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EXCERPTS

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# 5

# Tropical Economies and Weather Information

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## INTRODUCTION

The thesis of this chapter is that investment in certain weather and climate-related research and applications presents an opportunity to many developing countries for making large economic gains. Most less developed countries (LDCs) fall within the tropical and the monsoon regions of the world [see (1) and also Chapter 1 of this volume for a definition of these regions]. Food and agricultural production in these countries is critically influenced by weather and, since these countries are predominantly agricultural, their overall performance is highly sensitive to weather uncertainties. Moreover, many parts of the developing world are climatically "hostile" areas (such as flood-prone, drought-prone regions and deserts) or are vulnerable to weather disasters such as cyclones and typhoons.

Some examples are valuable. During the period 1961–1970, 22 countries in the Far East and the Pacific region sustained damages of $9.9 billion from floods and typhoons, an amount that was almost as large as the World Bank loans to these countries during that period (2). The 1970 cyclone in Bangladesh killed at least a half million people and displaced twice as many. In India, extensive investments and efforts have gone into achieving 2–3% annual growth in agricultural production, whereas one bad growing season brought on by an abnormal monsoon can lower the season's agricultural output by as much as 15% [see (3) and the earlier issues of the same publication]. Because of the economic structure of these societies, weather has a deep impact on the prices and availability of goods, employment and growth prospects, and the economic well-being of literally billions of people.

It is, of course, true that a complete scientific understanding of weather and climate does not exist at present; in fact it might even be unrealistic to expect that such an understanding will be achieved in the foreseeable future. What is not realized generally, however, is that a perfect understanding of weather is neither necessary nor economically desirable. Indeed, beyond some point, the costs of obtaining the information would exceed the gains. The social gain from producing and distributing certain kinds of weather information, on the other hand, can be substantial if the cost of such information and its potential gains are kept in mind.

Many advances have taken place in the last few decades in understanding climate and weather. Some of these advances are directly applicable in developing countries with immediate and large payoffs, while for others it is yet to be demonstrated how they can be applied in a practical sense and more research is needed. In the past, policymakers have not been sufficiently aware of the ways in which the available scientific knowledge in this area can be applied in improving the functioning of economic activities. This chapter is an attempt to provide the needed perspective. Some parts of it draw from earlier works by the author (4, 5).

First, features of developing economies that are important to understanding the economic impact of weather are examined, as are certain aspects of the economics of weather and climate information. This is followed by a discussion of the state of the art of and the economic potential offered by different climate- and weather-related activities, highlighting those specific research activities and applications that might be the most promising candidates for investment and public support.

## 1 CLIMATE AND DEVELOPING ECONOMIES

The Tropic of Cancer and the Tropic of Capricorn broadly separate the developing and developed countries. Most developed countries lie outside these two tropics in the *temperate* region. Developing countries, on the other hand, are located between the two tropics, that is, in the *tropical* region. Within this region are located most of those countries in which monsoons are a distinctive feature of the annual weather cycle, such as Bangladesh, Burma, India, Indonesia, Malaysia, Malagasy Republic, Tanzania, and Thailand.

Many observations have been made regarding the possible climatic differences between the tropical and the temperate regions. Some of these are:

1. The year-to-year variability in the tropical rainfall is higher than that in the temperate region resulting, at times, in markedly different tropical weather and climate in successive years.
2. The tropical rainfall has greater seasonality, that is, intense rainfall in the tropics occurs only during certain short periods within a year.
3. The tropics have great extremes of climate present side by side, such as arid deserts in the neighborhood of wet and flood-prone plains.
4. In terms of human and animal suffering and loss, weather disasters have a deeper impact in the tropics.

More recently, however, it has been recognized that caution must be exercised when making such generalizations (6). The tropics contain a wide range of climate, and so do the temperate regions. More importantly, the influence of climate on human activities is far more complex than what can be captured through climatic variables alone. A host of mutually interrelated factors are involved, such as topography, soil and vegetation types, land-use patterns, and the structure of the economy.

For this chapter the most important view is that the nature of economic activities in tropical countries is highly sensitive to the variability of weather. The most obvious feature of tropical economies is their dependence on agriculture, which is critically sensitive to weather. In contrast, a larger proportion of economic activities in temperate countries consists of manufacturing and services, which are relatively weather insensitive. Also, the capacity of the temperate societies to absorb climatic shocks is higher. For example, a drought in the United States, a hard winter in the United Kingdom, or an extensive frost in the Soviet Union do have obvious economic ramifications, but these societies are at such levels of economic output that they can generally absorb the damage quickly. In contrast, much of the Sahelian population lives near subsistence and at the same time is dependent on meager and uncertain rainfall. Abnormal monsoons and droughts in the last two decades have caused starvation for more than 10 million of the Sahelian people, wiped out 30–80% of its livestock, and almost all of its other forms of savings as well as exports. This disruption of the Sahelian economy has been a tormenting experience from which recovery can only be slow and prolonged.

