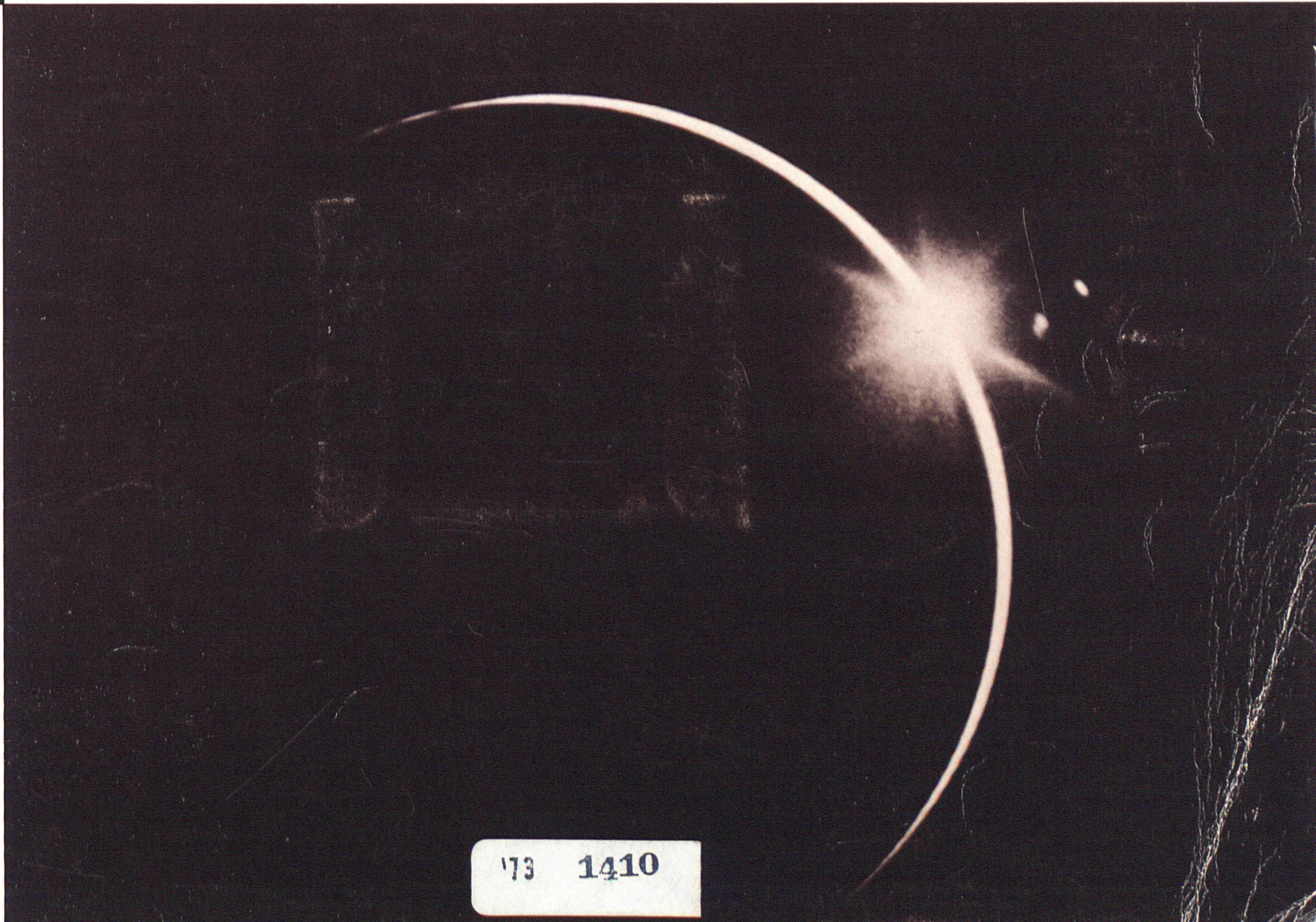
SPACE
ENVIRONMENTAL VANTAGE POINT



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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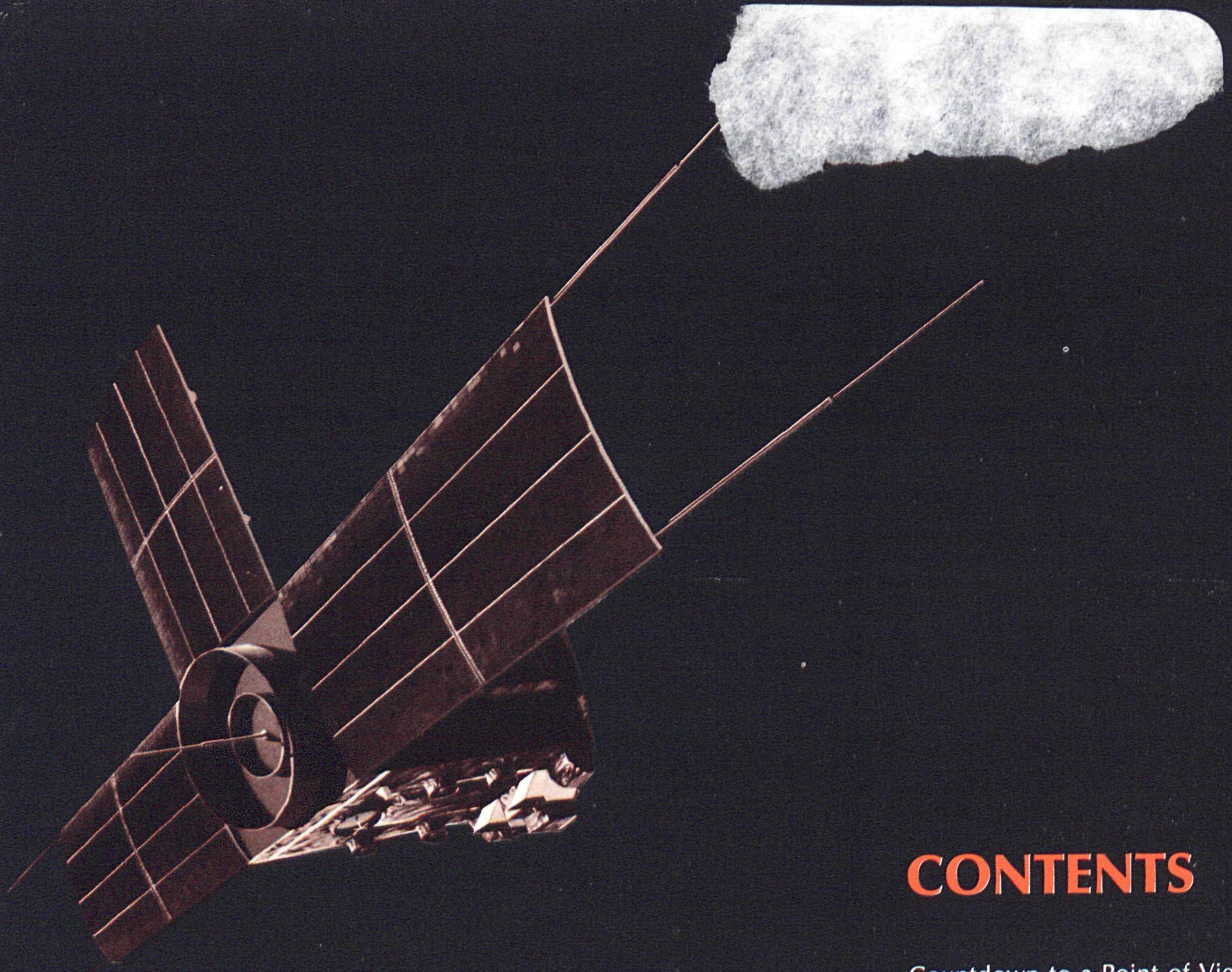

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COVER. Seen from moonbound **Apollo 12,** the earth eclipses the sun to provide a dazzling symbol of the physical environment man studies from a vantage point in space. (NASA photo)

Space object 1970-106A sweeps past the rim of sunlight into Arctic night, past the Pole, then southward over Greenland and the dim sparkle of the Atlantic, 900 miles below. Its sensors scan the darkness, the thin layer of dense atmosphere, the exposed surface of the sea.

Then, as the Maritime Provinces pass beneath the satellite, a signal comes: "Tell us what you see." An image made of warms and colds, darks and lights, flows out through the spacecraft antennas to be made into pictures of nighttime cloud cover by men and machines on the ground.

As revolutions, hours, days go by, the satellite's masters test and interrogate. "What do your cameras see? Your radiometers? Your proton counters? Are your panels drawing power from the sun? How do you feel?"

This is NOAA-1, launched December 11, 1970, the descendant of TIROS, *Nimbus,* and a decade of environmental satellite technology. Like a modern child, the spacecraft is larger and more sophisticated than most of its ancestors. NOAA-1, and its second-generation successors, represent a new effort to use this technology to ease the human burden of storms on land and sea, of thunderstorms and tornadoes, hurricanes and typhoons, floods and winter storms, catastrophic heat and catastrophic drought, and the myriad atmospheric and solar variations which enhance, discomfort, or threaten human life and prospects.

In a lower orbit flies 1960-*Beta-2*, the now-silent TIROS I*, which first took television cameras into space. Nine other experimental TIROS spacecraft are still aloft, as are the nine TIROS Operational Satellites called ESSA and the second-generation prototype, launched January 23, 1970, called ITOS-1. Some are dead, some are dormant, some continue with the work ITOS-1 and the NOAA operational series are assuming in the 1970s.

Some 20,000 miles farther into space, suspended like silver spiders above the planet's equator, two satellites nearly a hemisphere apart consolidate their claim upon the future. Cameras carried into earth-synchronous (or geostationary) orbits by these Applications Technology Satellites have confirmed that a near-continuous view of the earth's surface is one of the greatest gifts environmental scientists have had from space technology.

The new satellites—ITOS and ATS—are the keystone of a National Operational Environmental Satellite system, first authorized as a meteorological system after those early, rather rudimentary television pictures were returned from space, and since matured to a broader point of view. The national system is operated and managed by the National Environmental Satellite Service of NOAA, the U.S. Commerce Department's National Oceanic and Atmospheric Administration.

The second-generation operational system began on June 15, 1970, when ITOS-1 control shifted to the U.S. Department of Commerce and the data from this improved spacecraft began to feed into weather and space analysis and forecasting centers here and around the world. It is a major step toward full maturity for the national system. With the advent of GOES, a satellite descended from the ATS vehicles, and the operational readiness of new sensors, the national system can achieve full capability in the second decade.

The emphasis upon an environmental, rather than a meteorological view, has pervaded this effort to use satellite technology to help describe man's physical world—the interacting composite of earth, sun, and atmosphere, of oceans, and oceanic life. The *Pageos* satellite is the photographic target for the satellite geodesists of NOAA's National Ocean Survey, which is linking continents with precise triangulation schemes. SOLRAD and the *Explorer* spacecraft series are long-time contributors to the attempts of the Environmental Research Laboratories to describe and predict earth-sun interactions. Now an environmental satellite system has begun to pull together this broad descriptive task.

Man has needed an environmental vantage point. He has found one in the cold vacuum of space.

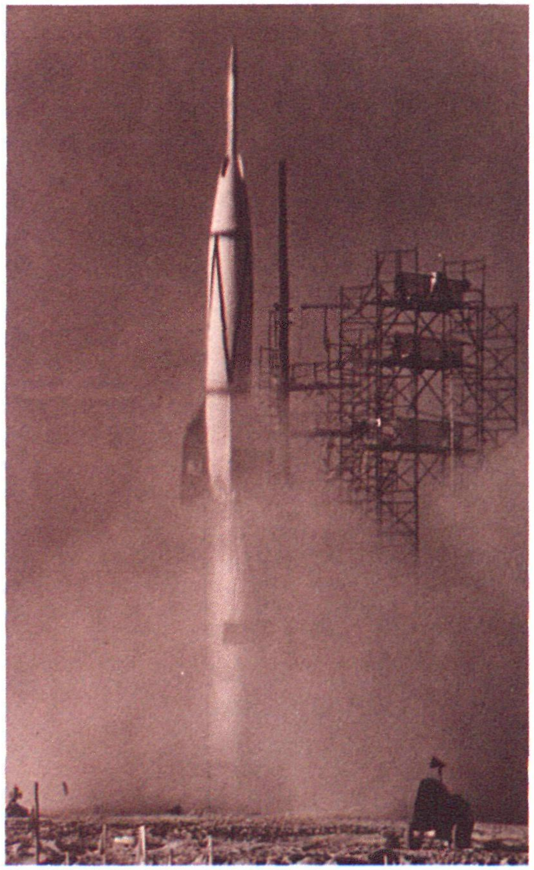
*TIROS is the acronym for Television InfraRed Observational Satellite; TOS, the acronym for TIROS Operational System, in which the spacecraft themselves were called ESSA, for Environmental Survey Satellite. ITOS is the acronym for Improved TIROS Operational System, the first of which was designated TIROS M until successfully launched, then ITOS-1. Successive satellites in the ITOS series will be designated NOAA, for the operating agency, and numbered consecutively. ATS is the acronym for Applications Technology Satellite; GOES for Geostationary Operational Environmental Satellite.

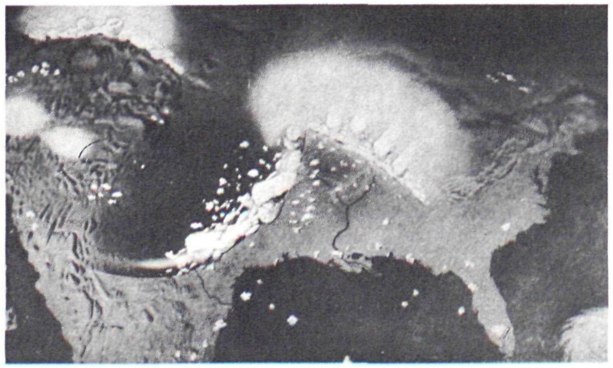
COUNTDOWN TO A POINT OF VIEW

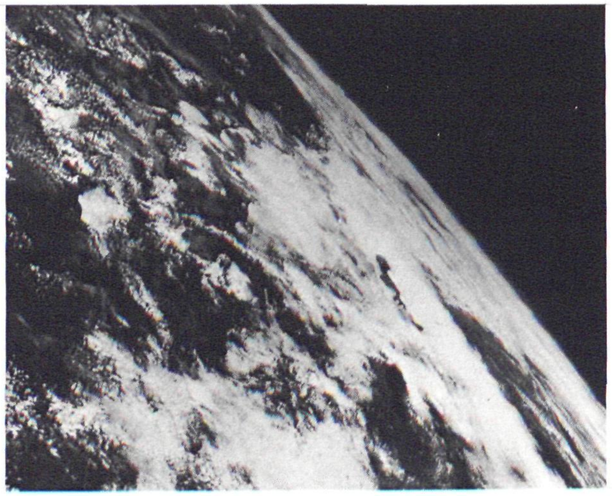
A long view of our planet has been the perennial dream of meteorologists, for, until the middle of this century, these reporters and prophets of weather had seen the atmosphere only from within, and mostly from below. Their world view was a composite of observations taken simultaneously at separate locations, a very grainy "photograph" of weather, with large patches over oceans and southern continents sparsely shown, or blank.

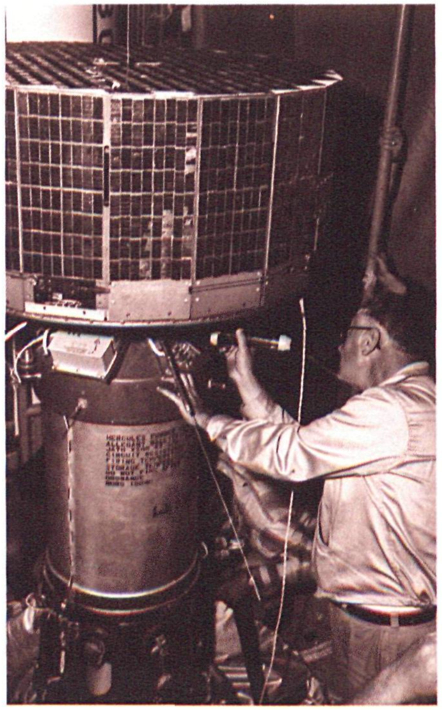
As late as 1952, a Weather Bureau pamphlet on forecasting began: "If it were possible for a person to rise by plane or rocket to a height where he could see the entire country from the Atlantic to the Pacific . . ." and showed a drawing of what the author thought one would see. Experiments with captured German V2 rockets carried cameras to altitudes above 100 miles, and pointed up the wealth of detail available through photography from above — detail that does not appear in a groundling's graphic estimate.

An earth-orbiting satellite could add this type of detail to the view of meteorologists on the ground, and bring a deeper reality to their symbol-covered maps. Most important, though, was the prospect that satellites would reduce the number of lethal surprises from the atmosphere. Cameras in space could pick up hurricane-generating









Rockets like the V-2 at left boosted cameras to altitudes of 100 miles and more, and showed how much atmospheric detail escaped the illustrator's conception of weather. TIROS I, launched by a *Thor-Delta* booster on April 1, 1960, added continuity to this overview.

disturbances long before the storms matured and threatened life and property. Dangerous thunderstorms hidden by frontal clouds could be detected in advance, and warning given communities in their path. And, the feeling went, this would barely touch the rich potential of this new technology to improve the human condition.

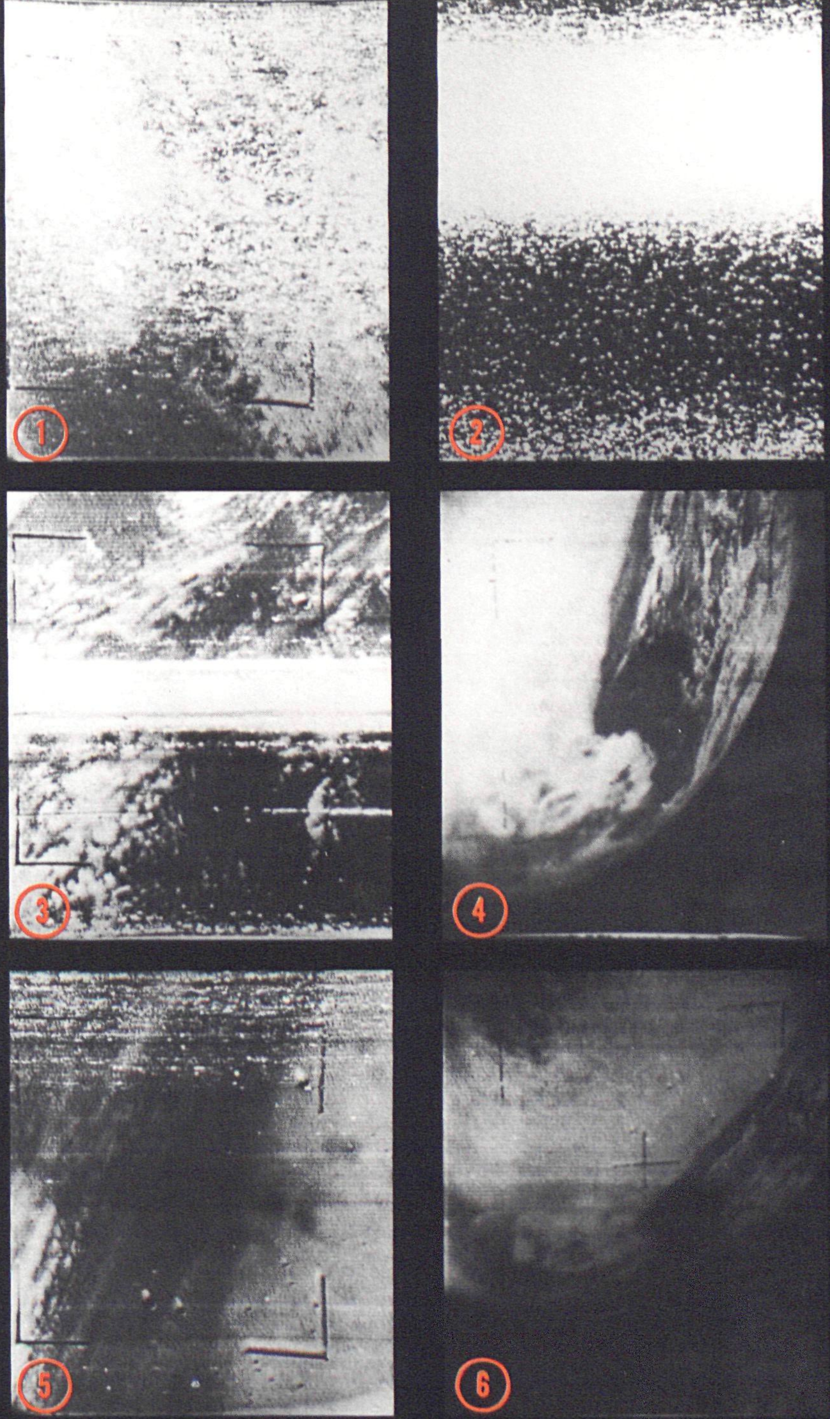
What later became Project TIROS began in 1958 in the Advanced Research Projects Agency, U.S. Department of Defense. In April 1959, Project TIROS moved to the six-month-old National Aeronautics and Space Administration, where, with the cooperation of the Weather Bureau's Meteorological Satellite Laboratory, the project entered its final development phase.

TIROS I, the first meteorological satellite to be equipped with a television camera system, was successfully launched at 6:40 a.m., April 1, 1960, from the Atlantic Missile Range. During an operating life of 78 days, the satellite transmitted some 23,000 cloud photographs, more than half of which were meteorologically useable.

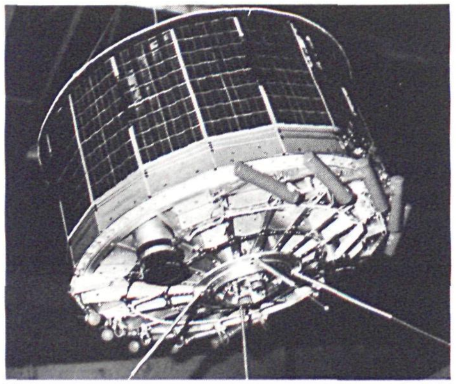
This early success led to long-range planning for the National Operational Meteorological Satellite System, and to rapidly increasing experience in handling satellites and their data. In January 1961, a few months after the second TIROS launch, the U.S. Navy announced development of a prototype airborne television camera and transmitter which could broadcast photographs directly to ground stations. Automatic picture transmission became part of the system planned for the mid-1960s, and a critical satellite component in the budding World Weather Program.

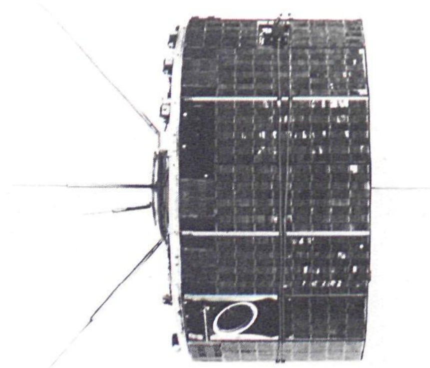
The proposed system would operate under the overall management of the Department of Commerce, with NASA carrying out satellite research and development, testing, launch control, and other supporting activities. The operational system would have three essential features. First, it would provide global atmospheric coverage regularly and reliably, day and night, including automatic picture transmission to ground stations within radio range of the satellite. Second, it would provide continuous viewing of weather systems, and also serve as a relay point between remote sensors and meteorological centers. Finally, the operational system would be able to sound the global atmosphere on a regular basis to provide measurements needed in numerical weather prediction models.

A dozen satellites and four years lay between the planning and the partial achievement of the first of these objectives. By the end of the first decade of what is now called satellite meteorology, the means of achieving the rest of these requirements existed in the form of working hardware.

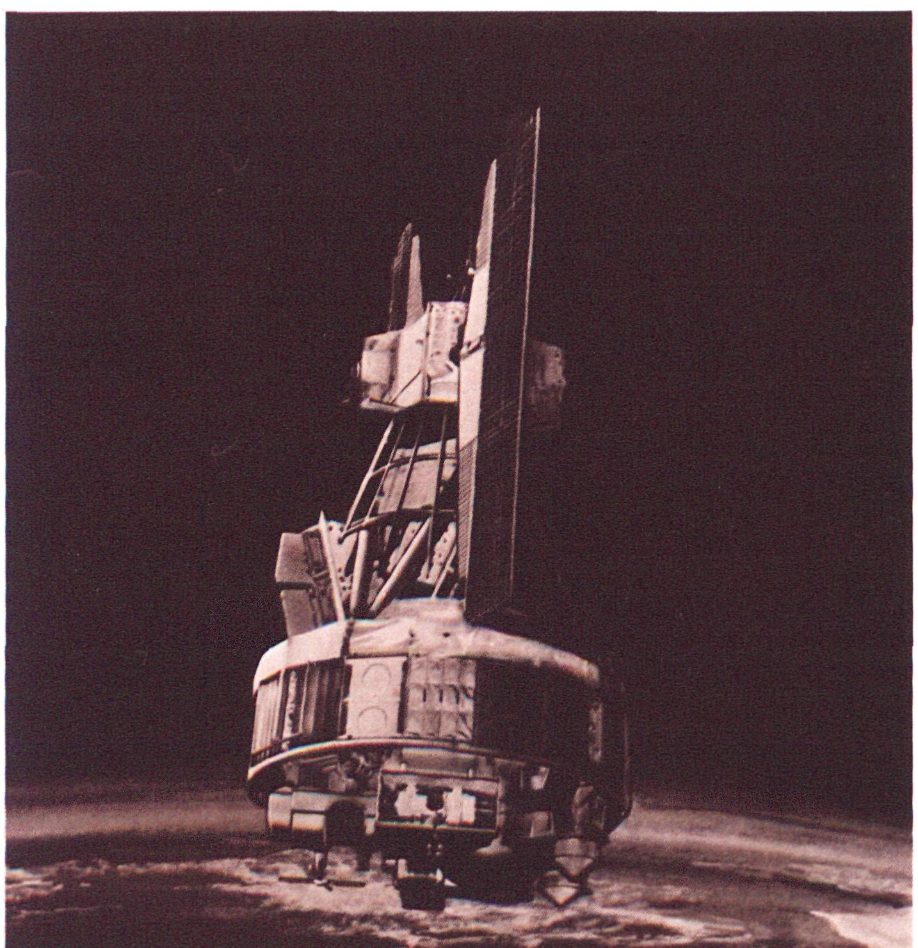


Series of photos transmitted by TIROS I seven hours after launch on April 1, 1960, began the era of satellite meteorology. Pictures were taken when the satellite was over the eastern United States with its cameras pointing downward and toward the west. Photos 4 and 6 were made by the satellite's wide-angle camera, the others, by the narrow-angle (high-resolution) camera.





