History of Rocketry and Astronautics

Proceedings of the Eighteenth and Nineteenth History Symposia of the International Academy of Astronautics

Lausanne, Switzerland, 1984

Stockholm, Sweden, 1985

Tom D. Crouch and Alex M. Spencer, Volume Editors

R. Cargill Hall, Series Editor

AAS History Series, Volume 14

A Supplement to Advances in the Astronautical Sciences

IAA History Symposia, Volume 8

AAS Publications Office
P.O. Box 28130
San Diego, California 92198

Affiliated with the American Association for the Advancement of Science
Member of the International Astronautical Federation

First Printing 1993

ISSN 0730-3564

ISBN 0-87703-374-9 (Hard Cover)
ISBN 0-87703-375-7 (Soft Cover)

Published for the American Astronautical Society
by Univelt, Incorporated, P.O. Box 28130, San Diego, California 92198

Printed and Bound in the U.S.A.

AAS 92-315

Chapter 15

A SURVEY OF THE WORLD METEOROLOGICAL AND ENVIRONMENTAL SATELLITES - 1960-1985*

Abraham Schnapf†

A new era in meteorological observations and forecasting was ushered in with the launching and orbital operations of the TIROS-I (Television and Infra-Red Observation Satellite) weather satellite on April 1, 1960.

Before the advent of the Space Age, observations of the atmosphere over the oceans—which cover over 70 percent of the surface of the planet—were provided by ships at sea and were, at best, very sparse and untimely. Little or no data was available from inaccessible jungles, deserts or the polar regions. The satellite has made it possible to view the entire Earth on a routine and timely basis. Today a pair of operational polar orbiting advanced TIROS-N/NOAA environmental satellites provide global coverage every six hours, on a continuous and reliable basis.

A complementary high altitude system GOES (Geostationary Operational Environmental Satellite) East and West satellites placed in geostationary orbit provide observations of the hemisphere every 30 minutes. The TIROS-N/NOAA and the GOES operational satellites are the mainstay of NOAA's space observation systems. These remote-sensing space systems make it feasible to secure environmental data in an integrated way, rather than the point-to-point measurements obtained from conventional Earth-bound observations in which the field has to be deduced.

The TIROS/NOAA system provides day and night imaging, vertical temperature and moisture profiles of the atmosphere, collection of data from fixed and moving platforms, measurement of sea surface and land temperatures, cloud top temperatures, rainfall and moisture patterns, Earth radiation thermal balance, mapping sea ice and snow cover, measurement of the solar energetic particles, ozone mapping, data collection from remote fixed or moving platforms, vegetation mapping and international search and rescue experiments.

Remote sensing from space by satellite has proliferated over the past 25 years. Since 1960 over 130 meteorological satellites, including technology or experimental

---

* Presented at the Nineteenth History Symposium of the International Academy of Astronautics, Stockholm, Sweden, 1985.

† Aerospace Consultant, 41 Pond Lane, P.O. Box 150, Willingboro, New Jersey 08046.

spacecraft, as well as operational systems, have been placed in orbit by the U.S., U.S.S.R., ESA, Japan and India. Figure 1 depicts a quarter century of environmental satellite activity. Table 1 summarizes the U.S. civilian meteorological satellites.

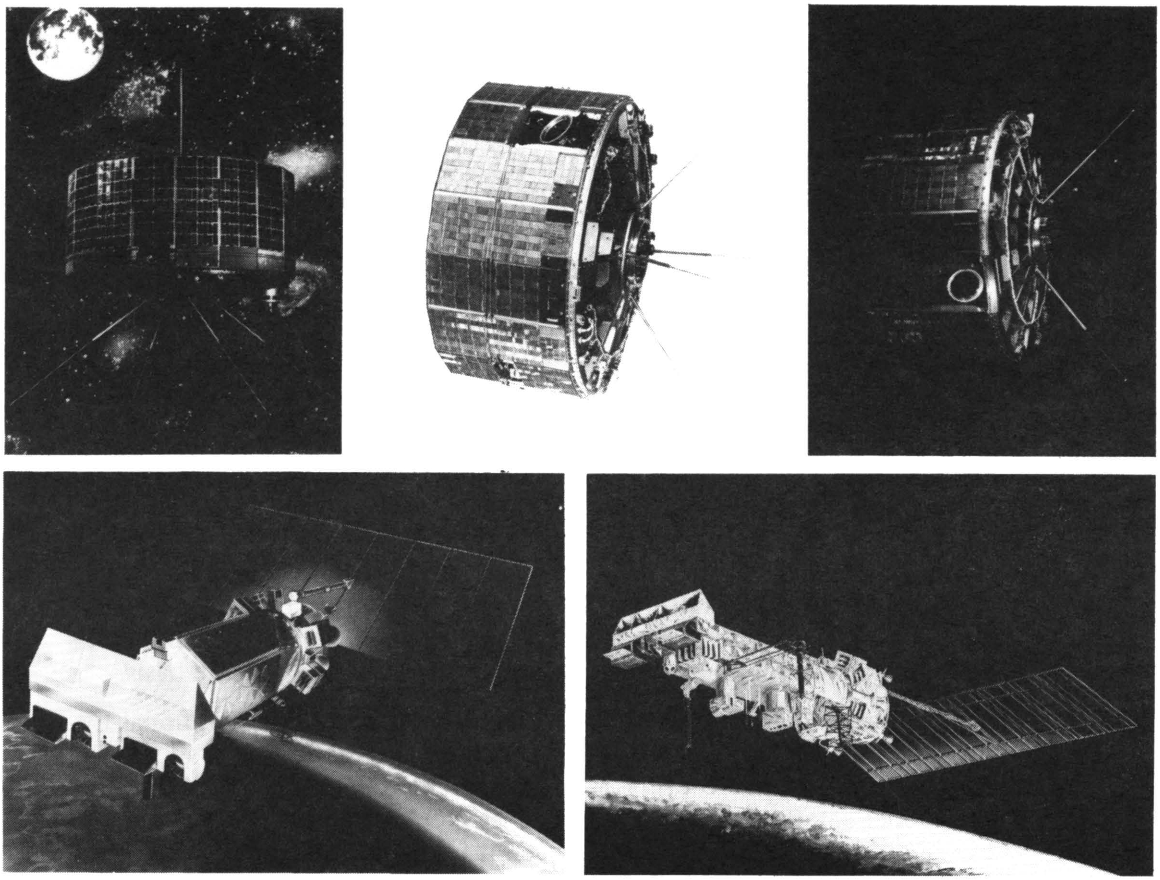

Figure 1 A summary of meteorological satellites.
Top left—TIROS R&D, 1960-1965, 2 ft, 283 lbs (Courtesy: National Air & Space Museum)
Top center—TIROS IX (wheel), 1965, 2 ft, 320 lbs (NASA Photo 66-H-31)
Top right—ESSA, 1966-1969; ESSA-AVCS, 2 ft, 340 lbs; ESSA-APT, 2 ft, 300 lbs (Courtesy: National Air & Space Museum)
Not shown—ITOS-1, 1970-1972, 4 ft, 690 lbs; NOAA-2, 1972-1976, 4 ft, 750 lbs
Bottom left—TIROS-N, 1978-1982, 12 ft, 3,127 lbs (NASA Photo 78-H-291)
Bottom right—Advanced TIROS-N, 1983-1988, 14 ft, 3,800 lbs (NASA Photo 82-H-770).

EVENTS LEADING TO THE TIROS PROGRAM

The initial development of the TIROS program materialized when the Army Ballistic Missile Agency at Redstone Arsenal responded favorably to an RCA proposal. RCA's initial award in 1956 was to conceive a TV system for a satellite for weather reconnaissance to be launched by the Jupiter C rocket. The program at that time was designated JANUS. The resultant design was a slender rod-shaped 20-pound (9.07 kg) spacecraft measuring five inches (12.7 cm) in diameter and approximately 30 inches (76.2 cm) long and equipped with a single TV camera. In mid-1958, the configuration weighed 85 pounds (38.6 kg), was 19 inches (45.7 cm) in diameter and was 30 inches long (76.2 cm).

Table 1
SUMMARY OF U.S. CIVILIAN METEOROLOGICAL SATELLITES

Name	Launched	Period (Min)	Perigee (km)	Apogee (km)	Incli-nation (Deg)	Remarks
TIROS I	01APR60	99.2	798	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
GOES-4	9SEPT80	1436.1	35,600	35,600	0.5	VAS, DCS, SEM,WEFAX
GOES-5	22MAY81	1436.1	35,600	35,600	0.5	VAS, DCS, SEM, WEFAX
NOAA-7	23JUN81	101.92	852	869	98.9	AVHRR, HIRS-2, SSU, MSU, HEPAD, MEPED

Table 1 (Continued)

NOAA-8	28MAR83	101.2	826	801	98.2	AVHRR, HIRS-2, SSU, MSU, SEM, SAR
GOES-6	28APR83	1,436.1	35,803	35,771	0.1	VAS, DCS, WEFAX, SEM
ERBS	05OCT84	96.8	608	598	5.7	ERBE, SAGE-II
NOAA-9	12DEC84	102.0	862	841	98.9	AVHRR, HIRS-2, SSU, MSU, SEM, SAR, SBUV, ERBE

