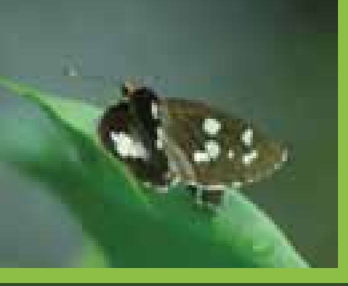
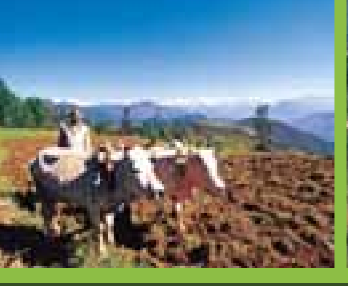
INCCA Report # 2

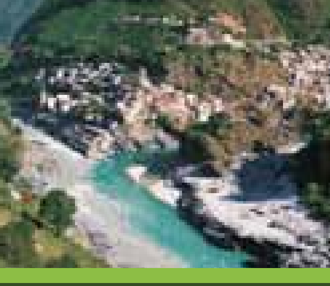
Climate Change and India: A 4x4 Assessment

A sectoral and regional analysis for 2030s

Executive Summary







INCCA: Indian Network for Climate Change Assessment

November 2010

Ministry of Environment & Forests
Government of India




Climate Change and India: A 4x4 Assessment

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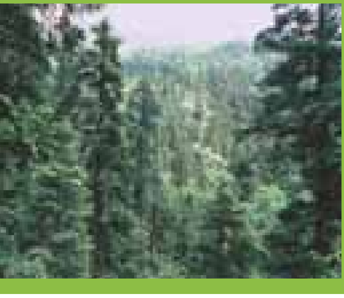
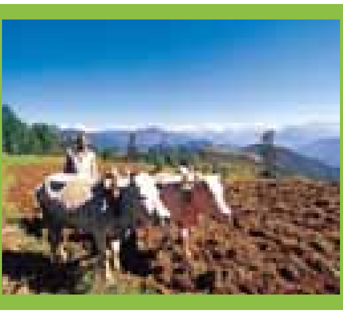
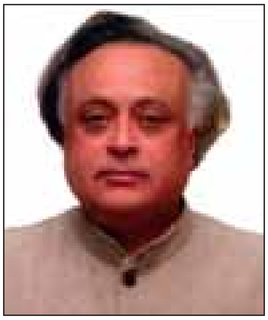





Foreword



I have great pleasure in introducing the report ***"Climate Change and India: A 4X4 Assessment A sectoral and regional analysis for 2030s"***, prepared by the Indian Network for Climate Change Assessment (INCCA). This report provides an assessment of impact of climate change **in 2030s on four key sectors** of the Indian economy, namely *Agriculture, Water, Natural Ecosystems & Biodiversity and Health* in **four climate sensitive regions** of India, namely *the Himalayan region*, *the Western Ghats, the Coastal Area and the North-East Region*. It is for the first time that such a comprehensive, long term assessment has been undertaken based on rigorous scientific analysis. It is also for the first time that an assessment has been made for the 2030s (all previous assessments were for the 2070s and beyond).

As I have said in the past, **no country in the world is as vulnerable, on so many dimensions, to climate change as India.** Whether it is our long coastline of 7000kms, our Himalayas with their vast glaciers, our almost 70million hectares of forests (which incidentally house almost all of our key mineral reserves) – we are exposed to climate change on multiple fronts. Rigorous science based assessments are therefore critical in designing our adaptation strategies.

It was in this context that we formally launched the Indian Network of Climate Change Assessment (INCCA) last year. **INCCA is a network-based programme that brings together over 120 institutions and over 220 scientists from across the country to undertake scientific assessments of different aspects of climate change assessment.** As I have stated earlier, we need to make the "3 M's" – **Measure, Model and Monitor** – the foundation of our decision-making and we need to build indigenous capacity for this. We should not be dependent on external studies to tell us for example about the impact of climate change on our glaciers, on our monsoons, and indeed even on sea level rise. Indeed, recent evidence suggests the "scientific consensus" on many of these is debatable.

We need to build our own independent and credible research capacity on these issues. This report is a step in this direction. In particular, the knowledge and understanding of impacts as deduced from the Global Circulation Models and Regional Climate Models are not adequate to assess the impacts and implications for India. A need has been felt for comprehensive national as well as state level impact assessment. This assessment is an attempt to use PRECIS (providing climate investigation studies) based on HadRM (Hadley Regional climate Model) to generate climate change scenario for 2030s.

This is the third major publication of INCCA and I look forward to many more. I congratulate the scientists and experts associated with this Study.

Jairam Ramesh
Minister of State for Environment & Forests
(Independent Charge),
Government of India

Executive Summary

Climate change is recognized as a significant man-made global environmental challenge. It is also treated as a threat. Consequently, there is now a growing recognition of the vulnerability of key sectors of economy and development due to climate change. The various assessment reports brought out since 1990s by the Intergovernmental Panel on Climate Change (IPCC) have progressively tracked the development and build up of knowledge and understanding of the science, impacts and mitigation of climate change at the global and regional levels. The IPCC has concluded that the impact of human activities on climate is unequivocal (IPCC, 2007). The debate at this point is on the extent and magnitude of climate change.

The Fourth Assessment Report of the IPCC provides the latest understanding regarding climate change at the continental level but the details at the regional and subregional levels are rather inadequate. The assessment emphasizes the need for more comprehensive studies and information at such levels. Wide-ranging implications and adverse impacts due to climate change have been projected on developing countries.

As a part of India's Initial National Communication to the UNFCCC, impacts of climate change on water resources, agriculture, natural ecosystems and forestry, human health, infrastructure and energy were assessed and reported for the 2050s and 2080s. The assessment did not specifically articulate impacts at sub national level, especially the impacts on climate sensitive regions in India.

With a view to enhance knowledge about the impacts of climate change at the national and sub national level, the Minister for Environment & Forests announced the launch of the Indian Network of Climate Change Assessment (INCCA) on October 14, 2009. INCCA has been conceptualized as a network-based scientific programme designed to (a) Assess the drivers and implications of climate change through scientific research; (b) Prepare climate change assessments once every two years (greenhouse gas estimations and impact of climate change, associated vulnerabilities and adaptation); (c) Develop decision support systems and (d) Build capacity towards management of climate-change related risks and opportunities. The programmes envisaged under the aegis of INCCA are shown in figure ES1.

The INCCA is visualized as a mechanism to create new institutions and engage existing knowledge institutions already working with the Ministry of Environment and Forests (MoEF) as well as other agencies. Currently, the institutions of the various ministries such as that of the MoEF, Ministry of Earth Sciences, Ministry of Agriculture, Ministry of Science &Technology, Defence Research and Development Organisation etc., along with research institutions, such as the Indian Space Research Organisation, Council of Scientific and Industrial Research, Indian Council of Agriculture Research, Department of Science & Technology, Indian Council of Medical Research, Indian Institute of Technology, Indian Institute of Management, prominent state and central universities and reputed non-governmental organizations and industry associations are working on the various studies on climate change.

This report brings together a review of what is known about the impacts of climate variability in the four major climate sensitive regions in India, namely, the Himalayan region, the North-Eastern region, the Western Ghats and the Coastal region. Further, it presents an assessment of the impacts of climate change in the 2030s on four key sectors of the economy that are climate dependent, namely, Agriculture, Water, Natural Ecosystems and Biodiversity and Human Health. Assessments made at such short time lines are useful, as they can be used to develop adaptation strategies for a foreseeable future.

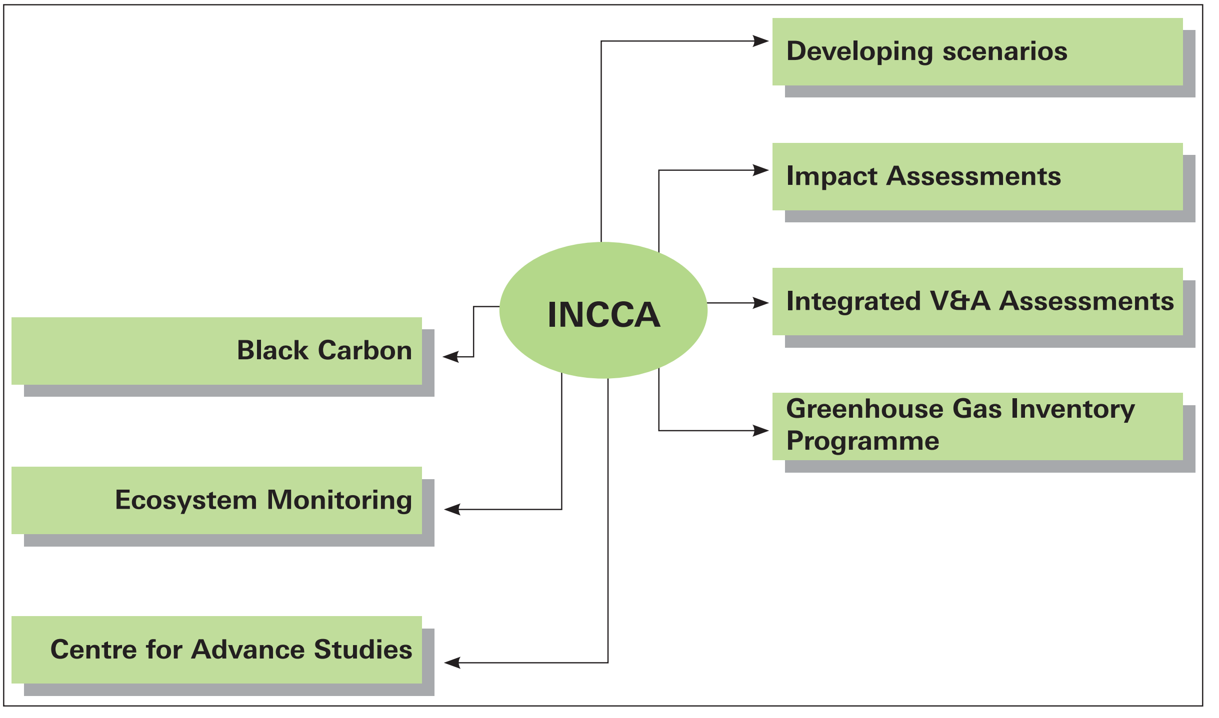


Figure ES1: Programmes envisaged under INCCA

Approach

About 18 institutions and 43 researchers participated in this assessment (see figure ES2). The methodologies for assessing each of the components of this study are described below.

1. Climate change scenarios

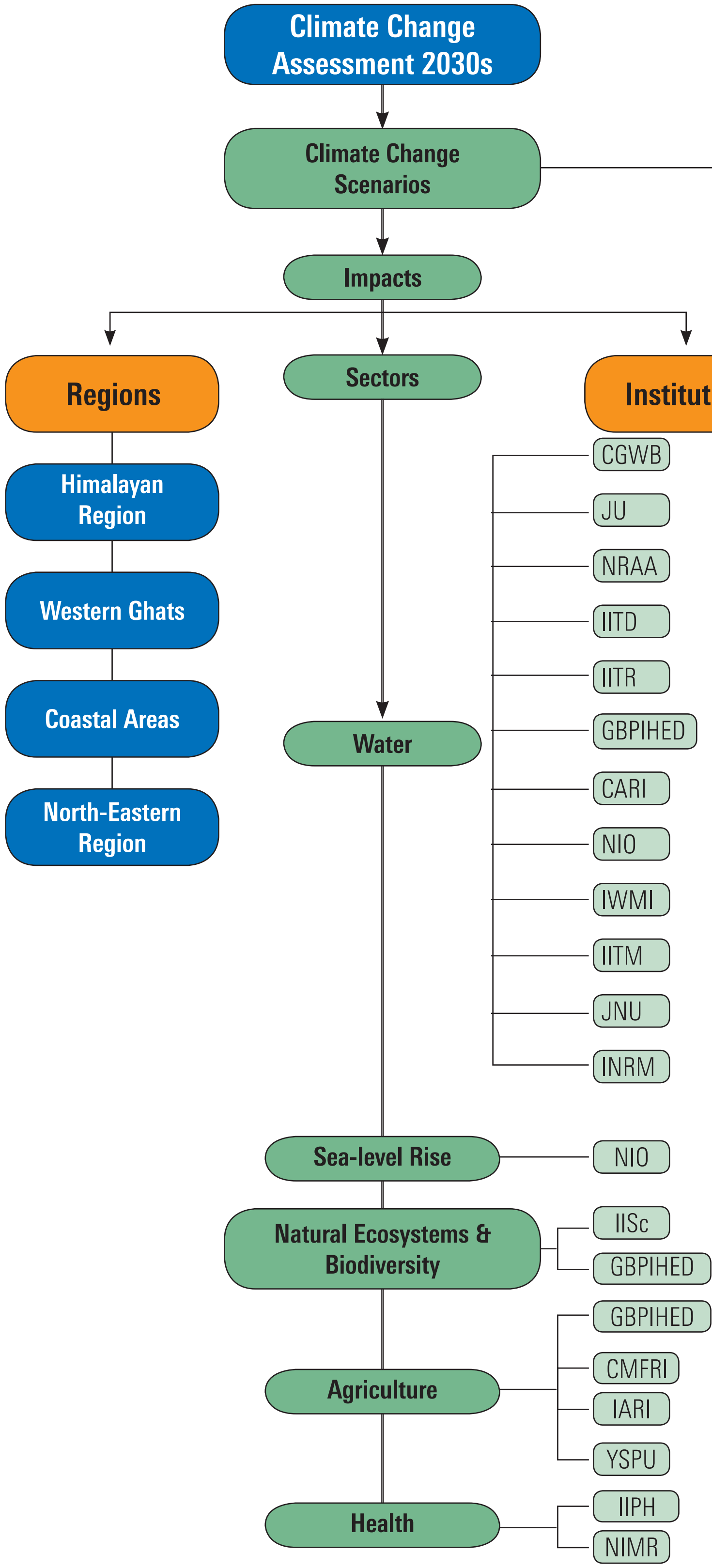
The climate change scenarios have been derived from a regional climate change model PRECIS (a version of HadRM3 developed by the Hadley Centre, UK) with a resolution of 50km x 50km and forced by a greenhouse gas (GHG) emission scenario emanating from A1B IPCC SRES (Special Report on Emission Scenario; IPCC, 2000). The 2030s is the average of the period between 2021 to 2050. All the changes in the 2030s are with respect to the average of the period 1961 to 1990s, also referred to as the 1970s or the baseline.

