

Carbon Dioxide and Climate Change:  
Implications for Mankind's Future

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ABSTRACT

The fact that the atmospheric concentration of carbon dioxide has been steadily increasing in this century due to the burning of fossil fuels, and that this increase could appreciably warm the earth in the decades ahead, seems to have been largely ignored in discussions of future energy and environmental policy here and abroad. Already the warming trend has brought the northern hemisphere to an average temperature higher than at any time in the past 500 years or more, and such a trend will also affect the distribution of rainfall and snowfall. It seems unlikely that the community of nations will voluntarily renounce fossil fuel use to avert the climate change. This suggests that governments and other organizations should begin to factor climate change into their long range plans. Some are beginning to do so. The actions that could be taken to mitigate the effects of a gradual climate change turn out to be useful steps to soften the impacts of short-term variations as well, such as droughts, hot and cold waves, floods, and so forth.

## 1. INTRODUCTION

As early as the turn of this century the possibility that mankind could modify the climate of the Earth was pointed out, but this startling hypothesis seems to have attracted little public attention for the next half-century. The suggestion was that we are taking carbon out of the earth in the form of fossil fuels and burning it, thereby adding carbon dioxide to the atmosphere. An increase in atmospheric carbon dioxide warms the lower atmosphere, as will be explained below.

In the past two decades we have learned a great deal about the global system that determines the Earth's climate, and the question of the influence of increasing carbon dioxide has received special attention--both in scientific circles and in the media. Our "best guess" is that the next several decades will witness a continuing gradual global warming, and that patterns of prevailing winds, temperatures, and rainfall will shift dramatically. To be sure, there are many uncertainties about just how these shifts will take place, but some of the features of the future climate in store for us all are beginning to emerge more distinctly.

It is therefore not too early to begin to ask the next set of questions concerning climate change. These have to do with the impacts that climate change will have on human activities that are sensitive to weather and climate --as indeed most of our activities are. And this is only the beginning, for we must then be concerned with the implications that such climatic impacts will have for the future of our economic and societal systems. We must somehow seek to trace these implications into the very

structure of our complex global society--at least, to the extent that we are able to.

This hierarchy of problems leading from the expected physical changes to possible social effects is shown schematically in Figure 1. Notice that there are closed loops or "feedbacks" here, since at each stage there are reverse influences on society and on the natural environment in which we live. For example, as climate change is perceived by people and their governments there will inevitably be actions to modify our way of doing things in order to cope with the change.

It is an unfortunate fact, however, that our knowledge of how our societal systems function is even more incomplete than our knowledge of the climate system. The tools that are at hand to assess and predict the outcome of a climate change in human terms are woefully blunt. Most economists and social scientists are pessimistic about our ability to make such predictions, except perhaps in the broadest terms. No doubt we can improve those tools, but we have a long way to go.

In the meantime, starting immediately, we are obliged to provide some guidance to those who are in a position to make provisions for the changes ahead. We cannot ignore that challenge. What can we say to our policy makers in government, industry, agriculture, forestry, and development of natural resources when they ask for advice? We cannot tell them: Go away and do not bother us until we have done more homework.

Instead, scientists of many disciplines who have been studying the subject must carefully explain in non-technical language what they think they know about the implications of future climate change--and where our

uncertainties lie as well--and then proceed to give sensible advice about the adaptive measures that seem to make the most sense.

That is the theme of this report. It is based to some extent on a recently completed study sponsored by the Aspen Institute for Humanistic Studies and supported by the U.S. Department of Energy. A fuller account (complete with references) will be found in the book "Climate Change and Society" by this author and Robert Schwart (Westview Press, Boulder, Colorado, U.S.A., 1981), and in our article "Society, Science and Climate Change" (Foreign Affairs, Vol. 60, Summer issue, 1076-1109, 1982). Further details may be sought in the "List of Additional Sources of Information" at the end of this paper.

## 2. DEVELOPMENT OF CLIMATE SCENARIOS

Research on the influences of increasing carbon dioxide on the climate system has been vigorously pursued by a number of organizations and individuals, and has been competently reviewed elsewhere. If we conceive the ultimate objective of this research to be a self-consistent and credible picture of the climate of a future warmer earth, and also an estimate of the rate at which the change will occur, then the effort can be characterized by the following three components:

### 2.1 Estimating the Time-Table for the Human Influences

There are a variety of large-scale changes that mankind has brought about on the surface of the earth and in the atmosphere, and all must have had some influence on climate, at least regionally. Notable are the modifications of the face of the earth by agriculture, deforestation, and

urban-industrial development; the introduction of particles of smoke and smog into the atmosphere; and, most important from the climatic point of view, the production of atmospheric carbon dioxide from burning fossil fuels. Carbon dioxide is a long-lived and infrared-absorbing gas that traps some of the outgoing infrared radiation from the surface that would otherwise escape to space, and the resulting warming of the surface is often referred to as "the greenhouse effect." (There are other persistent infrared-absorbing trace gases that we are producing, such as methane, the chlorofluoromethanes, carbon monoxide, ozone, and nitrous oxide, all of which can contribute further to the greenhouse effect of carbon dioxide.)

The rate of increase of carbon dioxide depends on the rate at which we burn fossil fuels, other possible anthropogenic sources of carbon dioxide such as deforestation in the tropics, and the operation of natural sinks for this trace gas. The oceans are undoubtedly the major sink.

The dominant factor that will determine the buildup of carbon dioxide in the decades ahead is the rate of burning of fossil fuels. Estimates of this rate vary widely among the experts. It is not a geophysical problem (though geophysical factors enter into the calculation in an important way), but rather a problem of guessing what the global energy demands will be, the technological developments that will lead to alternatives to fossil fuel, and the world economic order. There are no crystal balls that we can use to answer this kind of question.

A not unreasonable upper limit of rate of increase of carbon dioxide can be based on the assumption of a continued 4 percent per year rate of increase of fossil fuel use, leading to a doubling of its pre-industrial

("natural") concentration of about 270 parts per million by volume (ppmv) before the middle of the next century. Similarly, a lower limit would be based on the assumption of a decreasing rate of growth in the use of fossil fuels to the point of no further growth in 50 years; and this would still lead to an increase of concentration of carbon dioxide from the present 340 ppmv to over 400 ppmv in the next 50 years, and perhaps a doubling late in the next century. The most likely course is somewhere in between these two limits, and this gives us an idea of the time scale for the change to occur. There may, however, be delays of a decade or two in the resulting temperature change due to the thermal inertia of the oceans.

Figure 2 is a nomogram for estimating the date at which we may reach the doubling of carbon dioxide from the pre-Industrial Revolution concentration. It depends on the rate of increase of fossil fuel use in both the developing and developed world, assuming that approximately the same fraction of the added carbon dioxide remains airborne.

If we combine a kind of "best guess" about the rate of future fossil fuel use (about 2 percent per year increase) with the theoretical estimate of the greenhouse effect for a given carbon dioxide increase (see next section), we can arrive at a rate of change of global mean temperature with time, shown in Figure 3. It also shows the rates of change for the upper limit ("high") and lower limit ("low") just discussed, and an estimate of the changes in the Arctic.

## 2.2 Calculations of the "Greenhouse Effect": the Magnitude of the Change

We have already referred to the fact that carbon dioxide and some other quasi-permanent trace gases that are building up in the atmosphere are absorbers of infrared radiation. This alters the heat balance of the entire atmosphere, warming the surface and lower atmosphere and cooling the stratosphere. The purely radiative effects are quite well understood, but the interactions within the climate system as a result of the radiative changes are complex and difficult to take into account in our theoretical models. A frequently quoted estimate for the mean global surface temperature increase resulting from a doubling of the pre-Industrial Revolution level of carbon dioxide (260 to 280 ppmv) is  $3^{\circ} \pm 1.5^{\circ}\text{C}$ , and there is good reason to believe that the north polar regions will experience a 2 or 3 times larger change. The south polar regions will probably respond with somewhat more than the mean change, but less than in the north.

