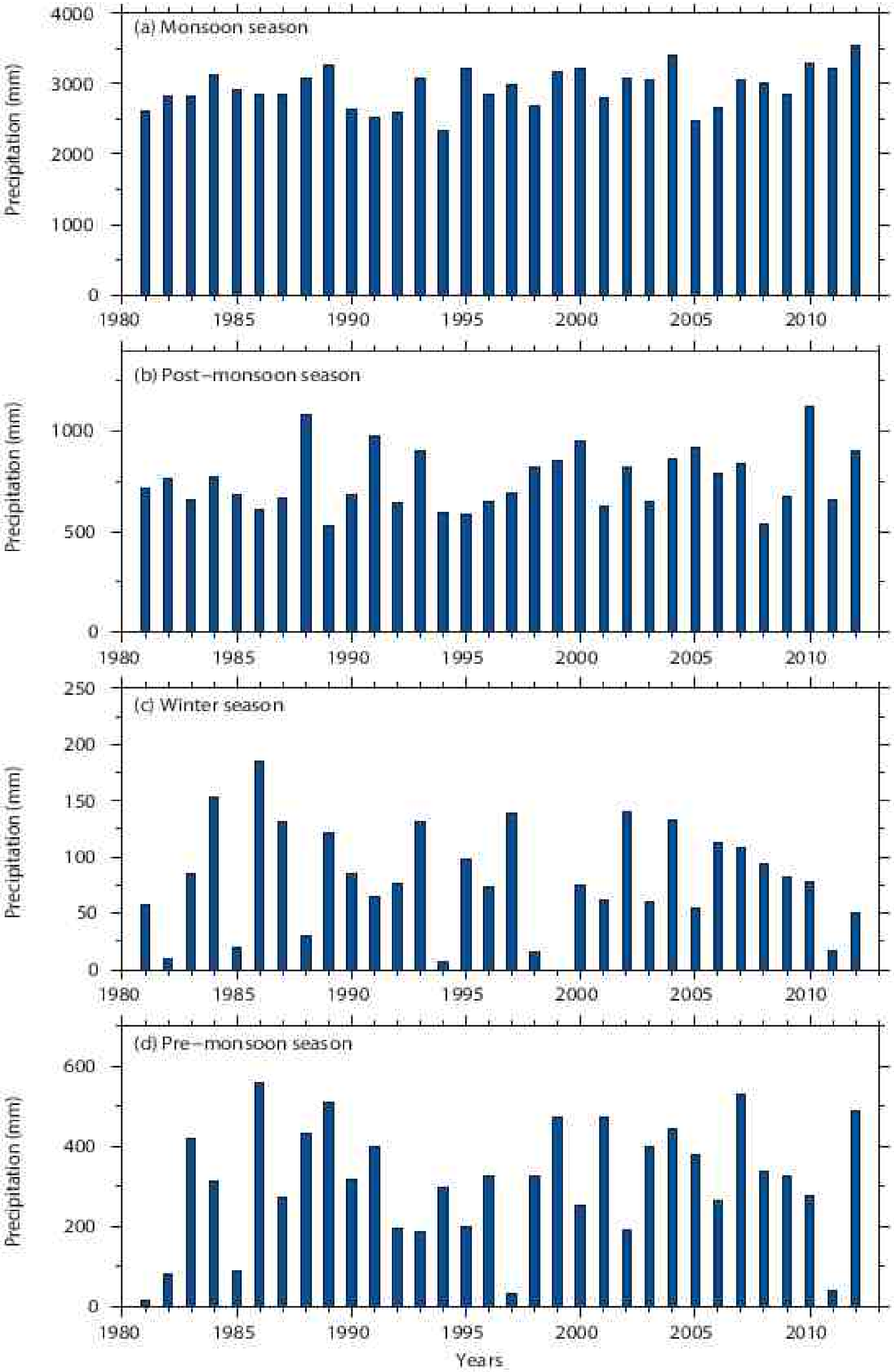

Figure 23. State average precipitation for (a) monsoon (JJAS), (b) post-monsoon (ON), (c) winter (DJFM) and pre-monsoon (AM) seasons for the period of 1981-2012.

The spatial analysis of the precipitation events and intensity reveals that although the temporal variation of the monsoon season precipitation does not show much significant changes, however, the trends were found to be different throughout the State (Figure 24).

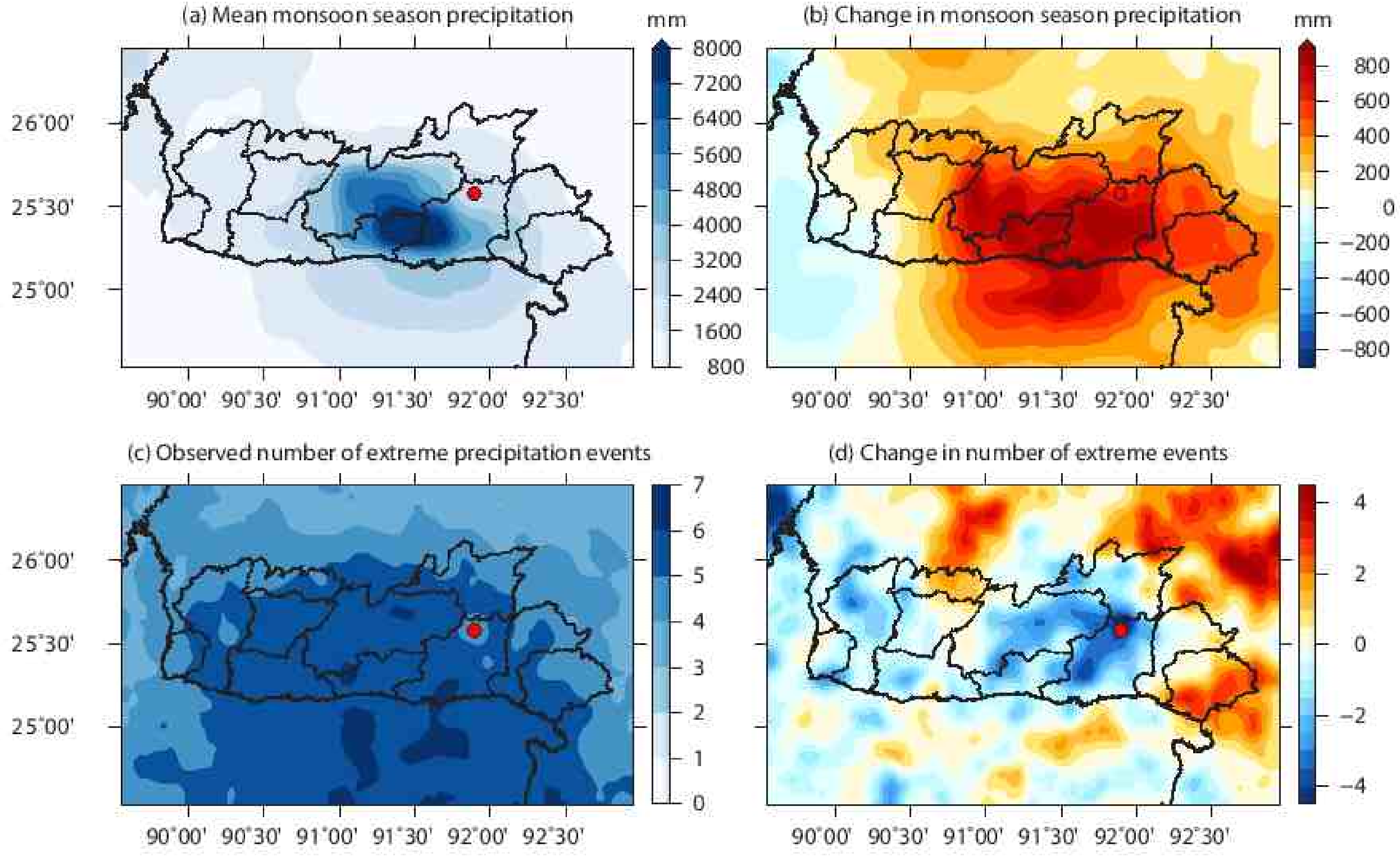

Figure 24. (a) Observed mean monsoon season precipitation, (b) Change in monsoon season precipitation, (c) Observed number of extreme precipitation events (precipitation greater than 95th percentile values), and (d) Change in number of extreme events during the period 1981-2012.

Considering the extreme events which exceeds 95th percentile of occurrence, the usual number of such events in the State was in the range of 4 to 7 (Figure 24c). The changes in frequency of such events were uniformly spread through the region, with almost equal area covered with increasing, decreasing and neutral changes of extreme precipitation events (Figure 24d).

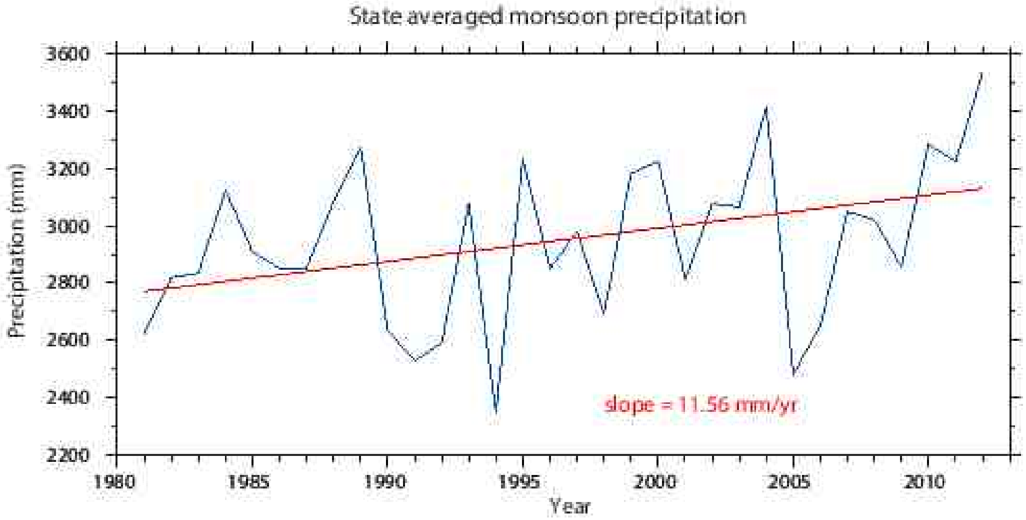

Figure 25. State averaged monsoon season precipitation and its trend for the period of 1981-2012. Slope of mean monsoon precipitation of 1981-2012 is shown in red.

The State averaged monsoon season precipitation provided a general trend of change in monsoon season precipitation levels for the period of 1981-2012. The incremental change is found to be 11.56 mm per year for the observed period (Figure 25).

Section summary

- 72% of total precipitation, 2950 mm was received in the months of June-September. A consistent long term average annual precipitation of 4085 mm was observed in the period 1981-2012. Apart from the central part, which receives 4000 - 8000 mm, rest of the State experienced relatively moderate rainfall of 2000 mm. The average annual precipitation in the State shows an increasing trend (11.56 mm/yr) while the monsoon season precipitation shows steady values.
- Though the State on an average shows steady change in precipitation levels, the central parts (West Khasi Hills, South West Khasi Hills and East Khasi Hills) show very high precipitation levels as well as higher rise in intensities.
- The rise in the frequency of extreme precipitation events was not much in the most part of the State. And, West Khasi Hills, South West Khasi Hills, East Khasi Hills and Ri-Bhoi showed a decline in number of extreme precipitation events. The changes in the frequency of extreme events is rather uniform throughout the region.

4.1.2 Extreme precipitation events Drought and Wet Periods

Extreme precipitation related events are significant for the study of vulnerable area identification. In this study, SPEI and SPI were used to identify such events. The SPEI/SPEI values less than -1.3 shows moderate to extreme drought years while such values greater than 1.3 shows moderate to extreme wet years.

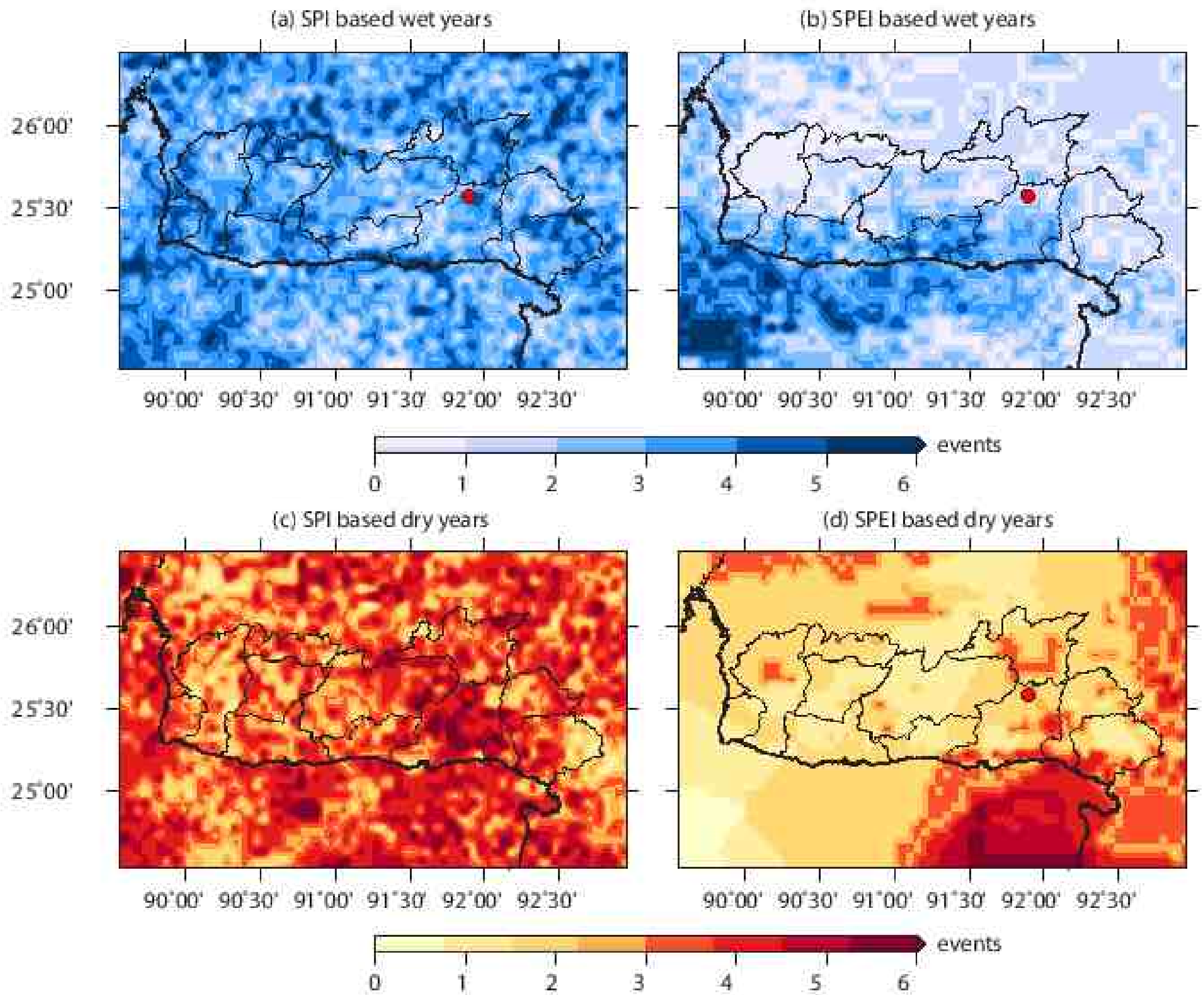

Figure 26. SPI based number of observed extreme (a) wet years and (c) dry years for the period of 1981-2012; SPEI based number of observed extreme (b) wet years and (d) dry years for the period of 1981-2012.

Since, SPI does not take evapotranspiration factor into account, therefore, SPEI is also used, which is sensitive to the changes in air temperature. The SPI/SPEI values considered here are the four month period at the end of monsoon i.e. September month, of every year. The base period for all calculations for SPI and SPEI was 1981-2012.

Figure 26 shows variations in frequencies of drought and wet years. SPI based drought and wet years were relatively uniform throughout (3-5 spells), with some exception of higher number of drought events (5-6 years) in the East Khasi Hills **(Figure 26a & 26c)**. Such surplus and deficit periods based on SPEI shows quite different picture, regions such as South-West Garo Hills, South Garo Hills, West Khasi Hills, East Khasi Hills and southern parts of West Garo Hills experienced 3-4 wet years, while the rest of the State faced fewer surplus periods (0-2 years) **(Figure 26b & 12d)**. Most parts of the State was safe in terms of extreme drought events. A nominal frequency of 1-3 of such periods were observed throughout the State, with some parts of eastern districts facing higher number of drought periods.

Section summary

- SPI and SPEI show slightly different patterns in terms of frequency of wet and drought years. SPI values indicate that all parts of the State faced 3 - 5 extreme wet years and 3-6 extreme drought years with East Khasi Hills faced higher (5-6) drought years.
- Based on SPEI, some parts of West Garo Hills, South-West Garo Hills, South Garo Hills, South-West Khasi Hills, South-West Khasi Hills and East Khasi Hills faced 3-4 extreme wet spells while rest of the State faced 0-2 such periods. The frequency of extreme drought spells were rather uniform in the range of 1-3 spells. East Khasi Hills, East Jaintia Hills and Ri-Bhoi faced higher number (1-5) of extreme drought periods.

4.1.3 Air Temperature

Changes in air temperature pattern show rather comforting results as compared to other parts of the country or closely lying States, in that respect. The maximum, mean and minimum temperature showed patterns conforming to the elevation changes in the terrain.

The central Meghalaya experienced lower temperatures in the range of 14-18 °C than the rest of their region (20-25 °C) **(Figure 27a, 27c & 27e)**. This may be attributed to the Hills and plateau in the central part.

The State averaged temperature shows an incremental change with a rate of 0.031 °C per year. This rising temperature may pose a serious threat to the ecology of the State. In the years 1991 and 1992 a drop in temperature beyond normal shows some recovery, but for the rest of the period, temperature increased consistently, and with 1 °C rise between 1981 and 2012.

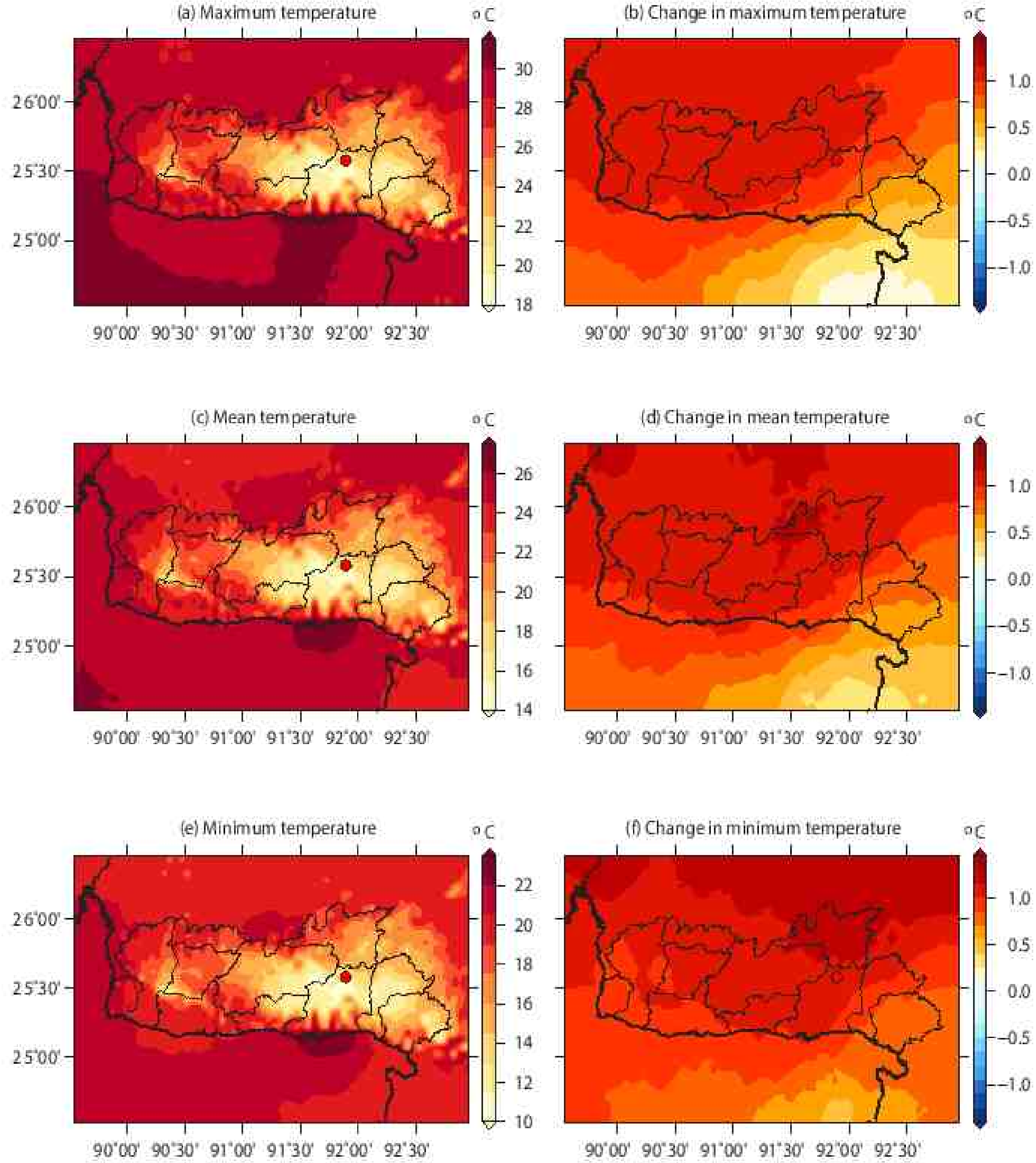

Figure 27. (a), (c) and (e) Observed annual mean of daily maximum, mean and minimum temperatures respectively; (b), (d) and (f) changes in maximum, mean and minimum temperatures during 1981-2012.

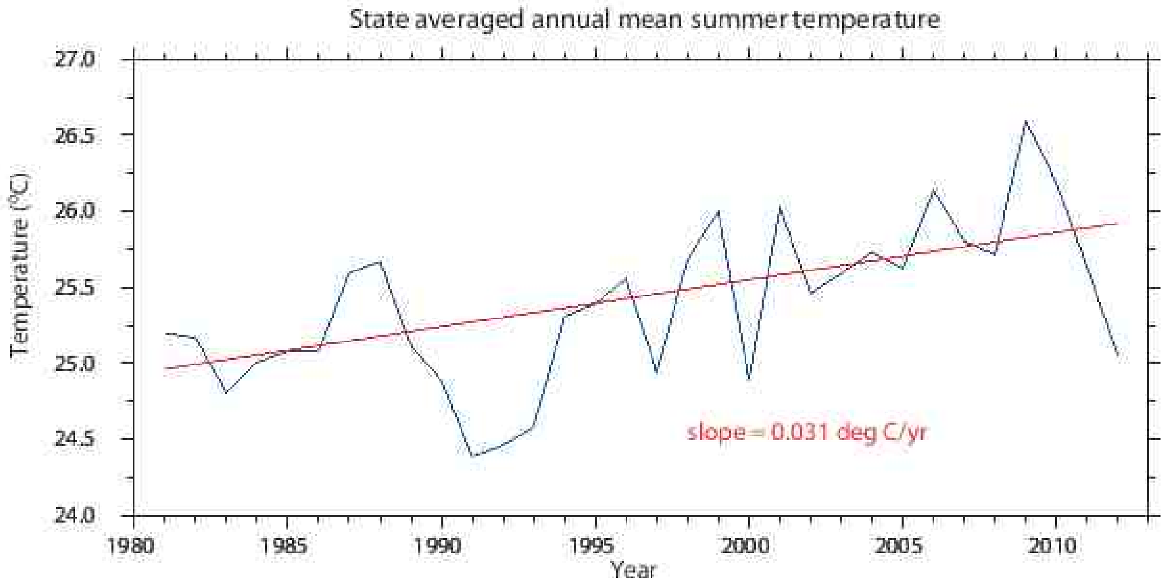

Figure 28. State averaged annual mean summer temperature and its trend for the period of 1981 - 2012 for Meghalaya ; Slope of mean temperature for the period of 1981 - 2012 is shown in red.

4.1.4 Extreme temperature events Hot/Cold days/nights & Heatwaves

Extreme temperature days are not usual. A day is considered as a hot day if the maximum temperature exceeds the 95% threshold of temperature. Similarly, hot nights occur when minimum temperatures higher than 95% threshold. Cold day/night are those days/nights which are unusually cold and which have lower than 5% of the daytime or night time temperatures, respectively.

The temporal analysis of spatial average of annual mean temperatures shows highly fluctuating frequencies of hot days, hot nights, cold days and cold nights. The average frequencies of hot days and nights for the State were 5.9 and 43.4 days per year, respectively (**Figure 29a & 29b**). The frequency of hot nights was very high. The frequencies of cold days and nights were 6 and 2 days per year, respectively (**Figure 29c & 29d**).

When comparing **Figure 28** and **Figure 29**, it is apparent that the number of hot days and nights dropped between 1990 and 1994 while cold days and nights increased. After year 1995, the changes in the frequency of these events is apparent. The number of hot days and nights show an increasing trend while that of cold days and nights show a declining trend. These are some of the indications of a consistently warming region.

The State faced mostly average of 6-7 hot days per year, with Ri-Bhoi, West Khasi Hills, East Khasi Hills and some parts of West Jaintia Hills in the higher frequency ranges (8-10) (**Figure 30a**). The changes in the period of 1981-2012 show moderate changes in hot days, which may seem different from the observations from **Figure 29a**. The changes computed here are averaged over time which reduces the temporal variability. Hot nights shows relatively higher frequency throughout the region (17-20 days per year) (**Figure 30c**). The change in hot nights shows an increase of 4-5 % in the frequency (**Figure 30d**).

The patterns of the frequency of cold days and cold nights were different than that of hot days and nights, a typical scenario observed in warming regions. The number of cold days and cold nights were almost uniform in the region (4.55-4.6 days per year for cold days and 4.55 days per year for cold nights) (**Figure 31a & 31c**). Change in cold night frequency seems neutral throughout, with exceptions in northern part of North Garo Hills, East Garo Hills and West Khasi Hills region, which showed very mild positive change (**Figure 31b**). While, cold night frequency had negative changes (-3 to -4 days per year) (**Figure 31d**).

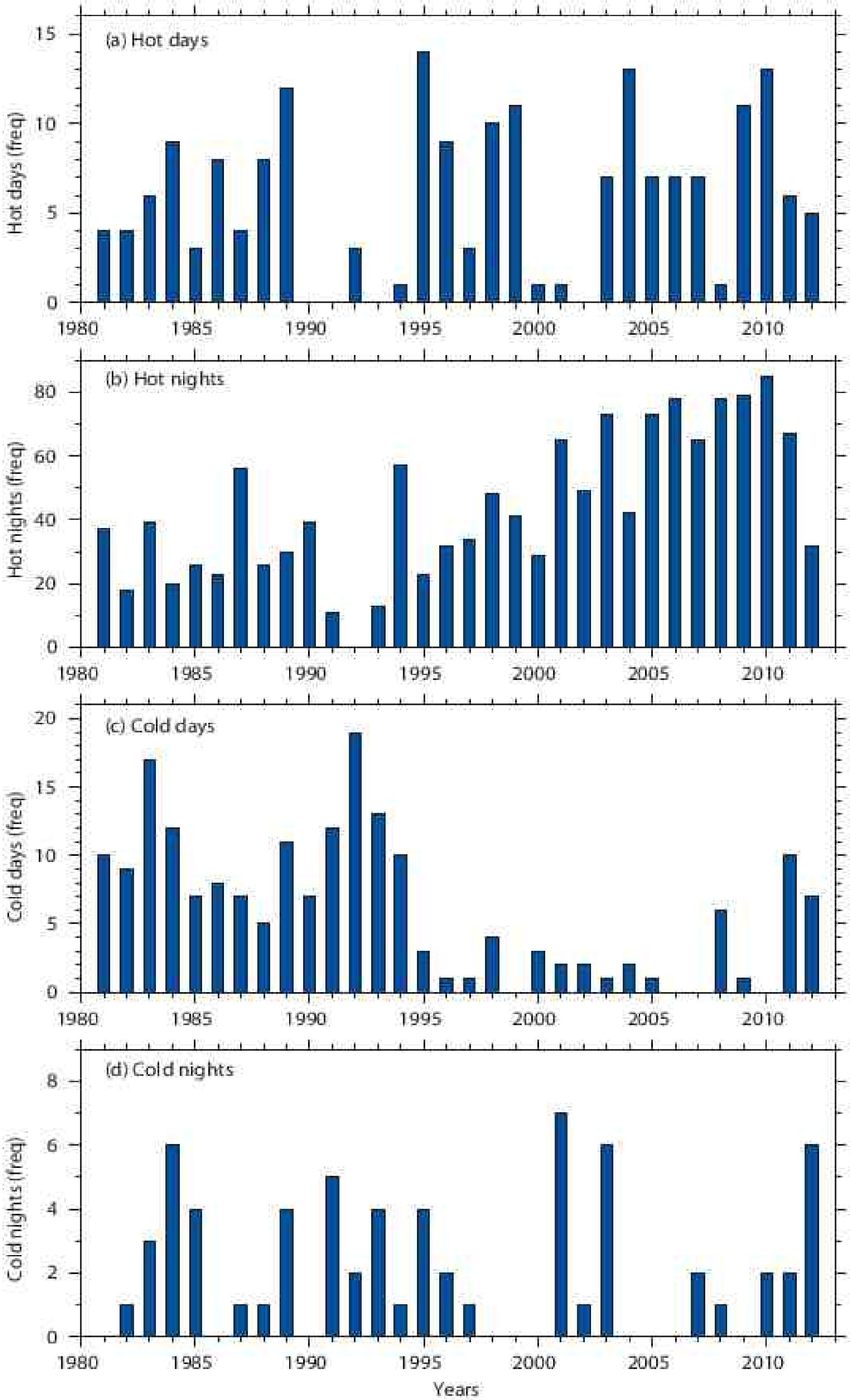

Figure 29. State averaged frequencies of (a) hot days, (b) hot nights, (c) cold days and (d) cold nights.

