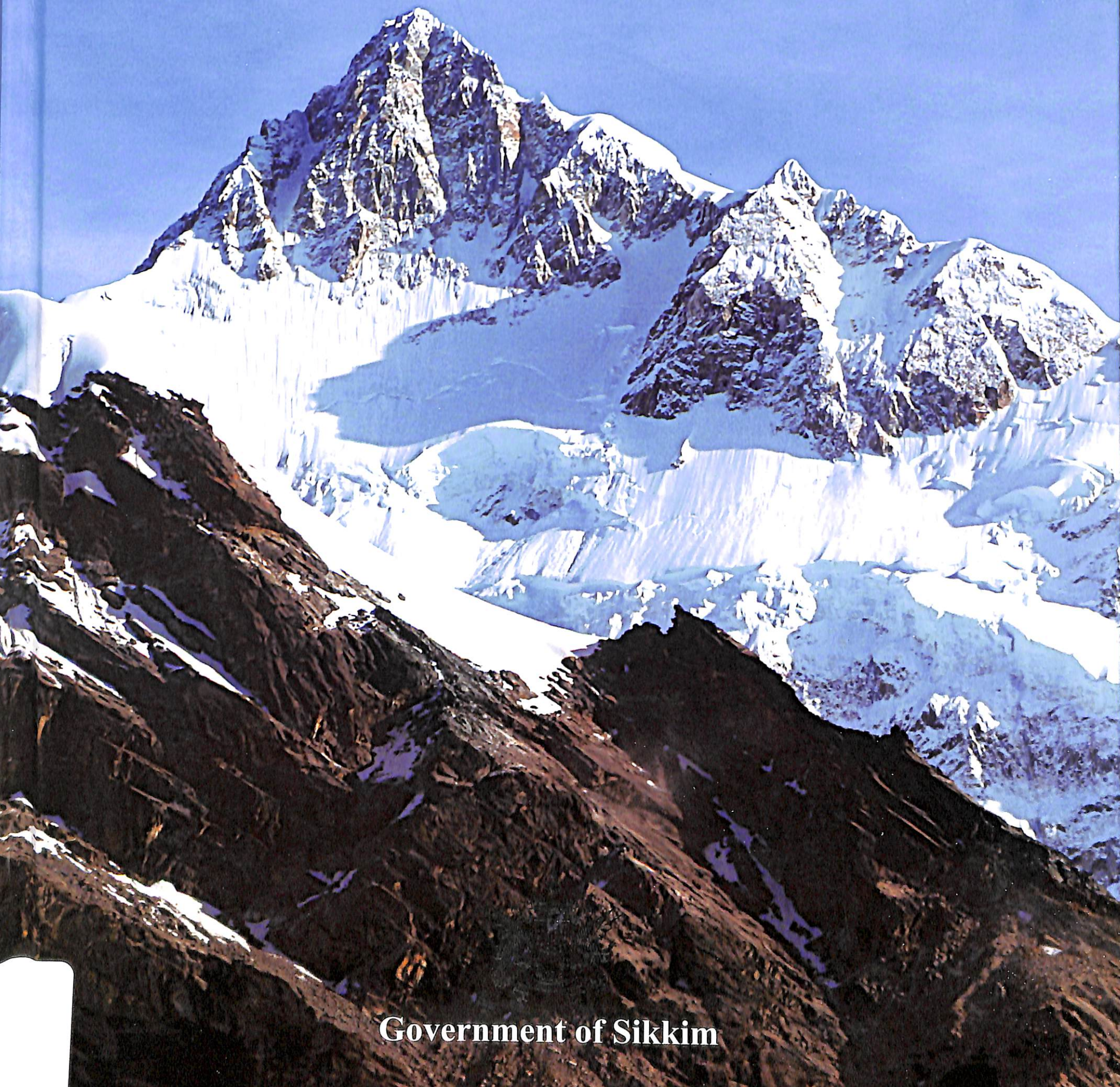


# **Climate Change in Sikkim**

**Patterns, Impacts and Initiatives**



**Government of Sikkim**



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# Climate Change in Sikkim

## Patterns, Impacts and Initiatives

### Editors

M. L. Arrawatia, IFS (Retd.)  
Sandeep Tambe, IFS



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# Climate Change in Sikkim Patterns, Impacts and Initiatives

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**Front cover:** Mt. Khangchendzonga, the third highest peak in the world (8,598 m) dominates the Sikkim landscape and is regarded as the guardian deity

**Front spread:** Semi-frozen Sungmoteng Tso glacial lake (also known as Samiti lake) in the Khangchendzonga National Park. There are more than 500 lakes in the state which provide vital ecosystem services and a few also serve as favourite tourist destinations

**Inner before title:** Gochela Peak, adjacent to Mt. Khangchendzonga is a favoured high altitude trekking destination

**Back cover:** Mountain women have traditional knowledge to adapt to changing climatic conditions

**Back inner:** The Teesta river has carved out a gorge and along with its tributaries provides vital hydrological, recreational, economic and ecosystem functions

**Back spread:** *Rhododendron campylocarpum* - Sikkim is home to as many as 38 species of Rhododendrons, many of which occur in the alpine zone and are sensitive to changes in climate

**Disclaimer:** The views and information provided by the various authors in this book are entirely their own and do not necessarily reflect the views of the Government of Sikkim

**Online release:** This book is also available online at : [www.sikervis.nic.in/climate-change-in-sikkim](http://www.sikervis.nic.in/climate-change-in-sikkim)

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**Pawan Chamling**  
(*Honoris Causa*)  
Chief Minister of Sikkim

## FOREWORD

Climate change is emerging as a new challenge that governments have to address effectively. Mountain regions are facing accelerating climate change, thereby adversely impacting ecosystems services, biodiversity elements and livelihood security. Mountain ecosystems due to their sensitive and fragile nature act as a laboratory where the impacts of climate change get amplified and can be studied closely and understood better. Impacts on mountain ecosystems are diverse and include receding glaciers, reduced snowfall, frequent natural hazards, higher surface runoff and soil erosion and declining lean season base-flow of rivers, streams and springs. Biodiversity gets affected due to phenology changes, reduced food availability in the wild, forest fires, degradation in habitat quality and even extinction. Also, livelihood security gets compromised due to reduced productivity, water shortage, increased pest attacks, weed infestation and depredation by wildlife.