APT	Automatic Picture Transmission TV	PMR	Pressure Modulated Radiometer
AVCS	Advanced Vidicon Camera System (1" Vidicon)	SAM-II	Stratospheric Aerosol Measurement-II
AVHRR	Advanced Very High Resolution Radiometer	SAMS	Stratospheric and Mesospheric Sounder
BUV	Backscatter Ultraviolet Spectrometer	SAR	Search and Rescue
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
ERBE	Earth Radiation Budget Experiment	SCR	Selective Chopper Radiometer
ESMR	Electronic Scanning Microwave Radiometer	SEM	Solar Environmental Monitor
FPR	Flat Plate Radiometer	SIRS	Satellite Infrared Spectrometer
FWS	Filter Wedge Spectrometer	SMMR	Scanning Multichannel Microwave Radiometer
HB	Heat Budget Instrument	SPM	Solar Proton Monitor
HEPAD	High Energy Proton and Alpha Particle Detector	SR	Scanning Radiometer
HIRS	High Resolution Infrared Sounder	SSU	Stratospheric Sounding Unit
HRIR	High Resolution Infrared Radiometer	T&DR	Tracking and Data Relay
IDCS	Image Dissector Camera System	TED	Total Energy Detector
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 Reference Equipment
MEPED	Medium Energy Proton and Electron Detector	VAS	VISSR and Atmospheric Sounder
MRIR	Medium Resolution Infrared Radiometer	VHRR	Very High Resolution Radiometer
MSU	Microwave Scanner Unit	VISSR	Visible Infrared Spin-Scan Radiometer
MUSE	Monitor of Ultraviolet Solar Energy	VTPR	Vertical Temperature Profile Radiometer
NEMS	Nimbus E Microwave Spectrometer	WEFAX	Weather Facsimile

In late 1958 the Thor-Able launch vehicle was made available, and the project, then called Cloud Cover, was renamed TIROS. TIROS-I spacecraft grew to 270 pounds (122.5 kg) in weight, and its size was increased to 42-inch (1.07 m) diameter and was 22.5 inches (0.57 m) high, plus the extended antenna on top and bottom of the spacecraft. Two compact 1/2-inch (1.27 cm) vidicon television cameras (one wide angle and one narrow angle), plus two video recorders, were included in the spacecraft. During these early development years the management of the program shifted from the Army Ballistic Missile Agency to ARPA (Advanced Research Projects Agency), to the U.S. Army Signal Corps, and finally, in early 1959, to NASA/GSFC (Goddard Space Flight Center).

THE EVOLUTION OF THE TIROS METEOROLOGICAL SATELLITE SYSTEM

Low Altitude TIROS Research and Development Satellites TIROS I-X, 1960-1965

TIROS I, the world's first meteorological satellite, was launched April 1, 1960. The primary objective was to demonstrate the feasibility of observing the Earth's cloud-cover by means of slow-scan miniature television cameras in an Earth orbiting, spin stabilized satellite that was placed in a circular orbit 400 miles above the Earth at a 48 degree inclination to the equator. The first historic television pictures from space were received on the first orbit, demonstrating the feasibility of the system. With the reception of pictures from TIROS-I, a new and powerful tool for the meteorological community became a reality.

TIROS II, launched November 23, 1960, demonstrated the utility of an experimental 5-channel scanning IR radiometer and a 2-channel nonscanning IR instrument. The instruments measured the thermal energy of both the Earth's surface and atmosphere, in order to determine the planet's heat balance, thus adding a new tool for the understanding of weather. TIROS III, IV, V, VI and VII were launched between July 1961 and June 1963 to provide continuous observation of the Earth's cloud cover for limited operational use.

TIROS VIII, launched in December 1963, included a 1/2-inch (1.27 cm) TV camera and a 1-inch (2.54 cm) APT (Automatic Picture Transmission) very slow scan readout requiring 200 seconds to transmit its 800 TV-line image. By virtue of its 2-kHz bandwidth, the APT system permitted direct real-time transmission of its TV scene to a series of relatively inexpensive APT ground stations located around the world. Many nations are capable of receiving 2 to 4 orbits of direct transmissions of weather data, which covers an area within a 2,000 mi (3219.0 km) radius.

TIROS IX, launched in January 1965, into a Sun-synchronous orbit, was reconfigured like an Air Force meteorological satellite, with its two television cameras aligned with the radius of the cylindrical satellite rather than parallel to its spin-axis. This "wheel" spacecraft was capable of imaging the entire planet in a 24-hour period. Thus, daily global coverage capability of the satellite increased four-fold. TIROS IX was the forerunner of the TOS (TIROS Operational System) operations meteorological system, also similar to the Air Force system.

TIROS X, the last of the research and development series was launched in July 1965 to provide hurricane and tropical storm observations.

The TOS (TIROS Operational System) ESSA Satellites, 1966-1969

The world's first operational weather satellite system was placed into service with the launching of the ESSA-1 (Environmental Satellite Service Administration) on February 3, 1966, and ESSA-2 on February 28, 1966. The commitment to provide routine daily worldwide observation without interruption in the acquisition of data from satellites was fulfilled by the introduction of the TOS program. This system employed a pair of ESSA satellites in a Sun-synchronous orbit, each configured for a specific mission. Through their onboard storage recorder systems, the AVCS (Advanced Vidicon Camera System) provided global weather data to the U.S. Department of Commerce's CDA (Command and Data Acquisition) stations in Wallops Island, Virginia, and Fairbanks, Alaska. It then relayed received data to the National Environmental Satellite Service at Suitland, Maryland, for processing and dissemination to forecasting centers of the U.S. and nations overseas. The odd numbered satellites (ESSA 1, 3, 5, 7, 9), with redundant AVCS system, were the global readout satellites.

The second configuration in the ESSA series was equipped with the redundant APT cameras, and was capable of providing direct real-time readout of the APT television pictures to simple stations located around the world. The even numbered ESSA satellites (ESSA 2, 4, 6, 8) were the APT configuration. The ESSA satellites operated from an orbit of approximately 900 miles (1,450 km).

ITOS (Improved TIROS Operational System) System, 1970-1978

The second decade of meteorological satellites was introduced by the successful orbit of ITOS-1 on January 23, 1970. The ITOS system evolved from the spin-stabilized spacecraft to a 3-axis stabilized Earth-oriented spacecraft. ITOS-1 provided the combined capability of two ESSA spacecraft, the direct readout APT System, and the global stored images of the AVCS system in a single spacecraft. Additionally, ITOS-1 provided, for the first-time, operational 2-channel scanning radiometer (SR) for day-and-night radiometric data in real-time, as well as stored data, for later playback to the CDA station. The APT, AVCS and SR were redundant systems. Global observations of the Earth's atmosphere, land and oceans were provided every 12 hours with a single ITOS spacecraft as compared to every 24 hours with two orbiting ESSA satellites. A second ITOS spacecraft, NOAA-1 (National Oceanic and Atmospheric Administration), was launched on December 11, 1970.

The ITOS system evolved further with the ITOS-D system. A new sensor complement provided day-and-night imaging by means of VHRR (Very High Resolution Radiometer) and the medium resolution SR (Scanning Radiometer). A VTPR (Vertical Profile Radiometer) was added for temperature sounding of the atmosphere, and the SPM (Solar Proton Monitor) was added for measurements of the proton and electron flux in the vicinity of the satellite. The VHRR, SR and VTPR included a set of redundant instruments. The APT and AVCS cameras were eliminated. The ITOS-1 series weighed 683 pounds (309.8 kg) and the ITOS-D series weighed 750 pounds (340.2 kg). Three additional ITOS-D satellites were launched; NOAA 3, 4, and 5 were placed in orbit in 1973, 1974 and 1975, respectively.

The Current TIROS-N/NOAA Operational System - 1978-1989

The third generation operational polar-orbiting environmental satellite system, designated TIROS-N, completed development and was placed into operational service in 1978. This series consists of eleven spacecraft, TIROS-N/NOAA (A-J), providing operational service from 1978-1989. This series consists of two configurations, five spacecraft designated TIROS N/NOAA (A-D) and six spacecraft of the ATN group (Advanced TIROS-N) NOAA (E-J). Figure 2 depicts the ATN configurations, respectively. Table 2 highlights the physical characteristics of TIROS-N and ATN.

THE TIROS-N/NOAA (A-D) SYSTEM

The TIROS-N system provides NOAA with the global meteorological and environmental data required to support both the operational system and the experimental World Weather Watch Program. The TIROS-N/NOAA series has a new complement of data-gathering instruments. The AVHRR (Advanced Very High Resolution Radiometer) increases the amount of radiometric information for more accurate sea-surface temperatures and identification of snow and sea ice, in addition to day-and-night imaging in the visible and infrared bands. The TOVS (TIROS Operational Vertical Sounder) provides improved vertical sounding of the atmosphere. The DCS (Data Collection System) receives environmental data from fixed and moving platforms such as buoys, balloons and fixed remote platforms.