TIROS AND NIMBUS—ORBITING TEST BEDS



The research and development program which produced present-day meteorological satellite systems centered on two NASA experimental spacecraft, TIROS and *Nimbus*. Although these vehicles are vastly different, their contributions have been mutually complementary, and basic to the achievements of the decade past and the new one just beginning.

The TIROS program had the primary objective of showing the feasibility of weather observation from earth-orbiting satellites. The craft itself was approximately cylindrical, 22.5 inches high and 42 inches in diameter, and weighed about 300 pounds. Solar cells on the top and sides of the "hatbox" structure provided electrical power. A single top-mounted antenna received commands from ground stations; four whip antennas extending from the baseplate transmitted television pictures and telemetry information on satellite temperature, pressure, and other data.

Equipment aboard early TIROS models varied from mission to mission. Both TIROS I and II carried one camera with a wide-angle lens for broad coverage and one with a narrow-angle lens for detailed photography of smaller areas. After TIROS II, only wide or medium-angle cameras were used. The vidicon cameras flown on TIROS I through VII, IX, and X converted light patterns to electronic signals which were stored on magnetic tape, then transmitted to ground stations on command.

TIROS VIII flight tested a new device—the Automatic Picture Transmission (APT) camera system, which relayed photographs of local cloud cover to ground stations within radio range. The comparatively inexpensive receiving equipment used with APT encouraged the general use of satellite data in the preparation of local weather forecasts, and pointed up the international potential of the satellite system. When operational, APT photographs of regional cloud cover would become a staple item for the world's younger meteorological services, and a boon to forecasters in the more industrialized nations.

Dramatic as early TIROS photographs were, the spacecraft configuration, orbit, and orientation imposed serious limitations. TIROS I through VIII carried cameras which pointed outward at right angles to the satellite baseplate. In orbit, the satellite was spin-stabilized like a top, always pointing in the same direction in space, regardless of the position of the earth's surface. This meant that the cameras pointed earthward only about 25 percent of the time. The inclination of the orbit to the plane of the equator (48° for TIROS I-IV, 58° for TIROS V-VIII) further reduced the ability of these satellites so that only 20 percent of the earth's surface could be photographed each day.

TIROS IX pioneered a remedy—and the operational mode—by flying in a near-polar orbit with its two cameras pointing outward from the rim of the satellite, in the orbital plane. The cameras were mounted 180 degrees apart and were triggered only when pointing directly downward at the earth's surface. Because of the near-polar orbit, the satellite's orbit could be made sun-synchronous—one in which the orbit maintains the same position with respect to the sun while the earth rotates beneath it. The combination of cartwheel mode and sun-synchronous polar orbit permitted the first complete daily coverage of the entire sun-illuminated portion of the globe.

The initial TIROS development program ended with TIROS IX; however, the Weather Bureau purchased TIROS X to ensure continuous satellite coverage during the 1965 hurricane season. This conventional TIROS craft carried its cameras on the baseplate, but was placed in a near-polar, sun-synchronous orbit.

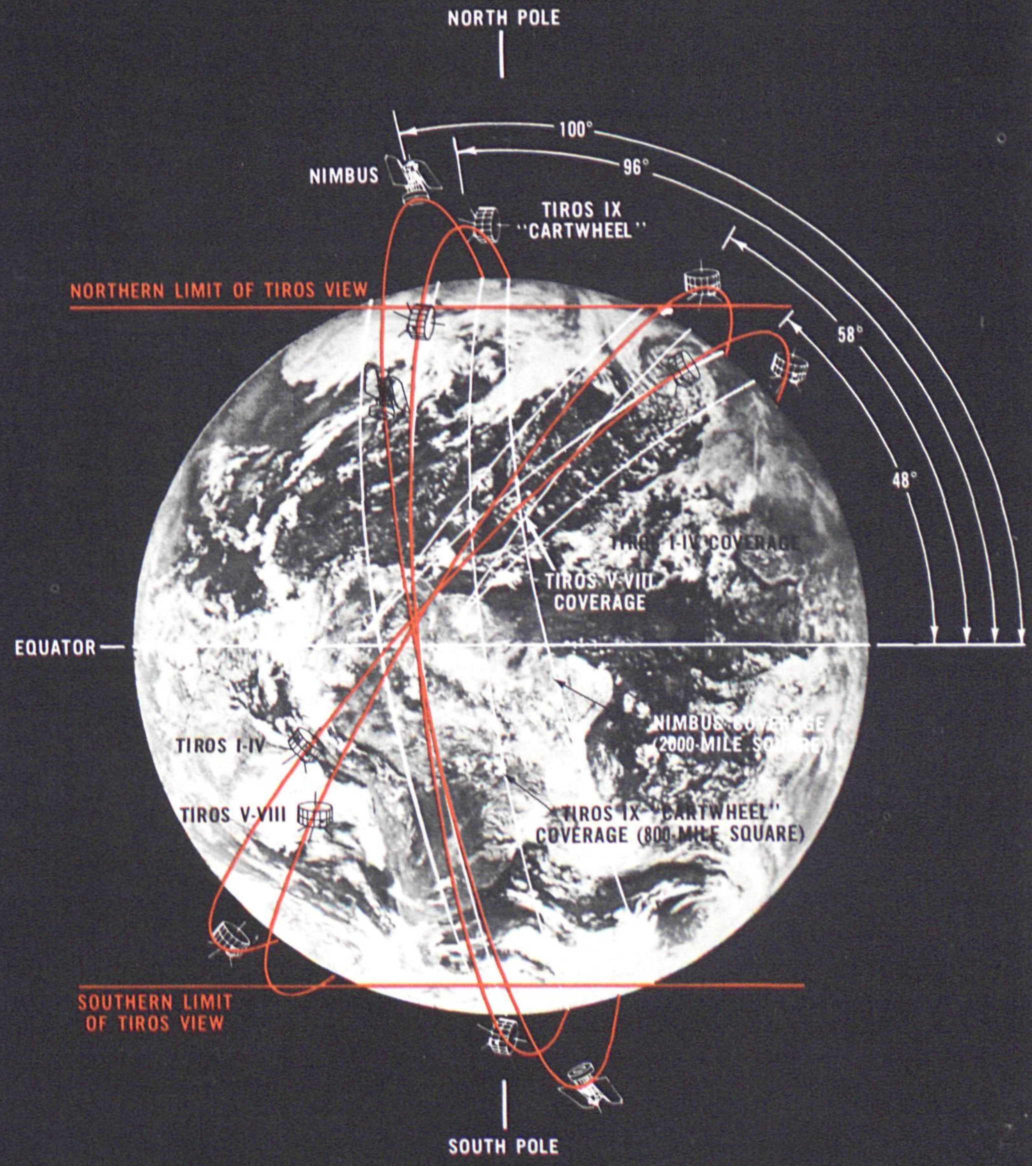
Nimbus, the Latin word for cloud, identifies a more sophisticated NASA research and development spacecraft about three times the size and weight of TIROS. Originally conceived as the operational successor to TIROS, *Nimbus* has since become an advanced test bed for new cameras and sensors.

Nimbus I, launched August 28, 1964, and *Nimbus* II, launched May 15, 1966, successfully initiated this program, which continues with *Nimbus* III*, successfully orbited April 14, 1969, and *Nimbus* IV, launched April 8, 1970. Two additional spacecraft in the series will be orbited in early 1972 and 1973.

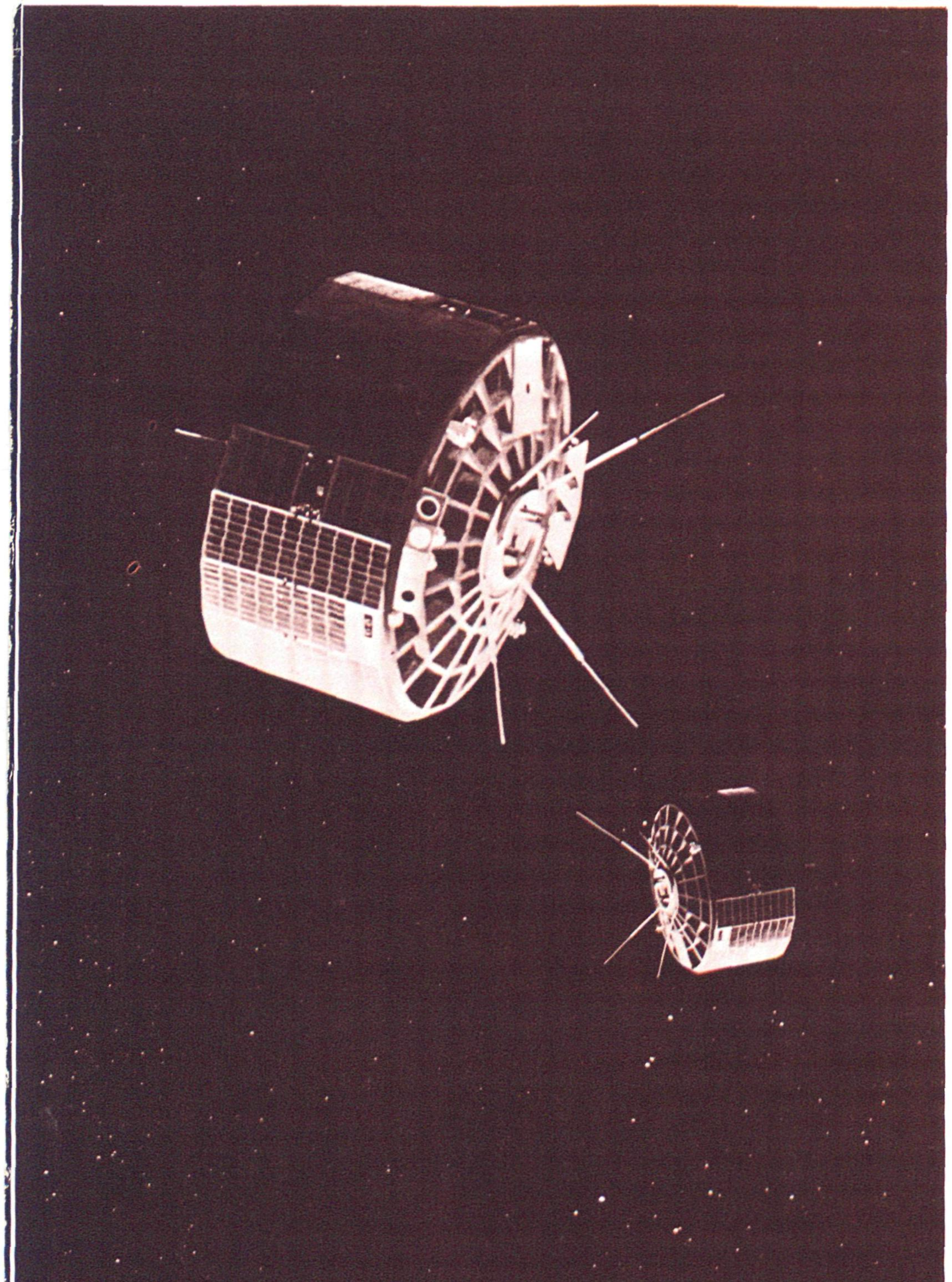
The big, half-ton *Nimbus* vehicle is shaped something like a winged chess king. The base is a sensory ring, containing modular arrangements of cameras and other instruments; the crown is a stabilization control assembly. An open tripod framework connects the two ends of the spacecraft. Two wing-like solar panels attached to the control unit structure generate spacecraft electrical power, rotating to face the sun when the craft is in sunlight. The gas-jet and momentum wheel stabilization control system keeps the cameras and other sensors pointing earthward at all times. The orbit is near-polar and sun-synchronous, with a mean altitude of about 700 statute miles.

The satellite has been an extremely successful test bed for advanced instruments. *Nimbus* flight-tested the APT and Advanced Vidicon Camera Systems (AVCS) used on the operational TIROS (ESSA) series, the high-resolution infrared scanning radiometers used on ITOS, the atmospheric sounding devices, and the data relay devices planned for future ITOS vehicles. The big satellite will continue to carry milestone environmental sensors into space as the program evolves.

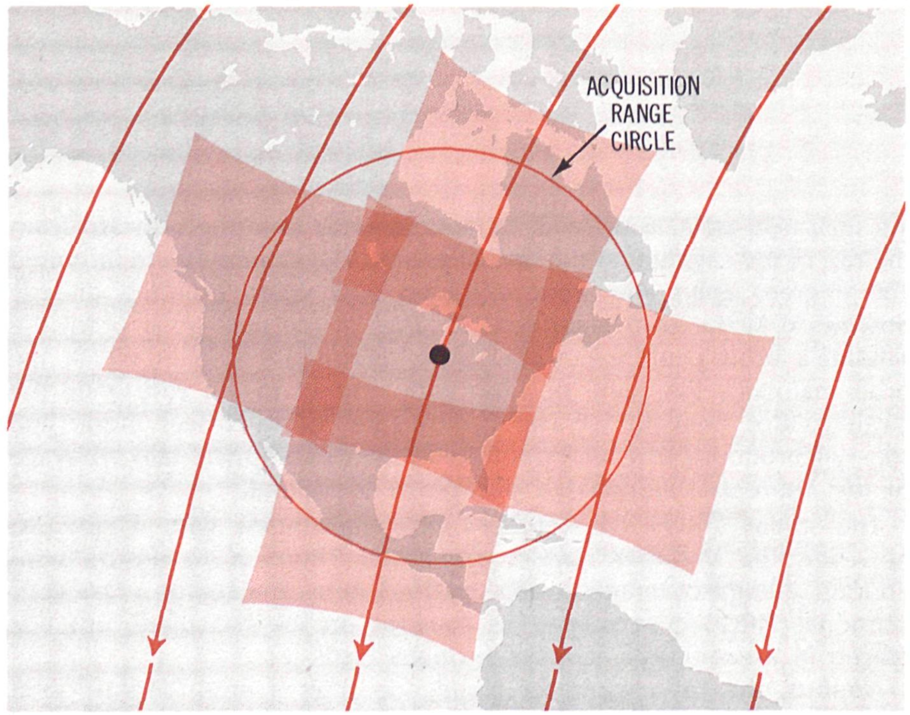
* The vehicle originally scheduled to fly as *Nimbus* III was lost when its malfunctioning booster had to be destroyed shortly after a May 1968 launch.



Changing orbits, orientation, and coverage mark the evolution of weather satellite systems. The low inclination and space orientation of early TIROS spacecraft greatly reduced their effectiveness. TIROS IX pioneered both a cartwheel mode and a polar orbit. *Nimbus*, carrying more advanced cameras at nearly twice the orbital height of earlier satellites, took earth-oriented photographs 2,000 miles square. This cartwheel mode and higher polar orbit were blended in the operational satellite system.



The TIROS Operational Satellite (called ESSA) system used two vehicles to provide both stored-data and automatic picture transmission (APT) capabilities. The ESSA spacecraft in foreground is recognizable as the stored-data satellite because it carries the radiometers (black and white discs on the satellite's rim); the APT satellite had no radiation sensors.

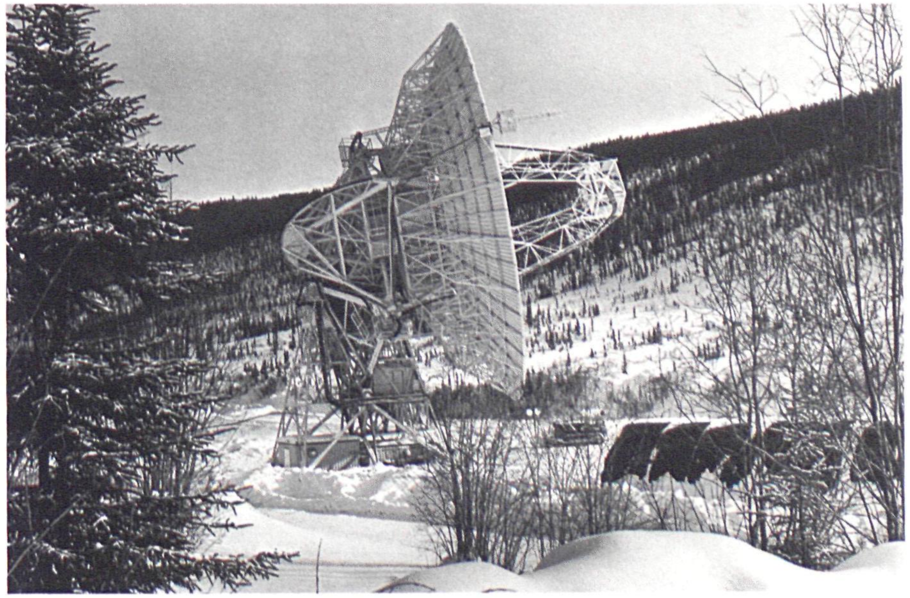


Acquisition of APT photos from ESSA spacecraft is shown here for Chicago. As many as five photographs could be received in a single day; the direct-readout infrared radiometers on second-generation NOAA (ITOS) spacecraft doubled this rate of acquisition.

TOS AND THE ESSA PAIRS

The first spacecraft in the TIROS Operational Satellite (TOS) system was launched February 3, 1966. Called ESSA 1, this satellite carried vidicon cameras of the type used on the TIROS series into a relatively low (475-mile) near-polar orbit. ESSA 1, closer in design to TIROS IX than to its successors, straddled experimental and operational eras.

ESSA 2, carrying two APT cameras, went into the nominal 850-mile-high, near-polar TOS orbit on February 28, 1966; on March 15, NASA transferred control of ESSA 2 to the Department of Commerce. With the operation of paired ESSA vehicles, one taking and storing pictures, the other taking and transmitting them automatically to ground stations within radio range, the National Operational Meteorological Satellite System became a functioning reality.



Both generations of operational satellite (TOS and ITOS) are controlled by the U.S. Commerce Department's National Environmental Satellite Service through Command and Data Acquisition (CDA) stations at Wallops, Va., and Gilmore Creek, Alaska. Above, CDA technicians interrogate NOAA-1 for stored image and radiation data. At right, the big 85-foot antenna at Gilmore Creek braves Alaskan winter.

Spacecraft in the TOS system retained the general design and cartwheel mode of TIROS IX. Each system pair included an APT satellite and an AVCS satellite; because ESSA 1 carried the TIROS IX vidicon camera systems, the first operational satellite to carry the AVCS was ESSA 3, launched October 2, 1966.

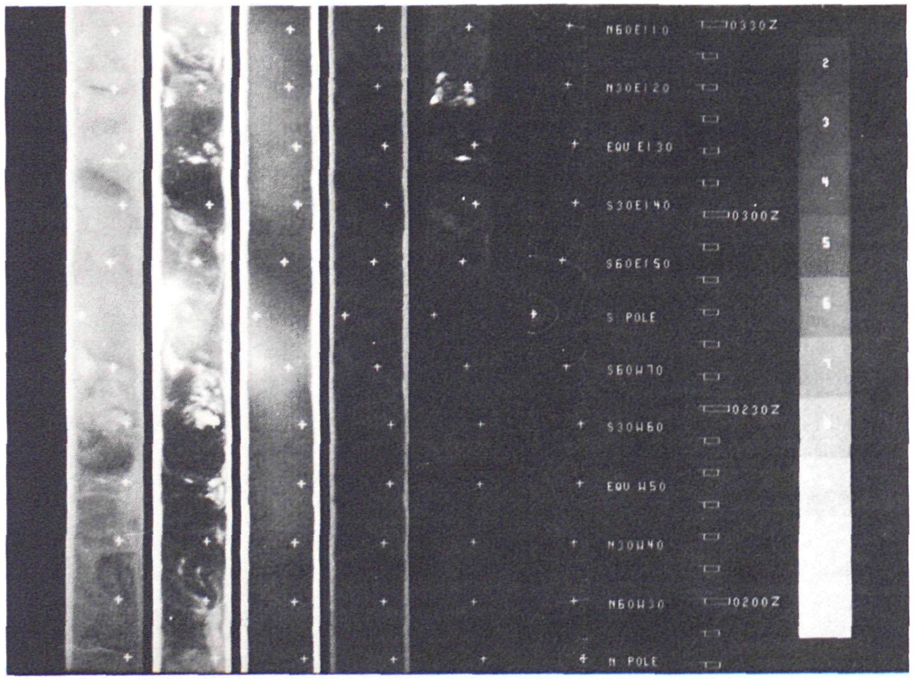
The spacecraft carried two television cameras mounted diametrically apart on the rim of the baseplate assembly, looking outward at right angles to the spin axis. Camera systems in both units used a wide-angle (90°) lens, producing pictures with 800 scan lines covering an area on the earth's surface about 2,000 miles on a side, or about four million square miles. Picture resolution from the TOS system was about two miles per scan line directly below the camera and about five miles at the picture edge.

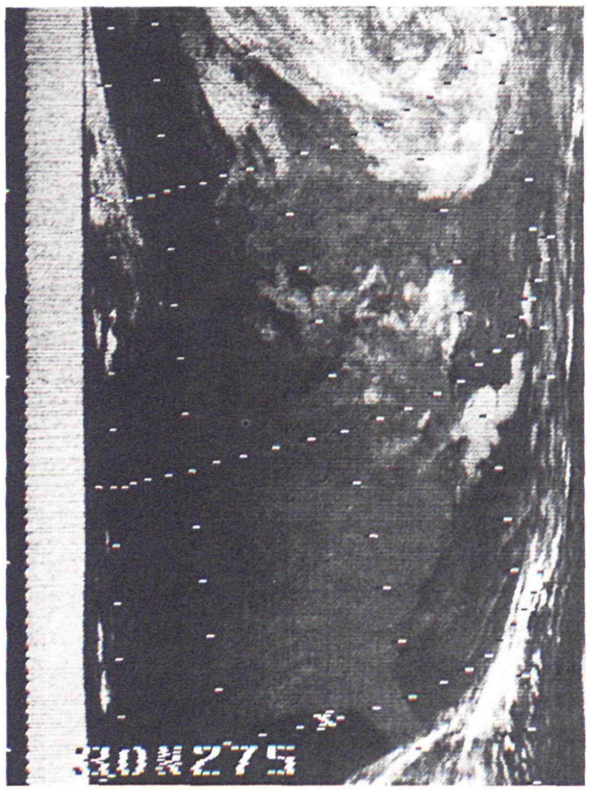
The first two ESSA spacecraft were launched from Cape Kennedy, Florida. Subsequent satellites in the series were launched from the Western Test Range, Lompoc, California; a polar orbit is more easily achieved from Lompoc than Cape Kennedy because the vehicle can be launched on a direct path without endangering populated areas. The launch vehicle was the reliable thrust-augmented, improved *Delta*, a three-stage, 75-ton system 92 feet long overall.

The TOS system orbit was nearly circular, with an average altitude of 865 miles, a 78.6-degree retrograde inclination to the plane of the equator, and a period of 113.5 minutes. An eastward drift, or precession, of slightly less than one degree per day at the equator was intended to keep the orbital plane properly oriented to the sun during the earth's year-long revolution. Although successive ESSA spacecraft occupied orbits close to this optimum, any satellite's orbit is not precisely the same as the one before or the one after. Some orbital changes occur as well. For example, in some cases a gradual drift of the orbit's orientation with the sun moved the equator crossing hour gradually toward dawn or dusk.

The APT satellite crossed the equator at 9:00 a.m. local time every revolution, heading south (descending node), always three hours ahead (west) of the sun's equatorial noon point. In this way, the APT satellites were southbound over the northern hemisphere during the morning hours, and their data could be used in planning the day's activities.

The AVCS satellite, which relayed stored data to two National Environmental Satellite Service Command and Data Acquisition stations (one at Wallops, Virginia, the other at Gilmore Creek, Alaska, near Fairbanks) crossed the equator at 3:00 p.m. local time every day, northbound (ascending node). This orbit provided data at an hour when meteorologists prepared the next day's analyses and forecasts.