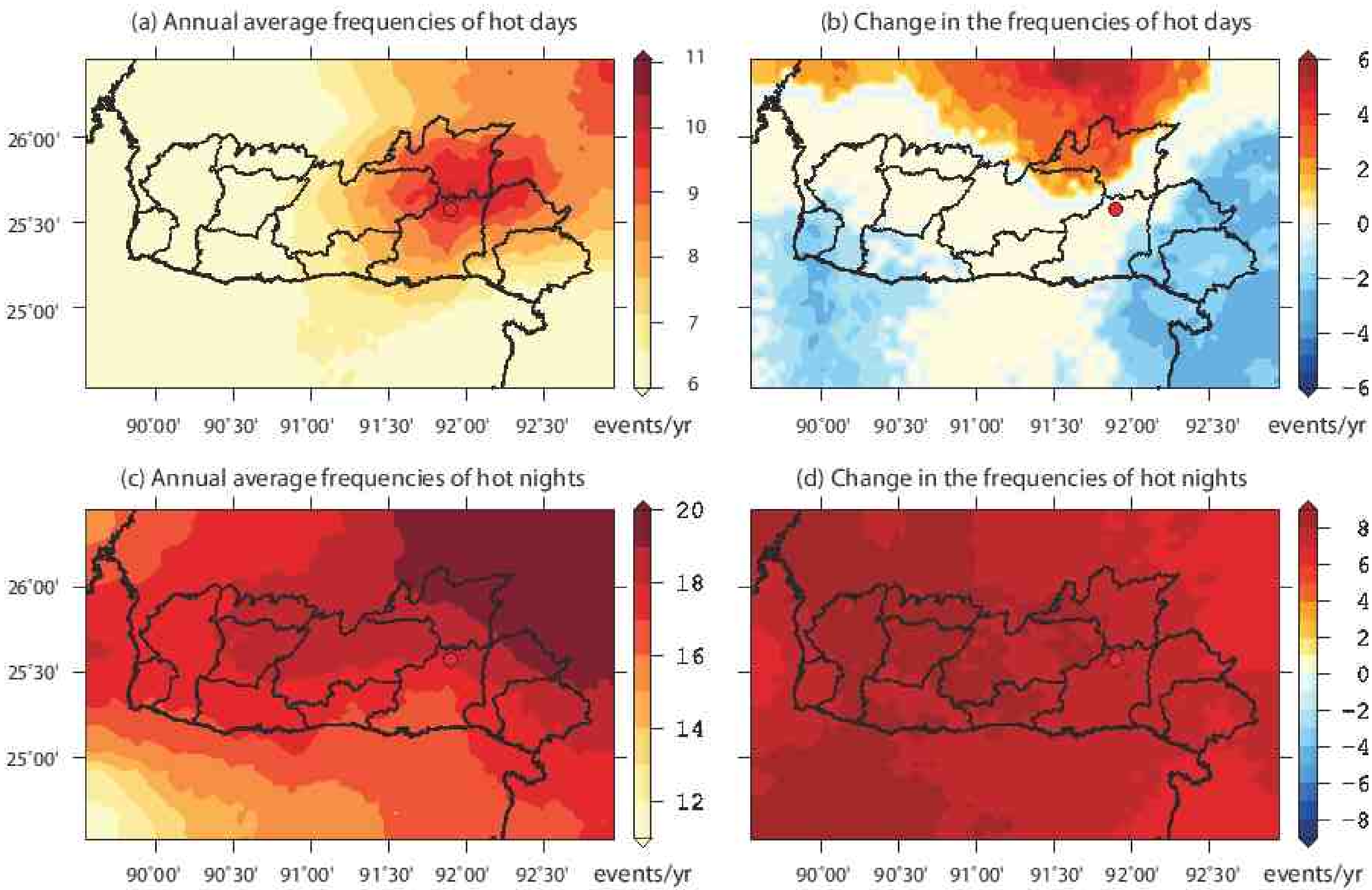

Figure 30. Annual average frequencies of (a) hot days and (c) hot nights; (b) change in the frequencies of hot days and (d) change in the frequencies of hot nights for the period of 1981-2012.

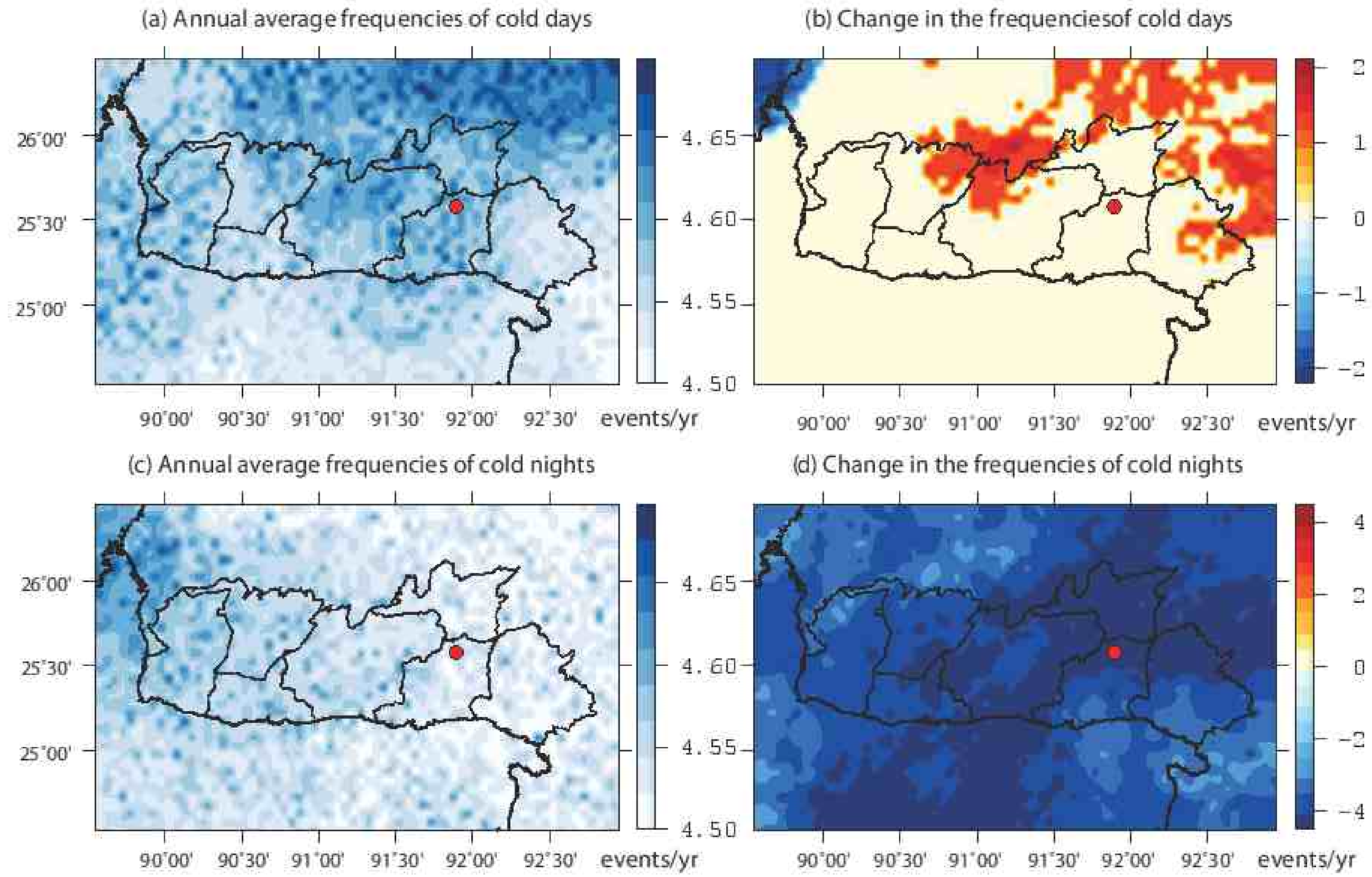

Figure 31. Annual average frequencies of (a) cold days and (c) cold nights; (b) change in the frequencies of cold days and (d) change in the frequencies of cold nights for the period of 1981-2012.

Temperature based hazards also includes heatwaves, or a spell of continuous hot days. These are very much common in the Indian peninsula. The north eastern regions seldom faces such hazards, but a thorough analysis is warranted in the warming climate. Heatwaves in this region are very few if we consider the absolute definition of heatwaves by IMD, but considering continuous extreme hot days spells (more than 95th percentile of maximum temperature) for each grid, we can observe such patterns. Figure 32 shows the spatial variation of average frequency of heatwaves. On an average the State of Meghalaya faced 7-9 heatwaves (0.25 – 0.3 heatwaves per year) during the observed period. East Khasi Hills experienced least number of heatwaves while some regions of West Khasi Hills, East Garo Hills and North Garo Hills faced higher numbers (0.40 heatwaves per year). Here, terms such as higher and lower frequencies of heatwaves are relative, but comparing other parts of the country, the frequencies are much lower for the State.

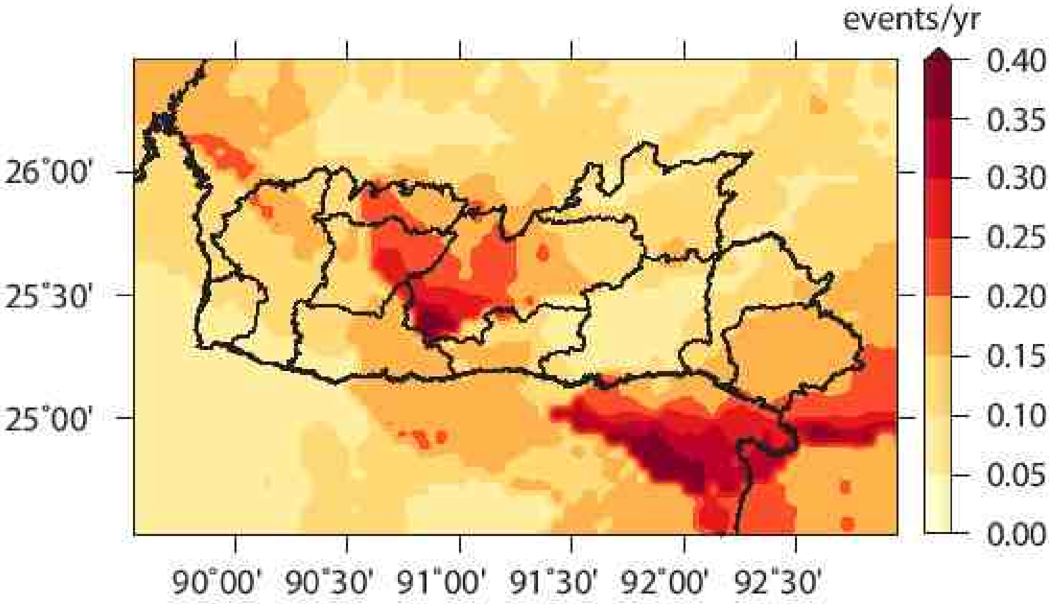

Figure 32. Spatial variation of heatwaves per year for the period of 1981-2012.

Section summary

- The mean frequencies for hot day, hot nights, cold days and cold nights were 6, 43.4, 6 and 2 events per year. Higher number of hot nights frequencies is a matter of concern for the State.
- Spatial variation of hot days shows moderate values (6-7) in the State with higher frequencies (8-10) in Ri-Bhoi, some parts of West Khasi Hills, East Khasi Hills and Jaintia Hills. While hot nights were of higher frequency (17-20) in the State relative to nearby regions, except for the north eastern parts, which faced higher number of hot nights. The changes in number of hot days shows nearly neutral change and a positive change in the number of hot nights in most part of the State.
- The variations and intensity of cold days and cold nights were uniform in the range of 4.55-4.6 and 4.6 events per year, respectively. Number of cold days shows nearly neutral changes in frequencies, with some regions of East Garo Hills, West Khasi Hills and Jaintia Hills facing mild positive changes (1-2). On the other hand, cold nights show nearly uniform decrease change in its frequency (-3 to -4) in the region.
- The State seems to be on the safe as far as events of heatwaves are concerned' as on an average the State experienced only 0 - 4 heatwaves only in the observation period.

Table 2. Block-wise summary of average annual change in mean temperature (°C) and average monsoon season rainfall for the period of 1981-2012.

S. No.	District	Block	Average annual change in mean temperature (°C)	Average change in monsoon season rainfall (mm)
1	SWGH	Zikzak	1.06	458.62
2		Betasing	1.07	470.94
3	WGH	Dalu	1.06	482.12
4		Gambegre	1.06	494.92
5		Rongram	1.08	466.95
6		Dadengre	1.08	486.31
7		Selsella	1.08	448.77
8		Tikrikilla	1.08	487.07
9	NGH	Kharkutta	1.09	622.43
10		Resubelpara	1.08	561.07
11	EGH	Samanda	1.09	532.30
12		Rongjeng	1.09	611.77
13		Songsak	1.08	547.11
14	SGH	Gasuapara	1.06	493.25
15		Baghmara	1.08	565.74
16		Chokpot	1.07	480.76
17		Rongra	1.07	601.93
18	WKH	Mairang	1.05	335.57
19		Mawnshynrut	1.09	628.70
20		Mawthadraishan	1.10	675.29
21		Nongstoin	1.11	644.86
22	SWKH	Mawkyrwat	0.97	445.02
23		Ranikor	0.94	413.86
24	Ri Bhoi	Jirang	1.16	111.73
25		Umsning	1.10	234.10
26		Umling	1.12	187.48
27	EKH	Shella Bholaganj	0.79	357.21
28		Pynursla	0.78	356.82
29		Mawsynram	0.84	390.17
30		Mawkynrew	0.80	393.04
31		Mawphlang	0.86	393.93
32		Mylliem	0.86	368.39
33		Mawryngkneg	0.85	366.00
34		Laitkroh	0.84	407.49
35	WJH	Thadlaskein	0.85	303.60
36		Amlarem	0.75	348.74
37		Laskein	0.77	302.30
38	EJH	Saipung	0.69	298.92
39		Khliehriat	0.68	317.44

4.2 Climate Change Projections

4.2.1 Precipitation

Multimodel mean change in precipitation shows positive changes with respect to the historic period data (1981-2012). The projections were divided into near (2013-2040), mid (2041-2070) and long (2071-2100) terms, so as to observe progression of changes in the variables in space as well as in time domain.

RCP 2.6 shows 40-300 mm increment in precipitation intensities in near term (2013-2040), 70-180 mm in mid term (2041-2070) and 78-180 mm in long term (2071-2100) (Figure 33, RCP 2.6). RCP 4.5 shows higher changes, 50-160 mm in near term, 80-190 mm in mid term and 95-350 mm in long term (Figure 33, RCP 4.5).

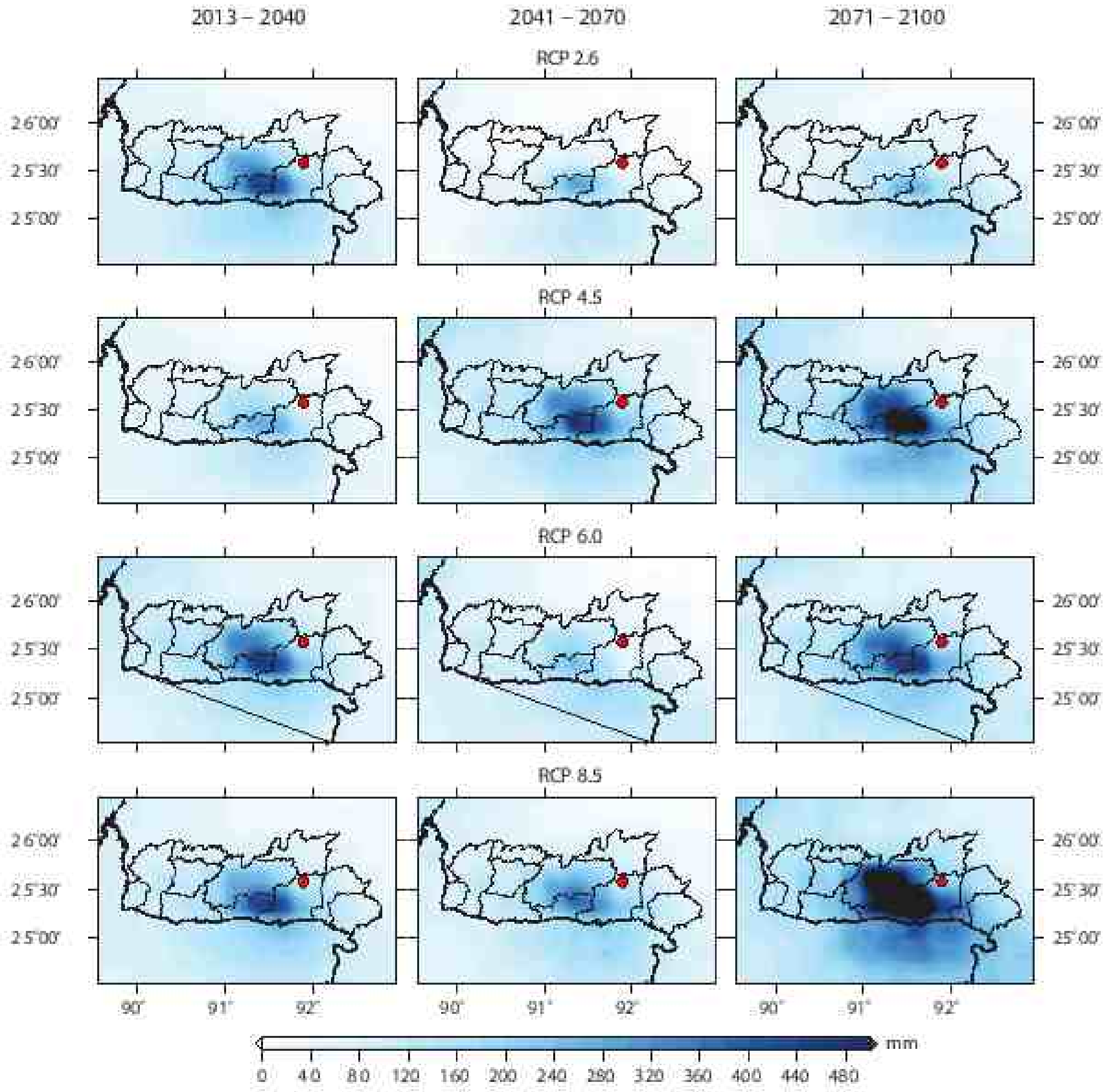

Figure 33. Multimodel ensemble mean projected change (mm) in monsoon season precipitation for the Near, Mid and Long temporal term. Changes were estimated against the historic mean for the reference period (1981-2012).

The central region of Meghalaya is projected to face higher changes in precipitation in all scenarios.

Table 3. Multimodel ensemble mean projected change (mm) in monsoon season precipitation for the Near, Mid and Long temporal term. Changes were estimated against the historic mean for the reference period (1981-2012). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 14.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	167.98	69.83	90.89	112.04	184.98	233.46	190.87	92.54	206.92	170.73	172.05	273.16
	Betasing	167.98	69.83	90.89	112.04	184.98	233.46	190.87	92.54	206.92	170.73	172.05	273.16
WGH	Dalu	167.98	79.74	93.34	112.04	184.98	233.46	190.87	94.68	206.92	170.73	172.05	273.16
	Gambegre	167.98	79.74	93.34	112.04	184.98	233.46	190.87	94.68	206.92	170.73	172.05	273.16
	Rongram	167.97	75.30	90.89	110.73	182.52	233.23	190.83	98.47	206.25	170.06	169.17	272.71
	Dadengre	167.97	75.30	90.89	110.73	182.52	233.23	190.83	96.18	206.25	170.06	169.17	272.71
	Selsella	167.97	75.30	90.89	110.73	182.52	233.23	190.83	96.18	206.25	170.06	169.17	272.71
	Tikrikilla	167.97	75.30	90.89	110.73	182.52	233.23	190.83	96.18	206.25	170.06	169.17	272.71
NGH	Kharkutta	171.40	81.83	95.55	116.34	192.72	251.17	197.72	104.19	214.66	172.35	184.69	279.77
	Resubelpara	169.29	77.33	93.34	113.06	187.17	240.27	192.32	94.68	207.40	170.76	178.05	273.93
EGH	Samanda	169.29	77.33	93.34	113.06	187.17	240.27	192.32	94.68	207.40	170.76	178.05	273.93
	Rongjeng	169.29	77.33	93.34	113.06	190.02	240.27	192.91	94.85	207.44	170.76	180.24	278.69
	Songsak	167.98	69.83	90.89	112.04	184.98	233.46	190.87	92.54	206.92	170.73	172.05	273.16
SGH	Gasuapara	167.98	69.83	90.89	112.04	184.98	233.46	190.87	92.54	206.92	170.73	172.05	273.16
	Baghmara	167.98	77.33	93.90	112.04	187.17	240.27	192.32	98.47	206.92	170.73	178.05	273.16
	Chokpot	167.98	75.64	93.34	112.04	184.98	233.46	190.87	94.68	206.92	170.73	172.05	273.16
	Rongra	169.41	81.97	95.43	115.64	187.09	236.60	190.87	102.66	207.44	171.55	174.85	274.58
WKH	Mairang	137.46	67.64	106.48	118.89	130.33	139.98	133.68	96.98	224.07	184.51	121.58	223.05
	Mawnshynrut	169.41	56.41	97.92	114.03	192.72	248.40	200.55	98.47	214.92	171.04	178.86	289.55
	Mawthadraishan	205.76	69.83	106.21	129.64	237.53	307.03	283.24	109.68	235.33	213.23	188.40	420.60
	Nongstoin	216.74	81.91	105.23	135.53	269.82	342.85	287.36	116.69	270.17	225.74	212.85	410.43
SWKH	Mawkyrwat	338.08	182.21	176.01	180.56	164.15	154.49	182.88	177.33	256.39	269.75	173.77	324.59
	Ranikor	176.29	170.82	168.66	169.41	164.15	154.49	162.14	176.33	244.64	192.91	137.39	253.57
Ri Bhoi	Jirang	58.15	169.56	160.22	166.52	111.59	108.80	114.99	178.61	229.35	189.15	100.50	202.74
	Umsning	50.68	36.45	78.53	61.85	88.93	100.62	112.41	47.18	127.70	107.70	95.94	192.84
	Umling	46.64	34.37	78.53	53.82	89.00	95.46	109.81	45.48	127.10	100.51	88.96	184.55

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
EKH	Shella Bholaganj	93.89	115.51	137.37	148.35	101.77	121.25	114.99	109.53	217.27	189.03	103.57	214.66
	Pynursla	100.75	87.94	140.69	128.06	105.56	121.28	115.64	80.48	202.50	184.51	104.19	218.59
	Mawsynram	111.93	152.81	150.18	158.36	118.92	140.79	124.34	142.73	224.07	192.91	120.72	235.33
	Mawkynrew	108.29	77.75	123.70	98.61	118.92	140.79	124.34	75.36	214.29	167.04	120.72	235.33
	Mawphlang	108.10	125.64	150.18	160.62	118.92	139.33	124.34	104.30	227.44	190.38	120.72	224.33
	Mylliem	93.74	112.41	123.70	103.60	117.50	131.89	118.82	83.93	200.62	164.61	104.19	210.75
	Mawryngkneg	87.96	77.75	109.81	78.10	118.83	124.35	115.62	80.32	198.23	145.29	107.75	208.36
	Laitkroh	108.10	112.76	135.50	152.09	118.92	140.79	120.58	103.94	227.44	189.03	112.66	224.33
WJH	Thadlaskein	74.58	61.52	104.04	61.96	99.46	114.31	112.87	65.76	150.72	113.79	100.16	204.40
	Amlarem	107.06	89.25	130.69	90.85	123.15	131.89	120.12	87.53	202.08	162.56	114.01	223.05
	Laskein	69.26	61.52	104.04	61.96	93.74	106.92	106.55	60.36	144.79	113.79	92.97	202.74
EJH	Saipung	59.14	52.37	79.29	53.93	83.88	100.24	92.16	61.73	120.12	103.67	86.05	181.63
	Khliehriat	88.46	65.95	119.95	74.51	107.97	136.41	109.89	83.93	141.26	126.17	107.75	206.97

Exceptionally wet rainy events can be defined as the rainfall events below which 95% of the precipitation values lies. These are rainfall events which are rare and are of high intensity. The number of exceptional precipitation events shows an overall increasing trend (Figure 34). The increasing trend is minimal in the State of Meghalaya as compared to the surrounding regions. Western, north-eastern and southern regions may face most of the higher increments in the extreme precipitation events. RCP 2.6 shows an average increment in number of extreme events with 0.6-1.5 in near term, 0.6-1 in mid term and 0.4-1.3 in long term. For RCP 4.5 and 6.0, increments of 0.3-2 are consistent throughout the near, mid and long terms. RCP 8.5 suggests 0.8-3.5 increment in average number of exceptional precipitation events.

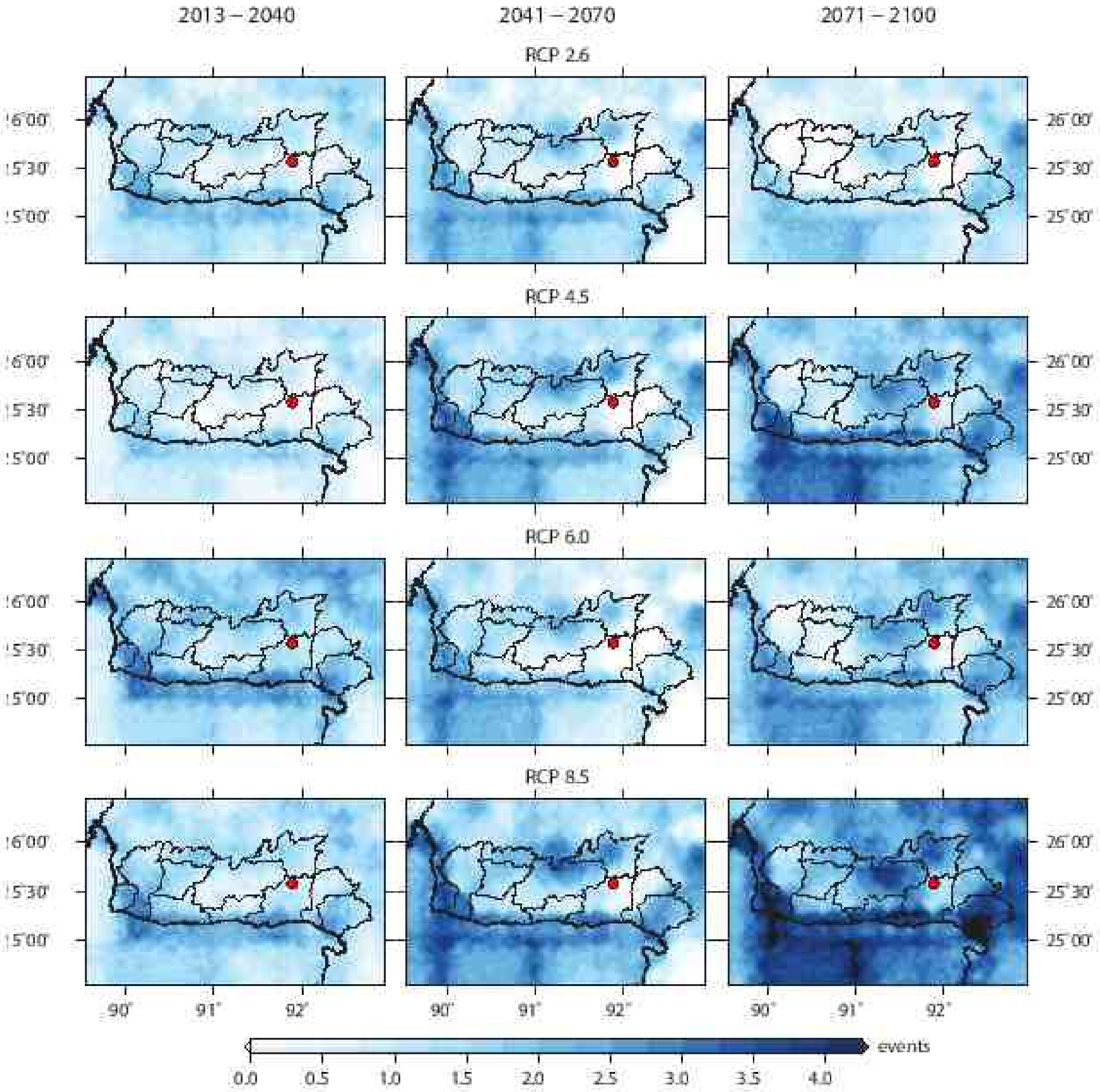

Figure 34. Multimodel mean projected change in number of extreme precipitation wet events (i.e. change in number if events estimated using 95th percentile threshold from historic period of rainy days; base period 1981-2012. Rainy days are the days when precipitation is greater than 1mm).

Table 4. Multimodel mean projected change in number of extreme precipitation wet events (i.e. change in number if events estimated using 95th percentile threshold from historic period of rainy days; base period 1981-2012. Rainy days are the days when precipitation greater than 1 mm). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 15.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	**Block**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**
SWGH	Zikzak	0.73	0.73	0.44	0.53	1.02	1.64	1.10	0.74	1.29	0.85	1.34	2.21
	Betasing	0.73	0.73	0.44	0.53	1.02	1.64	1.10	0.74	1.29	0.85	1.34	2.21
WGH	Dalu	0.73	0.76	0.70	0.56	1.08	2.03	1.14	0.74	1.59	0.85	1.37	2.70
	Gambegre	0.73	0.76	0.60	0.56	1.08	1.92	1.14	0.74	1.48	0.85	1.37	2.67
	Rongram	0.75	0.61	0.25	0.56	1.02	1.23	1.15	0.75	0.87	0.90	1.34	1.97
	Dadengre	0.73	0.71	-0.04	0.56	1.08	1.08	1.15	0.75	0.71	0.90	1.34	1.72
	Selsella	0.75	0.65	0.37	0.56	1.08	1.47	1.15	0.75	1.10	0.90	1.34	2.18
	Tikrikilla	0.68	0.59	0.18	0.50	1.00	1.28	1.06	0.75	0.86	0.82	1.24	1.97
NGH	Kharkutta	0.71	0.76	0.44	0.50	1.08	1.52	1.09	0.74	1.25	0.79	1.37	2.27
	Resubelpara	0.70	0.63	0.19	0.47	1.08	1.08	1.10	0.74	0.83	0.83	1.33	2.07
EGH	Samanda	0.71	0.73	0.26	0.49	0.99	1.32	1.09	0.74	0.93	0.83	1.28	2.09
	Rongjeng	0.67	0.73	0.24	0.36	1.02	1.14	1.06	0.74	0.87	0.80	1.29	2.08
	Songsak	0.73	0.73	0.17	0.53	1.02	1.11	1.10	0.74	0.75	0.85	1.34	2.01
SGH	Gasuapara	0.73	0.73	0.44	0.53	1.02	1.64	1.10	0.74	1.29	0.85	1.34	2.21
	Baghmara	0.71	0.62	0.09	0.38	0.88	1.16	1.04	0.64	0.86	0.83	1.14	1.97
	Chokpot	0.73	0.72	0.43	0.53	1.02	1.54	1.10	0.74	1.09	0.85	1.28	2.15
	Rongra	0.73	0.63	0.49	0.53	0.99	1.71	1.10	0.66	1.33	0.83	1.33	2.38
WKH	Mairang	0.90	0.90	1.33	0.52	1.02	2.10	1.04	0.90	2.01	0.90	1.68	2.78
	Mawnshynrut	0.63	1.02	0.56	0.34	1.31	1.60	1.01	0.98	1.39	0.75	1.58	2.43
	Mawthadraishan	0.60	0.82	0.56	0.30	1.15	1.61	0.99	0.81	1.45	0.71	1.37	2.49
	Nongstoin	0.71	0.76	0.70	0.50	1.08	1.92	1.09	0.74	1.59	0.78	1.37	2.67
SWKH	Mawkyrwat	0.85	0.66	1.04	0.52	0.64	1.70	0.88	0.59	1.43	0.89	0.78	2.28
	Ranikor	1.62	0.89	1.21	0.83	0.88	2.27	1.49	0.96	1.95	1.28	1.17	3.22
Ri Bhoi	Jirang	1.24	0.85	1.14	0.72	0.76	0.70	0.61	1.00	1.70	1.09	0.75	1.68
	Umsning	0.84	0.72	0.90	0.45	0.61	1.25	1.06	0.69	1.52	0.96	0.75	1.66
	Umling	1.03	0.81	1.04	0.63	0.61	1.25	1.14	0.90	1.70	1.07	0.75	1.66
EKH	Shella Bholaganj	1.48	0.81	1.28	0.75	0.65	1.33	1.27	0.90	1.78	1.28	0.77	2.27
	Pynursla	1.28	0.75	1.02	0.69	0.56	1.22	1.26	0.75	1.37	1.24	0.75	2.08
	Mawsynram	1.70	0.82	1.20	0.69	0.76	1.33	1.24	0.82	1.84	1.13	0.77	2.27
	Mawkynrew	0.83	0.66	0.94	0.53	0.32	0.80	1.22	0.57	1.01	0.99	0.45	1.59
	Mawphlang	1.02	0.79	1.09	0.58	0.61	1.33	1.24	0.70	1.56	1.05	0.75	2.27
	Mylliem	0.92	0.70	1.02	0.56	0.41	1.07	1.01	0.63	1.08	1.01	0.66	1.69
	Mawryngkneg	0.71	0.68	0.96	0.52	0.36	0.74	1.01	0.59	1.03	0.94	0.48	1.41
	Laitkroh	1.13	0.71	1.02	0.63	0.46	1.12	1.24	0.65	1.19	1.10	0.73	1.84
WJH	Thadlaskein	0.60	0.60	0.88	0.44	0.29	0.95	1.00	0.49	0.93	0.93	0.47	1.82
	Amlarem	1.24	0.72	0.91	0.58	0.44	1.00	1.06	0.63	1.08	0.99	0.54	1.84
	Laskein	0.97	0.70	1.09	0.60	0.46	1.22	1.18	0.65	1.30	1.00	0.70	2.17
EJH	Saipung	1.22	0.96	1.65	0.73	1.10	2.26	1.50	0.96	2.18	1.30	1.96	3.57
	Khliehriat	1.75	1.08	1.37	1.06	0.91	2.07	1.97	0.90	1.96	1.64	1.88	3.40

Section summary

- Different projected scenarios of near and mid-term projections indicate concentrated increment in precipitation intensity in the central part as compared to rest of the State.
- Extreme precipitation frequency may rise in RCP 4.5, 6.0 and 8.5 scenarios in mid and long terms, and this change is prominent mostly in the southern and north-eastern regions of the State.

