CHAPTER 3

CLIMATE CHANGE AND TEMPERATURE

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3.0 Introduction

The 'Climate Change is Real' and 'the temperatures are rising' worldwide. There is a sense of mutual agreement among the world's leading climate agencies about this 'Change' as shown in Figure 3.1. About 97% of the research papers published in the field of climate science agree that the humans are the real drivers of the global warming and the climate change in recent times (Cook et al., 2016). The Paris Agreement (United Nations Framework Convention on Climate Change, UNFCCC, 2015) is specifically materialised and executed for developing effective plans for mitigating the greenhouse gases (GHGs)emissions and limit the global average temperature increase up to 1.5^{0}C above pre-industrial levels to avert the adverse and catastrophic impacts of climate change worldwide. India is also committed to achieve the emission reduction targets through reducing emission rates by 2030 and utilizing more of the non-fossil fuels and through carbon sequestration, increasing forest cover and changing land use land cover (LULC), particularly in agricultural sector.

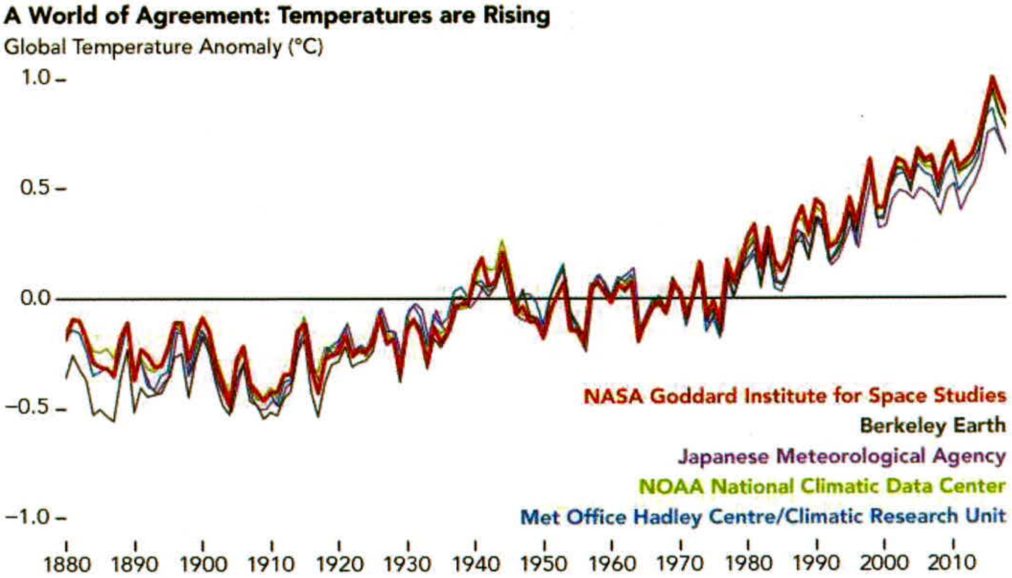

***Figure 3.1**: The rising temperatures (Source: https://climate.nasa.gov/scientific-consensus/)*

India has 17.5% of the world's population but occupies only 2.4% of the land resources and 4% of the water resources of the planet as a whole. India has agrarian economy and about 60% of the Indian agriculture is rainfed and hence the impacts of climate change on this sector will be far reaching on food and nutritional sustainability and has been placed at the 13th position among the most vulnerable countries to the climate change in the world. Notably, the temperature is one of the most important parameter of the climate system as a whole. The Assessment Report 5 (AR5) of the Intergovernmental Panel on Climate Change (IPCC, 2014) states that the surface temperature (ST) will increase during the 21st

century under all emission scenarios and will have daunting impacts on agriculture, land and water resources, environment, ecosystems, biodiversity and society as a whole as shown in Figure 3.2.

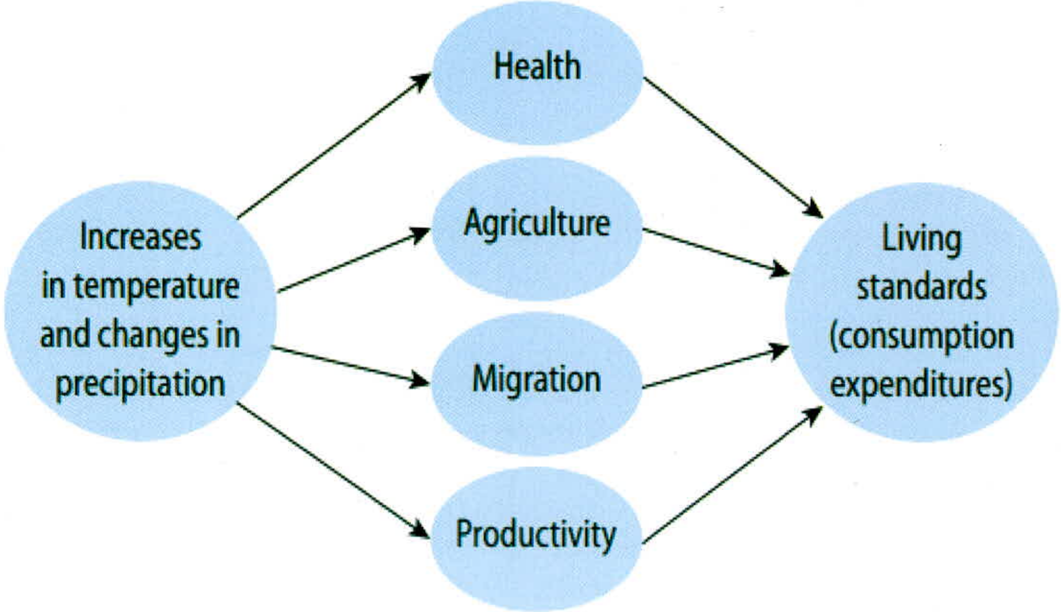

***Figure 3.2**: Interlinkages of climate change and different systems (Source: Mani et al., 2018)*

The anthropogenic influences on Earth's climate system are very pronounced and the emission of the GHGs (mainly Carbon dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), and fluorinated gases (F-gases) have increased since the pre-industrial era, which is largely attributed to the ever growing industrial, economic and other developmental activities coupled with the population growth (IPCC, 2014). Other than the land use land cover (LULC) change and anthropogenic aerosols, the GHGs are one of the most significant drivers of climate change phenomenon (IPCC, 2013), in which the CO_2 is the major component (73%) of GHGs followed by CH_4 (18%), N_2O (6%), and F-gases (3%).The CO_2 emissions from fossil fuels/energy are higher as compared to the other GHGs during the period of 1990-2017 (Figure 3.3). This rise in CO_2 concentrations is mainly attributed to the large scale industrialization (Olivier and Peters, 2018).

If we look at the climate history of the Earth relative to pre-industrial baseline (1850-1900) between evolution of life, global carbon cycle and temperature anomaly as shown in Figure 3.4 (Salawitch et al., 2017), the *Era 1* shows that there has been continuous increase of atmospheric CO2 due to anthropogenic activity leading to a temperature anomaly of 0.8^0C to 1.0^0C at a global scale. Notably, the climate change will be one of the greatest socio-environmental-economic threats to the entire world in the 21st century (Mahmood and Babel, 2014). The climate change phenomenon is unequivocal and has been accelerating since 1950s and the GHGs emissions are one of the major forcings/determinants impacting the change phenomenon at large. Most of the studies find that, if the current pace of unbounded economic growth continues, then by the end of the 21st century, the GHGs concentration may even cross the barrier of RCP 8.5. At a large, there are enough evidences of the anthropogenic footprints on the global warming (Basha et al., 2017). The climate change will further pose several constraints to the growth and developmental activities in South Asia, particularly in India (Ross et al., 2018). It may further adversely impact the agricultural production, water quality and quality, hydro-power production, and on overall economy (Bapuji Rao et al., 2014; Ali et al., 2018; Duran-Encalada et al., 2017; and Gupta et al., 2014) an on many other aspects necessary for sustaining coupled human-environment systems.

The climate change phenomenon and their impounding impacts on nature and society have been greatly dwelt upon by various researchers, e.g., Sanchez et al. (2004), Mishra et al. (2015), Rohini et al. (2016), Mishra et al. (2017), and Panda et al. (2017). The climate change will have further severe impacts on the intensity and duration of winter and summer storms, heat waves, and hot and cold days and nights (Mastrandrea et al., 2011; Mahmood and Babel, 2014).

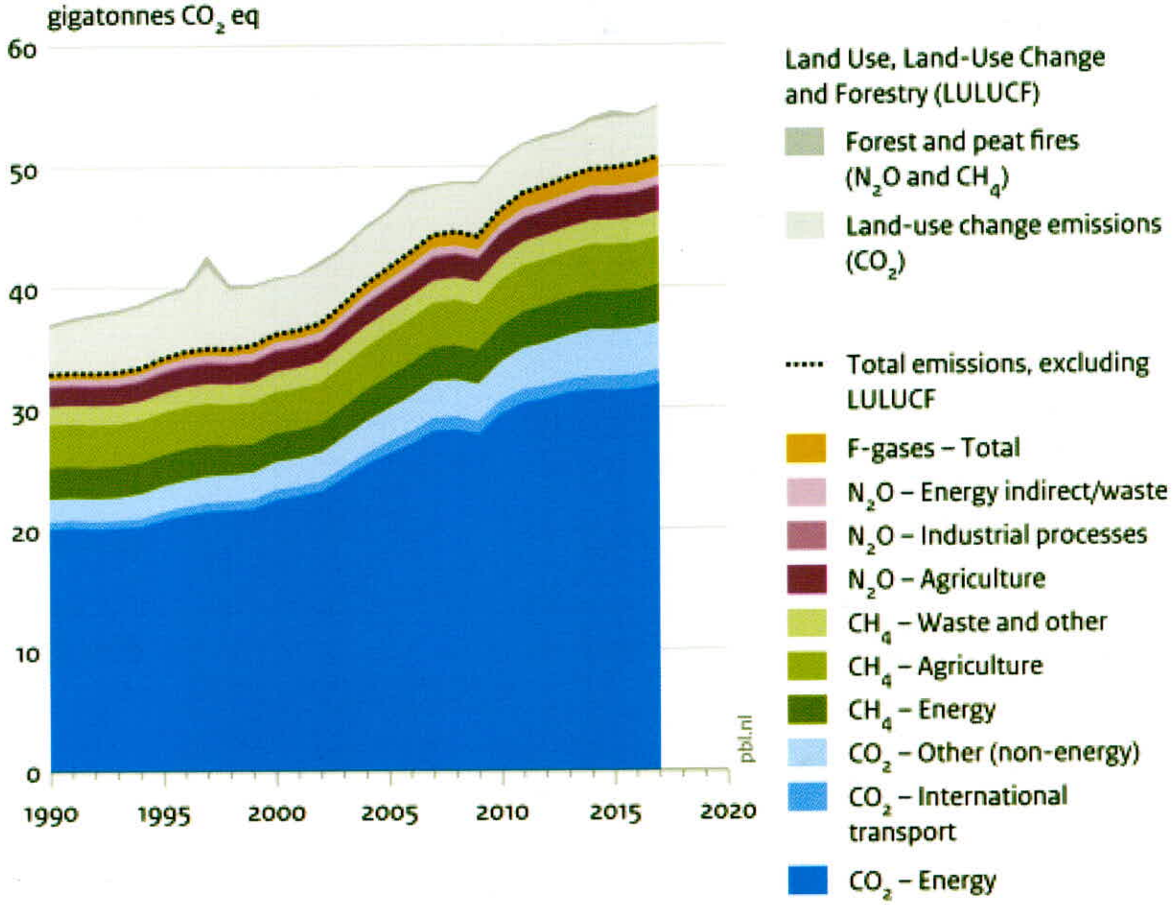

***Figure 3.3**: Trends in global GHGs emissions: types and sources (Source: PBL Netherlands Environmental Assessment Agency, Olivier and Peters, 2018)*

Worldwide, there is an increase in the number of warm days and nights and decrease in the number of cold days and nights between the period 1951 and 2010 (IPCC, 2013). In addition, there has been a continuous increase in the intensity, duration and frequency of warm spells and heat waves since the year 1950 (IPCC, 2013), which could lead to significant adverse impacts on the environment and society as a whole. The temperatures rise will further result into an increase in the frequency of heat waves and the extreme precipitation events will become more severe and frequent in nature in most parts of the world. Mondal et al. (2015) analysed the seasonal and annual temperature trends and percentage of change all over India for the period of 1901–2007 and they found that the mean temperature is significantly increasing in the majority of the regions and all seasons.

The Western Himalayas are found to have the highest increase in mean temperature, whereas, the entire northern and central India have significant rise in maximum temperature. Further, for India as a whole, they reported an increase in the mean temperature of 0.003°C/year. Similarly, Annual Climate Summary (ACS) by India Meteorological Department (IMD) (2017) reported a rapid rise in all India mean STs over India, particularly since about 1980 during all the seasons and on annual average as shown in Figure 3.5. Here, it would be appropriate to mention that during the period of 1980's, India has improved its growth rate to 5.7% with a greater stability in most of the sectors, especially in industrial, domestic and agriculture (Nagaraj, 2000).

