WEATHER SATELLITES

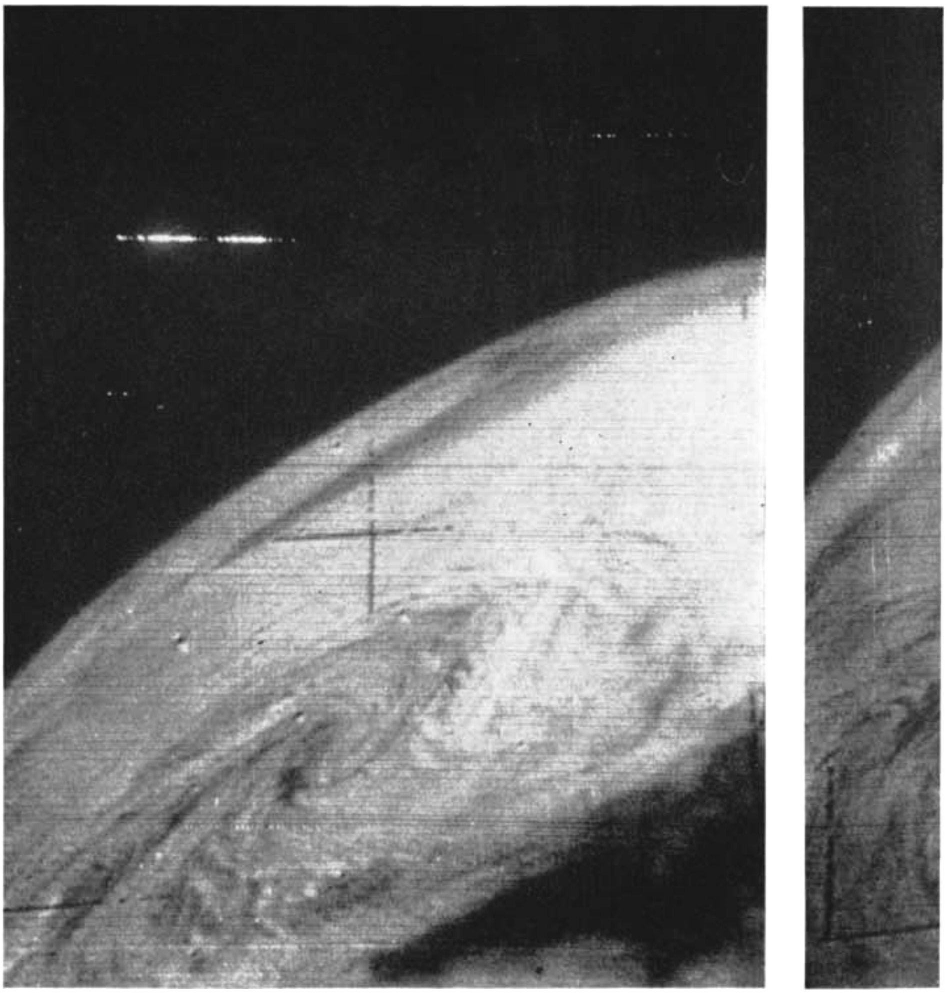
Tiros I and *Tiros II* have provided a broad view of the circulation of the atmosphere. Future satellites will gather even more useful information on this circulation and the earth's total heat budget

by Morris Neiburger and Harry Wexler

A little more than a year has passed since meteorologists saw for the first time the large-scale weather patterns they plot on their charts. The first view was provided by the weather satellite *Tiros I*, launched on April 1, 1960, which produced some 14,000 good pictures of the earth and its cloud cover during its 78 days of operation. *Tiros II*, launched last November, has returned about 24,000 useful pictures and is still operating as this article goes to press. In addition, *Tiros II* has been gathering—at the rate of some 2.5 million readings a day—the first comprehensive measurements of the visible and infrared radiation leaving the top of the earth's atmosphere. This radiation is made up partly of reflected sunlight and partly of infrared waves emitted by the earth's surface and the atmosphere.

How have these pictures and radiation measurements affected the science of meteorology and the practice of weather forecasting? Have they given rise to new concepts? Have they improved the accuracy of forecasts? This article will present some preliminary answers. The behavior of the atmosphere is so complex that it was not to be expected that a few months of satellite observation would suddenly clarify weather processes or lead to an immediate improvement in forecasts. Nevertheless, meteorologists who have been following the data received from *Tiros I* and *Tiros II* are convinced that weather satellites will have a revolutionary impact on their science.

Because of this conviction an enlarged series of weather satellites is being planned by the U. S. Weather Bureau in co-operation with the National Aeronautics and Space Administration. The series will include at least four more *Tiros* satellites, which utilize simple spin stabilization and are therefore said to be space-oriented; this means that their central axes tend to remain pointed in a fixed direction in space. The more advanced *Nimbus* series, to be placed in polar orbit, will be earth-oriented, meaning that they will keep their central axes pointed constantly toward the earth. The still more advanced *Aeros* series of weather satellites will circle the Equator at a distance of about 22,000 miles and at the same speed the earth is turning, thus permitting them to view the same area of the earth at all times. This series of space vehicles will cul-



INDIAN OCEAN CYCLONE, photographed by *Tiros I*, provides a majestic view of the vast expanses covered by ordinary weather processes. Not to be confused with a hurricane, which is much smaller and more violent, this storm has a diameter of almost 1,000 miles.

minate in a fully integrated system of weather satellites.

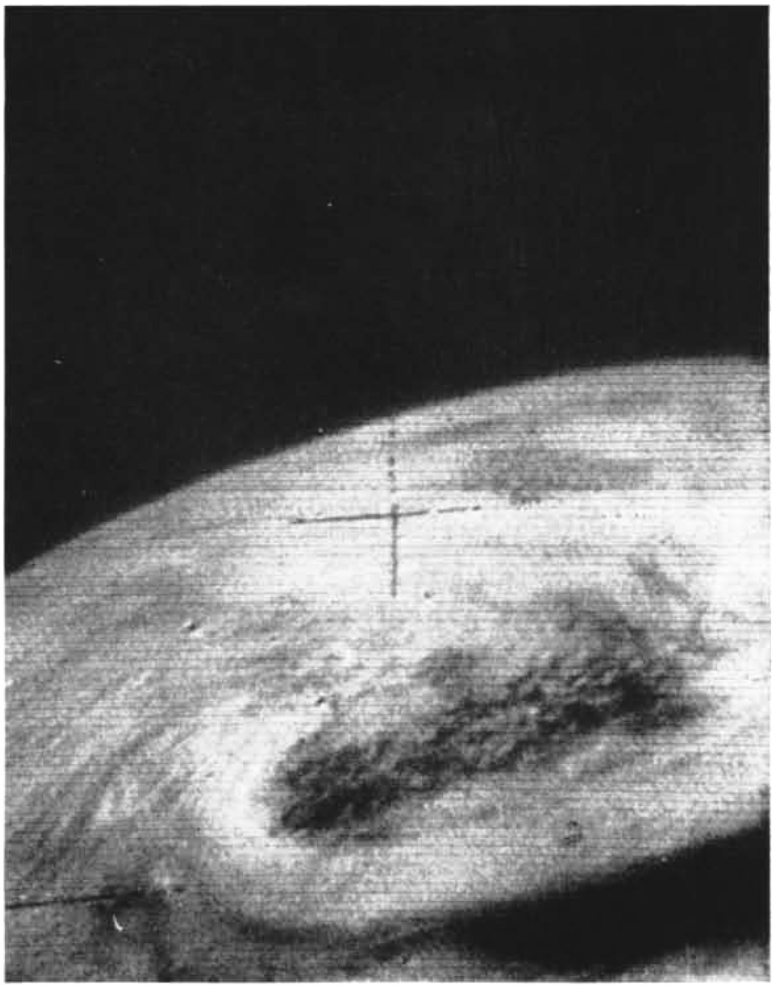
One can visualize an ideal weather service in which satellites automatically feed their global reports into electronic digital computers that process the data and produce weather forecasts without human intervention. One can look much further in time and imagine computer-controlled devices capable of modifying the predicted weather—if it is unfavorable—before it has a chance to develop.

A New View of Clouds

The most spectacular product of the first weather satellites has been the thousands of television pictures of clouds. Meteorologists were not sure in advance what could be learned from such pictures or how they could be used in weather forecasting. Each of the *Tiros* satellites carried aloft two cameras. One is provided with a wide-angle lens able to cover an area about 800 miles across if the lens is pointed straight down; the second camera has a narrow-angle lens covering an area 80 miles across. The resolving power of the wide-angle lens is about three miles; that of the narrow-angle lens, about .3 mile.

The first day's pictures from *Tiros I* disclosed two important features of the organization of cloud patterns, subsequently confirmed by many more examples. The first is that large-scale low-pressure areas, and their associated cyclonic wind patterns, are almost always accompanied by circular cloud patterns, up to 1,000 miles or more in diameter [*see illustrations on these two pages*]. These cloud patterns have a banded structure reminiscent of the smaller (and much more rapidly rotating) cloud patterns that occur in hurricanes. The second important type of pattern revealed by *Tiros I*, perhaps more surprising than the first, consists of an extensive area populated by many crescent-shaped or doughnut-shaped cloud cells, each some 30 to 50 miles in diameter [*see illustrations on page 83*]. The cells are too large to be seen whole from the ground and too small to be revealed by the widely spaced data that are plotted on conventional weather charts. Apparently the cloud cells are associated with large convection currents, which probably play an important role in transferring heat, water vapor and momentum from the ground and the ocean to the lower layers of the atmosphere.

The pictures from *Tiros I* show a number of other interesting features: spiral cloud bands of a tropical cyclone (the term used in the South Pacific for a hurricane or typhoon) north of new Zealand; cirrus streamers associated with a jet stream over the southern Andes; double-vortex clouds in cyclones that apparently have only one low-pressure center; cumulus-cloud "streets" (long parallel rows of puffy clouds) in the tropics; a single long, thin cloud about five miles wide and several hundred miles long (perhaps an airplane-con-



The first view (*left*) was taken April 30, 1960, on the satellite's 416th orbit of the earth; the next view (*middle*) was taken on the next pass, about 100 minutes later; the third view (*right*) was taken on the 429th pass, the next day. The photographs were made from an altitude of about 450 miles with the satellite's wide-angle television camera, which was pointed west-southwest.

