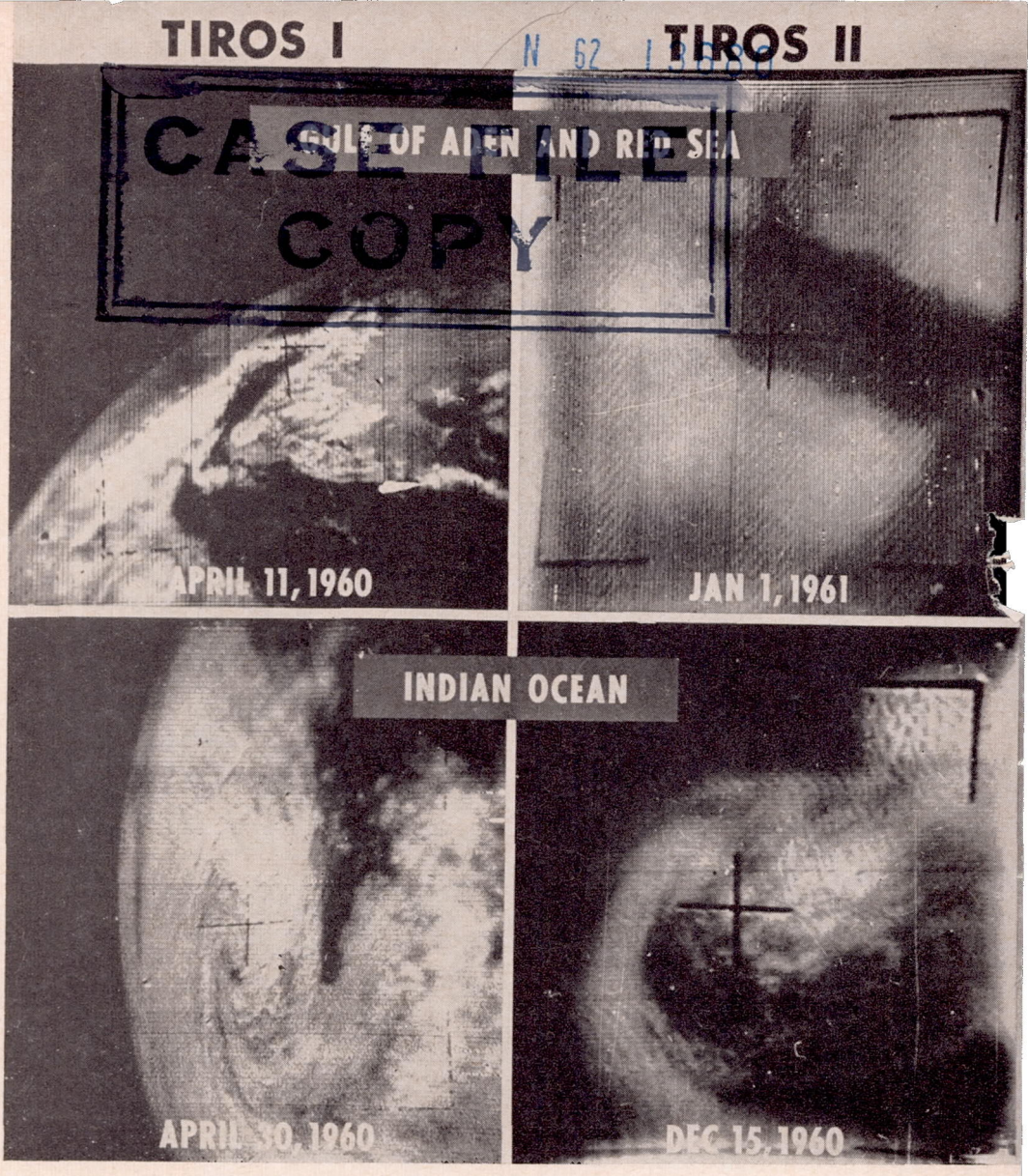

Comparison of wide-angle camera pictures from TIROS I and TIROS II over the same geographical areas. Although the pictures from TIROS I are clearer and show more detail, the pictures from TIROS II show general land features and larger cloud masses.

