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Priorities of Developing Countries in Weather and Climate

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Summary. – The LDC performance is crucially dependent on climate, and the application of climate sciences can produce substantial benefits. This paper discusses: (1) the state-of-the-art and the potential of: climatology, weather forecasting, weather modification, and long-term trends in the Earth's climate; (2) economically attractive applications and research; (3) available climate-related capabilities in LDCs; and (4) rough estimates of costs, benefits, lead-times and institutional requirements for investments in weather and climate. Immediate investment in applied climatology and operationally oriented weather prediction is found highly desirable. The benefits would be substantially higher than costs if investments respond to priority needs. International cooperation would reduce cost and lead-time for LDCs.

1. INTRODUCTION

Although climate affects human activities everywhere, the impact of climate is felt more deeply in developing countries. Food and agricultural production in developing countries is critically sensitive to climate, and most developing economies are dependent on agriculture for their overall performance. Also, many parts of the developing world are climatically hostile areas (such as flood-prone, drought-prone areas and deserts) or are vulnerable to climatic disasters such as cyclones and typhoons. For example, during 1961–70, 22 countries in the ECAFE region sustained damage of $9.9 billion from typhoons and floods, an amount which was almost as large as the World Bank loans to these countries during this period (World Meteorological Organization, 1975, p. 69). The 1970 cyclone in Bangladesh killed about half a million people and displaced twice as many. In India, extensive investments and efforts have gone into achieving 2–3% annual growth in food production, whereas one bad growing season can lower the agricultural output by over 15%. Because of the structure of these societies, the total impact of climate goes much deeper in influencing the availability of goods and capital, prices, employment, growth prospects and the well-being of people.

Many advances have taken place in the last few decades in the understanding of climate and how it influences human activities. Some are directly applicable to development activities with immediate and large payoffs, while other advances require support in order to be useful in the near future. In the past, policy-makers have been been sufficiently aware of the ways in which the available knowledge of climate sciences can be applied in creating new opportunities and in improving the functioning of current economic activities. Given the crucial impact that climate has on developing countries, it is important to understand climate-related problems and the state-of-the-art in solving some of these problems. Such an understanding would help in identifying the knowledge of climate which can be used in various developmental situations, and also in guiding research on climate in a direction which has potential for the greatest contribution to economic development.

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The main categories of activities in weather and climate are: (1) collection and analysis of past climate data to improve medium and long-term planning in various sectors such as irrigation, plant husbandry, housing design and land use planning; this category is known as climatology; (2) short-term and medium-term prediction of weather – such as the prediction of rainfall, temperature, hail, cyclone etc.; (3) weather modification – such as rain formation, hail suppression and mitigation of natural disasters; and (4) understanding long-term trends in the Earth's climate due to both natural causes and human activities. These categories are related scientifically, but they differ from one another over the state-of-the-art, the likely potential, the lead time after which knowledge can be applied operationally, the relevance to developmental problems and costs and benefits in extending the knowledge beyond what exists at present.

In this article, we first present the differences between developed and developing countries regarding their climate and the impact it has on their economic functioning. With these differences in mind, we discuss the state-of-the-art and the promises offered by each of the four activities cited above. Then with a short discussion on the existing capabilities in developing countries, we proceed to suggest priorities for them in this field.

2. DEVELOPED AND DEVELOPING COUNTRIES

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 what is called the 'temperate' region. Developing countries are located within the two tropics, i.e. in the 'tropical' region.

Many observations have been made in the past regarding the dominant climatic differences between the tropical and the temperate regions. Some of these are: (1) The year-to-year variability in the rainfall in the tropics is higher than in the temperate region. This would mean markedly different tropical climate in successive years, and also that the tropical climate is less predictable. (2) The tropical rainfall has greater seasonality, i.e. intense rainfall in the tropics occurs only during certain short periods in a year. (3) Tropics have great extremes of climate present side-by-side, such as arid deserts in the neighbourhood of wet and flood-prone plains. (4) Climatic disasters occur more frequently in the tropics.

More recently, however, it has been recognized that caution must be exercised while making such generalizations (Jackson, 1977). Tropics contain a wide range of climatic phenomena, 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 single or multiple climatic variables alone. A host of mutually interrelated factors are involved, such as: the geographical patterns, soil and vegetation types, land-use patterns and the nature of economic activities.

