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Climate change and agriculture – An Indian perspective

Sulochana Gadgil

In this paper, we examine the major predictions made so far regarding the nature of climate change and its impacts on our region in the light of the known errors of the set of models and the observations over this century. The major predictions of the climate models about the impact of increased concentration of greenhouse gases are at variance with the observations over the Indian region during the last century characterized by such increases and global warming. It is important to note that as far as the Indian region is concerned, the impact of year-to-year variation of the monsoon will continue to be dominant over longer period changes even in the presence of global warming. Recent studies have also brought out the uncertainties in the yields simulated by crop models. It is suggested that a deeper understanding of the links between climate and agricultural productivity is essential for generating reliable predictions of impact of climate change. Such an insight is also required for identifying cropping patterns and management practices which are tailored for sustained maximum yield in the face of the vagaries of the monsoon.

THE last decade has witnessed a rapid increase in the awareness of global change and triggered widespread apprehension amongst scientists and governments about the implications for their part of the globe. The major-facets of global change are changes in climate, the concentration of atmospheric constituents (such as CO_2, CH_4, etc.), land surface cover (e.g. desertification, deforestation) and biodiversity. The changes in these facets are of concern to us because of the impact on human beings and on resources critical to their survival. On the other hand, the changes in many of these facets have a large anthropogenic component, e.g. deforestation, loss in biodiversity, the increase in CO_2 due to burning of

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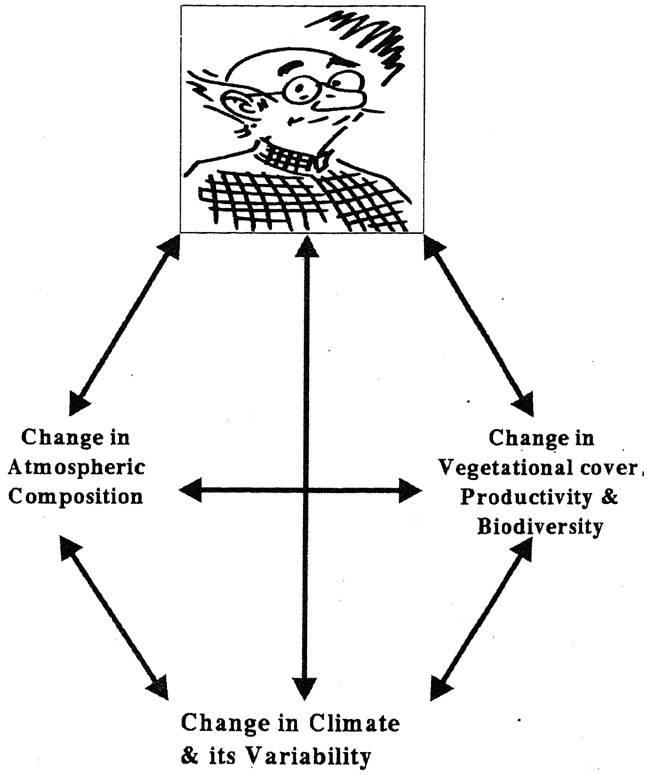

Figure 1. Major facets of global change – induced by and having an impact on humans.

fossil fuels, etc. It is important to note that many of these changes are interlinked (Figure 1). Thus increase in CO_2 (which is a greenhouse gas) can lead to climate change. Change in land surface cover can also have a large impact on the climate and particularly the rainfall in the tropics. Changes in atmospheric constituents can either have a direct impact on the inhabitants of the earth (such as higher incidence of skin cancer due to the depletion of ozone caused by the chloroflurocarbons (CFCs)) or an indirect impact via the induced change in climate as expected from the increase in CO_2.

I focus here on climate change. Climate change on long timescales of thousands of years, as between ice-ages and interglacials, is believed to be the result of natural factors such as changes in parameters of the earth's orbit around the sun. Anthropogenic factors are likely to have an impact on the timescales of about a century. Perhaps the most prominent facet of climate change over this century is global warming. The mean global surface temperature exhibits an increase over the last decades, with particularly sharp increase from 1970s (Figure 2). This warming has occurred during a period in which the composition of the atmosphere has changed significantly with a marked increase in the concentration of several gases contributing to the greenhouse effect such as carbon dioxide and methane (Figure 3). A major intergovernmental effort[1] in scientific assessment of climate change (IPCC) concluded that 'we are certain that emissions resulting from human activities are substantially increasing the atmospheric concentration of greenhouse gases such as CO_2, methane, CFCs, etc. These enhance the greenhouse effect, resulting in an additional warming of the earth's surface (on an average). The main greenhouse gas, water vapour, will increase in response to global warming and further enhance it.'

Several predictions have been made about the nature of climate change induced by an increased concentration of greenhouse gases and the possible impacts on critical resources such as agriculture. For example, a major study of implications for India of climate change[2] concludes 'cereal production is estimated to decrease and the nutrition security of the population-rich but land-hungry region of India would be hampered, an increase in the local tropical cyclone activity may occur over the next century, posing serious problems as large areas in the coastal regions have a dense population.'

Most of the studies using climate models to estimate change associated with enhancement of greenhouse gases suggest that the summer rainfall over South Asian region will increase by 5 to 15% (ref. 1). Some studies

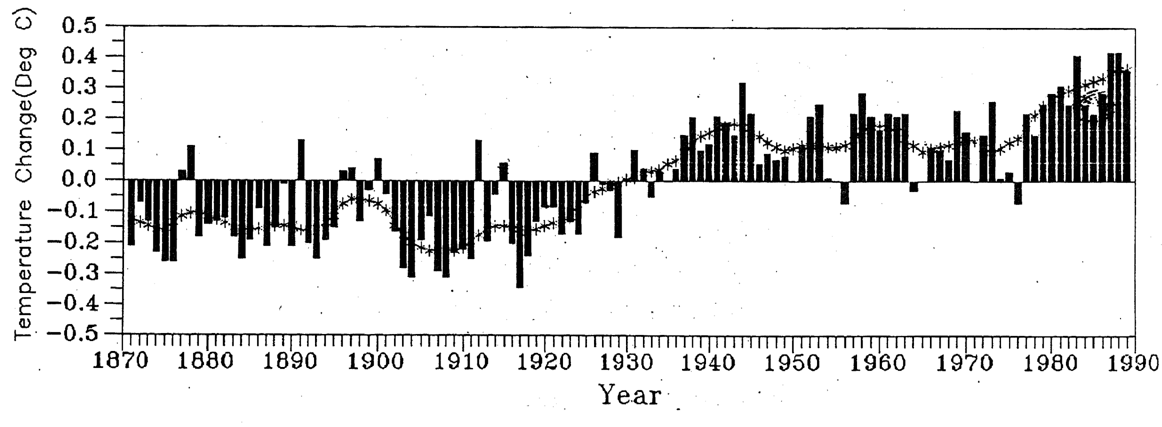

Figure 2. Annual deviation of the global mean combined land–air and sea-surface temperature for the period 1861–1989. The curve shows the results of a smoothing filter applied to the annual values.

