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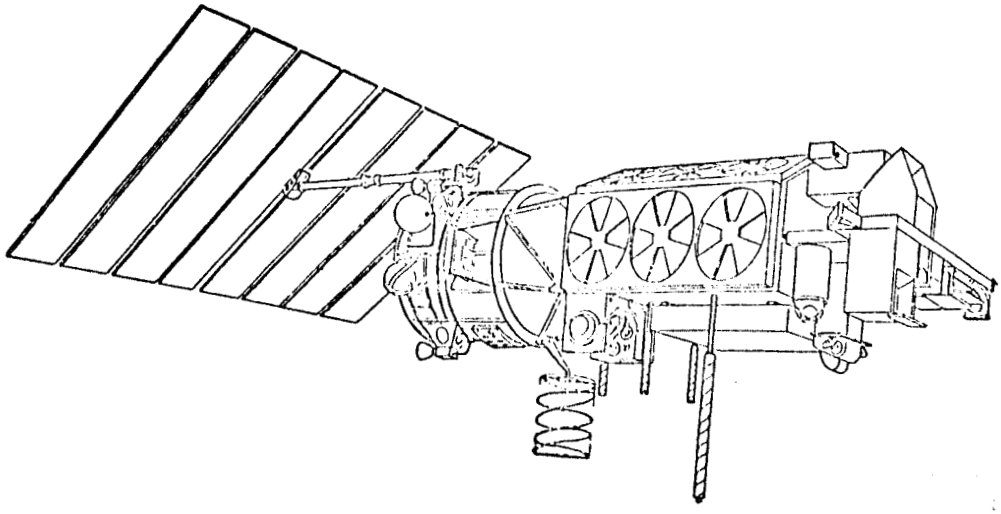
THE TIROS-N POLAR ORBITING ENVIRONMENTAL SATELLITE SYSTEM



1978

by

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TIROS-N GROUND SYSTEM PROJECT MANAGER

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NATIONAL ENVIRONMENTAL SATELLITE SERVICE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

U.S. DEPARTMENT OF COMMERCE

WASHINGTON, D.C.

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TIROS Satellites and Satellite Meteorology

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ABSTRACT

The Improved TIROS Operational Satellite (ITOS), launched in its current configuration with radiometers as NOAA-2 in October 1972, is the present type of NOAA polar orbiting operational satellite. The current NOAA-5 ITOS spacecraft is the last of this second generation series of operational polar orbiting satellites.

The third generation polar system, TIROS-N, carries into space new environmental instruments which are major technological advances over the ITOS instrumentation. Specifically these new capabilities include:

(1) Higher resolution, day and night cloud cover observations on a local and global scale.

(2) Improved observations of vertical temperature and water vapor profiles on a global scale.

(3) First operational flight of a high capacity data collection/relay and platform location system.

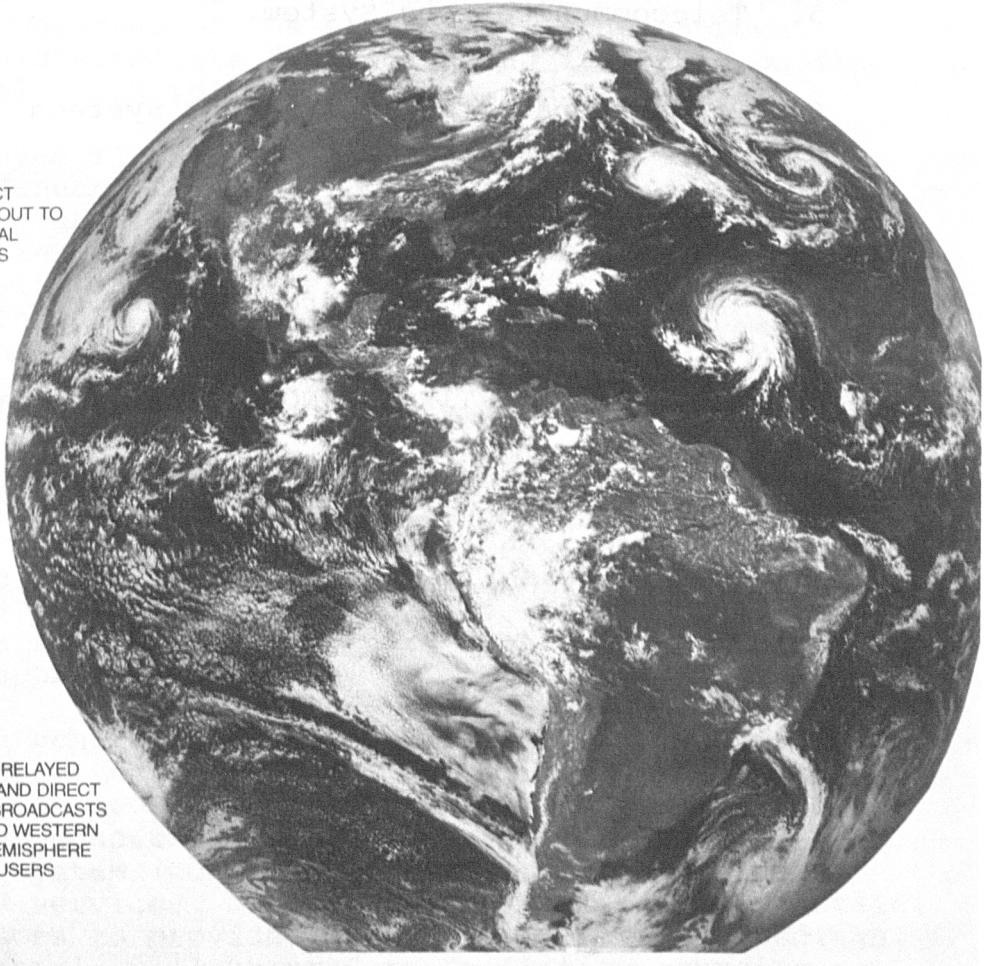
This paper emphasizes the satellite and ground system capabilities of interest to the users of direct readout services from this new system.

NOTE: This paper was presented at the Tenth Session of the ESCAP/WMO Typhoon Committee on October 28, 1977 in Tokyo, Japan.

NATIONAL ENVIRONMENTAL SATELLITE SERVICE

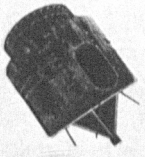
DIRECT
READOUT TO
GLOBAL
USERS

TIROS·N
POLAR
ORBITING
SATELLITE



SMS/GOES
GEOSTATIONARY
SATELLITE

RELAYED
AND DIRECT
BROADCASTS
TO WESTERN
HEMISPHERE
USERS



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1. INTRODUCTION

The third generation polar system, TIROS-N, scheduled for launch in mid-1978 and the first follow-on spacecraft, NOAA-A, to be launched in the fall of 1978 will mark the beginning of a new era of environmental satellite operations. The new TIROS-N system has evolved from the world's first meteorological satellite, TIROS-1, which was launched into orbit on April 1, 1960 from Cape Canaveral, Florida. This spacecraft was cylindrically shaped, 57cm high and 107cm in diameter and weighed about 136kg.

The TIROS-1 type spacecraft evolved to the TIROS Operational Satellite (TOS) which was first launched on February 3, 1966. These "wheel-type" TOS satellites were designed to fill the need for a relatively low cost, fully operational weather satellite system to provide worldwide photographic coverage of the earth and its atmosphere. In effect, this satellite "rolled" along its orbit on its rim as a wheel would roll along the earth's surface.

The Improved TIROS Operational Satellite, ITOS-1, launched on January 23, 1970 ushered in the second generation polar orbiting satellite system. It dramatically exceeded the capabilities of the first generation TOS system. The ITOS spacecraft is approximately a cube, 102cm by 102cm by 122cm and weighs 284kg. This satellite is earth oriented, stabilization being provided by a flywheel rotating at 150rpm. The Solar Proton Monitor flown on the ITOS satellites was the first non-meteorological instrument to be carried on the operational satellites. The currently operational and last of the ITOS series spacecraft, NOAA-5, was launched on July 29, 1976. Based on the previous history of the ITOS sensor performances, it is predicted that the APT services will continue to be available from either NOAA-4 or NOAA-5 until late 1978. It is also predicted that we may lose the HRPT services in early 1978 if past instrument performance records are approximated.

