Global Meteorology (I): Experiments in the Tropics

Weather changes in the tropics are traditionally unpredictable, and, despite the increasing sophistication of computerized atmospheric models and satellite-based observational techniques, forecasts in tropical areas often leave much to be desired. In part this lack of predictive skill reflects both the complexity of atmospheric processes in the tropics, many of which are still not understood, and the lesser attention given to tropical meteorology in the past. But new and more intensive efforts, including large-scale field experiments, are now being made because of a widespread appreciation that atmospheric processes in all parts of the world are interconnected. In fact, many scientists believe that one of the weakest links in the understanding of atmospheric motions—and hence in the ability to predict weather and climate—is the meteorology of the tropical oceans.

In order to understand the atmospheric processes that make weather, meteorology is of necessity becoming a global science. Dust storms in north Africa, for example, or rain squalls in the western Pacific may within a week's time significantly influence the weather in distant parts of the world. The new scope of meteorological research has led to organizational changes as well. In recent years meteorologists have been planning an intensive international effort known as the Global Atmospheric Research Program (GARP) with the aim of improving knowledge of weather and climate. The first major GARP experiment, now in its final planning stages, will be concentrated on tropical phenomena. The GARP experiment will build on the results of an earlier large-scale field study in the tropics, the Barbados Oceanographic and Atmospheric Experiment (BOMEX) which was conducted by U.S. and Canadian scientists during the summer of 1969. Preliminary results of the BOMEX study, including new information on the interaction of the atmosphere and the tropical oceans and on the cloud formations that are characteristic of the tropics, are just now becoming available.

The crucial role of the tropics is that of providing much of the energy that drives the major circulation patterns of the atmosphere. Heat input from the sun's radiation is absorbed in the tropical oceans, converted to latent heat through the evaporation of water vapor, and transported upward by giant cumulus clouds to warm the atmosphere. However, the processes that control the release of this energy are still largely an enigma; the cumulus clouds do not appear in random locations throughout the tropics but, instead, seem to be organized into definite patterns. In fact satellite observations and other studies indicate that there are at least four different scales of motion in the tropics. At the smallest scale is the individual cumulus cloud, usually a few kilometers in diameter. The clouds are often organized into rings or linear bands that are themselves associated with still larger cloud clusters and disturbances extending up to 1000 kilometers in horizontal scale. These in turn seem to be influenced by wave motions of even larger scale in the equatorial atmosphere.

Meteorologists hypothesize that the larger disturbances have a strong influence on the formation of clouds and, hence, on the amount of heat that is released within the atmosphere. At the same time the individual clouds, by releasing heat, influence the evolution of the larger phenomena. But exactly what relationships exist between clouds, cloud bands, and large disturbances is not understood and these relationships are a major focus of research in tropical meteorology. Despite progress in theoretical studies, many meteorologists believe that comprehensive observations on several scales of motion—like those planned for the next tropical experiment—are required.

One difficulty that meteorologists have in studying the tropics is in obtaining data. Much of the tropical atmosphere is over water so that few permanent weather stations exist. In mid-latitude weather systems the wind velocities can often be inferred from sea-level pressure maps together with atmospheric temperature profiles by utilizing the effects of the earth's rotation (the coriolis effect). But the coriolis effect decreases toward the equator and satellite measurements of temperature, which could be a major source of information in mid-latitudes, are not as effective in the tropics because temperature variations are much smaller and temperatures must be measured to correspondingly higher accuracies to obtain equivalent information. There are large variations in the tropical wind velocities, however, and many meteorologists believe the measurements of the tropical winds will be necessary.

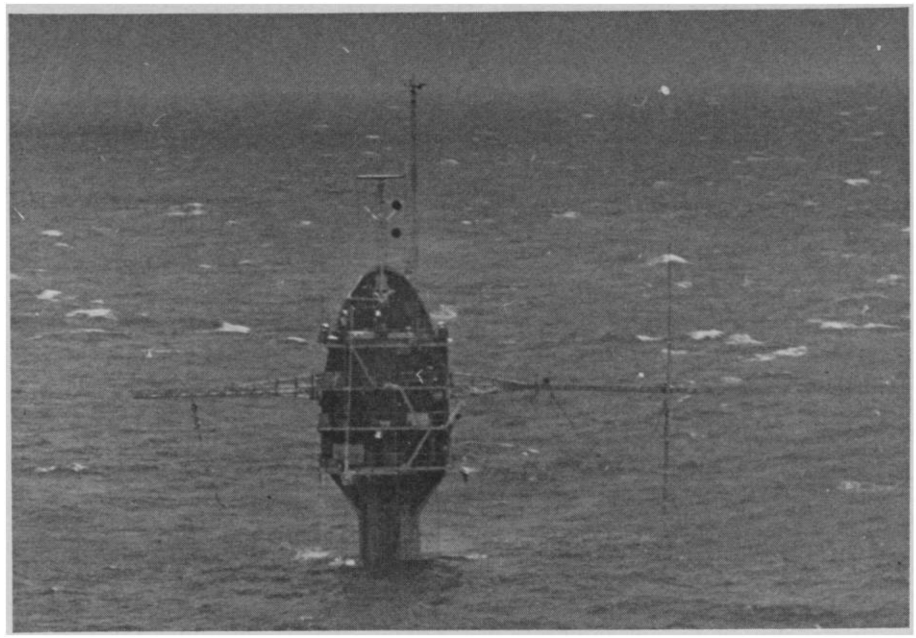
Several methods of obtaining wind information have been proposed. One method would use satellite pictures of cloud movements to infer the wind velocities. Some preliminary trials with this method have indicated that the technique can be very successful, but it appears to be limited to cloudy regions and to altitudes at which clouds form. Another possible method depends on constant-level balloons—overinflated balloons that drift with the wind at a constant altitude. This system would also have limitations, however, because ice forms on the balloons and, hence, rules out sampling at certain altitudes. Still another but presumably very expensive possibility that is under consideration is the use of sounding devices dropped from aircraft or balloons. Meteorologists are hopeful that some combination will provide better information about the tropical atmosphere.

