EARTHWATCH

GLOBAL ENVIRONMENT MONITORING SYSTEM

The Potential Socio-Economic Effects of Climate Change

a summary of three regional assessments

UNITED NATIONS ENVIRONMENT PROGRAMME

UNEP

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The Potential Socio-Economic Effects of Climate Change

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UNITED NATIONS ENVIRONMENT PROGRAMME

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Executive Summary

This report summarises the major conclusions of three regional studies of the potential impact of climate change undertaken by national governments with the support of the United Nations Environment Programme (UNEP). The three studies were in Brazil, in Indonesia, Malaysia and Thailand and in Vietnam. Full details of the studies' results are given in their respective project reports.

The regional assessments adopted a variety of different approaches to assessing potential impacts. In Brazil the emphasis was on identification of the effects that can occur now as a result of the present variability of climate from year to year and season to season. Impacts from climatic variability are thus taken to be a useful analogue of potential future effects of longer-term climate change. In contrast the Indonesia/Malaysia/Thailand study took the current best estimate of possible future climate, using the results of experiments with General Circulation Models of the earth's atmosphere, and considered its economic implications by modelling effects on yields of agricultural crops, etc. The study in Vietnam adopted an approach somewhere between these two, assuming likely long-term changes in climate and describing (rather than modelling) their potential effects.

The study in Brazil is based on 14 regional assessments in the semi-arid Northeast, the industrialized Southeast and South and at the agricultural frontier of the Midwest. The most substantial effects of present-day variability of climate are due to drought, particularly in the Northeast where drought-induced falls in agricultural production cause hunger and malnutrition in peasant communities. Although such drought impacts are still severe, as for example most recently in 1983 and 1987 in the State of Ceará, there is a long experience of government response to the issue which can illuminate the potential range of measures for adapting to both short-term and long-term changes of climate. These include emergency relief actions such as make-work programmes (*frentes de emergência*) and efforts to strengthen the regional capacity to cope with droughts such as major public works (i.e. dams, roads and other aspects of rural infrastructure).

While droughts can have a massive social impact in semi-arid parts of northeast Brazil, dry spells in the Midwest, Southeast and South tend to reduce output and have an economic rather than social effect on the more developed economies of these regions. Ironically, however, their effect is greatest on the people of the Northeast owing to increased rural unemployment of immigrant workers from that region. The effects of floods are greatest in the South and Southeast, in both rural and urban areas. Frosts can cause substantial damage to the coffee and citrus industry here also.

The Brazilian case studies indicate that human actions have frequently led to increased vulnerability of society to climatic variability. The nature of the consequent effects of droughts, dry spells, floods and frosts therefore varies greatly from region to region according to the economic and social circumstances that prevail. Policies must be sensitive to these differences and seek to promote sustainable development as a secure means of reducing social vulnerability to climate.

The study in Indonesia/Malaysia/Thailand employed a hierarchy of models to simulate the possible effects of potential future climate change. Outputs from GCMs were used as inputs to models that simulate rice yield and water supply. Expert judgement was then used to assess the economic effects at the enterprise and regional levels, and policy exercises were devised bringing together scientists and policy makers to explore the range of appropriate responses by national governments.

An equivalent doubling of atmospheric CO_2, currently estimated to occur in about 2030 assuming current trends in emissions continue, is projected to lead to an increase in mean annual temperatures in the region of about 3-4°C by about 2050. Rainfall may increase in some areas but decrease in others and these patterns of change cannot at present be predicted with any confidence.

Increases in rainfall might occur over parts of Indonesia and be sufficient to compensate for higher rates of evaporation due to higher temperatures thus leading to an extension of the irrigable area for rice cultivation. However, even in these circumstances, water availability for crops might be reduced in the early part of the growing season leading to an overall reduction in yields of the major crops (rice, maize and soybean)

In addition, higher temperatures would tend to shorten the maturation period for these crops and increase their demand for irrigation. Studies in Malaysia thus concluded that yields of rice might decline by between 12 and 22 percent and the demand for rice irrigation increase by about 15 percent.

If sea levels were to rise by 10 to 30 cm, the current best estimate by 2030, extensive damage could occur to the fish and prawn industry throughout South-East Asia. In Vietnam, as well as in Indonesia, Malaysia and Thailand, mangrove forests, which are an important breeding ground for fish, could be threatened particularly where these are now backed by a bund that would prevent landward migration. Some low-lying parts of coastal areas could become permanent swamps or lakes due to a rise of the near-coastal water table and it is possible that the rise in groundwater would be accompanied by the upward movement of subterranean salt resulting in saline damage to rice fields and farmland soils.

An additional complication in South-East Asia is the effect that the El Niño Southern Oscillation (ENSO) phenomenon can have on offshore fisheries in the region. Off the Vietnamese coast in ENSO years there occurs a substantial geographical displacement of areas of upwelling and down welling of waters causing a shift of the productive fishery areas.

A conclusion that emerges from these studies is that, while we cannot yet predict with sufficient precision the nature of likely future changes of climate, we can begin to explore the range of potentially useful measures of response that governments could adopt to mitigate the negative effects of climate change and exploit the more positive ones.

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Introduction

The scope of this report

In 1985 a meeting of scientists at Villach in Austria recommended that priority should be given to regional-scale studies of the impact of climate changes that could result from the emission of greenhouse gases (WMO, 1986). As a consequence of this, a number of research projects were established by the World Climate Impacts and Responses Programme which is supported and managed by the United Nations Environment Programme (UNEP). These projects have now been completed for three regions: in Brazil, in Indonesia, Malaysia and Thailand and in Vietnam. Their conclusions have been reported in full elsewhere (Magalhães and Neto, 1989; Parry, et al., 1991; Ninh, et al., 1991).

The purpose of this report is to summarize the major conclusions of these studies. In order to be intelligible to the non-specialist, technical details have been kept to a minimum. These will be found in the full reports referred to above.

The current assessment of possible changes of climate

Our current 'best estimate', based on the judgement of the Intergovernmental Panel on Climate Change (IPCC) which reported in 1990, is that, if emissions of greenhouse gases (GHG) continue to grow as currently projected (a so-called 'Business-as-Usual' scenario), then global mean temperatures will increase by 0.2°C–0.4°C per decade over the next century (IPCC, 1990). There is a quite clear indication that a warming of the globe has occurred over the past century, amounting to 0.3°C–0.6°C. Much of this warming has been concentrated in two periods, between about 1920 and 1940 and since 1975; the six warmest years on record have all been in the 1980s. The size of this warming is broadly consistent with the predictions of climate models but, because of the natural variability of the Earth's climate, scientists are not yet able to say that they have detected the unequivocal 'signal' of man-made climate change. There is some agreement, however, on the broad directions of possible future changes.

Warming in high latitudes

There is relatively strong agreement that greenhouse gas-induced warming will be greater at higher latitudes. This would reduce current temperature constraints on agriculture and forestry particularly in northern parts of North America, Europe and Asia. Soil and terrain constraints imply, however, that such gains in potential at high latitudes will do little to compensate for quite possibly substantial negative effects of climate change in mid- and low latitudes.

Poleward advance of monsoon rainfall

In a warmer world monsoon rains would be likely to penetrate further poleward, both in Africa and Asia, as result of an enhanced ocean-continent pressure gradient (itself the result of more rapid warming of the land than the ocean in the pre-monsoon season). If this were to occur—and it should be emphasized that there remains much uncertainty here—then total rainfall could increase in currently drought-prone regions such as the Sahel and north-west India. It is possible, however, that the increase in rainfall would come largely in the form of more intensive rainstorms occurring over a shorter rainy period. If current levels of pre-monsoon

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rains, which are important for the germination of crops at the beginning of the growing season, were to diminish then growing seasons could be shortened and thus the potential for agriculture reduced. In addition, more intense rainfall could exacerbate problems of flooding and soil erosion.