The third generation polar orbiting system, TIROS-N, is currently scheduled for launch on an Atlas launch vehicle in May 1978 and the second of the series, NOAA-A, in September 1978. The two-spacecraft TIROS-N system will overlap the current ITOS system (NOAA-5) for a short time to assure uninterrupted services. The TIROS-N satellite will contain advanced sensors to provide improved temperature soundings. Microwave channels will be used to facilitate sounding retrieval in cloudy areas. This satellite will provide advanced multi-channel images and will have a new data collection and platform location system on-board. The design lifetime for this operational spacecraft is two years. During the lifetime of the TIROS-N series, new sensors or instruments may be added or substituted for others. Therefore, the spacecraft is designed for a growth capability of 25 percent in terms of weight, volume, power, command, and telemetry.

2. SPACECRAFT DESCRIPTION

The TIROS-N spacecraft as shown in Figure 1 is a five-sided box-like structure which is 3.71 meters long and 1.88 meters in diameter. Four of the side faces are equal in size and accommodate thermal control louvers. The fifth side is wider than the other four and accommodates the earth-facing communications antennae and some of the earth viewing sensors. The spacecraft will weigh a total of 1409kg at launch including expendables.

At one end of the central body known as the Equipment Support Module (ESM) is the Reaction Support Structure (RSS) which includes the last stage launch injection motor, an attitude control propulsion system and a boom-mounted solar cell array. The solar array is 11.6 sq. meters in size and it is motor driven to rotate once per orbit so that it will continuously face the sun during the daylight portions of the orbit.

At the other end of the ESM is the highly stable Instrument Mounting Platform (IMP) on which are mounted the attitude control sensors and the instruments whose scan directions must be very accurately controlled. With the exception of the Space Environment Monitor (SEM), all instruments face the earth when the satellite is in its mission mode. The earth oriented platform will be controlled to within $\pm$ 0.2° of the local geographic reference for all axes.

A most important spacecraft subsystem is the data handling subsystem which consists of four primary components:

1. TIROS Information Processor (TIP)
2. Manipulated Information Rate Processor (MIRP)
3. Digital Tape Recorders
4. Cross Strap Unit

All data available for transmission to the ground are processed by some or all of these components. The TIP formats all low bit rate instrument and housekeeping telemetry data and controls the data outputs. The instrument data which are processed by the TIP include the TIROS Operational Vertical Sounder (TOVS), the Space Environment Monitor (SEM), and the Data Collection System (DCS).

The MIRP processes the high bit rate data from the Advanced Very High Resolution Radiometer (AVHRR) in order to provide separate outputs for Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) transmissions in real time, recorded Global Area Coverage (GAC) of reduced resolution data for central processing and recorded Local Area Coverage (LAC) of high resolution data also for central processing. LAC is similar to the recorded HRPT data of the present ITOS system known as VREC.

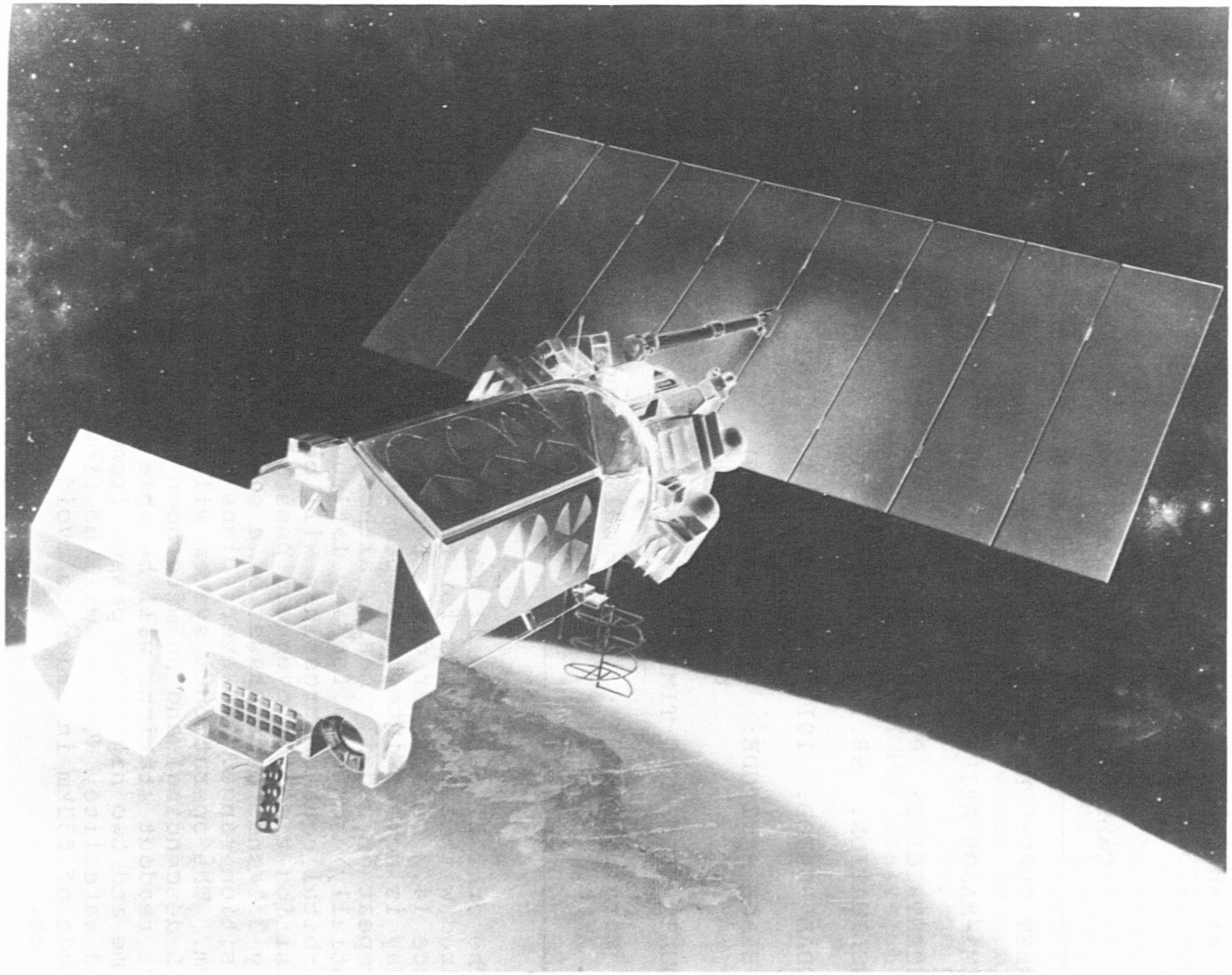


Figure 1. TIROS-N Spacecraft

3. ORBIT DESCRIPTION

The initial TIROS-N spacecraft will be launched into an afternoon orbit with local equator crossing at 1500L. As shown in Table 1, it will be in a near polar, sun synchronous orbit at an average altitude of 870km as compared with the average 1475km altitude of the current ITOS/NOAA satellites.

Table 1. TIROS-N/NOAA ORBIT PARAMETERS

ORBIT TYPE:	Near Polar, Sun Synchronous
SEMI-MAJOR AXIS:	7211.54km
ECCENTRICITY:	0.0000064
INCLINATION:	98.70 degrees
NODAL PERIOD:	101.58 minutes (14.2 orbits per day)
AVERAGE ALTITUDE:	870km (TIROS-N) 833km (NOAA-A)
EQUATOR CROSSING TIMES:	
Morning Orbit:	0730 Local Descending (NOAA-A)
Afternoon Orbit:	1500 Local Ascending (TIROS-N)

The orbital period will be 101.58 minutes for TIROS-N as compared with 115 minutes for the ITOS satellites. This will produce 14.2 orbits per day. Because the number of orbits per day is not an integer number, the suborbital tracks do not repeat on a daily basis, although the local solar time is essentially unchanged for any latitude. For this reason, the orbital equator crossings will occur at varying longitudes. Acquisition time for overhead passes will be reduced approximately 35% and fewer passes of a single satellite will be within acquisition range. However, plans call for a two satellite system. The operational system will include a morning orbit (0730L descending) and an afternoon orbit (1500L ascending). Direct readout stations will be able to acquire at least two daytime and two nighttime passes from each spacecraft. The second satellite, NOAA-A, will be flown at a somewhat lower altitude of 833km in order to avoid extended periods of readout conflict.