2. Sea-level rise

The sea-level rise projection along the Indian coastline is in sync with the global projections as assessed in the IPCC Fourth Assessment Report. Because the ocean has an enormous thermal inertia, it takes many decades for sea level to adjust to the quantity of heat that it absorbs. This delay means that even if man-made GHG emissions were completely halted today, sea-level will continue to rise to the end of this century.

3. Impacts on Agriculture

The impact on productivity of four cereals (wheat, rice, maize and sorghum) and coconut plantations have been assessed through a simulation model called InfoCrop. The analyses were done for every 1°x1° grid for Western ghats, North Eastern region and the Coastal regions with inputs of (a) observed weather data from the India Meteorological Department at 1°x1° scale for the 1970s; (b) Soil data rescaled to grid values from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) and ISRIC World Soil information data base; (c) Crop management parameters, that is, normal crop practices as followed by farmers; (d) Genetic coefficients of varieties best suitable for different regions; and (e) Climate change scenarios of PRECIS A1B for 2030. Due to lack of required climate data at



CARI – Central Agricultural Research Institute
CMFRI – Central Marine Fisheries Institute
CGWB – Central Ground Water Board
GBPIHED – G.B. Pant Institute of Himalayan Environment and Development
JNU – Jawaharlal Nehru University
IARI – Indian Agricultural Research
IIPH – Indian Institute of Public Health
IISc – Indian Institute of Science
INRM – Integrated Natural Resource Management
IITD – Indian Institute of Technology Delhi
IITM – Indian institute of Tropical Meteorology
IWMI – International Water Management Institute
IITR – Indian Institute of Technology Roorkee
JU – Jadavpur University
NIMR – National Institute of Malaria Research
NIO – National Institute of Oceanography
NRAA – National Rainfed Area Authority
YSPU – Dr. Y S Parmar University

Figure ES2: Institutional Arrangement for the 4x4 Climate Change Assessment

$1^{o}x1^{o}$ scale, no assessment using the crop model could be carried out for the Himlayan region, However, an assessment of the production of apples in the future in Himachal Pradesh in the Himalayan region has been made based on observed productivity trends *vis a vis* the changes in temperature in the state.

Also, this section deals with the likely impacts of climate change on coastal fisheries based on observation of trends of current fish productivity, climate and sea parameters. Impacts on livestock productivity have also been analysed on the basis of temperature and humidity projections from PRECIS for the 2030s. These parameters have been used to estimate the temperature–humidity index (THI), which is related to animal stress, and an increase in this index is directly related to decline in productivity of milk at different temperature ranges.

4. Natural ecosystems and biodiversity

The assessment of the most of the natural ecosystems in this report is mainly based on review of available literature, however, specifically, a dynamic vegetation model IBIS driven by the climate change scenarios generated for this assessment has been used to understand the likely impacts on forest vegetation and Net Primary Productivity the main climatological parameters required by IBIS are monthly minimum, maximum and mean temperature (^{o}C), monthly mean precipitation rate (mm/day), monthly mean relative humidity (%), wind speed (m/s) and monthly mean cloudiness (%). The main soil parameter required is the texture of soil (i.e, percentage of sand, silt and clay). The model also requires topography information. Observed climatology is obtained from Climate Research Unit (CRU) and the projected climate obtained from the runs of regional model PRECIS.

5. Human Health

A qualitative as well as a quantitative approach has been used to assess the impacts of climate change on human health. The qualitative approach describes the likely impact of climate change on morbidity and mortality due to changes in extreme temperatures, flooding due to extreme precipitation, melting of glaciers, and sea level rise. The quantitative approach has been applied to assess the transmission of malaria in the 2030s. The transmission windows have been defined in terms of temperature as well as temperature and relative humidity.

6. Water

For the present analysis, water yield and other hydrological budget components such as rainfall, evapotranspiration, and sediment yield have been obtained through simulation of runoff in all the river basins lying in the four regions under focus using SWAT - A Soil and Water Assessment Tool driven by climate scenarios generated as a part of this assessment.

Challenges of the assessment

Impact assessment research is a complex challenge because it includes physical, biological and socio-economic aspects, and the tools used for these assessments need to continuously evolve so as to upgrade the scientific rigour of the findings. The challenges encountered in the assessment and the research gaps are as follows.

1. Demarcating the regions

- India is a climatologically diverse country. Its climate is characteristic of the subregional physical features, which also typifies its very diverse biological reserves and natural resources. Therefore the climate of each region though being very distinctive, also merges seamlessly and hence demarcating these four regions has been difficult, as they do not conform to the standard agroclimatic zones or the climatic zones. Climatologically, the entire Indian region is divided as western Himalayas, north-west, north-east, northern-central region, eastern coast, western coast and the interior plateau.

- The description of the extent and location of Western Ghats is taken from literature. They were then used to extract grids for deciphering the observed climate and climate projections. Demarcating the costal region has been a challenge. The coastal zone includes an area 5,500km along the mainland and 20,000km along its various islands. Demarcating the coastal zone as defined in the CRZ (Coastal Regulatory Zone) notification 2010 of MoEF, would have been a separate task in itself. For convenience, only the coastal areas along the mainland have been included in the assessment and the impacts have been estimated for the region that encompasses the coastal districts.

2. Uncertainties in modelling and data gaps

- Inherent uncertainties in the key assumptions about and the relationships between future population, socio-economic development and technical changes that constitute the basis of the IPCC SRES Scenarios and the uncertainty in emissions can be allowed for by making climate projections for a range of these SRES emissions scenarios. Also, the imperfect understanding of some of the processes and physics in the carbon cycle and chemical reactions in the atmosphere generates uncertainties in the conversion of emissions to concentration. Uncertainties also arise because of incomplete description of key processes and feedbacks in the model. It can be reduced by running ensembles of future climate projections using the same model and the same emission or concentration scenarios. Further, regionalization techniques carry with them errors in driving the general circulation model (GCM) fields.

- The resolution of the RCM should be high enough to resolve the fine scale details that characterize regional forcings. The PRECIS at 50km resolution can provide good simulations of daily precipitation over the broad plateau region in India. However, detailed projections for a particular inner Himalayan valley, the hills in the North-East and the Western Ghats require a much higher resolution. Therefore, it is perceived that a higher resolution model (at least 25km x 25km or less) will be more appropriate for capturing the orography of the Indian region.

- Observations from satellite measurements indicate that the sea level has risen about 80 per cent faster, at 3.4 millimetres per year, than the average IPCC model projection of 1.9 millimetres per year (Nature, http://www.nature.com/climate/2010/1004/full/climate.2010.29.html, accessed on 18 October, 2010). The difference between the semi-empirical estimates and the model-based estimates of the IPCC can be attributed largely to the response of continental ice to greenhouse warming. The IPCC range assumes a near-zero net contribution of the Greenland and Antarctic ice sheets to future sea-level rise, on the basis that Antarctica is expected to gain mass from an increase in snowfall. Observations show, however, that both ice sheets have been losing mass at an accelerating rate over the past two decades. A number of recent studies, taking the semi-empirical approach, have predicted a sea-level rise exceeding one metre in the twenty-first century if GHG emissions continue to escalate—a figure much higher than that projected by the IPCC. Because of the limitations of the physical climate models used by the IPCC, alternative approaches to estimating sea-level rise may be explored which are semi-empirical in nature and based on the idea that the rate of sea-level rise is proportional to the amount of global warming—the warmer it gets, the faster ice melts. Past sea level and temperature data are used to quantify this effect. Also, melting of glaciers in the Himalayas may contribute to the rise in local sea level along the Indian coastline.

- The InfoCrop model does not take into account socio-economic trends. Hence technological improvements in future, farmers' economic status, market demand, future land use for agriculture, and so on, which drive the changes in yields and production to a large extent, have not been considered. Further, even though the model has provision, the pests and disease scenarios are not integrated in this assessment due to lack of proper scientific data.

- Apart from the above, primary database on farm inputs applied by the farmers needs to be developed on a fine gridded level. In this simulation analysis, the yields are calibrated to current district-level yields to overcome such limitation. There is a need to link other influential biophysical and socio-economic driving forces, which are indirectly impacted by the climate change but influence agriculture, for working out the comprehensive impacts.

- The IBIS model used for assessing changes in vegetation and net primary productivity in forests in the 2030s requires an extensive finely gridded database on soil, water and climate parameters in addition to types of biome. As the full set of input parameters could not be assembled satisfactorily at even one of the locations, exploratory runs were made based on database using a range of default/ approximate values. These could reproduce the current vegetation patterns only to a low level of accuracy. For example, the tropical forests such as those in the Western Ghats are highly diverse with vegetation changing every few kilometers. It is necessary that a long-term observational plan be set in place that identifies the vegetation type at least within 1km x 1km.

- Similarly, the SWAT model used for assessing water yields in the various regions requires information on terrain, soil profile and land use of the area as input. These have been obtained from global sources in the absence of accessibility to nationally generated data. Further, the study determines the present water availability in space and time without incorporating any man-made changes like dams, diversions, etc. These entities are assumed to be static for future as well, which might not be the case. Therefore, a scenario projection is required that can realistically capture the trends of these parameters.

Key results of the 4x4 assessment for the 2030s

Climatologically, the entire Indian region is divided into the western Himalayas, north-west, north-east, northern-central region, eastern coast, western coast, and the interior plateau. The projected climate change information obtained from PRECIS driven by IPCC A1B scenario for these regional entities have been adapted for the present assessment as per the regions in focus. For example, the projections for the Western Ghats refer to projections for the western coast. Projections for the coastal region represent the climate projections for the western coast and the eastern coast together. Projections for the Himalayan region represent climate of the western Himalayas and projections for the North-Eastern region represent the climatological entity of the north-east.

1. Temperature

PRECIS simulations for the 2030s indicate an all-round warming over the Indian subcontinent associated with increasing GHG concentrations. The annual mean surface air temperature is projected to rise by 1.7°C and 2.0°C in 2030s. Seasons may be warmer by around 2.0°C towards the 2030s. The variability of seasonal mean temperature may be more in winter months. On a regional scale, the variations in temperatures are described below [see figure ES3 (a) for the observed mean temperatures in the 1970s and simulated by PRECIS for the same period. Also see figure ES3 (b) for changes in temperature in the 2030s].

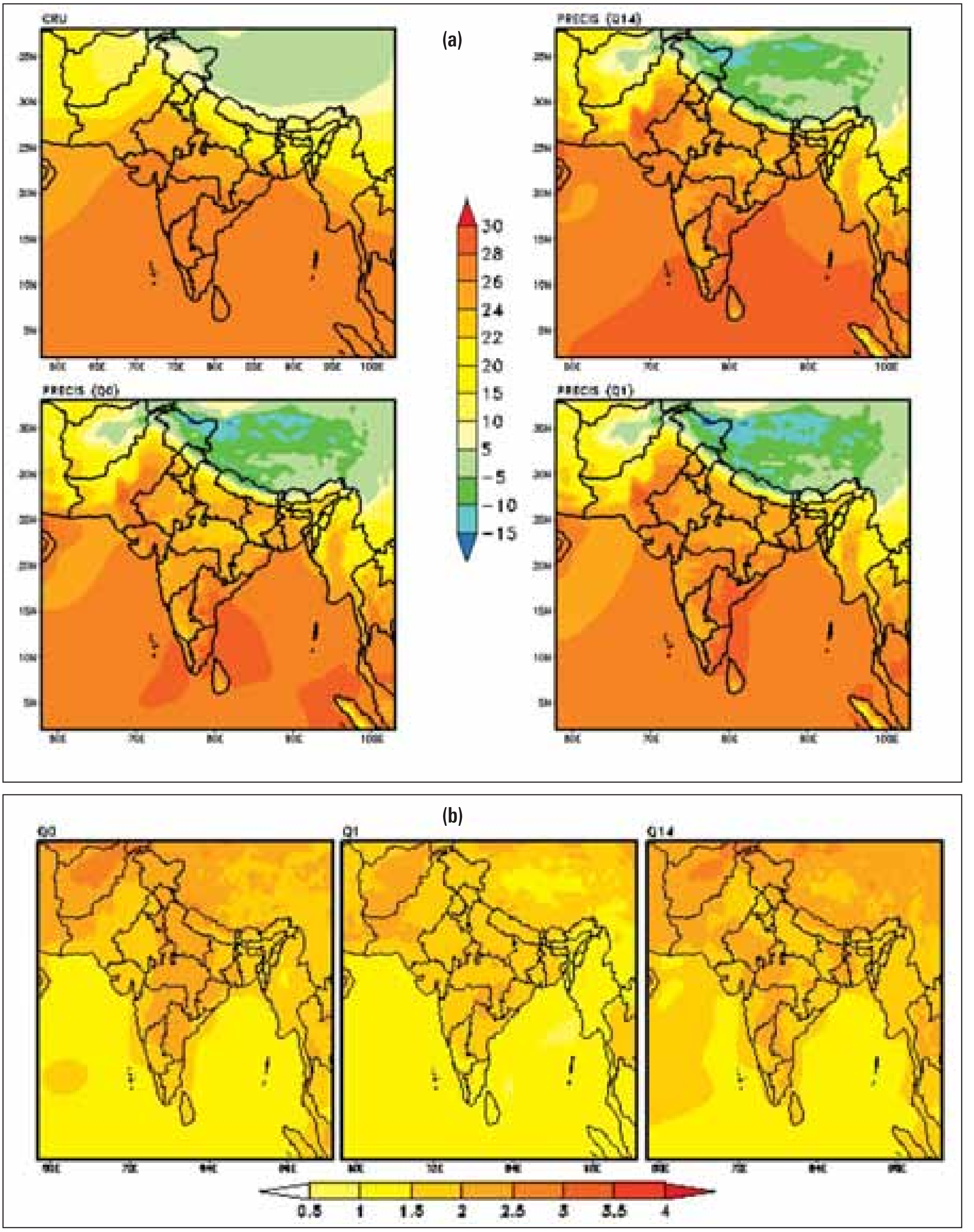


Figure ES3: (a) Mean annual surface air temperature climatology simulated by three PRECIS runs compared with the observed climatology (upper left panel) for baseline period (1961–1990). (b) Projected changes in the annual surface air temperature in the 2030s with respect to the 1970s.

Himalayan region: The mean annual temperature is projected to increase from 0.9±0.6°C to 2.6±0.7°C in the 2030s. The net increase in temperature ranges from 1.7°C to 2.2°C with respect to the 1970s. Temperatures also show a rise in all seasons.

North-Eastern region: The mean annual temperature in this region is projected to rise by 25.8±0.8°C to 26.8±0.9°C in the 2030s. The rise in temperature with respect to the 1970s ranges from 1.8°C to 2.1°C.