The sophisticated output of the medium resolution infrared radiometer on *Nimbus* III shows objects about 30 miles across, in five sensory channels corresponding (from left) to upper-level moisture, cloud top temperature, stratosphere temperatures, and lower-level moisture. At left, images transmitted by the high-resolution radiometer can detect objects about half a mile across. The picture is a negative of what the infrared sensors see; a positive print would show the coldest objects as the darkest, so that the high, frozen cirrus would be black. Future operational satellites will probably bypass medium-resolution systems in favor of combined infrared atmospheric sounding devices like SIRS and high-resolution radiometers.

INFRARED SENSING–SIGHT ON A BLIND SIDE

The description of TIROS and ESSA as "weather eyes in the sky" accents what was most remarkable about them—from space they returned photographs that were something like the eye would see, although without the resolution or the color. But this same feature also describes their most serious limitation. The eye, and the "weather eye," are blind to all but a narrow band of electromagnetic radiation.

This means that the larger world of energy is invisible to us and to our satellite cameras. Everything at temperatures between about 7,000 and minus 300 degrees Fahrenheit emits energy* in the infrared region of the spectrum, the longer-than-optical waves of heat energy, the pervasive store of force that drives the great engines of ocean and atmosphere. To get more than a photograph of the visible, to get an insight, a measurement, scientists looked toward sensors which could see the dynamic warms and colds, absorptions and emissions, of our planet.

TIROS II, III, IV, VII, and the ESSA stored-data spacecraft carried low-resolution radiometers to measure total incoming solar radiation and radiation emitted and reflected by the earth. Information of this type is needed to determine the effect of radiation on large-scale circulation processes in the atmosphere.

Infrared sensors with better resolution held the key to sight for instruments scanning the night side of the earth, and to useful determinations of atmospheric heat distribution. The first high-resolution infrared radiometer went into orbit with *Nimbus* I, and sent back information which found a variety of uses; subsequent *Nimbus* satel-

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* Objects which do not emit energy are said to be at absolute zero.

lites also carried the high-resolution radiometers. A two-channel variety of this instrument is built into the ITOS system.

Interpreted graphically, infrared data can be presented as pictures of nighttime cloud cover, and, as demonstrated by *Nimbus* II, either stored for central analysis or transmitted over the satellite's APT channels. This technique promised to increase the frequency of satellite observations available to ground stations from APT cameras.

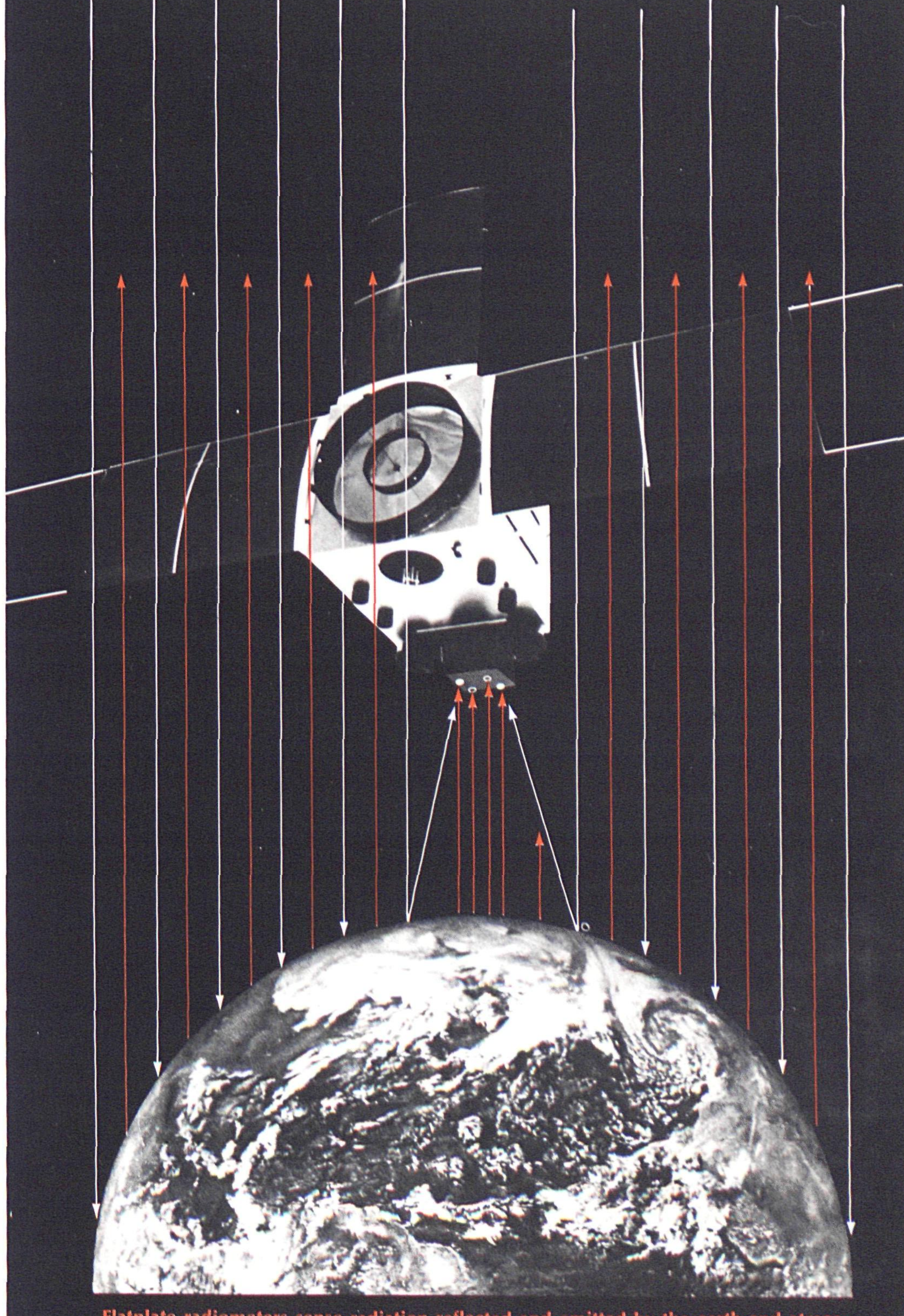
Interpreted in quantitative terms, high-resolution infrared sensings provide information about temperatures of earth, sea, and clouds. Because the energy received at the sensor increases with the temperature of the object being viewed, and because temperatures in the troposphere normally decrease with height, it is possible to determine cloud-top heights from infrared data, and so to make a more objective determination of cloud types. In cloud-free areas, the data can be used to measure sea-surface temperatures, and to distinguish between warm and cold ocean currents, clouds and snow, ice and water. This makes infrared sensing valuable to oceanographers as well as weathermen.

Scientists working on numerical weather prediction—the use of mathematically simulated atmospheres and real data to forecast weather—have desperately needed more and better information to plug into predictive models. The greatest lack has been profiles for the atmospheric column above the open ocean area and less developed continents; but there has also been a need for more continuity than the synoptic schedules for rawinsonde (twice daily) and radiosonde (four times daily) balloon profiles can provide.

If satellites could provide daily, global profiles of temperature, water vapor, and other weather elements, numerical prediction models could be brought closer to reality, and tested on the coming generation of bigger, faster electronic computers, and weather forecasting could take an unprecedented 10-day step into the atmospheric future.

Next to development of weather satellites themselves, this was the most difficult objective for system developers to achieve. But sensors provided such soundings before the first decade of satellite meteorology had ended.

In April 1969, signals received from a new instrument aboard *Nimbus* III indicated that a major breakthrough had been achieved in this area. Called SIRS-A*, the instrument was developed by the National Environmental Satellite Service to measure radiation flux from the



Flatplate radiometers sense radiation reflected and emitted by the earth and atmosphere, providing a means of comparing incoming and outgoing solar energy, and thus of determining the planet's heat balance. Black discs sense radiation in both the visible (white arrows) and infrared from 0.3 to 30 microns. White discs sense only infrared emissions from 7 to 30 microns (red arrows).

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* For Satellite InfraRed Spectrometer; "A" indicates first model.

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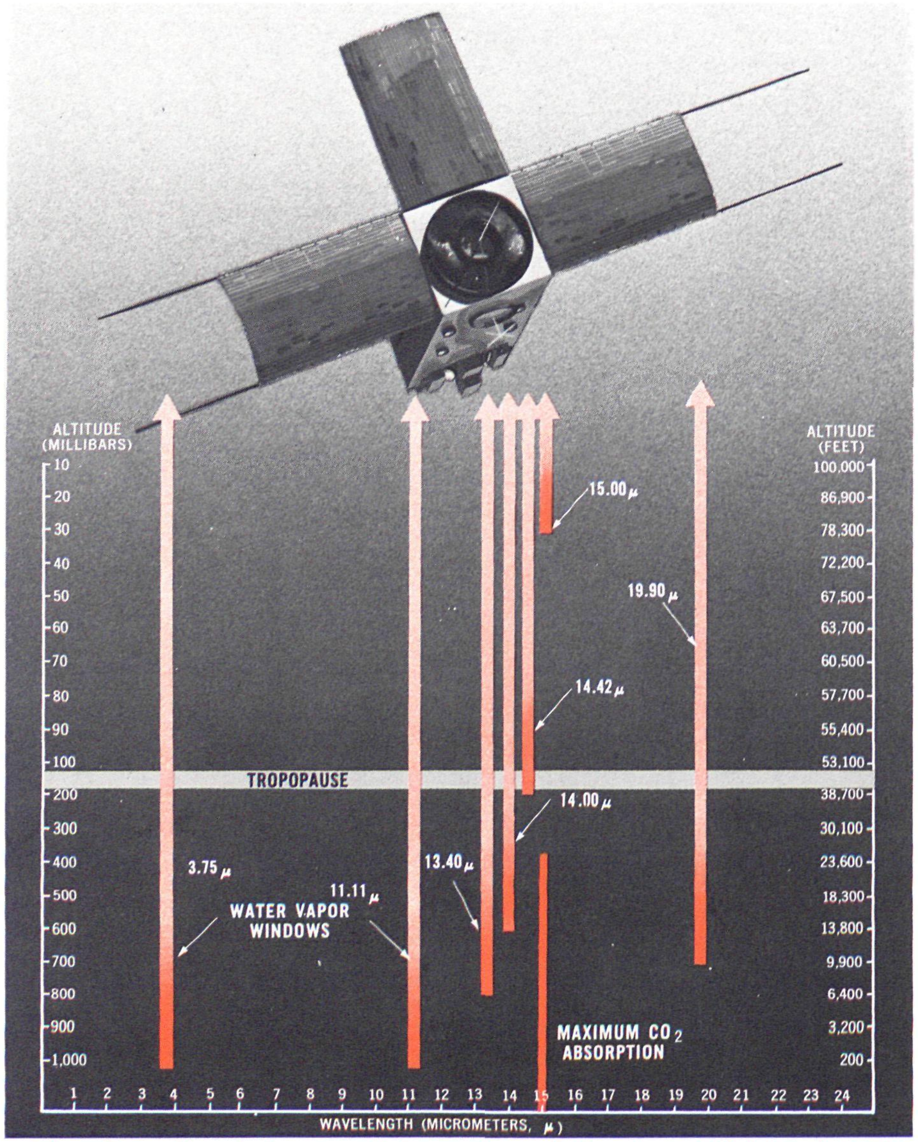


Infrared sounding devices operate by sensing radiation at spectral intervals corresponding to temperatures found at different atmospheric levels. The diagram shows how a seven-channel infrared radiometer would profile atmospheric temperatures and geopotential (pressure) heights. At far left, two channels sense at wavelengths where atmospheric water vapor is transparent to infrared—the so-called water vapor windows—and measure radiation originating at the surface or the tops of clouds. Other channels measure radiation originating at higher layers of the atmosphere. Taken together, useful profiles along the satellite's track can be computed.

atmosphere and earth's surface, sensing in eight channels of the infrared spectrum beyond the visible.

Water vapor and carbon dioxide, although comparatively small constituents of the atmospheric gas mixture, are decisive in maintaining the planet's heat balance. Like greenhouse glass, they admit large amounts of solar radiation in the shorter, optical wavelengths, but absorb much of the longer-wave radiation from the earth. The exceptions to this are two bands, called atmospheric "windows," one near visible red and another at about 11 microns.

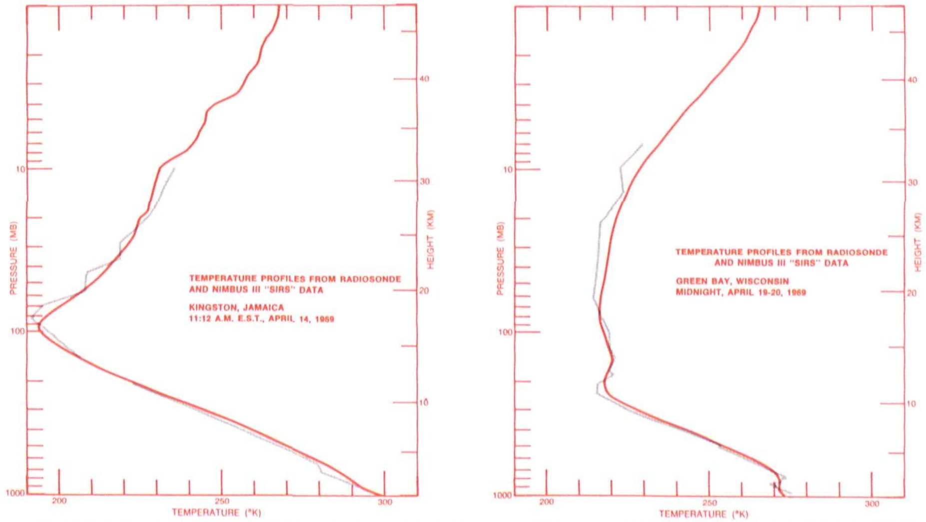
SIRS-A measures radiance in one spectral interval near the "window" at 11 microns, where the atmosphere is virtually transparent to infrared radiation and where the earth's emissions are strongest; and at seven spectral intervals from 13.3 to 14.9 microns, leading toward the center of the carbon dioxide absorption band at 15 microns. Radiances sensed at 11 microns originate from the surface or from the tops of clouds; radiance at the other seven intervals originates from progressively higher layers of the atmosphere as the intervals approach the maximum carbon dioxide absorption at 15 microns.

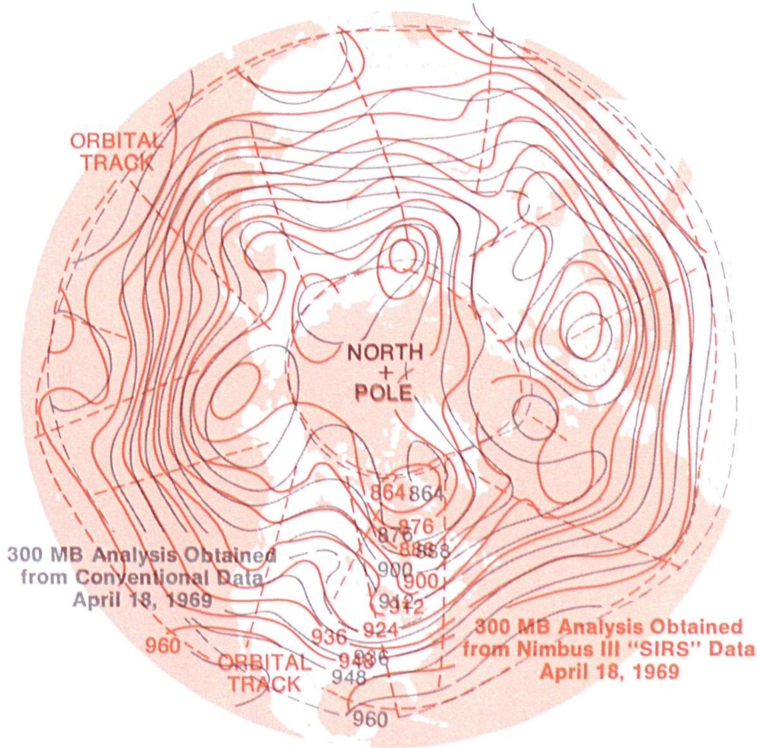
The quality of SIRS-A data matched the optimism of its developers. During the first two weeks of the *Nimbus* III flight, a verification and testing program compared SIRS-derived temperature and pressure-height profiles with those obtained from special radiosonde profiles. SIRS-A results showed excellent agreement with radiosonde data, and some six weeks after *Nimbus* III was launched, the satellite soundings became a regular input to the hemispheric analyses of the National Weather Service.

Experimental SIRS-A was not designed to provide measurements with the spatial distribution and resolution needed for weather analysis. The soundings follow the satellite's orbital track and have a spatial resolution of about 140 miles; as a result, soundings are about 1700 miles apart at the equator, and observations are often "contaminated" by clouds because of the large field of view.

SIRS-B, a smaller, lighter, more sophisticated descendant of SIRS-A, was launched aboard *Nimbus* IV in 1970. This device senses earth radiances in 14 spectral intervals, eight of which are about the same as those on SIRS-A, and six of which are in the water vapor rotation band* between 18 and 37 microns; the additional channels provide

* In the molecular spectrum, the absorption bands attributed to changes in molecular rotation.





Comparisons of atmospheric temperature profiles obtained conventionally (grey) and by computation from SIRS data (red) show good agreement. These radiosonde and SIRS profiles are the atmosphere over the Caribbean near Kingston, Jamaica, and over Green Bay, Wisc. Temperature is in degrees Kelvin (Celsius degrees plus 273.16); altitude is shown in millibars (pressure) and kilometers (height). At right, height contours of the 300-millibar pressure surface derived from conventional (grey) and SIRS (red) are compared and show good agreement except where conventional data are sparse. The contour patterns are closely related to atmospheric circulation at about 30,000 feet, which tends to move parallel to the contours at a speed inversely proportional to the contour spacing. Heights shown are in meters.

data from which gross vertical water-vapor distribution can be calculated. The improved instrument's beam is step-scanned to provide a side-looking capability which permits soundings between, as well as along, orbital tracks, improving geographic coverage. SIRS-B provides soundings with a maximum spacing of about 435 miles.

Despite the high quality of their data, today's SIRS are primitive progenitors of a more advanced line. ITOS will eventually carry the Vertical Temperature Profile Radiometer (VTPR), which senses in eight infrared spectral intervals (six in the carbon dioxide absorption band, one in the water vapor window, and one in the water vapor rotation band); the Infrared Temperature Profile Radiometer (ITPR), to be flown on the next *Nimbus*, will sense in seven channels, of which four will be in the carbon dioxide absorption band, one in the water vapor rotation band, and two in the water vapor windows at 3.8 and 11 microns. Both VTPR and ITPR will permit derivations of temperature distribution even in the presence of considerable cloudiness. Spacing of good soundings down to the earth's surface should be about 300 miles with these instruments, and both will provide measurements used to calculate the horizontal distribution of total precipitable water.

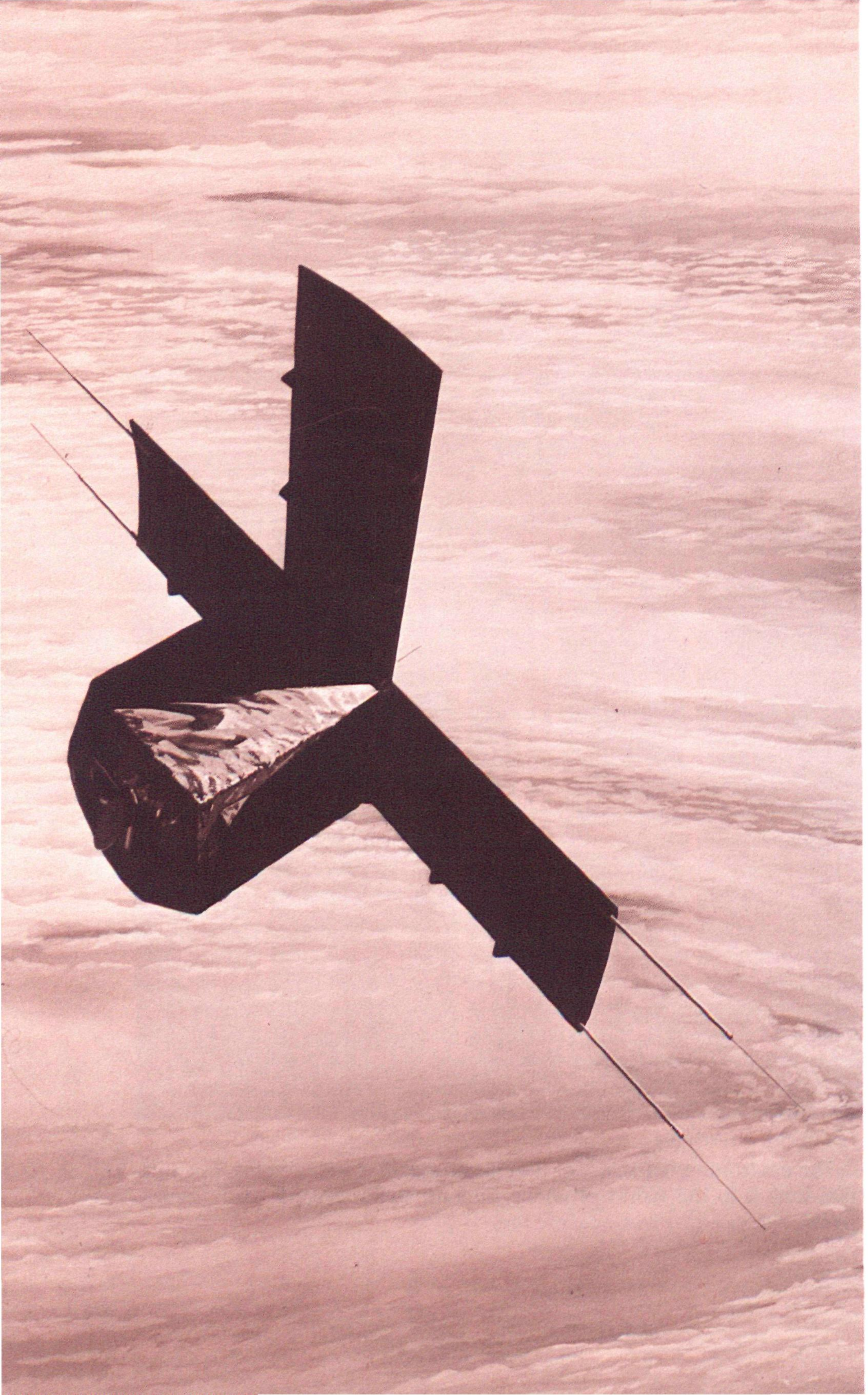
The *Nimbus* series has also been flight-evaluating IRIS*, a NASA-developed instrument which not only senses temperature and water vapor profiles, but which also provides data on carbon dioxide, nitrous oxide (N_2O), and methane (CH_4) levels in the atmosphere. These constituents have special significance in an age threatened by catastrophic pollution of the air.

Other prototype infrared devices flying on *Nimbus* include the selective chopper radiometer, an experiment developed in England, which measures the temperature profile from cloud-top levels to altitudes of about 40 miles.

But the development of infrared sensing devices for environmental satellites has only just begun. If there is a single "quantum jump" between the TOS system of the 1960s and ITOS system of the 1970s, it is the development of these advanced instruments. For the meteorological users of the National Operational Environmental Satellite System, they have meant the virtual realization of several very elusive technical objectives.

For environmental science, they have meant a meaningful, quantitative look into the world of energy linking sun and solid earth, atmosphere and oceans, and oceanic life.

* For InfraRed Interferometer Spectrometer.



SECOND GENERATION, SECOND DECADE

With ITOS, the capability of the first operational system was dramatically exceeded, and the national system moved closer to achieving its goals. The second-generation spacecraft, twice the size and weight of TOS, combines the direct-readout and stored-data functions of both ESSA vehicles, and adds an important new capability: high-resolution scanning radiometers obtain direct-readout and stored images of the earth's night side, providing global coverage at 12-hour, rather than 24-hour, intervals. The infrared sensors also gather data which can be used to infer cloud-top heights and temperatures, and sea-surface temperatures.

ITOS itself is quite unlike the old "hatbox" weather satellites. The equipment module is an oblong box, about 40 inches square and 48 inches long. The solar array consists of three panels, which present a total area of 48 square feet to the sun. The spacecraft weighs about 700 pounds and, with solar panels deployed, is about 14 feet across.

