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By

Sigmund Fritz

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National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

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January 26, 2009

Meteorological satellites

The years 1960–1961 were marked by a major addition to meteorological observation techniques. The Tiros satellites for the first time took pictures of entire cloud systems with great detail; they also measured the radiation distribution over large sections of the earth. All the Tiros satellites were launched from Cape Canaveral, Florida, under the management of the National Aeronautics and Space Administration (NASA).

Cloud pictures. *Tiros I* launched on April 1, 1960, contained two television cameras; one had a field of view of about 800 miles across when pointed straight down; the second had a field of view of about 80 miles, but with higher resolution. The cameras took over 20,000 pictures until mid-June, 1960, when picture transmission was terminated. Among the most prominent phenomena which *Tiros I* televised were numerous extratropical cyclones in various stages of development in both the Northern and Southern Hemispheres. Although each storm was different, they were generally characterized by wide, cold-front cloud systems which spiraled towards the cyclone center. Marked streakiness in the broad cloud masses served to outline the spiral character more clearly. *Tiros I* also observed many interesting mesoscale phenomena, such as tornado-producing cloud masses, clouds arranged in cellular patterns, and cloud streets. *See* NEPHANALYSIS; *see also* MOUNTAIN LEE WAVES.

A still further advance in observational capability occurred when *Tiros II* was launched on Nov. 23, 1960, for *Tiros II* contained five radiation sensors in addition to the two types of television cameras. Unfortunately, the pictures taken with the wide-angle camera on *Tiros II* appear somewhat blurred. Nevertheless, the pictures were adequate for operational use and produced interesting views of the winter-snow-clad continents. Moreover, the narrow-angle camera was used to demonstrate the capability of ice reconnaissance of the sea surface. Using both airplanes and *Tiros II*, the Weather