Western Ghats: In the Western Ghats, the mean annual temperatures are likely to increase to 26.8±0.4°C–27.5±0.4°C in the 2030s. The rise in temperature with respect to the 1970s will be between 1.7°C and 1.8°C.

Coastal region: In the eastern coastal region, the mean annual air temperature is likely to rise from 28.7± 0.6°C to 29.3±0.7°C. The rise in temperature with respect to the 1970s is around 1.6°C to 2.1°C. In the western coastal region, mean annual temperatures are likely to increase to 26.8±0.4°C to 27.5±0.4°C in the 2030s. The rise in temperature with respect to the 1970s will be between 1.7°C and 1.8°C

2. Precipitation

All the regions under consideration show a small increase in annual precipitation in the 2030s with respect to the baseline, that is 1970s. Figure ES4 (a) shows the summer monsoon rainfall climatology simulated by the three PRECIS simulations compared with the observed climatology (upper left panel) for the baseline period. Figure ES4 (b) shows projected changes in summer monsoon precipitation in the 2030s with respect to the 1970s.

Himalayan region: The annual rainfall in the Himalayan region is likely to vary between 1268±225.2 and 1604±175.2 mm in 2030s. The projected precipitation is likely to increase by 5% to 13% in 2030s with respect to 1970s.

North-Eastern region: The mean annual rainfall is projected to vary from a minimum of 940± 149 mm to a maximum of 1330±174.5mm. The increase in the 2030s, with respect to the 1970s, is of the order of 0.3% to 3%.

Western Ghats: In the Western Ghats in the 2030s, the mean annual rainfall is likely to vary from 935±185.33mm to 1794±247mm, which is an increase of 6%–8% with respect to the 1970s.

Coastal region: In the eastern coast, the rainfall is likely to range between 858±85.8mm to 1280± 204.8mm in the 2030s. The increase in the 2030s with respect to the 1970s is estimated to range between 0.2% to 4.4%. Projections for the western coast indicate a variation from 935±185.33mm to 1794±247mm, which is an increase of 6%–8% with respect to the1970s.

3. Extreme temperatures

The analysis of the model runs indicate that both the daily extremes in surface air temperature, that is, daily maximum and daily minimum may intensify in the 2030s. The spatial pattern of the change in the lowest daily minimum and highest maximum temperature suggests a warming of 1°C to 4°C towards the 2030s. The warming in night temperatures is more over the south peninsula and central and northern India, whereas daytime warming is more in central and northern India, as seen in figures ES5 (a) and ES5 (b).

Himalayan region: In this region, minimum temperatures are projected to rise by 1°C to 4.5°C, and the maximum temperatures may rise by 0.5°C to 2.5°C.

North-Eastern region: Minimum temperatures are likely to rise from 1°C to 2.5°C and maximum temperatures may rise by 1°C to 3.5°C.

Western Ghats: In the Western ghats region, minimum temperatures may rise by 2.0°C to 4.5°C, with minimum increase in those parts of Karnataka that lie in the Western Ghats. Within the region bordering the state of Kerala, the maximum temperature is likely to rise by 1°C–3°C.

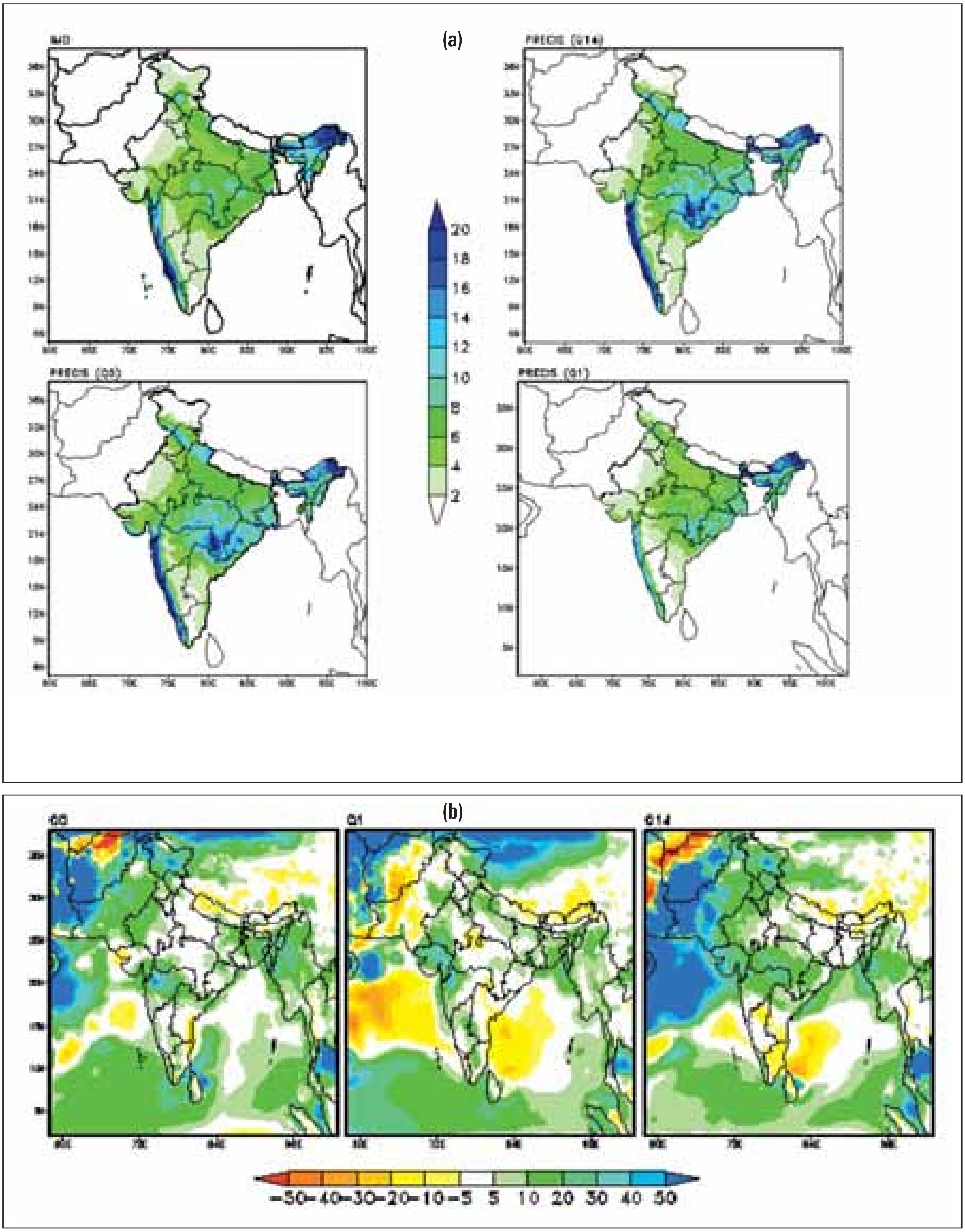


Figure ES4: (a) Summer monsoon rainfall climatology simulated by the three PRECIS simulations compared with the observed climatology (upper left panel) for the baseline period (1961–1990). (b) Projected changes in summer monsoon precipitation in the 2030s with respect to the 1970s.

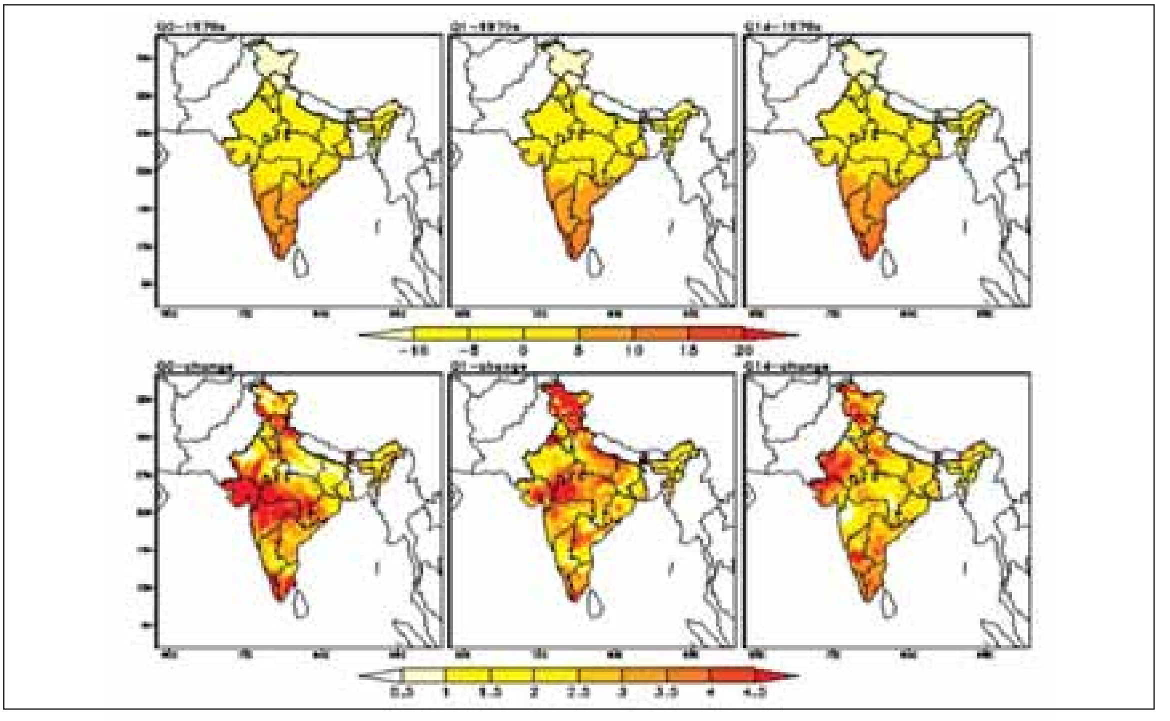


Figure ES5 (a): Lowest minimum temperature attained in baseline simulations (upper panels) and the change in the lowest minimum temperature in the 2030s (lower panels).

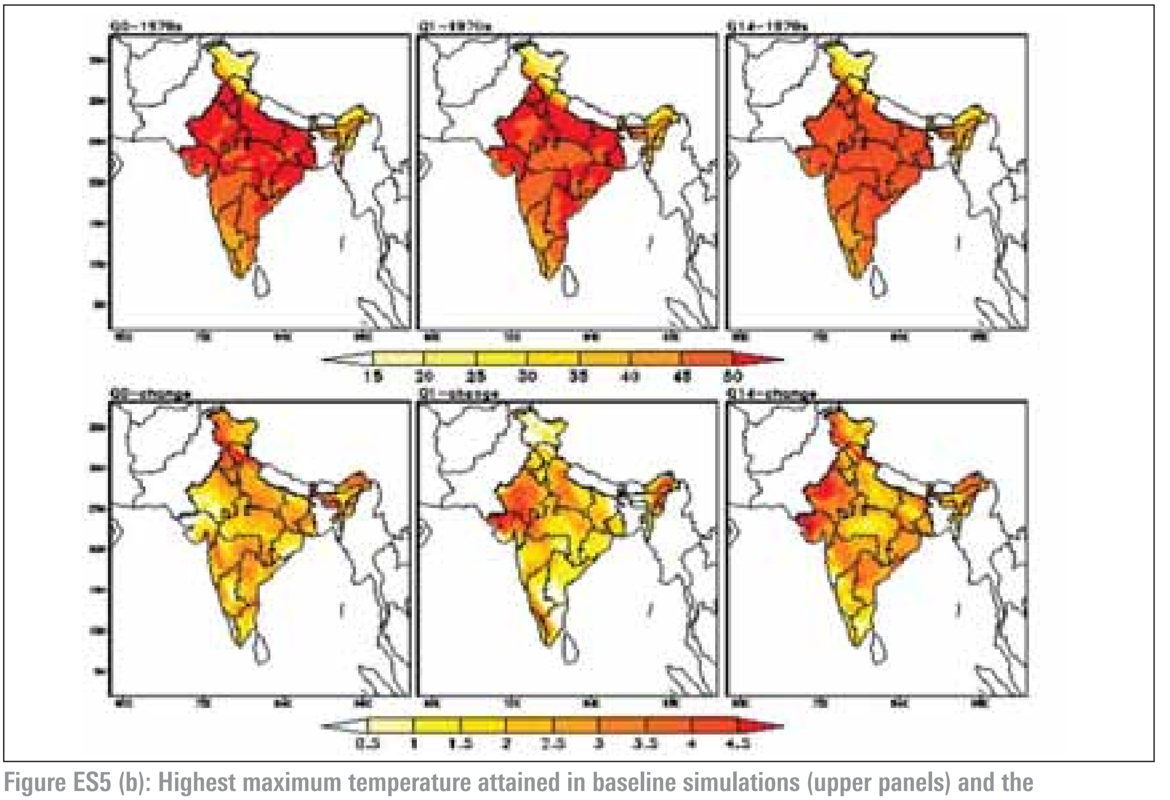


Figure ES5 (b): Highest maximum temperature attained in baseline simulations (upper panels) and the change in the highest maximum temperature in the 2030s (lower panels).

Coastal region: The rise in minimum temperatures along the eastern coastal regions is likely to be lower than in the western coastal region. The change in minimum temperatures along the eastern costal region is projected to range from 2.0°C to 4.5°C, the higher end of the change being limited to Tamil Nadu. The change in maximum temperature in the 2030s with respect to 1970s ranges between 1°C and 3.5°C. The western coast experiences similar extremes in temperature as the Western Ghats.

4. Extreme precipitation

Extreme precipitation can be defined in terms of number of rainy days if it exceeds the currently observed average number of rainy days in a year (exceeding 2.5mm) as well as the volume of rainfall in a day if it exceeds a particular threshold. Currently, the frequency of rainy days is more in East and North-East India and less over western India. Projections for the 2030s, however, indicate that the frequency of rainy days is likely to decrease in most parts of the country. Presently, the intensity of a rainy day is more along the western coast, especially in the Western Ghats, and North-East India. The intensity of rainy days increases in a more warming scenario. At a regional level in the 2030s extreme precipitation events are projected as follows (see Figure ES6a, b and c):

Himalayan region: The number of rainy days in the Himalayan region may increase by 5–10 days on an average in the 2030s. They will increase by more than 15 days in the eastern part of the Jammu and Kashmir. The intensity of rainfall is likely to increase by 1–2mm/day.

North-Eastern region: In the North-Eastern region, the number of rainy days is likely to decrease by 1–10 days. The intensity of rainfall in the region is likely to increase by 1–6mm/day.