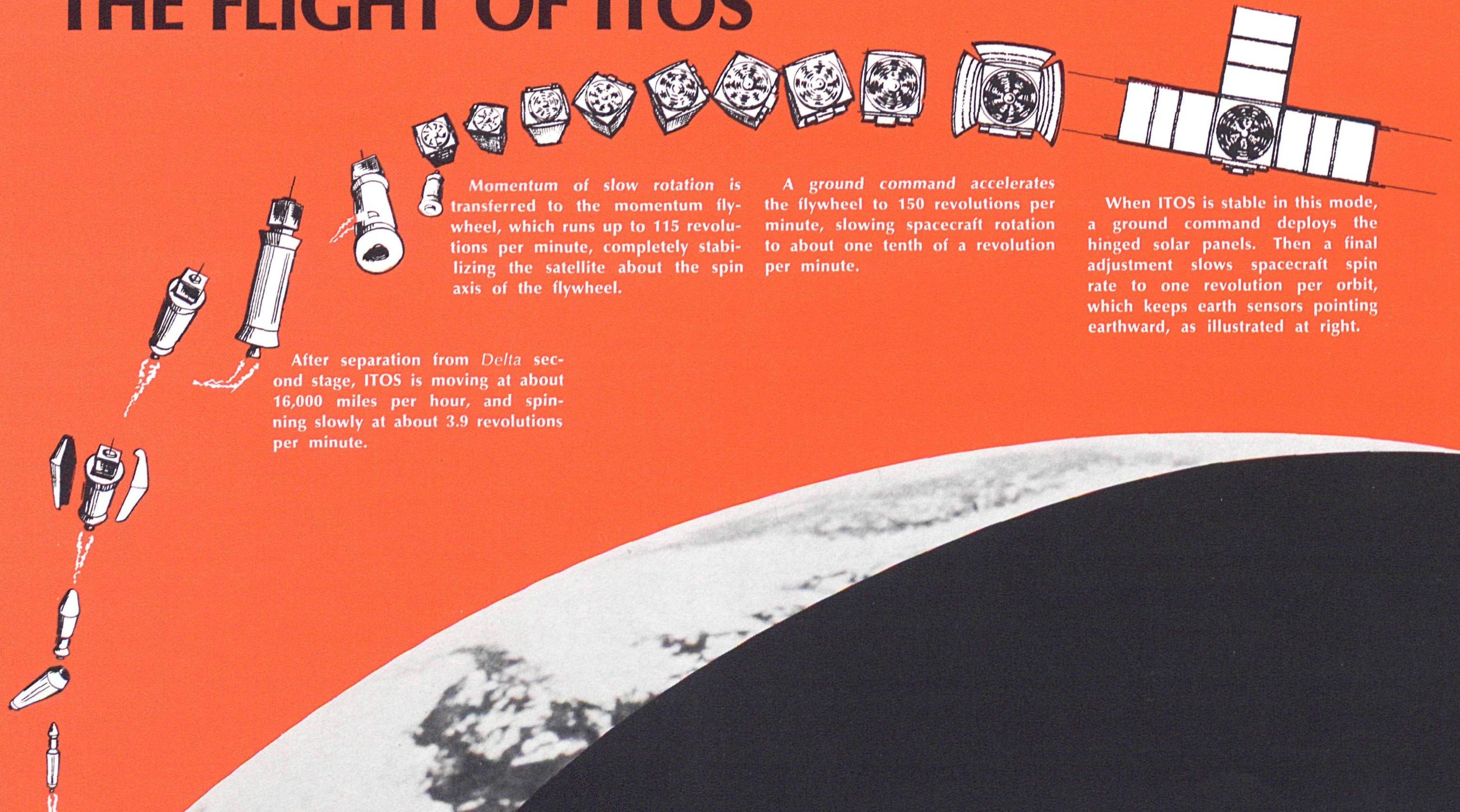
Unlike the TOS series, ITOS keeps its cameras and other earth-directed sensors pointing along the local vertical, and the solar panels approximately in the plane of the orbit, facing the sun. A magnetic torquing system and a special motor-driven momentum flywheel on the equipment module stabilize the satellite, and are the key to ITOS control. A pitch-control system regulates flywheel speed based on signals from infrared earth-sky horizon sensors. Magnetic coils correct roll and yaw errors, and liquid dampers reduce satellite nutation, or nodding. The sensor plate is kept pointing earthward by maintaining a satellite rotation rate of one revolution per orbit.

Thermal control of the satellite is a mix of passive and active techniques. Most of the satellite, except for primary sensor openings and the areas used for active thermal control, is covered with multilayer insulation blankets, and a "thermal fence" on one end of the satellite limits the amount of solar heating. To provide a still narrower range of operating temperatures, automatic thermal flaps are installed on the equipment module.

ITOS is controlled by the National Environmental Satellite Service, Suitland, Md., via two command and data acquisition stations, one at Wallops, Va., the other at Gilmore Creek, Alaska.

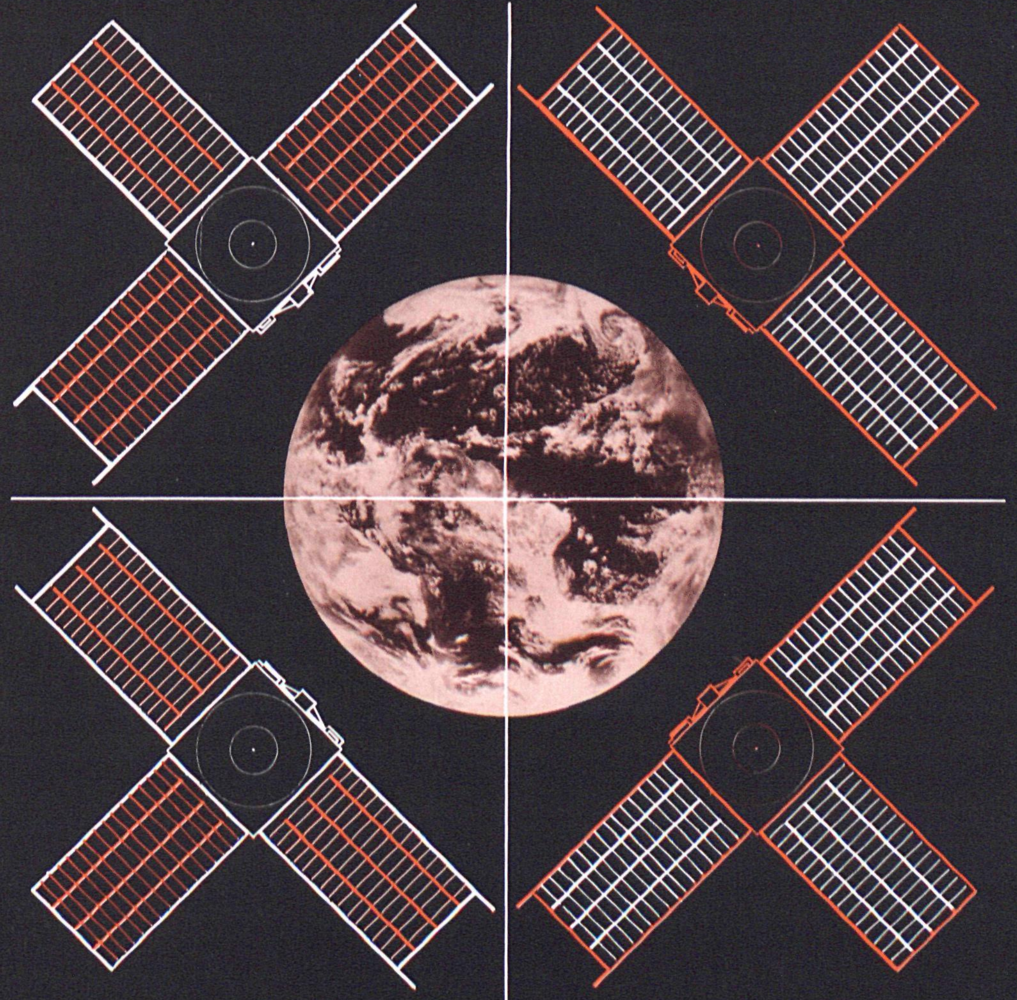
ITOS-1 cameras take south-to-north strips of the earth's cloud cover on November 25, 1970, as the planet turns eastward beneath the satellite's polar orbit. Successive photographs read from south to north; successive passes, from east to west. National Environmental Satellite Service computers rectify these strips into digitized polar and equatorial projections, and certain special-purpose products.

THE FLIGHT OF ITOS



After separation from the second stage of the *Delta* booster, ITOS is moving at about 16,000 miles per hour, tied to the earth environment by the thin, taut string of gravitational attraction. Its solar panels are flat against its sides, its long axis lies at right angles to the plane of its orbit, and the oblong box is spinning slowly at about 3.9 revolutions per minute.

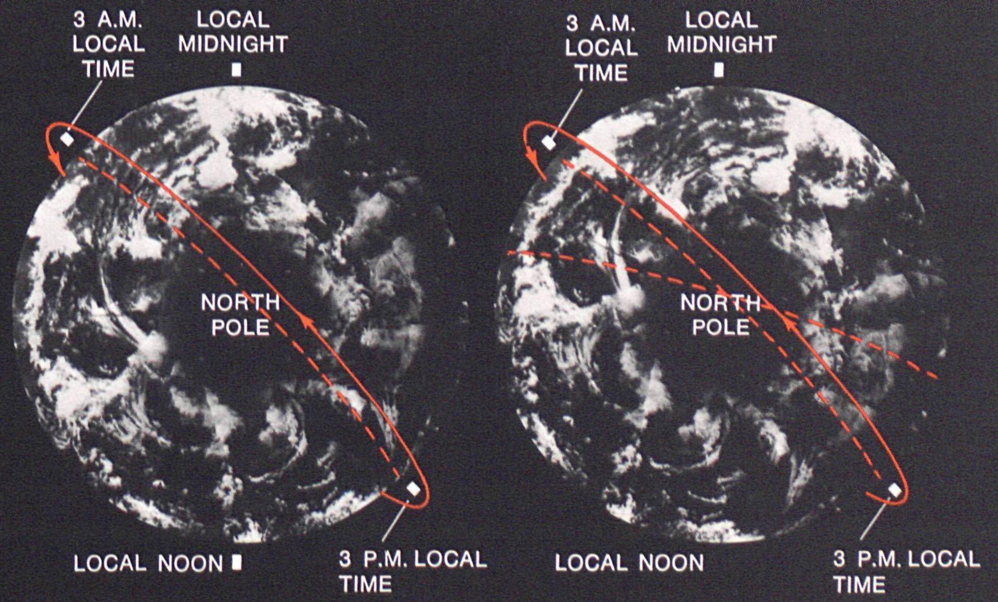
The momentum of this slow rotation is transferred to the momentum flywheel, which was energized at the time of separation and which runs up to 115 revolutions per minute, completely stabilizing the satellite about the spin axis of the flywheel. Then, upon ground command, the flywheel is accelerated to 150 revolutions per minute, slowing the spacecraft's rotation to about one tenth of a revolution per minute. When ITOS is stable in this mode, a ground command deploys the hinged, spring-loaded solar panels, which lie in the orbital plane



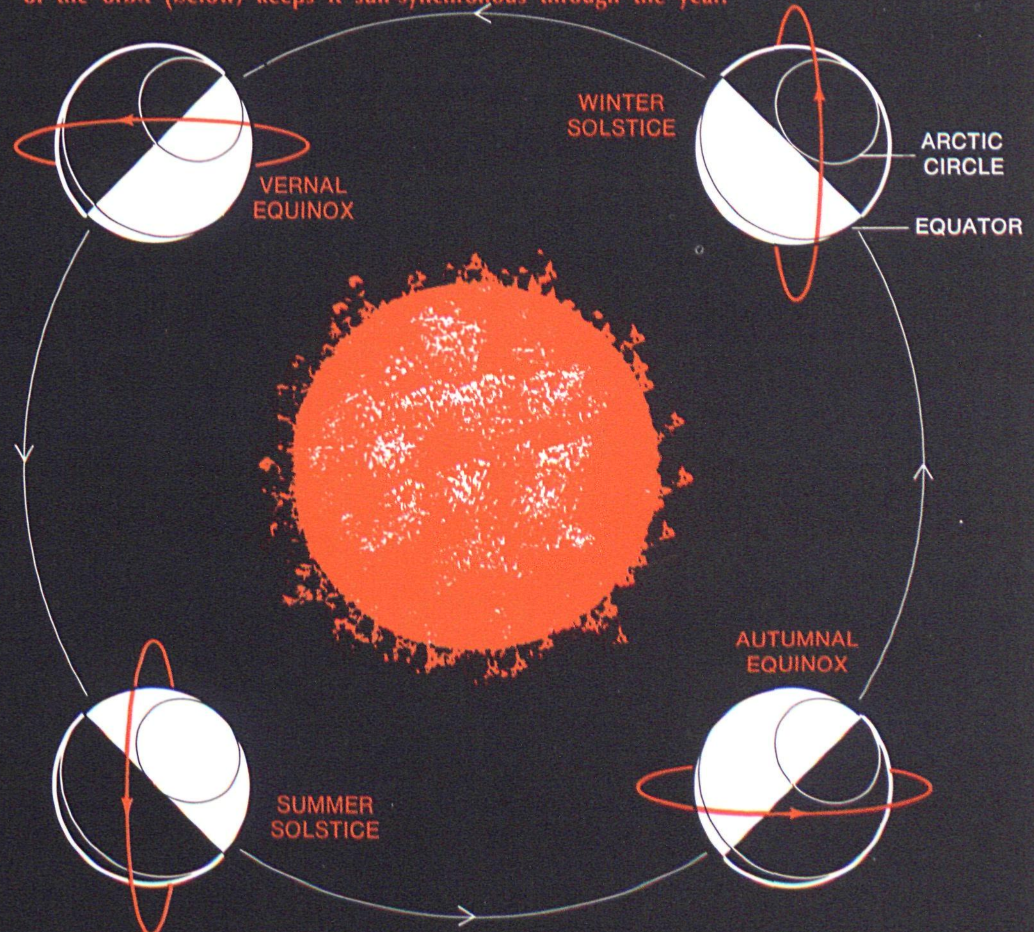
and fully face the sun on the daylight side of the earth. Finally, the pitch-control electronics are switched to a closed-loop mode of operation and the spacecraft spin rate slows to one revolution per orbit.

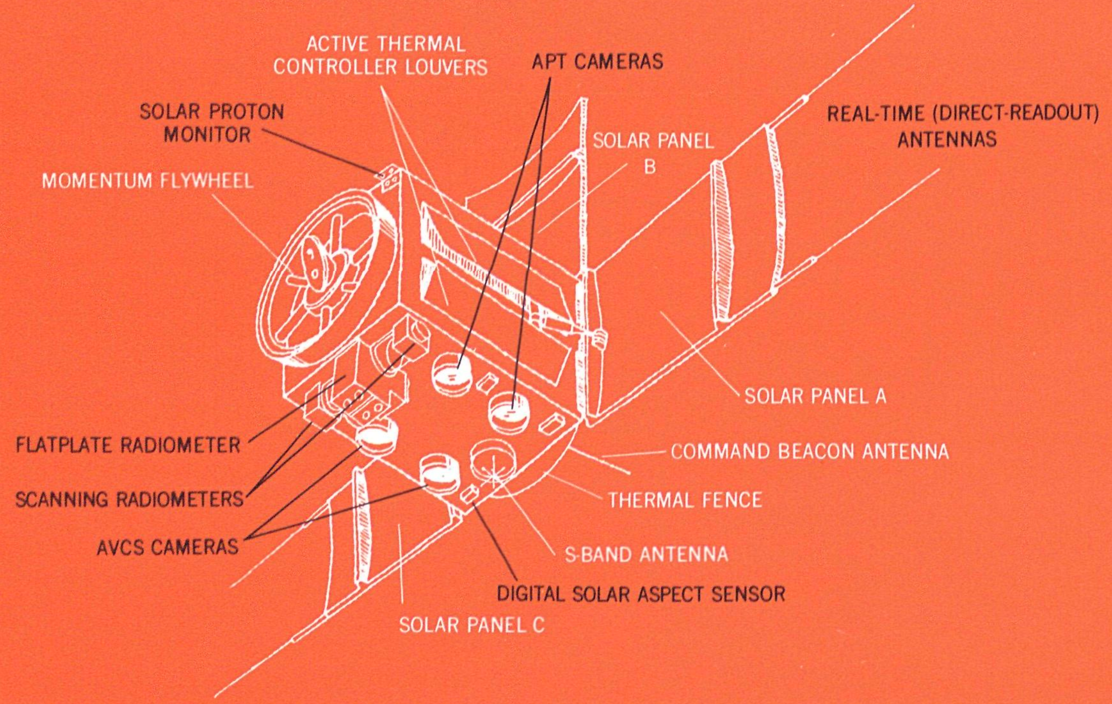
A nominal ITOS orbit is a circular, 909-mile-high, near-polar orbit, inclined about 102 degrees to the plane of the earth's equator. The orbital period for ITOS is 115 minutes, during which the earth turns about 28.5 degrees to the east; the slightly retrograde polar orbit makes successive photographs run almost north and south.

The orbit is sun-synchronous, with ITOS crossing the equator northbound about three hours (45°) behind the local noon point of the sun, and, southbound, about three hours behind local midnight. An eastward drift (or precession) of the ITOS orbit of about one degree per day keeps the satellite properly oriented through the earth's year-long journey around the sun.



The nominal ITOS orbit is about 900 miles high, nearly circular, and nearly polar. ITOS crosses the equator northbound three hours behind (3 p.m. local time) and southbound nine hours ahead (3 a.m. local time) of the sun. An eastward drift of the orbit (below) keeps it sun-synchronous through the year.





Payload of the omnibus ITOS spacecraft is quite flexible. The present TIROS M/ITOS-1 design carries two APT and two stored-data cameras, two scanning radiometers for day-and-night cloud cover images and surface temperatures, a solar proton monitor, and a flatplate radiometer.

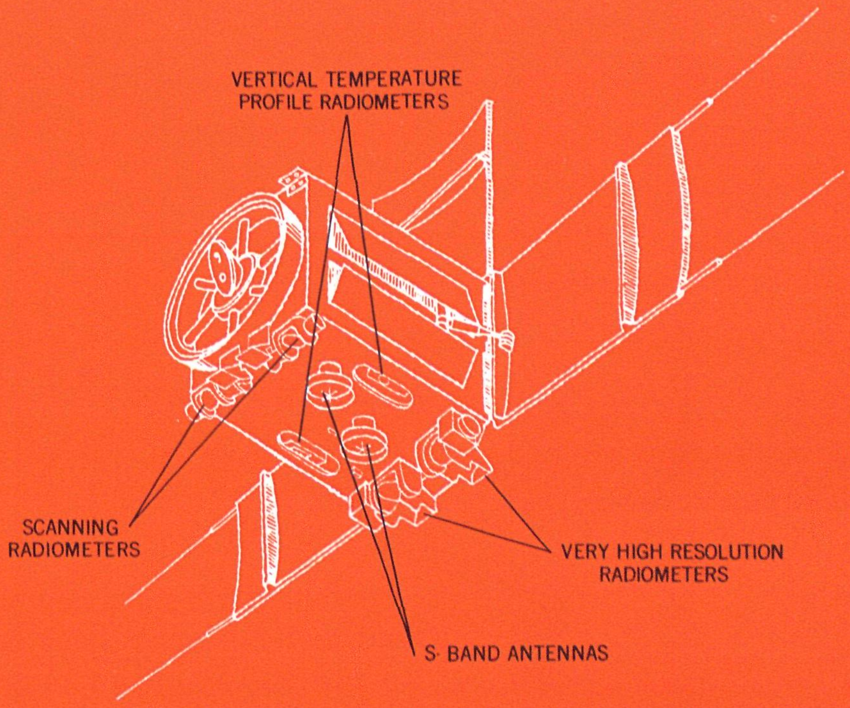
ITOS SENSORS, PRESENT AND PROJECTED

To do the work of a pair of ESSA spacecraft, NOAA satellites carry four cameras: two AVCS units and two APT cameras. One of each can handle the ITOS mission; the second units are backup in the event of equipment failure. Picture-taking operations of the AVCS are controlled by a program of instructions transmitted to the satellite by a command and data acquisition station. The APT cameras, once turned on by ground command, transmit continuously in real time to receivers within range.

Both systems take 11-picture sequences, with each picture taken at 260-second intervals. Each picture covers an approximate 2,000-mile square, or about 4 million square miles of cloud cover, with a resolution of about two miles.

During each orbit, the earth rotates about 28.5 degrees to the east, so that successive strips of photographs are displaced westward. This displacement produces a slight lateral overlap in coverage at the equator, with the amount of overlap increasing with latitude. The overlap of successive pictures taken along the orbital track is about 50 percent, to reduce the possibility of important gaps.

The scanning radiometers aboard ITOS work day and night. During the daylight portion of the orbit, the radiometers sense reflected radiation in the 0.52- to 0.73-micron region of the visible spectrum, and emitted radiation in the 10.5- to 12.5-micron region of the infrared spectrum during orbital day and night. This technique permits measurement of surface temperatures—ground, sea, or cloud tops—during both the dark and sunlit portions of the orbit. Measurements in the visible range have a higher calibration accuracy and dynamic range than television camera systems now in use, and are not subject to the shading which occurs across the face of the vidicon cameras. The ITOS radiometer data are available as either stored-data or direct-readout transmission, and covers about the same area as the cameras.



As the system matures, more advanced TIROS D and E designs omit the flatplate radiometer but replace AVCS and APT cameras with very high resolution scanning radiometers, and carry vertical temperature profile radiometers (VTPR) and a second S-band antenna.

As with the camera systems, the satellite carries two radiometers, to ensure a backup instrument. As the spacecraft moves along its orbit, the radiometer repeatedly scans the surface from horizon to horizon, at right angles to the orbital plane. Scanning is done by a continuously rotating, inclined mirror.

ITOS, like its operational predecessors, carries a flat plate radiometer array that measures the amount of heat emitted by the earth. In addition to helping determine the planet's heat balance, this program hopes to determine long-term changes in earth emissions, which will indicate whether we are heating up or cooling down.

The second-generation meteorological satellite is also a first-generation environmental satellite. Its scanning radiometer permits measurement of sea surface temperatures, which should lead to valuable products for marine environmental activities, including research. The solar proton monitor aboard ITOS is designed to measure proton fluxes at satellite altitudes, and to convert these measurements to a digital record for transmission to ground stations. From data obtained by ITOS (and by other solar-monitoring satellites), NOAA's Space Disturbance Forecast Center can provide timely warning of bursts of solar energy that could endanger astronauts in space, and air travelers at high altitudes, where the atmospheric shield is very thin. The warnings also indicate disruptions of certain regions of the radio telecommunications spectrum, permitting operators to change frequencies during the interruptions.

As the ITOS series matures, the flexible satellite will carry a broader and more sophisticated array of environmental sensors. Beginning in 1972, the scanning radiometers introduced on ITOS-1 will fully assume the duties of present APT and advanced vidicon cameras, and ITOS will carry a very high resolution radiometer to provide ½-mile resolution pictures, day and night, for direct readout by local receivers. This information will require more complex ground equipment than that used with today's radiometer and APT systems.

Vertical sounders will appear on ITOS in 1972, providing global temperature soundings and gross moisture data for use in numerical weather prediction programs and large-scale analyses. This information will be collected centrally, as the stored-data photographs are now, and distributed internationally as appropriate.

Satellites of the late 1970s may carry instruments that sense radiation in other spectral regions, as, for example, the ultraviolet and the microwave. They may also carry a data-relay capability by which observations can be collected by radio from such *in-situ* environmental sensing platforms as buoys, ships, and free-drifting balloons.

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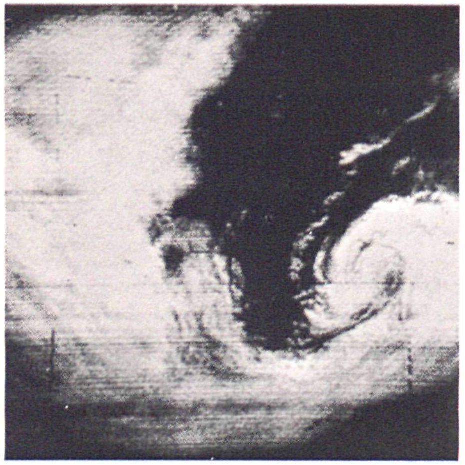
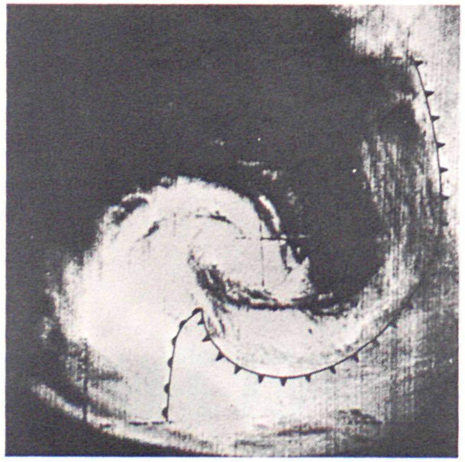
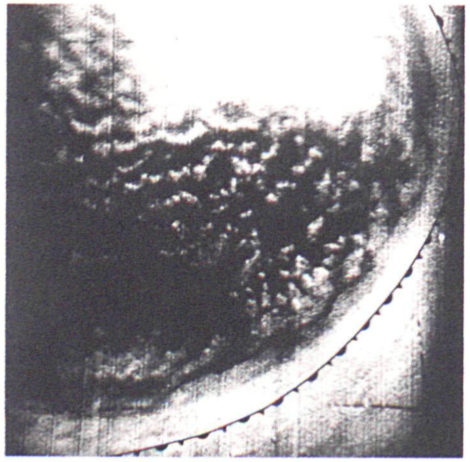
THE ATMOSPHERIC GALLERY




The life cycle of a northern hemisphere wave cyclone became more than theory when photos like these were returned from TIROS I. In these photos (which are not a continuous sequence) a cyclone is born, matures, and dies along the theoretical lines laid down by Bjerknes, the pioneer Norwegian meteorologist, half a century earlier. Satellite data also brought important modifications of meteorological theory, especially in relating cyclonic circulations to winds in the high troposphere, and to the general circulation. (From R. J. Boucher and R. J. Newcomb, "Synoptic Interpretation of Some TIROS Vortex Patterns: A Preliminary Cyclone Model," Journal of Applied Meteorology, June 1962.)