4.2.2 Extreme Precipitation events: Wet Periods

Changes in the number of wet monsoon season were estimated for the projected future climate for the RCP 2.6, 4.5, 6.0 and 8.5 (Figure 35 & Figure 36). To understand changes in extreme wet periods during the monsoon season under the projected future climate SPI and SPEI were used.

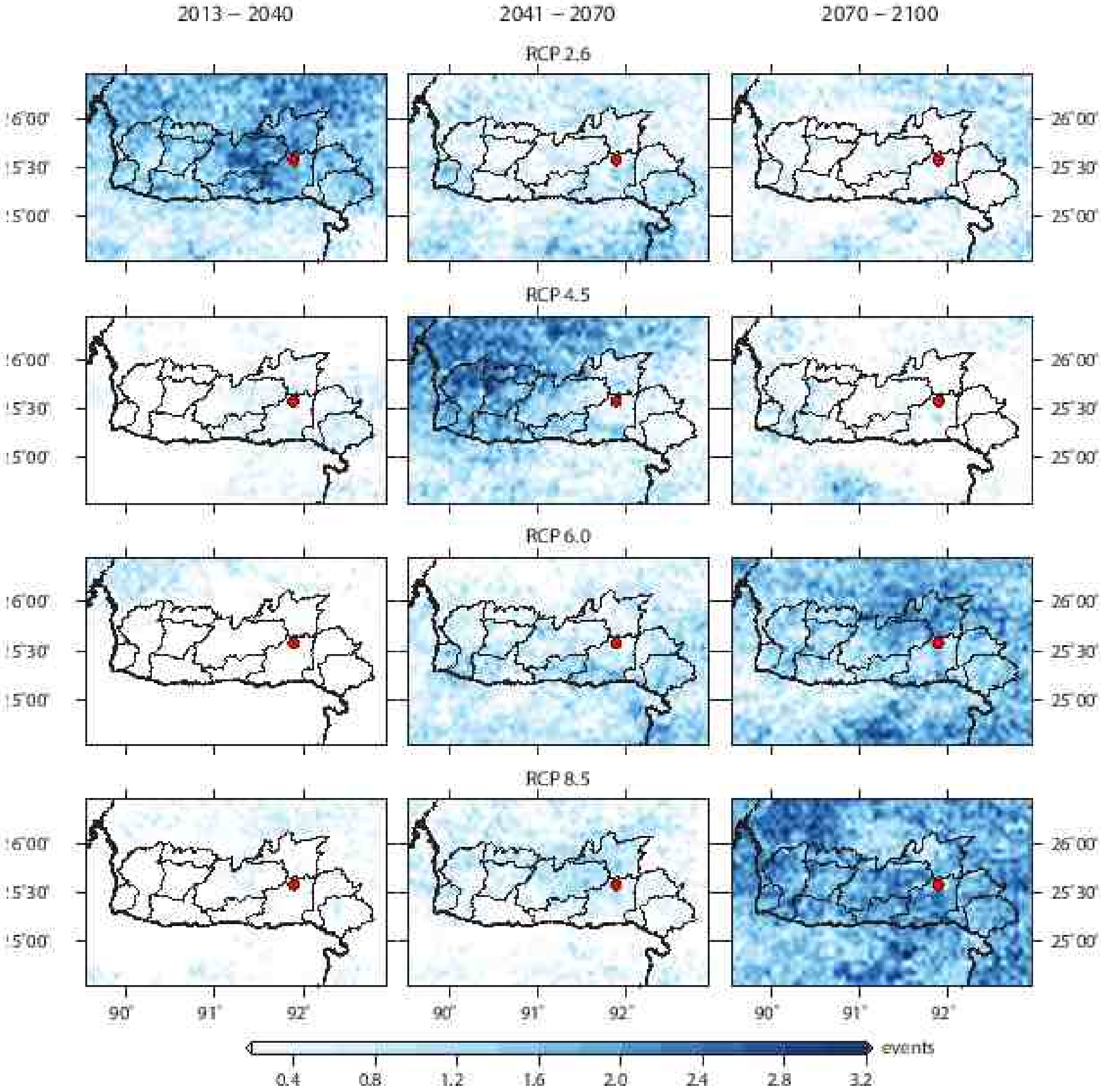

Figure 35. Multimodel ensemble mean projected change in number of severe exceptional wet monsoon season years (estimated based on Standardized Precipitation Index > 1.3).

Table 5. Multimodel ensemble mean projected change in number of severe exceptional wet monsoon season years (estimated based on Standardized Precipitation Index > 1.3). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 35.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	1.40	0.60	0.20	-0.40	1.40	0.20	-0.60	0.80	1.20	-0.40	0.60	1.80
	Betasing	1.60	0.60	0.20	-0.20	1.40	0.40	-0.60	0.80	1.20	-0.20	0.60	1.80
WGH	Dalu	1.60	0.60	0.20	-0.20	1.40	0.20	-0.60	0.80	1.20	-0.20	0.40	2.00
	Gambegre	1.60	0.60	0.20	-0.20	1.40	0.20	-0.60	0.80	1.20	-0.20	0.40	2.00
	Rongram	1.20	0.40	0.00	-0.40	1.40	0.20	-0.60	0.80	1.20	-0.40	0.40	1.80
	Dadengre	1.40	0.60	0.20	-0.20	1.40	0.20	-0.40	0.80	1.20	-0.20	0.60	2.00
	Selsella	1.60	0.60	0.20	-0.20	1.40	0.20	-0.40	0.80	1.20	-0.40	0.60	2.00
	Tikrikilla	1.60	0.60	0.20	-0.20	1.40	0.20	-0.40	0.80	1.20	-0.40	0.60	1.80
NGH	Kharkutta	1.60	0.40	0.20	0.00	1.20	0.20	-0.40	0.80	1.20	-0.20	0.60	1.80
	Resubelpara	1.60	0.40	0.00	-0.40	1.40	0.00	-0.60	0.60	1.20	-0.40	0.60	1.80
EGH	Samanda	1.40	0.40	0.00	-0.40	1.40	0.20	-0.60	0.80	1.20	-0.40	0.60	1.80
	Rongjeng	1.60	0.40	0.00	-0.40	1.40	0.20	-0.60	0.80	1.20	-0.40	0.60	1.80
	Songsak	1.60	0.40	0.20	-0.40	1.40	0.40	-0.60	0.80	1.20	-0.40	0.60	1.80
SGH	Gasuapara	1.40	0.40	0.20	-0.40	1.20	0.20	-0.60	0.80	1.00	-0.40	0.60	1.80
	Baghmara	1.40	0.40	0.00	-0.20	1.40	0.20	-0.60	0.80	1.20	-0.40	0.40	1.80
	Chokpot	1.60	0.40	0.20	-0.20	1.40	0.40	-0.60	0.80	1.20	-0.20	0.40	2.00
	Rongra	1.60	0.40	0.00	-0.20	1.40	0.20	-0.80	0.80	1.00	-0.40	0.20	1.80
WKH	Mairang	2.00	0.40	0.40	0.80	0.60	0.00	-0.20	0.80	1.40	-0.20	1.00	1.40
	Mawnshynrut	1.60	0.40	0.20	0.00	1.40	0.20	-0.40	0.80	1.20	-0.20	0.80	1.80
	Mawthadraishan	1.80	0.60	0.20	0.00	1.20	0.20	-0.40	0.80	1.20	0.00	0.80	2.00
	Nongstoin	1.80	0.40	0.20	0.20	1.20	0.00	-0.40	0.80	1.40	-0.20	0.80	2.00
SWKH	Mawkyrwat	1.80	0.40	0.40	0.80	0.80	0.20	-0.40	1.20	1.00	-0.20	0.60	1.60
	Ranikor	1.60	0.40	0.20	0.80	0.60	0.00	-0.40	1.20	1.00	-0.20	0.40	1.60
Ri Bhoi	Jirang	1.90	0.00	0.40	1.00	0.60	0.00	-0.20	1.00	0.60	-0.40	0.80	1.20
	Umsning	1.80	0.40	0.40	0.80	0.80	0.00	-0.20	0.80	1.40	-0.40	0.80	1.40
	Umling	1.80	0.20	0.20	0.80	0.60	-0.20	-0.20	1.00	1.60	-0.20	0.80	1.20
EKH	Shella Bholaganj	1.60	0.60	0.40	0.80	0.60	0.00	-0.40	1.20	1.00	-0.20	0.40	1.60
	Pynursla	1.40	0.40	0.40	0.80	0.60	0.00	-0.40	1.20	1.20	-0.40	0.40	1.60
	Mawsynram	1.60	0.80	0.40	0.80	0.60	0.00	-0.40	1.20	1.20	-0.20	0.40	1.60
	Mawkynrew	1.40	0.80	0.40	0.80	0.40	0.00	-0.40	1.20	1.00	-0.20	0.60	1.60
	Mawphlang	1.60	0.40	0.40	0.80	0.60	0.20	-0.40	1.00	1.00	-0.20	0.60	1.60
	Mylliem	1.60	0.40	0.40	0.80	0.40	0.00	-0.40	1.00	0.80	-0.20	0.60	1.40
	Mawryngkneg	1.40	0.40	0.40	0.60	0.40	0.00	-0.40	1.00	1.00	-0.40	0.40	1.60
	Laitkroh	1.60	0.40	0.40	0.80	0.40	0.00	-0.40	1.00	1.00	-0.20	0.60	1.60
WJH	Thadlaskein	1.40	0.40	0.40	0.80	0.40	0.00	-0.40	1.00	1.20	-0.40	0.40	1.40
	Amlarem	1.20	0.60	0.20	0.80	0.40	0.00	-0.60	1.00	1.00	-0.40	0.40	1.40
	Laskein	1.40	0.20	0.40	0.80	0.40	0.00	-0.60	1.00	1.00	-0.40	0.60	1.60
EJH	Saipung	1.60	1.00	0.40	0.80	0.40	0.00	-0.40	1.20	1.20	-0.20	0.40	1.60
	Khliehriat	1.20	0.80	0.20	1.00	0.40	0.00	-0.40	1.20	1.00	-0.20	0.40	1.40

Multimodel ensemble mean changes in frequency of extreme wet monsoon season were estimated with respect to the historic reference (1981-2012) period for the near, mid and long terms.

Using SPI as indicator for extreme wet monsoon season, RCP 2.6 shows increase in extreme wet monsoon seasons in near (1-2), mid (0-1) and long term (0-1) (Figure 35, RCP 2.6). RCP 4.5 shows changes in the range of 0 - 1 years in near term, 0-2 wet years in mid term and 0 - 1 years in long term (Figure 35, RCP4.5). RCP 6.0 shows similar patterns in terms of intensities in mid and long term while near term changes were higher than the RCP 4.5 near term values (Figure 35, RCP 6.0). RCP 8.5 shows the extreme scenario where the long term increment in frequency is expected to be 1-2 wet years (Figure 35, RCP 8.5).

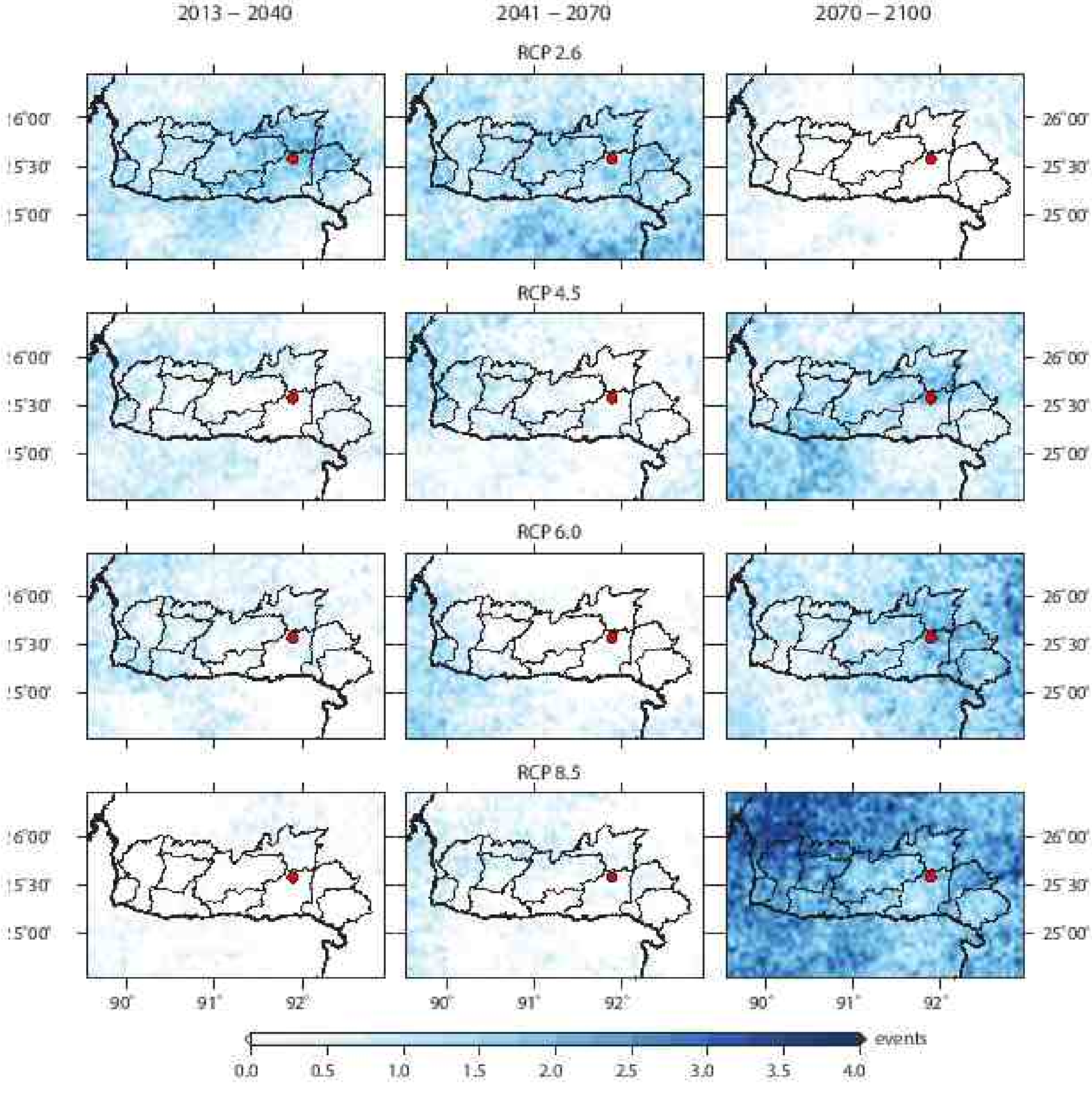

Figure 36. Multimodel ensemble mean projected change in number of severe exceptional wet monsoon season years (estimated based on Standardised Precipitation and Evapotranspiration Index > 1.3).

Table 6. Multimodel ensemble mean projected change in number of severe exceptional wet monsoon season years (estimated based on Standardised Precipitation and Evapotranspiration Index > 1.3). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 36.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	**Block**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**
SWGH	Zikzak	1.20	1.40	-0.40	0.20	0.60	1.20	0.40	-0.20	0.60	-0.40	0.00	2.20
	Betasing	1.20	1.40	-0.40	0.20	0.60	1.20	0.40	-0.20	0.80	-0.40	0.00	2.20
WGH	Dalu	1.20	1.20	-0.40	0.40	0.40	1.40	0.40	0.20	0.80	-0.20	0.00	2.00
	Gambegre	1.20	1.20	-0.40	0.40	0.60	1.40	0.40	0.20	0.60	-0.20	0.00	2.20
	Rongram	1.20	1.20	-0.40	0.40	0.60	1.20	0.40	0.20	1.00	-0.40	0.00	2.20
	Dadengre	1.20	1.20	-0.40	0.40	0.60	1.00	0.20	0.00	0.80	-0.40	0.00	2.20
	Selsella	1.20	1.20	-0.40	0.40	0.60	1.00	0.40	0.20	0.80	-0.60	0.00	2.20
	Tikrikilla	1.00	1.20	-0.40	0.40	0.60	1.00	0.40	0.00	0.80	-0.40	0.00	2.20
NGH	Kharkutta	1.20	1.40	-0.40	0.20	0.40	1.20	0.20	-0.20	0.80	-0.20	0.00	2.20
	Resubelpara	1.20	1.20	-0.40	0.40	0.60	1.20	0.40	-0.20	0.80	-0.40	0.00	2.40
EGH	Samanda	1.20	1.20	-0.40	0.20	0.60	1.20	0.40	0.00	0.80	-0.40	0.00	2.20
	Rongjeng	1.20	1.20	-0.40	0.20	0.40	1.20	0.40	-0.20	1.00	-0.20	0.00	2.20
	Songsak	1.20	1.20	-0.40	0.20	0.60	1.20	0.20	-0.20	0.80	-0.60	0.00	2.20
SGH	Gasuapara	1.20	1.20	-0.40	0.20	0.40	1.40	0.40	-0.20	0.60	-0.40	0.00	2.20
	Baghmara	1.20	1.20	-0.40	0.20	0.60	1.40	0.40	-0.20	0.80	-0.40	-0.20	2.00
	Chokpot	1.20	1.20	-0.40	0.20	0.60	1.40	0.40	-0.20	0.60	-0.20	-0.20	2.00
	Rongra	1.40	1.20	-0.40	0.20	0.60	1.40	0.20	0.00	0.80	-0.20	-0.20	2.00
WKH	Mairang	1.60	0.80	-0.40	0.60	0.20	0.80	0.20	-0.40	1.40	-0.40	0.00	1.40
	Mawnshynrut	1.20	1.40	-0.40	0.20	0.40	1.20	0.40	0.00	1.00	-0.20	0.20	2.00
	Mawthadraishan	1.20	1.40	-0.60	0.00	0.20	1.20	0.40	-0.20	1.00	-0.20	0.20	2.00
	Nongstoin	1.20	1.40	-0.60	0.00	0.40	1.20	0.20	-0.40	1.00	-0.40	0.00	2.00
SWKH	Mawkyrwat	1.60	0.80	-0.60	0.40	0.40	0.60	0.20	-0.20	1.40	-0.40	-0.20	1.60
	Ranikor	1.40	0.80	-0.40	0.60	0.80	0.40	0.20	0.00	1.40	-0.20	-0.20	1.40
Ri Bhoi	Jirang	1.80	0.20	-0.20	1.00	1.00	-0.20	0.20	0.20	1.40	0.20	0.00	1.40
	Umsning	2.00	1.00	-0.20	0.80	0.40	0.80	0.40	0.00	1.80	0.20	0.00	1.60
	Umling	1.80	0.80	-0.20	1.00	0.40	0.60	0.40	-0.20	1.60	0.20	0.00	1.60
EKH	Shella Bholaganj	1.40	0.80	-0.40	0.60	0.60	0.40	0.00	0.00	1.40	-0.20	0.00	1.40
	Pynursla	1.20	1.00	-0.40	0.60	0.40	0.40	0.00	-0.20	1.60	-0.20	-0.20	1.60
	Mawsynram	1.40	0.60	-0.40	0.60	0.60	0.40	0.00	-0.20	1.40	-0.40	-0.20	1.40
	Mawkynrew	1.40	1.00	-0.40	0.40	0.40	0.40	0.20	0.00	1.60	-0.20	0.00	1.60
	Mawphlang	1.40	0.80	-0.40	0.60	0.60	0.40	0.20	-0.20	1.40	-0.40	0.00	1.40
	Mylliem	1.40	0.80	-0.40	0.40	0.40	0.40	0.20	-0.20	1.60	-0.20	0.00	1.60
	Mawryngkneg	1.60	1.00	-0.40	0.60	0.40	0.40	0.20	-0.20	1.60	-0.20	0.00	1.60
	Laitkroh	1.40	1.00	-0.40	0.40	0.40	0.40	0.20	0.00	1.60	-0.20	0.00	1.40
WJH	Thadlaskein	1.80	1.00	-0.40	0.60	0.40	0.40	0.20	0.00	1.60	-0.20	0.20	1.60
	Amlarem	1.20	1.00	-0.40	0.60	0.60	0.40	0.20	-0.20	1.60	-0.20	0.00	1.60
	Laskein	1.60	1.00	-0.40	0.60	0.40	0.40	0.20	0.00	1.60	-0.20	0.00	1.60
EJH	Saipung	0.60	0.60	-0.40	0.60	0.20	0.20	0.00	-0.20	1.60	-0.60	-0.40	1.40
	Khliehriat	1.00	1.00	-0.40	0.60	0.20	0.20	0.20	-0.20	1.60	-0.40	-0.20	1.40

When considering SPEI as an indicator for exceptional wet monsoon, an increasing number of extreme wet monsoon is expected in the projected future **(Figure 36)**. RCP 2.6 shows an increment of 0-2 wet seasons in near term, 1-2 in mid term and -1 - 0 in long term **(Figure 36**, RCP 2.6**)**. RCP 4.5 projects increments of 0-1 spell in near term, 0-1 spell in mid-term and 0-2 spells in long term **(Figure 36**, RCP 4.5**)**. RCP 6.0 shows 0-1 such spell in near term, -1 - 0 spell in mid term and with a large coverage in long term change of 1-2 spells in the region (**Figure 36**, RCP 6.0). As for the most extreme scenario, the change in near term is expected to be -1 - 0 spell, in mid term -1 - 0 spells and in long term 1-3 spells in the State of Meghalaya (**Figure 36**, RCP 8.5). Changes in drought spells were nearly negligible for the projections, thus were not included in the documentation.

Section summary

- The projections suggest an overall increase in number of extreme wet monsoons.
- Extreme precipitation frequency may rise in all RCPs in mid and long terms, and this change is prominent mostly in the southern and north-eastern regions of the State in long term.
- Changes in frequency of droughts were negligible.

4.2.3 Air Temperature

The Multimodel ensemble mean changes based on the downscaled and bias corrected data from the five best CMIP5 models were estimated for all four RCPs and for the Near (2013-2040), Mid (2041-2070) and Long term (2071-2100).

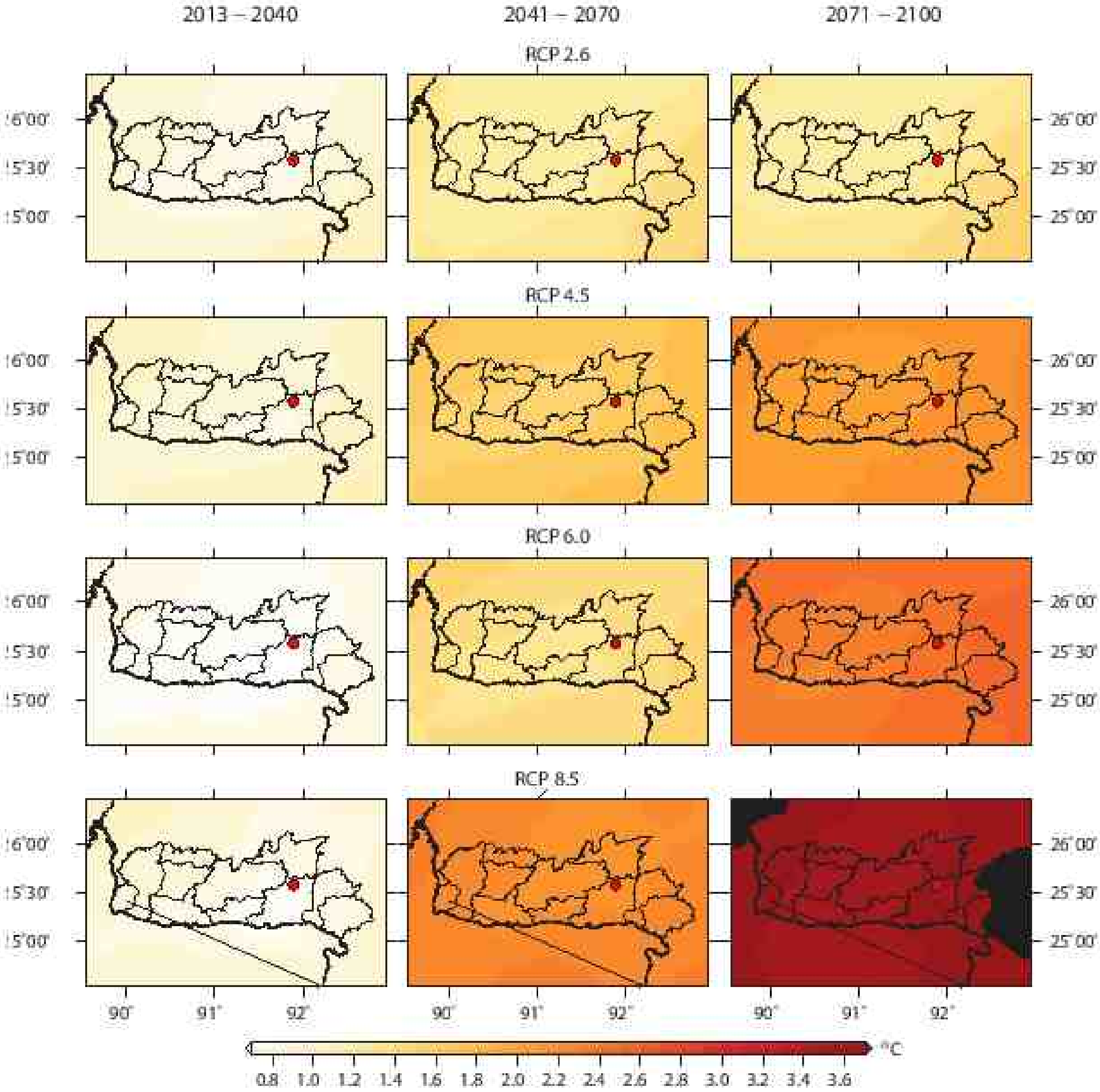

Figure 37. Multimodel ensemble mean projected change in Mean temperature (°C).

Mean annual maximum temperature is projected to rise by 0-1.5 °C in the near, mid, and long terms. The intensity may be the same but spatial extents may be quite different (**Figure 37**, RCP 2.6). RCP 4.5 shows higher increase in temperature with 0.9-1.7 °C in the near and mid term while in the long term it is projected to rise by 1.3-2.2 °C (**Figure 37**, RCP 4.5). RCP 6.0 shows milder increases in air temperature, in near term the increase is projected to be 0.7-0.8 °C, while in the mid and long term the changes are projected be to 1.4-2.5 °C (**Figure 37**, RCP 6.0).

The RCP 8.5 shows even higher rise in temperature: 0.7-0.9 °C in the near term, 1.4-2.2 °C in the mid term and more than 3.5 °C in the long term (**Figure 37**, RCP 8.5). The changes are lower in the central plateau for all the scenarios. These regions may face lower temperature changes as compared to other regions.