Reduced crop-water availability

Probably the most important consequences of projected changes in climate would stem from higher actual evapotranspiration, primarily as a result of higher temperatures of the air and land surface. Even in the tropics, where temperature increases are expected to be smaller than elsewhere, the increased rate of moisture loss from plants and soil would be considerable. It may be somewhat reduced by greater humidity and increased cloudiness during rainy seasons, but could be more pronounced in dry seasons. The implications of these potential changes of climate are considered in the three regional assessments summarized in this report.

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1 Brazil

There are three broadly different ways of studying the impacts of possible future climate changes. Firstly, one can develop climatic and socioeconomic scenarios of the future, studying the effects of increases in the concentration of atmospheric carbon dioxide (CO_2) in General Circulation Models (GCMs) to simulate how the Earth's climate might respond to increases in greenhouse gases (GHGs). Secondly, one may consider past greenhouse-gas enhanced climates and analyse the effects of these 'palaeoclimates' on their terrestrial environment. Thirdly, one may use present-day climatic variations and their effects as an analogue of the potential effects of future climate change. This third alternative assumes that, if there is a change in average climate in the future, the pattern of year-to-year or season-to-season climatic variability will be essentially the same as today. There will be droughts and floods in the future, although they may be more or less frequent. Studying the effects of present-day climatic variability, especially of extreme events such as drought and floods, may thus provide a useful indication of what may happen in the future. Also, studying past and present societal and governmental responses to climate variability may provide useful lessons to prepare society to cope with possible future changes.

There is another reason for studying present climatic variability. In many countries of the world, and in the developing countries in particular, climatic variability is a major present-day problem. Droughts in Northeast Brazil and in the Sahel, and floods in Bangladesh and in China are a major current cause of concern for humanity because of the immense economic losses and human suffering they bring. Improvement of our knowledge of these phenomena and how we can best respond to them should be a priority in itself.

This report is part of a worldwide effort supported by UNEP aimed at improving knowledge of the impacts of climate variability and change on society and on the environment. In 1988, UNEP and the Government of the State of Ceará provided cooperative support to undertake a comprehensive project on Socioeconomic Impacts of Climatic Variations and Policy Responses in Brazil. Fourteen case studies were undertaken by twenty eight researchers, comprising four Brazilian regions: the semi-arid Northeast, the industrialized Southeast and South and the agricultural frontier of the Midwest. The Northern region (the Amazon) was not included because it had been the object of a specific UNEP project for the Latin American humid tropics. The selected case studies assessed several types of socioeconomic impacts that might result from climate change. They aimed at improving the understanding of the impact of climatic variability on the Brazilian economy and environment, to evaluate possible responses to mitigate its adverse effects and to encourage application of this information in government policy.

The Case Studies

The UNEP/SEPLAN-CE Project is a benchmark in climate impacts research in Brazil. For the first time, a group of academic personnel and experts working in different regions joined as an interdisciplinary team to study how society and the economy react to a variety of adverse climatic events. Titles and authors of case studies are listed in Appendix 1, and the location of the studies is given in Figure 1.

Table 1 Regions of Brazil: percentage of area and population

Region	%Area	% Population
North (Amazon)	45.2	5.9
Northeast	18.2	28.5
Southeast	10.9	43.6
South	6.8	15.2
Midwest	18.9	6.9
Brazil	100.0	100.0

Figure 1
The map on the right shows the location of study areas in Brazil

The studies covered a little less than half the area of Brazil, but almost 90 percent of its population (Table 1, above). Several case studies dealt with the problems of droughts, especially in the Northeast region. Droughts here are a major problem, because 60 percent of the Northeast is semi-arid and because the region is largely overpopulated and under-developed. Floods are a phenomenon that is present in all regions, but they are particularly serious in the South and in the Southeast where they have caused serious damage in the two largest cities of Brazil, São Paulo and Rio de Janeiro. In the Southeast and South, extreme low temperatures (i.e. frosts) can cause serious losses in agriculture, particularly in fruit and vegetable farming. This was studied in the state of Sao Paulo and elsewhere.

Impacts from Drought

In the semi-arid Northeast, droughts are responsible for sharp drops in agricultural production, followed by mass unemployment in the agricultural sector. Since agriculture is a major source of employment, the social impact of drought is very great. This is enhanced by the fact that the majority of the population is very poor and the regional economy provides few rural employment alternatives to agriculture. While droughts have been traditionally associated with the problem of poverty in the Northeast the studies show that droughts do not create poverty. Social and economic consequences of droughts are mainly explained by local factors such as social organization, education and technological level as much as by variations of weather.

Traditional agriculture in the Northeast is characteristically vulnerable to droughts. Falls in agricultural production resulting from irregular rainy seasons induce rural unemployment and migration to urban centres. Some migrants are absorbed into low-productivity branches of the services sector (e.g. transport, street cleaning) but, depending on the type and dimension of government relief action, a great part of the affected population will remain in the rural area to obtain temporary occupation in government public work programs or 'work fronts' (*frentes de emergência*).

One of the aims of work fronts is to establish a monetary flow in the rural economy during the drought period. This enables the tertiary sector to expand through the sales of food and other consumption goods and state revenues can thus expand through the tax system. If drought occurs during a period of expansion of the national economy, the flow of federal transfers to finance the work fronts may increase and inject money into the regional economy, offsetting the drop in agricultural production. If, however, the national economy is shrinking and the Federal Government is facing budget difficulties, than the monetization of the economy may not be sufficient to offset the fall in agricultural production and the resulting impacts of droughts may consequently be heavier.

Falls in agricultural production are associated with hunger and malnutrition in peasant communities. Brain damage in infant population is the most serious consequence. Infectious diseases stressed by malnutrition rank as the most frequent causes of mortality during droughts. The study of a time series for 30 municipalities in Brazil for the period 1977/84 (of which 1979/83 were drought years) showed a trend in decreasing infant mortality in the first three years of drought and an increase from the fourth year onwards. It may be that during the initial years of drought the relief actions are sufficient to offset its most adverse effects. But, as the drought deepens (as in 1983, and especially after a run of dry years), the adverse effects of droughts become severe. If more frequent extreme droughts were to occur as a result of long-term changes of climate, the impact on the rural poor would probably be greatly increased.

In the Northeast there is a one-hundred-year history of governmental response to droughts. Many public works have been built, including roads and other forms of rural infrastructure. The main objective of these responses has been centred on the creation of temporary jobs in the work fronts, in order to provide a means of survival for workers displaced from agriculture. During the droughts of the 1980s the traditionally passive behaviour of the rural population towards the relief actions started to give way to the participation of organized communities, and led to different patterns of social pressure—traditionally exerted only by the large land owners—and political legitimation. In the last two decades, action by the Catholic Church and by political parties has altered the reaction of the poor rural population to droughts. They are beginning to be considered a challenge to be faced, not a tragedy to be suffered; and the quality of government response to drought is now being questioned. For example, since droughts are recurrent and inevitable, responses should include both relief emergency actions and the long-term strengthening of the regional capacity to cope with droughts.