An obvious response to the high sensitivity of tropical economies to weather fluctuations has been to change the composition of economic activities toward greater weather insensitivity; for example, to have a greater dependence on irrigation rather than on rainfall for agriculture. This response is clearly desirable and, as we shall see later, it requires substantial information concerning weather and climate. Furthermore, we need to recognize that the scope of this response is limited by natural conditions as well as by resource limitations and time considerations. In India, for example, it is projected that by the year 2000 only 42% of the agricultural land can be irrigated (7). Such projections not only reflect the resource constraints over time, but also the fact that in many regions irrigation is technically not feasible and is prohibitively costly. Also, the dependence of a sizable part of the population on climatically marginal areas (areas in which agricultural productivity is most sensitive to weather fluctuations) is likely to continue, given the lack of alternative employment opportunities.

Under such circumstances, it would be prudent to recognize the potential gain from developing the use of climate and weather information, and consider generation and dissemination of useful information on weather and climate as an important form of productive public investment in tropical countries.

## 2 ECONOMICS OF WEATHER INFORMATION

Economists have made significant progress in the last two decades in understanding the nature of information and the role it plays in economic behavior. Some of this understanding is directly relevant to how one should think about weather information. [Gilbert and Stiglitz (8) and Stiglitz (9) provide a comprehensive discussion.]

First, information has an economic value only when it changes individuals' actions. If people take one action when they possess certain information, and another action when they do not, then the value of information is the expected gain from the former action *minus* the expected gain from the latter action. Naturally, information is valueless if people take the same action whether they do or do not possess the information.

This economic perspective is often not the one through which physical scientists view information. Information on past climate patterns collected on computer tapes, for example, might be considered highly valuable by atmospheric scientists. From an economic viewpoint, however, value arises only if the data lead to a determination of decision rules that users (say, farmers) adopt (in their own self-interest) while selecting among alternative courses of action. Therefore, the units of measurement of information that physicists and communication engineers typically employ, such as *entropy* or *bits*, are of little or no consequence from an economic viewpoint; what matters is the money value of information *in use*. Further, the same piece of information may have different values for different individuals, depending on its use. One would expect, for example, a large farmer to gain more, in an absolute sense, from agriculture-related climate information than a smaller farmer. If one abstracts from the refinements of social cost–benefit analysis, then the society's gain is the aggregate of all individuals' gains. The net social benefit (or the rate of return) is obtained by deducting the total cost from the aggregate gain.

This approach to measuring the value of information has some consequences in setting up research priorities. Clearly it is better in the short term to focus scientific efforts on generating a type of information that is likely to have higher value to the users. This, however, is not always the kind of research that is most appealing in scientific terms.

Two other points need to be mentioned. First, weather information differs in some important ways from certain other kinds of information. In a stock market, for example, one person's gain from having inside information concerning a corporation depends on how many other people have the same information. In the agricultural use of weather information, any one farmer's output is not affected by the information of others.

Second, it has sometimes been suggested that the users of better weather information might not gain because of what economists call the general equilibrium effects (10). Specifically, it is argued that if all farmers use better information, then their output would be higher which in turn, might reduce the prices of farm output leading to a social loss. This is quite a narrow view; it ignores not only the gains to consumers from lower prices but also a number of other aspects such as the possibilities of international trade and the movement of productive factors across different economic activities within the economy.

A final important feature of weather information in developing countries is that, at least in the near term, it is the governments and not the private sector that will have to supply it. Until tropical weather data sources and forecasting capabilities have reached an acceptable minimum, as they have in developed countries, private firms will not have sufficient incentive to invest in weather and climate research and applications.

## 3 CLIMATE- AND WEATHER-RELATED ACTIVITIES

The three main categories of climate- and weather-related activities are: (1) climatology, which entails collection and analysis of past weather data, and provides a more rational basis for making choices of activities in various sectors such as irrigation, plant husbandry, housing design, and land use planning; (2) weather and climate prediction, that is, the short-term and medium-term prediction of weather variables such as rainfall, temperature, hail and cyclones, and prediction of average weather conditions on monthly, seasonal, and interannual time scales; and (3) study of climatic trends, on still longer time scales, due to both natural causes and human activities. Though these categories are related scientifically, they differ in how far the available knowledge has advanced, the likely economic potential, the lead time after which the resulting information can be applied operationally, and the costs and benefits in extending the technology beyond what exists at present. A fourth category, not discussed here, consists of weather modification, such as rain formation and hail suppression. See Sah (4) for a discussion.

