WILL IT RAIN TOMORROW?

Professor G. C. Asnani

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PROFESSOR G.C. ASNANI

Born in India (1922).

He was the holder of Competitive Government Scholarshi[ ]hroughout his secondary education. Passed Maticulation Examination [i]n 1939 with Distinction. Passed B.Sc. Honours in Mathematics and Physics in 1943 and M.Sc. in Applied Mathematics in 1945 from Bombay University. He immediately joined Indian Meteorological Department and after training, started working as a weather forecasting officer.

He worked at aviation and non-aviation forcecasting offices in India until 1961. While in service, he also carried out research in the field of forecasting for which he was awarded Ph.D. degree of Bombay University in 1959.

He was invited as a visiting scientist in the Department of Meteorology, University of California, Los Angeles, where he worked for one year (1962), particularly in computer simulation of the General Circulation of the Earth's atmosphere.

On return from U.S.A., he headed the section which was to prepare the "Mannual of Weather Forecasting" for the Indian region.

In 1964, he joined the first batch of senior officers recruited in India for the newly formed Indian Institute of Tropical Meteorology, Forecasting Research Division.

In 1968, he became the Head of a new Division for Training in Advanced Studies and Research Techniques.

In 1972, he became the head of Theoretical Studies Division.

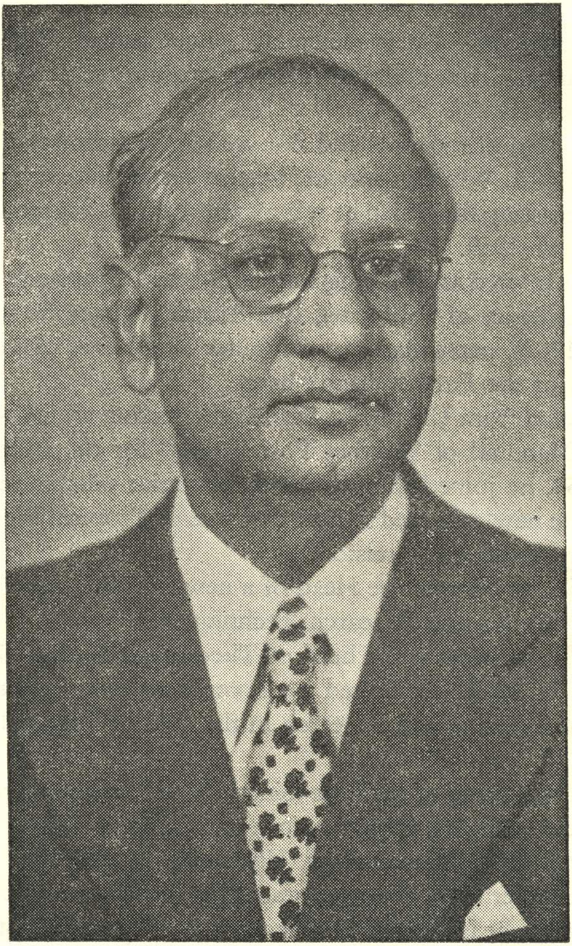
While in India, he served on several national committees for planning of Training and Research in the field of Tropical Meteorology.

In the beginning of 1975, he joined United Nations Organization (World Meteorological Organization) and came as WMO Expert in the Department of Meteorology, University of Nairobi.

In December 1976, he was promoted as Professor of Meteorology. Since that time, he is also the Chairman of the Department of Meteorology.

He is Life member of the Indian Meteorological Society, Member of the American Meteorological Society and Fellow of the Royal Meteorological Society, London.

His chief research interests lie in the field of improvement of weather forecasting in tropical regions through the application of of dynamical equations and the computer techniques.



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1. INTRODUCTION

I have been in the field of weather forecasting for more than 33 years, being in operational forecasting offices for about 16 years and in full-time research and teaching of this subject for about 17 years, and participating in weather forecasting discussions all these years.

For me, weather forecasting has always been a challenging job; a few occasions have been extremely embarassing. But I have always believed that we as weather forecasters should take the public into confidence and explain how we do our job, what the difficulties are and what we are doing to overcome these difficulties. I am sure that even if the forecast at the end goes wrong, you will appreciate the difficulties of the problem.

In a way, the title of to-day's talk is symbolic of the science of meteorology of which weather forecasting is an important component.

Meteorologists are being asked to answer a variety of questions like the following:

a) On which date will the rainy season start this year?
b) Is it going to be a year of floods or drought this year?
c) Are the seasons shifting?
d) Is the climate changing?
e) Are the deserts creeping?
f) Can we control rains and climate?
g) Are the satellites helping you to give better forecasts?
h) Is the air pollution affecting weather and climate?

These are all excellent questions and give evidence of public interest in weather and weather man's work. After all, meteorology is an expensive business. It is being financed from public funds and the public should be informed about what the meteorologists are doing.

In today's talk, I shall touch upon the questions mentioned above, directly or indirectly.

2. UNIVERSITY DEPARTMENT OF METEOROLOGY

Before I go into the Science of meteorology, I am sure that you will be glad to know that this University of Nairobi is the only one University in black Africa teaching meteorology at B.Sc., M.Sc. and

Ph.D level. We get our students not only from Kenya, Tanzania and Uganda but also from all other African countries like Zambia, Burundi, Malawi, Zimbabwe, Botswana, Lesotho, Mauritius, Nigeria, Ghana, Sierra Leone, Liberia, Somalia and Ethiopia.

I myself am here on behalf of the United Nations. I am absolutely sure that the African teachers and African students graduating from this Department of Meteorology will, before long, be going around to different countries of Africa and to other developing countries, teaching and spreading the knowledge of meteorology as experts under the programme of TCDC (Technical Co-operation among Developing Countries).

Here, I am happy to say that it has been my privilege to work with Africans, in African conditions, teaching and investigating meteorological problems which are of immediate importance to Africa.

This department started with practically one professor and one student, with United Nations support, at a time when all the officers in East African Meteorological Department were expatriates, the Africans themselves occupying only junior positions of Assistants and observers. Today, the three meteorological services of Kenya, Tanzania and Uganda are fully africanised and practically all of them have graduated from this Department of meteorology. Besides, the senior African meteorological officers of other African countries have also been trained in this department of meteorology of the University.

Today, we are turning out every year, about 30 B.Sc.'s/Postgraduate Diploma holders specialised in meteorology, about 4 M.Sc's and 1 Ph.D. In addition, we give introductory course in Atmospheric Science to about 40 students at First Year B.Sc level. These are the students who will not specialise in meteorology but will find meteorology useful in their field of specialization which is generally biological sciences. Furthermore, we conduct service courses for Faculty of Architecture and also for post-graduate students in the Department of Zoology.

Our Kenyan students who have specialised in meteorology are in great demand not only in the Kenya Meteorological Department but also in the Department of Water Development and Agriculture. Some of our courses specially deal with water resources, water management, relationship between agricultural crops and weather conditions, artificial weather modification, crop climatology, animal climatology, air pollution, satellite meteorology and forecasting with computers. These are taught at B.Sc. as well as at M.Sc. levels. The research topics at M.Sc as well as Ph.D. levels deal with the same problems. So far, there has been no dearth of jobs for our successful students and we see no dearth of jobs for them for the next five to ten years. At the moment, supply is less than the demand. We want more B.Sc.'s, more M.Sc.'s, and more Ph.D.'s in meteorology.