A Report on the Meteorological Satellite Program

MORRIS TEPPER, *Chief, Meteorology Programs, National Aeronautics and Space Administration*

THE Meteorological Satellite Program of the National Aeronautics and Space Administration comprises research and development activities designed:

1. to provide the meteorologist with the with the data which will increase his understanding of the atmosphere and his ability to predict weather events.
2. to develop the spacecraft prototype and the basic principles of an operating meteorological satellite system.
3. to insure the progressive improvement

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OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM

of meteorological sensors, spacecraft, and satellite systems through a continuing flight program.

THE TIROS SATELLITE FAMILY

The development and launch of the TIROS family of meteorological satellites represents the first significant step toward the attainment of these objectives. TIROS I was launched successfully on 1 April 1960, and TIROS II on 23 November 1960. The structural and operational details of these two satellites are well known. It will probably be more informative to dwell on the fundamental achievements of these two flights.

ACHIEVEMENTS

I. A spacecraft and supporting ground system were developed around special sensors (TV cameras, infrared radiation detectors) and transmitted with satisfactory fidelity the measurements of these sensors to the earth.

The almost 23,000 pictures acquired by TIROS I, and the similar number acquired by TIROS II, as well as the considerable volume of IR radiation data, all provide the most convincing testimonial of successful satellite system operation. The brilliance of this performance is only slightly dulled by the fact that the wide-angle camera in TIROS II was somehow defocused during launch. The resulting pictures, although not of the same quality as those from TIROS I, still show clearly the larger cloud and land areas, and lack only detail.

This remarkable performance required the successful operation of many interdependent and delicate subsystems, components, and electronics. In several instances new, previously untried technological advances were involved (e.g., firing of spin-up rockets on ground command after seven weeks in space environment, partial control of satellite attitude also on ground command, operation of

lubricated ball bearings in space environment).

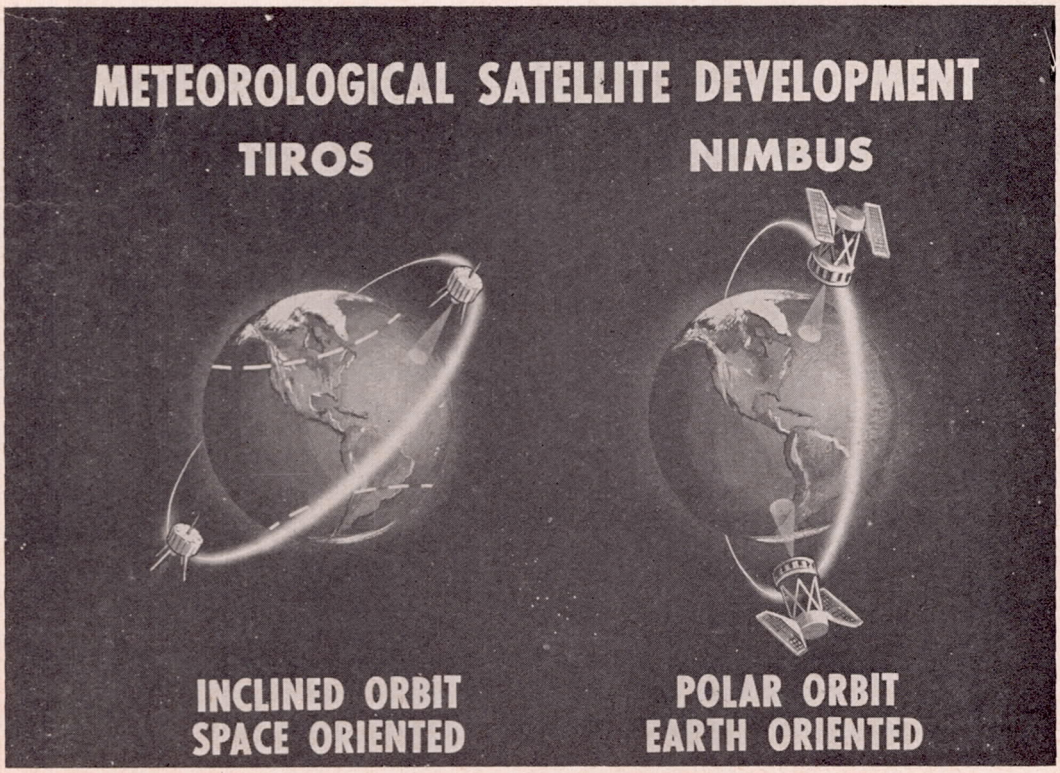
II. The satellite measurements were found to contain useful meteorological information.