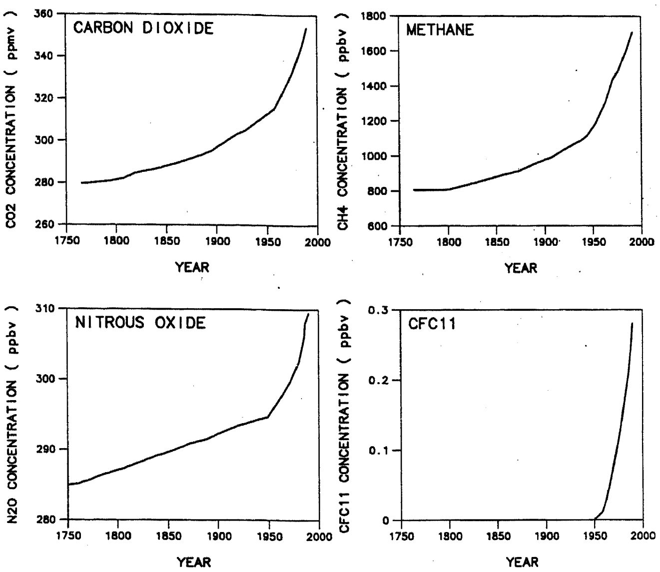

Figure 3. Variation of the concentration of some atmospheric constituents during the last century.

predict an increase in the intensity of daily rainfall events. In the thematic review of agriculture 'Climate Change over Asia', Suppiah *et al.*[3] state, 'Studies of simulated daily rainfall from enhanced greenhouse experiments indicate that a systematic increase in the average intensity is a common feature. Associated with this is an increase in the frequency of heavy rainfall events. Indeed, there is a reason to be more confident that rainfall intensity will increase in south and southeast Asian regions under enhanced greenhouse conditions. This pattern of change has serious implications for agricultural activities.' Parry and Swaminathan[4] suggest that 'the changes in climate could provoke serious reduction in food production potential, particularly in regions that are at present vulnerable to climate variability such as the agricultural zones in semi-arid and humid tropics'.

Such predictions about the nature of climate change and its impacts on agriculture are widely publicized. Thus the headlines of an article based on a study of Rosenzweig and Parry[5], which appeared in several newspapers across the country, read 'Impact of global warming to be hardest on have-nots. Less food if earth warms; more hunger in developing countries'. However, there is hardly any discussion about how reliable these predictions are. Predictions about the nature of climate change due to enhancing the concentration of greenhouse gases are generally made using climate models which are run for the present concentration and enhanced concentration of these gases. Assessments of impacts on agriculture such as that of Rosenzweig and Parry[5] involve using outputs of such models in conjunction with crop models and models of world trade. There are systematic errors in each of these models. Obviously, an assessment of the reliability of such predictions over the region of interest – here India, is an essential prerequisite to generating policy recommendations about possible mitigatory measures, and the strategies of research and development.

In this article, the major predictions made so far regarding the nature of climate change and its impacts for our region are examined in the light of the known errors of the set of models and observations over this century. The aim of this article is to identify problems which are of particular importance for our region and start a dialogue amongst concerned scientists to evolve a programme of research and development appropriate to the Indian situation.

Nature of climate change – Predictions and observation

Let us consider first the use of climate models for prediction of climate change and variability over the S. Asian monsoon region. It is important to note that simulation of the summer monsoon over this region has proved to be an extremely challenging problem. This is evident from Figure 4, in which the observed pattern of the mean rainfall for July is shown along with the mean pattern simulated by three atmospheric general circulation models (GCMs) for the period 1979–88 as a part of a

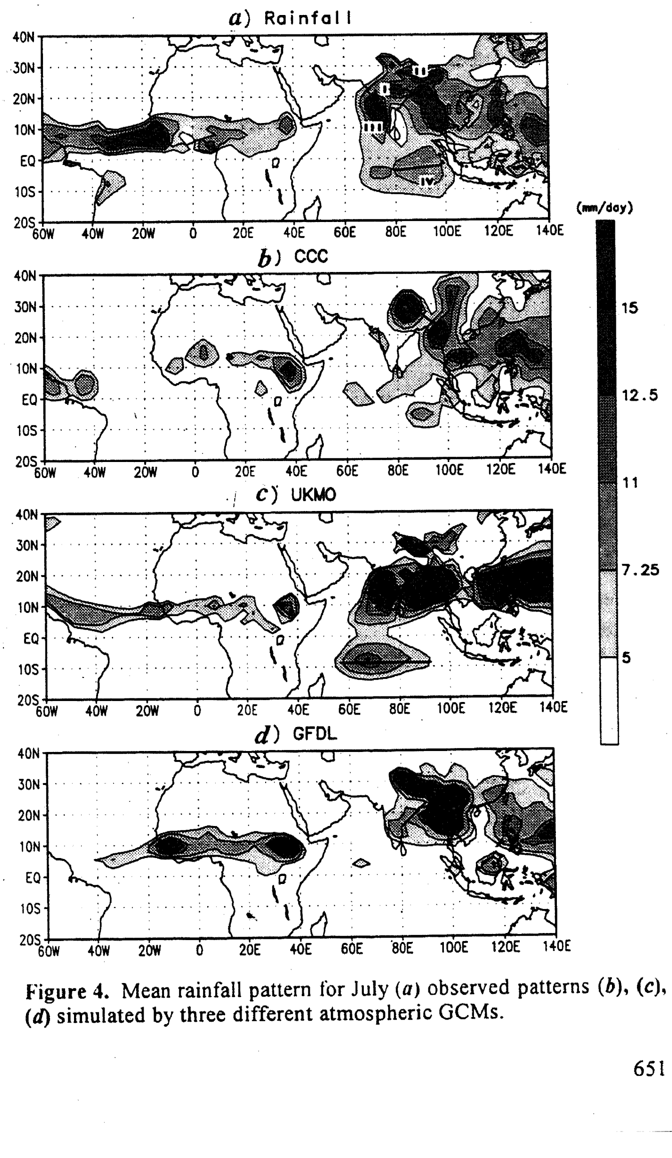

Figure 4. Mean rainfall pattern for July (*a*) observed patterns (*b*), (*c*), (*d*) simulated by three different atmospheric GCMs.