The strategy to combat climate change impacts will involve a greater use of science in decision making, new multi-sectoral institutional mechanisms and innovative use of financial resources. Rural areas where livelihoods are sensitive need to be addressed first. Activities related to conserving springs, streams and lakes, supplementing recharge of underground aquifers and better water storage infrastructure need to be prioritized. The rainwater harvesting potential of forest lands needs to be fully utilized and wider opportunities for non-farm employment need to be provided in rural areas.

We have initiated a number of scientific studies to better understand climate change in the local context, established institutional mechanisms for implementing multi-sectoral programs, undertaken resource survey of water sources, taken up large-scale construction of water storage tanks at household and community level, initiated revival of springs, streams and lakes, expanded the network of minor irrigation channels and torrent control measures, ensured universal sanitation, strengthened the last mile delivery of social assistance and safety net programs, undertaken climate change related vulnerability assessment at Gram Panchayat level, launched the State Green Mission, the Sikkim Organic Mission and the Ten Minutes to Earth annual programme. Also the State Action Plan for Climate Change has been prepared after detailed multi-stakeholder consultations.

Our rich mountain ecosystems, glaciers, lakes and forests are all held sacred and revered as a sacred landscape by our people. My Government has been sensitive to the challenges that are impacting these systems due to global warming and climate change. We are conscious and alert to the fact that these mountains and forests are a water reservoir for not only our people but also our countrymen across in the plains.

This book contains articles detailing the patterns of climate change, signals and indications, impacts on livelihoods, ecosystems and biodiversity and vulnerability and adaptation experiments. I am confident that this book will help to highlight this important global issue. At a time when consensus in the global climate change debate is still awaited, nations and states should not miss the opportunity to act locally and effectively to safeguard the long term interests of their citizens.

(Pawan Chamling)

Dated: 1<sup>st</sup> August 2012



## PREFACE

The Himalayas are under impact of rapid climate change, adversely impacting the mountain ecosystems, rich biodiversity and sensitive livelihoods. Being a new, external threat, local communities are also not fully prepared to combat and adapt satisfactorily. Studies of long term weather data indicate that climate change in Sikkim is manifested in the form of reduction in the temporal spread of rainfall, rise in its intensity and frequent winters droughts. Nights have become warmer and days cooler, with increase in the minimum and decrease in maximum temperatures. Major environmental impacts are manifested in the form of receding glaciers, declining lean season base flow of rivers, streams and springs, higher surface runoff, reduced groundwater recharge, ascending and more frequent forest fires, upward shifting of tree line and snow line, shortages in food availability in the wild, increased man-animal conflicts and disturbed phenology of flowering and fruiting.

Climate change discussions which were earlier restricted to academic circles are now taking place amongst farmer's clubs, elected representatives, development institutions and donor agencies. Mountain farming is facing higher risk due to declining productivity of cash crops, long winter droughts, difficulty in seed storage and increased pest attacks. Also farmers have to cope with a higher frequency of extreme weather events like hailstorms, landslides and flash floods. Consequently, the production of important cash crops like large cardamom, ginger, orange and fruits has declined, while crops such as maize, broom grass and turmeric are found to be more resilient. Local communities are coping by improving the water storage infrastructure and storing spring water overnight in tanks and containers. Crop residue is being stored for use as winter fodder for livestock and seed bank expanded and new preservation methods tried out. There is now a greater participation in off-farm employment opportunities in rural areas.

The Chief Minister of Sikkim – Shri Pawan Chamling has been sensitive to this emerging threat and proactive steps are already underway to mainstream climate change adaptation in the development planning of the State. Scientific studies, adaptation programs, multi-sectoral institutional mechanisms and village consultations have been organized to better understand and tackle this threat. The State has taken several pioneering steps in the field of climate change:

- Identifying a nodal department for climate change and setting up of the Sikkim State Council of Climate Change for providing policy direction for effective implementation of various climate change programs.
- Constituting the glacier and climate change commission under the aegis of which several studies have been taken up in collaboration with various Central Government institutes. To better understand the climate change impacts, the state has proactively taken up studies in collaboration with national institutions on glaciers and different aspects of climate change. Studies related to wetland mapping, snow cover mapping, forest fire impacts have also been taken up.
- The State Action Plan on Climate Change has been prepared after detailed multi-sectoral consultations and village PRAs in consonance with the National Action Plan on Climate Change and is currently under review by the Ministry of Environment and Forests, Government of India.
- Sikkim is the first state to complete a pan-state, micro-level climate change related vulnerability assessment of the rural communities at the Gram Panchayat level. This study found that the subtropical villages (less



than 1000m) especially in the drought prone zone are more vulnerable due to an increased outbreak of pest, disease and weeds. Spring water sources are drying up and preservation of seeds during the warm winter is becoming risky. A high variation was found in the sensitivity and adaptive capacity due to the diverse developmental profile of the villages. Hence while climate change adaptation related developmental interventions need to have a diverse sectoral profile, however they must geographically target areas with specific interventions.

- Mountain springs emanating naturally from unconfined aquifers are the primary source of water for the rural households in the Himalayan region. With impacts of climate change, manifested in the form of rising temperatures, rise in rainfall intensity, reduction in its temporal spread and a marked decline in winter rain, the problem of drying springs is being increasingly felt across this region. The lean period (mar-may) discharge is perceived to have declined by nearly 50% in drought prone areas and 35% in other areas over the last decade. Action research has been initiated to revive drying springs, streams and lakes under the *dhara vikas* initiative using rainwater harvesting and geohydrology techniques and is showing encouraging results.