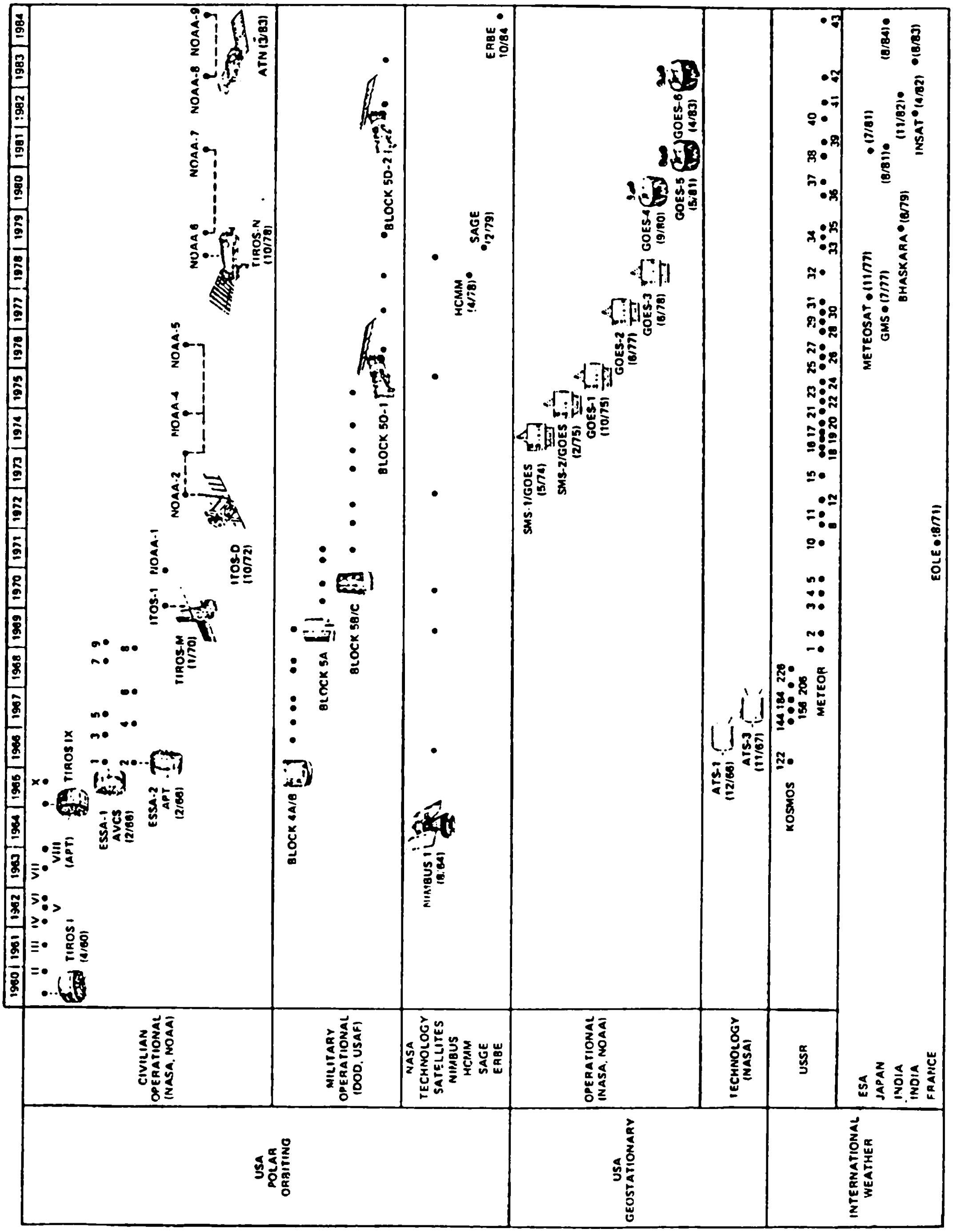

Figure 2 The TIROS ATN configuration.

Table 2
TIROS-N/NOAA (A-J) PHYSICAL CHARACTERISTICS

	TIROS-N/ NOAA A-D	Advanced TIROS-N (NOAA E-J)
Weight	lb. (kg)	lb. (kg)
Lift-off	3,127 (1418)	3,725 (1690)
On Orbit	1,640 (744)	2,235 (1014)
Payload	510 (231)	810 (367)
Size	in. (cm)	in. (cm)
Length - Nondeployed	146 (371)	165 (419)
Diameter	74 (188)	74 (188)
Length - Deployed	256 (650)	294 (747)
Power	Watts	Watts
Array	1,260	1,470
Bus - Load	266	286
Payload	146	263

The data is transmitted to central stations for processing and relay to various users. The SEM (Solar Environment Monitor) is included to measure proton, electron and alpha particle densities for solar disturbance. The data collected by the TIROS-N instruments is processed and stored on board the satellite for transmission to NOAA's central processing facility at Suitland, Maryland, via the CDA station. Satellite data is also transmitted in real-time at VHF and S-band frequencies to remote stations distributed throughout many nations.

The TIROS-N satellite, launched by an Atlas E/F launch vehicle from the Western Test Range, operates in a near-polar circular Sun-synchronous orbit with a nominal altitude of either 833 or 870 km. In the operational configuration, two satellites were positioned with a nominal orbit plan separation of 90 degrees. Orbits for the TIROS-N and ATN series are subject to the same constraints as previous satellites with operational requirements dictating whether the satellite is launched in an afternoon (ascending node) or a morning (descending node) operational orbit. Both the NOAA and Air Force low altitude meteorological satellites employed the same spacecraft bus.

THE TIROS-N/NOAA (A-D) INSTRUMENT PAYLOAD

The instrument payload for the TIROS-N/NOAA (A-D) consists of the following instruments providing direct real-time readout and remote recording or environmental data during day and night operation.

AVHRR (ADVANCED HIGH RESOLUTION RADIOMETER)

The TIROS N/NOAA system objective is to provide timely day-and-night images of the atmosphere, the Earth's surface, sea-surface temperature, snow, ice, water vapor, and temperature of clouds and land. The AVHRR is used to satisfy the following requirements:

- o Direct readout to ground stations of the Automatic Picture Transmission (APT) class, worldwide, at a resolution of 4 km with reduction of panoramic distortion,
- o Direct readout to ground stations of the High Resolution Picture Transmission (HRPT) class, world wide, at a resolution of 1 km,
- o Global Area Coverage (GAC) of on board recorded data at a resolution of 4 km for central processing and distribution of NOAA, and
- o Local Area Coverage (LAC) of on board storage of data from selected portions of each orbit at a high resolution of 1 km for NOAA processing and distribution.

The AVHRR was initially a four-channel, crosstrack scanning instrument that provides image and radiometric data in the visible, near-infrared and far-infrared portion of the spectrum. AVHRR channels 1 and 2 are used to discern clouds, land-water boundaries, snow and ice extent. When data from the two channels are compared, they provide an indication of ice/snow melt inception. The data from Channel 4 (IR window) is used to measure cloud distribution day and night, and to determine the temperature of the radiating surface. Channels 3 and 4 are used to determine the Sea Surface Temperature (SST). By using the two data sets it is possible to remove any ambiguity introduced by the presence of clouds. Channel 5 has been added on the AVHRR/2 installed on NOAA-7, (formerly NOAA-C) and most of the ATN series, to further enhance sea-surface temperature measurements in the tropics. Table 3 summarizes the characteristics of the AVHRR channels. Figures 3 and 4 depict products from the AVHRR instrument.

Table 3
TIROS-N AVHRR CHANNEL CHARACTERISTICS

Channel*	Resolution at Subpoint	Wave-Length (μm)	Primary Use
1	1 km	0.55-0.90	Daytime Cloud & Surface Mapping
2	1 km	0.725-1.10	Surface Water Delineation
3	1 km	3.55-3.93	SST, Nighttime Cloud Mapping
4	1 km	10.5-11.5	SST, Day/Night Cloud Mapping
5	1 km	11.5-12.5	SST

*Channel 1 wavelength will be 0.58 μm to 0.68 μm for instruments after the TIROS-N flight model. Channel 4 wavelength will be 10.3 μm to 11.3 μm for all AVHRR/2 instruments. Channel 5 has been added to the AVHRR/2 instrument to further enhance Sea Surface Temperature (SST) measurements in the tropics.

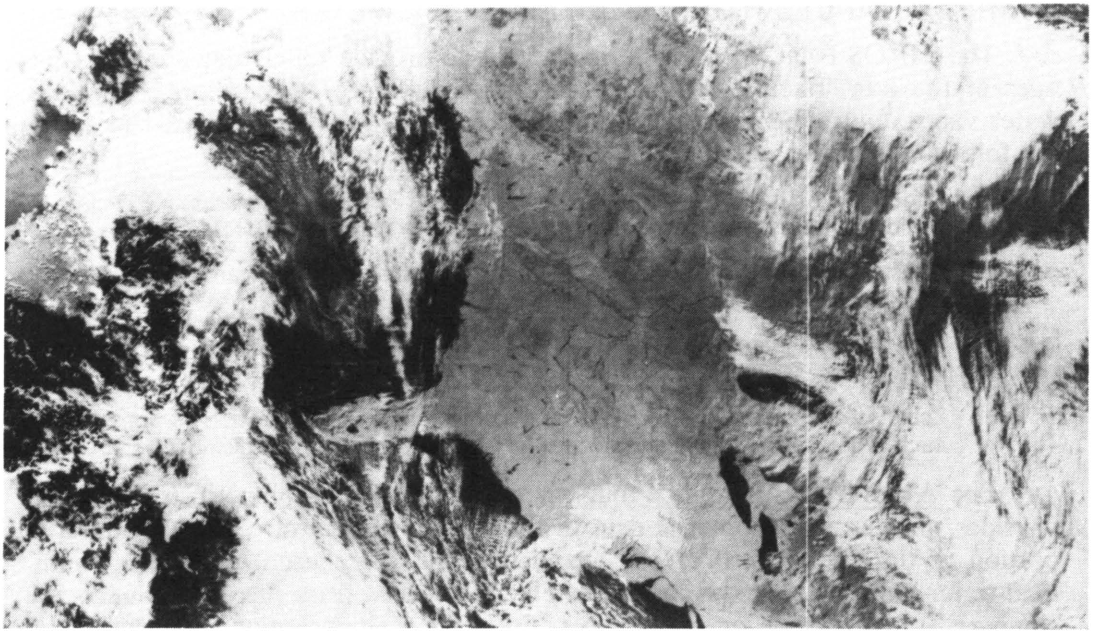

Figure 3 TIROS-N - AVHRR visible channel (NASA Photo 78-H-629).