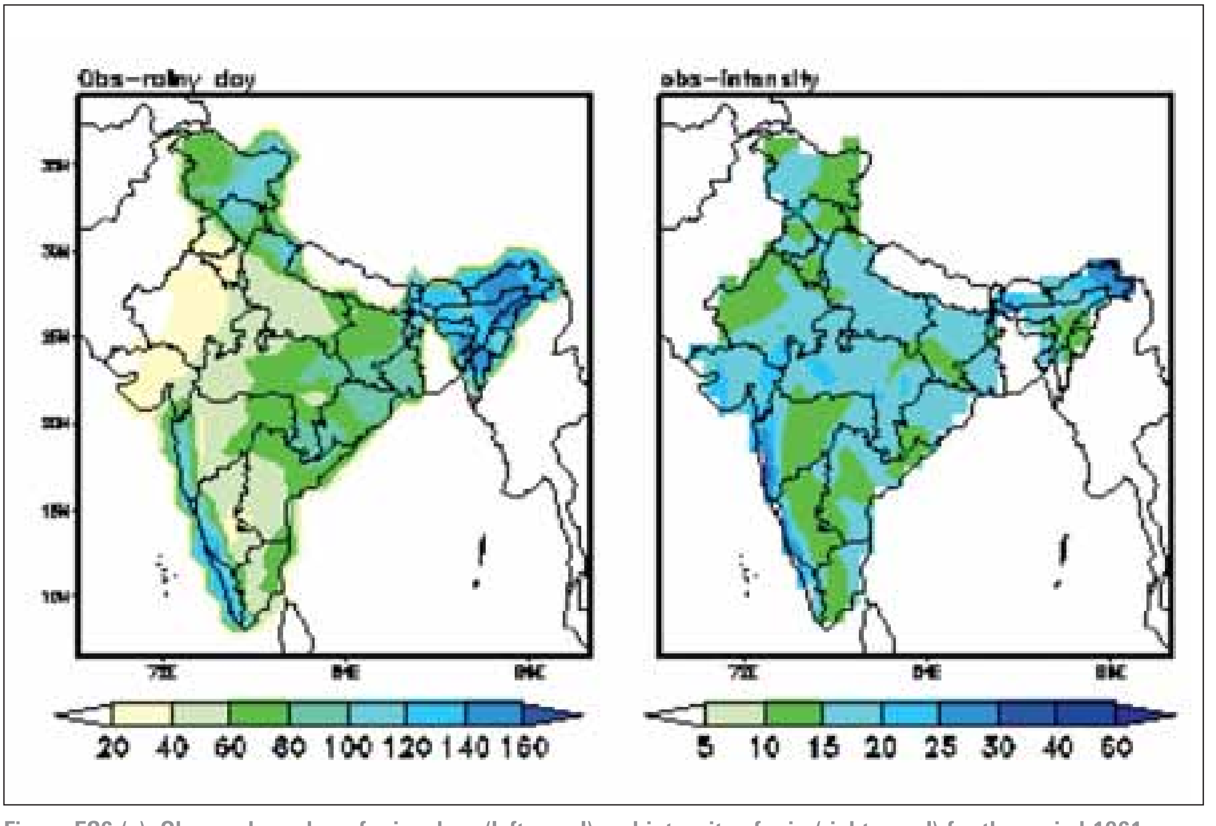


Figure ES6 (a): Observed number of rainy days (left panel) and intensity of rain (right panel) for the period 1961–1990 using IMD gridded dataset.

Western Ghats: The number of rainy days are likely to decrease along the entire western coast, including in the Western Ghats. However, there may be an increase in rainfall in the range of 1-5 days in the Karnataka region of the Western Ghats. The intensity of rainfall is likely to increase by 1–2mm/day.

Coastal region: In the eastern coast, the number of rainy days are likely to decrease by 1–5 days, with a slight increase along the Orissa coast. The intensity of rainfall is likely to increase between 1mm/day and 4mm/day. The projections of extreme precipitation events for the western coast are same as projected for Western Ghats.

5. Cyclones

Since 1986, a decreasing frequency in cyclones along the eastern coast surrounded by the Bay of Bengal and the northern Indian Ocean has been observed. Also, no trend is seen in the western coast for the same period which is along the Arabian Sea. The projected number of cyclonic disturbances along both the coasts in the 2030s is estimated to decrease with respect to the 1970s. However, cyclonic systems might be more intense in the future.

6. Storm surges

Storm surge[1] return periods could only be estimated at a 100 year time scale. It is found that all locations along the eastern coast of India, that are north of Visakhapatnam, except Sagar and Kolkata, show an increase in 100-year return periods of storm surges by 15% to 20 % with respect to the 1970s. For the two stations

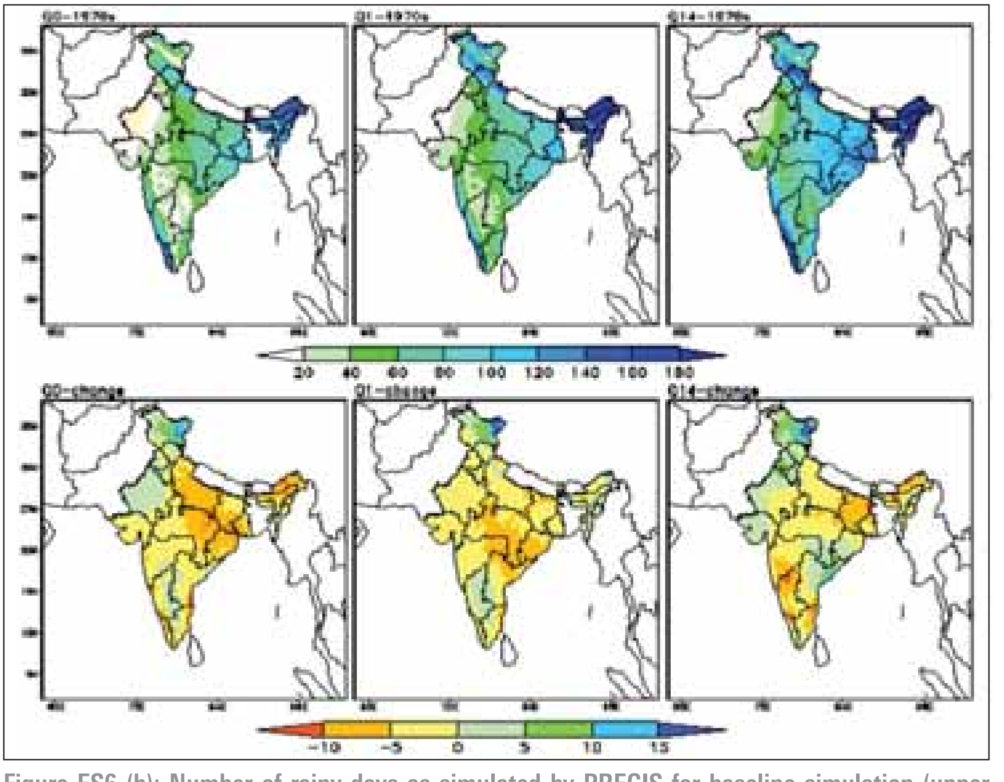


Figure ES6 (b): Number of rainy days as simulated by PRECIS for baseline simulation (upper panels). The change in the frequency of rainy days in the 2030s (lower panel).

[1] The storm surge projections have been made using IPCC SRES A2 scenario. The A2 storyline and scenario family describes a very heterogeneous world underlying self-reliance and preservation of local identities with economic development primarily regionally oriented.

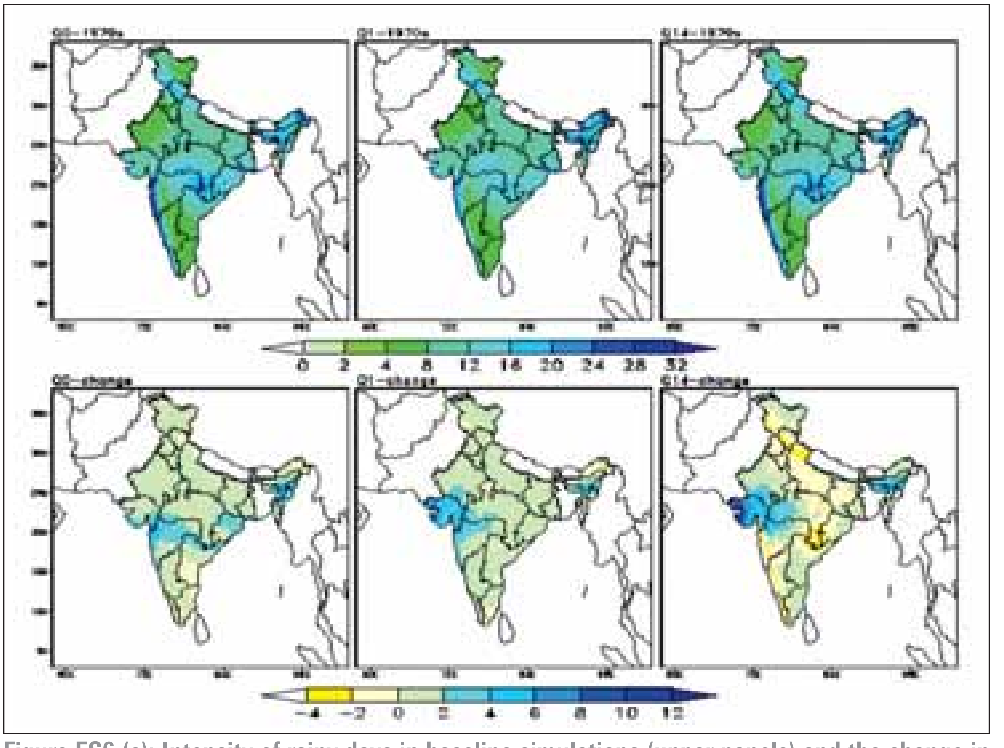


Figure ES6 (c): Intensity of rainy days in baseline simulations (upper panels) and the change in intensity in the 2030s (lower panel).

considered in the head Bay, namely, Sagar and Kolkata, increase in 100-year return periods for the future scenario were found to be less than 5%.

7. Sea-level rise

Global sea-level change results mainly from two processes, mostly related to recent climate change, that alter the volume of water in the global ocean through a) thermal expansion and b) the exchange of water between oceans and other reservoirs (glaciers and ice caps, ice sheets, other land water reservoirs, including through anthropogenic change in land hydrology and the atmosphere). Some oceanographic factors such as changes in ocean circulation or atmospheric pressure also cause changes in regional sea level, while contributing negligibly to changes in the global mean. All these processes cause geographically non-uniform sea-level variations. Vertical land movements, such as resulting from Glacial Isostatic Adjustment (GIA), tectonics, subsidence and sedimentation, influence local sea-level measurements.

Observations based on tide gauge measurements along the Indian coast, for a period of 20 years and more for which significantly consistent data is available indicate that the sea level along the Indian coast has been rising at the rate of about 1.3mm/year on an average.

Globally, sea level is expected to continue to rise over the next several decades. During 2000 to 2020 under the SRES A1B scenario in the ensemble of Atmosphere-Ocean General Circulation Models (AOGCMs), the rate of thermal expansion is projected to be 1.3 ± 0.7mm/year, and is not significantly different under the A2 or B1 scenarios (Meehl *et al.*, 2007). The sea-level rise at such short-term timelines is mainly due to committed thermal expansion caused by constant atmospheric composition at year 2000 values.

In the absence of the availability of regional projections, for the 2030s, global projections can be used as a first approximation of sea-level rise along the Indian coasts in the next few decades.

8. Impacts on agriculture

Western Ghats

Rice: The productivity of irrigated rice is likely to reduce by 4% in most of the areas in this region. However, irrigated rice in parts of southern Karnataka and northern-most districts of Kerala is likely to gain. In case of rain-fed rice, all areas in the region are likely to lose yields by upto 10%. The results thus indicate that irrigated rice is able to benefit due to CO_2 fertilization effect as compared to the rain-fed rice, which is supplied with less amount of fertilizers (see Figure ES7).

Maize and sorghum: Climate change is likely to reduce yields of maize and sorghum by up to 50% depending upon area in this region. These crops have C4 photosynthetic systems and hence do not have relative advantage at higher CO_2 concentrations.

Coconut: Coconut yields are projected to increase as much as 30% in the majority of the region by the 2030s. Increase in coconut yield may be mainly attributed to the projected increase in rainfall (~10%) and relatively less increase in temperatures, apart from CO_2 fertilization benefits. However, some areas like south-west Karnataka, parts of Tamil Nadu and parts of Maharashtra may show reduction in yields up to 24%.

Livestock productivity: The Temperature Humidity Index (THI), an index used to define losses due to thermal stress is highest in the months of September–April and is likely to remain under highly stressful conditions in the 2030s. The heat-stress days per annum are likely

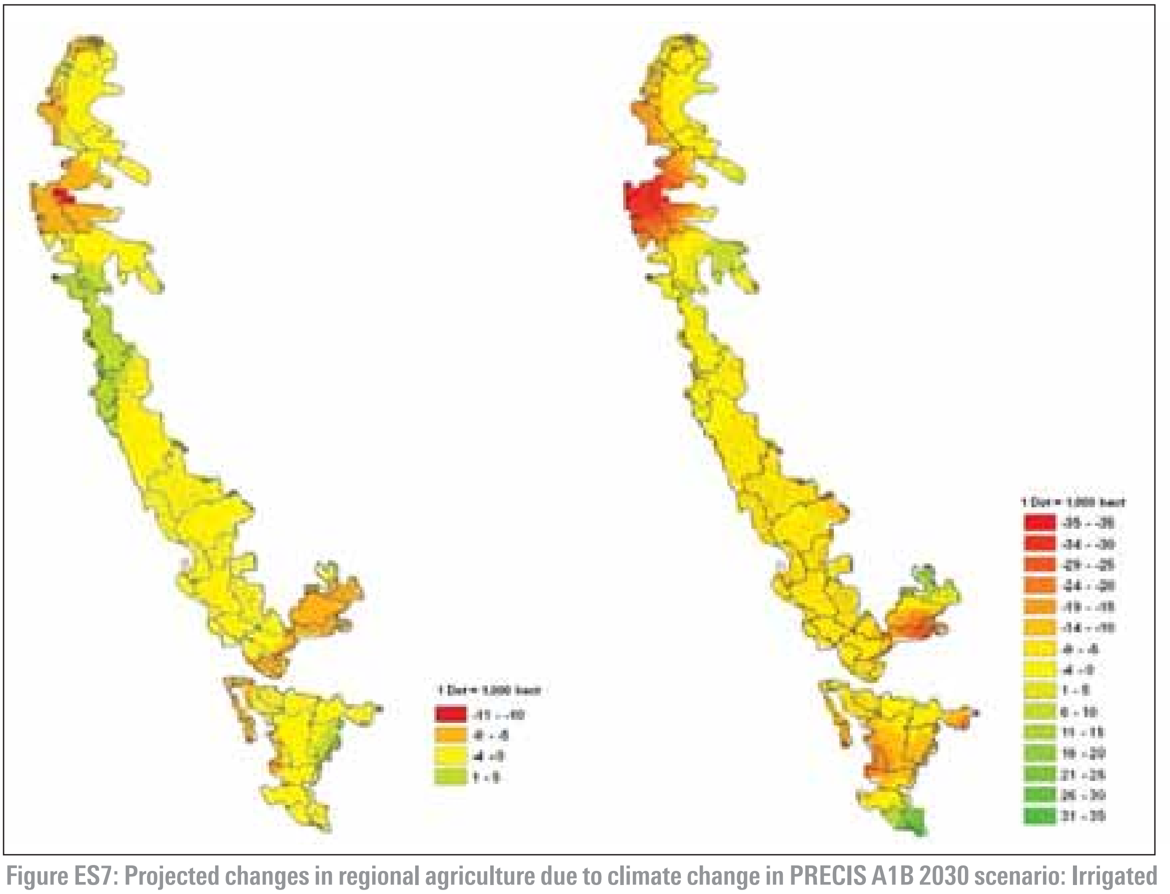


Figure ES7: Projected changes in regional agriculture due to climate change in PRECIS A1B 2030 scenario: Irrigated rice (left panel) and rain-fed rice (right panel).

