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Meteorological Satellites

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METEOROLOGICAL SATELLITES

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ABSTRACT

This paper presents an overview of the meteorological satellite programs that have been evolving from 1958 to the present and reviews plans for the future meteorological and environmental satellite systems that are scheduled to be placed into service in the early 1980's. The development of the TIROS family of weather satellites, including TIROS, ESSA, ITOS/NOAA, and the present TIROS-N (the third-generation operational system) is summarized. The contribution of the Nimbus and ATS technology satellites to the development of the operational polar-orbiting and geostationary satellites is discussed. Included are descriptions of both the TIROS-N and the DMSP payloads currently under development to assure a continued and orderly growth of these systems into the 1980's.

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EVOLUTION OF THE U.S. METEOROLOGICAL SATELLITE PROGRAMS

TIROS

The TIROS (Television and Infra-Red Observation Satellite) system and its successor, TOS (TIROS Operational System), the ITOS (Improved TIROS Operational System) system, and TIROS-N, the current operational system, have been the principal global operational meteorological satellite systems for the United States over the past 20 years. Table 1 highlights the launch dates, orbits, and payloads for the U.S. weather satellites. Figure 1 depicts the performance in orbit for each of these systems. These systems matured from a research and development program, marked by the successful mission of TIROS-I in April 1960 (Allison and Neil, 1962). A semi-operational system soon evolved in which nine additional TIROS satellites were successfully launched in the period from 1960 to 1965. Each TIROS satellite carried a pair of miniature television cameras and in approximately half of the missions a scanning infrared radiometer and an earth radiation budget instrument were included with the instrument complement.

ESSA

The commitment to provide routine daily worldwide observations without interruption in data was fulfilled by the introduction of the TIROS Operational System (TOS) in February 1966. This system employed a pair of ESSA (Environmental Science Services Administration) satellites, each configured for its specific mission. Through their on-board data storage systems, the odd-numbered satellites (ESSA 1, 3, 5, 7, 9) provided global weather data to the U.S. Department of Commerce's CDA (Command and Data Acquisition) stations in Wallops Island, Va., and Fairbanks, Alaska, and then relayed to the National Environmental Satellite Service at Suitland, Maryland, for processing and forwarding to the major forecasting centers, of the United States and to nations overseas. The even-numbered group of satellites (ESSA 2, 4, 6, 8) provided direct real-time readout of their APT (Automatic Picture Transmission) television

Table 1

U.S. Meteorological Satellite Programs

Name	Launched	Period (Min)	Perigee (km)	Apogee (km)	Incli-nation (Deg)	Remarks
TIROS I	01APR60	99.2	796	867	48.3	1 TV-WA and 1 TV-NA
TIROS II	23NOV60	98.3	717	837	48.5	1 TV-WA, 1 TV-NA, passive & active IR scan
TIROS III	12JUL61	100.4	854	937	47.8	2 TV-WA, HB, IR, IRP
TIROS IV	08FEB62	100.4	817	972	48.3	1 TV-WA, IR, IRP, HB
TIROS V	19JUN62	100.5	680	1119	58.1	1 TV-WA, 1 TV-MA
TIROS VI	18SEP62	98.7	783	822	58.2	1 TV-WA, 1 TV-MA
TIROS VII	19JUN63	97.4	713	743	58.2	2 TV-WA, IR, ion probe, HB
TIROS VIII	21DEC63	99.3	796	878	58.5	1st APT TV direct readout & 1 TV-WA
Nimbus I	28AUG64	98.3	487	1106	98.6	3 AVCS, 1 APT, HRIR "3-axis" stabilization
TIROS IX	22JAN65	119.2	806	2967	96.4	First "wheel"; 2 TV-WA global coverage
TIROS X	02JUL65	100.6	848	957	98.6	Sun synchronous, 2 TV-WA
ESSA 1	03FEB66	100.2	800	965	97.9	1st operational system, 2 TV-WA, FPR
ESSA 2	28FEB66	113.3	1561	1639	101.0	2 APT, global operational APT
Nimbus II	15MAY66	108.1	1248	1354	100.3	3 AVCS, HRIR, MRIR
ESSA 3	02OCT66	114.5	1593	1709	101.0	2 AVCS, FPR
ATS I	06DEC66	24 hr	41,257	42,447	0.2	Spin scan camera
ESSA 4	26JAN67	113.4	1522	1656	102.0	2 APT
ESSA 5	20APR67	113.5	1556	1635	101.9	2 AVCS, FPR
ATS III	05NOV67	24 hr	41,166	41,222	0.4	Color spin scan camera
ESSA 6	10NOV67	114.8	1622	1713	102.1	2 APT TV
ESSA 7	16AUG68	114.9	1646	1691	101.7	2 AVCS, FPR, S-Band
ESSA 8	15DEC68	114.7	1622	1682	101.8	2 APT TV
ESSA 9	26FEB69	115.3	1637	1730	101.9	2 AVCS, FPR, S-Band
Nimbus III	14APR69	107.3	1232	1302	101.1	SIRS A, IRIS, MRIR, IDCS, MUSE, IRLS
ITOS 1	23JAN70	115.1	1648	1700	102.0	2 APT, 2 AVCS, 2 SR, FPR, 3 axis stabilization
Nimbus IV	15APR70	107.1	1200	1280	99.9	SIRS B, IRIS, SCR, THIR, BUV, FWS, IDCS, IRLS, MUSE
NOAA 1	11DEC70	114.8	1422	1472	102.0	2 APT, 2 AVCS, 2 SR, FPR
NOAA 2	15OCT72	114.9	1451	1458	98.6	2 VHRR, 2 VTPR, 2 SR, SPM
Nimbus 5	11DEC72	107.1	1093	1105	99.9	SCMR, ITPR, NEMS, ESMR, THIR
NOAA 3	06NOV73	116.1	1502	1512	101.9	2 VHRR, 2 VTPR, 2 SR, SPM
SMS 1	17MAY74	1436.4	35,605	35,975	0.6	VISSR, DCS, WEFAX, SEM
NOAA 4	15NOV74	101.6	1447	1461	114.9	2 VHRR, 2 VTPR, 2 SR, SPM
SMS 2	06FEB75	1436.5	35,482	36,103	0.4	VISSR, DCS, WEFAX, SEM
Nimbus 6	12JUN75	107.4	1101	1115	99.9	ERB, ESMR, HIRS, LRIR, T&DR, SCAMS, TWERLE, PMR
GOES 1	16OCT75	1436.2	35,728	35,847	0.8	VISSR, DCS, WEFAX, SEM
NOAA 5	29JUL76	116.2	1504	1518	102.1	2 VHRR, 2 VTPR, 2 SR, SPM
GOES 2	16JUN77	1436.1	35,600	36,200	0.5	VISSR, DCS, WEFAX, SEM
GOES 3	15JUN78	1436.1	35,600	36,200	0.5	VISSR, DCS, WEFAX, SEM
TIROS-N	13OCT 78	98.92	849	864	102.3	AVHRR, HIRS 2, SSU, MSU, HEPAD, MEPED
Nimbus 7	24OCT78	99.28	943	955	104.09	LIMS, SAMS, SAM-II, SBUV/TOMS, ERB, SMMR, THIR, CZCS
NOAA-6	27JUN79	101.26	807.5	823	98.74	AVHRR, HIRS-2, SSU, MSU, HEPAD, MEPED

APT	Automatic Picture Transmission TV	NEMS	Nimbus E Microwave Spectrometer
AVCS	Advanced Vidicon Camera System (1" Vidicon)	PMR	Pressure Modulated Radiometer
AVHRR	Advanced Very High Resolution Radiometer	SAM-II	Stratospheric Aerosol Measurement-II
BUV	Backscatter Ultraviolet Spectrometer	SAMS	Stratospheric and Mesospheric Sounder
CZCS	Coastal Zone Color Scanner	SBUV	Solar Backscatter Ultraviolet Spectrometer
DCS	Data Collection System	SCAMS	Scanning Microwave Spectrometer
ERB	Earth Radiation Budget	SCMR	Surface Composition Mapping Radiometer
ESMR	Electrically Scanned Microwave Radiometer	SCR	Selective Chopper Radiometer
FPR	Flat Plate Radiometer	SEM	Solar Environmental Monitor
FWS	Filter Wedge Spectrometer	SIRS	Satellite Infrared Spectrometer
HB	Heat Budget Instrument	SMMR	Scanning Multichannel Microwave Radiometer
HEPAD	High Energy Proton and Alpha Particle Detector	SPM	Solar Proton Monitor
HIRS	High Resolution Infrared Radiation Sounder	SR	Scanning Radiometer
HRIR	High Resolution Infrared Radiometer	SSU	Stratospheric Sounding Unit
IDCS	Image Dissector Camera System	T&DR	Tracking and Data Relay
IR	Infrared - 5 Channel Scanner	THIR	Temperature Humidity Infrared Radiometer
IRIS	Infrared Interferometer Spectrometer	TOMS	Total Ozone Mapping Spectrometer
IRLS	Interrogation, Recording and Location Subsystem	TV	Television Cameras (½" Vidicon)
IRP	Infrared Passive		NA Narrow Angle – 12°
ITPR	Infrared Temperature Profile Radiometer		MA Medium Angle – 78°
LIMS	Limb Infrared Monitoring of the Stratosphere		WA Wide Angle – 104°
LRIR	Limb Radiance Infrared Radiometer	TWERLE	Tropical Wind Energy Conversion and Reference Level Experiment
MEPED	Medium Energy Proton and Electron Detector	VHRR	Very High Resolution Radiometer
MRIR	Medium Resolution Infrared Radiometer	VISSR	Visible Infrared Spin-Scan Radiometer
MSU	Microwave Scanner Unit	VTPR	Vertical Temperature Profile Radiometer
MUSE	Monitor of Ultraviolet Solar Energy	WEFAX	Weather Facsimile

pictures to simple stations located around the world. Nine ESSA satellites were successfully launched between 1966 and 1969. One of them, ESSA-8, remained in operation until March 1976. Larger television cameras (2.54cm vidicon) developed for the Nimbus satellite program were adapted for use on the ESSA series, providing a significant increase in the quality of the cloud cover pictures over that obtained from the earlier TIROS cameras, which used a 1.27cm vidicon (Schwalb and Gross, 1969).

ITOS

The second decade of meteorological satellites was introduced by the successful orbiting on January 23, 1970, of ITOS-1,* the second-generation operational weather satellite. This satellite dramatically surpassed the capabilities of the predecessor ESSA satellites, moving rapidly closer toward the objectives of the U.S. National Operational Meteorological Satellite System. ITOS-1 provided in a single spacecraft the combined capability of two ESSA spacecraft—the direct readout APT system, and the global stored images of the AVCS system. Additionally, ITOS-1 provided, for the first time, day-and-night radiometric data in real time, as well as stored data, for later playback. Global observation of the earth's cloud cover was provided every 12 hours with the single ITOS spacecraft as compared to every 24 hours with two of the ESSA satellites. A second ITOS spacecraft, NOAA-1 (ITOS-A), was launched on December 11, 1970.

As the ITOS system evolved to become the ITOS-D system, the flexibility inherent in the spacecraft design permitted a broader and more sophisticated array of environmental sensors to be carried, with only minor changes to the spacecraft. This new sensor complement provided day-and-night imaging by means of Very High Resolution Radiometers (VHRR's) and medium resolution Scanning Radiometers (SR's) (Conlan, 1973). It included Vertical Temperature Profile Radiometers (VTPR's) for temperature soundings of the atmosphere and a Solar Proton Monitor

*This spacecraft was originally designated TIROS-M. After being placed into orbit, it was redesignated ITOS-1. Subsequent spacecraft in this series were named NOAA-1, NOAA-2, etc. by the National Ocean and Atmospheric Administration, the successor to ESSA as operator of the system.

(SPM) for measurements of proton and electron flux. Six spacecraft (ITOS-D, E-2, F, G, H, and I) were planned for the ITOS-D series. NOAA-2 (ITOS-D), the first satellite in this series, was successfully launched on October 15, 1972. Three additional satellites of this type (NOAA-3, NOAA-4, and NOAA-5) were placed into orbit in 1973, 1974, and 1976, respectively (Fortuna and Hambrick, 1974). Due to the longevity experienced in orbit by the ITOS/NOAA satellites, ITOS E-2 and I launches were cancelled. The ITOS system, as it matured, brought closer the realization of the goals of the U.S. National Operational System.

The ITOS satellite system evolved from the proven technology of the TIROS and ESSA spacecraft. Many devices and techniques employed on the earlier series were enhanced, and the enhanced versions were used on the ITOS spacecraft. This orderly evolution permitted growth from a spin-stabilized spacecraft to a 3-axis stabilized earth-oriented despun platform.

The principal objectives of this growth pattern during the evolvement from an R&D satellite to a global operational system were improved performance, the provision for increased quality and more frequent acquisition of meteorological data, and more timely dissemination of the processed data to the users. The evolving system had to be compatible with the global ground network of local receiving stations as well as the two principal command-and-data acquisition sites. Finally, the operational system had to be cost-effective and have the capacity for future growth.

TIROS-N

The third-generation operational polar-orbiting environmental satellite system, designated TIROS-N, completed development and was placed into operational service in 1978. Eight spacecraft in this series will provide global observational service from 1978 through 1984. This new series has a new complement of data-gathering instruments. One of these instruments, the Advanced Very High Resolution Radiometer (AVHRR), will increase the amount of radiometric information for more accurate sea-surface temperature mapping and identification of snow and sea ice, in addition to day-and-night imaging in the visible and infrared bands. Other instruments, contained in a subsystem known as the TIROS Operational Vertical Sounder (TOVS), will provide improved vertical sounding of the atmosphere. These instruments are the High Resolution Infrared Radiation Sounder (HIRS/2), the Stratospheric Sounding Unit (SSU), and the Microwave Sounding Unit (MSU). A Data Collection System (DCS) will receive environmental data from fixed or moving platforms such as buoys or balloons and retain it for transmission to the ground stations. A Solar Environmental Monitor is included to measure proton, electron, and alpha particle densities for solar disturbance prediction (Hussey, 1979). Figure 2 depicts the evolution of the TIROS-ESSA-ITOS-NOAA family of satellites.

The TIROS-ESSA-ITOS-NOAA spacecraft series was designed and built by RCA Astro-Electronics under the technical management of the National Aeronautics and Space Administration, Goddard Space Flight Center, and procured (operational series) and operated by the U.S. Department of Commerce; National Oceanic and Atmospheric Administration.

NIMBUS

The Nimbus satellite program was initiated by the National Aeronautics and Space Administration in the early 1960's to develop an observational system capable of meeting the research and development needs of the nation's atmospheric and earth scientists.

The general objectives of the program were: (1) to develop advanced passive radiometric and spectrometric sensors for daily global surveillance of the earth's atmosphere and thereby provide a data base for long-range weather forecasting; (2) to develop and evaluate new active and passive sensors for sounding the earth's atmosphere and mapping surface characteristics (Press and Huston, 1968); (3) to develop advanced space technology and ground techniques for meteorological and other earth-observational spacecraft; (4) to develop new techniques and knowledge useful for the exploration of other planetary atmospheres; (5) to participate in global observation programs (World Weather Watch) by expanding daily global weather observation capability (National Research Council, 1978); and (6) to provide a supplemental source of operational meteorological data.

The Nimbus System was designated to be (1) the test bed for advanced instruments for the future operational TIROS polar-orbiting satellites and (2) the research system for remote sensing and data collection. The Nimbus spacecraft system was developed under NASA/GSFC management, with the General Electric Company as the spacecraft integration contractor. RCA, Hughes, ITT, T.I., and a number of other companies and universities provided sensors and data processing and storage equipment for the Nimbus series. The project has matured to become the nation's principal satellite program for remote-sensing research. Each new satellite in the Nimbus series has represented significant growth in sophistication, complexity, weight, capability, and performance.

A total of seven Nimbus spacecraft was successfully placed into orbit from 1964 through 1978 (Staff Members, 1965). The final spacecraft, Nimbus 7, was launched in November 1978. This spacecraft was instrumented with sensors to monitor the atmospheric pollutants, oceanography, and weather and climate (Figure 3) (Staff Members, Goddard Space Flight Center 1976, Vostreys and Horowitz, 1979). The payload consisted of eight instruments:

1. *Scanning Multichannel Microwave Radiometer (SMMR)*—Measures radiances in five wavelengths and ten channels to extract information on sea surface roughness and winds, sea surface temperature, cloud liquid water content, total water vapor content, precipitation (mean droplet size), soil moisture, snow cover, and sea ice.

2. *Stratospheric and Mesospheric Sounder (SAMS)*—Measures vertical concentrations of H_2O N_2O, methane (CH_4), carbon monoxide (CO), and nitric oxide (NO); measures temperature of stratosphere to ~90km and trace constituents.

3. *Solar-Backscattered Ultraviolet/Total Ozone Mapping System (SBUV/TOMS)*—Measures direct and backscattered solar UV to extract information on variations of solar irradiance, vertical distribution of ozone and total ozone on a global basis.

4. *Earth Radiation Budget (ERB)*—Measures short- and longwave upwelling radiances and fluxes and direct solar irradiance to extract information on the solar constant, earth albedo, emitted longwave radiation, and the anisotropy of the outgoing radiation.

5. *Coastal Zone Color Scanner (CZCS)*—Measures chlorophyll concentration, sediment distribution, *gelbstoff* (yellow substance) concentration as a salinity indicator, and temperature of coastal waters and open ocean.

6. *Stratospheric Aerosol Measurement II Experiment (SAM II)*—Measures the concentration and optical properties of stratospheric aerosols as a function of altitude, latitude, and longitude. Tropospheric aerosols can be mapped also if no clouds are present in the IFOV.

7. *Temperature-Humidity Infrared Radiometer Experiment (THIR)*—Measures the infrared radiation from the earth in two spectral bands (11 and 6.7 μm) both day and night to provide pictures of cloud cover, three-dimensional maps of cloud cover, temperature maps of clouds, land and ocean surfaces, and atmospheric moisture.

8. *Limb Infrared Monitoring of the Stratosphere Experiment (LIMS)*—Makes a global survey of selected gases from the upper troposphere to the lower mesosphere. Inversion techniques are used to derive gas concentrations and temperature profiles.

ATS, APPLICATIONS TECHNOLOGY SATELLITE

The increased launch vehicle capabilities available during the middle 1960's permitted satellites to be placed at geostationary altitudes and thus provided atmospheric scientists with a new dimension in observations, namely: continuous observations of almost one-third of the earth's surface. A NASA research program involving geostationary satellites was implemented in the Applications Technology Satellite (ATS) series. Although primarily designed to demonstrate communications satellite technology, several of the ATS series carried high-resolution cameras for atmospheric observation.

On December 7, 1966, ATS-1 was placed into geostationary orbit. One function of this technology satellite was to demonstrate the capability of providing a picture of the western hemisphere every 20 minutes through the use of a spin-scan camera. Useful data was provided from approximately 55°N to 55°S latitude. The ability to receive sequential photographs of the same area improved the possibility of early detection of severe storms and tornadoes, and provided real-time data of cloud and frontal movements.