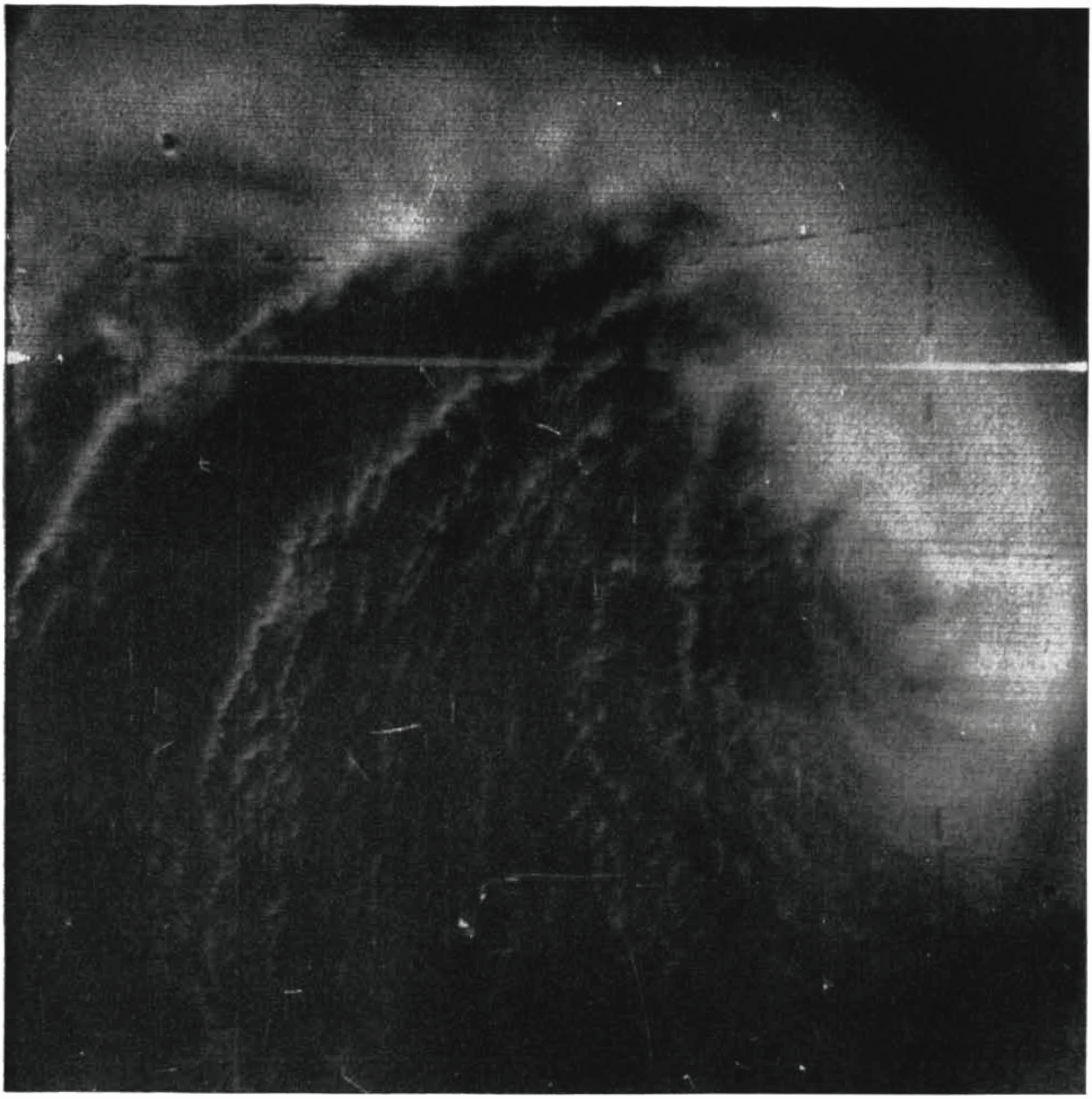
densation trail) east of Florida; a long, thin cloudless streak embedded in an otherwise unbroken cloud deck near Madagascar. The satellite picture of an isolated "square" (actually rhombic) cloud about 100 miles across raises the possibility that tornado-producing clouds may be distinguished from hundreds of ordinary thunderstorm-cloud formations [*see illustrations on pages 88 and 89*]. The pictures also show features of the earth's surface; for example, bright sand and darker rock areas in the North African deserts, a broken pattern of sea ice in the Gulf of St. Lawrence, snow fields in the Alps and in the Himalayas, and the sparkling reflection of the sun on water surfaces.

The *Tiros* pictures have been most immediately useful to weather forecasters in providing information in regions from which data is otherwise unavailable. For instance, there are areas of the Pacific larger than the U. S. in which no routine weather observations are made. Even where routine observations can be had the satellite pictures often reveal large-scale patterns that cannot be observed either from the ground or from aircraft.

Using data received from *Tiros II*, the National Meteorological Center in Suitland, Md., has been preparing "nephanalyses," which are graphic analyses of cloud distributions observed between 55 degrees North latitude and 55 degrees South. These analyses have been transmitted over the regular weather facsimile channels in time for use by forecasters in the U. S. and in several foreign countries.

Radiation Input and Output

Whereas the output of a camera is fascinating and almost immediately readable and applicable, it may not in the long run yield as much basic knowl-

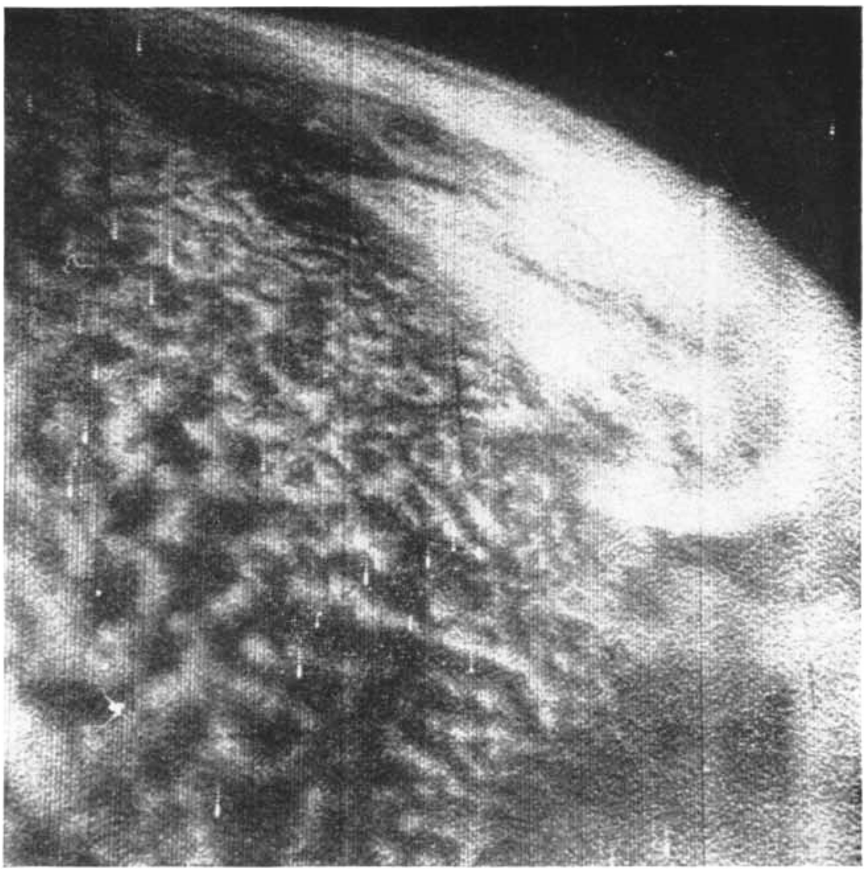


HURRICANE IN THE SOUTH PACIFIC was photographed by *Tiros I* on its 10th day in orbit: April 10, 1960. The big storm (commonly called a tropical cyclone when in the South Pacific) was 300 miles north of New Zealand. View is to the southwest.

edge as many other instruments that a weather satellite can carry. A satellite can "look" down at the atmosphere in many ways; it can also "look" up, which may be just as important. With instruments pointed outward, toward the sun, satellites can for the first time measure continuously the amount and kinds of energy flowing from the sun to the earth's atmosphere.

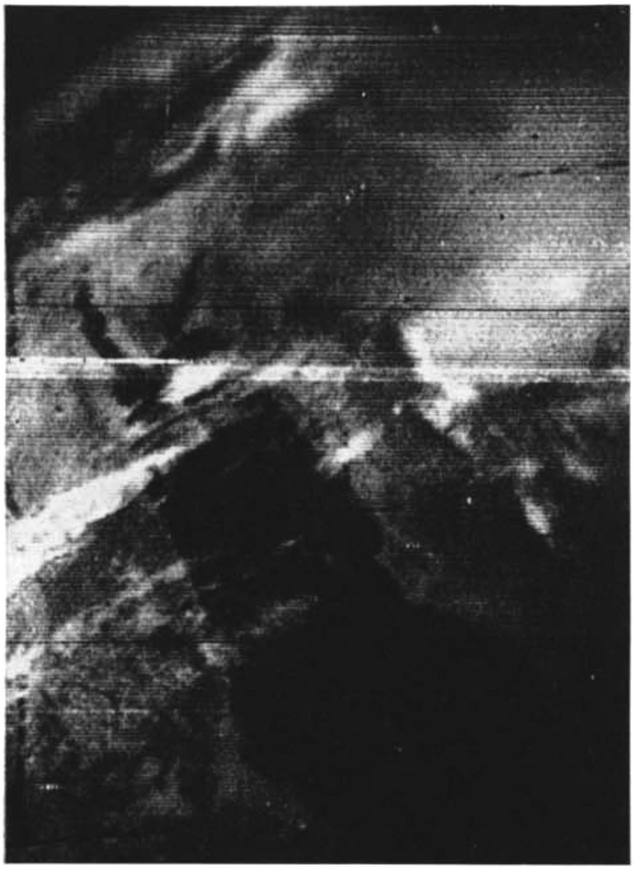
The atmosphere is the thermodynamic fluid of an engine that ultimately derives practically all its energy from the sun. The response is by no means as immediate and direct as the response of an automobile engine to the change in fuel supply when the throttle is varied, yet it is clear that variations in solar energy must have some influence on the weather. How much influence—is the effect amplified or is it damped?—has not been determined in spite of years of investigation. The question has remained unresolved largely because no one has known exactly how much the input of solar energy varies in amount and character. The magnitude of these variations can now be established by satellites, which will be able to monitor the sun's electromagnetic radiation at various wavelengths and also the sun's corpuscular, or plasma, emissions. The best current estimates are that the total variation of solar electromagnetic radiation is less than .3 per cent; but it has been suggested that corpuscular emissions (chiefly barrages of high-energy protons) may at times augment the energy the earth normally receives from the sun by as much as 10 per cent in the latitudes where auroras most frequently occur. Although the corpuscular emissions are absorbed high in the atmosphere (almost always higher than 35 miles), it is conceivable that their indirect influence could subsequently be felt at lower levels. Tracing and testing possible influences would be much aided by a continuous record of the intensity of the emissions leaving the sun and reaching the outer limit of the atmosphere. If it is established that variations large enough to influence the lower atmosphere do occur, if the nature and consequences of this influence can be clearly understood and if there is sufficient time lag between the solar "cause" and the atmospheric "effect," the observation of solar energy of various kinds from space vehicles would give meteorologists an important new key to forecasting.

