X-650-63-166

N64-15859

Code 1

(TMX 54565)

OTS

23p

SYSTEM PERFORMANCE OF METEOROLOGICAL SATELLITES

Rudolf A. Stampfl AUGUST 1963 23p

OTS PRICE

XEROX $ 2.60 ph

MICROFILM $ 0.89 mf

NASA

GODDARD SPACE FLIGHT CENTER

GREENBELT, MD.

SYSTEM PERFORMANCE
OF
METEOROLOGICAL SATELLITES

Dr. Rudolf A. Stampfl
Aeronomy and Meteorology Division, GSFC

August 1963

Goddard Space Flight Center
Greenbelt, Maryland

ILLUSTRATIONS

SYSTEM PERFORMANCE OF METEOROLOGICAL SATELLITES

Dr. Rudolf A. Stampfl
Aeronomy and Meteorology Division, GSFC

Meteorological satellites are unique in their system requirements. Carrying a variety of sensors, these satellites provide the greatest capability for data collection, and must therefore be flexible in their system design.

From the point of view of system performance, the meteorological satellite program has been the most successful space program to date; all launchings have resulted in successful performance, and have yielded enormous quantities of data. So far, seven TIROS satellites have been launched and operated, and TIROS VI and VII are now in routine operation.

A speaker at a technical conference such as this Congress is expected to reveal the unique approaches taken, attributing the achievement of success to the uniqueness of finesse of the design. None of this can I offer you. The TIROS system was designed as early as 1958, to comply with time-tested and conservative standards; it uses FM/FM and PAM/FM/FM for telemetry. What, then, can be its secret of success? With no claim to completeness, I venture to list a few ingredients:

- Simplicity of design
- Use of state-of-the-art components and techniques
- Meticulous attention to detail
  and, finally, if I may borrow a line from a great contemporary,
- The liberal use of blood, sweat, and tears demanded by a rigorous testing program.

Much information has been published both about the scientific results and about the design of the satellite instrumentation. It is the purpose of this paper to show how the entire system has performed. Let us, then, take a look at the TIROS system, inspect some of the results, and critically examine the manner in which malfunctions have pointed the way to the development of more reliable designs.

Figure 1 is a picture of TIROS, which is shaped like a pillbox approximately 42 inches in diameter and 19 inches high. It is a spinning satellite, launched by the Thor-Delta rocket. The sides and top of the pillbox are covered with solar cells which provide power to the satellite. In the spinning satellite are two independent cameras whose optical axes are arranged to be parallel to the spin axis. These two cameras can be operated independently in two different modes: by commanding

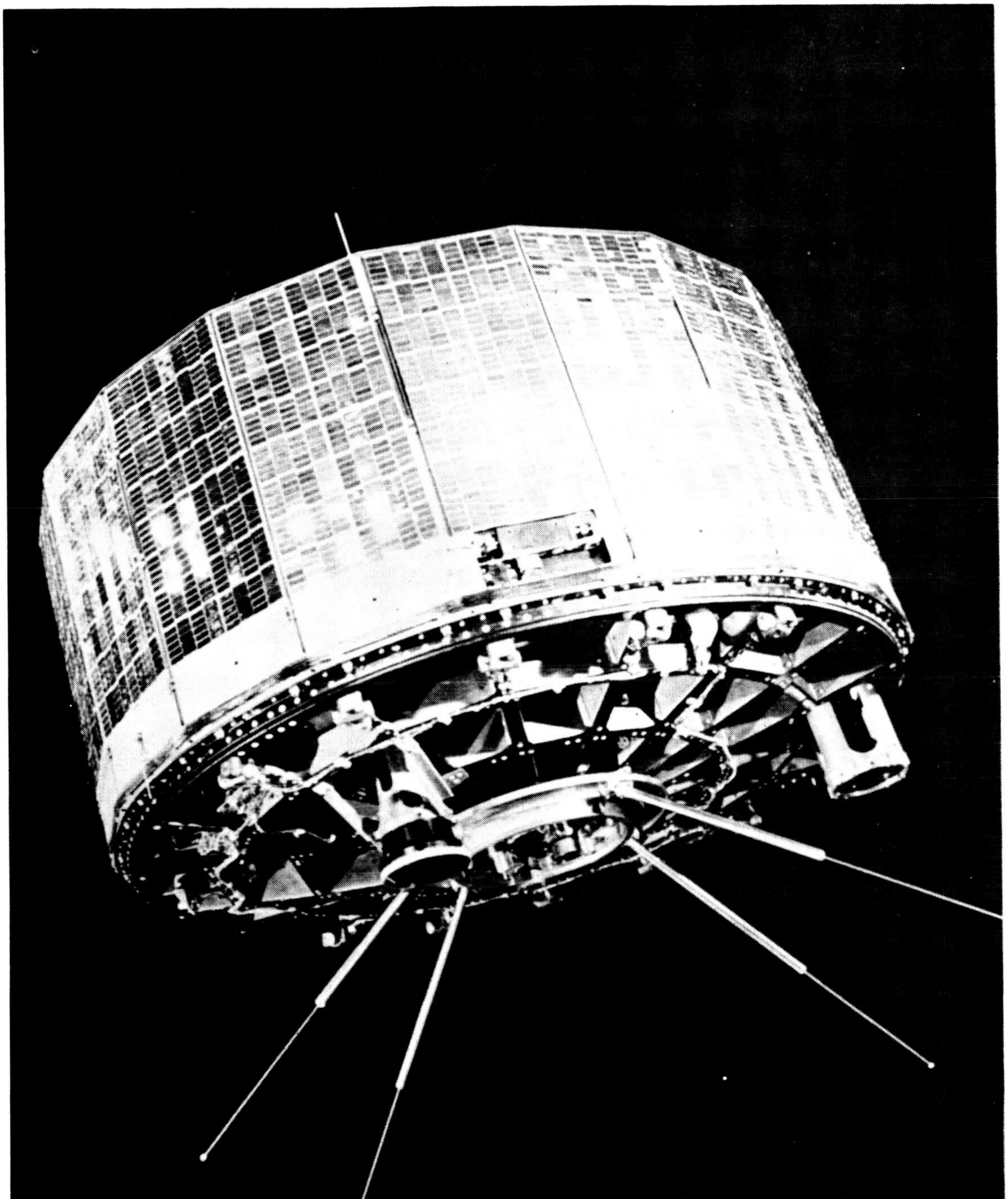

Figure 1–TIROS Spacecraft

the system ON when it comes into communication range, direct pictures can be taken; or, the satellite can be commanded to take a series of 32 pictures remotely and store them on magnetic tape for readout when the satellite comes within range of a ground station. For communication, a subcarrier is frequency-modulated and in turn modulates a 2-watt FM transmitter. A tone command system is used to activate various satellite functions. Time of a remote picture sequence is determined by a series of pulses sent to the satellite, each pulse designating a certain time increment; when the time has elapsed, the picture series starts and stops, automatically keeping a 30-second interval between pictures. The pictures are displayed on the ground by means of film. When a series of pictures is received, it is recorded on magnetic tape for permanent storage, and the signals are simultaneously sent through demodulators to a kinescope camera which immediately converts the electrical signals to film.