A second technology satellite, ATS-3, was launched November 1967. This satellite, using a multispectral spin-scan camera, returned the first color images of the full earth disc. Copies of these pictures have been used for many applications in addition to meteorology. ATS-1 and ATS-3 were developed by NASA GSFC, with Hughes Aircraft as the prime contractor (Suomi and Vonder Haar, 1969).

The performance history of the Nimbus and ATS technology satellites is shown in Figure 4.

SMS/GOES (OPERATIONAL GEOSTATIONARY SATELLITE)

The successful application of atmospheric observations from geostationary altitudes led to NASA's development of a satellite designed specifically for that purpose. This satellite, the SMS/GOES, was designed and integrated by the Aeronutronic Ford Corporation's Western Development Laboratories. NASA's prototype Synchronous Meteorological Satellite, SMS-1, was successfully launched in May 1974. Placed over the equator at 45°W longitude, it provided continuous hemispheric coverage. The principal instrument for SMS is a 16-inch aperture telescope for visible and infrared scanning. Built by the Santa Barbara Research Center and called VISSR (Visible and Infrared Spin Scan Radiometer), this sensor permits day and night observation of clouds and the determination of temperatures, cloud heights, and wind fields (Johnson, 1979).

The SMS also relays data received from remotely located data collection platforms such as river gauges, ocean buoys, ships, balloons, and aircraft. Its space environmental monitor (consisting of an X-ray sensor, an energetic particle sensor, and a magnetometer) detects unusual solar activity, such as flares, and measures the flow of electron and proton energy and the changes in the geomagnetic field. Observation and forecasting of atmospheric phenomena not specifically related to meteorology are thus possible on an operational basis (Corbell et al., 1976).

Four additional satellites of the SMS design have been launched: SMS-2 on February 6, 1975; the first operational version, GOES-1 (Geostationary Operational Environmental Satellite), on October 16, 1975; GOES-2 on June 16, 1977; and GOES-3 in June 1978. These operational satellites are owned and operated by NOAA. The SMS/GOES satellite history is depicted in Figure 5.

The SMS/GOES satellites have been maneuvered to various stations to optimize the data and support special tasks. The following is the disposition of SMS/GOES as of May 1980.

SMS-1 is at 130°W longitude, and SMS-2 is at 75°W. GOES-1 is at 90°W, but the VISSR is inoperative. GOES-2 is at 105°W and GOES-3 is located at 135°W longitude. GOES-2 is being used to relay weather products to this hemisphere and to assist underdeveloped countries in the receipt of processed satellite data.

TIROS-N SPACECRAFT SYSTEM

The following section contains a more technical description of the TIROS-N system.

Table 2

TIROS-N Spacecraft System (See Figure 6)

TIROS-N/NOAA A-G:	Protoflight, NASA funded Follow-on flights (7) are NOAA funded
Ground Station:	NOAA funded and operated
Launch:	NOAA/NASA funded; USAF managed (Atlas E/F vehicles) Launched from Western Test Range, Lompoc, California on October 13, 1978
Characteristics:	Orbit near polar, sun-synchronous 833 or 870 km (450 n. mi.; 470 n.mi.) 102 minute period morning descending or afternoon ascending Physical weight - 1421 kg (3127 lbs) payload weight - 194 kg (427 lbs) size - length - 3.71 meters (146 inches) diameter - 1.88 meters (74 inches) solar array - 11.6 square meters (125 sq ft) Design Lifetime 2 years
Manufacturer:	RCA, Hightstown, New Jersey (except for sensors)
Special Services:	Realtime transmission of sensor data to a wide range of users worldwide. High Resolution Picture Transmission (HRPT) Service Automatic Picture Transmission (APT) Service Direct Sounder Transmission (DST) Service

TIROS-N INSTRUMENTS

Advanced Very High Resolution Radiometer (AVHRR)

The Advanced Very High Resolution Radiometer (AVHRR) for TIROS-N (Schwalb, 1978) and four follow-on satellites will be four channel scanning radiometers, sensitive to visible/near IR and infrared

(IR) radiation. The instrument channelization (Table 3) has been chosen to permit multispectral analyses which are expected to provide improved determination of hydrologic, oceanographic, and meteorological parameters. The visible (0.6 μm) and visible/near IR (0.9 μm) channels are used to discern clouds, land–water boundaries, snow and ice extent, and when the data from the two channels are compared, an indication of ice/snow melt inception. The IR window channels are used to measure cloud distribution and to determine temperature of the radiating surface (cloud or surface). Data from the two IR channels will be incorporated into the computation of sea surface temperature. By using these two data sets, it is possible to remove an ambiguity introduced by clouds filling a portion of the field–of–view. On later instruments in the series, a third IR channel will add the capability for removing radiant contributions from water vapor when determining surface temperatures. Prior to inclusion of this third channel, corrections for water vapor contributions will be based on statistical means using climatological estimates of water vapor content.

TIROS Operational Vertical Sounder (TOVS)

The TIROS Operational Vertical Sounder (TOVS) system consists of three separate and independent instruments, the data from which may be combined for computation of atmospheric temperature profiles. The three instruments are:

a. The High Resolution Infrared Radiation Sounder (HIRS)
b. The Stratospheric Sounding Unit (SSU)
c. The Microwave Sounding Unit (MSU)

The TOVS has been designed so that the acquired data will permit calculation of (1) temperature profiles from the surface to 10mb, (2) water vapor content at three levels of the atmosphere, and (3) total ozone content.

High Resolution Infrared Radiation Sounder (HIRS/2)

The High Resolution Infrared Radiation Sounder (HIRS/2) is an adaptation of the HIRS/1 instrument designed for and flown on the NIMBUS 6 satellite. The instrument, being built by

Table 3

AVHRR Channelization

Protoflight Instrument (1)	Four-Channel Flight Instruments (4)
1.* 0.55 - 0.90μm	1. 0.55 - 0.68μm
2. 0.725 - 1.10μm	2. 0.725 - 1.10μm
3. 3.55 - 3.93μm	3. 3.55 - 3.93μm
4. 10.5 - 11.5μm	4. 10.5 - 11.5μm
5. Channel 4 data repeated	5. Channel 4 data repeated

AVHRR/2 - Five Channel Instruments (3)

1. 0.58 - 0.68μm
2. 0.725 - 1.10μm
3. 3.55 - 3.93μm
4. 10.3 - 11.3μm
5. 11.5 - 12.5μm

Characteristics	Channels				
	1	2	3	4	5
Spectral Range (μm)	0.58–0.68	0.725–1.1	3.55–3.93	10.3–11.3	11.5–12.5
Detector	Silicon	Silicon	InSb	HgCdTe	HgCdTe
Resolution (km)	1.1	1.1	1.1	1.1	1.1
IFOV (mγ)	1.3	1.3	1.3	1.3	1.3
NETD @ 300 k	–	–	0.12	0.12	0.12
S/N 0.5% albedo	>3:1	>3:1	–	–	—
MTF (IFOV/ single bar	0.3	0.3	0.3	0.3	0.3

Optics: 8 inch diameter a focal cassegrainian telescope

Scanner: 360 rpm hysteresis synchronous motor

Cooler: 2 stage passive

*In-orbit data obtained after completion of the protoflight instrument has shown the necessity of eliminating spectral overlap with channel 2 if snow cover areal extent is to be accurately measured.

the Aerospace/Optical Division of ITT, measures incident radiation in 20 spectral regions of the IR spectrum, including both longwave (15 μm) and shortwave (4.3 μm) regions.

The HIRS/2 utilizes a 15 cm (6 in) diameter optical system to gather emitted energy from the Earth's atmosphere. The instantaneous field of view (IFOV) of all the channels is stepped across the satellite track by use of a rotating mirror. This cross-track scan, combined with the satellite's motion in orbit, provides coverage of a major portion of the Earth's surface.

The energy received by the telescope is separated by a dichroic beam-splitter into longwave (above 6.4 μm) energy and shortwave (below 6.4 μm) energy, controlled by field stops and passed through bandpass filters and relay optics to the detectors. In the shortwave path, a second dichroic beam-splitter transmits the visible channel to its detector. Essential parameters of the instrument are shown in Table 4. Primary system components include:

a. Scan system
b. Optics, including filter wheel
c. Radiant cooler and detectors
d. Electronics and data handling
e. Mechanics

Stratospheric Sounding Unit (SSU)

The Stratospheric Sounding Unit (SSU) is supplied by the United Kingdom Meteorological Office. It employs a selective absorption technique to make measurements in three channels. The principles of operation are based on the selective chopper radiometer flown on Nimbus 4 and 5, and the Pressure Modulator Radiometer (PMR) flown on the Nimbus 6. Basic characteristics are shown in Table 5.

The SSU makes use of the pressure modulation technique to measure radiation emitted from carbon dioxide at the top of the Earth's atmosphere. A cell of CO_2 gas in the instrument's optical path has its pressure changed (at about a 40 Hz rate) in a cyclic manner. The spectral characteristics of the channel and, therefore, the height of the weighting function is then determined by the pressure in the cell during the period of integration. By using three cells filled at different pressures, weighting functions peaking at three different heights can be obtained. The primary objective of the instrument is to obtain data from which stratospheric (25-50km) temperature profiles can be determined. This instrument will be used in conjunction with the HIRS/2 and MSU to determine temperature profiles from the surface to the 50 km level.

Instrument Operation

The single primary telescope with its 10° IFOV is step scanned perpendicular to the sub-point track. Each scan line is composed of eight individual 4.0 second steps and requires a total of 32 seconds, including mirror retrace.

Table 4
HIRS/2 System Parameters

Parameter	Value
Calibration	Stable Blackbodies (2) and Space Background
Cross-Track Scan	±49.5° (±1120km)
Scan Time	6.4 Seconds
Number of Steps	56
Optical FOV	1.25°
Step Angle	1.8°
Step Time	100 Milliseconds
Ground IFOV (Nadir)	17.4km Diameter
Ground IFOV (End of Scan)	58.5km Cross-Track by 29.9km Along-Track
Distance Between IFOV's	42km Along-Track
Data Rate	2880 Bits/Second
Dectors: Long Wave	HgCdTe
Short Wave	InSb
Visible	Silicon

Table 5

SSU Characteristics

Channel Number	Central Wave No. (cm^{-1})	Cell Pressure (mb)	Pressure of Weighting Function Peak	
			mb	km
1	668	100	15	29
2	668	35	5	37
3	668	10	1.5	45

Calibration	Stable Blackbody and Space
Angular Field-of-View	10°
Ground IFOV - Nadir	147.3km
Number of Earth Views/Line	8
Time Interval Between Steps	4 Seconds
Total Scan Angle	±40° from Nadir
Scan Time	32 Seconds
Data Rate	480 Bits/Second
Detector	TGS Pyroelectric

The SSU uncooled pyroelectric detectors integrate the radiance in each channel for 3.6 seconds during each step. The integrated output signal level is sampled 8 times during this period. Quantization is to 12 bit precision.

Microwave Sounding Unit (MSU)

The Microwave Sounding Unit (MSU) is an adaptation of the Scanning Microwave Spectrometer (SCAMS) experiment flown on the Nimbus 6 satellite. The instrument, which is being built by the Jet Propulsion Laboratory of the California Institute of Technology, is a 4-channel Dicke radiometer making passive measurements in 4 regions of the 5.5mm oxygen region. The frequencies are shown in Table 6, which lists the instrument parameters.

Table 6

MSU Instrument Parameters

Characteristics	Value				Tolerance
	CH 1	CH 2	CH 3	CH 4	
Frequency (GHz)	50.3	53.74	54.96	57.05	±20MHz
RF Bandwidth (MHz)	220	220	220	220	Maximum
NEΔT °K	0.3	0.3	0.3	0.3	Maximum
Antenna Beam* Efficiency	>90%	>90%	>90%	>90%	
Dynamic Range °K	0–350	0–350	0–350	0–350	
Calibration	Hot Reference Body and Space Background Each Scan Cycle				
Cross-Track Scan Angle	±47.35°				
Scan Time	25.6 Sec				
Number of Steps	11				
Step Angle	9.47°				
Step Time	1.84 Sec				
Angular Resolution	7.5° (3 db)				
Ground IFOV (Nadir)	109 km				
Data Rate	320 bps				

*>95% Obtained

The instrument has two scanning reflector antenna systems, orthomode transducers, four Dicke superheterodyne receivers, a data programmer, and power supplies.

The antennas scan ±47.4° either side of nadir in 11 steps, The beam width of the antennas is 7.5° (half power point), resulting in a ground resolution at the subpoint of 109 km.

DATA COLLECTION SYSTEM (DCS)

The Data Collection and Location System (DCS) for TIROS-N was designed, built, and furnished by the Centre National d'Etudes Spatiales (CNES) of France, who refer to it as the

ARGOS Data Collection and Location System. The ARGOS provides a means for obtaining environmental (e.g., temperature, pressure, altitude, etc.) data, and earth location from fixed or moving platforms. Location information, where necessary, may be computed by differential doppler techniques using data obtained from the measurement of platform carrier frequency as received on the satellite. When several measurements are received during a given contact with a platform, location can be determined. The environmental data messages sent by the platform will vary in length depending on the type of platform and its purpose. The ARGOS (DCS) system consists of three major components:

a. Terrestrial platforms
b. On-board instrument
c. Processing center

Platforms

The terrestrial platforms may be developed by the user to meet his particular needs so long as it meets the interface criteria defined by CNES. Before being accepted for entry into the system, the platform design must be certified as meeting these criteria. By international agreement, entry into the system is limited to platforms requiring location service or for those situated in polar regions out of the range of the DCS on geostationary satellites. General platform criteria are shown in Table 7.

On-board Instrument

The on-board instrument is designed to receive the incoming platform data, demodulate the incoming signal, and measure both the frequency and relative time of occurrence of each transmission. The on-board system consists of three modules: the power supply and command interface units, the signal processor, and the redundant receiver and search units.

Platform signals are received by the receiver, search unit at 401.65 MHz. Since it is possible to acquire more than one simultaneous transmission, four processing channels [called Data Recovery Units (DRU)] operate in parallel. Each DRU consists of a phase lock loop, a bit synchronizer, doppler counter, and a data formatter. After measurement of the doppler frequency, the sensor data are formatted with other internally generated data and the output transferred to a buffer interface with the spacecraft data processor (TIP). The DCS output data rate is controlled to 720 bits per second.

Table 7

ARGOS Platform Characteristics

Carrier Frequency	401.650MHz
Aging (During Life)	±2kHz
Short Term Stability (100ms)	1:10^9 (Platform Requiring Location) 1:10^8 (Platform Not Requiring Location)
Medium Term Stability (20 min)	:0.2Hz/min (Requiring Location)
Long Term (2 hr)	:±400Hz
Power Out: 34.8dbm (3W) Nominal	
Range During Transmission (Stability)	:0.5db
Antenna:: Vertical Linear Polarization	
Message Length: 360ms to 920ms	
Repetition Period for Message:	40-60 sec (Requiring Location) 60–200 sec (Not Requiring Location)
Data Sensors: 4–32 Eight-Bit Sensors for Environmental Data	
Total Number of Platforms:	4,000 global 450 Within View

SPACE ENVIRONMENT MONITOR (SEM)

The Space Environment Monitor (SEM) has been designed and built by the Ford Aerospace and Communication Corporation. The instrument measures solar proton, alpha particle, and electron flux density, energy spectrum, and the total particulate energy disposition at satellite altitude.

The three components of the SEM are:

a. Total Energy Detector (TED)
b. Medium Energy Proton and Electron Detector (MEPED)
c. High Energy Proton and Alpha Detector (HEPAD)

This instrument is a follow-on to the Solar Proton Monitor (SPM) flown on the ITOS series of NOAA satellites. The new instrument modifies the SPM capabilities and adds the monitoring of high energy protons and alpha flux. The package also includes a monitor of total energy deposition into the upper atmosphere. The instrument will augment the measurements already being made by NOAA's Geostationary Operational Environmental Satellite (GOES).

Total Energy Detector (TED)

The TED uses a curved plate analyzer and channeltron detector to determine the intensity of particles in the energy bands from 0.3KeV to 20KeV. Four curved plate analyzers (two measuring electrons, two protons) measure incoming particles reaching the instrument.

Medium Energy Proton and Electron Detector (MEPED)

The MEPED senses protons, electrons, and ions with energies from 30KeV to greater than 60MeV. This instrument is comprised of four directional solid-state detector telescopes and one omni-directional sensor. All five components use solid-state nuclear detectors. Outputs from the detectors are connected to a signal analyzer which senses and logically selects those events which exceed specific threshold values.

High Energy Proton-Alpha Detector (HEPAD)

The HEPAD senses protons and alphas from about 370MeV to greater than 850MeV. The instrument is essentially a Cerenkov detector. The Cerenkov crystal is installed within a telescope in association with two solid-state detectors; the telescope is shielded to establish the instrument's field-of-view.

The NOAA F and G spacecraft (Fig. 7) will be equipped with the SBUV (Solar Backscatter Ultraviolet Instrument) and the ERBE (Earth Radiation Budget Experiment). These instruments will be used to measure the earth's ozone and radiation to and from the earth's atmosphere.

THE EARTH RADIATION BUDGET EXPERIMENT (ERBE)

The requirements for the ERBE were specified to overcome the previous problems of existing radiation budget observations (Curran, 1980). The experiment incorporates three sets of radiometers on different satellite platforms. Two of the satellites are the sun-synchronous TIROS-N/NOAA satellites with differing equatorial crossing times. The third satellite is the medium inclination ($i \simeq 46$) Earth Radiation Budget Satellite (ERBS). This satellite is to be Shuttle launched. The medium inclination orbit can be accomodated with a Shuttle launch from the Kennedy Space Center in Florida. It is anticipated that a payload will be scheduled to fully utilize the Shuttle capabilities permitting the launch of other free flying satellites or onboard (Spacelab) experiments which are compatible with this orbital inclination. The free flyer will be lifted from the pallet by the articulated arm. While still attached, the entire system including instruments and spacecraft will be checked. Once free of the environment of the Shuttle, onboard thrusters will propel the ERBS spacecraft to the nominal 600 km altitude orbit.

The 600 km orbit and the 46° inclination will provide an orbital precession rate relative to the earth-sun vector of better than 180° per month. This precession rate will permit a minimum of one observation per hour angle per month for each 1000 km by 1000 km area in the tropics and much better sampling at mid-latitudes. The combination of ERBS and the near-polar orbiting satellites will provide a large number of samples uniformly distributed in space and time permitting higher precision and less biased estimates of the monthly averaged radiation budget components.

The instrumentation to be used for the radiation budget observations consists of two parts: a fixed field of view section and a scanner section. An artist's concept of the instrumentation on the ERBS is illustrated in Fig. 8. The fixed field of view section has 5 radiometers, 4 earth viewing and one shuttered sun viewing. The earth viewing radiometers consist of pairs of broadband (0.2 to 50 + μm wavelength) and shortwave (0.2 to 5μm wavelength) detectors. The two spectral bands are also represented by two different instantaneous fields of view, one of which views the entire earth from limb to limb while the other has a restricted field of view with a "foot print" of approximately 1000 km.