The models used in these calculations include as many of the physical factors as human ingenuity and computer capacity will permit, but they are still somewhat inadequate in their treatment of the ocean circulations, cloudiness, and the vertical exchange of latent heat in the atmosphere at low latitudes. There is much work to be done to improve climate models and the estimates of the effects of increasing carbon dioxide.

## 2.3 Describing Regional and Seasonal Changes

Our models of the climate system give relatively little information about the regional distributions of temperature change and shifts of precipitation patterns, yet it is the regional effects that are of most impor-



tance to planners. We are convinced that the temperature difference between equator and pole will be less with an increase in carbon dioxide, and that this will undoubtedly change the large scale circulation patterns that determine the weather of each place on the earth, but the actual patterns of change are still unclear. This situation has led us to look at a variety of ways to estimate the regional and seasonal changes, and the effort has been termed "development of climate scenarios."

Climate scenarios, or depictions of conditions on a warmer earth, should not be taken as predictions, but rather likely examples of what could occur. They should be based on physical reasoning and a knowledge of what has happened in the past, and should be as self-consistent as possible. Some aspects of a given climate scenario may be identified as quite probable, while others must admittedly be more conjectural.

Such climate scenarios are essential first steps in studies of how various economic sectors (especially agriculture) would be impacted by a carbon dioxide-induced climate change, in studies of likely societal responses, and in making plans for the future. They must, however, always be accompanied by caveats to the effect that they are illustrative examples and not firm predictions--though there is always the danger that they will be misused in spite of the caveats. (It is this danger that has caused most climatologists to shy away from climate scenario development until very recently.) Nevertheless, in Figure 4 we present a climate scenario depicting the possible changes in soil moisture that could occur throughout the world with a warming due to increase of carbon dioxide.

It will be noted that in the scenario shown in Figure 4 we call for a general decrease of soil moisture in the middle of the continents at mid-latitudes, and for a general increase in the semi-arid and arid regions of the subtropics--areas where the majority of the less developed countries exist. That rainfall and soil moisture are highly important factors in the formation of both natural ecological systems and agricultural or pastoral productivity is unquestionable. Figures 5 and 6 illustrate this point. It is therefore evident that such shifts of soil moisture as are illustrated in Figure 4 could have significant impacts on where the major food crops are grown, and this is suggested in Figures 7 and 8. It will be noted that the countries that currently account for most of the production of wheat, maize, and barley (the U.S.A. and the U.S.S.R.) are just the ones that could suffer a trend towards drier average conditions. We have referred to food (grain) production here, and in the next section impacts on other economic or social sectors will be outlined as well.

As pointed out above, the time scale for this transition to a warmer earth will depend to a large extent on the rate at which mankind uses fossil fuel--and also on some geophysical factors such as the thermal inertia of the oceans that could slow the rate of change of temperature. We may be talking about 50 years or over 100 years for a doubling of carbon dioxide, but all evidence now seems to suggest that in any case we will begin to definitely notice the effects of climate change well before the turn of this Century--in fact, it is probably already taking place, though hard to identify unambiguously as due to increasing carbon dioxide.

### 3. IMPACTS OF CLIMATIC CHANGE

The World Climate Programme, established in 1979 by the World Meteorological Organization (WMO), has as one of its goals defining climatic variability and change in terms of what they mean for societies. In the past few decades short term weather anomalies and slowly developing changes of climate have triggered severe economic, social, and political dislocations. Developed and developing countries alike find themselves increasingly vulnerable to "abnormal weather," of the sort that struck a number of countries in 1972 and again in 1982. Furthermore, there is a growing realization that a carbon dioxide-induced climatic change could have much larger impacts than any of these short term and more or less random events.

Studying such climatic impacts is already an established practice. What appears to be new about climatic impact studies is the attempt to take into account many factors, all dealing specifically with the carbon dioxide/climate problem. Here are some of the potential impacts on several climate sensitive activities. These include:

#### 3.1 Energy Supply and Demand

The largest single use of energy in the temperate latitudes of the industrialized world is for space heating and cooling; this is markedly influenced by temperature variations. Energy is also needed in many areas for pumping water for irrigation; during dry years more is needed. There are other sectors, such as transportation and tourism, whose energy demands are affected by climate. However, in practice it is often hard to separate the effects of climate variations from the other economic and social factors involved.

Energy supply is also affected by climate, as in the case of the cold winter of 1976-77 in the eastern United States, when fuel shortages accounted for an estimated one million unemployed by February 1977. However, part of this shortage was due to the fact that the utility and pipeline companies neglected to plan ahead and store fuel reserves.

There is a current move to replace centralized fossil fuel and nuclear power sources with renewable sources such as hydroelectric, solar, wind, and biomass. Though this may be desirable, it will tend to make our energy supplies more sensitive to the vagaries of the climate, depending as they do on rainfall, sunshine, and steady winds.

Energy demand in the tropics would probably change little if global temperatures rose due to an increase in carbon dioxide. However, at middle latitudes there would be a decrease of demand for heating in the winter and an increase in demand for air conditioning in summer, shifting the kind of power from heating fuel to electricity. The pattern of energy demands will not shift uniformly poleward, since, as we have emphasized, the regional changes of temperature and rainfall will be complex.

### 3.2 World Food Production

Some aspects of the projected climatic changes due to carbon dioxide could be beneficial for crops and other ecosystems, depending on where they are growing. More carbon dioxide is known to enhance photosynthesis and plant growth, and we may expect an increase in the average growing rate of plants from this cause alone of about 5 percent by the turn of this century.

A 1°C rise in average summertime temperatures at middle latitudes increases the average growing season by roughly ten days, an obvious advantage. The increase of precipitation in the semiarid regions of the subtropics called for in our scenario could also be advantageous. Figures 7 and 8, however, illustrate that the major producers of grain (except for rice) may be adversely affected by a hotter and drier climate.

Of course, every food crop responds differently to a given climatic change. For several major food crops the relationships between climate and productivity are fairly well known. But for other crops, particularly those grown in the subtropics, further study is still needed.

Equally important to food production may be the changing climate's effects on the frequency and severity of pest outbreaks. Currently, agricultural losses due to pests are about 25 percent. Thus, a temperature increase may make pest control even more difficult than it already is. The same may be true for a number of plant diseases, such as stripe rust on winter wheat.

Even though agricultural technology has given us hardy crop strains, many experts believe that agricultural monocultures are far more vulnerable to climatic variations and change than the natural diverse ecosystems they replaced. It should be noted that 95 percent of human nutrition is derived from no more than 30 different kinds of plants; just three crops--wheat, rice, and maize--account for over 75 percent of our cereal production.

In principle we can use new crop varieties that are better adapted to a changed climate. But plant geneticists are concerned about the rapidly decreasing stocks of vigorous wild strains and disease resistant food

crops; these are being pushed out as their natural ecosystems are damaged or eliminated.

### 3.3 Global Ecology

While agricultural systems may depend on a few specialized plant species, natural ecosystems--or "biomes"--are usually characterized by a great diversity of plants and animals. These organisms interact and live together in an intricate balance--that is, until this balance is disturbed by humans or by climatic change. Few biomes, if any, remain untouched by human influence. Among the major biomes that are still close to their original states are the remote tropical forests that have not yet been exploited, and the unpopulated tundra areas of the Arctic.

The kind of biome that will thrive in a given region is determined by temperature, precipitation, soil type, and availability of sunlight, among other variables. The first two are generally the most important, as illustrated in Figures 5 and 6. A slow climatic change will affect temperature and precipitation, forcing the biomes to shift, as some species in each region die out and others succeed them. This has occurred many times throughout geological history. For example, during the warm Altithermal Period some 5000 years ago the spruce forests of central Canada extended 300 to 400 kilometers further north than they do now. At that time the Sahara was not a desert but a semiarid grassland that supported grazing animals and nomadic people.