TIROS is tracked by 136-Mc 30-mw beacons which are modulated by a horizon-scanner signal for attitude determination; alternately, a 40-point stepping switch can be turned on and engineering telemetry can be transmitted by means of the beacon.

Although the two television cameras are the most important subsystems of TIROS, another subsystem is carried on many of the TIROS satellites to perform a variety of experiments. A five-channel chopping-type infrared radiometer is mounted on TIROS so that its optical axis is inclined 45 degrees to the spin axis; the spin of the satellite performs a scan on the earth's surface, and its orbital motion will advance this scan. The shape of a scan line, a complex function resulting from the intersection of a cone with the earth sphere, will naturally change from line to line; obviously, only large-scale computer processing can manage the analysis and interpretation of the data. The purpose of the infrared radiometer is to measure reflected solar energy and thermally emitted terrestrial energy; using these measurements, the heat budget of the earth can be computed from areas approximately 40 miles square. The field-of-view of the radiometer is approximately 5 degrees. In addition to computing the heat budget, measurements are being conducted in the 12-micron atmospheric window and elsewhere.

The five radiometer signals frequency-modulate five subcarrier-oscillators whose outputs are linearly summed and fed to a tape recorder of the endless-loop type which can record for up to 100 minutes at slow speed. Upon ground command to play back, the reocrder speed increases thirtyfold so that an entire orbit can be read out in approximately 3 minutes. Associated with this satellite infrared subsystem is a ground system which includes demultiplexers and analog-to-digital conversion. By this means a digital computer tape is prepared for processing in large-scale digital machines. Overall absolute accuracy, in watts per square meter for instance, is on the order of 4 percent. Figure 2 is a block diagram of the airborne part of the system.

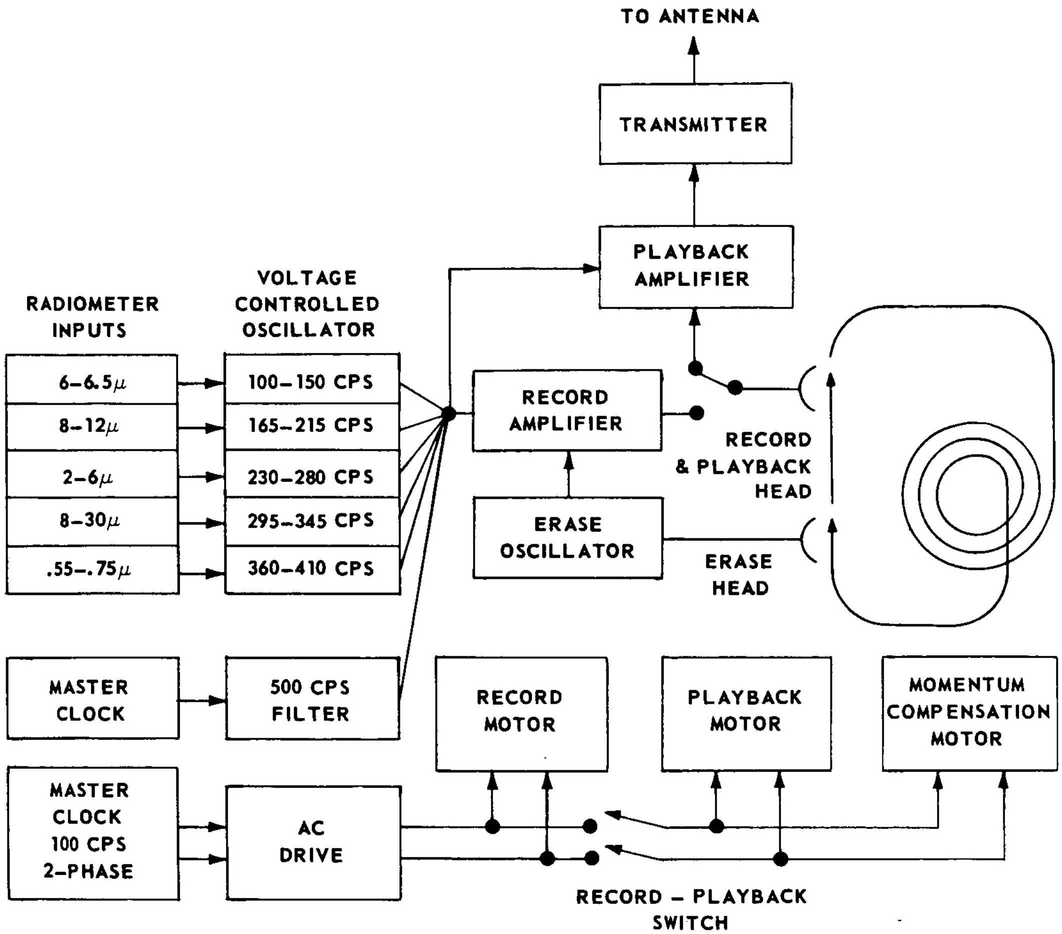

Figure 2–TIROS Medium Resolution Infrared Radiometer, Block Diagram

A complex satellite system such as TIROS requires elaborate ground installation. TIROS uses two ground stations, one located at the NASA test station at Wallops Island, Virginia, the other at San Nicolas Island, California, a part of the Pacific Missile Range. Both stations are equipped with high-gain antennas which automatically track the satellite after acquisition. San Nicolas Island uses a 60-foot parabolic dish antenna and low-noise receivers; Wallops Island uses an array of phased disc cone antennas. Operation of these two stations is directed from the TIROS Technical Control Center, at Goddard Space Flight Center, Greenbelt, Maryland, where the program for particular TIROS interrogations is prepared and sent to the stations over teletype links. The U.S. Weather Bureau staffs the stations with a team of meteorologists who analyze prints of the pictures as fast as they become available and extract the meteorologically useful information, which is then sent to the National Weather Center, Suitland, Maryland, and further on into the worldwide meteorological network in the form of teletype messages and facsimile nephanalyses.

