Synthesis of meteorological observations and modelling studies to assess climate change mitigation strategies over India

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Proper appraisal of climate change is important for a developing country like India. The Inter-government Panel on Climate Change (IPCC), jointly set up by the World Meteorological Department and United Nations Environment Program provided background material to support the threat due to increase of atmospheric temperatures associated with the increasing level of carbon dioxide and other greenhouse gases. The Framework Convention of Climate Change was adopted at the United Nations in May 1992 and 155 countries ratified it. India is one among these and is committed to provide information as 'national communications' and to adopt effective measures to mitigate climate change while fulfilling economic targets. In this paper, our primary focus is to synthesize scientific researches pertaining to climate change in the Indian region based on meteorological observations and climate models. Related issues about strategic actions needed for mitigating greenhouse gas emissions are also discussed.

Meteorological observations in India

The meteorological data of Indian stations are archived and processed at the National Data Center, Pune under the India Meteorological Department. Rainfall data for some stations have been recorded from the past century but the number of well distributed stations have increased in later years, and therefore, the results based on 475 surface meteorological observations since 1901 have been reviewed in this study. The upper air data are available from 1951 onwards for 31 stations. Tide gauge observations are also available with Survey of India, Dehradun which enable us to draw some inferences pertaining to the sea level changes near the coasts.

Decadal variations of meteorological parameters, namely temperature (surface air, maximum, minimum and upper air up to middle troposphere levels), surface level pressure, and seasonal & annual rainfall were studied for the period 1901 to 1986 (upper air data from 1951 onwards). Tests of significance applied to data series (station wise as well as country as a whole) show that the temperature is showing a decreasing trend in almost all the northern parts of the country (north of 23°N) and a rising trend in southern parts (south of 23°N). Atmospheric pressure, on the other hand, shows a fall between 1920 and 1930, but does not indicate any significant change after 1930 (ref. 1). It is also of interest to note that the increase in the mean temperatures over India is only seen in the maximum temperature, while the trend of minimum temperature was nearly zero. A lesser number of meteorological stations was used for a study by Rupa Kumar *et al.*[2], and a similar trend was found. Decadal analysis of seasonal (June–September) and annual rainfall also indicated that variations in rainfall are also within statistical limits. The observed trend of decreasing rainfall over the hilly regions is largely attributed to increasing deforestation and change in ecology. On the other hand, 30 years 'normals' for the years 1931–1960 and 1961–1990 show a slight increase in rainfall over a few urban and industrial cities in India[3] for reasons not fully understood. It is of interest to note that the area affected by drought in India each year shows a decreasing trend[4].

The influence of aerosols on climate trend in the Indian region has been examined. Rain water samples have not shown a significant trend as found in the pH values due to excess of SO_2, aerosol except for certain areas having anthropogenic influences[5]. The injection of large quantities of sulphur during the volcanic eruptions of El Chichon and Mount Pinatubo (Philippines) into the stratosphere and the subsequent effects on the earth's climate changes in the solar and infrared radiation budget caused by the eruption could produce a cooling of the climate which could affect atmospheric circulation. In addition, heterogeneous chemical reactions on the surface of sulphate aerosol particles render the ozone molecules more vulnerable to atmospheric chlorine and hence to man-made chlorofluorocarbons. Their long-term influence on climate change is, however, open to question.

Global radiation data from 1957 to 1987 show a decreasing trend during winter months for a number of stations[6]; Jodhpur shows a decreasing trend throughout the year, while an increasing trend is found in diffuse radiation over India during the winter months. Analysis of ozonesonde data indicates an increasing trend in the troposphere. This is also supported by the surface ozone observations at Pune (Srivastava, S. K. pers. commun.), implying that marginal decrease in stratospheric ozone could be anticipated over the Indian region. However, total ozone observations using Dobson's spectrometer do not show any significant decrease.