### 3.1 Climatology

It is easier to understand climatology if it is distinguished from weather and weather prediction. "Climate" is the statistics of the "weather." Climatology involves collection and analysis of past weather data on rainfall, temperature, sunshine, and wind patterns to obtain reliable inferences on the overall pattern and the range of weather that is likely to occur in the future. These inferences are then employed along with a variety of other data to identify those activities that are likely to be more compatible with the local climate than other activities. Thus, climatological information can lead to a better choice in areas such as irrigation design, groundwater extraction, crop type and cropping pattern, construction and transportation design, and plans for mitigating natural disasters. In contrast, prediction of weather—say, one day to a couple of weeks in advance—is best used in selecting the timing of operations, such as scheduling of sowing, irrigation, harvesting, construction, and recreation. This set of decisions is more operational in nature.

Some examples can present a picture of what climatology can do (11). If the past climatic data at a place shows large year-to-year variation in the number of rainy days in a cropping season, then subject to soil and hydrological characteristics of the region, it might be preferable to use those seed varieties that have shorter growth periods. These varieties may have lower yield in any one year but, over a number of years, the average yield may be better than varieties requiring longer growing periods and hence having higher overall susceptibility to weather fluctuations. These concerns have led to some interest in studying certain crop varieties and farming techniques that might better accommodate the peculiarities of monsoon behavior. Swaminathan discusses this in Chapter 6.

Climatological information has also been found useful in defining favorable periods for sowing and harvesting, estimating the irrigation needs of a region, determining optimal irrigation schemes (to avoid under- and over-irrigation), suggesting useful timing and methods for frost prevention and protecting plants and animals. Climatic variables, for example, have a pronounced impact on the growth and the intensity of attacks by pests, insects, locusts, and a variety of animal diseases. Depending on current conditions and past experience, warning can be quite useful to cultivators on the likely areas and the nature of an impending attack, so that the resulting losses could be reduced.

A landmark example of what can happen when climatological information is not employed is the East African Groundnut Scheme of Great Britian (12). In 1947, the British government implemented a scheme for mechanically cultivating groundnuts on 3.2 million acres of monsoon areas in East and Central Africa. The British government reported the capital cost to be about £24 million at that time, and the operating cost to be about £7 million per year. The project was expected to bring a net annual benefit of £10 million to the British government. Groundnut was the crop choice because the average annual rainfall appeared to be suitable for it. However, no analysis was done of the weekly pattern of rainfall within a year and the year-to-year variability in the timing and the amount of rainfall. It turned out that the variation of rainfall within a year and between years was such that groundnut was a doomed crop. Not surprisingly, the project had to be abandoned within five years with large losses. This financial disaster occurred because climatological factors were not taken into account.

A number of areas exist, other than agricultural, in which climatological information can be substantially beneficial. In land-use planning, such information can lead to a better allocation of land for activities such as agriculture, dwelling, pasture, industry, and recreation. In the past, many settlements have attempted to defy their local climate with unfortunate consequences. The imperial city of Fatehpur Sikri in India, for example, was begun in 1570 by Akbar and abandoned only 16 years later, primarily because of a severe lack of water.

In more recent times, we do not abandon, we just live in misery. The accumulation of industrial pollutants in many newly growing Asian cities is an important example of what can happen when industrial units are located in complete indifference to the prevailing wind direction.

Furthermore, a number of large-scale developmental schemes are being undertaken in developing countries for which no precedent and very little experience exist. Some of these activities include deforestation of large areas for agriculture and habitation, reforestation schemes, introduction of new animal and seed varieties, development of alternative sources of energy, large housing and town planning schemes, and opening up of areas previously uninhabited because of harsh environmental conditions. Not only are many of these projects crucial for the development of the areas concerned but also the success of these schemes is highly dependent on an adequate knowledge of the climate. In fact, an incomplete understanding of the local climate and its interaction with other factors could lead to costly mistakes. In all new agricultural projects it is necessary to insure that the agricultural practices adopted do not erode the soil—an experience common in many parts of the world. Such mistakes may be irreversible. It takes thousands of years for soil to acquire productive properties that it could lose almost instantaneously.