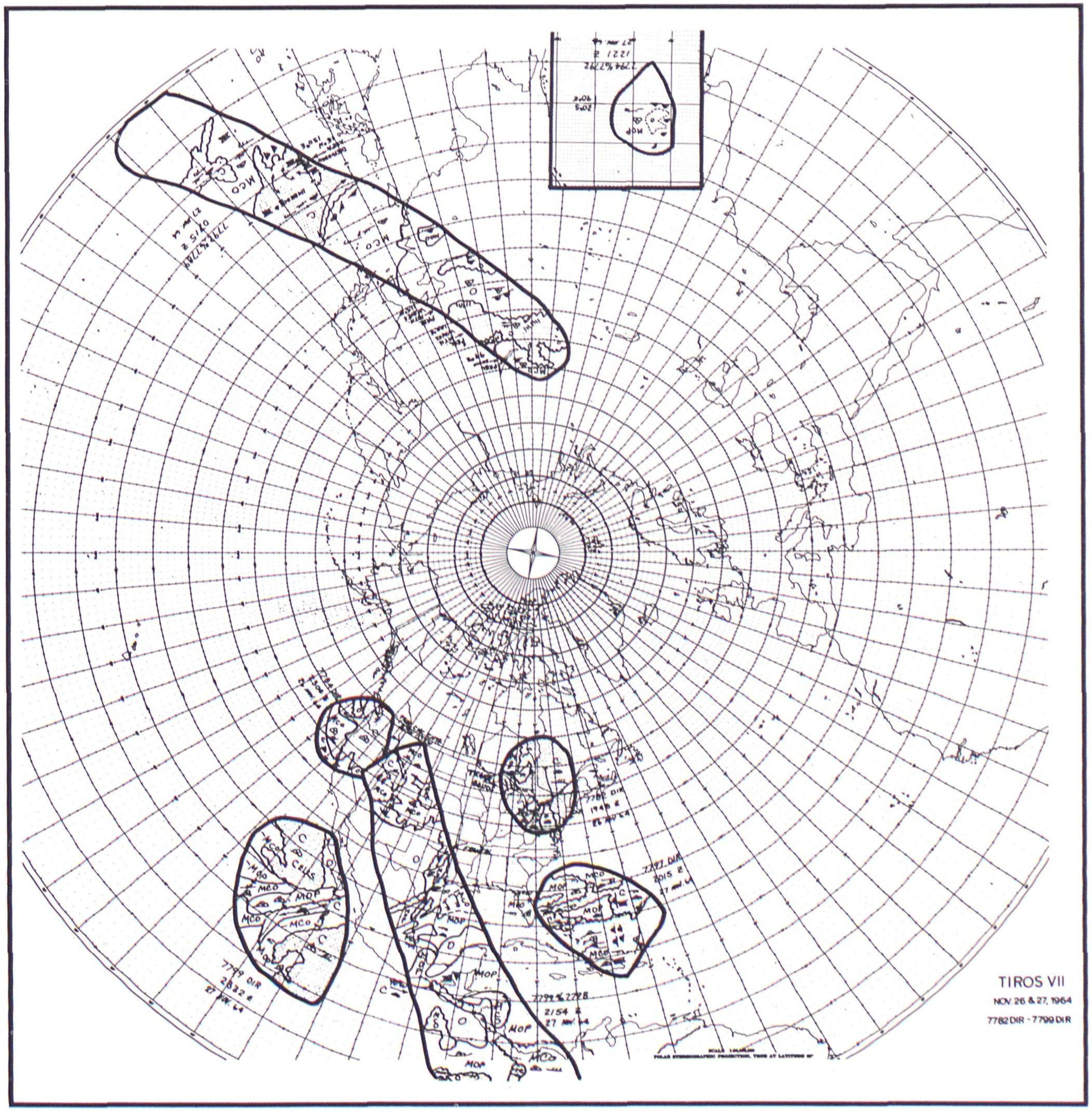
Satellites are still a new way to collect environmental data, and meteorologists have only in the past few years learned to use the abundant information sent back by sensors in space. The story of satellite meteorology is one of innovation, of theories confirmed, complicated, or refuted, of science learning to employ the most advanced technology.

The level of skill involved here has risen several orders of magnitude since TIROS I sent back its first rather blotchy but tremendously exciting signals. Today, meteorologists of the National Environmental Satellite Service have learned to read the proverbial thousand words from these pictures.

They can tell much about the position and extent of fronts, cyclones, cyclonic storms, the jet stream, severe weather patterns, tropical storms, sea-ice conditions, and snow cover. In some cases, they can infer the existence of turbulence, the degree of tropospheric stability, the orientation of surface winds, sea state, and even whether the ground is wet or dry.

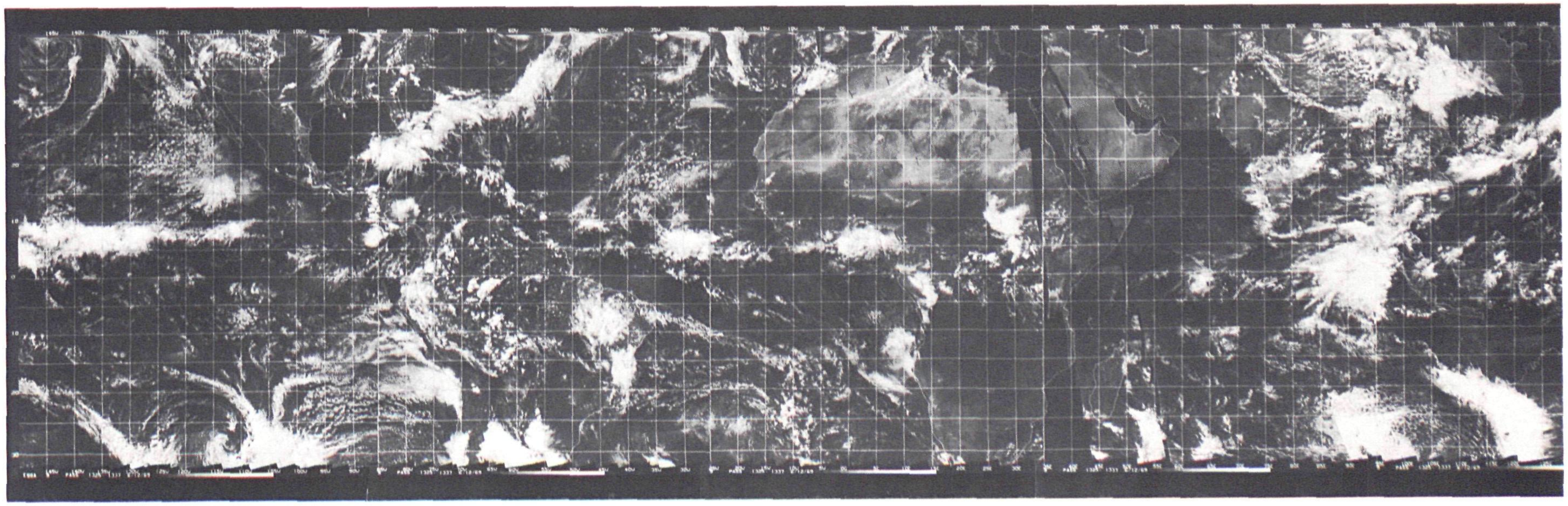
Still, it is a new kind of data, and its rich potential has barely been tapped.

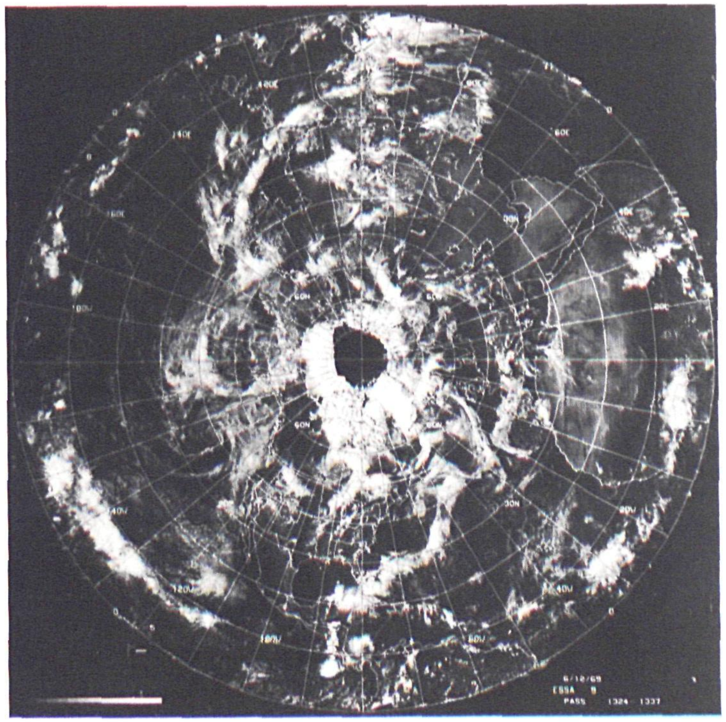
Even to the untrained eye, the view from earth-orbiting satellites is dramatic. Here the cloudy bands and whirlpools that are the visible elements of weather appear as they are, not as men estimate them from the ground. One cannot browse in this atmospheric gallery without excitement.



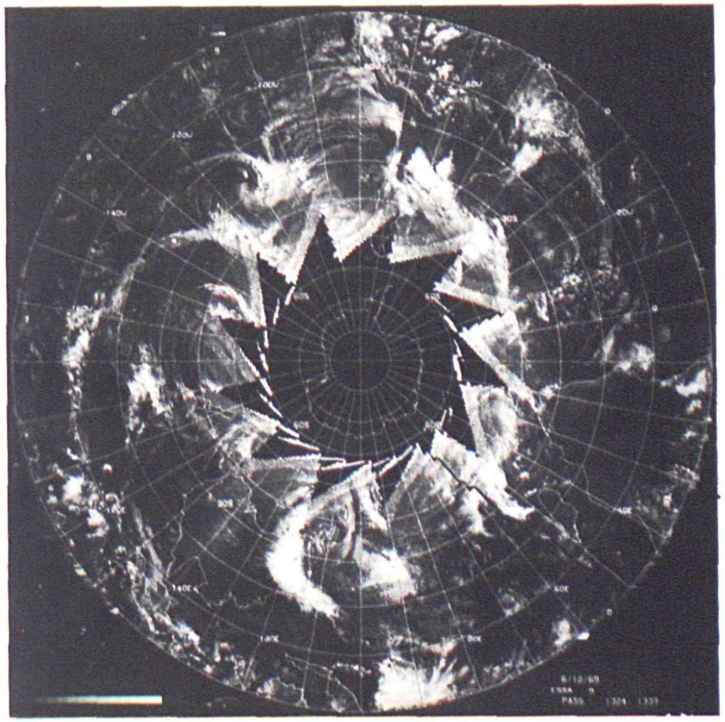
To make satellite pictures useful to meteorologists, cloud-cover photographs were translated into nephanalyses (Greek *nephelé*, cloud, + -analysis); the photos shown here were taken by TIROS VII on November 23, 1963. The nephanalyses prepared from TIROS VII photos for November 26 and 27, 1964, show cloud types, and also point up how spotty TIROS coverage was in the early days of satellite meteorology.

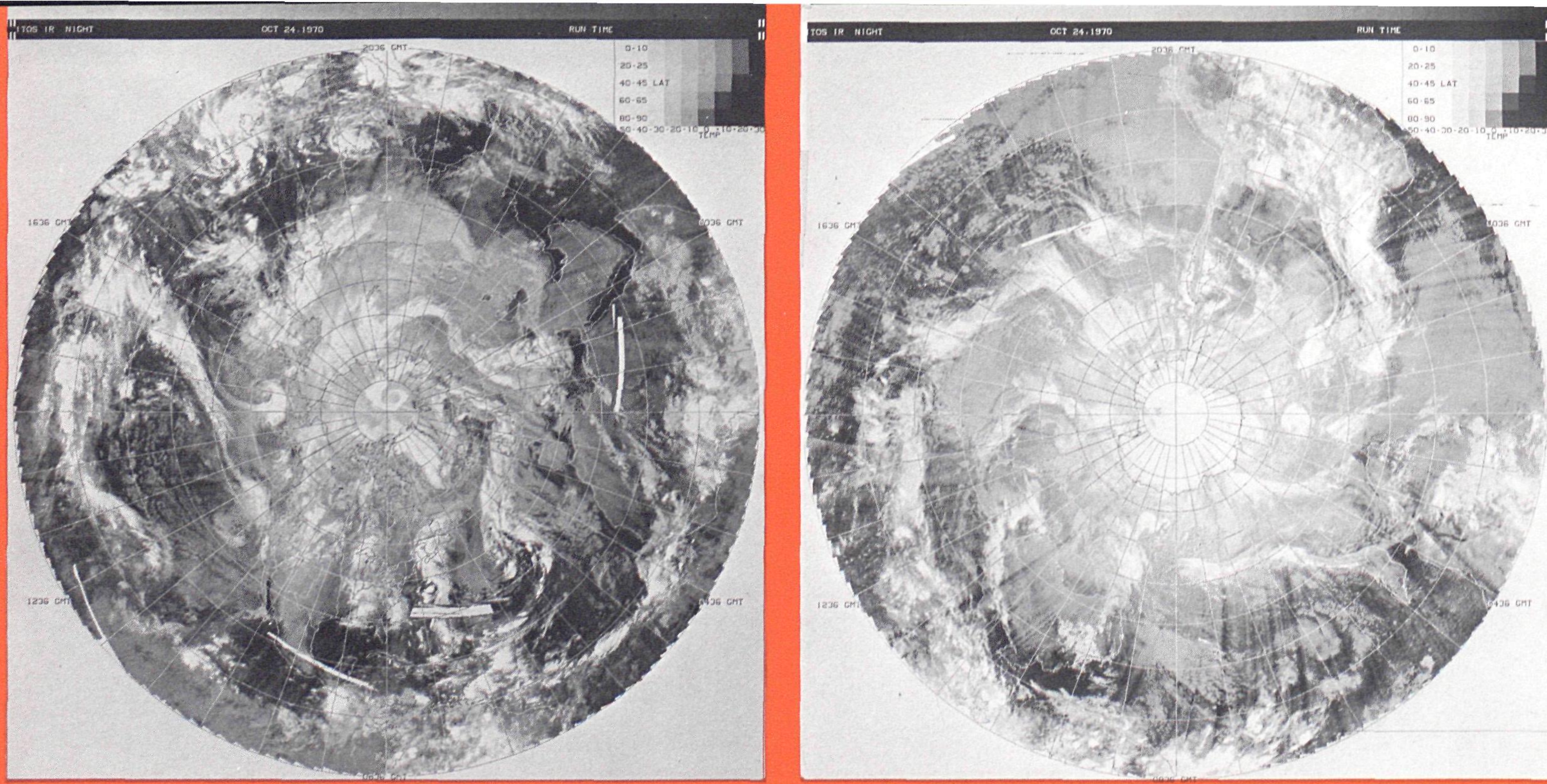
Polar orbits, cartwheeling satellites, and computers made the difference. TIROS IX, the prototype cartwheel satellite in polar orbit, produced data from which this first full view of world weather was made. The photomosaic used 450 pictures taken during the 24 hours of February 13, 1965. Scalloping at bottom results from camera's viewing the horizon at the beginning of each photo sequence.





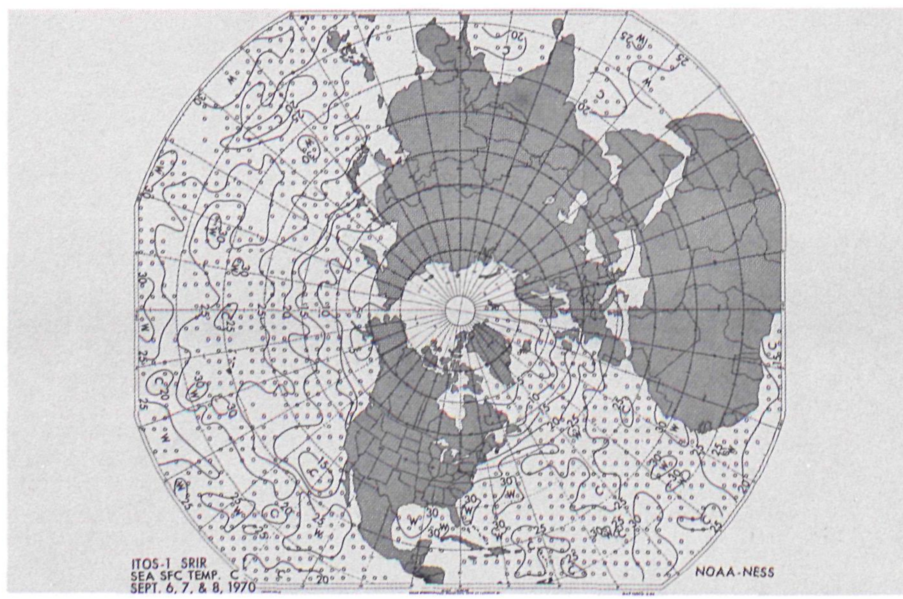
The old mosaics were made with scissors and glue. With the ESSA stored-data satellites and suitable computer programs, digitized mosaics could be translated into polar and equatorial projections of world cloud cover, like these ESSA 9 products for June 12, 1969. The computer adds geographic grid lines and outlines of land masses.



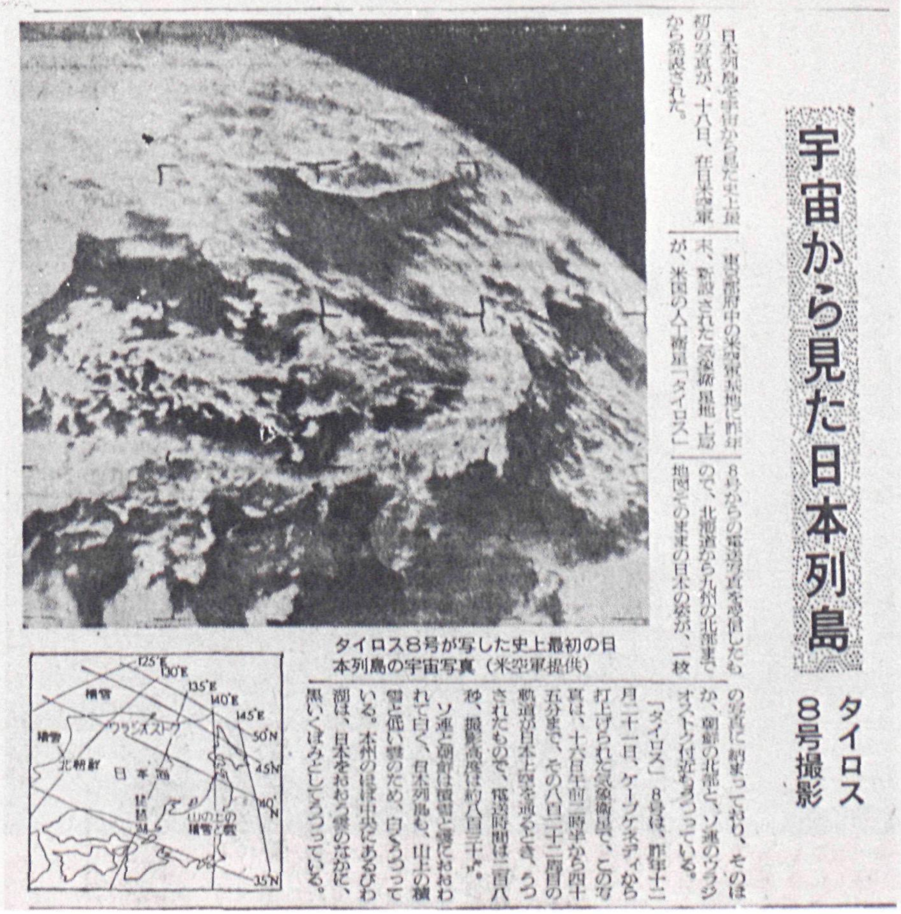


ITOS-1 infrared scanners provided image data used to construct these digitized polar projections of global weather after dark on October 24, 1970. The diagram at upper right describes the relationship, at various latitudes, of image tones and surface (or cloud-top) temperatures in degrees Celsius.

Typical strips show what infrared sensing means to coverage. The strip at left was taken by ITOS scanning radiometers operating in the visible range, and shows how suddenly the information content drops to zero as the satellite passes the earth's terminator. The strip at right is an infrared scan taken during the same pass, and the information is continuous, day and night.



ITOS-1 data have been transformed into this map of sea surface temperatures. This type of information is a fundamental and important step toward longer-range, reliable environmental prediction.



宇宙から見た日本列島

タイロス8号撮影

日本列島を宇宙から見た史上最初の写真が、十八日、在日米空軍から発表された。

東京都府中の米空軍基地に昨年末、新設された気象衛星地上局が、米国の人工衛星「タイロス」8号からの電送写真を受信したもので、北海道から九州の北部までの地図そのままの日本の姿が、一枚の写真に納まっており、そのほか、朝鮮の北部と、ソ連のウラジオストク付近もうつっている。

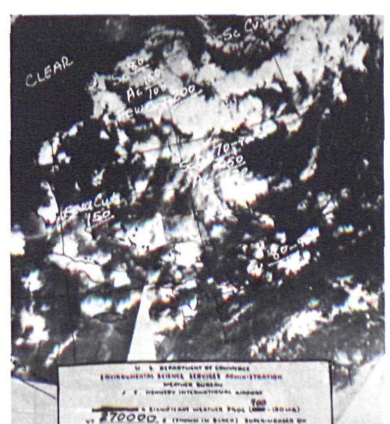
「タイロス」8号は、昨年十二月二十一日、ケープケネディから打上げられた気象衛星で、この写真は、十六日午前二時半から四十五分まで、その八百二十二周目の軌道が日本上空を通るとき、うつされたもので、電送時間は三百八秒、撮影高度は約八百三十キロ。

ソ連と朝鮮は積雪と雲におおわれて白く、日本列島も、山上の積雪と低い雲のため、白くうつっている。本州のほぼ中央にあるびわ湖は、日本をおおう雲のなかに、黒いくぼみとしてうつっている。

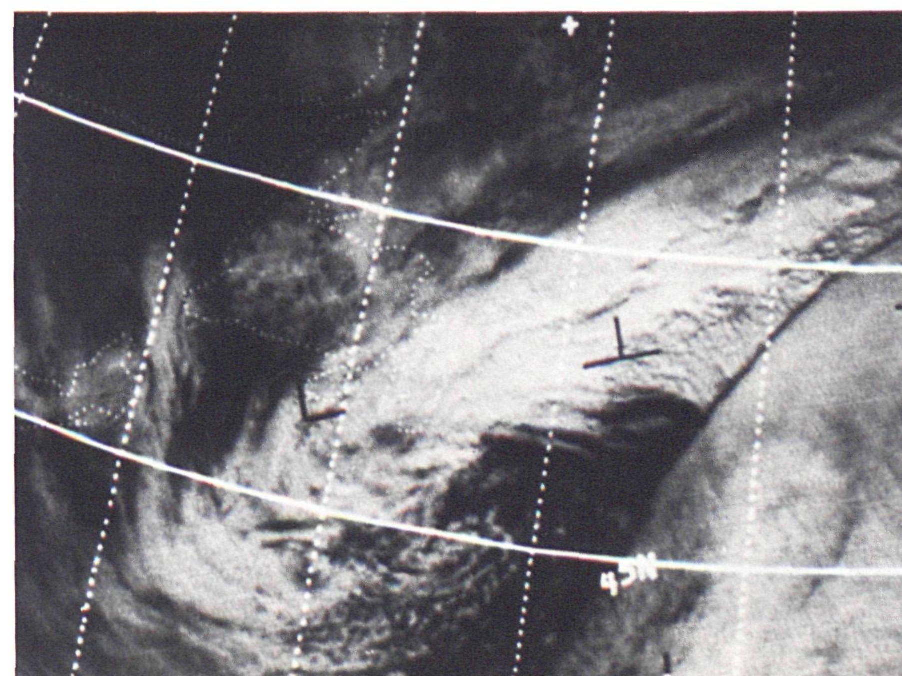
タイロス8号が写した史上最初の日本列島の宇宙写真（米空軍提供）

Automatic picture transmission, or APT, opened weather satellite technology to meteorologists around the world. This picture was received from TIROS VIII, the first APT satellite, by a station in Japan.

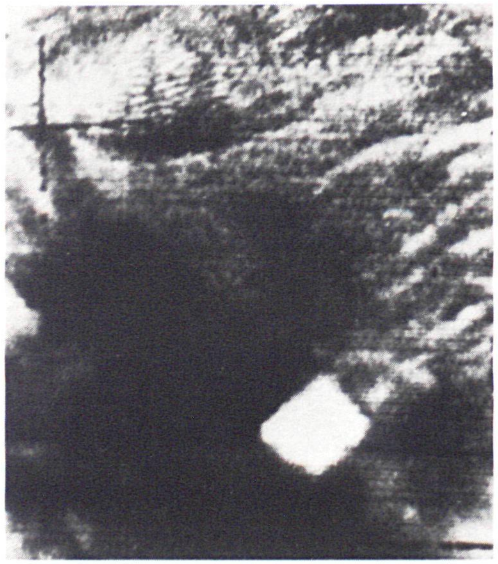
Helix antennas, like this one at the Seattle airport, mark the local reception points for direct-readout satellite data. In the United States, facsimile circuits carry APT photographs and other data to National Weather Service facilities across the country.



