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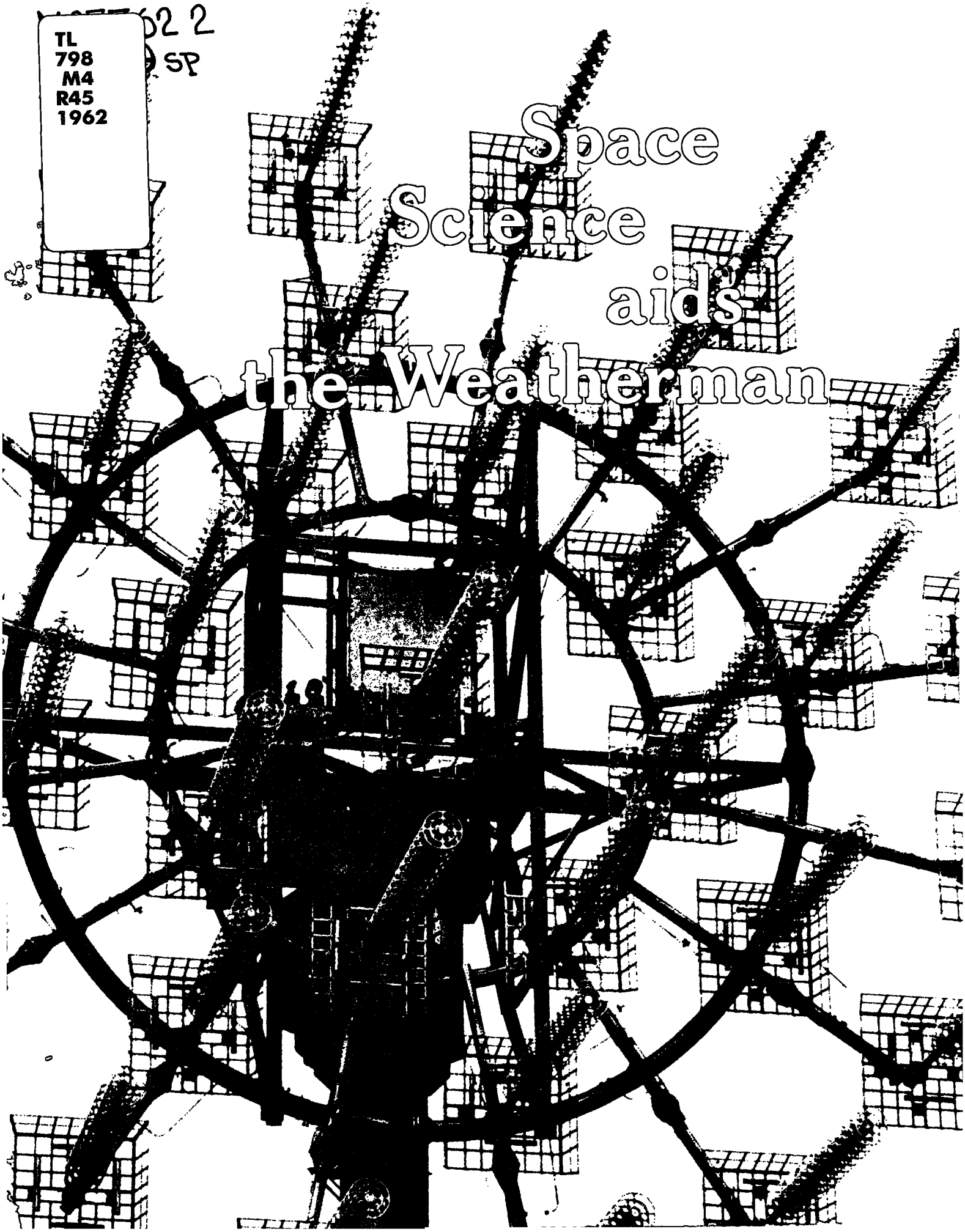
Space Science aids the Weatherman



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Cover: *This sensitive and complex antenna system at Wallops Island, off the Virginia coast, receives information transmitted by the weather satellites.*

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Space Science aids the Weatherman

by Francis W. Reichelderfer
Chief of the United States Weather Bureau
U. S. Department of Commerce

127 772

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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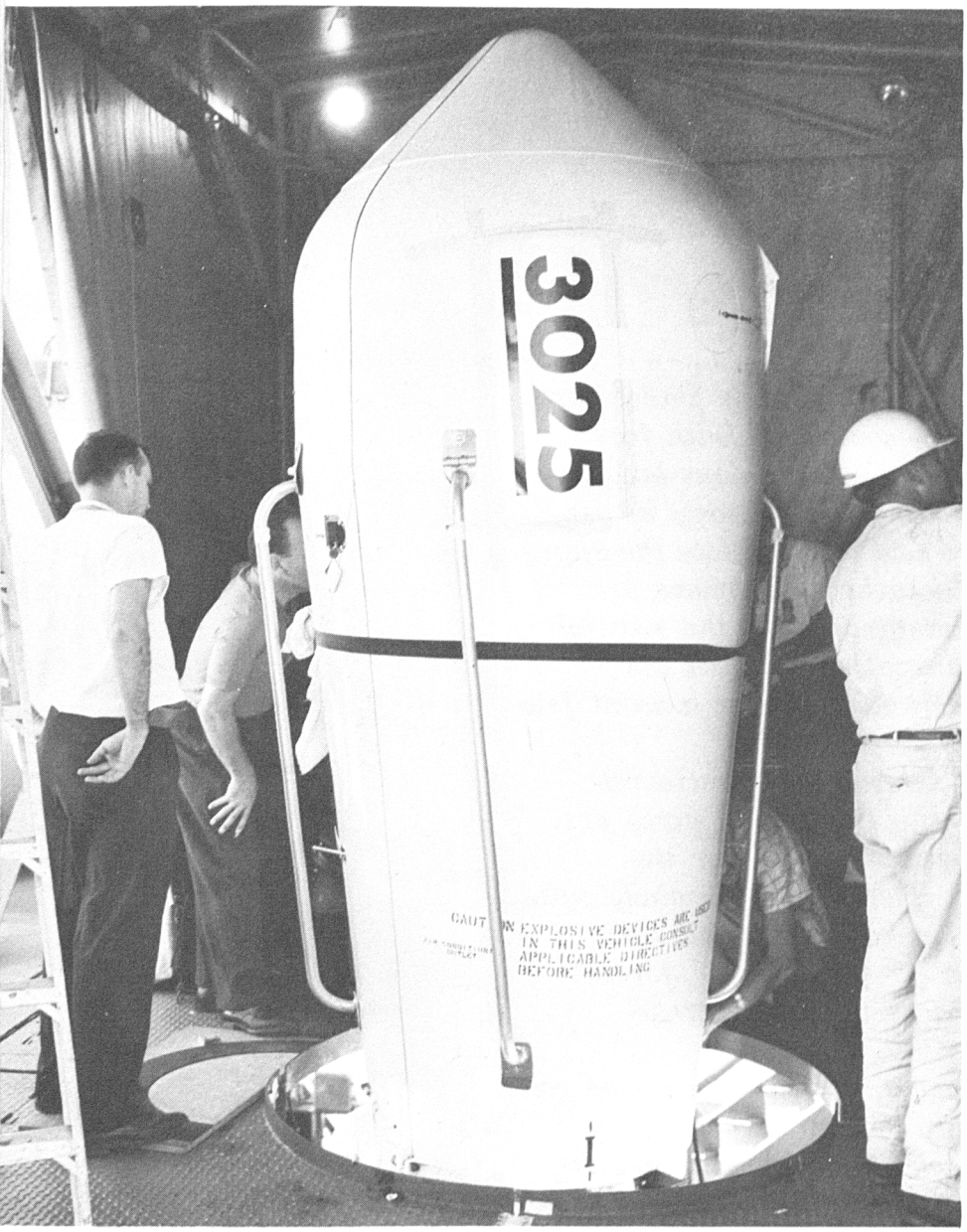
INTRODUCTION