Whether ecosystems can adapt successfully to a climatic change will depend on how fast the change occurs. This is because, while the life span

of individual trees and some other plants is many decades, the response of an entire ecosystem occurs over several plant lifetimes.

A special biome exists in the Arctic tundra, where few trees grow and permafrost (permanently frozen ground) inhibits drainage, slowing the decay of dead plants. The result is the accumulation of deep layers of water-saturated or frozen organic matter, called peat. If there is a general warming trend--and recall that the warming is expected to be greatest in the Arctic--permafrost will gradually retreat northward, trees will encroach on what had been tundra, and the peat bogs will thaw to a greater depth in summer and dry out in their upper layers. As a result, the upper layers of organic matter will oxidize once they become exposed to the air for the first time. This will probably release carbon dioxide (and also some methane) and add further to the warming--an example of a "positive feedback."

Hence, a gradual climate change will cause the distribution of biomes to shift as each seeks to adapt and achieve a new equilibrium. These shifts are fairly predictable, provided that natural processes alone are involved. However, in many parts of the world human intervention will have a larger ecological impact than the shifting climate in the next 50 to 100 years.

### 3.4 Water Resources

We depend on a reliable supply of fresh water for survival. A climate change will surely shift patterns of precipitation, and this will directly affect the water resources of every region. Areas with marginal water

resources will be the hardest hit if there is a decrease in rainfall; our tentative scenario indicates that such areas may be in the midwestern United States and the Soviet Union, as shown in Figure 4.

Similarly, many developing countries in the semiarid parts of the subtropics are now expected to experience a general increase of precipitation and soil moisture if a warming occurs. Changes in precipitation and soil moisture are key elements in food and forest production. Hence, the climatic warming could perhaps adversely affect the two "superpowers" and help a great many developing countries.

Many of the dams, aqueducts, pumping stations, reservoirs, and water distribution networks around the world have been designed to cope with seasonal and year-to-year fluctuations of water supply and demand. The lifetime of such facilities is typically 50 to 100 years or more, so the anticipated climatic change will occur while they are still in place. Whether they will still be adequate is the question that must be answered.

In any case, any measures taken now to guarantee more reliable water supplies will be advantageous regardless of longer term climatic changes. Even without a future shift of precipitation patterns they will probably be cost effective.

### 3.5 Fisheries

Up until the early 1970s rivers, lakes, and coastal areas of the world were generally viewed as vast, almost limitless resources of food. As late as the 1960s and early 1970s scientists had reported that fish catches could be greatly increased, and would provide a large supplement to food



production on land. However, after 1972 global fish catches declined from their peak of 26.5 million tons to 18.5 million tons in 1973, according to the U.N. Food and Agriculture Organization. There has recently been a partial recovery, but not to the levels attained in the early 1970s.

Decreases in fish landings can be caused by a number of factors, either singly or in combination. These factors include overfishing, poor fishery management practices, and oceanographic and climatic fluctuations or changes. In 1972 and 1973 climatic fluctuations resulted in shifting ocean currents, sea surface temperatures, and wind patterns that may have been partly responsible for the general reduction in fish landings, and specifically in Peruvian coastal waters. The anchovy population there depends on an upwelling of nutrient rich cold deep water to the surface. There are other coastal zones that depend on upwelling to provide nutrients to the fish population; all are subject to similar year-to-year fluctuations of currents and water temperatures.

Another example of the influence of climate on fish catches is the West Greenland cod supply. Up to about 1950 North Atlantic temperatures increased, and during this period the catch also increased, reaching a peak of some 450,000 tons in the early 1960s. However, since then there has been a cooling trend, and in recent years catches of cod have been so low that they have been banned off Greenland.

While there seems to be good reason to believe that winds, temperatures, and ocean currents all play a part in determining the favorable environments for fish, the marine ecosystem is still poorly understood. It is difficult to separate the climatic impact from the human influence, such

as overfishing. In any case, it appears that the sea is not so bountiful a source of food as once believed.

### 3.6 Health, Comfort, and Disease

Human beings can survive environments from extremely hot ( $50^{\circ}\text{C}$ ) to extremely cold ( $-60^{\circ}\text{C}$ ). However, most people thrive best in a temperature range known as the "comfort zone," ranging a few degrees above or below the optimum of about  $20^{\circ}\text{C}$ .

The prevalence of most diseases is also affected by climate, demonstrated by the seasonal outbreaks of certain illnesses in temperate regions and the limitations of other diseases to certain climatic zones in the tropics. Some human diseases depend on insects, snails, or other "vectors" for their spread, which are subject to temperature, moisture, and other climatic constraints.

But diseases are not solely linked to climate, since they are also affected by the condition of water supplies, food sanitation, and refuse disposal. Not surprisingly, most of the serious diseases are disproportionately concentrated in the poor and developing countries of the world, nations which tend to be in the tropics or subtropics. In short, poverty provides favorable conditions for the spread of disease, which also helps to perpetuate poverty.

In the course of a global warming a number of diseases that are now mostly confined to the tropics might spread to more temperate regions. These diseases include schistosomiasis, bacillary dysentery, hookworms, yaws, and malaria. However, they could be eradicated by hygienic and other measures, so their spread is by no means inevitable.

### 3.7 Population Settlements

Many population shifts have been at least partly due to an adverse climate. The emigration to the U.S. and Britain during the Irish Potato Famine in 1845 to 1851, and the abandonment of farms in the Great Plains of Nebraska, Kansas, Texas, and Oklahoma during the dry periods of the 1890s, the 1910s, and the 1930s, are examples. Of course, the latter was triggered by abnormally low rainfall and high temperatures in the Great Plains, but poor grazing and plowing practices and economic depressions were contributing factors. The drought of the 1950s in the same region did not cause as much disruption.

The developing world, which will probably contain more than three-quarters of the world population by 2000, is especially vulnerable to the pressures of climatic variations and change. The Sahelian disaster of 1968-1973, when over 100,000 North African nomads died, illustrates this point.

If a climatic warming caused sea level to rise, a definite possibility in the next century or two, the densely populated coastal regions would face serious consequences. It is obvious that a sea level rise would affect all coastal areas of the world.

It must be emphasized that glaciologists do not agree on the time scale for such an event, whose primary cause will be the shrinking or breakup of part of the great ice sheets of Greenland or Antarctica. The West Antarctic ice sheet has attracted the most attention, since it sits largely on bedrock below sea level, but whether it would disintegrate in a matter of centuries or millenia following a major warming is still being debated.

Thus, while it is clearly too early to make evacuation plans, we can begin to prepare for this contingency by applying what we know about land use and flooding in areas where water levels are already rising. For example, land is subsiding or shifting in Venice, Italy; Long Beach, California; and Galveston, Texas. This creates an apparent sea level rise for non-climatic reasons.

### 3.8 Tourism and Recreation

An increasing number of communities, and even entire countries, are becoming dependent on the income from tourism. It is an important economic sector that is also remarkably sensitive to climatic variations and change. The best example of this is a ski resort without adequate snow-fall.

Health through recreation is becoming more popular throughout the world--that is, where people can afford the luxury of recreation. Climatic change will clearly affect the development of vacation facilities.