Both of these radiometers have cosine law detectors. The wide field of view radiometers because of their cosine response and nadir viewing direction, measure the flux of upwelling radiation from the observable earth at satellite altitude. These flux measurements will be used in accurately determining the global radiation energy balance and its variation with season. These observations of the fluxes at satellite altitude are the only earth flux observations which do not require knowledge of the angular nature of the radiation leaving the earth. To meet the scientific requirements of the ERBS, transformation procedures must be defined to change the observations into the scientifically useable product.

The solar observations will be made with a cavity radiometer, based on the technology of the Solar Maximum Mission. This type of detector will provide periodic observations of the sun to extend the period of solar observations and will also serve as a secondary standard through simultaneous solar observations with the cavity radiometer and all the earth viewing detectors.

The separate scanning instrument consists of shortwave, longwave and broadband channels which scan perpendicular to the velocity vector of the spacecraft. The instantaneous fields of view of the scanning channels are 3°. Calibration of these channels will take place both through observation of an internal blackbody source and observations of a diffuser plate exposed to direct sunlight. The specifications of the ERBE instrumentation were developed with the cooperation of a number of scientists at NASA, NOAA/NESS and several universities. The implementation of the scientific objectives of the ERBS will be carried forward by a team of scientists recently selected through an Announcement of Opportunity procedure.

The ERBS will carry two instruments in addition to the ERBE scanner and nonscanner. One instrument is the SAGE-II (Stratospheric Aerosol and Gas Experiment) instrument which will provide observations of the stratospheric aerosols, ozone, and nitrogen dioxide. Both ozone and stratospheric aerosols are thought to have an effect on the earth's radiation budget and in turn, are thought to be affected by the magnitudes of the shortwave and longwave fluxes passing through the atmosphere. This is particularly true following major volcanic eruptions which inject particulates and gases into the stratosphere. The ERBS instruments and the SAGE-II instrument will be used in climate studies of the interrelationships between the earth radiation budget, stratospheric aerosols and ozone. The second additional instrument on ERBS is the Halogen Occultation Experiment (HALOE) instrument. This instrument is part of a study of environmental quality and files on ERBS as a satellite of opportunity.

VAS

GOES-D, E and F, which will be launched in the early and mid-1980's will carry the VAS (Visible Infrared Spin-Scan Radiometer Atmospheric Sounder). This is an advanced version of the Visible Infrared Spin-Scan Radiometer (VISSR) developed for world-wide geostationary meterological satellite systems. The VISSR is a dual-band (visible and infrared) spin-scan imaging device utilized for day and night, two-dimensional, cloud cover pictures. The VAS retains the VISSR dual-band imaging function. However, the infrared channel capabilities have been expanded using a more complex detector configuration together with selectable narrow-band optical filters. The additional spectral bands provided are sensitive to the effects of atmospheric constituents which makes it possible to determine not only the surface and cloud-top temperatures, as in VISSR, but also the three-dimensional structure of the atmospheric temperature and water vapor distribution.

The VAS system consists of a Scanner which contains a telescope assembly, and a separate Electronic Module. The telescope assembly is a 40.6 cm (16.0-inch) diameter aperture optical system with an object-space scan mirror for accomplishing the N-S step scan (Staff Members, 1980(a)). The complete Scanner contains:

1. A position-controlled object-space scan mirror
2. A Ritchey-Chretien primary collecting optics subassembly
3. A set of secondary optics, optical filters, detectors and preamplifiers for the visible and infrared channels
4. A two-stage radiation cooler for passively cooling the infrared channel detectors
5. A separate optical focus drive assembly for the visible and the infrared channel
6. Two (a primary and redundant) scan mirror drive motor and optical position angle encoder subassemblies
7. An optical subassembly with reduced size aperture to permit an inflight radiometric check-of-calibration of the visible channels on the sun
8. A temperature monitored, heatable, calibration blackbody and motor drive/shutter subassembly to permit an inflight radiometric calibration of the infrared channels
9. Eighteen scanner temperature sensors
10. A scan mirror stow (electromagnet latch) subassembly
11. High voltage power supplies for the visible channel detectors
12. A temperature-controlled twelve-position spectral filter wheel assembly for selecting the infrared optical passband.

The VAS has six infrared detectors. Two have a subpoint resolution of 6.9 km (IGFOV of 0.192 x 0.192 mr) and are used primarily for imaging. Four have a resolution of 13.8 km (IGFOV of 0.384x0.384 mr) and are used for sounding information. The two small infrared channel detectors are mercury-cadmium-telluride (HgCdTe) long-wavelength detectors. Two of the large infrared channel detectors are HgCdTe. The other two are indium antimonide (InSb).

Although there are six VAS infrared detectors, only two will be in use during any satellite spin period.

The following are the three VAS operating modes:

1. *VISSR:* The sensor operates in a normal cloud mapping mode.
2. *Multispectral Imaging*: This mode provides the normal VISSR cloud mapping function. In addition, it supplies data in any two additional spectral bands selected with a spatial resolution of 13.8 km. This mode of operation takes advantage of the condition that the VAS infrared imaging detectors (small HgCdTe) are offset one scan line in the N-S plane. Using the data from these detectors simultaneously produces a complete infrared map when they are operated every other scan line. This allows using the larger detectors during half of the imaging/scanning sequence period to obtain additional spectral information.
3. *Dwell Sounding*: Up to twelve spectral filters covering the range 680 cm^{-1} (14.7 μm) through 2535 cm^{-1} (3.9 μm) can be positioned into the optical train while the scan mirror is on a single N-S scan line. In addition, the filter wheel can be programmed so that each spectral band (filter) can dwell on a single scan line for from 0 to 255 space-craft spins. Either the 6.9km or 13.8km resolution detectors can be selected for the seven filter positions operating in the spectral region 703 cm^{-1} (14.2 μm) through 1490 cm^{-1} (6.7 μm). For the remaining five spectral bands the 13.8km resolution detectors are used. Selectable frame sector size, position and scan direction are the same as in the Multispectral Imaging (MSI) mode of operation (Montgomery and Endres, 1977).

In some of the spectral regions, multiple line data are required to improve the signal-to-noise ratio of the sounding data. The total number of satellite spins at the same N-S scan line position required to obtain the desired sounding data for all spectral bands is called the VAS "spin budget." The VAS "spin budget" for sounding a N-S swath having a 30x30 km resolution is approximately 157 spins. Therefore, with the appropriate interlacing of scan lines formed by the detector FOV pairs, the time required to accomplish sounding over 0.65° N-S swath (400 km) with a resolution of 30x30 km will be 23 minutes.

THE DEFENSE METEOROLOGICAL SATELLITE PROGRAM (DMSP)

EVOLUTION

Data from DMSP satellites has been routinely transmitted directly to U.S. Air Force and Navy ground terminals and Navy carriers since 1966. Previous spacecraft which have been launched (Figure 9) have had a tactical (direct readout) as well as a strategic (stored data) capability. Sixteen air transportable data receiving terminals are now located in the Philippines, Spain, Guam, Okinawa, Alaska, the Canal Zone, Germany, Korea, the Kwajalein Missile Range, and the continental U.S. to provide tactical commanders with real time DMSP data. The Navy is currently operating direct data readout sites at Rota, Spain and at San Diego, California.

In March 1969, DOD approved a joint-service development effort. As a result, a feasibility model shipboard receiving terminal was developed by the Air Force with assistance from Navy personnel attached to the DMSP System Program Office (SPO). This terminal was installed aboard the USS Constellation and proved extremely effective in several deployments to Southeast Asia. A prototype station has since been placed in operation on the USS Kennedy and production units are in operation on the USS Independence, the USS Kitty Hawk, the USS Midway, and the USS Enterprise. All CV class carriers are slated for eventual receipt of this equipment.

In December 1972, DMSP data were declassified and made available to the civil/scientific community through the National Oceanic and Atmospheric Administration (NOAA) Nichols, 1975a; 1976; Brandli, 1976).

In September 1976, the first Block 5D satellite was launched. Although anomalies precluded collection of operational data immediately after launch, the satellite was restored to nominal operational condition and provided meteorological data of previously unmatched quality. The second, third, and fourth Block 5D satellites have subsequently been launched and placed in operation (Figure 9).

DMSP spacecraft history prior to 1 July 1965 is still classified. Since 1965, there have been two major spacecraft models flown: Block 4, Versions A & B; and Block 5, Versions A, B, C, and D.

Block 4. Block 4 employed a pair of VIDICON cameras to acquire television pictures showing the earth's cloud cover and some terrain features as they appeared in the visible wavelength region. The resolution of these pictures was approximately 1.5 nautical miles at nadir, but degraded rapidly toward the picture edge. A supplementary system to roughly measure albedo was also incorporated on later Block 4 spacecraft. This system of 16 thermopile sensors, known as the "C" system, acquired data on energy emitted by large areas of the earth in two selected IR intervals: 0.4 to 4.0 micrometers (energy from reflected sunlight) and 8.0 to 12.0 micrometers (energy self emitted by the earth). Resolution was on the order of 100 nautical sq. miles.

Block 5. The first Block 5 was launched in February 1970. Block 5 version A, B, C, replaced the VIDICON cameras in the "C" system with a new primary sensor known as the Sensor Avenue Package (SAP) to gather Visual and Infrared data at improved resolutions. Visual data and IR data were collected at one-third nautical mile resolution and smoothed to two nautical miles. The one-third nautical mile data were available to U.S. Air Force Global Weather Central (AFGWC), Omaha, Nebraska, while the smoothed data were routinely transmitted directly to AF and Navy tactical sites around the globe. Versions B and C incorporated various special sensors for vertical profiling of atmospheric temperature, for measuring precipitating electron activity at spacecraft altitude, for atmospheric density profiling, etc. Many of these sensor package packages have been improved for Block 5D.

Block 5D. The first Block 5D was launched in September 1976. Although anomalies precluded collection of operational data immediately after launch, the satellite was restored to nominal operational condition and provided meteorological data of extremely high quality. The second, third, and fourth Block 5D satellites have subsequently been launched and placed in operation. The 5D version included a new primary sensor, the Operational Linescan System (OLS), which provided improved resolution of 0.3 nautical miles for both visual and IR fine data and 1.5 nautical mile for smoothed data. The biggest improvement over the SAP was the OLS resolution uniformity along the scan line. At 800 nautical miles from nadir, the SAP experienced a degraded resolution of 13 nautical miles while the OLS maintained a resolution of two nautical miles or better.

The following section will describe the Block 5D-1 and -2 instruments and system in more detail (Nichols, 1975b):

<u>DMSP Block 5D-1</u>: DOD Meteorological Satellite Program satellites 5D-1 replaced the 5C models. DOD funded (Fig. 10(a)).

Ground Support: DOD funded and operated. The satellites are commanded and controlled from sites located at Loring AFB, Maine (Site 2) and Fairchild AFB, Washington (Site 1) which also receive stored data from tape recorders on board the spacecraft. This data is relayed to AFGWC at Offutt AFB, NE (Site 3) and FNWC at Monterey, CA over a communication satellite link.

The Program's Command and Control Center (CCC) is at Offutt AFB, Nebraska (Site 5). The 4000th Aerospace Applications Group (SAC) is responsible for the on-orbit commanding through Sites 1 and 2 and the orbital telemetry analysis performed at the CCC.

Launch:	The first Model 5D-1 was launched on September 11, 1976 on a Thor (LV-2F) booster by Aerospace Defense Command's 10th Aerospace Defense Squadron at Vandenberg AFB, California.
Characteristics:	Orbit: near polar circular sun-synchronous Altitude: 833 km (450 ± 9 nm) Inclination: 98.7 ± 1.3 degrees Period: 101 minute Sun Angle: 0 - 95 degrees (morning descending or afternoon ascending, and noon orbits)

<u>Physical:</u>

weight	468 kg	(1032 lbs)
payload weight	136 kg	(300 lbs)
size - length w/solar array extended	5.89 m	(232 inches)
diameter	1.21 m	(48 inches)
solar array	8.92 sq m	(96 sq ft)
power	300 watts	

<u>Design Lifetime</u>

2 years

Manufacturer:	RCA, Hightstown, New Jersey (except for sensors)
Special Services:	Realtime Direct Digital Transmission (DDT) of fine visual and smoothed infrared imagery or smoothed visual and fine infrared imagery to Air Force and Navy tactical sites world wide.
<u>DMSP Block 5D-2</u>:	DOD Meteorological Satellite Program satellites 5D-2 replaces the 5D-1 models. DOD funded (Figure 10(b))
Ground Support:	DOD funded and operated. The satellites are commanded and controlled from sites.located at Loring AFB, Maine (Site 2) and Fairchild AFB, Washington (Site 1) which also receive stored data from tape recorders on board the spacecraft. This data is relayed to AFGWC at Offutt AFB, NE (Site 3) and FNWC at Monterey, CA over a communication satellite link.

The Program's Command and Control Center (CCC) is at Offutt AFB, Nebraska (Site 5). The 4000th Aerospace Applications

Group (SAC) is responsible for the on-orbit commanding through Sites 1 and 2 and the orbital telemetry analysis performed at the CCC.

Launch: The first Model 5D-2 is to be launched in 1981 on a Thor (LV-2F) booster by Aerospace Defense Command's 10th Aerospace Defense Squadron at Vandenberg AFB, California.

Characteristics: Orbit: near polar circular sun-synchronous altitude

Altitude: 833 km (450 ± 9 nm)

Inclination: 98.7 ± 1.3 degrees

Period: 101 minutes

Sun Angle: 0 - 95 degrees (morning descending or afternoon ascending and noon orbits)

Physical:

weight	698 kg	(1540 lbs)
payload weight	159 kg	(350 lbs)
size - length w/solar panel extended	6.39 m	(250 inches)
diameter	1.21 m	(48 inches)
solar array	11.15 sq m	(120 sq ft)
power	400 watts	

Design Lifetime

3 years

Manufacturer: RCA Hightstown, New Jersey (except for sensors)

Special Services: Realtime Direct Digital Transmission (DDT) of fine visual and smoothed infrared imagery or smoothed visual and fine infrared imagery to Air Force and Navy tactical sites world wide.

The primary objective of the 5D-2 development is to increase on-orbit life through improved reliability. The 5D-2 design for reliability improvement is based on "Functional Module Redundancy." The 5D-2 system is subdivided into functional modules which are made redundant and independently controllable as to use of primary or backup. This approach allows switching around failed units until both modules of a required function have failed. In addition to the

"Functional Module Redundancy" design feature, the quality of parts, materials and processes will be significantly upgraded. Other objectives are increasing command and control performance, improving producibility, and providing minor performance improvements.

The 5D-1 Sensor Processing System (SPS) has incurred major alterations. The power supply has been removed and, in the 5D-2 configuration, exists as a separate unit with redundant supplies. The 5D-1 SPS analog circuit boards have been moved to the PSU box, leaving the SPS a pure digital subassembly. All SPS functional blocks–memory, processor, I/O and SDS and SDF formatters are redundant.

The RTD and SSP formatters and processors in the 5D-2 configuration are redundant and are located in the Special Sensor Processing Unit (SPU).

The 5D-2 configuration includes three encrypters and four tape recorders; an addition of one each. The 5D-1 encryption interface box has been eliminated. The Output Switching Unit (OSU) is fully redundant.

BLOCK 5D INSTRUMENTS

OPERATIONAL LINESCAN SYSTEM (OLS)

The OLS is the primary data acquisition system on the Block 5D satellite. This system gathers and outputs in real time or stores multi-orbit day and night visual and infrared spectrum data from earth scenes for transmission to ground stations with appropriate calibration, indexing, and auxiliary signals. Data is collected, stored, and transmitted in fine (0.3 nm) or smoothed (1.5 nm) resolution.

Fine Resolution Visual Data

The visual daytime response of the OLS is in the spectral range of 0.4 to 1.0 microns to provide maximum constrast between earth, sea, and clouds in the image field, The visual fine resolution (0.3nm x 0.3nm) is provided for day scenes only.

Smooth Resolution Visual Data

The smooth resolution (1.5nm x 1.5nm) visual data is provided across a dynamic range from full sunlight down to quarter moonlight. Night time visual data is provided from a photomultipler tube operated in the same spectral range and energized automatically as the radiance decreases. Daytime, smooth resolution data is derived from fine mode data by analog and digital data processing by the OLS. Five fine mode resolution cells are averaged along the scan line to produce a series of 0.3nm x 1.5nm cells. Then five such cells are digitally averaged along the track to produce a single smooth resolution cell, 1.5nm x 1.5nm.

Fine Resolution Infrared

The OLS infrared detector is a segmented tri-metal (HgCdTe) detector operating at approximately 105K with a spectral response of 8.0 to 13.0 microns to provide optimal detection of both water and ice crystal clouds. The sensor output is normalized to equivalent blackbody temperature of the radiating object such that the sensor output voltage is a linear function of scene temperature. The tri-metal detector is accurate to within one degree K rms across the temperature range 210-310 degrees K.*

Smooth Resolution Infrared

The Smooth Resolution data is obtained from fine Resolution Infrared data in the same manner as described for the smooth resolution visual data. Fine mode visual and infrared data are gathered through the same optics and are digitally identified; the smooth mode data are also digitally identified. Thus corresponding visual and infrared data cells maintain a unique one-to-one location correspondence throughout the data processing chain.

OLS Data Processing

The OLS data processing subsystem performs command, control, data manipulatory, storage, and management functions. All data is processed, stored, and transmitted in digital format.

*With F-4, the OLS IR Spectral Band was changed from 8-13 μm to 10.5-12.6 μm to improve the sea surface temperature resolution.

Special Sensor data and OLS telemetry data are merged by the OLS into the smooth data stored format.

OLS Data Transmission

S-band transmitters are provided for data transmission. Two may be operated simultaneously for stored data playback. A third S-band transmitter is dedicated to transmission of Direct Digital Transmission (DDT) to tactical sites world wide at 1.024 Mbps. DDT data is normally encrypted.

The OLS system including the Sensor Subsystem, Signal Processing System, and the Recording Subsystem weighs about 200 lbs and requires 170 watts power.

The 5D-2 OLS System has the same performance requirements as the 5D-1 System as previously described. The basic premise of the 5D-2 OLS is to increase overall system reliability by providing functional redundant circuitry, although some changes, such as increased IR digitization (from 7 to 8 bits), and improved sensitivity to low temperature values (190° –210°K) have been incorporated.

Characteristics of the Operational Linescan System (OLS)

Meteorological Data Collected in Visible and Infrared Spectra

Visible Data Collected as 0.3nm x 0.3nm during day and 1.5nm x 1.5nm at night

Infrared Data Collected as 0.3nm x 0.3nm at all times

Oscillating Scanner Collects Data in Both Directions Along 1600nm Swath.

Near Constant Resolution as a function of Scan Angle

Three Digital Tape Recorders for Data Storage

Each Recorder can store 20 minutes of interleaved visual and infrared 0.3nm x 0.3nm of data.