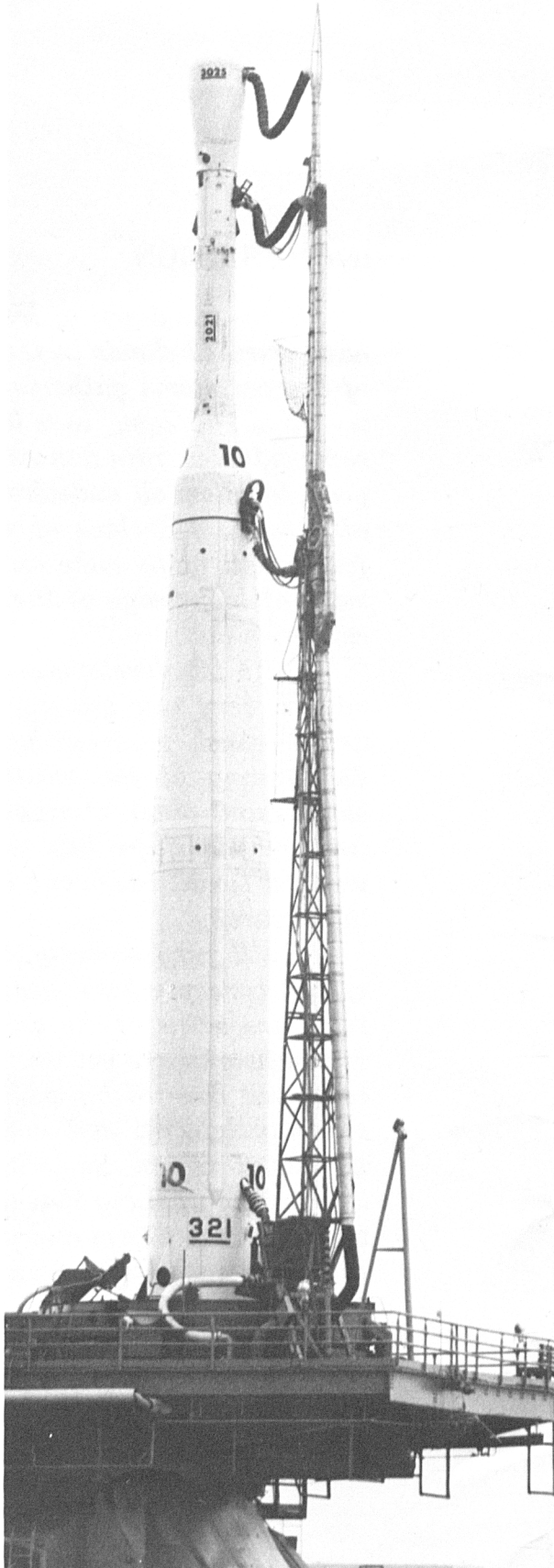
Since the dawn of history, men all over planet earth have watched clouds in the sky—sometimes with fear of a great storm gathering, sometimes anxious because no rains had come in a long time. Even today in some cultures, rain dances are held to propitiate the angry gods, to whom all undesirable weather phenomena are attributed. This lack of understanding of the natural forces that go to make up the weather typified the state of knowledge of the entire human race a scant few centuries ago.

With the development of the science of meteorology—a very new science, as the chronology gives evidence—much progress has been made in our understanding of the weather. The study of wind, rain, clouds, and other atmospheric phenomena and their inter-relationships has made it possible to forecast weather conditions over a short period with increasing accuracy.

Until very recently, however, forecasts based on scientific concepts have generally had to be limited to inhabited areas of the globe where fairly dense observing networks are set up. In the vast areas of the earth not covered by such networks, a great storm often starts undetected and sweeps on its course toward a populated region. Sometimes the storm is detected too late for the warning that would have enabled people to protect their lives and property. Now, with the weather satellites, such storms can be seen and reported.



Technicians finish installing the protective nose fairing around the TIROS V payload which contains cameras and instruments to study weather conditions. This fairing breaks away before the satellite goes into orbit.



TIROS V within its fairing is mated to the top of a Thor-Delta launch vehicle for its flight into space June 19, 1962. They are seen on the launch pad ready for the count-down.

Communications and the Weather

Progress in meteorology and weather forecasting has gone hand in hand with advances in communications technology. Thus, the United States Army Signal Service (later the Signal Corps) was the logical place for America's first national weather service to begin, primarily because of the Signal Service's existing communications network, in which the telegraph played a major role for the gathering of information from widespread points.

Later, the use of radio—and the Weather Bureau was one of the earliest users of Marconi's wireless telegraphy—permitted a great step forward. And progressively through the years, improved communications devices such as the teletypewriter and the facsimile transmitter kept pace with and aided in distributing the data from improved observational devices such as high-altitude radiosonde balloons, storm detection radar and other instruments.

But with TIROS I, the first experimental "weather eye" satellite launched by the United States Government's National Aeronautics and Space Administration (NASA) on April 1, 1960, a whole new era in weather observation and communication was opened. The TIROS family of weather satellites and its successors are making weather observation on a global scale possible for the first time.

Before examining the enormous potentialities of weather satellites, however, it might be well to consider briefly what makes up the weather.

Weather is the condition of the atmosphere at a given time.

Many factors make up what is known as weather. Some of these are air temperature, air pressure, wind direction, wind speed, relative humidity, cloudiness, and kinds and amounts of precipitation (snow, rain, hail, etc.).

Weather, as it affects man, is confined mainly to the dense lower layer of the earth's atmosphere, known as the troposphere. The troposphere, which may be thought of as a turbulent fluid, is subjected to strong heating and cooling as it moves over the rough, rotating earth. Air masses, large sections of the troposphere whose temperature and moisture characteristics at various levels are uniform, are formed as a result of heating and cooling. An air mass gets its temperature and moisture characteristics from the surface of the earth over which it has hovered.

As the air mass moves it also imposes its own conditions of temperature and humidity on the areas over which it passes. Changes in weather depend in large measure upon the way these air masses move, change and interact with other air masses.

Forecasting weather depends not only on knowledge of how air masses move and interact, but upon an up-to-the-minute knowledge of the present state of the atmosphere. From this knowledge the characteristics of existing air masses can be determined. This information is then used to forecast weather. The more complete the information, the better the forecast is likely to be.

With weather satellites, it is possible to photograph cloud systems that accompany many air masses and thus to obtain weather information that is not available in any other way.

What Is a Weather Satellite?