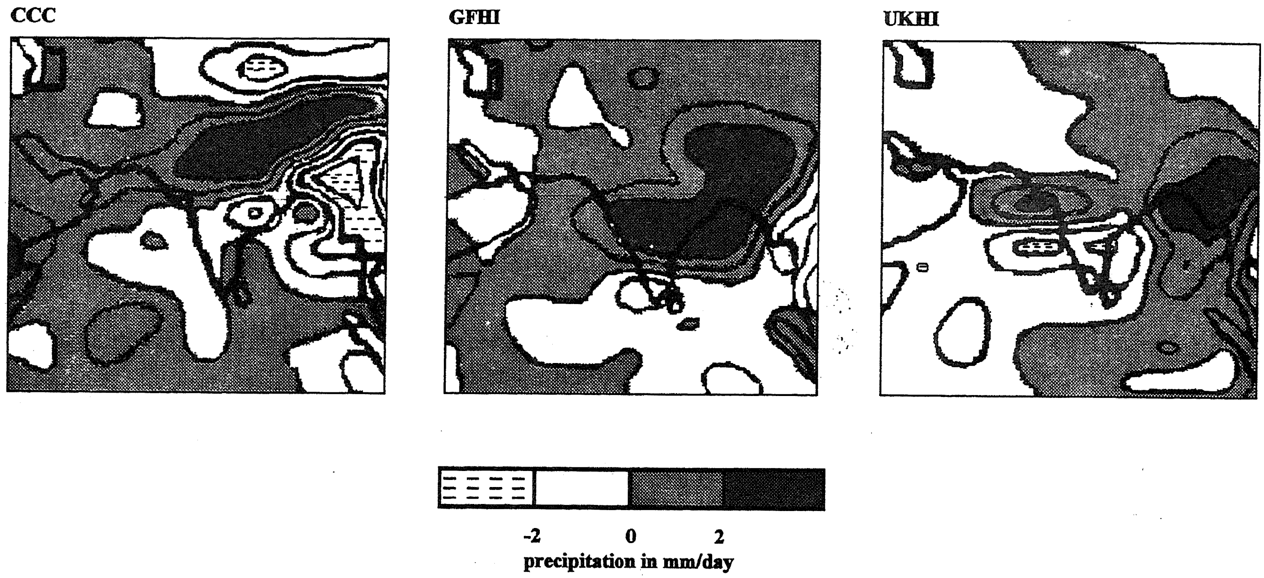

Figure 5. Change in precipitation (smoothed 10-year means) due to doubling CO_2 during June–August as simulated by some models (adapted from IPCC).

major Atmospheric Model Intercomparison Experiment[6]. It is important to note from Figure 4 *a* that while over the African region there is only one rainbelt around 10°N, over the Indian longitudes there are four. The large-scale monsoon rainfall is associated with the rainbelt I which extends north westward from the Bay of Bengal onto the Indian subcontinent. Northward of this monsoon rainbelt, is the rainbelt II along the foothills of the Himalayas. In addition, there is the rainbelt III along the west coast of the Indian peninsula due to the Sahyadris, and the rainbelt IV on the warm waters of the equatorial Indian ocean. The presence of so many favourable lacations for the rainbelt makes it extremely difficult for models to simulate the rainfall pattern realistically[7]. Generally only some of the rainbelts are simulated and that too not always at a realistic location. Thus, the CCC model simulates only the rainbelt II and the oceanic rainbelt IV. In the UK Meteorological Office (UKMO) simulation, the rainbelt over the continent is primarily on the peninsula, with hardly any rain over the monsoon zone (rainbelt I); the Himalayan belt II and oceanic belt IV are also simulated. The most realistic simulation of rainbelt I in Figure 4 is by the GFDL model. However, the oceanic belt IV is totally absent in the GFDL simulation. The simulation of the year-to-year variation of the summer monsoon over the Indian region is found to be even more difficult than that of the average pattern. Thus even models which simulate the mean pattern reasonably well, are not able to simulate realistically the interannual variation between poor and good monsoons[7].

So far we have been discussing simulation by atmospheric GCMs for the period 1979–88 with the sea surface temperature specified from observations. Because of the large inertia, the timescales of response of the ocean are much longer than those of the atmosphere. Hence for generating predictions over timescales of a week or less, or for studying subseasonal variation (such as fluctuations of the monsoon between active and dry spells), atmospheric GCMs run with specified sea surface temperatures are useful. However, for simulating variations on long timescales such as the century-scale on which we expect a change of greenhouse gas concentration to have an impact, it is necessary to use climate models in which the ocean is also an active player. These climate models are models of the coupled atmosphere–ocean system, which are necessarily more complex than the component atmospheric or ocean models. Not surprisingly, the simulation of the summer monsoon rainfall pattern by such models is also generally not realistic (e.g. Lal *et al.*[8]).

Some differences in the simulated and observed patterns of rainfall and its variability are to be expected. As Gates[9], one of the leaders in the field, has pointed out, 'The demand for climate scenarios for impact estimation far exceeds the supply of reliable information climate modelers have in their possession. Climate models certainly have systematic errors, most of these errors are poorly understood and, in general, poorly documented'. We have seen that it appears particularly difficult to simulate the South Asian monsoon and its variability by atmospheric GCMs or climate models, perhaps because of the presence of multiples equilibria[7]. Such limitations have to be borne in mind when we consider the implications of climate change derived by climate models.