In order to ensure that we in our Department do not live in ivory tower isolation from the realities of life, from the demands of our society, we have maintained very close liaison with the Government departments and Research Committees so that we know which problems need immediate attention in our research and teaching. We have special relationship with Kenya Meteorological Department which has its Headquarters at Dagoretti. You will be glad to know that there is a Joint Council having representatives from both the University Department of Meteorology as well as from the Government Department of Meteorology. It co-ordinates training and research programmes at both the places. Professor Odhiambo is the Chairman of that Council. This makes our training and research programmes responsive to the needs of society. I personally feel very happy with this arrangement and I hope that such close co-operation prevails between the Government and the University in many other disciplines also. To make our teaching of practical utility, we have once in a week, weather map discussion in our Department at the University. Charts of the preceding seven days are brought from Dagoretti and presented by an officer of Kenya Meteorological Department who has actively participated in the analysis of the charts and in issuing daily weather forecasts from Dagoretti. The students and teachers at the University actively participate in the discussion that follows the presentation of these charts.

Satellite pictures received daily at Dagoretti are also presented during this weekly map discussion.

Several post-graduate students writing their research theses work at Dagoretti. We teachers of the University regularly visit Dagoretti to help them. During the academic session of the University, we have joint seminars, once in a fortnight. The speakers and participants are both from the University and the Kenya Meteorological Department. The venue of the seminars is generally alternated between Dagoretti and Chiromo. Library facilities at the two places are also jointly shared.

In the international scheme of forecasting, Nairobi is to function as a Regional Forecasting Centre, issuing weather forecasts for not only Kenya but also for half a dozen other neighbouring countries. The forecasters will use the latest computer and satellite technology. Our University Department is assisting Kenya Meteorological Department to achieve this objective early.

In addition to the co-operation with the Kenya Meteorological Department, we also have co-operation with Water Department, Agriculture Department, Kenya's National Committee for Geodesy and Geophysics and Kenya's National Committee for International Hydrological Programme.

Some of our Ph.D. and M.Sc. students are writing their research theses on the following topics:—

i) Kericho hailstorms—mechanism of generation and possibilities of hail suppression.

ii) Is the climate changing over Africa in general and over East Africa in particular? Are the deserts creeping outwards in East Africa?

iii) Monsoons of Africa.

iv) Characteristics of Kenya rainfall with applications for agriculture.

v) Rainfall over Tana and Nzoiya river catchments.

Some of theses completed are:

i) Pressure-wind relationship in tropical Africa.

ii) Air pollution in Nairobi.

iii) Estimation of evaporation over Lake Nakuru.

iv) Periodities and trends in annual rainfall over Africa.

v) Wind power in Kenya.

vi) Low level jet of East Africa.

Two of our recent findings are:

a) existence of periodicities but absence of persistent trend in rainfall over Africa.

b) 5-day oscillation in the low level jet over East Africa.

You would be interested to know that our Department of Meteorology has also been very closely involved in the UNEP/WMO programme of monitoring air quality on Mount Kenya. We analysed the data collected on Mount Kenya during the Feasibility Study period of about 18 months ending 30th June, 1978. You will be glad to know that on the evening of that date, after detailed analysis and discussion of the data, it was decided that Mount Kenya is a suitable site and that steps be taken to establish a Base Line Station to form a part of the global network of air monitoring stations.

3. APPLICATIONS OF METEOROLOGY

Meteorology has developed essentially as an applied science. With the growing pace of development throughout the world, greater and greater need is being felt for the climatological data of various kinds and also of the meteorological forecasts for longer and longer periods. Some of the services which are being rendered today by the Meteorologists throughout the world are sketched below:

a) **Aviation:** You may have noticed that an aircraft always takes off in the direction from which the wind is blowing. It also lands against the wind. The reason is that this somewhat ensures the stability and safety of the take off and the landing operations. Wind changes direction during the course of the day and also from season to season. With the help of the past meteorological data about wind directions, the Civil and Military aviation authorities are advised about the most frequent directions of winds so that the runways are constructed only in those directions from which the wind is frequently blowing at a place.

Before the aircraft takes off, there is flight planning. The temperature of the air at the time of take off determines the maximum load that the aircraft can carry. En route, the aircraft may encounter "head" winds or "tail" winds. The pilot wishes to take advantage of the "tail" winds, to save fuel if possible. He therefore plans a level of flight which is most favourable. If he has no way of escaping strong "head" winds, he must take extra fuel and correspondingly reduce the cargo. At the terminal, he may encounter adverse weather conditions like bad visibility (due to fog, dust haze or heavy precipitation) and severe turbulence due to thunder clouds and he may not be able to land. In such a case, he has to be prepared for a diversion to another airport. He should have sufficient fuel for such a diversion. He should also be immediately informed which airfield is open to receive him. The meteorological information is readily available to him for his help and guidance. To avoid last minute confusion and to ensure the safety of crew and passengers, the aviation authorities throughout the world have made it obligatory for the crew of an aircraft to get weather briefing from the meteorological office at the airport before the plane is allowed to take off. In this briefing, the pilot receives information about the actual as well as the anticipated weather conditions at the airport of take off, along the route and at the terminal. After he takes off also, the pilot is continuously in contact with the local Flying Control and Area Control, gives information about the weather conditions he has been encountering, and, in turn, receives information about any unforeseen weather conditions not included in the weather forecast which he is carrying with himself. When he lands, he tells the meteorological office at the other end what he thinks of the weather forecast which he received.

There are certain types of clouds which are hazardous for the aircraft, in any case for light and medium size aircarft and the pilots are advised to avoid getting into these clouds. Inside such clouds, one encounters heavy rain and even snow and hail, ice accretion on the wings, severe turbulence and blinding lightning strokes. Light and medium size aircraft try to avoid penetration into such clouds and try to go around them. Sometimes there is a long wall or squall-line of such clouds and the pilot cannot go round the cloud. The base of the clouds is also too low to allow the pilot to go under the clouds. The tops of such clouds are very high, sometimes as high as 15 km above the ground, too high for light and medium size aircraft to go above the clouds. Under such circumstances, the pilot has to turn back if he wants safety for himself and his cargo.

In the free atmosphere, there are zones of Clear Air Turbulence (CAT). There are no clouds; yet the aircraft experiences turbulence and passengers feel as if a vehicle is being driven along a rough road. This turbulence can at times be very severe and hazardous. Meteorological Office is expected to track such regions and caution all pilots flying through the regions.

It will be appreciated that while the passengers in an aircraft are resting or planning their programme after landing at the airpot, there is a whole community of meteorologists and aviation authorities at work to see that passengers arrive safely at the destination. The pilot himself is a sort of a meteorologist. Before a pilot gets an independent Flying Licence, he has to pass an examination in meteorology.

b) **Sea Navigation:** Please be sure that the vast oceans are not always as calm as you would wish them to be. The wind drives the oceans at the surface. There are weather situations, now quite familiar to the meteorologists but at one time intriguing, when the winds over an oceanic region become as strong as 150 kilometres per hour and continue being that strong for a few days at a stretch . Due to the exchange of momentum between the air and the sea according to the now well-known physical laws of turbulence, the sea water continously gains momentum from these winds, and literally gets churned by the winds. The sea waves grow in size and menacingly approach the ships sailing on high seas. In olden days, the captains sometimes became nervous when they found themselves caught into such winds associated with what are now called cyclones, typhoons or huricanes, gave sudden sharp turns to their boats and were lost on the high seas. There have also been occasions when seeing the approaching huge waves, the passengers on the deck all rush to the opposite side of the deck. The centre of gravity of the ship gets shifted. Then the impact of the wave water on the side of the ship further creates conditions for the ship to tilt to the side of the frightened passengers and the ship tilts further, throwing the passengers out into the turbulent waters. Fortunately, such incidents are now very rare.