Even if the sun's output of energy were absolutely constant, this would not mean that the earth and its atmosphere absorb the incoming energy at a constant rate; a variable and unknown fraction of

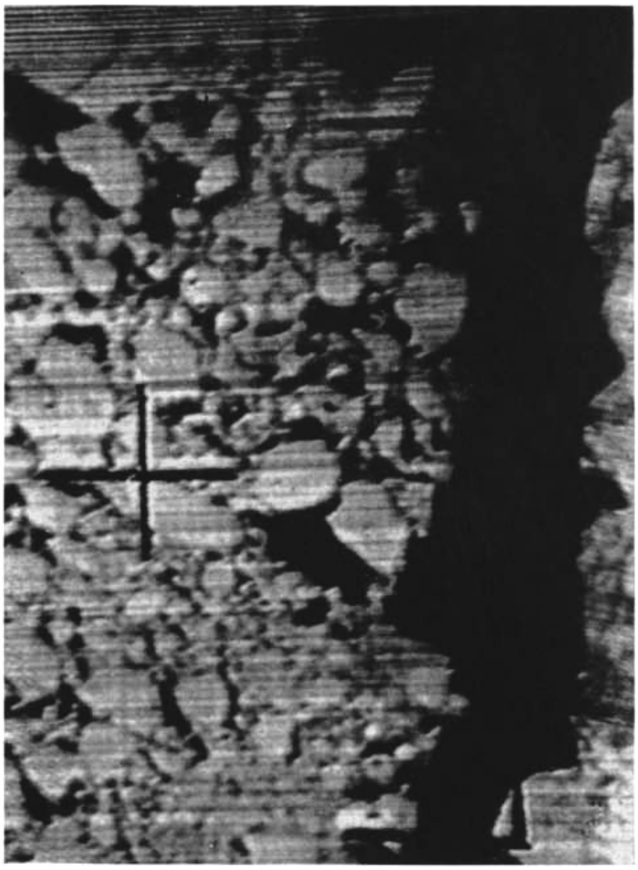


CLOUDS FORMED BY CONVECTION CELLS were photographed northeast of Bermuda by *Tiros I* on April 4, 1960. The individual crescent-shaped clouds are about 50 miles across.

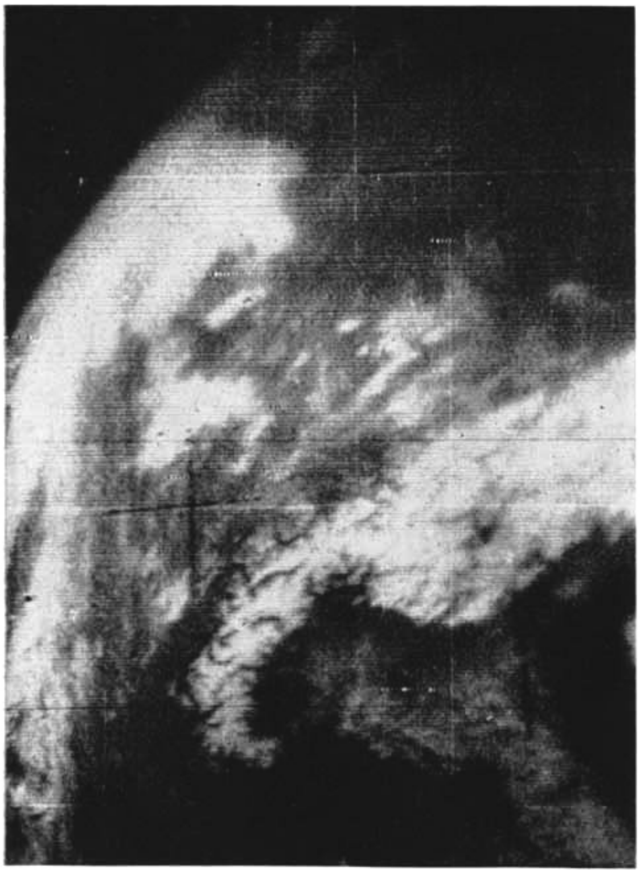
CLOSE-UP OF CELL CLOUDS was made with the narrow-angle camera at the same time as the wide-angle view at the top of page. The cloud pattern was new to meteorologists.



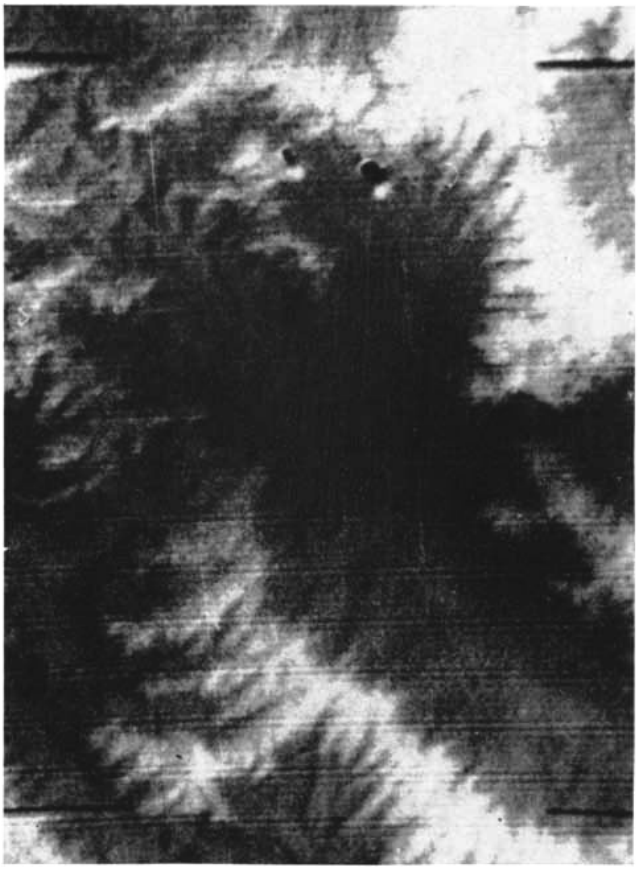
JET-STREAM CLOUDS, associated with high, fast-moving winds, were photographed over the Red Sea by *Tiros I* on April 4, 1960.



FIELD OF ICE FLOES extending to the edge of Newfoundland (*far right*) was photographed by *Tiros II* on March 23, 1961.



SNOW-COVERED ALPS, with the Italian peninsula projecting toward southeast, was photographed by *Tiros I* on April 2, 1960.

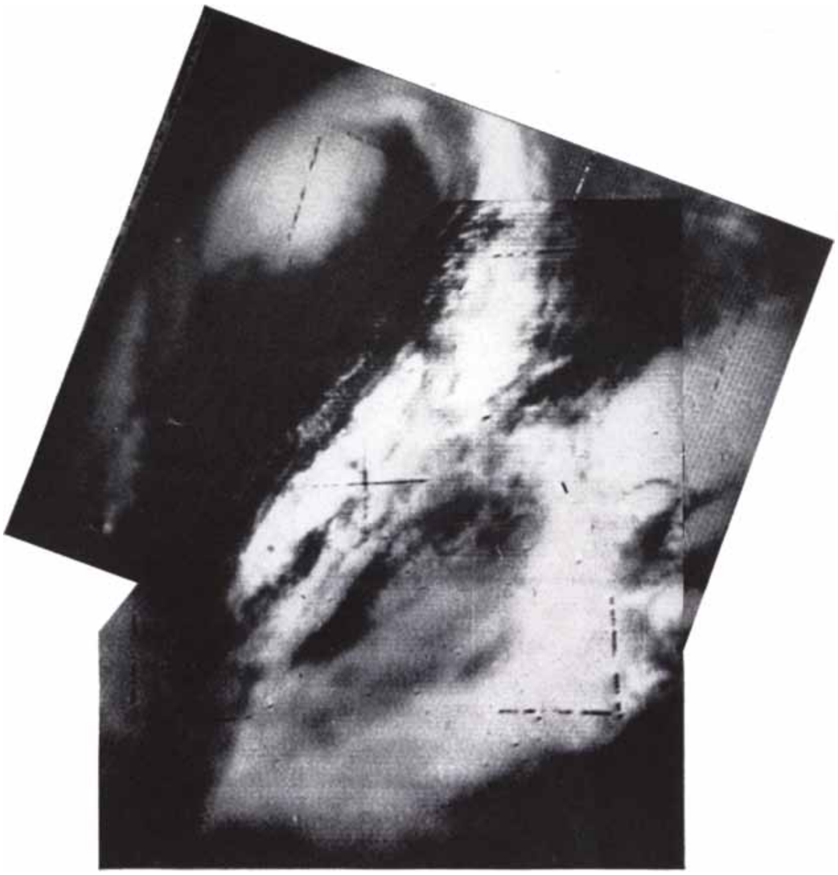


SNOW-COVERED HIMALAYAS appear in narrow-angle picture about 80 miles from top to bottom, made by *Tiros I* on May 13, 1960.

the arriving energy is reflected by the earth's surface (particularly the areas covered with snow), by clouds and by the dust and haze in the air. For example, the amount of solar energy reflected back into space by clouds depends both on the amount of the earth's surface blanketed and on the particular reflectivity of the clouds present. If we assume an average cloud reflectivity of 70 per cent, it is evident that a change of 5 per cent in the fraction of the earth's surface covered by clouds would produce a change of 3.5 per cent in the energy available to drive the atmospheric circulation. This, in turn, would be 10 times the present estimated maximum variation in the sun's output, and the variation would be entirely in that portion of the energy which penetrates to the lower layers of the atmosphere. Variations due to changes in the area covered by snow, and in the reflectivity of the snow (due to aging), may be of similar magnitude. Measurements from satellites of the radiation reflected back from the earth to space would thus provide valuable information concerning the energetics of the atmosphere.

Another variable in the energy budget of the atmosphere is the amount of infrared radiation leaving the earth and the atmosphere. Infrared waves are emitted by any body that is not at absolute zero; the warmer the body, the more infrared energy it radiates. Part of the infrared radiation emitted by the earth's surface and by clouds is absorbed by the water vapor, carbon dioxide and ozone in the atmosphere; these gases in turn radiate according to their own temperatures and at their own characteristic wavelengths. The net radiation flowing from the atmosphere into space depends, therefore, not only on the distribution of the temperature of the earth's surface and at the tops of clouds but also on the distribution of temperature, water vapor, carbon dioxide and ozone throughout the atmosphere. To estimate by conventional methods the energy lost to space would require a large program of observations, which at their best would not be very accurate; from a satellite such a measurement would be accurate as well as fairly simple.

In order to measure instantaneously the total output of both visible and infrared radiation from the entire earth, it would be desirable to have two satellites very high up, say 200,000 miles—one might be a station on the moon and the other could be on the opposite side of the earth. To measure the pattern of outgoing energy in detail, a number of satellites orbiting in the region between 300



LARGE CYCLONIC STORM was photographed over central U. S. with the wide-angle camera of *Tiros I* at 2:28 p.m. Central Standard Time of its first day in orbit: April 1, 1960. The satellite was over the Gulf of Mexico about 100 miles south of New Orleans; its cameras were aimed to the northwest. Southern edge of the round cloud (*top*) is over Oklahoma.