Table 7. Multimodel ensemble mean projected change in Mean temperature (°C). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 37.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	**Block**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**
SWGH	Zikzak	0.86	1.24	1.26	0.93	1.58	2.02	0.73	1.37	2.33	0.86	2.19	3.54
	Betasing	0.86	1.24	1.26	0.93	1.58	2.02	0.73	1.37	2.33	0.86	2.19	3.54
WGH	Dalu	0.86	1.24	1.26	0.93	1.57	2.02	0.72	1.37	2.31	0.85	2.19	3.54
	Gambegre	0.86	1.24	1.26	0.93	1.58	2.02	0.72	1.37	2.32	0.85	2.19	3.54
	Rongram	0.86	1.24	1.26	0.93	1.59	2.03	0.73	1.37	2.33	0.86	2.19	3.55
	Dadengre	0.86	1.24	1.27	0.93	1.59	2.03	0.73	1.37	2.33	0.86	2.19	3.55
	Selsella	0.86	1.24	1.27	0.93	1.59	2.03	0.73	1.37	2.33	0.86	2.19	3.55
	Tikrikilla	0.86	1.24	1.27	0.93	1.59	2.03	0.73	1.37	2.33	0.86	2.19	3.55
NGH	Kharkutta	0.86	1.24	1.25	0.93	1.58	2.02	0.72	1.37	2.33	0.85	2.19	3.54
	Resubelpara	0.86	1.24	1.26	0.93	1.58	2.03	0.73	1.37	2.33	0.86	2.19	3.54
EGH	Samanda	0.86	1.24	1.26	0.93	1.58	2.02	0.73	1.37	2.32	0.86	2.19	3.54
	Rongjeng	0.86	1.24	1.25	0.93	1.58	2.02	0.73	1.37	2.33	0.86	2.19	3.54
	Songsak	0.86	1.24	1.26	0.93	1.58	2.02	0.73	1.37	2.33	0.86	2.19	3.54
SGH	Gasuapara	0.86	1.24	1.26	0.93	1.58	2.02	0.73	1.37	2.32	0.86	2.19	3.54
	Baghmara	0.86	1.24	1.25	0.93	1.57	2.01	0.73	1.36	2.32	0.86	2.19	3.54
	Chokpot	0.86	1.24	1.26	0.93	1.57	2.01	0.73	1.37	2.31	0.86	2.19	3.54
	Rongra	0.86	1.24	1.26	0.92	1.57	2.01	0.72	1.36	2.31	0.84	2.19	3.54
WKH	Mairang	0.85	1.26	1.30	0.91	1.59	2.06	0.73	1.40	2.39	0.79	2.17	3.58
	Mawnshynrut	0.86	1.24	1.25	0.94	1.58	2.01	0.74	1.37	2.32	0.87	2.18	3.54
	Mawthadraishan	0.86	1.24	1.25	0.94	1.58	2.01	0.73	1.37	2.32	0.86	2.18	3.54
	Nongstoin	0.85	1.24	1.25	0.93	1.58	2.02	0.72	1.37	2.33	0.84	2.18	3.54
SWKH	Mawkyrwat	0.84	1.24	1.47	0.88	1.59	2.04	0.82	1.49	2.34	0.76	2.19	3.55
	Ranikor	0.85	1.24	1.47	0.89	1.59	2.03	0.82	1.49	2.33	0.77	2.20	3.54
Ri Bhoi	Jirang	0.85	0.86	2.18	0.86	1.24	1.27	0.91	1.56	2.03	0.73	1.37	2.33
	Umsning	0.88	1.29	1.33	0.93	1.61	2.10	0.76	1.45	2.42	0.80	2.18	3.61
	Umling	0.87	1.24	1.33	0.94	1.61	2.09	0.76	1.44	2.42	0.80	2.17	3.58
EKH	Shella Bholaganj	0.94	1.30	1.47	0.89	1.61	2.12	0.83	1.50	2.45	0.74	2.20	3.64
	Pynursia	0.94	1.33	1.47	0.93	1.63	2.12	0.83	1.50	2.46	0.77	2.20	3.66
	Mawsynram	0.93	1.28	1.47	0.88	1.61	2.09	0.82	1.49	2.41	0.74	2.20	3.60
	Mawkynrew	0.93	1.33	1.47	0.93	1.63	2.12	0.82	1.49	2.46	0.78	2.19	3.67
	Mawphlang	0.93	1.29	1.47	0.89	1.60	2.09	0.82	1.49	2.42	0.74	2.19	3.62
	Mylliem	0.93	1.30	1.47	0.91	1.61	2.10	0.82	1.49	2.43	0.77	2.19	3.63
	Mawryngkneg	0.93	1.33	1.47	0.94	1.63	2.12	0.82	1.49	2.46	0.79	2.19	3.66

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
	Laitkroh	0.93	1.31	1.47	0.89	1.61	2.11	0.82	1.49	2.45	0.74	2.19	3.65
WJH	Thadlaskein	0.93	1.36	1.47	0.97	1.67	2.14	0.82	1.49	2.49	0.82	2.19	3.68
	Amlarem	0.94	1.36	1.47	0.98	1.67	2.12	0.82	1.49	2.47	0.83	2.20	3.68
	Laskein	0.96	1.37	1.47	1.00	1.68	2.14	0.83	1.50	2.50	0.85	2.20	3.69
EJH	Saipung	1.00	1.43	1.50	1.05	1.71	2.16	0.84	1.52	2.52	0.89	2.23	3.70
	Khliehriat	0.98	1.39	1.47	1.03	1.69	2.14	0.82	1.49	2.49	0.87	2.22	3.69

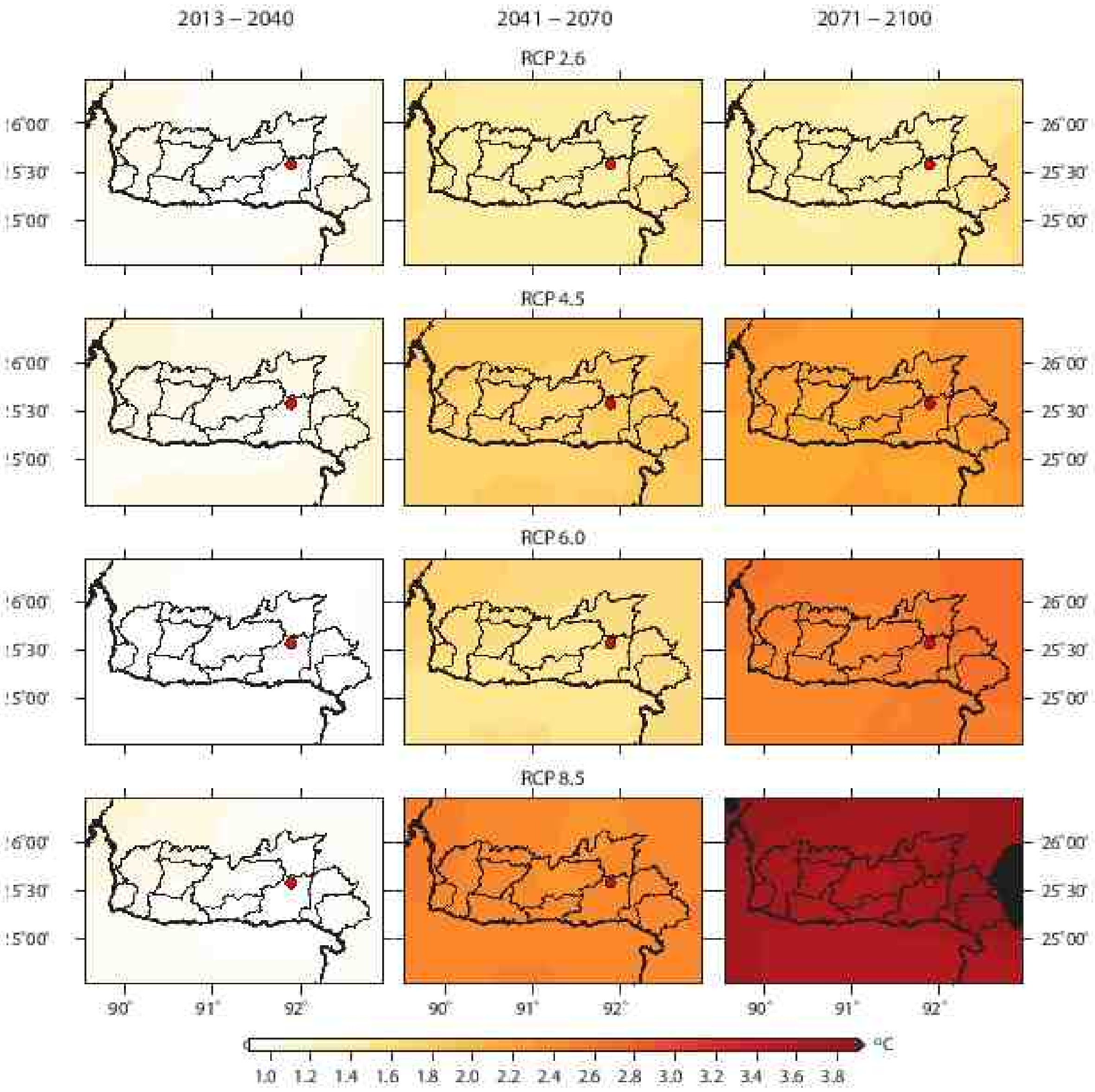

Figure 38. Multimodel ensemble mean projected change in Maximum temperature (°C).

Figure 38 shows changes in Maximum temperature for all the RCPs. RCP 2.6 suggests an increase of 0.8-1.6 °C in near, mid and long term with different spatial coverage (Figure 38, RCP 2.6). RCP 4.5 shows increase of 1-2.3 °C change in the near, mid, and long terms (Figure 38, RCP 4.5). RCP 6.0 shows milder changes in the range 0.8-2.6 °C which may be expected in the projected future (Figure 38, RCP 6.0). RCP 8.5 shows severe cases, with changes of 0.8-2.5 °C in the near and mid terms, and 3.7-3.8 °C in the long term (Figure 38, RCP 8.5).

Table 6. Multimodel ensemble mean projected change in Maximum temperature (°C). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 36.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	**Block**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**	**NT**	**MT**	**LT**
SWGH	Zikzak	0.93	1.44	1.42	1.00	1.75	2.20	0.79	1.57	2.47	0.92	2.41	3.67
	Betasing	0.93	1.44	1.42	1.00	1.75	2.20	0.79	1.57	2.47	0.92	2.41	3.67
WGH	Dalu	0.92	1.44	1.41	0.99	1.75	2.19	0.78	1.56	2.45	0.91	2.41	3.66
	Gambegre	0.92	1.44	1.41	0.99	1.75	2.19	0.78	1.56	2.45	0.91	2.41	3.66
	Rongram	0.93	1.44	1.42	1.00	1.76	2.20	0.80	1.57	2.47	0.92	2.41	3.67
	Dadengre	0.93	1.44	1.42	1.00	1.76	2.20	0.80	1.57	2.47	0.92	2.41	3.67
	Selsella	0.93	1.44	1.42	1.00	1.76	2.20	0.80	1.57	2.47	0.92	2.41	3.67
	Tikrikilla	0.93	1.44	1.42	1.00	1.76	2.20	0.80	1.57	2.47	0.92	2.41	3.67
NGH	Kharkutta	0.92	1.44	1.41	0.99	1.76	2.20	0.79	1.57	2.46	0.91	2.40	3.67
	Resubelpara	0.93	1.44	1.41	1.00	1.76	2.21	0.79	1.57	2.47	0.92	2.41	3.67
EGH	Samanda	0.93	1.44	1.42	1.00	1.75	2.19	0.79	1.57	2.46	0.92	2.41	3.67
	Rongjeng	0.93	1.44	1.41	1.00	1.75	2.19	0.79	1.57	2.46	0.92	2.41	3.67
	Songsak	0.93	1.44	1.42	1.00	1.76	2.20	0.79	1.57	2.47	0.92	2.41	3.67
SGH	Gasuapara	0.93	1.44	1.41	1.00	1.75	2.19	0.79	1.56	2.45	0.92	2.41	3.67
	Baghmara	0.92	1.44	1.41	0.99	1.75	2.18	0.79	1.56	2.44	0.91	2.41	3.66
	Chokpot	0.93	1.44	1.41	1.00	1.75	2.19	0.79	1.56	2.45	0.92	2.41	3.67
	Rongra	0.92	1.44	1.41	0.98	1.75	2.18	0.78	1.56	2.44	0.90	2.41	3.66
WKH	Mairang	0.91	1.43	1.47	0.98	1.79	2.26	0.80	1.60	2.54	0.85	2.40	3.73
	Mawnshynrut	0.93	1.44	1.41	1.02	1.76	2.20	0.81	1.58	2.45	0.94	2.40	3.66
	Mawthadraishan	0.93	1.44	1.42	1.01	1.76	2.20	0.80	1.57	2.45	0.93	2.40	3.66
	Nongstoin	0.92	1.43	1.41	0.99	1.76	2.20	0.79	1.57	2.46	0.91	2.40	3.67
SWKH	Mawkyrwat	0.89	1.42	1.59	0.93	1.76	2.21	0.85	1.62	2.48	0.81	2.41	3.67
	Ranikor	0.90	1.43	1.59	0.94	1.76	2.19	0.85	1.62	2.46	0.81	2.42	3.67
Ri Bhoi	Jirang	0.92	0.93	2.40	0.93	1.45	1.42	0.96	1.74	2.21	0.80	1.57	2.47
	Umsning	0.94	1.44	1.51	1.00	1.81	2.29	0.83	1.63	2.58	0.86	2.41	3.78
	Umling	0.93	1.42	1.51	1.01	1.81	2.29	0.83	1.62	2.58	0.86	2.39	3.76
EKH	Shella Bholaganj	1.00	1.45	1.63	0.93	1.80	2.26	0.88	1.66	2.55	0.80	2.41	3.76
	Pynursla	0.99	1.47	1.63	0.95	1.82	2.26	0.88	1.65	2.56	0.81	2.41	3.78
	Mawsynram	0.97	1.43	1.61	0.93	1.78	2.24	0.86	1.64	2.53	0.79	2.41	3.71
	Mawkynrew	0.97	1.48	1.61	0.97	1.84	2.28	0.86	1.64	2.57	0.82	2.42	3.79
	Mawphlang	0.97	1.43	1.61	0.94	1.80	2.26	0.86	1.64	2.56	0.80	2.41	3.74
	Mylliem	0.97	1.44	1.61	0.96	1.81	2.27	0.86	1.64	2.56	0.82	2.42	3.76
	Mawryngkneg	0.97	1.48	1.61	0.99	1.84	2.28	0.86	1.64	2.59	0.85	2.43	3.80
	Laitkroh	0.97	1.45	1.61	0.93	1.82	2.27	0.86	1.64	2.56	0.80	2.41	3.77
WJH	Thadlaskein	0.99	1.51	1.59	1.03	1.87	2.30	0.86	1.65	2.62	0.88	2.44	3.82
	Amlarem	0.98	1.51	1.59	1.03	1.85	2.27	0.85	1.63	2.58	0.88	2.43	3.80
	Laskein	1.02	1.53	1.63	1.05	1.88	2.30	0.88	1.66	2.62	0.90	2.44	3.82
EJH	Saipung	1.05	1.58	1.67	1.10	1.93	2.34	0.90	1.68	2.64	0.93	2.45	3.85
	Khliehriat	1.02	1.54	1.60	1.07	1.88	2.29	0.86	1.64	2.60	0.90	2.43	3.81

Changes in minimum temperature show mild changes in RCP 2.6 with 0.8-1.4 °C in near, mid and long terms (**Figure 39**, RCP 2.6). RCP 4.5 suggests an increase in the range of 0.8-1 °C in the near term, 1-2 °C in mid and long terms (**Figure 39**, RCP 4.5). RCP 6.0 shows an expected rise in minimum temperature in the range of 0.7-0.8 °C in near term, a similar rise in the range of 1.1-2.4 °C in the mid and long terms (**Figure 39**, RPC 6.0). RCP 8.5 shows 0.7-0.8 °C in near term, 1.2-2 °C in mid term and 2.2-3.5 °C in the long term.

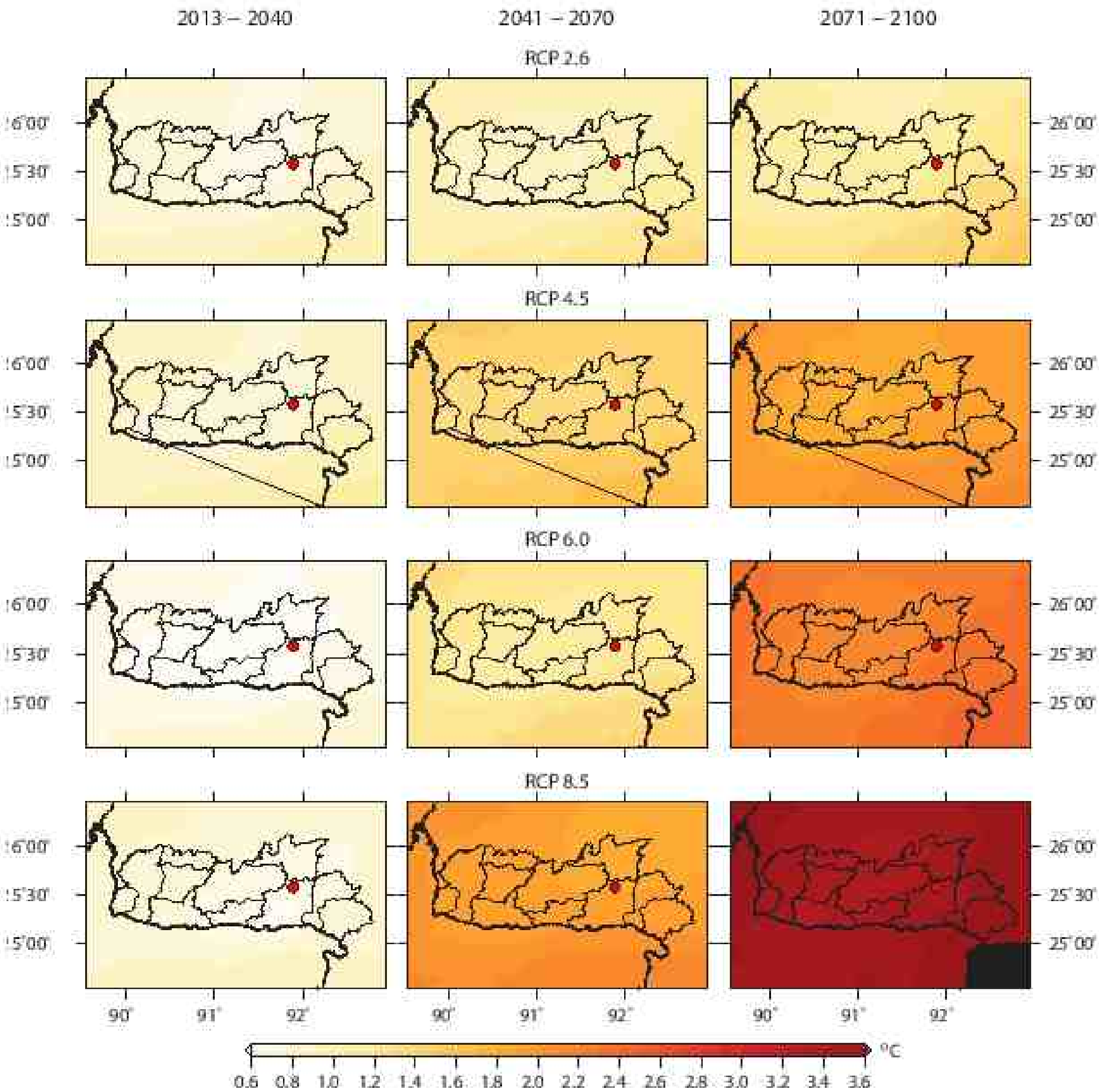

Figure 39. Multimodel ensemble mean projected change in Minimum temperature (°C).

The peaks and plateau of Meghalaya State tends to be less sensitive towards temperature changes due to the topography of the region. Major changes in temperature were observed in South-West Khasi Hills, West Garo Hills, East Khasi Hills and East Jaintia Hills.

Table 9. Multimodel ensemble mean projected change in Minimum temperature (°C). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 39.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.38
	Betasing	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.38
WGH	Dalu	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.38
	Gambegre	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.38
	Rongram	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.14	0.79	1.93	3.38
	Dadengre	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.14	0.79	1.93	3.38
	Selsella	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.14	0.79	1.93	3.38
	Tikrikilla	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.14	0.79	1.93	3.38
NGH	Kharkutta	0.79	0.97	1.11	0.86	1.39	1.81	0.66	1.15	2.13	0.78	1.93	3.36
	Resubelpara	0.79	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.37
EGH	Samanda	0.79	0.97	1.11	0.87	1.38	1.82	0.66	1.15	2.13	0.79	1.93	3.37
	Rongjeng	0.79	0.97	1.11	0.87	1.39	1.81	0.66	1.15	2.13	0.79	1.93	3.36
	Songsak	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.38
SGH	Gasuapara	0.80	0.97	1.12	0.87	1.39	1.82	0.66	1.15	2.13	0.79	1.93	3.38
	Baghmara	0.80	0.96	1.12	0.87	1.38	1.81	0.66	1.15	2.13	0.79	1.93	3.36
	Chokpot	0.80	0.97	1.11	0.87	1.38	1.82	0.66	1.15	2.13	0.79	1.93	3.37
	Rongra	0.80	0.97	1.12	0.87	1.38	1.82	0.66	1.15	2.13	0.79	1.93	3.37
WKH	Mairang	0.78	1.00	1.16	0.85	1.37	1.84	0.66	1.18	2.17	0.73	1.87	3.38
	Mawnshynrut	0.79	0.96	1.11	0.87	1.38	1.80	0.67	1.15	2.12	0.80	1.93	3.35
	Mawthadraishan	0.79	0.97	1.11	0.87	1.38	1.80	0.67	1.15	2.13	0.79	1.93	3.36
	Nongstoin	0.79	0.97	1.12	0.86	1.38	1.81	0.66	1.14	2.13	0.78	1.92	3.36
SWKH	Mawkyrwat	0.79	0.97	1.38	0.84	1.41	1.85	0.80	1.32	2.15	0.71	1.93	3.40
	Ranikor	0.81	0.98	1.38	0.85	1.41	1.84	0.80	1.32	2.14	0.72	1.95	3.40
Ri Bhoi	Jirang	0.78	0.79	1.92	0.80	0.97	1.13	0.85	1.37	1.83	0.67	1.15	2.14
	Umsning	0.81	1.03	1.20	0.87	1.39	1.87	0.68	1.24	2.22	0.74	1.85	3.41
	Umling	0.80	1.02	1.20	0.87	1.39	1.87	0.69	1.23	2.20	0.74	1.84	3.41
EKH	Shella Bholaganj	0.89	1.06	1.38	0.87	1.45	1.95	0.80	1.32	2.31	0.71	1.91	3.49
	Pynursla	0.89	1.08	1.38	0.91	1.45	1.95	0.80	1.32	2.32	0.75	1.91	3.50
	Mawsynram	0.88	1.03	1.38	0.85	1.45	1.93	0.80	1.32	2.27	0.71	1.92	3.46
	Mawkynrew	0.88	1.07	1.38	0.89	1.45	1.95	0.80	1.32	2.31	0.74	1.92	3.48
	Mawphlang	0.88	1.04	1.38	0.84	1.43	1.90	0.80	1.32	2.25	0.70	1.91	3.44
	Mylliem	0.88	1.04	1.38	0.86	1.41	1.89	0.80	1.32	2.26	0.72	1.89	3.44
	Mawryngkneg	0.88	1.06	1.38	0.88	1.43	1.92	0.80	1.32	2.29	0.73	1.90	3.47
	Laitkroh	0.88	1.06	1.38	0.86	1.45	1.95	0.80	1.32	2.30	0.70	1.92	3.48
WJH	Thadlaskein	0.86	1.07	1.38	0.91	1.44	1.94	0.80	1.32	2.32	0.76	1.89	3.49
	Amlarem	0.90	1.09	1.38	0.94	1.45	1.95	0.80	1.32	2.33	0.79	1.92	3.49
	Laskein	0.90	1.09	1.38	0.95	1.45	1.95	0.80	1.32	2.33	0.79	1.91	3.50
EJH	Saipung	0.95	1.15	1.38	1.01	1.47	1.97	0.79	1.31	2.37	0.84	1.94	3.52
	Khliehriat	0.94	1.13	1.38	0.99	1.47	1.97	0.80	1.32	2.35	0.83	1.93	3.51

Section summary

- Maximum temperature has increasing tendency, with central plateau facing the lower amount of change. The extreme scenario (RCP 8.5) shows increase up to 3.8 °C while in mild scenario (RCP 4.5), the increment is limited to 2.65 °C in the long term.
- Mean temperature shows similar spatial variation as in maximum temperature. The increments in the extreme and mild scenario are limited to 3.7 and 2.2 °C respectively.
- Minimum temperature is also expected to rise and is limited to 3.5 and 2 °C in the extreme and mild scenarios for the long term.

4.2.4 Extreme temperature events Hot/Cold days/nights & Heatwaves

In the projected future climate, the summers are projected to be hotter which leads to higher number of hot days and nights. These effects are not only detrimental to the human lives, but may also adversely affect the maturity period of crops, as the growing degree days may change.

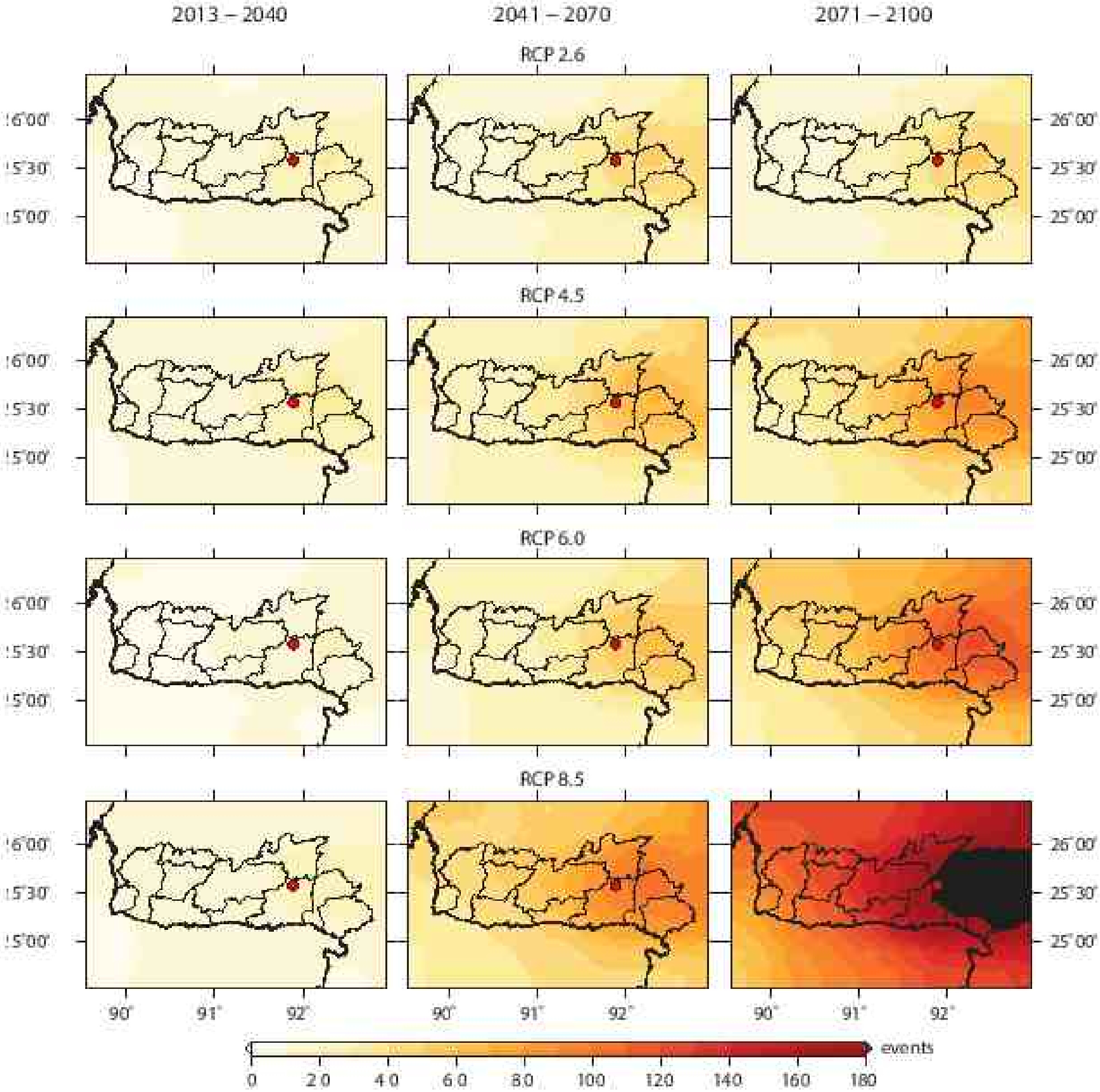

Figure 40. Multimodel ensemble projected change in number of extreme hot days. A day may be considered as extremely hot day if the maximum temperature is above 95th percentile threshold temperature of the historic period (1981-2012).

Table 10. Multimodel ensemble projected change in number of extreme hot days. A day may be considered as extremely hot day if the maximum temperature is above 95th percentile threshold temperature of the historic period (1981-2012). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 40.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	12.30	20.75	19.95	14.46	27.59	38.78	9.09	26.07	55.89	13.13	50.77	125.45
	Betasing	12.30	20.75	19.95	14.46	27.59	38.78	9.09	26.07	55.89	13.13	50.77	125.45
WGH	Dalu	12.30	20.75	20.08	14.45	27.52	38.52	9.14	25.45	55.38	12.55	49.87	125.44
	Gambegre	12.30	20.75	20.08	14.45	27.52	38.52	9.14	25.45	55.38	12.55	49.87	125.44
	Rongram	12.26	20.63	19.88	14.39	27.46	38.44	8.91	25.41	55.21	12.99	49.81	125.25
	Dadengre	12.26	20.63	19.88	14.39	27.46	38.44	8.91	25.41	55.21	13.07	49.81	125.25
	Selsella	12.26	20.63	19.88	14.39	27.46	38.44	8.91	25.41	55.21	12.91	49.81	125.25
	Tikrikilla	12.26	20.63	19.88	14.39	27.46	38.44	8.93	25.41	55.38	13.27	49.81	125.25
NGH	Kharkutta	13.36	22.29	22.02	15.65	30.42	44.72	9.71	28.12	63.34	14.02	55.87	133.34
	Resubelpara	12.41	20.75	20.08	14.67	28.27	40.63	9.27	26.47	58.41	13.57	52.15	127.52
EGH	Samanda	12.38	20.75	20.08	14.67	28.07	40.27	9.26	26.45	57.76	13.06	51.83	126.53
	Rongjeng	13.08	21.67	21.25	15.30	29.38	42.61	9.45	27.57	60.82	13.73	54.43	131.54
	Songsak	12.30	20.75	19.95	14.46	27.59	39.08	9.26	26.34	56.66	13.44	51.12	125.45
SGH	Gasuapara	12.30	20.75	19.95	14.46	27.59	38.78	9.09	26.07	55.89	13.13	50.77	125.45
	Baghmara	12.31	20.75	19.95	14.67	27.68	39.18	9.18	26.26	56.53	13.07	50.91	125.87
	Chokpot	12.30	20.75	19.95	14.43	27.52	38.52	8.95	25.45	55.38	12.55	49.87	125.44
	Rongra	12.30	20.75	20.08	14.45	27.52	38.52	9.14	25.45	55.38	12.55	49.87	125.44
WKH	Mairang	21.44	33.66	39.68	22.53	47.55	67.95	15.05	43.21	92.29	18.57	79.82	166.14
	Mawnshynrut	13.93	22.84	22.47	16.23	31.66	46.32	9.99	29.06	65.68	14.38	57.60	136.70
	Mawthadraishan	14.20	23.34	23.06	16.58	32.35	46.78	10.22	29.59	66.20	14.54	58.54	138.69
	Nongstoin	15.12	25.18	25.06	17.50	34.72	51.03	10.89	31.42	70.97	15.18	62.87	144.31
SWKH	Mawkyrwat	17.11	25.06	38.74	17.19	33.87	49.31	14.11	32.35	68.94	14.53	61.47	143.76
	Ranikor	15.21	22.35	38.74	15.43	29.42	41.54	14.11	30.08	58.88	13.11	53.18	131.19
Ri Bhoi	Jirang	17.83	15.35	49.23	15.78	26.02	26.20	14.43	33.13	52.30	11.12	32.33	72.63
	Umsning	26.33	37.59	47.51	24.85	53.72	76.25	16.87	49.01	100.57	21.00	86.99	172.82
	Umling	21.61	27.74	47.51	19.12	42.88	63.84	15.69	38.67	86.48	16.48	72.85	157.64
EKH	Shella Bholaganj	23.30	34.52	49.19	22.47	46.21	66.15	15.65	42.12	91.14	17.55	79.02	168.65
	Pynursla	23.77	37.02	49.10	24.10	49.73	69.25	16.23	46.60	96.86	18.09	82.19	173.46
	Mawsynram	20.46	29.45	48.25	19.82	39.10	57.64	14.67	35.46	79.39	15.93	69.30	156.94
	Mawkynrew	25.53	37.40	48.25	24.18	50.18	69.58	16.44	47.41	97.73	17.62	82.67	174.36
	Mawphlang	23.04	35.99	48.25	23.73	48.63	69.07	15.65	44.76	94.96	17.62	81.85	170.70
	Mylliem	24.89	36.64	48.25	24.07	49.69	69.25	16.24	45.92	96.28	17.62	82.17	173.09
	Mawryngkneg	27.30	37.05	49.00	24.13	49.74	69.58	16.33	46.94	97.08	17.62	82.19	173.54
	Laitkroh	23.89	37.00	48.25	23.88	49.74	69.58	16.05	45.57	96.01	17.62	82.19	173.22
WJH	Thadlaskein	29.36	41.31	50.48	26.69	55.15	75.86	16.84	51.91	104.79	19.28	88.84	181.77
	Amlarem	24.29	37.66	49.10	24.85	50.72	70.85	16.23	47.49	97.82	18.66	83.87	174.36
	Laskein	27.81	41.31	49.81	26.69	55.15	75.86	16.84	51.91	104.79	19.28	88.84	181.77
EJH	Saipung	25.67	42.19	48.75	27.20	56.42	77.18	16.84	52.80	106.39	19.71	89.97	182.71
	Khliehriat	23.30	37.05	47.12	24.17	49.74	69.25	15.73	46.98	97.08	17.62	82.19	173.54

Extreme hot days or nights are those days/nights which are rare hottest 5% days or nights, respectively. Similarly, the cold days or nights are the days/nights which are rare coldest 5% days or nights, respectively.

Figure 40 shows the changes in the frequency of hot days under the projected future. The patterns mostly follow the trends of changes in temperatures. RCP 2.6 shows a probable increase in number of hot days in the range of 12-50 days per year for the near, mid, and long terms (Figure 40, RCP 2.6). For RCP 4.5 the projected changes may be in the range of 14-57 days per year in the near and mid terms, while in long terms the change may rise to 38-60 days per year (Figure 40, RCP 4.5). RCP 6.0 suggests increments in the range of 9-100 days per year in near, mid and long terms (Figure 40, RCP 6.0). RCP 8.5 Shows the extreme changes of 13-182 days in near, mid and long term, where in latter periods, the regional extent of higher number of hot days may be larger.