The meteorologists monitor the weather over the open oceans day and night, identify hazardous weather situations and immediately alert all ships in the region. On board the ship, the captain regularly receives the briefing about the weather conditions in this region and he has to plan his operations accordingly. There is, by national and international arrangements, a continuous exchange of weather information between the ships on the high seas and the meteorological offices located on land. The Captain and the Navigator of a ship have to pass an examination in meteorology before they are given their professional certificates to sail on the high seas.

c) **Tropical Cyclone hits the Coast:** When the cyclones approach the coast, they bring with themselves the high winds of the open seas. The waves get enhanced by the physical blocking offered by the coastal shelf. The sea becomes more furious as if demanding free passage for itself right into the land along with the air of the cyclone. The coastal water rises as a wall, three to six metres high, roars and rushes over the land. At the same time, one gets very heavy rain, terrific winds, blinding lightning, deafening thunder and sometimes even earthquake tremours, as if all the elements of Nature have conspired to annihilate the society around the coast. The tidal wave roars and moves forward with determination, devastating the whole piece of coastal land, swallowing man and animal alike. It can penetrate even ten kilometres inland with a breadth of fifty kilometres along the coast. Once the people get caught by this tidal wave, survival becomes practically impossible. The devastation becomes more severe if the time of natural astronomical high tide coincides with the time of the cyclone crossing the coast. Situation becomes worse if the coastal land is flat. The record death toll in a single such tropical cyclone has been as high as 200,000 human beings, let alone the loss of cattle and other property. The saline sea water also leaves the land uncultivable for some time to come as also the well water unsuitable for drinking or irrigation. The roads are destroyed, human and animal corpses stink and spread disease and misery all around. It becomes a big national calamity.

It is the responsibility of each national meteorological service to look out for such cyclones and issue timely warnings to the public and to the administrative authorities to minimise losses. Fortunately, Kenya is not prone to the visits of such tropical cyclones.

d) **D-day Planning:** Meteorological information is regarded as strategic information in war time. Government meteorological departments then use secret codes to transmit meteorological information even inside their own countries.

Military operations like D-day operations during World War II were planned on the hope that particular weather conditions would prevail in the area of Allies activity. Meteorologists were consulted for that planning.

e) **Inexhaustible Sources of Energy:** At one time, petrol resources were considered almost inexhaustible and also readily usable. Events of the last decade have shaken the world out of this complacency and the world is seriously looking for alternative sources of energy. It is now universally appreciated that wind, water and sunshine are the inexhaustible sources of energy. Science of meteorology does not directly deal with the technology that is necessary before the energy can be made economically usable. However, the observations or estimates of wind, water and sunshine are directly the business of the meteorologists. Any plan for large-scale utilization of these inexhaustible sources of energy must involve active participation of the meteorologists.

Here deserts hold a new promise for the world. Weather regimes in deserts are generally stable, giving bright sunshine during the day. Wind regime is also stable. Vast lands are un-inhabitated; hence there is no difficulty in arranging power grid systems spreading over hundreds of square kilometres. With current pace of technological progress, it is not difficult to visualise that extensive solar and wind energy grid systems will be installed in the desert regions to supply pollution-free energy to large continents of the world, particularly in the border lands of semi-deserts where the need for energy is greatest.

f) **Agriculture and Water Management:** Crops greatly depend on weather conditions for short periods and for long periods. In many countries, the respective national meteorological departments issue weather warnings to agriculturalists informing them of the coming hazardous weather conditions like strong winds, low temperatures, frost, floods and droughts. Long term weather forecasts also help in making of long-term crop-yield forecasts.

Desert locusts breed faster under a particular set of weather conditions. As such, meteorologists do give a hint about the places where they are perhaps breeding fast, thus helping in locating them and possibly destroying them in their early stages of growth. If the locusts have already grown and are in readiness to fly in search of food, the meteorologists tell about the direction and speed of their flight because the locusts generally fly with the prevailing wind.

For design of irrigation works like dams, the meteorological departments advise the water departments about the normal as well as the anticipated extremes of rainfall in the catchment areas.

g) **Climatic Change:** To-day the public is more conscious about weather than before. Weather anomaly observed at any place in the world receives considerable publicity. There are speculations and public enquiries whether the climate of the earth is now changing. If so, in which direction is it changing? The present position in this respect is as follows:

i) Quantitative meteorological records over most areas of the world are less than one hundred years old. At very few places they are two to three hundred years old. Analysis of the meteorological records of the last 100 years shows that during this period, there is no evidence of a persistent trend of one-way change of weather conditions over large parts of the earth. Over small regions where townships and industrial areas have sprung up, temperatures are generally warmer than their open surroundings. However, this heating is taken as a small scale change and is disregarded in discussions of climatic changes.

While persistent trends over large regions during the last century can be taken to be absent, there is undisputable evidence of quasi-periodic oscillations of various periods. We say quasi-periodic because the oscillation periods are not very regular. Several periods make their appearance in the analysis of these past data. When we attempt to extrapolate the time series and try to forecast for the future, we run into great difficulties. There are oscillations with periods of 2, 5, 11, 30 years and more. The trouble is that between 2 and 5 years also, other periods like 2.3, 3.5, 4.2 and 4.7 are seen. Another difficulty is that two stations 300 kilometres apart may not show identical or even near-identical periods. There is even a possibility that the periodicities mentioned above are manifestations of random perturbations superimposed on a uniform mean state.

ii) The above statement is in respect of the meteorological data recorded during the last 100 years or so. This is not to say that there have been no climatic changes in the distant past. Defining climate as a statistical ensemble of weather conditions for a period of about fifty years, we can say with confidence that there have been several changes of climate in the past. This evidence has been collected from several sources like sediments, ancient soils, marine shore lines, layered ice cores, closed-basin lakes, mountain glaciers, tree rings, etc.

From evidence of this nature, it has been inferred that the earth has a major climatic period of 100,000 years each period or cycle consisting of a cold (glacial) and a warm (interglacial) epoch. Nine such periods have been identified covering a period of 900,00 years B.P. (Before Present). During glacial period, the temperatures are cold, water accumulates on land in form of ice sheets, tropical belt shrinks, the sea level falls, etc. The reverse happens during warm epoch. We are now in the warm epoch which started about 10,000 years back. Inside this 100,000-year cycle, there are smaller period fluctuations which can also be called climatic changes. Between 1500 and 1850 A.D., the earth passed through what is now termed as "Little Ice Age".

It may be remarked that between the Glacial and Inter-Glacial ages, the mean temperature of the earth's surface changes by about 10°C.

iii) The causes of these past climatic changes have been natural and are attributed to two types of causes:

Terrestrial: Wandering of poles
Continental drifts
Rising and sinking of mountains
Volcanic eruptions
Aerosols in the atmosphere
Ozone
Carbon Dioxide
Sea surface temperature
Ice sheets and glaciers

Extra-terrestrial:

i) Changes in earth-orbital parametres, changing the mean distance between the earth and the sun.

ii) Changes in intensity of solar radiation.

While in the past, these changes in climate had natural causes, the situation is slightly different now in as much as man's recent activity has been on such a large scale that possibility is not ruled out that man may cause, if he has not already caused, some changes in the climate on a large scale. Man is responsible for changes in Carbon Dioxide and aerosol content of the atmosphere and also for changes in forest cover over the earth. These can cause climatic changes as shown below.

