SP-168 EXPLORING SPACE WITH A CAMERA

SECTION ONE

ABOVE THE ATMOSPHERE

[**2**] A satellite 22 300 miles above the Earth at 95° W longitude photographed the storms both north and south of the equator January 21, 1968. "The color camera worked well," JOSEPH R. BURKE, Applications Technology Satellite Program Manager, reported, "although it had been turned off for about a month to let unexpected gas accumulation leak out. The ground equipment still was being tuned to give a better color balance. Both coasts of both North and South America are visible, and you can glimpse the Great Lakes through the clouds over Canada."

[3] ABOVE THE ATMOSPHERE

NEVER HAS THE STATEMENT "It's a small world" seemed as true as since the advent of the artificial satellite. Less than a century ago circumnavigation of the Earth was measured in years. The steamship shrunk this time to months and then weeks. The aircraft reduced the time for such a journey to days.

The satellite has revolutionized all this. At low altitudes a satellite circles the globe in about 90 minutes, and by sequential passes makes possible detailed observations of the entire Earth and its atmosphere twice a day. From very high altitudes, such as the 22 300-mile geostationary orbit, a satellite can remain ever watchful of the scene below and in uninterrupted communication with nearly half the Earth. Thus man's ability to observe his dynamic environment has for the first time begun to equal his needs.

Meteorology has been one of the first beneficiaries of space flight. The Earth's atmosphere may be likened to a gigantic heat pump, driven by the energy from the Sun and the coriolis forces of the rotating Earth, and throttled by its own gigantic energy exchanges of evaporation and condensation. Weather everywhere is coupled to weather everywhere else, if not today-then tomorrow, or next week, or next month.

This dynamic global character of meteorology demands frequent if not continuous coverage on a global basis if man is to fully

understand his atmospheric environment, predict it well in advance, and someday even influence it. Before the satellite most of the Earth's weather went unobserved since most of the Earth's surface is uninhabited. Today that has changed-thanks to the meteorological satellite.

The photos on the next two pages were taken before a camera could be kept in orbit. Such demonstrations of its usefullness in space prompted the suggestion that the difficulties of recovering films be obviated by placing television cameras on satellites. This was done with Tiros I in 1960, and transmissions from the Tiros satellites have been a mainstay for 8 years now in meteorological research. During the early excitement, Tiros was mentioned in the title of nearly every scientific paper in which information from it was used. Now the availability of such data is assumed.

Operational meteorologists, meanwhile, have expressed ever more strongly their desire for quantitative measurements such as the early researchers needed. The use of radiometers to take measurements in both visible and infrared regions has become routine.

To receive the first satellite telemetry carrying cloud picture data, multimillion-dollar command and data acquisition stations were needed. Sending it on to local forecasters via landlines or radio often delayed and degraded the quality of the pictures. Placing an Automatic Picture Transmission System on satellites has removed this difficulty. With relatively inexpensive receiving equipment, any station within the line of sight from a satellite that is automatically transmitting pictures now can receive a picture directly within 3 minutes of the time it was taken.

Addition of color channels to a camera of the Applications Technology Satellite (ATS) type has made it possible to obtain views such as the one on the opposite page and the frontispiece of this book. With ATS-III, color pictures can be taken every 21 minutes. When taken throughout a day, researchers can study both cloud motions over the entire disk and color changes in the day-to-night terminator as it moves across the Earth. These color changes are expected to be helpful in determining heights of clouds and possibly other matters of interest to meteorologists. The timemotion study of weather dynamics made possible by such synchronous satellites as ATS-III may add a new dimension to our understanding of atmospheric processes.

[4] Prelude to Progress

Cameras carried on sounding rockets and missiles first demonstrated the value of high-altitude photography in meteorology. These pictures were recovered from film packs carried aloft. They stimulated the development and employment of equipment to televise views obtainable from satellites to stations on Earth. The photo below was taken from a development flight of a missile high over the Atlantic Ocean on August 24, 1959.

GEN. DONALD N. YATES, who commanded the Air Force Missile Test Center in the 1950's, recalls that: "A 16-mm motion picture camera was placed on the stabilization system during an Atlas flight. This photograph was taken early in the flight, showing the booster separating from the nose cone [below], with the Earth's horizon reflected from its polished surface."

From less comprehensive pictures than the one on this page, ...

....mosaics such as those on the next page were put together. The upper one consists of photos taken in 1954 by an Aerobee sounding rocket that was launched from White Sands, N. Mex.

LESTER F. HUBERT, of the National Environmental Satellite Center, remembers it well: "The spiral cloud pattern in the upper left center was produced by a tropical disturbance that had moved over Texas from the Gulf of Mexico. Decreasing in intensity, it did not disturb the surface winds, but maintained a tight cyclonic circulation in the upper atmosphere. At a glance, this picture documented a flood-producing circulation that was undetected by routine means after moving over Texas.

"Photography from rockets stimulated the meteorological satellite program, but no previous picture had been as dramatic as this, nor as convincing that satellite surveillance of hurricanes was feasible. Here was the first demonstration that storms could be detected by ultra-high-level photographs (since borne out by thousands of satellite pictures).

"This mosaic was constructed by Otto Berg, who was in charge of the Naval Research Laboratory's rocket photography."

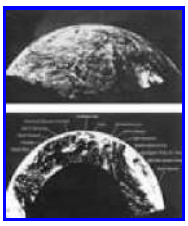
The lower picture on the next page was a further demonstration of the potentialities of space technology. GEN. BERNARD A. SCHRIEVER, USAF (Ret.), explains how it was obtained:

"Taken from an altitude of 700 miles, this panoramic photograph was an early spectacular achievement of our space effort. It shows an Earth segment from North America through the Caribbean to the coast of Africa, including massive storm fronts over the Atlantic Ocean and the Tropics.

"The panorama was constructed from motion pictures taken by a 16-mm camera carried on the Mark 2 reentry vehicle of our Atlas IIC R&D flight of August 24, 1959. This flight was one of a series in which we experimentally stabilized the reentry vehicle with an infrared horizontal stabilization system. The camera was in the capsule that was ejected from the reentry vehicle and recovered."

---

[5]



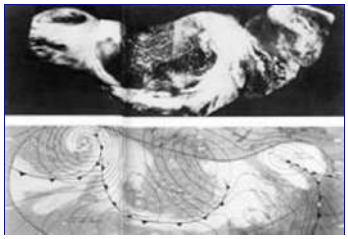
[6-7] The Clouds Draw a Map

The first Tiros (Television infrared Observational Satellite) began observations on April 1, 1960, that have figured prominently in meteorological progress ever since. It transmitted 22 592 pictures to Earth during its 1302 revolutions. The mosaic at the right illustrates the way many of those pictures were assembled and used.

From the very first, says MORRIS TEPPER, Deputy Director, Space Applications Program, NASA, "pictures taken by the Tiros satellites showed that the Earth's cloud cover was highly organized on a global scale. Coherent cloud systems were found to extend over thousands of miles and were related to other systems of similar dimensions. Moreover, it was soon readily apparent that these cloud patterns were in fact 'signatures' of weather systems.

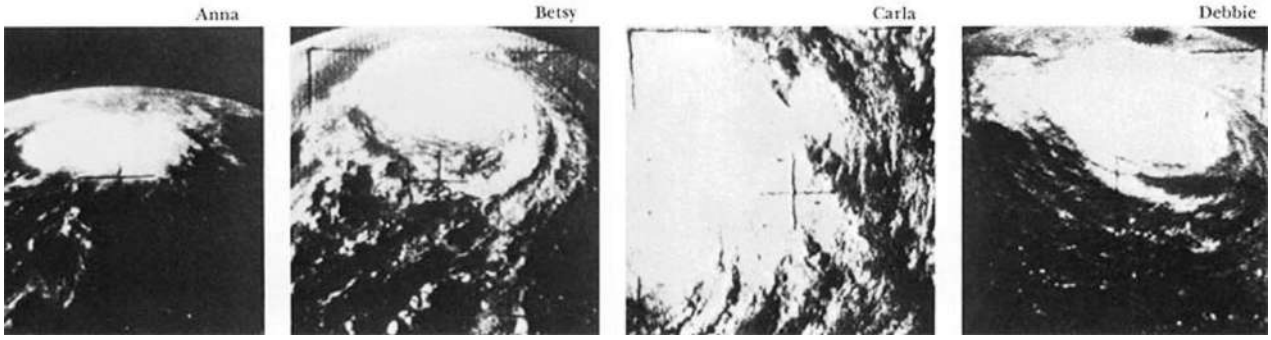
"The upper portion of the figure is a mosaic of overlapping video pictures taken by Tiros I on May 19 and 20, 1960. Below it is the associated weather map showing three active storm systems: from left to right, a very intense one in the North Pacific, one on the west coast of the United States, and one in the Midwest. The cloud structure as seen by Tiros has been superimposed on the weather map. It is remarkable how closely the cloud systems delineate the weather systems. It is as if Nature were actually drawing her own weather map directly onto the Earth."

