the ignition of over 300 fires within minutes of the earthquake. Response to the fires was hindered by the failure of the water supply system and the disruption of the traffic system. At least 12 major conflagrations developed and burned for 24–48 hours. Within 24 hours, fire companies had arrived from as far away as Tokyo. The number of homeless people requiring shelter was estimated to be approximately 300,000, which is 20% of the population of Kobe.

Implications for California

Currently, available evidence does not suggest any difference between the source characteristics of the Kobe earthquake and those of crustal earthquakes that occur in California, and our preliminary evaluation of the ground motions from the Kobe earthquake indicate that they were comparable to those we would expect from a California earthquake of the same magnitude. Since the 1933 Long Beach earthquake, California has not experienced a strike-slip earthquake that ruptured directly into a heavily populated urban region and has never seen a strike-slip earthquake rupture into the downtown region of a major city. Although the 1994 Northridge earthquake occurred within an urban region, almost all of the fault rupture occurred at depths greater than 10 km, and the great majority of the multistorey buildings in the San Fernando Valley were at least 20 km from the closest part of the fault rupture. However, many urban regions in California and other states contain strike-slip faults that can rupture to or near the ground surface, as occurred in Kobe. There is no doubt that these faults will produce earthquakes eventually. The urgent questions for earthquake scientists and engineers are whether the ground motions from these earthquakes will be as severe as those experienced in Kobe, and whether these ground motions will cause the tragic loss of life and disastrous damage to Californian cities that they brought to Kobe.

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Climate change studies: Need for a refocusing*

S. M. Kulshrestha

While there is considerable work done on global-scale assessments of the likely impacts of climate change, the confidence in regional-scale assessments based on global climate models is still low. But it is at the regional or country level where cost-effective response strategies and policy options have to be formulated and implemented. For this, we need to make a transition from global generalities to regional/country specifics. This calls for a refocusing in studies of climate change and its impacts.

THE subject of climate change is undoubtedly one of the areas that has received very considerable public exposure in the recent times and more so during the past 10 years. Thanks to the political and media attention and the varying perceptions emanating from these, it has also become controversial to a large extent and seems to have acquired a geopolitical complexion. At the same time, it is also an area of considerable scientific effort worldwide.

In such a situation, it is inevitable that a very large (and growing) body of scientific data, analyses and interpretations emanate from different parts of the world and different scenarios are put forth enthusiastically. But limited or selected observations may not constitute representative samples; short-term variations would not always indicate long-term changes; and above all, scenarios should not be taken as predictions.

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It is encouraging to note that efforts are being made by the world scientific community to strive for an integrated approach covering different disciplines. The growing concern for the future of our spaceship Earth and its inhabitants (present and future) has helped in attracting the attention of scientists, opinion leaders, policy makers, and the enlightened public. Furthermore, it has imparted a sense of urgency for understanding the ramifications of climate change.

Yet, all this awareness and activity seems to be somewhat defocused on a collective scale. The amount of information on climate change has increased rapidly but still remains tentative, incomplete and inadequately assimilated. Very often, it appears difficult to keep abreast of the emerging results of climate change studies, not to speak of coping with the problems and taking effective action to combat its adverse effects. The World Commission for Environment and Development (1987) had stated in their report[1] as follows:

> 'A major reorientation is needed in many policies and institutional arrangements at international as well as national level because the rate of change is outstripping the ability of scientific disciplines and our current capabilities to assess and advise.'

Since then, the available literature on climate change, suggested methodologies for assessment of impacts, and response strategies has grown considerably and the pile is increasing at a faster rate. This is an encouraging trend but there is a strong need to consolidate, especially at regional and country levels.

In the midst of all this, time seems to have come when a refocusing exercise appears necessary in order that the actions are not only timely and effective but also cost-effective. In this paper, an attempt is made to delineate the elements of a much needed refocusing of climate change studies.