A satellite revolving about the earth can be regarded as an artificial, man-made moon. It looks down on conditions of the atmosphere from above, and then reports by radio and television on what it "sees."

In the past, meteorologists have been handicapped by having only fragmentary knowledge of what is going on in the atmosphere at any one time—three-fourths of the globe, particularly the vast ocean areas, remained unknown, with very sparse weather observation coverage.

Now the weather satellite provides an instrument that can observe and record by remote control weather information on

a worldwide scale. It is the key to nature's own weather maps, which appear primarily in the form of cloud patterns.

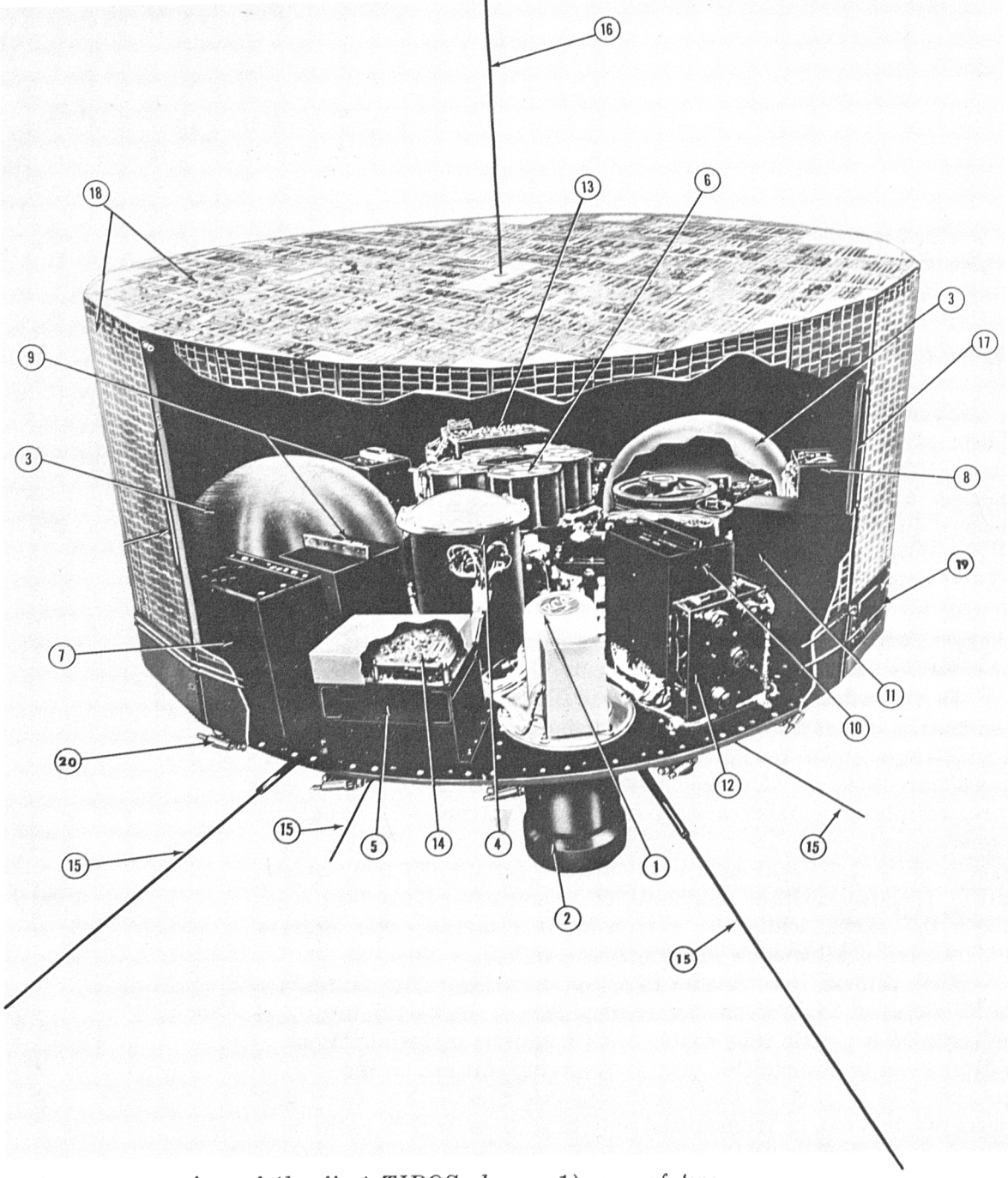
How the Weather Satellite Works

Each member of the TIROS family (Television and Infra-Red Observation Satellites) of experimental weather satellites is about 107 centimeters (42 inches) in diameter and 48 centimeters (19 inches) high, shaped somewhat like a drum or hatbox. Its sides and top are studded with devices called solar cells that convert sunlight into electrical energy. Composed of materials sensitive to light, they create an electromotive force when struck by the rays of the sun, and thus supply power to charge batteries—which, in turn, store and supply electricity to operate the satellite's instruments.

In the cut-away picture of the TIROS I weather satellite can be seen one of the two television cameras it bears. It has a wide-angle lens to take pictures of a broad area; the other camera has a narrow-angle (long focal length) lens for detailed pictures of a much smaller area. After TIROS II only wide-angle cameras were used. The wide-angle cameras in each photograph cover 1,690,000 square kilometers (about 650,000 square miles) from an altitude of about 700 kilometers (450 miles) above the earth, while the narrow-angle cameras cover only 16,900 square kilometers (6,500 square miles).

Each camera is connected to a tape recorder which stores up to 32 pictures. Light from the camera lens is converted into patterns on a plastic tape coated with magnetic material. These patterns can be transmitted later to receiving stations on the ground. The storage of the pictures in this form is necessary because pictures can be transmitted only to stations within radio range of the satellite. If the pictures were not stored in this way, they would be available only from areas within 1,900 kilometers (1,200 miles) of a station. For TIROS I, the stations were located at Fort Monmouth, in New Jersey, and Kaena Point, in Hawaii. The Fort Monmouth station was later moved to Wallops Island, in Virginia, and the Kaena Point station to Point Mugu, in California. Operators on the ground can communicate with the satellite and command it to perform certain functions on later orbits, but they can do this only when the satellite is passing over the station, for about a 10-minute period on each pass.

Suppose that meteorologists want pictures of clouds over



This cut-away view of the first TIROS shows: 1) *one of two television cameras;* 2) *wide-angle camera lens;* 3) *tape recorders;* 4) *electronic timer for controlling picture-taking time;* 5) *television transmitter;* 6) *storage batteries;* 7) *camera electronics;* 8) *tape recorder electronics;* 9) *control circuits;* 10) *auxiliary controls;* 11) *power converter for tape motor;* 12) *voltage regulator;* 13) *battery charging regulator;* 14) *auxiliary synchronizing generator for television;* 15) *transmitting antennas;* 16) *receiving antenna;* 17) *solar sensor to measure position of satellite with respect to sun;* 18) *solar cells;* 19) *de-spin mechanism;* 20) *spin-up rockets.*

the ocean in the vicinity of Australia. As the satellite passes over a station, instructions are transmitted to it by radio so that the television cameras will automatically take and store pictures during the succeeding orbit. When the satellite passes over Australia, the cameras will start as instructed, take pictures, and store them as patterns on the magnetic tape. Within a very short time the satellite will be over a station again, as it circles the earth every 100 minutes. A radio signal from a station will command the satellite transmitter to send its pictures, which the station will receive and show on a video screen not unlike the picture tube in a home television receiver. The cloud distribution is photographed from this screen and is soon ready for the weather man to assess.