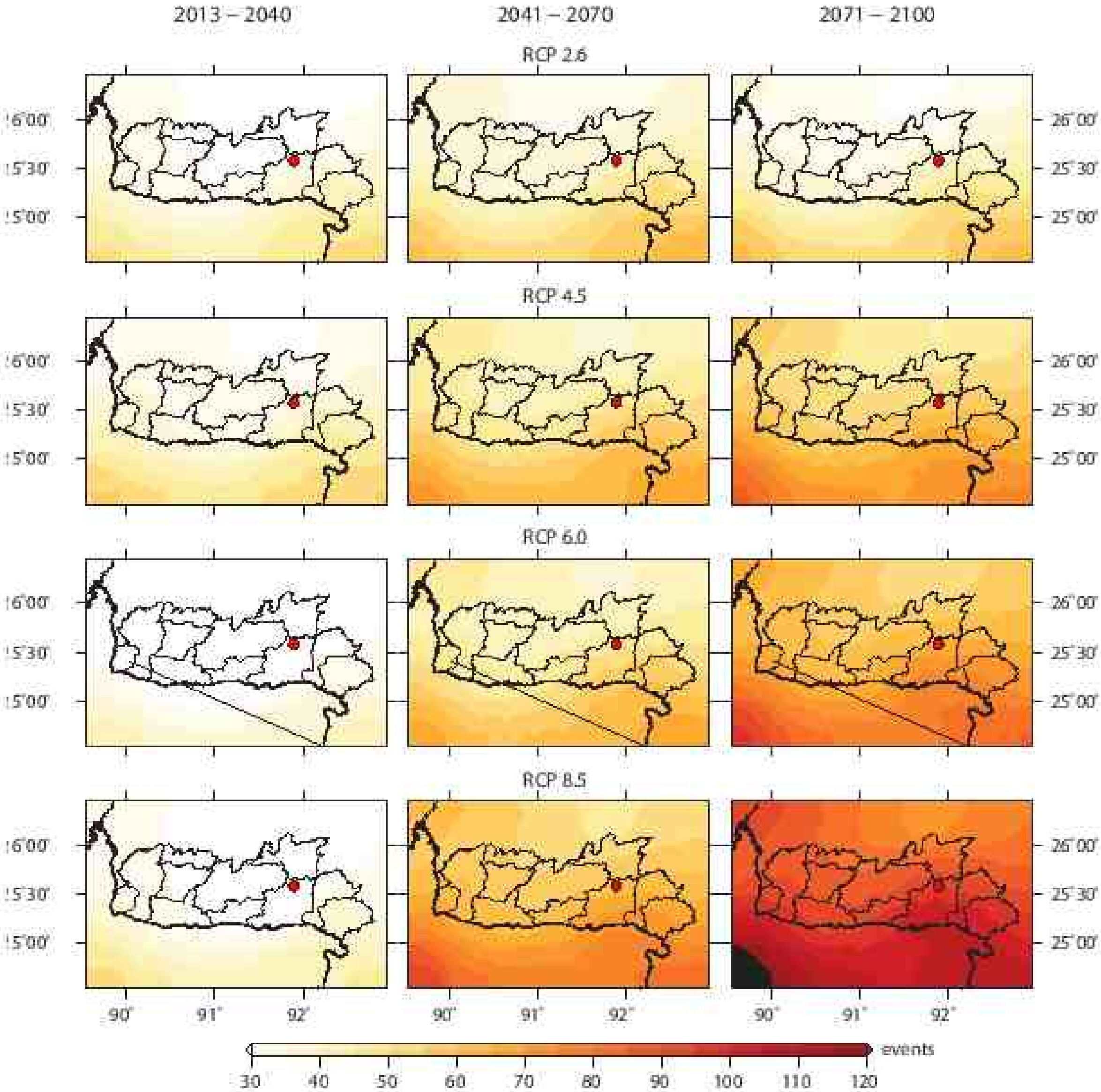

Figure 41. Multimodel ensemble projected change in number of extreme hot nights. A night may be considered as extremely hot, if the minimum temperature is above 95th percentile threshold temperature of the historic period (1981-2012).

Table 11. Multimodel ensemble projected change in number of extreme hot nights. A night may be considered as extremely hot, if the minimum temperature is above 95th percentile threshold temperature of the historic period (1981-2012). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 41.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	30.36	37.31	35.44	33.11	45.41	53.78	23.40	45.10	62.53	28.10	59.12	90.43
	Betasing	30.36	37.31	35.44	33.11	45.41	53.78	23.40	45.10	62.53	28.10	59.12	90.43
WGH	Dalu	30.50	37.52	35.76	33.11	45.65	54.25	23.40	45.78	63.10	28.10	59.55	91.15
	Gambegre	30.50	37.51	35.72	33.11	45.61	54.25	23.40	45.54	62.97	28.10	59.55	91.15
	Rongram	30.52	37.17	35.27	33.20	45.28	53.73	23.40	44.83	62.34	28.21	59.05	90.40
	Dadengre	30.52	36.86	34.90	33.20	45.08	53.67	23.40	44.81	61.89	28.21	58.86	89.57
	Selsella	30.52	37.21	35.28	33.20	45.52	54.07	23.40	44.95	62.57	28.21	59.36	90.02
	Tikrikilla	30.52	37.12	35.16	33.20	45.32	53.70	23.40	44.83	62.47	28.21	58.95	89.94
NGH	Kharkutta	29.69	36.68	34.72	32.17	44.58	52.56	23.20	44.55	61.31	27.80	57.87	89.14
	Resubelpara	29.95	36.66	34.65	32.87	44.51	52.56	23.36	44.50	61.18	28.06	57.87	89.14
EGH	Samanda	30.33	36.94	34.93	33.00	44.93	53.37	23.36	44.63	61.72	28.06	58.77	89.75
	Rongjeng	29.85	36.68	34.73	32.78	44.58	52.62	23.36	44.55	61.31	28.06	57.95	89.20
	Songsak	30.26	36.65	34.59	33.11	44.51	52.58	23.40	44.42	61.10	28.10	57.90	88.92
SGH	Gasuapara	30.36	37.31	35.44	33.11	45.41	53.78	23.40	45.10	62.53	28.10	59.12	90.43
	Baghmara	30.36	37.17	35.34	33.11	45.32	53.70	23.40	44.92	62.42	28.10	58.95	90.40
	Chokpot	30.50	37.40	35.55	33.11	45.51	54.07	23.40	45.12	62.60	28.10	59.49	90.67
	Rongra	30.50	37.52	35.76	33.11	45.65	54.25	23.40	45.50	63.00	28.10	59.55	90.95
WKH	Mairang	29.55	36.48	37.67	31.74	43.83	51.29	23.67	45.29	60.73	26.13	56.54	87.24
	Mawnshynrut	29.62	35.97	33.88	32.24	43.91	51.03	23.39	43.78	59.87	27.93	56.37	87.24
	Mawthadraishan	29.91	36.34	34.37	32.31	44.30	51.82	23.30	44.23	60.69	27.87	57.14	88.41
	Nongstoin	29.69	36.68	34.72	32.12	44.58	52.56	23.05	44.55	61.31	27.39	57.87	89.14
SWKH	Mawkyrwat	30.91	38.34	50.57	31.82	47.01	56.05	32.08	46.86	64.67	25.37	61.07	92.90
	Ranikor	31.93	39.10	50.57	32.74	47.81	56.73	32.08	46.94	65.05	26.08	62.09	92.95
Ri Bhoi	Jirang	27.86	28.53	57.48	30.11	37.68	36.15	32.08	44.30	54.37	23.54	45.93	63.64
	Umsning	29.45	36.23	37.83	31.56	42.90	50.00	23.90	44.86	58.29	25.87	54.54	82.22
	Umling	28.46	33.44	37.83	30.52	40.01	46.42	23.90	44.30	55.33	25.07	50.77	77.64
EKH	Shella Bholaganj	37.17	45.60	50.57	38.02	53.30	60.59	32.08	53.19	69.22	29.45	65.65	94.75
	Pynursla	38.24	46.42	50.57	39.76	53.46	60.89	32.08	53.26	69.47	31.21	65.98	95.39
	Mawsynram	36.81	43.75	50.57	34.73	52.25	61.32	32.08	52.15	69.73	27.12	66.50	96.64
	Mawkynrew	37.80	45.70	50.57	37.93	53.30	60.89	32.08	53.11	69.54	29.97	65.98	96.64
	Mawphlang	37.07	41.49	50.57	33.38	49.76	58.89	32.08	49.46	68.59	25.97	64.01	95.16
	Mylliem	37.07	41.02	50.57	33.93	48.56	56.68	32.08	48.19	65.92	27.01	61.73	94.06
	Mawryngkneg	37.07	42.39	50.57	35.55	49.64	57.99	32.08	49.43	66.71	28.00	62.43	94.16
	Laitkroh	37.07	44.93	50.57	36.45	52.86	61.08	32.08	52.64	69.57	28.28	66.07	96.17
WJH	Thadlaskein	34.48	42.07	50.57	35.80	48.46	56.25	32.08	48.55	64.38	28.22	60.48	90.01
	Amlarem	40.28	46.35	51.77	40.47	53.37	60.89	32.59	53.23	69.47	32.33	65.98	95.89
	Laskein	37.07	44.55	50.57	38.73	50.42	57.70	32.08	50.46	65.95	31.21	62.52	91.33
EJH	Saipung	40.47	49.04	49.89	43.08	54.96	61.95	32.87	54.44	70.77	34.64	66.87	96.23
	Khliehriat	42.31	50.06	52.79	44.24	56.89	64.07	33.36	56.71	73.11	35.72	69.32	99.71

Similar to the frequency patterns of hot days in the projected future, hot nights also show an overall increase in all the RCPs. With milder changes in RCPs 2.6 and 4.5, the projected range of such changes is 27-64 days per year (Figure 41, RCP 2.6, and RCP 4.5). RCP 6.0 shows changes in the range of 23-56 days per year in the near and mid term. The long term changes are projected in the range of 54-73 days per year (Figure 41, RCP 6.0). RCP 8.5 shows an increase in the number of hot nights in the range of 25-70 for the near and mid terms, while a severe case in the long term projection shows changes in the range of 78-100 days per year (Figure 41, RCP 8.5). The changes in the number of hot and cold days are consistently positive for the regions with higher changes in magnitudes of temperatures.

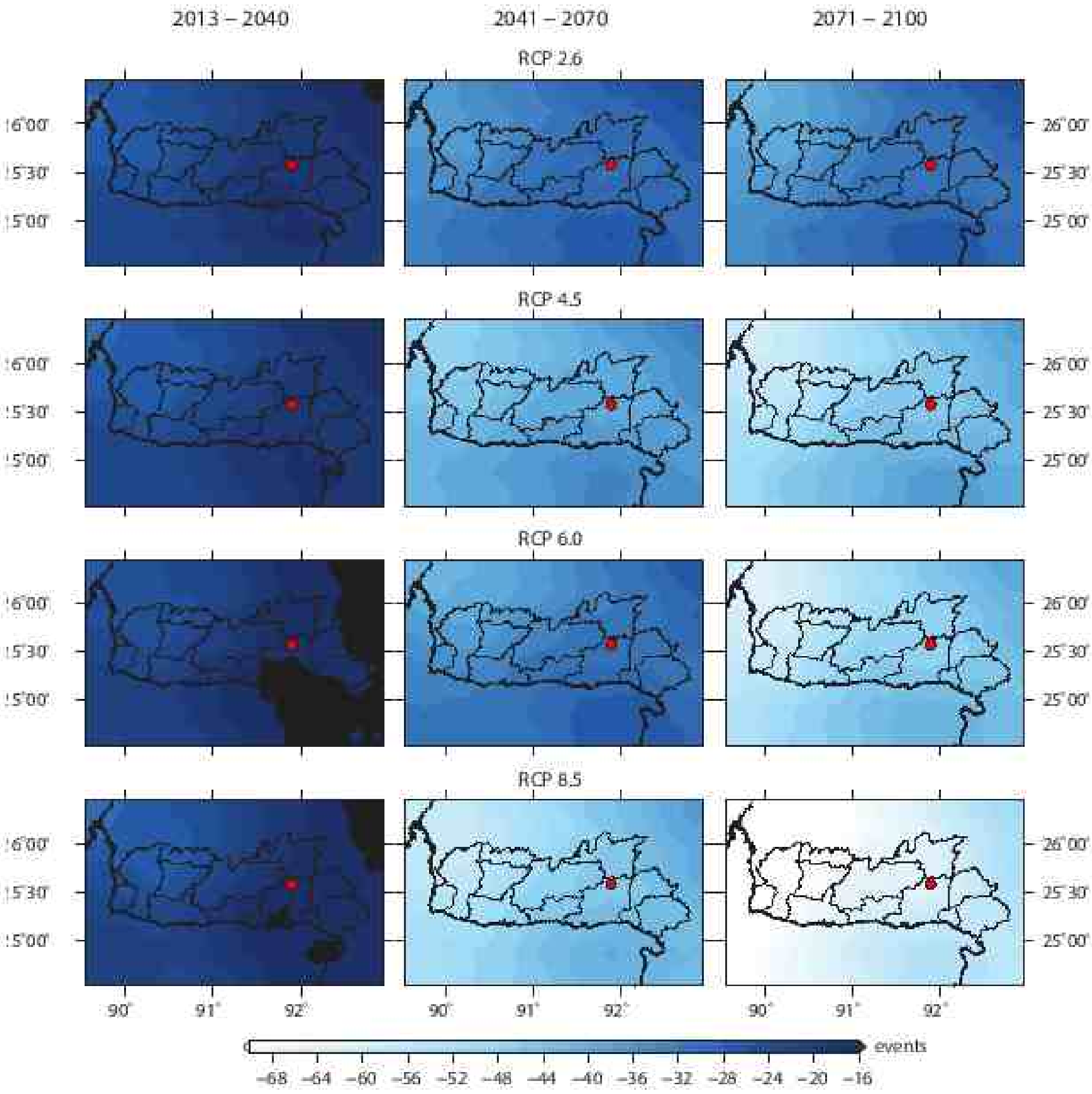

Figure 42. Multimodel ensemble projected change in number of extreme cold days. A day may be considered as cold, if the maximum temperature is below 5th percentile threshold temperature of the historic period (1981-2012).

Table 12. Multimodel ensemble projected change in number of extreme cold days. A day may be considered as cold, if the maximum temperature is below 5th percentile threshold temperature of the historic period (1981-2012). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 42.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	-21.3	-30.5	-32.3	-22.3	-39.3	-45.9	-20.1	-32.2	-47.9	-21.4	-47.8	-63.0
	Betasing	-21.3	-30.5	-32.3	-22.3	-39.3	-45.9	-20.1	-32.2	-47.9	-21.4	-47.8	-63.0
WGH	Dalu	-21.1	-30.2	-32.2	-22.1	-38.9	-45.6	-19.7	-31.7	-47.6	-21.0	-47.3	-62.7
	Gambegre	-21.1	-30.2	-32.2	-22.1	-38.9	-45.6	-19.7	-31.7	-47.6	-21.0	-47.3	-62.7
	Rongram	-21.3	-30.5	-32.4	-22.5	-39.4	-46.0	-20.2	-32.2	-48.0	-21.5	-47.8	-63.3
	Dadengre	-21.3	-30.5	-32.4	-22.5	-39.4	-46.0	-20.2	-32.2	-48.0	-21.5	-47.8	-63.3
	Selsella	-21.3	-30.5	-32.4	-22.5	-39.4	-46.0	-20.2	-32.2	-48.0	-21.5	-47.8	-63.3
	Tikrikilla	-21.3	-30.5	-32.4	-22.5	-39.4	-46.0	-20.2	-32.2	-48.0	-21.5	-47.8	-63.3
NGH	Kharkutta	-21.1	-30.2	-32.1	-22.0	-39.1	-45.6	-19.7	-32.0	-47.6	-21.0	-47.2	-62.5
	Resubelpara	-21.3	-30.3	-32.3	-22.3	-39.2	-45.9	-20.0	-32.1	-47.8	-21.4	-47.5	-63.0
EGH	Samanda	-21.3	-30.3	-32.3	-22.3	-39.2	-45.9	-20.0	-32.1	-47.8	-21.4	-47.5	-63.0
	Rongjeng	-21.3	-30.3	-32.3	-22.3	-39.2	-45.9	-20.0	-32.1	-47.8	-21.4	-47.5	-63.0
	Songsak	-21.3	-30.5	-32.3	-22.3	-39.3	-45.9	-20.1	-32.2	-47.9	-21.4	-47.8	-63.0
SGH	Gasuapara	-21.3	-30.5	-32.3	-22.3	-39.3	-45.9	-20.1	-32.2	-47.9	-21.4	-47.8	-63.0
	Baghmara	-21.3	-30.3	-32.3	-22.3	-39.2	-45.9	-20.1	-31.9	-47.9	-21.4	-47.8	-63.0
	Chokpot	-21.3	-30.5	-32.3	-22.3	-39.3	-45.9	-20.1	-32.2	-47.9	-21.4	-47.8	-63.0
	Rongra	-21.1	-30.1	-32.1	-22.0	-38.7	-45.4	-19.5	-31.6	-47.5	-20.8	-47.2	-62.5
WKH	Mairang	-19.0	-29.6	-31.4	-20.1	-38.5	-44.8	-17.7	-31.7	-46.8	-18.3	-45.0	-60.7
	Mawnshynrut	-21.4	-30.7	-32.5	-22.6	-39.7	-46.4	-20.3	-32.8	-48.3	-21.8	-48.1	-63.5
	Mawthadraishan	-21.1	-30.5	-32.2	-22.4	-39.4	-46.0	-20.1	-32.3	-47.8	-21.4	-47.6	-63.0
	Nongstoin	-20.3	-30.1	-31.6	-21.6	-38.9	-45.4	-19.2	-31.8	-47.3	-20.4	-46.8	-62.2
SWKH	Mawkyrwat	-18.7	-28.8	-31.0	-19.8	-36.7	-41.1	-17.9	-30.6	-45.7	-18.3	-42.4	-54.4
	Ranikor	-18.8	-28.7	-31.1	-20.1	-36.6	-41.1	-18.2	-30.6	-45.4	-18.6	-42.4	-54.4
Ri Bhoi	Jirang	-19.1	-21.8	-45.8	-20.8	-30.5	-32.6	-20.8	-38.1	-46.1	-19.3	-32.3	-48.2
	Umsning	-18.9	-29.4	-31.2	-19.8	-38.4	-44.1	-16.9	-31.6	-46.3	-17.9	-44.0	-58.9
	Umling	-18.9	-29.1	-31.1	-20.1	-38.6	-44.3	-17.6	-32.4	-46.3	-18.3	-44.3	-59.3
EKH	Shella Bholaganj	-19.0	-28.7	-31.4	-19.2	-36.5	-41.1	-16.4	-30.5	-45.3	-17.3	-42.1	-54.4
	Pynursla	-18.8	-28.6	-31.4	-19.2	-36.6	-41.1	-16.4	-30.5	-45.3	-17.3	-42.1	-54.4
	Mawsynram	-18.7	-28.5	-31.3	-19.1	-36.4	-41.1	-16.4	-30.5	-45.3	-17.3	-42.4	-54.4
	Mawkynrew	-18.8	-28.7	-31.4	-19.2	-36.7	-41.1	-16.4	-30.6	-45.8	-17.3	-42.4	-54.4
	Mawphlang	-18.8	-28.7	-31.4	-19.4	-36.7	-41.1	-16.7	-30.9	-45.9	-17.5	-42.4	-54.4
	Mylliem	-19.0	-28.7	-31.4	-19.4	-36.7	-41.1	-16.6	-31.3	-45.9	-17.4	-42.4	-54.4
	Mawryngkneg	-18.8	-28.7	-31.4	-19.3	-36.7	-41.1	-16.4	-30.9	-45.9	-17.3	-42.4	-54.4
	Laitkroh	-18.7	-28.7	-31.4	-19.2	-36.7	-41.1	-16.4	-30.6	-45.5	-17.3	-42.4	-54.4
WJH	Thadlaskein	-19.1	-29.4	-31.5	-19.4	-37.3	-41.1	-16.6	-31.0	-45.9	-17.3	-42.4	-54.4
	Amlarem	-18.9	-28.6	-31.5	-19.4	-36.7	-41.0	-16.5	-30.6	-45.4	-17.3	-42.3	-54.4
	Laskein	-19.1	-29.0	-31.4	-19.4	-37.0	-41.1	-16.6	-30.8	-45.4	-17.4	-42.1	-54.4
EJH	Saipung	-19.4	-29.6	-31.7	-19.1	-37.4	-41.5	-16.3	-30.8	-44.7	-17.5	-42.4	-54.4
	Khliehriat	-18.9	-28.7	-31.0	-19.0	-36.7	-40.7	-16.3	-30.2	-44.9	-17.2	-42.0	-54.4

With projected increase in temperatures, the frequency of cold days is expected to decline in the future. RCP 2.6 shows a decline of 18 to 30 days in the near, mid, and long terms (Figure 42, RCP 2.6). RCP 4.5 shows decline in the range of 16 to 40 days in the near and mid terms, and 40-46 days decline in the long term (Figure 42, RCP 4.5). RCP 6.0 shows a decline in 16-32 days per year in the near and mid terms, and 45-48 days per year decline in the long term (Figure 42, RCP 6.0). RCP 8.5 shows decline of 17-21 days per year in the near term, 32-48 days per year in the mid term and more than 54 days decline in the long term (Figure 42, RCP 8.5).

Cold nights are also projected to decline. RCP 2.6 shows a milder decline in the range of 14-22 days per year in the near, mid, and long terms (Figure 43, RCP 2.6). RCP 4.5 shows a decline in 15-26 days per year in the near, mid, and long terms (Figure 43, RCP 4.5). RCP 6.0 shows 14-40 days per year in the near and mid terms, while a decline of 6-9 days is expected in the long term (Figure 43, RCP 6.0). For the RCP 8.5 a decline of 14-15 days in the near term and 20-61 days decline is projected in the mid and long terms (Figure 43, RCP 8.5).

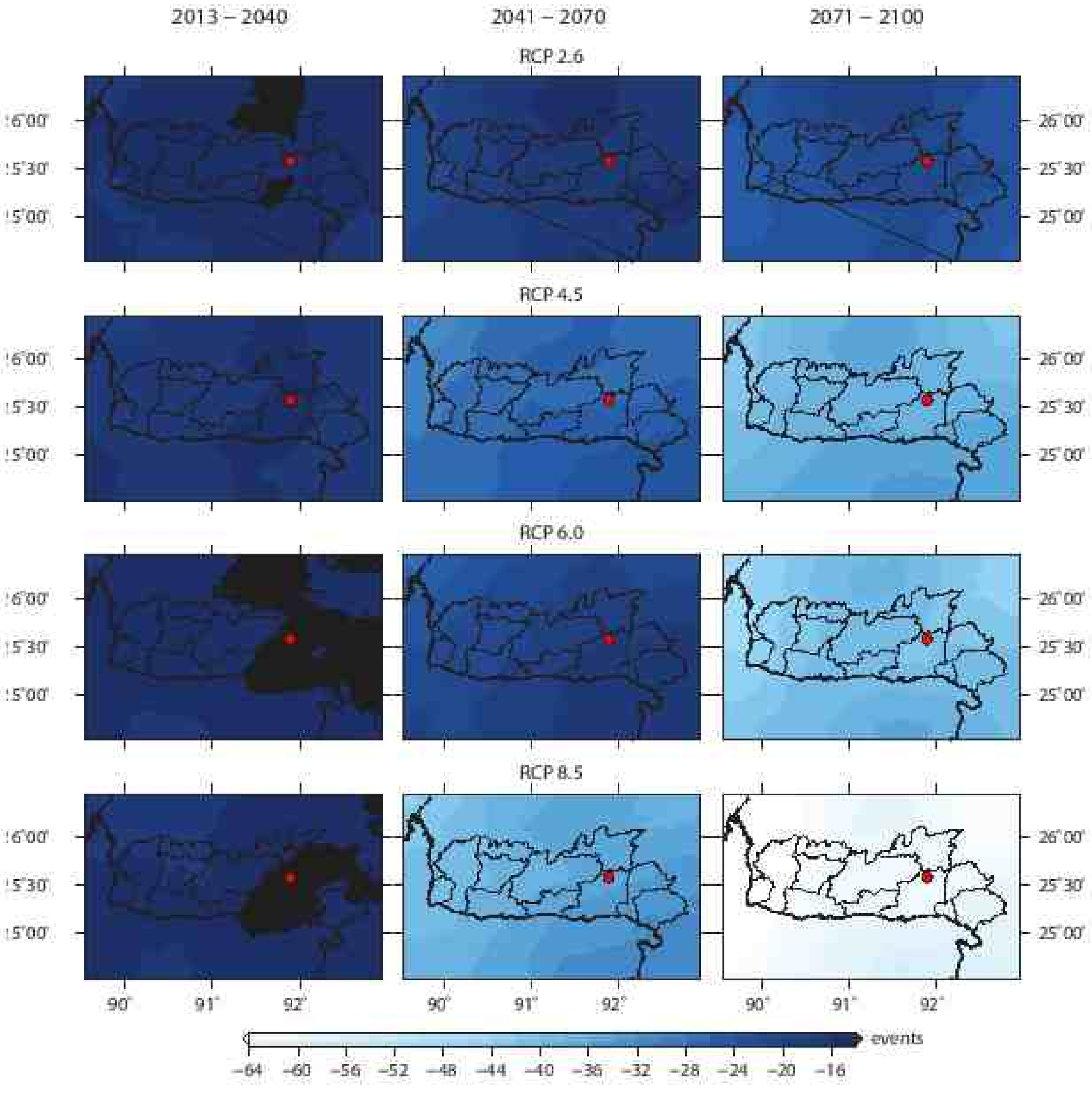

Figure 43. Multimodel ensemble projected change in number of extreme cold nights. A night may be considered as cold, if the minimum temperature is below 5th percentile threshold temperature of the historic period (1981-2012).

A general decline in number of cold days is expected in a warming climate. The declining pattern conforms to that of the changes in temperatures.

Table 13. Multimodel ensemble projected change in number of extreme cold nights. A night may be considered as cold, if the minimum temperature is below 5th percentile threshold temperature of the historic period (1981-2012). NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 43.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	NT	MT	LT
SWGH	Zikzak	-15.2	-17.7	-21.7	-16.6	-26.1	-36.5	-14.8	-19.9	-39.3	-15.5	-36.7	-60.7
	Betasing	-15.2	-17.7	-21.7	-16.6	-26.1	-36.5	-14.8	-19.9	-39.3	-15.6	-36.7	-60.7
WGH	Dalu	-15.1	-17.6	-21.7	-16.6	-26.0	-36.4	-14.9	-19.8	-39.2	-15.4	-36.5	-60.6
	Gambegre	-15.1	-17.6	-21.7	-16.6	-26.0	-36.4	-14.8	-19.8	-39.2	-15.4	-36.5	-60.6
	Rongram	-15.1	-17.7	-21.8	-16.7	-26.1	-36.5	-14.6	-19.9	-39.4	-15.5	-36.7	-60.7
	Dadengre	-15.1	-17.7	-21.8	-16.6	-26.1	-36.5	-14.7	-19.9	-39.4	-15.6	-36.7	-60.7
	Selsella	-15.1	-17.7	-21.8	-16.5	-26.1	-36.5	-14.7	-19.9	-39.4	-15.5	-36.7	-60.7
	Tikrikilla	-15.1	-17.7	-21.8	-16.6	-26.1	-36.5	-14.7	-19.9	-39.4	-15.5	-36.7	-60.7
NGH	Kharkutta	-15.0	-17.1	-21.3	-16.6	-26.0	-36.4	-14.8	-19.9	-39.1	-15.6	-36.5	-60.6
	Resubelpara	-15.1	-17.6	-21.6	-16.7	-26.1	-36.5	-14.7	-19.9	-39.3	-15.7	-36.6	-60.6
EGH	Samanda	-15.2	-17.6	-21.7	-16.7	-26.1	-36.5	-14.8	-19.9	-39.3	-15.7	-36.6	-60.6
	Rongjeng	-15.1	-17.4	-21.5	-16.7	-26.1	-36.4	-14.7	-19.9	-39.2	-15.7	-36.6	-60.6
	Songsak	-15.2	-17.7	-21.7	-16.7	-26.1	-36.5	-14.7	-19.9	-39.3	-15.7	-36.7	-60.7
SGH	Gasuapara	-15.2	-17.7	-21.7	-16.6	-26.1	-36.5	-14.9	-19.9	-39.3	-15.5	-36.7	-60.7
	Baghmara	-15.2	-17.7	-21.7	-16.7	-26.1	-36.4	-14.9	-19.9	-39.3	-15.5	-36.6	-60.7
	Chokpot	-15.2	-17.7	-21.7	-16.7	-26.1	-36.5	-14.8	-19.9	-39.3	-15.5	-36.7	-60.7
	Rongra	-15.1	-17.6	-21.7	-16.6	-25.9	-36.3	-14.9	-19.7	-39.2	-15.5	-36.3	-60.5
WKH	Mairang	-14.4	-16.1	-21.3	-15.8	-26.1	-36.6	-14.3	-19.4	-39.2	-14.5	-34.9	-60.7
	Mawnshynrut	-15.1	-17.1	-21.3	-16.7	-26.1	-36.4	-14.9	-20.0	-39.0	-15.8	-36.6	-60.7
	Mawthadraishan	-15.1	-17.1	-21.5	-16.7	-26.1	-36.4	-14.9	-19.9	-39.3	-15.7	-36.5	-60.7
	Nongstoin	-15.0	-16.9	-21.3	-16.5	-26.1	-36.4	-14.8	-19.7	-39.1	-15.3	-36.2	-60.5
SWKH	Mawkyrwat	-14.8	-15.9	-22.3	-15.5	-23.9	-35.4	-14.4	-18.9	-38.8	-14.4	-32.0	-58.0
	Ranikor	-14.8	-15.9	-22.3	-15.6	-23.9	-35.4	-14.7	-19.1	-38.6	-14.5	-32.0	-58.0
Ri Bhoi	Jirang	-14.0	-15.6	-35.5	-15.3	-17.8	-21.9	-16.2	-25.6	-36.5	-14.7	-20.1	-39.4
	Umsning	-14.2	-16.1	-21.5	-15.6	-26.4	-37.1	-14.1	-19.3	-39.9	-14.3	-34.8	-61.3
	Umling	-14.0	-15.8	-21.4	-15.6	-25.8	-36.6	-14.0	-19.5	-39.2	-14.3	-34.8	-60.5
EKH	Shella Bholaganj	-14.8	-15.9	-22.3	-15.3	-23.9	-35.4	-14.0	-17.6	-39.0	-14.3	-32.0	-58.0
	Pynursla	-14.8	-15.9	-22.3	-15.4	-23.9	-35.4	-14.0	-17.6	-38.9	-14.3	-32.0	-58.0
	Mawsynram	-14.6	-15.9	-22.3	-15.2	-23.9	-35.4	-14.0	-17.8	-38.7	-14.3	-32.0	-58.0
	Mawkynrew	-14.6	-15.9	-22.3	-15.4	-23.9	-35.4	-14.0	-17.6	-39.0	-14.3	-32.0	-58.0
	Mawphlang	-14.6	-15.9	-22.3	-15.3	-23.9	-35.4	-14.0	-17.9	-39.0	-14.3	-32.0	-58.0
	Mylliem	-14.6	-15.9	-22.3	-15.4	-23.9	-35.4	-14.0	-18.0	-39.0	-14.3	-32.0	-58.0
	Mawryngkneg	-14.6	-15.9	-22.3	-15.5	-23.9	-35.4	-14.0	-17.9	-39.0	-14.3	-32.0	-58.0
	Laitkroh	-14.6	-15.9	-22.3	-15.2	-23.9	-35.4	-14.0	-17.6	-39.0	-14.3	-32.0	-58.0
WJH	Thadlaskein	-14.7	-15.9	-22.3	-15.8	-23.9	-35.4	-14.0	-18.1	-39.0	-14.2	-32.0	-58.0
	Amlarem	-14.8	-15.9	-22.3	-15.9	-23.9	-35.3	-14.0	-17.8	-38.7	-14.2	-32.0	-58.0
	Laskein	-14.8	-15.9	-22.3	-16.0	-23.9	-35.4	-14.0	-17.8	-39.0	-14.3	-32.0	-58.0
EJH	Saipung	-15.1	-15.8	-22.2	-16.2	-23.8	-35.4	-13.8	-16.7	-39.0	-14.3	-32.0	-58.3
	Khliehriat	-15.0	-15.9	-22.4	-16.2	-23.9	-35.3	-13.9	-17.1	-38.7	-14.3	-31.9	-58.0

The projected rise in temperature also suggest an increment in continuous exceptional warm days. Heatwaves in such a scenario is expected to rise in future. Figure 44 shows changes in frequency of heatwaves. The change in frequency in RCP 2.6 is expected to be in the range of 3-7 per year in near, mid and long term (Figure 44, RCP 2.6). RCP 4.5 shows changes in heatwaves in the range of 4-7 per year in near term, 4-8 per year in mid term and 4-10 per year in long term (Figure 44, RCP 4.5). RCP 6.0 shows 5-7 per year change in region for near term, 5-8 per year in mid term and 5-13 in long terms (Figure 44, RCP 6.0). RCP 8.5 shows rise in the frequency in the range of 6-9 per year in the near term, 6-13 per year in mid term and 7-20 per year in the long term. The rise in temperature in general and rise in the number of hot days promotes heatwaves.