Analog Filtering and Digital Averaging is used to smooth data to 1.5nm x 1.5nm for on board global storage.

Each recorder can store 400 minutes of interleaved visual and infrared 1.5nm x 1.5nm of data.

Telemetry and special meteorological sensor data are included within the primary smoothed data stream.

Real time encrypted transmission of 0.3nm and 1.5nm data.

SPECIAL SENSOR H (SSH)–A HUMIDITY, TEMPERATURE, AND OZONE SOUNDER

This instrument is an infrared multispectral sounder for humidity, temperature and ozone. Soundings of temperature and of humidity and a single measurement of ozone is provided for vertical and slant paths lying under and to the side of the sub-satellite track.

The SSH is a 16-channel sensor with one channel (1020 cm^{-1}) in the 10-micrometer ozone absorption band, one channel (835 cm^{-1}) in the 12-micrometer atmospheric window, six channels (747, 725, 708, 695, 676, 668 cm^{-1}) in the 15-micrometer CO_2 absorption band, and eight channels (from 453 cm^{-1} to 333 cm^{-1}) in the 22- to 30-micrometer rotational water vapor absorption band. The instrument consists of an optical system, detector and associated electronics, and a scanning mirror. The scanning mirror was stepped across the satellite subtrack, allowing the SSH to view 25 separate columns of the atmosphere every 32 s over a cross track ground swath of 2000 km. While the scanning mirror is stopped at a scene station, the channel filters are sequenced through the field of view. The surface resolution is approximately 39 km at NADIR. Radiance data are transformed into temperature water vapor and ozone profiles by a mathematical inversion technique.

A Cassegrain objective forms a 2.7 degree FOV centered on an axis parallel to the flight path. A step-rotating diagonal scanning mirror scans the FOV according to a pre-established scan program in a plane normal to the flight path.

The SSH instrument weighs 29 pounds and consumes 8 watts power.

Spacecraft F-1 through F-4 carried the SSH-1 as described. SSH units starting with F-5 are designated SSH-2 and do not include the spectral channel for ozone sounding. That filter has been replaced by an atmospheric window channel at about 800 μm.

SPECIAL SENSOR M/T (SSM/T)–A PASSIVE MICROWAVE TEMPERATURE SOUNDER

The SSM/T is a 7-channel scanning passive microwave radiometer which measures radiation in the 50–60GHz frequency region to provide data for temperature profiling from the earth's surface to above 30km. The SSM/T scans in synchronization with the SSH (an infrared temperature and humidity sounder). The microwave sounder complements the infrared sounder by providing temperature sounding over previously inaccessible cloudy regions of the globe. Temperature profiles to higher altitudes are also provided (than was previously possible with infrared sensors alone).

The SSM/T will operate in the 50–60GHz absorption band of molecular oxygen. Since the mixing ratio of oxygen is essentially constant in the atmosphere, the contribution of any layer of the atmosphere to the total signal of a given frequency received by a radiometer flown on a spacecraft is primarily a function of the temperature and density of the layer and the amount of absorption in the atmosphere above the layer. By choosing frequencies with different absorption coefficients on the wing of the 0_2 absorption band, a series of weighting functions peaking at preselected atmospheric heights may be obtained. Frequencies were chosen to obtain seven channels with weighting functions peaking at altitudes ranging from the surface to above 30 km. The surface channel at approximately 50GHz was chosen to permit removal of background terrain contributions to the channels which peak in the lower atmosphere. Other frequencies were chosen (Table 8) to peak at altitudes that produce an optimum temperature profile.

The Multi-channel, Single Antenna

Radiometer scans across the NADIR track on seven scan positions and two calibration positions (cold sky and 300 deg K). The dwell time for the crosstrack and calibration positions is 2.7 s each. The total scan period is 32 s. The instrument has an instantaneous field of view of 14 deg and scans plus or minus 36 deg from NADIR.

Table 8

SSM/T Channel Specifications

Number	Peak Height (km)	Frequency (GHz)	NETD* (°K)
1	0	50.5	0.3
2	2 ± 2	53.2	0.3
3	6 ± 2	54.35	0.3
4	10 ± 2	54.9	0.3
5	16 ± 2	58.825	0.3
6	22 ± 3	59.4	0.4
7	30 ± 3	58.4	0.5

*Noise Equivalent Temperature Difference

The SSM/T weighs 25 pounds and consumes 18 watts of power.

SPECIAL SENSOR B (SSB)–GAMMA DETECTOR

The SSB or the SSB/O sensors are gamma radiation measurement sensors which were carried on each 5D-1 spacecraft except F-4.

The SSB sensor system consists of a four detector array, each positioned 30 degrees from the vertical. Each detector is basically a scintillator disc coupled to a photomultiplier tube. The scintillator is surrounded by a tantalum ring shield to give a directional characteristic. The SSB also contains a piggy-back electronics (PBE-2) package which is an optical system for gathering background information. It contains three selectable silicon sensors.

The SSB/O is sensitive to X-rays in the energy range of approximately 1.5 KeV to more than 100 KeV. It uses large area proportional counter and cadmium telluride (CdTe) solid state detectors to provide excellent spectral resolution and high detection efficiency. By virtue of its extended low energy response, the SSB/O is able to identify signals associated with Bremsstrahlung generated by energetic electrons precipitating in the upper atmosphere.

SPECIAL SENSOR J* (SSJ*)–SPACE RADIATION DOSIMETER

The SSJ* measured the radiation dose in silicon under aluminum shielding of four thicknesses representative of the Block 5D DMSP spacecraft. The dosimeter was launched aboard the first Block 5D satellite (F-1).

The interest in such data was engendered by the discovery of the "softness" of current CMOS circuitry to radiation (10^4 rads results in failure) coupled with the present substantial uncertainty and controversy concerning the natural energetic electron dose received by a satellite in a low polar orbit. Direct measurement of this dose, correlated with performance of onboard circuitry, was therefore of crucial importance in providing data for planning of future missions (particularly where use of CMOS components is envisioned).

The dosimeter used technology proven by flight aboard many USAF and NASA satellites. The instrument consisted of four separate single-detector units, each using small cubical lithium drifted silicon detectors to perform two major functions. First, it directly measured the ionization in the silicon cube caused by natural radiation (the radiation dose). Second, the dosimeter served as an electron-proton spectrometer, thus yielding the fluences of energetic electrons and protons encountered in the DMSP orbit as a function of time.

A space radiation dosimeter is scheduled to fly on spacecraft F-7. Although different in manufacture, its operational objectives remain essentially the same as the 5D-1 dosimeter carried on F-1.

SPECIAL SENSOR D (SSD)--ATMOSPHERIC DENSITY SENSOR

The Atmospheric Density Sensor (SSD) provides a measure of major atmospheric constituents (Nitrogen, Oxygen and Ozone) in the earth's thermosphere (100 to 250km in altitude) by making earth-limb observations of the ultraviolet radiation from this atmospheric region. The sensor measures the radiation emitted in the ultraviolet spectral region from excitation of molecular nitrogen by impinging solar radiation. The intensity of the emitted radiation is proportional to the excitation rate and the number of molecules at any given altitude. Funneltrons and a photomultiplier tube will detect the radiation after it passes through a collimator which provides a 0.1 x 4.0° field-of-view. The SSD is mechanically driven to scan vertically through the earth's limb in about 30 seconds. The instrument provides approximately 50 sets of density profiles on the daylight portion of each orbit.

The SSD is currently being evaluated aboard the DMSP F-4 satellite launched in June 1979. This is an experimental sensor with no current Program Office plans to integrate it onto subsequent 5D spacecraft.

SPECIAL SENSOR J (SSJ)–PRECIPITATING ELECTRON SPECTROMETER

A small, lightweight (3 lb) sensor, the SSJ counts ambient electrons with energies ranging from 60 eV to 20 KeV. Utilizing a time-sequenced variable electrostatic field to deflect the particles toward the channeltron detector, the sensor determines the number of electrons having energies within certain sub-ranges of the 60 eV to 20 KeV spectrum.

The SSJ is an electron spectrometer that detects and analyzes low energy electrons precipitating into the atmosphere producing the auroral display.

The SSJ units for Block 5D-2 will incorporate the capability to measure precipitating protons in the 50 eV to 20 KeV energy range as well as electrons measured on 5D-1. It is expected that this change will give new information relative to magnetic substorm activity.

SPECIAL SENSOR C (SSC)–SNOW/CLOUD DISCRIMINATOR

The Snow/Cloud Sensor is an experimental unit that is being used in conjunction with the OLS sensor on spacecraft F-4. The experiment being performed by the simultaneous in-orbit use of these two sensors is primarily that of proving the proposition that snow/cloud scene discrimination can be obtained though the combination of near IR (1.6 micrometer wavelength) sensor data and OLS L-Channel (visual) information.

The Snow/Cloud Sensor is a "push-broom" scan radiometer that will depend upon orbital velocity of the 5D spacecraft to provide the along track scan and a linear array of 48 detector elements at the image plane of a wide angle lens to provide a 40.2° cross track scan. The sensor depends upon reflected solar energy in the 1.51 to 1.63 micrometer spectral band for its input signal.

SPECIAL SENSOR M/I (SSM/I)–MICROWAVE ENVIRONMENTAL SENSOR SYSTEM

The SSM/I is currently undergoing system development for integration aboard later Block 5D-2 vehicles. The sensor is a passive microwave imager which scans in seven channels. It will operate at four frequencies, three with both vertical and horizontal polarization (19.35, 37.0, 85.5 GHz), and one frequency (22.23 GHz) with only vertical polarization.

The SSM/I will be designed to scan cross track (with respect to the satellite's velocity vector) in a conical scan pattern, and will gather data over an approximate 1400km swath width. The data gathered will provide information which will be used to determine the location, extent, and intensity of precipitation. In addition, the data collected will provide for a determination of soil moisture content, wind speed over the ocean, and the morphology and extent of sea ice.

SPECIAL SENSOR I/P (SSI/P)–PASSIVE IONOSPHERIC MONITOR

The SSI/P is a high frequency (HF) receiver which passively monitors the ionspheric noise breakthrough frequency used in ionospheric forecasting. Noise from man-made and natural sources below the ionospheric F2 layer peak can be detected by an HF topside receiver only at frequencies above the F2 critical frequency (foF2). By sweeping through the HF spectrum, the SSI/P can monitor the frequency of the noise breakthrough. This frequency agrees to within

1 MHz of the measured foF2 above 85% of the time over mid-latitude land masses. The foF2 is a prime parameter used in constructing electron density profiles used in forecasting the state-of-the-ionosphere.

SPECIAL SENSOR I/E (SSI/E)–IONOSPHERIC PLASMA MONITOR

The SSI/E is an electron and ion probe designed to measure the average ion mass, satellite potential, electron density, and electron and ion temperatures at the spacecraft altitude. The SSI/E provides a measurement of the electron density and parameters for the calculation of the plasma scale height at the satellite altitude. The latter information is a prime input to the production of existing vertical electron density models.

The SSI/E to be carried on Block 5D-2 satellites will have the additional capability of making scintillation measurements at orbital altitudes. This instrument will be identified as SSI/ES.

DMSP BLOCK 6

At the time of this writing, technical requirements for a shuttle compatible (BLOCK 6) satellite system is being defined based on expected user requirements for the late 1980's (Staff Members, 1979a). At least in the early shuttle compatible spacecraft, sensor missions will be similar to those for BLOCK 5D-2 and will include a derivation of the current OLS, and growth versions of the sensors described in the preceding instrument section.

MINIMUM OPERATIONAL REQUIREMENTS

Ground support will be DOD funded and operated. The satellites will be commanded and controlled once orbit is achieved as previously described for BLOCK 5D-2 but with expanded capabilities. Up to four satellites may be controlled at one time and real time relay of global data to a centralized CONUS (Continental United States) location with a maximum delay of 30 minutes.

Launch will be from Vandenberg AFB, California by the Space Transportation System (STS). Retrieval of BLOCK 6 satellites is an option consideration.

Orbit characteristics: The basic orbit will be sun synchronous circular with two to four satellites utilized. The altitude, inclination, period, and sun angle of BLOCK 5D-2 will be supported with an add on capability for some orbits to 1850 km (1000 nm).

Physical characteristics have not yet been determined as of this writing. Payload weight, spacecraft size, and power requirements are all expected to increase reflecting sensor growth for improved performance and reliability.

Design lifetime is to be 5-7 years.

PRIMARY SENSOR (OLS-3)

The DMSP primary sensor is the Operational Linescan System (OLS). Changes shall be made to the 5D-2 OLS to provide for greater over all system operational flexibility, increased reliability and additional mission data.

Global cloud cover imagery will be provided in one or two visible and as many as three infrared bands. Resolution: fine data, 0.3 nm—one visible and one infrared; smooth data, 1.5 nm—all bands.

The OLS-3 will be derived from the 5D-2 primary sensor. Data storage functions will be deleted and optical system redundancy will be added. Visible imagery will be provided down to one quarter moonlight. Infrared bands will include 1.5, 6.7, and 11 microns.

OLS Data Transmission S-band transmitters will be provided for data transmission. Two 66.56 KBPS channels and one 1.33 MBPS channel will provide 100% duty to the CONUS site. One 1.024 MBPS channel is dedicated to DDT to tactical sites world wide.

Initial units will weigh approximately 65 lbs maximum and require a maximum of 50 watts power.

SPECIAL SENSORS

The BLOCK 6 mission requires a complement of other sensors in addition to the primary sensor. The special sensor complement will vary from spacecraft to spacecraft. This flexibility in sensor complement provides a combined sensor package to meet minimum mission requirements.

Infrared Sounder SSH-4

An Interferometer instrument which will measure radiance values in narrow spectral bands in the infrared absorption bands of H_2O and CO_2 to determine vertical temperature and water vapor profiles of the atmosphere. An operational instrument is currently under study.

Microwave Sounder SSM/T-2

Using a scanning antenna, this instrument will measure the microwave temperature of the atmosphere at selected frequencies from 50 to 183 GHz to determine vertical temperature and water vapor profiles in the atmosphere. The 50 GHz is operational (SSM/T-1) and higher frequency instruments are planned. May ultimately replace the infrared sounder.

Ionospheric Sensor SSIE

Presently operational on BLOCK 5D. Only modest changes are anticipated if any.

Topside Ionospheric Sounder SSI

This system was developed for BLOCK 5D-2. Minimum changes expected for BLOCK 6.

Precipitating Electron Spectrometer SSJ/3

An operational instrument on BLOCK 5D. Minimum changes expected for BLOCK 6.

Microwave Images SSM/I-2

This instrument is currently under development for 5D-2 in smaller aperture form. BLOCK 6 instrument may incorporate both active and passive microwave techniques to meet user requirements.

Low Energy Gamma Detection SSB

BLOCK 6 instrument based on the advanced operational instrument for 5D–2.

Microwave Scatterometer SSM/S

An advanced version of SEASAT–A scatterometer incorporating an active microwave sensor with range, doppler and radar cross section analysis of returns.

INTERNATIONAL WEATHER SATELLITES

As part of the international cooperation and participation within the World Meteorological Organization, the United States, Japan, the European Space Agency (ESA), and the U.S.S.R. have placed satellites in orbit which supported the First GARP Global Experiment (FGGE) during 1978-79. A summary of international weather satellite evolution is shown in Figure 11. Japan's geostationary satellite (Himawari-1) was launched on July 14, 1977 and positioned over the western Pacific Ocean. The ESA's geostationary satellite (METEOSAT) was launched on November 23, 1977 and positioned over the eastern Atlantic Ocean. Both were launched by the U.S., each aboard a NASA Delta launch vehicle from Cape Canaveral, Florida. The Himawari-1 and the Meteosat are shown in Figures 12 and 13, respectively. More complete descriptions of these two geostationary satellites and the USSR Meteor system may be found in articles by Hirai, et al., 1975; Morgan, 1978; and Diesen, 1978, respectively.

OCEANOGRAPHIC SATELLITES

The oceans, which cover about two thirds of the earth's surface, have important influences on our weather and climate and are a vital natural resource needing further exploration (McClain, 1980).

SEASAT–A

SEASAT–A (Fig. 14) was launched in June 1978 and carried instruments fully dedicated to oceanic prediction (NOAA Staff Members, 1977).

The sensor applications are as follows:

1. *Altimeter*—A nadir-looking instrument that measures the displacement between the satellite and the ocean surface to a processed accuracy of 10 cm every 18 km and a rms roughness of that surface to 10 cm.
2. *Radar*—A 100 km, swath-width image of the ocean surface with a 25 m spatial resolution viewed every 18 days.
3. *Scatterometer*—Low to intermediate surface wind velocity determined over a swath-width of 1200 km, providing global coverage (±75 deg latitude) every 36 h on a 100 km grid basis.
4. *Microwave Radiometer*—Ice boundaries and leads, atmospheric water vapor, sea surface temperature, and intermediate to high wind speeds are provided over a swath-width of 1000 km every 36 h. Spatial resolution of ice features is 25 km, and 125 km for sea surface temperature (Gloerson and Barath, 1977).
5. *Visible and IR Radiometer*—Provide a 7 km spatial resolution imagery for feature identification for the microwave data.

NOSS

The National Oceanic Satellite System (NOSS) is proposed to provide a limited operational capability to obtain global ocean measurements from a space platform. It is a NASA/NOAA/DOD triagency program with a 5 year demonstration period using two spacecraft, commencing in 1986. Utilizing the experience gained from Seasat-A and Nimbus 7, the NOSS will develop and test new techniques for sea surface monitoring for incorporation into civilian and military operational weather and oceanographic forecast systems (Staff Members, 1980(b)).

NOSS Sensors and Measurements
(Figures 15 and 16)

Altimeter (ALT)	Sea state, ocean surface topography, ice sheet height, surface wind speed at nadir and ocean currents

Scatterometer (SCATT)	Surface wind speed and direction
Large Antenna Multi-Channel Microwave Radiometer (LAMMR)	Surface wind speed, sea surface temperature, sea ice cover, thickness, age, atmospheric water vapor and liquid water content
Coastal Zone Color Scanner (CZCS)	Chlorophyll and diffuse attenuation coefficient (K)

Table 9 lists the predicted NOSS system capability. Complementary systems will include the global positioning system (GPS). In addition, a 25 percent growth potential (power, weight and data) is allowed for special sensors that are to be considered as future proof-of-concept experiments.

NOSS CHARACTERISTICS

- 3-year design life per spacecraft
- Sun-synchronous orbit (~98° inclination, 700 km)
- 3-axis attitude, precise to .03°, using star-tracker
- Earth location to 400 m using GPS
- Shuttle launch
- Data relay to ground via TDRSS (Tracking and Data Relay Satellite System) and retransmission via DOMSAT

ICEX (ICE AND CLIMATE EXPERIMENT

An ICEX concept is currently under study for a possible future mission. However, as of this writing, it is not an approved program.

The scientific objective of ICEX is a clearer understanding of the roles of ice and snow in geophysical processes. Special attention will be given to the interactions between the cryosphere and the rest of the planetary system that determine our climate; to the massive ice sheets of Greenland and the Antarctic, because they contain such a large fraction of the Earth's fresh water; and because the fluctuations observed in the ice sheet volume would serve as precursors of sea level changes (Staff Members, 1979b).