The Northeast of Brazil can also suffer from droughts that occur outside its borders. For example, 93 percent of the power supply in the Northeast comes from the São Francisco River, whose headwaters are in Minas Gerais. Drought occurred in Minas Gerais in 1986, reducing the water flow of the São Francisco River to 55 percent of its average value. This affected the production of hydroelectricity and caused power rationing of 10–15 percent in several Northeast states during most of 1987. As a consequence, households experienced cuts in electricity consumption and there was a decrease in household expenditures, while industry experienced a fall in production and employment.

Impacts from Dry Spells

Unlike the long droughts of the Northeast, with their substantial social effects, the impact of shorter dry spells in the Midwest are primarily economic rather than social. Dry spells occur every year in this highly fertile agricultural region and last from one to three or four weeks during the plant growing season. In some years, they cause substantial losses in yield and in production with the greatest losses being in rice and to a lesser extent in maize (corn). The reduction in agricultural production is less a consequence of the total number of days lacking rainfall in a given rainy season than of the number of successive days without rain, particularly if the dry spell lasts for seven days or more. Any change in the frequency and duration of dry spells as a result of greenhouse gas-induced changes of climate could thus have a marked effect on output in the midwest of Brazil.

In the case of the Pantanal (Great Swamp) region of the Mato Grosso state, in the Midwest region, droughts bring benefits, favouring the growth of grass and the livestock activity.

In the Southeast and South where agriculture is highly productive and capitalized, dry spells are usually associated with falls in yield and production but are not generally a cause of social dislocation as in the Northeast. However, a great part of the farm labour force in the Southeast is made up of immigrants from the Northeast that live in the cities and travel each day to the farms. Unemployment amongst these workers tends to increase in the case of droughts in this region.

In general, it may be that sensitivity to dry spells and droughts is increasing. In the state of São Paulo, statistical models applied to seven leading agricultural products (cotton, rice, coffee, sugar cane, citrus, corn and soybeans), for a 30-year time series of weather data (1957/86) showed that agriculture is highly sensitive to variations in water supply. New technology and increasing productivity have caused an increase in water requirements and any shortfall in moisture has a greater impact today than it did in the past.

Impacts from Flood

While floods are generally a cause of damage in both rural and urban areas in Brazil, in the Pantanal region of the Mato Grosso they play an important role in weed control and in restoring the productive capacity of land. The occurrence of floods and droughts are part of the environmental equilibrium of this region, but this is currently threatened by forest removal and soil erosion which affect livestock and agricultural production. Climatic variability is not an adverse factor here, but unplanned and uncontrolled settlement is.

The effects of floods are generally more short-lived than those of droughts. Some agricultural production is feasible when flood levels fall and water returns to normal levels. Thus, the impacts of floods on society and on the economy in the Northeast are less intense than those of droughts, but frequently they are more evident and cause substantial hardship. In the South and Southeast regions floods are generally less serious a problem, but the largest Brazilian urban centres are located in the Southeast, and the impacts of flooding can be substantial because of the high densities of population and economic activity. To illustrate, in Rio de Janeiro in February 1988 rainfall over 24 hours was equivalent to 3 months of normal precipitation. About 300 people died, 1,000 were injured and thousands were homeless. Economic losses were estimated at US$1000 million.

Impacts from Frost

Even in the South and Southeast regions, where freezing temperatures can result in economic loss, crops are more sensitive to variations in the amount of available water than to variations of temperature. Frosts are however very important in the case of some crops, such as coffee and citrus, both of which are important in the Brazilian economy. Some extreme frosts, such as the one in 1975 in the state of Paraná, caused an almost total loss of production and led to the migration of coffee cultivation to less frost prone areas such as the state of Minas Gerais.

Citrus production is evidently less sensitive to frosts in Brazil than in Florida. It is closely associated with the food processing sector, which has provided support for research leading to the development of new varieties more resistant to low temperature variations. As a result, citrus production is more sensitive now to export prices than to local climate variability, but it is still strongly affected by climatic variability because frosts in Florida can affect export prices and thus influence the buoyancy of citrus production in Brazil.

Lessons from Experience

The research summarised here indicates that different kinds of climatic variability can have a substantial impact on society, the economy and the environment. Each year, much human suffering has been caused by climatic hazards in Brazil and billions of dollars have been lost. Current climatic variability is therefore a very important issue in Brazil and should be a cause of much more policy concern than it has been up to now. Improved knowledge of how climate can affect different regions, activities and social groups, and how society and government have reacted to the impacts of adverse climatic events, can be used to help formulate policies to reduce the adverse effects of present-day climatic extremes and can also help in the design of responses to possible future changes of climate.

The Brazil study concludes that human actions have inadvertently led to increased societal vulnerability to climate variations. Deforestation in the Northeast has made the semi-arid region more vulnerable to droughts. Inadequate urban planning in Rio de Janeiro has made the city much more vulnerable to floods. Deforestation in the Upper Paraguay River Basin may be altering the pattern of floods and droughts in the Pantanal (Great Swamp) region, thus contributing to ecological imbalance.

On the other hand, some action has been taken to increase resilience to climate variations. The modernization of the salt industry in the state of Rio Grande do Norte has made that industry more resistant to heavy rains. Agricultural research has led to the development of several new crop varieties more resistant to climate variability. Relief action in Northeast Brazil has contributed to reduce the very heavy impacts of droughts on the poor rural population.

It is clear that the same climatic event may have different impacts according to local socio-economic and environmental characteristics. Rainfall that brings terrible floods to Rio de Janeiro is a beneficial event in the Pantanal area. Drought may cause huge losses to agriculture in the Northeast but can also bring economic benefits for the salt industry in the same region. Moreover, while the majority of the poor population will suffer from droughts, a small group of large land owners and businessmen may indeed profit from them. Climatic variations can thus have differing effects on different regions, ecosystems, economies and social classes.

Government policy needs to integrate short-term relief actions during extreme climatic events with long-term actions aimed at increasing societal resilience to climate variability and change. It also needs to pursue a goal of sustainable development, by seeking to increase the technological capacity of people to face climatic extremes, reduce the social impacts of the weather, reduce poverty (since the poor are the most vulnerable) and improve our knowledge and thus increase our capacity to accommodate adverse variations of climate. A policy of sustainable development would pursue both a reduction in greenhouse gases emissions and an improvement in the capacity of the environment to adapt to possible future climate changes. To achieve this will require international cooperation to enable the transfer of resources and technology that will allow developing countries to use the most environmentally appropriate available technologies in their development process.

2 Indonesia, Malaysia and Thailand

Of the three broad types of impact assessment considered in this report (scenario-based, analogue and sensitivity study) the scenario-based assessments are ultimately those which, when linked with sufficiently accurate predictions of climate change, will be most useful for policy development. A small number of preliminary scenario-based assessments, using the outputs of General Circulation Models, have been completed but these have all been based in developed economies and have mainly been in northern midlatitude countries. The purpose of this study was: a) to generate estimates of potential impacts in a form likely to be of use to policy-makers; and b) to test our capability for assessing impacts in tropical developing economies using available information from General Circulation Models (GCMs).

Three countries were chosen for study: Indonesia, Malaysia and Thailand. National study teams were selected from scientists in national meteorological offices, environmental agencies, agricultural research institutes and local universities. In order to develop usable impact estimates policy-makers were involved both in the design and implementation of the study.

In this report a summary is given of the methods and models used in the study, the possible physical and economic impacts that may stem from continued emissions of greenhouse gases, and the array of policy responses that may be appropriate. Details of the study's conclusions may be found in the full report (see Appendix 2).