Let us consider next the predictions made for enhanced greenhouse gases. The most authoritative review is by the IPCC[1]. While all models indicate that surface temperature

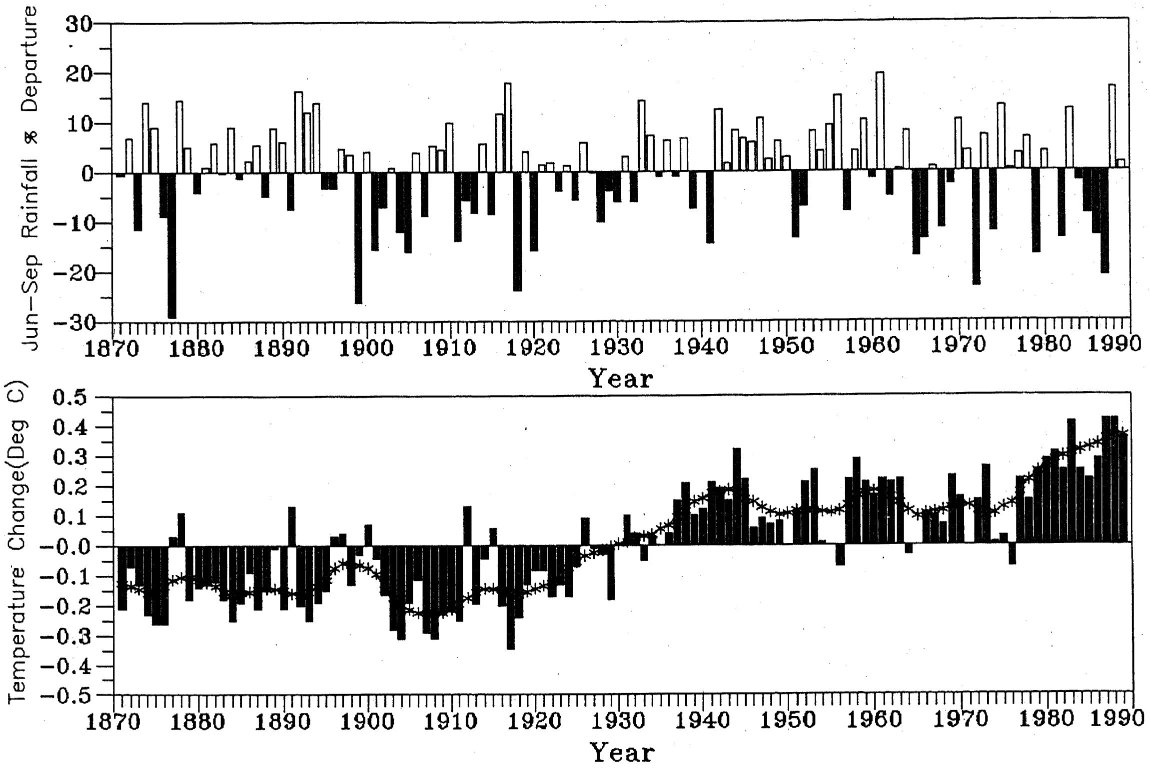

Figure 6 *a*. Variation of the all-India summer monsoon rainfall over the last century. Global warming of Figure 1 is also shown.

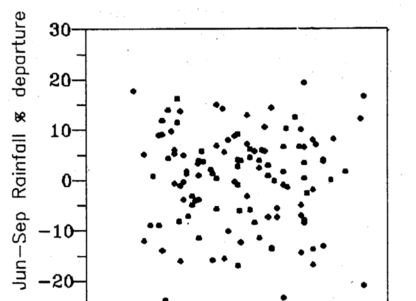

Figure 6 *b*. Percentage departure from normal of all-India summer monsoon rainfall versus global surface temperature anamoly.

will increase over the Indian region (up to 2°C during the summer) the response in terms of precipitation changes is more difficult to assess. Although most models simulate an enhancement of precipitation over the South Asian monsoon region, the change in precipitation is relatively small compared to the interannual variations. Also, there are considerable differences between models (Figure 5). However, all the three models shown in Figure 5 imply an increase over the region north of 20° N, i.e. over the monsoon zone of Figure 4 *a*, over which most of the large-scale monsoon rainfall is received. Lal *et al.*'s[10] study of anticipated changes in India's climate also suggests an increase in rainfall over this region.

Let us now consider how the prediction of an increase in the Indian monsoon rainfall in association with global warming compares with observations. The observed variation of the all-India summer monsoon rainfall over India over the last 100 years and the global warming during this period are shown in Figure 6 *a*. The variations of all-India rainfall over this short period of about a century do not seem to be correlated with the observed global warming (Figure 6 *b*). We note that there is no clear increasing trend observed on the century scale in Figure 6. *Rather, the most prominent variation is on the interannual scale (from year to year), between good and poor monsoons*. The change on the decadal or century scale is in the frequency of deficit monsoons or droughts. Joseph[11] was the first to point out that there are three distinct epochs in this series – the first up to about 1920, characterized by frequent droughts; the period 1930–64 by relatively less frequent droughts and the period 1965–87 again by frequent droughts. Thus what is important for the Indian region as far as change in climate is concerned, is the change (if any) in the frequency of extreme events such as droughts of floods, i.e.

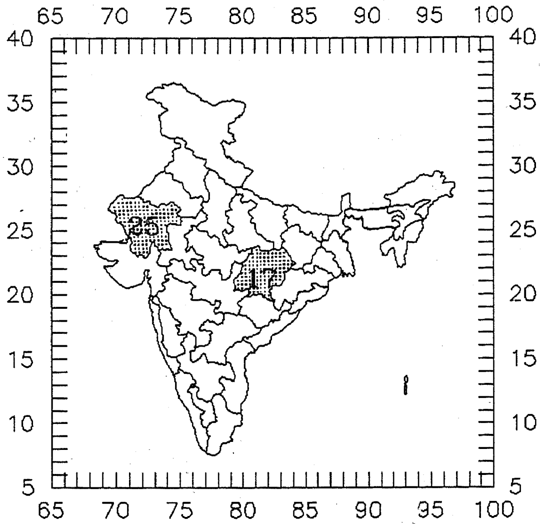

Figure 7 *a*. Coherent rainfall zones after Gadgil *et al.*[13].

changes in the important facets of climate variability. Although there are changes in the frequency of droughts on the decadal scale, these do not appear to be simply related to global warming[12]. For example, although the epoch of frequent droughts till 1920 coincides with the relatively low global temperatures, and the warming up to 1945 occurred in an epoch of low frequency of droughts, in the warm epoch during 1965–88, a high frequency of droughts is observed.