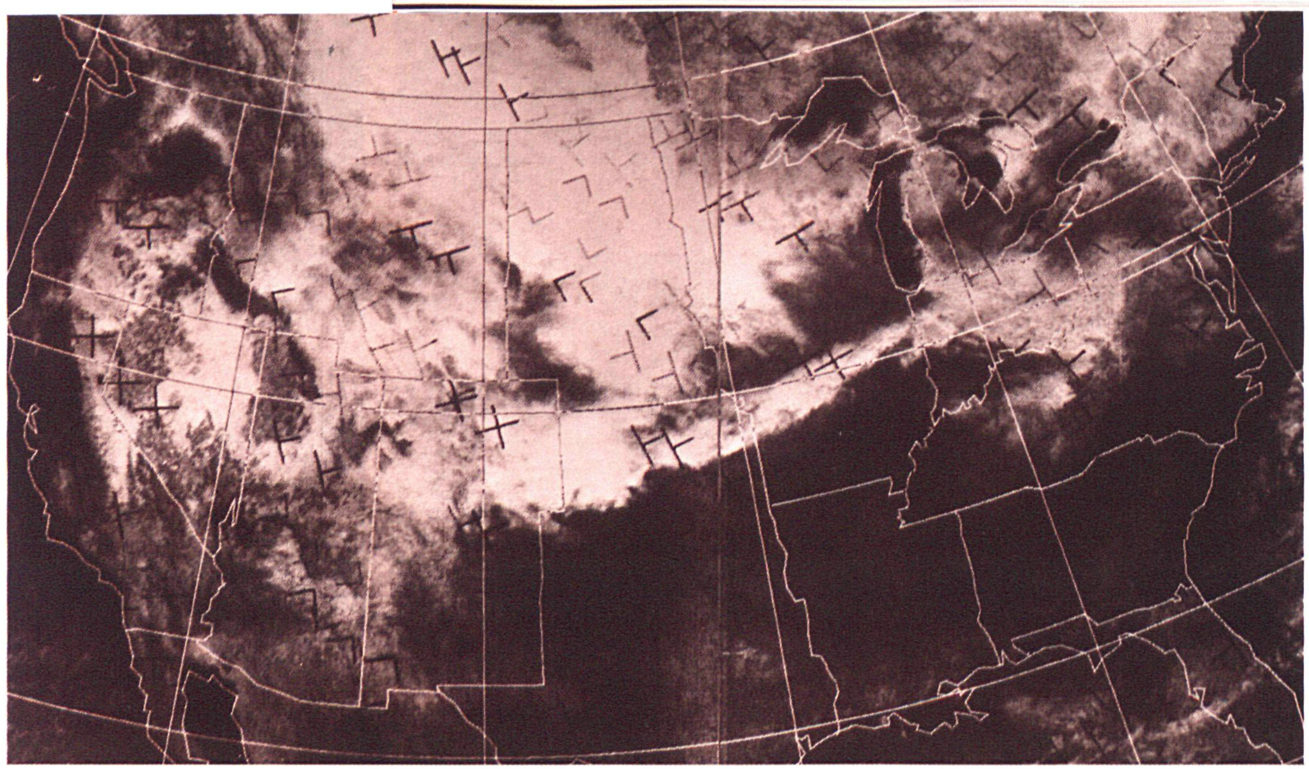
Photomosaic is marked for transAtlantic flights out of New York's JFK International. Still a rather individual effort, APT photographs are being converted into this general type of information by innovative National Weather Service personnel at major aviation terminals.



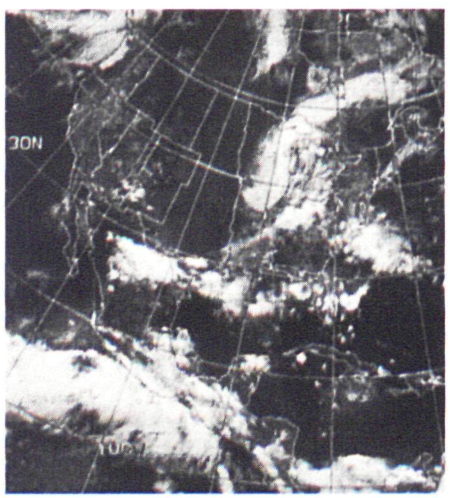
The position of the jet stream, the high-speed winds of the upper troposphere, is marked by a shadow cast by the edge of a cirrus deck on a layer of lower clouds.



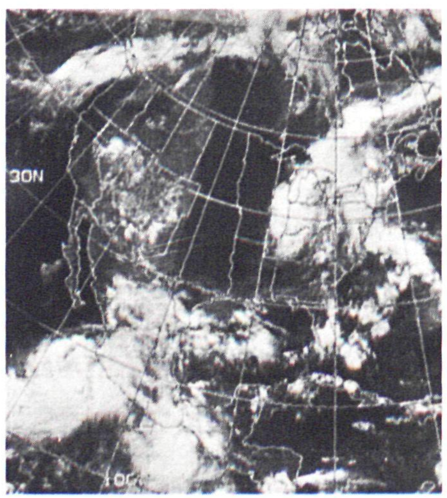
The "square cloud" photographed by TIROS I at 2 p.m. Central Standard Time, May 19, 1960, was centered about 50 miles west northwest of Wichita Falls, Texas. Surface observations showed this cloud mass to be composed of large cumulonimbus (thunderstorm) systems, which spawned tornadoes and hail as the system moved northeastward. The large cloud area at left was associated with the storms that later hit Kansas, leaving destruction reminiscent of a bombing raid at Meriden.



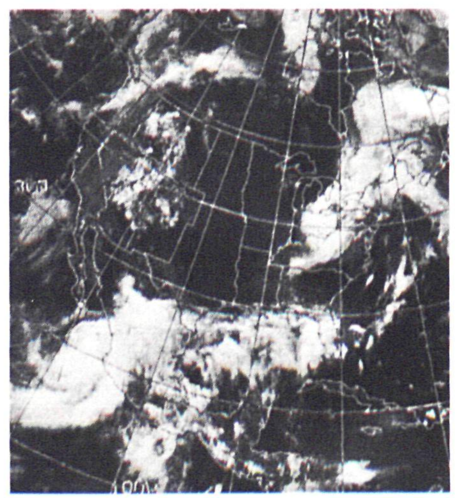
Special products are more the rule than the exception at the National Environmental Satellite Service. Here, a computer program has composed an image made up of the least bright image elements for every data point in five days' satellite data, effectively screening all but some stationary Atlantic cloudiness, and providing a cloud-free view of the winter snowpack. This information was used to good advantage by hydrologists forecasting the disastrous spring 1969 floods in the American middle west.



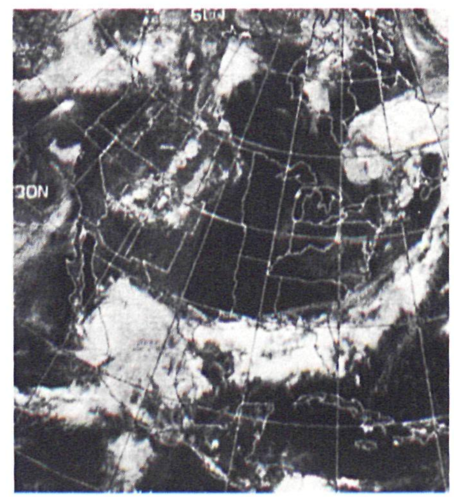
September 9, 1968



September 10, 1968

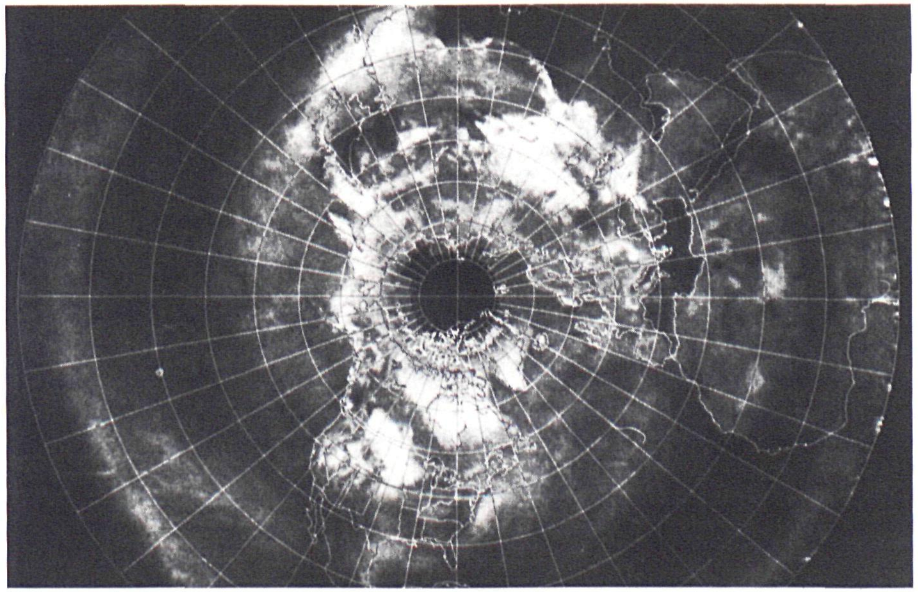


September 11, 1968

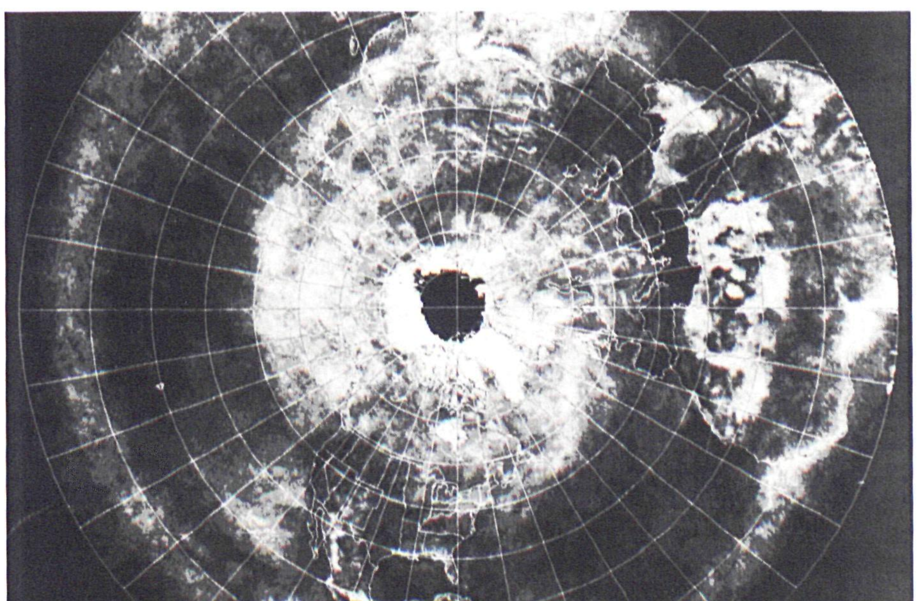


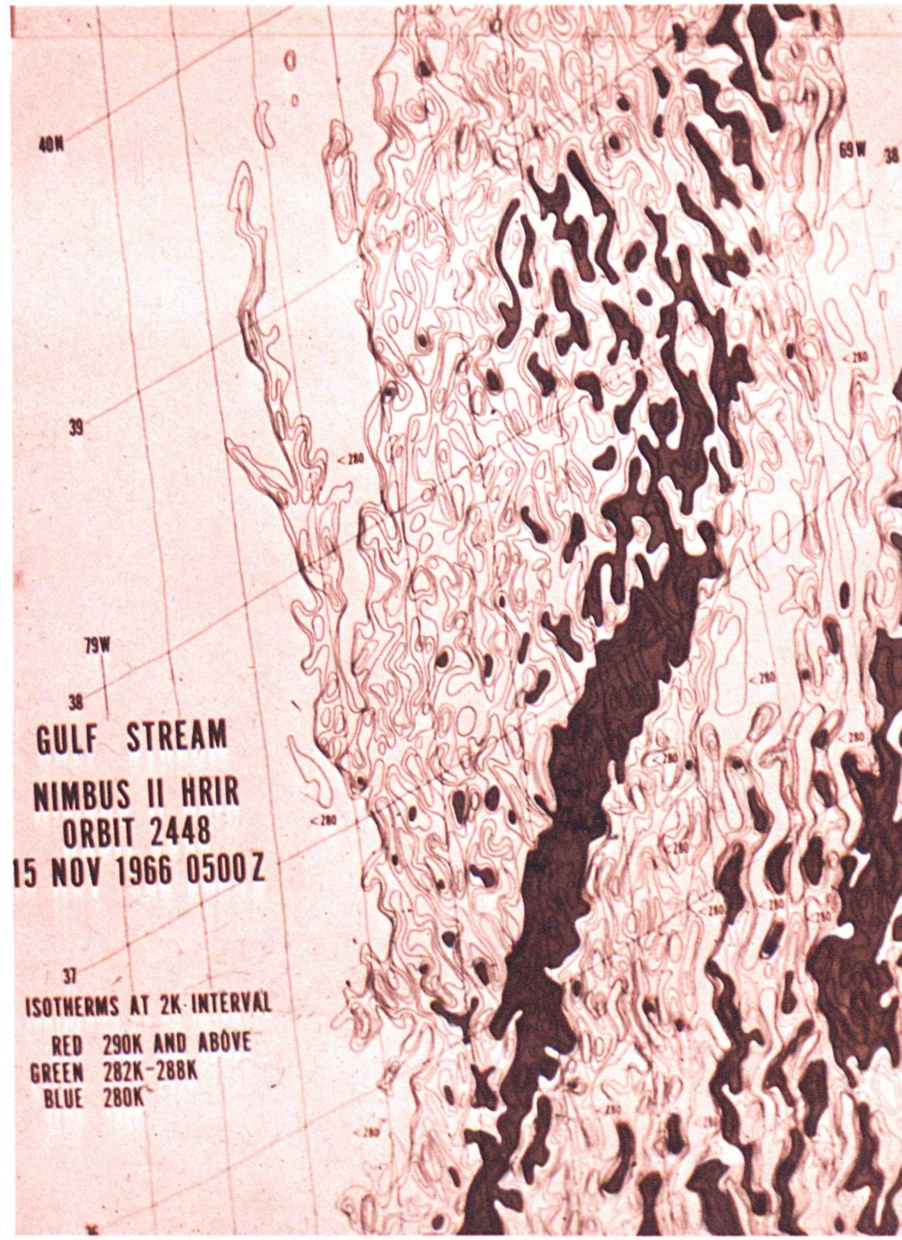
September 12, 1968

Although meteorologists have learned to combine graphic clues—e.g., vertical development as shown by extremely bright tops of cumulonimbus towers and jet stream position—with surface observations, forecasting heavy weather is still more art than science. The kind of complexity facing the weatherman is shown here, where disturbances west of Mexico and over the Great Lakes gradually become linked by a band of frontal clouds.

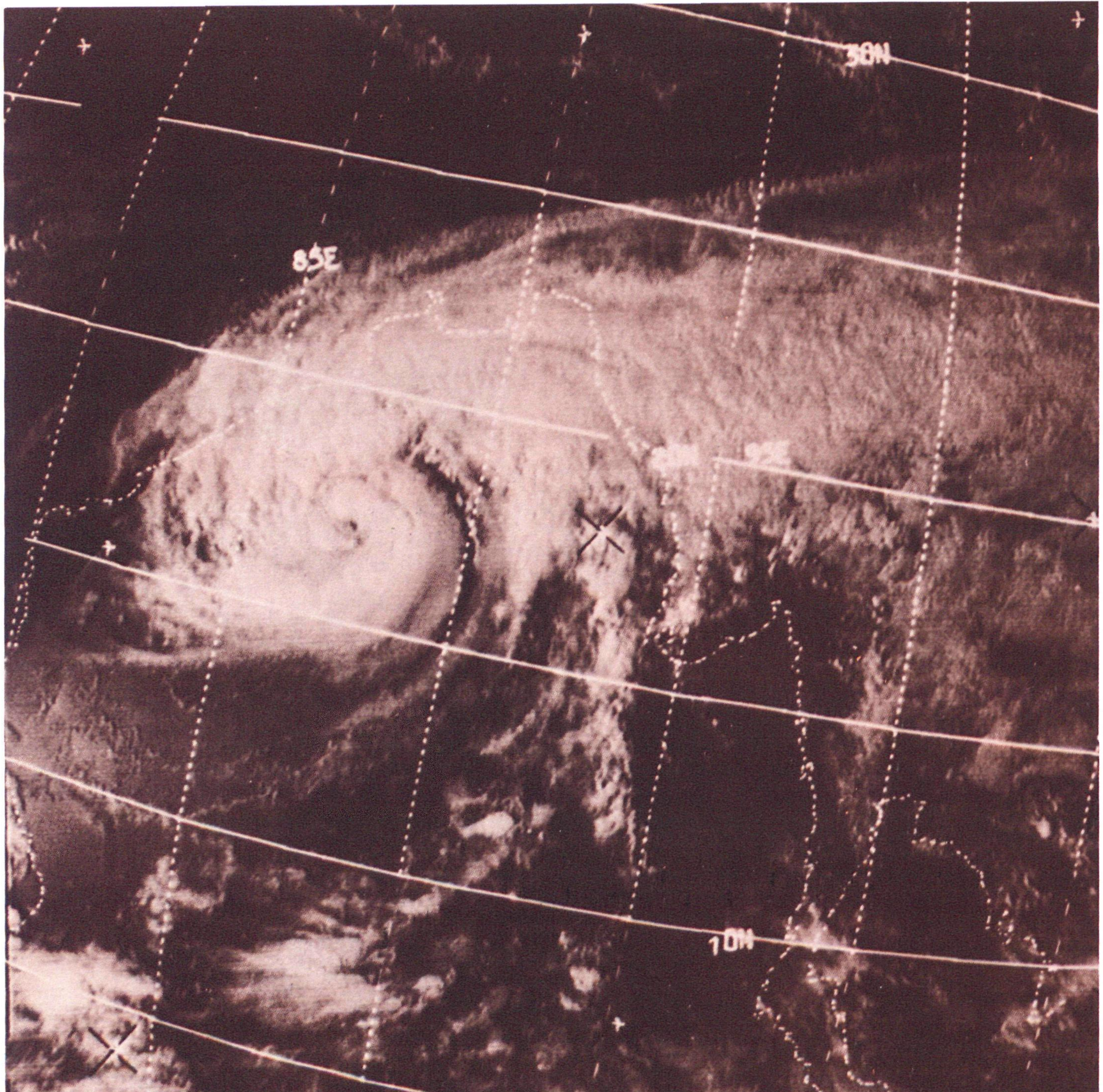


Satellite photographs can be developed into weather history as well as weather news. In these photographs, 30 days' February-March 1969 weather and 30 days' June-July 1969 weather have been averaged through multiple exposure to show *winter and summer cloud-cover patterns over the northern hemisphere.*





Data from infrared sensors can be used to detect warm and cold ocean currents, and to map sea surface temperatures to within about one degree Celsius in cloud-free areas. Here, data from *Nimbus* II have been used to construct a thermal map which clearly shows the Gulf Stream off the eastern United States.



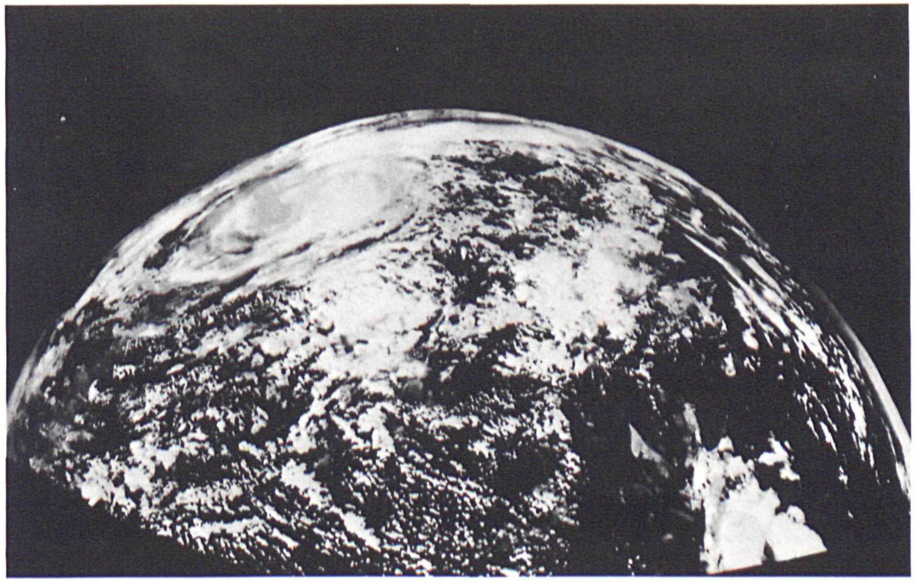
ITOS-1 earned its hurricane-hunting spurs in 1970, at home and around the world. Here, its cameras discover the lethal Bay of Bengal cyclone which caused an estimated quarter million fatalities when it struck the Ganges Delta country of East Pakistan in November.

SATELLITES AND HURRICANES— THE NATURALS

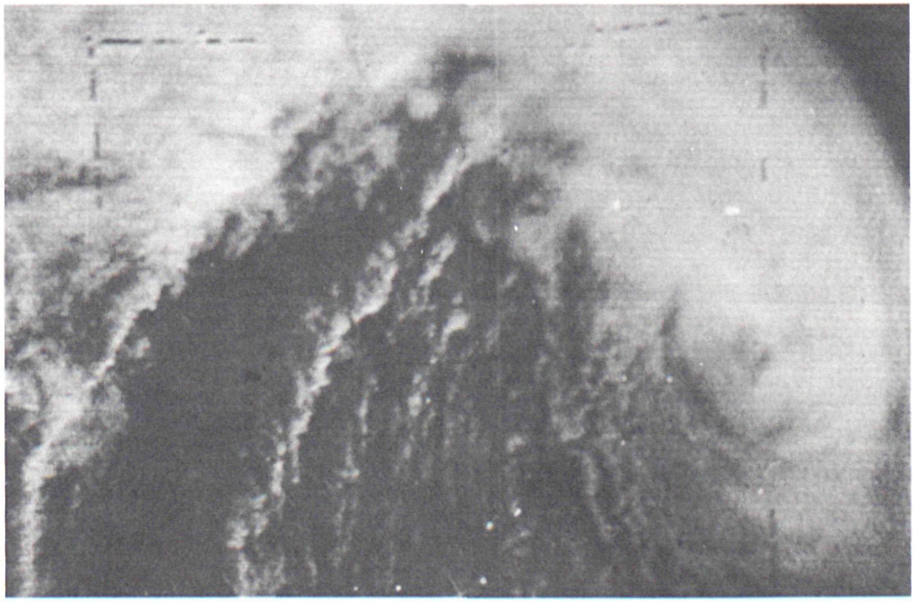
Nowhere have weather satellites paid their way more demonstrably than in the early detection and near-continuous tracking of tropical cyclones—the hurricanes of our east and southeast, the typhoons of the Pacific, the cyclones of the southern hemisphere. From the earliest ventures of cameras into space, the great storms have been a central figure.

For those whose lives have had to pass through the fear and fury brought by the hurricane, satellites from TIROS I to ITOS occupy a special, even sentimental, place. Life has always been hard in hurricane country, in hurricane season; but it was much harder in the years before satellites arrived.

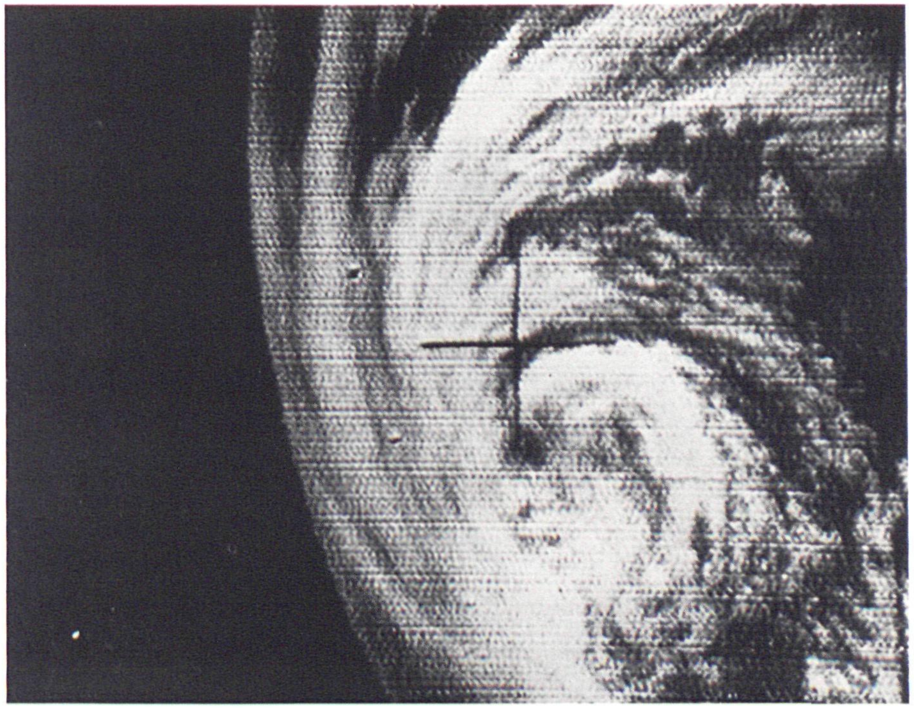
Satellites and the great coiled storms are naturals for one another, and have been from the beginning. In this gallery of violent natural events are displayed some of the worst storms of the first decade, and those which began the decade of ITOS.