Many more such mosaics were produced as the Tiros flights continued. The most significant milestone passed in these flights, says ROBERT M. RADOS, NASA's Tiros Project Manager, was "to demonstrate the feasibility of an operational meteorological satellite system and its application to regular worldwide weather analysis and forecasts, aimed toward increasing man's ability to understand and cope with his physical environment."



TIROS I

[8] A Satellite Discovers a Hurricane . . . and Begins to Save Lives



TIROS III

"Sometimes," William Shakespeare noted, "we see a cloud that's dragonish"-but not always soon enough from Earth's surface. Hurricanes emerge from large bodies of warm, moist air near the equator, vary their courses, and differ in ferocity. Tiros III photographed 1961's first five hurricanes from an altitude of more than 400 miles-and that's how Esther, the big one on the next page, was discovered.

S. FRED SINGER, Deputy Assistant Secretary for Scientific Programs, Department of the interior, provided this account of the hurricanes pictured below and the dragonish sight on the facing page:

"Esther was the first hurricane to be discovered by a satellite, but Tiros III also took valuable pictures of Anna, Betsy, Carla, and Debbie in 1961. In all cases, the Tiros pictures provided important supplements to reconnaissance aircraft observations and to data obtained by ground-based observations, by fixing the position of the hurricane center and showing the extent of the spiral cloud bands.

"The photographs here were selected to show all of the hurricanes at the stage of their maximum development; their organization in spiral patterns can be seen very clearly. It has now become possible to deduce the strength of the hurricane winds from the degree of organization seen in satellite pictures.

"Hurricane Anna went into the southern Caribbean and hit Central America.

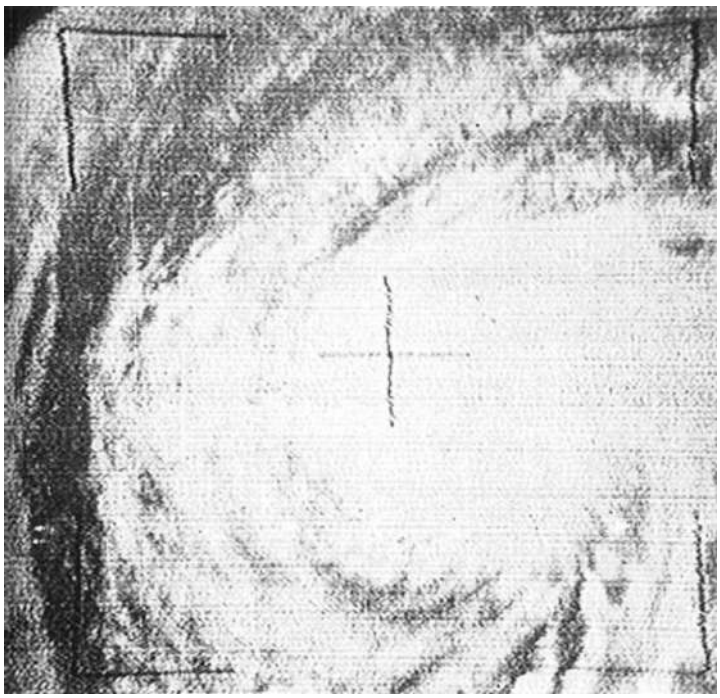
"Betsy, on the other hand, never was a threat to land areas and apparently caused no damage to shipping.

"While Betsy was developing in the Atlantic, however, Carla-a giant hurricane-was discovered some 300 miles north of Panama. It eventually turned out to be one of the most destructive hurricanes in recent history, causing 46 fatalities in the gulf coast region and over $300 million property damage in Texas and Louisiana. More than 300 000 people were evacuated from the gulf coast.

"Debbie never hit North America, but curved back and caused deaths and heavy damage on the western coasts of Ireland and Scotland.

"Esther will be assured a place in meteorological history. She was the first hurricane to be discovered by satellite, moved in a complex loop off the east coast of the United States, threatening New England, and was the guinea pig for a seeding experiment with silver iodide."

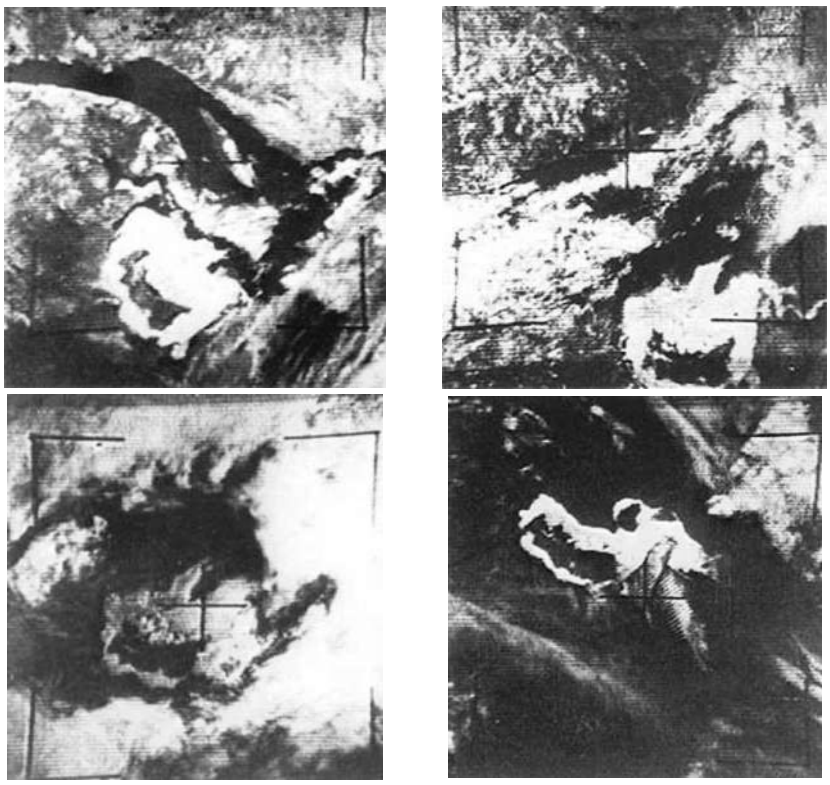
[9]



Esther

TIROS III

[10-11] Ice Is Tracked



TIROS IV

Four photos at the tops of these pages [above] showed satellites can alert seamen to ice as well as to storms. J. R. H. NOBLE, Director, Meteorological Branch, Department of Transport, Canada, pointed out the significance of these photographs:

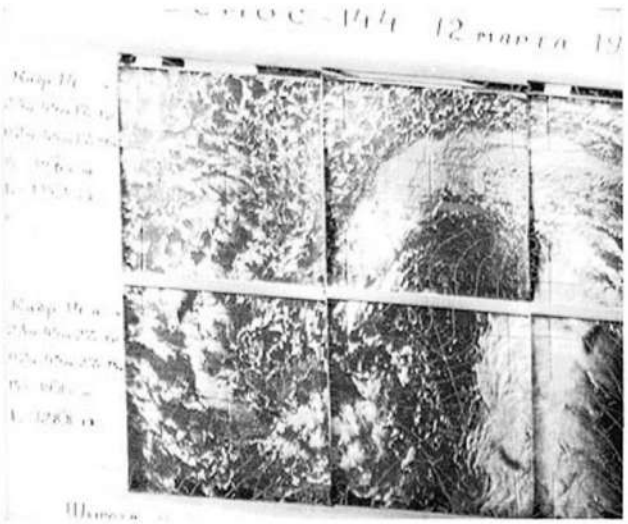
"Cameras of Tiros IV focus on the Gulf of St. Lawrence. The river estuary and northern portion of the gulf contrast sharply with the dull gray of land. The ice retreating southward shows brilliantly white, and clouds are reproduced in a variety of shades. In the first picture the icepack surrounds Prince Edward island, stretching toward the Magdalens with ice tongues from Chaleur Bay and southward from the Strait of Belle isle. Following the sequence through April 12, the main pack is gradually driven southeastward. On the last day, ice areas appreciably decrease with the drift past Cape Breton Island. An interesting feature is the amount of ice held back by Cape Breton and Magdalen islands. Information from visual sorties for ice reconnaissance along the ice edges confirmed to a remarkable degree the results from the satellite; thus space technology now assists mariners."