This book which has been packaged as an academic coffee-table book is second in the series after *Biodiversity of Sikkim*, and is a compilation of a diverse set of articles from eminent scholar and academicians. The articles include patterns of climate change, signals and indications, historical perspective, impacts of climate change on forests, glaciers, lakes, environment, flora, fauna, agro-biodiversity, indigenous livelihoods, vulnerability assessment, adaptation experiments and initiatives which are being up-scaled and mainstreamed in the ongoing development programs.

Most of the photographs have been contributed by the authors themselves, and the photo credits have been explicitly indicated only when others have done so. The synthesis article has been authored by renowned biodiversity expert - Dr. Kamaljit S. Bawa, Distinguished Professor at the Massachusetts Institute of Technology, Boston, USA. The whole book has also been made available online at the official website of the forest department - [www.sikervis.nic.in/climate-change-in-sikkim](http://www.sikervis.nic.in/climate-change-in-sikkim).

We are thankful to the Secretary, Information and Public Relations Department and the Chief Minister's Office for all assistance and cooperation provided in bringing out this publication. We would like to express our heartfelt thanks to all those who selflessly contributed in the making of this publication. This effort would have served its purpose if it brings about a clearer understanding of the global issue of climate change, which is emerging as the single biggest challenge for mankind.

**Place:** Gangtok

**Date:** 30<sup>th</sup> July, 2012

#### **Editors**

M. L. Arrawatia, IFS (Retd.)

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# CLIMATE CHANGE SYNTHETIC SCENARIO OVER GANGTOK

K. Seetharam

## ABSTRACT

Climate change studies have gained importance following the recent reports of Intergovernmental Panel on Climate Change (IPCC) and United Nations Framework Convention on Climate Change (UNFCCC) in regard to the increase in the extreme weather events and global warming. Climate change is evident all over the globe. Studies indicate small to large changes in the day temperatures, reduction in the diurnal variation of temperatures, small to large changes in the maximum and minimum temperatures and also changes in the rainfall amounts. Increase in the extreme weather events is also indicated. The studies were both on temporal and spatial scales. In order to assess the climate change scenario over Gangtok, the capital of Sikkim, a study has been conducted and the observed synthetic scenario is discussed in the light of the observations collected by the Meteorological Center, Gangtok for the period 1957-2005 with computed climatological normal's based on 30 years of meteorological data of 1951-80 and 1961-1990. In this paper, the study has been confined to changes in maximum temperature, minimum temperature and rainfall. The climatic variability in the five years period 2006-2010 has also discussed on the basis of climate change projections based on the study period.

**KEYWORDS:** *Maximum temperature, Minimum temperature, Diurnal variation in temperature, Climate variability*



Limited studies in a few localized areas indicate that the warming in the Himalayas is three times greater than the global average





Mt. Khangchendzonga - the guardian deity of Sikkim, is also the third highest peak in the world. Mountain ecosystems are especially sensitive and mountain communities vulnerable to the impacts of climate change



Increase in the greenhouse concentrations arising out of the human activities have been pin pointed as the culprits for observed rise in temperature around the globe. The changes that have been observed in the environment during last few decades are man-made. The predicted rise in temperature is more than 3°C by the end of the 21<sup>st</sup> century. Sea levels rose during the 20th century by 0.17 metres. By 2100, sea level is expected to rise between 0.18 and 0.59 metres. Intergovernmental Panel on Climate Change (IPCC) was able to conclude in a cautiously worded statement that “*the balance of evidence suggests that there is a discernible human influence on the climate*” (Attri 2006).

Carbon-di-oxide concentrations did not rise much above 280 parts per million by volume (ppmv) until the Industrial Revolution. By 1958, when systematic atmospheric measurements began, they had reached 315 ppmv, and they are currently ~370 ppmv and rising at a rate of 1.5 ppmv per year. The Methane Gas concentrations increased rather smoothly by about 1% per year from 1978, until about 1990. The rate of increase slowed and became more erratic during the 1990s. About two-thirds of the current emissions of methane are released by human activities such as rice growing, the raising of cattle, coal mining, use of land-fills, and natural gas handling, all of which have increased over the past 50 years. Additional ozone, created locally by the action of sunlight upon air polluted by exhausts from motor vehicles, emissions from fossil fuel burning power plants, and biomass burning. Nitrous oxide (N<sub>2</sub>O) is formed by many microbial reactions in soil and water, including those acting on the increasing amounts of nitrogen-containing fertilizers. Some synthetic chemical processes that release nitrous oxide have also been identified. Its concentration has increased approximately 13% in the past 200 years. Atmospheric concentrations of CFCs rose steadily following their first synthesis in 1928 and peaked in the early 1990s. Many other industrially useful fluorinated compounds (e.g. carbon tetrafluoride, CF<sub>4</sub>, and sulfur hexafluoride (SF<sub>6</sub>), have very long atmospheric lifetimes, which is of concern, even though their atmospheric concentrations have not yet produced large radiative forcings. Hydrofluorocarbons (HFCs), which are replacing CFCs, have a greenhouse effect, but it is much less pronounced because of their shorter atmospheric lifetimes.

Besides greenhouse gases, human activity also contributes to the atmospheric burden of aerosols, which include both sulphate particles and black carbon (soot). Both are unevenly distributed, owing to their short lifetimes in the atmosphere. Sulphate particles scatter solar radiation back to space, thereby offsetting the greenhouse effect to some degree.

The observed warming has not happened at a uniform rate. Virtually all the 20th century warming in global surface air temperature occurred between the early 1900s and the 1940s and during the past few decades. The troposphere warmed much more during the 1970s than during the two subsequent decades, whereas Earth's surface warmed more during the past two decades than during the 1970s (National Research Council). The causes of these irregularities and the disparities in the timing are not completely understood. The glacier is mostly considered as best indicators of climate change. The mass balance technique is the one that gives the difference between the snowmelt and the snowfall over the given area.