It is well known that the variations of seasonal rainfall over India do not occur in phase across the country. When some parts of India experience drought, there are floods in others, and so the average all-India rainfall is not very meaningful. Hence, we consider variations of rainfall over zones, which are coherent with respect to variations of the summer monsoon[13]. We find that there is no clear trend of increasing or decreasing rainfall over the century scale for any of the zones although there does appear to be some signal on decadal scales, leading to a persistence of above or below average rainfall for several years in a row (e.g. Figure 7). Earlier studies of trends over subdivisions or macrozones (reviewed by Pant *et al.*[14]) also found no significant trend over most of these regions. Rupa Kumar *et al.*'s[15] analysis of rainfall time-series at 306 stations across India showed that very few stations had significant trends.

An increase in the intensity of daily rainfall and frequency of heavy rainfall events has also been predicted[16]. The variation of the frequency of the heavy

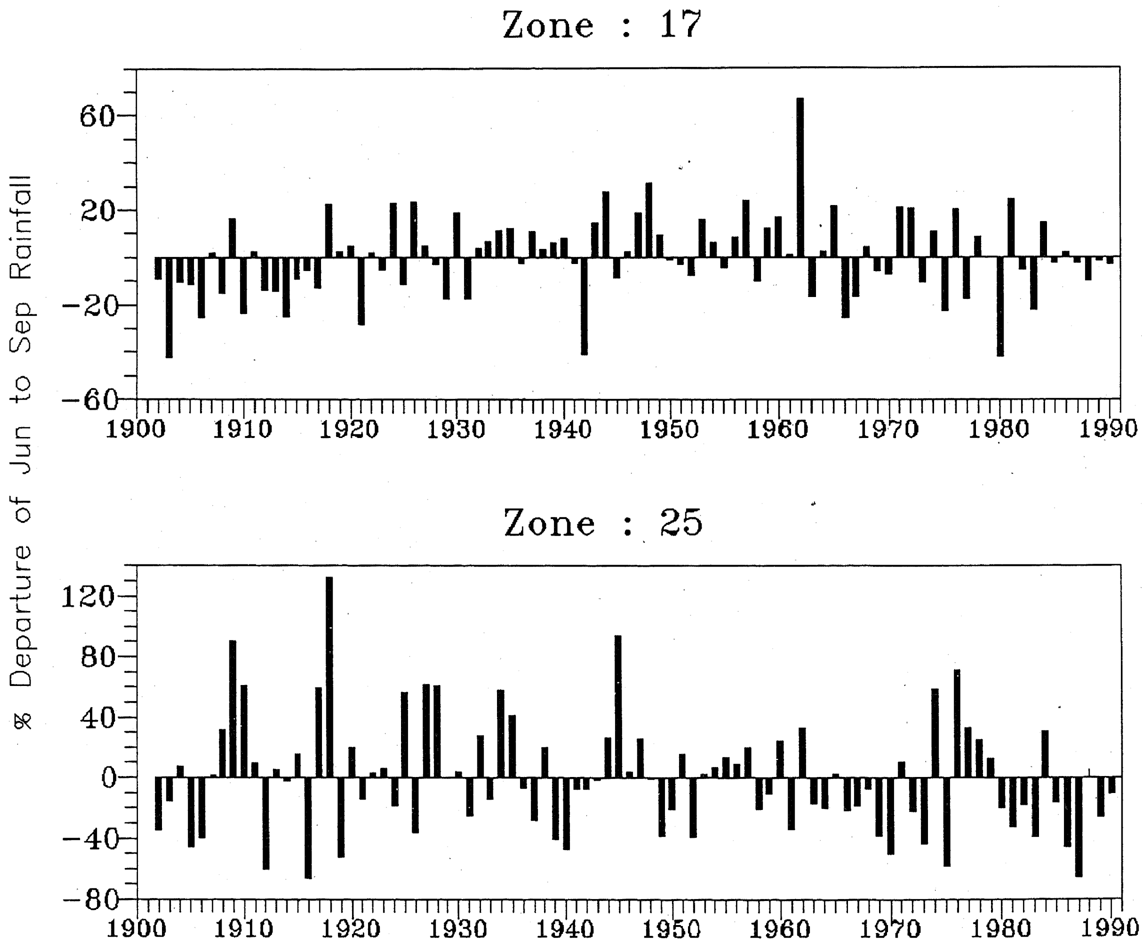

Figure 7 *b*. Variation of the summer monsoon rainfall over one zone 25 (below) over the North Western part of the monsoon zone, and zone 17 (above) over the eastern part of the monsoon zone.

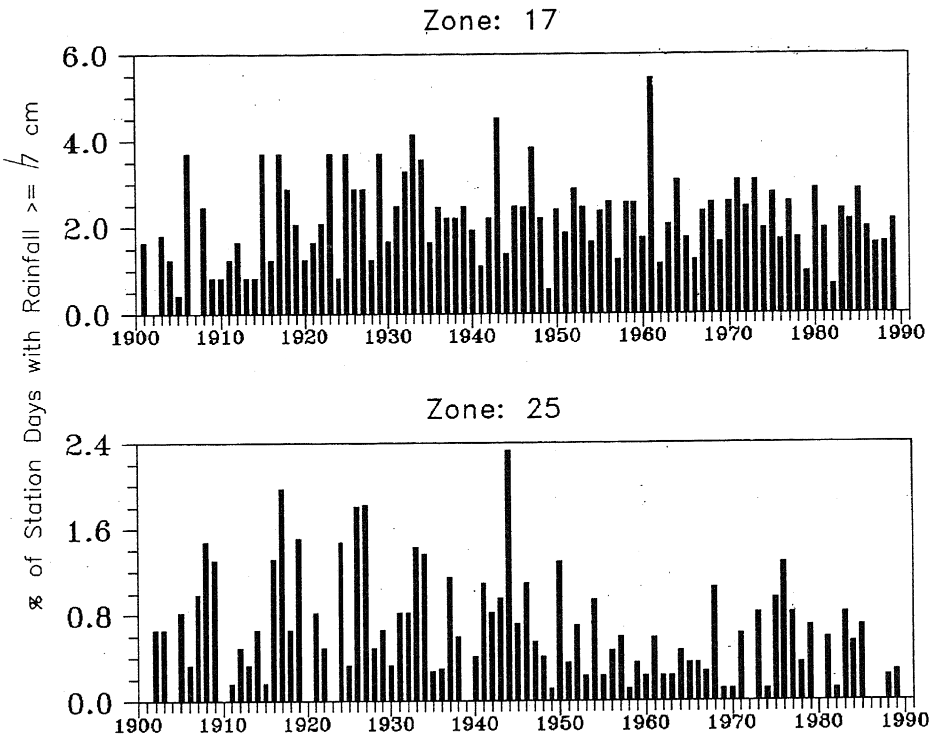

Figure 8. Variation of the frequency of heavy rainfall events (> 7 cm per day) over the two zones in Figure 7.

rainfall (greater than 7 cm a day) for two zones of Figure 7 is shown in Figure 8. Again there is no clear trend indicating increase of heavy rainfall events in association with global warming. In fact the frequency appears to decrease in the last two decades.