It is obvious that a large proportion of the population in developing countries is dependent on agriculture and related sectors. These sectors are critically sensitive to weather. The economic performance of most developing countries is, thus, dependent on climate, and the ability of these countries to utilize their resources and manpower is restricted.[1] A larger proportion of economic activities in developed countries, on the other hand, is relatively weather insensitive. Also, the capacity of these societies to absorb climatic shocks is higher. For example, a hard winter in the USA, a drought in the UK or an extensive frost in the USSR do have economic ramifications, but the societies are capable of quickly absorbing the damage. The Sahelian population, in contrast, is dependent on meager and uncertain rainfall. The drought there in the last decade has caused starvation for about 10 million people, wiped out 30–80% of its livestock and almost all of the exports. This disruption of the Sahelian economy is a tormenting experience from which recovery could only be slow and prolonged. Thus, given the nature–man inter-relationships in developing countries, climate plays a more crucial role in these countries than in developed countries.

The response to the above situation has often been an attempt to modify the composition of economic activities in developing countries toward greater weather insensitivity. This response is restricted by natural conditions as well as by resource and time considerations. Policy-makers clearly recognize the need to strengthen agriculture and related sectors as an essential part of any kind of development. Also, the dependence of a sizeable 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 man–land ratio in these countries and given their pressing need for agricultural commodities. Irrigation can reduce only partially the impact of climate on agricultural yield because climate influences agricultural yield in many other ways than through water availability alone. In any case, irrigation has well-known constraints. In India, for example, it is projected that by the year 2000 only 42% of the agricultural land can be irrigated (Government of India, 1976, p. 139). Apart from reflecting the overall resource constraints over time, this projection reflects that in many regions irrigation is technically not feasible and prohibitively costly. It has also been found that the sensitivity of yield to climate has increased with the introduction of new crop varieties and other inputs, especially in unirrigated areas (Hanumantha Rao, 1975, p. 19).

Under such circumstances, it would be unwise to ignore the contributions that can be obtained by using the knowledge of climate sciences. A better knowledge of local climate would not only improve the selection of economic activities but would also add to the productivity in all sectors. The investment in acquiring and disseminating useful information on weather and climate thus becomes an alternative form of public investment. Economic prudence would suggest that the return on investment in weather and climate research and application should at least be examined to compare it with other investments.

3. CLIMATOLOGY

Understanding climatology is easier if it is distinguished from weather prediction. Climatology involves collection and analysis of past climatic data on rainfall, temperature, sunshine and wind patterns which, together with other data, provides conclusions on the type of medium- and long-term planning which would be most congruent with the expected weather in the future. Thus, climatology influences the 'capital' kind of decisions on assets and activities such as: irrigation design, groundwater extraction, crop type and cropping pattern, construction and transportation design, and plans for mitigating natural disasters. On the other hand, prediction of weather – say, one day to a couple of weeks in advance – would influence the timing and mode of operations, such as scheduling of sowing, irrigation, harvesting, construction, recreation etc.: a set of decisions which are more operational in nature.

Some examples can present a picture of the range and importance of climatology (Berggren, 1975). 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 hydrology characteristics of the region, it might be preferable to use those seed varieties which 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 other varieties requiring longer growth periods and hence having higher susceptibility to weather fluctuations. Apart from more desirable crop-mix and seed varieties, climatological information has been found useful in defining favourable periods for sowing and harvesting, in estimating the irrigation needs of a region and optimal equipment types to avoid under- and over-irrigation, and in suggesting the most useful timing and methods for frost prevention. An understanding of climate is also useful in plant and animal protection. The climatic variables have a pronounced impact on the growth and the intensity of attack of pests, insects, locusts and a variety of animal diseases. Depending on the situation and past experience, warning can be issued to cultivators on the likely areas and the nature of attack, so that the cost of prevention can be reduced.

In land use planning, i.e. the allocation of land for activities such as agriculture, dwelling, pasture, industry and recreation, it is important to use climatological information, so that the location of specific activities is in harmony with the climate. Historically, many settlements and activities have defied their local climate with unfortunate consequences. The city of Fatehpur Sikri in India, for example, was built by Emperor Akbar and abandoned mainly for climatic reasons. In more recent times, we do not abandon, we just live in misery. The accumulation of industrial pollutants in many Asian cities, for example, is a common feature because industrial units are located in complete indifference to the prevailing wind direction.