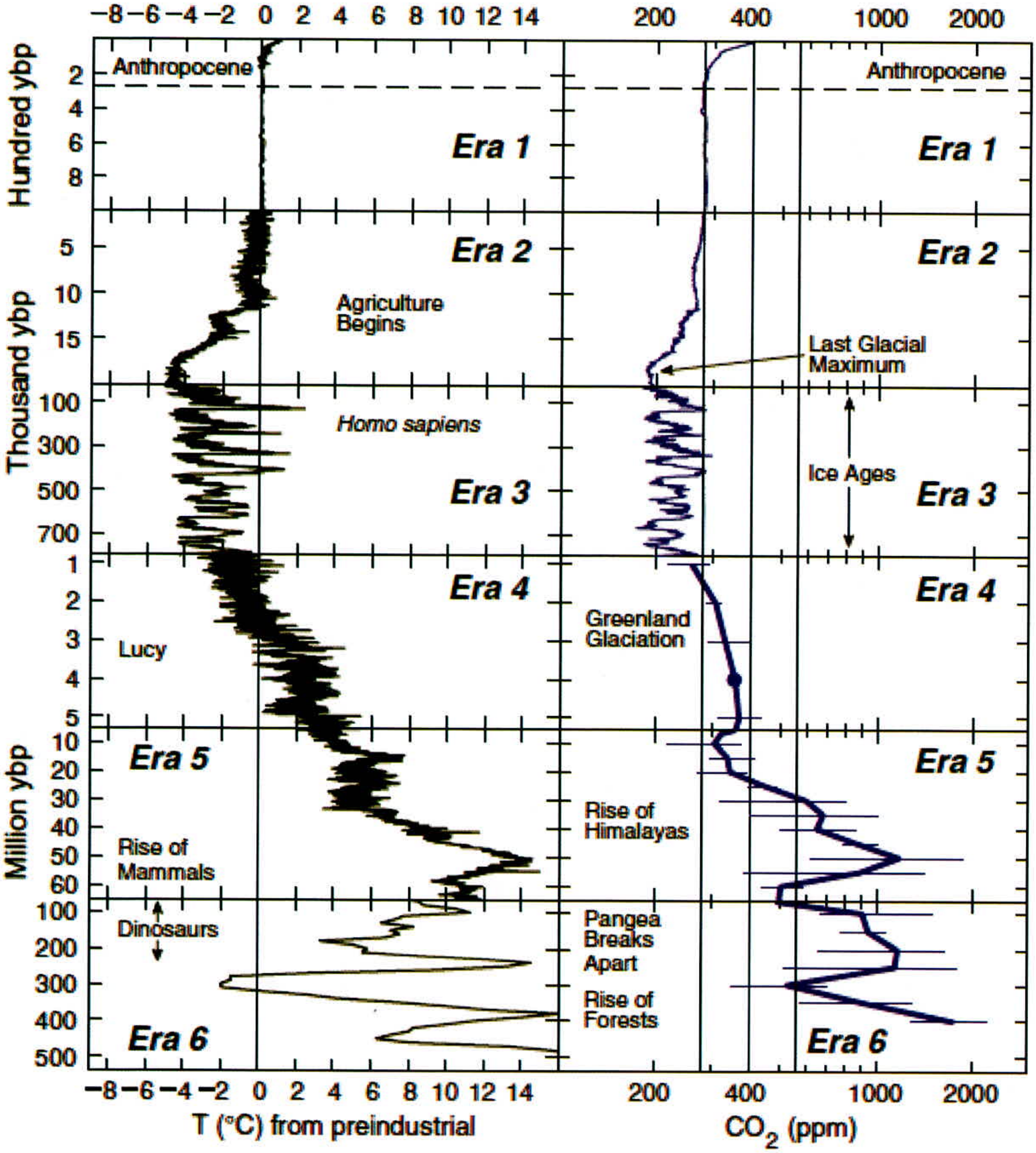

Figure. 3.4.: Climate history of Earth, past 500 million years (Salawitch et al., 2017).

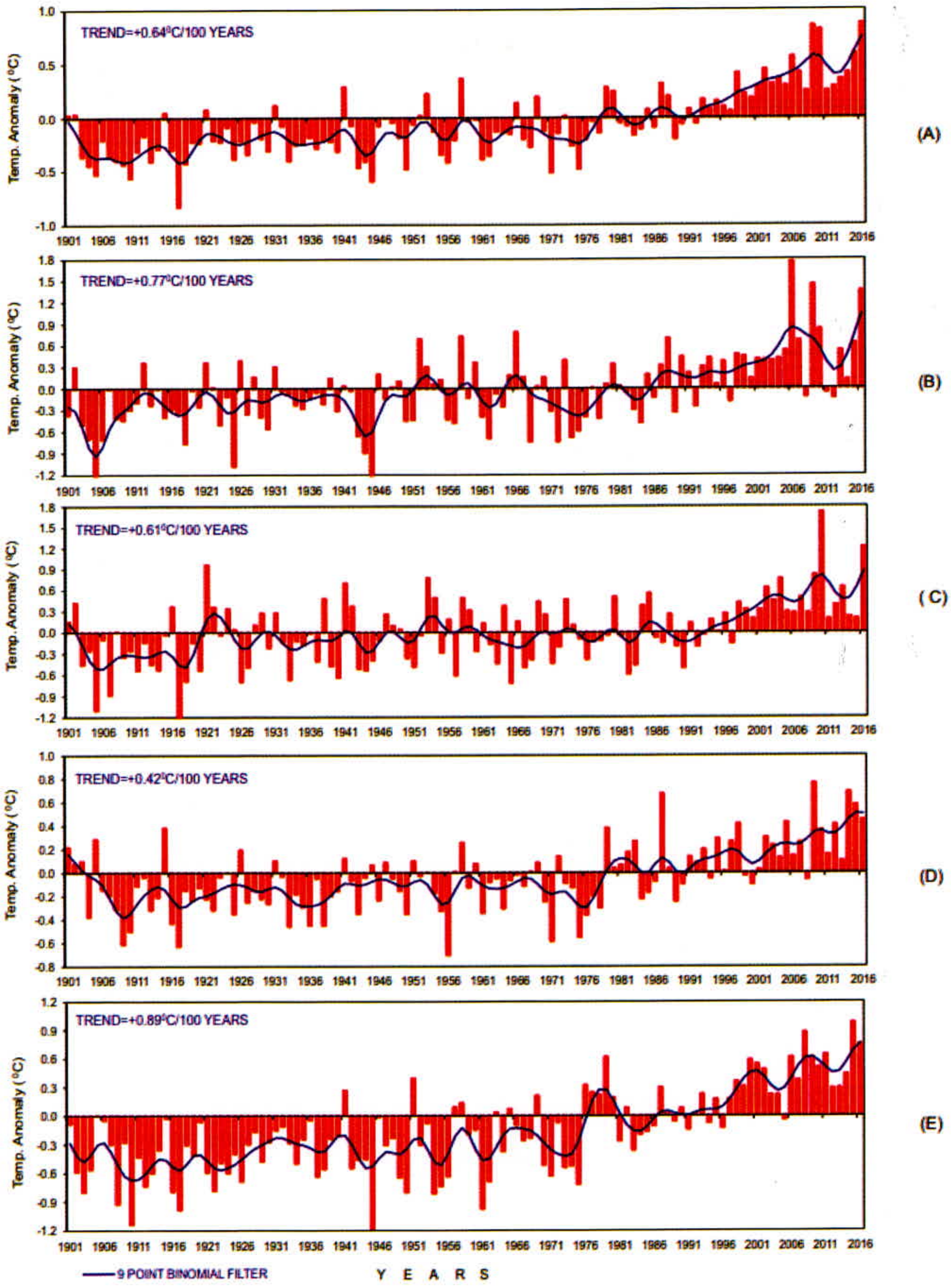

Figure 3.5: *All India mean temperature anomalies for the period of 1901-2016. (A)-represents annual, (B)-winter, (C)-pre-monsoon, (D)-monsoon, and (E)-post-monsoon. (Source: Annual Climate Summary, IMD, 2017).*

Keeping-in-view of the above, it would be interesting to diagnose the nature and patterns of long-term temperature changes over India and the world as a whole and explore the major factors/forcings responsible for making this phenomenon to happen. This diagnosis will help understand how these changes may effect various policy decisions for the sustenance of agricultural, infrastructural and industrial, water and land resources systems in India.

3.1 Past Surface Temperature Trends

3.1.1 Global Scenario

An understanding of the climate of the past will help improve our understanding on the behaviour of the modern climate change (Folland et al., 2001; Jansen et al., 2007; Mann et al., 2008). The study of past surface temperature trends is also essential for an accurate assessment of relative contributions of natural and anthropogenic influences on Earth's climate (Huang et al., 2000) as has also been very categorically shown (with respect to *Era*) in Figure 3.4. For this purpose, before 19th century, the 'proxy' data sources such as tree rings, corals, ice-cores and historical records were widely in use worldwide (Mann et al., 2008). The global mean surface temperature (GMST) is widely used as an indicator of global climate change (Rahmstorf et al., 2017) and has increased by 0.85^{0}C [0.65-1,06] ^{0}C over the period of 1880-2012 (IPCC, 2013) since the late 19th century and 0.89^{0}C [0.69-1.08] ^{0}C over the period of 1901-2012 based on independently produced dataset as shown in Figure 3.6 (IPCC. 2013).

Recently, Rahmstorf et al. (2017) conducted a change point analysis (CPA) of the past GMST change using five datasets, namely, NASA GISTEMP (Hansen et al 2010, GISTEMP Team 2016), NOAA (Smith and Reynolds, 2005; Smith et al., 2008), HadCRUT4 (Morice et al., 2012), the revision of HadCRUT by Cowtan and Way (2014), and the Berkeley Earth Surface Temperature (Rohde et al 2013) as shown in Figure 3.7. It can be seen from Figure 3.7 that the year 1980 can be taken as a change point or point of inflection. As for as pre-1980 is concerned, there have been both increasing and decreasing trends in global temperature and 1912 and 1945 can be taken as the points of inflection. From 1945 to 1980, there is a decreasing trend in the GMST change, whereas from 1912 to 1945 there is an increasing trend is GMST change.

3.1.2 Indian Scenario

According to the Annual Climate Summary (ACS) (IMD, 2017), the annual surface temperatures in India have increased during the period of 1901-2017 and this rise in temperature is mainly due to increase in GHGs concentrations in the atmosphere (Kothawale and Rupa Kumar, 2005; Jaswal et al., 2015; and Bal et al., 2016; Basha et al., 2017; and Ross et al., 2018). The long-term (1981-2015) annual average temperature and its linear trends for different parts of the country were developed by Centre for Climate Change Research- Indian Institute of Tropical Meteorology (CCCR-IITM) (2017) and are shown in Figure 3.8. The warming trends are more pronounced in the western Himalayan region, north west and extreme eastern parts of the country. The study also shows that the southern part show comparatively lower warming trends as compared to the rest parts of the country. For reference, the temperature homogeneous regions of the India are also shown in Figure 3.9.

The ACS states that there is an increasing trend in annual average temperature of 0.66^{0}C/ 100 year with the maximum variation during the post-monsoon season, i.e., 0.79^{0}C/100 year and the least, i.e., 0.43^{0}C/100 year during the monsoon season over the for the period of 1901-2017 (ACS-IMD, 2017). Purnadurga et al. (2017) investigated the daily maximum temperature variability over India for the period of 2001-2014 and 1971-2001 as base-line and found that the temperature difference (increase) is more pronounced in the northern parts as compared to the southern parts to the order of 1.4^{0}C-0.8^{0}C as shown in Figure 3.10. The values of mean maximum temperature for different homogeneous regions and India as a whole are also given in Table 3.1.

Long-term trends (for 107 years, i.e., 1901-2007) for minimum, maximum and mean temperatures for all the seven temperature homogeneous regions and India as a whole were analysed by

Mondal et al. (2015) and shown in Figure 3.11. This shows that the minimum temperature of EC, WC and IP regions of India is having an increasing trend over a time span of 107 years and a decreasing trend for NW region of India. The WH region is found to have highest increase in minimum temperature (0.008^0C/year) in the post monsoon season with significant decrease (-0.006^0C/year) in the winter season. Figure 3.11 also show that there is significant increase in maximum temperature in all the seven regions of India with highest increase in WH region (0.006^0C/year). This increase in maximum temperature is found to be the highest during the winter season (0.013^0C/year). The other regions such as WC, IP, NW, NC, NE regions of India show increasing trend in maximum temperature. A similar trend was also reported by Subash and Sikka (2014). The annual mean temperature is found to increase for all the regions and seasons of India with highest increase in WH region, i.e., 0.004^0C/year over the span of 107 years. The increase in the mean temperature is found to be highest during the winter season (0.009^0C/year) followed by pre-monsoon (0.008^0C/year) and post-monsoon season (0.006^0c/year) (Mondal et al., 2015). Remarkably, the increase in max. min., and mean temperatures is dominant during the post-monsoon and winter seasons.

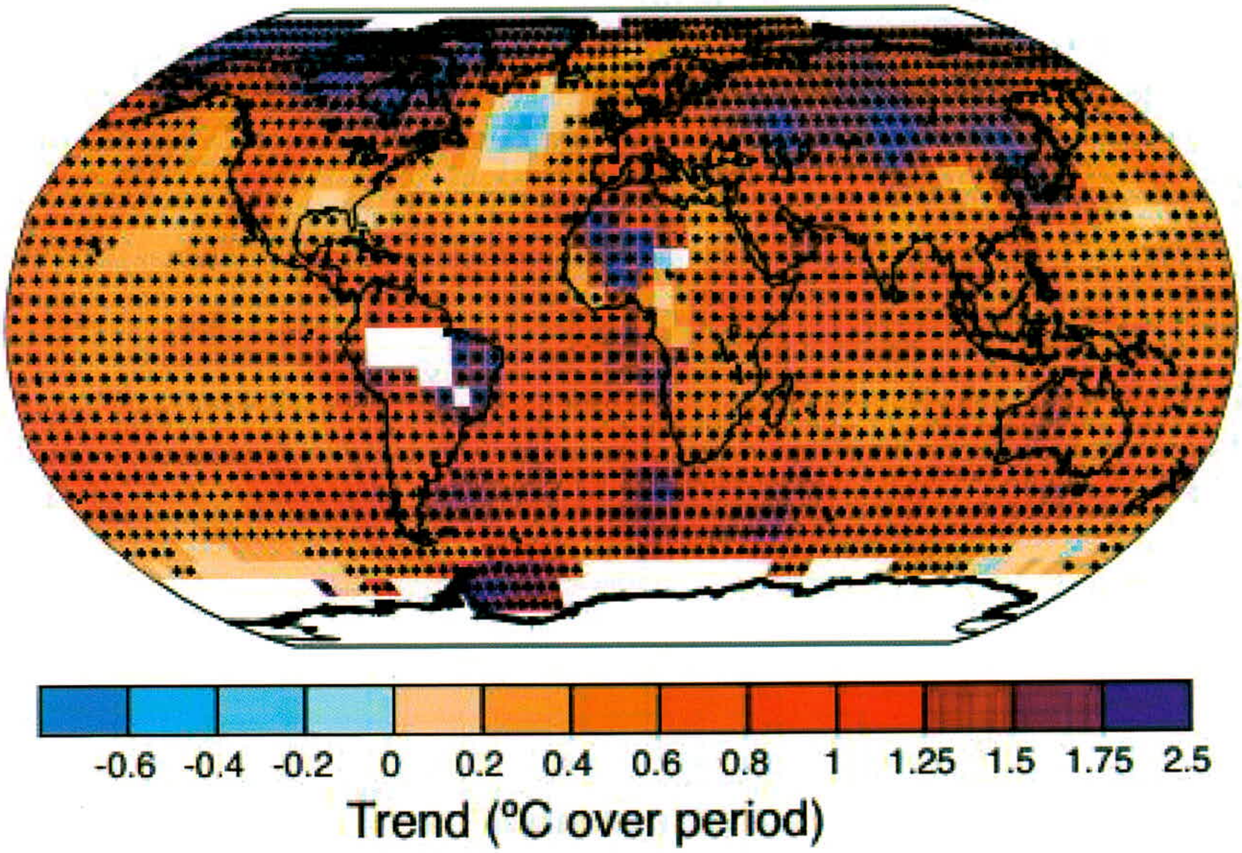

Figure 3.6: *Surface temperature trends across the world since 1901 to 2012 (IPCC, 2013).*

