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Impact of Climate Change on India

J. Srinivasan

What tools are available to study climate change? What evidence is available to understand changes in Indian climate during the twentieth century? What do climate models predict regarding likely changes due to climate change in the twenty-first century? This chapter will provide a brief introduction to understanding the science of climate change in India and its impacts, organized around the aforementioned questions. While this is a complex topic, the aim here is to provide a baseline level of knowledge from which to engage and understand climate policy debates in India.

The Tools of Climate Science

Do we really understand the factors that control global and Indian climate? We know that the earth would have been more than 30°C colder if minor gases like carbon dioxide (CO_2), methane, ozone, and water vapour were absent (Mitchell 1989). Although the amount of these gases in the earth's atmosphere is very small, they have a huge impact on earth's climate because of their ability

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to absorb radiation emitted by the earth's surface (like the glass in a greenhouse).

The global mean temperature is calculated based on thousands of thermometers on land and measurements by ships over the ocean. They show that the global mean temperature has increased by around 0.85°C during the period 1880–2012 (Intergovernmental Panel on Climate Change [IPCC] 2013). This increase has been shown to be primarily on account of the increase in CO_2 and other greenhouse gases (GHGs) in the atmosphere, and this was proven by running climate models with and without the increase in all GHGs for 120 years. The climate models use all the laws of physics and the number-crunching capability of modern computers. The increase in global mean temperature predicted by these models agrees with observations by thermometers, validating the use of these models to understand the effects of CO_2 emissions on the trajectory of global mean temperature (Hegerl et al. 2007).

The amount of CO_2 in the earth's atmosphere has increased by more than 40 per cent during the past 150 years, on account of burning of fossil fuels (coal, oil, and natural gas), deforestation, and other land use changes (Hartmann et al. 2013). This increased CO_2 not only has direct effects on climate change but also has indirect effects, or so-called positive (accelerating warming) and negative (decelerating warming) feedbacks. In an example of a positive feedback, an increase in global mean temperature caused by a rise in CO_2 levels in turn leads to increase in water vapour, which then causes more thermal radiation emitted by earth to be trapped. Another factor that can cause positive feedback is the melting of ice in the polar region, and in the Himalayas, due to higher average temperatures; ice reflects most of the sun's radiation, while water absorbs most of the sun's radiation, further amplifying warming.

During the Ice Ages, which have occurred many times in the past, CO_2 and methane levels in the earth's atmosphere were much lower than the present. We know this based on measurements of the composition of the air trapped in the ice samples obtained from Arctic, Antarctic, and Himalayas, which allow an analysis of the air composition and temperature record going back 400,000 years. The amount of CO_2 in the air trapped in these ice samples varied between 180 parts per million and 280 parts per million (Jansen et al. 2007:

Figure 6.4). In contrast, in the early years of the twenty-first century, the concentration of CO_2 had crossed 400 parts per million. When combined with the evidence from models of the effect of CO_2 on global average temperatures, this steep increase provides grounds for concern.

In addition to changes induced by human beings, there are also natural factors, such as volcanic eruption and variation in the sun's energy incident on earth, that can cause changes in the earth's climate. However, based on the evidence from the techniques described earlier, in the twenty-first century, the changes induced by human beings will have a much greater impact on earth's climate than natural causes.

In addition, there are also impacts caused by regionally specific factors, such as change in land use and particulates (like sulphates and soot). As we describe later, these factors also complicate the understanding of global climate change since they may exacerbate or dampen these effects. Hence, it is not easy to attribute regional climate change to a single factor such as the monotonic increase in CO_2.

The IPCC was created by the United Nations (UN) to enable scientists from all parts of the world—using techniques such as those described earlier—to provide an authentic summary of our present understanding of the climate change induced by human beings and indicate the ways to mitigate this climate change or adapt to it (IPCC n.d.). The reports published by the IPCC between 1990 and 2013 have provided the scientific basis for the range of historic agreements between countries on addressing climate change, including the one concluded in Paris in December 2015 to reduce CO_2 released by human activities.

Projected Climate Change in the Twenty-First Century

What are the observed changes in climate variables from the twentieth century till date, both globally and in India? While climate change is expected to accelerate based on existing trends, some evidence already exists from data on temperature, rainfall, and glaciers, the three important ways in which climate change is likely to manifest.