## 4. POLICY DECISIONS AND MEASURES DEALING WITH THE CARBON DIOXIDE/CLIMATE PROBLEM

### 4.1 Long Range Strategies

While there are many long range strategies that can increase our resilience to climatic variability and change--or to at least delay the change--there are also certain obstacles to accepting and implementing them. Among these obstacles are the following:

- Incomplete information. Since climatologists still cannot predict with certainty future temperature and precipitation changes, either regionally or seasonally, it is not surprising that policy makers and the public are reluctant to commit resources to long range measures in order to mitigate a situation that might never occur.
- Poor planning and information distribution. Climatological information, though available in archives, has not been properly consulted in a number of well documented cases. This seems to have been due to a lack of awareness on the part of the public and its planners of the opportunity and need for taking such information into account.
- Discounting the future. When weighing risks and benefits there is the tendency to opt for near term gratification rather than longer term rewards. This tendency is especially strong when dealing with benefits to be reaped by future generations. What is their future worth to us today? Residents of flood plains, for instance, have denied the possibility of another flood occurring--at least, in their lifetime. This irrational discounting of the future often serves to their disadvantage, and governments as well as individuals can fall into the same trap. The same is true for carbon dioxide. Are we willing to accept the future risk of added carbon dioxide to the atmosphere for the present benefit of burning fossil fuels?

When societies have perceived the need to adopt some kind of long-range strategy there are, in principle, four possible alternative courses of action. These are shown diagrammatically in Figure 9. They range from the most aggressive on the left to the most passive on the right. In the

next two sections we comment on the likelihood of the adoption of the more aggressive courses of action and the kinds of steps that could be taken to adapt to the change, once the inevitability of the change is recognized.

#### 4.2 Averting the Change

A common first reaction to the thought that a climate change could be caused by burning fossil fuels is to call for a cutback on their use. This is in principle a reasonable course to take, but we do not live in a "reasonable world." Some of the reasons for skepticism with regard to such a cutback of fossil fuel use are the following:

- Fossil fuel is a major economic commodity, and a great majority of countries have developed the costly infrastructures to use it. The powerful vested interests and the large capital outlays involved will both dictate against the abandonment of such a convenient energy resource.
- Since the buildup of carbon dioxide is a global phenomenon and the cause is the worldwide use of fossil fuels, any course of action to reduce their use would have to be agreed upon and implemented internationally. There is no international mechanism now that could arrive at such a decision--much less enforce it. (See Section 5.2 below.)
- The climate change in store for the world will very likely be perceived as advantageous by some countries, at least in its early stages. They would be reluctant to make a sacrifice of a convenient energy source for a negative reward.

- Finally, the scientific community is admittedly uncertain about many of the features of a future warmer earth, and there are still some who even refuse to agree with the consensus that the change will indeed occur. These heated and well publicized debates among scientists suggest to the public and its leaders that no big decisions should be taken until the prediction of climate change can be made with more universal conviction. We may have to wait until the earth has demonstrably proven our prediction to be right.

These are but some of the arguments against relying on international action to reduce fossil fuel burning. There may be economic and technical incentives to encourage a changeover, but they will probably be slow to operate. Thus, it seems prudent to proceed on the assumption that atmospheric carbon dioxide will continue to increase, that a climate change will occur, and that mankind should take the necessary steps to mitigate its impacts.

#### 4.3 Mitigating the Effects

Regardless of whether carbon dioxide builds up and results in a future climatic change, problems caused by weather and climate variability occur now and will continue to do so. Thus, we should strive to reduce the vulnerability of human settlements and activities. As it turns out, a variety of long range strategies to mitigate the impacts of future climatic change would be wise steps to take for more immediate problems. Therefore these strategies should be implemented in any case.

We have identified three classes of long-range strategies with short term benefits: those that increase resilience (or decrease vulnerability) to climatic change; those that help to slow the increase of carbon dioxide; and those that lead to making better choices.

#### 4.4 Strategies that Increase Resilience to Climate Change

- Protect arable soil. Agriculture and animal husbandry depend on soil that can grow plants. This resource is being poorly managed and lost through erosion and salinization. One of the world's most pressing environmental problems, it threatens our ability to produce enough food.
- Improve water management. Societies will continue to depend on water supply systems that can ameliorate floods and provide water during periods of drought.
- Apply agrotechnology. New agricultural techniques led to the "Green Revolution," and they may help us provide food for a growing population in the face of adverse climatic events and longer term climatic change.
- Improve coastal land use policies. Coastal communities need to make better use of climatic information to mitigate the effects of floods, hurricanes, and typhoons. A future sea level rise is one more factor that should be a part of their planning, even though its time scale is still uncertain.
- Maintain global food reserves. Future shifts of temperature and precipitation patterns will affect some for the better, some for the



worse. Thus, maintaining global food reserves to help the losers is a sound policy, both now and in the future.

- Provide disaster relief. Catastrophes will still require emergency aid from international relief organizations to alleviate their impact.

#### 4.5 Strategies that Help Slow the Increase of Carbon Dioxide

- Conserve energy. There are strong incentives to make energy conservation the basis for a sound energy policy, since it reduces the demand for all fuels, including those from fossil sources.
- Use renewable energy resources. By the same token, use of renewable energy resources, such as solar energy, biomass conversion, and hydroelectric power will reduce the demand for fossil fuels.
- Increased use of nuclear energy. While there is considerable public opposition to nuclear energy on the grounds of its possible health and ecological hazards, it also has some advantages, one of which is the fact that it does not generate carbon dioxide.
- Reforest. Replanting trees in areas where deforestation has taken place, as in many parts of the tropics, not only replaces a valuable economic resource and prevents soil erosion, but also takes some carbon dioxide out of the atmosphere as the trees grow.

#### 4.6 Strategies that Lead to Improved Choices

- Employ environmental monitoring and warning systems. International organizations have already established global environmental monitoring and warning systems, notably the U.N. Environment Programme's Global Environmental Monitoring System (GEMS).

- Provide improved climate data for direct use. The newly established World Climate Data Programme and World Climate Applications Programme, part of the WMO's World Climate Programme, should improve the availability and application of climate data for planning and operations. There are many countries that lack the expertise or the mini-computers needed to make use of our knowledge of climate and its influence on human activities.
- Inform and educate the public. Dissemination of the latest results of climate studies should raise the general level of public awareness about the carbon dioxide/climate problem. This will lead, one can hope, to better choices by political leaders and a greater public acceptance of long term measures to cope with climatic variations and change.
- Transfer appropriate technology. The transfer of technology to developing countries has been taking place for a long time, but it has not always been appropriate. Technology tailored to developing countries' needs will help in agriculture, water resources, the development of export products, and land use.

Clearly, nations need to take vigorous initiatives to cope with our variable and changing environment. Whether societies will have the resources needed to adapt to climatic changes will be determined by several indices, most of them economic: gross national product (GNP), an indicator of the economic resources available to build new facilities or move people; ratio of investment to GNP (or gross rate of investment), an indicator of the rate of turnover of new facilities and capital stock (a faster turnover

implies more flexibility); the flexibility and diversity of the capital stock, which, though it may increase costs and lower output somewhat, offers insurance against changing conditions; and the ability to foresee changing conditions and adapt to them quickly, which comes with public information and education.

A first conclusion of the above--hardly an original conclusion--is that the wealthier, generally industrialized, countries will be more likely to be able to cope with a worldwide environmental change than the developing world. This "first conclusion" may be misleading, however, when we consider the distinct possibility, illustrated in Figure 4, that the developing countries in the semi-arid and sub-tropics may actually benefit from the climate change as they receive more rainfall. The major powers in the temperate latitudes may not fare so well if they become both hotter and drier. We will return to this point later on.

## 5. INTERNATIONAL INSTITUTIONS AND LEGAL MECHANISMS

### 5.1 History of Organizations for Environmental Cooperation

Formal recognition of the need for international collection and exchanges of meteorological and oceanographic observations occurred in 1873 with the establishment of the International Meteorological Organization (IMO). In 1951 the IMO became the WMO, one of the United Nations' specialized intergovernmental agencies; it now has its headquarters in Geneva, Switzerland.

Until recently the WMO devoted most of its effort to improving weather forecasting and exchanging worldwide meteorological observations twice a

day through the World Weather Watch (WWW) system. However, more attention has been paid to climate in the past few years. In February, 1979, the WMO held the first World Climate Conference in Geneva to approve a draft proposal for a new World Climate Programme. This Programme was implemented at the beginning of 1980.