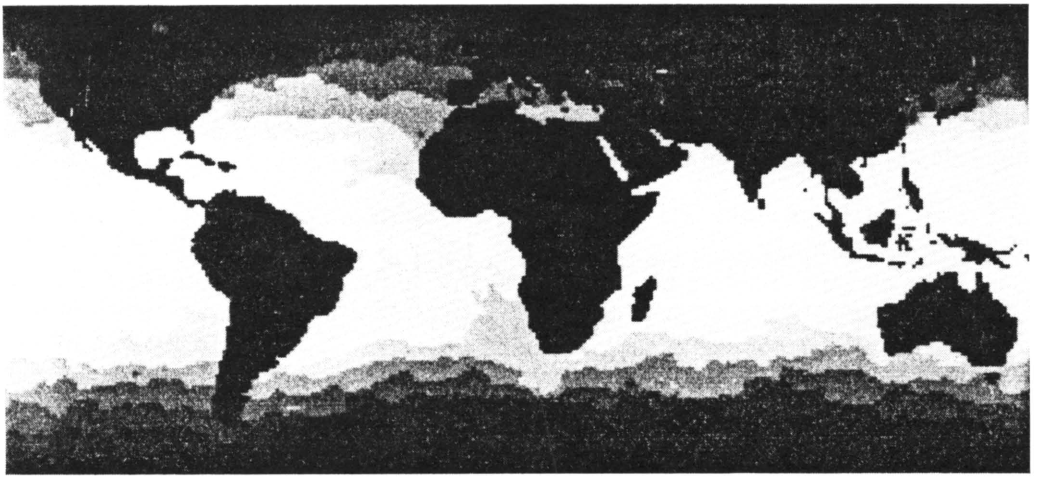

Figure 4 TIROS-N sea surface temperature composite.

TOVS

This is a sounding instrument system, consisting of three separate instruments, that provides temperature profiles of the atmosphere from sea level to 10 mb, water vapor contents, and total ozone content of the atmosphere on a grid spacing at the Earth's surface of 250 km or less, even in the presence of clouds. (1) HIRS/2 - The HIRS/2 is a 20-channel instrument that measures incident radiation of the IR spectrum, including the longwave (15 μm) regions. The instrument provides data that permits calculations of: (a) temperature profile of the atmosphere from the surface to 10 mb; (b) water vapor content in three layers in the atmosphere; and (c) total ozone content.

The HIRS/2 spatial resolution is 17 km, and its temperature accuracy is approximately 1.5 to 2.5°C. (2) SSU - The SSU is a 3-channel, pulse-modulated, step-scanned far infrared spectrometer used to produce temperature profiles of the stratosphere. The primary objective of this instrument is to obtain data from which the stratospheric (25 to 50 km) temperature profile can be determined. Resolution at the subpoint is 147 km. (3) MSU - The MSU is a 4-channel, step-scanned spectrometer with response in the 60 GHz 0 band, used to produce temperature profiles in the atmosphere in the presence of clouds. Resolution at subpoint is 109 km.

DCS

The DCS is a random-access system that provides the means of obtaining data such as temperature, pressure, winds, altitude, river flood stages, snow depth, velocity of platforms, etc., from fixed- and/or free-floating terrestrial and atmospheric platforms. When necessary, location of the platforms may be computed by differential Doppler techniques. Position can be determined to within 3-to-5 km rms, and velocity to within 0.5-to 1.5 m/sec rms.

SEM

The SEM payload consists of three separate instruments and a data processing unit. The multi-detector unit is used to monitor solar particulate energies in the vicinity of the satellite. SEM will measure solar proton, alpha particles and electronflux-density energy. The SEM equipment contains the following instruments:

1. TED (Total Energy Detector) measures a broad range of energetic particles from 0.3 keV to 20 keV in 11 bands.
2. MEPED (Medium Energy Proton and Electron Detector) senses protons, electrons, and ions with energies from 30 keV to several tens of MeV.
3. HEPAD (High Energy Proton and Alpha Detector) senses protons and alpha from a few hundred MeV up through relativistic particles above 840 MeV.

ATN (ADVANCED TIROS N) NOAA (E TO J) SYSTEM

The last six spacecraft in the TIROS N/NOAA series NOAA (E-J) have been modified to add payload capacity, without changing the basic environmental mission of the series. The spacecraft was stretched by approximately 20 (50.8 cm) inches, and the solar array was enlarged to provide additional power for the add-on payloads. Incrementally added to the payload starting with NOAA-8 (formerly NOAA-E) was the Search and Rescue payload, NOAA-9 (formerly NOAA-F) also included the ERBE (Earth Radiation Budget Experiment) and the SBUV (Solar Backscatter Ultraviolet Radiometer). Figure 5 depicts the Advanced TIROS-N (ATN).

SAR

The Search and Rescue system is a random access system to acquire data from Emergency Locator Transmitter (ELT) and Emergency Position Indicating Radio Beacons (EPIRB) carried on general aviation aircraft and come classes of marine vessels. A downed aircraft or a ship in distress will automatically transmit its emergency signal, which will be received by the SAR payload on NOAA satellite and will be retransmitted directly to the ground, where the data is processed and relayed to the emergency rescue organizations. The SAR experiment is a joint U.S., Canadian, French program. The Soviet Union is participating in the program by launching the COSPAS spacecraft with a search and rescue payload.

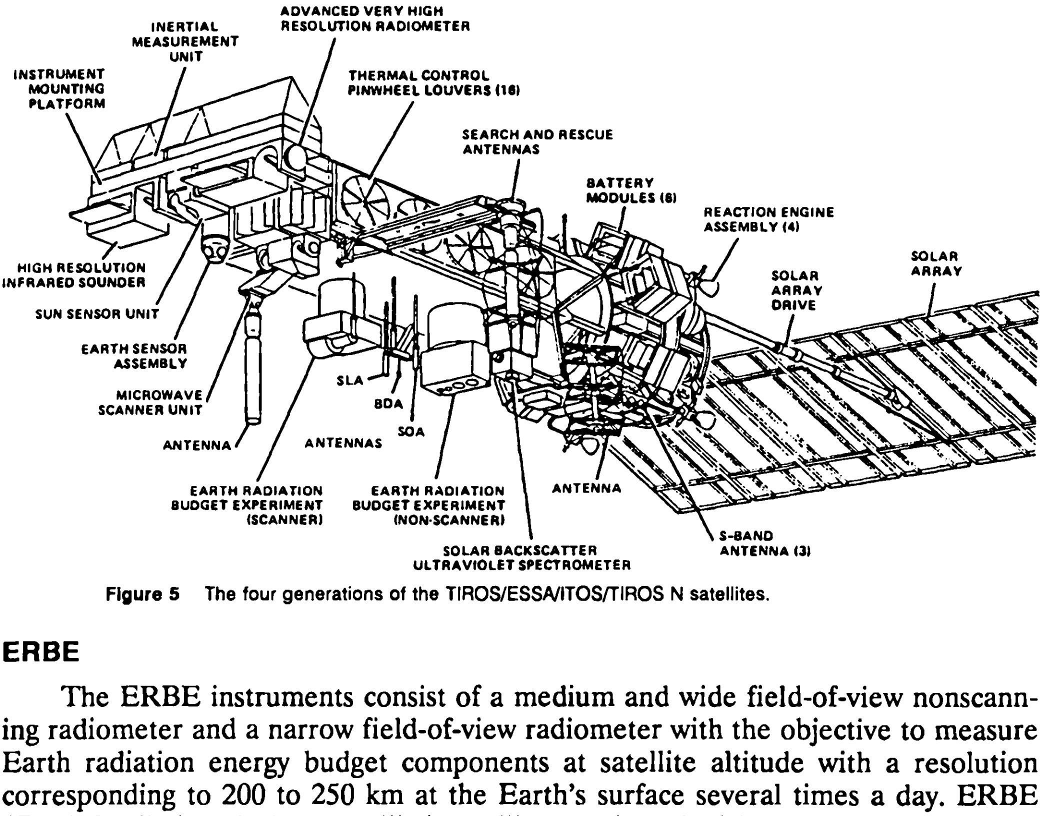

Figure 5 The four generations of the TIROS/ESSA/ITOS/TIROS N satellites.

ERBE

The ERBE instruments consist of a medium and wide field-of-view nonscanning radiometer and a narrow field-of-view radiometer with the objective to measure Earth radiation energy budget components at satellite altitude with a resolution corresponding to 200 to 250 km at the Earth's surface several times a day. ERBE (Earth Radiation Budget Satellite) satellite was launched in 1984 to augment the NOAA-F and -G ERBE experiment. The data from this experiment will provide monthly average Earth radiation budget on a regional and global scale.

SBUV

The SBUV/2 is a non spatial scanning, nadir-viewing instrument designed to measure scene radiance in the spectral region from 160 nanometers (nm) to 400 nm. The data gathered will be used to determine the vertical distribution of ozone in the Earth's atmosphere, total ozone in the atmosphere, and solar spectral irradiance. The Instrument complement in each of the TIROS-N/NOAA (A-J) series is shown in Table 4.