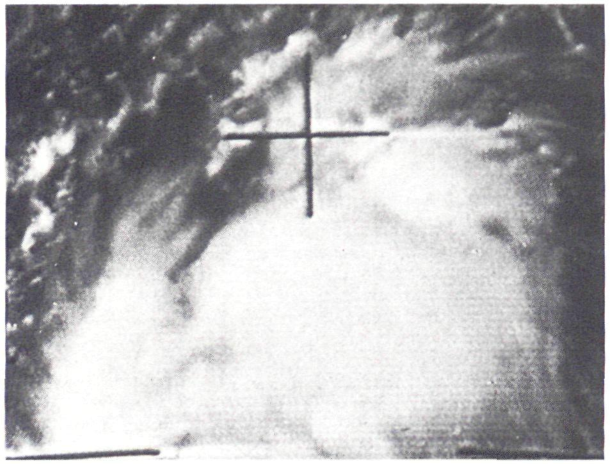
An Aerobee rocket over White Sands, N. M., took the 100-mile-high photographs from which this early weather mosaic was made. The 1954 experiment inadvertently picked up the tropical storm at upper right, and gave impetus to the development of a hurricane-finding "eye in the sky."

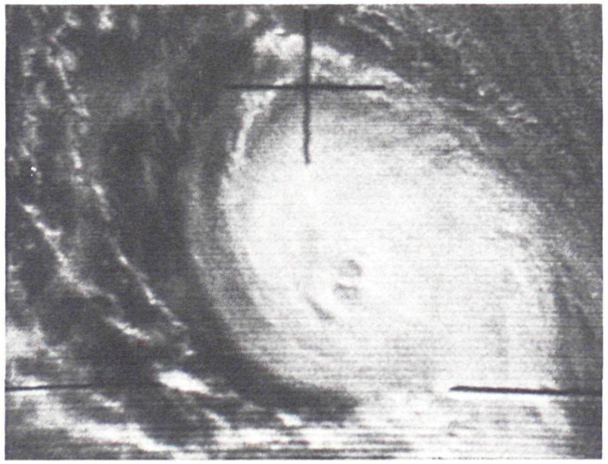


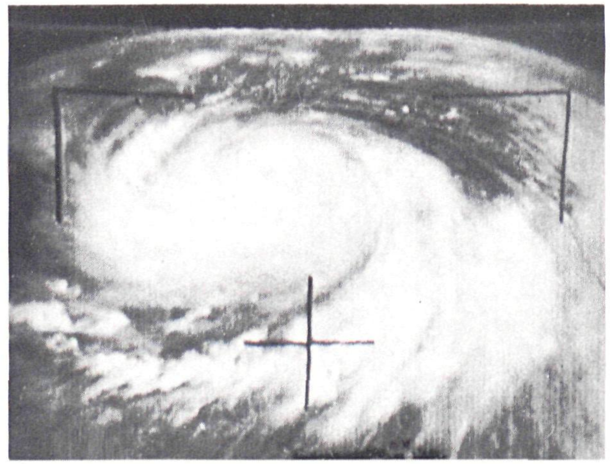
TIROS I photographed this typhoon over the South Pacific, permitting early warning to be given threatened areas.



TIROS III demonstrated how effectively satellites could do the hurricane-detection job by catching storms in both oceans. Shown here are hurricane Anna (above) just north of the Columbia-Venezuela Caribbean coast, and tropical storm Liza, west of Baja California.

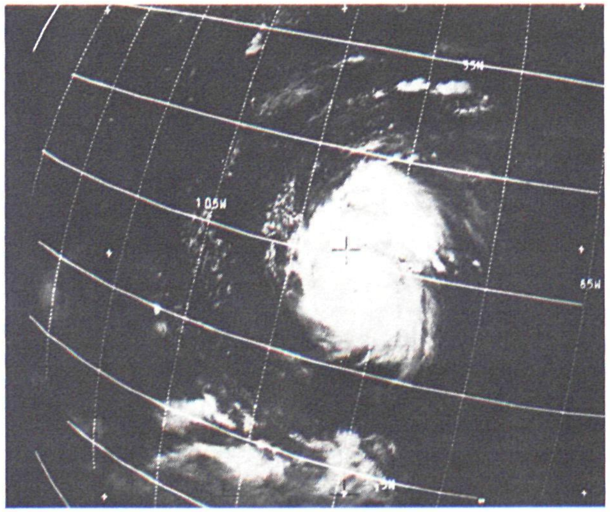




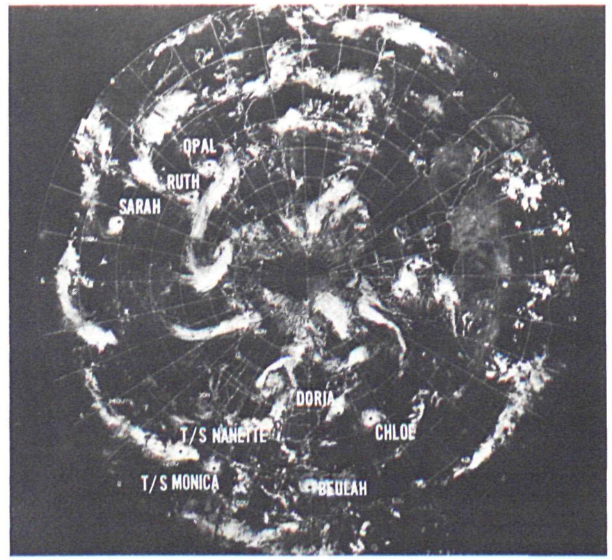


A bad year for hurricanes, 1964 battered the American coast with Cleo (August 20-September 5), which whirled up the Atlantic coast from Miami to Virginia, Dora (August 28-September 16), which cut across northeastern Florida and made a very unusual southward curve into the Caribbean, and Hilda (September 28-October 5), which brought death and destruction to coastal Louisiana. Photographs by TIROS VII on August 26 (Cleo), September 4 (Dora), October 1 (Hilda).

Hurricane Betsy (August 27-September 12, 1965) caused $1.7 billion estimated damage in southern Florida and Louisiana. The photograph was taken by TIROS X, on August 29.



Hurricane Beulah struck the Rio Grande delta country on September 20, 1967, and was the worst in many years, partly because of catastrophic flooding, partly because it spawned a record 115 tornadoes. In "ESSA v. Beulah," *Time* for September 29 captioned a satellite photo of the storm, "Not much of a killer, thanks to a hatbox on high."



ESSA 5 tracks eight major storms on September 14, 1967, Beulah among them, in this polar stereographic projection made from stored-data camera transmissions by Satellite Service computers. Storm centers, or "eyes," are indicated by black dots in each cloudy spiral.

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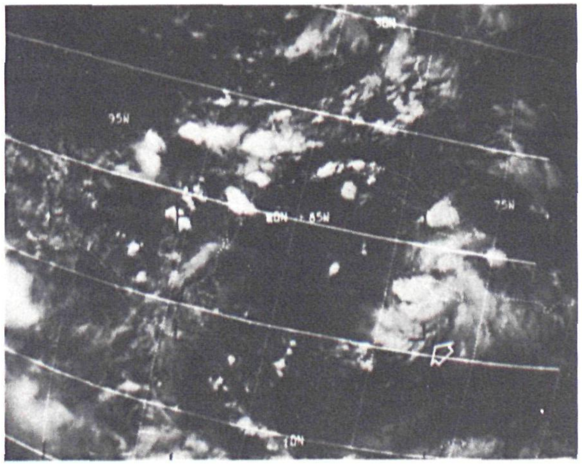

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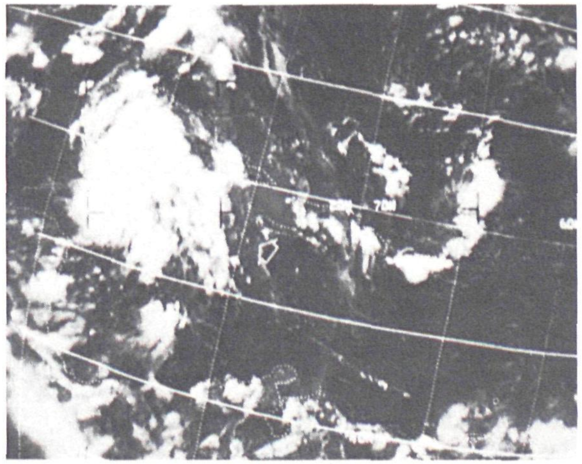

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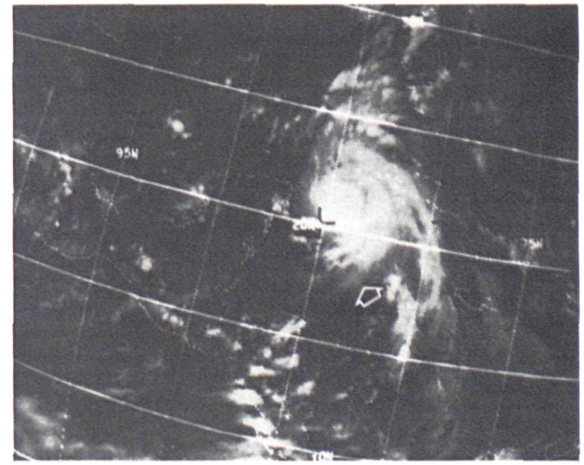

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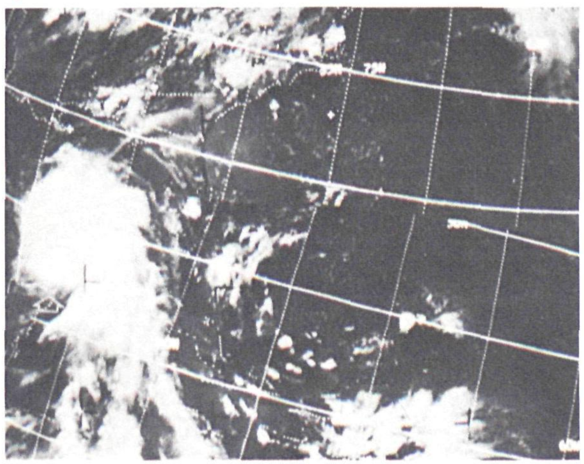

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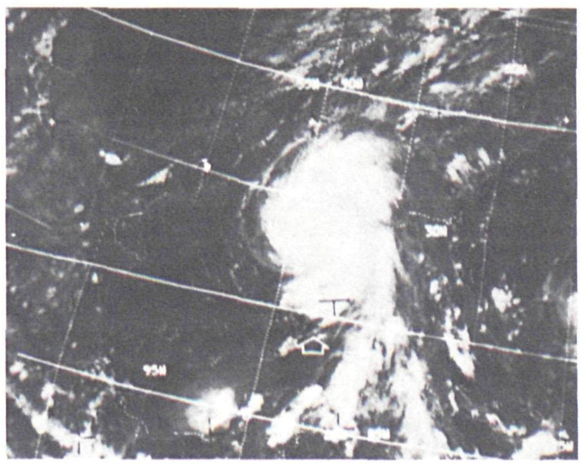

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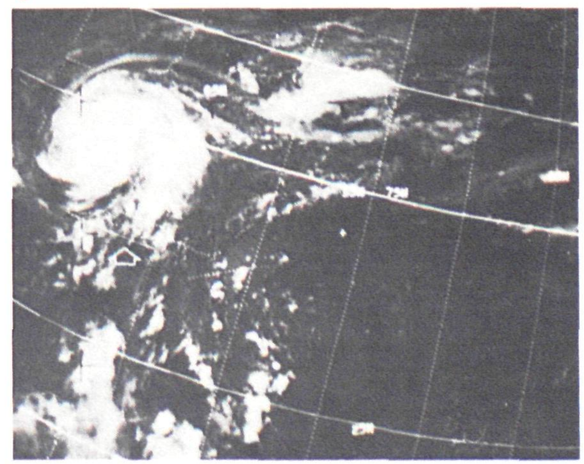

The growth, destructive life, and slow death of hurricane Camille, the worst hurricane on record for the United States mainland, are sequenced in these ESSA 9 photographs. The disturbance is first detected south of Cuba on August 13, 1969 (1), and begins to drift northward (2), intensifying by August 15 into a storm of hurricane force (3) as it crosses the Gulf of Mexico (4) and strikes into the Louisiana-Mississippi coast (5) on August 17. Moving inland on August 18 (6), the storm weakens and combines with other systems (7) to produce the atmospheric freak which brought disastrous flash flooding to the Appalachian foothills of Virginia and West Virginia. Camille drifted out into the Atlantic, regained hurricane strength for a short time before entering extratropical weather systems off Nova Scotia.

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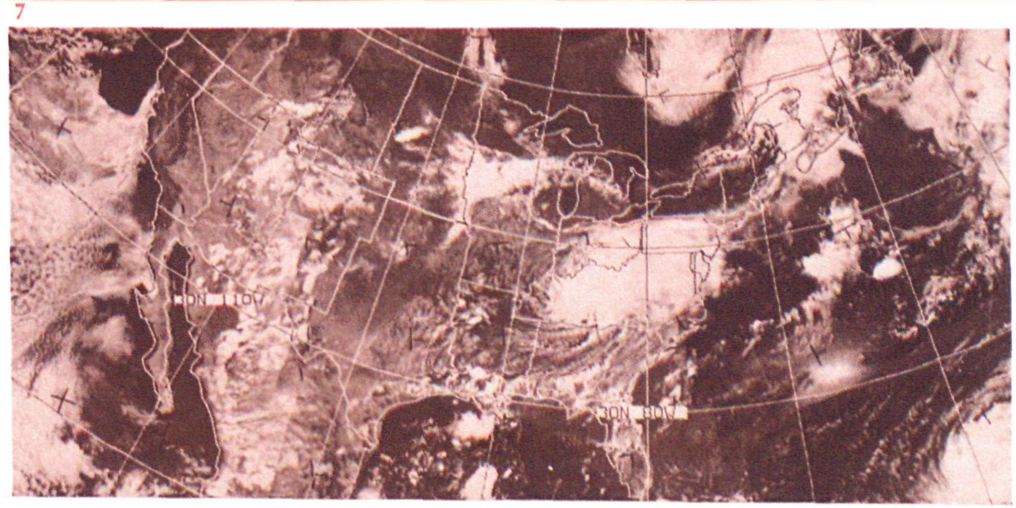
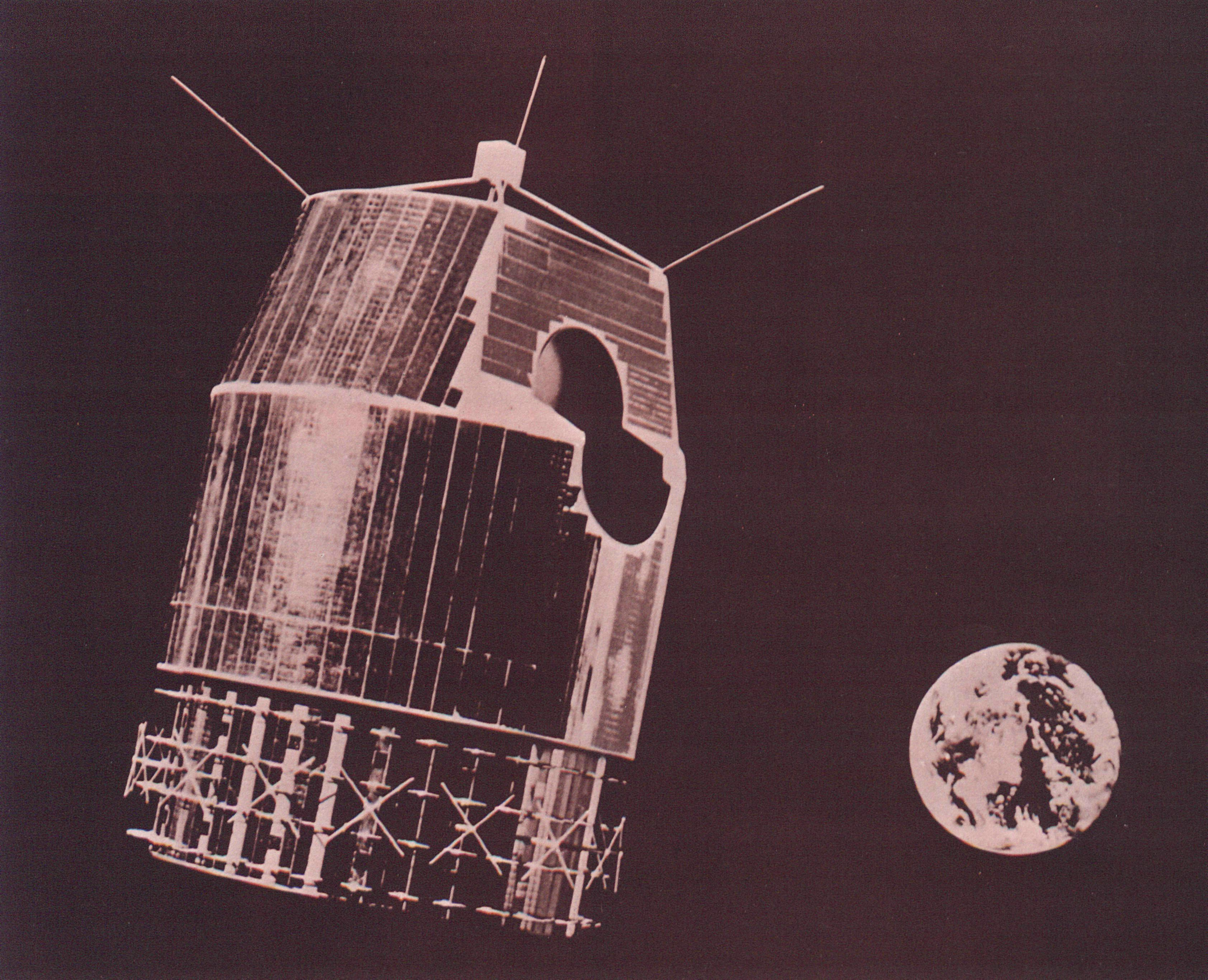




From its geostationary orbit 22,300 miles above an equatorial point near the mouth of the Amazon River, Applications Technology Satellite (ATS) 3 photographs the earth's disc every 22 minutes. This dawn-to-dusk series was taken from a three-color ATS-3 sequence made in November 1967.

GOES – THE NEXT STEP

Remarkable as the development of polar-orbiting, low-altitude satellites has been, it represents only half an achievement. The operational system required two additional capabilities: continuous viewing of the earth's cloud cover, and a data-relay between weather centers and outpost sensor platforms. While the first low-altitude, polar-orbiting series began returning its operational products, space scientists were readying equipment to meet these objectives.

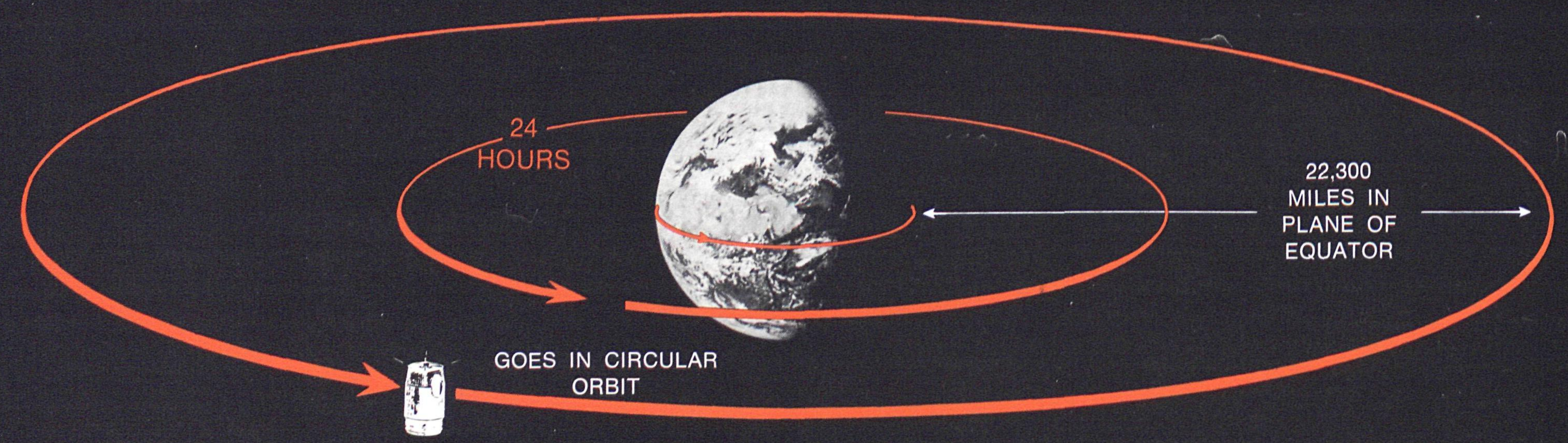
There was nothing theoretically new about placing satellites into geostationary orbits. An object injected at sufficient speed, in the right direction, can be orbited at any altitude about the atmosphere; however, as the distance between satellite and planet increases, the speed required to maintain an orbit decreases. At an altitude of about 22,300 miles, the orbital speed is down to about 6,800 miles per hour, and the period of a circular orbit becomes 24 hours. If this 22,300-mile-high orbit lies in the plane of the earth's equator, the satellite and earth turn through the same arc distance in the same time, so that the satellite is always above the same point on the equator. Earth-synchronous, geosynchronous, and geostationary are the terms coined to describe such an orbit.

By 1966, considerable expertise in achieving geostationary orbits had been developed on civilian communications projects like Early Bird, launched in April 1965, and some military projects. The first meteorologically important system began NASA's Applications Technology Satellite (ATS) series.

Launched December 7, 1966, ATS-1 went into a geostationary orbit over a Pacific equatorial point at about 150 degrees west longitude. On December 11, its spin-scan cloud camera began transmitting essentially continuous photographic coverage of most of the Pacific Basin. The photographs, taken by scanning from 55 degrees north to 55 degrees south latitude as the spin-stabilized satellite turns, are completed every 22 minutes, and have a central resolution of about two miles. The camera is peak-sensitive in the green region of the visible spectrum which permits maximum information to be obtained from black and white photographs.

Even after four years, this very successful experimental satellite continues to transmit photographs and has become an important part of analysis and forecast activity for this data-sparse ocean area. The National Environmental Satellite Service controls ATS-1 video during much

At an altitude of 22,300 miles, a satellite in the plane of the equator and the ground point directly below it are moving at the same relative speed—that is, they sweep through the same angular distance in the same time. The satellite is then said to be geostationary.



of its daylight hours, and the spacecraft's graphic data have found a wide variety of uses. Because the viewing is nearly continuous, it is possible to make motion-picture loops of cloud-system movement from which low-level winds can be measured. Film loops also show storm system life cycles, air mass migration, interhemispheric mixing, and weather systems of such short duration that their development cannot be traced by the long intervals between polar-orbiting satellite coverage.

For meteorologists analyzing weather patterns over the southern hemisphere and Pacific Ocean area, the ATS-1 graphics have meant the first significant filling of a virtual information vacuum.