Applications of climatological information are highly desirable for several reasons. First, the state of the art for the collection and analysis of climatological data for many applications is well developed and can be employed immediately. Variations on the applications will obviously be required in different countries since there are climatic differences not only across countries but also within a country; but new research is not required to make use of climatic information. The crucial needs are trained personnel, reliable data collection, and proper analysis of the predominant local activities and the needs. Once these have been achieved, the applications must be tested and the results of the experiments effectively communicated. Second, the cost of climatological information is quite small compared to the possible benefits. For example, the cost of climatological information as a percentage of the total cost of a project has been estimated at about 0.01% for large hydrological works, 0.02–0.03% for housing construction and about 0.5% for town planning. The resulting benefit–cost ratios have been found to range from 50:1 to 2000:1 depending on the application (11).

## 3.2 Weather and Climate Prediction

A complex and dynamic interaction takes place in the earth's atmosphere which involves solar radiation, water vapor, oceans, icecaps, plants, and animal organisms. These interactions are the key to weather and climate prediction. The interrelationships, however, are only partially understood at present as the reader will discover later in this volume.

The three principal methods of predicting weather, with increasing sophistication, are: synoptic forecasting, statistical methods, and numerical (dynamical) modeling. These methods, or some combination of them, may, in principle, be used for climate prediction. However, the feasibility of using dynamical models for operational climate prediction has only begun to be studied (see Chapter 16).

In synoptic forecasting, the recent trends in weather or climate are examined and compared to similar situations experienced in the past. The forecast is based on the extrapolation of current trends arising out of such an analysis. Forecaster experience plays an important role in this method.

In statistical approaches, a large number of atmospheric and oceanic data at different places in the world are analyzed to obtain the best statistical correlations with the weather or climate at the prediction location. The summer monsoon in India, for example, has been found to have some statistical correlation on monthly and seasonal time scales with parameters such as the rain in South America and the snow accumulation over the Himalayas (see Chapter 16). In the recent past, satellite observations have enhanced the potential of statistical methods by providing worldwide observations (13).

The most sophisticated technique for weather prediction is numerical modeling. Here, the physical laws governing the atmosphere are used in a large computer model of the atmosphere to forecast its future state from current weather data. This methodology has undergone extensive development in and for the temperate regions and is now being used by many national weather services for operational forecasting. Some experimentation has been done with numerical modeling for the monsoon weather system, particularly for the Indian monsoon system. (See Chapters 15 and 16.)

In recent years, a combination of these three methods has been used in many Western countries to make operational weather predictions for the Northern Hemisphere mid-latitudes. The hourly forecasts of rainfall and temperature during winter are reliable up to 36–48 hours in advance and experiments have demonstrated useful forecasting skill up to one week in advance (14). Heavy snow can be predicted with skill 24 hours in advance. The prediction that a thunderstorm or tornado will hit somewhere within a prescribed area can be made several hours in advance. Average daily temperature and total precipitation forecasts are routinely available 3–5 days in advance. Most of these developments have occurred during the last two decades or so, with the advent of computers and satellites, which have facilitated the tasks of data collection, communication, storage, and processing. More recently, empirical or synoptic/statistical methods have been used by a few temperate zone countries for climate prediction on monthly and seasonal time scales. In the United States for example, for the past several years both operational and experimental forecasts have been available (15, 16).

In contrast, weather and climate prediction capabilities in tropical countries vary from nonexistent to qualitative predictions made 10–12 hours in advance, though exceptions exist such as in India (17). (See Chapter 17.) Typical forecasts have extremely limited usefulness for economic activities. Also, the advances that have taken place in the prediction of temperate weather are not always transferable to the tropics. The data requirement in the tropics often is different, and the present understanding of the tropical atmosphere is somewhat limited compared to that of the temperate atmosphere.

In the last decade, special efforts have been made to collect data on the tropical atmosphere. These efforts have been directed and financed largely by countries in the temperate region. A major reason is that some of the data needed for prediction beyond several days in advance in the temperate zones is the same as that needed for short-term and medium-term prediction in the tropical regions. This situation has resulted in bilateral and multilateral basic research efforts, the most ambitious of which was the Global Atmospheric Research Program (GARP), organized jointly by the World Meteorological Organization and the International Council of Scientific Unions (18–20).