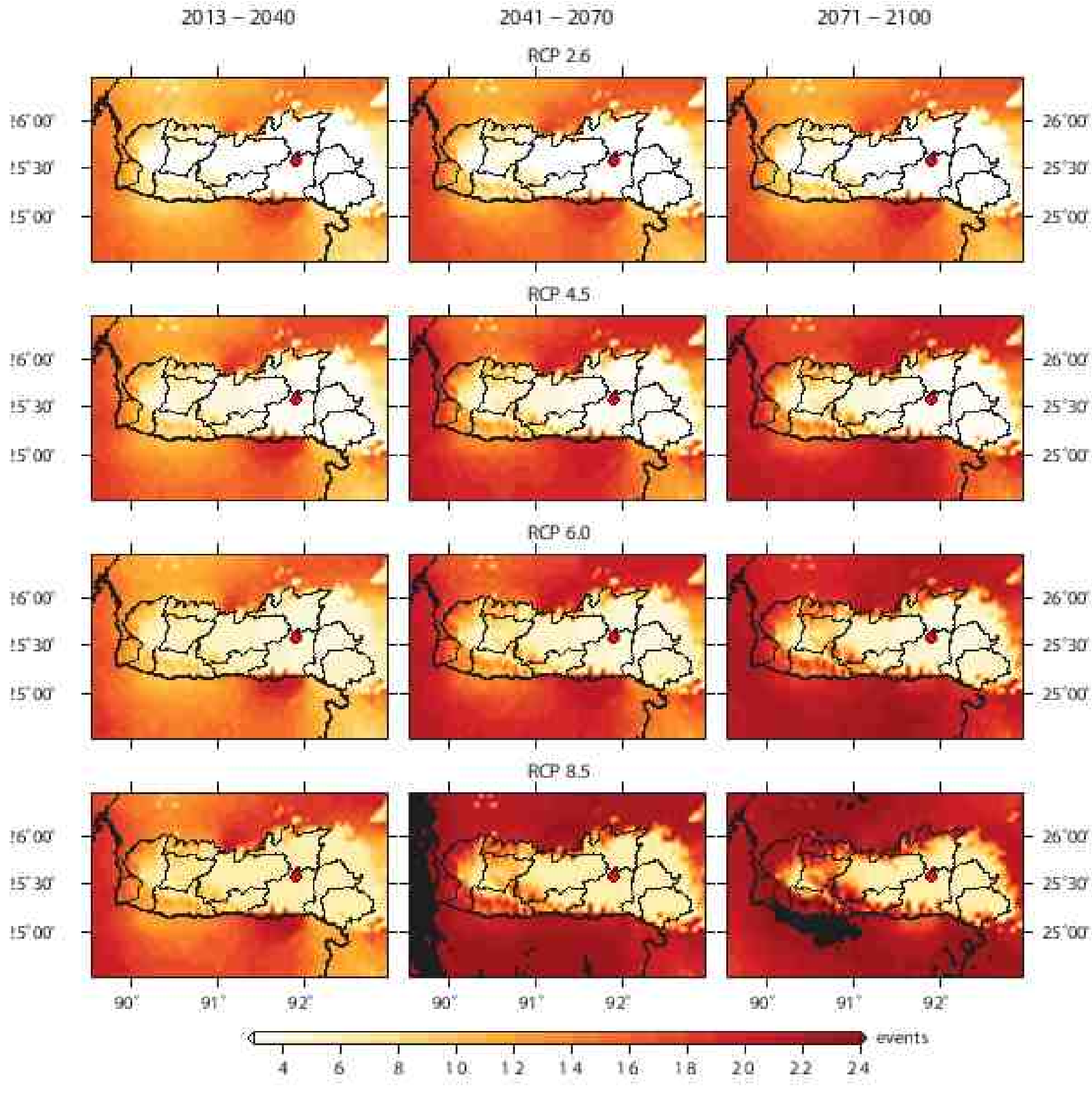

Figure 44. Multimodel ensemble projected change in frequency of heatwaves in the projected future. The base period for change calculation is 1981-2012. A spell of length greater than 6 days with maximum temperature greater than 95th percentile threshold of the observation period (1981-2012) is considered as heatwave spell.

Table 14. Multimodel ensemble projected change in frequency of heatwaves in the projected future. The base period for change calculation is 1981-2012. A spell of length greater than 6 days with maximum temperature greater than 95th percentile threshold of the observation period (1981-2012) is considered as heatwave spell. NT (Near Term 2016-2040); MT (Mid Term 2041-2070); and LT (Long Term 2071-2100). Refer figure 44.

		RCP 2.6			RCP 4.5			RCP 6.0			RCP 8.5		
District	Block	NT	MT	LT	NT	MT	LT	NT	MT	LT	**NT**	**MT**	**LT**
SWGH	Zikzak	4.28	5.00	4.90	5.92	6.90	7.40	6.58	7.90	10.50	8.44	11.70	18.00
	Betasing	4.28	5.00	4.90	5.92	6.90	7.40	6.58	7.90	10.50	8.44	11.70	18.00
WGH	Dalu	4.96	5.90	5.70	6.68	8.10	9.10	7.48	9.10	13.10	8.98	13.20	20.00
	Gambegre	4.88	5.90	5.60	6.58	7.90	8.90	7.18	8.80	12.00	8.68	12.80	19.60
	Rongram	3.48	4.10	3.90	4.98	5.50	5.70	5.90	6.90	8.00	7.46	9.50	13.20
	Dadengre	4.30	5.60	4.90	6.28	7.20	7.70	6.80	8.30	10.50	8.44	11.80	17.80
	Selsella	4.76	5.70	5.40	6.38	7.50	8.60	7.18	8.60	11.50	8.50	12.50	19.10
	Tikrikilla	4.40	5.60	5.10	6.30	7.20	7.70	6.90	8.40	10.60	8.44	11.80	18.10
NGH	Kharkutta	3.80	4.60	4.10	5.10	6.20	6.50	6.20	7.40	9.20	7.50	10.40	16.20
	Resubelpara	4.76	5.90	5.40	6.30	7.50	8.70	7.18	8.70	12.00	8.56	12.50	19.50
EGH	Samanda	3.48	4.10	3.80	4.80	5.30	5.70	5.88	6.90	7.90	7.48	9.40	13.30
	Rongjeng	3.78	4.60	4.00	5.08	6.00	6.30	6.20	7.40	8.60	7.50	10.10	15.00
	Songsak	3.96	4.80	4.30	5.56	6.40	7.00	6.50	7.80	9.40	7.96	10.90	16.30
SGH	Gasuapara	4.28	5.00	4.90	5.92	6.90	7.40	6.58	7.90	10.50	8.44	11.70	18.00
	Baghmara	4.28	5.00	4.80	5.82	6.70	7.30	6.58	7.90	10.40	8.42	11.60	17.80
	Chokpot	4.26	5.00	4.80	5.74	6.60	7.10	6.50	7.90	10.40	8.36	11.40	17.70
	Rongra	4.76	5.70	5.40	6.30	7.50	8.70	7.10	8.60	11.60	8.56	12.50	19.20
WKH	Mairang	2.30	2.50	2.50	3.70	3.70	3.70	5.00	5.00	5.00	6.30	6.40	7.70
	Mawnshynrut	2.90	3.40	3.10	4.28	4.90	4.90	5.50	6.30	7.30	6.90	8.40	12.20
	Mawthadraishan	2.90	2.90	2.90	4.20	4.20	4.20	5.50	5.50	5.70	6.80	7.10	8.30
	Nongstoin	2.90	2.90	2.90	4.20	4.50	4.60	5.50	5.80	6.70	6.80	7.90	11.10
SWKH	Mawkyrwat	2.90	4.00	4.00	4.20	4.60	4.30	5.50	6.10	6.60	6.80	7.60	9.40
	Ranikor	3.58	6.70	7.00	4.80	5.80	5.70	6.28	7.40	8.90	7.28	9.10	14.60
Ri Bhoi	Jirang	3.74	6.80	7.40	4.50	5.20	5.50	5.82	6.90	8.70	7.10	8.80	13.20
	Umsning	2.30	2.90	2.50	3.60	3.60	3.60	4.90	4.90	5.00	6.20	6.40	7.60
	Umling	2.30	6.70	7.30	3.96	4.70	4.70	5.10	6.30	7.10	6.40	7.80	10.60
EKH	Shella Bholaganj	2.60	4.10	4.30	4.00	4.60	4.10	5.30	6.10	6.80	6.50	7.40	9.30
	Pynursla	2.40	4.00	4.00	3.90	4.00	4.00	5.20	5.40	6.20	6.40	7.40	9.80
	Mawsynram	2.70	6.70	6.70	4.28	4.90	5.00	5.40	6.30	7.10	6.60	7.90	10.60
	Mawkynrew	2.30	3.40	3.50	3.80	3.80	3.80	5.10	5.10	5.20	6.38	6.40	7.70
	Mawphlang	2.50	3.40	3.50	3.80	3.80	3.80	5.10	5.10	5.20	6.40	6.40	7.50
	Mylliem	2.40	3.40	3.50	3.80	3.80	3.80	5.10	5.10	5.20	6.40	6.40	7.50
	Mawryngkneg	2.30	3.40	3.50	3.80	3.80	3.80	5.10	5.10	5.10	6.40	6.40	7.50
	Laitkroh	2.50	3.60	3.50	3.80	3.90	3.80	5.10	5.20	5.50	6.40	6.50	8.30
WJH	Thadlaskein	2.30	2.50	2.50	3.60	3.70	3.70	4.90	5.00	5.00	6.20	6.30	6.70
	Amlarem	2.40	3.30	3.20	3.80	3.90	3.80	5.10	5.20	5.50	6.40	6.50	7.70
	Laskein	2.40	2.60	2.60	3.80	3.80	3.80	5.10	5.10	5.10	6.40	6.40	6.90
EJH	Saipung	2.60	2.60	2.60	3.90	3.90	3.90	5.20	5.20	5.20	6.50	6.50	7.00
	Khliehriat	2.50	3.70	3.50	3.80	3.80	3.90	5.10	5.10	5.50	6.40	6.70	9.00

Section summary

- The increase in temperature may also result in the increase in extreme hot days and nights. The hot days in the extreme scenario (RCP 8.5) may rise by more than 100 days per year, while in the mild (RCP 4.5) scenario, the change may be above 50 days per year. Similarly, hot nights frequency is expected to increase by more than 80 days in the extreme scenario (RCP 8.5), while the increments in the mild scenario (RCP 4.5) may be expected to rise by 60 days per year in the long term.
- The increase in temperature may also result in the decrease in extreme cold days and nights. The cold days in the extreme scenario (RCP 8.5) may drop more than 60 days per year while in the mild (RCP 4.5), the change may be above 40 days per year. Similarly, cold nights frequency is expected to drop by more than 60 days in the extreme scenario (RCP 8.5), while the decrease in the mild scenario (RCP 4.5) may be expected to be 30 days per year in the long term.
- Heatwaves frequency is expected to rise by more than 20 spells per year in the extreme (RCP 8.5) scenario and up to 12 events per year in mild (RCP 4.5) scenario in long term.

4.3 Climate Vulnerability Hotspots

Climate vulnerability hostspots are those regions which are more susceptible to changes in climate. These regions can be identified by analyzing the influencing factors individually. Previous sections dealt with the analysis for individual factors. To have a complete understanding of risks, an assessment based on multiple factors is needed, which can help us to identify hotspots and develop adaptation strategies.

We developed the two indices based on air temperature and precipitation to identify the regions that are vulnerable to climate change hazards using the methodology described in Hagenlocher et al. (2014) with some modifications. These indices are Precipitation Based Vulnerability Index (PBVI) and Temperature Based Vulnerability Index (TBVI). For each index, some sub indicators (SI) were used to represent the contribution from each of them. For instance, PBVI has historic median precipitation (1981-2012), changes in projected precipitation (2013-2100), and projected frequency of extreme precipitation events (2013-2100) as sub-indicators. TBVI has historic mean temperature (1981-2012), projected temperature change (2013-2100) and projected frequency of extreme hot and hot nights (2013-2100) as sub indicators.

To capture changes in projections from different RCPs, average values of all RCPs was used for each SI. In terms of vulnerability, all sub-indicators can be considered contributing with equal weightage. All the SIs were then normalised, so that the variables become comparable in magnitude. The normalisation range is also kept same, that is, 0 to 1, since the weightage of all SIs are equal. Normalisation is a process of changing the magnitudes of a datasets to a desired range (here, the range is 0 to 1). Normalisation can be done for variables (Var_{old}) to obtain new values (Var_{new}) in the desired range using following equation:

Combined Vulnerability Index (PBVI and TBVI) was then computed by adding the normalised values (in the range of 0 to 1) of all the SIs considered and finally dividing the sum by the number of SIs used. This procedure gave values in the range of 0 to 1 for of PBVI and TBVI for each grid considered in the study domain. Based on severity of the vulnerability index, the indices (PBVI and TBVI) were categorised as mild (0 to 0.4), high (0.4 to 0.7), and extreme (0.7 to 1) (**Figure 45** and **Figure 46**). So, a higher value represents a region at higher risk in terms of climate change hazards based on precipitation or temperature events and vice versa.

Table 15 shows the median of PBVI and TBVI of all the grids that are falling within the boundary of a block. The values in red show highly vulnerable blocks, blue represent moderate, and black represent less vulnerable block with respect to precipitation and temperature events.

Figure 45 shows the climate vulnerability map of Meghalaya with respect to precipitation based events. South West Khasi Hills, West Khasi Hills, some parts of East Khasi Hills, South West Garo Hills and West Garo Hills are at high risk with respect to precipitation based hazards. East Jaintia Hills, Ri Bhoi and South Garo Hills are at moderate risk while the rest of the State face mild risk.

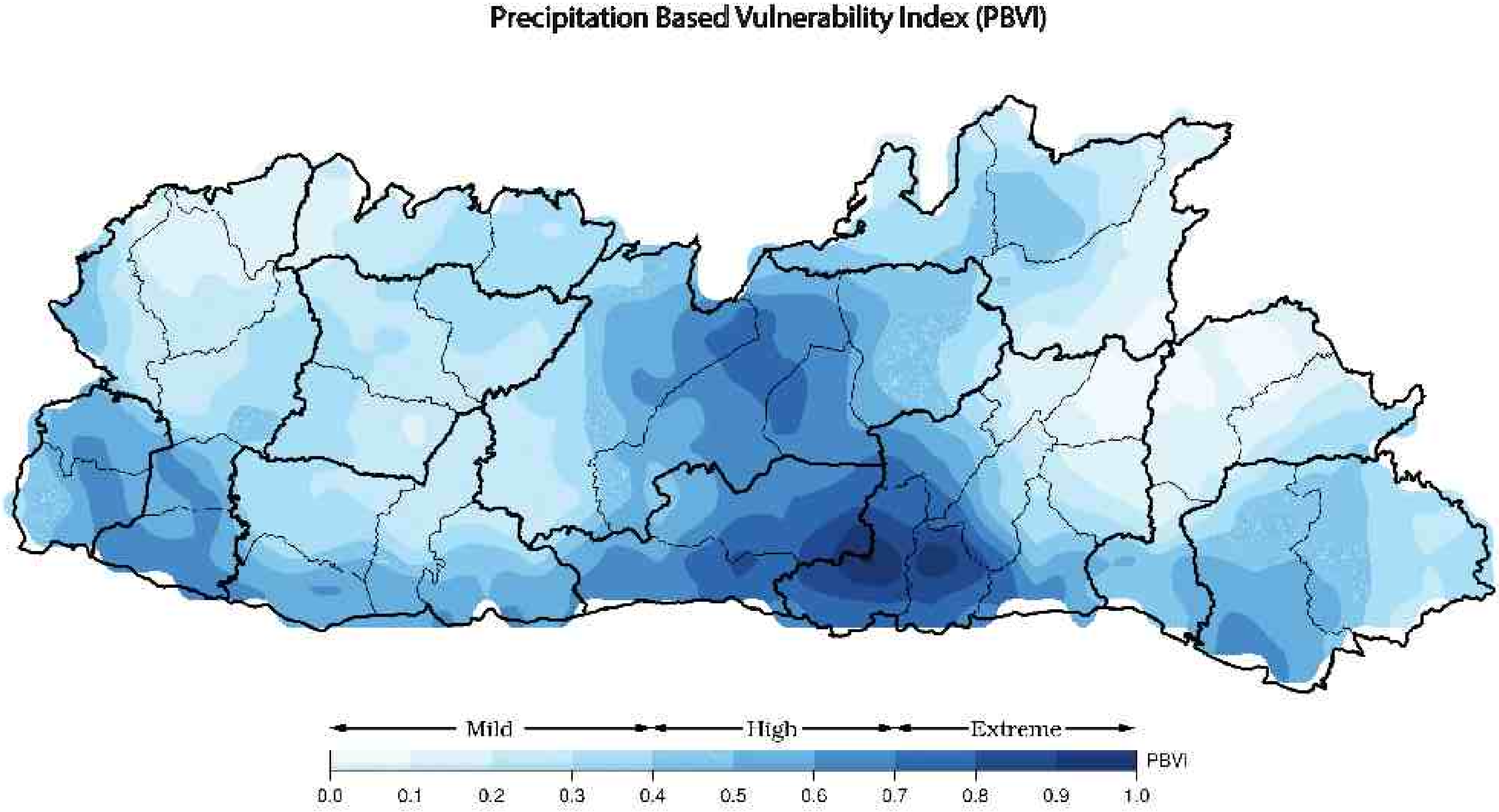

Figure 45. Map showing climate vulnerability hotspots with respect to precipitation events for the State of Meghalaya.

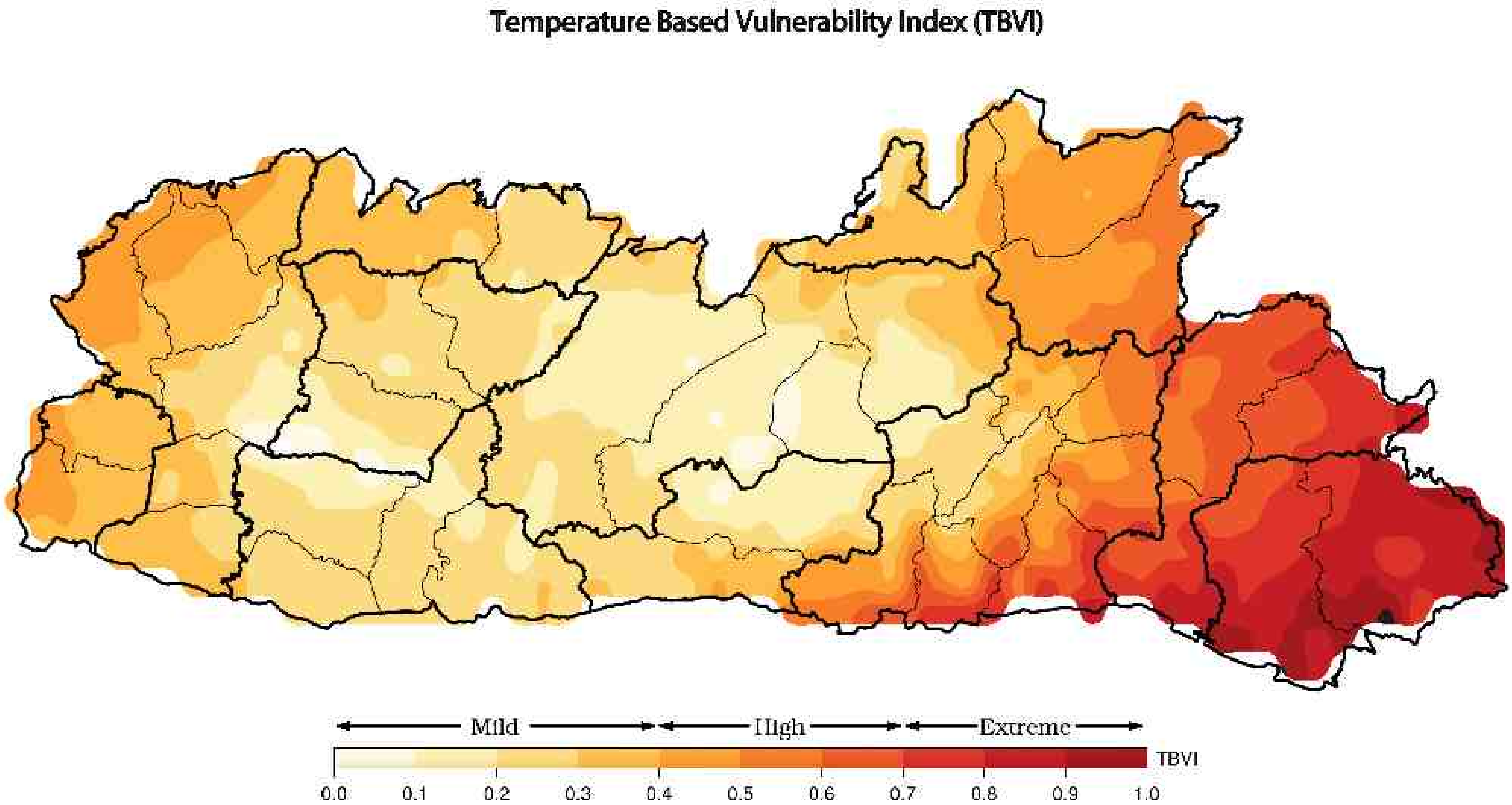

Figure 46. . Map showing climate vulnerability hotspots with respect to temperature events for the State of Meghalaya.

Table 15. The table shows median values of Temperature Based Vulnerability Index (TBVI) and Precipitation Based Vulnerability Index (PBVI) for each block in the State of Meghalaya. The values in red represents high (0.6-1), blue shows moderate (0.3-0.6), and black shows mild (0-0.3) vulnerability of the blocks with respect to temperature or precipitation.

S. No.	District	Block	Median PBVI	Median TBVI
1	SWGH	Zikzak	0.462	0.23
2		Betasing	0.472	0.23
3	WGH	Dalu	0.523	0.24
4		Gambegre	0.507	0.24
5		Rongram	0.347	0.22
6		Dadengre	0.287	0.24
7		Selsella	0.363	0.24
8		Tikrikilla	0.330	0.24
9	NGH	Kharkutta	0.357	0.22
10		Resubelpara	0.312	0.24
11	EGH	Samanda	0.354	0.21
12		Rongjeng	0.327	0.22
13		Songsak	0.323	0.23
14	SGH	Gasuapara	0.472	0.23
15		Baghmara	0.338	0.22
16		Chokpot	0.356	0.21
17		Rongra	0.475	0.23
18	WKH	Mairang	0.436	0.30
19		Mawnshynrut	0.405	0.20
20		Mawthadraishan	0.513	0.17
21		Nongstoin	0.539	0.20
22	SWKH	Mawkyrwat	0.672	0.27
23		Ranikor	0.640	0.31
24	Ri Bhoi	Jirang	0.358	0.37
25		Umsning	0.179	0.48
26		Umling	0.261	0.44
27	EKH	Shella Bholaganj	0.408	0.56
28		Pynursla	0.372	0.58
29		Mawsynram	0.593	0.47
30		Mawkynrew	0.269	0.54
31		Mawphlang	0.439	0.46
32		Mylliem	0.335	0.47
33		Mawryngkneg	0.202	0.54
34		Laitkroh	0.369	0.52
35	WJH	Thadlaskein	0.131	0.59
36		Amlarem	0.335	0.59
37		Laskein	0.259	0.62
38	EJH	Saipung	0.357	0.81
39		Khliehriat	0.487	0.70

Figure 46 shows climate vulnerability hotspots with respect to temperature based hazards. Districts such as East Jaintia Hill, West Jaintia Hills, and some parts of East Khasi Hills and Ri Bhoi are at high risk, while the rest are at mild risk with respect to temperature events. The central plateau and Garo Hills region may face mild risk with respect to temperature based hazards.

5. Inferences

Based on the study following conclusions can be made:

1. The State of Meghalaya received an average rainfall of 4085 mm in the observed period. Out of this, around 72% of the rainfall is received during the monsoon season. The amount of precipitation received in different parts of the State varies considerably. We find that the average monsoon season precipitation changed at the rate of 11.56 mm/yrin the period 1981-2012. However, this change was not uniform throughout the State. The central districts, West Khasi Hills, South West Khasi Hills and East Khasi Hills, showed higher changes than the rest of the State. The change in the frequency of extreme rainfall events was mostly uniform in the region with relatively higher values for East Khasi Hills district.

2. Based on SPI/SPEI it is concluded that the northern regions of the State has fewer extreme wet monsoons (0-2) than the rest of the State (2-4). The number of extreme dry periods in the State were uniform (1-3).

3. The central Shillong plateau and Garo Hills has the lowest temperatures in the State. In general, the spatial average temperature showed an increase of 0.031 °C per year in the observed period, which clearly indicates warming of the region.

4. The number of extreme hot nights has a high frequency (43 days per year). The high values has increased in the later part of the observed period (1981-2012). While the number of hot and cold days showed inconclusive changes, the number of cold nights has declined during the period of 1981-2012.

5. The State stood comfortable with heatwaves, as the region faced an average of 4 heatwaves in 30 years of 1981-2012.

6. Future projections, based on the best five CMIP5 models, showed variability in both precipitation and temperature for different scenarios (RCPs 2.6, 4.5, 6.0 and 8.5). The time period of evaluation was divided into the near term (2013-2040), mid term (2041-2070), and long term (2071-2100).

7. Precipitation is projected to increase in the State under the future climate. The central plateau regions are projected to experience an increase in precipitation at a higher rate than the rest of the State. An increase is projected to be about 3 to 7% under the various scenarios in the near term with 30 to 40% spatial coverage of the State. The mid-term evaluations suggest 3 to 6% increase in precipitation with a spatial coverage of 20 to 40% in different scenarios. The long term increase in precipitation is projected to be in the range of 5% to 13%.

8. The frequency of extreme precipitation events are set to rise as per the projections. Both the near and mid-term projections showed an increase in the frequency of these extreme events.

Their frequency is projected to increase under the RCP 4.5, 6.0 and 8.5 scenarios in mid and long terms. Number of extreme wet monsoons are also projected to rise in the long term in all scenarios.

9. The extreme scenario (RCP 8.5) shows an increase of as much as 3.8 °C, while in mild scenario (RCP 4.5), the increase in maximum temperature is limited to 2.6 °C in the long term. The daily mean and minimum temperatures also show an increasing trend. The mean temperatures are projected to increase up to 3.7 °C and 2.5 °C for the extreme (RCP 8.5) and mild (RCP 4.5) scenarios, respectively, in the long term projections. Similarly, an increase is projected in the minimum air temperature under the projected future climate in the State of Meghalaya.

10. Hot days are projected to rise by as much as 180 and 105 days/year under the RCP8.5 and RCP 4.5 scenarios under the projected future climate. Changes in hot nights were milder. The rise in number of hot nights is severe in the south western part of the State and may rise up to 115 days in the extreme (RCP 8.5) scenario. Cold days and nights are projected to decline in the near, mid and long term under all the RCPs.

11. Heatwaves in the past were very few and in the projections the rise is projected to 110 events/30-year in the long term under the RCP 8.5. Under the RCP 4.5, the projected number of heatwaves is 45/30-year under the long term.

6. Linking Impacts to Adaptation

6.1 Introduction

The Paris Agreement entered into force on 4 November 2016. 148 Parties out of total 197 Parties to the UNFCCC have ratified it so far. According to Paris Climate Change Agreement, "Parties recognize that adaptation is a global challenge faced by all with local, subnational, national, regional and international dimensions, and that it is a key component of and makes a contribution to the long-term global response to climate change to protect people, livelihoods and ecosystems, taking into account the urgent and immediate needs of those developing country Parties that are particularly vulnerable to the adverse effects of climate change. " The earlier Copenhagen Commitments (2009) by world leaders, "to achieve the ultimate objective of the Convention to stabilize greenhouse gas concentration in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system, we shall, recognizing the scientific view that the increase in global temperature should be below 2 °C, on the basis of equity and in the context of sustainable development, enhance our long-term cooperative action to combat climate change. We recognize the critical impacts of climate change and the potential impacts of response measures on countries particularly vulnerable to its adverse effects and stress the need to establish a comprehensive adaptation programme including international support". The Cancun Agreement (2010) had strengthened this resolution to limit the global temperature increase below 2^{0}C over the pre-industrial levels. The Durban Outcome (2011) stressed that, even if the two-degree scenario is met, developing countries, especially the poorest and most vulnerable, will still need much more support to adapt to the change that is already embedded in the global climate system. The Warsaw Agreement (2013) agreed to bind nations together into an effective global effort to reduce emissions rapidly enough to chart humanity's longer-term path out of the danger zone of climate change, while building adaptation capacity. The Lima COP 20 (2014) agreed on elevating adaptation onto the same level as the curbing and cutting of curbing greenhouse gas emissions. Manuel Pulgar-Vidal, the Minister of the Environment of Peru and the COP-20 President, said "Lima has given new urgency towards fast tracking adaptation and building resilience across the developing world—not least by strengthening the link to finance and the development of national adaptation plans" (http://newsroom.unfccc.int/lima/limacallfor-climate-action-puts-world-on-track-to-paris-2015/).

The countries therefore agreed in Paris that "Parties recognize that the current need for adaptation is significant and that greater levels of mitigation can reduce the need for additional adaptation efforts, and that greater adaptation needs can involve greater adaptation costs." Climate change is projected to have severe adverse impacts on India's population, natural ecosystems, and socio-economic parameters. India's vulnerability to climate change impacts is profound since around 650 million Indians are dependent on rain-fed agriculture for their livelihoods; around 250 million Indians live along a 7500 km of coastline that is at high risk due to sea level rise and extreme weather events; many of the 10,000-odd Indian glaciers are receding at a rapid rate; and deforestation is happening. India occupies 2.4% of the global land area, supports 17% of the global population and contributes less than 4% of global greenhouse gas emissions. Sustainable development is at the core of Indian planning process and India has been making huge efforts for enhancing the quality of life of her people including sustained poverty alleviation efforts. The number of people below poverty line has declined from 469 million to about 388 million during 2005 to 2010. Even then roughly three-fourths of Indian population lives below a daily income of US$ 2 (PPP). This also highlights the extent of number of people who are vulnerable to adverse impacts of a changing climate. India is much concerned about climate change impacts. According to IPCC AR5, adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. The below 2 °C target also unequivocally includes the combined and cumulative risks of mitigation and adaptation actions. These risks however are over different time scales – with adaptation risks being faced now. For instance, the global insurance industry, the largest industry in the world at total direct premiums of about 4.8 trillion US$ in 2014 (over double the Indian GDP), had insured losses due to natural disasters in the United States alone in the first half of 2015 at $12.6 billion, well above the $11.2 billion average in the first halves of 2000 to 2014, according to a July 2015 presentation by Munich Re and the Insurance Information Institute (http://www.iii.org/fact-statistic/catastrophes-us).