Although conceived as an experiment in meteorological satellites, TIROS today is yielding much useful operational data. As it was designed to be an experiment, it does not provide 100-percent coverage of the globe; Figure 3 shows the limitation of coverage inherent in the system. TIROS is launched from Cape Canaveral by the Thor-Delta rocket in a northeasterly direction, so that the spin axis points toward the center of the earth approximately over Arabia. At that time, for reasons of solar-power conversion, the angle between the spin axis and the satellite/sun line is less than but desirably close to 60 degrees. Initially, the spin axis lies in the orbital plane; this plane drifts slowly westward because of the torque exerted on the orbital angular velocity vector by the equatorial bulge of the earth. This motion has a period of approximately 67 days. The figure shows the illuminated portion as a function of days after launch; the illuminated latitude, initially in the northern hemisphere, is seen to extend slowly from north to south with increasing satellite lifetime. Assuming for a moment that the spin axis can be pointed toward these illuminated latitudes during all orbits, it is clear that pictures can be taken only over the illuminated areas.

A second limitation on coverage is imposed by the location of the two ground stations. Figure 4 is a Mercator projection of the earth showing the two acquisition circles of the ground stations. The figure shows that the orbital path of TIROS projected on this map is a sinewave. Orbit A is the first of a series of orbits which can be interrogated by the Wallops Island station; a sequence of seven or eight orbits can be interrogated by Wallops and San Nicolas, the last orbit B being denoted on the map. A limitation exists in the satellite clock, in that only a remote program can be started 5 hours after a command to do so is inserted into TIROS. As there are 14 or 15 orbits per day, there is a gap of seven or eight orbits—a period longer than 5 hours—during which neither station can perform readout. To enable picture-taking over the equatorial Atlantic for purposes of hurricane research, location, and tracking, a command station has been activated at Santiago, Chile, which can set the TIROS clock in orbits of the C or D type to take pictures over the Atlantic for subsequent readout by Wallops Island.

System performance can be assessed by viewing samples of the data received. Figure 5 is a picture of a hurricane over the Atlantic taken by TIROS III in 1961. Its diameter is hundreds of miles, and the eye is not visible because of the oblique angle of the camera's optical axis. Figure 6 is a carefully prepared mosaic consisting of 12 pictures taken over the equatorial Atlantic, northeast of the Caribbean islands, showing two hurricanes (Esther and Debbie) which were tracked by the same TIROS on previous orbits. The pictures also show a large number of organized and unorganized clouds associated with or remote from these storm centers. As mentioned before, a meteorologist located at one of the ground receiving stations examines the pictures and mosaics and extracts the meteorologically useful information by transposing cloud patterns on to maps, using the standard meteorological polar