Such collaborative programs can be quite useful to many developing countries since their resource limitations may inhibit mounting similar programs on their own. Apart from obtaining global data, a country can acquire access to modern equipment and a well-trained body of international scientists at a relatively small cost. However, these collaborative efforts should be viewed as complementary since the physical processes to be modeled in the tropics are often different from those in the temperate regions. The models constructed for medium-range prediction of temperate zone weather would probably not incorporate some of the aspects of the tropical atmosphere and may not be useful for tropical day-to-day forecasting. It would be necessary, therefore, to construct regional models with greater details of local weather in the tropical countries. This is being done by some atmospheric scientists but their research is in its early stages (see Chapter 16). The operational forecasting centers in developed countries continue to focus on their regional weather and climate requirements and this is not likely to change. Tropical countries must therefore invest in the development of their own forecasting capability.

The most important point here concerns the kind of weather prediction that developing countries should attempt. Alternatively stated, what aspects of weather and climate prediction are likely to be most profitable? The main aspects of a prediction are its lead time (one day in advance versus one month in advance), the time resolution of prediction (hourly forecast versus daily forecast), the spatial resolution (single prediction for 100 $km^2$ versus 10,000 $km^2$), and the conditionality of forecast (prediction of rain on the seventh day from today, if there is rain on the third day from today).

From an earlier discussion on the value of information, it should be obvious that finer information (or more detailed information) has a higher value, since more detailed information would never be worse. But at the same time, the technology for obtaining finer information has a higher direct cost; also it takes more time to develop, and the research venture is typically riskier. All of these add to the real cost of the project. Furthermore an examination of economic activities in the tropics indicates, as we shall see below, that the kinds of weather prediction which would bring large economic benefit does not necessarily involve great detail.

In South Asia, about 65% of the food-grain output is produced during the summer monsoon (June to September), the sowing for which is done immediately after the first major shower around June. The success of the sowing depends crucially on the onset of the monsoon, that is, whether the first major shower is followed by days of extensive rainfall. Up to 60% of the seedlings can die because of severe moisture stress if the seven days after sowing are completely dry. This occurs every year in at least some regions in India with varying levels of intensity. The losses from futile sowing can be substantially reduced if a prediction is available that today's rain will not be followed by a week of completely dry weather. This prediction is obviously far less detailed than, say, an hourly prediction of the exact amount of rainfall seven days in advance.

Similarly, South Asian farmers gamble against nature during harvest time which roughly coincides with the withdrawal of the summer monsoon. Heavy rains, which usually accompany the withdrawal, can destroy up to 30% of the ripe crop if the crop is still standing in the field. On the other hand, if farmers opt for an early harvest, then the yield is lower because the crop has yet to mature. A prediction that indicates whether there will be no rain, some rain, or heavy rain in the next week would improve the farmers' prospects substantially. The main point of these examples is that it is important to examine the nature of economic activities to determine the actual requirements and from there decide what is the most desirable direction of research; the most sophisticated research on weather and climate may not be advantageous.

In this context, one should be aware of the time involved in developing weather and climate prediction capabilities. Past experience has shown that the time lag between completing research and routine application is anywhere between 5 and 15 years. Thus while basic research is under way, less sophisticated but immediately available methodologies can be developed and used. Predicting weather more than a few days in advance, while routine in developed countries, is very much at the research stage for the tropics. Thus if sustained efforts are made now by tropical countries, it could take 10–15 years to make reliable weather prediction 1 week to 10 days in advance.

An issue related to weather prediction is disaster amelioration, which is critically important in many tropical countries. The past emphasis has been to alleviate the misery after a disaster has occurred. The best response requires a mixture of long-term planning for disaster-prone areas (based on climatological information) and a reliable prediction and communication system. (Swaminathan discusses strategies to accomplish this in Chapters 6 and 19.) For weather disasters such as cyclones and typhoons, predicting the timing and path of disaster (once the storm has been identified) has been facilitated by the use of satellite, coastal radar, and instrumented aircraft. Beyond that, the prediction of disasters is still in the early stages of research and further work is needed to improve reliability and increase the lead time for which predictions can be made.

It is worth emphasizing here, however, that even with the very best weather prediction, it is nearly impossible to save most of the economic assets in disasters such as major floods and cyclones. Also, these disasters usually occur in the same general locations, that is, they are part of the climatology of a region. Although weather prediction can play an important role in disaster amelioration, it is no substitute for more permanent remedies such as land-use planning based on climatological information.

The cost of creating a major center for weather prediction in a tropical country is estimated to be in the range of $15–18 million. (These and other estimates of investments mentioned later in this chapter are updated from references 4 and 21.) The benefits can be much larger. A modest advancement in the weather prediction capability in India, for example, could save an average of $200–$300 million every year in food production alone. This saving, representing an increase of less than 1–1.5% in the food production, is easy to visualize given that there are widespread crop losses from futile sowing and damaged harvests. In the years in which monsoon abnormalities are more widespread, the country's food production is drastically reduced. For example, the food production in 1979–1980 was 110 million tons compared to 132 million tons in 1978–1979—a drop of 16% in a year, much of which is attributable to weather and/or climatic irregularities.