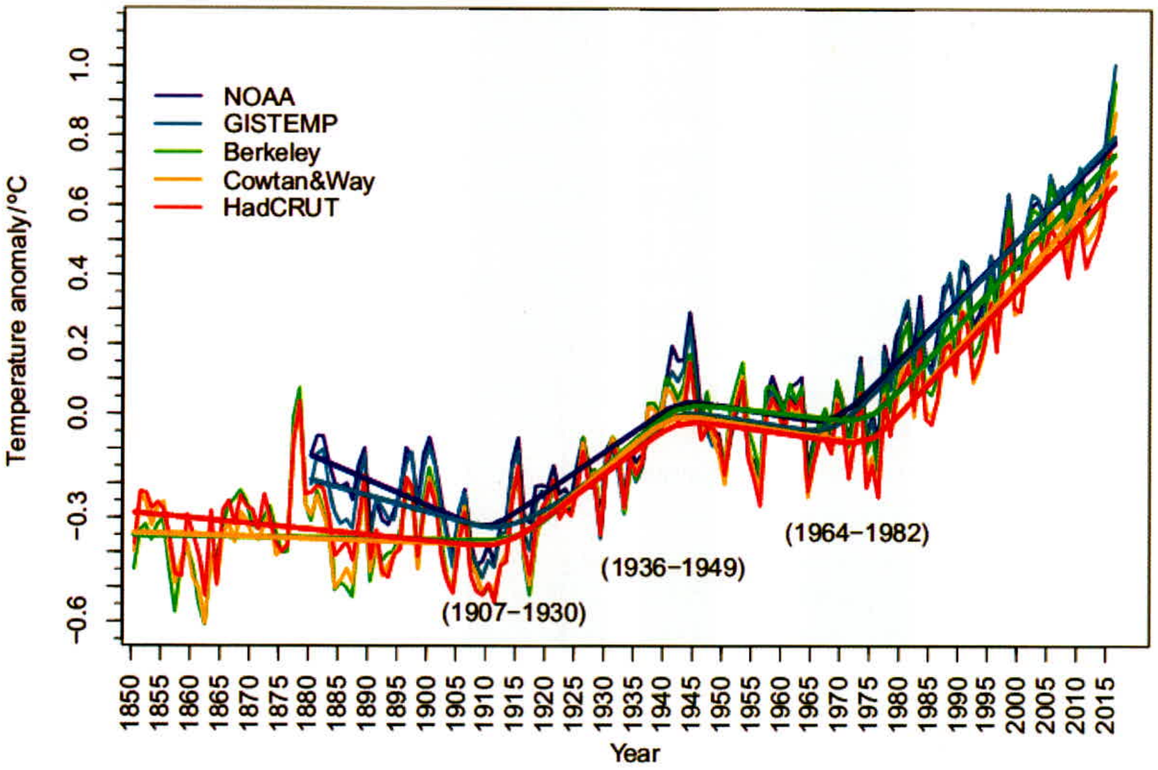

Figure 3.7: *Global mean surface temperature (GMST) trends from 1850-2015. (Source: Rahmstorf et al., 2017)*

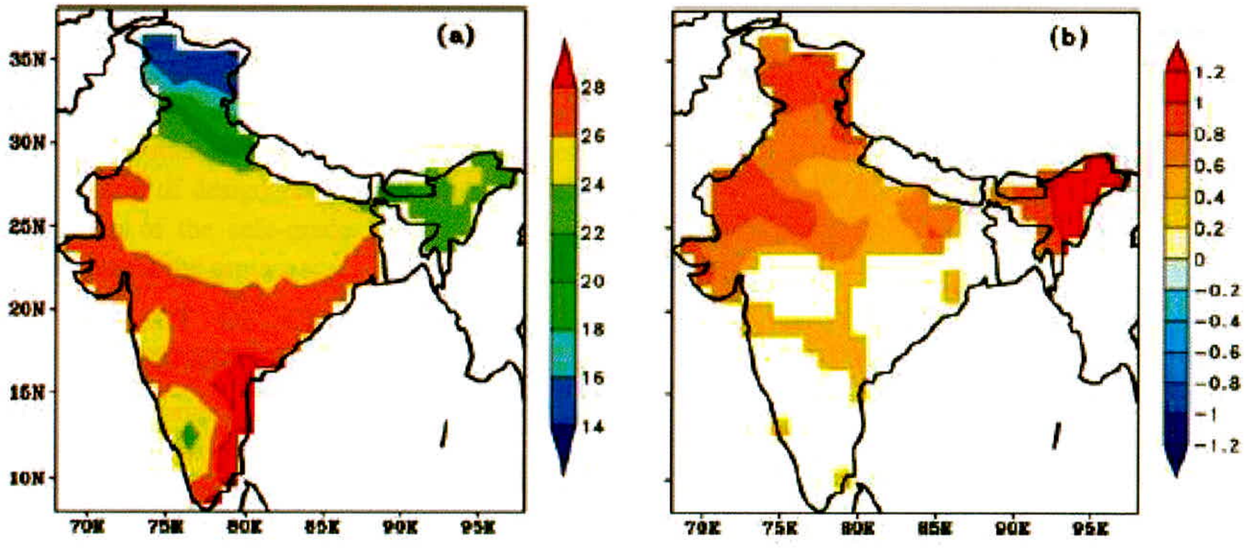

Figure 3.8: *Long-term (1981-2015) annual average temperature (a) and variability trends (b) for India (Source: CCCR-IITM, 2017).*

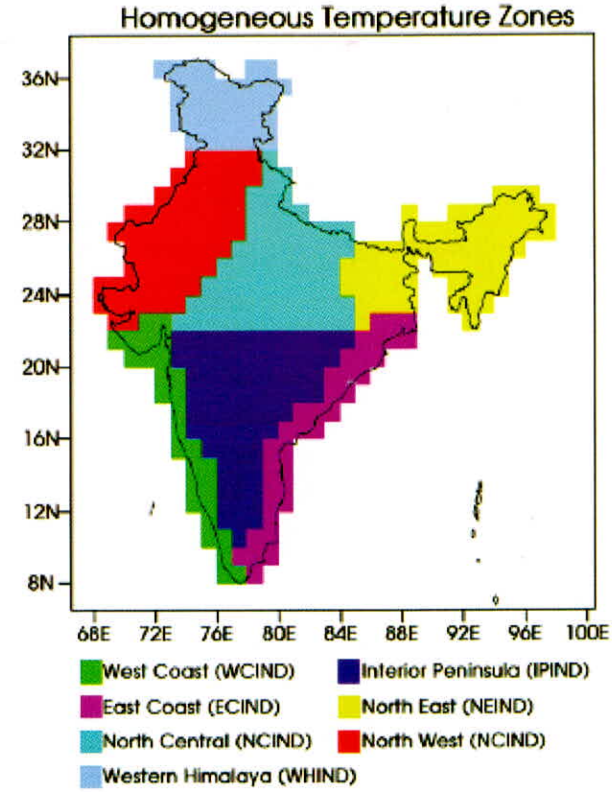

Figure 3.9: *Homogeneous temperature zones in India (Dillepkumar et al., 2018).*

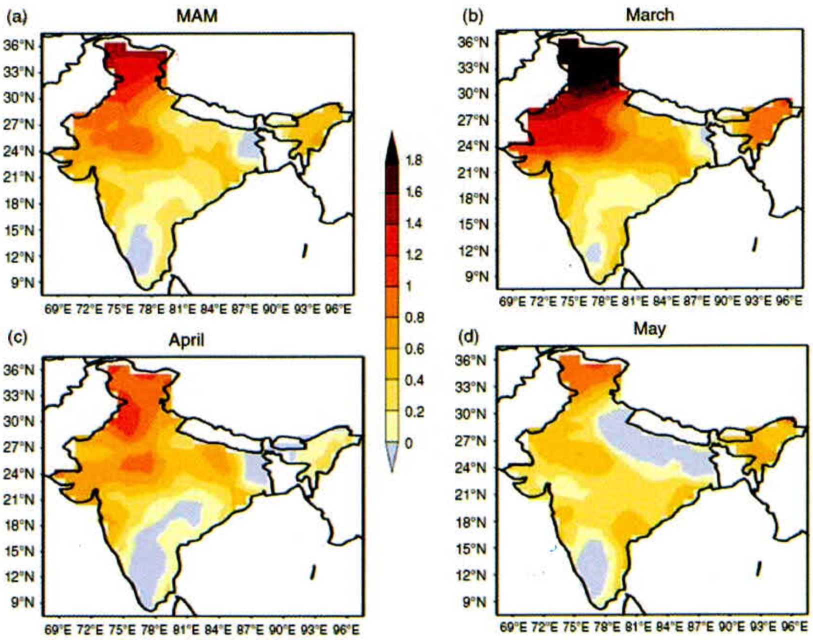

Figure 3.10.: *Maps showing difference in the max. temperature variability between the periods of 2001–2014 and 1971–2000 for (a) summer season (March, April and May average), (b) March, (c) April and (d) May as an individual (Source: Purnadurga et al., 2017).*

Table 3.1. Long-term mean maximum temperature (^{0}C) over India and seven homogeneous regions over the periods of 1971–2000 and 2001–2014 (Source: Purnadurga et al., 2017).

Region	March		April		May		MAM	
	1971-2000	2001-2014	1971-2000	2001-2014	1971-2000	2001-2014	1971-2000	2001-2014
All India	31.2	32.0	34.9	35.3	36.3	36.7	34.1	34.7
WH	16.2	18.4	22.6	23.5	26.7	27.6	21.8	23.2
NW	29.9	31.3	36.7	37.5	40.2	40.5	35.6	36.4
NC	32.4	33.2	38.4	38.9	41.1	37.3	37.3	37.7
NE	28.1	29.0	29.3	29.4	31.0	29.3	29.3	29.8
WC	34.9	35.3	36.9	37.4	37.1	36.2	36.2	36.6
IP	36.4	36.6	39.3	39.4	40.7	38.7	38.7	38.9
EC	35.0	35.4	37.2	37.4	38.9	36.9	36.9	37.2

where: WH= Western Himalayas; NW= North West; NC= North Central; NE= North East; WC=West Coast; EC= East Coast; and IP=Interior Peninsula.

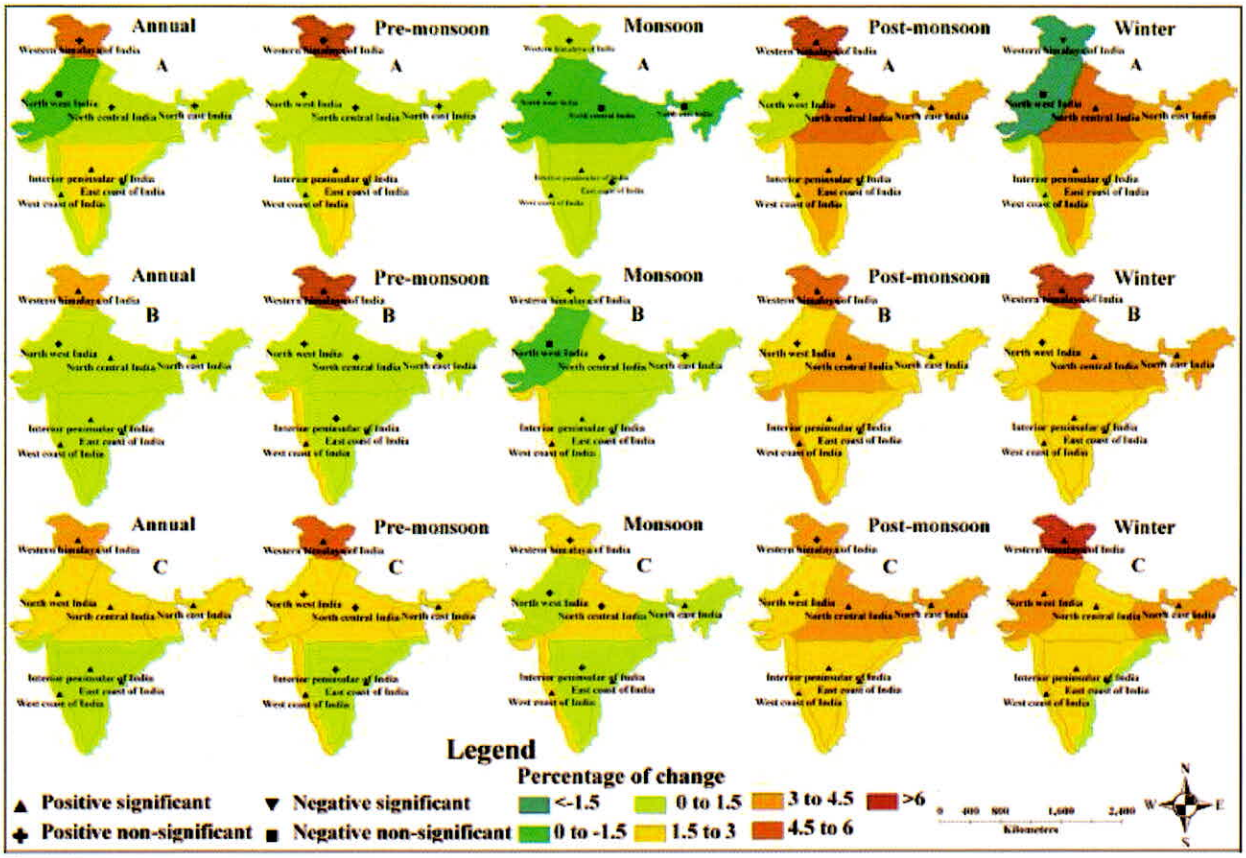

***Figure 3.11**: Spatial patters of the trends for minimum (A), mean (B) and maximum (C) temperature for seven regions and all India for a span of 107 years (1901-2007) (Source: Mondal et al., 2015).*

3.2 Projections of Surface Temperature due to Climate Change

The climate models have been developed to study the Earth's present climate and explore the Earth's past and future climate systems along with an assessment of the impacts of variability of drivers/forcings of the climate system in space and time. The simulations developed by these models along with different RCPs are used for future projections of climatic variables, such as temperature, precipitation, etc.