In Canada, claims on the insurance industry reached $3.2-billion in 2013, after floods, hail and ice storms caused devastating damage across the country, (http://www.theglobeandmail.com/ report-on-business/economy/severe-weather-leads-to-record-32-billion-in-insurance-ayouts/article16405099/). This is roughly twice the next highest year on record and a tenfold increase from the losses sustained a decade ago. Similarly in the UK, the wettest winter on record is likely to result in £446 million being paid in insurance claims to customers whose homes, businesses, and vehicles were flooded during the two-month period 23 December 2013 to 28 February 2014 (https://www.abi.org.uk/News/News-releases/2014/03/6-7-million-a-day-in-insuranceclaimsfrom- customers-hit-by-the-recent-flooding). The climate change related claims have been rising steadily in the insurance industry, much faster than anticipated by them (http://www.cbc.ca/news/business/fort-mac-climate-insurance-1.3576918).

The estimate for a single heavy rain event in Uttarakhand, India in 2013 is estimated cost US $ 1.1, billion economic losses (EMDAT, 2015). The subsequent sections provide a framework to assess the Adaptation Gap.

6.2 What is Adaptation to climate change?

The changing climate is posing unprecedented challenges to existing human and economic activities, natural ecosystems, and man-made ecosystems in many ways. Firstly, it is creating new risks for their existence as well as safe and economically viable operations. For instance, infrastructure assets are planned with some visibility of magnitude and type of potential climate induced risks [Hallegatte, 2009]. However due to climate change, new dimensions are being added to the risk profile of these assets. Climate is changing the conceptual basis of risks and some specific risks may become more critical for the asset in future, which are either not visible today or do not hold importance in the basket of risks that the asset currently faces [Stern, 2007]. Secondly, climate change appears to exacerbate the existing risks faced today. For example, higher variability in the Indian monsoons and temperature profiles temporally and spatially could make certain crops uncultivable in present form at locations where they are being cultivated presently. Similarly floods and droughts could become more uncertain and severe. Thirdly, climate change threatens the usable life span of assets, products and even services. Regulatory or product and technology risks could make the asset redundant sooner than the planned lifespan or physical risks could reduce the usable life of the asset [Grimm & Peter, 2008]. Tourism services face major uncertainty due to changing weather conditions and unpredictable weather at tourist destinations during peak tourist seasons. Finally, it creates allied risks that arise out of disruptions in network of infrastructure such as supply chain risks [Schenker-Wicki, Inauen, & Olivares, 2010]. In human systems, the process of adjustment to actual or expected climate and its effects in order to moderate harm or exploit beneficial opportunities is normally termed as Adaptation. In natural systems, this process of adjustment to actual climate and its effects, and human interventions that may facilitate adjustment to expected climate is called Adaptation. Adaptation is supposed to reduce risks and enhance resilience of natural and man-made systems towards adverse impacts of climate change.

Risks can only be managed and cannot be completely eliminated. The palliative financial burden, as discussed in subsequent chapters and demonstrated through an example of Uttrakhand tragedy in north India during June 2013, could be huge and economic implications can only be evaluated till the first or the second order and therefore the total indirect palliative impacts may be lower than the actual losses that many sectors and regions may face. Therefore, the choice of right adaptation practices may not always be easy to determine as the costs are unambiguous. The preventive costs may therefore many a times appear to be infructuous. Further, the concave nature of (preventive and palliative) adaptation cost curve could also mean that the relationships between prevention costs and palliative damage costs due to an event may be directly related or inversely related, depending upon the type of investment and its purpose under discussion. For instance, construction of a dam to avoid drought is a preventive mechanism and some expenditure would be required for the same. But if drought does happen subsequently, one may have to spend on palliative damages as well. The palliative costs may be high at times due to food grain prices going up on supply-demand shortages etc. It may appear that the expenditure on building the dam was infructuous in the first place as it did not prevent droughts from occurring. This also shows a direct relationship between preventive and palliative costs as expenditure is required to restore the damages due to an event for which some preventive expenditure was already made. On the other hand, the same dam may also be used as a flood prevention mechanism. In such a situation, if it does present floods from occurring, palliative costs would be minimum, indicating an inverse relationship between preventive and palliative costs. Consequently, it becomes important to plan for potential climate-induced risks keeping in view the other factors like the time frame for results in case of a particular adaptive practice or costs for inducing the adaptive measure, what all types of risks the practice covers etc.

According to IPCC AR5 report of WG-2, benefits from adaptation therefore can already be realized in addressing current risks, and can be realized in the future for addressing emerging risks. However economic impact estimates completed over the past 20 years vary in their coverage of subsets of economic sectors and depend on a large number of assumptions, many of which are disputable, and many estimates do not account for catastrophic changes, tipping points, and many other factors. With these recognized limitations, the incomplete estimates of global annual economic losses for additional temperature increases of ~2°C are between 0.2 and 2.0% of income (±1 standard deviation around the mean; medium evidence, medium agreement). Losses are more likely than not to be greater, rather than smaller, than this range (limited evidence, high agreement). Additionally, there are large differences between and within countries. Losses accelerate with greater warming (limited evidence, high agreement) [IPCC, 2014].

6.3 What is Adaptation Gap?

The UNEP Adaptation Gap (2014) defines it generically as the difference between actually implemented adaptation and a societally set goal, determined largely by preferences related to tolerate climate change impacts, and reflecting resource limitations and competing priorities.

Developing countries such as India have national targets on development with poverty alleviation, education, health, energy, water, and provision of infrastructure being among the top priorities.

These were mostly aligned with the Millennium Development Goals (MDGs) for 1990-2015 and also the Sustainable Development Goals for 2015-2030. Resource limitations and competing priorities put constraints on achieving these goals. Changing climate dynamically interacts with these goals and may or may not adversely impact them. Adaptation gap therefore is perceived as a dynamic concept in this report. Strong mitigation actions today could reduce the climate change induced impacts on various systems after a few years. Uncovered mitigation gap today, could therefore lead to a larger adaptation gap in longer-term. However it should also be noted that any mitigation action today will not be able to fill the adaptation gap in short to medium-terms, which have been caused by unbridled GHG emissions from Annex-1 countries in the past. It would only reduce the adaptation gap in the longer-term. That is the adaptation dividend of current mitigation actions would be realized in future. Therefore common but differentiated responsibility (CBDR) paradigm of climate actions under UNFCCC does not only require more mitigation by developed countries now so that the world does not face much adverse consequences in future, but also more support by them to developing and least developed countries to fill their present adaptation gaps.

Apart from this time gap between mitigation induced impact reductions achieved in future and impacts occurring now that would need adaptation, adaptation is also locale specific as against a more global character of mitigation. One million tons of GHG emissions mitigated in a developed country would have the same mitigating effect of one million tons of GHG emissions mitigated in a developing country due to fungibility of mitigation actions. But one million litres of additional potable water made available to a water-affluent location will have much less positive externalities than one million litres of potable water made available to a water-starved region. Adaptation actions, and therefore actions to reduce Adaptation Gap, have to be very locale specific. Similarly an extreme rainfall event occurring over 3 days in a state like Meghalaya could cause more damage than a similar rainfall over 3 weeks.

The most vulnerable communities and systems, in all probabilities, would not have contributed to their present climate misery due to their almost miniscule GHG emissions in the past. They may not be even aware of the global reasons of the climate impacts they have to face today and tolerate without any choice. Therefore tolerable impacts should ideally not be included as part of the adaptation that is already occurring for they may be involuntary, and should ideally be included in the Adaptation Gap. Someone is already paying to bridge this gap – may be the individuals concerned themselves or their governments – both should not be ideally doing it under a Common But Differential Responsibility (CBDR) paradigm. Examples for involuntary tolerated adaptation could be the adverse impacts due to changed excessive heat wave patterns in a developing country. We define the various adaptation needs through a risk coverage paradigm, rather than a simple gap based relationship.

6.4 Adaptation Gap and Adaptation Dilemma

We consider the decisions on how much climate change impact risks are acceptable and how much are not acceptable. The unacceptable risks constitute Adaptation Gap (Figure 47). Therefore determining the right balance between preventive and palliative adaptation measures determines the Adaptation Gap. For any society, and region there remains a range of risks that are acceptable. What constitutes as acceptable risk is a function of several factors that include level of development, preparedness, resources, norms and values that any society places on goods, services and human life. Beyond this range of acceptable risks, societies are faced with the possibility of being impacted in an unacceptable way. Such impacts have damage costs associated with them and are typically unacceptable to a society.

Risk coverage depends upon resources available and competing priorities. The unacceptable risks may be due to lack of understanding of those risks currently, or lack of available resources to cover those risks, or due to a conscious decision to tolerate those risks, or a combination of these. The Adaptation Gap is basically risks that one would like to cover but is unable to cover. Tolerated risks are therefore generally considered part of the Adaptation Gap if they indicate forced and involuntary choices. The risk coverage process induces Adaptation Dilemma that is how much risks are acceptable and how much are not. The latter may or may not be covered given the resources available and their opportunity costs. Climate change adaptation measures heavily depend on the risk perceptions and management strategy to cover these risks. Managing all risks through adaptation could be an expensive proposition. For instance, according to the 12th Five-Year Plan of the Government of India (2013), adaptation costs for new infrastructure could be in the range of 3–10 per cent of the total investment, although for certain sectors and locations this may be higher. The number for existing infrastructure is likely to be as high as 25 per cent of their present construction costs [Planning Commission, 2013], and could therefore run into trillions of dollars.

Excessive adaptation and prior over estimation of risks leads to a type 1 or α error. It means that one plans for some event but it does not take place. In our earlier example, this could be building a dam for drought prevention, but the drought does not happen. The decision to build a dam may therefore be looked as infructuous in hindsight, since it could be difficult to estimate potential losses that could have occurred if a drought would have happened, especially depending upon its intensity and time of occurrence, both of which are hypothetical in this case.

On the other hand, under investment in risk mitigation and adaptation strategies leads to a type 2 or β error, that is, one does not plan for an event to occur, but it occurs. In the example above, one does not built any dams thinking that no droughts or floods would occur, but they do occur. The palliative damages could be very high in such a situation. Under adaptation means that risk assessment may have been inadequate. Therefore, nations invest in mitigating risk e.g. building a wall to prevent flooding associated with sea level rise. These investments are borne by individual actors, groups of individuals or governments as preventive costs. However, it often happens that not all risk can be covered. This uncovered risk can be classified into three types – uncovered risk, residual risk and intolerable risk. Each of these risks is associated with an increasing set of palliative damage costs and requires different mechanisms to mitigate the same. The first would generally have a palliative cost. These could be transferred to a third party but at a high premium, which may not be acceptable to the affected party since α error exists. The residual risks are generally involuntary and have damage costs. The Intolerable risks have huge costs, including deaths and migrations. The decision about the quantum of risk to be covered (i.e. acceptable versus unacceptable) and the associated resource investment is termed as the 'Adaptation Dilemma'. The policy dilemma therefore is how much to invest a priory in adaptation. Climate proofing natural or manmade systems does not mean that all possible risks are eliminated; it just implies that they have been made more resilient towards climate-induced risks. Thus the adaptation dilemma revolves around choosing an acceptable level of risk from a wide spectrum and covering the unacceptable risks appropriately.

6.5 Adaptation Gap is a dynamic concept

It must also be recognised that the Adaptation Gap is dynamic in nature and is based upon possible future transitions – both climate change parameters and resilience of the population and various eco-systems. Future climatic parameters could shift towards right with a changed mean, a changed distribution, or a combination of both. For instance, current rainfall distribution may just shifts towards right **(Figure 47)** retaining its distribution pattern. If we assume that the resilience of populations and various eco-systems do not change over time, then the Adaptation Gap would increase in future. In case the distribution also changes with much higher variance **(Figure 47)**, the Adaptation Gap could be much larger in future. Therefore, gap analysis must be a periodic exercise based on the most recent science.

Moreover as various RCPs could manifest in future, the Adaptation Gaps would be different under alternate RCPs. For instance, the Adaptation gap under RCP 8.5 scenario would be much more than that under an RCP 2.6 scenario. Since nations have to hedge for the worst possible impacts, the adaptation policies and measures may have to be ready for RCP 8.5 extremes. This also means that more and more resources have to be committed to adaptation and as per CBDR, more and more resources have to flow to developing countries and emerging economies from developed countries.

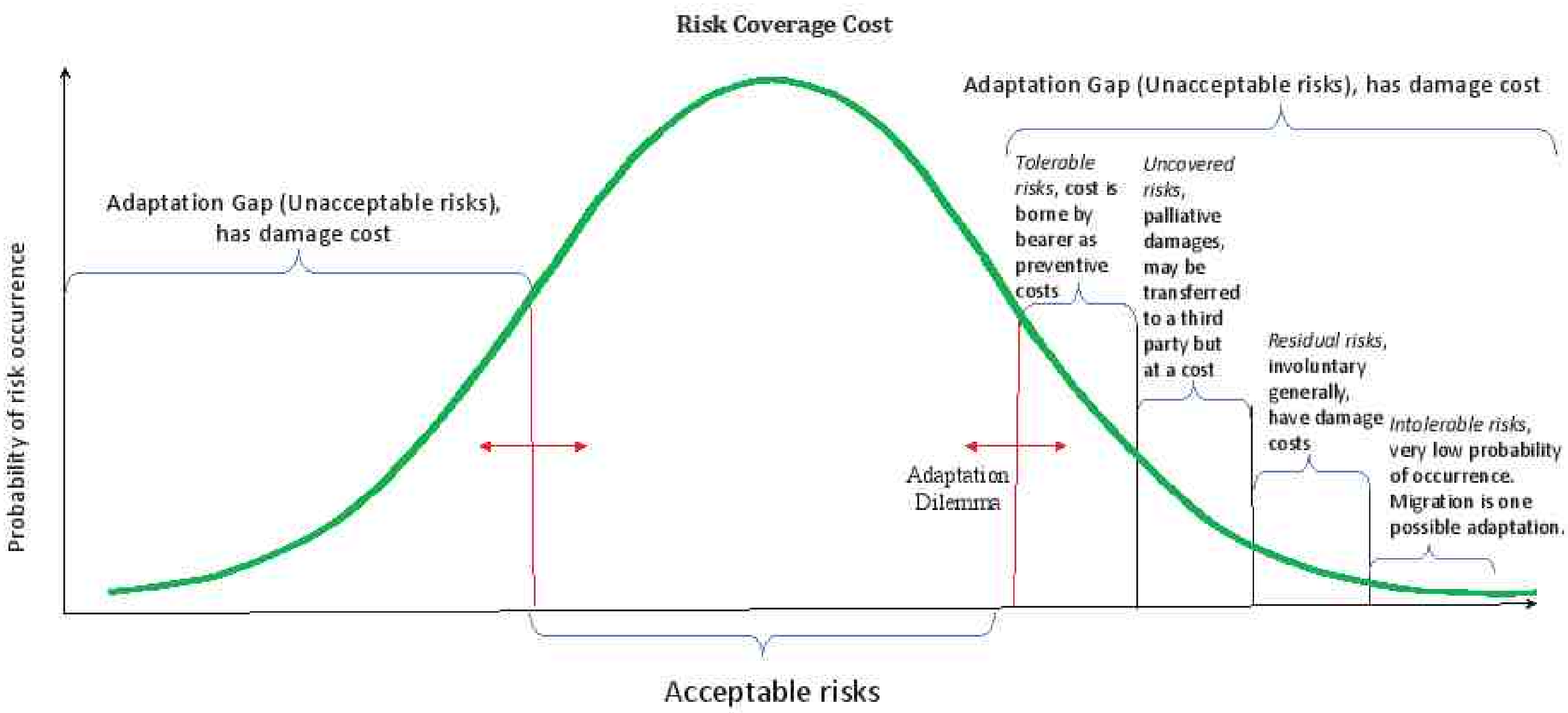

Figure 47. The Adaptation Dilemma

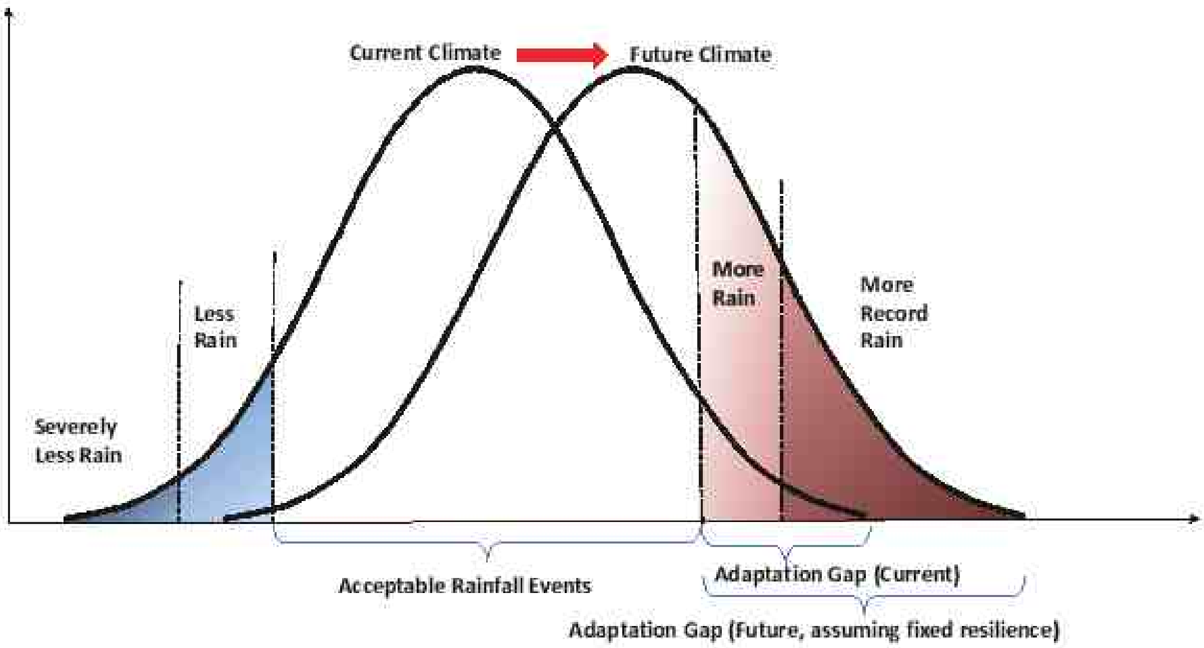

Figure 48. The need for adaptation is projected to generally enhance in future

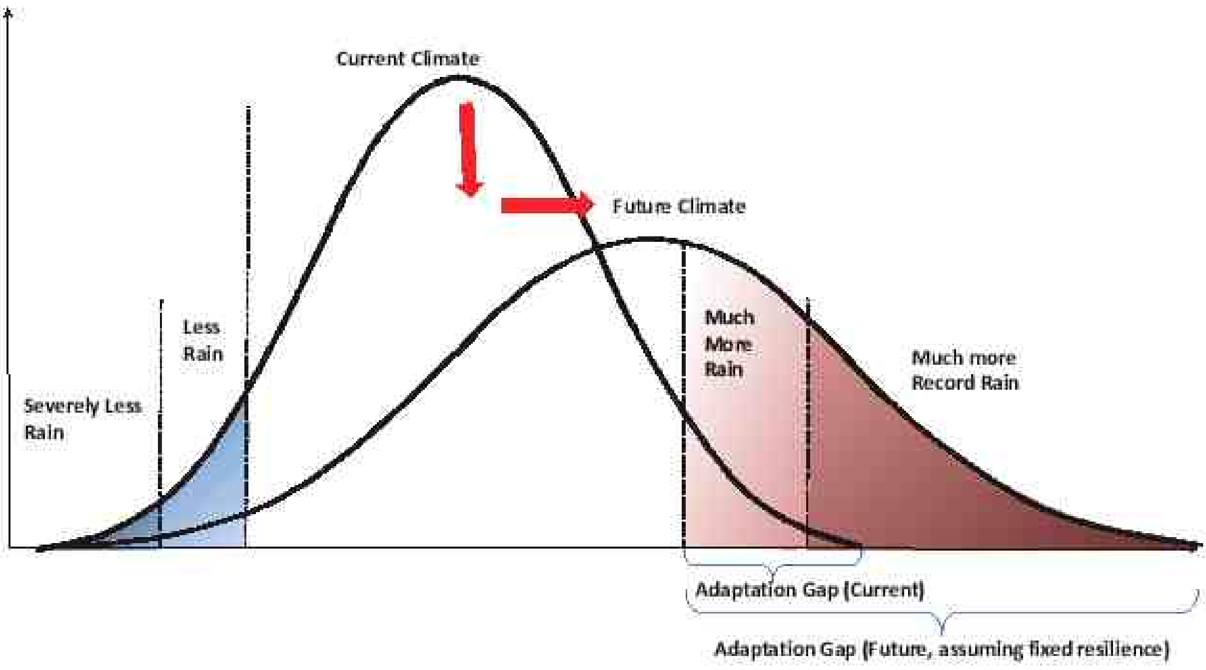

Figure 49. Adaptation Gap could enhance much more in future.

6.6 Ways of filling the Adaptation Gap

Conventionally, Adaptation Gaps may be filled in through managing the associated risks – either covering them through preventive investments or through paying the palliative costs of unacceptable risks. Involuntarily tolerated risks and also the residual risks form part of the uncovered risks in an adaptation gap. All the unacceptable risks, in turn, may be covered by the bearer or someone else through a prior arrangement where in the palliative damages are restored by a third party (the impacted party, the host country government, international bodies, reinsurer or someone else). Since CBDR is not currently implemented in adaptation effectively, these unacceptable risks (and associated palliative costs) mostly fall on the host country governments as a sovereign obligation, and to a very lesser extent on developed country parties and multilateral donor agencies who take these as a welfare measure and not as a liability measure. It may also be argued that US$ 100 billion/year by 2020 contribution commitment to the Global Climate Fund by developed country parties is based on a Welfare paradigm, and if this paradigm is changed to a Liability paradigm based on consistent and unequivocal IPCC findings on anthropogenic nature of climate change, the CBDR damage payments towards filling the Adaptation Gaps in all developing countries and emerging economies could be almost 10-times than this amount. Strong CBDR regimes in future would therefore change adaptation finance flows and technology transfers in favour of developing countries.

Risk management can be classified under four possible response options - avoid, mitigate, retain, and transfer the risk. The first two responses (avoidance and mitigation) may be categorized as risk control and the latter two (retention and transfer) as risk financing. The normal approach to risk management is to control all those risks that could be controlled within the physical resources available and finance the remainder. Effectively, risk financing funds those losses that remain after the application of risk control techniques, including both those risks accepted as not being able to be controlled and those where controls proved inadequate to contain the risk [AACI, 2003]. All these response options are summarized below [Kapshe, 2002].

(a) Risk Avoidance

An entity chooses to proceed with a particular investment on the basis of its perception of risk and whether the entity is willing to assume the risk; effectively the threshold is the tolerance for risk. This tolerance for risk will be a function of both the willingness to accept the risk and also the circumstances in which the entity is operating. If investors in a country, for instance, become too risk averse then investments in human and economic activities, and man-made ecosystems may dry down. However, it will not be possible for the government not to invest in their development even if the perceived risks of future climate change are high in any region. Therefore, risk avoidance for climate change related impacts may not be a suitable choice for governments in most of the human and economic activities, natural ecosystems, and man-made ecosystems if these are otherwise expected to contribute towards development.

(b) Risk Mitigation

The measures such as loss prevention and loss control can be categorized as risk mitigation. In a traditional insurance context these measures may include security measures and safety standards. In many instances adherence to required risk mitigation measures is a prerequisite for any project to be sanctioned. There is a need to revise the safety standards in view of the likely climate change impacts in future, as the present day standards do not have any explicit consideration for these impacts.

(c) Risk Transfer

A risk that one organization is unwilling to bear may be transferred to another. This is what is commonly understood as insurance! In exchange for the payment of an agreed amount (the premium), the insurer agrees to indemnify the client for losses that result from specified perils.

Options and hedges also operate to transfer risk from one party to another. In some instances the counter-parties may be entities specifically established to engage in the hedging or option trading, but in many instances they will be entities whose risk arises from the opposite movement in a price or volume of supply. In case of infrastructure projects there are many mechanisms existing for transfer of risks arising from the perceived uncertainties. However, there are no well-developed mechanisms specially designed to transfer the climate change impact risks.

(d) Risk Retention

Risk retention can result from both a voluntary and involuntary action. Voluntary retention of risk results from a conscious decision to accept that a certain level of risk from any source should be retained rather than transferred to another party at a cost. Voluntary risk retention also includes acceptance of a level of risk that may be imposed by insurers. Involuntary risk retention occurs when a firm fails to identify and deal with a risk from within or outside the business and thus bears the risk unknowingly. Failure to recognize or understand a risk results in retention of the risk, which the firm will have to face in eventuality of the occurrence of event.

6.7. Implications for Alternate Scenarios

We have projected the future climate under alternate scenarios for Meghalaya. We use those results to articulate Adaptation gaps. The adaptation gap increases in future (Figure 48) as precipitation distributions shift to right in the near term (2016-2045), and longer term (2046-2075) for various RCP scenarios. These shifts are more pronounced under RCP 4.5, RCP 6.0 and RCP 8.5. This expansion of the adaptation gaps would require more financial resources to be committed for managing extreme rainfall events, and possible damage to eco-systems. Many species may get extinct, including vegetative, land based, marine and aerial. The financial implication estimations could be around 80% more in real terms than present.

Under future climate change, it is evident that there is a right-ward shift in the distribution of risk. The shifts imply that new and additional resources are required to cover risks. It can be seen from Figure 50 to Figure 53 that this spread may increase upto 2.5 times for RCP 2.6 and up to 4 times for RCP 8.5 than the present. This change in spread requires understanding the dynamic concept of acceptable risk and investing accordingly. Preventive adaptation to "expand" the range of acceptable risks would require much more investment as the risk profile is projected to shift to the right. This shift is crossing the right tails of present climate risk distributions under RCP 4.5, 6 and 8.5 during 2016-2045 itself. Almost no overlap remains during 2046-2075 risk profiles and the current risk profile. Most of the risks in future would therefore fall under unacceptable domains, from present perspective thus increasing the palliative costs much faster. This also implies that future would become much more uncertain and risky, therefore increasing the chances of β errors much more. α errors may almost become negligible since whatever preventive measures would be taken, there would be hardly any chance of them going wasted.

Two approaches can be used while making these additional investments – wait and watch or take advance preventive actions. The wait and watch approach requires taking adaptation action (and investments) in future. This strategy implies lower preventive costs in the short term, but may lead to higher palliative costs in future. This is because a higher proportion of risk may be uncovered. The advance preventive actions require making investments now. This strategy implies higher expenditure in the short term, but may lead to lesser palliative costs in future. This is because a larger proportion of risk is then covered. These resource deployment can be made in advance as the risks are perceived (advance strategy) or retrospectively (wait and watch approach). Therefore, there is an inherent trade-off between these two strategies. State Governments are required to choose optimal strategies based on the risk they want to cover. And as they say, a stitch in time may save nine.

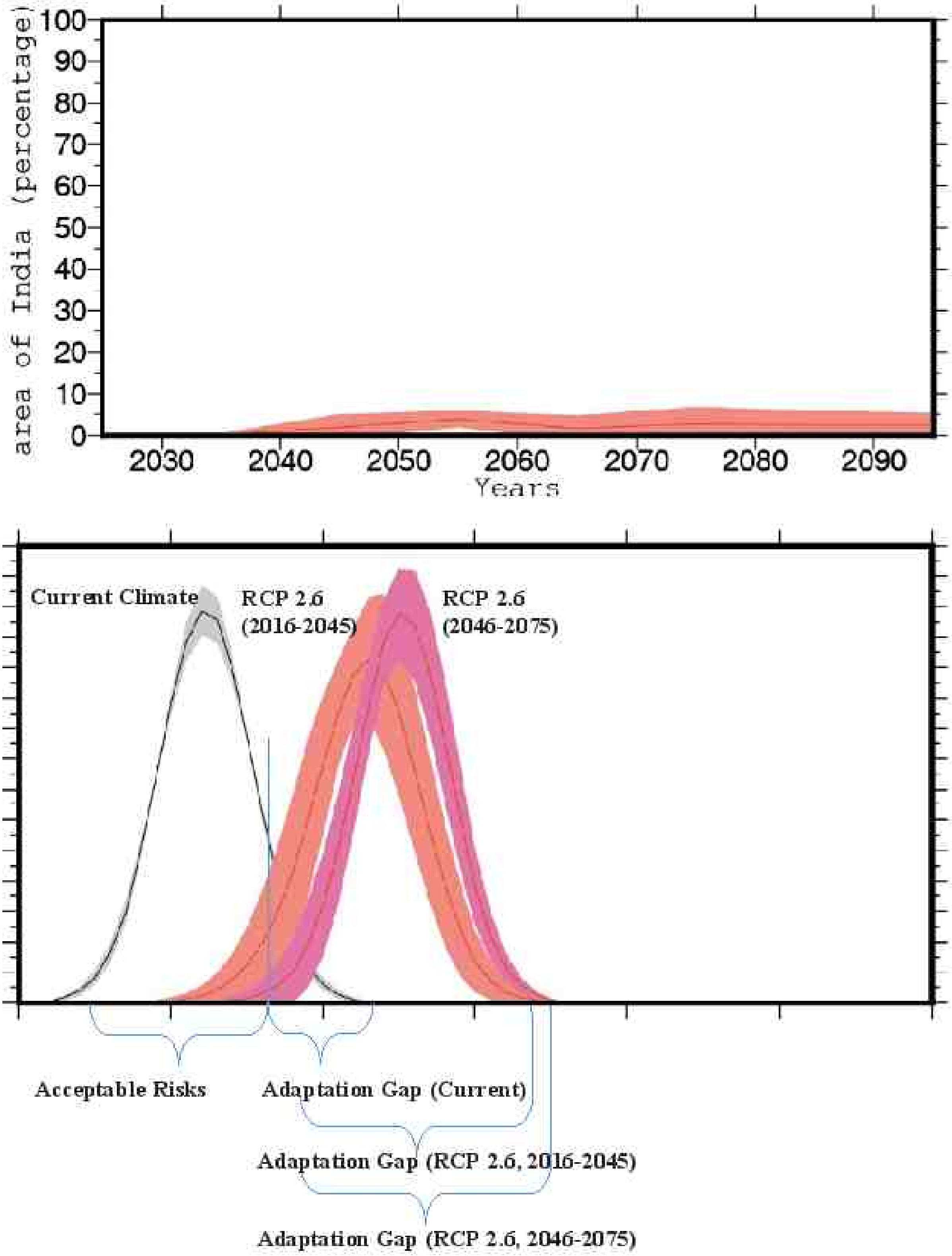

Figure 50. Articulating adaptation gap under RCP 2.6 future projections.