Temperature

Presently, the rate of increase in global mean temperature is much faster than the changes in the global mean temperature that have occurred in the past on account of natural climate variations. When the earth emerged from the last Ice Age, about 20,000 years ago, the global mean temperature increased at the rate of 1°C in 1,000 years (Jansen et al. 2007). However, the global mean temperature has increased by around the same amount, that is, 1°C, in the last 120 years alone, with a large increase occurring during the last 40 years of the twentieth century, a rate about *ten times* faster than that driven by natural climate variation alone (Smith and Reynolds 2005). Hence, we need to be concerned that natural ecosystems may not be able to adjust to the rapid changes in temperature witnessed in the twentieth century.

The simulations by complex climate models have shown that this increase in temperature, as mentioned earlier, is primarily on account of a 40 per cent increase in CO_2 in the atmosphere during the past 150 years (Hartmann et al. 2013). The amount of CO_2 in the earth's atmosphere has increased by 120 parts per million in the last 150 years. Indeed, the rate of increase of CO_2 seen in the twentieth century has been *hundred times* faster than the rate of increase observed in the past due to natural climate changes, especially in comparison to what was observed when the earth emerged from the last Ice Age. Hence, we can conclude that such a large increase in CO_2 could not have occurred on account of natural causes alone.

In India, we have excellent observations recorded by the India Meteorological Department, based on more than 1,000 stations, for the past 120 years. These stations contain thermometer, rain gauge, and instruments to measure winds and relative humidity. Based on these records, the all-India annual mean surface air temperature has increased by 0.6°C during the period 1901–2010 (Rajeevan and Nayak 2017). Most of the increase was seen during the past 30 years during the pre-monsoon season and in winter. The change in mean temperature has been primarily on account of a long-term trend of an increase in daily maximum temperature. There is only a short-term, 30-year trend of increase in daily minimum temperatures, but the reasons for this variation in minimum temperatures are not well understood. In contrast, the increase in global mean temperature is primarily on account of an increase in daily minimum temperature. The sea surface temperatures in the oceans around India have also risen by 0.6°C during the past 50 years, with the largest increase seen around the equatorial Indian Ocean (Rajeevan and Nayak 2017).

In addition, the number of heatwaves during the pre-monsoon period has shown an increasing trend. During the period 1970–2005, the number of hot days—defined as days with maximum temperature in the top 10 percentile—increased from 2 days to 20 days in the west coast of India (Kothwale, Revadekar, and Rupa Kumar 2010). The number of cold days decreased by 10 days during the same period. In some high-altitude stations in Nepal, the surface air temperature has increased by 1°C per decade during the last 30 years of the twentieth century (Shrestha et al. 1999). This is much larger than that observed in most stations in India. In summary, the temperature records show that temperature has increased in most parts of India in the last 100 years.

Rainfall

The trends in rainfall are less clear as compared to temperature, both because of confounding factors and because of changes in the distribution of rainfall across a year. Most of the rainfall in India occurs during the summer monsoon (June–September). The all-India summer monsoon rainfall has not shown any large trend during the last 140 years, for the most part falling within 10 per cent of the long-term mean. However, at the regional level, some trends are visible. Chhattisgarh has shown a significant decline in rainfall, the cause of which is unknown. Kerala too has shown a declining trend in rainfall for the past 50 years and some climate models indicate that this is related to global warming (Rajeevan and Nayak 2017; Rajendran and Kitoh 2008).

However, there are other confounding factors that affect these trends. The Indian summer monsoon rainfall can be much lower (or higher) than normal during El Niño (La Niña) years, when the sea surface temperatures in the equatorial Pacific Ocean are warmer (or cooler) than normal. The Indian rainfall can be above (or below) normal if the sea surface temperatures in the western equatorial Indian Ocean are above (or below) normal. The changes in the sea surface temperatures in the tropical oceans thus exert a strong influence on the Indian summer monsoon.

In addition, small solid particles suspended in the atmosphere, called aerosols, can also influence the Indian summer monsoon rainfall. The emission from thermal power plants (that burn coal or oil) can lead to large emissions of sulphur dioxide, which later become sulphate aerosols. The sulphate aerosols cool the earth's surface and the atmosphere, and hence can lead to a decrease in Indian summer monsoon rainfall. On the other hand, soot emitted from incomplete combustion (diesel engine exhaust or burning of firewood for cooking) heats the atmosphere and cools the surface. The impact of soot on Indian summer monsoon rainfall can be complex, and hence it is not certain if the presence of soot will lead to an increase or decrease of monsoon rainfall. Natural aerosols such as dust can also influence rainfall during the pre-monsoon season. At present, we do not have sufficient understanding of the impact of aerosols such as dust or soot on monsoon rainfall.