Definitions

Before proceeding further, it would be advisable to have a clear understanding of the following terms:

Climate. The climate of a place describes the overall character of the daily weather that prevails there from season to season and from year to year. But it is more than average weather. Climate not only describes average or typical values of meteorological parameters, it includes statistics such as the annual range and extreme values. Thus, climate is the totality of all statistical weather information that would describe the variation of weather over a particular place or region.

Climate is not 'atmosphere alone' phenomenon. It is a complex coupled system involving atmosphere, hydrosphere, biosphere and geosphere. Land, oceans and atmosphere being the major players in the complex climate system, climate is essentially a land ocean–atmosphere system. Incoming solar radiation is the prime mover of the system but the resultant warming depends on many factors. Oceans are the major regulators of climate. It is known that the ocean circulation undergoes major changes gradually over a period of time. But the role of biosphere is not yet understood well.

Climate variability. Climate variability is defined as the fluctuations of the climate system parameters (temperature, rainfall, etc.) due to the inherent natural variability of the system on a specified time scale (such as decadal) which are not influenced by factors external to the system or by human activities.

Climate change. The UN Framework Convention on Climate Change[2], which came into force on 21 March 1994 after a prolonged process of international negotiations and governmental ratifications, defines climate change as 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'.

Relative magnitudes of climate change and climate variability. According to the evidence so far, the two are of the same order of magnitude and, therefore, difficult to distinguish in many aspects. The 1990 Scientific Assessment Report[3] by the Intergovernmental Panel on Climate Change (IPCC) had concluded and its 1992 Supplementary Report[4] has maintained that 'the size of this warming is broadly consistent with predictions of climate models, but it is also of the same magnitude as the natural climate variability. Thus, the observed increase could largely be due to this natural variability; alternatively, this variability and other human factors could have offset a still larger human-induced greenhouse warming'.

Climate change – Some basic points

There is indisputable evidence of an accelerated change in climate parameters over the last 100 years. There is also the palaeoclimatic record to show that climate has changed in the past as well.

Some physical linkages (such as the anthropogenic greenhouse effect and the warming in the lower troposphere) are clearly evident and the physical connection between enhanced greenhouse effect and climate change is quite sound. However, the magnitudes are uncertain due to the complex interactions among the components of the climate system and climate feedbacks. Furthermore, as already mentioned, climate has its own inherent natural variability.

The irony of the situation is that in this complicated web of natural and anthropogenically caused processes leading to climate change, human beings are the perpetrators as well as the victims.

Three main arenas of climate change

The following are the three main manifestations of climate change:

- Global warming due to the enhanced greenhouse effect arising from anthropogenic causes, and the resultant variation in rainfall patterns and the possible impact on extreme weather events.
- Sea level rise in a warmer world.
- Ozone depletion – mostly in Antarctic and Arctic regions and also in temperate latitudes.

Basically, all the above three manifestations of climate change trace their origin to the increased accumulation of major greenhouse gases (GHGs), the concentrations of which in the atmosphere have increased appreciably since the beginning of the industrial era. The main greenhouse gases are: carbon dioxide, chlorofluorocarbons, methane and nitrous oxide. Ozone is also a greenhouse gas but most of it occurs in the stratosphere. There also exists an evidence that ozone in the troposphere could be increasing but the consequential feedback processes and the resultant forcings affecting the climate system are not yet clearly understood.