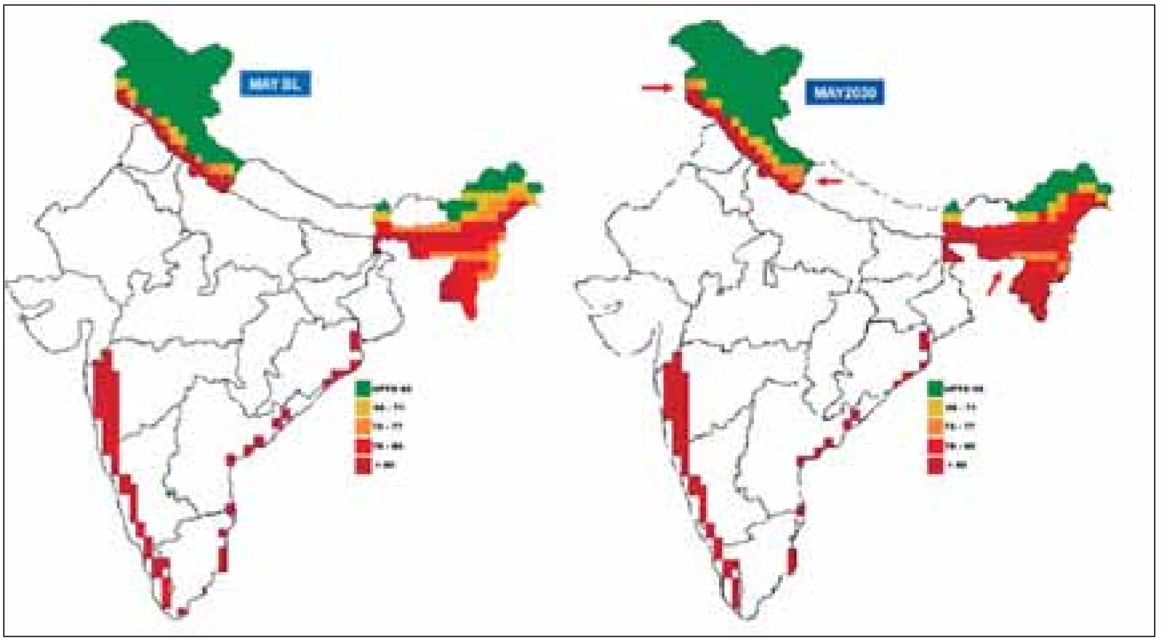


Figure ES8: Projected changes in thermal stress for 2030 (right) relative to the baseline period (left) for the month of May.

to increase with THI above 80 in the 2030s in the Western Ghats, leading to severe thermal discomfort of the livestock and hence, negative impact on livestock productivity is expected (see Figure ES 8).

Coastal region

Rice: The yields of irrigated rice are projected to decrease by about 10% to 20% in this region. However, in some coastal districts of Maharashtra, northern Andhra Pradesh and Orissa, irrigated rice yields are projected to marginally increase by 5% with respect to the 1970s. On the other hand, rain-fed rice yields are projected to increase up to 15% in many districts in the east coast but reduce by up to 20% in west coast (see Figure ES9).

Maize and sorghum: Impacts of climate change on irrigated maize in coastal districts are projected to be much higher with projected yield loss between 15% and 50%, whereas in the case of rain-fed maize, the projected yield loss is up to 35%. In some districts of coastal Andhra Pradesh, rain-fed maize yields are likely to increase by 10%. Projected increase in seasonal maximum temperature in these areas is less than 1°C in the 2030 scenario.

Coconut: Yields of coconut are projected to increase in the west coast of India by up to 30% (provided current level of water is made available in the future as well), while in the east coast, yields may increase by about 10% in the north coastal districts of Andhra Pradesh. All other coastal districts in eastern coast and those in the Gujarat coast are projected to lose coconut yields up to 40%.

Livestock productivity: The livestock in the Coastal regions are likely to be highly vulnerable with consequent adverse impacts on its productivity throughout the year in the 2030 scenario with THI above 80.

Fisheries: (a) Oil Sardines- An increase in recruitment and catches of oil sardine during the post-southwest monsoon season along the coastal region, especially along the Kerala coast, is expected in the future due to warming, elevated Sea Surface Temperature (SST), favourable wind (and perhaps current) and increasing Coastal Upwelling Index (CUI) inducing higher chlorophyll-a concentration during the southwest

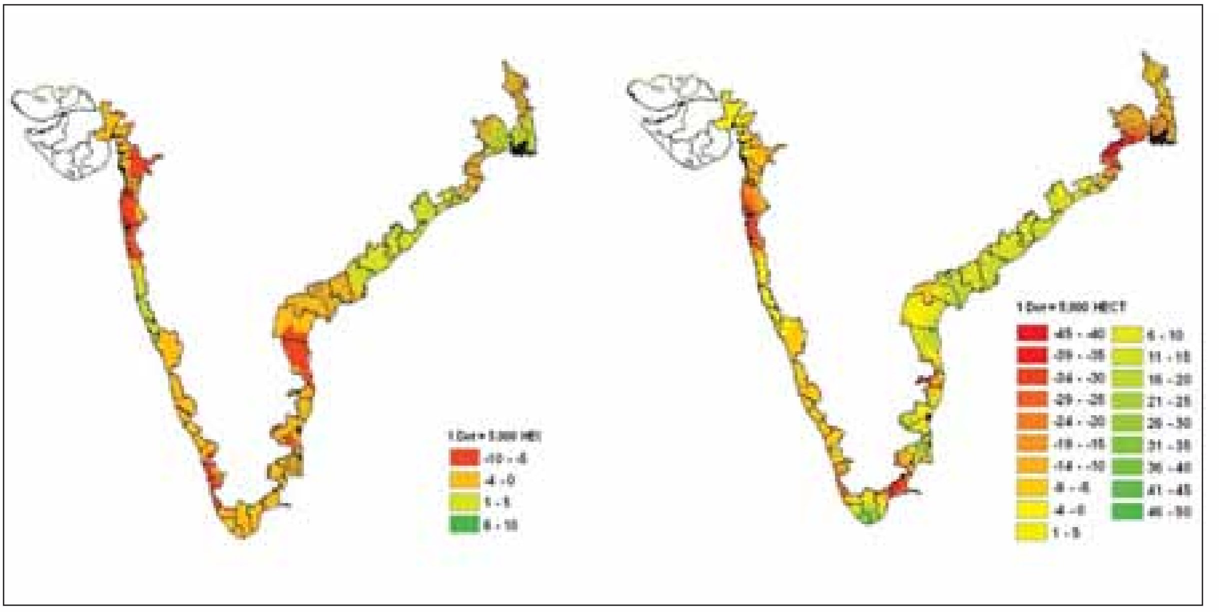


Figure ES9: Impact of climate change on crops in coastal area in PRECIS A1B 2030 scenario. Irrigated rice and maize (left panel); Rain-fed rice and maize (right panel).

monsoon. (b) Indian mackerel- The Indian mackerel is predominant in the south-west coast. However, the mackerel catch along this coast that contributed about 81.3% to the all-India mackerel catch during 1961–76, has decreased to 56.1% during 1997–06. The catch in north-west coast and north-east coast has increased from 7.5% of the total mackerel catch in 1961–76 to 18% during 1997–2006. The Indian mackerel is able to take advantage of the increase in temperatures of subsurface seawater. Therefore, with increase in global temperatures and sea surface temperatures, it is likely to move northwards and deeper into the seas surrounding it. (c) Threadfin breams- Threadfin breams (*Nemipterus Japonicus* and *Nemipterus Mesoprion*) are distributed along the entire Indian coast at depths ranging from 10m to 100m. They are short-lived (longevity: about three years), fast growing, highly fecund and medium-sized fish (maximum length: 30–35cm). The threadfin bream spawns optimally in SST between 27.5°C and 28.0°C and when the SST exceeds 28.0°C, the fish shift the spawning activity to seasons when the temperature is around the preferred optimum. Therefore in the climate change context, in the 2030s if the SST exceeds 28°C during April to September, an increase in catch might take place in the comparatively cooler months of October to March.

North-Eastern region

Rice: Irrigated rice yields in this region may range between –10% and 5%, with respect to the 1970s, while the rain-fed rice yield may vary between–35% to 5% with respect to 1970s. (see Figure ES10).

Maize: Maize crop yields are projected to reduce by about 40%.

Livestock productivity: In this region, the THI is likely to increase during April–October months with THI > 80.

Himalayan region

Apples: Apple production in the Himachal Pradesh region has decreased between 1982 and 2005 as the increase in maximum temperature has led to a reduction in total chilling hours in the region—a decline of more than 9.1 units per year in last 23 years has taken place (see Figure ES11). This reduction was more during the months

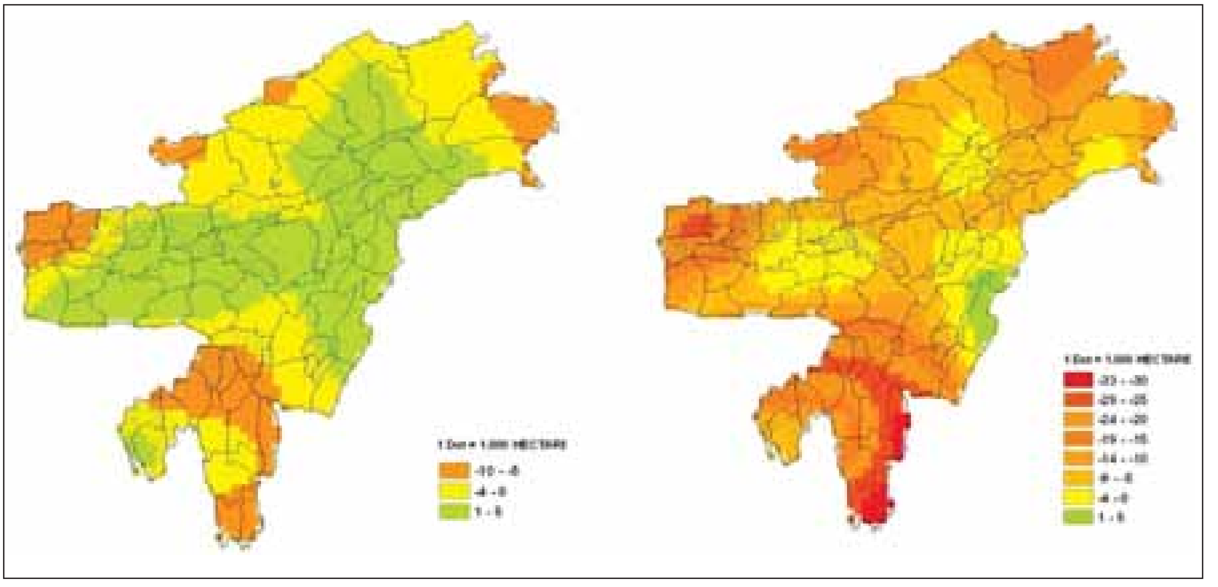


Figure ES10: Impact of climate change on rice crop in the North-Eastern region in PRECIS A1B 2030 scenario. Irrigated rice (left panel); Rain-fed rice (right panel).

of November and February. With increasing temperatures, it is anticipated that there may be an all-round decrease in apple production in the Himalayan region, and the line of production may shift to higher altitudes.

Livestock productivity: THI is projected to rise in many parts of Himalayan region during March–September with a maximum rise during April–July in 2030s with respect to 1970s.