The gain, in fact, could be even larger since the benefits of weather prediction accrue to the nonagricultural sectors of the economy as well. A notion of the economic desirability of weather prediction can also be obtained from some calculations made for industrialized countries. In some west European countries, for example, the benefit–cost ratio of the investment in 4–10 day weather forecasts was estimated at 25:1 (22).

Though formal social cost–benefit analysis has not been done for LDCs since the detailed data required for such an analysis are not available, it is expected that the gains to these countries from investment in weather forecasting are likely to be quite high. Moreover, the cost of starting centers for weather prediction are primarily fixed costs (e.g., creating scientific institutions); the recurring costs are relatively small. The benefits, on the other hand, will accrue year after year. Furthermore, even if scientific advances are modest, in the sense that any one individual makes only a small gain, the total gain to the society would be quite large because weather affects the economic well-being of such a large proportion of the population in most developing countries.

However, to be of economic value, improvements in forecasts must be accompanied by effective communication of those forecasts and efforts to educate the farmers and other users. This point cannot be stressed too strongly; improved forecasts are of no practical importance unless the people have ready access to them and understand how to use them.

## 3.3 Study of Climatic Trends

Since the beginning of this century, experts have attempted to understand changes in the earth's climate on different time scales (e.g., changes occurring within a decade versus changes over hundreds of years). A host of factors interact in a way which is intimidatingly complex, and this interaction produces changes in the earth's climate. Some of the factors are the passage of the solar system through the galaxy, variability of solar radiation, varying orbit and wobble of the earth in relation to the sun, continental drift, volcanic activity, atmospheric composition, and the dynamics of the oceans and polar ice caps. A precarious balance exists among these factors, and small changes can have big effects. (Kutzbach and Shukla discuss these interactions in Chapters 10 and 16.)

It is also recognized that the variability of climate is the rule rather than an exception. Thus major climatic changes in the future would be as normal as those that occurred in the past. Numerous climatic changes are recorded within living memory. The Tigris–Euphrates valley and Indus valley once supported large agricultural societies. North Africa was the fertile granary of the Roman Empire. The Little Ice Age occurred in Europe in the sixteenth to nineteenth centuries when carnivals were held on the frozen Thames.

Other climatic changes occur over much shorter time durations. The productive fishery in Peru, Ecuador, and Chile, for example, depends on the cold nutrient water brought up every year to the ocean surface by a combination of winds and ocean currents. Periodically, the absence of this upwelling, known as El Niño, disrupts fishing with serious consequences on the economy of this region (see reference 23 on the recent El Niño). Similarly, the occurrence of drought once in every 5–10 years in Asia and Africa represents the normal variability of climate rather than an abnormality.

Another dimension has been added by the collective human activities which inadvertently could influence the earth's climate. The changes in the spatial and ecological nature of human activities, such as deforestation and urbanization, since the beginning of this century have been rapid compared to those in the preceding history. The possibility that these changes can affect climate has been raised with many persuasive examples. According to one study, 5.7% of the earth's surface, an area larger than Brazil, is man-made desert created in the last two thousand years (24). Another study has indicated that the Sahelian desert is expanding at the rate of about 19 inches an hour (25). The warming of the atmosphere due to increased carbon dioxide emissions from rapidly rising fossil fuel consumption has become a major issue of discussion and concern (26, 27).

More recently, some researchers have asserted that the climate during the last half century has been unduly kind to human beings and that this kindness may not last long. However, current understanding of the complex interactions which determine the earth's climate is so incomplete that the available projections of the long-term trends represent opinions rather than rigorous and widely acceptable scientific conclusions. In fact, final conclusions may not be available for some time to come. Nevertheless, concern over these issues has led several organizations in the West and in the USSR to put considerable effort into investigating long-term trends. The results of this research, when available, could be useful to other countries as well.

## 4 PRIORITIES FOR THE FUTURE

Weather and climate services have existed in many developing countries since the beginning of this century and, over the years, have grown in size. The incentive for this growth in most less developed countries has come primarily from the meteorological needs of civil and military aviation and navigation; for example, from the needs of international airports that must satisfy the requirements of weather facilities prescribed by international regulations. As a result, most weather scientists in these countries remain specialists in aviation weather; policymakers, on the other hand, have continued to fund ongoing activities without considering the new opportunities offered by weather-related research. As a consequence, many useful applications of weather information in agriculture and industry continue to be neglected. Also, the vital link between weather scientists and other professionals, such as plant scientists, irrigation engineers, hydrologists, and livestock experts, have not been nurtured at all.