Meanwhile, in the satellite system the picture patterns on the tape—which is 122 meters (400 feet) long—are automatically erased and the tape machine is ready to record the next series of pictures.

TIROS I — First Weather Satellite

TIROS I was launched April 1, 1960. The satellite went into a near-circular orbit with a perigee of 698 kilometers (436 miles) and an apogee of 738 kilometers (461.3 miles). The Thor-Able launch vehicle is a reliable liquid-fueled rocket 19.5 meters (65 feet) tall with a thrust of 67,506 kilograms (150,000 pounds) as a first stage, topped by modified Vanguard engines as second and third stages.

TIROS I made meteorological history, giving scientists an unprecedented opportunity to study the earth's cloud patterns and relate them to the weather. Among the striking patterns seen for the first time in their entirety were large-scale cyclones with spiral bands sometimes covering an area 1,600 kilometers (1,000 miles) across.

Photographs transmitted by its two television cameras also indicated the presence of jet streams, or streams of air blowing at speeds of as much as 320 kilometers (200 miles) an hour, at high altitude; regions of moist and dry air, thunderstorms, fronts, and many types of cloud patterns. Experimental studies based on these data will lead to improved understanding of how the atmosphere works and eventually to increased accuracy of weather forecasting, particularly over large ocean areas.

About midnight June 29, 1960, after TIROS I had completed 1,302 orbits around the world, its power supply failed and

attempts to interrogate the satellite ceased. Its effective lifetime, during which it transmitted 22,592 pictures, was at an end.

TIROS II—Measures "Heat Balance"

The TIROS II satellite was launched November 23, 1960. In addition to the television cameras carried by TIROS I, this second member of the experimental TIROS family carried special infrared instruments for measuring solar and terrestrial radiation—key to the heat balance of the earth that plays such an important part in the varying aspects of the earth's climate.

The infrared radiation information is received in a form that requires considerable processing before it can be used, and accordingly, the United States Weather Bureau's Meteorological Satellite Laboratory, in cooperation with NASA, has developed methods for processing the data on digital computers. To date, all usable radiation intelligence from TIROS II has been processed and recorded on magnetic tape for research use with high speed computers. From these tapes, a series of maps of the radiation measurements were produced which are already being used in research. A catalogue shows 172 of these radiation maps from TIROS II.

The most useful radiation measurements so far are those made in the eight to 12-micron region of the radiation spectrum. This region is known as the "water vapor window" because radiations with wave lengths of eight to 12 microns can pass through the atmosphere without being absorbed by the water vapor. The radiation measurements in this region are being used to study the distribution of cloud patterns under both day and night conditions. Researchers also are attempting to find means to use these data to determine the heights of cloud tops. In addition, other radiation data will be used in preliminary studies of general circulation patterns.

TIROS II cloud pictures were used to make nephanalyses for immediate use by the weather services. The last of these nephanalyses (cloud analysis maps) were made from pictures received April 28, 1961. However, useful pictures were still being received occasionally more than a year after launch.

TIROS III—Storm Hunter

TIROS III, the third experimental weather satellite, launched July 12, 1961, featured two wide-angle cameras instead of the