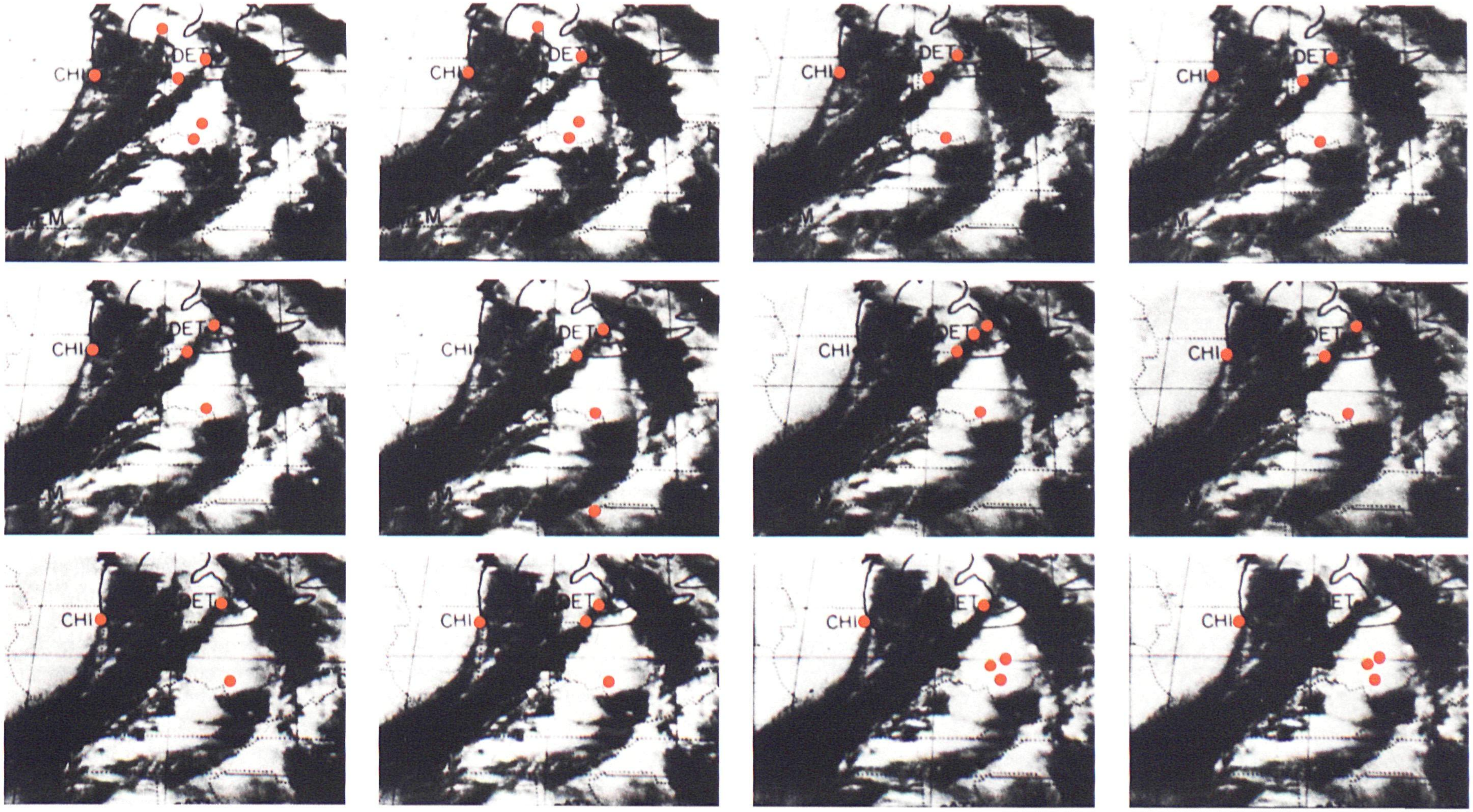
ATS-3, launched November 5, 1967, was also a major success. From its geostationary vantage point, the satellite's field of view covers much of the North and South Atlantic Ocean area, all of South America, much of North America, and the western edges of Africa and Europe. This experimental spacecraft carried a multi-color spin-scan camera, which operated much the same way the ATS-1 camera does, but returned red, green, and blue outputs—or did until its red channel failed during the first year of operation. Until *Apollo* gave men a better camera on a higher platform, ATS-3 photographs provided the best view ever obtained of our planet's full face.

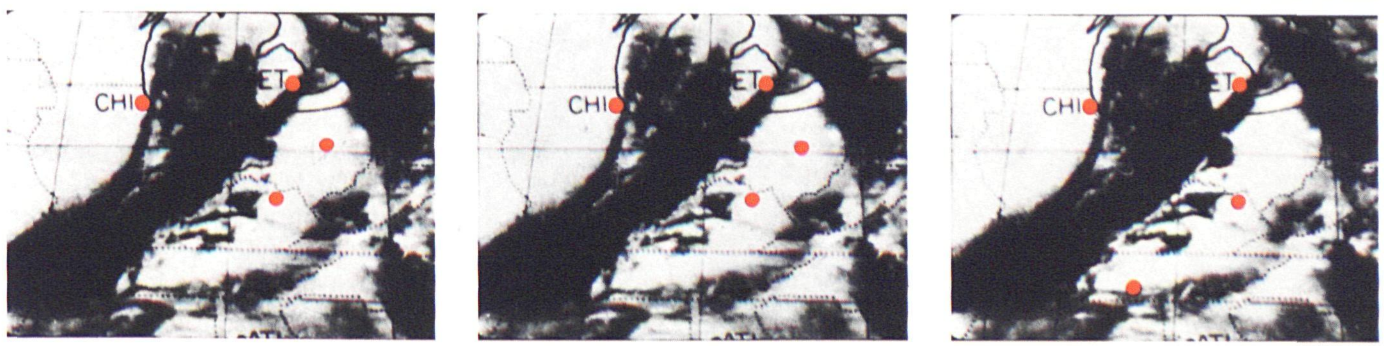
Both ATS-1 and ATS-3 also pioneered important weather communications techniques, for example, the transmission of weather data from a command and data acquisition station to the satellite and back down to local APT receivers. Data were in the form of weather maps and nephanalyses transmitted from NOAA's Suitland, Md., facility, to the satellite and APT stations.

In another series of important experiments, the ATS spacecraft were used to collect data from remotely located sensors. For example, the satellite was used to interrogate rain and river gages, and to relay their observations to a river forecast center. In other cases, such as drifting buoys, ships, and aircraft, the location of the platform also had to be determined. Here, the platforms also received Omega* navigation signals and relayed them, along with the sensor data, via ATS to a central analysis point.

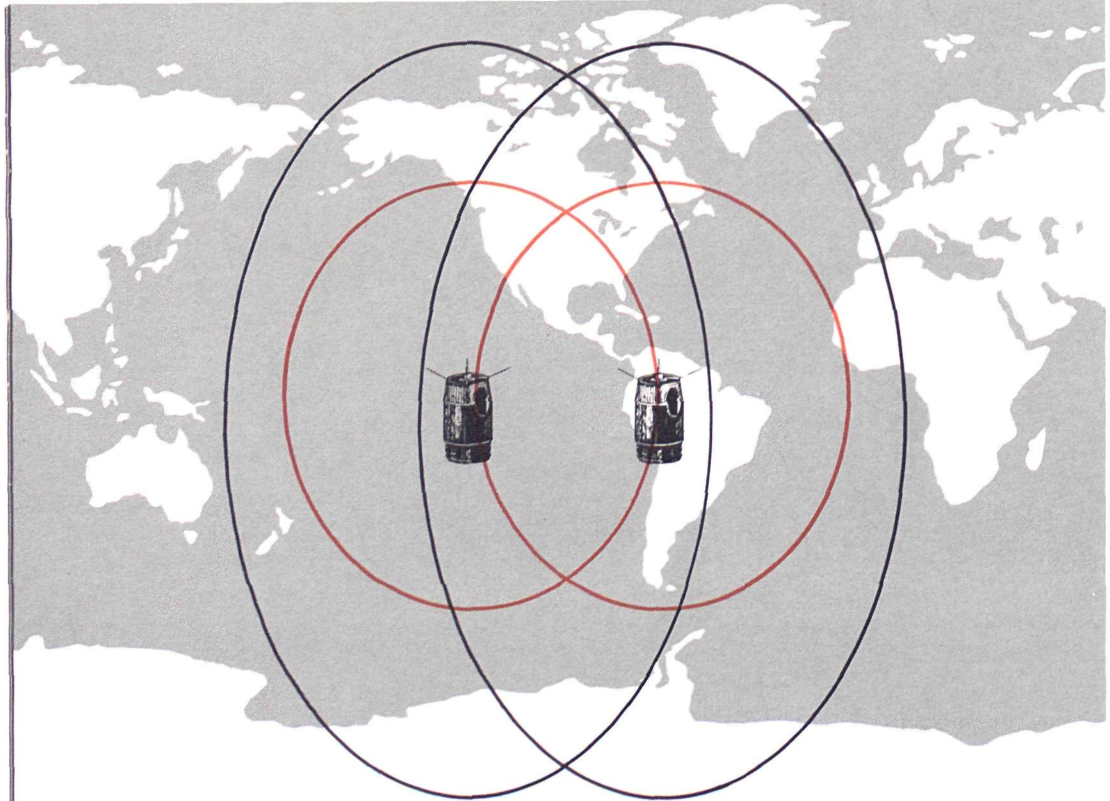
Perhaps more important than cloud-system and windfield data available from the geostationary satellite photographs is the relatively small scale of events which can be continuously watched. It takes 12 hours for the earth to turn far enough to bring a budding storm system back beneath the ITOS cameras for a second view, and most local events—

* Omega is a global navigation system which uses the principle that position can be determined by comparing the phases of very-low-frequency (VLF) signals received from widely separated transmitters. Omega signals received by a platform and relayed to a central point via the satellite are processed to learn the platform's location.





Experiments by the National Environmental Satellite Service include this combination of ATS-3 photographs, the positions of known tornadoes (red dots), and geographic information. The objective here is to determine whether ATS photographs can be used to detect tornado-producing conditions.



Two GOES spacecraft positioned over the equator at 70° and 130° West Longitude cover the Americas and adjacent ocean areas. Red ellipses show high-resolution picture reception areas; black ellipses show communications range. Below, meteorologists at the National Meteorological Center use geostationary satellite photographs to help fill large data gaps over the southern hemisphere.

the ones of such crucial importance to human safety—have formed, done their damage, and decayed long before that time has elapsed.

The ATS cameras, repeating their photographs at about 20-minute intervals, can watch a thunderstorm develop from cumulus clouds, and, possibly, improve the early detection of severe local storms and tornadoes. Attempts to correlate the photographs with tornado occurrences in the central United States have had some promising results, and ATS-3 photographs are now being received routinely in real time at the National Severe Storms Forecast Center, in Kansas City, Mo. Taken with radar, ground, radiosonde, and other observations, these ATS photographs contribute to effective tornado warning operations.

ATS data have also become a routine part of the information available to the National Hurricane Center in Coral Gables, Fla. Used in conjunction with ITOS and other satellite data, and radar and aircraft reconnaissance reports, the geostationary view can improve the warning operation. Hurricane Camille of August 1969 was tracked by ATS-3, a definite factor in there having been a reliable and timely warning for the threatened area of the Gulf coast.

The ATS successes form the technological base from which GOES, the Geostationary Operational Environmental Satellite, will begin. Like its experimental predecessors, GOES will be a spin-stabilized cylinder whose sensors will use the satellite's spin (parallel to the plane of the equator) for horizontal scanning of the earth's disc.

Where present geostationary satellites view the earth only in daylight, GOES will carry a 16-inch aperture telescope for visible and infrared scanning.* This sensor will permit day-and-night, objective determinations of cloud types, temperatures, and heights, and wind fields, using film loop and computerized wind-determining techniques.

GOES will collect and relay data sensed by remotely located environmental observing platforms, including river gages, ocean buoys, ships, and perhaps balloons and aircraft. The satellite will provide communications links for the Pacific Tsunami Warning System, relaying data from ocean-wide networks of seismometers and tide gages to a central facility at NOAA's Honolulu Observatory. The geostationary spacecraft will also be capable of disseminating certain products from the National Meteorological Center and National Environmental Satellite Service using the technique successfully demonstrated with ATS-1 and ATS-3.

* One of the lessons of ATS-3 was that 3-color coverage was not an operational necessity for GOES, but that infrared is.

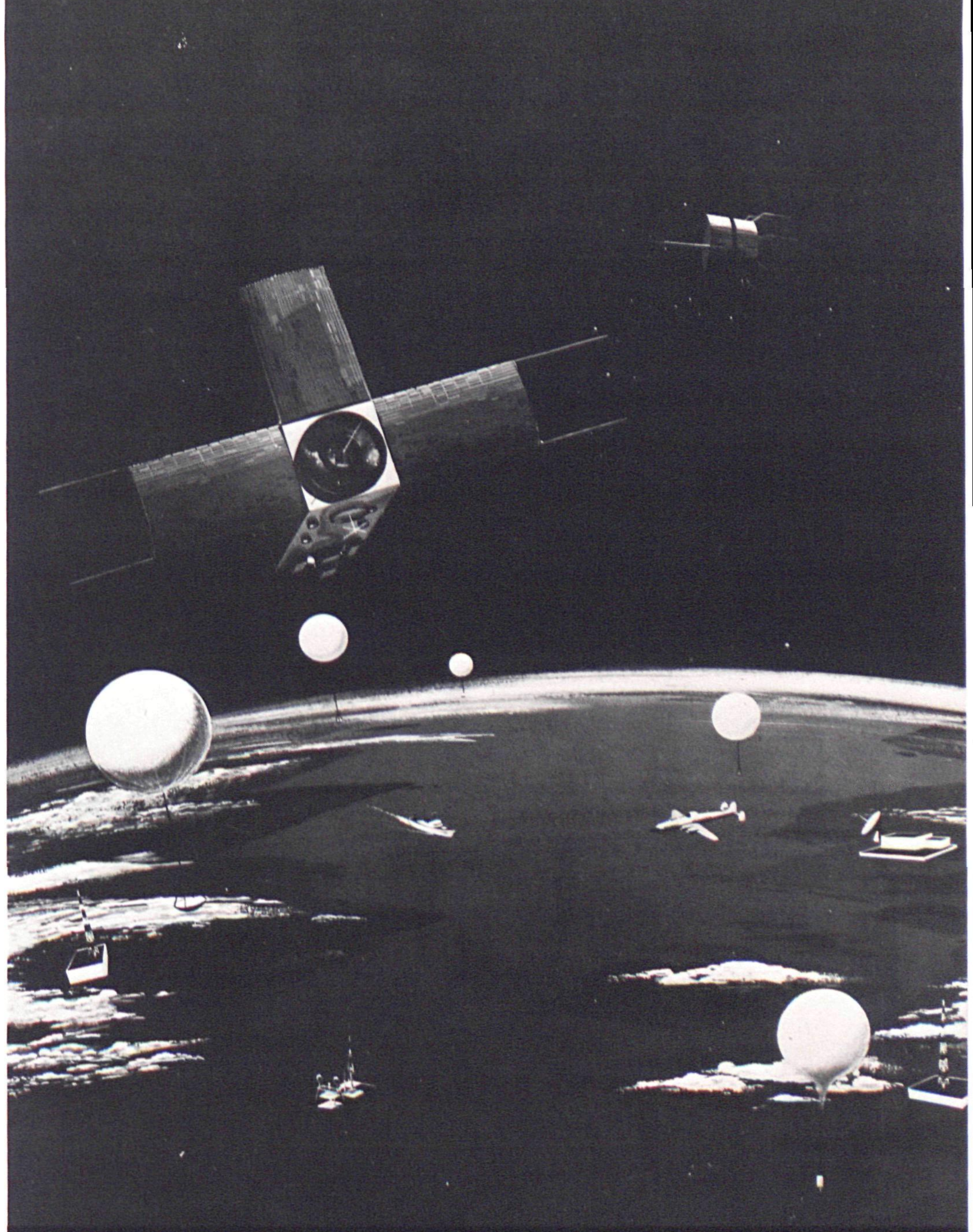
NATIONAL SYSTEM, GLOBAL JOB

During 1972, the first GOES unit will be lofted into a geostationary orbit over the equator at about 100 degrees west longitude, joining the ITOS spacecraft in the national operational environmental satellite system. ITOS will be the polar-orbiting element of this system, providing global imaging and direct readout services, probably with scanning radiometers rather than vidicon cameras, and also providing regular soundings for temperature, humidity, and certain atmospheric constituents. GOES will provide wind and cloud-top data, relay environmental information between distant points, and watch the middle-scale, short-term atmospheric events which enhance or threaten life on our temperate continent. Image data from the GOES will be transmitted to a central command and data acquisition station, then rebroadcast through the satellite to the super APT stations which the 1970s will see.

This single GOES and single ITOS combination represents a minimum national system. In 1973, assuming a long life for the first GOES, a second geostationary unit will be placed in operation. The two spacecraft will be positioned to provide near-continuous coverage of the Pacific, the Americas, and the Atlantic. Between them, these three satellites could provide solid coverage for North America's present and future weather.

But this national system also constitutes the American contribution of satellite technology to the World Weather Program, an intergovernmental research and observation effort under the auspices of the World Meteorological Organization and the International Council of Scientific Unions.

To achieve the full, global capability required for the World Weather Watch and Global Atmospheric Research Program, the GOES-ITOS system must be enhanced by the addition of two more geostationary satellites, so that four satellites 90 degrees apart can completely cover the globe with real-time observations; and by a second polar-orbiting satellite, to reduce the time-span between sets of atmospheric soundings and polar video coverage.

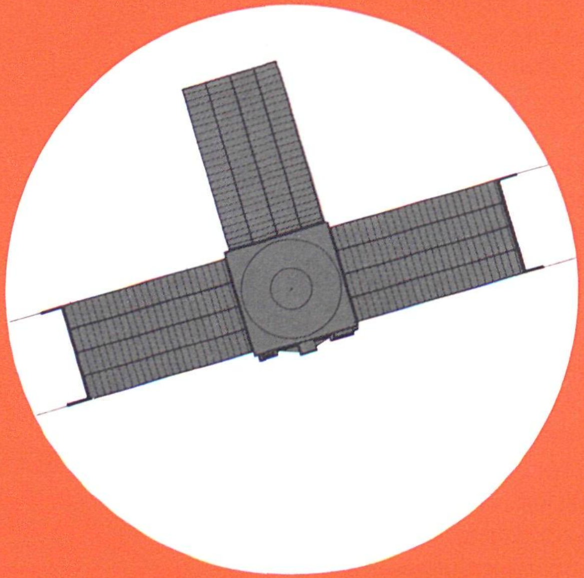


In this illustrator's conception of an evolving global environmental data acquisition system, polar-orbiting and geostationary spacecraft relay their own data, and data from sensors on moving ships, aircraft, free-drifting balloons, and ocean buoys, to centers for use in environmental analysis and predictions.

sounding of the atmosphere—and present and future APT systems represent a kind of shirtsleeve data exchange.

The 1970s will see highly concentrated observation programs made internationally, and very much dependent upon satellite support. There will also be man's most ambitious attempt to comprehend the complex air-sea interaction: TROPEX, the tropical oceanographic and meteorological experiment, will bring together many nations—and many environmental satellites—to explore man's physical environment. It is too large a task for single nations.

This expansion is expected to be a truly cooperative and international undertaking, along the free-exchange lines already a tradition in meteorology. The United States and Soviet Union have exchanged satellite data over direct Washington-Moscow circuits for years, and such free trading of scientific data is becoming more and more the rule, distributing important information not only between major industrial powers but to less-developed nations as well. Certainly everyone linked through the World Meteorological Organization will enjoy the results of the numerical prediction techniques developed around satellite-



The forces which make science and technology converge across national boundaries have also blurred the boundaries between scientific disciplines. Increasingly, the view of meteorologists, oceanographers, aeronomers, geodesists, geologists, seismologists, hydrologists, geomagneticians, marine biologists is an environmental one, linked and interwoven with other disciplines to much the same degree that earth, sun, atmosphere, oceans and oceanic life are linked through interactions.

Satellites have reflected this diffusion of interest, this broadening of viewpoint. Meteorological satellites of the 1960s sensed radiation as well as visible weather. Those of the 1970s measure processes in the solar atmosphere as well as the terrestrial one, in the ocean of water as well as the ocean of air. Soon the technology of environmental satellites will send off another branch, that of earth resources monitoring, and another decade will bring a host of valuable applications which are inconceivably remote today. The only certainties are that the vantage point in space is a good one, getting better, and that our uses of it will multiply and mature.

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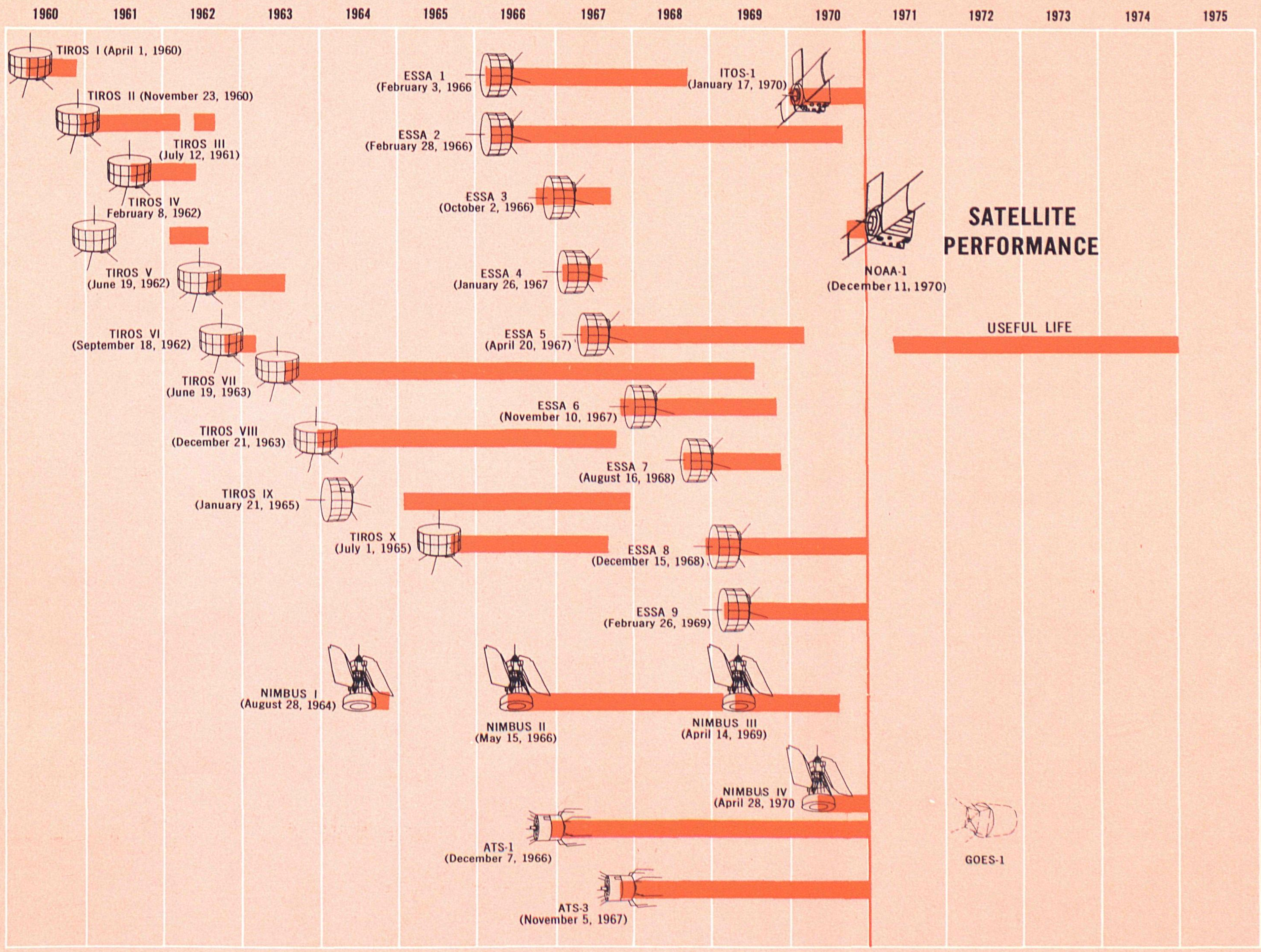

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TIROS I (April 1, 1960)
TIROS II (November 23, 1960)
TIROS III
(July 12, 1961)
TIROS IV
February 8, 1962)
TIROS V
(June 19, 1962)
TIROS VI
(September 18, 1962)
TIROS VII
(June 19, 1963)
TIROS VIII
(December 21, 1963)
TIROS IX
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TIROS X
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ESSA 1
(February 3, 1966
ESSA 2
(February 28, 1966)
ESSA 3
(October 2, 1966)
ESSA 4
(January 26, 1967
ESSA 5
(April 20, 1967)
ESSA 6
(November 10, 1967)
ESSA 7
(August 16, 1968)
ESSA 8
(December 15, 1968)
ESSA 9
(February 26, 1969)
ITOS-1
(January 17, 1970)
SATELLITE
PERFORMANCE
NOAA-1
(December 11, 1970)
USEFUL LIFE
NIMBUS I
(August 28, 1964)
NIMBUS II
(May 15, 1966)
NIMBUS III
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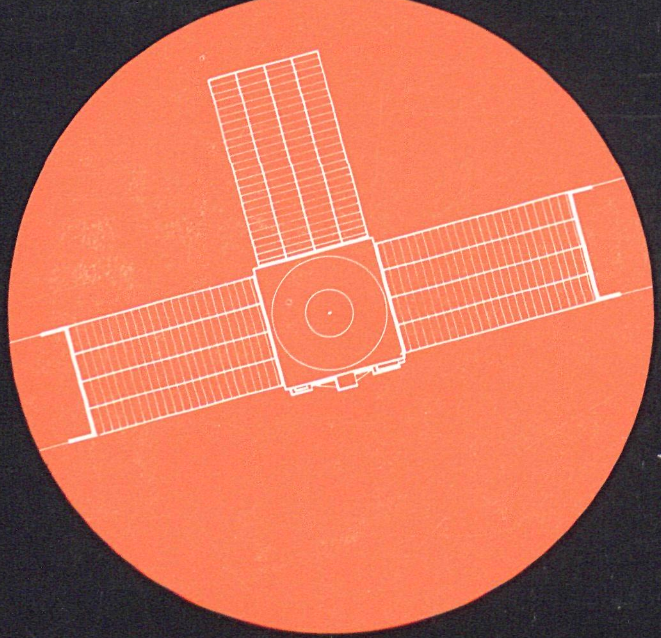
ATS-1
(December 7, 1966)
ATS-3
(November 5, 1967)
GOES-1



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