3.2.1 Global Scenario

The global average temperature is found to increase in the range of 0.65–1.06 ^{0}C with an average of 0.85 ^{0}C for the period of 1800–2012 (IPCC, 2013), and an overall increase of 0.74±0.18 ^{0}C during the period of 1906–2005 (IPCC, 2007). This increasing trend in temperature is further projected to accelerate during the 21st century under all the RCPs (Mahmood and Babel, 2014) and it is projected to increase by 5.5^{0}C by the end of 21st century (Stocker et al., 2013). The projected values of increase in global mean surface temperature at the end of 21st century will be in the range of 0.3–1.7 ^{0}C (RCP 2.6), 1.1–2.6 ^{0}C (RCP4.5), 1.4–3.1 ^{0}C (RCP 6.0), 2.6–4.8 ^{0}C (RCP 8.5) relative to 1986–2005 and shown in Figure 3.12a (IPCC, 2014). The spatial variation of the global mean surface temperature is also shown in Figure 3.12b. Table 3.2 shows the global mean surface temperature relative to 1865-2005 for the mid and late 21st century for RCP 2.6 and RCP 8.5. Table 3.2 also depicts the range of the variation of the global mean surface temperature (min. and max.) with their mean value.

Steffen et al. (2018) coined the term "Hothouse Earth" which indicates an increase of global average temperature of 4-5°C higher than the pre-industrial level with an increase of sea level from 10-60 m higher than today's sea levels. The authors find that the planet 'Earth' will become un-inhabitable, if the "Hothouse Earth" condition becomes a reality. It was found that the GHGs are the major forcings responsible for these conditions and advocated for an emission-less world trade and economy.

Table 3.2: Projection of global mean surface temperature for the periods of 2046-2065 to 2081-2100 relative to the 1986–2005 (IPCC, 2014).

		2046-2065		2081-2100	
	Scenario	Mean	Likely range	Mean	Likely range
Global mean surface temperature change (^{0}C)	RCP2.6	1.0	0.4-1.6	1.0	0.3 to 1.7
	RCP4.5	1.4	0.9-2.0	1.8	1.1 to 2.6
	RCP6.0	1.3	0.8-1.8	2.2	1.4 to 3.1
	RCP8.5	2.0	1.4-2.6	3.7	2.6 to 4.8

Bathiany et al. (2018) analysed 37 climate models for detecting the changes in the standard deviation (SD) of monthly temperature anomalies using the data comprising of the historical simulations from 1850 to the 21st century with the highest greenhouse gas emission, i.e., RCP8.5. The study reported several hotspots of increase in SD of monthly temperature anomalies over Amazonia, Southern Africa, Australia, the Sahel, the Arabian Peninsula, India, and Southeast Asia as shown in Figure 3.13.

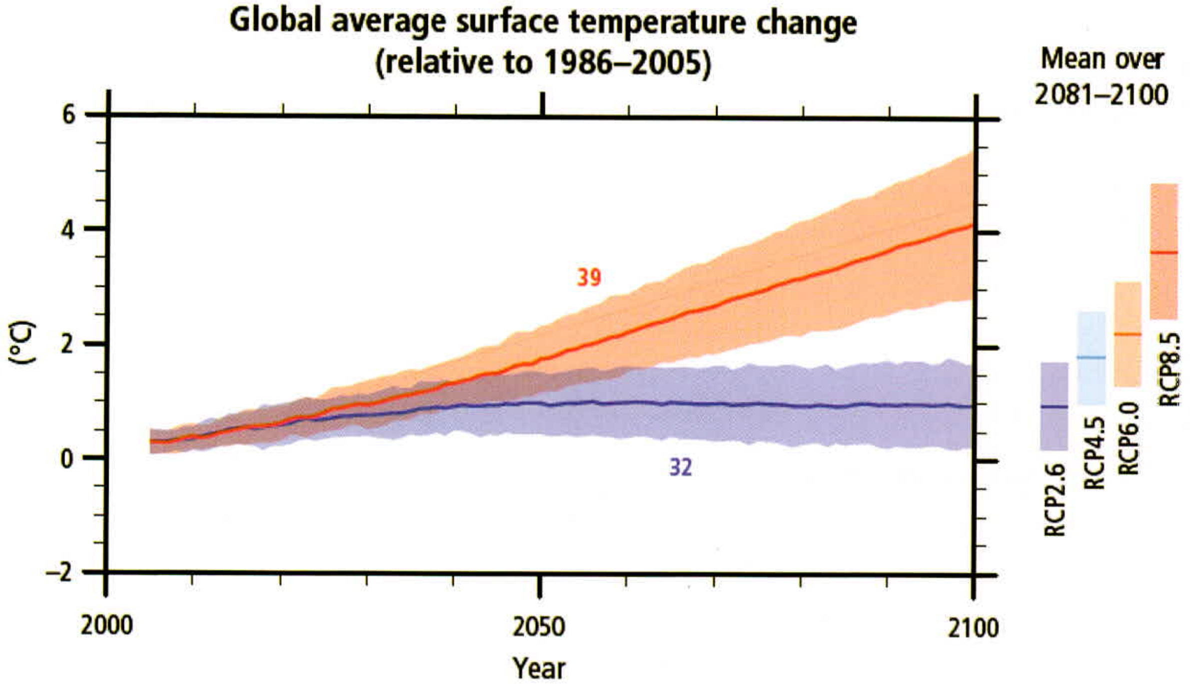

***Figure 3.12a**: Global average surface temperature change. The shading represents 5-95% confidence interval (Source: IPCC, 2014).*

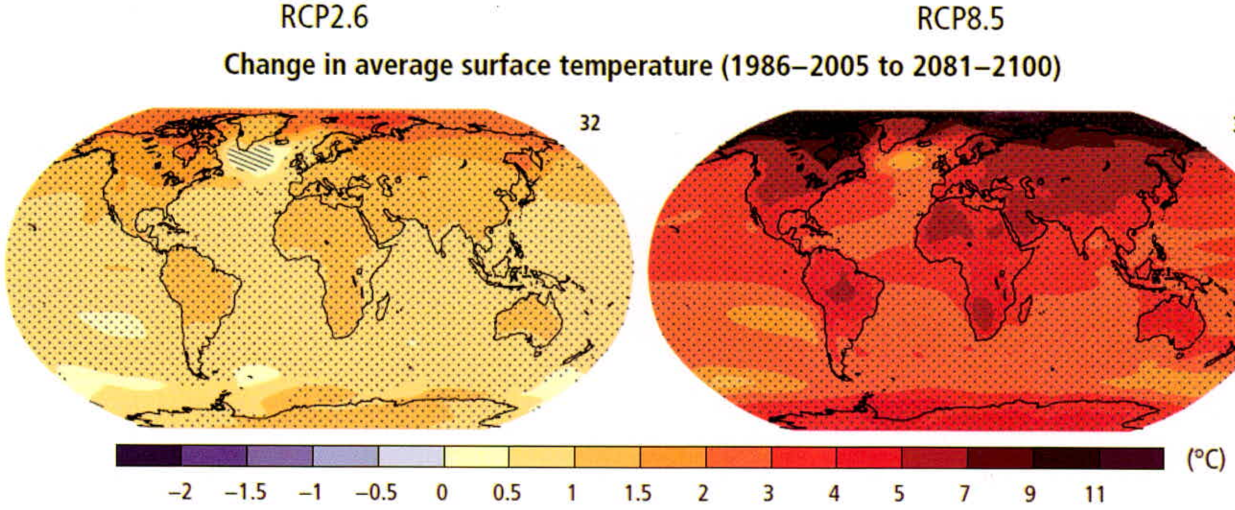

***Figure 3.12b**: Spatial variation of global average surface temperature change (Source: IPCC, 2014).*

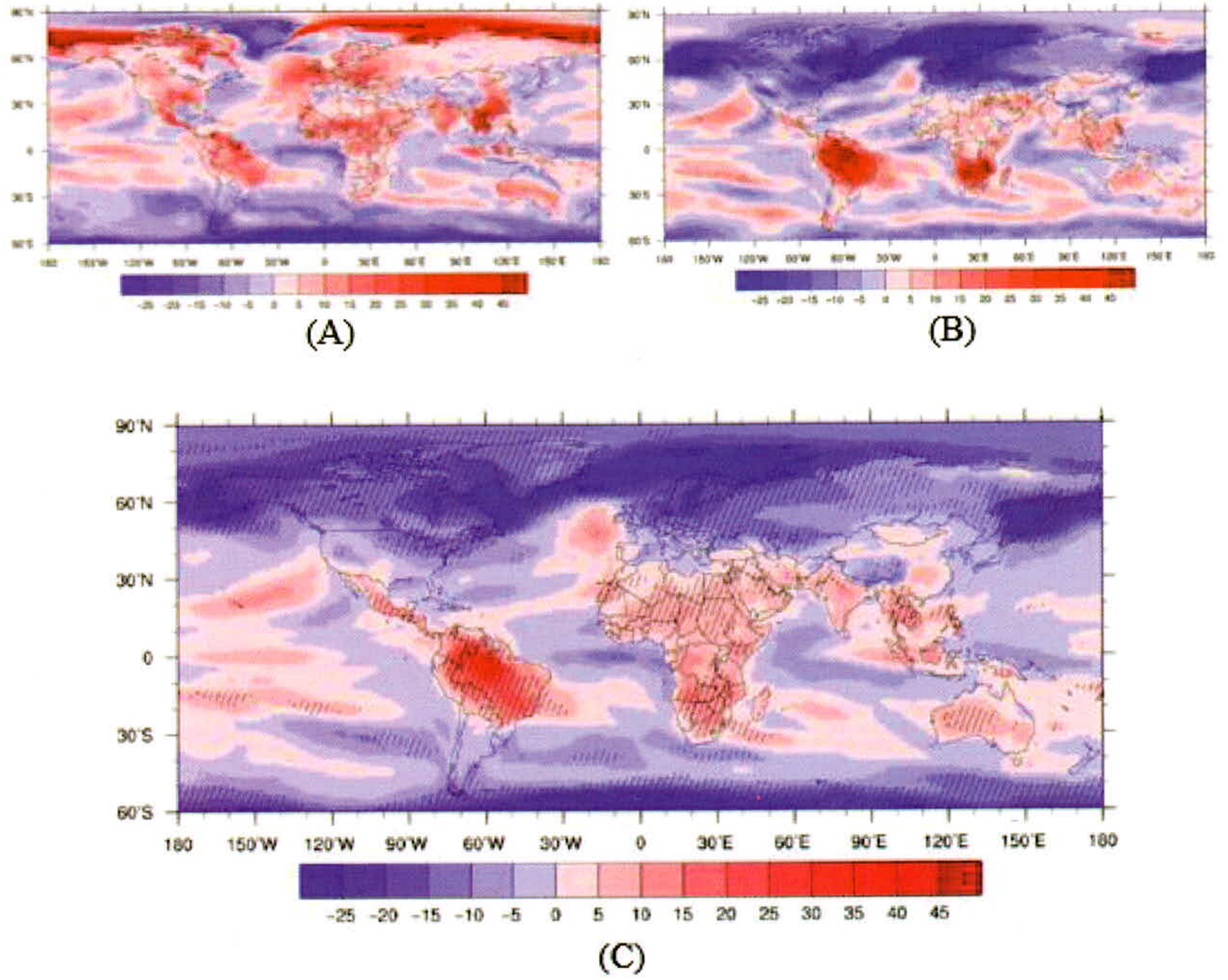

***Figure 3.13**: Relative changes of SD of monthly temperature anomalies for the period of 1850- 2100. (A): Boreal summer-June-July-August (JJA), (B): Austral summer-December- January-February (DJF), and (C): the whole year. (Source: Bathiany et al., 2018)*

3.2.2 Indian Scenario

India is highly vulnerable to climate change and a consistent increasing trend in mean, minimum, and maximum temperatures over India has been observed during the last century (Kothawale and Kumar, 2005; Kothawale et al., 2010; and Murari et al., 2015) with unevenness in trends during the different seasons of the year (Das and Hunt, 2007). Kumar et al. (2013) found that the temperature rise may range from 2.5 °C to 5.5 °C with maximum susceptibility over Himalayas, north, central and western parts of India with a lower influence on the southern part of India and will have more warm days and nights as compared to the cold days and night. As mentioned previously, the climate change phenomenon in India is largely attributed to the complex interactions between natural and anthropogenic forcings (Bal et al., 2016; Basha et al., 2017).

Bathiany et al. (2018) also found that the climate change in India is mainly due to larger influence of atmospheric variability than the soil drying, i.e., a reduction in soil moisture. Bal et al. (2016) used PRECIS simulations and found that India may experience an increase of 3.4 ^{0}C in the maximum air temperature by the end of 21st century with reference to the baseline (1975-2005) under A1B scenario. Future changes in maximum and minimum temperatures across all the states of India were also projected by Bal et al. (2016). It was found that the change in the maximum temperature will vary from 0.9⁰C-1.1⁰C, 1.9⁰C-2.5⁰C, and 2.4⁰C-4.2⁰C for 2020s (2005-2035), 2050s (2035-2065) and 2080s (2065-2095), respectively under SRES A1B scenario.

Future projections of STs for India were also developed by Basha et al. (2017) by using RCP2.6 and RCP8.5 and it was found that the mean temperature will increase by 3.2⁰C by the end of the 21st century as shown in Figure 3.14. A similar projection was also made by Bal et al. (2016) as discussed above. These findings show that there will be on an average increase of average annual ST by 3.2⁰C all over India and therefore suitable measures have to be adopted to mitigate the adverse impacts arising out of this increase in the surface temperature. The study also finds that the increase in the temperature relative to 1901–1960 base line under different RCPs, i.e., RCP2.6, RCP4.5, RCP6.0 and RCP8.5 will be 1.8 ⁰C, 2.0 ⁰C, 3.5 ⁰C, and 5.0 ⁰C, respectively. The study indicates a warming trend of 0.2 K/decade over India, if the long-term (2006-2099) period is considered for analysis. Further, the far-future projections, i.e., the period from 2080-2099 indicates a cooling trend for all over India, except for southern India.