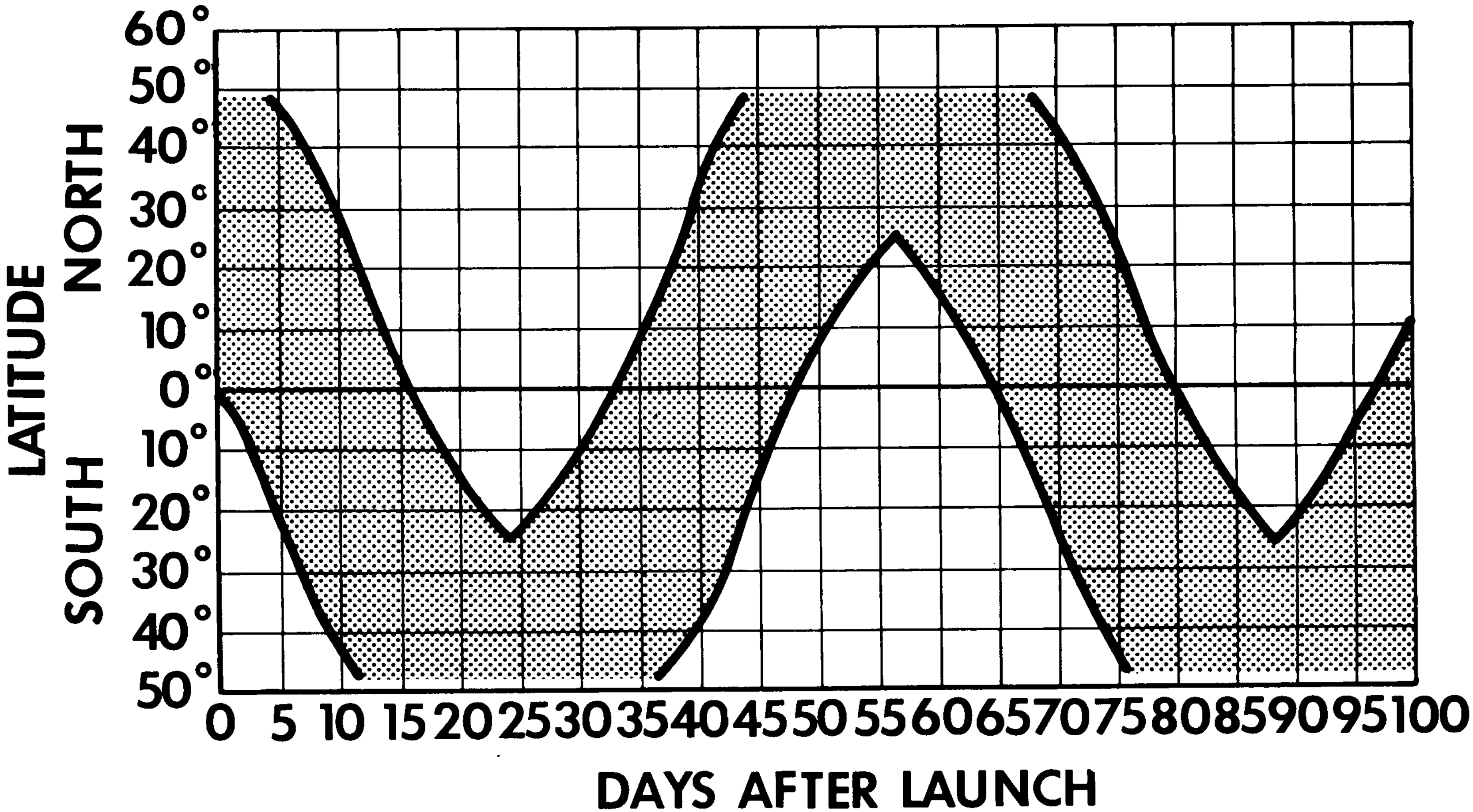

Figure 3–Illuminated Latitudes vs. Lifetime

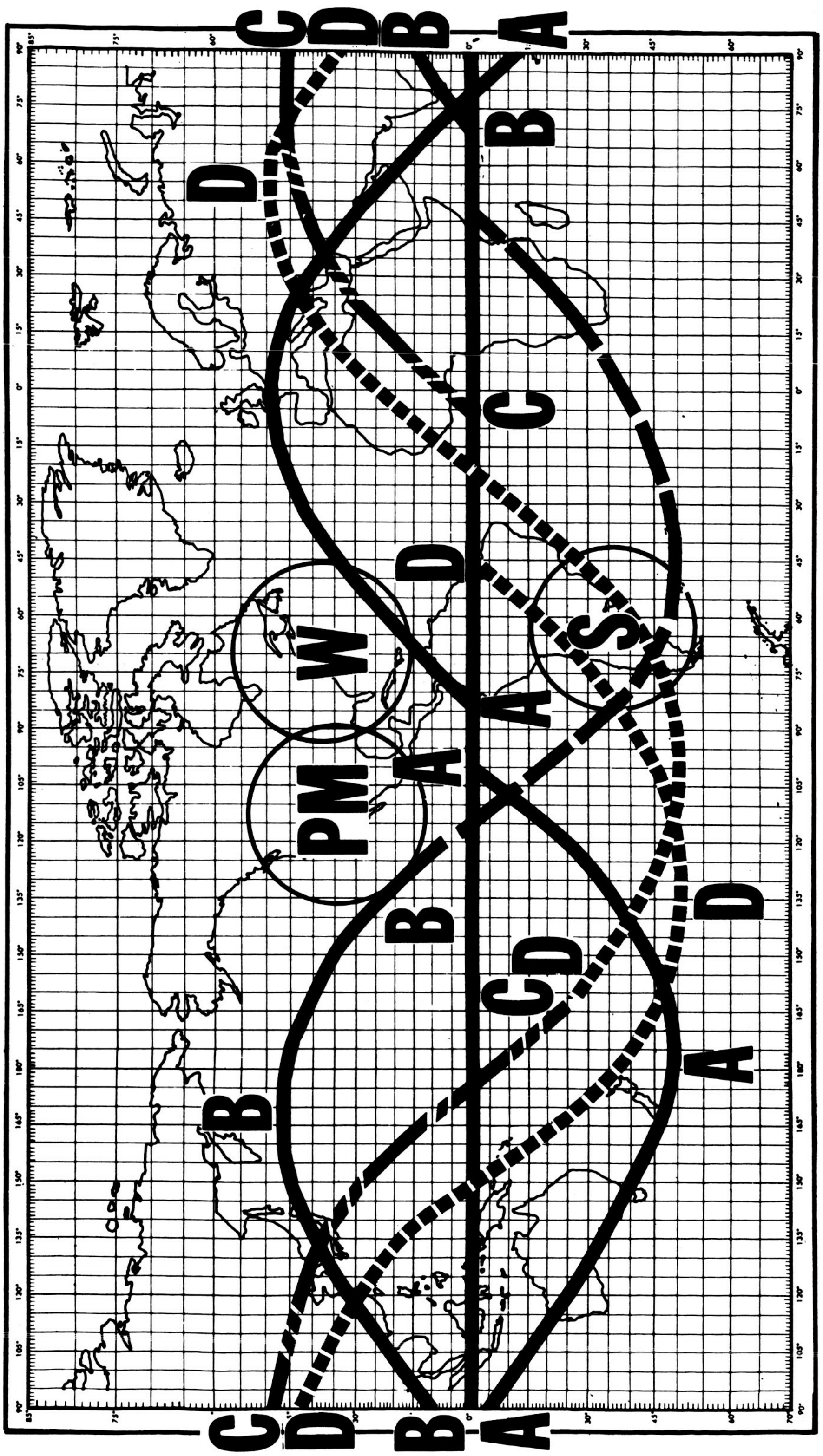

Figure 4—TIROS Orbital Paths

Figure 5–Hurricane Betsy, Taken by TIROS III

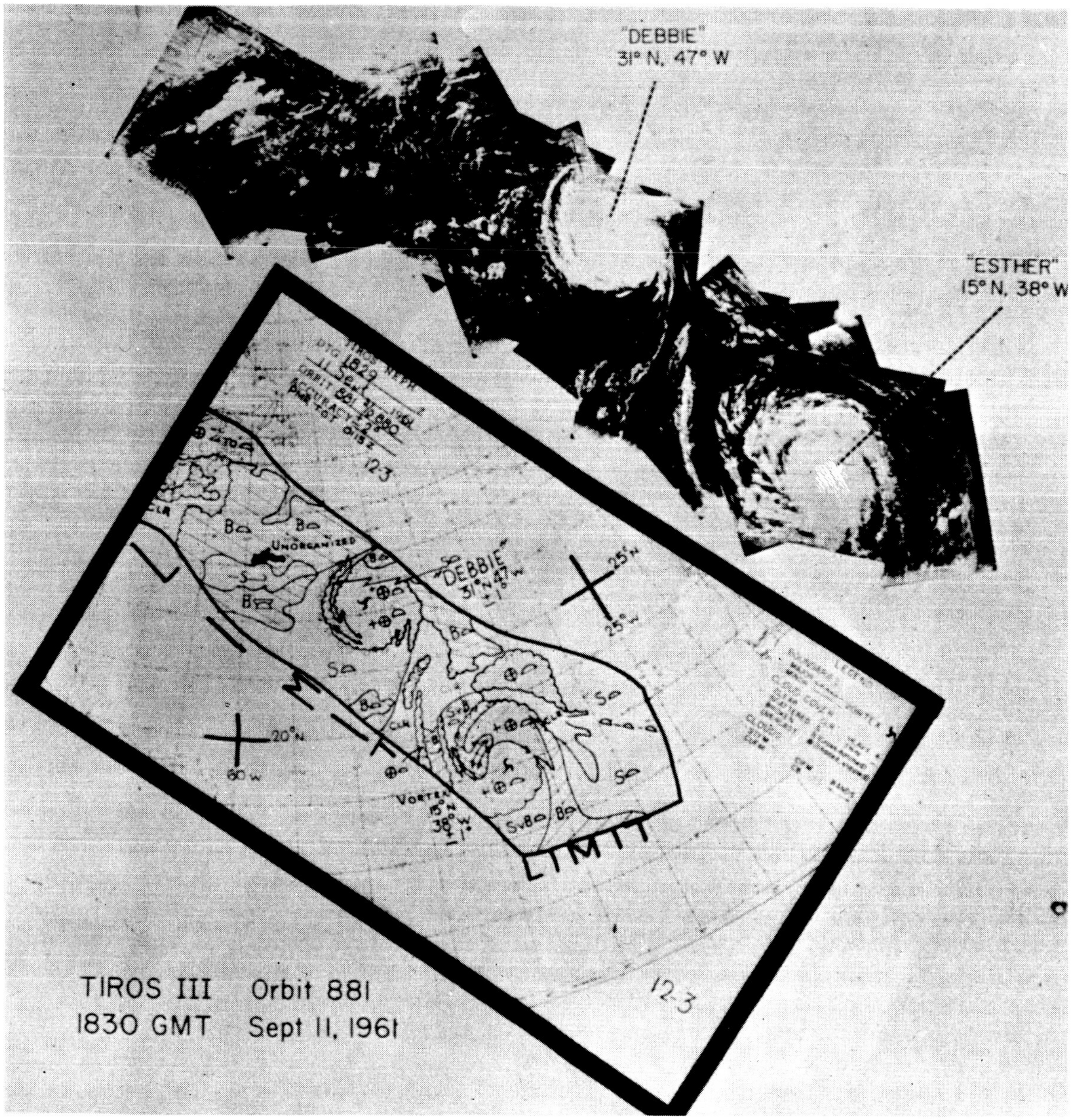

Figure 6--Hurricanes Esther and Debbie, Taken by TIROS III

stereographic projection. The same figure shows the nephanalysis prepared in this manner.

A most successful day in August 1961 produced Figure 7, which is a composite nephanalysis prepared from TIROS III and TIROS IV shown on a polar stereographic projection. A large number of vortices is shown on this map, including that of Typhoon Katie, which was then at its most dangerous state. Numerous similar occurrences during the past 2 years have proved conclusively the usefulness of weather satellites, and have yielded a great amount of operational data for the weather analysis system.

Figure 8 is a picture of unique interest to this area. Taken by TIROS III in the spring, it shows the Mediterranean, the Riviera coast, and the snow-covered Alps. There are very few clouds in this picture, located primarily at the upper and lower left. Comparison with maps will identify many landmarks, particularly Lake Leman, many of the lakes in northern Italy, and a large number of the dark valleys visible in the picture. Resolution is not sufficient to identify manmade objects such as the larger towns of Geneva or Genoa which are included in the photograph.