....and a Cold Line Opens

ARNOLD FRUTKIN, Assistant Administrator for international Affairs, NASA, reports regarding the picture at the right [below]:

"In June 1962 representatives of NASA and of the Academy of Sciences of the U.S.S.R. agreed upon a cooperative meteorological program. The two sides were to develop first experimental and then operational meteorological satellites capable of photographing the Earth's cloud cover. They were to establish a conventional high-capacity communications link between Washington and Moscow, dividing the cost, to exchange cloud photographs obtained by their respective satellites, together with analysis of cloud information.

"By November 1964, the communications link called the 'cold line' had been established. As 1967 drew to a close, the link had been used to exchange conventional weather data and a few satellite cloudcover photographs per day. It must, therefore, be regarded as in the earliest experimental stage. The accompanying photograph is an example of the cloud-cover photographs provided by the Soviet Union over the 'cold line.'"



TIROS IV - COSMOS CXLIV

[12] 480 Pictures in 24 Hours Girdle the Globe

"Tiros IX provided this dramatic 'first' complete view of the world's weather," according to ROBERT M. WHITE, Administrator, Environmental Science Services Administration. "As Tiros IX circled the Earth once every 2 hours in its polar orbit, its 2 television cameras obtained 40 pictures on the Sun-illuminated side of the Earth. Once each orbit the picture signals were received by radio at ground stations in Alaska and Virginia and immediately relayed to Washington, D.C., where the signals were converted into picture form. After circling the Earth 12 times during the 24-hour period of February 13, 1965, all of the Sun-illuminated portion of the Earth had come within the field of view of the cameras aboard the satellite. The 480 pictures taken during this period were then placed together to produce this bird's-eye view of the world's cloud systems.

"A tropical storm can be seen over Ceylon and the southern tip of India, and another is over the south Indian Ocean. In the lower right, a storm is [**13**] approaching the southern coast of Australia; this storm had moved approximately 500 miles to the east 24 hours later, as seen in the pictures of the same area at the left of the mosaic. The thin band of clouds extending from central North Africa across the Red Sea to Saudi Arabia indicates the location of the jet stream in this part of the world, a strong current of air moving from west to east high above the Earth's surface. The remnants of an old storm are indicated by the comma-shaped cloud array over the North Atlantic Ocean.

"A strong weather front is depicted by the clouds extending across the southeastern United States; another storm is moving into the northwestern United States from Canada.

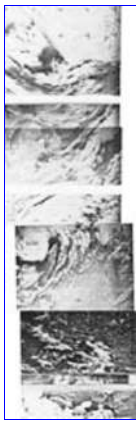
"The importance of this picture lies in the fact that it provides the meteorologist with weather information over the entire Earth, whereas conventional observations before satellites provided information on less than 20 percent of the Earth's atmosphere. This global observing capability of space platforms, and the rapid development of space technology, has led to the establishment by the United States of the world's first operational weather satellite system, which is now providing similar pictures of the world's weather every day."

TIROS IX

[14] Latest Pictures Are Broadcast

Automatic Picture Transmission (called APT) that was flown on Nimbus I reduced the time required and the cost of getting photographic information from a satellite to local weather forecasters. The four pictures at the right were received at Wallops Island, Va.

F. W. REICHELDERFER, former Chief of the U.S. Weather Bureau, wrote of them: "In this four-frame sequence, Nimbus I reveals many things about the weather in a 900-mile swath from Venezuela to the Canadian Arctic as viewed on August 29, 1964, from orbit approximately 550 statute miles from Earth. Through APT, the local or regional weather forecaster receives pictures of the cloud arrays as the satellite passes overhead. APT receivers are fairly simple and inexpensive.



NIMBUS I

"The two top pictures show clouds typical of systems of fronts. In mid-latitudes and the subarctic, warm fronts produce cloud 'decks' of cirrostratus and altostratus. Cold fronts produce convective cumulus and line-squall cumulonimbus. Intermediate frontal forms give the complex combinations of cloud forms and arrays seen in the pictures-their orientations and shapes being indicative of different wind currents, etc.

"The third picture looks down upon historic Hurricane Cleo over South Carolina and Georgia. The characteristic spiral bands of clouds first seen in full by rocket and satellite photos make it easy for satellites to discover tropical cyclones far at sea outside the usual networks of ship reports.

"In the fourth picture the many cumulus 'streets' often found in the trade winds can be seen; also southward are the cloud masses of an intertropical convergence zone.

"Perhaps most promising for future weather analysis and forecasting is the increasing study of clouds and their arrays as symptoms' and thus diagnostic means for identifying atmospheric dynamic systems which make the weather."

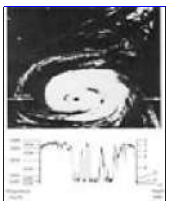
[15] In-Depth Research

"As Hurricane Gladys neared the southeast coast of the United States (66.5° W, 25.5° N), the high-resolution infrared radiometer (HRIR) scanning system aboard the Nimbus satellite acquired the facsimile at the left [below] of the clouds of the hurricane and the surrounding water masses," according to WILLIAM G. STROUD, of the Goddard Space Flight Center, NASA.

"At the time, Gladys was a fully mature hurricane about 450 miles in diameter. Winds were about 125 mph near the center, with hurricane winds extending 115 miles northward and 85 miles southward. Nimbus I tracked Gladys through its 12-day life as a hurricane.

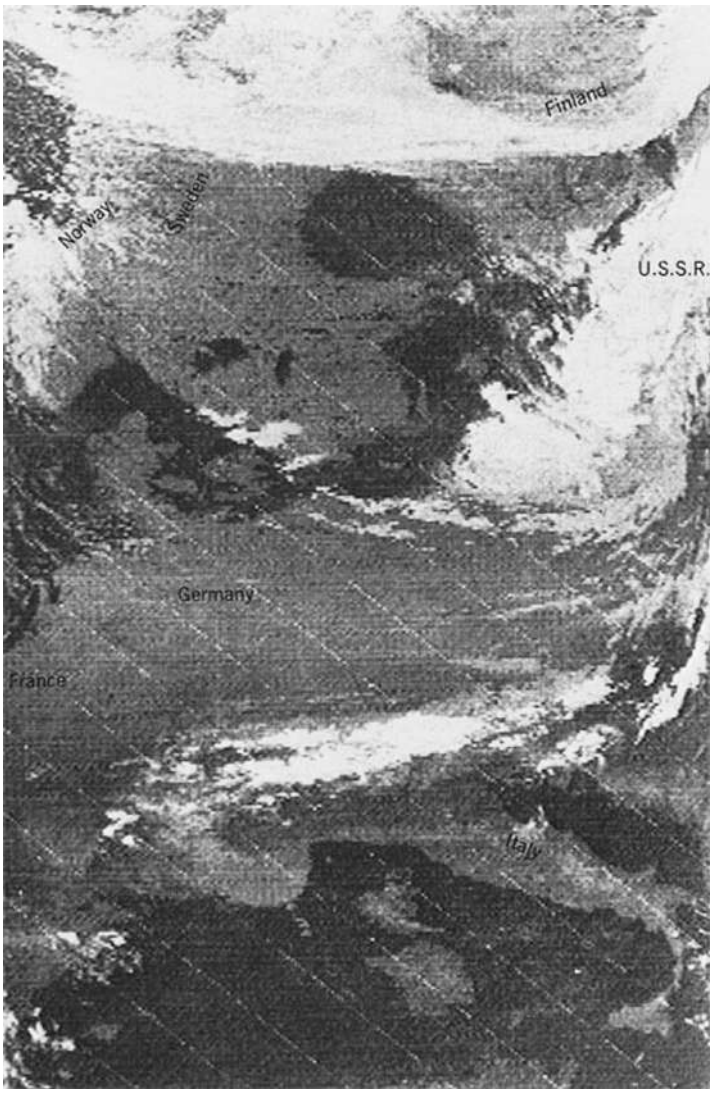
"The HRIR aboard Nimbus I and II senses radiation from the land, water, and cloud surfaces in the 3.6- to 4.2-micron region of the spectrum. The shades of gray are proportional to the blackbody temperature of the radiating surfaces: the white areas are the tops of the clouds and the coldest areas; the black areas are the surface of the sea, and warmest.