With the receipt of the very first pictures from TIROS I, it became apparent that the satellite system was producing photographs of clouds, cloud formations and cloud patterns. The meteorological research teams at USWB, AFRC and NWRF and other institutions attacked the problem of interpreting the TIROS pictures in terms of weather information content. These studies indicated excellent correspondence between the cloud formations and meteorological patterns, such as the following: Low pressure cyclonic storm systems (these appear as spiral cloud formations in the photographs), cold fronts, large areas of stratus cloudiness, unstable areas having cellular shaped clouds, local severe storms, jet and mountain clouds. As a matter of fact, these findings confirmed previous suggestions based on limited photographs from high altitude rockets that Nature was drawing her own weather map by means of clouds.

The extraction of meteorological information from the TIROS II IR measurements is proceeding at a much slower rate. The signals from the satellite must be converted into meaningful physical measurements which must then be plotted on a map for proper study. Preliminary results have been very satisfying. Areas of satellite low temperature measurements have been associated with cloudy zones and areas of high temperature with cloud-free high pressure regions.

III. The useful meteorological information was extracted and transmitted to the weather services in time to be of value in weather analysis and forecasting.

In anticipation of the possible utilization of TIROS data for operational purposes, teams of civilian and military meteorologists were stationed at the data acquisition stations to study the incoming data in "real



Development of meteorological satellites. The limitation of the TIROS satellites will be overcome by the satellites in the Nimbus family.

time." Within 60 hours after TIROS I was launched, picture data less than six hours old was being interpreted and analyses forwarded via facsimile transmission to the National Meteorological Center at Suitland. These transmissions were incorporated into the regular analyses and forecasts of the Weather Bureau; copies were also relayed to our air and naval services both in this country and overseas, where they proved to be very useful. These weather services have indicated that these cloud analyses:

> "establish, confirmed or modified surface frontal positions; assisted in the briefing of pilots on accurate weather; were used in direct support of overwater deployment and aerial refueling of aircraft; gave direct support to an Antarctic resupply mission; confirmed the position of a Pacific typhoon; verified and amplified local analyses particularly over areas with few reports" etc.

The quality of the IR radiation data has been excellent. However, these have to be reduced and plotted on maps before they can be properly interpreted. From this point of view, until rapid processing techniques can be developed, the IR data are not as useful as the picture data for operational use.

NATIONAL OPERATIONAL METEOROLOGICAL SATELLITE SYSTEM

The effectiveness of the operational utilization of TIROS data has fired the imagination of the weather services. An interagency committee of experts (Panel on Operational Meteorological Satellites—POMS) has drawn up a plan for an operational meteorological satellite system to provide global data continuously. As originally planned, this system will draw heavily from and build firmly on the NASA research and development Meteorological Satellite Program.

The plan considers a system having several satellites in space simultaneously and read-out stations both in the U. S. and in foreign countries. Communication radio links connect the satellites with the read-out stations and surface data links connect the read-out stations and national weather central (NMC).

The full implementation of the operational system, including possible international participation, will not come about for several years—at least not until the second generation, more advanced meteorological satellite (Nimbus) is developed.

In the meantime, NASA is augmenting its TIROS program with a sufficient number of spacecraft in order to insure the continuous flight of at least one of these satellites at all times. Plans call for the launch of four *more* TIROS satellites after TIROS III at about four-month intervals, with the last launch overlapping the first Nimbus launch.

TIROS III

TIROS III was successfully launched on 12 July 1961. Its lifetime overlaps the hurricane season, and thus it will be possible for this satellite to produce important observations, both of cloud pictures and IR, of this storm phenomenon. TIROS III has two wide-angle cameras instead of one wide-angle and one narrow-angle camera. In addition to the IR experiments carried on TIROS II, it also transports a Suomi IR experiment similar to that carried on Explorer VII. About two weeks after launch one camera system failed. The nature of the malfunction is being investigated. All other sensors are working exceptionally well and providing good data; operational use of the cloud picture data was begun on the day of launch. All subsequent TIROS Satellites will be similar to TIROS III. Also NASA is studying the possibility of a 60° inclination orbit for future TIROS satellites in order to increase the picture and radiation coverage.