Model projections

Numerical models of the earth's atmosphere and oceans are developed to simulate the behaviour of the climate system, to assess likely impact of greenhouse warming and to predict some aspects of climate fluctuations of different time scales. Early results based on well-established models showed that for a $2 \times CO_2$ scenario, a global temperature increase of 2 to 4°C during winter and 1 to 2°C during summer could occur[7]. Further refinement of general circulation models led to a second assessment of climate change which led IPCC to project a lower increasing global mean temperature of 1° to 3°C. Even if the doubling of CO_2 takes place in about 100 years, it can be seen that the projected rate of warming is quite large compared to that seen from the actual observations of the recent past, which is of the order of 0.4°C and is similar to global mean trend. The thermal inertia of a mixed layer of the ocean has been shown to have the effect of delaying equilibrium and surface warming by almost three decades[8].

Bhaskaran *et al.*[9] reported that doubled CO_2 concentrations over India would give rise to an increase of surface temperature of the order of 1 K to 4 K during winter and monsoon months, using United Kingdom Meteorological Office (UKMO) coupled climate model. The model simulated monsoon circulation shows a shift by 10° latitude towards the north. The number of days of heavy rainfall could increase while the inter-annual variability of monsoon onset dates may not change significantly. A close examination of surface temperatures based on the decadal trends has brought out a different picture with decreasing temperatures over the northern region. The quantum of rainfall predicted by the model differs widely based on the decadal trends of rainfall[6]. The projections about evaporation over land areas, soil moisture and frequency of heavy rainfall days also remain uncertain.

Fossil fuel combustion has two competing effects on the climate system, a warming due to the emission of CO_2 and other trace gases and cooling due to sulphate particles formed from the SO_2 emission. Sulphate particles and aerosols reflect solar radiation back to space (direct effect) and enhance cloud albedo (indirect effect). A detailed parameterization of the relationship between fossil fuel burning and the SO_2 effect on back scattering and cloud albedo was studied by Rajeevan *et al.*[10] in a one-dimensional radiative–convective model for assessing the climatic impact. It was shown that the cooling induced by the combined effect of SO_2 completely counteracts the CO_2 greenhouse warming. The model predicts that by the year 2060 the direct effect of SO_2 is likely to counteract CO_2 warming more efficiently than the indirect effect in the near future. Attempts to slow pace the fossil fuel burning by leveling off and further reduction (IPCC scenario D) will decrease CO_2 concentration which could further decrease global warming. Effect of transient increase in greenhouse gases and sulphate aerosols using ECHAM3 + LSG model on monsoon climate showed an increase in annual mean surface air temperature of 1.0°C over the land regions of the Indian subcontinent in the decade of 2040s with respect to 1980s (ref. 11). The annual mean surface air temperature based on this model showed a better agreement with the observational results[12]. However, influence of other aerosols is required in coupled ocean climate models, to simulate more realistic rainfall projections. Complications about future climate scenario arise during volcanic eruption epochs such as Mt. Pinatubo in Philippines during 1991.

It is well known that validity of the climate models lies in improving the representation of the aggregate effect of process that occur at a scale smaller than the model grid size. There is a need to resolve some aspects of mesoscale eddies in the ocean. This aspect is important keeping in view that contrary to the expectation of a strong sink for CO_2 in the Indian Sea, increasing concentrations of CO_2 were reported during southwest monsoon in 1995 over the Arabian Sea[13]. The recognized deficiencies in the modelling results over the Indian region are attributed to lack of meteorological observations over the Himalayas including Tibet plateau, oceanic areas adjoining Indian peninsula and chaotic nature of atmosphere over the tropical region. Also the following uncertainties in the model projections make the problem rather complex.

a) Large internal variability of dynamic weather systems like tropical cyclones, monsoon depressions, western disturbances, induced lows, troughs in easterlies and the movement of the axis of monsoon trough.
b) Possible changes in the timings or intensity of El-Nino Southern Oscillation (ENSO) and its influence on tropical belt.
c) Studies of the influence of glaciers.
d) Influence of future volcanic eruptions which could reduce the warming trends.