Another prediction is about a possible increase in frequency and intensity of tropical depressions and cyclones[10]. A detailed discussion about the nature of change in the depressions and cyclones over the last 100 years appears elsewhere[17]. The number of depressions and cyclones north of the equator in the Indian Ocean from Joseph's[17] study are shown in Figure 9. During the period 1970–90 when global warming is most rapid, the frequency of these systems is in fact decreasing. The frequency of tropical cyclones over the N. Atlantic also appears to have decreased in this period while there is no clear trend over the Pacific[18].

Studies of the observed changes in surface temperature over the Indian region have also been reviewed by Pant *et al.*[14]. The all-India mean annual surface temperature derived from 73 stations across India[19] shows a significant warming of 0.4°C per 100 years, which is comparable to the global mean trend of 0.3°C per 100 years. This increase is primarily contributed by the post-monsoon and winter seasons, there being hardly any trend in the monsoon-season temperatures. Of the 73 stations used to derive the all-India average, 30 stations show a significant warming trend while 6 show a cooling trend. *A comparison of the trends in rainfall*[15] *and temperature*[19] *indicates that generally increase in rainfall is associated with decrease in temperature.* In the belt north of 20°N where most models predict an increase, the eastern sector exhibits a decreasing trend while the western an increasing one, although neither is significant at a majority of the stations.

The observations about the variation of the summer monsoon rainfall over the Indian region over the last century during the period of global warming can be summarized as follows. The all-India summer monsoon rainfall does not exhibit an increasing trend; its variations do not appear to be correlated with global warming. No trends are apparent in the variation of the summer monsoon rainfall over different coherent zones of Indian region. There is no evidence to suggest that an increase in heavy rainfall events occurs with global warming. The frequency of depressions and cyclones over the Indian seas appears to have decreased markedly over the period 1970–90 when global warming was most

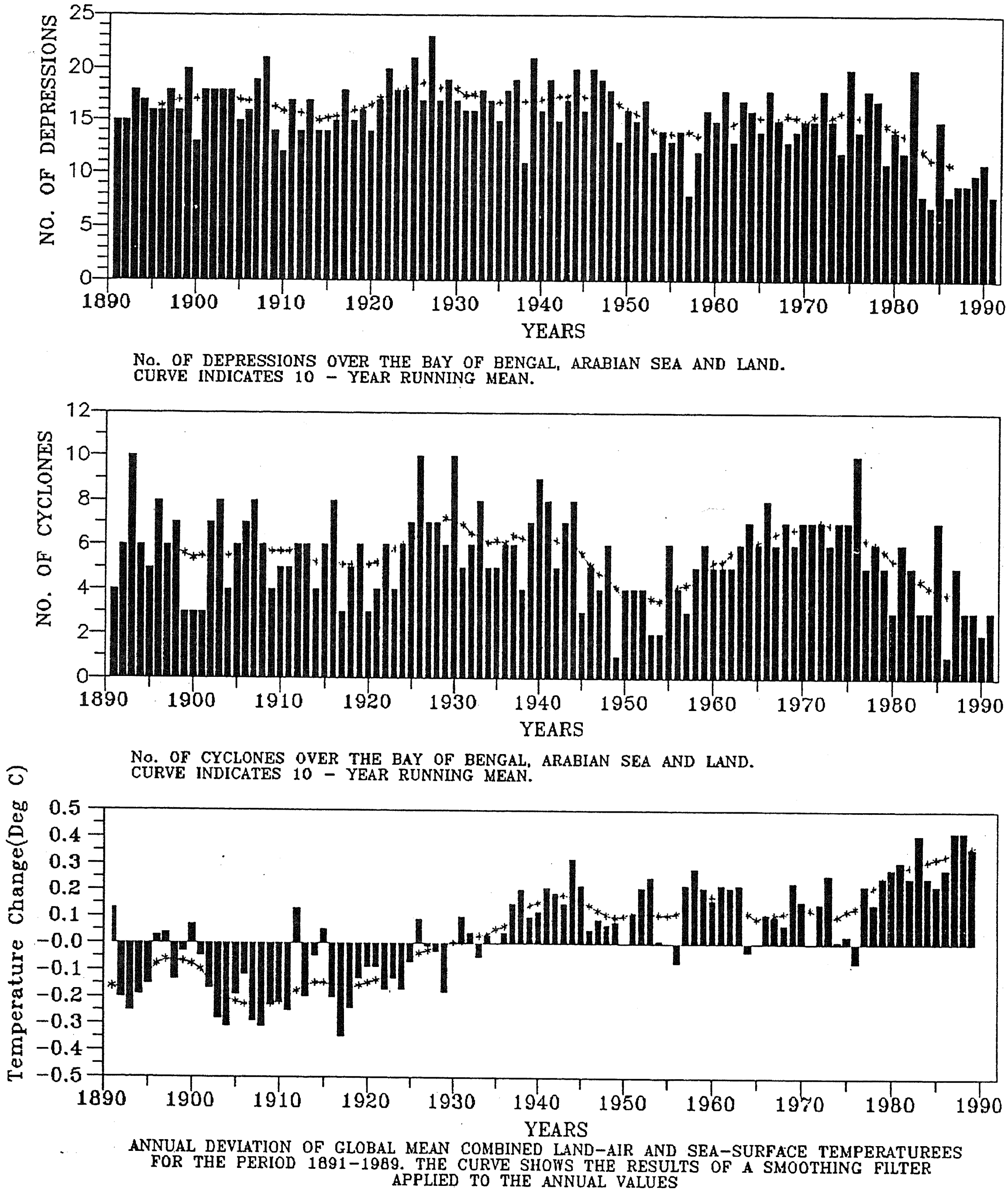

Figure 9. Variation of the frequency of depressions and cyclones over the Indian seas.

rapid. Hence the observations about the changes in rainfall pattern over the Indian region during this century appear to be at variance with the predictions generated so far by the existing climate models.