NIMBUS

Following the TIROS family of satellites will come the Nimbus series. As designed by the Goddard Space Flight Center of NASA, these satellites will have many components in common and a flexible capability for improving old and introducing new sensing systems, as required.

TIROS is severely limited in its coverage potential by its spin stabilization, which allows its cameras to scan the earth over only about 25 per cent of each orbit and by its inclined 50° orbit, which limits coverage to the area between about 55° N-S latitudes. The Nimbus family, whose first satellite is due to be launched in 1962, is designed to overcome these limitations. Being earth stabilized, its cameras and other atmospheric

sensors will always face the earth. Moreover, its polar orbit will cause it to view each area of the earth twice a day, at about 12-hour intervals.

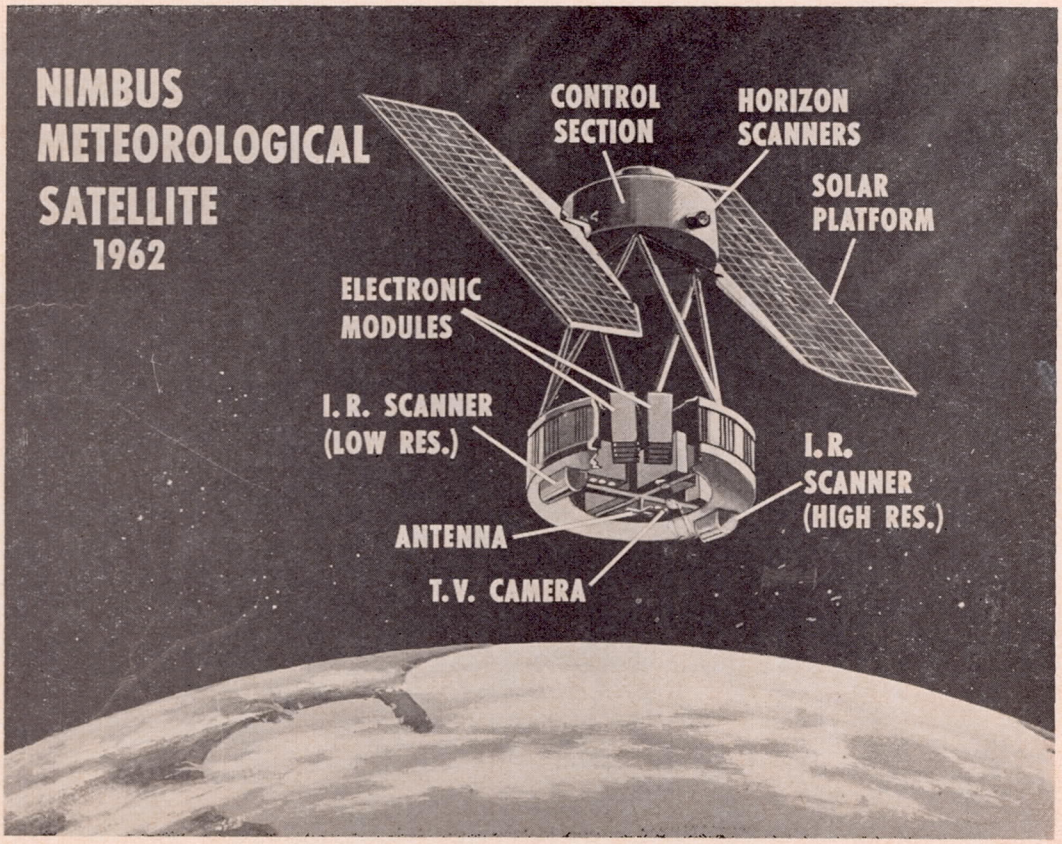
A better view of what Nimbus will look like is shown in the accompanying figure. As presently planned, the Nimbus sensors will include TV cameras with wider coverage and better resolution than TIROS and a number of improved radiation sensors. Also planned is a device for measuring the solar constant accurately.