The East African Groundnut Scheme of Great Britain could probably be called the greatest modern day climatological blunder. In 1947, the British Government planned a scheme for mechanically cultivating groundnuts on 3.2 million acres in East and Central Africa. The capital cost, at that time, was about £24 million, and the operating cost was about £7 million per year. The project was expected to bring a net annual benefit of £10 million to the British Government.[2] Groundnut was chosen as the crop because the statistical average of annual rainfall was found most suitable for it. No analysis, however, was done of the weekly pattern of rainfall within a year and the year-to-year differences in the timing and amount of rainfall. It happened that the variation of rainfall within a year and between years was such that groundnut was a doomed crop. As a result, the project was abandoned within 5 years with a large irrecoverable loss. This was solely because of an incomplete knowledge of the local climate.

In specific areas of human activities such as rural and urban housing, information on temperature, wind pattern and radiation direction can lead to greater comfort at a marginal cost. In town planning, apart from temperature range and wind direction which affect pollution and other discomforts, it is also important to consider precipitation variables in order to design the sewage system and the storm drainage. At present, the flooding during the rainy season of numerous Asian towns by sewage water is a common phenomenon. In almost all civil and industrial construction, a knowledge of the extreme values of the climate experienced in the past is useful in selecting material properties of inputs and designs. This helps to avoid the excessive cost of overprotection as well as the losses from underprotection. For example, in Ulianovsk in the USSR, the pipelines were always designed to sustain 15 cm of ice deposits. A climatological analysis indicated that the deposits have never exceeded 10 cm; this resulted in substantial savings. Similarly, climatological information can help in making wiser decisions on dam and spillway design, fishing harbours, fishing grounds and fishing timings. The recent interest in exploring new sources of energy such as solar and wind energy is also dependent on adequate climatological information for its success.

Climatology has an important role to play in the planning of areas which are prone to natural disasters. Even with the best prediction capabilities for disasters such as typhoons, floods, cyclones, often it is not possible to save most of the productive assets. Also disasters occur more frequently at those locations which have a history of disasters. Thus, climatological information can be used in identifying micro-regions which are most prone to disasters, so that planning of assets and activities can be done appropriately. This issue will be discussed further in the next section.

A few additional reasons make climatology immediately relevant for developing countries. Firstly, the state-of-the-art of methodology of collecting and analysing data for various applications is well developed. Modifications will have to be made by every country because there are climatic differences across countries as well as within every country, but no fundamental research is required. The crucial needs are: trained personnel, data collection, adaptation of the techniques of analysis to suit the local conditions, data analysis for specific purposes, experimental applications and the routine communication of useful results. Secondly, the cost of the above activities is not very high compared to the benefits. The cost of climatological information as a percentage of the total cost of the project has been reported in a World Meteorological Organization (WMO) document at about 0.01% for large hydrological works, 0.02–0.03% for housing construction and about 0.5% for town planning (Berggren, 1975). The same document indicates benefit–cost ratios of climatological applications ranging from 50:1 to 2000:1 depending on the situation.

Finally, a number of large-scale developmental schemes are being undertaken in the tropical countries for which no precedent and very little experience exists. Some of these activities are: deforestation of large areas for agriculture and habitation, reforestation schemes, introduction of new crops, animal and seed varieties, multiple cropping, new plant husbandry methods, and opening up of areas previously uninhabited because of severe natural problems. Not only are these projects crucial for the development of the concerned regions, but also the activities to be undertaken are highly weather-sensitive. Thus, an incomplete understanding of the local climate and its interaction with agricultural factors could lead to costly mistakes and resultant misery. In all new agricultural projects, for example, it is necessary to ensure that given the local climate, the agricultural practices adopted do not erode the soil – an experience which has been common in many parts of the world. Such mistakes are costly. It takes thousands of years for soil to acquire productive properties which could be lost almost instantaneously. In general, an extensive knowledge of local climate should precede all large developmental projects.