Table 9
Predicted NOSS System Capability

Parameter	Detectable Change	Accuracy	Range	Horizontal Resolution	Instrument
Wind					
Speed	1.5 m/s	±2 m/s or ±10% (whichever is greater)	0 to 50 m/s	17 km	LAMMR
Speed	1.5 m/s	±2 m/s or ±10% (whichever is greater)	4 to > 24 m/s	50 km/25 km*	SCATT
Direction	10°	±20°	0 to 360°	50 km/25 km*	SCATT
Speed (Nadir only)	1.5 m/s	±2 m/s or ±10% (whichever is greater)	4 to 24 m/s	<12 km	ALT
Sea Surface Temperature					
Global	1.0°	±1.5°C	-2 to 35°C	25 km**	LAMMR (C-band)
Local	0.2°C	±2.0°C	-2 to 35°C	1.0 km	CZCS/II
Waves (Sea State)					
Sign. Wave Ht.	0.5 m	±0.5 m or 10%	1 to 20 m	<10 km	ALT
Ice					
Cover	5%	±15%	0 to 100%	9 km	LAMMR
Thickness	2 m	±2 m	0.25 to 50 m	9 km	LAMMR
Age	1st yr, multi-yr	1st yr, multi-yr	two levels	9 km	LAMMR
Sheet Height and Boundaries	0.5 m height change	±2 m height change	-5 to +5 m/yr	~10 km	ALT
Water Mass Definition					
Pigment Concentration	10% (mg/m^3)	Within factor of 2	0.1 to 100 mg/m^3	1.0 km	CZCS/II
Diffuse Attenuation Coef. (k)	10% m^{-1}	Within factor of 2	0.01 – 6 m^{-1}	1.0 km (length scale)	CZCS/II
Geostrophic Currents					
Speed	15 cm/s	±15 cm/s	>15 cm/s	50 km	ALT
Direction	20°	±20°	0 to 360°	50 km	ALT
Water Vapor					
Integrated Atm. Water Vapor Content	0.2 grams/cm^2	±0.2 grams/cm^2	0–6 grams/cm^2	9 km	LAMMR

*50 km global resolution; 25 km resolution in selected storm regions.
**Avenues are being explored to improve this resolution.

The ICEX sensor system contains the following six remote-sensing instruments:

Large Antenna Multifrequency Microwave Radiometer (LAMMR)

Wide Swath Imaging Radar (WSIR)

Scatterometer

Ice Elevation Altimeter System (IEAS), Radar

Ice Elevation Altimeter System (IEAS), Laser

Polar Ice Mapping Radiometer (PIMR)

The LAMMR is a passive multichannel radiometer which will measure the radiative brightness temperature of the surface in seven microwave bands ranging from 1.4 GHz to 91 GHz (22.4 cm to 0.33 cm). The WSIR is an X-band (3 cm) synthetic-aperture, side-looking radar which produces images of the surface with a pixel size of either 100 m over a 360 km wide swath or 25 m over a 90 km swath. The scatterometer, a side-looking radar, has the capacity to measure the scattering cross section of surface irregularities at 14.6 GHz (2.05 cm). The IEAS is an altimeter which can measure ice altitude profiles with two complementary instruments: a microwave radar, to provide continuous coverage along the nadir track; and a laser ranging system with commandable pointing, to provide precision altitude determination, off-axis mapping, fine-scale profile resolution, and ranging to reflectors placed on the ice. The PIMR is a passive, 5-channel infrared radiometer (4 near-infrared channels detecting reflected solar radiation and one thermal infrared channel at 11 μm), which can map cloud cover, determine cloud parameters, measure surface temperatures, and aid in distinguishing surface ice and snow from clouds.

A Data Collection and Location System (DCLS), for locating and relaying telemetry from buoys and other in-situ platforms, is included in the spacecraft. It will use the ARGOS (or RAMS) principle, in which periodic transmission from the platforms will be received and located by the Doppler shift of the carrier as the satellite passes over the platform.

THE ICEX ORBIT

The orbit proposed for ICEX has an altitude of approximately 700 km and an inclination of 87° or 93°, so the spacecraft passes by the poles within 3 degrees of latitude. The altitude of the orbit is a compromise between the effects of atmospheric drag, area coverage and resolution requirements, and the transmitter power available from the active microwave sensors. The inclination is determined primarily by the requirements imposed on the IEAS to measure the ice sheets of the Antarctic. To encompass its most important areas, the nadir point of the spacecraft should approach the South Pole to within approximately 3° of latitude, thus providing coverage of about 98 percent of the continental area.

These selected orbit parameters apply even if the payload is carried on more than one spacecraft. In that case, all spacecraft must be placed in orbits having the same altitude and inclination to provide compatible data from the imaging sensors (WSIR, LAMMR, scatterometer, and PIMR).

THE ICEX SPACECRAFT

The GSFC has performed a preliminary study for a dedicated spacecraft capable of carrying the required sensors. The spacecraft selected for this study is an augmented Multimission Modular Spacecraft (MMS). It is 3-axis stabilized and supports an expandable instrument module. The design includes mission-unique equipment which meets all power, pointing, propulsion, and communication requirements imposed by the mission and payload. The spacecraft would be launched by Shuttle from the Western Test Range (WTR) and then flown into the ICEX orbit with the onboard propulsion system. The propulsion system can be made large enough to return the spacecraft to the Shuttle for service when required. The spacecraft is shown in Figure 17.

A proposed alternate spacecraft approach uses the NOSS placed into the ICEX orbit. This approach requires that the NOSS LAMMR, scatterometer, and radar altimeter be modified to meet ice measurement requirements, and that the laser altimeter and DCLS be added to the payload now proposed for NOSS. A separate spacecraft is required to carry the WSIR and PIMR. No studies for this spacecraft have been performed at this time.

SPACE SHUTTLE

From early in the 1980s, and at least throughout the following decade, the Shuttle will be NASA's transportation system for access to space. Beyond that, the joint venture with European countries in developing the Spacelab will provide a functioning manned laboratory facility in space. These two programs will play vital roles in the development of future remote sensors (Allison et al., 1978). The four functional categories that these programs will provide are as follows: (*a*) calibration of instruments on operational weather satellites, (*b*) direct monitoring of slowly changing earth/atmosphere parameters, (*c*) development and demonstration of new remote sensors, and (*d*) special experiments impossible or impractical by other means.

The difficulties inherent to calibration and correction for long-term drift of satellite instruments have, in the past, presented manifold problems. First, logistic problems associated with deployment of enough ground systems and interrelating their independent errors imposed severe limitations. A second factor is that ground instruments do not generally measure the same quantities as satellite instruments. For example, a satellite radiometer measures a T_B integrated over the entire scene in view, while ground truth data are restricted usually to point measurements. Thus, at least calibrations of satellite instruments over their several years of useful lifetimes and the ability to interrelate succeeding satellites, is a crucial requirement at least for the emerging U.S. Climate Program. The Shuttle can fulfill this requirement by periodic flight of instruments, calibrated against standards before and after flight, that can provide comparative measurements at points of orbit conjunction with the satellites when identical scenes are in view.

Experience with the Nimbus-6 ERB instrument substantiates the desirability of continuing total solar flux measurements at six-month intervals. Such measurements will provide an independent and highly calibrated set of data by themselves, but will also serve to interrelate the total solar flux measurements of the ERBE instrumentation. Other parameters that can be directly monitored by the Shuttle-Spacelab include a number of the well mixed atmospheric constituents, ozone, and tropospheric aerosols. For example, annual measurements are probably adequate for CO_2, CFMs, N_2O, NO_x, and CH_4.

The Spacelab will also provide the needed facilities to develop, test, and demonstrate new remote sensors. These include:

1. *Sea Surface Temperature*—Improvements that appear possible include increased signal-to-noise ratios and additional wavelengths to reduce errors due to atmospheric water vapor and clouds.
2. *Vertical Temperature Profile*—Accuracy of passive sounding below 20km altitude can be improved with measurements at 4μm and with bandwidths of 2 wave numbers. Active Lidar promises even higher accuracy along with an order of magnitude-improved vertical resolution.
3. *Winds*—Lidar techniques may be able to measure wind speed and direction in cloud-free regions.
4. *Stratospheric Aerosols*—Stellar sources provide a large number of occultations not limited to the ecliptic plane, so that reasonably good coverage of stratospheric aerosols is possible.
5. *Tropospheric Aerosols*—At present, no satellite technique exists for measuring tropospheric aerosols, but a pulsed lidar system is believed to hold promise.

As plans are formulated for the development of these instruments (as well as any others that may yet be identified) to the point where space flight development and testing can be visualized, the advantages that Spacelab can provide will be capitalized up to the maximum extent possible.

There are two particularly important special experiments in the area of remote sensing that are especially suited to the Spacelab capabilities. These are extended cloud physics and radiation studies and precipitation over land and water. In the case of the extended cloud and radiation studies a group of instruments, including two separate radiometers and a lidar system, are required. In the case of the precipitation studies, a microwave radiometer, a visible band radiometer, an IR radiometer, and a 10cm radar are required. A number of short duration flights are adequate to meet the objectives of both of these studies and the low orbiting Spacelab offers a unique capability for their accomplishment.

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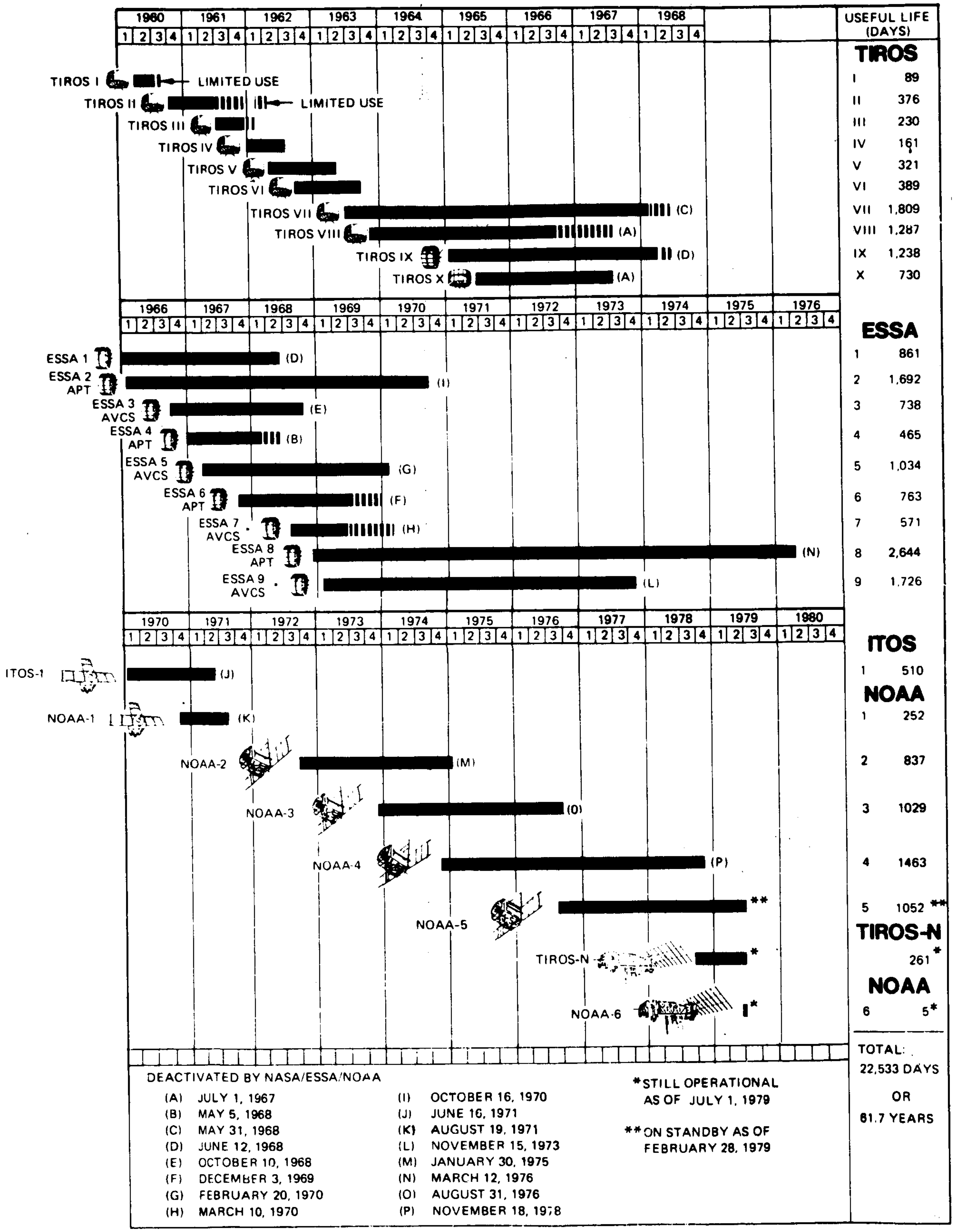