The lower section of Nimbus is being designed on a modular or standardized compartment basis, so that, in later versions of the satellite, discarded sensors can readily be replaced with improved or new types of equipment without making necessary a redesign of the entire satellite. By the third or fourth Nimbus, it may be possible to include new types of sensing equipment such as a radar set to provide data on areas of precipitation, a radiation spectrometer to provide information on the temperature structure of the stratosphere, and a sferics detector to identify thunderstorm areas.

Even the first Nimbus, although primarily an experimental research and development spacecraft, can and will be used to provide data for operational purposes. Plans exist for these data to be sent, in real time, from the data acquisition station at Fairbanks, Alaska, to the National Meteorological Center at Suitland, where they will be analyzed and the resulting information distributed to both civilians and military weather stations.

AEROS

As TIROS and Nimbus satellites rotate around the earth, they view different portions of the earth's geography during their transit. Thus, the evolution of a weather



Nimbus. The paddles, controlled always to face the sun, will be covered with solar cells to provide power. The control section will keep the axis and sensors always pointing to the earth. The lower section will contain the sensing systems.

system can be followed only as a result of successive passages of the satellite over the same area. This may be a matter of several hours. The meteorologist is interested in a capability of continuously observing the developments of a potential storm area. This is particularly true of short-lived and severe storms where the entire life history may be only a matter of a few hours. It is also important to be able to follow the development of nascent storms before they explode into maturity.

In order to satisfy this requirement, NASA is planning for the development of the Aeros family of satellites. This satellite will be launched into a "stationary" orbit of 22,300 miles and thus will appear not to move relative to the earth. Being in equatorial orbit, it will monitor events essentially in the tropical and temperate latitudes.

DATA PROBLEMS

In addition to the efforts that are required for the development of advanced spacecraft and associated systems, continuous attention is also needed for the solution of two fundamental data problems.

Data analysis: The volume of data already acquired by the TIROS satellites and the volume of data expected from future meteorological satellites are enormous. The Weather Bureau and the other weather users are analyzing these data in research programs and applying the results for operational weather purposes. Attempts are being made to encourage increasing numbers of investigators to study these data, through aggressive contacts with the scientific community in general and with university research groups in particular. Copies of the