Carbon Dioxide: Before the ushering in of the Industrial Revolution, carbon dioxide (CO_2) content in the atmosphere was 290 ppm (parts per million). In 1978, this has risen to 329 ppm. The current rate of CO_2 increase is 0.7 ppm per year. There are sources and sinks of CO_2. For example, plants absorb CO_2 during day and exhale CO_2 during night; man continuously adds CO_2 to the atmosphere through breathing process. Burning of charcoal and fossil fuel by man increases CO_2 content in the atmosphere. The recorded increase in CO_2 since the start of the Industrial Revolution has been attributed to excessive use of fossil fuels and charcoal burning in industry and locomotion. In the atmosphere, CO_2 has what is commonly called the "Green House" effect. CO_2 is nearly transparent to the incoming short-wave solar radiation which heats the earth's surface but CO_2 is practically opaque to the outgoing long-wave terrestrial radiation in certain wave-lengths emitted by the heated earth's surface. The heat which is caught by CO_2 warms up the atmosphere. The extra warming leads to increased evaporation and increased cloudiness. This leads to reduced penetration of incoming short-wave solar radiation and this type of braking influence operates in a chain fashion. Quantitative computations have shown that the net effect of increased CO_2 in the atmosphere to twice its present value would lead to the warming up of the atmosphere by about 2°C over tropical and middle latitudes and by about 10°C over the poles. Resulting changes in temperature gradient between tropical and polar regions would substantially alter the seasonal weather patterns at many places.

On account of the observed tendency of increase in CO_2 content of the atmosphere and its possible impact on the world climate, WMO is in the process of establishing a series of CO_2 monitoring stations. You will be glad to know that after about 18 months' observations on Mount Kenya and a few other possible alternate sites in Kenya, it was decided in the end of June 1978 that Mount Kenya is a suitable site for such monitoring purposes. Action is now in progress to build a permanent station there, involving co-operation between the Government of Kenya and the United Nations (UNEP and WMO).

Aerosols: Another element which man can contribute and which is considered important for climatic change is the aerosol content of the atmosphere. It influences radiative processes and hence the temperature in the atmosphere.

Some of the aerosols produced in industry have more than simple temperature effect. They can act as condensation nuclei favouring formation of large raindrops and thus enhance precipitation under certain meteorological conditions, if there be lack of such nuclei in some regions.

Still more than that, there are some industrial aerosols, for example, fluoro-carbons, which once produced, cannot be easily destroyed. Injected into the atmosphere, these act as enemies of ozone which is a trace constituent of the atmosphere, particularly in the stratosphere. In the total atmosphere of the earth, Ozone constitutes less than 0.1%. Yet, this small quantity of ozone protects life on this earth. It absorbs ultra-violet radiation component of the incoming solar energy up in the atmosphere before solar radiation reaches the ground. The heavy doze of ultra-violet radiation which is present in the original incident solar beam can cause skin cancer in human beings and possibly DNA damage leading to mutations. There can be equally severe damage to the health of other life species and plants on the earth-surface and in the upper layers of the ocean waters.

Fluoro-carbon aerosols are used in refrigeration, aviation oil, hair appliances, and personal anti-perspirant sprays.

Apprehending the permanent damage to life on this earth that can arise from unrestricted release of fluoro-carbons in the atmosphere, the Government of the United States recently enacted a law that effective from 15th October 1978, fluoro-carbons can no longer be sold to aerosol fillers and manufacturers. By 15th December 1978, aerosol manufacturers themselves are prohibited from using fluoro-carbons. After 15th April 1979, aerosols containing fluoro-carbons shall not be distributed in interstate commerce in USA. It is estimated that the fluoro-carbon propellant production in the United States which was more than 500 million pounds in 1973 will have decreased to less than 15 million pounds in 1979. More than 95% of the market in USA has been in fluoro-carbon 11 (CCl_3F) and fluoro-carbon 12 (CCl_2F_2). Of the releases of these aerosols in the atmosphere, more than 50% came from personal anti-perspirant/deodorant and hair appliances.

Canada intends to regulate the removal of fluoro-carbon propellants from anti-perspirant/deodorant and hair sprays by April 1979. Sweden and Norway are also expected to take action on similar lines.

Deforestation: Man has tended to remove forests, to use the cleared land for other purposes and to use the wood for fuel, furniture, building houses and for manufacturing paper, plastics and presently an increasing range of industrial articles. Deforestation on a large scale has great impact on climate of large regions. Incident solar radiation is partly reflected back because the earth's surface is not a black body surface. Forest surfaces allow only about 15% reflection while a barren land surface allows about 35% reflection. The solar energy which is caught by the earth's surface is utilised by plant life and other agencies. Excessive reflection over barren lands results in the net cooling and subsidence of the atmosphere over those regions. Subsidence leads to dessication of the atmosphere, less rain and more losses of water substance due to evaporation and evapo-transpiration. This is a sort of instability in which destruction of plants and trees leads to a chain process making the land more and more barren of plants and trees. This process is of particular significance near the broders of the deserts. It may be mentioned here that deserts cannot be entirely eliminated from the earth's surface because the equilibrium temperature difference between the tropical regions and the poles is such that with the present rate of rotation of the earth, the air has to rise in the tropical regions and has to subside in the sub-tropical regions. Laws of hydrodynamics demand this. There is no escape from this. It is for this reason that we see the earth's greatest deserts located in the sub-tropical region; for example the desert region extending along the Sahara, Arabia, Iran, northwest India and the Gobi region of China. Similarly we have the desert region in south America, south Africa and central Australia. Dry dust and sand blown out of these deserts has a tendency to create regions of excessive reflectivity with respect to incoming solar insolation and hence to create regions of atmospheric subsidence and regions of aridity on the earth's surface near the borders of these subtropical deserts. In other words, there is a natural tendency for the deserts to creep out to some extent. What we can do is to counteract this natural desert-spreading tendency through forest-conservation, aforestation, irrigation of border lands and introduction of plants and trees which can grow in such soil and weather conditions. Even the present soil structure has resulted from the weather conditions which have prevailed for thousands of years. We should not unwittingly resort to practices which will aggravate this tendency of the forests to creep out continually.

h) Weather Modification:

In winter, we wear warm clothes and heat our houses to keep the air temperatures in our immediate neighbourhood within certain limits which are comfortable for our bodies. Air conditioning came later on. We build wind breaks to keep air speeds low near our houses or agricultural farms.

On a slightly larger scale, rain-making was attempted through:

a) burning of incense and some plant leaves in continuous flames of fire.

b) firing shells of explosives and creating violent air vibrations in the atmosphere near the clouds and

c) chanting of religious hymns, prayers and performing rain-dances.

Subsequently, the sprinkling of charged sand particles into clouds was also attempted to induce rain but it had negative effect of dissipating the clouds. This however suggested that static electric processes have something to do with the rain process. During the last few years, this has received increasing attention.

A real revolution came in this field in 1946 when laboratory experiments of Langmuir and Schaefer showed that precipitation could be induced at environmental temperature of -1° to -2°C if we introduce artificial nuclei like solid carbondioxide while unaided by such nuclei, condensation may not take place until very low temperatures like -39°C were produced in the laboratory cloud chamber. This exciting discovery immediately led to experiments in the real open atmosphere where clouds having temperatures in the neighbourhood of -5°C were seeded with solid CO_2 or silver iodide. Some of these clouds were seen to develop pretty fast and they gave rain. Some did not and on the contrary rapidly dissipated after seeding with silver iodide. Those who were very much in favour of cloud seeding highly advertised successes and cloud seeding became a commercial venture. Several private companies sprang up, particularly in the United States, offering to make rain for private farmers. As is usual in commercial sales, there was aggressive advertisement of this technique of rain-making and real scientific interests began to wonder what was really happening in these commercial exercises. Scientific laboratories began to question the claims made by the commercial firms engaged in rain-making. They asked for statistical tests to prove that the rainfall which occurred would not have occurred without seeding. Some farmers complained that by seeding and getting the rain in upwind locations, somebody was depriving them of the rainfall which would have otherwise fallen over their fields. There were court litigations and inter-state disputes. Beautiful science went into disrepute. All claims of rain-making successes were looked upon with some sort of suspicion. To put back this subjet into its proper scientific place, the World Meteorological Organization has set up a committee to conduct controlled experiments, with proper statistical tests under the Precipitation Enhancement Project (PEP). It is hoped that within about five years from now, some reliable information will become available on the effectiveness of various techniques on artificial rain-making. Also in this project, greater emphasis will be placed on understanding of the micro-physical processes that operate inside the cloud above and below the freezing level before the precipitation is released. If the old techniques are not effective, some new techniques might be invented to get more precipitation. It must be emphasised that in this artificial rain-making business, no one hopes to get rain out of blue skies. There must already be clouds of some thickness which must be seeded. In other words, possibilities do exist for rain occurring by natural proceses without artificial seeding. It is here that the controversy arises. If we did not interfere with clouds, then also some rain is likely. How much then is to be attributed to artificial seeding? If artificial seeding only displaces the area of natural rainfall, then is it fair to deprive the down-wind areas from their share of natural rainfall?