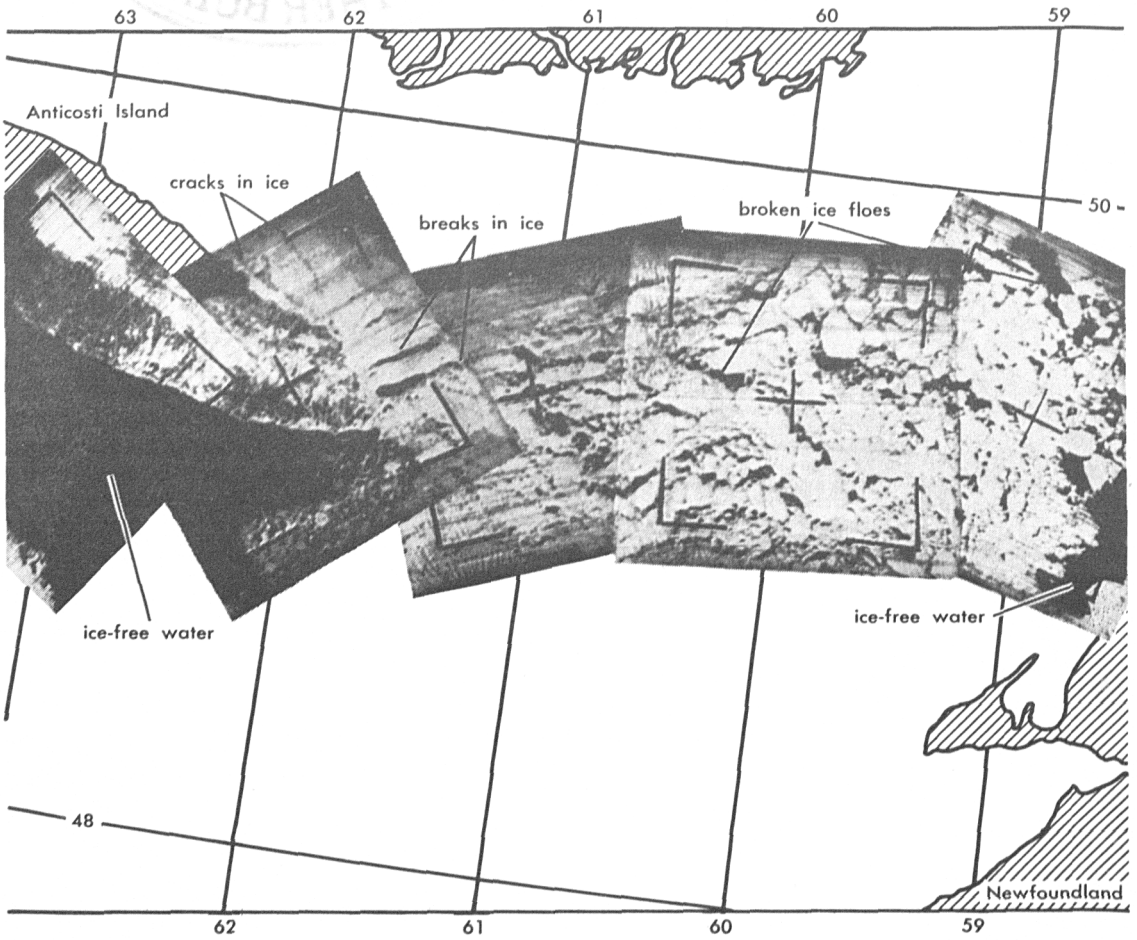

Fig. 1. Composite of *Tiros II* narrow-angle pictures showing ice reconnaissance from Anticosti Island in the Gulf of St. Lawrence to the coast of Newfoundland, March 23, 1961. Separated ice floes in eastern part of area contain elements several miles in diameter. (U.S. Weather Bureau–NASA)

Fig. 2. Composite of *Tiros III* pictures showing spiral cloud array and connecting circulation of tropical storms Liza and Madeline to the west of Mexico on July 23, 1961. (*U.S. Weather Bureau–NASA*)

Bureau and the Navy Hydrographic Office cooperated in a program to photograph the ice in the Gulf of St. Lawrence and over the area surrounding Newfoundland. Various patterns of ice were televised, including leads and cracks along the coasts and in the main body of the ice (Fig. 1).

Hurricanes and typhoons are violent, destructive storms which often form in oceanic areas where no surface observations are available. Thus satellites, with their world-wide observational capability, are especially valuable for early detection of these storms. Therefore *Tiros III* was launched on July 12, 1961, to assist in storm detection and tracking during the hurricane season which normally reaches its peak in September. *Tiros III* contained two wide-angle cameras (no narrow-angle camera) and radiation sensors similar to those in *Tiros II*.

The outstanding phenomena televised by *Tiros III* are the myriad of tropical storms, hurricanes, and typhoons it found over the Atlantic and Pacific Oceans. Figure 2 is a composite of photographs from *Tiros III* taken on July 23, 1961. The figure shows the spiral cloud array of tropical storm Liza (25°N, 138°W), whose circulation was connected with the circulation of tropical storm Madeline (14°N, 117°W). It is the array of cloud filaments, often spiraling into a large central cloud mass, which suggests the spiral wind pattern of a tropical storm. These two storms were located to the west of Mexico, a region particularly devoid of any weather observation. *Tiros III* was able to locate the storms and give their correct positions.

Every hurricane, at least as late in the season as Esther, was photographed at some stage in its development by *Tiros III*. Hurricane Anna, the first hurricane of the 1961 season, was photographed on many days as it moved from the Atlantic Ocean across the Caribbean Sea, until it hit the Honduras coast. Hurricane Debbie was photographed not only by *Tiros III* but also by the Project Mercury satellite launched on Sept. 13, 1961. The Mercury satellite contained a 70-mm camera loaded with color film, which was recovered with the satellite. The resolution and contrast of this system are much greater than in the Tiros system, so that more detail can be seen. Figure 3*a* shows Debbie televised by *Tiros III* on Sept. 11, while Fig. 3*b* shows Debbie from the Project Mercury satellite. The Mercury picture shows a small section of the storm, but contains a dark area which was probably associated with the "eye" of the hurricane. None of the *Tiros III* hurricane pictures shows a marked eye, suggesting that the resolution of the system is not yet adequate for delineating eye structure. Hurricane Esther was interesting because it was located in the tropical mid-Atlantic Ocean by *Tiros III* on Sept. 10, before meteorologists knew of its existence. Esther was photographed on many days as it approached the United States, skirting the entire coast from Hatteras, N.C., to Cape Cod, Mass.

Radiation. Satellites can observe the distribution of the reflected solar energy, and the long-wave terrestrial energy emitted, by the earth. *Explorer VII* was launched on October 13, 1959, containing, among other experiments, an omnidirectional, radiative heat budget (net incoming short-wave minus outgoing long-wave) instrument designed by V. E. Suomi of the University of Wisconsin. The measurements showed that the heat budget varies with cloudiness, as well as with latitude.