Figure 1. TIROS/ESSA/ITOS/NOAA Program Summary

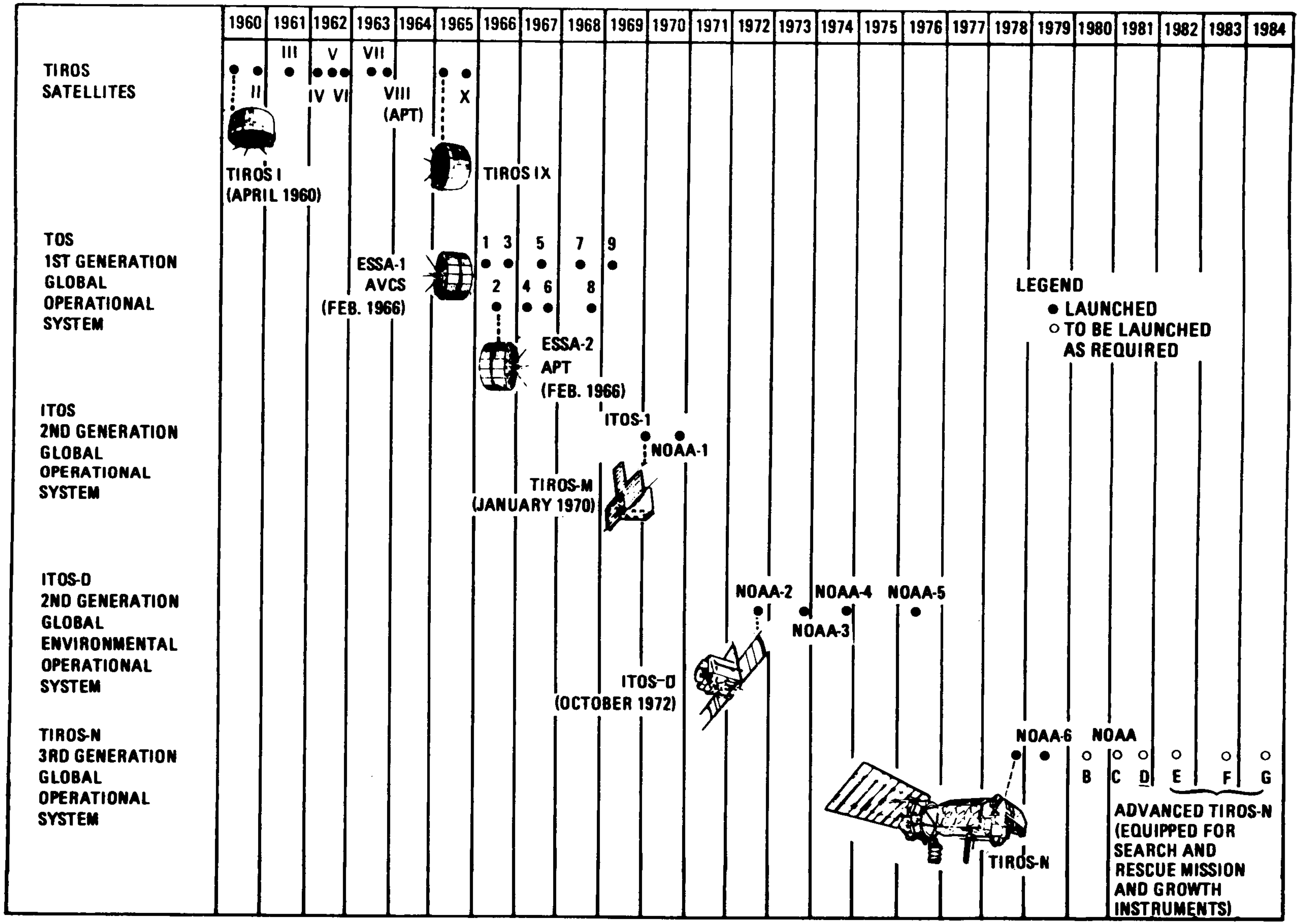

Figure 2. Evolution of TIROS/ESSA/ITOS/NOSS Meteorological Satellites

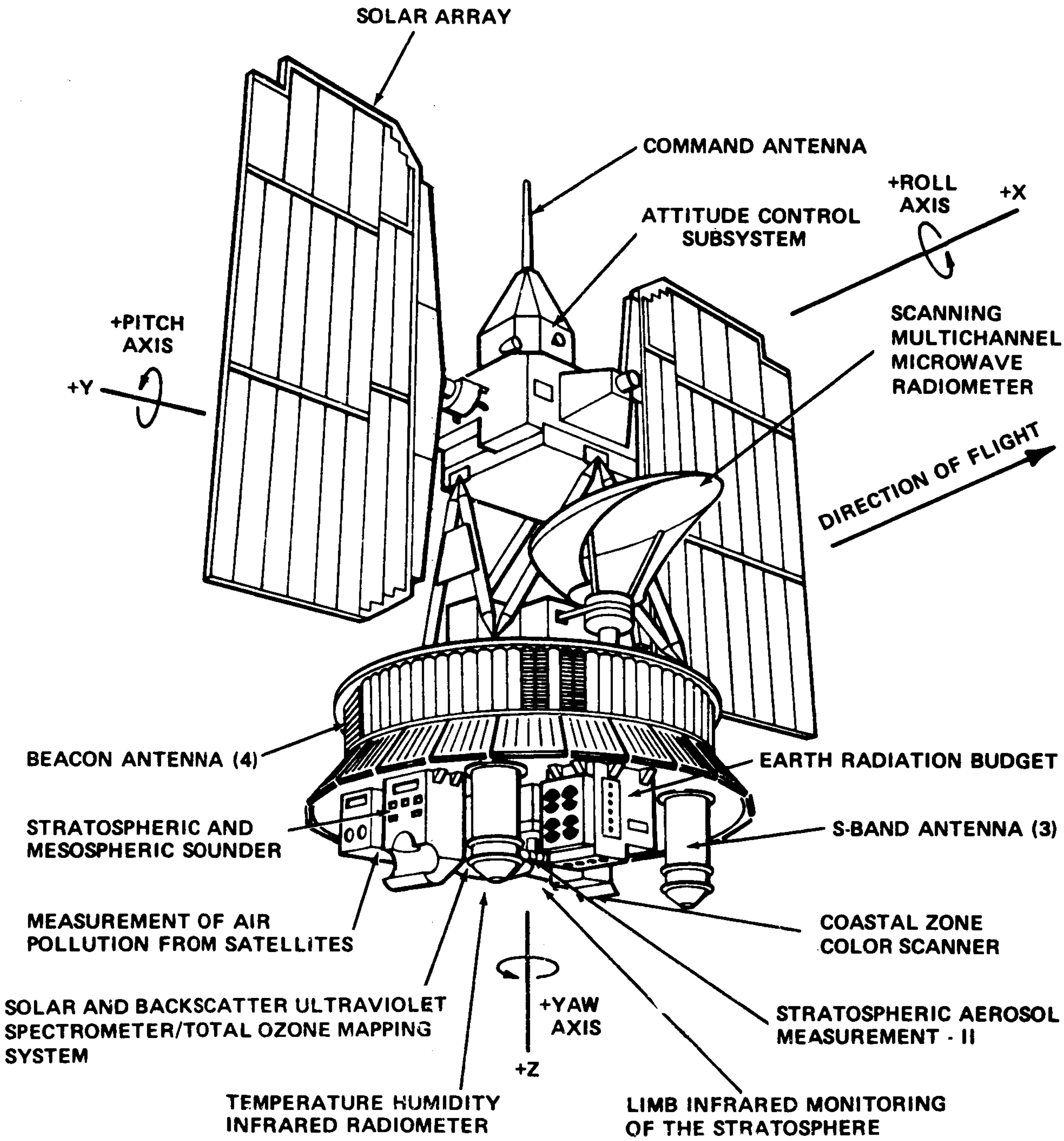

Figure 3. NIMBUS–7 Spacecraft

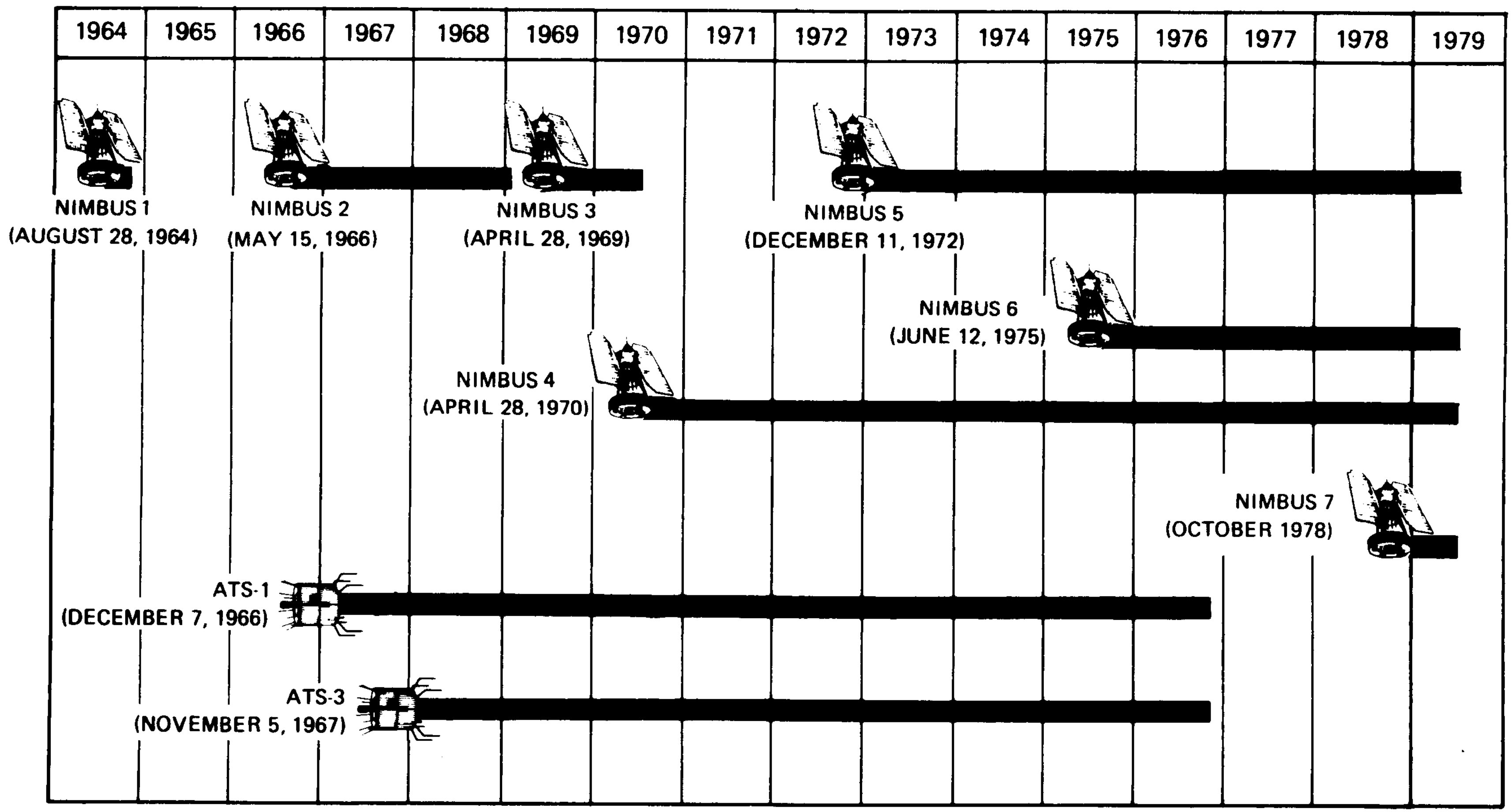

Figure 4. Meteorological Technology Satellites, Performance History

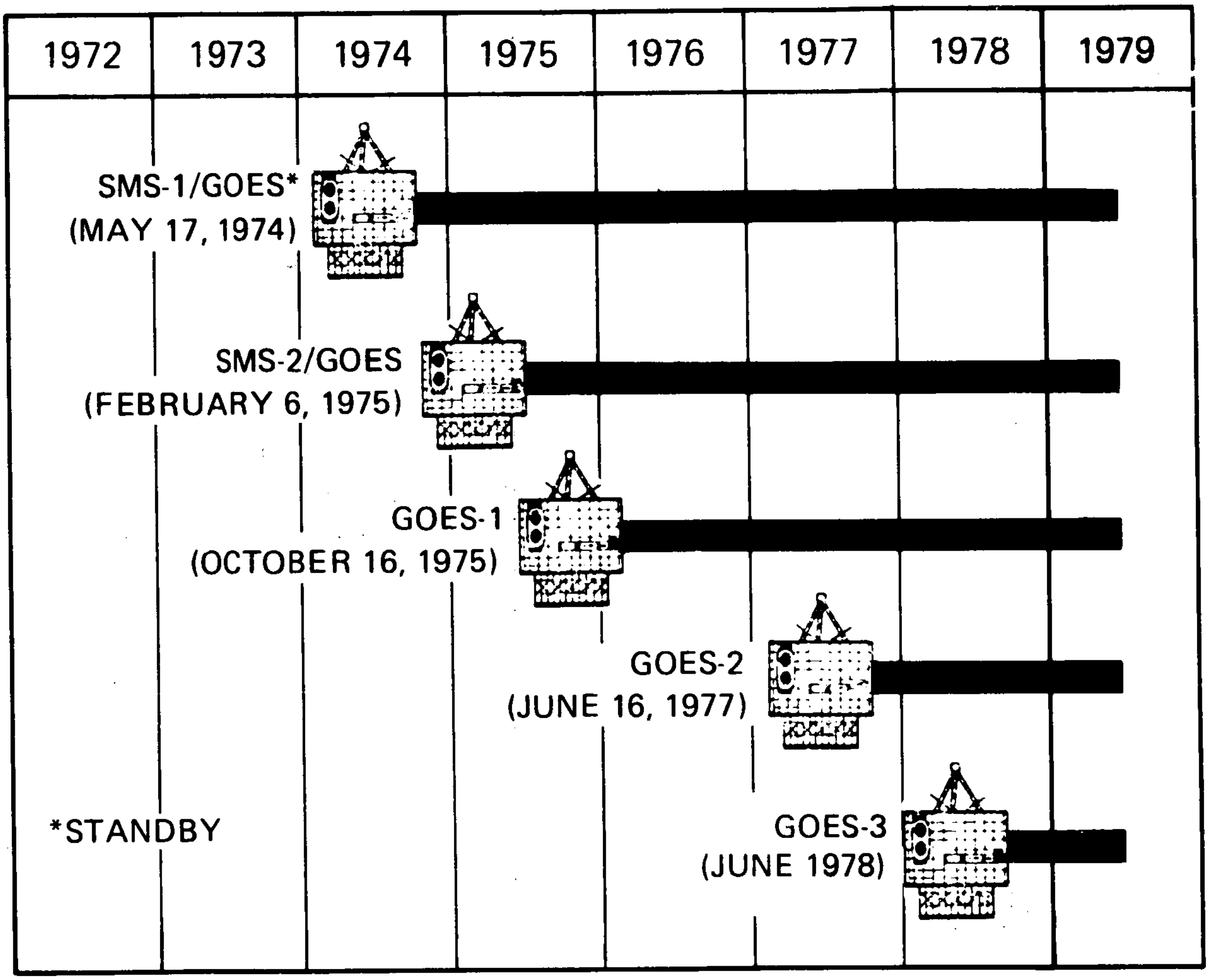

Figure 5. Geostationary Operational Environmental Satellites, Performance History