Orbit prediction for TIROS-N will require more sophisticated prediction techniques than those currently being used to predict ITOS/NOAA orbits. In particular, gravitational forces which are

relatively insignificant for a 1475km ITOS-type orbit become much more significant for a spacecraft operating at an altitude of 833km. Additionally, solar effects during the period of maximum solar activity in 1980 will introduce significant perturbations to the orbit.

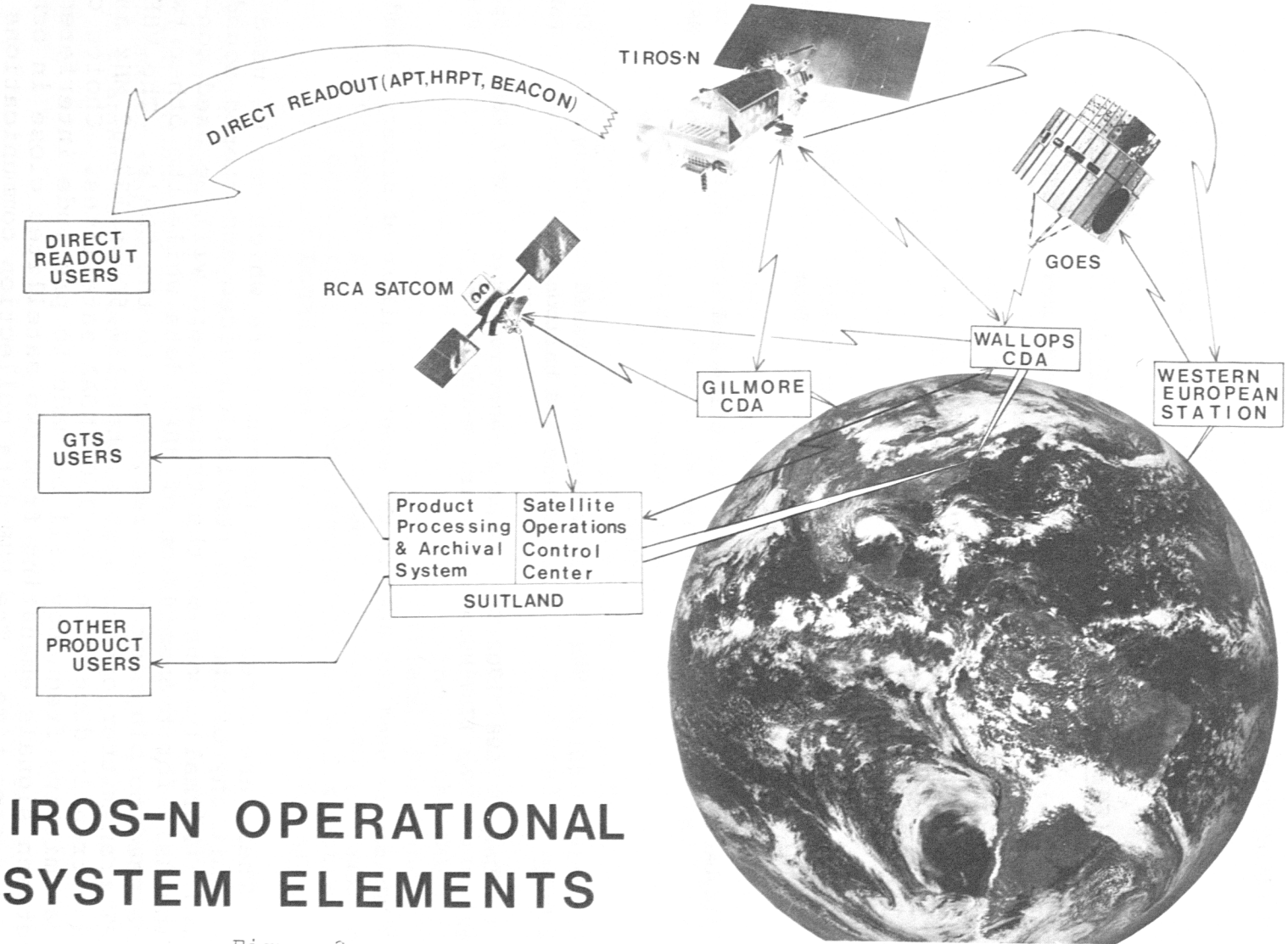
The afternoon satellite (1500L) will satisfy the majority of user needs for visible data. The morning satellite (0730L) will contain the earth's shadow in a large part of the visible imagery in the winter hemisphere. The quantitative requirements such as sea surface temperature observations are obtained from the thermal infrared data and are not affected by orbit times. Considerable analysis was performed to select the equator crossing times to provide the geographic coverage per synoptic data window and timely data retrieval and processing to meet the National Meteorological Center (NMC) analysis cycles.

4. TIROS-N OPERATIONAL SYSTEM ELEMENTS

Figure 2 depicts the major elements of the new TIROS-N operational system. The two primary Command and Data Acquisition (CDA) stations are located near Gilmore Creek, Alaska and Wallops Island, Virginia. The spacecraft programming and commanding will originate at the Satellite Operations Control Center (SOCC) located in Suitland, Maryland. The commands and spacecraft telemetry data will be relayed through a commercial satellite communications network between SOCC and the Gilmore CDA. The CDA's will communicate with the spacecraft using the S-band link and will readout the data stored on the satellite's digital tape recorders in addition to the real-time data.

During three sequential orbits and occasionally four on some days, the spacecraft cannot be acquired at either of the two CDA stations. To eliminate time delay in the receipt of the high priority sounding data, a Western European readout station is being established at Lannion, France as a joint venture of the United States and France. This station will acquire the stored sounding data and transmit it to the U.S. using the Data Collection System of the eastern GOES satellite located at 75°W longitude. Use of this readout station will reduce periods when the TIROS-N satellite is out of contact with the ground to a maximum of one orbit per day. The direct readout users will be able to receive APT, HRPT and sounding data via the satellite beacon telemetry system. The direct readout imaging capability is discussed in Section 7 of this paper.

The other major component of the TIROS-N system is the central product processing and archiving system. The stored data is recorded at the CDA's and then it is played back at a high data rate (1.33 megabits/second) via the commercial satellite link to Suitland. There, the raw satellite data are ingested, preprocessed and stored along with appended auxiliary information such as earth location and quality control parameters. The data are then archived on digital tape for later use and also passed on to the large NOAA computers (IBM 360/195's) for the generation of quantitative products to be distributed to the user community via the Global Telecommunication System (GTS) and other methods within the United States.



TIROS-N OPERATIONAL SYSTEM ELEMENTS

Figure 2

5. TELECOMMUNICATIONS SYSTEM

The TIROS-N telecommunications system consists of S-band, UHF and VHF data links. Table 2 below summarizes the characteristics of the TIROS-N data communication links, excluding the VHF command link.