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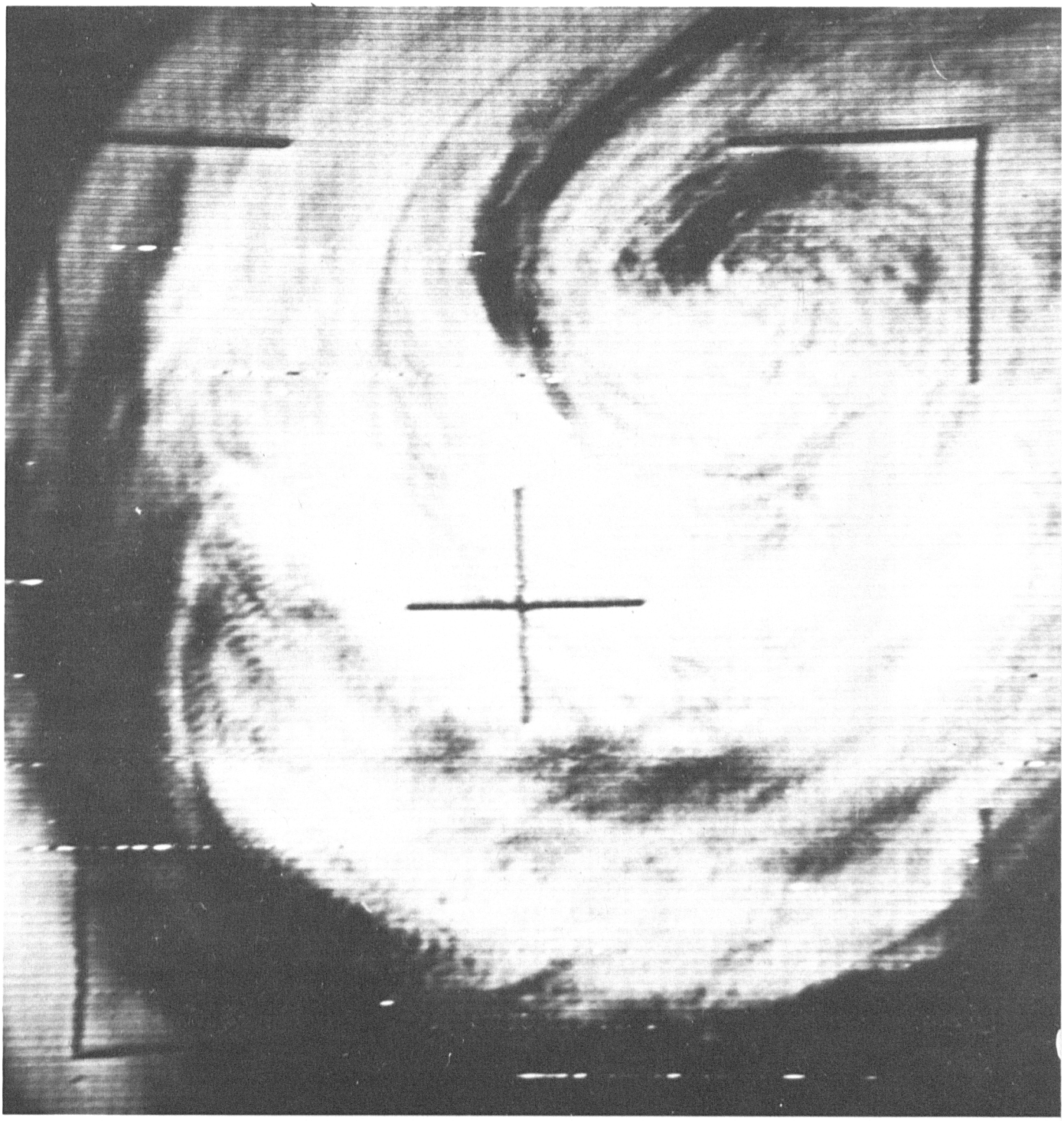
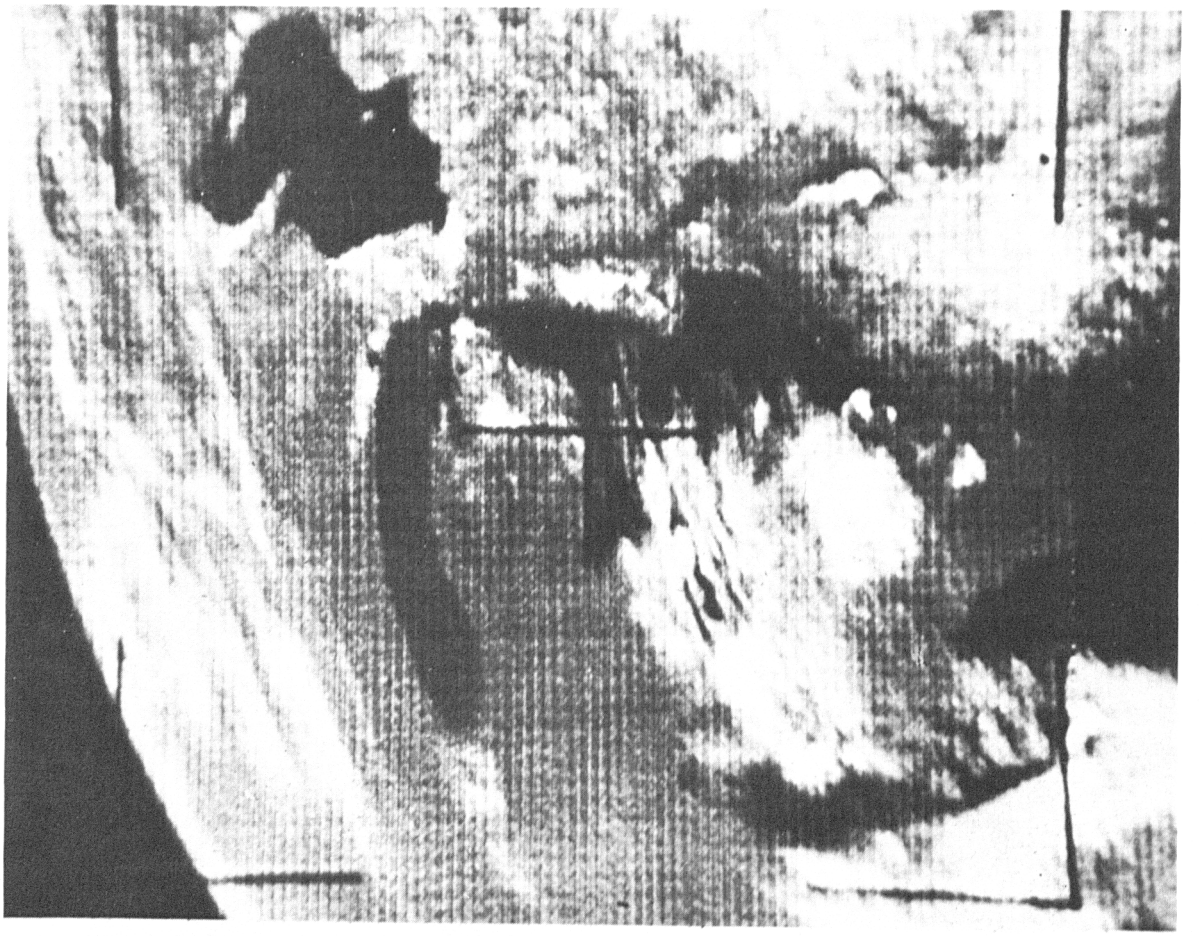
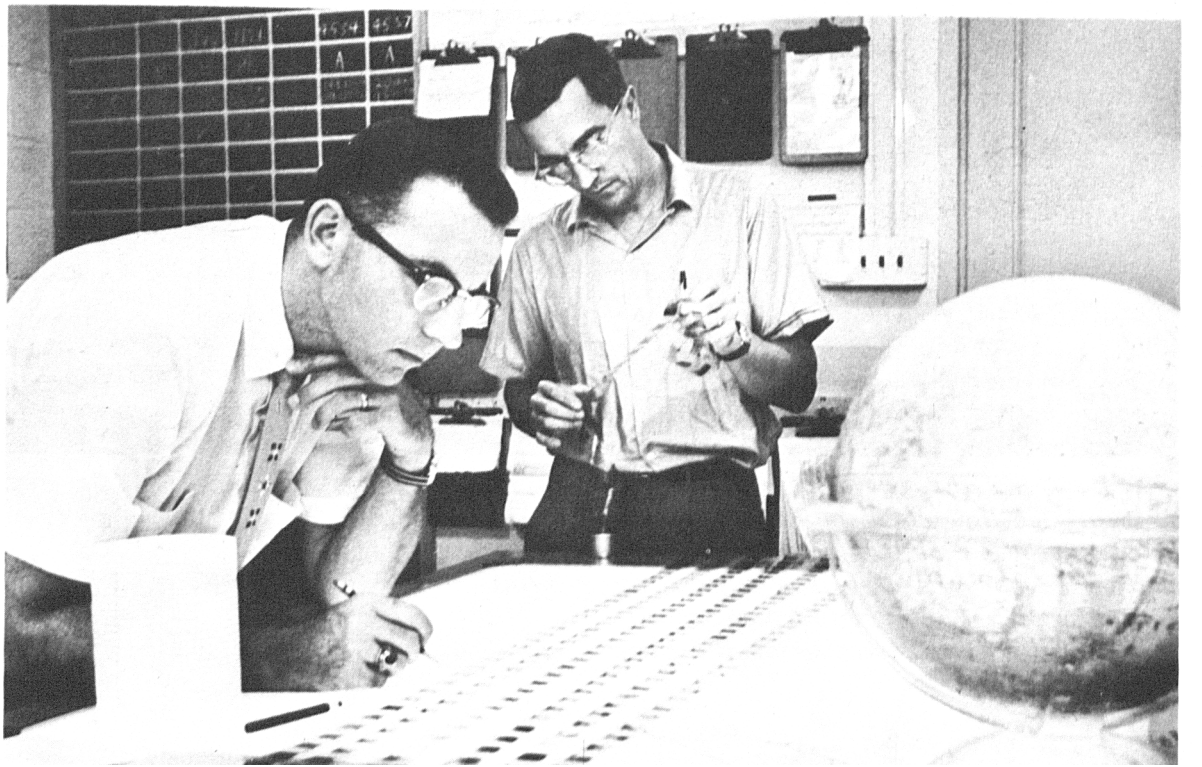


TIROS V saw this vortex of a storm off the northeast coast of Newfoundland on its third orbit June 19, 1962. This was received by the Wallops Island station in Virginia and is a typical single print of a weather satellite photo transmission. The cross marks the center of the camera eye.

The Great Lakes on the United States-Canadian boundary are seen in this TIROS photograph. The pendant lake is Lake Michigan and above it at left is Lake Superior. Cloud masses are seen in the area of Lakes Huron, Erie and Ontario. The men pictured are plotting strips of cloud photos sent by a weather satellite.