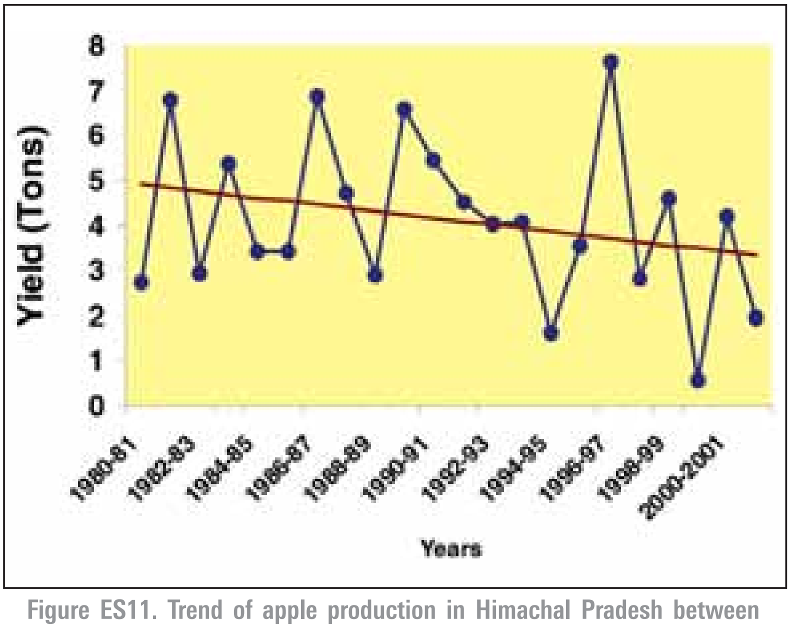


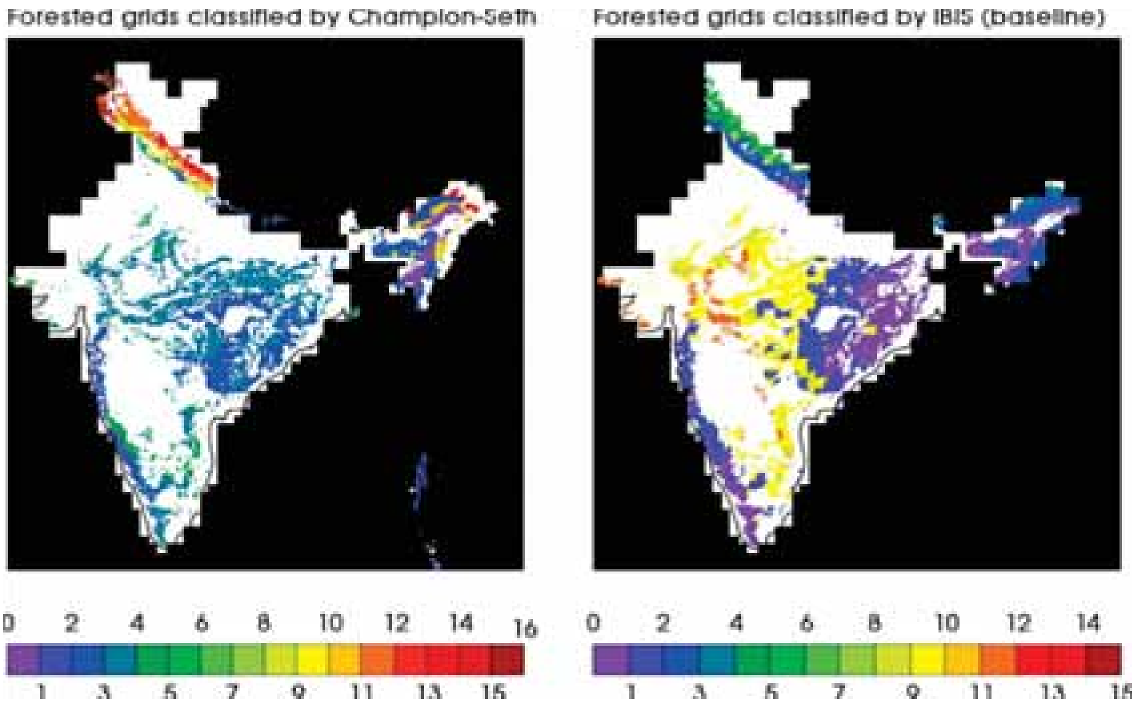
Figure ES11. Trend of apple production in Himachal Pradesh between 1980 and 2005.

9. Natural ecosystems and biodiversity

It has been concluded that the forest vegetation type of the four eco-sensitive regions are vulnerable to projected climate change in the short term, that is, in 2030s, even under a moderate climate change scenario (A1B). The impacts vary from region to region. Figure ES12 shows the observed and simulated vegetation for the 1970s. Figures ES13 (a), (b), (c) and (d) show the observed and projected impacts on forest vegetation in the Western Ghats, the Himalayan region, coastal region and the North-Eastern Region respectively.

Western Ghats: The entire Western Ghats region is covered by 54 forest grids, out of which 18% are projected to undergo change in the 2030s. The NPP of the region is projected to increase by 20% on an average.

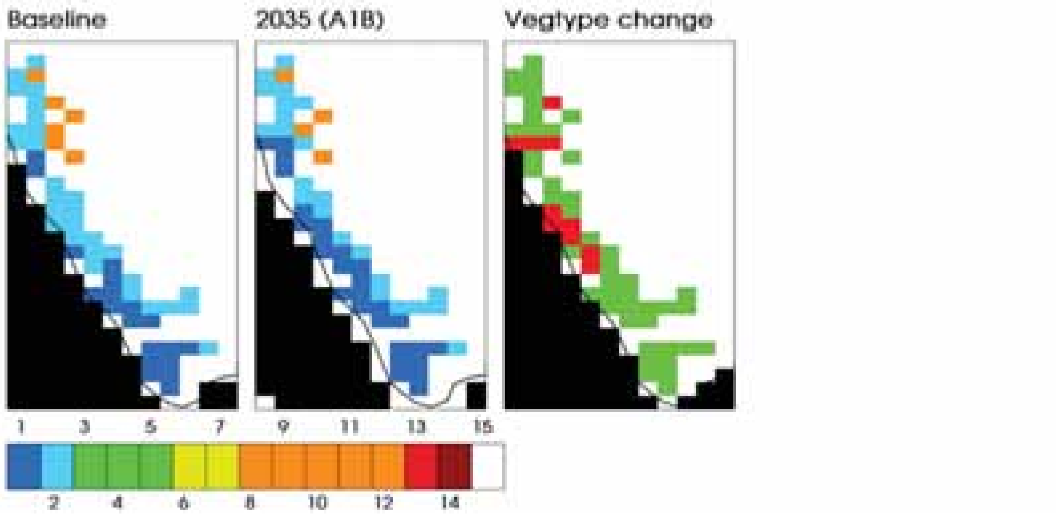
Himalayan region: The Himalayan region considered in the study includes the states of Jammu and Kashmir, Uttarakhand and Himachal Pradesh. Of the 98 IBIS grids covering this region, 56% of the grids are projected to undergo change in the 2030s. The Net Primary Productivity (NPP) is projected to increase in the region by about 57% on an average by the 2030s.



Key: 1. Tropical wet evergreen forests, 2. Tropical semi-evergreen forests, 3. Tropical moist deciduous forest, 4.Tropical dry deciduous forest, 5. Tropical thorny/scrub forests, 6.Tropical dry evergreen forest, 7.Littoral and swampy forest, 8. Subtropical broad-leaved hill forests, 9. Subtropical pine forests, 10.Subtropical dry evergreen forests, 11. Montane wet temperate forests, 12. Himalayan wet/moist temperate forests, 13. Himalayan dry temperate forests, 14. Subalpine forests, 15. Moist alpine forests, 16. Dry alpine forests

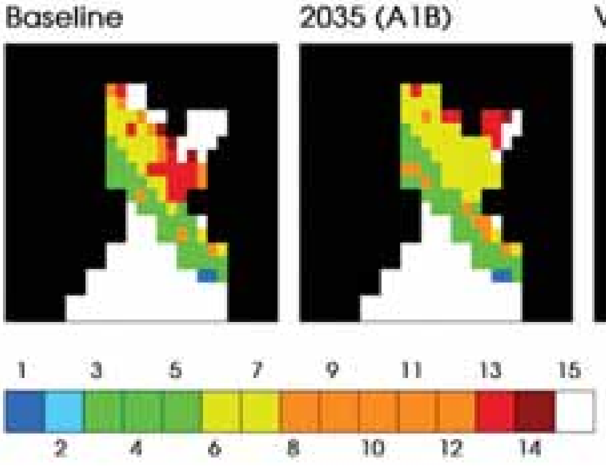
Key: 1: Tropical evergreen forest/woodland, 2: Tropical deciduous forest/woodland, 3:Temperate evergreen broadleaf forest/woodland, 4:Temperate evergreen conifer forest/woodland, 5:Temperate deciduous forest/woodland, 6: Boreal evergreen forest/woodland, 7: Boreal deciduous forest/woodland, 8:Mixed forest/woodland, 9: Savanna, 10: Grassland/steppe, 11: Dense shrubland, 12: Open shrubland, 13: Tundra, 14: Desert, 15: Polar desert/rock/ice

Figure ES12: Model generated (Chaturvedi et al, 2010) current vegetation distribution (right panel) compared with observed vegetation distribution (left panel, Champion and Seth, 1968).



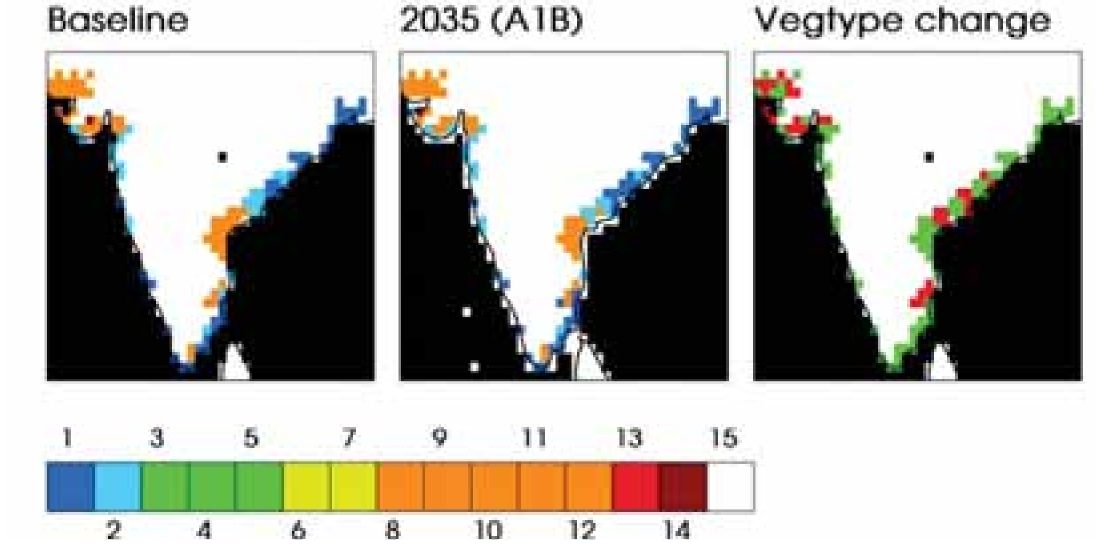
Key: 1: Tropical evergreen forest/woodland, 2: Tropical deciduous forest/woodland, 3: Temperate evergreen broadleaf forest/woodland, 4: Temperate evergreen conifer forest/woodland, 5: Temperate deciduous forest/woodland, 6: Boreal evergreen forest/woodland, 7: Boreal deciduous forest/woodland, 8: Mixed forest/woodland, 9: Savanna, 10: Grassland/steppe, 11: Dense shrubland, 12: Open shrubland, 13: Tundra, 14: Desert, 15: Polar desert/rock/ice

Figure ES13 (a): Simulated dominant vegetation in the Western Ghats region for the baseline (left panel) and 2035 (middle panel). The grids where a change in vegetation is projected are shown in red in the right panel.



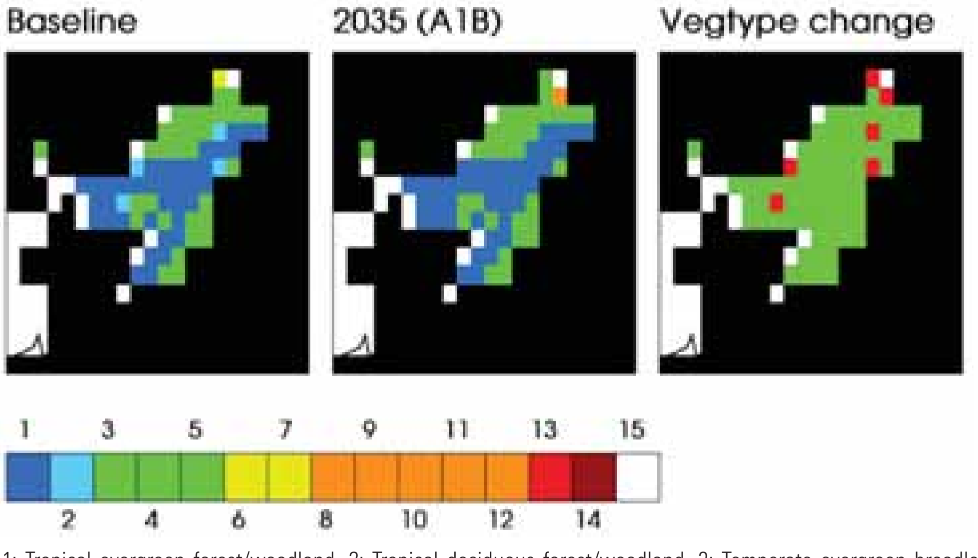
Key: 1: Tropical evergreen forest/woodland, 2: Tropical deciduous forest/woodland, 3: Temperate evergreen broadleaf forest/woodland, 4: Temperate evergreen conifer forest/woodland, 5: Temperate deciduous forest/woodland, 6: Boreal evergreen forest/woodland, 7: Boreal deciduous forest/woodland, 8: Mixed forest/woodland, 9: Savanna, 10: Grassland/steppe, 11: Dense shrubland, 12: Open shrubland, 13: Tundra, 14: Desert, 15: Polar desert/rock/ice

Figure ES13 (b): Simulated dominant vegetation in the Himalayan region for the baseline (left panel) and 2035 (middle panel). The grids where a change in vegetation is projected are shown in red in the right panel.



Key: 1: Tropical evergreen forest/woodland, 2: Tropical deciduous forest/woodland, 3: Temperate evergreen broadleaf forest/woodland, 4: Temperate evergreen conifer forest/woodland, 5: Temperate deciduous forest/woodland, 6: Boreal evergreen forest/woodland, 7: Boreal deciduous forest/woodland, 8: Mixed forest/woodland, 9: Savanna, 10: Grassland/steppe, 11: Dense shrubland, 12: Open shrubland, 13: Tundra, 14: Desert, 15: Polar desert/rock/ice

Figure ES13 (c): Simulated dominant vegetation in the Coastal region for the baseline (left panel) and 2035 (middle panel). The grids where a change in vegetation is projected are shown in red in the right panel.



Key: 1: Tropical evergreen forest/woodland, 2: Tropical deciduous forest/woodland, 3: Temperate evergreen broadleaf forest/woodland, 4: Temperate evergreen conifer forest/woodland, 5: Temperate deciduous forest/woodland, 6: Boreal evergreen forest/woodland, 7: Boreal deciduous forest/woodland, 8: Mixed forest/woodland, 9: Savanna, 10: Grassland/steppe, 11: Dense shrubland, 12: Open shrubland, 13: Tundra, 14: Desert, 15: Polar desert/rock/ice

Figure ES13 (d): Simulated dominant vegetation in the North-Eastern region for the baseline (left panel) and 2035 (middle panel). The grids where a change in vegetation is projected are shown in red in the right panel.

Coastal region: The coastal region is defined by all districts that lie on the Indian coast. The entire coastal region is covered by 96 grids, excluding the grids in the Western Ghats. Of this, 30% are projected to undergo change. The NPP in this region is predicted to rise by 31% on an average.

North-Eastern region: Much of the dense forests of Assam, Nagaland and Arunachal Pradesh are part of the Himalayan biodiversity hotspot. In the North-Eastern region, only about 8% of the 73 forested grids are projected to undergo change in the 2030s. The region is projected to see an increase of 23% in NPP on an average.