Table 2. COMMUNICATIONS LINK SUMMARY

	Link	Carrier Frequency	Information Signal	Baseband Bandwidth	Modulati
1.	Beacon	137.77 MHz or 136.77 MHz	Low bit rate instrument data and spacecraft telemetry, all from TIP.	8320 bps	Split-ph PSK
2.	VHF Real-time - APT	137.50 MHz or 137.62 MHz	Medium resolution video data from MIRP.	2 kHz	AM/FM
3.	S-band Real-time - HRPT	1698 or 1707* MHz	High resolution video data and TIP data from MIRP.	665.4 kbps	Split-ph PSK
4.	S-band playback to CDA's	1698, 1702.5 or 1707 MHz	High resolution and medium resolution video data from MIRP.	2.6616 Mbps	Randomiz NRZ-PSK
5.	Data Collection (Uplink Only)	401.65 MHz	Data from earth based platforms and balloons.	400 bps	Split-ph PSK
6.	S-band TIP Data Playback	1698, 1702.5 or 1707 MHz	TIP data recovered from on-board recorders.	332.7 kbps	Split-ph PSK

*1702.5 MHz may be used for HRPT in the event of failure of primary S-band transmitters.

There are three S-band transmitters which can be used to transmit any of the high resolution video and stored sounding data. Normally, one of the transmitters will be used continuously for transmission of HRPT data while the other two are used to playback tape recorders to the CDA's. The VHF APT transmitter operates at either 137.50 or 137.62 MHz as is currently done with the ITOS/NOAA satellites. Choice of transmitting frequency will be made to preclude interference between signals emanating from two satellites close in orbit at the same time. The UHF data collection communications frequency is for uplink only from earth-based platforms and balloons.

6. PRIMARY SPACECRAFT INSTRUMENT SYSTEMS

The four primary spacecraft instrument systems are listed below:

A. Advanced Very High Resolution Radiometer (AVHRR)
B. TIROS Operational Vertical Sounder (TOVS)
C. Data Collection System (DCS)
D. Space Environment Monitor (SEM)

A. Advanced Very High Resolution Radiometer (AVHRR)

The Advanced Very High Resolution Radiometer (AVHRR) will provide data for real-time transmission to both APT and HRPT users and for storage on the spacecraft tape recorders for later playback. Thus, the AVHRR instrument will continue and improve upon the present ITOS/NOAA satellite services related to stored and direct readout of radiometric data for day and night cloud mapping, sea surface temperature mapping and other oceanographic and hydrologic applications. The data from the AVHRR instrument will be available from the satellite in four operational modes:

1. Direct readout to ground stations of the Automatic Picture Transmission (APT) class, worldwide, at 4km resolution, of the visible and infrared data. Panoramic distortion will be removed.

2. Direct readout to ground stations of the High Resolution Picture Transmission (HRPT) class, worldwide, at 1.1km resolution, of all spectral channels.

3. Global on-board recording of 4km resolution data from all spectral channels Global Area Coverage (GAC) for commanded readout for processing in the NOAA central computer facility at Suitland, Maryland.

4. On-board recording of data from selected portions of each orbit at 1.1km resolution of all spectral channels Local Area Coverage (LAC) for central processing.

The AVHRR for TIROS-N and four follow-on spacecraft is sensitive in four spectral regions (see Table 3 below). A future change in the instrument design will add a fifth channel in the 12 micrometer region. The resulting five channel instruments are thus planned for flight on later spacecraft in the series.

Table 3. TIROS-N AVHRR CHANNEL CHARACTERISTICS

Channel*	Resolution at Subpoint	Wavelength (μm)	Primary Use
1	1 km	0.55 - 0.90	Daytime cloud and surface mapping
2	1 km	0.725 - 1.10	Surface water delineation
3	1 km	3.55 - 3.93	SST, nighttime cloud mapping
4	1 km	10.5 - 11.5	SST, day/night cloud mapping
5	1 km	11.5 - 12.5	SST

*Channel 1 wavelength will be 0.58-0.68μm for all instruments after the TIROS-N flight model. Channel 4 wavelength will be 10.3-11.3μm for all AVHRR/2 instruments. Channel 5 will not be on early AVHRR/1 flights but will be added with the AVHRR/2 instrument to further enhance Sea Surface Temperature (SST) measurements in the tropics.

AVHRR Channels 1 and 2 will be used to discern clouds, land-water boundaries, snow and ice extent; and when data from the two channels are compared, an indication of ice/snow melt inception. The data from Channel 4 (IR window) will be used to measure cloud distribution day and night and to determine the temperature of the radiating surface. Channels 3 and 4 will be used to determine the Sea Surface Temperature (SST). By using these two data sets, it is possible to remove an ambiguity introduced by clouds filling a portion of the field-of-view.

Figures 3 and 4 show sample HRPT products from the current ITOS/NOAA VHRR instrument. TIROS-N AVHRR HRPT products will be similar, but improved. Figure 3 shows an enlargement of a portion of a NOAA-5 VHRR infrared image extending from Cape Hatteras northward to Cape Cod taken on May 1, 1977. Warmest temperatures such as the Gulf Stream appear black, while objects with the lowest temperatures such as clouds appear white. Figure 4 shows a VHRR visible image from NOAA-3 taken on August 24, 1974 showing hurricanes Ione (lower left) and Kirsten (upper right) over the tropical eastern Pacific Ocean. Of particular note are the well defined storm "eyes" easily discerned in the picture.

B. TIROS Operational Vertical Sounder (TOVS)

The TIROS Operational Vertical Sounder (TOVS) system combines data from three complementary sounding instruments aboard the spacecraft.

Figure 3. NOAA-5 VHRR IR image taken on May 1, 1977 showing the Gulf Stream and warm eddies along the west edge.