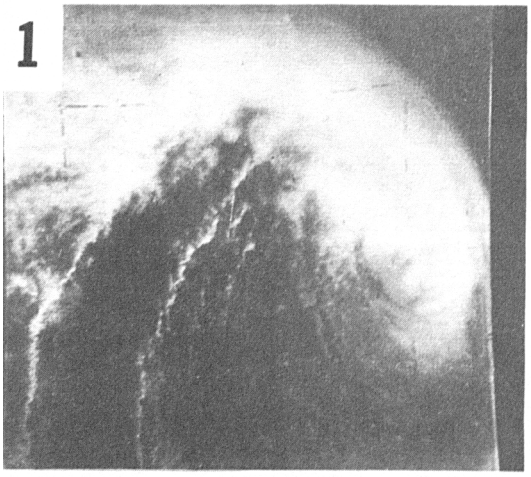


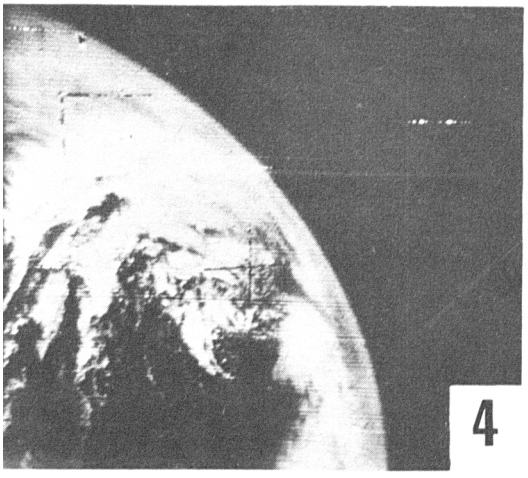


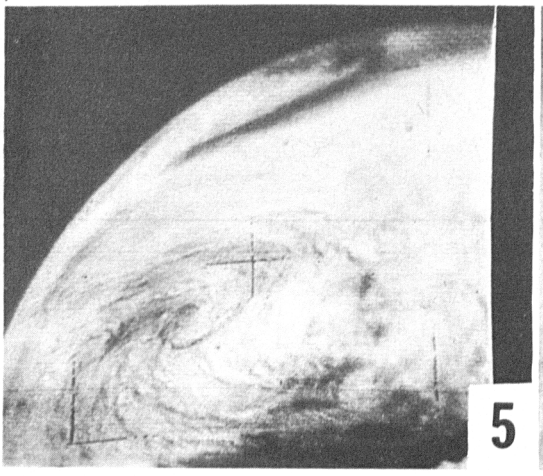
The Florida peninsula of the United States is clearly seen along with parts of the states of Georgia and South Carolina in this photo sent by TIROS IV. Broken cumulus clouds appear over the Gulf Stream area in the Atlantic Ocean right of the peninsula.

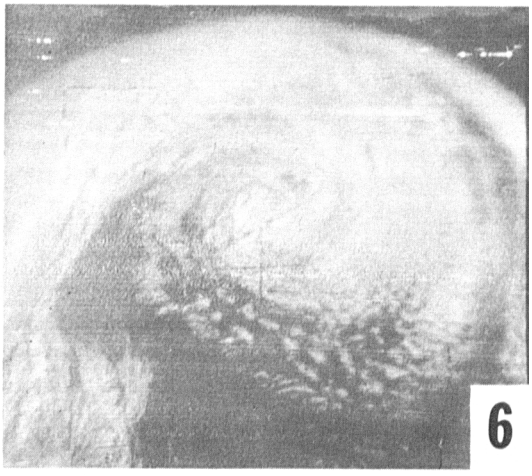
The cloud analysis (nephanalysis) map was made from the photo mosaic above it, which shows vortices of hurricanes Debbie and Esther over the Atlantic Ocean September 11, 1961. Photos in the mosaic were transmitted by TIROS III.

These vortices are typical storm centers photographed by weather satellites in areas of the southern hemisphere.

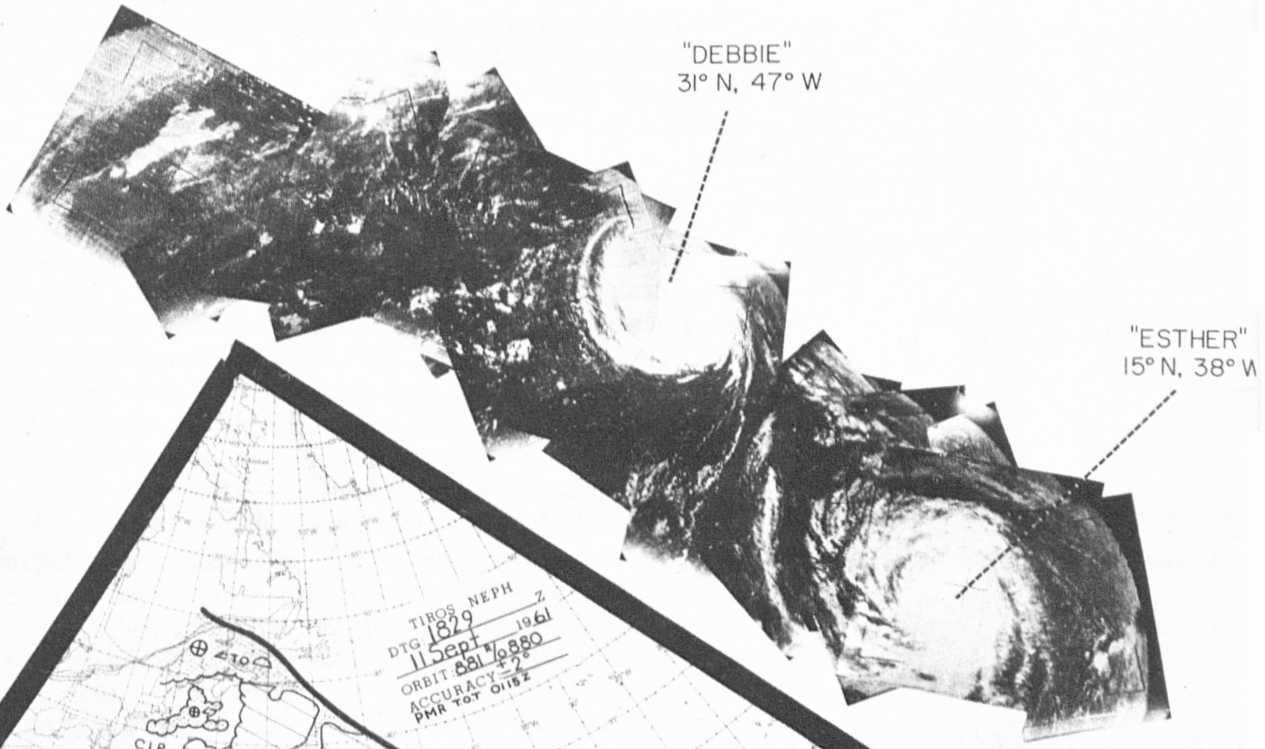








PICTURE MOSAIC



TIROS III Orbit 881
1830 GMT Sept 11, 1961

NEPHANALYSIS

one wide-angle and the one narrow-angle camera carried by TIROS I and II. In addition to the infrared devices of the type used in TIROS II, it carried an advanced "Suomi" infrared experiment (instrumentation named after the scientist who designed it), similar to that used in the Explorer VII scientific satellite. Cloud picture data collection began on the day of the launch, a date chosen so that the satellite would operate during the hurricane season.