Methods

The study was intended to be a partially integrated assessment of the regional impacts of possible future climate change. A fully integrated assessment would consider impacts at a number of different levels (e.g. the biophysical level, the level of farms and corporations and the national level). But such assessments are not possible until the full complement of systems models are available. The partially integrated approach adopted here has the following characteristics:

- outputs from GCMs are used to characterise possible future climates;
- models of first order relationships are used to estimate effects of climate change at the biophysical level (e.g. on runoff, on crop yields);
- expert judgement is employed to assess economic effects at the enterprise and regional levels;
- technical adjustments and policy responses are considered by using policy exercises to explore means of reducing negative impacts and exploiting positive ones.

The development of climatic scenarios

The study considered the effect of an equivalent doubling of atmospheric CO_2 on the climate of the region (a '2 x CO_2' climate scenario). In order to characterise this climate, outputs from experiments with three GCMs were applied to the baseline (current) climate (1951–75). The projected climate change is shown in Figures 2.1 and 2.2. These illustrate that, while no major changes are predicted in either the timing or other main features of the monsoon rains in the region, there may be significant changes in the amount of rainfall.

A second important feature is that all three models predict a warming in all months, although the average increase is 3–4°C. Since there may be over-estimation of such temperature increases, these estimates can be used as an upper limit when studying the potential effects on food production and water resources. One important implication of the projected temperature increases is the shortening of the growing period for crops with consequent reductions in potential yield.

A third feature of the 2 x CO_2 climatic scenario is that we cannot yet say what changes may occur in the day-to-day or year-to-year variability of climate. At present we must assume that current variability remains unaltered, and simply apply the changes in mean temperature, rainfall and radiation to the existing distribution of, for example, dry years and wet years.

Sea level scenarios

The most recent prediction, based on analyses for the Intergovernmental Panel on Climate Change (IPCC) and assuming the continuation of current trends in greenhouse gas emissions, is a global sea level rise of 20 cm by 2030 and 60 cm by 2090, with considerable regional variation. Even if GHG emissions were halted by the year 2030, global sea level would continue to rise to 40 cm by 2100, levelling off a century or so later. Given the uncertainties, and since topographic surveys do not enable the study of effects of sea-level rises of less than one metre, the scenario of a one-metre sea-level rise (highest high tide) is adopted in this report.

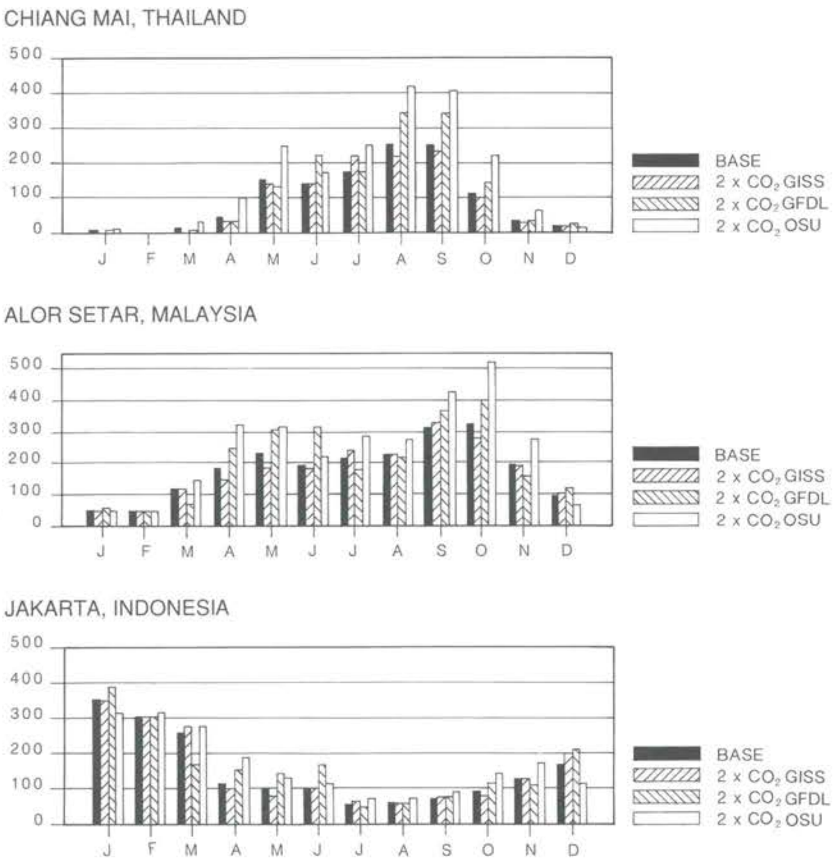

Figure 2.1
Changes in mean monthly rainfall in Southeast Asia under '2 x CO_2' climate scenarios projected by three General Circulation Models.
GISS = Goddard Institute for Space Studies.
GFDL = Goddard Fluid Dynamics Laboratory.
OSU = Oregon State University.
Base = Current climate (1951–75).

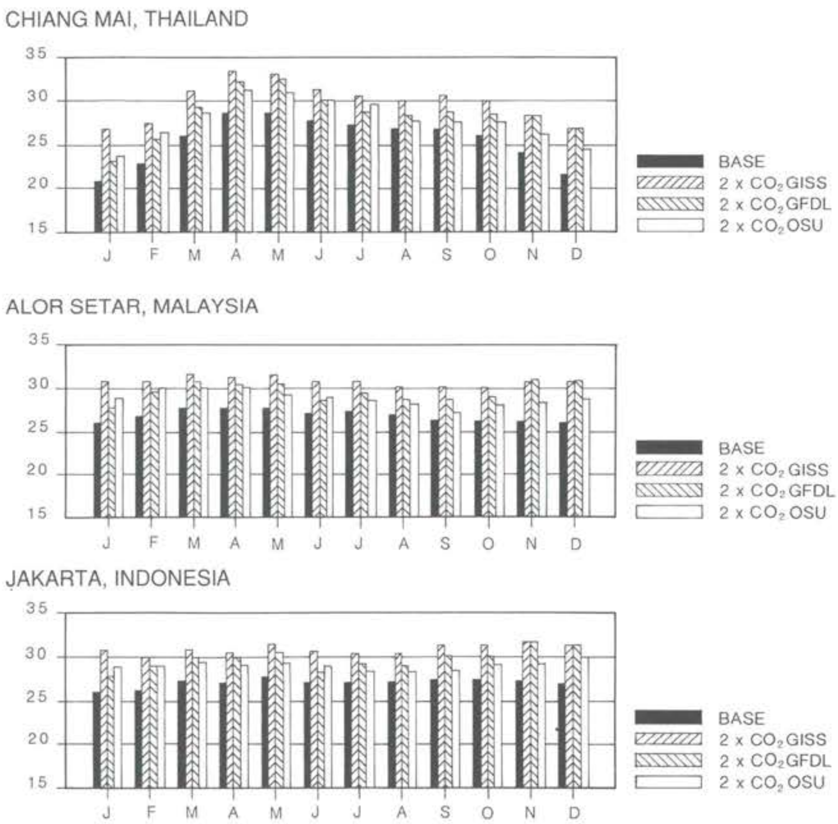

Figure 2.2
Changes in mean monthly temperature in Southeast Asia under '2 x CO_2' climate scenarios projected by three General Circulation Models.
GISS = Goddard Institute for Space Studies.
GFDL = Goddard Fluid Dynamics Laboratory.
OSU = Oregon State University.
Base = Current climate (1951–75).

Impact models

Two types of impact model were used to estimate the consequences of an altered climate in South-East Asia: models of the responses of crop growth, and models of runoff and soil erosion. Models of crop growth were run for three crops: rice, soya and maize. These were CERES or CERES-type models which require daily weather input for precipitation, maximum temperature, minimum temperature and solar radiation. Descriptions of the models are given in the full report.