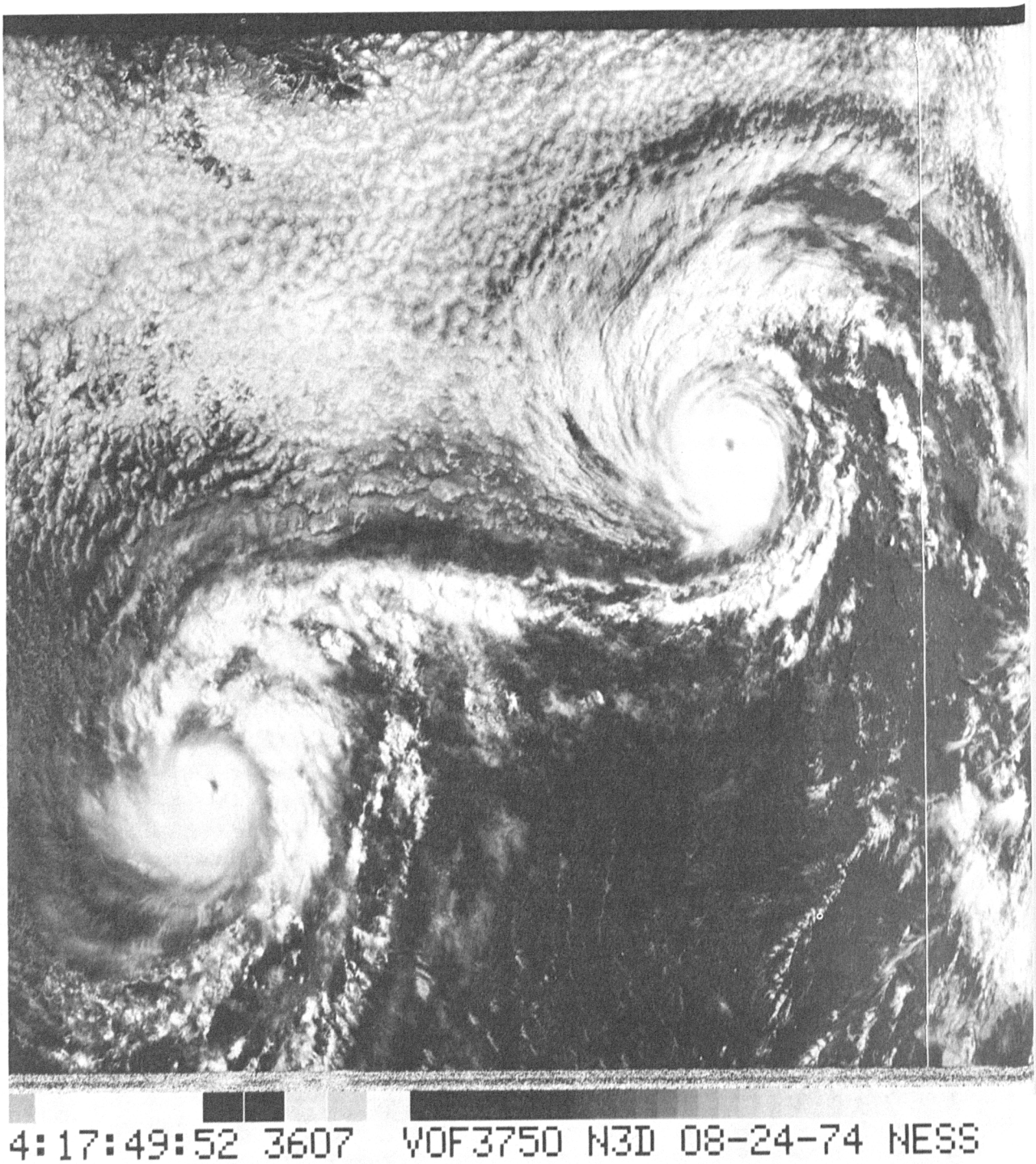


Figure 4. NOAA-3 VHRR visible image taken on August 24, 1974 showing twin hurricanes Ione (lower left) and Kirsten (upper right) in the eastern Pacific Ocean.

These instruments are as follows:

1. High Resolution Infrared Radiation Sounder (HIRS/2)
2. Stratospheric Sounding Unit (SSU)
3. Microwave Sounding Unit (MSU)

The primary instrument providing tropospheric data, HIRS/2, is sensitive to energy from the visible to the CO_2 region of the infrared spectrum. This instrument is designed to provide data that will permit calculation of temperature profiles from the surface to 10 mb, water vapor content at three levels of the atmosphere, and total ozone content. The SSU instrument, which is sensitive to energy in the CO_2 portion of the infrared spectrum will provide temperature information from the stratosphere. This instrument is being provided by the Meteorological Office of the United Kingdom. The third instrument, the MSU, is sensitive to energy in the oxygen region of the microwave spectrum and will be used in conjunction with the two IR instruments. The microwave data will permit computation to be made in the presence of clouds since measurements in this region are generally unaffected by non-precipitating water droplets.

Table 4 lists some characteristics of the three TOVS instruments discussed above.

Table 4. TIROS-N OPERATIONAL VERTICAL SOUNDER (TOVS) CHARACTERISTICS

Characteristic	Stratospheric Subsystem (SSU)	Tropospheric Subsystem (HIRS/2)	Microwave Subsystem (MSU)
Resolution at Subpoint	147 km	20 km	110 km
Field of View	10°	1.4°	7.5°
Spectral Regions Used	15 μm CO_2	15 μm CO_2 11 μm window 9.7 μm O_3 6.7 μm H_2O 4.3 μm CO_2 3.7 μm window 0.7 μm visible	53 GHz O_2
Number of Spectral Channels	3	20	4

Data from the TOVS instruments will be available from two separate real-time data transmission links. On-board the satellite, the TOVS data will be collected and formatted by

the TIROS Information Processor (TIP). Parallel outputs are provided for:

1. The real-time VHF beacon transmission link.

2. The Manipulated Information Rate Processor (MIRP) which combines the TIP data with the output from the AVHRR. This combined data stream is:

   a. Broadcast in real-time as the High Resolution Picture Transmission (HRPT) service.

   b. Stored on-board the satellite for later transmission to the ground.

It should be noted that all data from the TOVS are digital and that the data included within the HRPT format are identical to that broadcast on the beacon. Data from the TOVS will be available on both VHF and S-band data links. Those users receiving the high resolution transmission from the AVHRR (HRPT system) will probably find it most desirable to extract the TOVS data from this data stream. Use of two frequencies for this data is planned so that interference between transmissions from two satellites within view of a station may be eliminated. This problem is particularly severe in high latitudes where overlapping coverage is routine.

The VHF beacon data, also with two possible frequencies, is available for users who do not desire to install the more complex equipment necessary to receive data on the S-band frequencies. The lower data rates (8 kilobits/second versus 665.4 kilobits/second for HRPT) permit the user to install less complex and costly equipment to receive the data without degrading its quality.

C. Data Collection System (DCS)

The Data Collection System on-board TIROS-N is being provided by the Centre National d'Etudes Spatiales (CNES) of France. The French call this the ARGOS Data Collection and Platform Location System and it is illustrated in Figure 5. The ARGOS DCS will provide a means to locate and/or collect data from fixed and free floating buoy and balloon platforms. It will provide two new services not currently present in the geostationary satellite (GOES) data collection systems. First, it will have the capability to determine platform location, using an inverse doppler technique. Second, it will be able to acquire data from any place in the world, but most particulary in the polar regions, beyond transmission range of the geostationary satellites.