"Below the picture a single scan line passing through the center of the hurricane is displayed. On the left is the nonlinear equivalent-blackbody temperature scale. The scan line is from horizon to horizon, about 5000 km along the surface of the Earth, highly distorted at the edges. At the western (left) horizon the temperatures rise sharply from 210° K of the sky to 290° to 300° K, the approximate sea-surface temperatures. The temperatures at the cloud tops are as low as 210° to 220° K, and the observed temperatures in the eye of Gladys are about 290° K. These temperatures are converted to height above sea level by equating- them to actual temperatures measured by sounding balloons in the vicinity of the storm, as shown on the right. The 290°-K temperature over the eye of the hurricane corresponds to a height of about 2 km; the radiometer probably did not see the surface of the sea through the eye because of the usual high-level, thin, cirrus clouds covering the eye. The main cloud tops were at a height of about 12 km."



NIMBUS I

[16] Night Temperatures and Clouds



NIMBUS I

Nimbus I began a second generation of meteorological satellites in 1964. The Tiros satellites each had two cameras; Nimbus had three. It also bore other advanced equipment to be tested for use in future weather-satellite systems Since the clouds are "birds that never sleep," the equipment included devices for collecting information about them over dark as well as sunlit areas of the Earth.

SIGMUND FRITZ, Director of the Meteorological Satellite Laboratory of the Environmental Science Services Administration, noted that the picture at the left illustrated one of the additional services to his profession provided by Nimbus I He writes:

"This picture was made from quantitative measurements taken with the Nimbus I high-resolution infrared radiometer on September 12, 1964, at 2340 GMT. The area extends from Scandinavia through Italy to the Tunisian coast. In the picture, dark areas represent warm sources, and bright areas de note cold sources. Thus the colder land areas appear brighter than the surrounding water. More over, the very bright areas represent cold cloud-top systems whose heights can be estimated from the measurements.

"The meteorological situation can be to a certain extent deduced from the picture. The cloudless area over northwestern Europe was associated with an extensive high-pressure area. The clouds were mainly associated with low-pressure areas and frontal systems. Thus these Nimbus data can locate significant cloud systems at night, give insight into meteorological situations, and aid in estimating the heights of cloud tops."

NIMBUS II

"This is a Nimbus II high-resolution infrared radiometer picture taken near local midnight on October 7, 1966, HARRY PRESS, Nimbus Project Manager, Goddard Space Flight Center, NASA, says of the picture on this page. "It covers a wide swath from 15° N to 50° N over the eastern United States and Caribbean.

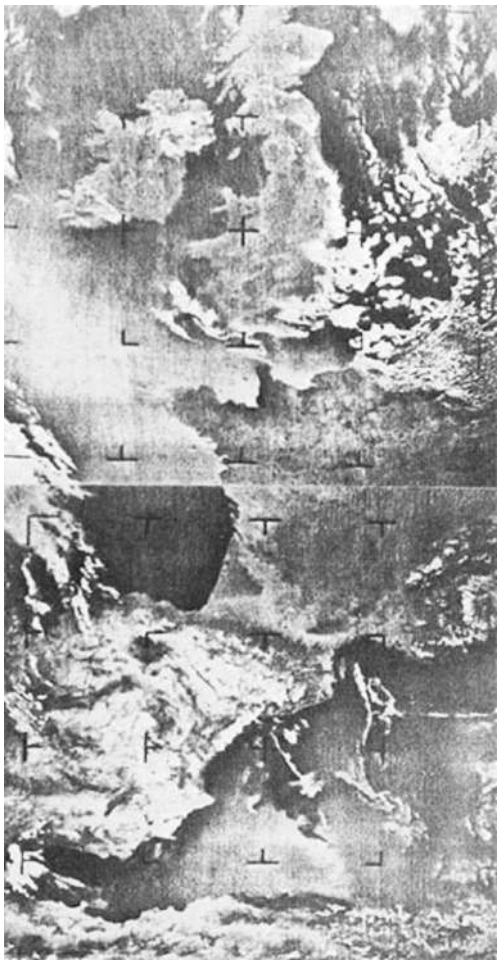
"The spiraling cloud mass at the bottom is Hurricane Inez whose center was located just north of the Yucatan Peninsula. The Great Lakes are visible at the top of the picture. Clearly distinguishable is the eastern coast of the United States from Maine to Georgia.

"Temperatures measured by the infrared scanner are converted to shades of gray, from white to black: the white being the coldest and the black the warmest temperatures measured. Grid points are at every two degrees of latitude and longitude.

"The white band of clouds off the east coast is associated with a cold front over the Atlantic. Noticeable are the colder water temperatures near the coast north of Cape Hatteras. The ocean here appears lighter (colder) than the dark (warmer) clear areas in the Caribbean and south of Cape Hatteras. The warmer temperatures south of Cape Hatteras and near the frontal cloud band outline the warm waters of the Gulf Stream."

---

[18] Europe Tunes In



NIMBUS I

In Lannion, France, on August 31, 1964, meteorologists received the pictures at the left from a passing Nimbus, showing western Europe from Scotland south to the Mediterranean.

JEAN BESSEMOULIN, Chief Engineer of Meteorology for the French General Secretariat of Civil Aviation, wrote of this display:

"On this assemblage of two successive photographs taken by satellite Nimbus I during its 46th orbit, France appears in the center exceptionally well, due to a sky almost completely devoid of clouds. The mirrored reflection of the Sun on the Atlantic and on the English Channel accentuates the clearness of the coastal outline of Brittany and Normandy. The Alps and the Pyrenees show some snow-covered peaks. In the southwest is an outline of the triangle of the forest of Landes. The British isles also enjoy a generally clear sky, with the exception of tumulus clouds visible particularly on the south coast and on the coast east of England.

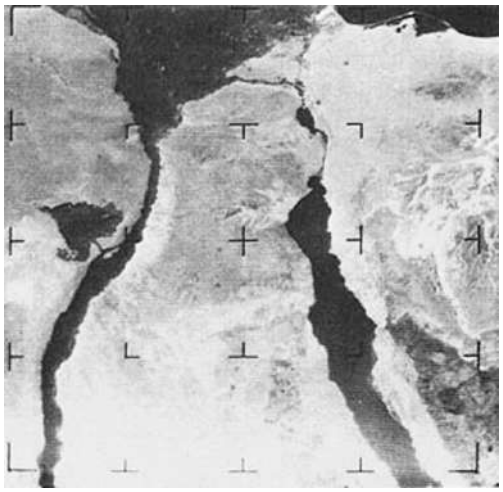
"In the Mediterranean, the Balearic islands, Corsica, and Sardinia are marked by clouds of diurnal evolution. And finally, to the northwest of the Iberian Peninsula, appear stratified cloud formations, in connection with perturbances located on the open sea in the Atlantic.

"The Lannion Center of Meteorological Space Studies exploits constantly this type of photograph, from which it establishes maps of cloud formations which are disseminated to meteorological centers on national and international channels."