As an example of infrared data received, the classic midnight cloud-cover picture obtained by TIROS II over New Zealand is shown in Figure 9. The spin axis of TIROS II was at an angle of approximately 45 degrees to the earth's surface; the optical axis therefore is nearly vertical in the center of the scan. Thermal isolines are plotted on the picture from measurements in the 12-micron window, and a nephanalysis is superimposed, showing good correlation between the cloud pattern existing on that day and the measurement made by the satellite.

Another example of infrared measurement is given by comparison of the next two pictures. Figure 10 was taken by TIROS III in an orbit passing over Venezuela and South America from northwest to southeast. Hurrican Anna was in the picture at that time, together with other large cloud masses. The IR measurements received during the same orbit from the channel measuring terrestrial thermal emission are shown in Figure 11, and the very low temperatures of the high-altitude clouds of the hurricane are evident.

It has been mentioned before that the spin axis must point in a desirable direction so that pictures may be taken; this is also necessary in order to optimize the spin-sun line angle for best power input into the satellite. Magnetic torquing is therefore used to exercise coarse control over the satellite spin axis. A coil of wires is wound around the circumference of the satellite; upon command, current increments are sent through this coil to change the magnetic moment of the satellite. Interaction of this electromagnet with the earth's magnetic field permits torquing the spin axis. TIROS I did not have this feature, and the