During the 1970s there was a growing concern for the environment and its finite natural resources. Following the U.N. Conference on the Human Environment in Stockholm in June, 1972, the United Nations Environment Programme (UNEP) was established, with headquarters in Nairobi, Kenya. Its charter includes dissemination of "information on major environmental problems and the efforts being made to respond to them, in order to identify gaps, set objectives, and establish priorities." To meet these goals, one step UNEP has taken was organizing the Global Environmental Monitoring System (GEMS). Among GEMS' functions is "assessing global atmospheric pollution and its impact on climate."

The International Council of Scientific Unions (ICSU), a non-governmental body, founded the Scientific Committee on Problems of the Environment (SCOPE) in 1969. This has expanded the opportunity for international collaboration. One of SCOPE's activities is a long term study of biogeochemical cycles of carbon, nitrogen, phosphorous, and sulfur which would be affected by climate change; and it has recently organized a study of methodologies for assessing climatic impacts.

Another organization conducting research on global problems is the International Institute for Applied Systems Analysis (IIASA), located in Laxenburg, Austria. Presently IIASA's membership consists of 17 national

scientific academies, and its research has included studies of world energy and food problems and their climatic implications.

There are also several regional associations of nations that are becoming more active in this field. The Council of European Communities, for example, has adopted a European Climate Programme for which the WMO and UNEP share responsibility, similar to the U.S. National Climate Program.

## 5.2 International Legal Mechanisms

We should not expect too much of international law when it comes to resolving cases that deal with injuries or damages caused by carbon dioxide-induced climate change. Ultimately, countries are free to comply with or ignore international law. In any case, there is currently no mechanism by which to set carbon dioxide standards and establish universally applied control measures, nor a policing body to enforce the so-called "global right to a clean atmosphere."

It would make sense, however, to encourage new international mechanisms that could, among other things: examine the likely effects of a carbon dioxide-induced warming on national and international activities; recommend to governments, as far as practical, measures to deter "excessive" use of fossil fuel or large scale deforestation; and exchange information on climate change and its impacts. The Climate Impact Studies Programme, a component of the World Climate Programme, may be in a position to fulfill some of these functions.

There are some existing international mechanisms that could become applicable to carbon dioxide related issues in the next few decades. They include:

- International agreements. There are several types of treaties and conventions being negotiated that apply principles of international law to established areas of transnational significance, such as marine pollution, nuclear weapons tests, exploitation of the Antarctic, and the use of outer space. Nations engaging in these agreements have taken preliminary steps toward clarifying the procedures through which regulations can be implemented.
- Regional organizations. There seems to be a growing acceptance of regional organizations such as the European Economic Community, the Organization for Economic Cooperation and Development, the Council for Mutual Economic Aid, the Association of Southeast Asian Nations, and the Latin America Free Trade Association, among others. These groups are set up to deal with specific supranational problems. They could be valuable in implementing carbon dioxide control strategies, and in compensating member countries for damages resulting from climate change.
- International commissions. The findings and recommendations of international commissions such as "conciliation commissions," "arbitral tribunals," and "commissions of inquiry" can sometimes influence international behavior. For carbon dioxide problems such commissions may be useful ad hoc devices to either arbitrate disputes or gather expert opinions on controversial legal, political, and scientific issues.
- International conferences. Conducting international negotiations through special conferences is becoming an accepted practice among

countries. The United Nations has encouraged this by convening such meetings as the Conferences on the Environment, the Law of the Sea, the Law of Treaties, and Science and Technology for Development. The value of recommendations made at international conferences is that they tend to call attention to matters that should be dealt with by the member states. To date, the World Climate Conference has been the largest international conference to investigate the impacts of climate change.

We have only dealt with a few of the possible international legal mechanisms for handling the political and economic consequences of a global carbon dioxide-induced climatic change. Special mention should also be made of diplomatic negotiations, the Permanent Court of Arbitration, and the International Court of Justice. Each of these may be used to resolve possible carbon dioxide related damage and compensation disputes. It seems unlikely, however, that any of them can be effective in achieving worldwide action to reduce fossil fuel use, as pointed out in Section 4.2.

## 6. CONCLUSIONS

These are a few of the more important points that emerge regarding societal impacts of a carbon dioxide-induced climatic change.

It should be clear by now that, while the general features of a global carbon dioxide-induced warming are beginning to become clearer as a result of research efforts in the past decade or more, there is still an urgent need for the development of climate scenarios describing the expected changes on a regional and seasonal scale. These climate scenarios need not

be considered definite predictions of the future, but they must be possible and internally consistent pictures of what could happen. The process of climate scenario development must be a continuing one, moving hand in hand with the improvement of theoretical climate models and better information about climates of the past. In fact, this process is an inescapable first step in any studies of the societal impacts of climate change, studies which must start with the specifics in various regions of the world.

While we may never be able to predict future climatic change in adequate detail and exactly how individual societies will respond to it, we can clarify the relative merits of alternative long term policies or strategies. We believe that the most useful strategies are those that can mitigate the adverse impacts of the changes and make specific activities--such as agriculture and human settlements--less vulnerable to climatic impacts from whatever cause.

Having made an initial (and by no means exhaustive) examination of the various useful strategies, we can see that each one will also help cope with short term weather and climate variability--devastating events such as droughts, floods, heat waves, and cold spells that cause hardship every year. Some strategies will also help alleviate chronic environmental problems such as the loss of arable soil and tropical forests; international and national measures to preserve these precious natural assets are long overdue. Perhaps the stimulus of an impending climate change will help to spur such actions.

Climatic impact studies will help to estimate the effects of climatic changes, which should enable us to better plan agricultural production,



land use, and human settlements, and to develop water resources and marketing strategies. However, new and improved methodologies of climate impact assessment are needed as well as more scientists interested in working on impact studies.

Apart from the research needed to improve our ability to carry out impact studies, it is imperative that we implement international programs to cope with carbon dioxide-induced changes. Some international mechanisms already exist that might help us deal with this unprecedented set of global problems. All of them should be explored and their use encouraged. Most importantly, nations should be made aware of the problem of climatic change and of the strategies that could mitigate its effects.

For some countries the change may be favorable, while for others it may be adverse. But we must emphasize that the prospect of a global climatic change is just one of a number of global environmental and societal problems. In the first half of the next century the world could well have twice as many people, consume three times as much food, and burn four times as much energy. Thus, impacts of climatic change must be superimposed on this backdrop. Our future problems will be serious even without a shifting climate.

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LEGENDS

- Figure 1. The interconnected factors that are involved in climate impact studies. Note that the impacts are determined by both "nature" and "society"--climate changes interact with existing societal structures to affect people, and the activities of people affect the climate.
- Figure 2. A nomogram relating the annual rates of increase of fossil fuel use in both developing and developed nations to the date at which carbon dioxide will be twice its pre-Industrial Revolution value of about 270 ppmv. It was prepared by Edward Friedman of the Mitre Corporation. (Source: Kellogg and Schware, 1981; 1982.)
- Figure 3. Past and future changes of global and Arctic mean surface temperature. The dashed line shows what it might have been without the addition of carbon dioxide. The stippled area shows the approximate range within which the global mean temperature has varied during the past 1000 years or more. See text for an explanation of the estimation of future trends. (Source: Kellogg, 1979; Kellogg and Schware, 1982.)
- Figure 4. Example of a scenario of possible tendencies of soil moisture on a warming Earth. It is based on paleoclimatic reconstructions of warm periods in the distant past, comparisons between recent warm and cold years or seasons in the northern hemisphere, and several climate model experiments. Where there seems to be general agreement on the tendency between two or

more of these sources we have indicated the area of agreement with a dashed line and a label. (Source: Kellogg and Schware, 1981; 1982.)