[**19**] CHARLES J. ROBINOVE, of the U.S. Geological Survey, commented as follows on the picture at upper right:

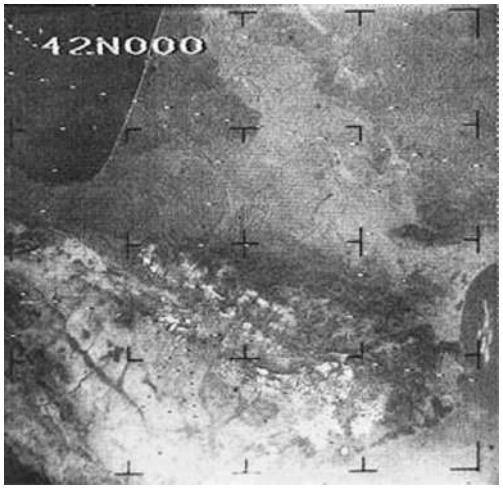
"The lower Nile-Sinai Peninsula picture taken by the Advanced Vidicon Camera System (AVCS) shows the open water and irrigated areas (dark), and the rocky and sandy desert (white and gray), and some of the high-contrast drainage patterns. Terrain features of high contrast show well in the picture, but low-contrast features do not. The dark area at left center is the El Faiyum depression, in which crops are irrigated by water diverted through canals from the Nile River. Although the AVCS camera is designed for meteorological use, striking and useful pictures of the Earth's surface have been taken of cloud-free areas. The ability of such space acquired imagery to portray large areas of the Earth's surface at a single instant of time is of great advantage to the Earth scientist in assessing and mapping large regional features and their relationships."

.



AVCS

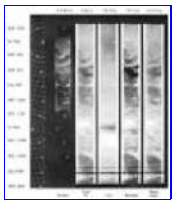
The lower photo here is a high-resolution picture of part of the same area shown on page 18 in lower resolution. STANLEY WEILAND, Nimbus Observatory Systems Manager, Goddard Space Flight Center, NASA, points out how much it encompassed: "The photograph comprises an area of about 41600 nautical square miles from a height of 409 miles. The Pyrenees show as a dark area across the center. Mountains usually show darker than lowlands because of their thicker vegetation cover and basalt rocks Another group of mountains, the Montagne Noire, appear as a dark tongue near the center right edge. The valleys of the Ebro River and its tributaries in western Spain (lower left quadrant) are a good example of a flood plain. Also evident because of its dark soil is the Grande Landes, an alluvial rich-humus flood plain in southwestern France (upper left quadrant). The course of the Garonne River can be traced to the junction with its tributary the Grou River, just north of Toulouse (center and upper right quadrant)."



AVCS

---

[20] More Than Men See



NIMBUS II

Multispectral imaging can tell scientists more about the cocoon of air around the Earth than human eyes can see. It is simply a matter of combining observations made with instruments that respond to different wavelengths in the electromagnetic spectrum - a technique nicely illustrated here.

WILLIAM NORDBERG of the Goddard Space Flight Center, NASA, explains this figure this way:

"Pictorial presentations of radiation emitted and reflected by the Earth and the atmosphere in various spectral bands have radically improved our capability to observe meteorological features from satellites. When interpreted quantitatively, these measurements lead to the description of the telluric temperature, cloud, and moisture fields. Results shown here were obtained with Nimbus 11 on May 17, 1966.

"Measurements were made in the five spectral regions of: total redected solar radiation (0.2 to 4.0 microns), total emitted thermal radiation (5 to 30 microns), CO_2 absorption (14 to 16 microns), the atmospheric "window" (10 to 11 microns), and water vapor absorption (6.4 to 6.9 microns) as Nimbus II passed from the south-central United States (bottom) over the Pacific, Antarctica, the Indian Ocean (center), India, and Siberia to North America. "The radiative energy balance can be determined from the difference between the first two channels. The CO: channel maps out the temperature field in the lower stratosphere, the water-vapor channel gives the moisture content in the upper troposphere, and the window channel shows Earth-surface temperatures and cloud heights. The hot surface, and moisture-laden atmosphere, of India are obvious in the picture (upper third). in emission, low-radiation intensities (cold, cloudy, or moist) are shown light; high-radiation intensities (warm, clear, dry) are dark. The reverse is depicted by reflection (0.2 to 4.0 microns)."

[21] The Curls in Clouds

For poets the clouds have long been "a volume full of wisdom." Now it is easier to read. The curls at the right [below] are an example of the details of the turbulent atmosphere that formerly eluded the eyes of both artists and scientists.

GUENTER WARNECKE, of the Planetary Radiation Branch of the Goddard Space Flight Center, NASA, points out:

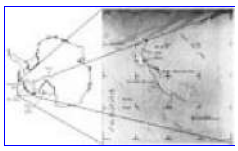
"This picture is a mosaic of photographs taken by Nimbus II off the west coast of North Africa at noontime on July 16, 1966. The Moroccan coast is recognizable under clear sky conditions; Cape Blanco is the prominent landmark in the lower section of the mosaic. The bright pattern exhibits a low-level cloud system embedded in the stable and permanent north-northeasterly air flow of the trade-wind regime of the subtropical Atlantic Ocean.

"The appearance of vortex structures within the cloud deck was not visually observed in the atmosphere before satellites became an observational tool, as these vortex patterns are too large to be observed from the surface and too small to be resolved in conventional weather maps.

"The northernmost series of the vortices is of outstanding regularity over a distance of more than 400 miles and reflects the apparent existence of a Karman vortex street underneath the cloud level in the wake of the 6100-foot-high obstacle of the island of Madeira. Farther south the irregular group of the Canary Islands creates a more complicated assembly of curls and horizontal wavelike structures reflecting the superposition of Karman-type vortex streets and gravity waves induced on the low-level trade-wind inversion by the mountainous islands."

NIMBUS II

[22] Help for Cartographers



NIMBUS I

RICHARD L. HALEY, Nimbus Program Manager, Space Applications, NASA, wrote of this picture taken September 9, 1964, from high over Antarctica: "In addition to the use of Nimbus data for meteorological purposes, the data have been utilized in such

scientific disciplines as glaciology, geology, and oceanography.

"For example, here is a Nimbus I Advanced Video Camera System (AVCS) picture taken as the satellite passed 950 kilometers above the ice-covered Antarctic Continent. The picture covers an area 530 by 530 kilometers approximately in the Marie Byrd Land and Ellsworth Highland region.

"Just to the left of center is the Getz Ice Shelf. The dark areas delineating the coast are probably due to pressure ripples and faults in the ice which attenuate the reflectivity of the surface. Cirrus cloud bands and their associated shadows produce the .striations at the top of the picture.

"The Nimbus pictures have been extremely valuable in the mapping of the little-known Antarctic Continent. This and other pictures aided cartographers to relocate Mount Siple correctly 2° farther west on their maps. Mount Siple is visible as a gray-white spot just above the Getz Ice Shelf. Other mountain ranges in Antarctica were correctly relocated, and the configuration of the ice fronts in the Filchner Ice Shelf, Weddell Sea, and Princess Martha Coast areas were determined more accurately and completely than ever before."

[23] Every Day's Weather Everywhere Becomes a Matter of Record

DAVID S. JOHNSON, Director of the National Environmental Satellite Center of the Environmental Science Services Administration, explains this picture's significance:

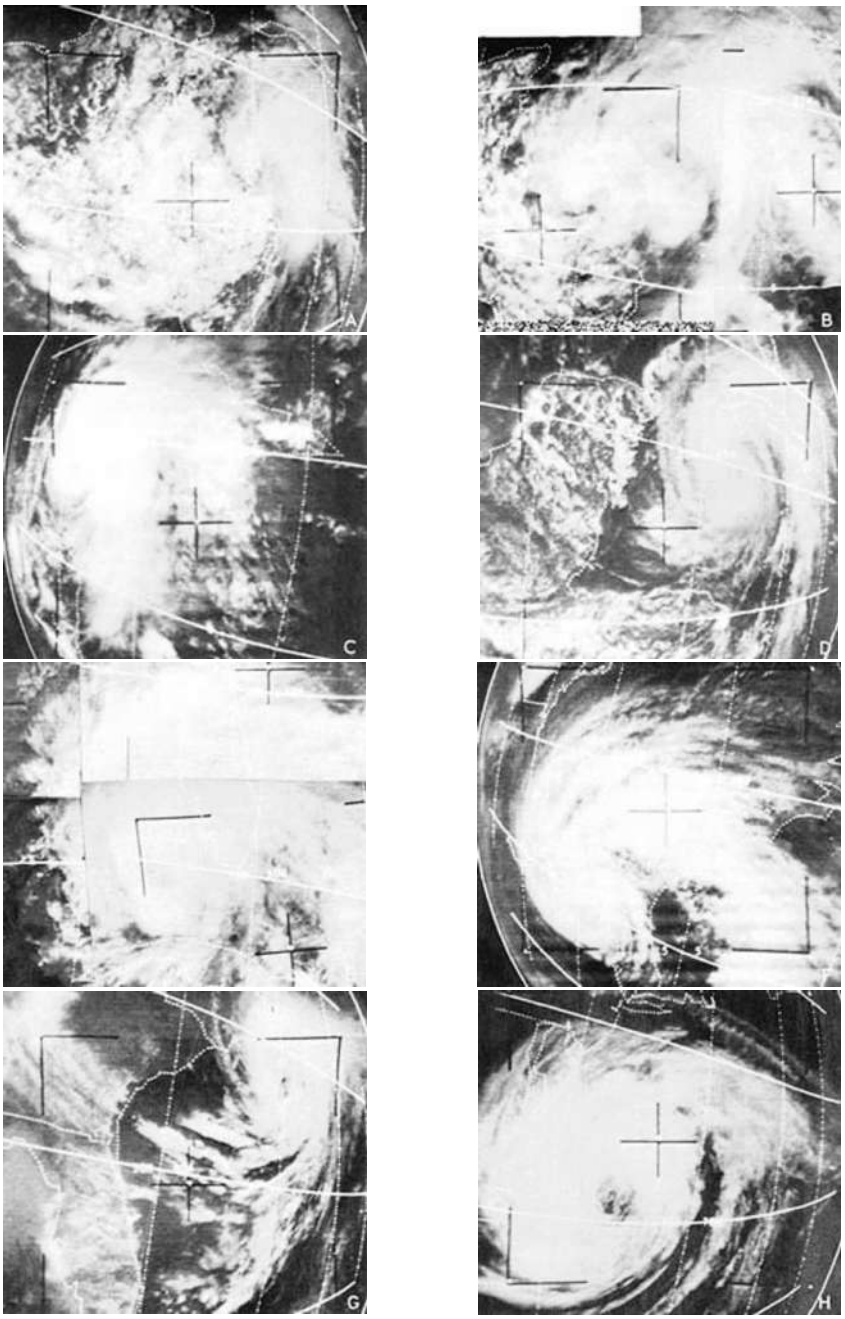
"This satellite view of Europe and North Africa obtained by ESSA I from 478 miles above the Earth's surface represents in capsule form the culmination of 6 years of space development by the United States, resulting in the establishment of the world's first operational weather satellite system. Here the meteorologist has a picture of weather conditions over an entire continent, plus sizable portions of two others. Conditions ranging from snow-covered Scandinavia and ice-covered Gulf of Bothnia in the north to the cloud-free area of North Africa are discernible at a glance. The exact location of a low-pressure center over Denmark is unmistakably outlined by its characteristic circular array of clouds.

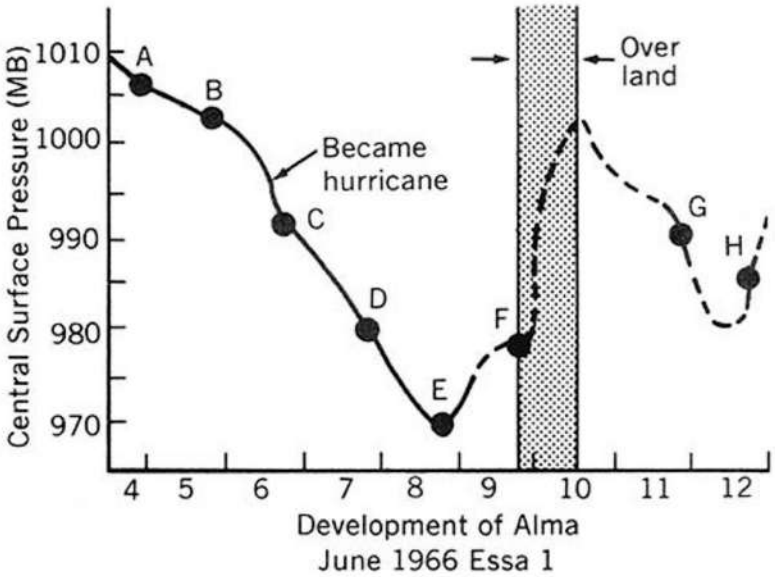
"The value of this mosaic is intrinsically great. On the day it was taken. March 1, 1966, it was used for pinpointing various meteorological features today it, and thousands of similar pictures, are used by scientists in studying the Earth's atmosphere to increase man's ability to forecast the weather.

"The not-so-obvious value lies in the knowledge that this same area, indeed the entire Earth, was photographed the clay before these pictures were taken, was photographed on all the succeeding clays, and will continue to be photographed every clay in the future. This is the essence of an operational weather satellite system: observation of the entire Earth reliably and regularly, day in and clay out, for the benefit of man."

ESSA I

[24-25] Alma's 9-Day Whirl


A
B
C
D
G
H


Central Surface Pressure (MB)
1010
1000
990
980
970
A
B
C
D
E
F
G
H
Became hurricane
Over land
4
5
6
7
8
9
10
11
12
Development of Alma
June 1966 Essa 1

ESSA I

ESSA I photographed Hurricane Alma while she was at sea, shortly after noon each day from June 4 to 12, 1966, for meteorologists to chart her pressure.

L. F. HUBERT of the National Environmental Satellite Center captioned these photos: "A grid of latitude-longitude lines at 5° intervals and dotted coastlines show that the storm became a hurricane just east of Central America and moved northward across Florida. The cloud masses in photos A and B reveal the intensification of a tropical storm in the Caribbean; C through H display patterns that are typical of mature hurricanes. These vast whirlpools of air are characterized by a calm, low-pressure eye which is clearly seen as a dark hole in the clouds in G and H.

"Hurricane intensity is inversely proportional to its central pressure; the graph illustrates the fluctuating pressure of Alma. Photo C was taken a few hours after Alma had reached hurricane intensity; the windspeed was 75 knots. On June 9, photo E, [**25**] the maximum windspeed was about 110 knots, but the effect of the peninsula of Florida reduced the surface winds to about 95 knots on June 9, photo F. Traversing the peninsula of Florida, Alma regained some of her intensity on June 11, photo G, but declined soon after June 12, photo H.

the technique has been devised to make reasonably accurate estimates of the maximum windspeed in storms by classification and measurement of their cloud patterns. Since February 1965, meteorological satellites have enabled meteorologists to classify and track every dangerous tropical storm, hurricane, and typhoon."

[**26-27**] **Weather Pictures for the Asking**

ESSA II

The Secretary General of the World Meteorological Organization in Geneva, Switzerland, D. A. DAVIES, wrote of the mosaic you see here:

"The launching of ESSA II added the Automatic Picture Transmission (APT) element to the world's first operational satellite system. Prior APT systems carried by Nimbus I and Tiros VIII had confirmed the enormous value of the facility for direct satellite readout at any point on the Earth's surface which the APT system presents. At the time of launching ESSA II, APT reception equipment had been installed at about 80 stations in 20 countries. Since then these numbers have increased steadily.

"This picture is a composite of 17 individual APT photographs taken on five orbits of ESSA II. The easternmost three orbits were acquired at Washington, D.C., and show how, within a space of some 4 hours, a clear presentation of the cloud systems over an area greater than the whole of North America may be directly obtained. The two westernmost orbits were obtained at San Francisco and Honolulu. The cloud formations of the depressions over the central Atlantic, near the Great Lakes, and off the west coast of the United States are very well displayed and follow closely the patterns to be expected from classical frontal theory. Indeed one of the revealing features of satellite cloud pictures is the striking confirmation they give of the frontal theory of the formation and development of depressions first enunciated by the Norwegian school of meteorologists nearly 50 years ago. The cloud formations of Hurricane Alma are visible in the western Caribbean Sea.

"The picture demonstrates also that cloudless land and water areas can be readily detected, including areas of frozen water in northern Canada, snow cover on the Rocky Mountains, and the icecap of Greenland."