Cloud seeding has been used not only to enhance precipitation but also to reduce hail damage. The essence of this technique is to introduce a large number of artificial seeds in "appropriate" regions of the growing cloud at "appropriate" stage of its growth so that a very large number of hail embryos compete to get a share from a limited supply of supercooled water in the cloud, with the result that none may get a very large share to grow into a large hailstone. There have been claims and counter claims in this business of hail suppression also. Opinion is divided at this moment if there is really a method of hail-suppression available at the moment. It may be stated here that one commercial firm had been functioning in Kericho area (Kenya) charging money from the owners of tea estates for their hail-suppression operations. It operated for a few years but is not operating there now. The commercial firm claimed success but vital statistical data which are necessary to assess objectively the results of these operations were not available to the scientific world. One of our students is writing Ph.D. thesis on these Kericho hailstorms and efforts at reducing their hail damage.

Under the heading of weather modification, we must also consider the efforts made at clearing fogs at some airports. Occasionally, airfields are enveloped in fog and no aircraft is able to land or take off. Under certain circumstances, it becomes very desirable to make the airfield open to aircraft as early as possible without waiting for nature to take its own course of fog-clearance. Fog is nothing but cloud at ground level itself. One way to lift this cloud is to heat it from below. This is the nature's process operative after sunrise. Solar insolation gradually heats the ground which in turn heats the fog cloud from below. It is lifted up in the form of low stratus cloud which later breaks up further to form fair weather cumulus clouds. Some airfields are provided with heating pipes close to the ranways to be operated in case of fog in the morning.

One can also disperse the fog by seeding the fog cloud with appropriate aerosols to hasten condensation and precipitation of substantial water substance from the cloud at the ground itself. The seeding material depends on the temperature of the fog cloud.

Artificial rain-making, hail-suppression and fog dispersal are relatively small scale operations in the field of weather modification. Larger ventures are:

a) reducing the intensity or altering the track of tropical cyclones;

b) Shifting the rain-belts over continents with a view to reduce the hardships of some semi-arid regions on the earth's surface.

Handling a tropical cyclone is a big affair and needs enormous effort in the terms of money and manpower. This investigation is financed by the U.S. Government Agency under the Project name "STORMFURY". They performed a few experiments inside the tropical hurricanes in the Gulf of Mexico. The results are still inconclusive. The Project meteorologists seeded the tall convective clouds in the outer part of the clould wall of the hurricanes believing that this would shift the cloud wall outwards and then by the law of conservation of absolute angular momentum, this would bring about reduction in the intensity of winds near the cloud wall. At present, the results are inconclusive.

There have been suggestions that the ice in the Bering seas may be artificially melted thus opening the communication between the arctic and north Pacific waters. It is difficult to forecast precisely as to what will happen. However, it is certain that some major changes in world climate can occur if by this process, we are able to alter significantly the temperature gradient between the tropical and polar regions. This may prove beneficial for some nations and harmful to others. There can be serious international disputes. It is not advisable to embark on such a project unless we know what would happen.

A few years back there was serious international debate whether heavy cloud seeding used in the Vietnamese war to flood the communication paths in strategic areas was responsible for large global anomaly in the weather during 1972.

4. HOW DAILY WEATHER FORECASTS ARE MADE

There is a global network of surface and upper air observatories which take meteorological obsevations at standard times, internationally fixed in terms of Greenwich Mean Time (GMT). This is three hours behind East African Standard Time (EAST). Standard hours of observation are 00, 03, 06, 09, 12, 15 and 18 hours GMT. Due to high cost of observations, many nations have agreed to arrange only four observation a day (00, 06, 12 and 18 GMT). Some observatories take only two observations (00 and 12 GMT).

Surface observations include pressure, temperature, humidity, wind direction and speed, cloud type and amount, estimated height of cloud base, visibility, present weather, past weather and rainfall during the period covered from the last standrad hour of observation.

Upper air observations are taken with the help of balloons, filled with hydrogen. The buoyancy force takes the balloons up while the horizontal wind drifts the balloon horizontally. By following the balloon with visual or radar telescope, we can estimate the wind direction and speed at various levels of the atmosphere. We can follow the balloon until it is lost either due to low angle of elevation as it drifts far away from the observatory or it bursts. Some of the balloons carry a package of instruments which measure pressure, temperature and humidity and also a small radio transmitter which telemetres to the ground observatories the readings as it moves up.

These surface and upper air observations are put in internationally agreed meteorological number codes and transmitted to the nearest national forecasting office by fastest available means of communication, including land line telegrams, wireless telegraphy and telephone. Forecasting offices exchange these observations through national and international teleprinter channels. This goes on day and night, all the year round.

At the forecasting office, the messages are decoded and plotted in pictorial form on the meteorological charts. When all the observations taken simultaneously at various observatories are plotted on charts and analysed, they reveal a pattern of weather in the form of areas of low pressure, high pressure, rain, cloudiness, fronts, etc.

These weather patterns move sometimes fast, sometimes slow and sometimes do not move at all. In course of time, they intensify and then decay and disappear altogether. The intensification is sometimes slow and sometimes fast.

Past observations and analyses have revealed some system in the development and movement of these weather patterns. Based on the experience gathered during the last hundred years of systematic observations accompanied by theoretical and laboratory investigations on the physics and dynamics of the atmosphere, something like forecasting rules have been formulated to predict the movement and intensity of different weather patterns over different places.

These rules were first formulated for the extra-tropical regions. Later a different sets of rules was formulated for the tropical regions. In the extra-tropical regions like England and the continent of Europe, there is a pattern of weather which moves, with a speed of the order of 10 metres per second, approximately from west to east, with a slight component of motion towards the poles, to the north pole in the northern hemisphere and to the south pole in the southern hemisphere. Isobars (lines of equal pressure) on sea level reveal a system of closed isobars with a low pressure at the centre, with a pressure dificiency of the order of 20 millibars while the normal sea level atmospheric pressure is of the order or 1000 millibars. These low pressure systems or extra-tropical cyclonic storms as they are called, are associated with warm and cold fronts and a relatively well-organised pattern of weather as observed at a single station, which experiences cirrus and cicro-stratus clouds and then alto-stratus clouds giving rain or snow of the warm type. This warm front is followed by warm air with light cloud and occasional rain till the cold front arrives. This gives a few sharp showers and is followed by early morning fog if the night conditions of cloud and wind are favourable. Then come relatively cloud-free skies but cold polar winds.

There is almost a continuous chain of these extra-tropical cyclonic storms throughout the year. The horizontal distance between two successive storm centres is of the order of 4000 kilometres. Since they are more with a speed of the order of 10 metres per second, a station experiences this cycle of weather about once in five days.