Figure 5. World biome types as determined by temperature and precipitation. The boundaries between types are approximate, as there are other factors involved such as soil condition. The dot-dash line encloses a wide range of environments in which either grassland or one of the types dominated by woody plants may form the prevailing vegetation. (Source: R.H. Whittaker, 1975: Communities and Ecosystems, Macmillan, New York.)

Figure 6. Data from the United States and Canada on acres of pasture land required per cow vs. average annual precipitation. It shows that precipitation rather than temperature is the major factor. (Source: Climate Impact Assessment Program [CIAP], 1975: Dept. of Transportation, Washington, DC.)

Figure 7. Distribution between countries of world production of wheat and rice in 1978, combined with a scenario of possible changes of soil moisture on a warmer Earth (see Figure 4). World food production data compiled by the Food and Agriculture Organization, Rome. (Source: FAO Production Yearbook, 1979: Statistics Series No. 22, Vol. 32.)

Figure 8. Same as Figure 7, showing production of maize (corn) and barley.

Figure 9. The choice of strategies when faced with the prospect of a future environmental (climate) change. Basically the alternatives are to take action to prevent the change or to accept it as inevitable and learn to live with it. The latter strategy is in effect a decision to do nothing at all, at least for the time being.

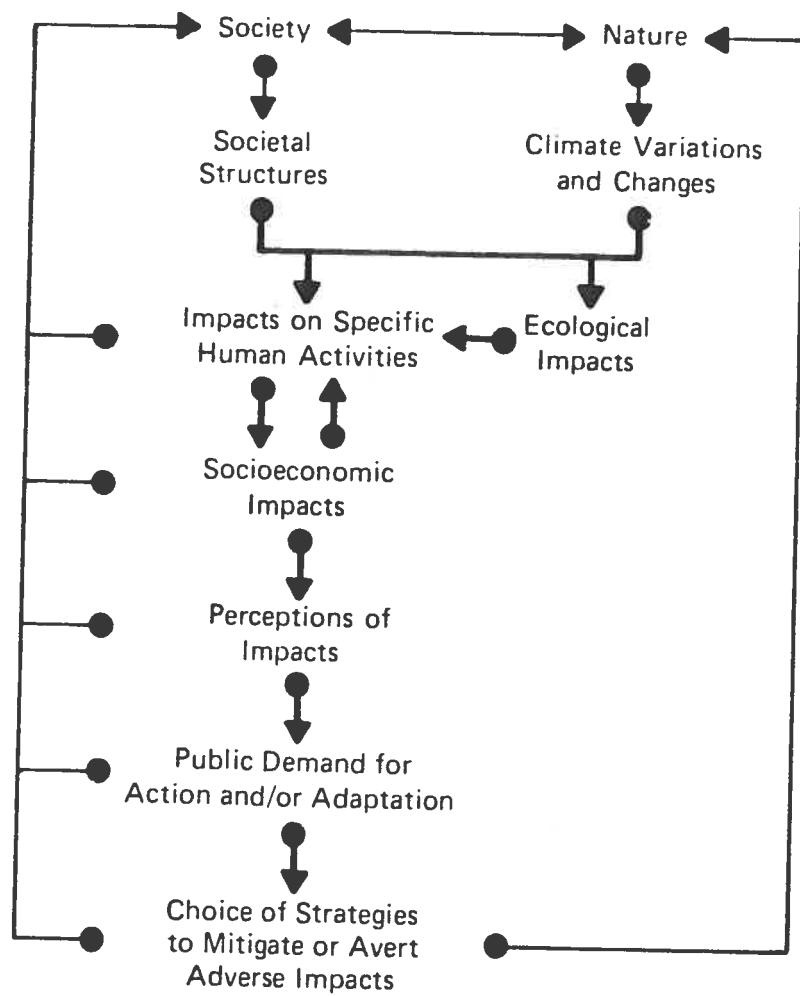


Fig. 1



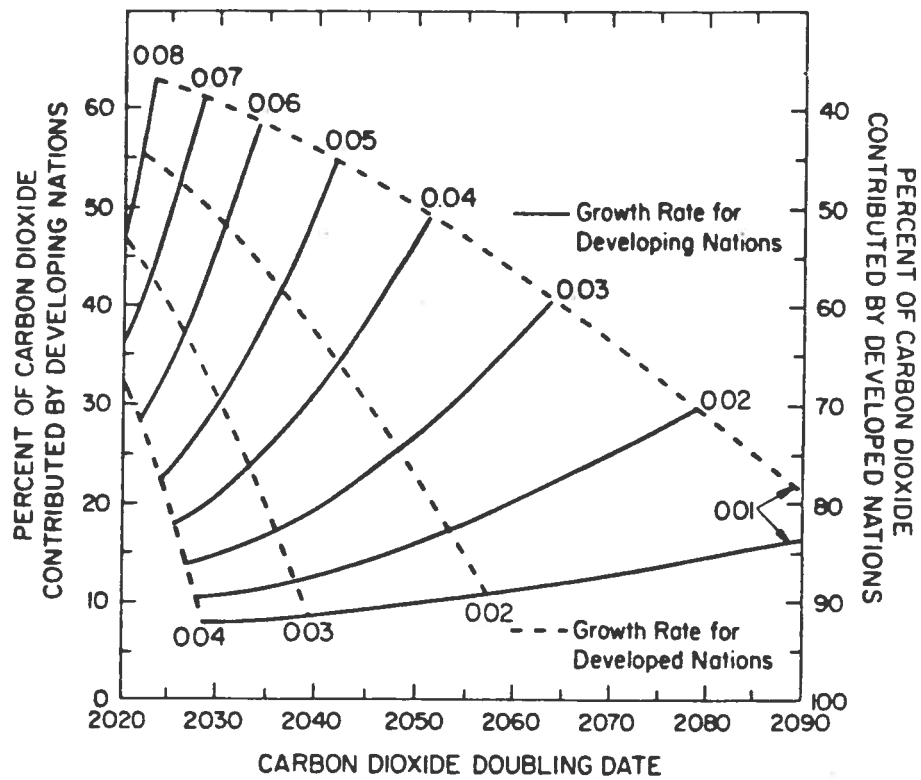


Fig. 2.