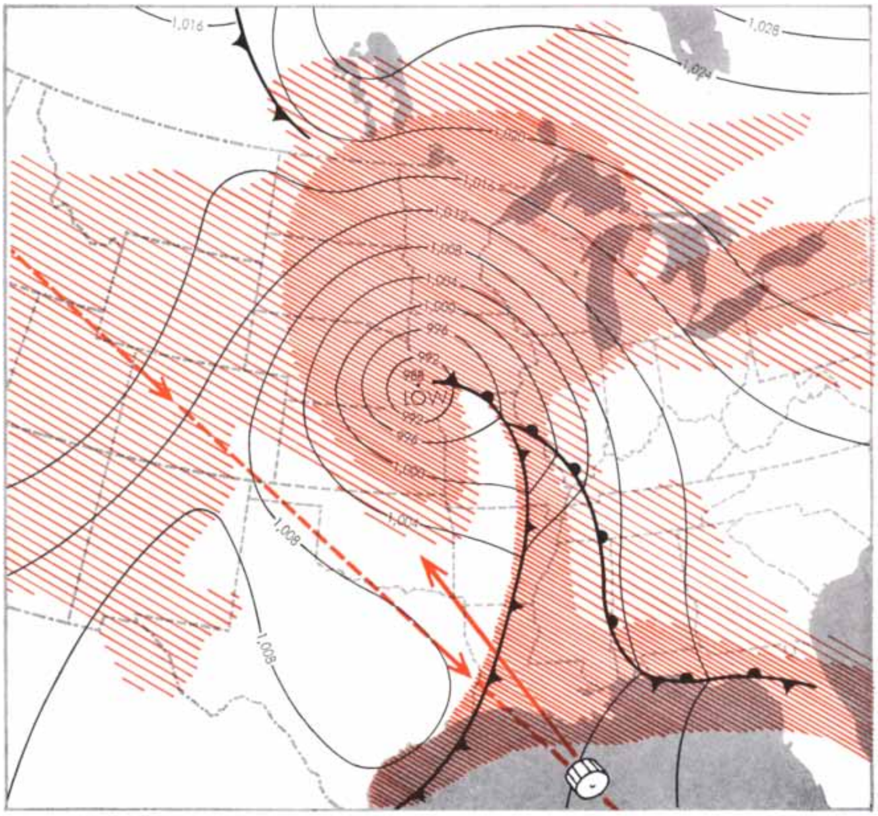
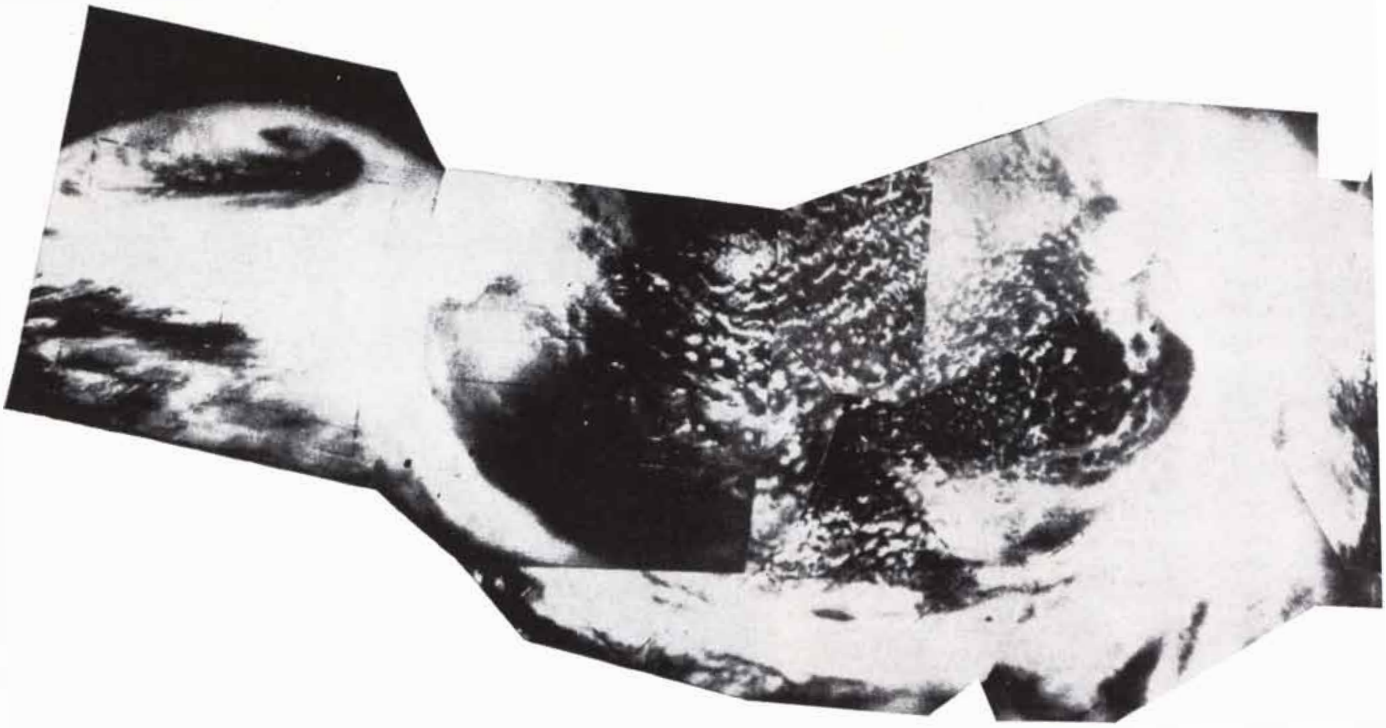


CHART OF CYCLONIC STORM, plotted from conventional meteorological readings taken on the afternoon of April 1, correlates well with the satellite pictures (*top of page*).



FAMILY OF STORM CLOUDS was photographed over the North Pacific, Canada and northwestern U. S. by *Tiros I* on May 20, 1960. The long-range connection between cloud systems emerged vividly when individual pictures were assembled in a montage. The clouds

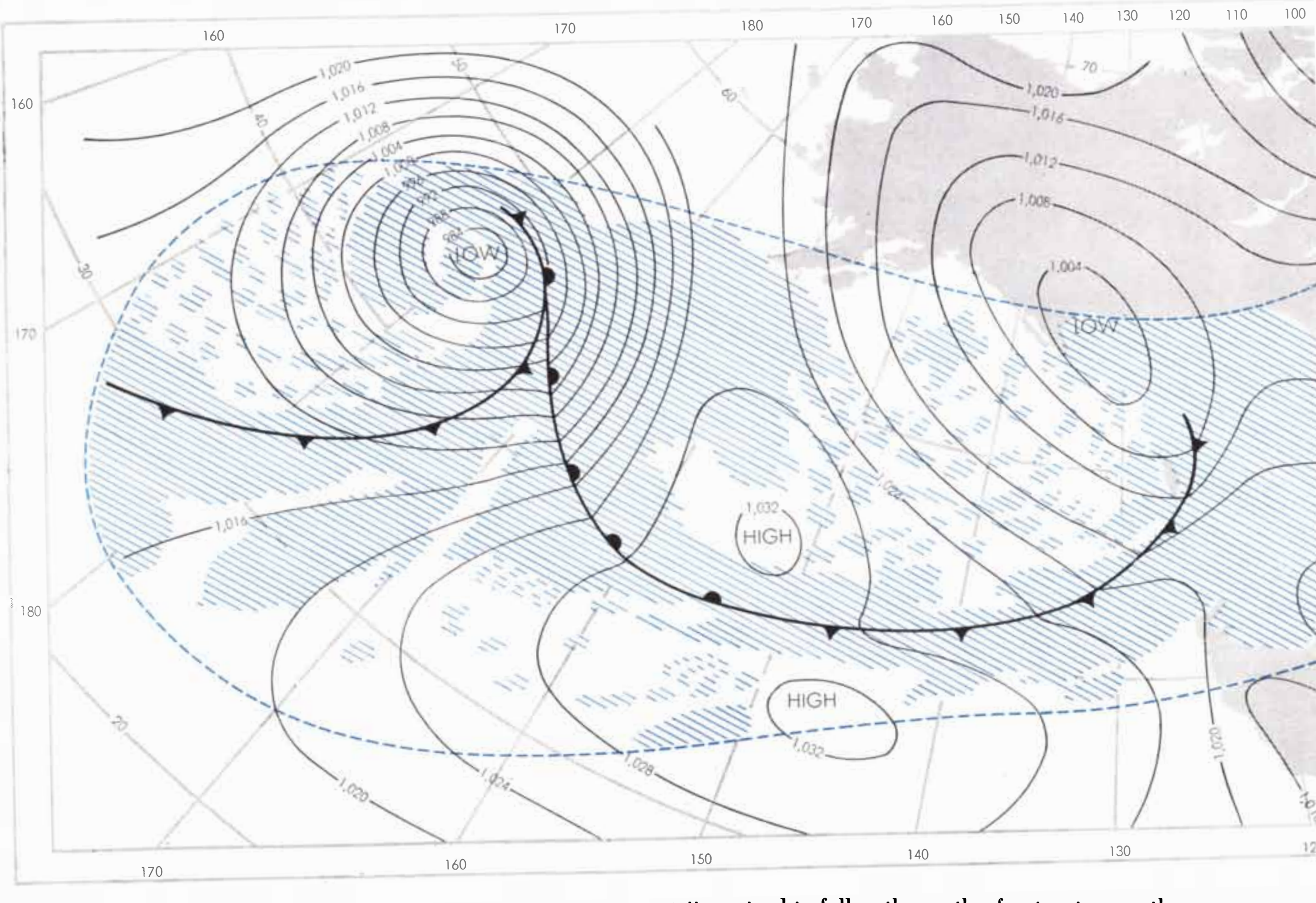
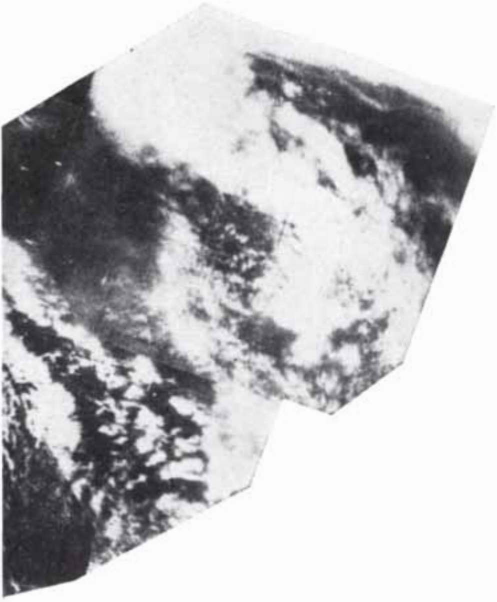
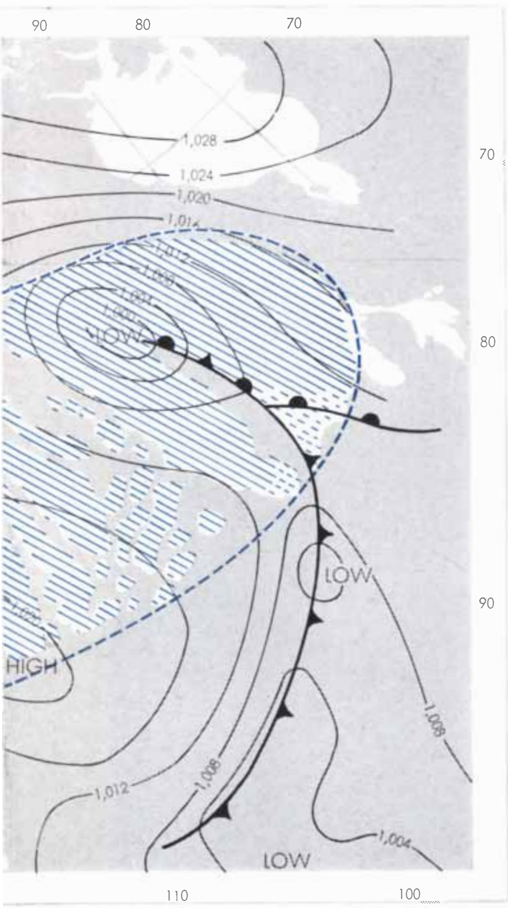