Table 4
POLAR SATELLITE SYSTEM LAUNCH SCHEDULES AND SPACECRAFT SYSTEMS (TWO SATELLITE SYSTEMS)

Satellite	Planning Date	Time of Day	AVHRR/2	Instrument Complement							
				HIRS/2	MSU	SSU	SEM	DCS	SAR	SBUV	ERBE
TIROS-N	10/78	PM	4-Channel	X	X	X	X	X			
NOAA 6	6/79	AM	4-Channel	X	X	X	X	X			
NOAA 7 (C)	6/81 Actual	PM	5-Channel	X	X	X	X	X			
NOAA 8 (E)	3/83 Actual	AM	4-Channel	X	X	X	X	X	X	D	D
NOAA 9	12/84 Actual	PM	5-Channel	X	X	X D	X 2,3	X	X	X	X
NOAA G	1/86	AM	4-Channel	X	X	X	2) 2,3	X	X	3)	X
NOAA H	10/86	PM	5-Channel	X	X	X	X	X	X	X	
NOAA D	3/87	AM	5-Channel	X	X	1)	2)	X		3)	
NOAA I	10/88	PM	5-Channel	X	X	X	X	X	X	X	
NOAA J	3/89	AM	5-Channel	X	X	1)	2)	X	X		
NOAA NEXT	10/90	PM	6-Channel	HIRS/3	AMSU		X	X	X	3)	

1) Two satellites will fly without an SSU
2) Three satellites will fly without an SEM
3) SBUV will fly only on PM satellites
4) D - Dummy Unit

As of July 1985 a total of 30 TIROS/ESSA/ITOS/TIROS-N satellites had been successfully orbited. Three additional satellites failed to achieve orbit due to launch vehicle failures. All of the polar-orbiting TIROS series of satellites designed and built by RCA Astro-Electronics, Div. have been managed by the NASA Goddard Space Flight Center. The prototype of each of the series was funded by NASA, while the operational satellites were funded and operated by NOAA.

FUTURE PLANS

The next series of the Polar-orbiting Operational Environmental Satellites (POES) will be configured with the Advanced Microwave Sounding Unit (AMSU), which will replace the 3 channel infrared absorption (SSU) and the 4 channel microwave sounding instruments (MSU) now in use. The AMSU will provide 15 channels of coverage in the 20-90 GHz range and 5 channels in the 90-184 GHz range. It will add new capabilities for atmospheric humidity measurements, distinguishing sea ice, and gathering information about snow thickness and soil moisture. AMSU will make soundings more accurate and will permit sounding through clouds over areas with active weather patterns. The current AVHRR imager will be improved by adding one or two new channels and sharpening others; some channel changes are planned for the High Resolution Infrared Radiation Sounder (HIRS). A major planned sensor addition is the Ocean Color Instrument (OCI), which will be introduced on an early spacecraft in this series. The other functions and services of the series will remain as they are currently. The next series will be configured to be compatible for launch by the space shuttle.

SPACE STATION COMPLEX

Plans call for the NASA Space Station Complex to consist of a core platform and co-orbiting platform in low inclination orbit as well as polar platform at a high altitude (possibly 800 km). The polar platform could contribute to the operational monitoring of the Earth's atmosphere, oceans and land masses. The payload for the platform would include instruments derived from the current operational environmental satellites. The platform would be astronaut-serviced. The space platform is expected to be in operation in the early-mid 1990's.

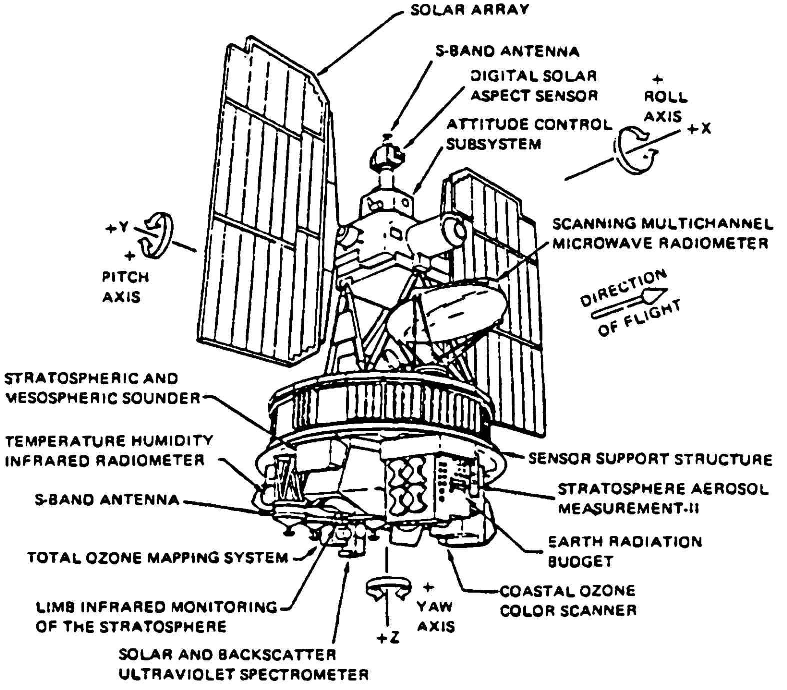

Figure 6 The configuration of the Nimbus spacecraft.

NIMBUS TECHNOLOGY SATELLITE

The Nimbus Technology satellite program was initiated by the National Aeronautics and Space Administration in the early 1960s to develop an observational system capable of meeting the research and development needs of all the nation's atmospheric and Earth scientists. The general objectives of the program were: (1) to develop advanced passive radiometric and spectrometric sensors for surveillance of the Earth's atmosphere and oceans, (2) to develop and evaluate new active and passive sensors for sounding the Earth's atmosphere and mapping surface characteristics, (3) to develop advanced space technology and ground data processing techniques for meteorological and scientific research, and (4) to participate in global observation programs (World Weather Watch). The Nimbus system became instead the test bed for some of the advanced instruments used on the operational TIROS satellites. In total, eight spacecraft were built: seven were successfully orbited, and one experienced a launch vehicle failure. These spacecraft much delayed were launched between 1964 and 1978. Table 1 highlights the launch dates of each of the Nimbus spacecraft and indicates the payload configuration for each flight. The configuration of Nimbus spacecraft is shown in Figure 6. The satellites ultimately were placed in a Sun-synchronous near polar orbit and operated in a high noon orbit.

ATS - APPLICATIONS TECHNOLOGY SATELLITES

A NASA research and technology program was initiated in 1966 to demonstrate improved communications technology with the ATS-1 satellite from geostationary orbit. The excess capacity of the ATS spacecraft permitted the inclusion of meteorological sensors for experimental observations of the Earth from a 22,000-mile (35,398 km) altitude. The Spin-Scan Cloudcover Camera (SSCC), developed by Dr. V. Suomi of the University of Wisconsin and built by Santa Barbara Research Center, provided, for the first time, continuous images of the Sun-lit Earth disk every half-hour. The spinning motion of the spacecraft, in conjunction with a telescope and photomultiplier tube assembly, generated line scans of the Earth and cloud cover. By incrementally moving the telescope with every spin of the satellite, an entire scene of the Earth's disc was generated in 20 minutes. The spatial resolution of the subpoint was 3.2 km. ATS-1 also included a WEFAX (Weather Facsimile) data relay, thus permitting the retransmission of weather data from a NOAA Central Station to ground stations within transmission range of the satellite. The ability to receive images every 30 minutes from a geostationary satellite provided the meteorological community with a powerful tool to view the same area continuously, which improved the forecasters' ability of early detection of severe storms and tornadoes and added the capability of deriving cloud motion and wind vectors. The on-orbit weight of the spacecraft was 304 kg. The satellite was 146 cm in diameter and was 134 cm long.

ATS-3, launched in November, 1967, was slightly larger than ATS-1 and was located over the equator at 70°W longitude, where it viewed the Western Hemisphere. The spin scan camera was modified to provide multicolor images.

SMS/GOES - OPERATIONAL GEOSTATIONARY SATELLITE SYSTEM

The successful application of atmospheric observations by the ATS-1 and -3 from geostationary orbits led to NASA's development of an operational satellite designed specifically for that purpose. Five spacecraft in this series, two SMS and three GOES were built and integrated by Ford Aerospace Corporation. NASA's proto-flight satellites, SMS-1 and -2, were successfully launched in May 1974 and February 1975.

Placed over the equator, these spacecraft provided continuous hemispheric coverage. The principal instrument, the VISSR, (Visible/Infrared Spin Scan Radiometer) was capable of day and night imaging with its two spectral bands. The visible channel (0.55 μm to 0.70 μm) and the infrared channel (10.5 μm to 12.6 μm) shared a common optics system, which was a 16-inch (4.06 cm) aperture telescope. The spinning motion of the satellite provided west-to-east scan motion while the north-to-south scan was achieved by incrementally tilting the scanning mirror at the end of each spacecraft rotation. The full scan of the Earth's disc took about 18.2 minutes and about 2 minutes to retrace the mechanism. During each scan, the field-of-view on the Earth was swept by a linear array of eight visible-spectrum detectors, each with a ground resolution of 0.9 km at zero nadir angle. The infrared portion of the spectrum was sensed with a horizontal resolution of approximately 8 km at zero nadir angle. The VISSR output was digitized and transmitted at 28 Mbps to the NOAA CDA at Wallops Island, Virginia. The signal was stored and time-stretched for transmission back to the satellite at reduced bandwidth (1.75 Mbps) for re-broadcast to smaller Data Utilization Stations for processing and subsequent distribution. Th entire process took place in near real-time with the retransmission of the stretched data occurring between the Earth-viewing portions of each scan. Figure 7 shows a typical image from the VISSR on board SMS-2.