The SWRRB Water model was used to estimate changes in runoff and soil erosion that might result from changes in climate. Since levels of runoff can affect the accumulation of water in reservoirs, the SWRRB model enabled an estimation to be made of changes in the amount of stored water available for rice irrigation.

Impacts in Indonesia

In Indonesia the projected warming under a 2 x CO^2 climate is estimated to lead to an increase in mean annual temperatures of about 3°C and a rise in average sea level of about 0.6 m Rainfall could decrease in some regions but might generally increase and, according to the Goddard Institute for Space Studies (GISS) 2 x CO_2 experiment, could double in some areas such as south-eastern Indonesia. Such changes in rainfall would be likely to have substantial effects on the amount of water available for irrigation (which might increase and therefore be beneficial), and on rates of soil erosion and soil leaching (which would generally be adverse in their effects on agriculture).

Considering effects on water supply, the estimated increases in rainfall would probably more than compensate for increasing evaporation due to higher temperatures and there would be more water to fill the reservoirs. There could, therefore, be a 30 percent increase in the irrigation area of the Brantas and Citarum Basins in the western part of Java. In the Saddan Basin the area of potential irrigation could increase by 130 percent. However, higher levels of rainfall are likely to increase the rate of soil erosion. Experiments with the SWRRB model for changes in rainfall and temperature projected under the GISS 2xCO_2 scenario indicate that erosion rates in the Citarum, Brantas and Saddan watersheds could increase by 14, 18 and about 40 percent respectively. The increase in erosion would result in losses of over 2000 tonnes in soybean production in the upper Citarum River Basin, 2500 tonnes in the Brantas Basin and 2700 tonnes in the Saddan River Basin. Levels of soil fertility would likely be diminished by higher rates of leaching of soluble nutrients, and the study concludes that average fertility levels could decline by 2 to 8 percent.

Rice yields are expected to decrease largely as a result of higher temperatures and, in some instances, reduced water availability. Largest losses would be in early season rice, but overall annual yield losses could be mitigated by increases in late season rice with the consequent average annual yield loss being about 4 percent.

Soybean, an important part of the diet for about three quarters of the Indonesian population, could frequently suffer a yield loss of over 10 percent, largely as a result of lower yields in the early season. If a decrease in insolation occurred, then further reductions in yield could not be avoided, but with appropriate management these potential losses could be compensated by increases in productivity, and overall yields could be expected to increase.

The most severe impacts could be expected on maize, where model experiments with the GISS 2 x CO_2 climate scenario indicate reductions in yield of between 25 and 65 percent. Improved management could mitigate these effects and keep the maximum decline to 50 percent.

Additional adverse effects on agriculture are estimated to occur as a result of land losses due to sea-level rise. For example, in the districts of Krawang and Subang 95 percent of the reduction in local rice supply (down 300 000 tonnes) is estimated to occur as a result of inundation of the coastal zone. In the same districts maize output would be reduced by 10 000 tonnes, about half of this due to inundation. Sea-level rise would also be likely to affect fish and prawn production. In the Krawang and Subang Districts the loss is estimated at over 7000 tonnes and 4000 tonnes respectively (valued at over US$0.5m). In the lower Citarum Basin sea-level rise could result in the inundation of about 26 000 ha of ponds and 10 000 ha of crop land. This could result in the loss of 15 000 tonnes of fish, shrimp and prawns and about 940 000 tonnes of rice.

The overall effect would be to reduce potential average income. The estimated reductions of yield would cost the rice farmer US$10.50 to US$17.30 annually, the soybean farmer US$22.0 to US$72.00 and the maize (corn) farmer US$25.50 to US$130.00 annually. It is estimated that the decrease in yield would cause, in the Subang District alone, about 43 000 farm labourers to loose their jobs. In addition more than 81 000 farmers would have to look for other sources of income due to the inundation of their rice fields or prawn and fish farms due to sea-level rise.

Impacts in Malaysia

In Malaysia the projected warming under the GISS 2 x CO_2 climate is equivalent to about a 3–4°C increase in mean annual temperature.There is no significant change in the seasonal pattern of rainfall, but increases in rainfall are projected, firstly, for the coastal regions of Sarawak in January and February, and secondly for southwestern Peninsular Malaysia in the intermonsoon period during March, April and May. Absolute levels of air humidity are projected to increase owing to higher rates of evaporation but, since air temperatures are also higher, relative humidity is not expected to alter greatly. No information is available concerning possible changes in the daily, seasonal and annual variability of climate.

Three sectors were chosen for the study of potential impacts from changes in climate, namely agriculture, water resources and coastal. For the agricultural sector, the production of rice, maize, oil palm and rubber were studied.

Potential impacts on rice production were studied in the region of Muda in the coastal plain of Kedah and Perlis, this being the largest rice growing area in Malaysia (126 000 ha producing 700 000 tonnes annually from two crops a year). The CERES Rice Model was run for current climate for 17 years (1968–84) and for the GISS 2 x CO_2 climate for 17 years. Under the altered climate the maturation period for rice is shortened by several days, with consequent reductions in yield from 12 to 22 percent and with the largest reductions in the main-season crop. Under the higher temperatures the increased demand for irrigation is 15 percent.

The study concluded that the implied reductions in rice yield would significantly affect levels of farm income. Since farms in the area are already small (averaging 1.4 ha), farmers might be forced to seek alternative income sources with the poorest perhaps relinquishing their land and average farm size increasing as a result. In general, levels of rural poverty might be expected to increase.

Although it is not easy to generalise at the national level from the Muda study, it does appear that there would occur a nationwide increase in the demand for irrigation for rice, that water would be limited as a consequence and that the practice of growing rice two times a year would need to be limited to a much smaller area than today. The effect on national rice output could be substantial. The study concludes that Malaysia's production, which currently satisfies about 60 per cent of demand, might be reduced to less than 50 percent.

The potential effects of the projected changes in climate on yields of maize were examined in the Serdang region. The crop is not significantly sensitive to small increases in temperature and rainfall, but is more substantially affected by changes in solar radiation. A 10 percent decrease in radiation causes a reduction of total biomass production by as much as 20 percent.

Increases in rainfall in the months of March, April and May could increase oil palm productivity in the alluvial coastal areas of Malaysia provided that solar radiation remains unaltered. But exceptionally high rainfall could limit yields unless soil drainage was improved. Overall, the study concludes that oil palm yields on alluvial soils would not be substantially altered under the projected changes of climate, but these conclusions are not applicable to oil palm plantations in inland regions of sedimentary soils.

Assuming an increase in mean annual temperature by 2°C and in rainfall by 10 percent, the east coast of Peninsular Malaysia may become too wet for rubber cultivation, with rainfall interfering excessively with tapping; and regions which are currently near the dry margins of current rubber production may become too dry. Overall, the study concludes that potential yield levels might, as a national average, be reduced by about 15 percent, but that improved clones could more than compensate for this by enabling a 25 to 50 percent yield increase. At present total rubber production is valued at M$3.6 billion. The potential effect due to climate-related yield reductions could amount to a quarter of this. The impacts are likely to be most strongly felt by rubber smallholders. There is already a trend toward smallholders selling out to larger estates, with consequent outmigration to urban areas. Climate change would be likely to aggravate this problem.