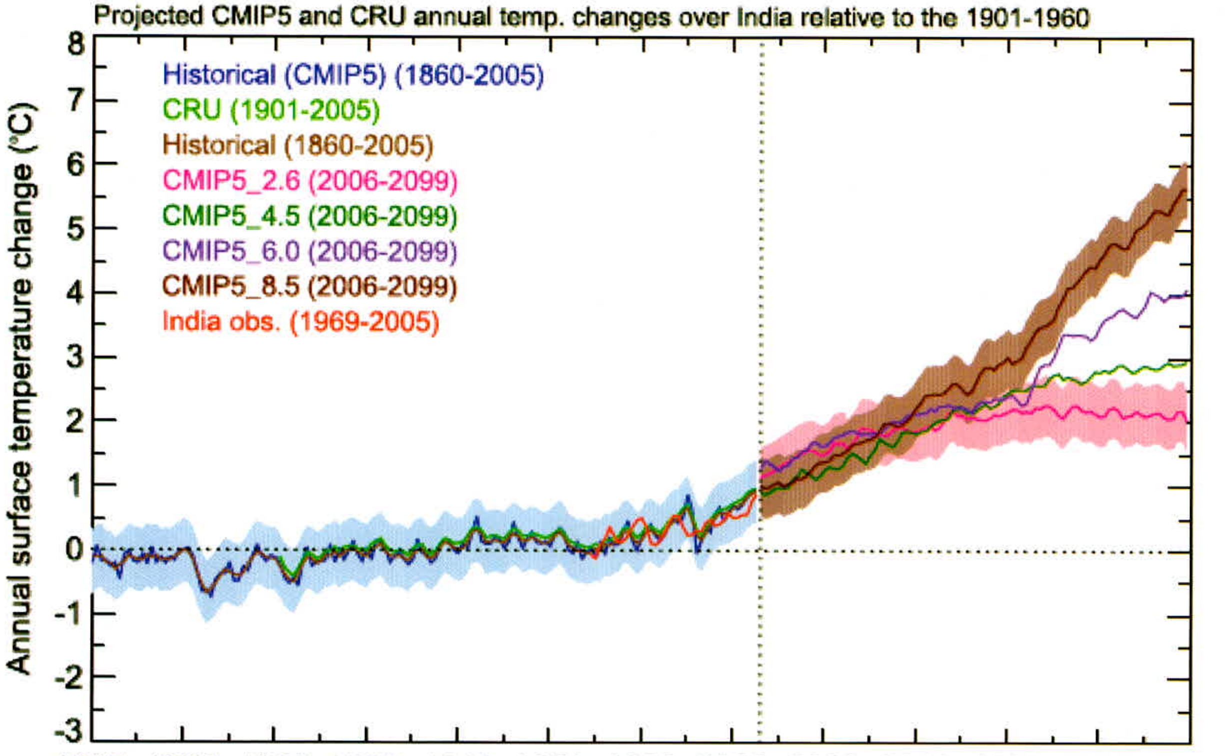

Figure 3.14: *Future projection of annual mean surface temperature over India for the period: 1860–2100 relative to the base-line period: 1901–1960. (Source: Basha et al., 2017).*

Patwardhan et al. (2016) assessed the impacts of climate change on seasonal maximum and minimum temperature and precipitation using PRECIS RCM model for five temperature homogeneous regions (Figure 3.15) excluding the hilly regions of country (i.e., Jammu and Kashmir, Himachal

Pradesh, Uttarakhand, North East regions). The study finds that the mean maximum surface air temperature for the pre-monsoon season (MAM-March-April-May) and mean minimum temperature for the winter season (JF-January and February) may increase by 4.0^{0}C by the end of 21st century using A1B scenario. Regions-wise the temperature anomalies (max. and min.) for different periods, i.e., 2020s, 2050s, and 2080s are also given in Table 3.2 and Table 3.3.It can be observed from the Table 3.2 and Table 3.3 that the rise in min. temperature is more than the rise in the max. temperature for all the regions, except Peninsular region at end of 21st century.

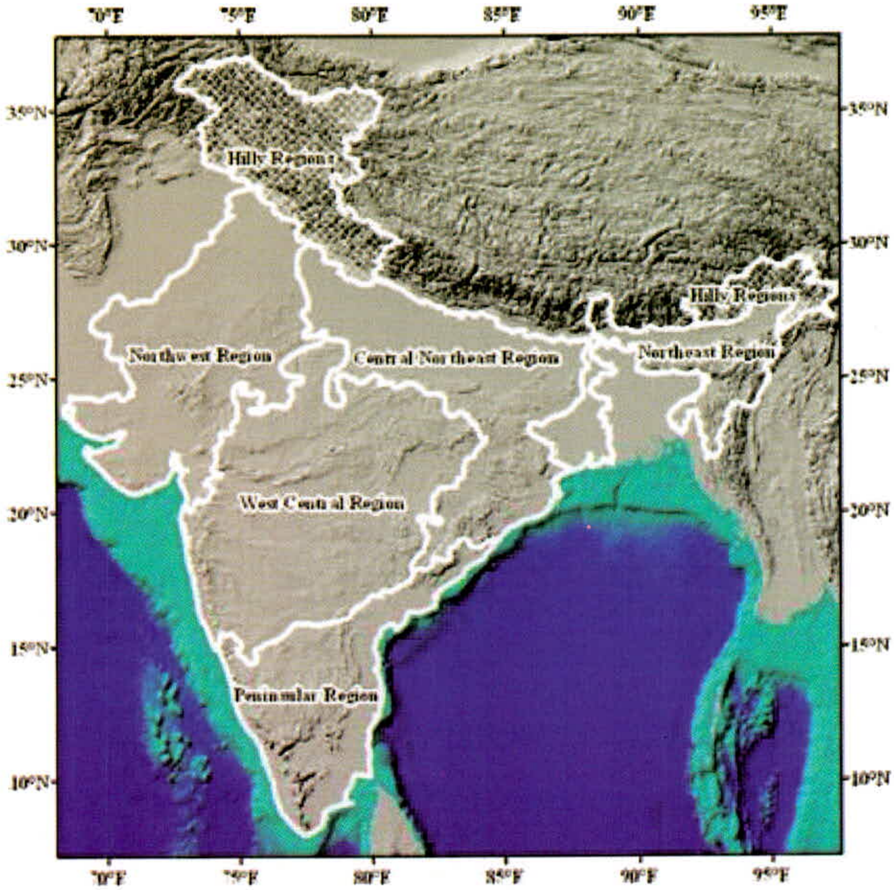

Figure 3.15*: Five temperature homogeneous regions excluding the hilly regions of country (Source: Patwardhan et al., 2016)*

Table 3.2: Anomaly in maximum temperature for future projections relative to 1970 based on A1B scenario for four different regions and MAM season of India (Source: Patwardhan et al., 2016)

Region	Anomaly in maximum temperature (^{0}C)		
	2020s	2050s	2080s
North-west	1.6 (1.3-1.9)	3.0 (2.6-3.6)	4.1 (3.7-4.5)
Central-NE	1.7 (1.4-1.9)	3.1 (2.7-3.5)	4.4 (4.1-4.7)
Northeast	1.2 (1.1-1.4)	2.5 (2.2-2.6)	3.7 (3.5-3.9)
West central	1.6 (1.5-1.7)	3.0 (2.6-3.5)	4.1 (3.7-4.3)
Peninsular	1.4 (1.2-1.5)	2.7 (2.4-2.9)	3.8 (3.6-3.9)

Table 3.3: Anomaly in minimum temperature for future projections relative to 1970 based on A1B scenario for four different regions and JF season of India (Source: Patwardhan et al., 2016).

Region	Anomaly in minimum temperature (^{0}C)		
	2020s	2050s	2080s
North-west	1.7 (1.5-1.8)	3.6 (2.8-3.6)	4.3 (3.6-4.7)
Central-NE	1.8 (1.7-1.9)	3.6 (3.4-3.7)	4.6 (4.4-4.9)
Northeast	1.7 (1.6-1.9)	3.4 (3.1-3.7)	3.6 (4.2-4.9)
West central	1.9 (1.5-2.0)	3.2 (2.9-3.5)	4.2 (4.0-4.4)
Peninsular	1.4 (1.0-1.7)	2.7 (2.5-2.9)	3.8 (3.7-3.8)

3.3 Impacts of Different Forcings on Surface Temperature

As discussed above, the anthropogenic activities led to the change in Earth's climate. A linear and deterministic response relationship may be assumed between the 'Earth System' and the anthropogenic influences by the humans or the society as a whole worldwide (Steffen et al. 2018), i.e. higher the anthropogenic forcing will lead to higher GHGs emissions and higher increase in global STs. The factors responsible for creating an imbalance between the natural Energy Balance system of Earth-Atmosphere either by anthropogenic or natural are known as climate forcings. These imbalances lead to change in the energy balance (warming or cooling) of the atmosphere, land and ocean systems. The anthropogenic influences such as increased rate of GHGs emissions, increased aerosols, LULC changes, volcanic activity are the main climate forcings responsible for global warming and increase in STs. These forcings are also known as radiative forcings(RF) responsible for perturbation of energy in Earth system and expressed in the unit of W/m^2. A value greater than zero indicates for near-surface warming and less than zero stands for cooling as shown in Figure 3.16. As per the AR5 (IPCC, 2014), total anthropogenic RF for 2011 relative to 1750 is 2.3 W/m^2 and this corresponds to a CO2-equivalent concentration of 430 ppm with an (uncertainty range 340 to 520 ppm).

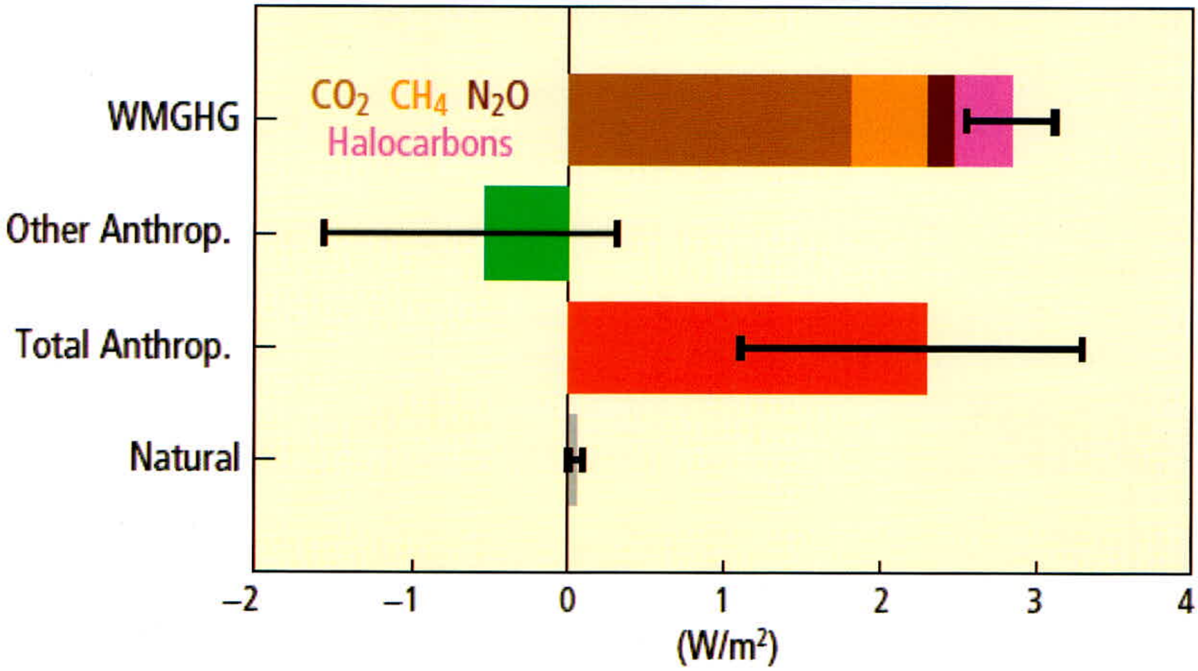

***Figure 3.16**: Variability of different forcings during the period of 1750-2011 (IPCC, 2014).*

3.3.1 Impacts of GHGs Emissions on Surface Temperature

As discussed in the beginning of this chapter and shown in Figure 3.3, the CO2 is the most important component of GHGs and has the largest contribution to the global warming. Figures 3.17 show a resemblance between the CO2 and long-term temperature change in late past at varying time scales. The warming is increasing consistently with CO2 level and the year 1975-80 can be taken as a point of inflexion.

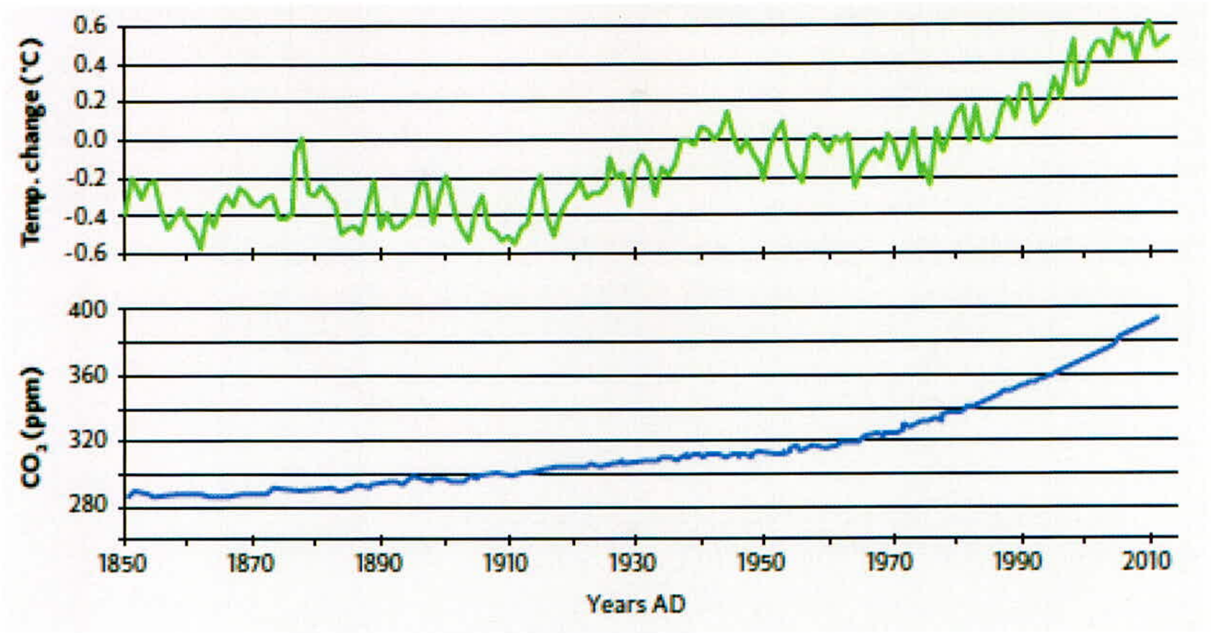

***Figure 3.17**: CO2 and corresponding temperature anomaly over the period of 1850-2010 (Source: The science of climate change: Questions and answers; Australian Academy of Science, Canberra, 2015).*

The increased concentration of GHGs is one of the major drivers of the climate change (Holmes et al., 2016; Dileepkumar et al., 2018) as depicted in Figure 3.18. The concentrations of the three major components of GHGs, i.e., CO2, CH4 and N2O has increased from 280 to 380 ppm, 800-1800 ppb, and 270-310 ppb, respectively over a span of 250 years (1975-2000) (IPCC, 2014). Figure 3.19 also shows the contribution of the internal and external forcings to global warming over the period of 1951-2010. The aerosols (Meehl et al., 2011, Morice, 2011, Kaufmann et al., 2011; and Wilcox et al., 2013), solar irradiance (Tett et al., 2002) and LULC (Bonan, 2008; Fall et al, 2010; Pielke et al., 2011; Deng et al., 2013; Zhang et al., 2016; Chang et al., 2018) also have propounding impacts on global warming. The aerosols may have negative warming impacts, i.e., cooling and the LULC change (LULCC) is the second largest contributor of global warming after GHGs (Mahmood et al., 2010). A brief discussion on the impacts of LULC change on global warming is being presented in the following sub-section.