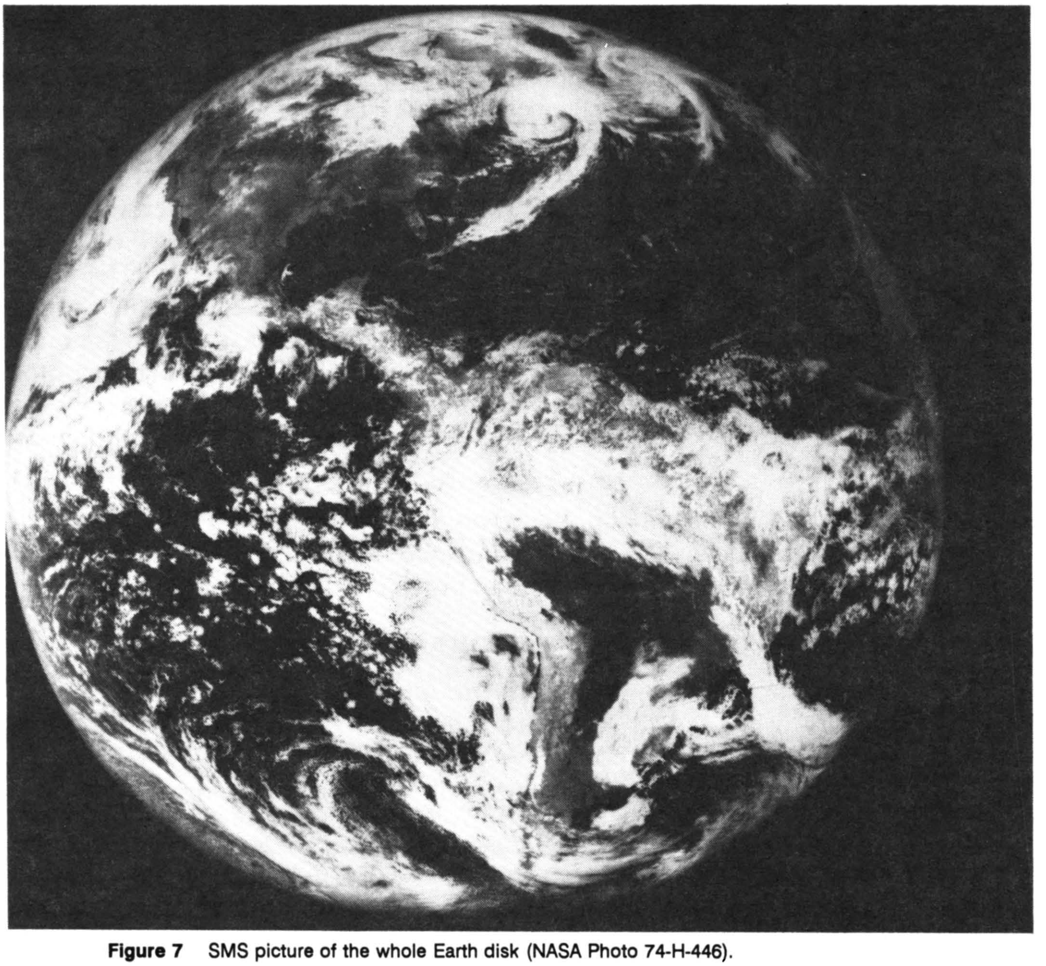

Figure 7 SMS picture of the whole Earth disk (NASA Photo 74-H-446).

In addition to the VISSR, the SMS/GOES was configured with a DCS (Data Collection System) to relay data from remotely located platforms. The communication system permitted the retransmission of narrow-band (WEFAX type) data to existing small ground based APT receiving stations from a larger weather central facility. The SMS/GOES also was configured with the SEM (Space Environment Monitor) that included a solar X-ray sensor, energetic particle detector, and a magnetometer. The SEM was able to detect unusual solar activity, measure electron and proton energy, and measure the magnetic field strength and direction in the vicinity of the satellite. The SEM data are used by NOAA's Environmental Research Laboratory in Boulder, Colorado, to monitor and predict Sun spots, flares, and their effects on the Earth's magnetic field. Three additional satellites of the SMS design, namely GOES 1, 2, and 3 were launched in October, 1975, June, 1977, and June, 1978, respectively. These operational satellites are owned and operated by NOAA. To support the operational mission, one GOES satellite is placed over the equator at 75°W longitude and a second is positioned at 135°W longitude.

GOES D THROUGH H

Five additional spacecraft designated GOES D-H have been procured by NOAA to support the operational requirements through the 1980s. The GOES D-H series have been modified to accommodate the new VAS (Visible Infrared Spin-scan Radiometer Atmospheric Sounder) instrument. The VAS instrument retains the VISSR dual-band imaging function, but with the added capability of obtaining radiometric data in the Earth's atmosphere. Water vapor and CO_2 absorption band will thus provide the capability for determining the three-dimensional structure of the atmosphere, with respect to temperature and humidity. The basic limitation of the VAS instrument in the Dwell Sounding mode cannot be used simultaneously with either the VISSR or Multispectral Imaging mode. Another significant change in the GOES D-H series is the use of a despun S-band and UHF antennas to provide for more effective communications with the GOES stations. GOES D, E and F have been launched by the Delta 3914 launch vehicle, in September, 1980, May, 1981, and April, 1983. Figure 8 shows the configuration of GOES D-H. The final two spacecraft in this series GOES G and H are scheduled to be launched in 1986. Additional improvements were incorporated to increase the life expectancy of this system, which will last into the early 1990s. The GOES D to H series were produced by the Hughes Aircraft Corporation.

GOES-NEXT

Key features of the NASA-developed follow-on GOES-Next will be an independent imaging and sounding system, rather than the current system, which is limited to either imaging or sounding at any given time; increased location accuracy for analysis and forecasting of small scale meteorological phenomena; improved monitoring of moisture; improved vertical resolution and accuracy in soundings; expanded data collection system to include Search and Rescue capabilities. The first flight of GOES-Next is expected to take place in 1990. Ford Aerospace will build the GOES I, J and K.

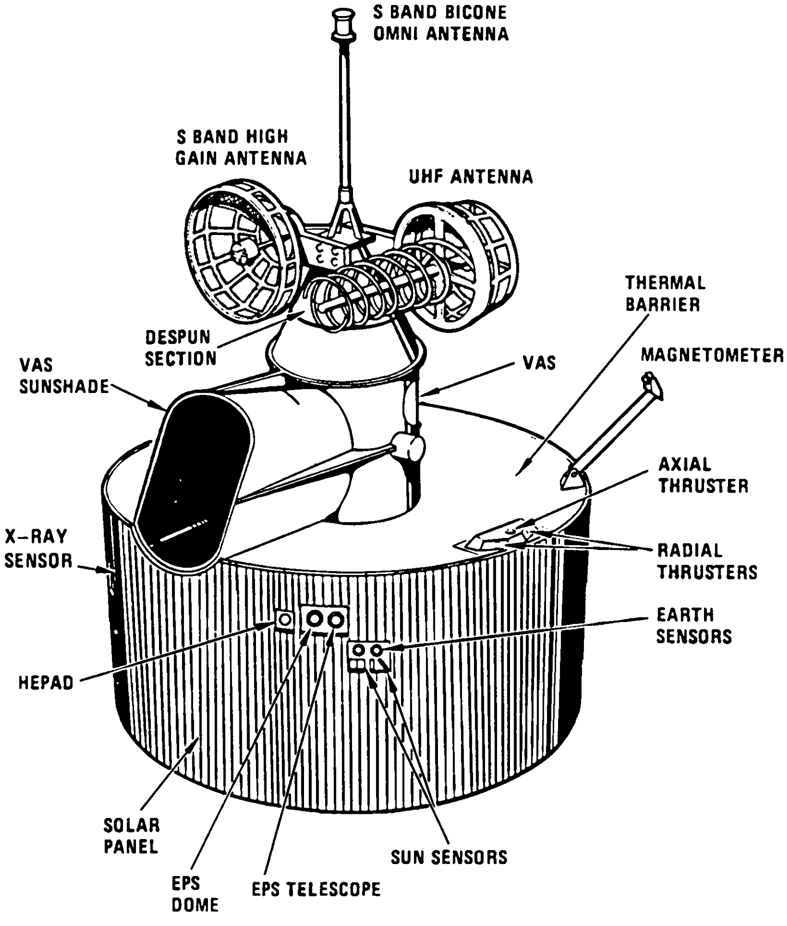

Figure 8 The configuration of GOES (D-H) (Courtesy: NASA).

DMSP - DEFENSE METEOROLOGICAL SATELLITE PROGRAM

The U.S. Department of Defense DMSP meteorological satellite program was initiated in the 1960s with a narrow set of well-defined military objectives. In 1966, with the successful launch and operation of the DMSP Block 4 satellite, its value to the military tactical users was clearly established. The DMSP system evolved through a series of satellite designs, including Block 4A, 4B, 5A, 5B, 5C and the current Block 5D-1 and 5D-2 operational system. A total of twenty-five spacecraft were launched between 1966 and July, 1985. During this period, the program experienced two launch vehicle failures. The DMSP system is managed by the Air Force System Command (AFSC) Space Division. Real time local day and night cloud cover pictures are transmitted directly from the satellite to ground tactical terminals and Navy aircraft carriers. The DMSP series of satellites are built by RCA Astro-Electronics Division. The DMSP satellites evolved from a small spin TIROS-like stabilized spacecraft, utilizing miniature television cameras, to a large sophisticated 3-axis stabilized spacecraft capable of supporting a large complex instrument payload, and which is capable of virtually autonomous operation.

BLOCK 5D-1 AND 5D-2 SYSTEM

During the mid-1970s a new generation DMSP spacecraft was developed to provide greater precision in the attitude control system, greater payload capacity and added redundancy for longer life in orbit. The attitude control system was able to maintain 0.01-degree pointing accuracy in all three axis. An on-board computer permitted greater flexibility in operating the large complex payload and permitted a degree of autonomous operation. The principal sensor, the OLS (Operational Linescan System) built by Westinghouse, was a 2-channel oscillating radiometer as compared to the prior 4-channel rotating mirror radiometer. The OLS provided constant ground resolution from the spacecraft nadir to the edge of the scan at approximately 0.5 km. The night time visible channel provided a near constant resolution of 2.4 km. To achieve global coverage, some of the high resolution data was smoothed on board the spacecraft to a 2.4-km resolution for transmission and processing on the ground.