CHART OF PACIFIC STORM SYSTEM was made from standard meteorological readings covering the same period as that represented in the *Tiros I* photographs at the top of the page. The cloud patterns tend to follow the weather-front systems as they are conventionally plotted by meteorologists. The symbols on the black line at far left leading into the low-pressure area denote a cold



trace out in dramatic fashion the large-scale processes and motions of the atmosphere.



front. The symbols then change to indicate a warm front and finally revert to indicate a cold front reaching to U. S. coast.

and 3,000 miles would be best. The detailed measurements would identify places where energy outflow exceeds inflow and vice versa. Daily determination of this distribution of energy sources and sinks would enter into the computation of the atmospheric circulation, which must, after all, transfer energy from the places where it has accumulated to places where it is lost.

Preliminary measurements of the radiation budget of the earth and atmosphere were made by *Explorer VII* (1959 Iota), which was launched in October, 1959, as part of the program of the International Geophysical Year. This satellite was equipped with six elements for sensing radiation: three measured total energy at all wavelengths from various directions, one measured long-wave (infrared) radiation and two measured short-wave (solar) radiation [*see top illustration on page 90*].

More refined infrared measurements are being obtained by *Tiros II*. It carries a radiometer containing a cluster of five sensors, the optical axes of which are inclined 45 degrees to the spin axis of the satellite. Each sensor has a 5-degree field of view, covering an area of about 30 by 30 miles; the spin and movement of *Tiros II* along its orbit provide the scanning motion. The sensors respond to the following bands of wavelengths: (1) .2 to 5 microns, a broad band that measures the energy of reflected solar radiation; (2) .55 to .75 microns, a narrow band in the visible region that provides data that can be correlated with television images; (3) 8 to 12 microns, a band indicating the approximate temperature of either the earth's surface or the tops of clouds, whichever happens to be beneath the satellite; (4) 7 to 30 microns, a very broad band bracketing most of the terrestrial infrared radiation; and (5) 5.6 to 7 microns, a narrow water-vapor emission band that provides the average temperature of the highest layer of the atmosphere in which there is an appreciable amount of water vapor.

By April 1, 1961, more than 1,000 100-minute orbits of radiation data had been obtained from *Tiros II*. It will be mid-July before the data have been reduced and somewhat longer before they have been completely analyzed. In general, the surface temperatures that can be inferred from radiation measurements made at the band between 8 and 12 microns fall somewhat below temperatures recorded on the ground, but they seem to correlate well with the surface temperature and cloud patterns observed by other means [*see bottom illustration on page 90*].

Tiros II also carries a second radiometer designed to provide gross heat patterns over an area within the field of view of the wide-angle television camera. In this radiometer one detector coated white reflects most of the visible radiation but absorbs a broad spectrum of infrared energy. A second detector coated black absorbs both visible and invisible radiation. Readings from the two provide differential measurements needed to compute temperatures. Although the computed temperatures are lower than expected, they are in general agreement with the patterns seen on surface weather maps.

Weather satellites now being built or designed should be able to provide much other useful information. For example, the distribution of clouds at night, which shows up only in the infrared measurements of *Tiros II*, could be detected directly by ultrasensitive television cameras (operating on moon- or starlight) as well as by radar. Satellites equipped with radar could do a variety of jobs, depending on the wavelength of the signal. Some wavelengths would be reflected from the tops of clouds, providing a measure of cloud height; others would penetrate the clouds and be reflected back from raindrops or snowflakes, providing the vertical distribution of precipitating layers. Radar could also detect the "bright-band" echo caused by the melting of falling snowflakes and could thereby locate the height of the 32-degree-Fahrenheit isotherm wherever suitable conditions exist. Thunderstorms could be detected without radar simply by television observations of the lightning strokes themselves or by radio detection of their static discharges.

Advanced versions of *Nimbus*, the polar-orbiting, downward-looking weather satellite, will carry a special infrared spectrometer to measure radiation at wavelengths around 15 microns, where carbon dioxide has a strong absorption band. Precise measurements of this band should provide average temperatures, as well as temperature gradients, of the atmosphere wherever it is free from clouds. Later generations of satellites may be able to measure accurately the amount of water vapor, carbon dioxide and ozone in the atmosphere.

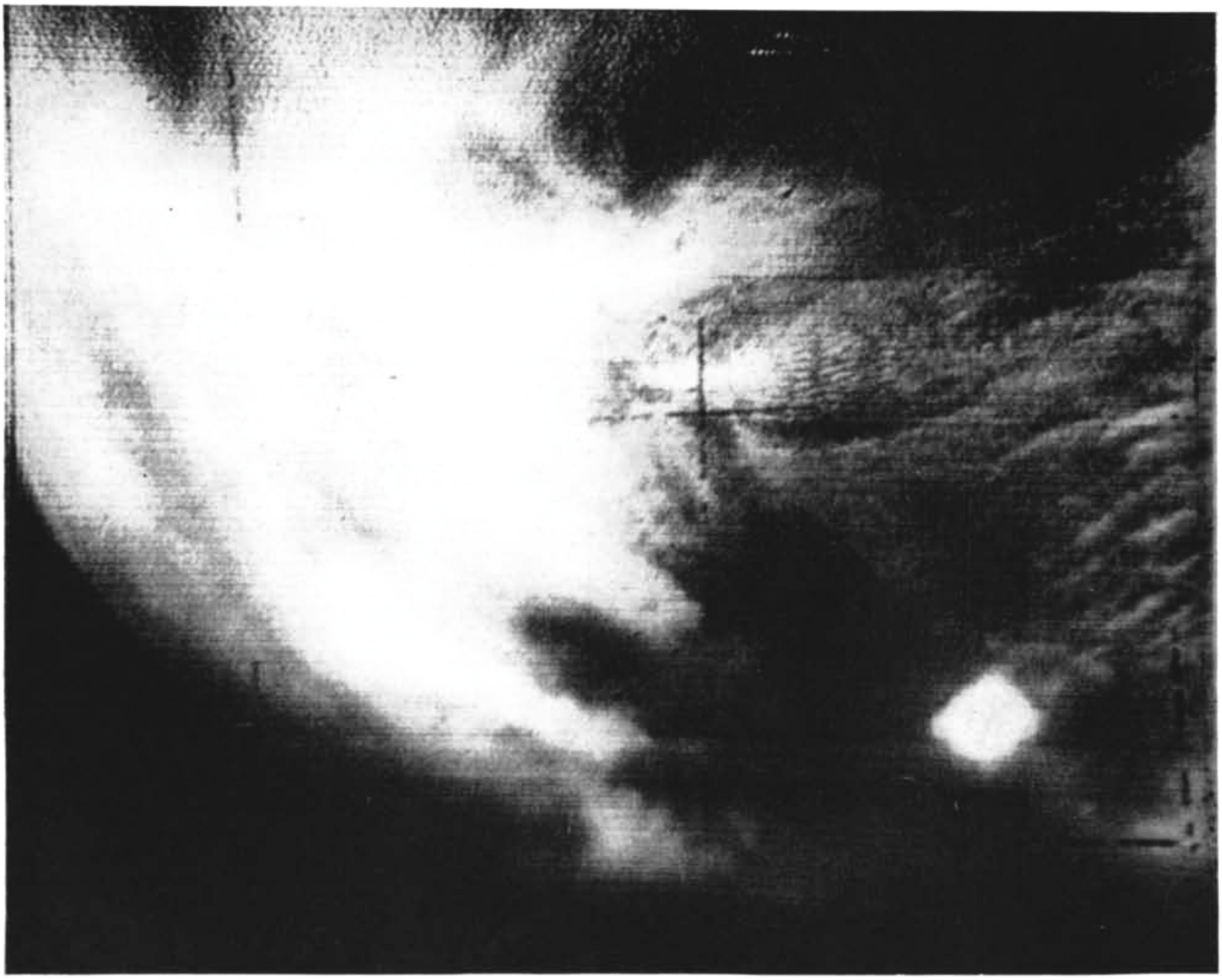
Precise information about barometric pressure and wind, both crucial in present methods of weather forecasting, are the hardest to obtain from vehicles outside the atmosphere. Even so, the problem is not hopeless. Clouds themselves may yield information about the wind and its vertical and horizontal gradients as our ability to interpret their patterns is increased. More accurate wind velocities and trajectories could be obtained by tracking hundreds of balloons set to float at predetermined heights. No one, however, has yet suggested a feasible method of determining barometric pressure from a satellite that would achieve the minimum desired accuracy of a few parts in a thousand.

No doubt with time new techniques will be developed for getting from satellites more complete and more precise measurements of the various quantities that are needed for weather forecasting. For the present it appears that the data from weather satellites will for the most part supplement observations made from the ground by filling in gaps in places where observations are not now available, by giving over-all patterns and details that elude even the densest ground networks and by providing important information about regional and over-all energy budgets of the atmosphere.

Techniques of Forecasting

Let us now look a little more closely at present weather forecasting procedures. These procedures are based on the assumption that future weather developments depend on the past and present behavior of the atmosphere. Over the past decade great advances have been made in numerical methods of forecasting, which have been made feasible by modern computers. In the numerical methods the motions of the air, as represented by the distribution of pressure at various levels, are inserted into mathematical equations that the computer solves to predict future patterns of wind and pressure. Formerly forecasters predicted the movement of the air and the development of pressure systems in part on the basis of past experience and in part by a crude qualitative application of the theory on which the mathematical equations are based. In both machine and nonmachine methods the atmosphere is treated as a self-contained, determinate system, in which the only disturbance from outside is the interaction of the atmosphere with the earth's surface.