The all-India surface temperature does exhibit a warming as predicted by the models, albeit at a much smaller rate. However, over regions where rainfall increase is observed (again of very small amplitude) generally the temperature decreases. So the observations suggest that a simultaneous increase in rainfall and temperature is unlikely.

This comparison of model predictions regarding the important climatic variables – temperature and rainfall with available observational data – suggests that until the performance of the models in simulation for the regional scale is sufficiently accurate, regional predictions of the impact of various factors such as enhancement of greenhouse gases generated on the basis of the results from such models have to be interpreted with caution. The observations may not be adequate for detecting the climate change signal from the natural variability. However, before making decisions regarding actions for mitigation, validation of the models by comparison with whatever observations are available for the major predictions, is absolutely essential.

Climate and agriculture

The strong links between the vagaries of the monsoon and agricultural productivity are well known. This link is evident in the variation of the production of rice and of the annual production of total food grain over India, shown in Figure 10, along with the all-India summer monsoon rainfall. It is clearly seen that superposed on the increasing trend due to the green revolution, are dips in the yield, which occur in years in which the all-India summer monsoon rainfall is deficit (e.g. 1965, 66, 72, 74, 79, 82). On the other hand, when the all-India rainfall is in excess of the normal (e.g. 1964, 70, 75, 78, 83), the yield is certainly higher. Thus the large year-to-year variations in monsoon rainfall are directly reflected in substantive variations of the yield. For example, the difference in the total annual food grain production between the poor monsoon of 1974 and the succeeding good monsoon of 1975 is about 20% of the yield.

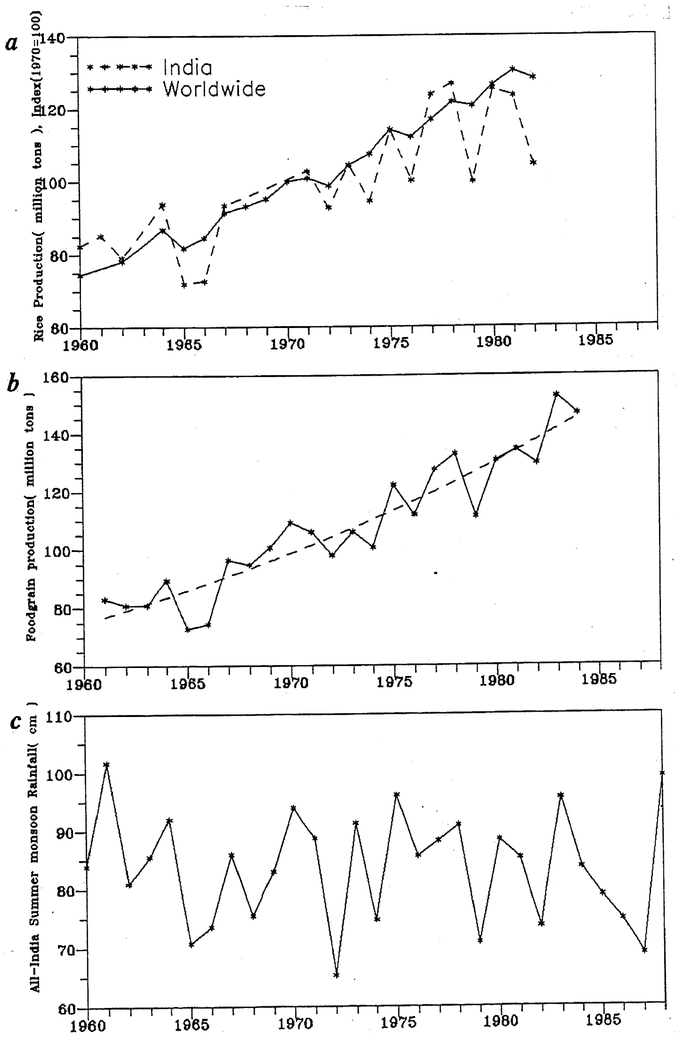

Figure 10. Variation during 1960–82 of (*a*) rice yield over the Indian region (after Swaminathan[23]), (*b*) total food grain production (after Parthsarathy *et al.*[24].), (*c*) all-India rainfall.

We note that in the epoch 1930–64 when the mean monsoon rainfall was high, the frequency of deficit years was low. Thus *a priori*, it would appear that if the monsoon rainfall were to increase (and frequency of droughts to decrease) as predicted by the climate models, the production of food grains would be enhanced. What then is the basis of the sensational predictions about decrease in yield with global warming? These are generated by the use of crop models to assess the impact of change in climate.

In general, the change in yield depends not only on the change in rainfall but also change in CO_2 concentration and temperature. While the increase in rainfall and concentration of CO_2 generally lead to an increase in yield, the impact of an increase in temperature is generally negative in the tropics. Thus if both rainfall and temperature increase, it is necessary to ascertain whether the impact of increased rainfall and CO_2 will overwhelm the impact of increased temperature and hence evapo-transpiration over specific regions for specific crops. However, as noted in the last section, it is not clear that over the Indian region temperature and rainfall will simultaneously increase.

So far we have focused on interannual variation and considered primarily the impact of fluctuations in the total seasonal rainfall, mean temperature, etc. However, the agricultural productivity is also a sensitive function of the distribution of the meteorological variables such as rainfall within a season[20]. The difference between a so-called good monsoon season and a deficit monsoon season is generally the presence of a long dry spell in the latter. Such dry spells induce moisture stress and have a major impact on the productivity when they occur in critical life history stages of the crop. Similarly if wet spells occur and promote the spread of pests and diseases, significant losses are incurred unless mitigatory measures are adopted[21]. The identification of such weather/climate events which have a large impact on the productivity of different crops is essential for making realistic impact assessments and choosing the appropriate management strategies for mitigatory measures.

With the rich data-set available in the meteorology department, the probabilities of the occurrence of such events in different stages in crop growth can be readily worked out for each region. For obtaining maximum sustainable yield in the face of this variability, the varieties and cropping patterns have to be chosen so that the occurrence of such events in the critical life-history stages is minimized. Thus, understanding such links between climate variability and agricultural productivity is also a pre-requisite to tailoring cropping patterns/varieties and management practices for maximum sustainable yields in different agroclimatic zones.