[**28**] **Characteristics of Churning Air**

RICHARD J. REED, of the Department of Atmospheric Sciences at the University of Washington, welcomed pictures such as the one below because, in his words:

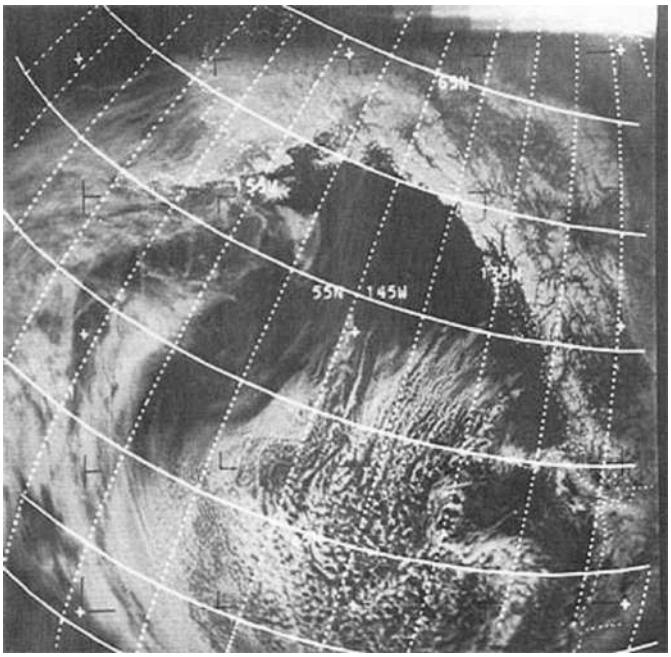
"Thin layers of fluid heated from below in laboratory experiments may, under proper conditions, overturn in cellular patterns. If the

upper part of the layer is in motion relative to the bottom, the overturning may take place in long, horizontal rolls whose axes point in the direction of the shearing motion.

"Cloud photographs taken from satellites reveal that analogous cellular patterns occur in the lower layers of the atmosphere when frigid air crosses a warm surface. In this picture cold, dry air is streaming southward from eastern Alaska and western Canada over the relatively warm waters of the Pacific.

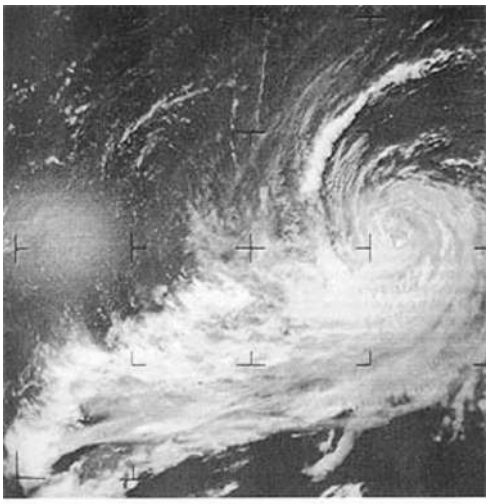
Moisture supplied by the ocean causes clouds to form in the cold-air stream after it has traveled some distance offshore. The initial cloud pattern consists of small cells arranged in bands, indicating that the heating is confined to a shallow layer of strong vertical wind shear. Farther south, where the heating extends through a greater depth, the cells are larger and have a honeycomb appearance. Rings of ascending, cloud-laden air surround open spots in which the air subsides.

"Pictures like this provide fundamental knowledge of the manner in which heat and moisture are transported from the ocean to the atmosphere. This knowledge will lead eventually to increased accuracy in long-range prediction where energy exchanges with the surface are an important factor."



ESSA II

[**29**] MICHAEL L. GARBACZ, Tiros/TOS Project Manager, Space Applications, NASA, points out that the photo of Hurricane Faith at the right was used both to locate it, about 300 miles off Cape Hatteras on September 1, 1966, and to determine its important characteristics. "The general cloud organization," he notes, "reveals the windspeeds at the center were on the order of 110 knots. This picture and others like it on preceding and succeeding days provided local forecasters with information on which to base forecasts and warnings. The bright spot to the left is the reflection of the Sun on the ocean's surface."



LEE M. MACE, of the Environmental Science Services Administration, notes that photos such as the one at the right here not only expose frontal systems but also provide valuable information on the location of snow and ice to hydrometeorological services.

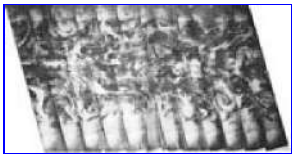
"Most of Scandinavia, under generally free cloud conditions, is clearly visible between two weather systems here," he points out. "The band of frontal cloudiness at the upper right has moved from west to east across Scandinavia, while another in the lower left is approaching. Abundant snow cover can be seen on the mountains of Norway and Sweden. The sharp valleys of the fiords are made visible by the apparent lack of snow and the shadows cast by mountains, Numerous frozen lakes with a snow layer on the ice are seen as bright patches in Finland. An area of solid ice covers the northern portion of the Gulf of Bothnia except for a wide northeast southwest lead in the ice along the west coast of Finland.

ESSA II

"The peninsula and islands of Denmark appear in the lower center of the picture. Other islands in the Baltic Sea are outlined by sun glint on the sea.

"The appearance of the ice which is filling the northern Gulf of Bothnia and the pack ice northwest of Norway are of interest to those engaged in fishing and shipping."

[30] Daily Global Weather Coverage



ESSA III

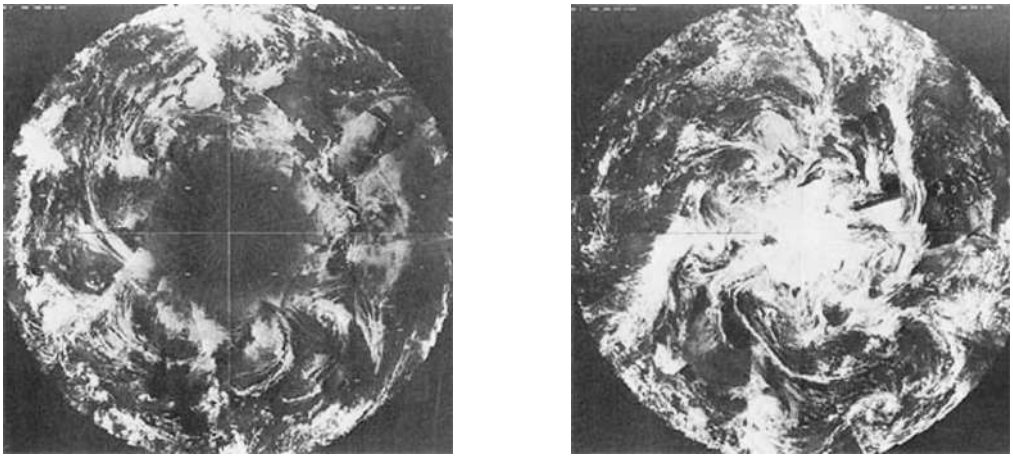
"This photomosaic depicts complete global coverage assembled from pictures taken during 12 consecutive orbits on October 31, 1966, by the ESSA III meteorological satellite, HERBERT I. BUTLER, Chief, Operational Satellites Office, Goddard Space Flight Center, NASA, tells us. "The mosaic typifies the daily output of the Advanced Vidicon Camera System obtained by the Tiros Operational Satellite (TOS) system for use by the U.S. Weather Bureau in preparing daily worldwide meteorological analyses and forecasts."

How high was the camera and how much of the Earth does each frame cover?

[**31**] "The ESSA III satellite was in a 750-mile altitude, circular orbit, inclined approximately 79° retrograde to provide Sun synchronism. Each picture covers approximately 3000000 square miles of the Earth's surface. In order to provide geographic location of meteorological phenomena, each picture was routinely gridded at ESSA in a latitude-longitude matrix. The South Pole and the Antarctic region are clearly visible in the concentric circles in each of the lower pictures. Africa and the Near East are readily recognized in the central portion of the mosaic.

"The significance of this group of photographs lies in the fact that it represents a truly operational product of the space age and the result of more than 6 years of research and development work in the Tiros and Nimbus programs."

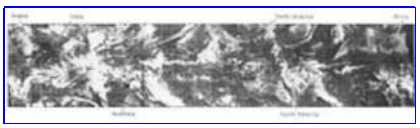
[32] Fast Service for Airmen



ESSA III

"One hundred and fifty vidicon camera images collected by the ESSA III satellite were combined in the pictures on this page to reveal the cloud cover over the entire Earth on January 6, 1967," CHARLES L. BRISTOR, Chief, Data Processing and Analysis Division, at the National Environmental Satellite Center, tells us. "Each (800 scan line) image signal has been converted into 640 000 separate digital brightness samples. The fastest computer presently available is used to partially correct each image for variations in solar illumination and camera-lens vignetting. The pictures are cropped to reduce overlap and then mapped in full resolution on northern and southern hemispheric polar stereographic projections (shown above). An overlapping Mercator mapping of regions bracketing the areas is below.