At present weather forecasts are a composite of the results of the subjective procedures and the numerical methods using machines. The machine computations yield charts of the large-scale distribution of pressure and wind, which are used by the forecaster as a basis for his detailed prognosis. The detailed fore-



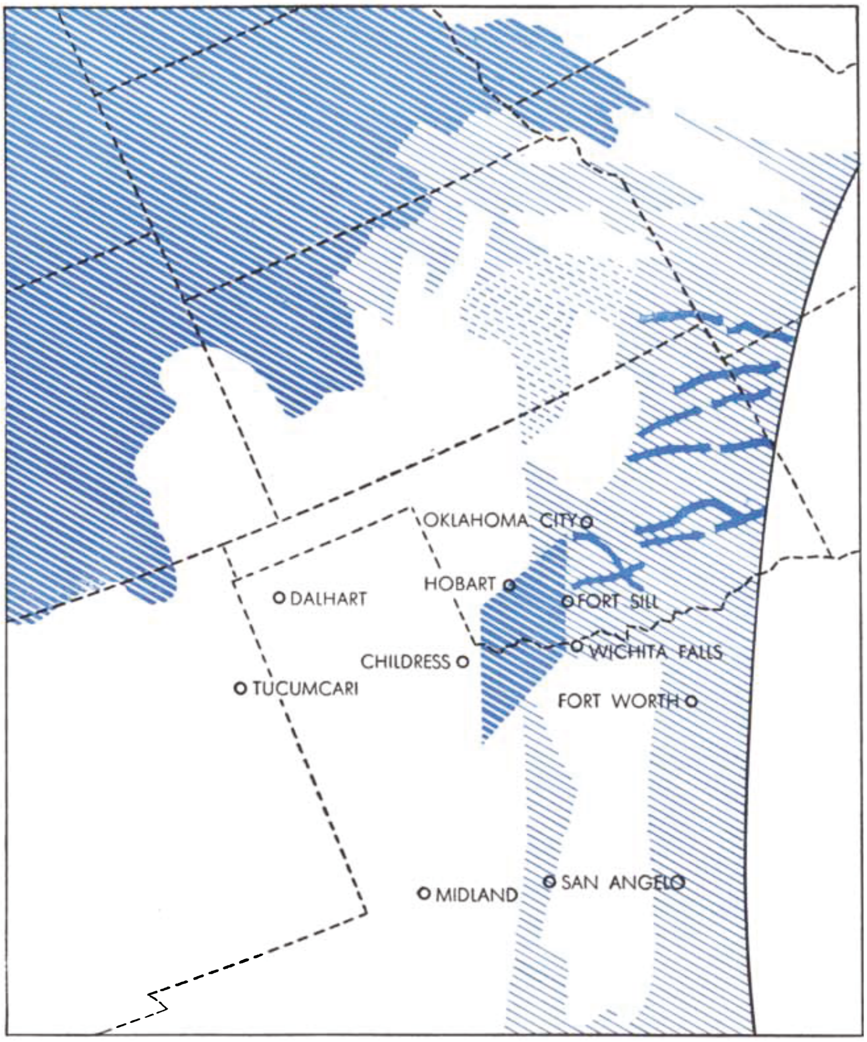
ISOLATED "SQUARE" CLOUD, about 100 miles across, turned up in a photograph of the southwestern U. S. taken by *Tiros I* at 2:00 p.m. C.S.T. on May 19, 1960. A rectified map of the picture shows the cloud to be rhombic (*right*). Two hours after the picture was taken five tornadoes struck between Fort Sill and Oklahoma City, a region northeast of the cloud. The cloud appears to be an

casts of temperature changes, clouds and precipitation come from his interpretation, by application of physical reasoning and previous experience, of the predicted pressure and wind patterns.

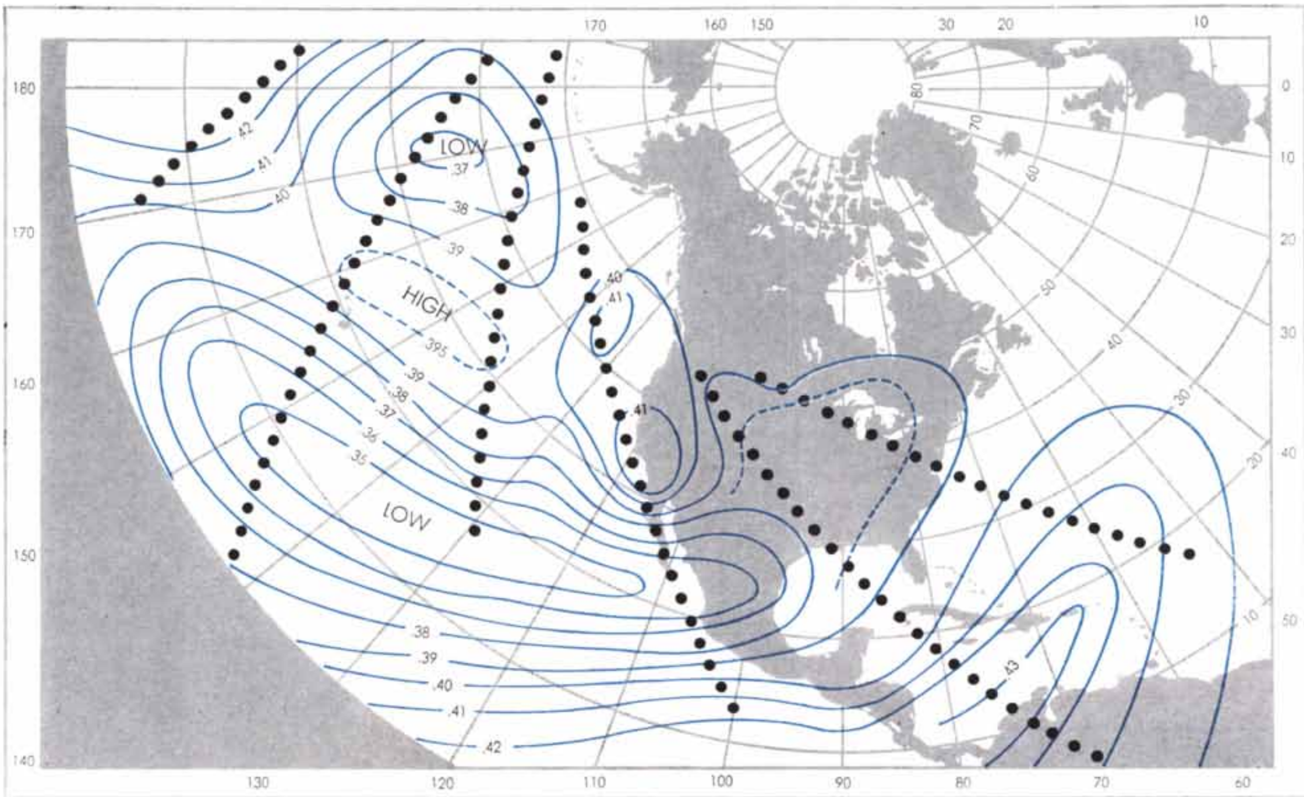
The first step in incorporating information from satellites will involve the interpretation of cloud data subjectively in terms of pressure and wind distribution, which then can be used in the conventional manner. Thus satellite pictures of the cloud system associated with a hurricane will enable the forecaster to estimate what stage a storm has reached in its development and the approximate speed and direction of the winds in various parts of it. These estimates, in turn, will help the forecaster predict the hurricane's speed and direction of travel. Similarly, the cloud patterns associated with fronts, with the cyclonic storms of high latitudes and with air masses of various sorts will help the forecaster to fill in the areas on his weather maps where data is otherwise unavailable. He can thereby learn of weather systems that may move into his forecast area or influence the behavior of those which actually move into it.

In the case of the numerical method any information at all—even intelligent guesses—over the areas where there are at present no observations will lead to considerable improvement in the forecasts; the prognostic equations are quite sensitive, and the forecast at any one

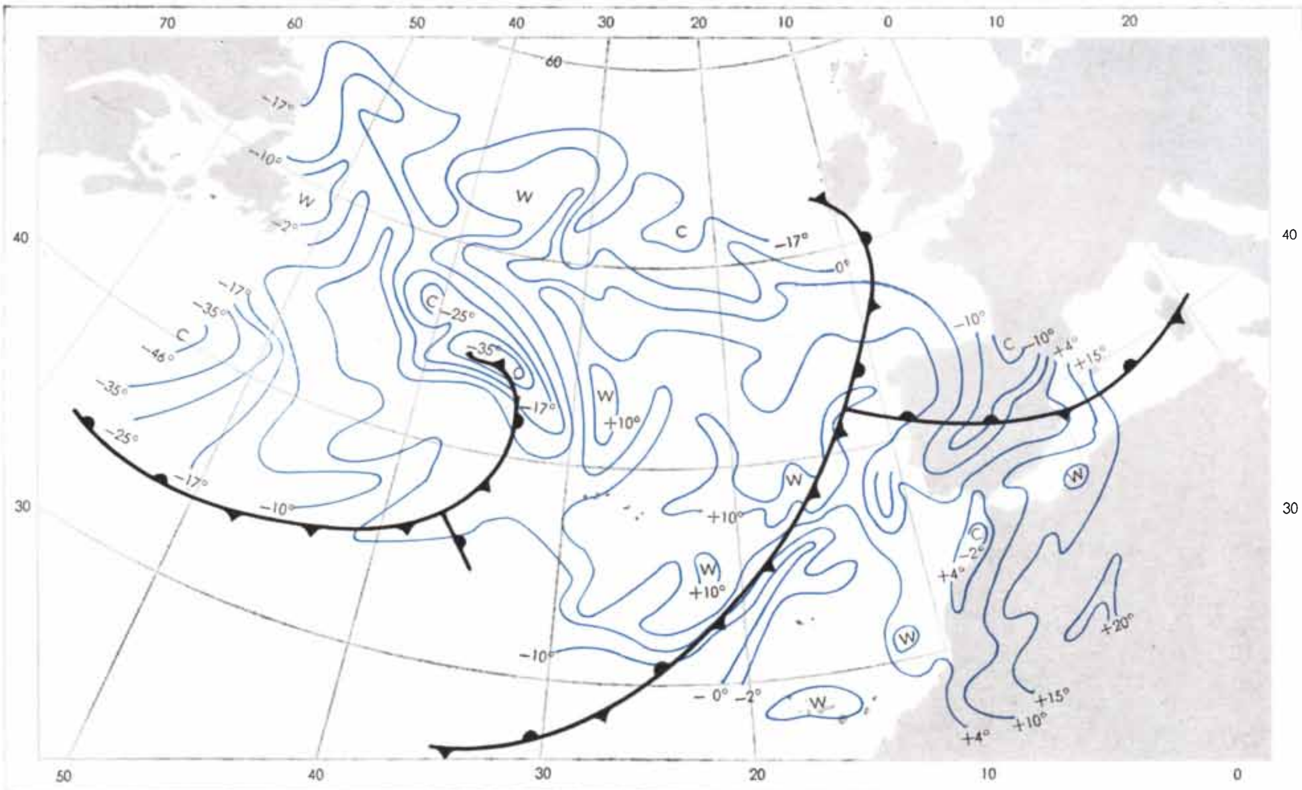
CLEAR
SCATTERED CUMULUS
BROKEN CUMULIFORM
OVERCAST STRATIFORM
CUMULUS STREETS



amalgamation of several "anvil-topped" cumulonimbus (thunderstorm) clouds in which tornadoes could have been embedded. On other occasions *Tiros I* photographed large isolated clouds, 100 to 200 miles across, that were associated with severe thunderstorms or tornadoes.