3.3.2. Impacts of LULC Change (LULCC) on Surface Temperature

The change in LULC affects the global climate change through biogeochemical, biogeographical, and biophysical effects (Zhang and Liang, 2018) on the terrestrial surface and atmosphere (Pielke et al., 2011). It alters the surface solar and long-wave radiation and change the heat, water vapour and CO2, aerosols, etc. (Pielke et al., 2011). The biogeochemical effects mainly account for the carbon cycle and associated changes in atmospheric CO_2, whereas, the biophysical factors accounts for land surface albedo, evapotranspiration (ET) and surface roughness (Brovkin et al., 2013a&b).

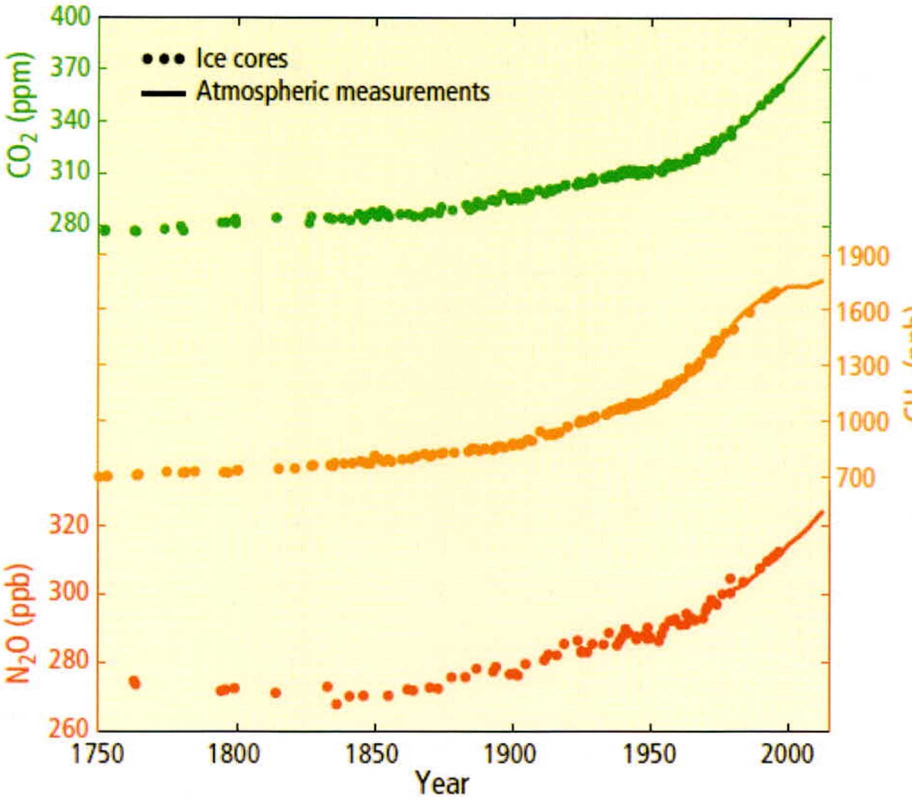

***Figure 3.18**: Variability of GHGs concentrations with time (Source: IPCC, 2014).*

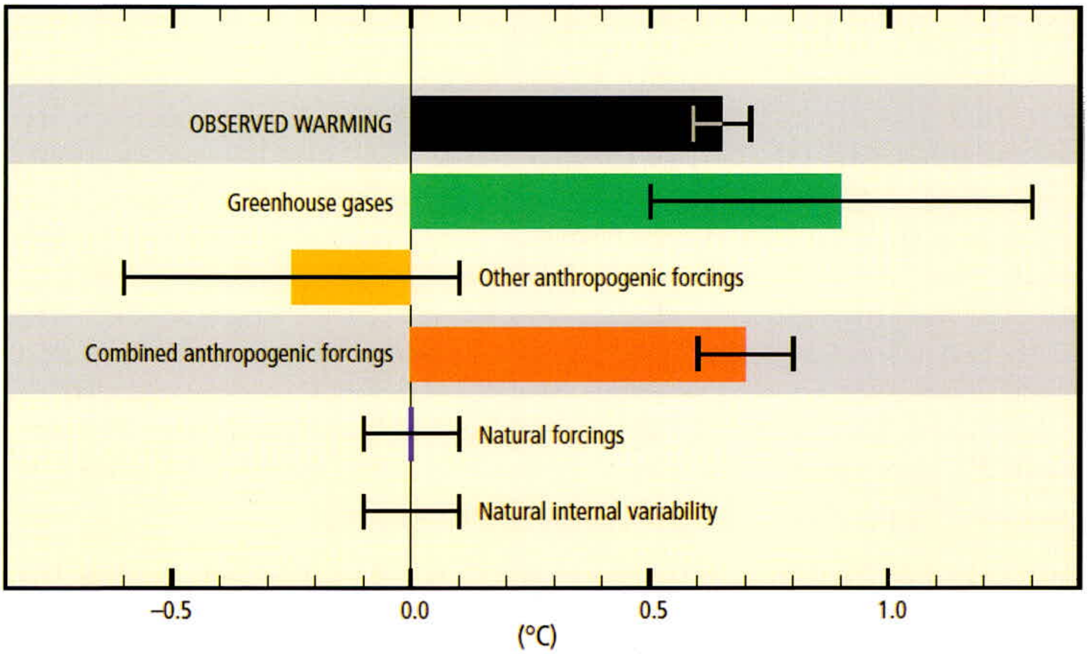

***Figure 3.19**: Contributions of internal and external forcings to global warming (Source: IPCC, 2014)*

According to de Noblet-Ducoudr′e et al. (2012), the biophysical factors are associated with the larger variability and uncertainty and depend on the location and time. Several studies have shown that the RF from LULCC also significantly impacts temperature trends (Bonan, 1997; Feddema et al., 2005; Christy et al., 2006, Roy et al., 2007; Wichansky et al., 2008) and there is a high consensus that the LULCC should also be included in characterizing climate change and modelling processes (Pielke et al., 2002, 2004, 2007; Joshi et al., 2003; NRC, 2005; Williams, 2005). It may also significantly influence many climatological variables such as maxi, mini. and diurnal temperature range (Gallo et al., 1996; Hale et al., 2006, 2008). As per AR5 (IPCC, 2014), there is an increase in the land surface albedo and decrease in the RF by -0.15 ±0.10 W/m^2due to global LULCC, which is resulting in a decrease in the land surface temperature (LST) and this could be one of the reasons that LULCC was not given due considerations in IPCC assessments (Pielke et al., 2011). At the same time, there may be the chances of an increase in the LST due to non-RF influences such as changes in plant phenology and ET, which could lead to an increase in the LST because of the decrease in ET (Pitman et al. 2009; Lawrence and Chase 2010), which depends upon the location and time. Some researchers also argue that land use changes to agriculture may further decrease LST (Mahmood et al., 2006; Roy et al., 2007; Lobell and Bonfils, 2008), however as discussed above it will depend on the location and time and hence more rigorous works are still needed to explore the impacts of LULCC on climate change possible coupling with the earth system models (ESMs), probably on regional scale.

Pielke et al., (2011) states that the distribution of LULCC is highly regionalised (Fig. 3.20) and depicts larger variability in LULCCs in Asia as compared to the rest of the regions of the world as analysed for a period of 10000BC to 2000 AD. Lawrence and Chase (2010) also states that that LULCC has a widespread regional warming but limited global influence on near-surface temperatures and precipitation. Zhang et al. (2016) explored region-wise temperature anomalies due to LULCC and found that there will be an increase in LST by 1.0^{0}C to 2.0^{0}C through reduced ET (+ve RF) in South Asia and East Asia regions (Niyogi et al.,2002; Davin and de Noblet-Ducoudré, 2010). The Europe and North America (high-altitude regions) will have a decrease in LST by 1.0^{0}C to 2.0^{0}C due to increased land surface albedo (Brovkin et al., 1999; Betts et al., 2007) and reduced RF. Zhang and Liang (2018) found that LSTs show a cooling effect when the crop land is transformed to forests (-ve RF) and a warming effect when the crop land is transformed in to urban land use (+ve RF). These results are shown in Figure 3.21 a-d. It is interesting to further note that the impacts of LULCC on climate change are largely governed by ET dynamics, rather than RFs (Lawrence and Chase, 2010). The changes in LULC may have their impacts at different scales, i.e., local, regional or global climatic processes (Brown et al. 2013). The LULC change is mostly anthropogenic in nature and it has direct impacts on STs. Halder et al. (2016) found that the LULC can cause for change in the daily maximum and mean temperature up to 1-1.5^{0}C. Nayak and Mandal (2012) found that LULC change from forest to agriculture and urban may contribute to the temperature increase by 0.06^{0}C per decade for the western part of India, and the combined impacts of LULC and GHGs may contribute up to 0.13^{0}C per decade for the western India.

Santer et al. (2013) specifically categorised the influence of anthropogenic factors on climate and found that the increased composition of GHGs, enhanced levels of aerosols, depletion of stratosphere ozone layer are the major external forcings inducing the climate change phenomenon. Christidis et al. (2012) also reported similar results and state that artificial forcings (all forcings-natural forcings) may quadrupled the probability of occurrence of occurrence of the warmer years than the warmest year since year 1900 in at least 23 identified regions of the world.

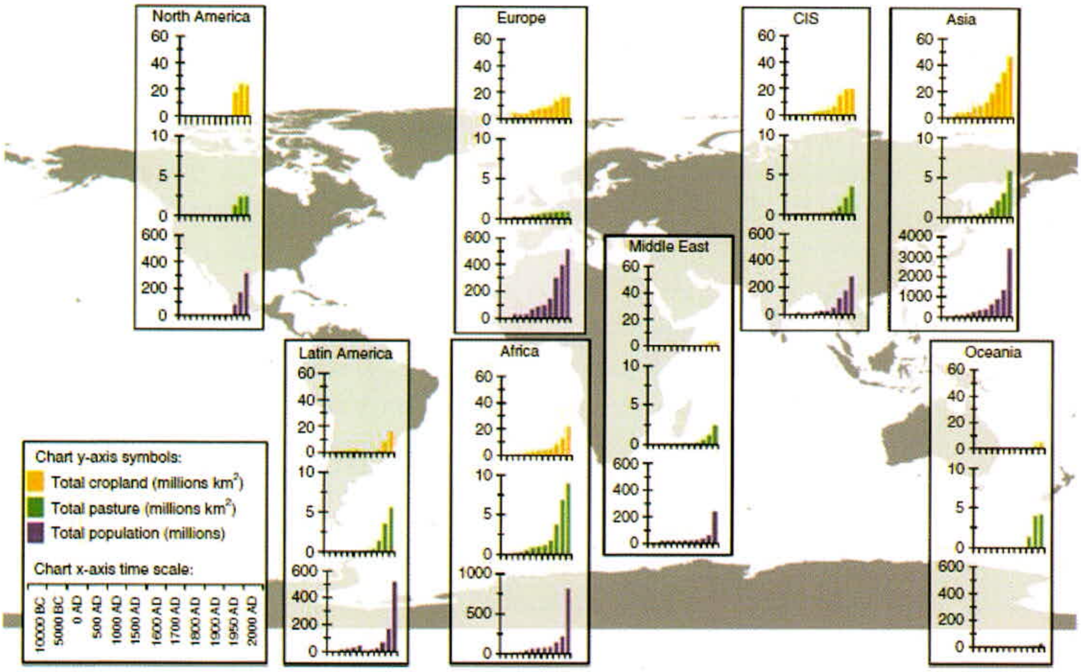

***Figure 3.20**: Long-term variability of regional population, cropland, and pasture (Source: Pielke et al., 2011)*

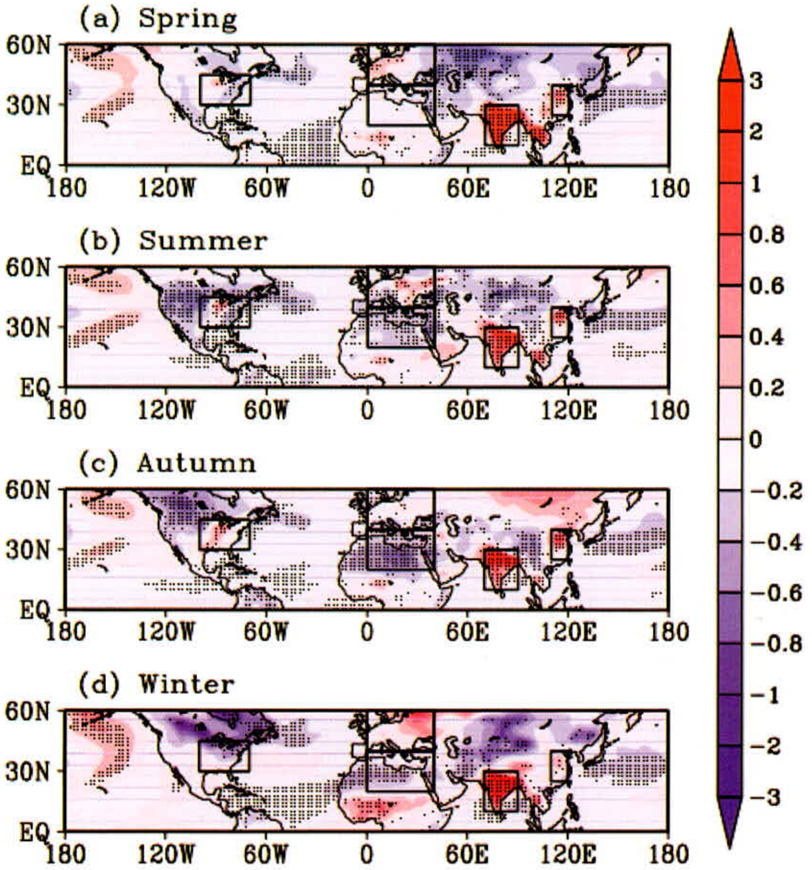

***Figure 3.21**: a-d: Regional temperature anomalies due to LULCC (IPCC, 2014).*

Therefore, an assessment of relative impacts of different natural/anthropogenic/all climatic forcings on STs will be of immense utility for building adaptive capacity and management practices to subvert the adverse effects of climate change on human and natural environment. Basha et al. (2017) categorically analysed the relative impacts of different forcings such as anthropogenic and natural on STs along with CRU STs over India for the 19[th] and 20[th] centuries are shown in Fig. 3.22a-f. The figures are self-explanatory and various inferences can be drawn as for as the least and most critical forcings are concerned.