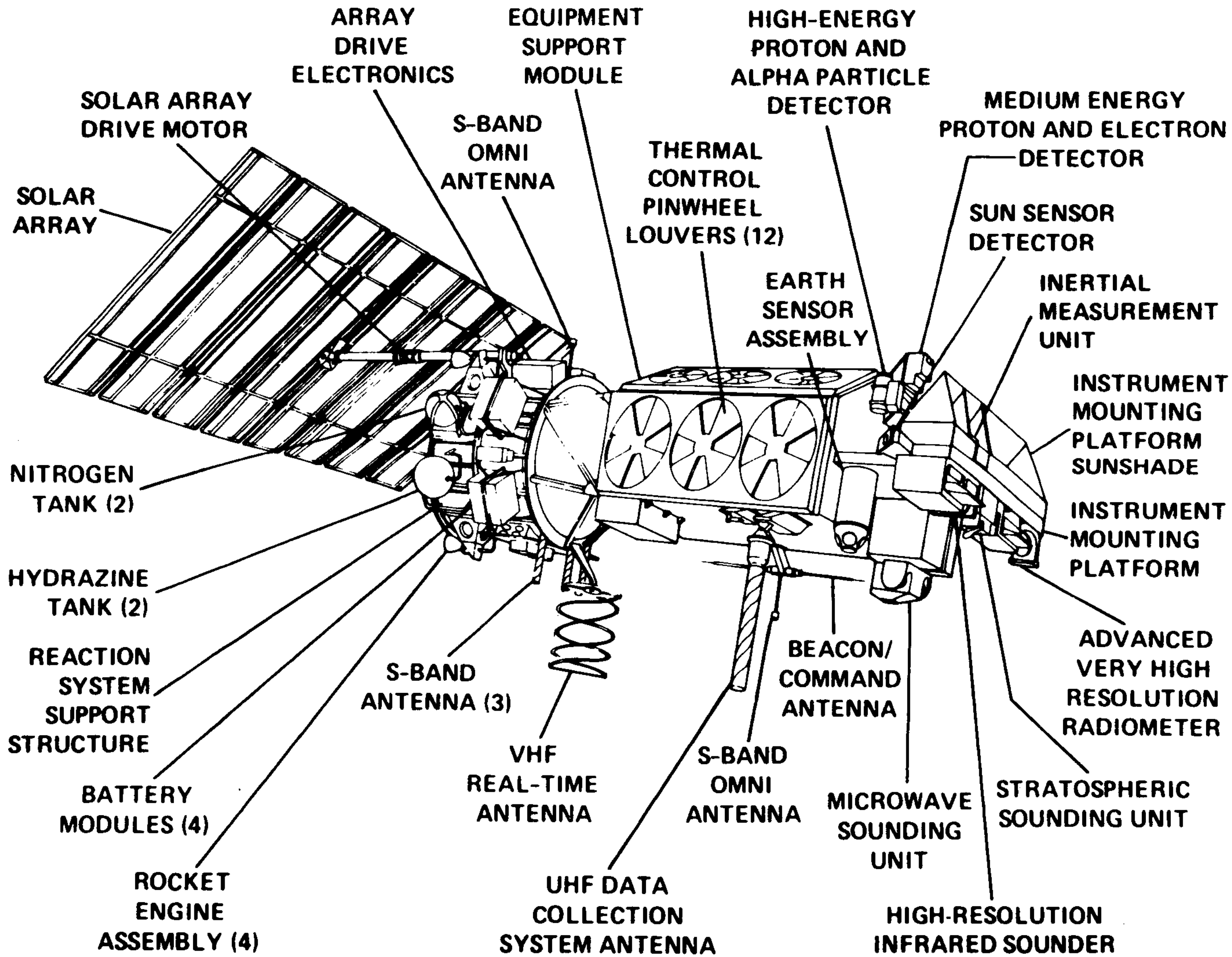

Figure 6. TIROS-N Spacecraft

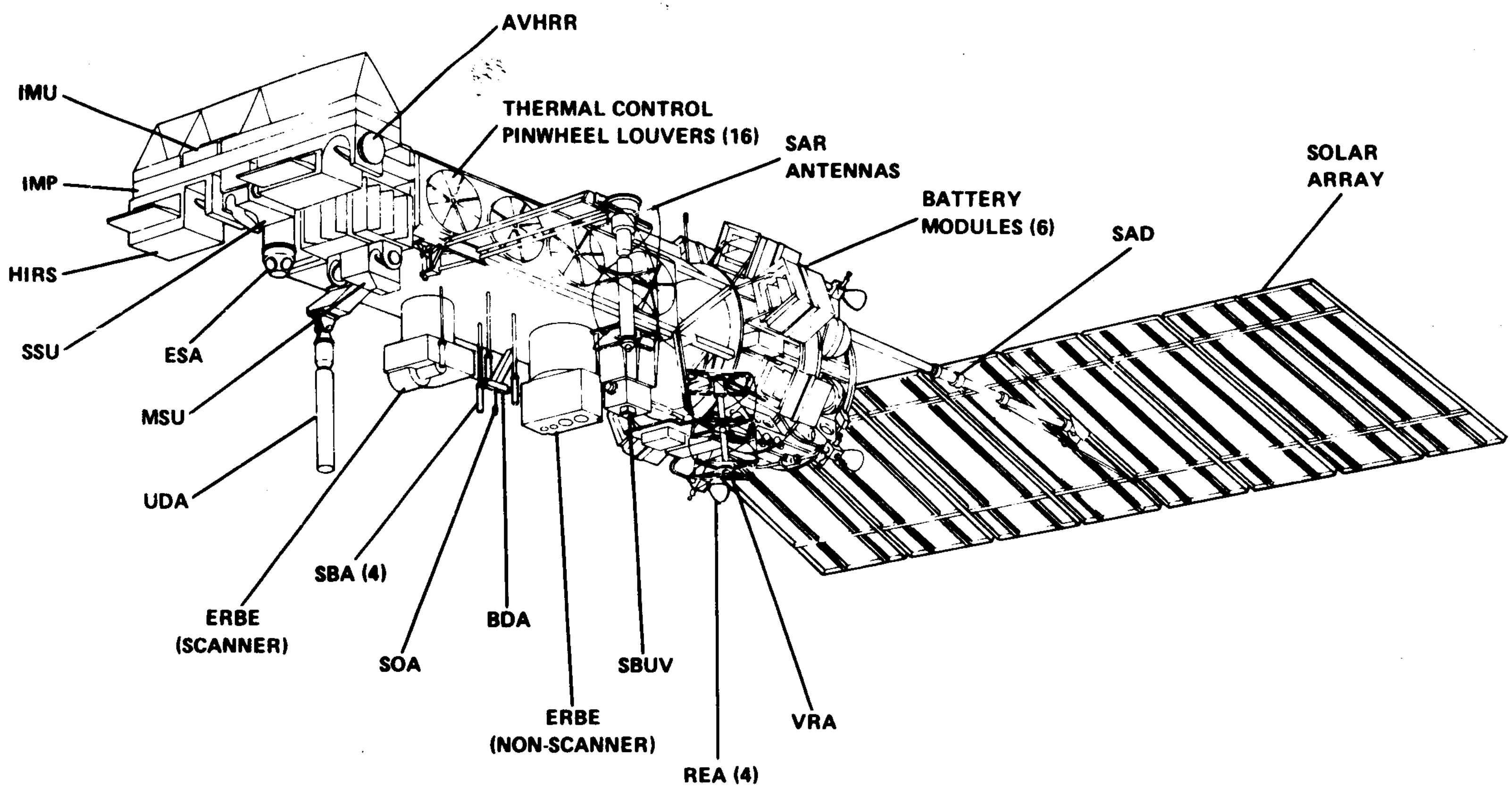

Figure 7. Advanced TIROS-N Spacecraft

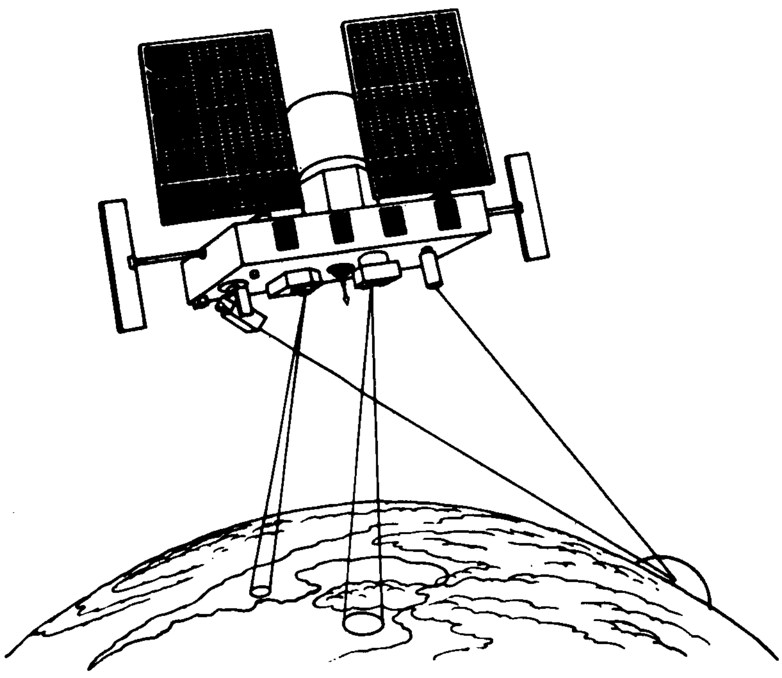

Figure 8. Artist's Concept of the ERBS

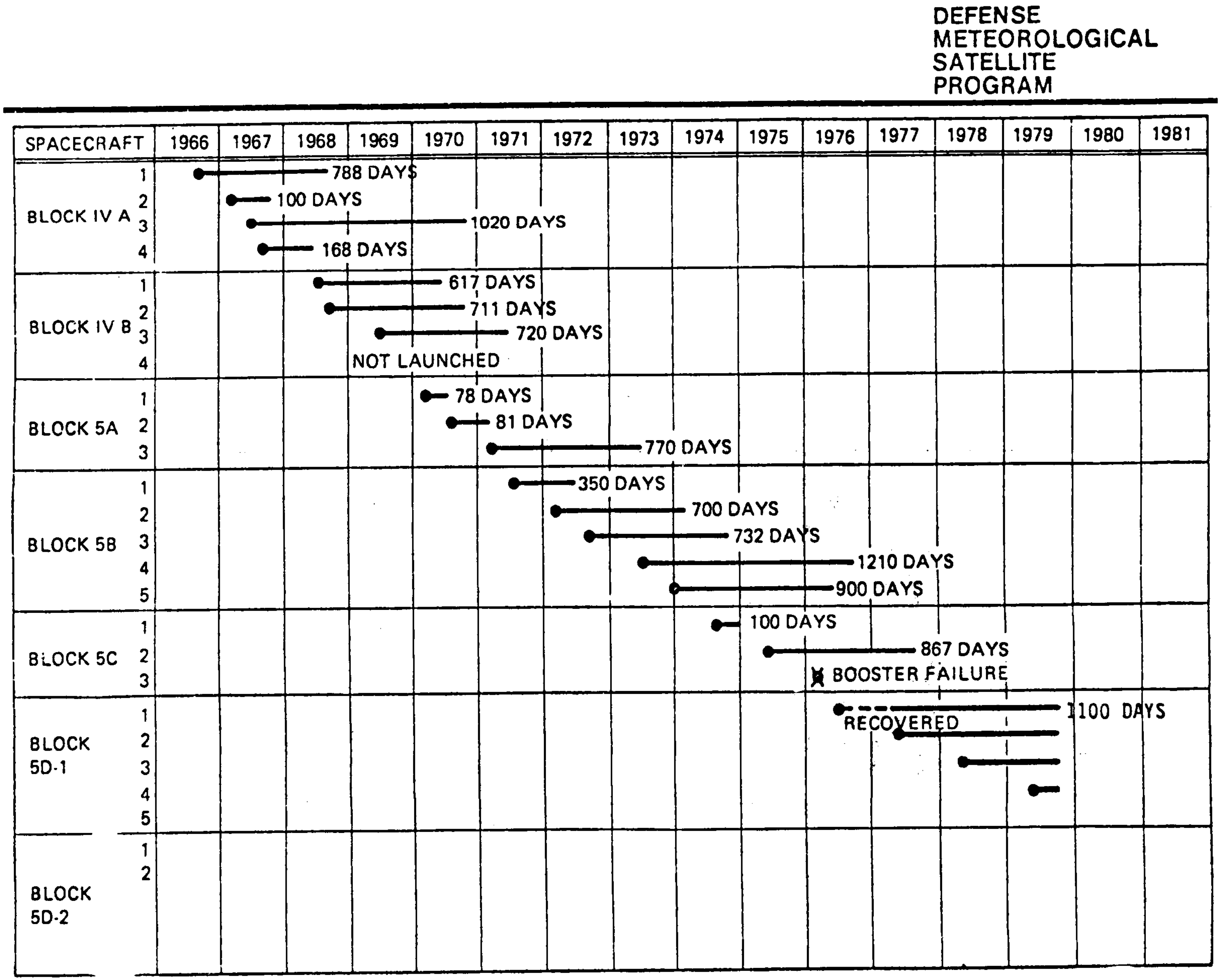

Figure 9. DMSP On-Orbit Performance

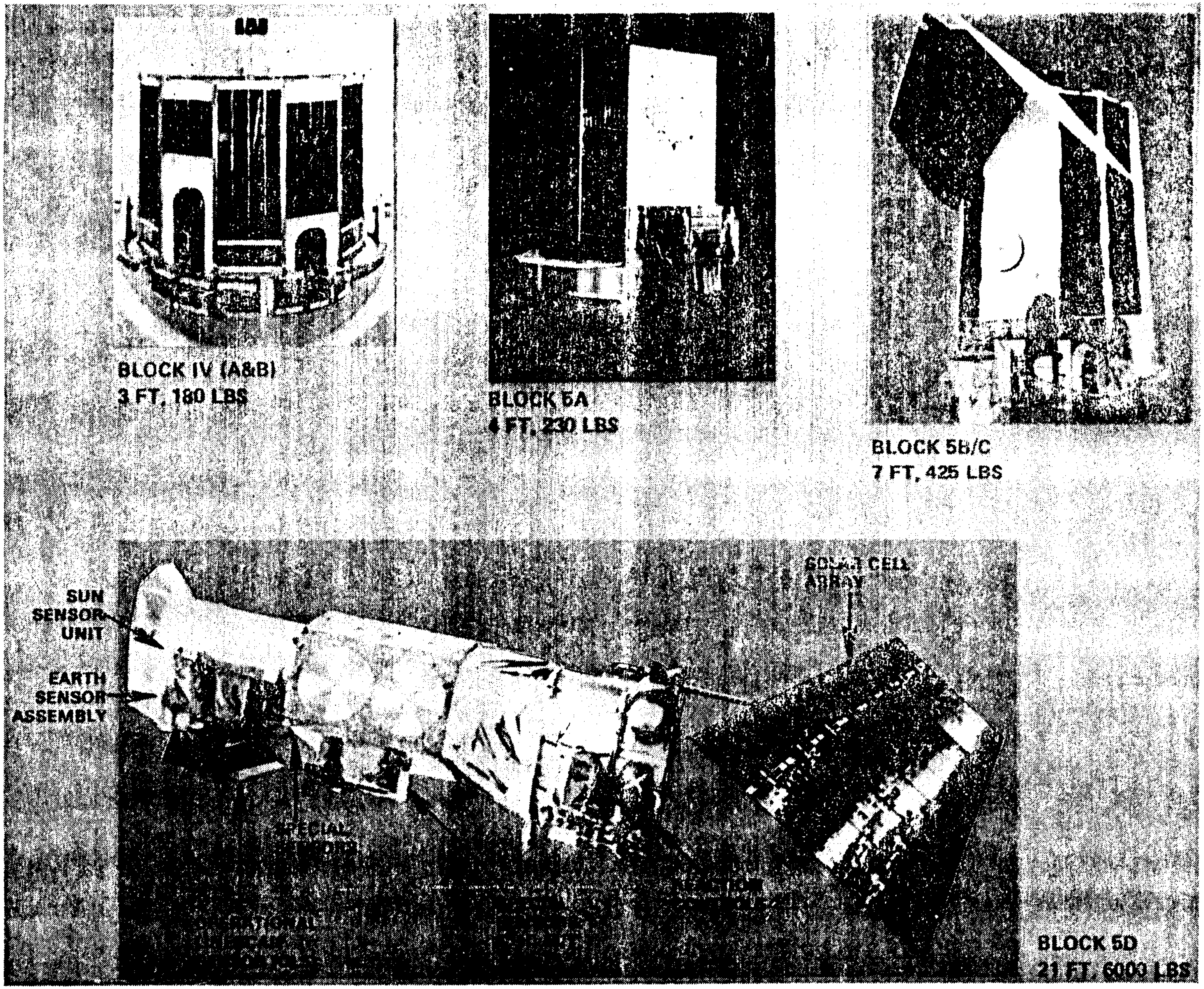

Figure 10(a). Evolution of the DMSP Space Segment

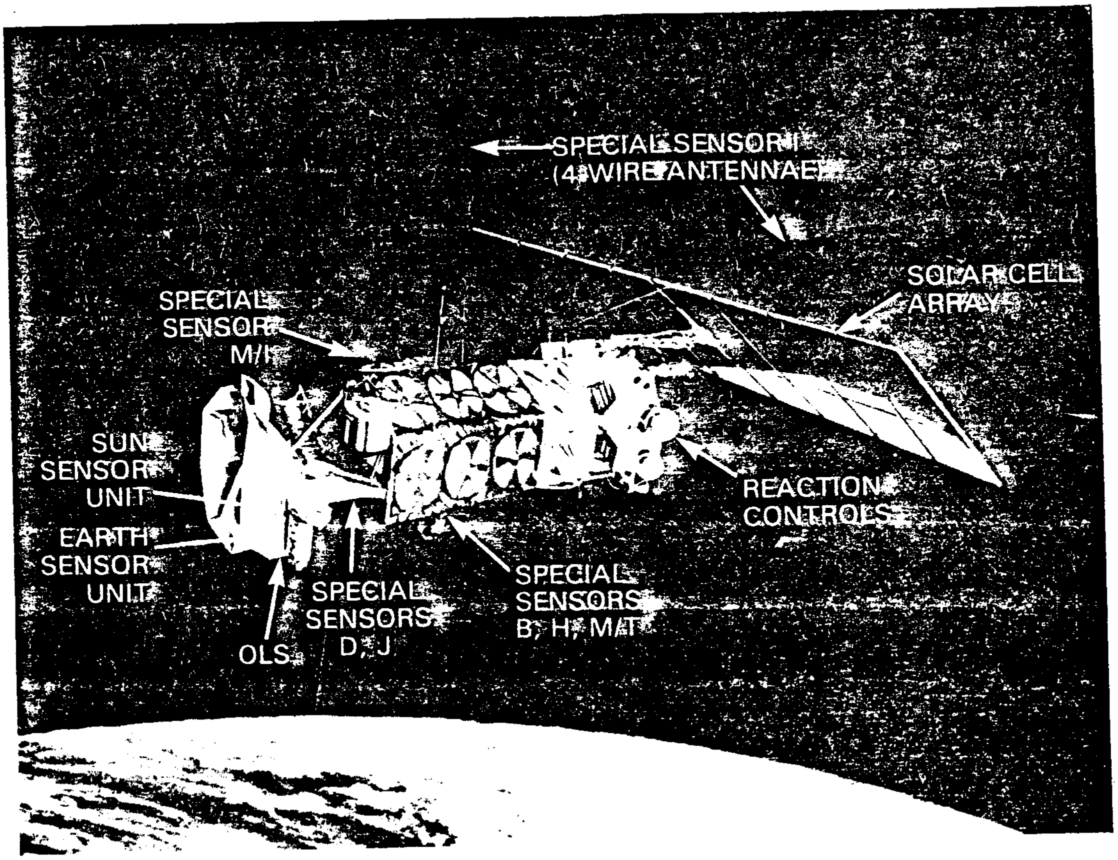

Figure 10(b). DMSP 5D-2 In Orbit

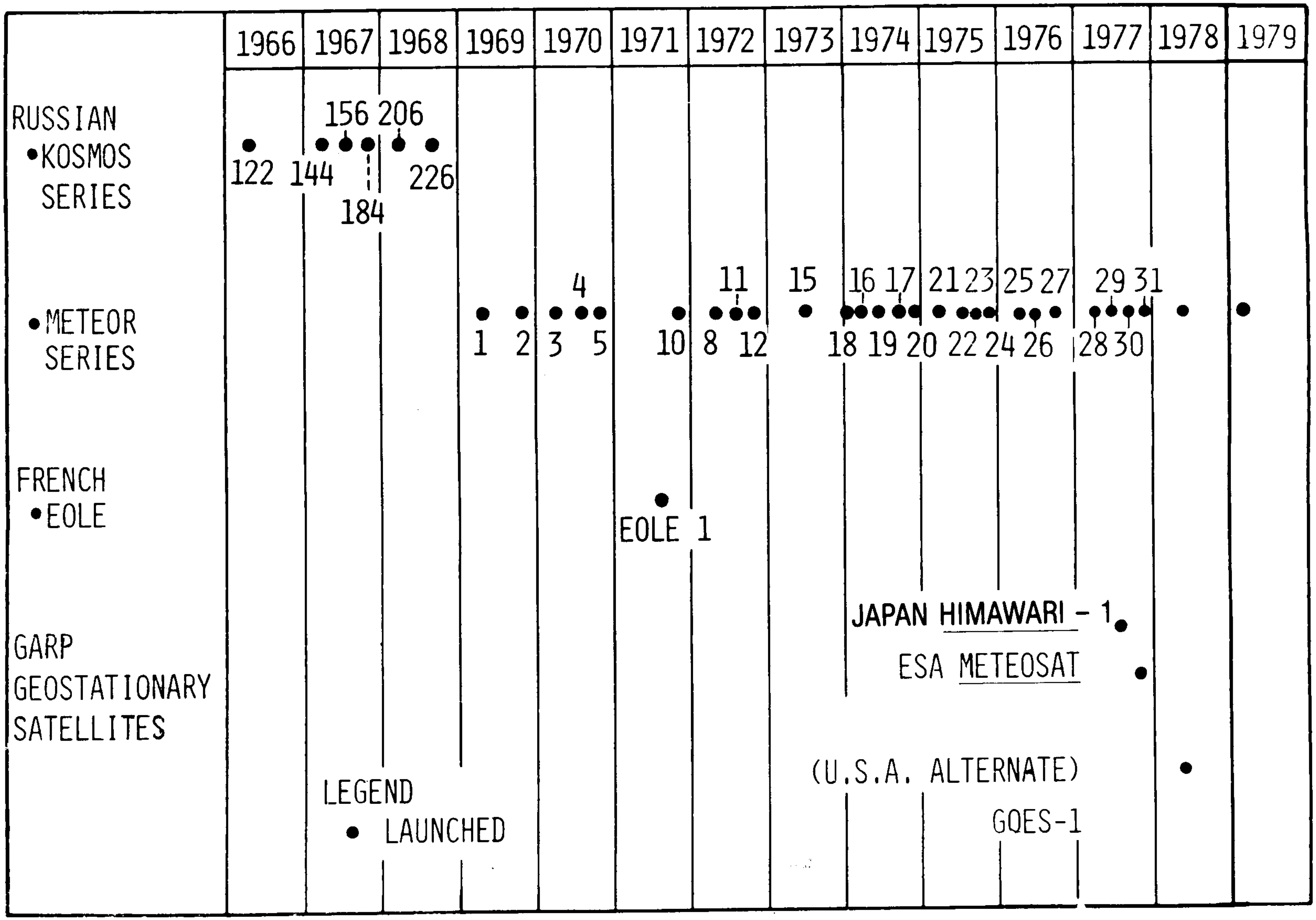

Figure 11. Evolution of International Weather Satellites

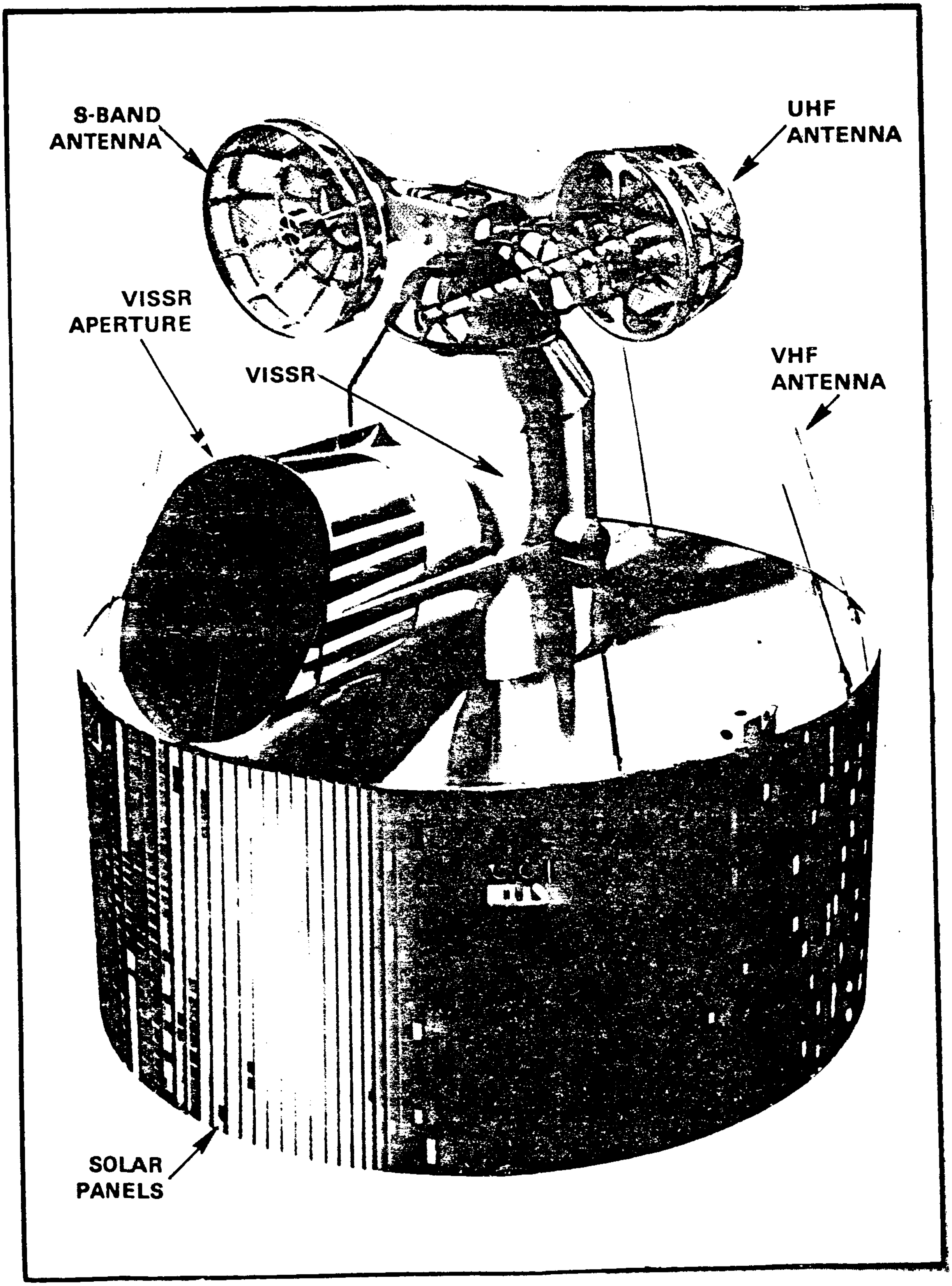

Figure 12. Geostationary Meteorological Satellite (GMS) (Himawari)