Climate change simulations for the period of 1990 to 2100 based on the IPCC emissions scenarios yield a globally-averaged surface temperature increase by the end of the century of 1.4 to 5.8°C relative to 1990. The wide range of uncertainty in these estimates reflects both the different assumptions about future concentrations of greenhouse gases and aerosols in the various scenarios considered by the IPCC and the differing climate sensitivities of the various climate models used in the simulations.

Most studies of potential climate change impacts have assumed changes in average climate conditions, but not in climate variability. These scenarios assume that only average annual or average monthly variables, such as



temperature and precipitation, change. Each day within a month or year is assumed to have the same absolute change in temperature and the same percentage change in precipitation. Thus, the pattern of daily climate and the inter-annual variability of climate stay approximately the same.

### **BASE LINE FOR CLIMATE CHANGE ASSESSMENT**

It is typical in impacts assessment to use a period of years of observed meteorological data to define a "current climate baseline". This set of years can be used to calibrate impact models and to quantify baseline climate impacts, e.g., crop yields under current climate. A 30-year continuous record of recent climate data is widely used for creating a baseline climate (Rosenzweig and Parry 1994). A 30-year period is likely to contain wet, dry, warm, and cool periods and is therefore considered to be sufficiently long to define a region's climate. The 30-year "normal" period as defined by the World Meteorological Organisation (WMO) is recommended by the Intergovernmental Panel on Climate Change (IPCC) for use as a baseline period (Carter et al. 1994). The current WMO normal period is 1961-1990. This period best defines current climate because it is recent. Since the quality and quantity of weather observations tend to improve over time, this period is likely to contain a more extensive network of observing stations and to record more variables than earlier periods. One problem with use of the 1961-1990 is however is that the 1980s were, globally, the warmest decade this century (Jones et al. 1994) although in some regions the 1980s were not warmer than prior decades. On an average, therefore, using 1961-1990 as a base period could introduce a warming trend into the baseline, which could bias the results of some impact assessments, particularly transient assessments that combine observed baseline climate with an underlying trend in climate variables. The trend is not a problem if one is reporting only averages and variances. Another recent 30-year period such as 1951-1980, which has no trends or less distinct trends, could perhaps be used. But earlier periods are more likely to have less comprehensive and poorer quality data. On balance, it is preferable to use the most recent period.

### **SYNTHETIC SCENARIOS**

Synthetic scenarios, sometimes referred to as arbitrary scenarios, are based on incremental changes in such meteorological variables as temperature and precipitation. For example, temperature changes of +2°C and +4°C can be combined with precipitation changes of 10 percent or 20 percent or no change in precipitation to create a synthetic scenario (Poiani and Johnson 1993). These incremental changes are usually combined with a baseline daily climate database to yield an altered 30-year record of daily climate. Synthetic scenarios usually assume a uniform annual change in temperature and other variables over a study area, although some studies have introduced temporal and spatial variability into synthetic scenarios. Some earlier developed different synthetic scenarios for annual average change in temperature and precipitation in wet and dry years in the Sahel and Venezuela (Robock et al. 1993). Some others developed different seasonal changes in temperature and precipitation patterns for the Czech Republic, but again applied them uniformly across the region (Kalvova and Nemesova 1995). Some more used different uniform changes in winter and summer temperature across climate zones of the United States (Rosenthal et al. 1995).

The main advantages of synthetic scenarios are their ease of use and transparency to policy makers and other readers of impacts studies. In addition, synthetic scenarios can capture a wide range of potential climate changes. One can examine small changes in climate 1°C up to large changes in climate 5°C to 6°C and one can examine increased and decreased precipitation scenarios. In addition, because individual variables can be changed independently of each other, synthetic scenarios also help identify the relative sensitivities of sectors to changes in specific meteorological variables. A further advantage of synthetic scenarios is that different studies can use the same synthetic scenarios to compare sensitivities. Synthetic scenarios are inexpensive, are quick and easy to construct, and generally require few computing resources. A major disadvantage of synthetic scenarios is that they may not be physically plausible.



Climate change indicates the change in average weather conditions over a place. The climate change can be limited to some geographical area or the climate change can extend to the whole of the globe. Climate change can be good to some or it could be bad to some. The increase in the frequency of tropical cyclones, increase in the sea level, more hotter atmosphere, increase in the snowfall area, increase in more intense rainfall events all these clearly indicate climate change. As studies indicate, climate change is a result of human activities on the globe rather than natural causes. The anthropogenic aspects include enormous pollution levels due to increase in industrialization and transportation. Other fields of human economic activities have contribution of their own.

### **CLIMATE CHANGE SCENARIO OVER INDIA**

The rainfall and temperature records from India Meteorological Department are available for more than 100 years and date back to the late nineteenth century. India Meteorological Department (IMD) maintains a well distributed network of more than 500 stations in the country for more than a century. The salient findings of the Indian Meteorological Department (IMD) studies (Attri 2006; Tyagi and Goswami 2009) are summarized as under:

#### **TEMPERATURE**

Analysis of data for the period 1901-2009 suggests that annual mean temperature for the country as a whole has risen by  $0.56^{\circ}\text{C}$  over the period. It may be mentioned that annual mean temperature has been generally above normal (normal based on period 1961-1990) since 1990. This warming is primarily due to rise in maximum temperature across the country, over larger parts of the data set. However, since 1990, minimum temperature is steadily rising and rate of its rise is slightly more than that of maximum temperature. Warming trend over globe of the order of  $0.74^{\circ}\text{C}$  has been reported by IPCC 2007.



The IPCC report predicts large scale changes in temperature and precipitation over the Asian land mass



Spatial pattern of trends in the mean annual temperature shows significant positive (increasing) trend over most parts of the country except over parts of Rajasthan, Gujarat and Bihar, where significant negative (decreasing) trends were observed. Season wise, maximum rise in mean temperature was observed during the Post-monsoon season (0.77°C) followed by winter season (0.70°C), Pre-monsoon season (0.64°C) and Monsoon season (0.33°C). During the winter season, since 1991, rise in minimum temperature is appreciably higher than that of maximum temperature over northern plains. This may be due to pollution leading to frequent occurrences of fog. Upper air temperatures have shown an increasing trend in the lower troposphere and this trend is significant at 850 hecto Pascal (hPa) level, while decreasing trend (not significant) was observed in the upper troposphere (Kothawale and Rupa Kumar 2002).