In the last two decades, a few institutions in the tropics have attempted to work on weather problems. In India, for example, weather bulletins are issued daily and longer-range forecasts for the northeast and southwest monsoons are issued two months in advance. In Tanzania and Nigeria, agrometeorological bulletins are issued routinely. An agricultural and hydrological institution has been organized in Niger with international support. Also, one of the activities of the International Rice Research Institute in the Philippines is the development of rice and other crop varieties and techniques better suited to monsoon conditions. These organizations, however, are too few and they typically have not received adequate support.

The lack of awareness of the potential benefits from weather and climate information has probably been the single most important obstacle to its application to economic problems. In the past there was little initiative by weather and climate scientists to change this situation; they had made little effort to demonstrate the economic usefulness of their subject. This is changing, particularly in the developed countries (see, for example, references 28–35). Economists, too, have typically disregarded the possible contribution that weather and climate information could make as an input in production and other decision making. Finally, the unavailability of resources and the associated lack of data, processing equipment, and trained manpower have retarded the development of weather and climate information technology in the tropics. Here too, the future looks more promising than the past. In 1979, the World Meteorological Organization established a World Climate Program designed to address these shortcomings (36). This program is a first step towards the establishment of climate data access and research and applications within the LDCs.

Among the categories of weather- and climate-related activities earlier discussed, climatology (especially applied climatology) deserves the highest overall priority in developing countries because of the very high potential benefit (compared to the cost) it offers. The time required to establish organizations that use climatology is relatively short and the technical requirements to create such organizations are not prohibitive. These organizations would require equipment for data collection, a small computer, an interdisciplinary team of applied climatologists, and an effective network for communicating useful results to users.

The collection of local climatological data can be facilitated to some degree by involving users. Similarly, the communication of results to users can be enhanced by giving greater emphasis to the immediate and pressing needs of users, and less emphasis to the questions of longer-term scientific interest. More than one such organization would be required in large countries with widely differing climates in their various regions. However, these centers would be relatively inexpensive, costing initially about $1.5 million each. The lead time in developing them would not be long. Many tropical countries already have some manpower in this field; others can acquire it in 3–4 years.

Another priority should be to create weather prediction capabilities. Setting up one or more major meteorological research and prediction centers would be required for this purpose, and joint efforts by neighboring small countries could be advantageous. The primary goal of these regional institutions should be to provide operationally oriented forecasts for different activities. This should include region-specific routine guidance for agricultural operations, water management and related activities, and with somewhat less emphasis, general purpose weather bulletins to be used by other sectors.

Typically these institutions would cost in the range of less than $15 to $18 million each including the cost of physical facilities, a large computer, and the training of scientists. The time before significant results could be expected could be at least 10 to 15 years. Despite that, the benefits from weather prediction would be more than commensurate, as discussed earlier. These institutions can reduce some of their cost and lead time if they make full use of the global and regional networks for data collection and processing. Also the institutions could draw upon the expertise and information that has been accumulated for more than a century by the World Meteorological Organization and more recently by centers such as the European Center for Medium-Range Weather Forecasts.

The prospects of economic gains from weather and climate information are in some ways similar to those from the Green Revolution. The initial impetus for the Green Revolution was provided by concentrated efforts, amid a great deal of skepticism, leading to certain scientific breakthroughs. These in turn, have brought an unprecedented growth in the yield of several crops in developing countries in the last three decades. What this chapter has argued is that for the world's developing nations, many of which are profoundly affected by the vagaries of the monsoon, a strong case exists for creating capabilities in weather and climate research and applications. Such an effort is inherently risky since scientific efforts of this nature need not always produce the desired outcomes, but it is worth undertaking since the potential gains are exceptionally large compared to the costs involved.