4. WEATHER PREDICTION[3]

A complex and dynamic interaction takes place in Earth's atmosphere which involves solar radiation, water vapour, oceans, ice-caps, plants and animal organisms. These interactions are the key to weather prediction. The interrelationships, however, are only partially understood at present.

The three principal methods of predicting weather, with increasing sophistication, are:

synoptic forecasting, statistical techniques and numerical modelling. In synoptic forecasting, extensive data on the recent trends and the history of past trends in weather is examined and the recent trends are compared to the similar situations experienced in the past. The forecast is based on the extrapolation of recent trends arising out of the above analysis. The experience of the forecaster plays an important role in this forecasting.

In statistical techniques, a large number of weather variables at different places in the world are compared to obtain the best correlations with the weather at the place for which prediction is being made. The summer monsoon in India, for example, has been found to have some statistical correlation with the rain in South America and the snow accumulation over the Himalayas. These methods, however, are largely statistical, and have inadequate physical basis – i.e. they do not fully incorporate the scientific laws of heat exchange and fluid dynamics. Past experience has shown that the reliability of these methods for predicting rainfall does not extend beyond 1–2 days in advance. Statistical techniques have also been used in making seasonal forecasts (e.g. the coming season will be wet, dry, humid, cold or hot).

The most recent technique of weather prediction is numerical modelling in which the physical laws governing the atmosphere are built into a large computer model of the atmosphere, to which past data on a large number of weather variables is added. This methodology has been extensively examined for the temperate regions and is now being used as the basic forecasting aid by many weather services. Not much experimentation has been done with numerical modelling for the tropical weather system, but the consensus indicates its potential for the tropics.

In recent years, a combination of the above three basic methods has been used in western countries. According to the existing state-of-the-art, the best predictions are available for the northern hemisphere, in mid-latitudes, i.e. North America, for which hourly forecasts of rainfall and temperature during winter are reliable up to 36–48 hr in advance. Heavy snow can be predicted 24 hr in advance. The prediction that a thunderstorm or tornado will hit somewhere within a large area can be made several hours in advance. Average forecasts for daily temperature and total precipitation are available 3–5 days in advance. Most of these advances have occurred during the last 20 years with the advent of electronic data processing and satellites, which have facilitated the task of data collection, communication, storage and processing.

Weather prediction capabilities in the tropics, in comparison, vary from non-existent to qualitative predictions made 10–12 hr in advance. The available forecasts have rather limited usefulness for economic activities. Also, the advances that have taken place in the understanding of temperate climate are not directly transferable to the tropics because the combination of physical factors governing the two local atmospheres are different. The data requirement in the tropics is different, and the present understanding of the physics of the tropical atmosphere is limited compared to the temperate atmosphere.

In the last decade, some efforts have been made to collect data on the tropical atmosphere on a large scale. These efforts have been directed and financed largely by developed countries for their own purposes. It happens that the data needed for medium-range prediction (beyond 10 days in advance) in the temperate zones is the same as that needed for short-term and medium-term prediction in the tropical regions. In other words, the developed countries can understand their own weather fully only if they understand the tropical weather.[4] This situation provides an unusual opportunity to developing countries for bilateral and multilateral efforts. The most ambitious of these collaborative efforts is the Global Atmosphere Research Programme (GARP), organized jointly by the WMO and the International Council of Scientific Unions. The GARP intends to study in detail the atmospheric processes in the monsoon areas of Africa, Asia and the Pacific. This understanding is expected to extend the weather prediction capabilities considerably. The first phase of GARP, costing about $100 million, began in summer 1974 in the eastern Atlantic ocean. In this phase, a widespread combination of ships, aircraft, balloons, land stations and satellites was coordinated to observe every aspect of weather. Over 5000 specialists participated from 72 countries, and this effort was considered a major international success (Hammond, 1975).

The collaborative programmes of the nature mentioned above are very useful to developing countries. Apart from obtaining the global data, developing countries can acquire access to modern equipment and a well-trained body of international scientists at a relatively small cost. However, there are vital differences in the scientific and operational requirements of weather prediction between developed and developing countries, and hence these collaborative efforts can play only a partial and complementary role. Firstly, the physical processes to be modelled in the tropics are different from those in the temperate regions. The models constructed for the medium-term prediction of the temperate climate would probably catch only the macro aspects of the tropical atmosphere and may not be useful for day-to-day forecasting in developing countries. Thus, constructing regional models with greater details of local climate (including the information on mountain ranges, forests, etc.) would be essential for a meaningful prediction of the tropical climate.