As mentioned earlier, the annual average all-India rainfall does not show significant trends, although there are regional trends. In addition, there has been a shift in the distribution of rainfall towards more extreme rainfall events. According to Goswami et al. (2006), heavy rainfall events (rainfall greater than 100 millimetre [mm]/day) have increased by 50 per cent in Central India in the past 50 years. This rapid increase in heavy rainfall events may be on account of global warming or increase in aerosols. The seasonal mean all-India monsoon rainfall does not show any long-term trend because the increase in extreme rainfall events has been compensated by a decrease in moderate rainfall events (rainfall below 100 mm/day). The number of cyclonic disturbances has decreased from seven per year in the mid-twentieth century to below two per year in the last decade of the twentieth century (Dash et al. 2007). In addition, there has been a decrease in winter snowfall in Western Himalayas in the period 1990–2010. Finally, the annual mean relative humidity, averaged over 244 stations in India, has increased from 63 per cent to 66 per cent during the period 1968–2008 (Rajeevan and Nayak 2017). These changes indicate that extreme rainfall events have definitely increased, while moderate rainfall events have decreased in the past 50 years. These trends have increased both floods and droughts in India.

Glaciers

There is a lot of concern about the impact of global warming on glaciers, which could reduce the water stored in the glaciers, and hence the world's freshwater supplies, including in India, as well as exacerbate sea-level rise. In most parts of the world, glaciers are retreating; quite rapidly in some parts (more than 20 metres per year) and more slowly in others. Our knowledge about glacier retreat is limited because less than 0.2 per cent of the glaciers on earth are monitored regularly (Bolch et al. 2012).

Climate change can affect glacier retreat in a number of ways. A glacier can retreat rapidly on account of warmer air above it and less snow falling on it. In addition to the change in temperature and snowfall, the rate of retreat of the glacier also depends upon the altitude of glacier. For example, at many high-altitude stations, the air temperatures have increased more rapidly than in stations at lower altitudes, thereby leading to high melt rates at higher altitudes.

In the Indian Himalayas, small glaciers (area less than 1 sq. km) have been retreating rapidly. In the Chenab basin in Himachal Pradesh, the area of small glaciers has decreased by 38 per cent during the period 1962–2004, while the area of large glaciers (greater than 10 sq. km) has decreased by 12 per cent in the same period (Kulkarni et al. 2007). Hence, many small glaciers in the Himalayas may disappear completely in the next 50 years.

Sea-Level

A rise in sea-level threatens coastal and deltaic areas, which house a large share of the world's population, and also exacerbates the effects of storm surges. Sea-level rise is caused by an increase in sea surface temperature that will lead to expansion of sea water, as well as by ice melting from land glaciers. The global sea-level has increased by around 190 mm from 1901 to 2010 (Church and White 2011;

IPCC 2013). The rate of sea-level rise was 1 mm/year in the early twentieth century and 3.3 mm/year during the last decades of the twentieth century (Church and White 2011). However, as with rainfall, sea-level rise is affected by local factors, such as subsidence, as much as by global factors. For example, in Mumbai, sea-level has increased by 0.77 mm/year during the past 100 years, while in Kolkata the sea-level has increased by 5.22 mm/year during the past 50 years (Unnikrishnan and Shankar 2007).

Sea-level rise is a major concern since most of the human population resides within 50 km of the sea coast. In India, the coastal states, such as West Bengal and Gujarat, are the ones most vulnerable to sea-level rise. The increase in sea-level will cause enhanced damage during storm surges that occur during cyclone landfall.

Interaction between Air Quality and Climate Change

In India the combination of declining air quality and climate change will pose new challenges. There has been a dramatic decline in air quality—defined by the presence of particulates and gases such as sulphur dioxide and oxides of nitrogen—in India during the last three decades. Air quality has significant, direct health impacts. Thus, the Lancet Commission on pollution and health has warned that air pollution is the largest environmental cause of disease and death in the world today (Watts et al. 2015). The Commission estimates that 9 million premature deaths in the world every year can be attributed to air pollution.

The increase in air pollutants affects climate outcomes through a variety of pathways. For example, these pollutants increase the amount of ozone at the ground level, which damages our lungs and the growth of plants. (By contrast, ozone in the stratosphere protects us from harmful ultraviolet radiation, which is why the 'ozone hole' over Antarctica was dangerous.) Particulates, or aerosols, reduce the solar radiation reaching the earth and hence cool the surface of the earth, which can lead to weakening of the Indian monsoon. Moreover, particulates in the atmosphere alter the life cycle of clouds. By altering the size distribution of droplets in clouds, they can lead to more heavy rainfall events, and also increase the duration of dry spells during the monsoon. The total cloud cover during the monsoon has declined from 72 per cent to 66 per cent during the past 50 years and the percentage of area under drought in India has increased from around 10 per cent to 20 per cent during the period 1959–2009 (Rajeevan and Nayak 2017).