## PRECIPITATION TRENDS

The all India annual and monsoon rainfall for the period 1901-2009 does not show any significant trend. Similarly rainfall for the country as a whole for the same period for individual monsoon months also does not show any significant trend. The alternating sequence of multi-decadal periods of thirty years having frequent droughts and flood years are observed in the all India monsoon rainfall data. The decades 1961-70, 1971-80 and 1981-90 were dry periods. The first decade 1991-2000 in the next 30 years period already experienced wet period. However, during the winter season, rainfall is decreasing in almost all the subdivisions except for the sub-divisions of Himachal Pradesh, Jharkhand and Nagaland, Manipur, Mizoram and Tripura. Rainfall is decreasing over most parts of the central India during the pre-monsoon season. However during the post-monsoon season, rainfall is increasing for almost all the sub-divisions except for the nine sub-divisions. The analysis for the monthly rainfall series of June, July, August, and September (% variation) for all the 36 subdivisions (Guhathakurta and Rajeeva 2008) shows significant variations on the regional scale which are summarized as under:



Snow fall in the higher reaches is also reported to have declined



- June rainfall has shown increasing trend for the western and south - western parts of the country whereas decreasing trends are observed for the central and eastern parts of the country. Its contribution to annual rainfall is increasing in 19 subdivisions and decreasing in the remaining 17 subdivisions.
- The contribution of July rainfall is decreasing in central and west peninsular India (significantly in South interior Karnataka (95%), East M.P. (90%), Vidarbha (90%), Madhya Maharashtra (90%), Marathwada (90%), Konkan and Goa (90%), and North interior Karnataka (90%)), but has increased significantly in the north eastern parts of the country.
- In August, four (ten) subdivisions have shown decreasing (increasing) trends in rainfall. It has increased significantly (at 95% significance level) over the subdivisions Konkan and Goa, Marathwada, Madhya Maharashtra, Vidarbha, West M.P., Telangana and West U.P.
- September rainfall is increasing significantly (at 95% level of significance) in Gangetic West Bengal and decreasing significantly (at 90% level of significance) for the sub-divisions Marathwada, Vidarbha and Telangana. During the season, three subdivisions viz. Jharkhand (95%), Chattisgarh (99%), Kerala (90%) show significant decreasing trends and eight subdivisions viz. Gangetic WB (90%), West UP (90%), Jammu & Kashmir (90%), Konkan and Goa (95%), Madhya Maharashtra (90%), Rayalseema (90%), Coastal A.P. (90%) and North Interior Karnataka (95%) show significant increasing trends. The trend analyses of the time series of contribution of rainfall for each month towards the annual total rainfall for each year in percentages suggest that contribution of June and August rainfall exhibited significant increasing trends, while contribution of July rainfall exhibited decreasing trends.

However, no significant trend in the number of break and active days during the southwest monsoon season during the period 1951–2003 were observed (Rajeevan et al. 2006).

## **DATA AND METHODOLOGY**

The climatological normal of monthly mean maximum temperature, monthly mean minimum temperature and monthly total rainfall computed for 30 years period 1951-1980 and 1961-1990 in respect of station Gangtok has been taken out from the publication brought out by the National Data Center, India Meteorological Department, Pune and the last five years monthly mean maximum temperature, monthly mean minimum temperature and monthly total rainfalls have been collected from the archives of the Meteorological Center, India Meteorological Department, Gangtok. The long period average computed for the period 1957-2005 (Seetharam 2008) has been extracted from the paper.

## **RESULTS AND DISCUSSION**

The present climatic variability that is slow and steady may lead to a sudden climate change over a period of time. The climate change is of creeping nature like a drought. As is now understood, human activities like agriculture, production factories, burning of fossil fuels for transportation, deforestation, urban development are changing the micro climate that in turn is changing the climate. Now, plenty of evidence is available to ascertain climate change and also to reconstruct the past climate. In this article only the temporal variation observed in meteorological parameters like maximum temperature, minimum temperature and rainfall that are monthly aggregated are considered restricting the study to a single location.

Keeping the base line period to 1951-1980, in the next 30 years period 1961-1990 the annual maximum temperature dropped by 0.6 °C and on monthly scale the decrease is maximum in March (0.8 °C) and minimum in monsoon months of June and August (0.1 °C) when this decrease in maximum temperature has implications about relative humidity and cloudiness. The reasons for increase in cloudiness or humidity need



to be ascertained considering the weather systems influence or due to presence of aerosols that scatter the solar radiation back to space. The fall in maximum temperature may also indicate the warming in 80s or prior. The fall in maximum temperature in comparison with the average maximum temperature noticed in the period 1957-2005 substantiate the view the climate change is evident and visible and the continuance of trend and the magnitude of fall in maximum temperature is more. However, the fall in maximum temperature is quiet steady with an annual maximum temperatures dropping by 0.2°C in all the months after the period 1961-1990 even if the base line climate is taken as the latest one. The projected figures indicate likely continuity of the same trend with some decades or 30 years period showing more rapid fall in maximum temperatures. The drop in maximum temperature indicates cooler day time.