The first really large-scale field study of energy transfer processes in the tropics was the BOMEX experiment that took place in the tropical Atlantic east of Barbados. The major emphasis of the study, conducted jointly by seven federal agencies, universities, and industrial laboratories with the assistance of the government of Barbados, was the interaction between the atmosphere and the ocean. Measurements were made of the transport of mass, energy, and momentum between the air and the sea from some 28 aircraft, 12 ships, several satellites and buoys, and hundreds of radiosonde balloons. The area studied included a "cube" 500 by 500 kilometers in horizontal dimensions and extending about 500 meters down into the ocean and up about 5 kilometers into the atmosphere.

Measurements were made by several methods, wherever possible, in an attempt to relate meteorologically important processes, such as evaporation from the sea surface, wind speeds, solar radiation, ocean temperature, and other variables. Evaporation is of interest, for example, because it is the source of the water vapor from which clouds form. Analysis of the massive amounts of data collected in the study are continuing; but preliminary results seem to indicate, according to Joshua Holland of the National Oceanographic and Atmospheric Administration (NOAA), that evaporation exceeded 6 millimeters of water a day, more than had been expected from climatological estimates. Perhaps even more surprising to meteorologists is evidence, based on oceanographic measurements, that the highest rate of evaporation occurred not in the morning, when the air is coolest relative to the water, nor at noon, when the heat input from the sun is at a maximum, but near sunset. The resulting energy transfer to the atmosphere, according to this finding, differs both in amount and in timing from that predicted by a widely used semiempirical method based on air temperature, wind speed, and humidity measurements. The cause of the discrepancy is not yet clear, but the BOMEX findings may lead to a reevaluation of meteorological measurements near the air-sea interface—techniques and interpretive formulas developed for estimating evaporation from land, for example, may not be as accurate over the oceans.

The BOMEX scientists also studied the transport of water vapor in the lower layers of the atmosphere. They found that large eddies, elongated in the downwind direction, were the dominant factor in transporting the water vapor vertically. As a result, the rate of water vapor transport differed significantly from that for heat transport, which appears to be controlled by the smaller eddies (less than 100 meters), a situation that is again quite different from that which usually prevails over land. Water vapor and heat transport are often treated as identical processes in theoretical studies; but the BOMEX evidence indicates that a more complicated treatment will be necessary in some circumstances.

The BOMEX measurements have also provided new information on the amount of solar radiation reflected by the ocean, the amount of dust in the tropical atmosphere, and other factors affecting the radiation balance in the tropics. Other BOMEX studies focused on the convective processes in clouds. Studies of cloud bands, for example, have yielded new insight into their structure and have indicated, according to Jule Charney of the Massachusetts Institute of Technology, that the concentration of moisture by wind patterns in the lowest kilometer of the atmosphere—the region known as the atmospheric boundary layer—may be an important factor in their development.



The Floating Laboratory Instiument Platform (FLIP) of the U.S. Navy was used to obtain both oceanographic and meteorological data during the BOMEX experiment. [National Oceanographic and Atmospheric Administration]

A second and more elaborate tropical experiment is being planned for 1974. Known as the GARP Atlantic Tropical Experiment (GATE), it will be a truly international project for which nine countries have indicated their intent to participate actively.

In setting up what many believe to be a model example of international cooperation, meteorologists involved in GARP have had to deal with a number of nonscientific problems as well, including some delicate political situations and some potentially troublesome conflicts. The GARP effort is a joint undertaking of the World Meteorological Organization (WMO), which is composed of the official weather services of member countries of the United Nations, and of the International Council of Scientific Unions (ICSU). This arrangement allows for participation both by governmental bodies through the WMO and by individual scientists through ICSU, even in countries where, for example, there are strong antagonisms between university-based scientists and their governments.

Overall planning for GARP is delegated to a 12-member international organizing committee of prominent meteorologists. Much of the detailed scientific planning is being done by study groups in many countries under the coordination of the organizing committee, while logistical plans are worked out by the governments involved.

The GATE experiment will include the area on either side of the equator, reaching from Central America to the eastern edge of Africa. Intensive observations will be concentrated in an area about 1000 kilometers square in the eastern Atlantic south of the Cape Verde Islands. The primary goal of the GATE experiment is to study the exchange of energy between the various scales of motion that occur in the tropical atmosphere. By understanding the physical mechanisms involved, meteorologists hope to find ways to represent the smaller scales of motion (individual clouds and cloud bands) in terms of parameters which can be measured on the larger scale; the resulting simplification would allow the development of improved numerical models and more accurate forecasting.

Experiments such as BOMEX and GATE will presumably lead to a better understanding of atmospheric processes. For practical purposes, however, the results are likely to be more accurate numerical models of the atmosphere, since predictive calculations for atmospheric motions are too lengthy to be carried out except by computer. Numerical modeling of the atmosphere and the use of such models in predicting weather and climate will be described in a second article.

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