The 8-channel IR Temperature Sounder was replaced with a 16-channel temperature sounder, a seven channel microwave sounder, an improved energetic electron, and a proton spectrometer and a plasma monitor. The overall spacecraft weight at lift-off was approximately 5,900 lbs. (2676.2 kg) with an on-orbit weight of 1131 lbs. (513.0 kg). A total of five Block 5D-1 spacecraft were launched between 1976 and 1980.

An improved version of 5D-1 was developed, and two have been launched. The designation of the improved series is 5D-2. The spacecraft size and power output increased, thus providing increased capacity for payload growth and added redundancy for greater reliability. The basic structure was stretched by 18 inches (0.46 m), and the power increased to 1850 lbs. (839.2 kg). To accommodate the increased weight, the Atlas-E launch vehicle was employed. Figure 9 depicts the evolutionary growth of the DMSP space segment.

THE EXPERIMENTAL SATELLITE PROGRAM

The National Aeronautics and Space Administration has flown a number of experimental satellites to gather data for various investigators in the field of atmospheric research. Two modular spacecraft, HCMM (Heat Capacity Mapping Mission) and SAGE (Stratospheric Aerosol and Gas Experiment), were launched by a Scout launch vehicle in April, 1978, and February 1979. Both spacecraft were built by the Boeing Company.

HCMM - HEAT CAPACITY MAPPING MISSION

The Heat Capacity Mapping Mission satellite, also known as the Applications Explorer Mission (AEM-A), provided day and night imagery of the Earth's surface in its two and one-half years of orbital operation. The satellite carried a 2-channel imaging radiometer capable of measuring reflected solar radiation and emitted thermal radiation emanating from the Earth's surface. HCMM operated from a 568 x 641 km altitude at a 97.6 degree inclination. The prime objective of the mission was to evaluate the utility of apparent thermal inertia information derived from diurnal thermal surveys for potential applications in a wide variety of Earth science disciplines, including meteorology, agronomy, oceanography and geology.

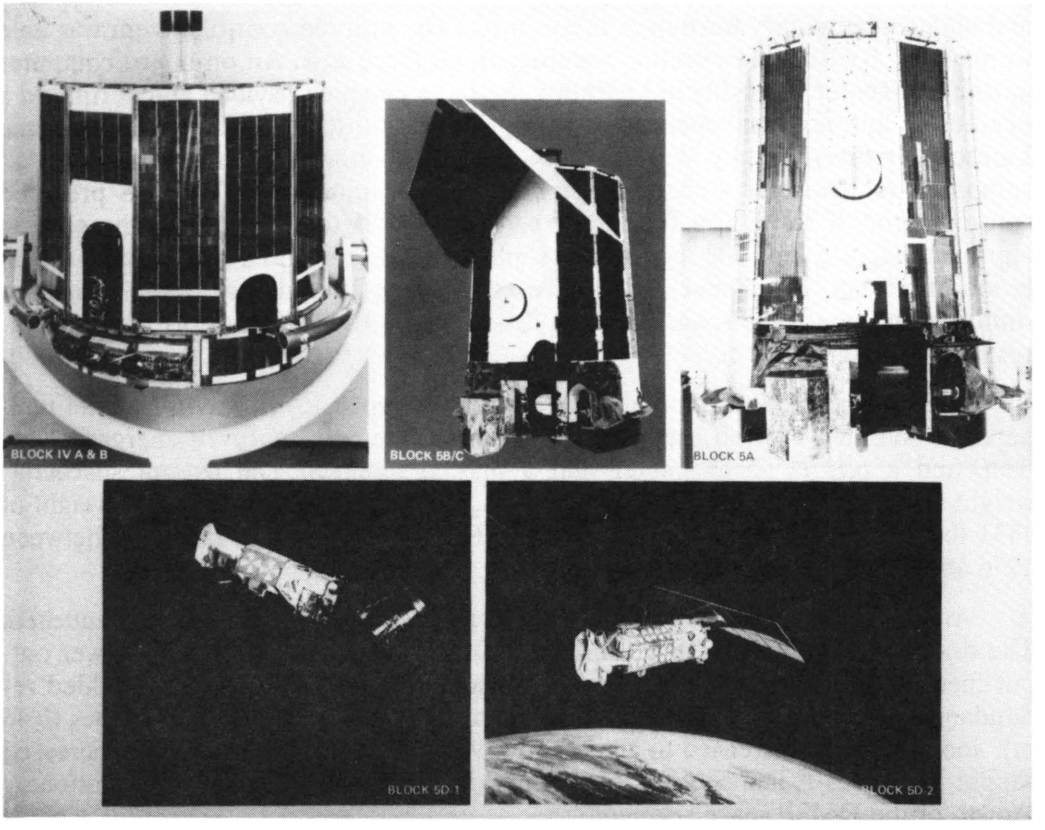

Figure 9 The evolutionary growth of the DMSP satellites (Courtesy: Martin Marietta).

SAGE - STRATOSPHERIC AEROSOL AND GAS EXPERIMENT

The Stratospheric Aerosol and Gas Experiment was of similar design to the HCMM spacecraft. SAGE was placed into a 550 x 640-km orbit at an inclination of 55 degrees. The SAGE experiment, which was supplied by NASA/Langley, measures the extinction coefficients of the solar wavelengths (at 0.38, 0.45, 0.60, and 1.0 micrometers) through the Earth's atmosphere during every spacecraft Sunset and Sunrise. The SAGE mission was declared a success. It was shown that SAGE was able to accurately measure remotely from space, vertical profiles of stratospheric aerosols and ozone.

ERBE - EARTH RADIATION BUDGET EXPERIMENT SATELLITE PROGRAM

The Earth Radiation Budget Experiment Program was initiated in 1984 with the successful launching of the ERBE spacecraft from the shuttle in August, 1984, and the launching of NOAA 9, in December, 1984. Both satellites carry an identical two-instrument package, called ERBE (Earth Radiation Budget Experiment). The ERBE spacecraft includes an instrument for monitoring the vertical distribution of stratospheric aerosols, ozone and nitrogen dioxide, called the SAGE II (Stratospheric Aerosol and Gas Experiment II). The ERBE satellite is placed in 600-km orbit at approximately 57° inclination. The data returned by the instruments will be analyzed by NASA Langley Research Center, then combined with the data taken by ERBE instruments aboard the NOAA satellites. NASA/GSFC and NOAA will share the reduced and combined data. Scientific investigators will also have access to the final data through the National Space Science Data Center. The ERBE Program is managed by NASA/GSFC and NASA Langley. The spacecraft is built and integrated by Ball Aerospace Systems Division.

UARS - UPPER ATMOSPHERE RESEARCH SATELLITE

The Upper Atmospheric Research Satellite Program has been under study by NASA and is planned for launch at the end of this decade. NASA recently awarded General Electric Space Div. to integrate and test the UARS Spacecraft. The mission of UARS is to provide data on a global basis for the study of the physical processes acting within and upon the stratosphere, mesosphere and lower thermosphere. Specifically, the areas of scientific study to be addressed are: energy input and loss, photochemistry, dynamics, and finally the coupling among processes and between atmospheric regions. The UARS is a single observatory spacecraft consisting of ten scientific instruments. The satellite will be shuttle launched and placed in a 600-km orbit at an inclination of 57 degrees.

INTERNATIONAL WEATHER SATELLITE PROGRAM

The advantage of monitoring the Earth's environment from space which, for the first time, permitted routine observations of remote areas on a continuous basis, was recognized by a number of international countries to enhance their meteorological services. In addition to the United States, the Soviet Union, the European Space Agency, France, Japan and India have developed and launched spacecraft which today are providing data contributing to a global satellite monitoring system.

Other nations such as China, Brazil and Argentina are also developing experimental satellite programs. Additionally, a large number of nations have the capability of receiving direct meteorological data for the satellites that transmit their data in real-time.

THE EUROPEAN SPACE AGENCY - METEOSAT SYSTEM

The Meteosat System is Europe's contribution to the WMO's World Weather Watch and the Global Atmospheric Research Program. Meteosat is one part of a network of five geostationary meteorological satellites providing full global coverage (except for the polar regions). The Meteosat system consists of a spacecraft located in geostationary orbit at 0 deg. longitude with the satellite control center located at Darmstadt, West Germany. The Meteosat spacecraft payload is comprised of a multispectral radiometer, a data collection system and a WEFAX weather facsimile service.

The multispectral radiometer consists of three spectral bands; (1) two identical visible adjacent channels in the 0.4-1.1-μm band; (2) a thermal infrared channel in the 10.5-12.5-μm band; (3) an infrared water-vapor adsorption band 5.7-7.1 μm, which can be operated in place of one of the two visible channels. The visible and Infrared Scanning Radiometer requires 25 minutes to image the full Earth disk. The visible and near-infrared bands have a resolution of 2.5 km at the local nadir. The thermal infrared wavelength is at 5.0-km resolution, and the water vapor band is at 5.0-km resolution. The Data Collection System (DCS) is a communication system similar to the DCS of GOES. The WEFAX system permits the relay of data from central ground stations to regional sites. The Meteosat spacecraft is composed of a main cylindrical body, on top of which is a drum shaped section and two cylinders that are stacked concentrically. The spacecraft is 2.1 meters in diameter and 3.2 meters long. The beginning of life weight of Meteosat is 293 kg; like GOES, it is a spin stabilized spacecraft rotating at 100 rpm. Figure 10 depicts the Meteosat spacecraft configuration. Two satellites have been launched in this series, Meteosat 1 in November, 1977, by the U.S. Delta Launch Vehicle and Meteosat 2 in June, 1981 by ESA's Ariane Launch Vehicle. In 1983 the EUMETSAT organization was formed to maintain, and operate a system of operational meteorological satellites, the initial one being the continuation of the current Meteosat preoperational system. EUMETSAT will rely on ESA to carry out the program. The Meteosat operational program foresees the launch of three satellites, in June of 1987, mid-1988 and 1990, and their continuation until 1995.