Slowing down of the growth rate of carbon dioxide in the atmosphere

It is interesting to note that the growth rates of carbon dioxide, methane and some of the halocarbons have shown a decrease over the past 10 years. In particular, atmospheric carbon dioxide (the major player among GHGs) showed a growth rate for 1992 at 0.5 ppm/year, which is about half of the average growth rate exhibited during the past decade[5]. Consequently, the concentration of carbon dioxide in the atmosphere continues to rise, albeit slowly, and is still below 360 ppm. This slowdown in the growth rate of carbon dioxide in the atmosphere implies that the uptake of carbon dioxide by natural systems in biosphere, geosphere and hydrosphere (plants, soil and oceans) would have been larger than usual. A number of hypotheses have been advanced to explain these intriguing observations. It has been suggested that more carbon could have been sequestered by plants and soil, oceans playing a secondary role; Mount Pinatubo eruption of 1991 could have slowed down the respiration rates of terrestrial systems and fertilized plankton in ocean waters; or prolonged El-Nino could have been the cause. But none of these provide a satisfactory explanation. In fact, no processes are known that could maintain this situation for long in the face of increasing emissions from fossil fuel burning, growing industrial activity and increasing population and deforestation. Actually, there are indications that the slowdown in the growth rate of atmospheric carbon dioxide has already reversed after 1992 – as inexplicably as it had begun earlier.

The position in respect of ozone depletion in the stratosphere is comparatively simple. The chlorofluorocarbons are mainly responsible for depletion of ozone in the higher latitudes, especially in the polar regions. However, now there are international conventions in force (Montreal Protocol and London Agreement) to limit and phase out the use and production of chlorofluorocarbons and to develop safe alternatives. Ozone depletion is a phenomenon of higher latitudes and there is no evidence (or known mechanism) so far of ozone depletion in the tropics, where traditionally the amounts of ozone have been comparable to the Antarctic ozone hole values. Therefore, at least for the tropical regions, climate change is likely to manifest mainly as global warming and sea level rise.

There also exists clear evidence that climate surprises or geological events (such as volcanic eruptions, meteorite/asteroid impact) or socioeconomic forcings (such as increasing population, expansion of megacities, automobile exhausts, consumption of forests) resulting in large-scale alteration of the environment may outscale the presently envisaged climate change. In other words, catastrophic events, human activities, changing dynamics of socioeconomic systems and consequences of technological advancements (which would include nuclear incidents and hazardous waste pile-up) may overwhelm the effects of any observed or envisaged climate change.

Attention at international fora

Though there is sufficient evidence of climate change on global scale induced by the increased concentration of GHGs, there are considerable uncertainties in respect of cause and effect, nature and extent, regional effects, and reversibility of the complicated processes involved. As already stated, various aspects of climate change have been the subject of intense scientific studies and international attention for quite some time. Apart from concerted scientific efforts at major research institutions round the world and the scientific results published in research journals, proceedings and reports, the subject has been officially dealt with at the following important international fora among others:

Global fora

- 1st World Climate Conf. (1979)
- 2nd World Climate Conf. (1990)
- IPCC First Assessment (1990)
- IPCC Supplement (1992)
- UNCED – Earth Summit (1992)
- Intergovernmental Meeting on World Climate Programme (1993)
- UN Framework Convention on Climate Change (FCCC) (1991–94)
- Conf. of Parties under FCCC (1995)
- IPCC Second Assessment (1995)

Regional fora (Asia)

- New Delhi Conference on Global Warming & Climate Change – Perspective from developing countries (1989)
- State of Environment in Asia and the Pacific (1990)
- 1st Asia Pacific Seminar on Climate Change (1991)
- 2nd Asia Pacific Seminar on Climate Change (1993)
- 3rd Asia Pacific Seminar on Climate Change (1994)

Major International Programmes

- World Climate Programme (WCP)
  - World Climate Research Programme (WCRP)
  - World Climate Impacts Assessment and Response Strategies Programme (WCIRP)
  - Tropical Ocean – Global Atmosphere (TOGA)
- International Geosphere Biosphere Programme (IGBP)
- Human Dimensions Programme (HDP)

Major International Organizations

- World Meteorological Organization (WMO)
- United Nations Environment Programme (UNEP)
- International Council of Scientific Unions (ICSU)
- Intergovernmental Oceanographic Commission (IOC)
- Intergovernmental Panel on Climate Change (IPCC)
- International Negotiating Committee for the UN Framework Convention on Climate Change (INC-FCCC)

Present status of scientific knowledge on climate change

What is understood well

- Greenhouse effect gets enhanced due to anthropogenic causes.
- Long persistence of the effect is due to long residence periods of greenhouse gases and the slow time response of the climate system.
- Natural climate variability overlaps the climate change due to the enhanced greenhouse effect.
- Earth's surface temperature, on a global average, has increased by 0.3–0.6°C over the past 100 years.
- The stratosphere is likely to cool due to increase of carbon dioxide and decrease of ozone.
- Global surface temperature rise would manifest generally as increase in minimum temperatures.
- Sea levels would rise.