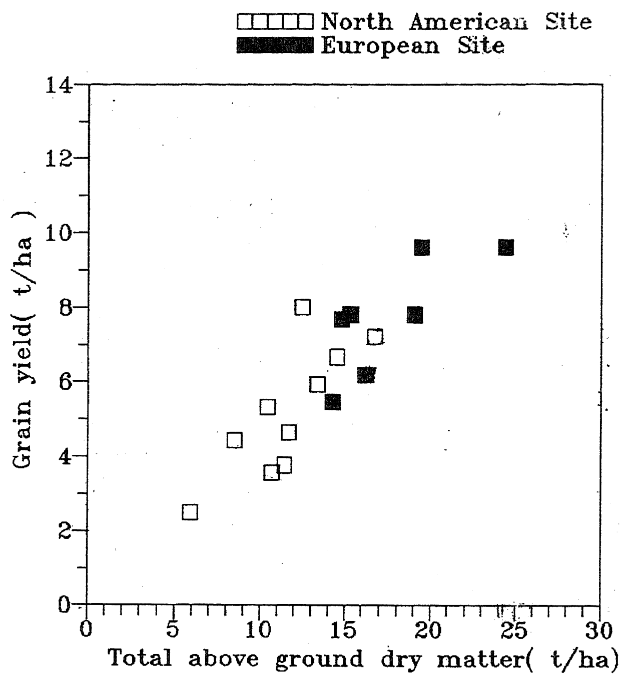

Figure 11. Scatter plot of simulated yield against biomass for the North American site and European site in the GCTE (after Ingram[22]).

A systematic analysis of the yields simulated by wheat models was recently conducted as a part of the IGBP Project on Global Change and Terrestrial Ecosystems (GCTE). This revealed a surprisingly large intermodel variation in simulated yield even when the climatic conditions were specified to be the same (Figure 11, after Ingram[22]). Thus it appears that the prediction of impact generated by using crop models in combination with climate models are likely to have significant errors. It is necessary to understand and validate each component/link with available observations and special field trials to determine the reliability of the predictions. For example, it may be worthwhile to investigate whether the existing crop models (of the kind used in Rosenzeweig and Parry's[5] study) can simulate the observed variation of the yields over the last century when the observed variation of the climatic parameters is specified.

It is also important to note that as far as the Indian region is concerned, the impact of year-to-year variations of the monsoon will continue to be dominant even in the presence of global warming. Thus neither the rainfall nor temperature is likely to change monotonically. The pertinent question to ask of climate models and observations is then the extent to which climate variability will change. In other words, on the interannual scale whether the frequency of extreme events such as droughts or floods will change and on the subseasonal scale whether the frequency of critical weather events such as dry and wet spells or hot and cold spells will change.

Concluding remarks

We have seen that predictions generated from climate models about the consequences of enhanced greenhouse gases such as increased monsoon rainfall, higher frequency of heavy rainfall events, etc. are at variance with observations over the last century characterized by global warming. Recent studies have also brought out the uncertainties in the yield simulated by crop models. Thus it is clear that understanding the important links between climate and agricultural productivity is an essential prerequisite to generating reliable predictions about impact of change in climate and variability.

In my view, the most important problem for our region is to elucidate in detail the climate component of agricultural productivity by systematic analysis of the available data on yields of different crops (at the different agricultural research stations as well as at district level) on the one hand and investigation and development (if necessary) of crop models with realistic sensitivity to climate on the other. This will pave the way for generating realistic impact assessments and identifying cropping patterns and management strategies which are tailored for sustained maximum yield in the face of the vagaries of the monsoon.

Meanwhile, we expect the rapid improvement of climate models across the globe in the last decade to be sustained. In the not too distant a future, these models should start yielding reliable results on regional scale for the nature of climate change in response to various factors such as enhanced greenhouse gases. By that time if the links to the productivity of the major crops are understood, reliable predictions of impact could be generated and strategies for coping with the anticipated climate change worked out.

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Opioid peptides in invertebrates: Localization, distribution and possible functional roles

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In this review the opioids that have been found in the invertebrates are discussed. Major emphasis is placed on the arthropods, molluscs and annelids. The article deals largely with the identification and functional roles of these peptides. These endogenous opioids are involved in a wide variety of physiological processes, often serving as neurotransmitter substances. Among the putative roles of opioids in invertebrates are mediation of the release of neurohormones, initiation of proper behavioural responses, control of thermoregulatory activities and mediation of immune responses. This review concludes with a section that suggests areas of future investigation, along with possible practical applications of these compounds.

In recent years a number of vertebrate-type neuropeptides have been discovered in the invertebrates. The discovery of these vertebrate-type peptides in invertebrate tissues has influenced research in comparative endocrinology in a major way. A class of such neuropeptides is known as the opioid family, based on the fact that among vertebrates these peptides show a potent capacity to mimic some key actions of morphine[1]. In mammals the enkephalins originate from at least two precursors, preproenkephalins A and B. Preproenkephalin A gives rise to one copy of leucine enkephalin (Leu-Enk), four copies of methionine enkephalin (Met-Enk) (Leu-Enk and Met-Enk are pentapeptides) and two C-terminally extended enkephalins, Met-Enk-Arg^6-Phe^7 (met-7) and Met-Enk-Arg^6-Gly^7-Leu^8 (Met-8)[2]. Preproenkephalin B contains no Met-Enk sequence but has three Leu-Enk-containing peptides, α/β-neoendorphin, dynorphin and rimorphin. The first enkephalins discovered, Met-Enk and Leu-Enk, were originally purified from the porcine brain[3]. There are a variety of opiate receptors (mu, delta, iota, kappa, epsilon) each of which appears to be the preferential ligand for one of the endogenous opioid peptides in mammals[4]. Endogenous opioids have been detected in all vertebrate species investigated[5,6]. These substances serve widely throughout the body as neuromodulatory substances.

The search for the presence of endogenous opioids in invertebrates initially met with some uncertainty. Early reports did not support the presence in several invertebrates of opiate-receptor-binding sites[7,8]. However, the development of appropriate techniques, especially immunocytochemistry, radioimmunoassay (RIA) and high-performance liquid chromatography (HPLC), made it possible to discover opioid peptides in several invertebrates. Among the invertebrates, studies have been undertaken mainly with arthropods, molluscs and annelids, and in this review we emphasize the studies that have been done on the localization, distribution and possible roles of the endogenous opioids in these groups.