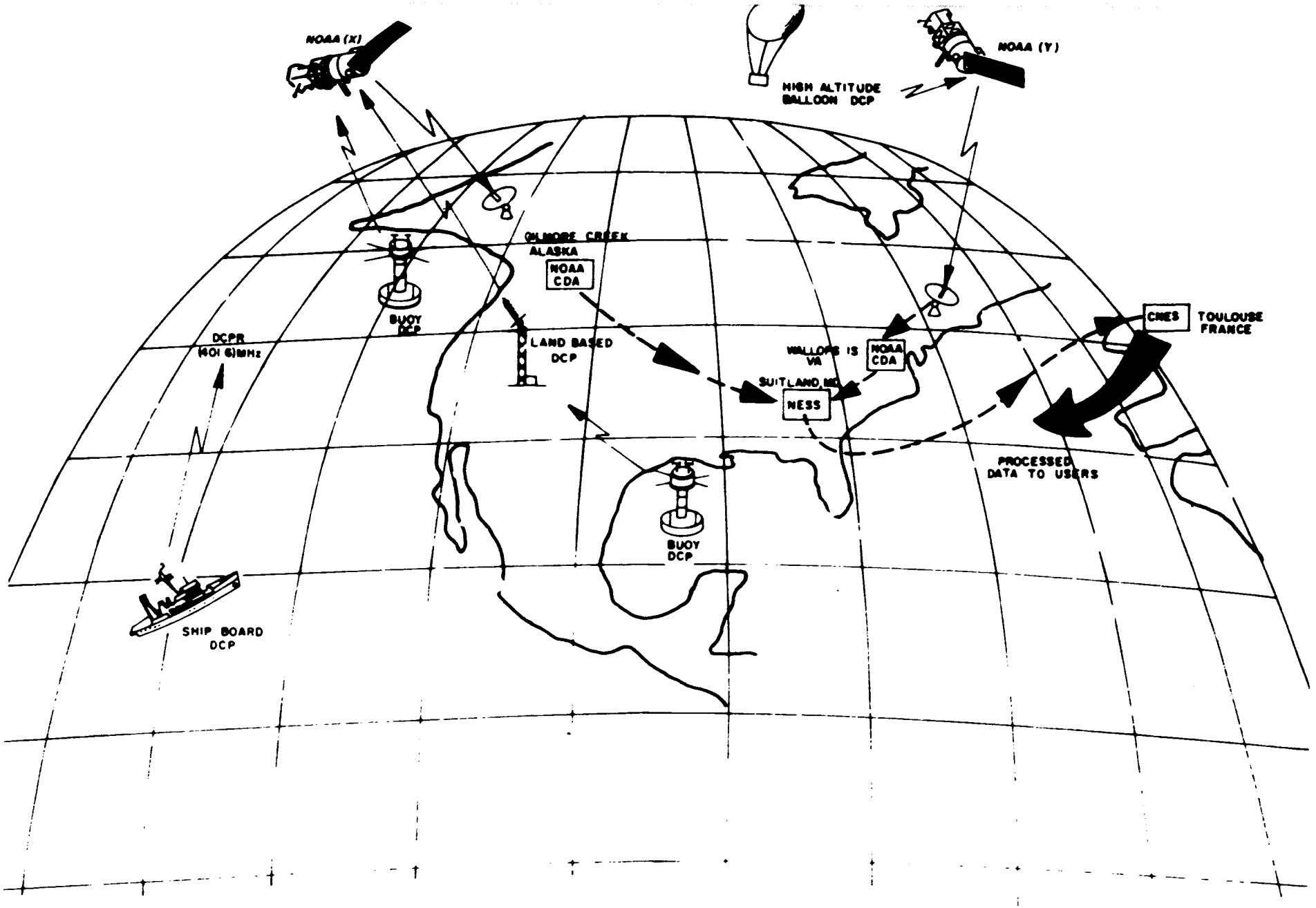


Figure 5 ARGOS DATA COLLECTION SYSTEM

The ARGOS DCS system will receive data from the platforms at UHF (401.65 MHz). The platforms will transmit independently of any interrogation from the spacecraft which uses a random access receiving system. Each platform will make continual transmissions, varying in length from 360 to 920 ms and a repetition interval from 40 to 200 seconds. As the spacecraft passes within range of a platform during its orbit, it will receive and record the successive transmissions. Once the spacecraft comes within range of a CDA, it will playback the recorded data to the ground facility. On the ground the data will be forwarded to Suitland, where the ARGOS data will be separated from the other spacecraft telemetry data and relayed to the CNES processing center at Toulouse, France. There, the platform locations will be computed and the data prepared for relay to the user. The location information is determined by measuring the platform carrier frequency received by the DCS instrument in the spacecraft at each transmission. When several transmissions are obtained from a particular platform, differential doppler techniques are used to determine the platform location to an accuracy of 3-5 km rms.

There will be a charge by CNES for the position location computations for moving platforms, except that special observing system platforms for the First GARP Global Experiment (FGGE) (e.g., the drifting buoy and constant level balloon systems) will be provided for free of charge. For non-moving platforms, there will be no charge unless special data processing is requested of the CNES processing center.

With two spacecraft operating in the TIROS-N operational system, a given platform will be in contact with the spacecraft during at least four intervals each day. The intervals will be about six hours apart. During any interval the platform will be "seen" by the spacecraft on at least two successive orbits, which would provide a minimum of eight reports a day. In the polar areas, as the orbital paths converge, many more contacts will be made. Up to twenty or more reports may be acquired, approximating the frequency of coverage available through the geostationary satellites.

The ARGOS system will also provide for the immediate rebroadcast of data received from platforms. These data reports will be included in the same data stream which contains the direct broadcast of sounder data. The spacecraft VHF beacon transmits the DCS data at the low rate. Only data from platforms so located that both the platforms and the receive site are simultaneously in view of the satellite will be available from this direct broadcast. The data in the direct broadcast will not permit platform location computations. However, for fixed platforms this may provide a simpler method of obtaining data regionally than going through the geostationary systems. In polar regions it will be the only method

available. If there is a need to obtain data from platforms more expeditiously than can be provided through the GTS or more economically then by providing separate communications, the direct readout method offers another alternative. Further information regarding the ARGOS system may be obtained by writing to:

Service ARGOS
Centre National d'Etudes Spatiales
18, avenue E.-Belin
31055 Toulouse Cedex
France

D. Space Environment Monitor (SEM)

The SEM instrument will not be flown on the initial TIROS-N spacecraft, but will be included on later flights, perhaps beginning with NOAA-A. The SEM will measure solar proton flux, alpha particle and electron flux density, energy spectrum and total particulate energy distribution at spacecraft altitude.

The three detectors included within this instrument are: (1) Total Energy Detector, (2) Medium Energy Proton and Electron Detector and (3) High Energy Proton and Alpha Detector. The Total Energy Detector measures the intensity of particles in the energy bands from 0.3 Kev to 20 Kev. The Medium Energy Proton and Electron Detector senses protons, electrons and ions in the range of from 30 Kev to around 60 Kev. The third component, the High Energy Proton and Alpha Detector, senses protons and alpha particles from 370 Kev to around 850 Mev. This instrument will augment the measurements currently being made by NOAA's geostationary GOES satellites.

The data from the SEM will be stripped out of the TIP data stream and combined with location parameters at the Suitland data processing center and transmitted over a dedicated data link to NOAA's Space Environment Laboratory (SEL) at Boulder, Colorado. These data will be transmitted within one hour of the spacecraft readout. At the SEL in Boulder, the TIROS-N data along with the GOES data will be used to monitor the state of solar activity which has a significant effect on terrestrial communications, electrical power distribution and high altitude flight in aircraft such as the Concorde SST.

7. DIRECT READOUT IMAGING SYSTEMS

Local users in line-of-sight of the TIROS-N satellite can receive real-time data directly from the spacecraft. TIROS-N will broadcast visible (VIS) and infrared (IR) data from the Advanced Very High Resolution Radiometer (AVHRR) as well as other data from the TIROS Operational Vertical Sounder (TOVS), the Data Collection System (DCS), the Space Environment Monitor (SEM), and the spacecraft housekeeping telemetry. This section will focus on the direct readout imaging systems of TIROS-N.

The AVHRR provides the data for transmission to both the Automatic Picture Transmission (APT) and High Resolution Picture Transmission (HRPT) users. The HRPT data will be transmitted at full resolution (1.1km) while the APT output will have reduced resolution (4km) to maintain bandwidth constraints. The APT system will transmit any two of the AVHRR channels (see Table 3). Once routine APT operations are established, the visible channel will be used to provide visible APT imagery during daylight and one IR channel will be used constantly (both day and night). A second IR channel will be scheduled to replace the visible channel observations during the nighttime portions of the orbit.

The HRPT system will transmit all of the channels. In order to avoid future changes on the spacecraft and in ground receiving equipment, the TIROS-N HRPT data format is being designed as though the AVHRR were already a five channel instrument. When operating with the initial four channel instrument, the data from Channel 4 (11 μm) will be inserted in the data stream twice so that the basic data format will be the same for both the four and five channel versions. Output from the low data rate system on-board the spacecraft will be multiplexed with the AVHRR data and become a part of the HRPT output available to direct readout users. The low data rate system includes the three instruments of the TOVS, the SEM, the DCS and the spacecraft housekeeping telemetry.

A comparison of the existing ITOS HRPT system to the future TIROS-N HRPT system is shown in Table 5 below:

Table 5. COMPARISON OF ITOS AND TIROS-N HRPT SYSTEMS

Parameter	ITOS/HRPT	TIROS-N/HRPT
Line rate	400 lines/minute	360 lines/minute
Data channels (spectral intervals)	2	4 (later flights will have five)
Data resolution	1.0 km	1.1 km
Carrier modulation	FM: analog	Digital split phase, PSK
Transmit frequency	1697.5 MHz	1698.0 MHz 1707.0 MHz
Transmit power	5 watts	5 watts
EIRP (approximate)	37.0 dBm	39.0 dBm
Polarization	Right hand circular	Right hand circular
Spectrum bandwidth	1 MHz	Less than 3 MHz

Note: The digital data format of the TIROS-N AVHRR transmission is one of the key differences which distinguishes TIROS-N HRPT data transmissions from those of the current ITOS satellites.

Some modifications will be required to convert present ITOS HRPT ground stations to receive TIROS-N HRPT data. These changes are briefly described below:

1) Current ITOS/NOAA HRPT data are transmitted on a center frequency of 1697.5 MHz, and require an RF bandwidth of 1 MHz. The TIROS-N HRPT data will be transmitted on either 1698.0 or 1707.0 MHz and will require an RF bandwidth of less than 3 MHz. The receiver output bandwidth (baseband) should be about 1.5 MHz. A preamplifier RF bandwidth of at least 15 MHz will be needed if the user wishes to receive HRPT from both types of satellites (ITOS and TIROS-N).

2) The TIROS-N data will be transmitted in digital form. Digital processing interface equipment will be required to achieve bit and frame synchronization and to decommutate the present four data channels. Digital to analog conversion will be necessary unless digital display devices are employed.