Tiros II and *Tiros III* each contained five radiation sensors which viewed the earth with higher resolution than *Explorer VII*. The resolution was about 40 miles when the sensors were pointing straight down. Two of the sensors measured radiative heat budget. But the radiation measurements which have so far been studied most are the so-called water-vapor "window" observations made with a third sensor. (The "window" is the spectral region in which water vapor absorbs heat.) As expected, deep, overcast cloud systems are observed as cold radiative sources; the earth's surface and low clouds are indicated as warm radiative sources. From measurements of the amount of radiation, the temperature of the radiating surface or overcast cloud can be estimated. Since meteorologists know at what height in the atmosphere each temperature

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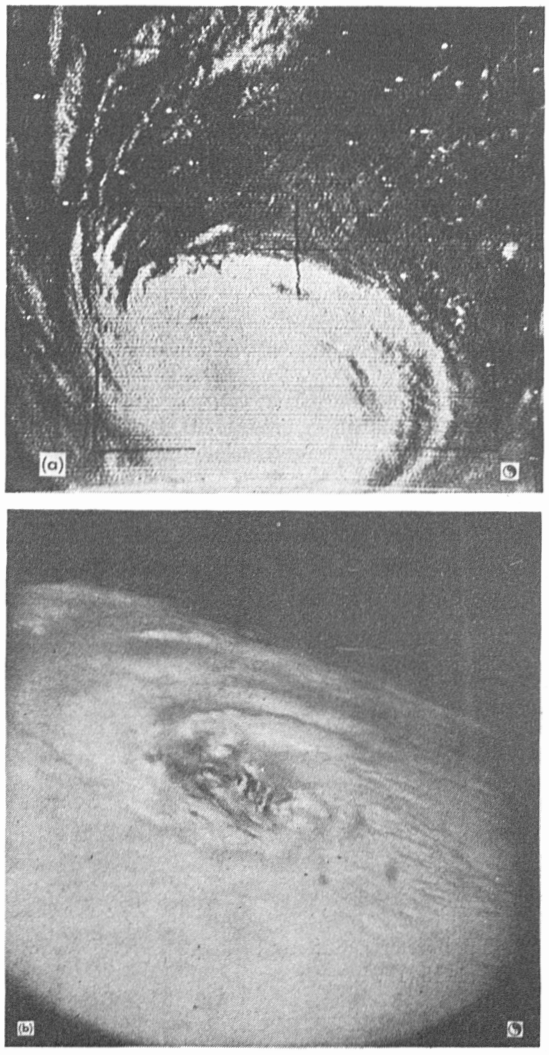

Fig. 3. Hurricane Debbie in the Atlantic. (*a*) As televised by *Tiros III* on September 11, 1961. (*b*) As photographed by Project Mercury satellite 12 minutes after launching on September 13, 1961. The storm lies 100 miles north of the projected flight line of the spacecraft. (*U.S. Weather Bureau–NASA*)

occurs, they can use the Tiros radiation measurements to estimate the height of the cloud tops. This is important in analysis of the atmospheric structure, as well as in determining weather effects on airplane operation.

An analysis of the "window" radiation data from one orbit of *Tiros II* over the United States, showed that the heights of cloud tops in well-developed systems could indeed be estimated with satisfactory accuracy, although cirrostratus clouds introduced some difficulty. For example, in a multilayered cold-front cloud system along the United States east coast, *Tiros II* data indicated the cloud top at 27,000 ft. The actual height of the cloud top was 33,000 ft. Over ocean areas, where radiosonde data are sparse or lacking, such an estimate would be considered quite accurate. The discrepancy was caused by the presence of cirrostratus clouds, in a layer 5000 ft thick, above an altostratus cloud whose top was at 14,000 ft. Since cirrostratus clouds are not as opaque as other types of thick clouds, energy reached the satellite not only from the top of the cirrostratus cloud, but also from the lower part of the cirrostratus cloud, where the temperature was warmer; a small amount of energy from the relatively warm altostratus cloud probably also penetrated the overlying cirrostratus cloud and reached the satellite. Thus the temperature observed by the satellite was warmer than the one corresponding to the cirrostratus top. But the main cloud pattern, showing cold, high clouds by contrast with areas of the warm, cloudless surface and of low clouds was well documented in the *Tiros II* data. Since these measurements were made both day and night, the radiation data show the major cloud systems during both day and night with coarse resolution. *See* GEOPHYSICAL SATELLITES; SATELLITE, ARTIFICIAL.

For background information *see* METEOROLOGICAL SATELLITES; RADIATION, TERRESTRIAL in the McGraw-Hill Encyclopedia of Science and Technology. [SIGMUND FRITZ]

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