These extra-tropical cyclones or storms have pronounced variations in the vertical. Upstairs, they appear as waves rather than as closed vortices. Their intensity in terms of wind strength is maximum at a height of about 10 km above sea level. Further upwards, they lose their identity almost completely at 20 km above the sea level. These vortices-cum-waves are called synoptic-scale weather systems. At a time, there are about 6 such waves in the extra-tropical belt in each of the two hemispheres.

There are waves larger as well as smaller than these synoptic scale waves.

Larger than these are quasi-stationary planetary scale waves with wave-length or the order of 10,000 km. These are excited in the atmosphere through the heating and the mechanical effects of large continental land masses and oceans. The most dominant wave number is 2, i.e. two waves round the globe, excited by two continental land masses and two oceans. One land mass consists of the Afro-Eurasian land mass and the other is the American continental land mass, these two land masses being separated by the Pacific and the Atlantic Oceans. One can rightly say that this is an over-simplified view because the two land masses mentioned above are unequal in size and different in disposition; there is great asymmetry of land mass on the two sides of the equator, etc. This is perfectly true. Correspondingly, these inequalities and asymmetries in land mass distribution excite a whole spectrum of wave numbers although wave number two is dominant in the seasonal flow patterns at several levels.

On the other side of the synoptic scale, we have the whole series of atmospheric waves with wave lengths from 1000 km to a few millimetres. A single thunder-cloud has horizontal diameter of the order of 5 km. Distance between the centres of two adjacent thunder-clouds is of the order of 10 km. In other words, the wave length is of the order of 10 km. This wave length is of great importance for individual showers by which the meteorological forecast is judged by the public. It is through such processes that while we get a heavy shower at Nairobi Airport, it may not rain over the Nairobi City Centre or at Dagoretti Corner. These thunder clouds also constitute a major weather hazard for aircraft, particularly at take-off and landing times, due to large horizontal and vertical velocities associated with these clouds below the cloud base. Some of these thunder clouds also generate devastating tornadoes.

Like the planetary scale waves, these sub-synoptic scale systems are also greatly influenced by surface heating and orography features of their own dimensions.

In the real atmosphere, there is interaction between the synoptic scale systems and the larger planetary as well as the smaller sub-synoptic scale systems.

The classical idea of turbulence that large vortices break up to give smaller and smaller vortices or that energy always cascades into smaller and smaller scales is not true when we deal with rotating systems like the atmosphere which rotates along with the earth almost like a solid. It has recently been discovered that the energy put into the atmosphere on synoptic scale goes partly into larger and partly into smaller waves, the so-called phenomenon of negative viscosity.

These interactions between different scales of motion are very complex and are being studied and modelled at many research centres at the moment.

When we come to the tropical region, the weather systems are somewhat different from the extra-tropical ones. In the tropics, we have the synoptic scale systems with wave-lengths of the order of 4000 km but the migratory synoptic scale systems are generally feeble in terms of pressure deficiency at the centre. While pressure defect at the centre of an extra-tropical synoptic-scale disturbance is of the order of 20 mb, that in the tropics is of the order of 2 mb, quite hard even to detect on our charts. Yet these disturbances cause considerable changes in the weather in terms of rain.

Also in the tropics, there are non-migratory standing waves which slowly vary in intensity, in quasi-periodic pulsations, difficult to detect on our daily charts but nevertheless producing alternately dry and wet weather.

A well-marked tropical weather system with length dimensions of a few hundred kilometres is a tropical storm or a cyclone. Anywhere in the world, a tropical cyclone is a major calamity when it strikes a township.

Due to these special characteristics of the tropical regions, tropical meteorology is developing as a separate specialised branch of meteorology.

Lack of data over oceanic regions is another difficulty. In extra-tropical regions as well as in the tropical regions, daily forecasts of weather issued to the public and covering a period of one to two days are based on weather charts prepared twice or four times a day. Synoptic scale systems are detected on these charts.

The life of a synoptic scale disturbance is of the order of 5 days. With two observations a day, we have about 10 stages of looking at the system. If it does not quickly vary in intensity or in its speed of motion, we can reasonably well extrapolate its behaviour during the next 24 to 48 hours.

When the horizontal scale is 4000 km, we can distinguish weather patterns over say 8 different parts of the system. In other words, we forecast a more-or-less homogeneous weather pattern over a length of about 500 km. Our whole observing and forecasting system is geared to this type of analysis. Surface observatories are located at a distance of approximately 200 km from each other; upper air observatories are generally located 500 km apart. Two to four observations a day over this network of observatories is adequate to detect and follow the synoptic scale weather systems and issue corresponding forecasts, provided that we adopt more sophisticated techniques of analysis over the tropics so as to detect the weak migratory systems.

5. DILEMMA OF A FORECASTER

Lack of data over the oceanic regions is a great handicap. Over the land, particularly in developing tropical regions, we do not have a good network of observatories. Even where we have observatories and good communication system, there are scientific problems. Small as well as large orographic undulations of the land surface excite a very wide range of weather systems, particularly sub-synoptic scale weather systems. Their total life is of the order of a few hours and horizontal extent of the order of 10 km. These are the systems which produce heavy showers of rain in which the public gets interested.

The present network of observations and the system of analysis is not designed to detect and follow the small sub-synoptic scale systems and to issue forecasts for small areas. There is really no firm scientific basis for a meteorologist to predict tomorrow's weather over the city centre. He can scientifically predict tomorrow's average weather pattern over an area 500 km × 500 km if the synoptic scale system is strong enough to be detected on his weather charts prepared twice or four times a day.

Public certainly needs much more than this. Meteorologist is well aware of this and he therefore tries his ingenuity to issue weather forecasts for small areas for the period of one day. He intuitively uses his knowledge of general climatology of smaller areas over smaller periods, stretches out his neck and issues forecasts for small areas for the period of a day. Naturally, there are some successes and some failures. He would like to say 70% chance, 30% probability, etc. But the public may not appreciate. So he translates his intuitive probability numbers into what he considers is the equivalent description. He says:

One or two showers; occasional showers; frequent rain;
scattered to very scattered showers;
local showers;
fairly widespread or widerspread showers, etc.

Language of this meteorological forecast sometimes looks dubious, ambiguous. But people can distinguish between sunny and rainy weather at least. If the meteorologist says "Occasional showers tomorrow" and the sun shines throughout the day, people are not going to listen to the probability ranges and explanations that there was 60% chance of 3 showers a day, 50% chance of 2 showers a day and 10% chance of no shower at all. His forecast is wrong, that is all that the public will say.

This is the real dilemma of a meteorologist who is obliged to answer the question:

"WILL IT RAIN TOMORROW?"

This is the situation throughout the world, more particularly in the tropics. But the meteorologists have to explain the situation to the people, to the public, take them into confidence and then the public will appreciate their problem which is 100% genuine.

6. OTHER TYPES OF FORECASTS

We have already referred to aviation weather forecasts for a few hours of flight as well as to the daily weather forecasts for the next 24 to 36 hours. In addition, meteorologists are required to issue forecasts for the next 5 to 7 days, for the period of a month and even for a few years ahead.

To forecast for the next 5 to 7 days, a meteorologist generally looks at the same charts as for 24-hour forecast. In some countries, special 5-day or 7-day average charts are prepared for the purpose. In either case, a forecaster looks for changes which have been taking place and, in his opinion, which are likely to take place, in respect of the quasi-stationary planetary scale waves with wave-lengths of the order of 10,000 km, i.e. bigger than synoptic scale waves.

To forecast for one month, a forecaster uses what is known as "analogue" method. He has before him his monthly averaged charts for each of the past several years. He searches for those years in the past in which weather situation had been "analogous" to the present one and then forecasts weather analogous to what happened in the past such years.

