# 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$^{o}$C by the end of the 21$^{st}$ 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 ($N_2O$) 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, $CF_4$, and sulfur hexafluoride ($SF_6$), 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$^{o}$C and +4$^{o}$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$^{o}$C up to large changes in climate 5$^{o}$C to 6$^{o}$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 $0.56^0$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 $0.74^0$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 ($0.77^0$C) followed by winter season ($0.70^0$C), Pre-monsoon season ($0.64^0$C) and Monsoon season ($0.33^0$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 $^{O}$C and on monthly scale the decrease is maximum in March (0.8 $^{O}$C) and minimum in monsoon months of June and August (0.1 $^{O}$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 |
| **Annual** | **19.8** | **19.3** | **19.1** | **-0.6** | **-0.2** | **-0.7** | **-0.3** |

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$^{o}$C – 0.8$^{o}$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 $^{O}$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 |
| **Annual** | **11.3** | **10.8** | **11.4** | **-0.5** | **0.6** | **0.1** | **0.2** |

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 21st 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 | 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 | 658 | -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 | 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** |

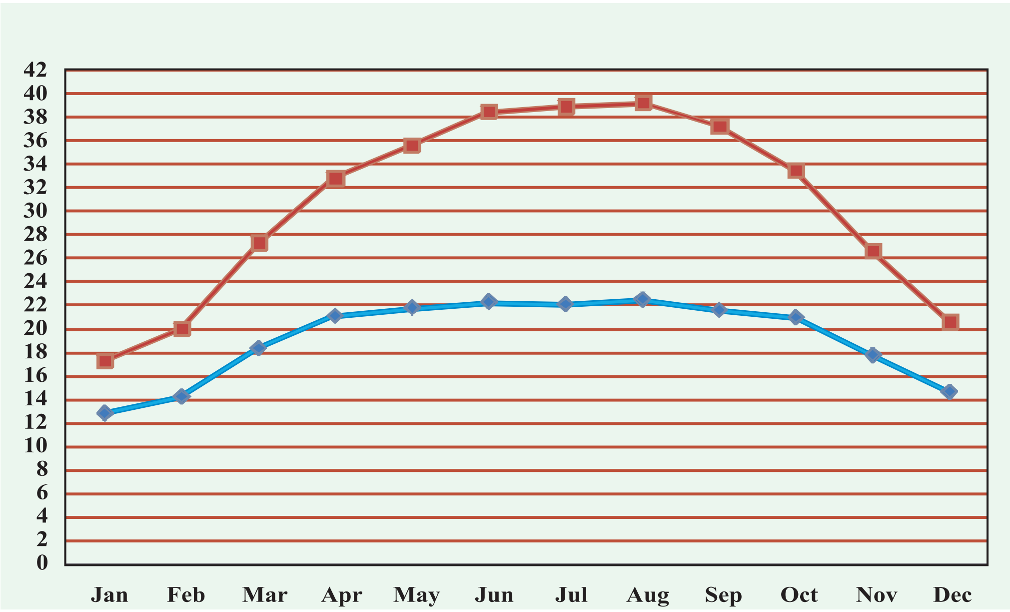


**Fig. 1:** Average monthly maximum and minimum temperature ($^{O}C$) from 1957-2005

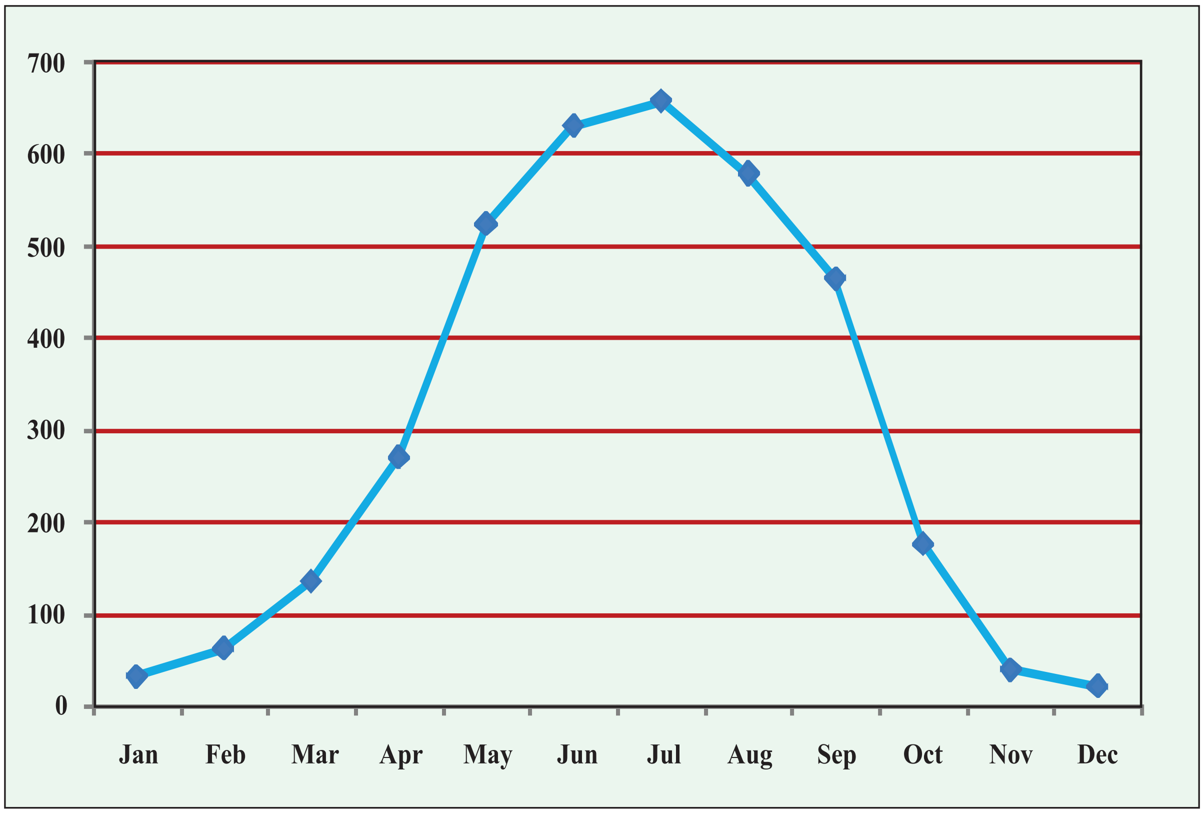


**Fig. 2:** Average monthly total rainfall (mm) 1957-2005

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$^{o}$C) but more marked increase in the minimum temperature (around 2$^{o}$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$^{o}$C) and change in the minimum temperature is considerable with 1.6$^{o}$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 $^0$C) | Change in Minimum Temperature (in $^0$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).


## ACKNOWLEDGEMENTS

The author hereby acknowledges his sincere gratitude for the constant persuasion, support and encouragement of Shri M.L.Arrawatia, the then Secretary, Department Science & Technology and Climate Change, Government of Sikkim that led to the materialization of this article.


## REFERENCES


Attri, S.D., 2006, “Climate Change and Agriculture-An overview”, Vayu Mandal, 32 (3-4), 10-26.

Carter, T.R., M.L. Parry, H. Harasawa, and S. Nishioka. 1994. IPCC Technical Guidelines for Assessing Climate Change Impacts and Adaptations. Department of Geography, University College, London.