From July 12 to October 12, 1961, TIROS III photographed many tropical storms. A total of 75 advisories or special warnings on these storms, based primarily on TIROS data, and other significant weather patterns were telephoned, radioed, or otherwise communicated to United States weather centers, and by international meteorological circuits were sent to weather offices of other countries.

For example, TIROS III pictures discovered hurricane Esther at 11°N, 30°W at 1800 hours GMT, September 10, 1961, and the San Juan and Miami hurricane centers were notified. Approximately 20 hours later, a second series of pictures from the satellite had been received and the existence of the storm was confirmed through aerial reconnaissance and ship reports. San Juan then issued Bulletin No. 1 on Esther, which thus became the first fully developed hurricane ever discovered and reported immediately by a meteorological satellite.

In addition to special warnings, cloud analysis maps based on TIROS III information were relayed to United States weather stations and to the weather services of other nations. These were transmitted either as diagrams by facsimile or in coded form by radio teletype.

A total of 755 of these analyses derived from TIROS III information had been transmitted by November 1, 1961. Deterioration of electronic components aboard the satellite forced a sharp curtailment of the operational program after October 1 because of poor quality pictures. Reports from stations receiving the analysis, both abroad and in the United States, indicated that the information was very useful in analysis and forecasting, when added to standard weather data from usual sources.

In all, during its first three months of full operation, TIROS III discovered a hurricane, saw 18 tropical cyclones, and viewed 60 significant storm circulations. It had acquired more than 25,000 pictures, and radiation data from several hundred orbits. The pictures are being used to further meteorological knowledge. The most dramatic data, the hurricane photos, were

the subject of intensive study.

There are many theories as to how and why hurricanes form but scientists have been unable to examine them in detail. Now, data from the satellites are helping research experts to scrutinize these storms thoroughly, to confirm or refute existing theories, and to formulate new ones.

TIROS IV—Increased International Use

TIROS IV was launched February 8, 1962. By the end of April, some 546 nephanalyses had been transmitted to users by facsimile and teletype. On April 15, the Weather Bureau began international radiofacsimile transmission of these cloud maps based on photographs received from TIROS IV. With the proper equipment, users in Europe, South America, Africa, the Far East, and the Southwest Pacific received these transmissions to supplement the coded cloud analyses now sent routinely on international radioteletypewriter networks.

The program will be continued if weather services abroad report that the maps are significantly more useful than the coded analyses transmitted by the Weather Bureau since July, 1961.

Formal notice of the experimental program was sent to the meteorological services of more than 100 nations, informing them of the broadcast frequencies and schedules and of the equipment needed for receiving the cloud maps.

At the time these additional services were begun, 17 special satellite storm bulletins had been dispatched to several countries including the Malagasy Republic, Mauritius, Australia, New Zealand, and Japan.

TIROS V—The Hurricane Hunter

On June 19, 1962, TIROS V was launched to study Atlantic hurricanes which usually reach their peak season in August and September, and the more-protracted Pacific tropical storms. It was similar to other weather satellites in the TIROS series, except that it was not equipped to obtain radiation data. It also gathered weather data from farther north and south than any of its precursors. It was launched into a somewhat elliptical orbit on an inclination of 58 degrees to the equator. This permitted it to gather data on Arctic and Antarctic weather phenomena in its periodic swings close to both the Arctic and Antarctic circles.

TIROS VI — Storm Stalker

TIROS VI, sixth in the series of weather satellites, was placed in a nearly circular orbit on September 18, 1962, primarily to transmit data on hurricanes in the Atlantic Ocean and tropical storms in the Pacific Ocean during the last half of the stormy weather season. TIROS V, with one camera disabled, was nevertheless transmitting usable data when TIROS VI was orbited. Thus two weather satellites were in orbit simultaneously, a policy which was to be continued until the more sophisticated NIMBUS series was ready. TIROS VI, transmitting remarkably clear pictures, was inclined 58 degrees to the equator, covering virtually the same areas of the earth as TIROS V. It orbited once every 98.7 minutes ranging from 425 to 442 miles (680 to 710 kilometers) above the earth. Like TIROS V, this satellite was not equipped to measure infrared radiation.