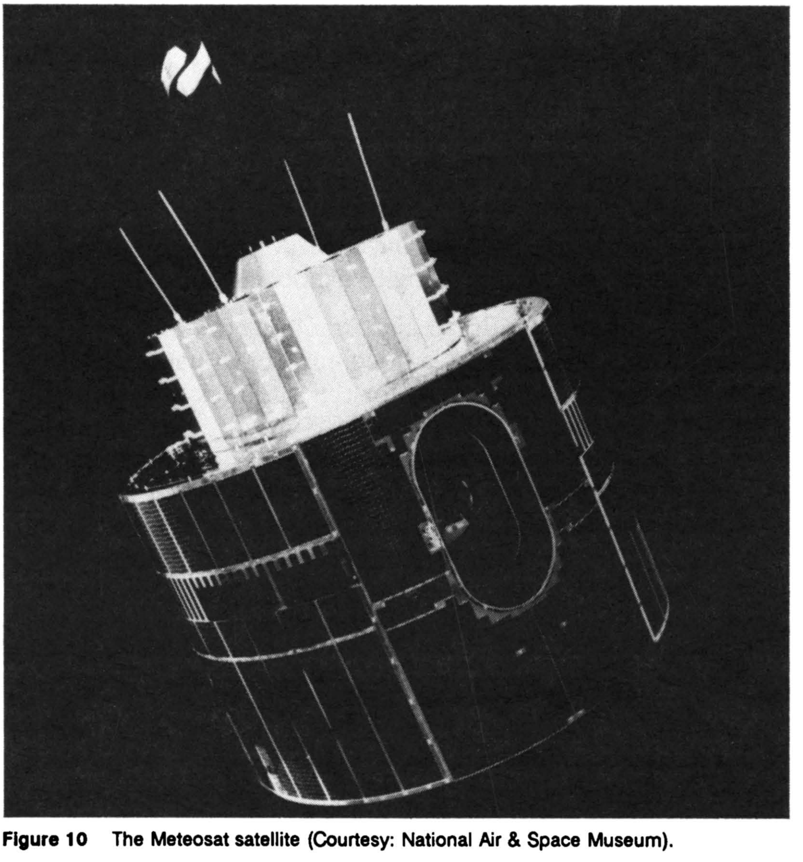

Figure 10 The Meteosat satellite (Courtesy: National Air & Space Museum).

JAPAN'S GMS (GEOSTATIONARY METEOROLOGICAL SATELLITE)

As a response to the WMO needs for GARP and WWW, Japan developed the Geostationary Meteorological Satellite (GMS) program. In July, 1977, HIMAWARI-1, the first of the GMS satellites, was successfully placed into geostationary orbit by a Delta Launch Vehicle, and placed over the equator at 140°E longitude. The GMS satellites are procured from Hughes Aircraft Corporation by Nippon Electric Company (NEC), and the program is managed by NASDA (National Space Development Agency of Japan). The instrument payload of the GMS system consists of the VISSR, SEM, DCS and WEFAX. The GMS spacecraft is a spin stabilized satellite rotating at 100 rpm, with the Earth oriented antenna mast being despun. The spacecraft is 2.1 meters in diameter and 4.4 meters long. At lift-off the satellite weighs 681 kg; at the beginning of life in orbit the system weighs 303 kg. GMS-2 was launched in August 1981, and the GMS-3 was launched in August, 1984. These spacecraft were launched by NASDA's N-Rocket. NASDA, in cooperation with the Japan Meteorological Agency (JWA) manages the program, launches the spacecraft, and after in orbit check-out, turns the operation of the satellite over to JMA. The CDA station is located in Hatoyama, Japan, and the data processing center in Kiyose, Japan. JMA and NASDA plan to launch GMS-4 in 1989.

THE U.S.S.R. KOSMOS AND METEOR SPACE PROGRAMS

The Soviet Union Meteorological Satellite Programs have been very active, and to some degree parallel the U.S. low altitude polar-orbiting programs. Their initial development satellites, Kosmos, were launched between 1966-1968. The follow-on series was Meteor-1 and Meteor-2 weather satellites. The Kosmos/Meteor satellites are generally launched in a 900 km orbit and at an inclination of 81.3 degrees. The Meteor satellites are considered to be the operational spacecraft. Two or three of these spacecraft are in operation at any given time. The Meteor series provide data relating to the state of the atmosphere, the Earth's thermal radiation, and charged particle measurements. The system has the direct real-time readout capability to over 60 stations in and near the U.S.S.R. The payload generally consists of optical-mechanical television sensors for the visible spectrum.

Also included is an infrared scanning sensor to obtain data on the moisture content of the atmosphere and the vertical temperature profile of the atmosphere. The data from Meteor is processed by the U.S.S.R. Hydrometeorological Service. The principal centers are located in Moscow, Novosibirsk and Khabarovsk. The U.S.S.R. agreed to participate in the GARP FGGE program by providing a geostationary satellite as well as polar orbiting satellites; however, the GOMS (Geostationary Observation Meteorological Satellite) has yet to make its appearance.

INDIA'S METEOROLOGICAL SATELLITE PROGRAMS

India's experimental satellite Bhaskara-1, launched by the Soviet Union in June, 1979, carried a television camera to observe the Earth in the visible and near infra-red spectrums. Also included on the Bhaskara satellite was a three channel microwave instrument operating at 19.35, 22.235 and 31.4 GHz. One of the objectives of this program was to measure the precipitable water vapor and liquid water content over the vast oceans surrounding India. Bhaskara II was launched in November, 1980. Both spacecraft were placed in a 550-km orbit at a 51-degree inclination. The current Indian National Satellite System (INSAT) is operational, with the successful launch of INSAT 1A in April, 1982, and the INSAT 1B, in August, 1983, by the Delta Launch Vehicle. The INSAT satellite is a dual mission program, in which the spacecraft combines telecommunications with meteorological remote sensing from geostationary orbit. The primary meteorological instrument is the Very High Resolution Radiometer (VHRR) operating in the visible channel (0.55-0.75 μm) with a resolution of 2.75 km and a thermal infrared (10.5-12.5 μm) with a resolution of 11 km. The INSAT satellites are located at 74°E longitude. Full frames are available every 30 minutes. A Data Collection System is also included. INSAT 1C will be launched in 1986. Figure 11 shows the INSAT spacecraft. The INSAT spacecraft are built by Ford Aerospace Corporation and launched by the U.S.A.

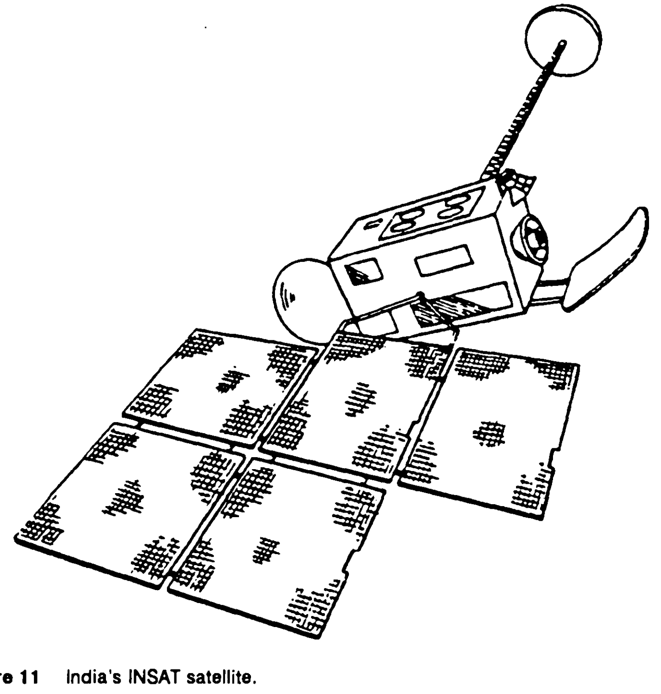

Figure 11 India's INSAT satellite.

FRANCE'S EXPERIMENTAL EOLE PROGRAM

Through its space agency, CNES (Centre National d'Etudes Spatiales), France developed the EOLE satellite that was launched in August, 1971, to collect data from free-floating balloons in cooperation with the U.S.

CHINA'S WEATHER SATELLITE PROGRAM

The People's Republic of China is developing an experimental 3-axis stabilizing polar-orbiting meteorological satellite to be launched in the near future. China is also planning to develop an experimental geostationary meteorological satellite.

CONCLUSION

The meteorological satellite program of the U.S.A., as well as that of the U.S.S.R., ESA, Japan, India and the participating nations receiving the satellite transmissions and/or its products, have all realized substantial benefits from the experimental and operational meteorological satellite systems. International exchange of weather data and joint activities in space programs has fostered a high degree of cooperation among nations. The meteorological satellite data is timely and comprehensive, resulting in improved forecasts and better understanding of the weather. People from all nations have greatly benefited from these programs. Further improvements in forecasting will be realized as these programs evolve in the decade ahead.