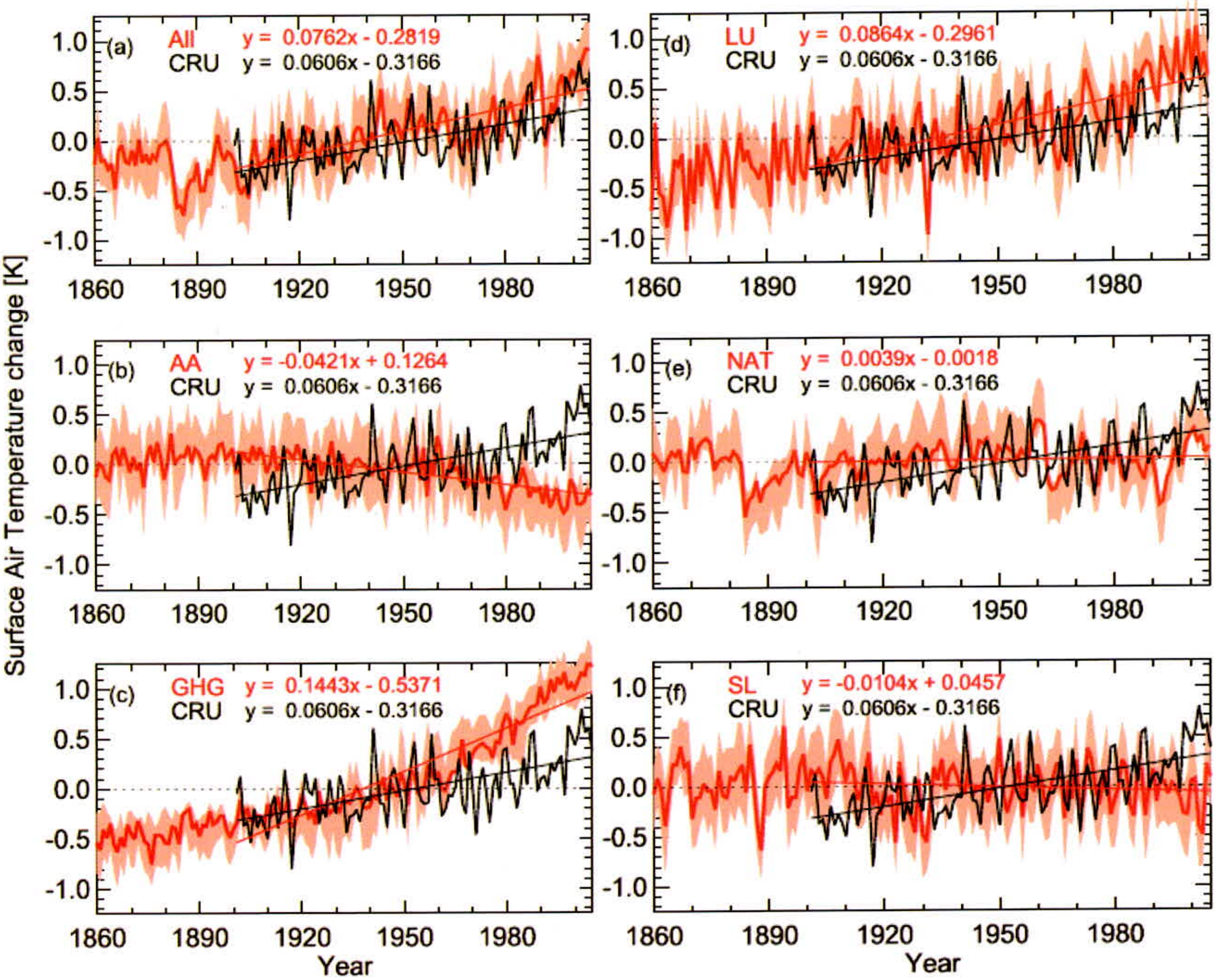

Figure 3.22: *(a-f): Annual ST anomalies variation with climate forcings (natural and anthropogenic) for the period of 1860–2005 (Source: Basha et al., 2017).*

It can be observed from Figures 3.22 a&d that there is a sudden rise in slope of the regression line as compared to the rest of the illustrations. This period of sudden rise is lying between 1960-70, the period of green revolution and industrial advancements in the country. Figure 3.22d shows that after the year 1970, there is a continuous increase in temperature anomaly due to LULC change. Figure 3.22c even has steeper slope than the Figure 3.22d. This shows that the industrial GHGs emissions are more responsible for temperature anomalies than the rest of the forcings.

Overall, the results show that the increasing trend in surface temperatures is more due to GHGs emissions as compared to LU and lowest for anthropogenic aerosols, natural (volcanic activity and solar irradiance) and solar radiation. The variability of different forcings, particularly for GHGs and LU is found to be more during winter and summer than the rest of the seasons. Therefore, the decreasing order of the relative impacts of various climatic forcings can be arranged as: GHGs>LULC>aerosols>solar radiation and natural forcings.

3.4 Climate Extremes

According to National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA), year 2018 was the warmest year since 1880 by an anomaly of 0.83^{0}C. Due to climate extremes, there will be an upsurge of the climatic extremes such as droughts, floods, frequency and duration of heat and cold waves and the number of population affected by these extreme events. Hence, there is a need to further explore the potential impacts of climatic hazards in the different regions /zones of the India and the population likely to be affected, particularly in the backdrop of 'Global Warming of 1.5^{0}C' and Paris Agreement (UNFCCC, 2015). As for as the modelling of the climate extremes is concerned, there are very few works available in climate literature exploring the phenomenon of heat waves, cold waves, their frequency and the length of days exceeding various temperature thresholds (Sterling et al., 2000). However, more recently, some noteworthy works have been done by Knowlton et al. (2014), Jaswal et al. (2015), Rohini et al. (2016), Mazdiyasni et al. (2017), Mishra et al. (2017), Ali and Mishra (2018), and Oldenborgh et al. (2018) on temperature extremes/heat wave and population exposure in current, 1.5 ^{0}C, and 2.0 ^{0}C worlds for India. In general, there is an increase in number of high-temperature (HT) days in the northern, southern and western parts of India with a decrease in the eastern parts of India (Jaswal et al., 2015).

India has witnessed severe heat related mortalities in the recent past, e.g., the events of year 2010, 2013 and 2015, which reported the human mortality of the order of 1300, 1500, and 2500 across India (Mazdiyasni et al., 2017 and Knowlton et al., 2014) and by the middle and end of the 21st century, there will be a manifold increase in population's susceptibility, i.e., of the order of 15 to 92 times respectively in 2.0^{0}C world (Mishra et al., 2017). Ghatak et al. (2017) found that in India, generally, the heat waves attain their peak during late May and early June of each year. It was also found that the heat wave phenomenon may get further re-enforced in agricultural intensive regions of North and Central India. Notably, most of these studies consider the daily-maximum or daily minimum or daily average air temperature for characterization of heat/cold waves in India and ignores the concurrency of these events. However, more recently, Mukherjee and Mishra (2018) have also considered the concurrency of the heat waves and found that the anthropogenic emissions are the major drivers for 1-day and 3-day concurrent hot day and hot night (CHDHN) events.

Mishra et al. (2017) have very categorically shown that there may be a sudden increase in the frequency of severe heat waves over India for 2.0^{0}C world by the end of 21st century. Figures 3.23a-c show the occurrence of the heat waves in India during 1951-2015 and Figure 3.24A-E show inter-relationship between temperature and heat waves in India for the period of 1960–2009. There has been an increase in the duration and the length of duration of heat waves in India (Rohini et al., 2016) and may be largely attributed to the atmospheric anomalies/variability mainly resulting due to an increase in the GHGs concentration. These heat waves will have a considerable impact on the health of humans and environment as well (Mishra et al., 2017) and may also increase the mortality rate (Mazdiyasni et al., 2017). Figure 3.24 shows that major part in (B, C, D, and E) is having red pixels indicating that heat waves are prominent in these regions. Southern and western regions of India experienced more heat waves as compared to the other regions during 1960-2009 period.

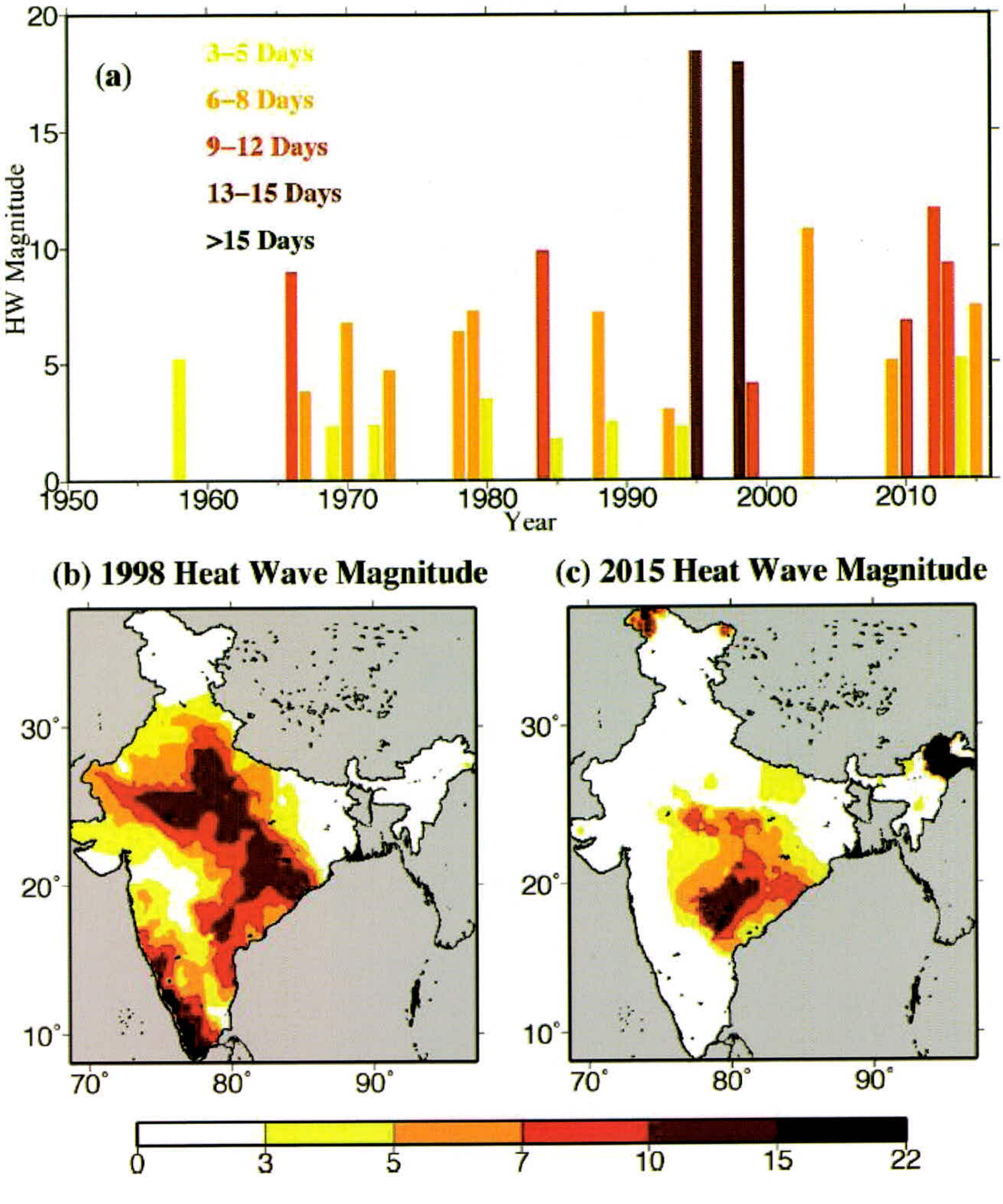

Figure 3.23a-c: *Occurrence of heat waves in India for the period of 1951–2015 (Source: Mishra et al., 2017).*