The second difference between developing and developed countries is in the nature of the predicition which should be pursued with higher priority. This difference is significant. It has always been realized that the lead time and investment required to achieve reliable prediction depend on the characteristics of the prediction that is aimed for. These characteristics are: the advance duration of prediction (one day in advance or one month in advance), the time resolution of prediction (hourly forecast or daily forecast), the disaggregation over area (single prediction for 100 km^2 or 10,000 km^2) and the conditionality of forecast (prediction of rain on the 7th day from today if there is rain on the 3rd day from today). The complexity of the task of prediction grows with the detail and fineness of prediction. The general trend in North America has been to develop capability for hourly prediction of rainfall and temperature, which is more difficult a task than, say, prediction of average daily rainfall only.

A careful examination of economic activities in developing countries, on the other hand, would indicate that the type of prediction which would bring large economic benefit does not necessarily involve great detail or fineness. For example, in India, 65% of the foodgrain 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 is crucially dependent on the correct assessment of the onset of the monsoon, i.e. whether the first major shower is followed by days of extensive rainfall. About 60% of the seedlings can die due to moisture stress if the 7 days after sowing are completely dry. This phenomenon occurs every year in at least a few regions in India, although the intensity differs across years. 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 less detailed than an hourly prediction of the exact amount of rainfall 7 days in advance.

Similarly, Indian farmers face uncertainty 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, a very early harvest produces lower yields because the crop is yet to mature. The desired prediction in this case should indicate whether there will be no rain, some rain or heavy rain in the next week.

Thus it is important to examine the nature of economic activities to ascertain the type of prediction which would be economically desirable. Such an economic sense of priority can influence research and application efforts in a more useful direction.

Thirdly, it is necessary to be aware of the lead time, costs and benefits which are involved in developing weather prediction capabilities, so that research can be carried out on the techniques with long lead time, and less sophisticated but immediately available methodologies can be developed and used in the meantime. Past experience has shown that the time lag between research and routine application is anywhere between 5 and 15 years. Researchers on temperate climate are now working on weather prediction which is one month to a season in advance. In contrast, for the tropical climate, the problem of predicting weather one week in advance is very much at the research stage. Thus, if suitable and sustained efforts are made now by developing countries, it could take 10–15 years to make reliable weather prediction one week to 10 days in advance.

Finally, disaster amelioration will have to be an important aim in many developing countries. The general emphasis so far has been to alleviate the misery after the disaster has occured. The correct emphasis should be on a mixture of long-term planning for disaster-prone areas (which would require climatology) and the prediction and communication system (which would require weather forecasting). For short-term climatic disasters such as cyclones, typhoons, etc., the task of predicting the timing and path of disaster (once the disaster has originated somewhere) 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 research can improve the reliability and the advance duration of prediction. However, in order to make full use of such predictions, it is necessary to have an extensive communication system. For example, a warning in Dacca that a cyclone is going to hit coastal Bangladesh a few hours from now will not be useful unless this information is communicated to the millions of farmers who often go out to scattered river bed lands in the outlying areas. Further, as mentioned in the last section, even with an ideal prediction and communication system, only human lives can be saved and not the sources of livelihood. Thus, a balance between the advance planning of assets and activities on one hand, and a prediction and communication system on the other is essential. The same is true for long-term disasters such as droughts. While scientists are working on seasonal drought forecasts, in most developing countries such prediction can be only of partial help. For example, in the Sahel, the knowledge of impending drought alone could not have saved the most important Sahelian asset, namely cattle, in the absence of fodder and water for survival.