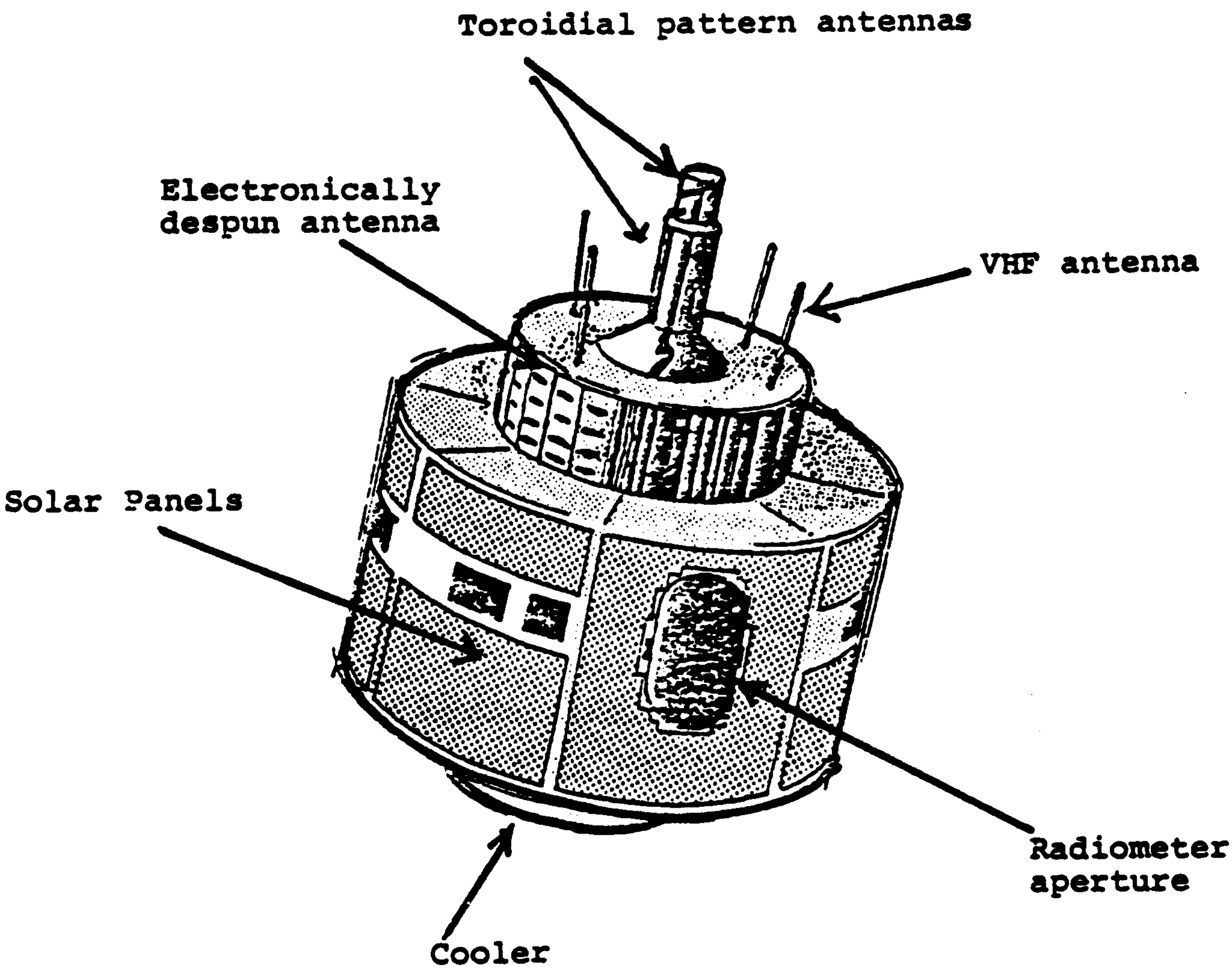

Figure 13. METEOSAT External Appearance

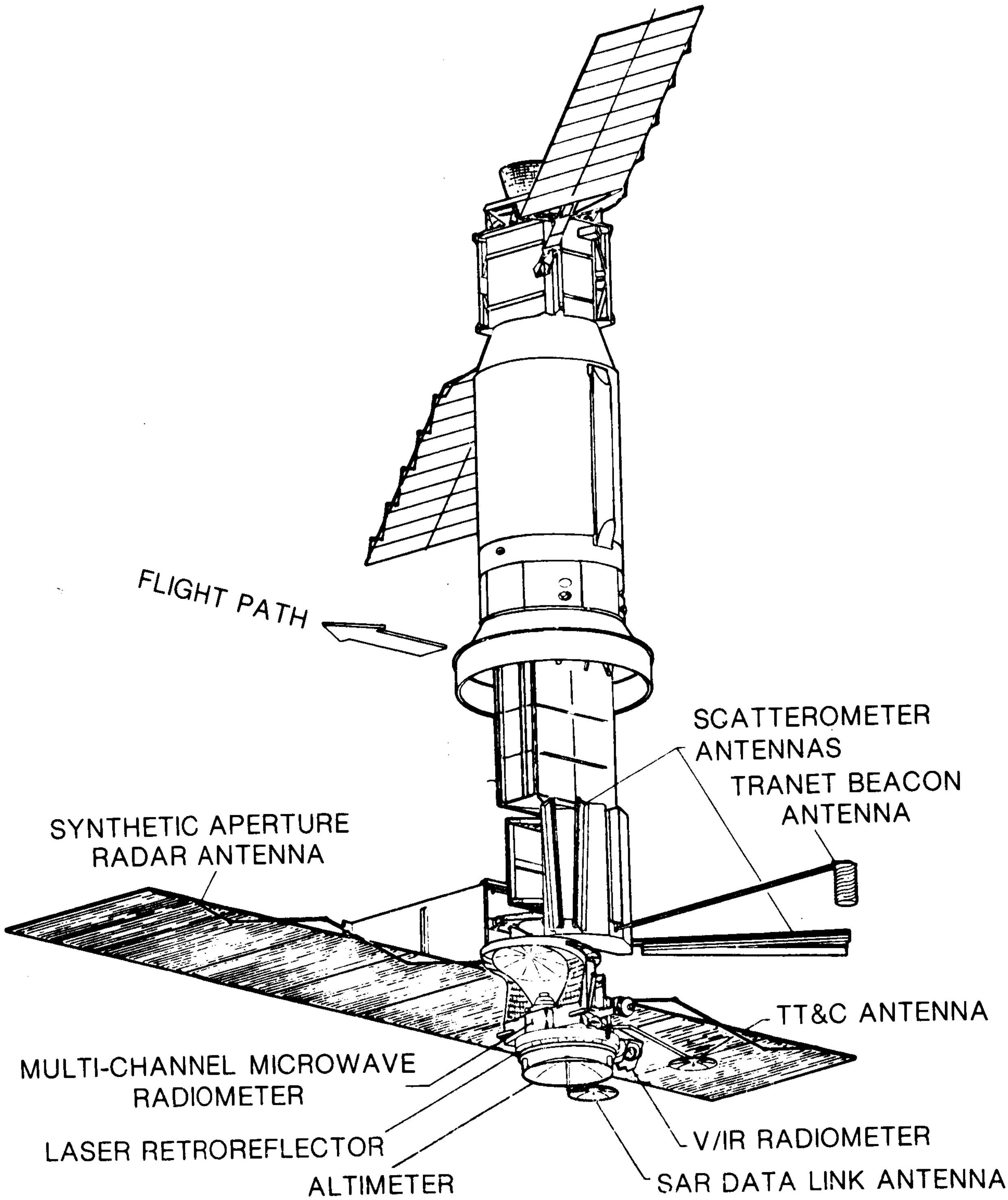

Figure 14. SEASAT-A

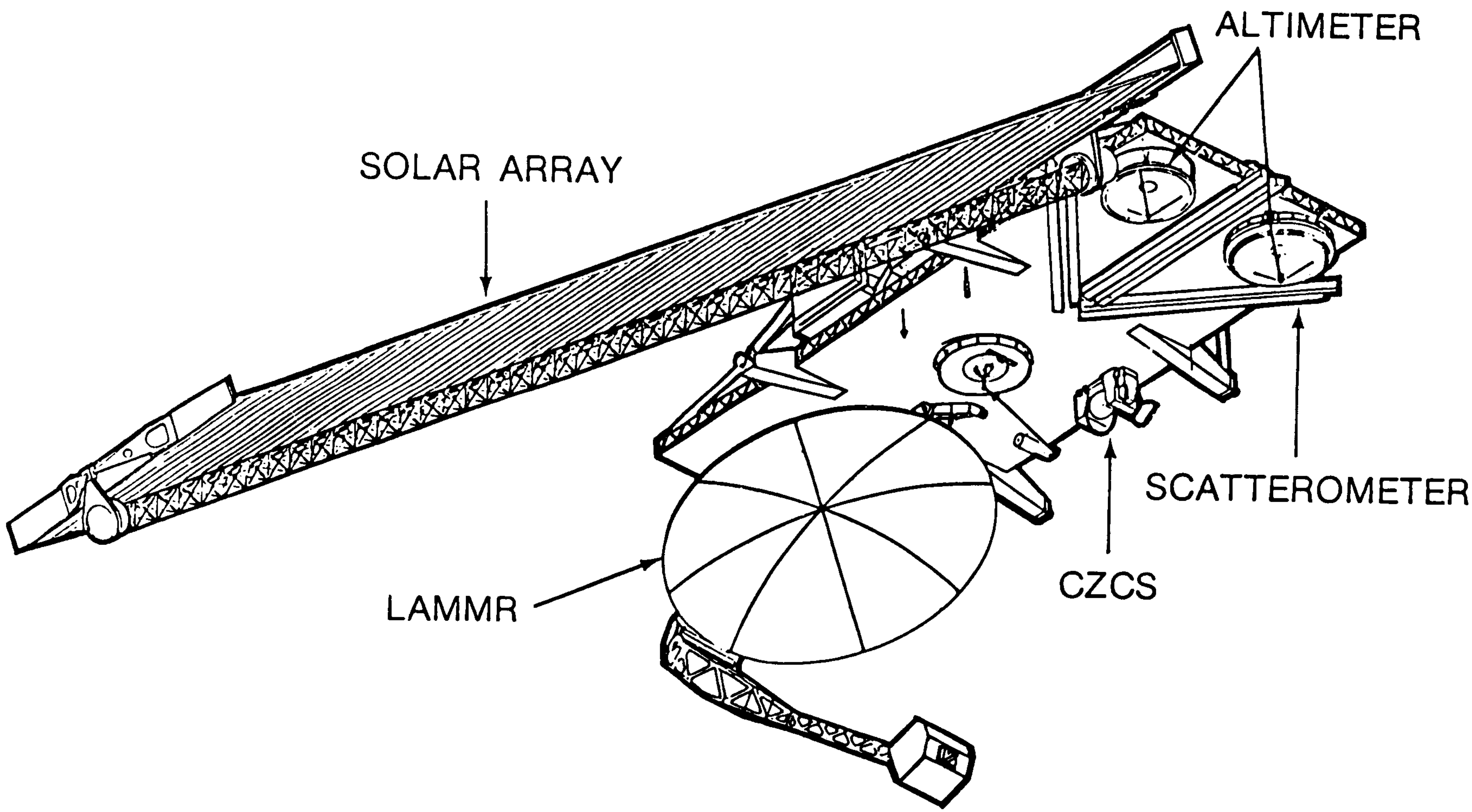

Figure 15. NOSS Spacecraft

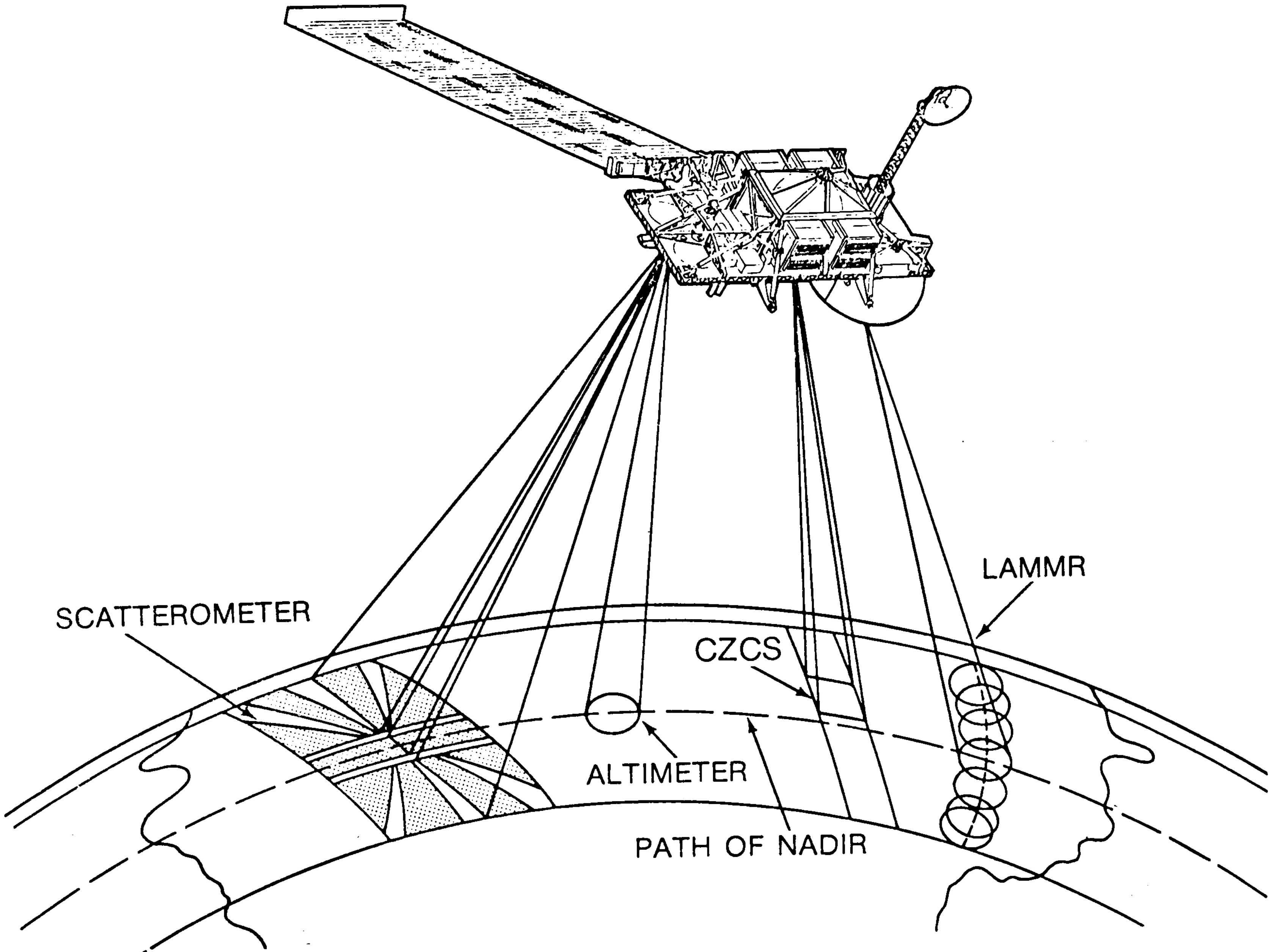

Figure 16. NOSS Sensor Coverage

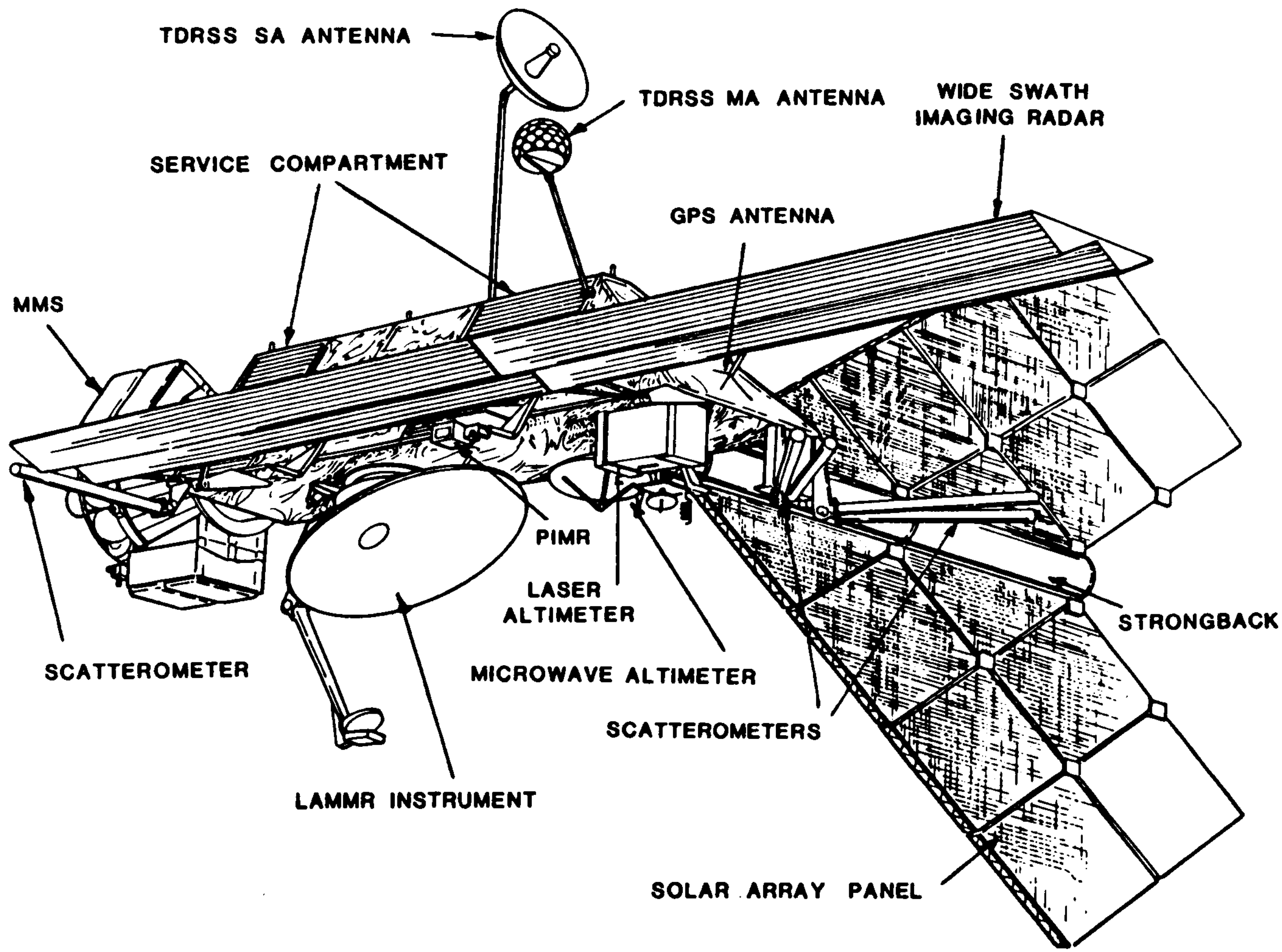

Figure 17. ICEX Spacecraft

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16. Abstract

This paper presents an overview of the meteorological satellite programs that have been evolving from 1958 to the present and reviews plans for the future meteorological and environmental satellite systems that are scheduled to be placed into service in the early 1980's. The development of the TIROS family of weather satellites, including TIROS, ESSA, ITOS/NOAA, and the present TIROS-N (the third-generation operational system) is summarized. The contribution of the Nimbus and ATS technology satellites to the development of the operational polar-orbiting and geostationary satellites is discussed. Included are descriptions of both the TIROS-N and the DMSP payloads currently under development to assure a continued and orderly growth of these systems into the 1980's.

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