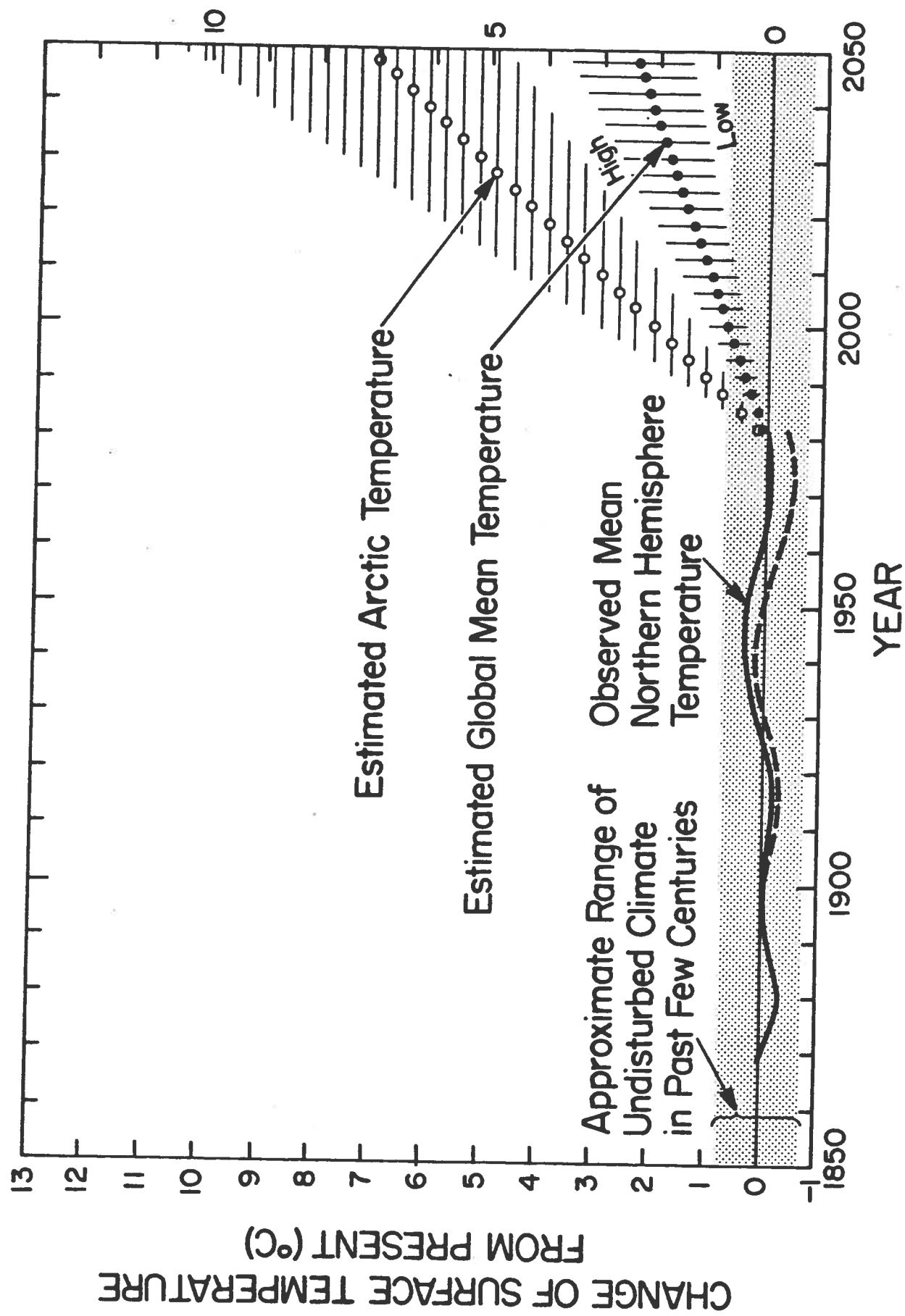


Fig. 3.



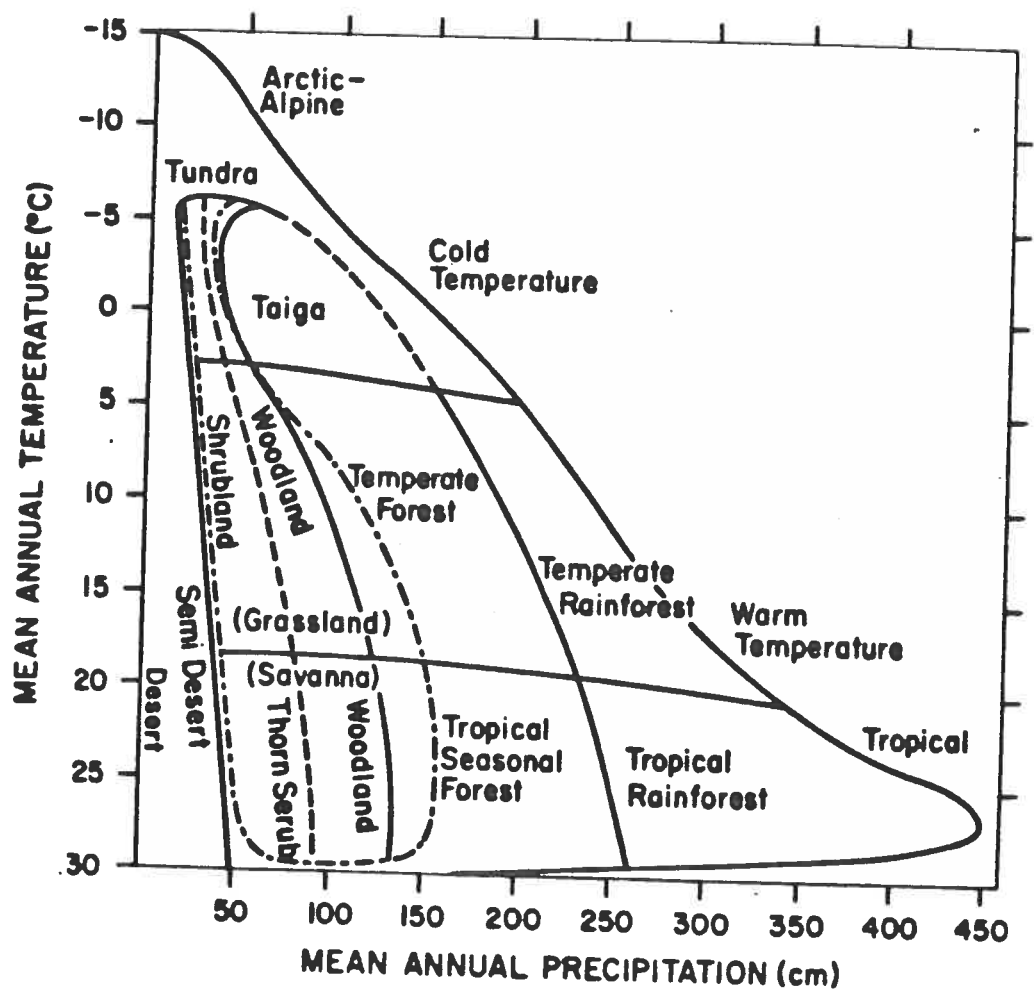


Fig. 5

SUSTAINABLE STOCKING RATES AT RANGE  
RESEARCH STATIONS AND PRECIPITATION  
Mid-continental natural pastures