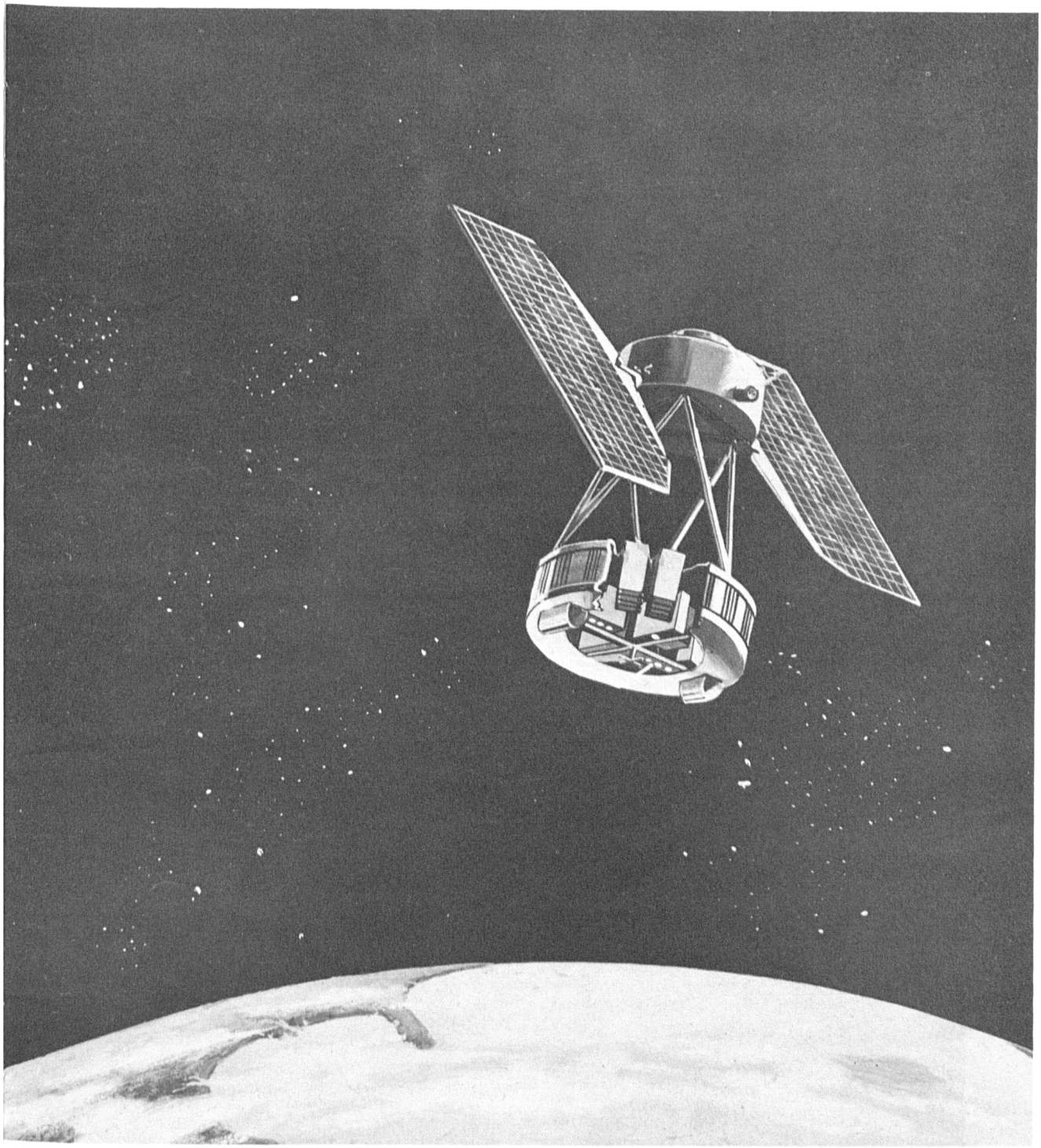
NIMBUS — Soon on the Job

Soon to follow the TIROS is the NIMBUS series, a satellite family with many components similar to those of TIROS—cameras, radiation sensors, data storage and transmission components and other instruments. Profiting from experience gained with its predecessor, NIMBUS will have improvements in many of the above systems, and in addition will introduce new sensory systems.

TIROS, despite the usefulness of the data it supplied, has severe limitations. Because of the characteristics of its stabilization system and of its orbit, its cameras can scan the earth no more than about 20 percent of the time on each orbit. Because its path is inclined to the equator, it can take pictures only in the areas lying approximately between the northern and southern extremities of the orbit, leaving the rest of the globe unobserved.

The NIMBUS family will not have these limitations. Being earth-oriented, its cameras and other atmospheric sensors will always face the globe. And, launched on an orbit over the poles, it will be able to view each area of the earth, including the significant weather-making areas at the North and South Poles, twice during every 24-hour period as the earth rotates beneath it.

To provide power, NIMBUS will carry paddles covered with solar cells controlled so as to face the sun at all times. The top section of the satellite will contain controls necessary to



This is an artist's conception of the proposed NIMBUS weather satellite in orbit. NIMBUS is more advanced than TIROS and will be stabilized so that its cameras always will point toward the earth.

Through weather satellites scientists hope to gain enough information to warn people when hurricanes will strike and thus save lives and property. Wind and waves show force of a hurricane wind on the Florida coast.

The aftermath of a storm at Galveston in Texas. The weather satellites promise hope of long-range predictions and short-range warnings to help reduce loss of lives and property.

keep the sensors always pointing toward the earth. A lower section will house the sensing systems. As now planned, these include television cameras with wider coverage and better resolution than those in the TIROS series, and a number of improved radiation sensors.

The lower section of NIMBUS is being designed on a modular basis; that is, it will have standardized compartments, so that in later NIMBUS versions, improved types of equipment can readily replace obsolete sensors without any need for redesigning the entire satellite.

Future NIMBUS satellites will include such new developments as radar to provide data on areas and intensity of precipitation, an infrared spectrometer to provide data for computation of vertical temperature distribution, and equipment to identify electrical storm areas.

All data will be sent from the command and data acquisition stations to Meteorological Satellite Activities of the Weather Bureau at Suitland, in the state of Maryland, where they will be analyzed and processed. All this information will be made freely available to all interested users.

A National, Then International System

The effectiveness of the operational application of TIROS data has fired the imagination of weathermen. A United States interagency committee of experts, the Panel of Operational Meteorological Satellites, has drawn up a plan for a national operational meteorological satellite system to provide data continuously over the entire earth.

The plan will employ a system of several satellites in space at once and stations both in the United States and abroad. Radio will link the satellites with the stations and high speed transmitters will connect the stations with global weather centrals. The first step toward a fully operational system, including possible early international participation, will be realized when the second-generation, more advanced NIMBUS is launched.

In the meantime, the government is augmenting the TIROS program with a sufficient number of spacecraft to ensure that at least one weather satellite is in orbit at all times. TIROS satellites are being launched at about four-month intervals. It is planned that the final TIROS will be just ending its useful lifetime when the first NIMBUS is launched.

In an address to the United States Congress January 30, 1961, President Kennedy specifically invited "...all nations... to join us in developing a weather prediction program...."

A few months later, addressing the United Nations General Assembly, the President proposed "...a program of international cooperation... under the United Nations." He cited better weather forecasting as a basic benefit of such cooperation.

The U.N.'s World Meteorological Organization is expected to play an important role in promoting international cooperation. The purposes of this organization, comprised of 116 member nations, are to:

> facilitate cooperation in establishing weather-observing networks; promote rapid exchange of weather information; encourage standardized meteorological observations; apply meteorology to many fields of man's industry and effort; and promote research and training in meteorology.

This promise for the future is being realized even today. The TIROS satellites, planned as experiments, had immediate practical use. Taking advantage of these operational capabilities, arrangements already have been made by the United States to transmit to other nations information about weather conditions observed by meteorological satellites. If, for example, an earth orbiting weather satellite observes a storm heading for a heavily populated area in Southeast Asia, a satellite data receiving station in the United States will collect and analyze the data and transmit the information to the weather services of the countries involved. The governments of those countries can then warn their peoples so that precautions can be taken to eliminate or lessen risk to life and damage to property.

Weather satellites, clearly a great technical achievement that will advance the science of meteorology, already have been of real and immediate benefit to man. The United States is using weather satellites to contribute to man's understanding of his atmospheric environment. In years to come, these satellites, as instruments for ever-better analysis of weather, will even more directly serve all people, as they participate in a global space weather system which will enhance peaceful and constructive life.

History of U.S. Weather Services

1870—National weather service created as branch of Army Signal Service (Corps) provided for meteorological observations at military stations.

1871—Hydrologic services inaugurated in the form of report of river stages.

1873—Reports and storm warnings initiated for the benefit of commerce and agriculture.

1891—National weather service transferred from Signal Corps to Weather Bureau of the Department of Agriculture.

1893—Hurricane warning service—special observations authorized from West Indies during hurricane season.

State weather service inaugurated. Research began; first study was concerned with the relation of climate to organic life.

1895—Professor Marvin began using kites to make weather observations.

1899—Marconi demonstrated wireless; Weather Bureau became one of first users.

1901—Hurricane service—establishing and equipping stations in the Hawaiian Islands authorized.

1902—Preliminary studies of surface winds at Kitty Hawk, N. C., made for Wright brothers as aid to airplane flight experiments.

1909—Beginning of free-balloon weather observations.

1913—Radio stations in Arlington, Virginia, and Key West, Florida, began broadcasting daily weather bulletins.

1919—First experiments with airplane weather observation.

1925—Daily airplane observations of weather made at Washington, D. C.

1928—First teletypewriter circuits installed.

1936—Use of radiosonde, a balloon-borne device that measures pressure, temperature, and humidity, and transmits information to earth by radio signals.

1939—Automatic telephone weather information services began.

1940—Weather Bureau transferred to Department of Commerce.

1948—Teletypewriters were supplemented by facsimile transmitters, a kind of wirephoto.

1954—First automatic observing station, making weather measurements and transmitting them automatically by teletypewriter.

1960—TIROS I, first experimental weather satellite, successfully launched, opening a new era in weather observation techniques.

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