What is understood fairly well

- Global mean precipitation would show an increase.
- Northern polar winters would experience greater warming, which could lead to reduction in northern sea ice, especially the polar ice sheets, which could become prone to breaking and may result in devastatingly huge ocean waves.
- Presently available coupled global climate models (CGCMs) give output products of understandable status up to intradecadal scales only.
- Observed global temperature changes are not inconsistent with model predictions.

What is not understood

- The role of oceans, biosphere (vegetation), geosphere (volcanoes).
- How to incorporate climate feedbacks in CGCMs.
- Land surface processes.
- Radiative forcings: the role of clouds, aerosols, tropospheric water vapour.
- What controls the concentration of carbon dioxide in the atmosphere.
- Regional distribution of changes in temperature, rainfall, soil moisture.
- Model uncertainties, especially in regional applications of CGCMs.
- Changes in ocean circulation and upwelling.
- Effect of (and on) major phenomena such as monsoons, El-Nino.
- Socioeconomic variables and future emission patterns of GHGs.
- Impacts of climate change on ecological and socioeconomic systems, including habitat, demographic migrations, food security, and biodiversity.

Regional approach

There is no denying the fact that climate has multidisciplinary and multidimensional facets with strong regional and local aspects. Climate change and the related scientific, technological and socioeconomic responses call for in-depth, well-balanced and cost-effective strategies in order to enable governments and peoples to respond to climate change through specific action plans at regional and country levels, where indeed the action lies in order to be effective. This brings out the advisability of adopting a regional approach to climate change assessment and response.

A regional approach to climate change is, in fact, a quest to assess regional or country vulnerability because it is only on the basis of a realistic assessment of regional/country vulnerability that appropriate response strategies can be evolved for the region/country. But most of the studies done so far have been based on the anticipated changes in climate-related global parameters or other forcing factors derived from global-scale assessments. This approach reverts us to the global scenarios because the forcing factors are based on projections assessed on global scale. This introduces considerable generality and subjectivity. Therefore, in order to make realistic impact assessments, we need to make a transition from global generalities to regional/country specifics. Objective assessments are not yet feasible because there are many uncertainties associated with the model projections for regional-scale climate change computed on the basis of global-scale climate parameter changes.

So what is to be done?

A new approach – Major climatological phenomena as basis for assessing regional impacts

It is the well-considered view of the author that it will be scientifically much more productive as well as cost-effective if we accord priority to detailed studies of those regional-scale aspects of climate that show promise of reasonably dependable predictability. In other words, it will be more fruitful to attempt assessment of climate variability and climate change on the basis of *major climatological phenomena that exhibit the following* attributes:

- Large scale.
- Well-organized.
- Quasi-permanent systems occurring fairly regularly.
- Amenable to a reasonable degree of empirical or semi-objective analysis and prognosis even if not predictable objectively.

A few examples of such major climatological phenomena are:

- The Indian summer monsoon.
- Droughts in India.
- Droughts in sub-Sahara Africa.
- East African monsoon.
- Rainfall over the Amazon region.
- El Nino.
- Cyclones, typhoons and hurricanes.

The author has been advocating this approach for over two years now and this approach seems to be gaining acceptability. He spoke about this at the National IGBP Seminar in Madras in 1993 and at the Second Asia Pacific Seminar on Climate Change in Bangkok, also in 1993. The latter appreciated this approach as a complementary methodology and the Seminar Report[6] 'noted that, given the current uncertainties associated with GCMs and the resources required for their application, these models should be integrated with complementary methodologies for climate predictions, even though in the long run they represent the best option'.