"Such routine mapping is creating montage images for timely use in weather briefing for pilots flying transoceanic routes and for use in improving weather analyses and forecasts. It also is providing vital input for further computer efforts toward the automatic extraction of information."



ESSA III

[33] Six Disturbances Seen Simultaneously

ATS-1

Applications Technology Satellites (ATS) are stationary with respect to the subsatellite point on the Earth because they rotate with the world. This and the pictures on the next four pages were obtained from such a satellite.

"The positions of six tropical disturbances were observed simultaneously on September 14, 1967, in this picture from the ATS I satellite over the Pacific," says the Applications Technology Satellite Program Manager, JOSEPH R. BURKE.

"Beulah was developing in the Caribbean, Monica was west of Mexico, and Nanette was developing south of Baja California. At the same time, Sarah had started south of Hawaii and Vera and Opal were off the coast of Japan. As in many other ATS pictures, the intertropical conversion zone is visible along the line of the equator. One of the chief advantages of geostationary satellites is that they permit the meteorologists to view a very large area simultaneously. "

[34] A Day Passes a Stationary Photographer

7:05 a.m.

ATS-I

The ATS-I satellite transmitted these pictures of night and day December 11, 1966. The times given are Eastern Standard, and the photo shows the changing cloud pattern over the visible hemisphere.

"These photos show the great advantage of viewing the Earth's storm clouds from a satellite in geostationary orbit," says VERNER E. SUOMI of the Space Science and Engineering Center at the University of Wisconsin. "Here the weather moves-not the satellite. The first photo shows the early morning sunlight over South America. A storm which looks like a white comma with its tail pointing west-southwest can be seen off the coast of Chile. By 3:45 p.m. and 5:45 p.m., the tail of the comma (really a cold front) has rotated a quarter turn to the north and the whole storm has moved farther east and south. Changes in the structure of another storm off the coasts of Oregon and Washington can be seen as the storm strikes the mountains. The snow-covered Sierra Nevada range can be seen northwest of Baja California, clearly visible in the 1:36 p.m. and 3:45 p.m. photos.

"Subtle changes in the convective clouds such as thunderstorms as the day proceeds are also visible over the Amazon and portions of the oceanic tropics. Even the equator appears to be visible due to the reduced cloudiness of the equatorial dry zone.

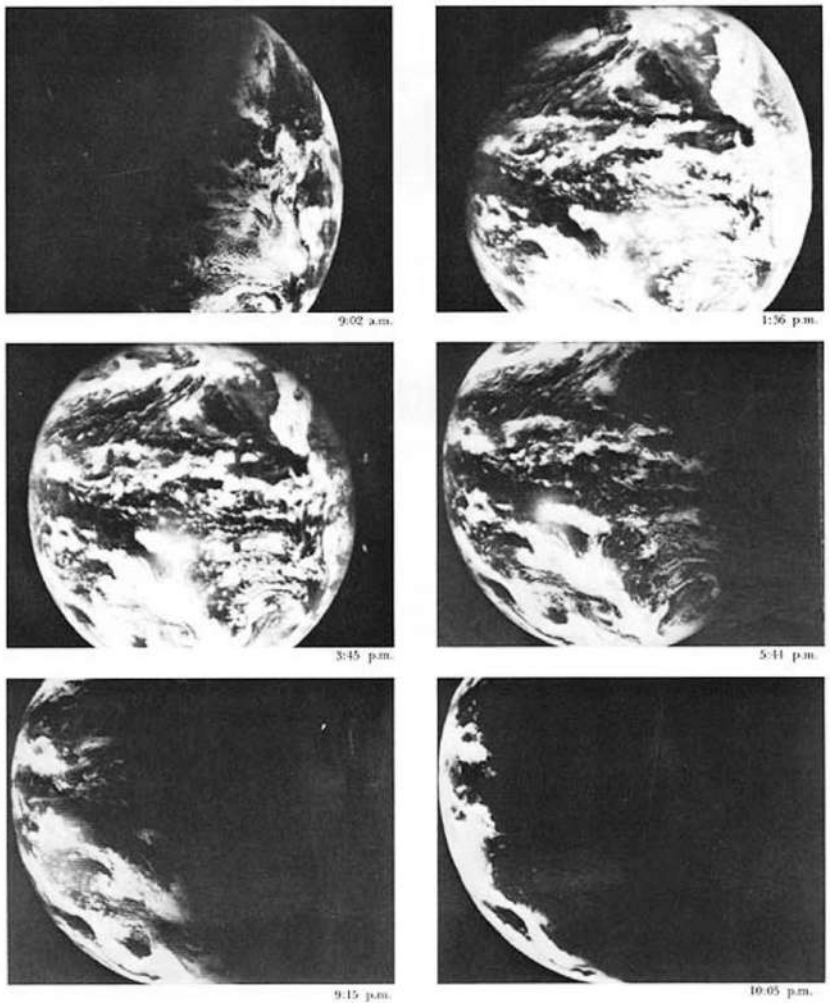
"Weather is air in motion. A camera on a satellite, stationary with respect to the Earth's surface, allows us to view the weather in a highly useful new dimension-time."

The camera that produced these pictures was at an altitude of about 22 300 miles, and was a "spin scan cloud camera." In reality, says ROBERT J. DARCEY, Applications Technology Satellite Project Manager at the Goddard Space Flight Center, NASA, "it is not a camera at all. It is a reflecting telescope with a pinhole aperture.

"Light which enters the pinhole is focused on a photomultiplier tube and its intensity is converted into electric impulses. The impulses are transmitted to the ground for processing on the terminal equipment which converts the impulses into photographic images. The east-west scan of the camera is accomplished by simply leaving the aperture open at all times, hence utilizing the satellite spin. The northsouth scan is accomplished by mechanically tilting the camera after each line has been generated. Two thousand lines are required for one picture."

Recording each of the seven pictures here took 20 minutes.

[**35**]



[From left to right, top to bottom: 9:02 a.m.; 1:36 p.m.; 3:45 p.m; 5:44 p.m.; 9:15 p.m.; 10:05 p.m.]

ATS-I

---

[36] Storms Are Photographed From Their Cradles Until They Die

---

January 2, 1967

January 3, 1967

January 4, 1967

January 5, 1967

January 6, 1967

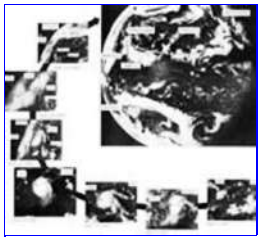
January 7, 1967

ATS-I

"This sequence of pictures taken by ATS-I," MORRIS TEPPER, Deputy Director, Space Applications Program, NASA, reports, "gave meteorologists one of their first opportunities to study, in detail, the life cycle of a cyclonic storm as portrayed in cloud-cover pictures. The storm can be seen as it developed January 2, 1967, in the left part of the picture just above the Equator. On succeeding days, it is seen to progress in a northeasterly direction until it reaches a peak on January 4 and 5. The storm then may be seen in the upper center of the Earth's disk. The storm's clouds were very well developed, indicating it had reached its full maturity. On January 6 and 7, the storm began to dissipate, its cloud structure becoming more diffuse. The organized circulation can no longer be seen in the final picture.

"Many storms such as this have been observed and studied during the lifetime of ATS 1. The dynamic character of storm development becomes even more striking when these pictures are viewed as a movie."

[**37**]



ATS-I

"Typhoon Sarah" (above), JOHN F. CLARK, Director, Goddard Space Flight Center, NASA, recalls, "caused considerable damage to Wake island the afternoon of September 16, 1967. As can be seen in this sequence, and particularly in the pictures taken on September 14 and 17, the storm passed Wake Island during the period of its peak intensity. The severest part of the storm, the right forward quadrant, lashed Wake on September 16. The overall track of the storm, and specifically the September 14 picture, was used to provide reliable advanced warning to the island of Wake. ATS-I had the capability for continuously viewing the same portion of the Earth and its atmosphere during daylight from its vantage point over the Pacific. Sequences such as this are of considerable interest, not only to the tropical forecaster but also to research meteorologists who can use this kind of data to study the behavior of tropical storms and the conditions surrounding their birth and death."

INDEX PAGE