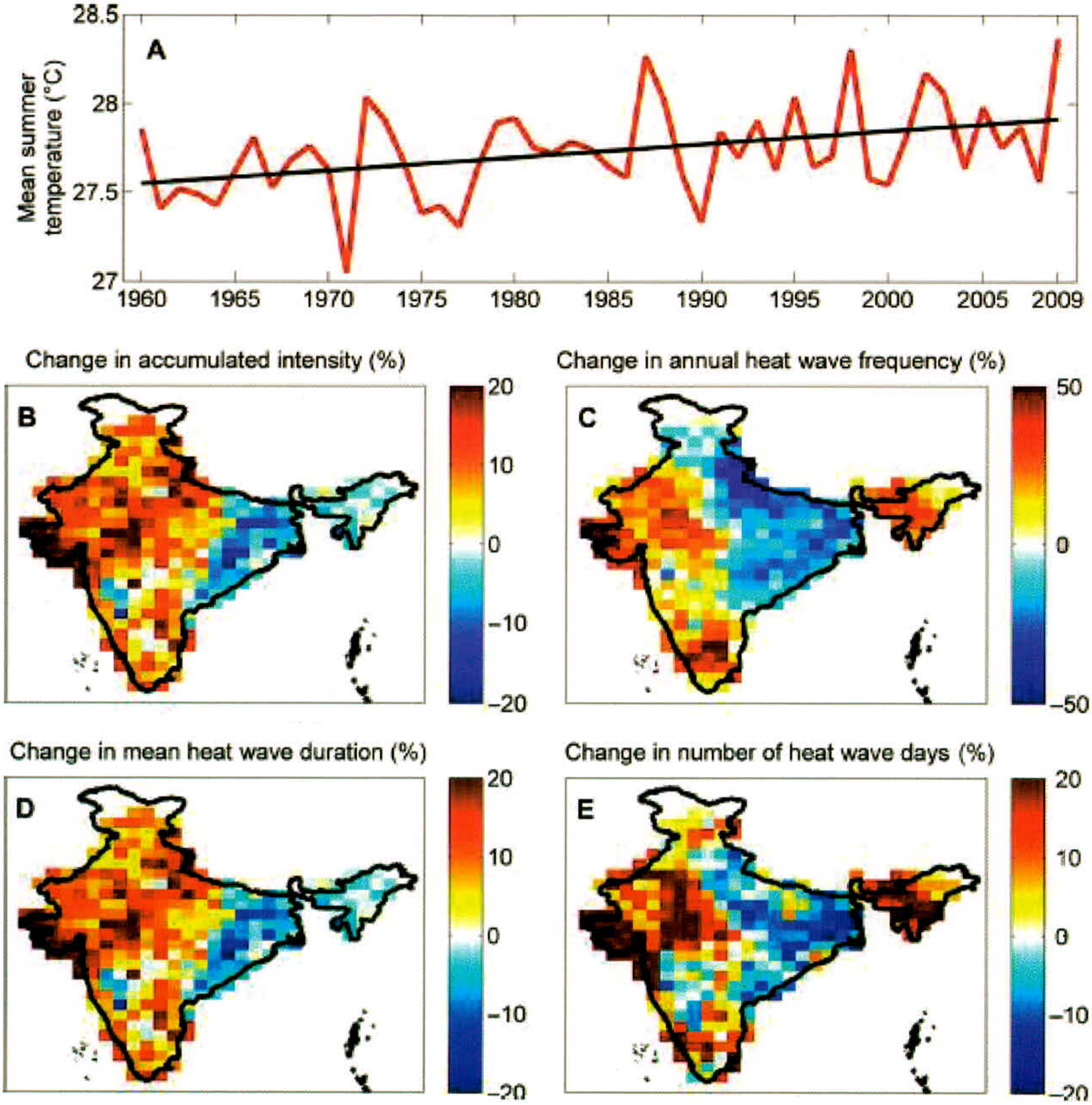

Figure 3.24A-E: *Inter-relationship between temperature and heat waves in India for the period of 1960−2009 (Source: Mazdiyasni et al., 2017)*

Mazdiyasni et al. (2017) found that the heat wave threshold across India is 36.0^{0}C, except for the WH and NE regions, which possess a lower value. The study finds that an increase of 0.5^{0}C in annual mean temperature will increase the mortality rate by 32% (Figure 3.25A) and the number of consecutive two or more heat wave days will increase the mass mortality rate from 46% to 82% (78% increase) (Figure 3.25B). Figure 3.25C shows the relationship between number of heat waves days, mean summer temperature and the probability of deaths > 100 persons.

The results indicate the degree of susceptibility of Indian population to heat waves and would be more severe looking in to the projected increase in the annual mean and maximum temperatures across the major regions of India. Therefore, the issue of heat waves in India is typical climate change phenomenon and needs due attention for minimizing its adverse impacts over the society as a whole.

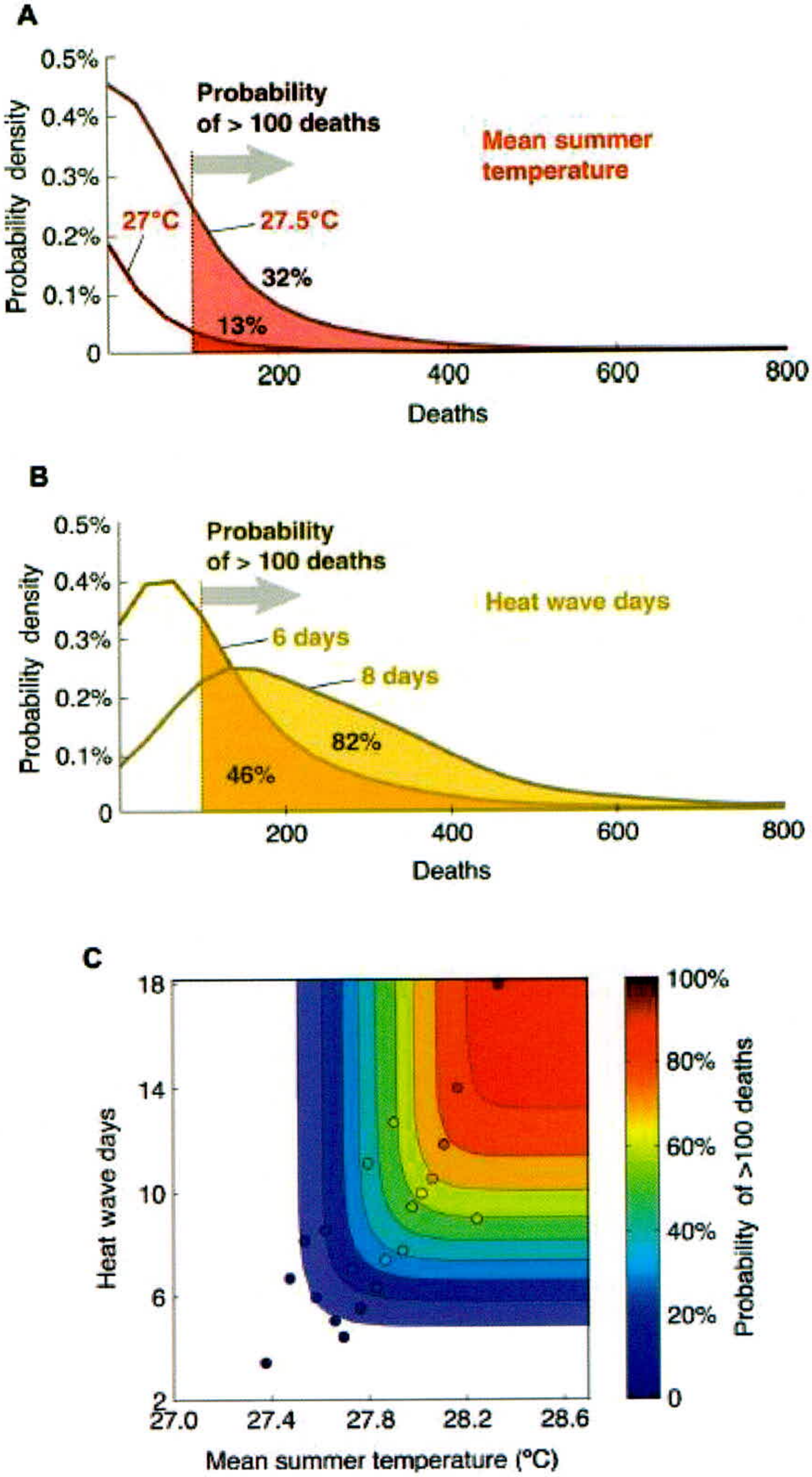

Figure 3.25 A-C*: Relationship between probability of deaths greater than 100, mean summer temperature, no. of heat wave days, and number of deaths (Source: Source: Mazdiyasni et al., 2017).*

3.5 Climate Change Performance Index (CCPI)

The climate change performance index (CCPI) is a standard index developed to enhance the transparency in climate politics worldwide through standard index developed to achieve the goal of the Paris Agreement by the partner countries and European Union. It has the ultimate aim to reduce the GHGs emission nearly 'zero' by 2050. The basic components of CCPI are given in Figure 3.26. The CCPI has four main components as: (1) GHGs emissions, (2) Renewable energy, (3) Energy use, and (4) Climate policy. Each country is evaluated based on the performance achieved in fourteen indicators (Figure 3.27) falling under these four groups. Based on the CCPI, Sweden is at the top position followed by Morocco and Lithuania. India is ranked at 11th place rated as 'High' with a score of 62.93 as shown in Figure 3.27. India has increased in CCPI ranking from 14th to 11th (Figure 3.27) by making use of more and more renewable energy resources and there is ample scope for further improvements by reducing the GHGs emission. (CCPI, 2019).

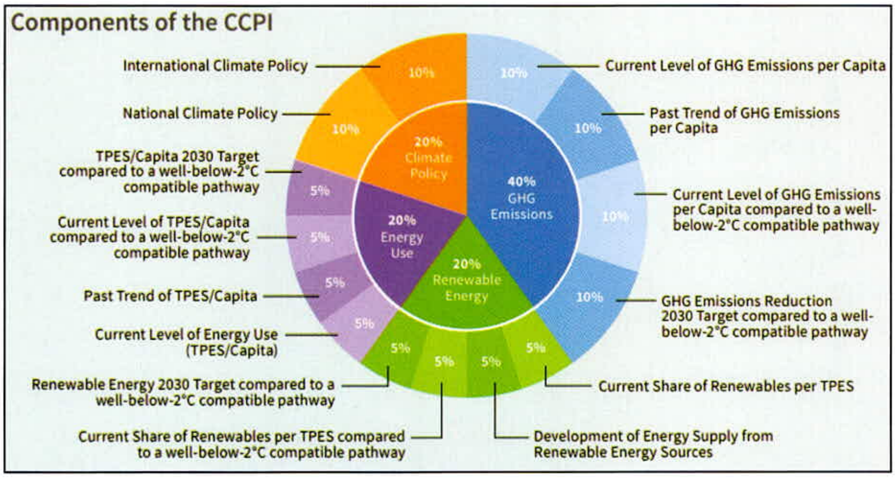

***Figure 3.26**: Components of CCPI (Source: Germanwatch, New Climate Institute & Climate Action Network).*

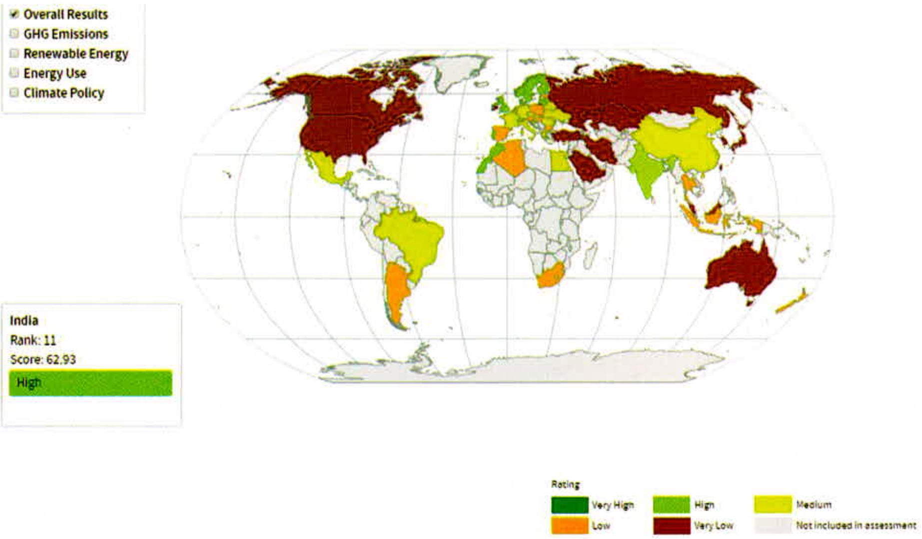

***Figure 3.27**: CCPI index of the world for 2019 (Source: https://www.climate-change-performance-index.org/).*

3.6. Concluding Remarks

1. Worldwide, the temperature is projected to accelerate during the 21st century under all the RCPs and it is projected to increase by 5.5^{0}C by the end of 21st century. The projected values of increase in mean temperature may vary in the range of 0.3–1.7 ^{0}C (RCP 2.6), 1.1–2.6 ^{0}C (RCP4.5), 1.4–3.1 ^{0}C (RCP 6.0), 2.6–4.8 ^{0}C (RCP 8.5) for 2081–2100, relative to 1986–2005.
2. There is a rapid rise in surface temperatures over India, particularly since about 1980 and may vary from 2.5 ^{0}C to 5.5 ^{0}C at the end of 21st century under GHG scenarios with maximum susceptibility over Himalayas, north, central and western parts of India with a lower influence on the southern part of India and will have more warm days and nights as compared to the cold days and night.
3. There is an increasing trend in annual average temperature of 0.006^{0}C per year with the maximum variation during the post-monsoon season, i.e., 0.0079^{0}C per year and the least (0.0043^{0}C/year) during the monsoon season for the period of 1901-2010.The temperature difference (increase) is more pronounced in the northern parts to the order of 1.4^{0}C-0.8^{0}C as compared to the southern parts.
4. There is a continuous and sudden variation in temperature anomalies over India due to GHGs and LULC change, particularly after the year 1970 (the period of green revolution and industrial advancements). The increasing trend in surface temperatures is more due to GHGs emissions as compared to LU and lowest for the anthropogenic aerosols, natural (volcanic activity and solar irradiance) and solar radiation. The climate change in India is mainly due to larger influence of atmospheric variability than the soil drying, i.e., a reduction in soil moisture.
5. There is an increase in number of high-temperature (HT) days in the northern, southern and western parts of India with a decrease in the eastern parts of India. Heat waves in India attain their peak during late May and early June of each year. The heat wave phenomenon may get further re-enforced in agricultural intensive regions of North and Central India.
6. There will be a sudden increase (30 times) in the frequency of severe heat waves over India for 2.0^{0}C world by the end of 21st century along with an increase in the duration and the length of duration and may also increase the mortality rate.
7. The "Hothouse Earth" condition (if developed?) would lead towards un-inhabitable planet and the GHGs would be the major forcings responsible for this condition. Hence, there is a need for emission-less world trade and economy.
8. There is a need of development of land-based CO2 removal through carbon sequestration/carbon sinks in forest, rural and agricultural landscapes to absorb the atmospheric carbon to achieve the Paris Agreement, i.e., to limit the global average temperature increase up to 1.5^{0}C (below 2.^{0}C) above pre-industrial levels.
9. There is also a need of action for 'natural climate solutions', which are very natural and cost effective, i.e., protection, management and restoration of various critical ecosystems — forests, grasslands, wetlands and croplands.

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