The possible effects of climate change on water resources was studied in the Kelantan River Basin in the northeast corner of Peninsular Malaysia. Under the higher levels of rainfall projected under the GISS 2 x CO_2 scenario and assuming current patterns of rainfall variability, the frequency of occurrences of peak discharge increases by 9 percent, implying more flood damage and a 5 percent increase in the size of the flood-affected population. In contrast, higher rates of evaporation would lead to approximately a one-third increase in water deficit in the dry season, resulting in shortage of water for irrigation, reduction of rice yields and a reduction of the cultivable area for rice.

The effects of sea-level rise could also be severe. Much of Malaysia is characterised by low lying coastal plain. In these areas topographical surveys have indicated that a 1 m rise in mean sea level would, on average, lead to a landward retreat of shoreline of about 2.5 km. This implies substantial losses of agriculturally productive land, of mangrove forests and of the fisheries associated with mangroves.

Impacts in Thailand

In Thailand the warming under the GISS 2 x CO_2 climate is equivalent to a 3°C to 6°C increase in current mean annual temperature, a projection that is broadly in agreement with other GCMs. There are, however, substantial differences between GCMs concerning changes in precipitation, which vary widely from normal but generally show a reduction under the GISS 2 x CO_2 scenario. Northern Thailand may be drier in most of the months except in July which is currently a dry period and this would appear to benefit cropping. However, August and September would experience only between 73 percent and 89 percent of present rainfall. Other GCMs however do not indicate such a reduction in rainfall and it is important to emphasise this uncertainty. Under the GISS 2 x CO_2 scenario winters are also drier but as very little rain is normally expected during that time of year the adverse implications may be less.

Two particular aspects of the Thai economy were studied with respect to potential impacts from these projected changes in climate: effects on rice production in Ayuthaya Province and effects of sea-level rise in Suratthani Province.

The CERES model was run for a 25-year set of daily climate variables (1964–1988). Model outputs for the current climate substantially exceeded observed values for transplanted rice and were lower than expected for yields of direct seeded rice. It was not possible, however, to conduct an adequate validation of the model and to re-tune it to observed data for Thailand. As a consequence, the results should be treated with caution.

The results indicate that under a change of climate projected for a doubling of CO_2 main crop rice cultivation in Ayuthaya Province would increase in the order of 8 percent. These benefits would however be, in most cases, quite marginal because they are substantially less than the existing year-to-year variation. The modelled yields were also characterised by marginally greater yield variations. Off season rice, planted from mid-December to early February, exhibits a 5 percent increase in average yield under the GISS 2 x CO_2 climate with concurrent increases in variation of 3–40 percent. However, little value can be placed on these results because of lack of model validation. Indeed, the results are not consistent with those for Chiang Mai which were validated against observed data, and which indicate a decrease in rice yield of about 5 percent under the GISS 2 x CO_2 scenario.

Thailand has approximately 2940km of coastline, much of which contains important economic activities such as shrimp farming and rice farming. The study considered the potential impact of a 0.5 m and 1 m rise of sea levels in the Suratthani Province in southern Thailand. This region is characterised by a sand dune line which may mark an ancient shoreline and has a consistent elevation about 1m above present sea level. It was therefore used as an indicative boundary to the area potentially affected by a 1m sea-level rise. The suggestion is that 7400 ha (37 percent) of the study area would be affected by inundation under a 1 m sea-level rise. About 4200 ha of productive agricultural land and large numbers of shrimp ponds would be lost.

The Effects of Sea–Level Rise

An integrated survey was made of the potential effects of sea-level rise on coastlines of Thailand, Malaysia and Indonesia. In general all three countries have a high proportion of coastal plains both sandy and swampy that would be physically and ecologically sensitive to sea-level rise. The issue may have particular importance because some of the coasts of South-East Asia are at present characterised by land subsidence which may be contributing to a more frequent occurrence of flooding, for example in the Bangkok region and in the coastal suburbs of Jakarta.

Where the coastal zone is characterised by steep and cliffed coasts they will tend to be undercut to form basal cliffs and slumping will become more frequent on the vegetative slopes. Receding cliffs are already a characteristic of the more exposed shores of promontories and islands especially those washed by ocean swell and waves generated by the SW monsoon as on the Andaman sea coast of Thailand and in south-west Sumatra.

On sandy beach coasts sea-level rise would tend to initiate beach erosion, or accelerate it where it is already taking place. In general, submergence will result initially in the deepening of near shore water so that larger waves break upon the shore, thus increasing erosion. It should be emphasised that it is not possible to predict the location of a sandy coastline in the next century if sea level has risen 1m but it is likely that most sandy coastlines will have retreated and that they will be eroding. Beach resorts and tourist facilities that have been developed extensively on low lying coasts in South-East Asia will be threatened (e.g. on Bali in Indonesia, at Port Dickson, Penang and Kuala Trengganu in Malaysia and at Pattaya and Rayong in Thailand). Structural work such as concrete sea walls and boulder ramparts will be necessary to protect developed seaside land, but such structures usually result in wave reflection which depletes the beaches that were the original tourist attraction. Artificial beach renourishment is an expensive alternative (about $3m/km) and may only be feasible in intensively urban resort areas such as Pattaya in Thailand, the north coast of Penang in Malaysia and the resort beaches on Bali.

There are large areas of swampy lowland on the coasts of South-East Asia, especially on the shores of the deltas built where large rivers have delivered vast amounts of silt and clay to prograde the coast. These are very extensive on the north-east coast of Sumatra and the south coast of Irian Jaya. Sedimentation from rivers is still prograding deltaic areas. Such deposition will accelerate if rainfall and runoff from the river catchments is augmented as a consequence of global warming. However, a rising sea level will tend to curb the growth of deltas and if the rate of submergence is greater than the rate of deposition, their shorelines will be cut back. Examples of this can already be seen on parts of subsiding delta coastlines which are receding because of a diminished fluvial sediment supply to the river mouth. On the north coast of Java some river mouths have changed naturally, during episodes of flooding, to a new outlet for subsequent delta growth. The outcome has been rapid erosion of the abandoned delta lobes.

The natural vegetation associated with the coastal lowlands of South-East Asia is mangrove swamp, backed by marshes and areas of freshwater forest, but in many areas this vegetation has been profoundly modified by human activities, notably drainage and land reclamation. In the three countries studied mangroves occupy a total of about 40 000 km^2. They grow in the upper part of the inter-tidal area, usually near mean tide line. Mangroves have become extensive on these coasts during the past 6000 years when sea level has remained constant. Prior to this there was a phase of rising sea level beginning about 18 000 years ago. The projected future sea-level rise could reverse this sequence, reducing and removing mangroves from the more exposed areas and confining them to inlets and estuaries where continuing muddy sedimentation, keeping pace with the rising sea, might allow them to survive. Under natural conditions mangroves are backed by low lying, estuarine and alluvial land which could be displaced if the rising sea drove the mangrove zone landward. However, over much of South-East Asia the hinterland has been reclaimed for agriculture, usually rice farming or plantations producing rubber, palm oil or coconut; and embankments (bunds) have been built at the inner margin of mangroves. Where there is a bund at the rear of the mangroves delimiting the present high tide limit, attempts would need to be made to maintain it as sea-level rises and to enlarge it to prevent wave overtopping and marine flooding. If this happens the retreating mangrove fringe will not be able to colonize the developed hinterland. It will become narrower and in many places will disappear altogether as the inter-tidal zone narrows and steepens. The coastline will thus become more artificial.