INFRARED RADIATION LOSS from the atmosphere and earth's surface was measured over the North Pacific and North America by *Explorer VII* in a series of passes (*dotted lines*) on December 2, 1959. The figures represent the heat loss in calories per square centimeter per minute, providing a clue to temperatures. Tops of clouds radiate less heat than warmer earth below.



APPROXIMATE TEMPERATURES, in degrees centigrade, were computed from radiation measurements made by *Tiros II* on November 25, 1960. The temperatures are for the earth's surface in cloudless areas and for cloud tops in areas of dense overcast. Such an overcast is indicated by cold regions (*C*) in western and middle Atlantic. Weather-front symbols are superimposed on the isotherms.

point is affected to some extent by the pressure distribution everywhere else.

At first the interpretation of satellite data will have to be subjective, but we can expect that methods will be quickly developed to carry out the process automatically by machine. A crude method might be to store in the memory of a suitable machine a library of cloud systems photographed by satellites and of the associated pressure distributions obtained by conventional means. As new satellite pictures are received, the machine would search out the cloud systems on file that resemble the new ones most closely and then fit the corresponding pressure distribution as well as possible into the distribution determined for other areas by actual observations of pressure. Still more refined methods are being developed in which the machine would use dynamical equations to seek out the horizontal wind field needed to produce the vertical velocities that must be present to produce the observed clouds.

The temperature data obtained from radiation measurements would give the subjective forecaster information about air-mass properties, which he could apply in forecasting temperature changes, pressure patterns, the probability of showers and the like. As the machine-forecasting methods become more sophisticated, temperature will play a more important role, and the availability of temperature data from areas where it would otherwise be unknown will also do much to raise the accuracy of forecasts.

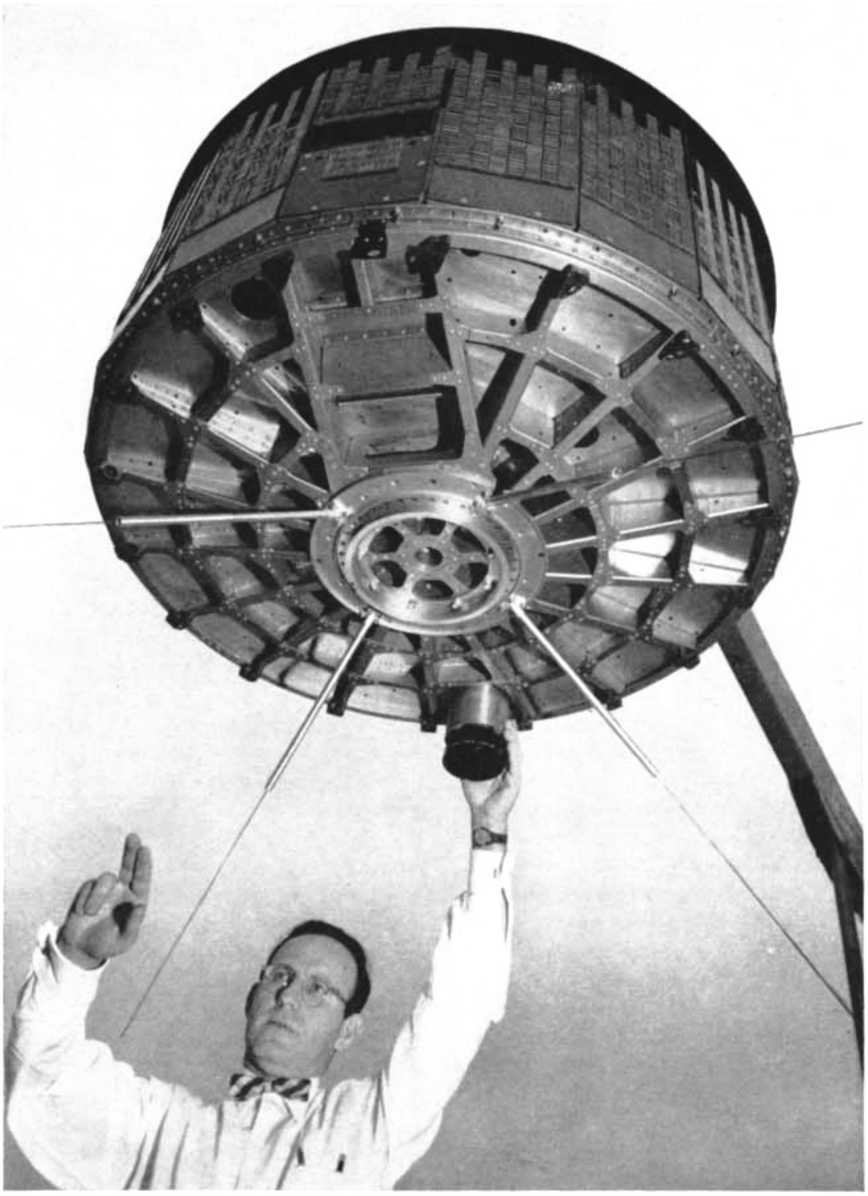
More important and more valuable, however, than any immediate improvement in the accuracy of weather forecasts is the great contribution that satellites can make to our basic understanding of weather processes. When we obtain data on the variations of the energy input into the atmospheric engine we will know to what extent the present forecasting methods—in which these energy variations are neglected—are valid. We will also be able to analyze in detail the effect of local energy surpluses or deficiencies. From these analytical studies we can expect to develop entirely new ways to use the radiation data provided by satellites in forecasting.

Weather Modification

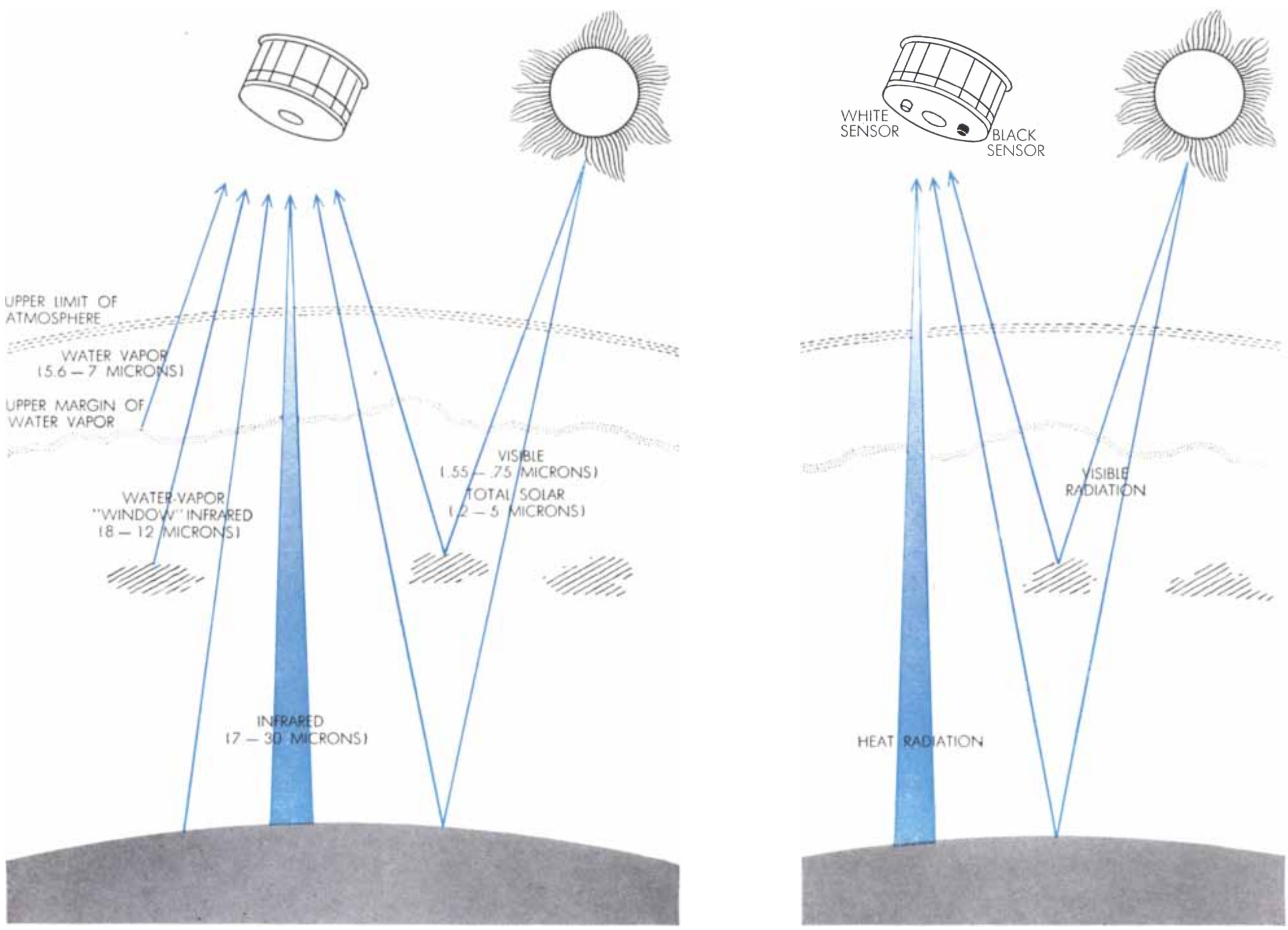
While there is much talk nowadays about weather control, we have only rudimentary knowledge of how to achieve it. Except for direct local modification of temperature (such as the heating of orchards to protect them from frost) and for cloud seeding, which under favorable circumstances has dissipated fog and clouds and may have influenced precipitation, there is no known way to affect the weather and climate of an area. Attempts to prevent hail and lightning and to influence the formation or movement of tropical storms have so far been unsuccessful. In view of such limited capabilities proposals for modifying the weather on a major scale require careful study and evaluation.