**Table 1:** Variation of maximum temperature over Gangtok in °C

Month	1951-80	1961-90	1957-2005	Change in temperature from 1951-80 to 1961-90	Change in temperature from 1961-90 to 1957-2005	Change in temperature from 1951-80 to 1957-2005	Projected figures based On 1957-2005
Jan	13.5	13.1	12.8	-0.4	-0.3	-0.7	-1
Feb	14.9	14.4	14.2	-0.5	-0.2	-0.7	-1.3
Mar	19.5	18.7	18.3	-0.8	-0.4	-1.2	-1.5
Apr	21.8	21.2	21	-0.6	-0.2	-0.8	-1.8
May	22	21.8	21.7	-0.2	-0.1	-0.3	-1.9
Jun	22.5	22.4	22.2	-0.1	-0.2	-0.3	-2
Jul	22.6	22.2	22	-0.4	-0.2	-0.6	-2
Aug	22.7	22.6	22.4	-0.1	-0.2	-0.3	-2.1
Sep	22.3	21.9	21.5	-0.4	-0.4	-0.8	-1.69
Oct	21.7	21.2	20.9	-0.5	-0.3	-0.8	-1.8
Nov	18.6	18	17.7	-0.6	-0.3	-0.9	-1.5
Dec	15.3	14.6	14.6	-0.7	0	-0.7	-1.2
<b>Annual</b>	<b>19.8</b>	<b>19.3</b>	<b>19.1</b>	<b>-0.6</b>	<b>-0.2</b>	<b>-0.7</b>	<b>-0.3</b>

Similar inferences can be drawn in case of minimum temperature also. In the 30 years period 1961-1990 in comparison with the 30 years period 1951-1980, the minimum temperature showed a falling trend with a drop in annual minimum temperature of 0.5°C along with maximum drop in minimum temperature in the month of April (0.7°C) and with a minimum drop in minimum temperature in the month of June and August (0.3°C). The figures substantiate the view the 80s were quiet warmer and subsequently the warming has slowed down. In comparison with the minimum temperature figures the minimum temperatures rose between 0.1°C – 0.3°C except in the month of April. Comparing the average figures of 1961-90 and 1951-1980 there is again an



increasing trend in minimum temperatures and the rise in minimum temperature is faster ranging from 0.5°C – 0.8°C. The projected figures based on 1957-2005 indicate further rise in minimum temperature that could be again a result of increase in humidity, increase in cloudiness or presence of green house gases during night either locally generated or transported from elsewhere.

The decrease in maximum temperature and increase in minimum temperature would mean a reduction in the diurnal variation that is decreasing at many locations globally. Decreases in the Diurnal Temperature Range (DTR) were first identified in the United States, where large-area trends show that maximum temperature has remained constant or has increased only slightly, whereas minimum temperature has increased at a faster rate. The possible reason could be increase in cloudiness possibly with an increase in the aerosols quantity in the atmosphere.

**Table 2:** Variation in minimum temperature over Gangtok in °C

Month	1951-80	1961-90	1957-2005	Change in temperature from 1951-80 to 1961-90	Change in temperature from 1961-90 to 1957-2005	Change in temperature from 1951-80 to 1957-2005	Projected figures based on 1957-2005
Jan	4.3	3.8	4.4	-0.5	0.6	0.1	0.6
Feb	5.7	5.1	5.7	-0.6	0.6	0	0.9
Mar	8.9	8.4	8.9	-0.5	0.5	0	1.1
Apr	11.9	11.2	11.7	-0.7	0.5	-0.2	1.3
May	13.7	13.2	13.8	-0.5	0.6	0.1	1.5
Jun	16	15.7	16.2	-0.3	0.5	0.2	1.8
Jul	16.8	16.3	16.8	-0.5	0.5	0	1.8
Aug	16.5	16.2	16.7	-0.3	0.5	0.2	1.9
Sep	15.5	15.1	15.6	-0.4	0.5	0.1	1.8
Oct	12.3	11.8	12.5	-0.5	0.7	0.2	1.5
Nov	8.7	8.1	8.8	-0.6	0.7	0.1	1.2
Dec	5.6	5.1	5.9	-0.5	0.8	0.3	0.8
<b>Annual</b>	<b>11.3</b>	<b>10.8</b>	<b>11.4</b>	<b>-0.5</b>	<b>0.6</b>	<b>0.1</b>	<b>0.2</b>

In case of rainfall, the comparison of figures of 1951-1980 and 1961-1990 indicate decrease in rainfall amount in the months of January, March, May, June, July and August and increase in rainfall in other months with an overall decrease in annual rainfall amount. This is indicative of the higher amounts of rainfall in 50s or less rainfall in 90s and overall decrease later in winter months, monsoon months and post monsoon months. The average annual rainfall in the period 1957-2005 is higher by 73 mm in comparison with that of the average annual rainfall in 1961-1990 indicative of the fact that the higher annual rainfalls in 50s with an increased winter rainfall, monsoon rainfall and post monsoon rainfall. However, monthly rainfall showed both increase



and decrease with substantial increase in rainfall in the month of June. Again, the comparison of rainfall figure of periods 1951-1980 and 1957-2005 suggest an increase in annual rainfall in the early decades of the 21<sup>st</sup> century. The projected figures are also indicative of the fact that the annual rainfall amounts will continue to rise further with increased rainfall activity especially in the monsoon months of July, August and October. The increase in annual total rainfall would indicate increase in thunderstorms in the months of April and May and heavy showers or thunderstorms again in July and August.

From Table 4 the Fig. 2 indicate a two percent increase in winter rainfall per decade, eighteen percent per decade, three percent increase in Southwest monsoon rainfall and fifteen percent per decade increase in the post monsoon season rainfall. On the whole, one percent increase in the annual rainfall is observed.