Extensive areas of mangroves have also been converted to ponds for the production of fish or prawns. The simplest ponds (traditional for many centuries on the north coast of Java) are located in banked areas with sluices to prevent the gravitational inflow and outflow of sea water and the entry of fish and prawn fry. In recent decades fish and prawn ponds have become more elaborate, especially in Thailand and Malaysia, with pumping systems to maintain a sea-water supply and the use of aerators, breeding techniques and fertilisers to generate high productivity from intensive aquaculture. Where the mangrove area has been converted to aquaculture, the sea-level rise will threaten to breach the enclosing banks and submerge the fish and prawn ponds. If these ponds are to be maintained the enclosing walls and the floors will have to be raised to match the levels of the rising sea. Alternatively a protective sea wall may be built and pumping systems introduced to control the inflow and outflow of sea water.

In addition to these direct effects, marine submergence of coastal areas in South-East Asia will raise the water table so that some low lying parts of coastal plains will become permanent swamps or lakes. The salinity of these will depend upon the interaction between sea water incursion and any increase in rainfall and freshwater runoff. It is possible that the rise in groundwater will be accompanied by the upward movement of subterranean salt, resulting in saline damage to rice fields and farmland soils. It may be tempting in such conditions to convert these areas into brackish-water, fish and prawn ponds to replace those threatened or lost in the mangrove areas.

Coral reefs occupy about 150 000 km^2 within the East Asian seas, and there are fringing reefs around many headlands and high islands. A slowly rising sea level will stimulate the revival of coral growth on reef flats and these may maintain their level relative to the rising sea. Upward growth of existing corals is in the range of 4-7mm/year and thus may be able to keep place with rising sea levels. However, as indicated above, many coral reefs are already under various kinds of ecological stress, and some of the less vigorous may fail to revive, being permanently submerged as sea-level rises. Fringing reefs are less likely to survive than outlying reefs because of increasing turbidity in coastal waters as larger waves erode the beaches and the land behind them.

It will be evident that some environmental changes are already in progress on the coasts of South-East Asia, and that substantial modifications, both natural and man-made, would have occurred on these coasts during the coming century even if there were no global warming and sea-level rise. Coastal erosion is already extensive and likely to continue, and coastal environments will be changed by further urban and industrial development. The combination of such pressures, together with possible future sea-level rise due to global warming suggests a number of possible strategies:

- Adapt and evacuate: Under this strategy land lost to submergence and erosion would include large areas of currently productive coastal land, especially fish and prawn ponds. It would not be difficult to convert rice fields into fish and prawn ponds as sea-level rises, but who would bear the cost of resettlement and land transformation for rice farmers?

- Hold the coastline: It has been estimated that the raising and elaboration of coastal defences to counter a sea-level rise of 20 cm along approximately 250km of coastline would cost US$1 billion; for a 1m sea rise the cost would be US$10 million per kilometre. In these terms the cost of preventing sea incursion on 5000 km of low lying coastline in Thailand, Malaysia and Indonesia would total about US$50 billion.

- Counter attack: The cost of building sea walls and putting in drainage and pumping systems to manage the land margin as sea-level rises would be great, and it is difficult to envisage South-East Asian countries achieving this on a large scale without substantial international assistance. An alternative solution may be to construct sea walls offshore and reclaim the enclosed shallow areas for productive use. Where this is possible, the economic returns from the land gained could offset at least part of the cost of building sea walls and associated structures. The disadvantage of building sea walls along the coast or offshore is the associated reduction in the extent of mangrove swamps and tidal mudflats, with consequent losses in the productivity of fish and shellfish resources.

In the short term, over the next few decades, the wisest response to the predicted sea-level rise is likely to be a reorganization of coastal land use planning in low lying coastal areas, delimiting these areas in relation to predicted submergence and erosion. For example, it is unwise to develop new resorts within 200m of the present high tide line on beach-rich terrain unless plans allow for abandonment or relocation during the coming century. Aquaculture could be restructured towards intensive production from relatively small and concentrated areas which can be protected from submergence and erosion as sea-level rises and can be adapted to new tidal levels.

Policy Implications

The study included two workshops (in Malaysia and Indonesia) to consider the policy implications of the reported results. The workshops were designed to inform policy makers about the magnitude and characteristics of potential future climate change, to consider the range of possible response strategies to mitigate adverse impacts and to outline the need for future research.

The workshops were conducted as policy exercises, bringing together policymakers and their scientific advisors at the national government level and scientists who had worked on the study to generate the impact assessments. Five major types of policy response were considered at these exercises: economic (changes in existing tax structure, subsidies, pricing systems, etc.), technological (breeding new varieties, constructing dams and coastal protection structures), institutional (enhanced or distorted market mechanisms, formal government regulations, legal instruments), research needs (information required for formulating adequate response strategies), and monitoring (characteristic signs of change, both biological and socio-economic, that could provide the necessary early warning to ensure timely action).

3 Vietnam

The purpose of this study was to consider the effects of present day climatic variability on the natural environment and economy of Vietnam, and to evaluate the implications of possible long-term climate changes due to emissions of greenhouse gases.

The present day interannual variability of climate in Vietnam seems to be quite strongly related to the occurrence of the El Niño-Southern Oscillation (ENSO) phenomenon. In ENSO years the annual average temperatures tend to be similar to that of the long-term average, but in the years after ENSO average temperatures in winter and spring are generally lower than the average for those seasons. In ENSO years the number of storms is about 20 percent less than in non-ENSO years, but those storms that do occur tend to have an above normal intensity.

Meteorological observations over the past 30 years indicate that there has been a recent increase in annual rainfall in the north and a decrease in the south of Vietnam. Temperatures have tended to be higher in recent years in the south, with this warming trend being most noticeable in the summer months. There is no evidence to suggest that, although consistent with changes in climate that might result from greenhouse gas emissions, these recent variations are part of a longer term change in climate.

It is not yet understood how the climate of Vietnam could be affected by long-term global warming. However, most general circulation model experiments indicate an increase in the annual temperature of about 0.5–1.5°C for a doubling of atmospheric CO_2. Assuming the IPCC Business-as-Usual scenario, which indicates a climate response to doubling of equivalent atmospheric CO2 in about 2060, the rate of warming might be in the order of 0.1–0.2°C per decade. Rainfall might increase in the northern half of Vietnam owing to more northward penetration of the summer monsoon. Effective rainfall might decrease in the south due to higher rates of evaporation (estimated to be 5–10 percent higher). Available moisture is expected to decrease in summer throughout Vietnam, and decrease in winter in the south but perhaps increase in winter in the north where increases in rainfall may more than compensate for increased rates of evaporation. The number of droughts may increase especially in the south of Vietnam.

There is evidence that sea level in the region has increased by about 5 cm over the past 30 years. The current estimate (under the Business-as-Usual scenario of the IPCC) is that mean sea level may increase 10–30 cm over the next 40 years. A more intense monsoon together with the possibility of more frequent storms acting on this higher sea level may have important implications for settlement and agriculture in low lying coastal areas.

Impacts on Agriculture

Extremes of climate can have a significant impact on agricultural output in Vietnam. Individual events such as typhoons have the greatest effect but the extent of their damage is generally limited. More extensive impacts can occur from drought and from flooding due to excess rainfall.

Current variability of crop production due to climate (which is largely the result of variations of rainfall) is greater in north than in south Vietnam, with spring crops being most variable particularly in the Red River Delta and other coastal areas in north central Vietnam.

The possible change of mean climate over the longer term could impose significant effects above this current variability. Increases in the incidence of drought, particularly in the south of the country, would be the major adverse effect. Increased evaporation and a prolonged dry season would affect the range of crops that could be grown. Increasing temperature and humidity in winter would tend to increase the frequency of outbreak of crop pests in winter and winter-spring crops.