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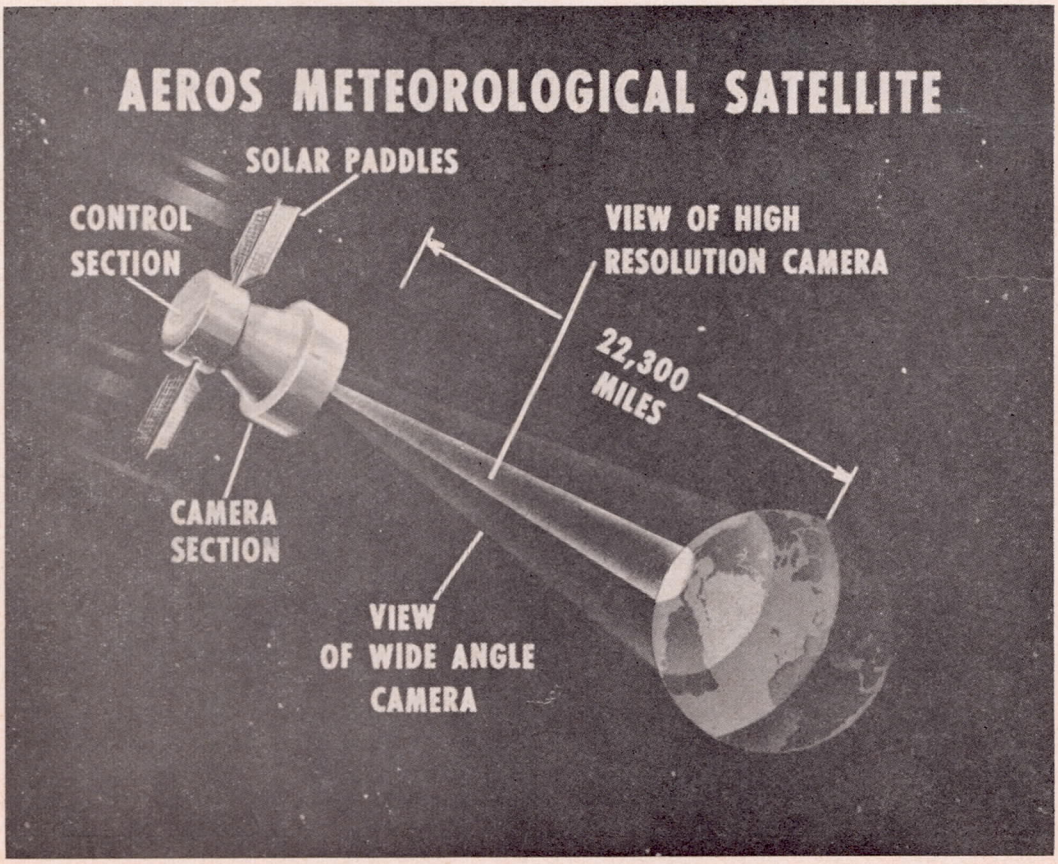
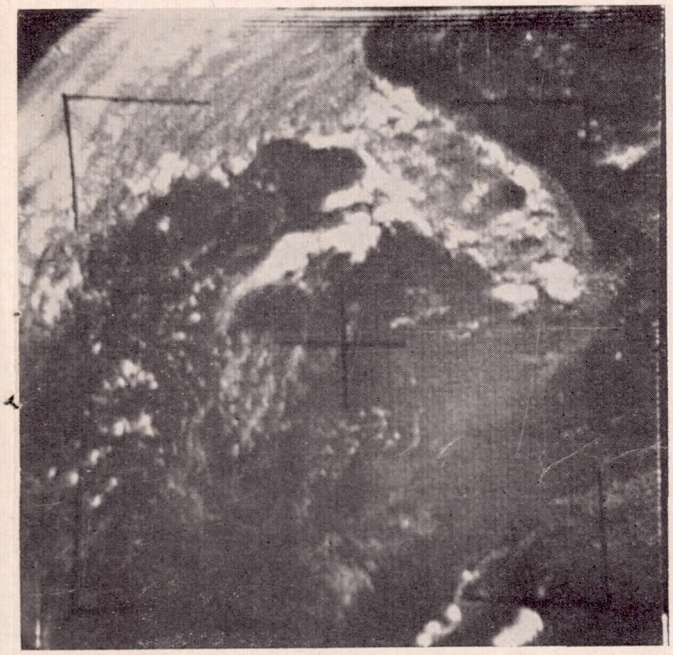


Preliminary concept of the future Aeros satellite.

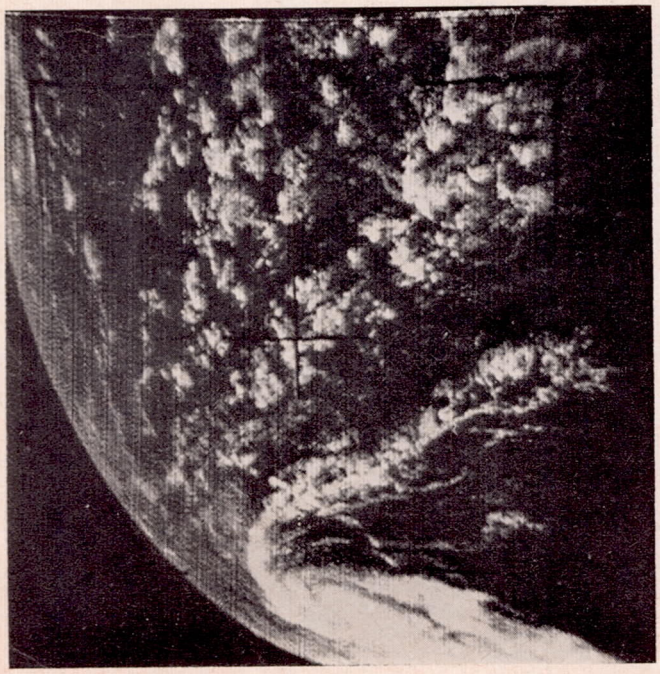


Gulf of Mexico, Florida, and a portion of the Bahamas, with well-developed convective cumulus clouds over the land areas. A squall line lies in Gulf, westward of Tampa, Florida. 14 July 1961.