10. Impact on Human Health

A qualitative assessment indicates that morbidity and mortality of the population in the regions under focus are likely to increase with warming temperatures and variable precipitation as they have direct as well as indirect effects. Direct effects can manifest as heat stress and indirect effects can be in terms of vector borne diseases, water borne diseases and malnutrition etc. A quantitative assessment has been carried out for determining the transmission of malaria in the 2030s. The transmission windows have been determined in terms of (a) temperature as well as (b) temperature and relative humidity requirements for transmission. It has been concluded that the projections based on Temperature (T) and Relative Humidity (RH) do not match with the observations made in the Himalayan region, Western Ghats and the Coastal areas. Thereby indicating that even if required humidity is not existing in the atmosphere the mosquito vectors seek micro-niche for their resting to get the required RH for survival. The reason of almost similar projections in North-Eastern states may be due to prevalent high RH. The specific regional projections are as follows (also see Figures ES14a, b, c and d):

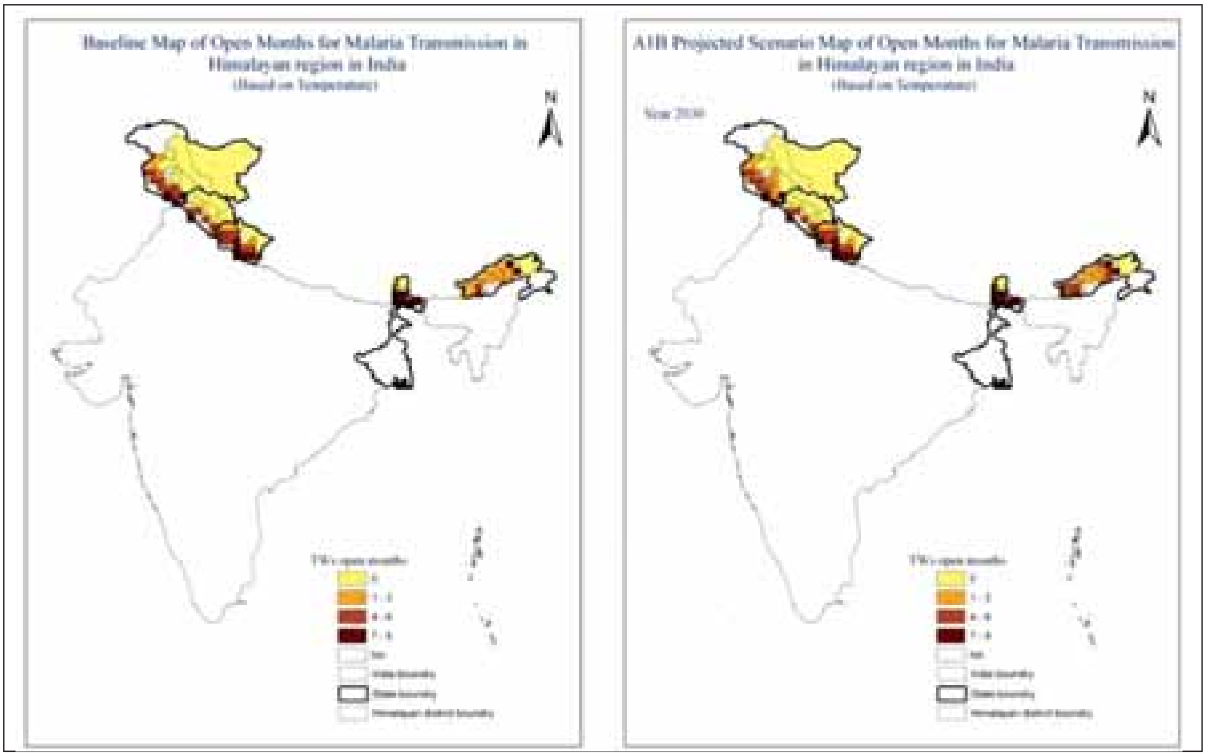


Figure ES14 (a): Transmission windows of malaria based on minimum required temperature under (a) baseline and (b) projected scenario (2030) in the Himalayan region.

Himalayan region: In this assessment, the study area in the Himalayan region includes the northern states in the North-Eastern region as well as the states of Jammu and Kashmir, Himachal Pradesh and Uttarakhand in the North-western Himalayas. Projections of malaria transmission windows for the 2030s, based on temperature, reveal introduction of new foci in Jammu and Kashmir and an increase in opening of more transmission months in districts of the Himalayan region and north-eastern states. The transmission windows in Jammu and Kashmir, however, still remain open only for 0–2 months in the 2030s [see Figure ES14 (a)].

North-Eastern region: There is a likelihood that the windows of transmission of malaria may increasingly remain open for at least 7–9 months and may even remain open for a larger number of months (10–12 months) in a year [see Figure ES14 (b)].

Western Ghats: Malaria transmission in the Western Ghats is projected to experience no change with respect to current scenario and likely to remain open for 10–12 months in a year [see Figure ES14 (c)].

Coastal regions: Malaria transmission in coastal areas, particularly the east coast, is projected to experience reduction in the number of months open for transmission. The number of times it is open for in 10–12 months may reduce by 34% [see Figure ES14 (d)].

11. Water

The water resources in this study have been assessed in terms of water yield in the various river basins that are part of these regions. The water yield is the total surface runoff, which is usually a function of the precipitation, its distribution, evapotranspiration (ET) and soil characteristics.

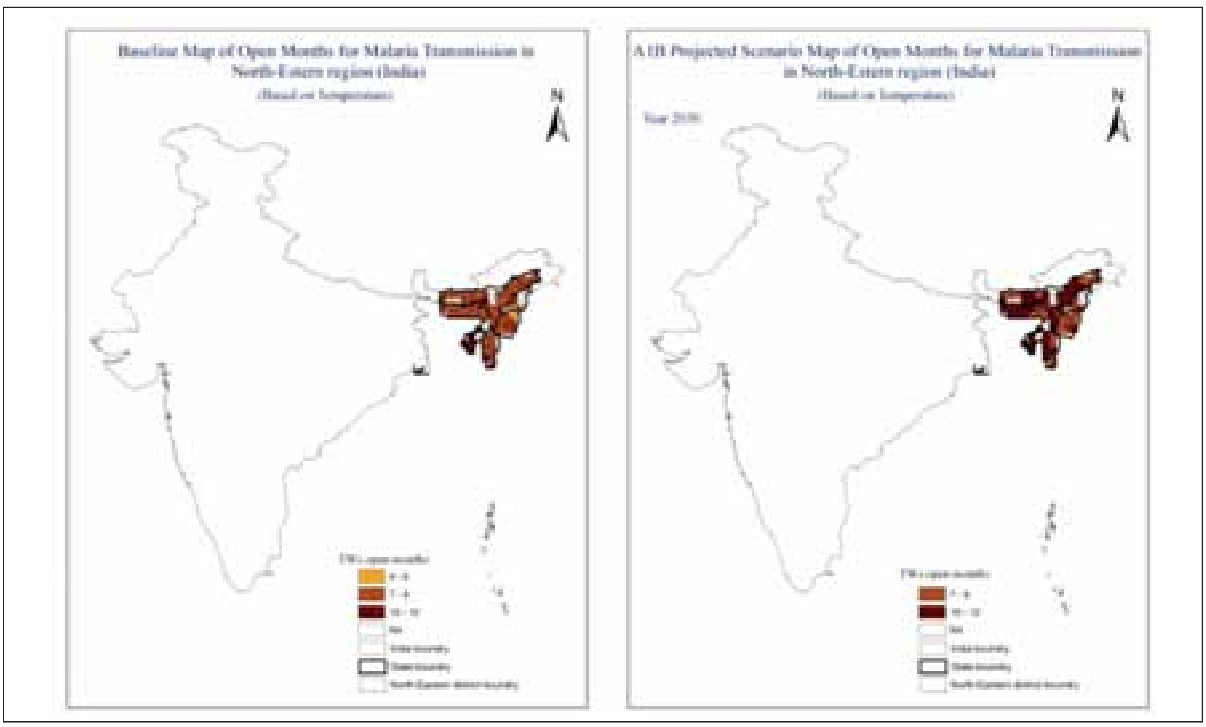


Figure ES14 (b): Transmission windows of malaria based on minimum required temperature under (a) baseline and (b) projected scenario (2030) in the North-eastern region.

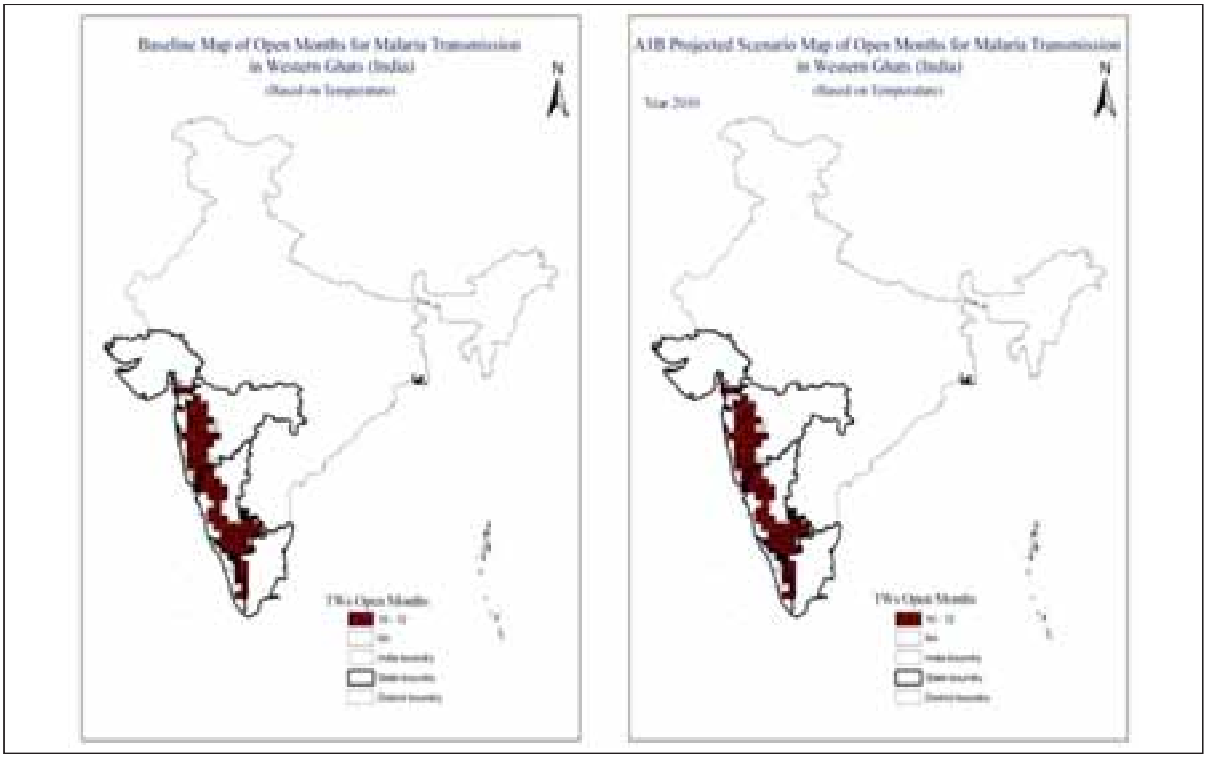


Figure ES14 (c): Transmission windows of malaria based on minimum required temperature under (a) baseline scenario and (b) projected scenario (2030) in the Western Ghats.

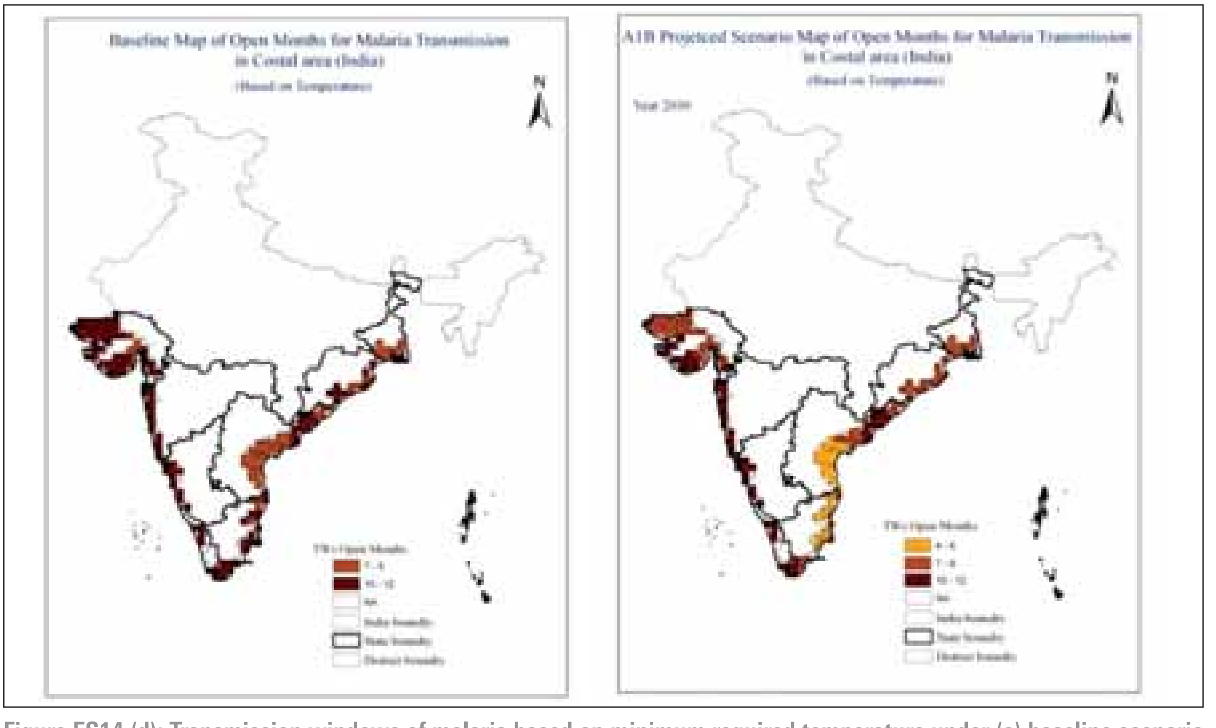


Figure ES14 (d): Transmission windows of malaria based on minimum required temperature under (a) baseline scenario and (b) projected scenario (2030) in the coastal region.

The region-specific projections for 2030s are (see ES15):

Himalayan region: The water yield in the Himalayan region, mainly covered by river Indus, is likely to increase by 5%–20% in most of the areas, with some areas of Jammu and Kashmir and Uttarakhand showing an increase of up to 50% with respect to the 1970s. The impact of increase in precipitation in this region has been reflected in an almost similar pattern of increase in the ET. Increase in the water yield is more for those areas that have experienced a low increase in ET.