In upland regions the increases in temperature would enable cultivation at higher altitudes (perhaps 200 m higher for each degree increase in mean annual temperature) but would, at the same time, tend to squeeze out crops currently grown in temperate upland areas. The Red River Delta in North Vietnam is the region of greatest sensitivity to current climatic variability because of its substantial inter-annual variations in rainfall. However, the projected decreases in available moisture, particularly in the southern part of the country, may have the greatest effect on the Mekong River Delta. Both of these regions are major centres of agricultural output and any substantial reductions in their agricultural potential could have consequences at a national scale.

Impacts on Human Health

Levels of heat and humidity in Vietnam are, at some times of the year, currently near the limit that is humanly comfortable. Even quite small increases in average temperature or in the frequency of hot days could substantially reduce levels of human comfort. It could also lead to a climatic environment more conducive to the development of intestinal diseases, measles and meningitis.

Impacts on Energy Production and Use

The report considers the effects of possible future climate change on the supply and use of electricity in two regions: Hanoi City in the north and Ho Chi Minh City in the south of Vietnam.

The primary impact from present day climatic variability comes in two forms; firstly, from increases in energy demand for domestic use in the cold season, when electricity demand may increase by as much as a quarter above the normal average; and secondly, from increased demand for power to irrigate agricultural production in the dry season.

Over the long term there is the possibility of reduced soil water availability in the south of Vietnam and consequently increased demand for power in irrigation. In north Vietnam increased temperatures in winter might reduce consumption in domestic space heating.

Impacts on Mangrove Forests

The extensive mangrove forests in Vietnam are particularly rich in their species composition, with greater variety in the south of the country where a specific study has been conducted in Minh Hai province.

The evident rise in mean sea level observed over the past thirty years (averaging perhaps 6mm per year) has tended to increase the rate of erosion of mangrove forests and to encourage their advance inland where this is not prevented by agricultural development. Where an advance inland has tended to occur the extent of mangrove forests has generally been reduced. A continued, and perhaps accelerated, reduction of mangrove area could be expected under long-term rises of sea level due to global warming.

Effects on Coastal Fisheries

In the year before an El Niño occurrence and in an El Niño year temperatures are commonly above average, while in the years following an El Niño occurrence they are below average. Sea-water temperatures in El Niño years tend to be above average in summer but colder than average in winter. The thermocline in non-El Niño winters appears at a depth of 60–100 m but in El Niño years it lies at 80–120 metres. In summer the thermocline lies at 40–60 m and 60–120 m in non-El Niño and El Niño years respectively. Levels of salinity are also affected by ENSO with average salinity commonly being higher in the years of El Niño and those immediately following it.

While the above factors are probably all significant for fisheries in Vietnamese waters, most important may be the location and magnitude of welling and down-welling. In non-El Niño summers there exist two up-welling areas: off-shore of Nhatrang/Phukanh and offshore east of Conson. There is also one centre of downwelling, offshore of Thnanhai. In the years when El Niño is active the intensity of this downwelling is increased and the locations are altered with the up-welling water off Conson no longer existing and the up-welling water off Nhatrang moving southward and shrinking and an additional down-welling area appearing opposite Quinhan/Danang.

Spawning of fish is, *inter alia*, affected by sea-water temperatures that may vary according to the vertical mixing described above. For example *Sardinella aurita* begin spawning in March when sea-water temperatures exceed 19°C, and are thus affected by El Niño occurrence. In the year before and the year after El Niño, March temperatures are usually lower than the limit required for spawning. The composition of the catch can also be distinctly affected by sea-water temperature, and therefore also by the incidence of El Niño. The most productive fishing areas are usually located at the edges of up-welling and down-welling regions. Displacement of these areas therefore results in shifts of the main fishing grounds. In the summers of non-El Niño years the most productive areas are around Cu Lao Thu and south east of Conson. However, during the 1982 El Niño the up-welling and down-welling areas were located off Nhatrang, Quy Nhon and offshore Vung Tau.

Long term changes of climate which might affect the incidence and intensity of El Niño would tend to also affect the location and magnitude of fisheries in Vietnamese waters.

Conclusions

This is the first survey that has been completed on the effects of present-day climatic variability in Vietnam and of the implications of possible long term changes of climate.

In the field of agriculture more detailed studies of agro-climatic potential should enable crop growth requirements to be matched more closely to existing climatic potential. The timing of various aspects of the crop calendar with respect to current climatic variability deserves closer scrutiny.

Research is needed on the value of mixed cropping strategies as a form of effective adaptation to climatic variability. A study is needed of the zones likely to be affected by rises in sea level and of the measures that may be appropriate to avoid the increased rate of intrusion of saline water into coastal groundwaters.

Research is necessary to evaluate the potential effect of possible increases in typhoons and the prolongation of the typhoon season, and of the possibility of increased risk of drought in south Vietnam resulting from higher rates of evapotranspiration in a warmer world.

Little study has yet been made of the potential effects of higher temperatures on crop pests and diseases and on human diseases, yet this is likely to be one of the most direct consequences for humans of long-term climate change.

Appendix 1

Titles and Authors of the UNEP/SEPLAN case studies in Brazil

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1. Pedro Demo. *Methodological Contributions Towards Societal Drought Management Practices*
2. Antonio Rocha Magalhães, José Rosa Abreu Vale, Antonio Bezerra Peixoto and Antonio de Pádua Franco Ramos. *Government Strategies in Response to Climatic Variations: Droughts in Northeast Brazil*
3. Liana Maria Carleial and Aécio Alves de Oliveira. *The Effect of Drought on Occupational and Employment Characteristics of Ceará in the Eighties*
4. Cesar Barreira. *Power and Survival in Brazil's Northeast*
5. Almir Caiado Fraga and Agamenon Tavares de Almeida. *The Effect of Droughts on the Economy of the State of Ceará*
6. Ronaldo de Albuquerque Arraes and Ivan Castelar. *The Effect of Drought on Public Finance in Ceará*
7. Ricardo Duarte. *The Effect of Power Rationing in Ceará*
8. Francisco de Assis Soares and Sandra Maria Santos Cartaxo. *The Effect of Climate on Ceará's Salt Industry*
9. Marcelo Gurgel Carlos da Silva. *Effects of Drought on Health and Nutrition in Brazil's Northeast*
10. Túlio Barbosa and Elmar Wagner. *The Effect of "Veranico" Dry Spells in Agriculture in Brazil's Midwest*
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12. Moysés dos Reis Amaral and Paulo Shiguenari Kanazawa. *The Effects of Floods on the Great Swamp of Mato Grosso*
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Appendix 2

Titles and Authors of the UNEP study in Malaysia, Thailand and Indonesia

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1. Martin Parry. *Aims and Methods*
2. Amos Eddy and Eric Bird. *Data and Models*
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4. Manuel Blantran de Rosari (ed). *Impacts in Indonesia*
   Sangsant Panich (ed). *Impacts in Thailand*
   Chong Ah Look (ed). *Impacts in Malaysia*
5. Eric Bird. *Effects of Sea-level Rise*
6. Ferenc Toth. *Policy Implications*
7. Martin Parry. *Conclusions and Recommendations*

Appendix 3

Titles and Authors of the study in Vietnam

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1. Hoang Minh Hien and Nguyen Huu Ninh. *Research on climate fluctuations and changes in Vietnam.*
2. Nguyen Huu Ninh, Tran Viet Lien and Hoang Minh Hien. *Climate impacts on agriculture in Vietnam.*
3. Phan Nguyen Hong, Nguyen Hoang Tri and Haong Thi San. *Climate and human impacts on Vietnam's mangrove ecosystem.*
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