## REFERENCES


1. C. S. Ramage, *Monsoon Meteorology*, Academic, New York, 1971.
2. World Meteorological Organization, *The Role of Meteorological Services in the Economic Development of Asia and South-West Pacific*, WMO No. 422, Geneva, 1975.
3. Government of India, *Economic Survey 1982–83*, The Controller of Publications, New Delhi, 1983.
4. R. K. Sah, *World Development*, **7**, 337–347 (1979).
5. R. K. Sah, in D. F. Cusack, Ed., *Agroclimate Information for Development*, Westview Press, Boulder, CO, 1983, pp. 295–300.
6. I. J. Jackson, *Climate, Water and Agriculture in the Tropics*, Longman, London, 1977.
7. Government of India, *Report of the National Commission on Agriculture, Vol. IV, Climate and Agriculture*, Ministry of Agriculture and Irrigation, New Delhi, 1976, p. 139.
8. R. J. Gilbert and J. E. Stiglitz, *Effects of Risk on Prices and Quantities of Energy Supplies*, Vol. 2, Electric Power Research Institute, Palo Alto, CA, 1978.
9. J. E. Stiglitz, *Information and Economic Analysis*, Oxford University Press, Oxford, in press.
10. L. B. Lave, *Econometrica*, **31**, 151–164 (1963).
11. R. Berggren, *Economic Benefits of Climatological Services*, World Meteorological Organization, Technical Note No. 145, Geneva, 1975.
12. A. Wood, *Groundnut Affair*, Bodley Head, London, 1950.
13. H. E. Landsberg, *The Value and Challenge of Climatic Predictions*, IX Meteorological World Congress, World Meteorological Organization, Geneva, May 19, 1983.
14. L. Bengtsson et al., *Bull. Amer. Meteor. Soc.*, **63**, 292 (1982).

15. D. Gilman, Long range forecasting: The present and the future, *Bull. Amer. Meteor. Soc.*, **66**(2), 159–164 (1985).
16. J. Namias, Remarks on the potential for long-range forecasting, *Bull. Amer. Meteor. Soc.*, **66**(2), 165–173 (1985).
17. R. A. Bryson and W. H. Campbell, *Environmental Conservation*, **9**, 51–56 (1982).
18. World Meteorological Organization, *An Introduction to GARP*, Vol. 1, ICSU/WMO GARP Publication Series, Geneva, 1969.
19. Global Atmospheric Research Programme, *The Monsoon Experiment*, GARP Publications Series 18, World Meteorological Organization, Geneva, 1976.
20. A. L. Hammond, *Science*, **188**, 1195–1198 (1975).
21. R. P. Pearce, *Research Priorities and Institutional Requirements in Tropical Meteorology Related to Agriculture and Hydrology*, mimeo, Consultant's Report to the Science and Technology Adviser's Office, The World Bank, Washington, D.C., March 1976.
22. Commission of the European Communities, Prospective Benefits from the Creation of an European Meteorological Computing Centre, Report by the Study Group on Benefit Analysis, No. 4, June 1972.
23. W. Brood, *The New York Times*, August 2, 1983.
24. C. Tickell, *The Climatic Dimension*, mimeo, Center for International Affairs, Harvard University, Cambridge, MA, May 1976.
25. N. Wade, *Science*, **185**, 2234–7 (1974).
26. W. W. Kellogg and R. Schware, *Climate Change and Society: Consequences of Increasing Atmospheric Carbon Dioxide*, Westview Press, Boulder, CO, 1981.
27. Carbon Dioxide Assessment Committee, *Changing Climate*, National Academy Press, Washington D.C., 1983.
28. Economic Commission for Africa and World Meteorological Organization, *The Role of Meteorological Services in Economic Development in Africa*, The World Meteorological Organization, Geneva, 1969.
29. W. J. Maunder, *The Value of the Weather*, Methuen, London, 1970.
30. R. Schneider, et al., *Applications of Meteorology to Economic and Social Development*, World Meteorological Organization, Technical Note No. 132, Geneva, 1974.
31. H. E. Landsberg, *Weather, Climate and Human Settlements*, World Meteorological Organization, Special Environmental Report No. 7, Geneva, 1976.
32. N. Nicholls, Long-range weather forecasting: Value, status and prospects, *Rev. of Geophy. and Space Phy.*, **18**(4), 771–788 (1980).
33. R. L. Winkler, A. H. Murphy, and R. W. Katz, The value of climate information: A decision-analytic approach, *J. Climatology*, **3**, 187–197 (1983).
34. B. G. Brown, R. W. Katz, and A. H. Murphy, On the economic value of seasonal precipitation forcasts: the fallowing/planting problem, *Bull. Amer. Meteor. Soc.*, in press.
35. A. H. Murphy, R. W. Katz, R. L. Winkler, and W. Hsu, Repetitive decision making and the value of forecasts in the cost-loss ratio situation: A dynamic model, *Mon. Wea. Rev.*, **113**(5), 801–813 (1985).
36. World Meteorological Organization, *Procedings of the World Climate Conference*, WMO No. 537, Geneva, 1979.