**Table 3: Variation in rainfall (mm) over Gangtok**

Month	1951-80	1961-90	1957-2005	Change in Rainfall from 1951-80 to 1961-90	Change in Rainfall from 1961-90 to 1957-2005	Change in Rainfall from 1951-80 to 1957-2005	Projected figures based on 1957-2005
Jan	40.4	25.5	32.6	-14.9	7.1	-7.8	-2.7
Feb	50.2	58.6	62.6	8.4	4	12.4	6.5
Mar	127.1	107.4	135.5	-19.7	28.1	8.4	-12.7
Apr	270.5	308.7	270.3	38.2	-38.4	-0.2	44.6
May	534.7	533.0	523.9	-1.7	-9.1	-10.8	50.7
Jun	650.4	590.9	630.9	-59.5	40	-19.5	-56
Jul	666.4	662.0	658.0	-4.4	-4	-8.4	67.9
Aug	578.2	552.2	578.9	-26	26.7	0.7	62.3
Sep	429.3	481.5	464.6	52.2	-16.9	35.3	-41.7
Oct	180.3	160.7	175.6	-19.6	14.9	-4.7	20.8
Nov	35.8	36.8	40.0	1.0	3.2	4.2	-2
Dec	17.2	21.6	21.2	4.4	-0.4	4	1.8
Annual	3580.5	3538.9	3611.7	-42	73	31	49.6



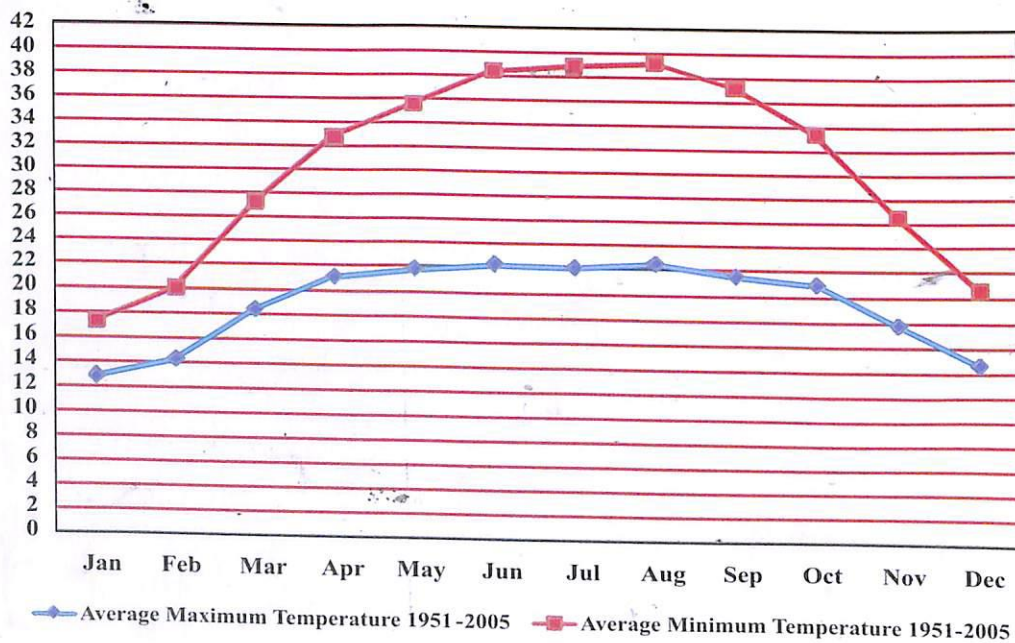


Dikchu river a tributary of the Teesta flowing down the subtropical landscape



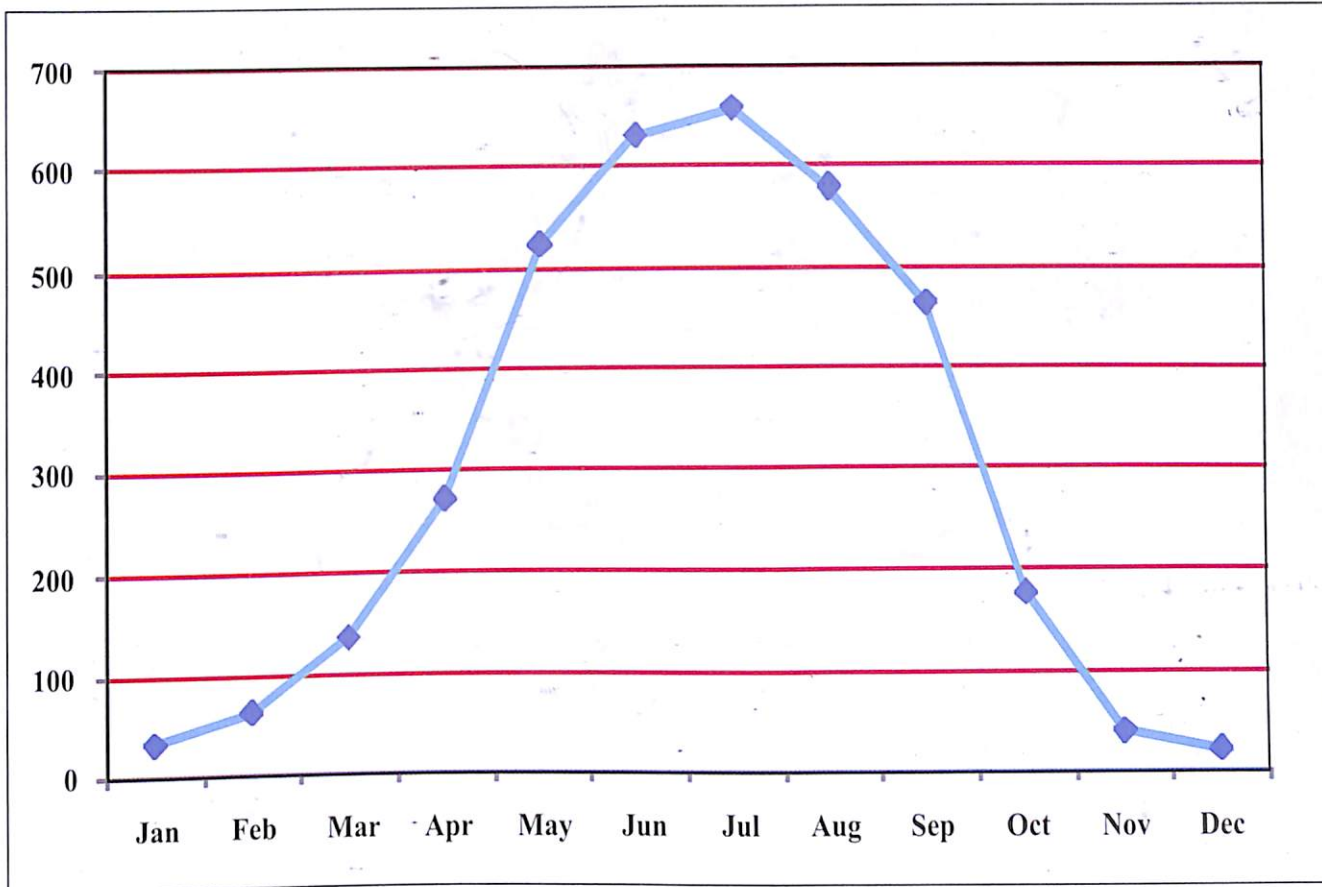
**Table 4:** Variation in rainfall (in percentage) over Gangtok