Space vehicles will contribute to weather modification primarily by increasing our knowledge of atmospheric processes, without which no intelligent control measures can be taken. Detailed observations from close-orbiting satellites should improve our understanding of the way storms form and develop, and could lead to discovery of means for stopping them at an early stage or altering their path. It has been suggested, for example, that the doughnut-shaped convection cells photographed by *Tiros I* and *Tiros II* are just about the right size to form the cloudless "eye" of a hurricane. Conceivably, when atmospheric conditions conspire, one cell out of hundreds will begin to grow, gather momentum and spawn a hurricane. If this conjecture is confirmed, the next step will be to discover what it is that triggers the growth of one particular cell and not others.

Only when satellites have provided



***TIROS I*, launched April 1, 1960, and still orbiting, is 42 inches across and weighs 270 pounds. Its name stands for "television and infrared observation satellite." Solar cells powered two television cameras, two tape recorders and other devices, together with a 1.9-watt transmitter. It transmitted some 14,000 usable cloud pictures to ground stations during 78 days of operating life. It was designed and built by the Radio Corporation of America.**



***TIROS* RADIATION DETECTORS provide five measurements in one instrument (*left*) and two measurements in a second instrument (*right*). The first instrument identifies the following: solar energy that is simply reflected (two channels between .2 and 5 microns), the total infrared radiation of the earth and atmosphere combined (7–30 microns), the infrared emitted mostly by the earth alone or by clouds (8–12 microns) and the emission from high-altitude water vapor (5.6–7 microns). The second instrument registers total visible and infrared radiation with a black sensing element and detects infrared alone with a white sensing element.**

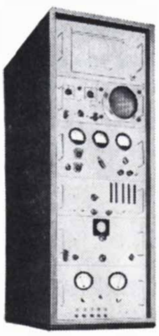
an extensive series of measurements of incoming and outgoing radiation will it be possible to determine how variations in these quantities affect the atmospheric circulation and the weather. Such measurements may also help to tell us if we are inadvertently modifying the climate of the earth by burning fossil fuels, which increase the carbon dioxide content of the atmosphere. Carbon dioxide contributes to the "greenhouse effect" by allowing short-wave radiation to enter the atmosphere and preventing long-wave radiation from leaving.

Some investigators have appealed to the greenhouse effect to explain the slight but general rise in temperatures that have been recorded in the Northern Hemisphere since the end of the 19th century. In the same period there is evidence that the amount of water locked up in glaciers and in polar ice has been diminishing. If the temperature rise should persist, bringing a continued melting of ice, low-lying coastal areas will eventually be flooded by the rising sea level. If weather satellites should demonstrate over the years to come that the earth is indeed receiving more radiant energy than it is losing, one would want to search for countermeasures. One expedient would be to hasten the replacement of fossil fuels with nuclear fuels; another would be to create artificial clouds to reduce the amount of solar energy received by the earth. On the other hand, there is evidence that beginning about 1940, in spite of an unabated rise in fossil-fuel consumption, winters have become colder, so perhaps the carbon-dioxide hypothesis of climatic change has been overrated.

It may well be that another aspect of man's activities, the cloudlike condensation trails produced by high-flying aircraft, may exert a greater influence on climate. The world cloud cover is the most important component in determining the earth's albedo, or reflectivity, and it serves as a natural thermostat to keep the world temperature within narrow limits. Whenever the cloud cover increases, less solar radiation reaches the earth; as a result the earth cools, convection currents are damped and the cloud cover declines. Whenever the cloud cover decreases, more solar radiation reaches the earth's surface, heating it and causing more clouds to form. The average cloud cover over the earth is estimated to be close to 55 per cent; the average albedo of earth and clouds combined, 35 per cent. A one-percentage-point increase in cloud cover causes a .4-point increase in albedo, which, by reflecting more solar radiation back to space, means a decrease of the earth's temperature by .7 degree F. A system of weather satellites could keep track of variations of the world's cloud cover as a first step in deciding if man is having a noticeable effect on climate.

The quantities of mass and energy that are involved in weather processes are tremendous compared with most of the sources that man has had at his disposal for possible modification of them;

WHO GUARDS THE GUARDIAN?



CM-122/DSM Signal Comparator

Look at some of the guardians of our Western civilization: Terrier, Talos, Polaris. Then ask yourself, as the Romans did, "Who guards the guardian?" Who makes certain that this regiment of space-age sentries stays ready for instant action?

Who? Varian Associates, for one. Varian has developed a CM-122/DSM Signal Comparator for the Navy's Bureau of Weapons. Its job: to test missile guidance and checkout systems to insure combat readiness of electronic components.

For commercial use, Varian supplies precision test systems such as the V-7200 Noise Measurement Test Set, to measure amplitude or frequency modulation noise from microwave sources.

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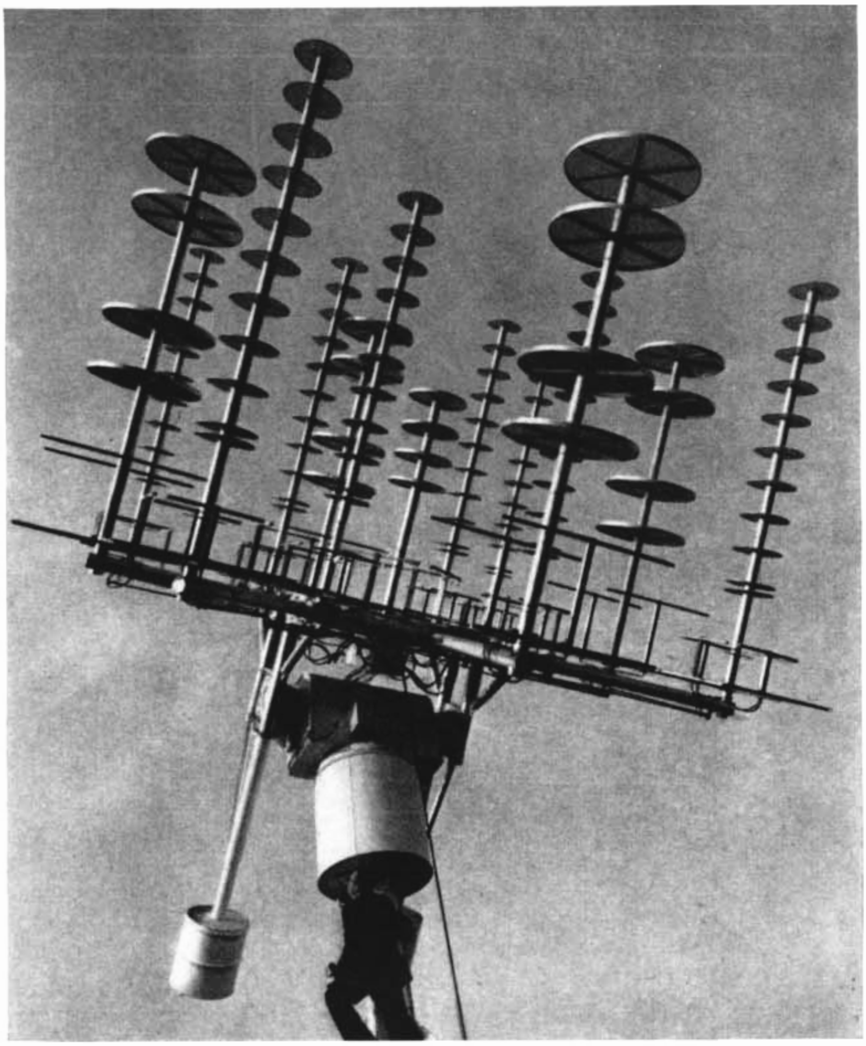

TRACKING ANTENNA at R.C.A. Space Center in Princeton, N.J., is designed to receive data from weather satellites. Most *Tiros I* data was actually received at Fort Monmouth, N.J., and Kaena Point in Hawaii; most *Tiros II* data, at Fort Monmouth and Point Mugu, Calif.

only a thermonuclear bomb involves energies of the same order of magnitude. Modification of the course of fully developed storms, if otherwise feasible, would require use of an energy source man is reluctant to use. It would be preferable from all standpoints, including the economic one, to achieve the desired changes with small expenditure of energy.

The best hope is that storms can be altered in an early stage of their development, when their future hangs in the balance and when a small impulse on one side would tip the scale away from an undesired development. That such unstable conditions exist at times is quite probable. Many Temperate Zone storms begin as small waves on the boundaries between air masses, and tropical storms often grow out of similarly small waves in the easterly trade winds. We have no way now of recognizing which small waves are unstable and which are not, nor do we know how to prevent or control the growth of the waves that are unstable. Because the network of observations is at present rather loose over much of the earth, it is seldom that a wave can be detected before it has begun to intensify into a storm. If satellite weather reconnaissance permits a more or less continuous watch for such atmospheric waves, it may be possible to perceive the conditions that make the waves unstable and to contrive ways to prevent or control the release of instability.

It is clear that we are far from the stage in which we will be able to press a button on the ground that will activate some exotic mechanism in a satellite able to dissipate a storm in one place or to make it rain in another. There is, however, every reason to expect that many new discoveries in meteorology will result from the use of satellites as global platforms from which to observe the energetic and restless atmosphere.

Imagine controlled processes that select, measure, collect, blend, form, package or distribute materials with perfect precision and timing, without the aid of human hands.

There *are* such systems now. They're busy grading beans, mixing ore, counting contents for containers, bringing materials to one point for processing. And Automatic Electric has helped on more than one occasion. For at AE we design and manufacture "educated" control systems that make machines and processes operate automatically.

If you have a control problem, we can help you find the solution. Whether you need engineering aid, basic components, a control "package," or a complete system, write the Director, Industrial Products Engineering, Automatic Electric, Northlake, Illinois.

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WORK
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Why do flowers smell good?

Why do I like the smell? Why don't they all smell alike . . . or like candy? Why?

To a child, the discovery of an enchanting new smell is reason to stop, to explore, to inquire. For just as instinctive as the indrawn breath that brings the flower smell is the curiosity it arouses. Happily, some children never seem to outgrow this curiosity or the joy of asking, searching and finding.

We know. We know because one of the important tasks of Shell Research is to seek out people with questioning minds, to encourage them and allow their rare talents to find the answers for the rest of us. Answers like TCP additive to make your car run better, insecticides to help grow healthier crops, new synthetics to augment and improve upon nature.

In today's swift-moving world we cannot have enough of this kind of mind—the mind of a grownup still as curious as a child's. To help develop such people, special educational programs are supported by Shell. These include scholarships for deserving students and the Shell Merit Fellowships that train science teachers in improved teaching techniques.

The success of such programs can be measured in many ways. We see in them a means of encouraging an eternal spirit of curiosity. The world was never more in need of people who keep asking why. People not afraid of the big questions. Why can't we feed the hungry of this world? Why?

Why is a child. *Why* is Shell Research.

We hope that the sign of the Shell reminds you of those who never stop asking why, never stop the quest for new ideas, new products, and new ways to serve you.

The Shell Companies: Shell Oil Company; Shell Chemical Company; Shell Pipe Line Corporation; Shell Development Company; Shell Oil Company of Canada, Ltd.

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