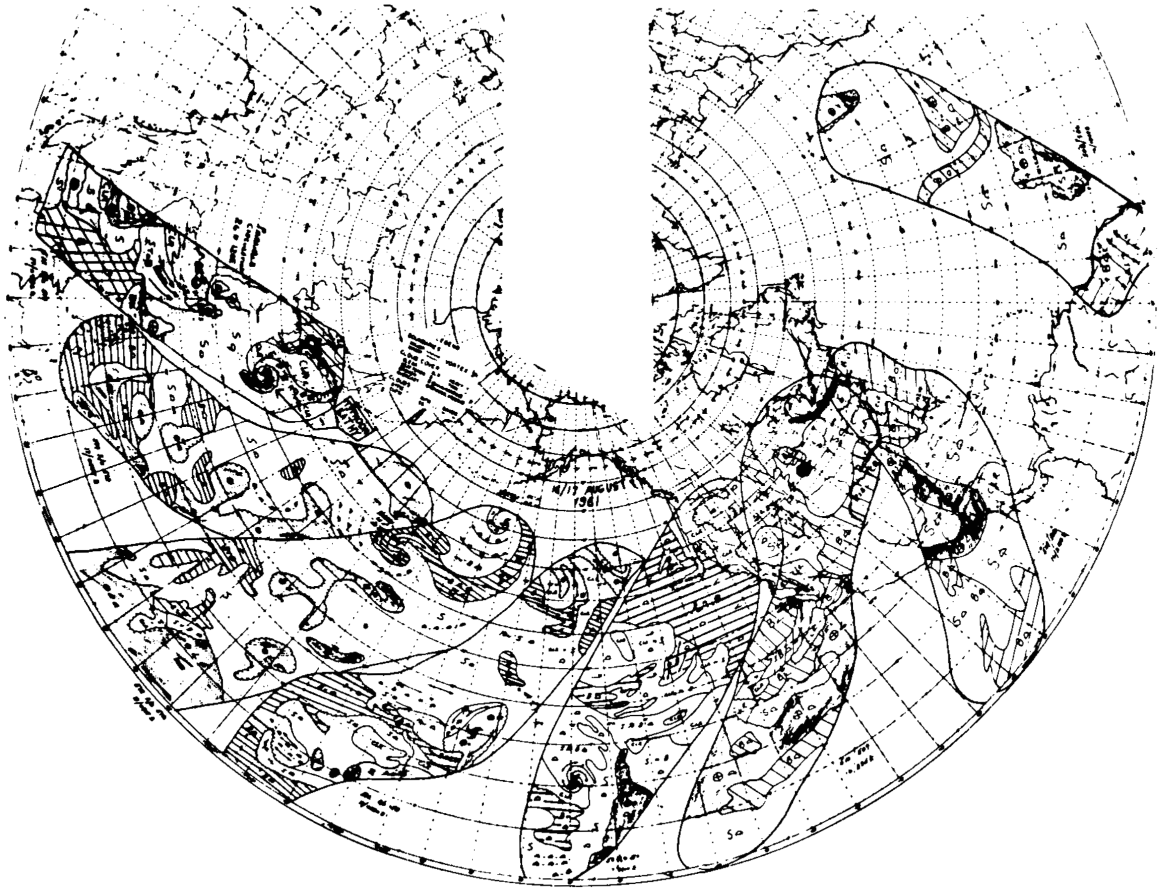

Figure 7--Composite Nephanalysis from TIROS III and IV

Figure 8–Snow on the Alps, Taken by TIROS III

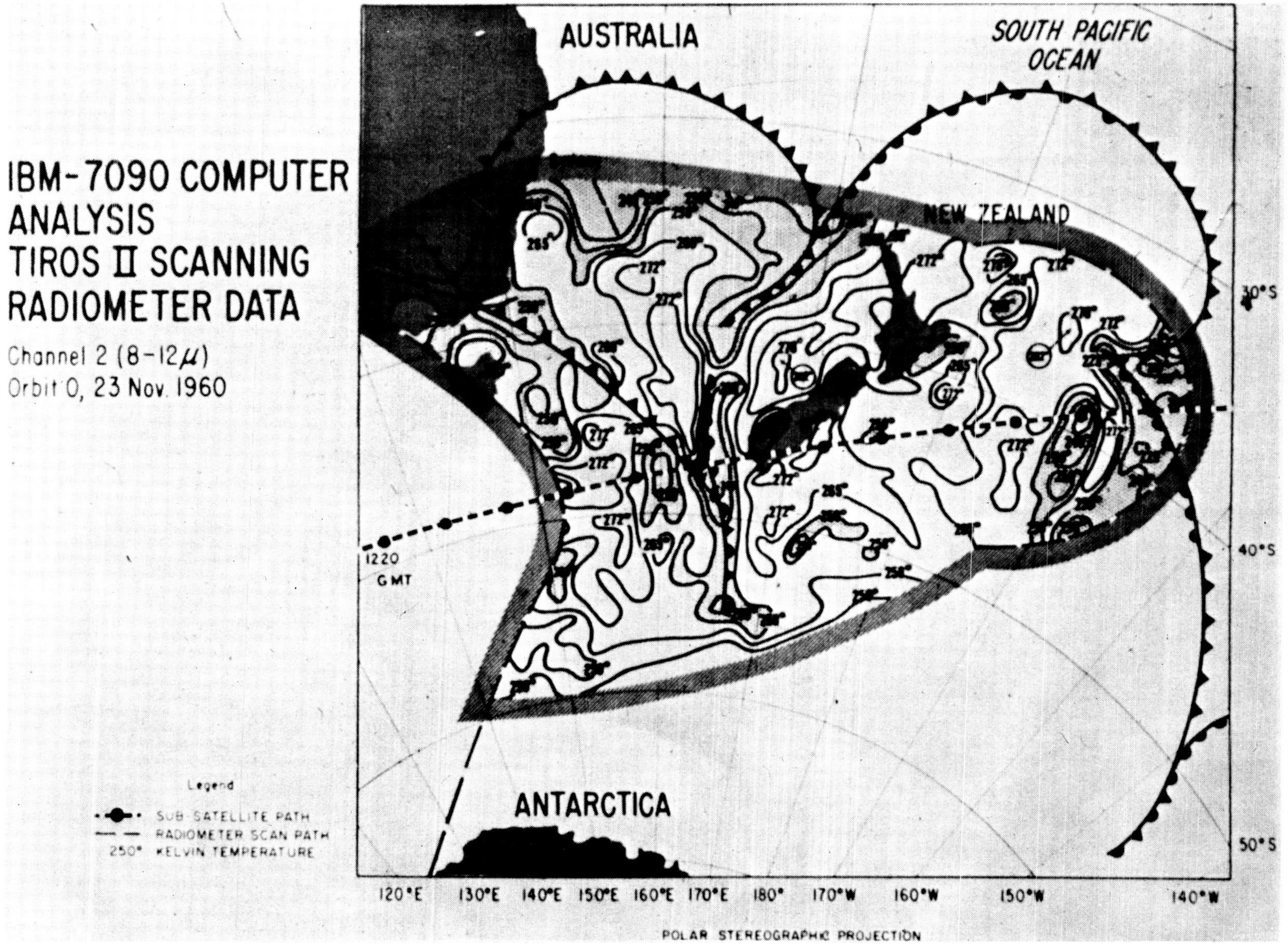

Figure 9–Cloud Cover Analysis over New Zealand, Taken by TIROS II

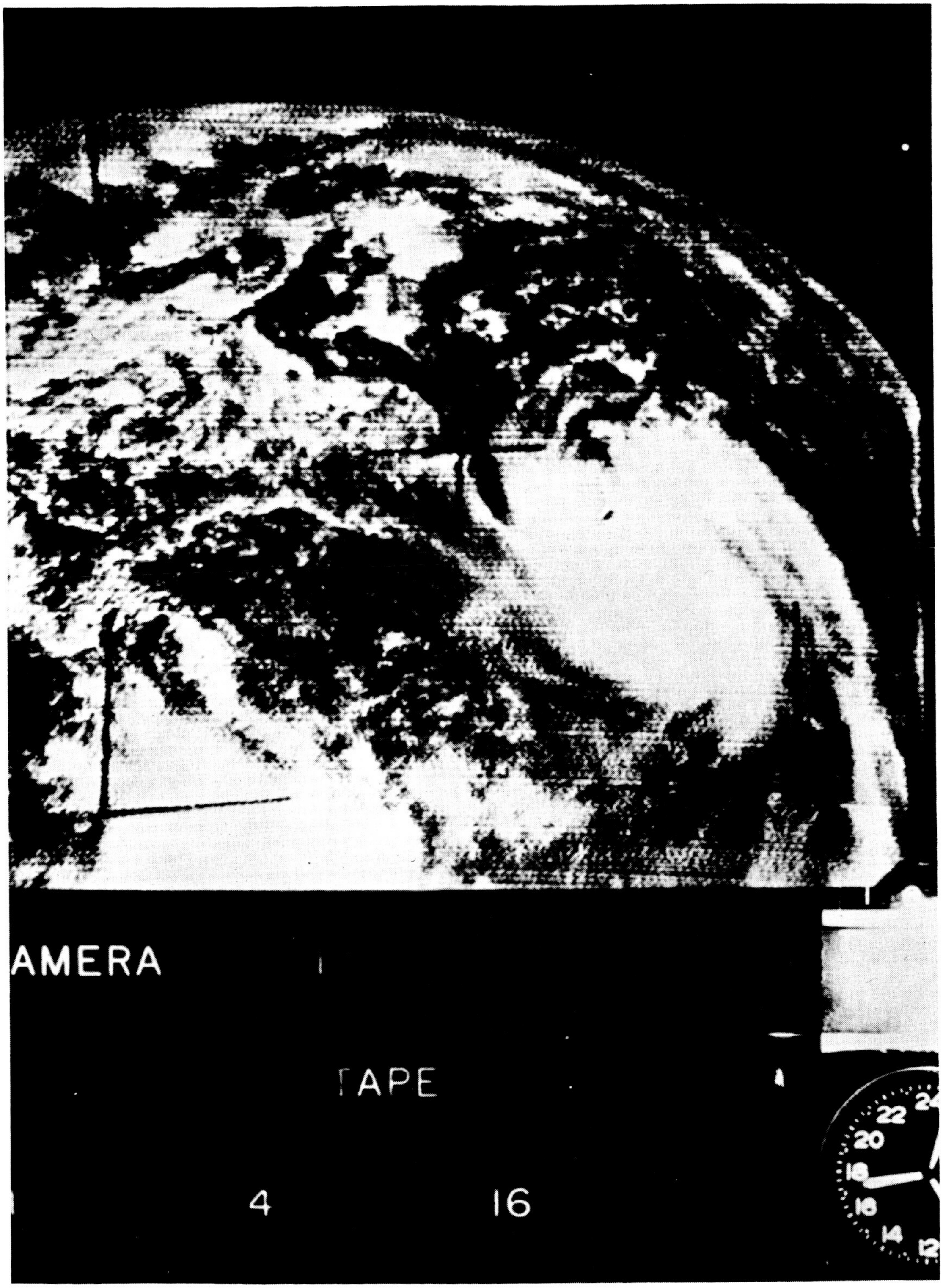

Figure 10–Hurricane Anna, Taken by TIROS III

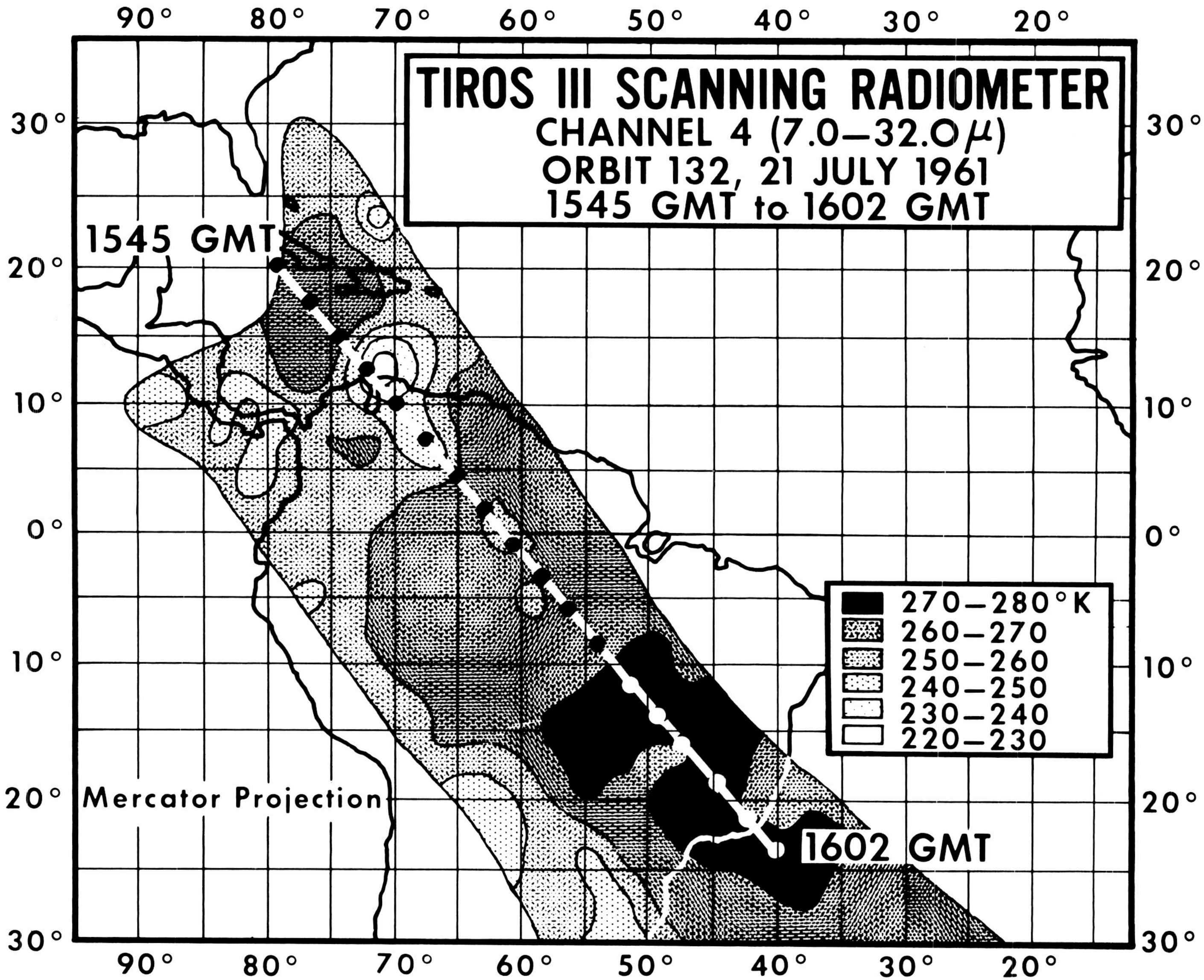

Figure 11–Infrared Measurements of Hurricane Anna

regular motion of the spin axis is shown in Figure 12, using an alpha-delta plot. A point on this graph shows the pointing of the spin axis in space, in terms of the conventional earth-centered astronomical coordinate system; two angles, declination (delta) and right ascension (alpha) suffice to define this vector. Dates shown on the graph represent the location of the spin axis as a function of satellite lifetime in orbit. Figure 13 shows the movement of the spin axis of TIROS V, which had an operating lifetime of 11 months. Similar plots have been prepared for TIROS II, III, and IV, and are in process of preparation for VI and VII. The technique of magnetic torquing has performed very well, and offers a reliable and simple means of controlling the pointing of a satellite in orbit in slow motions.