The cost of creating a major centre for weather prediction (discussed in the last section) in a tropical country is estimated to be in the range of \$10–\$15 million.[5] The benefits are much larger. A modest advancement in the weather prediction capability in India, for example, would save an average of \$200–\$300 million every year in food production alone. This saving, representing an average increase of 1–1.5% in the food production, is easy to visualize given that the localized crop losses from a futile sowing and damaged harvest are of the order of 50–60% and 60–80% respectively. In the years in which such events, along with other damage, are more widespread, the country's food production goes down drastically. For example, the food production in 1974–75 was 99.8 million tons compared to 120.8 million tons in 1975–76 – a difference of 20%, most of which is attributable to weather phenomena. The benefit figure presented above is only a part of the picture because weather prediction would be equally important to other sectors. A notion of the economic desirability of weather prediction can be obtained from some calculations which have been made for industralized countries. In West European countries, for example, the benefit–cost ratio of the investment in 4–10 days weather forecast was estimated (Commission of the European Communities, 1972) at 25:1. As mentioned earlier, the order of benefit will be larger in developing countries because of the higher weather sensitivity of their economic activities.

5. WEATHER MODIFICATION

The mythological rainmaker is back, not with his chants and whispers, but flying in a plane with a handful of silver iodide – so goes the popular impression. But in reality, the art of changing the weather is still considered to be in an experimental stage. The theory of seeding clouds to produce rainfall has been known for many decades. Several rain-making experiments have been conducted using different seeding materials. Different seeding mechanisms have been used, such as aircraft sprays, firing of rockets and shells and ground nuclei generators. Results have been reported from Australia, USA, Japan, USSR, Israel and India. But firstly, most experiments have not been accompanied by scientific scrutiny, and secondly, these experiments are inherently difficult and costly to monitor.

Some of the experiments have been examined by the international scientific community, and the final conclusion is yet to emerge. In a few cases, a definite increase in rainfall has been noticed over what could have been attributed to normal weather. In other cases, a decrease in rainfall has been observed either following the experiment or after a time lag. Also, the short and long-term ecological impact of extensive and regular weather modification in the region where modification is made and in the neighbouring regions is inadequately understood. Some other experiments have been attempted for fog dissipation, hail suppression and hurricane modification. Cold fog dissipation is now being done routinely at air terminals, but in very small areas. It is also claimed that Soviet hail suppression experiments in the Caucasus have been partially successful. But the results of all large-scale experiments, in general, have been varied and controversial. Despite these uncertainties, more than 60 developing countries have spent large sums of money to modify weather, mostly in the midst of a serious crisis. And a large number of scientific and commercial organizations, many of which are serious and genuine enthusiasts, are currently offering these services.

The WMO, after surveying available evidence, has concluded (cited in Goverment of India, 1976, p. 95) that weather modification is still largely at the research stage, and for this reason, weather modification should be undertaken only after the most careful study by experts of the particular situation, and on the understanding that the desired results may not always be achieved. Also the WMO has been planning an extensive experiment in weather modification, so that a more rigorous view on this subject can be taken.

An interesting way to look at rain formation is to consider it as one of the family of technologies which aim at deriving the maximum acre-footage out of the available water resources. Viewed in this way, the amount of water that can be obtained from rain formation at a given cost and uncertainty should be compared to the amount which can be saved from available sources by using new methods of conservation, utilization and management. Substantial water can be saved by using methods such as: spreading covering layers on ponds, reservoirs and tanks to reduce evaporation; replacing canals by conduits and lining canals to reduce seepage; placing overground moisture barriers to reduce soil evaporation; using underground barriers to reduce percolation etc. The utilization of water can also be improved by using innovative methods such as trickle irrigation, rainwater harvesting, run-off agriculture and saline water agriculture. The economics of some of these methods has been found promising, and can be improved by further research.[6]

6. LONG-TERM TRENDS IN THE EARTH'S CLIMATE

Since the beginning of this century, experts have attempted to scientifically understand the changes that are occuring in the Earth's climate in different time scales (ranging from the changes occuring within a decade to the changes over millions of years). It has been realized that a host of factors interact with each other at a scale which is intimidatingly complex, and this interaction produces the 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, composition of atmosphere and the dynamics of the oceans and polar ice-caps. A precarious balance exists among these factors, and small changes can have big effects. It is also realized that the variability of climate is a rule rather than an exception. Thus, major climatic changes in the future would be as 'normal' as the changes that have occured in the past.

Numerous climatic changes are recorded within living memory, even excluding the prehistoric changes such as many Ice Ages. 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 occured in Europe in the 16–19th centuries when carnivals were held on the frozen Thames.