3) If it is desirable to record data channels not being displayed during reception, a wideband recorder capable of direct recording of the 665 Kbps high data rate signal or the decommutated channels also will be necessary. Conventional facsimile displays having a writing rate of 120 rpm or 240 rpm can only be used with data stored and clocked out at the slower rates.

The changes from the existing ITOS APT system have been limited to the following:

1) The APT data rate is changed from the 48 lines-per-minute for ITOS to 120 lines-per-minute for TIROS-N. Also, TIROS-N will utilize a "linearized scan" technique to reduce the panoramic distortion inherent in the ITOS system.

2) In order to eliminate the ITOS ambiguity, the two TIROS-N APT channels will have different synchronization rates.

3) The spacecraft transmit antenna polarization will be changed from linear to right hand circular to provide most receivers with an improved signal-to-noise ratio.

A comparison of the current ITOS APT system to the TIROS-N APT system is shown in Table 6 below.

Table 6. COMPARISON OF ITOS AND TIROS-N APT SYSTEMS

Parameter	ITOS APT	TIROS-N APT
Line rate	48 lines/minute	120 lines/minute
Data resolution	IR 7.4 km subpoint Visible 3.7 km subpoint	4 km uniform
Carrier modulation	analog	analog
Transmit frequency	137.50 MHz 137.62 MHz	137.50 MHz 137.62 MHz
Transmit power	5 watts	5 watts
Transmit antenna polarization	linear	right hand circular
Subcarrier frequency	2.4 KHz	2.4 KHz
Carrier deviation	± 9 KHz	± 17 KHz
Ground station low pass filter	Varies with station & use; 450-1600 Hz in use	1400 Hz 7th order linear recommended
Synchronization	7 pulses at 300 Hz for both channels	7 pulses at 1040 Hz 50% duty cycle for Channel A; 7 pulses at 832 Hz, 60% duty cycle for Channel B

Some minor modifications will be required to convert APT stations currently receiving ITOS data to a capability to receive TIROS-N data. These changes are described below:

1) APT data will be output at a rate of 120 lines per minute with a "linearized scan" such that the resolution is essentially uniform across the scan. To produce this "linearized scan," AVHRR data at 1.1km resolution will be averaged and resolution reduced to approximately 4km. Each line of scan is divided into five zones from subpoint to the end

of the line. Each zone will use a different averaging algorithm. In the subpoint zone, four samples will make the average; in the next three; in the next two; in the next one and one-half; and at the end of scan individual data points will be retained. To obtain the 120 lines per minute rate, only every third line from the 360 lines per minute AVHRR HRPT output will be transmitted. Simulations have shown that this algorithm will retain all significant meteorological features while enhancing small scale features near the end-of-scan.

The change from the present 48 rpm display devices to 120 rpm must be accomplished mechanically, or a scan converter must be used to output single or side-by-side images compatible with the user's facsimile display. For most users, a gear change would be the simplest way to change display speed. When single, full-width images are desired, displays must be modified to 240 rpm with a blanking circuit to prevent interlacing of IR and visible scan lines. Alternatively, a scan converter may be used to produce full-width images on a 120 rpm display.

2) Synchronization rates have been changed to eliminate the ITOS ambiguity where the same rate is used for both channels of data. Synch pulse detection must be changed from the present 300 Hz to 1040 Hz for Channel A and 832 Hz for Channel B. Either IR or visible data can be programmed for Channel A or B. Displays using the seven 300 Hz synch pulses for AGC may have to be modified, since the pulse width time of the new references is much shorter. Display systems which used the former cold space pulse for AGC may be able to use the new space pulse with minor modifications. However, the pulse is modified to four successive lines to provide minute markers. Sample and hold circuits may be required to prevent erroneous reduction of AGC levels during time indications. The cold space pulse transmitted will be related to the sensor used for that channel. This is important because the pulse for the visible sensor is minimum amplitude.

3) Transmit antenna polarization will be changed to right hand circular to provide increased signal-to-noise ratio at most receiving stations. Antennas designed to receive ITOS APT signals should be capable of receiving TIROS-N APT signals provided that the antenna rotator mechanism is capable of driving the antenna from horizon to horizon in 16 minutes. Spacecraft altitudes of 833km and 870km mean that the satellite

will be above the horizon approximately 15.5 and 16.0 minutes respectively. Assuming that the spacecraft must be 5° above the horizon for useful data to be acquired, the average contact times are reduced to approximately 13 minutes.

4) Some changes of filters may be required to receive the highest quality TIROS-N data. Most APT receivers in use today are narrowband FM with bandwidths of 15 kHz. To receive TIROS-N reliably, this should be increased to at least 30 kHz, and for optimum performance bandwidths should exceed 40 kHz. With the present ITOS APT system, a post detection filter of 450 Hz for IR and 900 Hz for visible were recommended. These filters may be too severe for TIROS-N. A 1400 Hz filter is recommended for use with both the IR and visible channels. It should be noted, however, that existing filters may provide good quality pictures for some users.

Scanning radiometer instruments on the present ITOS series satellites provide APT images with a spatial resolution of 7.4km at nadir (sub-satellite point) and lesser resolution to the left and right of nadir. The ITOS scanning radiometer imagery also is characterized by panoramic distortion, or foreshortening, near the horizons. Any specific Index of Cooperation (IOC) for scanning radiometer data can be precisely correct only for two points in each scan line; the possible range of IOC's for the ITOS APT output is between 180 and 900.

On TIROS-N, on-board computer processing of the raw data from two of the four spectral channels of the AVHRR will produce a synthesized APT image with quasi-constant resolution and greatly reduced panoramic distortion. This on-board processing will reduce the IOC range to 260-390 over the central 93% of the image. The average IOC over the whole image is 326 for a satellite at an altitude of 833km and 347 for a satellite at an altitude of 870km. The recommended optimum IOC for users intending to modify their equipment for TIROS-N APT reception is an average of the two IOC's or 336.

NOAA/NESS plans to generate and distribute "standard" overlay grids for APT and HRPT images produced on specific types of display devices. It is tentatively planned to reproduce APT grids as a 35 mm film product and as a transparency scaled for direct overlay on an APT image. The particular type of APT device for which overlay grids will be produced has not been determined; however, it will be a type used by a majority of government-operated stations. Grids for HRPT products will be designed for overlay on Muirhead and Datalog images.

A handbook or guide to image gridding is planned, and should be available for distribution prior to the launch of NOAA-A in the latter half of 1978. This report will discuss techniques for producing grids manually as well as by computer, however, specific programs for computer grid generation will not be provided.

The following summarizes the specifications which will be used to generate APT and HRPT grids:

1) APT grids

An "average" 852km orbit with an Index of Cooperation of 336.

2) HRPT grids

a) An 870km orbit with an Index of Cooperation of 347.
b) An 833km orbit with an Index of Cooperation of 326.

Further information regarding direct readout imaging capabilities, overlay grids and construction or modification of ground receiving stations may be obtained by writing to:

Coordinator, Direct Readout Services
National Environmental Satellite Service/NOAA
Washington, D.C. 20233

8. INITIAL GTS PRODUCTS FROM TIROS-N

As has been previously discussed, the TIROS-N satellites will carry a variety of radiometric instruments that will provide an extremely large volume of digital data for the derivation of quantitative and imagery products. NOAA is committing considerable resources to produce an initial set of sounding products, oceanographic and hydrologic products, heat budget products and an array of mapped/gridded imagery products. The products derived from the quantitative processing of digital radiometric measurements will be processed in the NOAA IBM 360/195 central computer facility at Suitland, Maryland. The initial set of TIROS-N products to be transmitted over the Global Telecommunications System (GTS) are listed in Table 7 below.