Improvements in the modelling results could be based on the following:

i) Use of Global Positioning System (GPS) to have more accurate precipitable water estimates and vertical profiles of water vapour. Precipitation mapping through Tropical Rainfall Measuring Mission (TRMM) would be equally relevant.
ii) Quantification of soil moisture estimates through calibration of actual observations with that monitored by satellite microwave radiometers.

A significant improvement in regional scale modelling of southwest monsoon and understanding of weather patterns is expected through the analysis of data collected during Monsoon Trough Boundary Layer Experiment[14,15].

Strategic actions

The variations in climatic pattern remain uncertain but are subjected to changes over a longer time scale. This poses significant problems for future policy options. Government of India, having ratified UN Framework Convention on Climate Change (UNFCCC) in 1993, is committed to initiate steps to control the greenhouse gas emissions. It was expected that most countries would come under pressure for taking remedial actions and control of greenhouse gases during the third Conference of Parties (CoP-3) meeting of UNFCCC held in Kyoto in December 1997. However, no such targets were set for the developing countries which require immediate action and for the developed countries, the suggested cut is 5.2% annually from 1990 level by 2012. This shows how complex the actions needed are, to cut on greenhouse gas emissions. The developing countries should not sit back under the umbrella of no-cut. The emission trading introduced in the meeting will present tougher competitions and challenges for developing countries to be on the forefront of world politics. Thus, in spite of the fact that there are no immediate targets, policy options have to consider the long-term regional variations within the country. Here underlies the need for developing cogent adoptive strategies to improve the environment. A policy of technological innovation fits into the goal of self-reliance practised in the country since independence.

Energy is the key to development

Looking at the energy scenario in the country, the total energy consumption pattern comprises share of industry (50.4%), transport (24.5%), household (13.8%) and agriculture (9.0%) in 1995–96. Constant modernization and implementation of new energy technologies are needed for all these applications to achieve the reduction of pollution and mitigation of carbon emissions. Ever since the petroleum crisis in early 1970s, several energy conservation measures have also been initiated by the industry but there is no comprehensive energy policy which deals with R&D and technology issues. Rio Earth Summit in 1992 established the concern for global warming and reduction of carbon dioxide emission in energy sector has been highlighted. This further reinforces the need for policy for energy for R&D; as discussed in the following paragraphs.

The future energy demand and supply, and adoption of conservation strategies will be governed not only by the availability of local resources, the fuel mix, the consumption patterns and the life styles, but also the availability of new technologies and additional resources for them. Some attempts have been made in this direction and studies have been conducted to estimate CO_2 reduction potential of various fuel mix options[16], which has led to the recognition of the importance of new and improved energy and materials technology development in socio-economic sectors[17,18]. In a Workshop on Control Technologies for Greenhouse Gas Emissions organized by Department of Science and Technology in association with Confederation of Indian Industry in 1995, the need for developing a framework for catalysing and coordinating technology development projects in academic institutions and industries aimed towards energy-efficient technology was recommended.

Considerable research has been carried out for mitigating climate change decision-making strategies by IPCC and the energy technology sector is assigned highest priority for CO_2 reduction. During the First Assembly Meeting of the Global Environmental Facility (GEF) held in India from 1 to 3 April 1998, Secretary General, UNEP has stated that Kyoto Protocol will have profound impact on technological innovation, efficiency standards and consumption patterns in energy and transport sectors, while influencing the global markets. Similar views were expressed by the members of Science and Technology Advisory Panel (STAP) of the GEF, stressing the need for greater support of international collaborative Energy R&D and rapid progress towards commercialization of a wide range of energy technologies[19].

Finally, keeping in view the linkages of unique developments related to southwest monsoon in global warming and the greenhouse gas control strategies as well as the policy mechanisms needed to address the global environment concerns which include issues of technology transfer and trading, it is felt that a Greenhouse Gas Technology Centre in the country can only address this complex problem in an integrated manner.

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