There are other climatic changes which happen in much shorter time durations. The productive fishery in Peru, Ecuador and Chile, for example, is dependent on the cold nutrient water that is brought up every year to the ocean surface by a combination of wind pattern and ocean current. Periodically, the absence of this phenomenon, known as 'El Niño', disrupts the fishing. In 1972, the 'El Niño' coincided with a drought in the peninsula, both of which produced economic pressures.

Similarly, the occurence of drought once in every 5–10 years in Asia and Africa shows the normal variability of climate rather than its abnormality. One study has indicated that the Sahelian desert is expanding at the rate of 18 inches an hour (cited in Wade, 1971). More recently, one school of experts has 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, despite these assertions and evidence, we have very little understanding of the complex interactions which guide such phenomena. Therefore, the available projections of the long-term trends in the Earth's climate are more opinions than rigorous and widely acceptable scientific conclusions.

Another dimension has been added to the long-term changes in the Earth's climate by the collective human activities which inadvertently could influence the Earth's climate. The changes in the spatial and ecological nature of human activities since the beginning of this century have been vast and rapid compared to the preceding history. The possibility that these changes can affect climate has been raised with many examples. According to one study, 6.7% of the Earth's surface, an area larger than Brazil, is man-made desert created in the last two thousand years (cited in Tickell, 1976). The warming of atmosphere due to rapidly rising fossil fuel consumption has become a major issue of discussion and concern. Some doubts have also been raised on the possible climatic impact of the settlement schemes in the Sahel which might have altered the balance of climate. But no final conclusions are available and may not be available for some time to come.

Nevertheless, an awareness of these issues has led a few organizations in the West and the USSR to support scientific research enquiring into these long-term trends. The results of this research, when available, would be useful for developing countries in certain important ways. In the Sahel, for example, a knowledge that the intensity and coverage of the desert would grow or shrink in the next 50 years could substantially alter the development policies for these regions. Similarly, the type of productive activities to be promoted in the Thar desert in Rajasthan in India would be influenced by an understanding of the trend that the rainfall, temperature and humidity might assume in the future.

7. ORGANIZATIONS IN DEVELOPING COUNTRIES

Climate services were introduced in many developing countries by their colonial rulers around the beginning of this century. Over the years, these services have grown somewhat in size. The incentive for this growth has come mainly from the meteorological needs of civil and military aviation and navigation. For example, international airports – which are needed by all countries – must satisfy the requirements of weather facilities prescribed by international regulations. As a result, most weather scientists in developing countries remain specialists in aviation weather, and the funding of weather organizations continues to be guided by their traditional activities – despite the fact that modern aircraft need far less weather support than their counterparts of years ago. In most developing countries there is no plan for weather services, and the expenses incurred on weather organizations are treated as operating expenditures. This may well indicate that the policy-makers in developing countries have continued to fund the old activities over and over again, and that there is insufficient consideration of what is needed for the future.

Thus, despite the existence of weather organizations in developing countries, vast areas of useful applications in agriculture and industry remain neglected. Also, the vital link between weather scientists and other professionals, such as plant scientists, irrigation engineers, hydrologists and livestock experts has not been nurtured at all. In the last two decades, a few institutions in the tropics have worked on weather prediction with limited success. In India, weather bulletins are issued daily and medium-term forecasts for the Northeast and Southwest monsoons are issued two months in advance. In Tanzania and Nigeria, agrometeorological bulletins are issued routinely. Recently, an agricultural and hydrological institution has been organized in Niamey, Niger by the WMO with international support. These organizations, however, are few and generally do not receive adequate support. As a result, the performance of such organizations, including the forecasts issued by them, has been less than satisfactory.

The lack of awareness of benefits from the knowledge of climate was world-wide until a couple of decades ago. Since then, interest in this topic has grown in developed countries with reasonably good results. In developing countries, comparatively, climate is still treated by a large part of the people as an act of God about which very little can be done. The initiative to change this opinion has been lacking from climatologists as well as policy-makers. Climatologists the world over – especially those working on the tropical climate – have made very little effort to show the economic utility of their subject.[7] Economic planners, on the other hand, have disregarded climate in their theories of development either because of ignorance or because some elegance would be lost in the process.[8] The unavailability of resources, such as the data collecting and processing equipment and trained manpower, has also been a cause of the retarded growth of the climate sciences in the tropics.