Month	1951-80	1961-90	1957-2005	Change in Rainfall from 1951-80 to 1961-90 (in percentage)	Change in Rainfall from 1961-90 to 1957-2005 (in percentage)	Change in Rainfall from 1951-80 to 1957-2005 (in percentage)	Projected change in Rainfall based on 1957-2005 (in percentage)
Jan	40.4	25.5	32.6	-37	28	-19	-8
Feb	50.2	58.6	62.6	17	7	25	10
Mar	127.1	107.4	135.5	-15	26	7	-9
Apr	270.5	308.7	270.3	14	-12	0	17
May	534.7	533	523.9	0	-2	-2	10
Jun	650.4	590.9	630.9	-9	7	-3	-9
Jul	666.4	662	658	-1	-1	-1	10
Aug	578.2	552.2	578.9	-4	5	0	11
Sep	429.3	481.5	464.6	12	-4	8	-9
Oct	180.3	160.7	175.6	-11	9	-3	12
Nov	35.8	36.8	40	3	9	12	-5
Dec	17.2	21.6	21.2	26	-2	23	8
Annual	3580.5	3538.9	3611.7	-1	2	1	1



**Fig. 1:** Average monthly maximum and minimum temperature (°C) from 1957-2005.





**Fig. 2:** Average monthly total rainfall (mm) 1957-2005

Vegetation has transpirational and evaporational influences in the area it inhabits, affecting the surface energy budget. The presence of vegetation, as compared to bare soil, modulates the diurnal temperature cycle. During the day, transpiring vegetation partitions a greater portion of the incoming solar energy into latent heat, decreasing the maximum temperature. At night, the vegetated area radiates energy and allows condensation, increasing the minimum temperature via latent heat release (Hanamean et al. 2003).

#### **Last five years climate variability**

The study was based on the long period averages calculated in study and the projected figures in trend per decade as indicated in Tables 1 to 4 (Seetharam 2008). The last five year climate variability assessment (2006-2010) has shown that there is a marked decrease in rainfall in almost all the seasons and warmer nights and cooler days with increase in minimum temperature and decrease in maximum temperature respectively. It is also seen that there is a small decrease in maximum temperature ( $<1^{\circ}\text{C}$ ) but more marked increase in the minimum temperature (around  $2^{\circ}\text{C}$ ). The warming is more pronounced in winter even though considerable warming has been observed in other seasons too. The more cooling of days has been observed in the months of November and December (early winter in high latitudes). Coming to the rainfall, as most of the rainfall series do not exhibit any trends but alternating wet or dry periods, it can be inferred that the period 2006-2010 is exceptionally dry in months October to February and in the month of May in comparison with the long period averages for these months and the period 2006-2010 (last five years) could as well be followed by a wet period. On annual time scale, the rainfall decreased by about 9% with a small maximum temperature change of ( $0.2^{\circ}\text{C}$ ) and change in the minimum temperature is considerable with  $1.6^{\circ}\text{C}$ . The figures are depicted in Table 5.



**Table 5:** Observed trends in climate during the five years period 2006-2010

Month	% change in Precipitation	Change in Maximum Temperature (in °C)	Change in Minimum Temperature (in °C)
January	-79	0.4	2.2
February	-30	0.5	2.0
March	-7	-0.1	1.8
April	18	-0.3	1.6
May	-24	0.2	1.4
June	-7	-0.3	1.3
July	-7	-0.2	1.3
August	0	-0.4	1.1
September	-9	0.0	1.2
October	-24	-0.3	1.7
November	-41	-0.9	1.8
December	-44	-0.7	1.8
Annual	-9	-0.2	1.6



Sub-alpine ecosystems are sensitive to impacts from ascending forest fires, invasive species and water stress due to climate change





Lhonak river flowing down the glaciated trans-himalayan valley in Muguthang, North Sikkim



## IMPACT ASSESSMENT

Climate change will have wide-ranging effects on the environment, and on socio-economic and related sectors, including water resources, agriculture and food security, human health, terrestrial ecosystems and biodiversity and coastal zones. Adaptive capacity of many places is more for small changes. Changes in rainfall pattern are likely to lead to severe water shortages or flooding. Melting of glaciers can cause flooding and soil erosion. Rising temperatures will cause shifts in crop growing seasons which affects food security and changes in the distribution of disease vectors putting more people at risk from diseases such as malaria and dengue fever. Temperature increase will potentially severely increase rates of extinction for many habitats and species (up to 30 per cent with a 2°C rise in temperature). IPCC has recently concluded that, while there is extensive potential to adapt to small amounts of warming, and that the next few decades might even bring benefits to higher latitudes through longer growing seasons, at lower latitudes even small amounts of warming would tend to decrease yields and, beyond about 2°C of warming would decrease yields in almost all parts of the world (IPCC 2007).

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Study team on the Narsing glacier in West Sikkim. Findings of recent glacial studies in the Indian Himalayas reveal that during the last three decades of 20th century, degeneration of the glacier mass has been the highest in Jammu & Kashmir, relatively lower in Himachal Pradesh, even lower in Uttarakhand and the lowest in Sikkim, thus clearly showing a declining trend from north-west to north-east