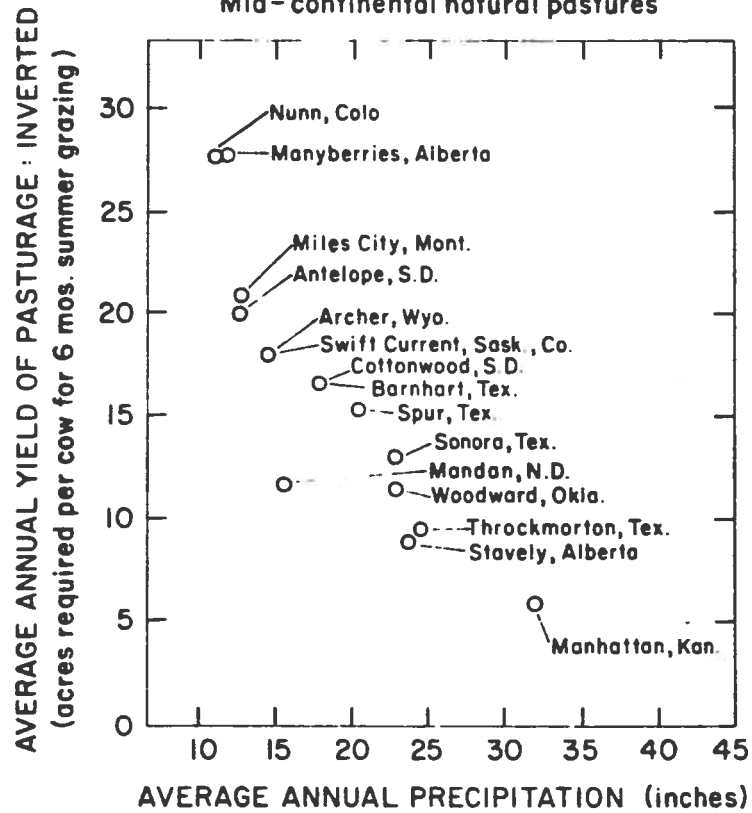


Fig. 6

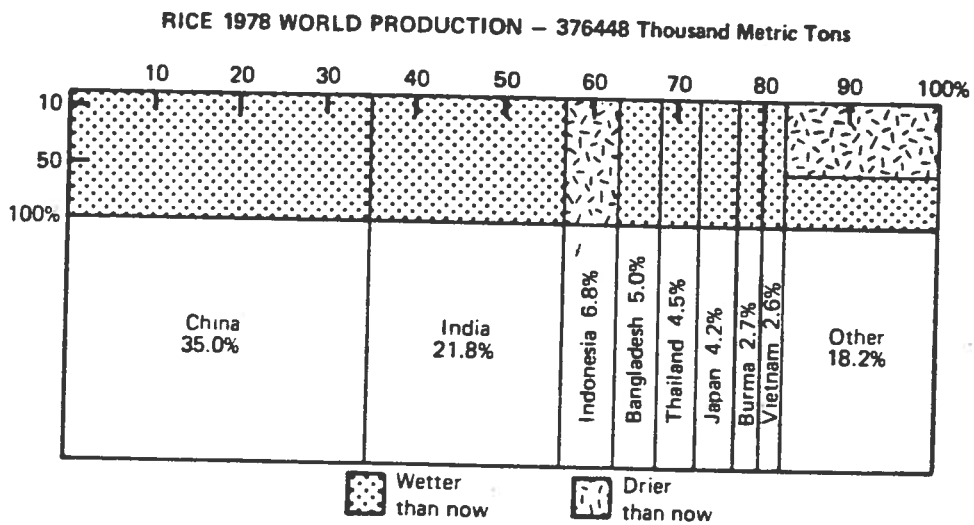
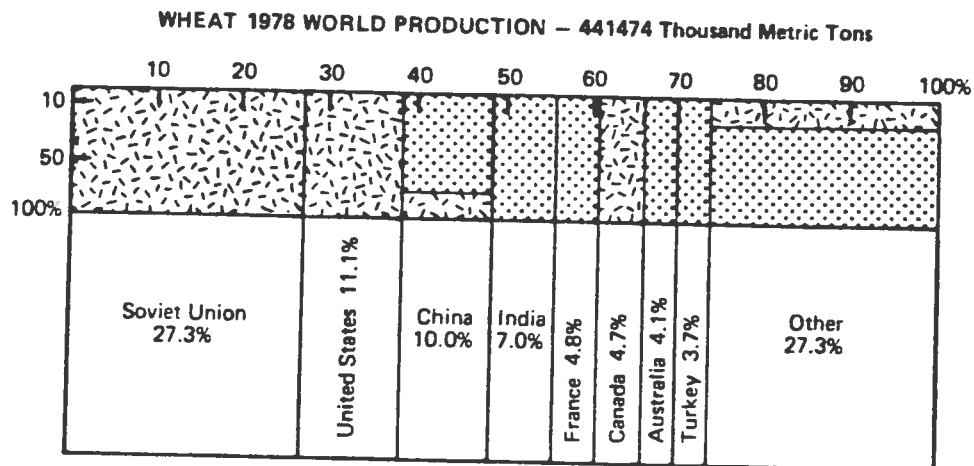
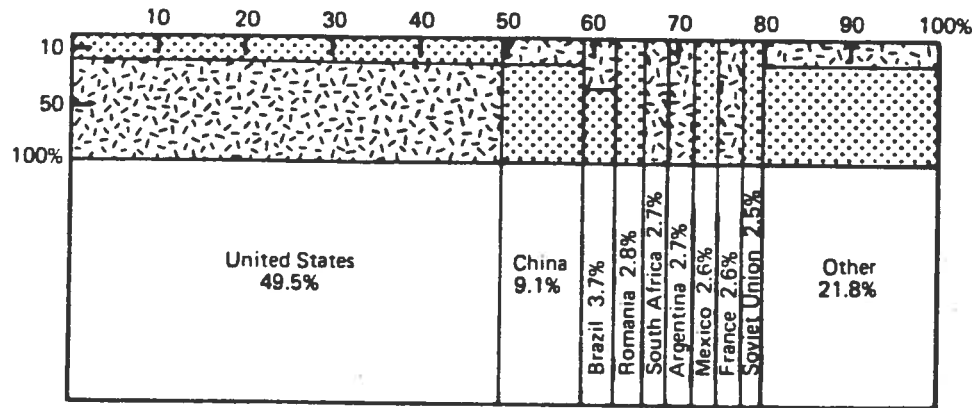
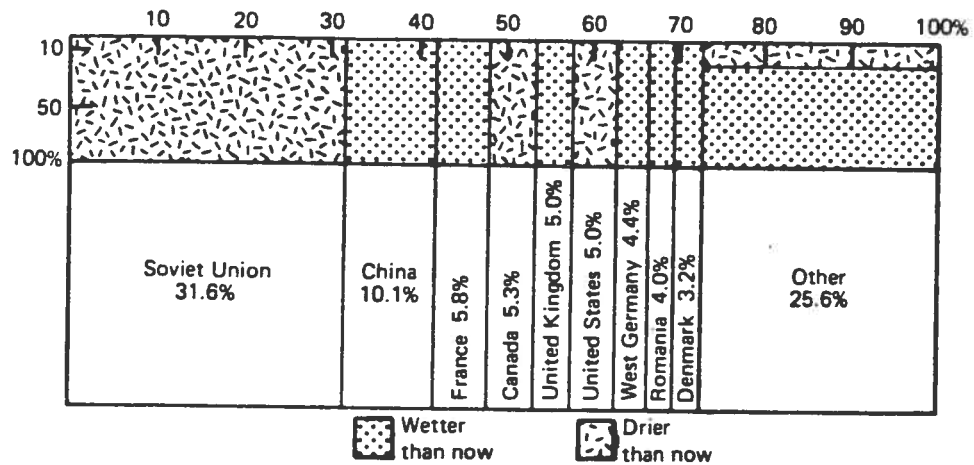


Fig. 7.

MAIZE (Corn) 1978 WORLD PRODUCTION – 362971 Thousand Metric Tons



BARLEY 1978 WORLD PRODUCTION – 196123 Thousand Metric Tons



Wetter than now

Drier than now

Fig. 8

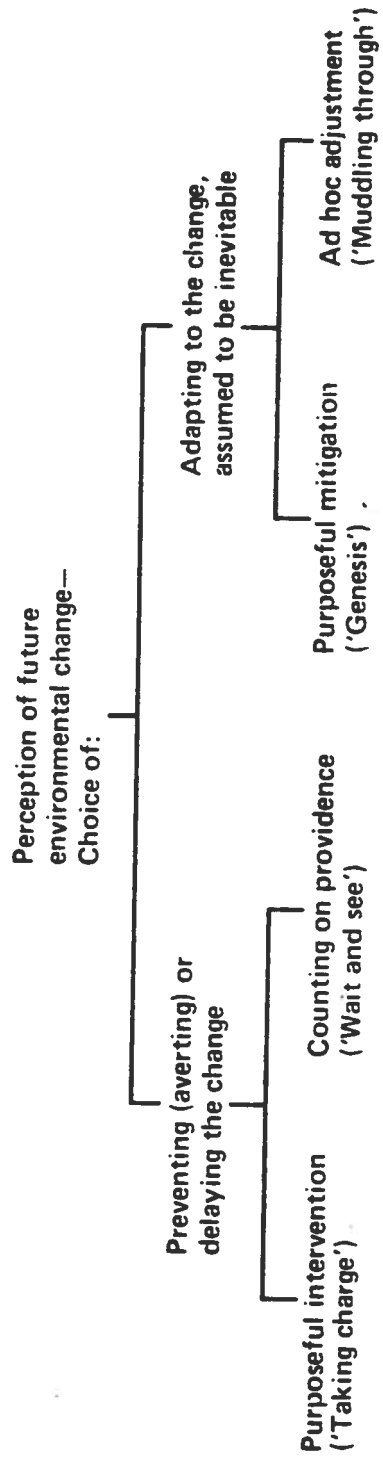


Fig. 9