In some countries like India where monsoon rains are of great economic importance and the Government would like to be prepared for difficult situations, if any, the meteorological department uses "statistical" techniques. Based on past events, statistical correlation co-efficients have been worked out between the monsoon rains and the preceding meteorological events. Every year, monsoon forecast is issued based on these correlations.

In each of these forecasting techniques, there is some "system", some science, though not the whole of it. There is scope for improvement and efforts are being made to achieve improvement.

Methods of forecasting mentioned above have been of some limited value. These have also come under criticism when the forecasts went wrong but this is the best that could be done. Either such forecasts should not be issued at all or these have to be accepted with some caution by the customers. In every country, the customers have opted to be supplied with these forecasts. At the same time, meteorologists are encouraged to carry on research for improvement of the forecasts.

7. NUMERICAL WEATHER PREDICTION

The end of the Second World War brought about almost a revolution in the field of meteorology. More persons took to the study of meteorology as a science. Older descriptive models were losing attraction for the new generation of young meteorologists. They searched for quantitative mathematical models. It had long been recognised that the atmospheric equations formed a "closed system" as an initial-value problem. In other words, given accurate information about the atmosphere at an initial instant of time and proper quantitative formulation of the physical processes operating in the atmophere, it is conceptually possible to forecast the future state of the atmosphere. However, the partial differential equations governing the atmospheric motions are non-linear, 4-dimensional and having highly variable co-efficients. As such, they cannot be solved exactly by the hitherto known analytical methods. Nor is there a hope of making detailed realistic simulation of the atmosphere in a physical laboratory. Approximate numerical methods were the only possible way to get a solution. But even these could not be adopted easily. There are problems, essentially of 3 types:

i) Volume of computations is large and hence one needs high speed computing facility.

ii) Whatever we may do, we shall never be able to simulate an analytical wave numerically, in an exact manner. There are bound to be some errors. The problem is how to keep these errors within reasonable bounds.

iii) For numerical methods, continuous atmosphere has to be replaced by discrete discontinuous grid points. Atmospheric phenomena smaller in size than grid-point distances cannot be incorporated easily.

One Quaker in England, L.F. Richardson, having consciencious objection to taking up arms in World War I, was assigned non-combatant duties near the war front. In such an environment, late in the evenings and on his "off" days, he used to spend his time in solving these atmospheric equations numerically. It took him a few years to solve one such set of equations. In the usual war activities near a war front, his working sheets got bundled up inside a charcoal bag and he recovered them after a year or two. He had great difficulty in finding financial "sponsorship" for publication of this long series of calculations in the form of a book. It was finally published in 1922 under the title of "Numerical Weather Prediction". It is inspiring to read the book even in the seventies today. One can now see the working of the mind of an idealist, a visionary who imagines future possibilities of things which clearly belonged to the realm of "absurdity" at the time of his writing, as judged by his "normal" contemporaries.

This book had remained almost unknown until in 1947, the young dare-devil meteorologists referred to this publication and drew inspiration from it. Now L.F. Richardson is respectfully referred to as the pioneer of "Numerical Weather Prediction" which is the latest field of research in meteorology.

In the late forties, the problem of Numerical Weather Prediction was re-formulated in a form that could be tackled in a manner relatively easier than Richardson's. Small electronic computers were at that time available only in research laboratories. These atmospheric equations were numerically solved on a computer in Princeton University with the co-operative effort of young meteorologists and the great mathematician Von Neumann. The solution had some resemblance to the real atmospheric situation as it developed. It was a great success!

More experiments were performed. Improvements were introduced in the model representing the atmosphere. Electronic computers also improved in size and speed. Bigger and faster computers encouraged the meteorologists to bring greater and greater sophistication in the atmospheric models and also to increase the horizontal and vertical extent of the domain of integration. They demanded still larger and faster computers. Supply increased the demand and the demand increased the supply. This interaction between the supply and the demand in the field of meteorological science on one hand and computer science and technology on the other hand has brought us to a stage where the biggest and the fastest electronic computers all the world over are being used by the meteorologists in the field of weather forecasting. It is also well-recognized now that improvements in computing facilities will lead to improvements in the modelling of the atmospheric processes. Furthermore, the science of meteorology is becoming more and more mathematical day by day. Mathematical problems arising out of computational instabilities and blow up of computations are being solved both analytically and empirically through trial and error. This has provided mutually beneficial interaction between meteorology and mathematics.

Numerical models are being employed to simulate the observed weather processes like development of fog, cloud, hailstorm, tornado, tropical cyclone, extra-tropical storm, atmospheric jets and what not?

Even the climatic changes of the past are being simulated. The philosophy behind this effort is that if with our physical and dynamical equations, we can simulate the atmospheric phenomena which have occurred in the past, it is a proof that we have largely understood the atmospheric processes in a quantitative manner. If so, then we can predict the future state of the atmosphere also.

One more recent development which has greatly influenced the pace and direction of advancement in meteorology is the appearance of satellites. When the first Sputnik went into orbit about two decades back, the whole world exclaimed "What a wonder!"

To get, at an initial instant of time, the precise information about the actual state of the atmosphere, which horizontally extends over the whole earth and vertically extends to hundreds of kilometres, could be considered only as a dream until the satellites went into orbit. Today, two decades after the first satellite went into orbit and after we have seen the performance of the orbiting and the geo-stationary satellites, we can say that this is not a dream. Nor can we say that it is an accomplished fact. We can however say that it is a goal within man's reach, perhaps in our own generation. The capabilities of remote sensing above the earth's surface, have ever been increasing. The observations started with the visual photographs of the clouds. Now we are able to get not only visual photographs in the sunlit hemisphere but also infra-red photographs in the night hemisphere, temperature profile through a great depth of the atmosphere and also total water vapour content of the atmosphere on routine operational basis. Visual displays of these parameters are being transmitted from the satellites to the ground-receiving stations, including Nairobi. Research workers in the field of remote sensing technology promise us vertical profiles of other atmospheric constituents like Ozone, Carbon dioxide, condensation nuclei, etc.

We now use geostationary satellites as fixed observatories with 'eyes' that can see about one fourth of the earth's total surface at an instant of time. These satellites actually move and orbit in the earth's equatorial plane with the same angular velocity as the earth's angular velocity around its polar axis. Hence the satellites "appear" fixed over the equator relative to the rotating earth. Thanks to International co-operation, five such geostationary satellites are already in position at the equator at longitudes 0°, 60°E, 140°E, 135°W and 75°W. This system of geostationery satellites is continuously watching the weather over the earth's surface roughly between latitudes 70°N and 70°S.

Fast mini computeres placed on board these satellites quickly process the weather information and transmit the same to the receiving ground stations. Polar regions are also adequately covered by a set of nearly polar-orbiting satellites scanning each pole about 15 times a day.

Initial state of the atmophere will be known from surface observations and from the satellites with certain observational errors, inherent in the observational system. Physical laws of the atmosphere in the form of equations of motion, energy equation, equation of state, law of conservation of mass, etc. are known. Can we now predict the future state of the atmosphere with the help of world's giant electronic computers? The answer is partly yes and partly no. From this position, we can forecast certain scales of motion for certain periods of time. We cannot forecast all scales of motion for all time to come. Here, we face what is presently called the predictability problem, what we can predict and what we cannot. That is why we answered 'partly yes and partly no'.