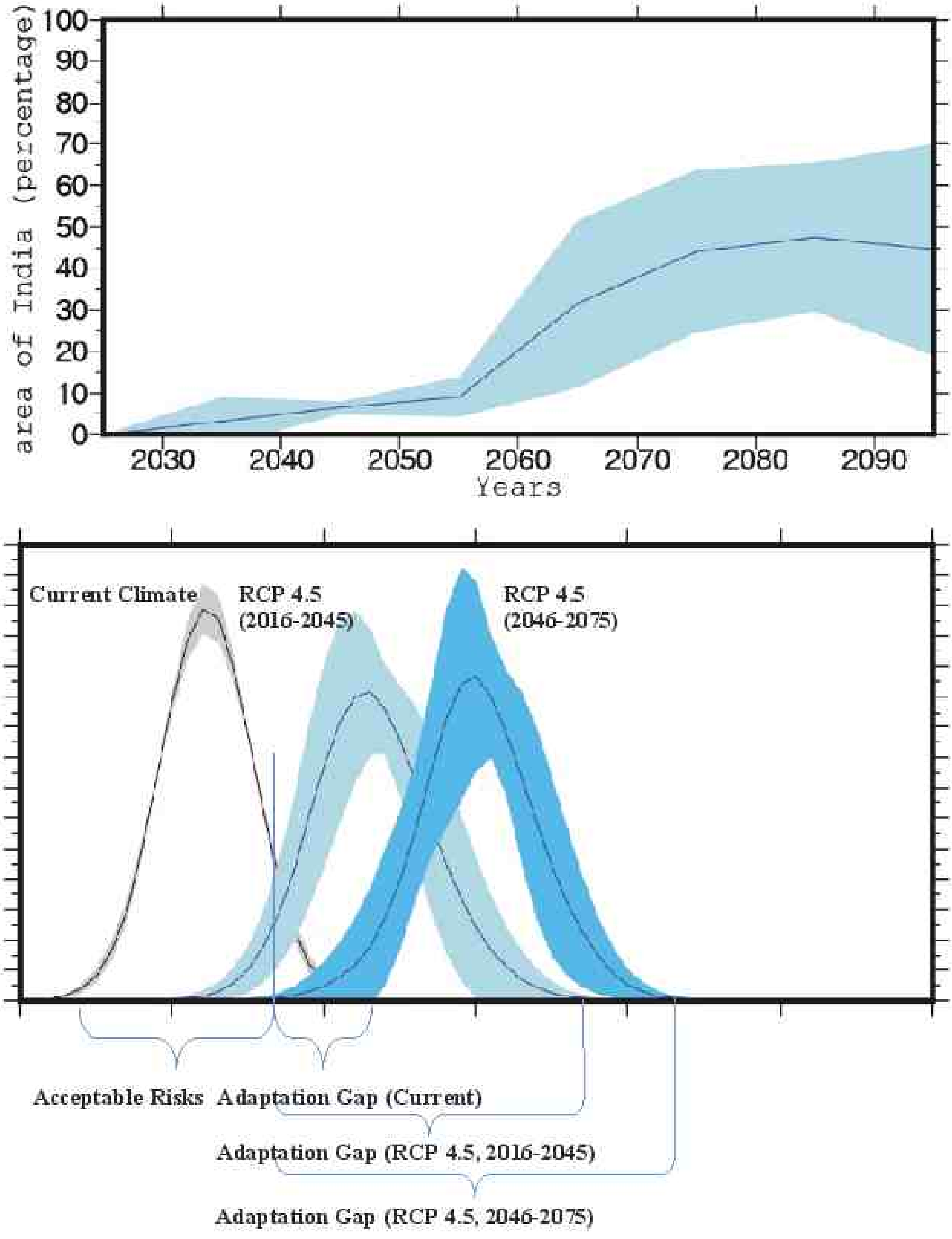

Figure 51. Articulating adaptation gaps under RCP 4.5 future projections.

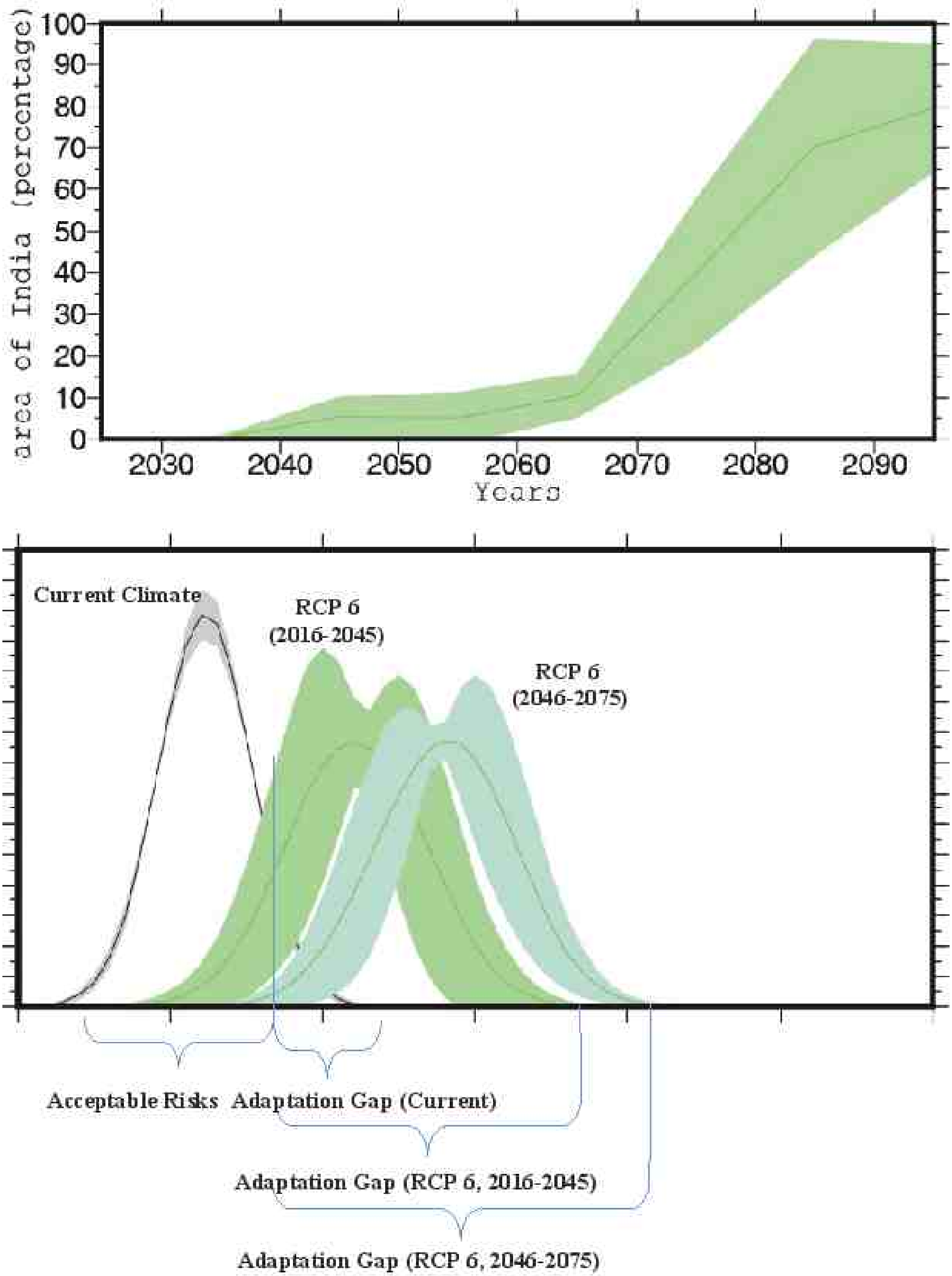

Figure 52. Articulating adaptation gaps under RCP 6.0 future projections.

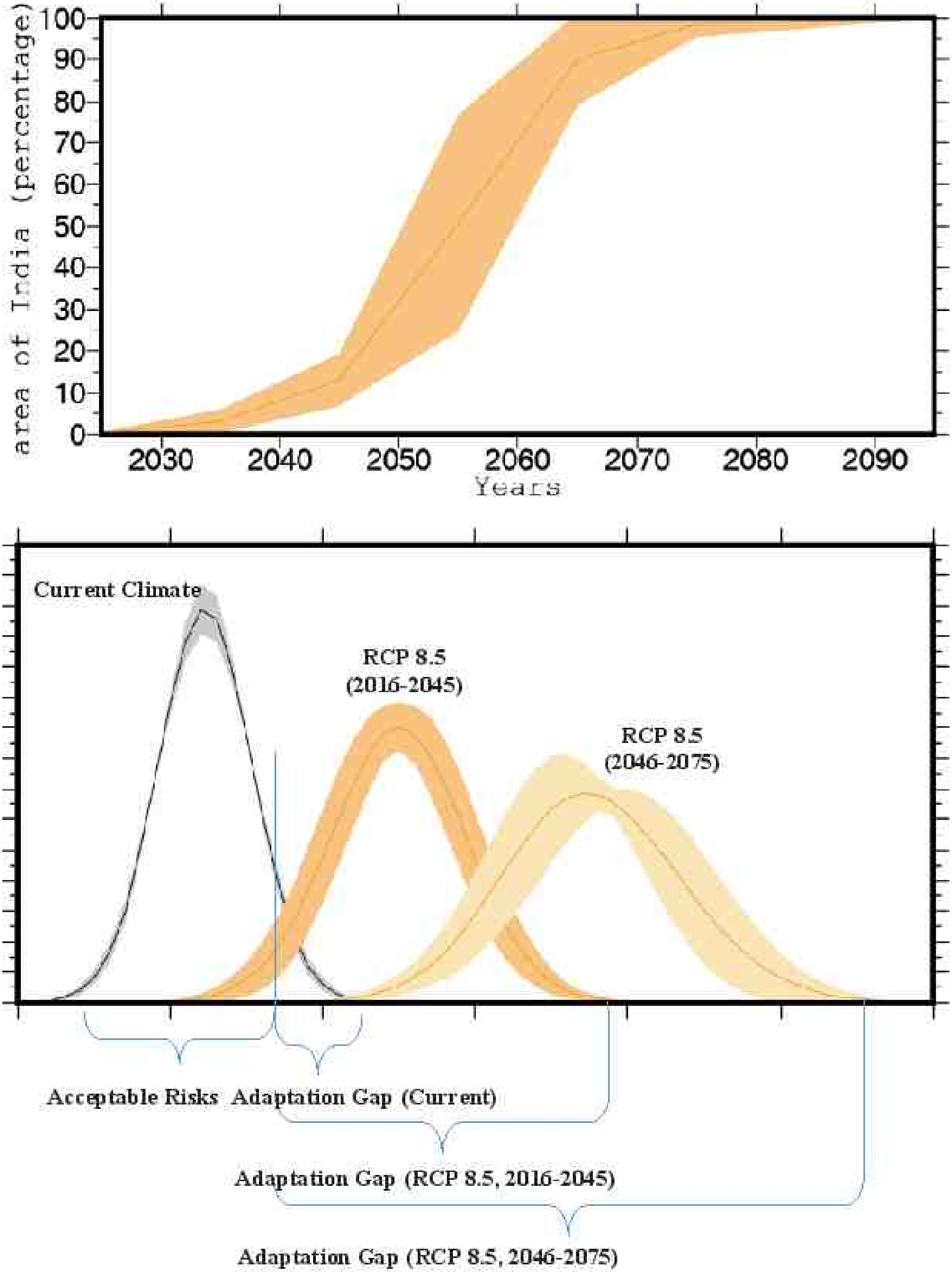

Figure 53. Articulating adaptation gaps under RCP 8.5 future projection.

7. Implications on Different Sectors

Global climate change has adverse effects on a different sectors with varying impacts. While there is a need for a separate impacts assessment for the key sectors, potential impacts of climate change on the selected sectors are described below:

1. **Forests & Water Resources:** Rise in air temperature has various implications for forests and water resources in Meghalaya. A careful sector-wise impacts assessment is needed to develop policies for adaptation. However, based on the findings, some implications can be expected. Due to a significant increase in air temperature, events of forest fires may be more frequent especially in pine and bamboo forests. Unchecked shifting cultivation (Jhum) may lead to increase in forest blanks and scrubs in the State. This may further cause land degradation and soil erosion. At the event of extreme precipitation episodes, it may increase the risk of landslip and landslides in high altitude hilly areas and siltation of water bodies in down streams. Siltation of streams affects aquatic ecosystem and productivity. The situation may become worse with an increase in the precipitation intensities as projected. The rise in temperature may cause water scarcity as well as it may have a devastating impact on water resources in low rainfall parts of the State. Adoption of water conservation measures is suggested for retention of water/soil moisture to avoid the dry spells/drought situations.

2. **Biodiversity:** Meghalaya is projected to experience the rise in temperature which may cause a gradual loss of biological diversity. Habitat loss coupled with forest/habitat fragmentation increases the risk of biodiversity loss of the State. Meghalaya is the house of some endemic and endangered/threatened plant species which becomes more vulnerable due to their restricted geographic and climatic range. In Meghalaya, few of the endemic plant species like Adinandra Friffithii, Clematis Apiculata, Ilex Venulosa and Ceropegia Arnottiana have become extinct in recent decades. The rise in temperature may cause loss of floral wealth of the State.

3. **Agriculture:** Most of the agriculture in the State is rainfed thus it becomes most vulnerable to rise in temperature. The crops response to rising in temperature may vary from crop to crop. However, as a generalized trend with the rise in temperature, crop growing degree days may increase which may result in reduced maturity period of the crop especially at the lower altitudes. Early maturity may result in decreased grain filling period and ultimately may result in low yield/production of the crop. The rise in temperature may also induce premature breaking of insects and pests dormancy which may cause insect and pests attacks on the standing crops and may further affect the production. Net crop yield is expected to decline with an increase in night temperature as it brings physiological changes leading to increased

rate of respiration and decreased rate of biomass accumulation [Hatfield et al., 2011]. This may also impact pollination in certain crops like Maize as documented by Hatfield and Prueger (2015). Rice also shows a similar temperature response to maize because pollen viability and production declines as daytime maximum temperature (Tmax) exceeds 33 °C and ceases when Tmax exceeds 40 °C [Kim et al., 1996].

4. **Human health:** With the rise in temperature and wetter monsoons, people diagnosed with diseases such as diarrhoea, malaria and other water or vector-borne diseases, are projected to rise. The risk associated with mortality related to extreme heat in the highly vulnerable regions of the State is also expected to rise. The effects of diseases and discomfort will be more pronounced and challenging for the low-income groups as well as residents of villages which have limited access to safe drinking water, sanitation services, and medical aid. A general rise in a number of people below the poverty level has risen from 2004-05 to 2009-10 for both rural and urban populations was observed by Planning Commission (provided by Ministry of Development of North Eastern Region (MODONER), http://www.mdoner.gov.in/content/poverty-estimates, accessed on 19 June, 2017). This suggests that the number of people who are less likely to be able to adapt to climate change is increasing. The region is economically highly differentiated, and land holdings are limited to some people. Local source of income for the majority of the population is natural resources based, for instance, agriculture and livestock, which are in itself at risk under the changing climate.

5. **Livestock:** Similar to the effects of harsher summers and heavy monsoons on humans, the livestock are also at risk. The mortality rate is expected to rise on account of increasing number of high-impact disease outbreaks such as foot-and-mouth disease (FMD), peste des petits ruminants (PPR), Avian Flu, Swine flu. The resilience of pathogens due to adaptation and frequency of outbreaks is projected to rise [Lubroth J., 2012].

8. Recommendations for policy makers

Following are the recommendations for policy makers:

1. In terms of hazards based on precipitation, the central region (West Khasi Hills, East Khasi Hills and South West Khasi Hills) and south-western region (South West Garo Hills and West Garo Hills) are projected to be more susceptible to rise in precipitation. Number of surplus monsoon periods are also expected to rise in these regions. With these observations, fair chances of increase in flash floods and flooding in the downstream can be expected.

2. The declining forest cover in the center as well as in near Garo Hills may pose a serious problem if deforestation continues unchecked. Whereas an expected rise in precipitation may be a boon to naturally irrigated fields of the region, which is at present more than 50% of the total agricultural fields. Observed and projected variability and changes in precipitation can be considered in the preparation of adaptation policies at the block level. Moreover, uncertainty in the climate change projections should also be incorporated while developing policies for adaptation at local and regional levels.

3. Due to projected increase in precipitation extremes, risks of floods and landslide hazards need to be evaluated, and measures need to be implemented to reduce the exposure to such hazards at local levels. Design and develop adaptive stormwater management practices. Update undersized culverts, redesign drainage systems including drainage canals for regions receiving heavy rainfall. Provide slope protection measures for high gradients, since most of these regions are expected to be more vulnerable to precipitation based hazards.

4. Remap river flood zones with discharges at projected rainfall intensities. The development strategies in and around these rivers should incorporate possible shifts in their usual profiles and paths. Reanalysis of sediment loads at projected stream discharge may help determine regions likely to be prone to bank cutting in this region. Some of the suggested adaptive measures are construction of small check dams, using geotextiles to reduce erosion and landslides, aggressive plantation and ravine restoration. Prepare strategies to restrict encroachment and/or upkeep of lakes and other surface water bodies. At the event of surplus rainfall, these acts as temporary storage structures.

5. A proper management strategy is required for slash and burn (or Jhum) cultivation. If not checked, it will result into more losses in forest cover and reduced land productivity. If necessary, the government should reclaim, restore and preserve regions grievously affected by Jhum.

6. Some regions face higher fluctuations than others in pre and post monsoon water table depths. Identifications of these regions will help to provide locations for recharge structures

required. Prevent or restrict extraction from shallow aquifers. Provide means of ground water recharge, subsurface storage structures, spring rejuvenation for regions with low water table in non-monsoon seasons. Surface water retention structures may help in better irrigation infrastructure as well as for domestic usages.

7. Both observations and climate model projections showed a significant increase in mean temperature and associated extreme temperature indices. The eastern part of the State, including East Jaintia Hills, West Jaintia Hills, East Khasi Hills and Ri Bhoi, is at high risk regarding Temperature based hazards. Garo Hills region may also face more effects of warming in the mild and severe scenarios in the long term. Part of Shillong plateau (West Khasi Hills and South West Khasi Hills), is projected to experience rather lower degrees of temperatures than the rest of the State. A careful impacts assessment is required for the agriculture, water resources, and forests sectors and the outcome of that need to be included in the upcoming policies for adaptation in the State of Meghalaya.

8. Temperature extremes have increased in the State during the observed record and projected to increase significantly under the future climate. Extreme temperature events (hot days, hot nights, and heat waves) can have far reaching implications on the health of people and animals, bio-diversity, and agricultural production. Moreover, these events can have greater impacts on cities that are centers of high population and economic growth. Public health related policies should consider the projected increase in extreme temperature events and heatwaves.

9. Identify, reclaim and protect ecologically sensitive areas in the region. A proper study is suggested for identification of regions and species sensitive to projected changes in the climate.

Glossary

Cold day: The day on which the maximum temperature is extremely low, usually below 5th percentile of all winter maximum temperatures.

Cold night: The night on which the minimum temperature is extremely low, usually below 5th percentile of all winter minimum temperatures.

Heatwaves: These are periods of extended rarely hot events whose length varies from few to several days (usually 3-6 days). A days is considered extremely hot when the maximum temperature rises above 95th percentile value of maximum summer temperatures. Such extremely hot days extending for a longer period than 3 days or more constitute a heatwave.

Hot day: The day on which the maximum temperature is extremely high, usually above 95th percentile of all summer maximum temperatures.

Hot night: The night on which the minimum temperature is extremely high, usually above 95th percentile of all summer minimum temperatures.

Percentile: It is a measure used in statistics indicating the value below which a given percentage of observations in a group of observations fall.

Precipitation: All forms of water that reach the Earth from the atmosphere. The usual forms are rainfall, snowfall, hail, frost and dew. In the context of this study, only rainfall is considered as available precipitation in the region.

Standardized Precipitation Index (SPI): It is a widely used index to characterize meteorological drought or surplus on a range of time scales. On short timescales (1-2 months), the SPI is closely related to soil moisture, while at longer timescales (9-48 months), the SPI can be related to groundwater and reservoir storage. The SPI can be compared across regions with markedly different climates. Values of SPI lower than -1.3 represents water stress due to scarcity (drought), while SPI value greater than 1.3 indicates surplus availability of moisture.

Standardized Precipitation and Evapotranspiration Index (SPEI): The Standardized Precipitation Evapotranspiration Index (SPEI) is an extension of the widely used Standardized Precipitation Index (SPI). The SPEI is designed to take into account both precipitation and potential evapotranspiration (PET) in determining drought. Thus, unlike the SPI, the SPEI captures the main impact of increased temperatures on water demand. Like the SPI, the SPEI can be calculated on a range of timescales from 1-48 months. Similar to SPI, values of SPEI lower than -1.3 represents water stress due to scarcity (drought), while SPEI value greater than 1.3 indicates surplus availability of moisture.

Model bias: The departure of model data values from that of observed data in the same time period is known as model bias. There are several method to remove such biases from model data such as Linear scaling, Quantile-Quantile mapping, etc.

References

Australasian Advisory Committee on Insurance (AACI), 2003. Risk, The Environmental and The Role of the Insurance Industry, *Report of UNEP Finance Initiative*. 112-140.

Aadhar, S. and Mishra, V. (2017). Real time drought monitoring in South Asia. *Submitted to Scienti�ic Data*.

Alory, G., S. Wijffels, and G. Meyers (2007), Observed temperature trends in the Indian Ocean over 1960–1999 and associated mechanisms, *Geophys. Res. Lett., 34*(2).

Barnett, T. P., J. C. Adam, and D. P. Lettenmaier (2005), Potential impacts of a warming climate on water availability in snow-dominated regions, *Nature, 438*(7066), 303–309.

Battisti, D. S., and R. L. Naylor (2009), Historical warnings of future food insecurity with unprecedented seasonal heat, *Science 323*(5911), 240–244.

Brown, Molly E. and Funk, Chris C. (2008). Food Security Under Climate Change, *Science*, 319(5863), 580-581.

Chaturvedi, R. K., J. Joshi, M. Jayaraman, G. Bala, and N. H. Ravindranath (2012), Multi-model climate change projections for India under representative concentration pathways, *Curr. Sci., 103*(7), 791–802.

Easterling, D. R. et al. (1997), Maximum and minimum temperature trends for the globe, *Science, 277*(5324), 364–367.

Easterling, D. R., G. A. Meehl, C. Parmesan, S. A. Changnon, T. R. Karl, and L. O. Mearns (2000), Climate extremes: observations, modeling, and impacts, *Science, 289*(5487), 2068–2074.

EMDAT (2015). *The International Disaster Management Database*. http://www.emdat.be/ Last accessed 17 November, 2015

Fischer, G., M. Shah, F. N. Tubiello, and H. Van Velhuizen (2005), Socio-economic and climate change impacts on agriculture: an integrated assessment, 1990–2080, *Philos. Trans. R. Soc. B Biol. Sci., 360*(1463), 2067–2083.

Funk, C., Peterson, P., Landsfeld, M., Pedreros, D., Verdin, J., Shukla, S & Michaelsen, J. (2015). The climate hazards infrared precipitation with stations--a new environmental record for monitoring extremes. *Scienti�ic data, 2*, 150066.

Grimm, N. B., Peters, D. P. C., Groffman P. M., Nadelhoffer, K. J., Collins, S. L., Michener, W. K. and Huston, M. A. (2008). Living in an increasingly connected world: a framework for continental-scale environmental science, *Frontiers in Ecology and the Environment*, 6(5), 229-237.

Hagenlocher, M., Lang, S., Holbling, D., Tiede, D., & Kienberger, S. (2014). Modeling hotspots of climate change in the Sahel using object-based regionalization of multidimensional gridded datasets. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, *7*(1), 229-234.

Hallegatte, S. (2009). Strategies to adapt to an uncertain Climate Change, *Global Environmental Change*, 19(2), 240-247.

Hatfield, J. L., Boote, K. J., Kimball, B. A., Ziska, L. H., Izaurralde, R. C., Ort, D., & Wolfe, D. (2011). Climate impacts on agriculture: implications for crop production. *Agronomy journal*, *103*(2), 351-370.

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: effect on plant growth and development. *Weather and Climate Extremes*, *10*, 4-10.

Intergovernmental Panel on Climate Change (2013), *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*.

Intergovernmental Panel on Climate Change (2014). Climate Change Impacts, Adaptation, and Vulnerability Part B: Regional Aspects, *Intergovernmental Panel on Climate Change*. Fifth Assessment Report.

Intergovernmental Panel on Climate Change (2014). Synthesis Report. *Intergovernmental Panel on Climate Change*. Fifth Assessment Report.

Kapshe, MM. (2002). Integrated Assessment of Energy and Environment Policy: Mitigation Impacts and Adaptation, *FPM Thesis*, Indian Institute of Management, Ahmedabad.

Karl, T. R., R. W. Knight, D. R. Easterling, and R. G. Quayle (1996), Indices of Climate Change for the United States, *Bull. Am. Meteorol. Soc.*, *77*(2), 279–292, doi:10.1175/1520-0477(1996)077<0279:IOCCFT>2.0.CO;2.

Kim, H. Y., Horie, T., Nakagawa, H., & Kuniyuki, W. A. D. A. (1996). Effects of elevated CO_2 concentration and high temperature on growth and yield of rice: II. The effect on yield and its components of Akihikari rice. *Japanese Journal of Crop Science*, *65*(4), 644-651.

Kumar, K. R., K. K. Kumar, and G. B. Pant (1994), Diurnal asymmetry of surface temperature trends over India, *Geophys. Res. Lett.*, *21*(8), 677–680.

Kumar, K. K., K. Kamala, B. Rajagopalan, M. P. Hoerling, J. K. Eischeid, S. K. Patwardhan, G. Srinivasan, B. N. Goswami, and R. Nemani (2011), The once and future pulse of Indian monsoonal climate, *Clim. Dyn.*, *36*(11-12), 2159–2170.

Lobell, D. B., and G. P. Asner (2003), Climate and management contributions to recent trends in US agricultural yields, *Science*, *299*(5609), 1032–1032.

Lobell, D. B., and C. B. Field (2007), Global scale climate–crop yield relationships and the impacts of recent warming, *Environ. Res. Lett.*, *2*(1), 014002.

Lobell, D. B., M. B. Burke, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon, and R. L. Naylor (2008), Prioritizing climate change adaptation needs for food security in 2030, *Science*, *319*(5863), 607–610.

Lubroth J. Climate change and animal health. In: Meybeck A., Lankoski J., Redfern S., Azzu N., Gitz V. (Eds), *Building Resilience for Adaptation to Climate Change in the Agriculture Sector: Proceedings of a Joint FAO/OECD Workshop. Rome: FAO; 2012.* pp. 63–70.

Maurer, E. P., Wood, A. W., Adam, J. C., Lettenmaier, D. P., & Nijssen, B. (2002). A long-term hydrologically based dataset of land surface fluxes and States for the conterminous United States. *Journal of climate*, *15*(22), 3237-3251.

Mishra, V., and K. A. Cherkauer (2010), Retrospective droughts in the crop growing season: Implications to corn and soybean yield in the Midwestern United States, *Agric. For. Meteorol., 150*(7), 1030–1045.

Mishra, V., Smoliak, B. V., Lettenmaier, D. P., & Wallace, J. M. (2012). A prominent pattern of year-to-year variability in Indian Summer Monsoon Rainfall. *Proceedings of the National Academy of Sciences, 109*(19), 7213-7217.

Mishra, V., D. Kumar, A. R. Ganguly, J. Sanjay, M. Mujumdar, R. Krishnan, and R. D. Shah (2014a), Reliability of regional and global climate models to simulate precipitation extremes over India, *J. Geophys. Res. Atmospheres.*

Mishra, V., R. Shah, and B. Thrasher (2014b), Soil Moisture Droughts under the Retrospective and Projected Climate in India, *J. Hydrometeorol.*, 141006071153004, doi:10.1175/JHM-D-13-0177.1.

Mishra, V. (2015), Climatic uncertainty in Himalayan water towers, *J. Geophys. Res. Atmospheres, 120*(7), 2689–2705.

Mishra, V., & Lilhare, R. (2016). Hydrologic sensitivity of Indian sub-continental river basins to climate change. *Global and Planetary Change, 139*, 78-96.

National Planning Commission. (2013). National development plan vision 2030.

Pai, D. S., Sridhar, L., Badwaik, M. R., & Rajeevan, M. (2015). Analysis of the daily rainfall events over India using a new long period (1901–2010) high resolution (0.25× 0.25) gridded rainfall data set. *Climate Dynamics, 45*(3-4), 755-776.

Peel, M. C., Finlayson, B. L., & McMahon, T. A. (2007). Updated world map of the Köppen-Geiger climate classification. *Hydrology and Earth System Sciences Discussions*, 4(2), 439-473.

Planning Commission (2013). Infrastructure Funding Requirements and its Sources over the implementation period of the Twelfth Five Year Plan (2012- 2017). Working Sub-Group on Infrastructure. Prepared for Working Sub-Group on Infrastructure Under Working Group on Savings Formulation of the Twelfth Five Year Plan. Planning Commission. Government of India.

Ramanathan, V., C. Chung, D. Kim, T. Bettge, L. Buja, J. T. Kiehl, W. M. Washington, Q. Fu, D. R. Sikka, and M. Wild (2005), Atmospheric brown clouds: Impacts on South Asian climate and hydrological cycle, *Proc. Natl. Acad. Sci. U. S. A., 102*(15), 5326–5333.

Rupa Kumar, K., A. K. Sahai, K. Krishna Kumar, S. K. Patwardhan, P. K. Mishra, J. V. Revadekar, K. Kamala, and G. B. Pant (2006), High-resolution climate change scenarios for India for the 21st century, *Curr. Sci., 90*(3), 334–345.

Schlenker, W., W. M. Hanemann, and A. C. Fisher (2007), Water availability, degree days, and the potential impact of climate change on irrigated agriculture in California, *Clim. Change, 81*(1), 19–38.

Schenker, W. A., Inauen, M. and Olivares, M. (2010). Unmastered risks: From crisis to catastrophe: An economic and management insight, *Journal of Business Research*, 63(4), 337-346.

Schmidhuber, J., and F. N. Tubiello (2007), Global food security under climate change, *Proc. Natl. Acad. Sci., 104*(50), 19703–19708.

Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association, 63*(324), 1379-1389.

Sheffield, J., Goteti, G., & Wood, E. F. (2006). Development of a 50-year high-resolution global dataset of meteorological forcings for land surface modeling. *Journal of Climate, 19*(13), 3088-3111.

Sheffield, J., and E. F. Wood (2008), Global trends and variability in soil moisture and drought characteristics, 1950-2000, from observation-driven simulations of the terrestrial hydrologic cycle, *J. Clim.*, *21*(3), 432–458.

Stern, N. (2007). The Economics of Climate Change: The Stern Review, *Cambridge University Press.*

Tanaka, S. K., T. Zhu, J. R. Lund, R. E. Howitt, M. W. Jenkins, M. A. Pulido, M. Tauber, R. S. Ritzema, and I. C. Ferreira (2006), Climate warming and water management adaptation for California, *Clim. Change*, *76*(3-4), 361–387.

Taylor, K. E., Stouffer, R. J., & Meehl, G. A. (2012). An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society*, *93*(4), 485-498.

Thrasher, B., Xiong, J., Wang, W., Melton, F., Michaelis, A., & Nemani, R. (2013). Downscaled climate projections suitable for resource management. *Eos, Transactions American Geophysical Union*, *94*(37), 321-323.

United Nations Environment Programme (2014). *The Adaptation Gap Report 2014*. United Nations Environment Programme.

United Nations Framework Convention on Climate Change (2009), Copenhagen Commitments. *United Nations Framework on Climate Change*, Denmark.

United Nations Framework Convention on Climate Change (2010), Cancun Agreements. *United Nations Framework on Climate Change*, Mexico.

United Nations Framework Convention on Climate Change (2011), Durban Outcomes. *United Nations Framework on Climate Change*, South Africa.

United Nations Framework Convention on Climate Change (2013), Warsaw Agreements. *United Nations Framework on Climate Change*, Poland.

United Nations Framework Convention on Climate Change (2015), Lima call for Climate Action. *United Nations Framework on Climate Change*, Peru.

Van Vuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., & Masui, T. (2011). The representative concentration pathways: an overview. *Climatic change*, *109*(1-2), 5.

World Meteorological Organization (2005), *Report of the meeting of the implementation coordination team on climate change/ variability and natural disasters in agriculture*, Commission for Agricultural meteorology, WMO, Geneva, Auckland, New Zealand.

Wood, A. W., Maurer, E. P., Kumar, A., & Lettenmaier, D. P. (2002). Long-range experimental hydrologic forecasting for the eastern United States. *Journal of Geophysical Research: Atmospheres*, *107*(D20).

Wood, A. W., Leung, L. R., Sridhar, V., & Lettenmaier, D. P. (2004). Hydrologic implications of dynamical and statistical approaches to downscaling climate model outputs. *Climatic change*, *62*(1-3), 189-216.

Yatagai, A., Kamiguchi, K., Arakawa, O., Hamada, A., Yasutomi, N., & Kitoh, A. (2012). APHRODITE: Constructing a long-term daily gridded precipitation dataset for Asia based on a dense network of rain gauges. *Bulletin of the American Meteorological Society*, *93*(9), 1401-1415.