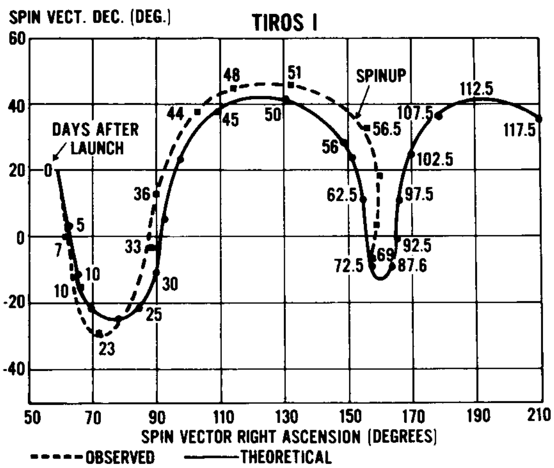

Figure 12–Alpha-Delta Curve
of TIROS I Spin Axis

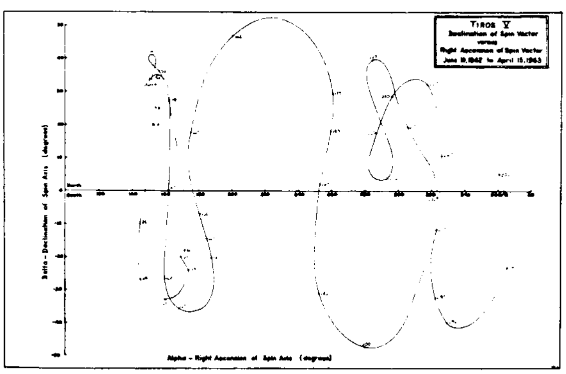

Figure 13–Alpha-Delta Curve
of TIROS V Spin Axis

The seven TIROS launches performed to date have all resulted in good orbits. Orbital characteristics and some other performance data are given in Table I.

Table I

TIROS	I	II	III	IV	V	VI	VII
Launch date	4/1/60	11/23/60	7/12/61	2/8/62	6/19/62	9/18/62	6/19/63
Apogee (km)	753	742	820	844	971	711	648
Perigee (km)	690	608	736	710	590	684	621
Inclination (deg)	48.40	48.57	47.90	48.30	58.10	58.32	58.20
Period (min)	99.15	98.18	100.49	100.47	100.55	98.73	97.40
Useful TV life (days)	77	76	145	120	325	Op'g.	Op'g.

As the table shows, TIROS satellites have been launched at an average rate of two per year from 1960 to 1963, and nearly circular orbits have been achieved in all cases. Note that the inclination was changed to a higher latitude between TIROS IV and V so that wider television coverage could be obtained. The table also shows the number of days of satellite lifetime during which useful television pictures have been received. A consistent increase in useful lifetime can be noted, starting with TIROS I to TIROS IV, with a distinct increase in reliability from TIROS V on.
What is the quantity of pictures received from TIROS satellites, and how many nephanalyses could be prepared from them? Table II, which contains statistics on this production, shows that TIROS compares favorably in this respect with terrestrial communications systems, although the latter can be designed for familiar environments and for long-life operation, and are operated mostly with someone in attendance. The table also shows the usability factor calculated in percentage.

A microfilm of every usable picture is kept at the National Weather Records Center, Asheville, North Carolina.

Although these data accurately reflect the number of useful television pictures, they do not distinguish between orbits of poor satellite performance and poor performance caused by communications difficulties at the ground station. A certain percentage of ground-station malfunction is attributable to equipment difficulties or adverse weather conditions.

Table II*

TIROS	Total no. of pictures	Meteorologically usable	Percent usable	Nephanalyses
I	22,952	19,389	84.4	333
II	36,156	25,574	70.7	455
III	35,033	24,000	68.5	755
IV	32,593	23,370	71.8	836
V	55,877	47,461	84.6	1783
VI	45,726	40,729	89.0	1401

*As of April 1963

Accurate tracking by the big movable installations is impaired by high winds or by ground equipment limitations. In general, it is more difficult to obtain good data from the San Nicolas Island station than from Wallops Island, because the data are sent by ground microwave communications links from San Nicolas to the mainland. The reliability factor of this link must be included in considering the resultant lower performance.

Performance of a system can be appraised in two ways: either by listing and examining the amount of data obtained, or by observing the performance and the malfunction which finally leads to inoperability of the system. Mention of the failures in no way diminishes the unequalled success of the TIROS series; on the contrary, it is valuable in showing which of the components are weak links in the system, and in demonstrating the road to improvement and eventual achievement of longer satellite life.

One camera chain in TIROS I experienced intermittent operation shortly after launch. The second camera chain performed very well over a period of 77 days, until a component failure prevented shutdown of the transmitter, which finally caused the power supply to be drained and prevented recharge. TIROS I did not carry an infrared subsystem.

Long after the useful life of TIROS II had ended, television pictures were still being received on an intermittent basis, indicating that the subsystem still performed although on a degraded level. The last television picture was received after 301 days of orbital life. The infrared subsystem carried on this satellite yielded useful data for 141 days, at which point the radiometer failed. The last interrogation of the remaining portion of the subsystem took place after 525 days. This is believed to be the longest continuous operation of a rather complex subsystem in orbit to date. General deterioration of the command and power subsystems finally prevented interrogation of the satellite, and the exact cause of final failure could not be determined.

TIROS III encountered trouble soon after launch in one of the two TV subsystems, because of failure in the camera shutter drive circuit. From the 12th day (when the failure occurred) until the 102nd day, the other camera carried on routine operation and delivered some spectacular hurricane pictures. After 128 days, the power supply became severely overloaded because of a short in the camera controls of the system which had already experienced shutter-drive failure; routine operation had stopped after 102 days because of general vidicon deterioration, however, so that the drain on the power supply was not the cause for complete termination. Finally, after 145 days, the tape recorder associated with the deteriorated but otherwise functioning camera failed, making abandonment of TIROS III advisable except for coarse tracking and occasional interrogation. The last picture (direct) was received on day 236.

The infrared subsystem as an instrument performed less satisfactorily than the one on TIROS II, although the data received were more accurate because of better initial calibration. Channels 3 and 5 degraded soon after launch, and channels 1 and 3 rapidly after 8 and 9 days respectively. A tape-recorder clutch engaged during playback did not disengage properly during the record cycle, but dragged intermittently after a few days in orbit. Although this difficulty resulted in only a small loss of data, it (or some other malfunction) made the tape recorder completely inoperable after 210 days. TIROS IV performed similarly to TIROS III.

One camera chain of TIROS V performed for approximately 11 months. The satellite did not carry an infrared subsystem, and the other television chain experienced a vidicon-filament failure soon after launch. TIROS VI is still operating routinely, ten months after its launch in September 1962. One of its two cameras failed in December 1962, after 74 days of successful operation; the other camera chain is performing without deterioration.

As the tables show, the quantity of data received from the TIROS satellites is enormous. Much manual operation is involved, putting a strain on the expeditious evaluation of perishable data. Weather changes continuously, and it is imperative that satellite-gathered data be analyzed and disseminated as fast as possible if it is to be of use in making forecasts. Present time spans are still too long, and considerable effort will be made over the next few years to shorten them.

From the point of view of information theory, the present TIROS system and the more advanced one, Nimbus, are wasteful in their channel capacity. Examination of pictures and resulting nephanalyses points this out clearly. As the meteorologically useful information in the pictures totals much less than the picture content, less information–and therefore less time–should suffice to deliver useful information to the meteorological community. Much effort needs to be expended on these problems in the future.