8. PRIORITIES OF DEVELOPING COUNTRIES

Of the four categories of climate-related activities cited earlier, climatology, especially applied climatology, should have the highest overall priority in developing countries because of its immediate and potential use, and also because the costs and technical requirements of creating organizations for climatology are not prohibitive. The activities of these organizations would include: routine collection of climatic and other data through a network of agroclimatic stations, processing and analysis of data to identify indices of local weather variation and their relationship with large-scale weather variations, preparation of water vapour budgets, soil studies and ground water accounting, crop modelling and crop planning, and assisting in other specific tasks of planning and operations management. These centres 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 in it. Similarly, the communication of results to users can be facilitated by giving greater emphasis to the immediate and pressing needs of users, and lesser emphasis to the rigour of scientific analysis. More than one such centre would be required in large countries with widely different climates in different regions. However, these centres would be relatively inexpensive, costing initially less than $1 million each.[9] The lead time in developing such centres would not be long. Many developing countries already have some manpower in this field; others can acquire it in 3–4 years.

Another short-term priority would be creating weather prediction capability in developing countries. The setting up of one or more major meteorological research and prediction centres would be required for this purpose, and joint efforts by neighbouring small countries would be especially useful. The primary goal of these institutions would be to provide operationally oriented forecasts for different activities. This would include region-specific routine recommendations for agricultural operations, water management and related activities, and with lesser emphasis, general purpose weather bulletins to be used by other sectors.

For maximum benefit, weather prediction research should respond to priority needs. For example, in Bangladesh, research on cyclone behaviour should assume a high priority, whereas an understanding of drought phenomena should be important in north-west Africa. Typically, these institutions would cost less than $15 million each including the cost of physical facilities, a large computer and the training of scientists. The time lag for significant results would be 10–15 years. Despite that, the benefits from weather prediction would be more than commensurate, as discussed earlier. These institutions can significantly reduce their cost and lead time if they make full use of the global and regional networks for data collection and processing.

Developing countries should participate as much as possible in the multilateral efforts of WMO related to tropical climate. The benefits from such cooperation would be mainly long-term and would depend on the efforts to construct regional models and collect local data to complement the larger-scale data collection, monitoring and model building. Access to global data and the international scientific community at a low cost (less than $0.5 million for a country) would eventually help to provide more accurate prediction of the monsoon. Also, in formulating their own plans for weather and climate, developing countries could draw upon the expertise and information that has been accumulated by the WMO over the last 100 years.

Weather modification is somewhat uncertain at this stage. Competing technologies are available which can improve water availability and utilization. The research on long-term trends in the Earth's climate requires long lead times and expensive scientific equipment. Developing countries have pressing needs as well as resource constraints. Thus, without minimizing their importance, it would be reasonable to suggest that developing countries should undertake some exploratory research on these topics. But large-scale involvement should await the outcome of WMO efforts.

Developed countries and international organizations could assist developing countries by first creating an awareness of the need for climate-related knowledge, and then by keeping in mind the balance between the short-term and long-term priorities of developing countries while formulating specific plans for assistance. The assistance could include providing fundamental advances in the scientific understanding of the world (and tropical) weather system – advances which require large expenditures and an infrastructure for scientific research. However, for both developed and developing countries, it would be useful to exhibit a sense of urgency and priority in the climate-related activities in the tropics.

NOTES

1. On the basis of interregional comparisons within India, K. N. Raj (1976, p. 230–231) suggests that fluctuations in agricultural output can seriously impede the industrial as well as the overall performance of a region. His paper also suggests that the poorest people are affected most adversely by these fluctuations.

2. Based on the original project proposal released by HMSO in the late 1940s.

3. Some of the technical information presented in the first three paragraphs of this section is based on Pearce (1976).

4. This observation was made by Drs. J. Smagorinsky and C. Weiss.

5. Based on Pearce (1976).

6. The publication of the National Academy of Sciences (1974) provides an interesting summary of these propositions.

7. For exceptions, see Berggren (1975); Maunder (1970); Raman (1974); Thompson (1972); WMO (1975).

8. For exceptions, see Kamarck (1976) and the references contained therein. Also, see Lave (1963).

9. This estimate of investment has been communicated by a leading climatologist. Other estimates of investment presented in this section are based on Pearce (1976).

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