Climate Change in the Twenty-First Century

To predict future climate change in India in the twenty-first century, we need to use climate models. All models indicate that the surface air temperature over India will increase, but the magnitude of the increase varies between 2°C and 4°C (by the end of the twenty-first century). Takahashi, Honda, and Emori (2007) have indicated that an increase in temperature will cause a large increase in mortality due to heatwaves in Asia. Most models also predict an increase in monsoon rainfall in the twenty-first century. However, because these models differ greatly in their ability to simulate and reproduce past patterns of summer monsoon precipitation over India in the twentieth century and match these to rainfall records, the rainfall predictions of these models for India must be used with great caution.

In order to inform adaptation policy, there is a great demand for predicting the effects of climate change at the district level; however, the techniques to accomplish this are, as yet, a work in progress. One approach is to use statistical downscaling of coarse resolution models, but this is not a reliable approach. Shashikanth et al. (2014) have shown that the key uncertainty in statistical downscaling is due to the uncertainty in local circulation pattern simulated by the parent models.

By contrast, the district-scale results obtained from high-resolution models (spatial resolution around 25 km) have more credibility. Rajendran and Kitoh (2008) have shown that a high-resolution climate model simulates the spatial structure of Indian monsoon rainfall very well. This model predicts that Indian monsoon rainfall will increase in most regions of India in the twenty-first century, on account of the increase in CO_2, but there will be a decrease in rainfall over Kerala (see Figure 2.1 [between pages 326 and 327]). This prediction is credible as it has been observed that during the past 50 years, there has been a decrease in rainfall over Kerala. Thus, we may be witnessing the impact of global warming already. At the same time, Bollasina and Nigam (2009) suggest that current models cannot, as yet, provide durable insights on regional climate feedbacks, nor credible projections of regional hydroclimate variability, suggesting the need for continued caution in how these models are used and their further development.

The impact of increase in temperature on agriculture has been discussed by many investigators. While an increase in rainfall and CO_2 may be beneficial for crops, it does not completely offset the adverse impact of increase in temperature. Panda (2009) and Aggarwal (2003) have estimated a 2–5 per cent decrease in yield potential of wheat and maize for a temperature rise of 0.5–1.5°C in India. Moreover, the impact of air pollution on the yield of crops is likely to be greater than the impact of increase in temperature. In a study in Punjab, Sinha et al. (2015) have shown that the yield of crops can decline by as much as 50 per cent when the ground-level ozone is very high. The evidence for other areas of economic productivity is less well known. For example, the impact of climate change on fisheries is complex since it depends upon changes in ocean temperature, ocean circulation, and oxygen content, and hence no reliable predictions are available.

The increase in surface temperature and changes in rainfall patterns may have an impact on vector-borne diseases. The increase in surface temperature over land, in theory, will make more areas conducive for the spread of malaria and dengue (Bhattacharya et al. 2006). While there has indeed been a large increase in malaria and dengue in India during the past 40 years, we do not have sufficient evidence to demonstrate, as yet, that this increase is linked in any way to global warming. Reiter (2001: 158) has stated that: 'The natural history of mosquito-borne diseases is complex, and the interplay of climate, ecology, vector biology, and many other factors defies simplistic analysis. The recent resurgence of many of these diseases is a major cause for concern, but it is facile to attribute this resurgence to climate change.' However, the interplay between changes in climatic variables such as temperature and rainfall on the one hand, and potential consequences on economic and social effects such as agricultural yields, fisheries, and health impacts on the other, continue to be an area of concern and active research, with implications for India.

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There is clear evidence to show climate change in India in the twentieth century, and this change will accelerate in the twenty-first century. One can expect more extreme rainfall, longer dry spells, higher sea-level, and more severe heatwaves in the future. In India, climate change will have more adverse impact as compared to many other countries. This is because India has a higher population density, larger spatial and temporal variability of rainfall, and more poor people who are vulnerable to climate variability. The climate models used to predict the climate change in the twenty-first century are not able to predict accurately the changes in regional climate. This is caused both by poor spatial resolution of the climate models and our incomplete understanding of the impact of aerosols, clouds, and land-use change on local climate. Adaptation policy has to operate with this imperfect understanding, even as we seek to improve our understanding of the science.

To tackle climate change, we need to take action both at the local and global level. At the global level, we need to ensure that the CO_2 released by human activities is reduced dramatically in the next 50 years. At the local level, we need to reduce air pollution, water pollution, and soil degradation as quickly as possible. This will demand innovations, new technologies, and new approaches to economic development.

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