North-Eastern region: The trend in precipitation in the North-Eastern region exhibits considerable spatial variability in water yield in the 2030s but is in line with the projected patterns of precipitation and evapotranspiration. The northern parts of the North-East in the 2030s, with respect to 1970s, show a reduction in precipitation by 12%. The central portion of the North-eastern region shows an increase in precipitation by 0% to 25%. However, the majority of the North-Eastern region except for Mizoram, Tripura, Manipur and Assam shows an increase in the evapotranspiration in the 2030s. As a result, a reduction in water yield by up to 20% is projected for Arunachal Pradesh. The increase in the water yield in Assam and Manipur is projected to increase by 40%.

Western Ghats: The Western Ghats region exhibit wide variability in water yield in the 2030s. The northern portion of the Western Ghats shows a decrease in the water yield, ranging from 10%–50% in the 2030s with respect to the 1970s. The central portion, however, indicates an increase in the water yield between 5% and 20%. The southern portions of Karnataka and Kerala show a decrease in the yields up to 10%.

Coastal region: There is a general reduction in water yield in the eastern coastal region of West

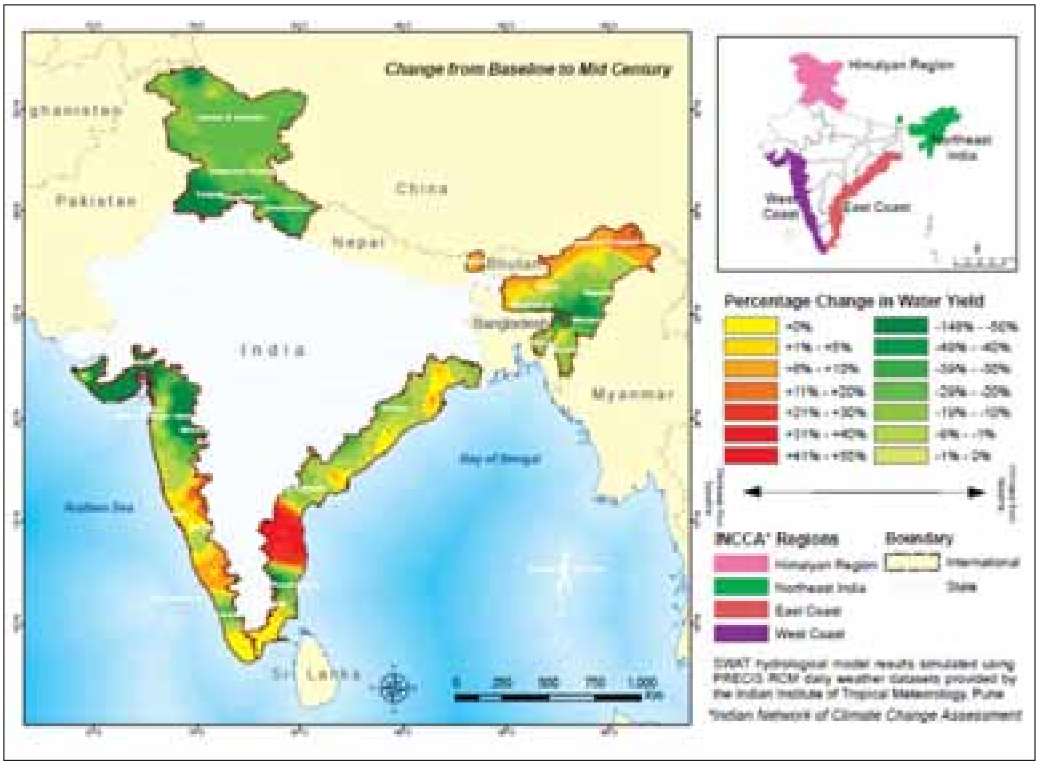


Figure ES15: Projected changes in water yields in percentages in the 2030s with respect to the 1970s in the Himalayas, North-Eastern region and the coastal regions of India.

Bengal, Orissa and the northern coastal regions of Andhra Pradesh. The reduction in water yield in the 2030s in this region is as less as 40%. However, in the southern parts of Andhra Pradesh and northern parts of Tamil Nadu, the water yield is projected to rise by 10%–40%. The western coastal region also shows an overall reduction in water yield (ranging from 1%–50%) except for the coast along Karnataka, which shows an increase in water yield in the 2030s by 10%–20% with respect to the 1970s. No change in water yield is projected for the 2030s in the southern tip of the coastal region.

12. Impact of climate change on frequency of droughts

The percentage change in the spatial distribution of Soil Moisture Deficit Index (SMDI) between the 1970s and 2030s has been used for defining the drought index. The weeks when the soil moisture deficit may start drought development (drought index value between 0 and -1) as well as the areas which may fall under moderate to extreme drought conditions (drought index value between -1 and -4) have been assessed. There is an increase in the drought development for those areas of various regions that have either projected decrease in precipitation or have enhanced level of evapotranspiration in the 2030s. Similarly, the weeks belonging to moderate soil moisture stress show an increase in severity of drought from baseline to the mid-century scenario, which is self-evident. It is very evident from the depiction that the moderate to extreme drought severity has been pronounced for the Himalayan region where the increase is more than 20% in many areas despite the overall increase in precipitation (see Figure ES16).

13. Impacts of climate change on floods

Possible floods have been projected using the daily outflow discharge in each sub-basin as generated by the SWAT model, ascertaining the change in magnitude of flood peaks above 99th percentile flow in 1970s and in 2030s. Change in peak discharge equal to or exceeding at 1% frequency in the 1970s and 2030s for various regions indicates that the flooding varies from 10% to over 30% of the existing magnitudes in most of the regions. This has a very severe implication for existing infrastructure such as dams, bridges, roads, etc., in the areas and will require appropriate adaptation measures to be taken up (see Figure ES17).

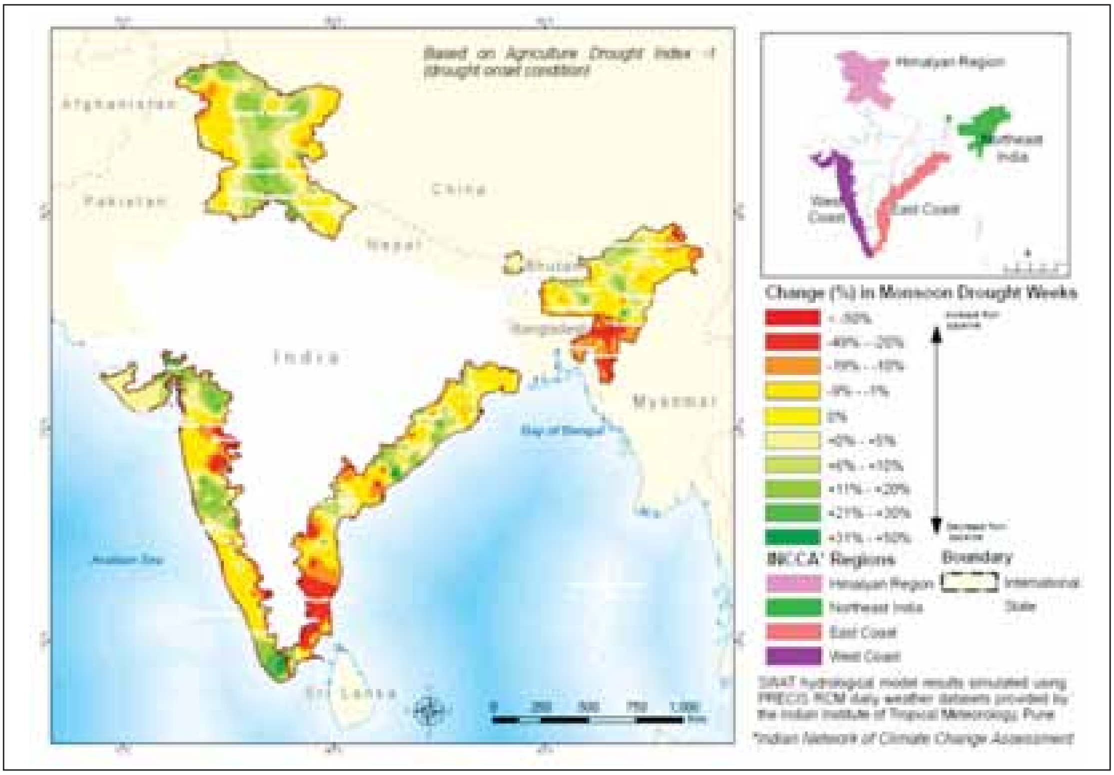


Figure ES16: Percentage change in monsoon drought weeks in the 2030s with respect to the 1970s.

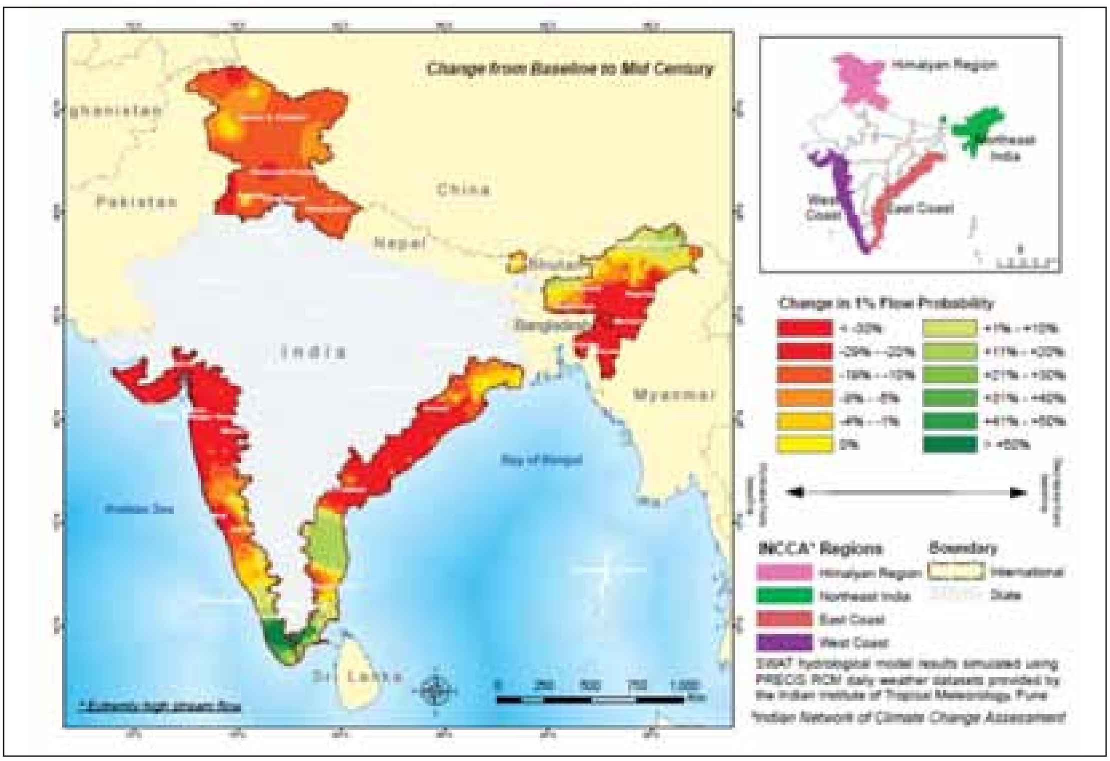


Figure ES17: Change in magnitude of flood (stream discharge at 99th percentile) towards the 2030s with respect to the 1970s percentage change.

The Way Forward

1. Addressing data gaps

There exists a significant data gap. Climate change is an interdisciplinary subject that cuts across physics, chemistry, biology, earth sciences, economics, technology development, etc. Therefore multiple data sets are required even to simulate the current situations by different models. So, current data on climate, natural ecosystems, soils, water from different sources, agricultural productivity and inputs and socio-economic parameters amongst others are continuously required. It is essential to have accessibility to databases that reflect national and regional concerns. Various agencies in India are presently collecting such data on a regular basis. However, efforts need to be made to establish an effective mechanism for sharing and accessing this data in formats that can be easily deciphered.

2. Systematic observations

New systematic observations that are long term in nature must be taken up on a continuous basis in India to add to the South–South database on physical and biological systems (for example, data on forest vegetation types). In India, forest observation plots were established in the early nineteenth century to observe the changes in nature of forest vegetation in different regions. However, most of these plots have not been continuously observed, and as a result we have failed to gather data on the vegetation types, forest soil characteristics etc. which could have been effectively used for modelling. The Forest Survey of India (FSI) is now making efforts to revive these plots. Even so, these have to be observed for a long period of time to attribute the effects of climate on various systems.

3. Accessing multiple regional climate models with higher resolution

So far, all the impact assessments published in India have been made using one regional climate model developed by the Hadley Centre, UK. Other regional models may be used but they have to be validated by simulating observed climate. This is important because multiple climate model outputs obtained using a large number of perceivable socio-economic scenarios can capture the probable path of growth. This gives a clearer picture of GHG emission trends, the behaviour of the future climate and impacts on various biophysical systems and the economic sectors dependent on such systems. Thus, it can reduce the uncertainty of our estimates to an extent.

4. Building capacity

A rapid building up of capacity is essential to enhance the level of climate change research in India. In this context scientific cooperation and collaboration is essential in the area of climate modelling, impact assessment, integrated impact assessments, research on mitigation of climate change concerns and adaptation to impacts of climate change. Extensive networking of researchers within India, through platforms such as the Indian Network for Climate Change Assessment can be used to create a critical mass of researchers who can carry forward the work on science, impacts and mitigation of climate change in India.

5. Making a pan-Indian regional assessment for informed policy-making at all levels

(a) Other regions in India are equally important and it would be worthwhile to make the future assessments keeping in view the division of the Indian region according to its climate. The impacts on all economic activities that are sensitive to climate need to be made in the regions such as the western Himalayas, north -west, north-east, northern-central region, eastern coast, western coast, and the interior plateau.

(b) The Government of India has launched the process of developing climate change action plans for the states. Therefore, it might be interesting to have a state-level assessment of impacts of climate change for sectors that are important for the state and will help in developing state-specific action plans for adapting to climate change. These can be made for short-, medium- and long-term periods, taking into account the requirements of planning of a perceptible future in the short term and the very nature of climate change issues, which are long-term.

INCCA Reports:

1. **India: Greenhouse Gas Emissions 2007**, *May 2010*
2. **Climate Change and India: A 4x4 Assessment** - A Sectoral and Regional Analysis for 2030s, *November 2010*

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