Present position of climate change studies

To summarize, the present position in respect of climate change studies is as follows:

- Build-up of the greenhouse gases in the atmosphere due to anthropogenic causes results in enhanced greenhouse effect, which in turn disturbs the delicate balance in the climate system, leading to climate change.
- In this affair, human beings are the perpetrators as well as the victims.
- The climate changes observed so far appear to be within the limits of the natural variability of the climate system but the rate of change has been faster in the past 100 years.
- There are many uncertainties in the climate change processes and many linkages (such as the role of clouds, aerosols and tropospheric water vapour) are yet to be understood clearly.
- Coupled global climate models have a long way to go before these are able to reproduce the observed changes faithfully over a long period of time.
- Usable applications of the models at regional/country scales are not yet in sight.
- It is the regional/country vulnerability which needs to be assessed because the responses can be formulated and implemented effectively only at these levels, taking into account the local requirements and sensibilities.
- An interim regional approach is to study the major regional-scale climatological phenomena which are quasi-permanent and amenable to a reasonable degree of predictability even by statistical or empirical methods.

Refocusing of climate change studies

In the light of what has been discussed in the preceding sections, an urgent need to consolidate the largely fragmented scientific studies and the advisability of adopting a regional approach for impacts assessment emerges clearly. For this, a refocusing of climate change studies is definitely called for. The essential elements of the refocusing could be as follows:

- While work on refining CGCMs should continue with greater vigour, their regional-scale applications should also receive equally high (if not higher) priority.
- Development of regional models of climate change should receive renewed emphasis.
- Studies of regional-scale climatological phenomena should be encouraged because studies of variability and predictability of regional-scale climate may yield quick and usable appreciation of the regional/country vulnerability on account of climate change.
- We need to make a transition from global generalities to regional/country specifics. This also points towards the advisability of making climate change assessment on the basis of major regional-scale climatological phenomena instead of the envisaged

changes in global-scale averages of climate parameters.

- Even for a single country, climate change will have multiple perspectives and intricate interconnections. Innovative response strategies, suited to its own requirements, will have to be developed and validated by each country. These can then be synthesized into a regional strategy or strategies.
- As climate change has strong geographical dependence, there cannot be a single global or even regional strategy. There would need to be a 'bunch of strategies' with subregional and sectoral (energy, transport, industry, agriculture, etc.) components or programmes. Large countries would also need subcountry programmes.
- The challenge lies not only in taking up in-depth studies of the implications of climate change but also in making it possible for different sections of the society (possibly subscribing to different views on the subject of climate change) to engage in a constructive dialogue. Hopefully, then workable programmes would emerge. The paramount need is to harmonize many a thought and many a talent to evolve a plan which will have a very large support base among intellectuals, scientists, policy makers, opinion leaders and the informed and concerned sections of the public in the country.
- Studies of climate change and its impacts transcend the boundaries of individual scientific disciplines. This necessitates cooperation and coordination not only among different scientific disciplines (meteorology, climatology, oceanography, physics, chemistry, biology, computer science and others) but also with social sciences (geography, economics, demography, etc.). Therefore, natural scientists and social scientists should come together to bring their expertise to study climate change and its impacts. Interface problems of interdisciplinary cooperation and coordination require intellectual and operational understanding. Hence, interdisciplinary groups should be convened to study how climate is likely to change at the national, subregional and regional scales; how the anticipated climate change might affect the natural and human environment on which people depend for their survival, sustenance and progress; and how the government and the society can respond to these likely impacts of climate change.

Conclusion

The above ideas on the need for a refocusing of climate change studies arise from the author's long association with the subject both as a researcher and policy adviser at the national as well as international level. The above-mentioned elements of the desirable refocusing are commended to the scientific community and the policy makers in general and to those in our country in particular.

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