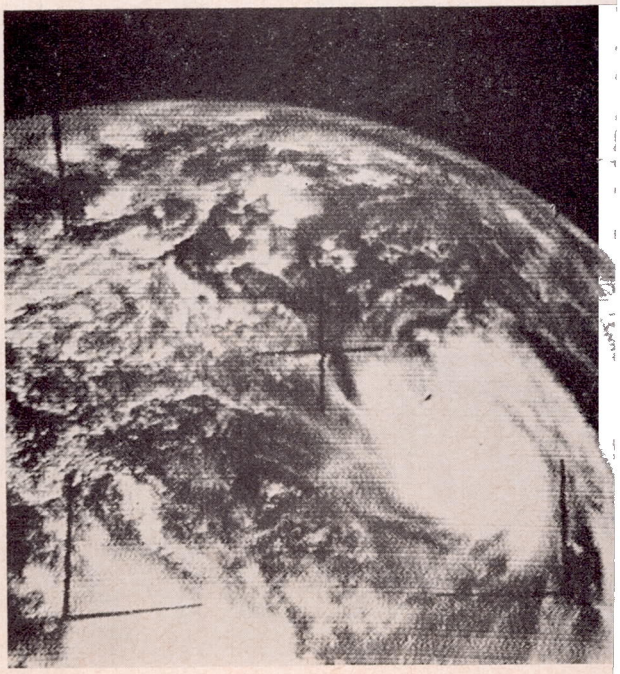
Spain and the Straits of Gibraltar. Clouds cover northern slope of the Pyrenees and the circular cloud pattern of a cyclonic storm shows prominently in the North Atlantic. 15 July 1961.

TIROS III PHOTOS

Hurricane ANNA near the coast of Venezuela at 13°N 65.5°W. The Leeward and Windward Islands appear as a line of bright spots transverse to the spiral band. 1445 GMT, 20 July 1961.



Hurricane ANNA at 14°N 72°W. The coast of Colombia near Barranquilla passes under the central cross mark. Lake Maracaibo shows a prominent dark area below. 1555 GMT, 21 July 1961.



Satellite (*Continued from page 136*)

photographs taken on the first 125 orbits of TIROS I have been furnished free to 23 university groups in the United States in order to stimulate the use of the pictures as a research resource.

Data transmission: A critical part of the data volume problem is the transmission of the meteorological data to the forecaster in as near real time as possible. This requires the determination of the significant meteorological content of the satellite output and the development of rapid transmission techniques to make this information available to field personnel in time for use. Developments under study include: satellite on-board analysis, ingenious techniques for data presentation, automatic analysis instrumentation, improved transmission facilities, advanced communications relays, etc.

INTERNATIONAL ASPECTS

The atmosphere is a global phenomenon, and meteorology is an international science. Thus, it is well recognized that in the U. S. Meteorological Satellite Program, maximum benefits will be derived only through international cooperation and participation. The following international activities are either in being or *are being planned* by NASA and the Weather Bureau.

1. Transmission of satellite nephanalyses to foreign countries.
2. Making available to all countries the basic satellite data through NWRC.
3. Encouraging supporting meteorological observations by foreign countries in connection with satellite passage over their area.
4. International seminar-workshop in satellite meteorology.
5. Ultimate direct readout of satellite data by foreign countries.
6. International participation in a unified global operational meteorological satellite system.

Tiros I Photographs Available to Public

Copies of the first seven reels of Tiros I photographs are now available from the National Weather Records Center in Asheville. The 100-foot reels, covering the first 120 orbits of the satellite, are unrectified and ungridded, but are labeled by orbit and frame.

The reels may be obtained in the form of 35-mm. positive transparencies for projection or 35-mm. duplication negatives from which opaque prints can be made. Individual frames or enlargements are not available.

Master negatives and positives of the pictures were prepared by the Navy Photographic Interpretation Center. Copies were then made by the NWRC for public distribution.

The price is $4.00 per reel—the complete set to date $28.00. Orders may be sent to the National Weather Records Center, Asheville, North Carolina. Make orders payable to the Treasurer of the United States.