The known physical laws of the atmosphere are valid for continuous atmospheric medium, for a continuous length of time. When we use electronic digital computers to integrate these equations of physical laws, we have to represent the continuous atmosphere by a series of regularly spaced grid points; we have also to split the continuous time into discrete regularly spaced points in a time continuum. These discrete points in space-time continuum are supposed to represent the volume and time interval around them. This creates a new physical and mathematical problem. If l and m be two quantities, their non-linear product lm averaged over time gives not only the product of l and m each averaged over time but also an additional term known as an 'eddy' term. Similarly representation of the continuous space by regularly spaced grid points creates the problem of sub-grid physical processes. Physical processes in the atmosphere occur at scales ranging from a fraction of a millimeter to planetary scales of the order of 10,000 km. Are we going to deal with all scales of motion at one time? No; that is just impossible. The world's largest computers now available do not permit horizontal resolution better than 300 km on a global scale and a time interval of about 12 minutes; i.e. the minimum horizontal distance between the grid points is, at best, of the order of 300 km and a minimum time interval that is represented by an instant of time is 12 minutes. If we considerably reduce the distance between two successive grid points to say 100 km, the number of grid points along a latitude circle increases 3-fold; similarly the number of points along each longitude circle increases 3-fold; i.e. at each horizontal level, the number increases 9-fold. For the meaningful vertical resolution, you have also to reduce the vertical distance between neighbouring points by a factor of 3. Hence, in space, the number of grid points has increased by a factor of 27. The demand on computer memory has increased by this factor.

There are problems of computational instability. It can be shown that with this reduced grid distances by a factor of 3, each time step in time-integration has to be reduced by a factor of 3 if we are to avoid problems of computational blow-up. The time step has to be reduced from 12 minutes to 4 minutes. With the increased number of grid points which a computer has to scan each time and with a reduced time step that is now possible, the same computer, if it can accommodate this number of grid points in its memory, will now take 81-fold time for integration upto the old time of 12 minutes. In other words, the demand on computer memory has increased 3^3 (=27) times and the demand on computer time has increased 3^4 (=81) times. This demand on computers arises from our desire to reduce the present-day 300 km grid-distance to 100 km. Since the physical processes in the atmosphere extend down to 10^{-3} metre size, there is no good reason why we should aim only at a grid distance of 100 km (10^5 metres). We should like to go to the resolution of 10^{-3} metres. But every attempt at finer resolution brings us to the problem of the memory and speed of the computers. Reduction from grid size of 100 km to 10 km would demand memory increase by another factor of 10^3 and speed increase by a factor of 10^4. Similarly, further improvement in resolution from 10 km to 1 km means computer memory increase by another factor of 10^3 and so on. It appears inconceivable at the moment that we shall ever have computers to meet such demands.

Is there a scientific way out? Yes, there is. A meteorologist is essentially a practical person. He accepts the situation and attempts to make the best use of what he has.

We accept, for the moment, that 300 km is about the shortest grid-distance and 12 minutes is about the shortest time interval that we can have in our computation schemes. Such a scheme can adequately deal with synoptic-scale weather systems which have horizontal wave length of the order of 4000 km and life history of the order of 5 days. We know that there are several other atmospheric phenomena which are not caught or adequately represented on our daily charts. For example, a cloud which gives us a shower in Nairobi and by which the merit of a meteorologist is going to be judged by the very influential public of Nairobi, has horizontal diameter of the order of 5 km. This is only one example of sub-synoptic or sub-grid scale atmospheric systems. Other sub-grid scale systems act as sources and sinks of momentum and sensible heat like hills, lakes, rivers, townships, industries, irrigation systems, etc. Even biggest tropical lake like Lake Victoria (size-300 km ×200 km) cannot be adequately caught in 300 km grid-length scheme. We know that Lake Victoria has its own circulation system which largely controls daily weather cycle upto a distance of at least 150 km from the boundary of the Lake. Kericho which is situated within this lake circulation regime experiences hailstorm frequency which appears to be the highest in the whole world! It is impossible to adequately represent the circulation systems of this nature in our analyses and computational schemes.

There is significant interaction between the synoptic and the sub-grid weather systems; one influences and is in turn influenced by the other. How are we to represent these interactions between synoptic and sub-synoptic scale weather systems without representing the sub-synoptic scales explicity in our numerical computer models? This is a big problem now facing the meteorologists. This is the problem of "parameterization", representing the sub-synoptic scale processes through parameters of the synoptic scale systems. The parameterization schemes have to satisfy certain conditions:

i) On the synoptic scale, mass of the atmosphere as a whole should remain constant.
ii) Not only total energy should be conserved but also energy spectrum—the relative distribution of energy in various scales of motion—should be saved from large distortions.

The problem is so huge and has also essentially to be solved for the real atmosphere which transcends national boundaries and which blows over the oceans, the continents, the poles and the tropics, that the nations of the world have agreed to make an international co-operative research effort to formulate different plausible parameterization schemes and to test them on the meteorological data to be gathered during some special periods. We now have Global Atmospheric Research Programme (G.A.R.P.) going on for about last 10 years in which all nations are participating. The First Garp Global Experiment (FGGE) is scheduled to start tomorrow 1st December 1978, and to end after one year. During the period of this experiment, there will be Special Observation Periods (S.O.P.'s) from 5th January to 5th

March, 1979, and from 1st May to 30th June 1979. There will be two components of this experiment of particular interest to us in Africa. These are:

Monsoon Experiment (MONEX)

West African Monsoon Experiment (WAMEX).

MONEX will concentrate on the region covered by the eastern parts of Africa, the Indian Ocean and Southeast Asia. WAMEX will concentrate on Western Africa and the adjoining Atlantic Ocean.

During FGGE, the obsevations will be taken by 5 geostationary satellites, at least 2 polar-orbiting satellites, all meteorological observatories on land established by the national governments, all commercial aircrafts in air, all commercial ships on the seas and in addition by more than 5 special research aircraft, more than 40 special research ships and over 250 drifting buoys in the ocean. The observations will be trassnmitted on international teleprinter channels to a few International Analysis Centres having arrangements for computer-controlled reception and having large man-power and machine power to plot and to analyse the observations on a daily basis. Since facilities for reception and analysis of such huge amounts of data on a daily basis cannot be created in all countries, groups of countries have agreed to co-operate and to join hands in reception and analysis of data at a few selected centres. Kenya will be sending some meteorologists to the International MONEX centre located at New Delhi in India.

The meteorological data collected during the FGGE period will be properly archived and will be available to research workers throughout the world. The World Meteorological Organization (WMO) headquartered at Geneva is looking after the organizational aspects of this unique Experiment. It is more than a mere experiment. It symbolises and underlines one-ness of the atmosphere, the colossal magnitude of the problem, the need of international co-operation and use of the latest advances in science and technology.

8. Forecast for Tomorrow*

Finally the question, "Will it rain tomorrow?"

Answer: "Yes, it will rain tomorrow".

*"It rained almost cotinuously from early morning till mid-day on 1st December 1978. Later it remained generally cloudy."

9. Conclusion

I am grateful to the authorities of the University of Nairobi, Kenya Meteorological Department, United Nations (UNDP and WMO) and Government of India for giving me the opportunity to work here in Kenya, in the University of Nairobi.

I have always enjoyed the science of meteorology.

And finally, I will say:

THE EARTH IS ONE.
THE ATMOSPHERE IS ONE.
THE PROBLEM OF WEATHER IS DIFFICULT.
BUT WE CAN SOLVE IT.
BY CO-OPERATION.
LET US ALL CO-OPERATE.
LET US USE THE LATEST IN SCIENCE AND TECHNOLOGY,
IN COMPUTERS AND SATELLITES.
AT THE SAME TIME,
LET US NOT POLLUTE THE ATMOSPHERE;
WE MAY CHANGE THE CLIMATE,
WE MAY DESTROY THE VERY LAYERS THAT PROTECT US.

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