Table 7. INITIAL GTS PRODUCTS FROM TIROS-N

Product	Accuracy Goals	WMO Code	Frequency
1. Thickness (m), Layer Mean Temp. (deg.) between Standard Pressure Levels	$\pm$ 1.5°C	FM86-VI Ext. SATEM	4 daily
2. Precipitable Water (mm) between Standard Pressure Levels	$\pm$ 30%	FM86-VI Ext. SATEM	4 daily
3. Tropopause Temp. (deg.) & Pressure (mb)	$\pm$ 2.5°C, $\pm$ 50 mb	FM86-VI Ext. SATEM	4 daily
4. Cloud Cover from Area of Soundings	$\pm$ 20%	FM86-VI Ext. SATEM	4 daily
5. Clear Radiances (mW/m^2 - Sr - cm^{-1})	$\pm$ 2%	FM87-VII Ext. SARAD	8 daily

The basic output of the TOVS instruments is a measure of the intensity of the upwelling radiation in the various spectral intervals that "peak" or occur as maxima over broad layers and depths of the atmosphere. These radiance measurements are processed into earth-located, calibrated radiance values, "clear" radiances (radiances corrected for cloud effects and angle of view), estimates of water vapor in three atmospheric layers (converted to precipitable water in these layers), mean temperatures for selected atmospheric layers, tropopause height and temperature estimates, and geopotential thicknesses of selected atmospheric layers.

The accuracies of the measurements are stated as goals because there is no operational experience with these instruments. Theoretical estimates were used to set the goals. Accuracies of $\pm$ 1.5°C in the layer-mean temperatures in the middle troposphere are theoretically possible if the broad layers corresponding to the peak responses of the instruments' channels are selected. As linear combinations of the peak responses are used to define thinner layer means, the accuracy decreases. A system of "accuracy indicators" has been developed that will be appended to the data to give an estimate of the reliability and relative accuracy of the measurements.

The National Meteorological Center (NMC) will receive the prepropocessed TIROS-N TOVS data which will be included in their numerical weather products which are transmitted over the GTS network. Meeting the NMC processing deadlines is constrained by the time that the sounding data can be acquired at the CDA, transmitted to Suitland, and processed in the NOAA 360/195 computers. Except for the 0400Z and 1600Z NMC cut-offs (for 0000Z and 1200Z synoptic data respectively), most of the data coverage can be received and processed in time for NMC's needs. The start of the NMC Large-Scale Analyses within one hour after the synoptic data windows of 21Z-03Z and 09Z-15Z will not allow sufficient time to process all of the sounding data that are valid for those windows. The 00Z Large-Scale Analysis will not have data in the Central Pacific either side of the Dateline and over Europe along the Greenwich Meridian. The 12Z Large-Scale Analysis will suffer data loss in the North Central Pacific along the Dateline and in the Southern Atlantic along 5°E. However, these data will be processed in time for the NMC "Final" analysis cycles.

9. FUTURE OF THE TIROS-N/NOAA SATELLITE SYSTEM

The third generation TIROS-N/NOAA series of polar orbiting satellites is planned to provide for continuous data coverage through 1985. Current plans call for the launch of TIROS-N in late May 1978. The second spacecraft in the series, NOAA-A, will follow around September 1978.

An eight to ten week activation and evaluation period is reserved following the TIROS-N launch to perform engineering tests. Instruments will be tested during the period, but transmission of usable data will be sporadic at best. Neither the AVHRR or the HIRS/2 instruments will be activated during the first two weeks following launch to allow for outgassing of contaminants from the spacecraft. For TIROS-N, the period of intermittent engineering evaluation may extend through several months. Operational data from NOAA-A can be expected much sooner after the initial evaluation period has been completed. The dual spacecraft TIROS-N operational system will be ready to provide data for FGGE and to the global community through the GTS and direct readout broadcasting systems by the end of 1978. The launches of TIROS-N and future NOAA operational spacecraft are illustrated in Figure 6.

A total of eight spacecraft are planned for the TIROS-N series through 1985. Initial planning has begun for the fourth generation of polar spacecraft (TIROS-O perhaps?) to be ready by 1985 to continue the uninterrupted acquisition of data from the earth's atmosphere, from its surface, and within its near space.

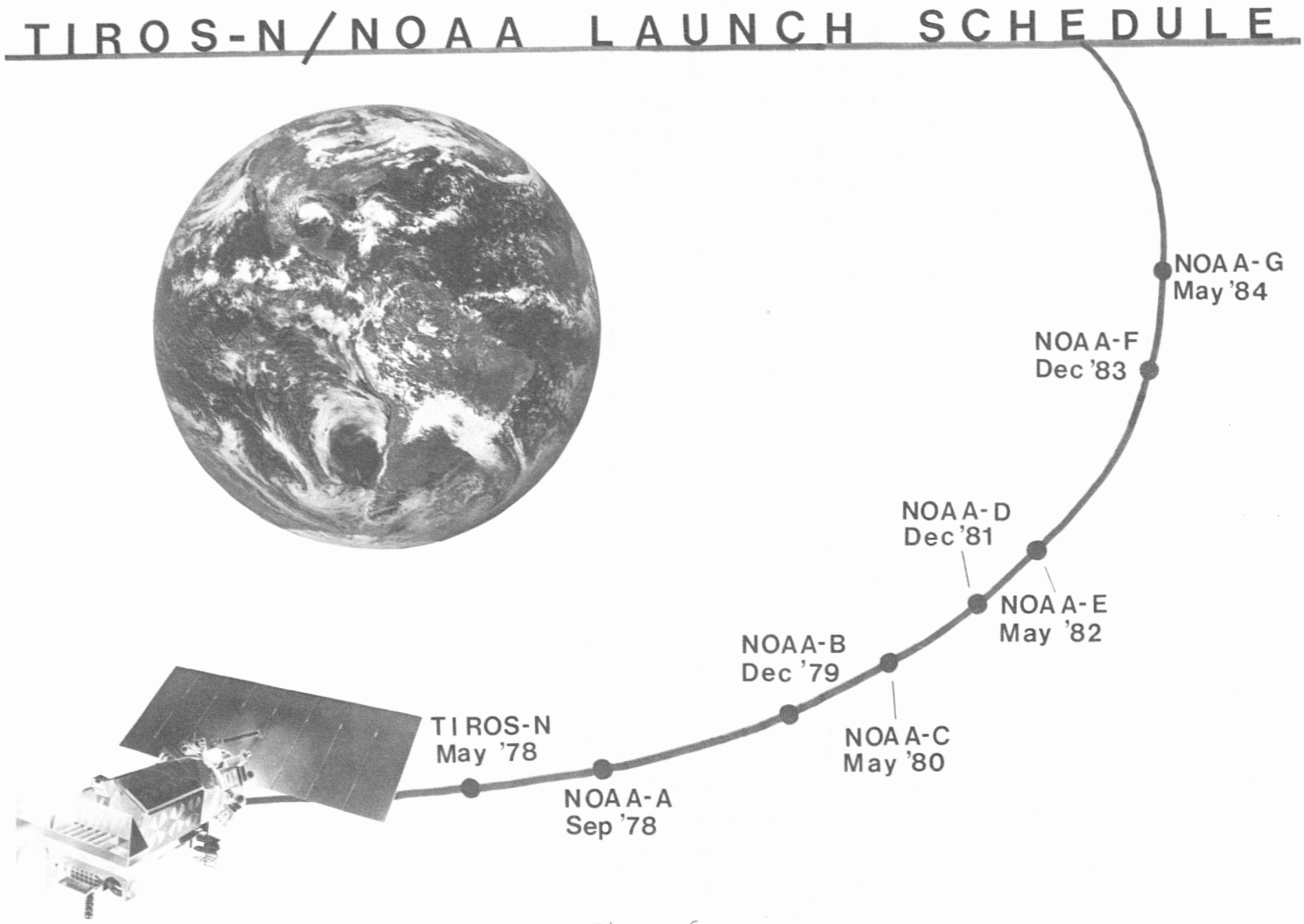

TIROS-N/NOAA LAUNCH SCHEDULE
TIROS-N
May '78
NOAA-A
Sep '78
NOAA-B
Dec '79
NOAA-C
May '80
NOAA-D
Dec '81
NOAA-E
May '82
NOAA-F
Dec '83
NOAA-G
May '84

Figure 6

10. ACKNOWLEDGMENTS

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