Climate change Science, an analysis of some key questions, committee on the science of climate change, division of Earth and life sciences, National Research Council, National Academy Presss, Washington, D.C.

Guhathakurta, P. and Rajeevan, M., 2008; “Trends in the rainfall pattern over India”, Int. J. Clamoto. 28:1453-1469

Hanamean Jr. J R, Pielke Sr. R A , Castro1 C L, Ojima D S, Reed B C and Gao Z, 2003, Vegetation greenness impacts on maximum and minimum temperatures in northeast Colorado, Meteorol. Appl. 10, 203–215

IPCC, 1996, Working Group II Report, Inter-governmental Panel on Climate Change. Cambridge University Press, New York.

IPCC. 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability- Contribution of Working Group II to the IPCC Fourth Assessment, Cambridge University Press, Cambridge.

Jones, P.D., T.M.L. Wigley, and K.R. Briffa. 1994. Global and hemispheric temperature anomalies — land and marine instrumental records. In Trends ‘93: A Compendium of Data on Global Change, T.A. Boden, D.P. Kaiser, R.J. Sepanski, and F.W. Stoss (eds). ORNL/CDIAC-65. Oak Ridge National Laboratory, Oak Ridge, Tennessee, USA.

Kothawale, D.R. and Rupa Kumar, K., 2002, “Tropospheric temperature variation over India and links with the Indian Summer Monsoon”, Mausam, 2002, 53, 3,289-308

Kalvova, J. and I. Nemesova. 1995. Czech Republic Climate Change Scenarios. Charles University, Prague. Mimeograph.

Poiani, K. A. and W.C. Johnson. 1993. Potential effects of climate change on a semipermanent prairie wetland. Climatic Change 24, 213-232.

Rajeevan, M., Jyoti, B., Kale, J.D. and Lal, B., 2006, High resolution daily gridded rainfall data for the Indian region: Analysis of break and active monsoon spells, Current Science, Vol. 91, No. 3.

Robock, A., R.P. Turco, M.A. Harwell, T.P. Ackerman, R. Andressen, H.S. Chang, and M.V.K. Sivakumar. 1993. Use of general circulation model output in the creation of climate change scenarios for impact analysis. Climatic Change 23, 293-335.

Rosenthal, D.H., H.K. Gruenspecht, and E.A. Moran. 1995. Effects of global warming on energy use for space heating and cooling in the United States. Energy Journal 16(1), 41-54

Rosenzweig, C. and M.L. Parry. 1994. Potential impact of climate change on world food supply. Nature 367, 133-138.

Seetharam, K., Climate change scenario over Gangtok. Letters to the editor. Meteorological center, Gangtok, Indian Meteorological Department, India. *Mausam*, 2008, **59**(3), 361–366.

Tyagi, A and Goswami, B.N., 2009, Assessment of Climate change and adaptation in India , Climate Sense, 68-70

## AUTHOR

**K.Seetharam**
India Meteorological Department,
Meteorological Center, Hyderabad
Email: drsridharseetharaman@gmail.com

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