A Guide to Environmental Satellite Data

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PREFACE

In the summer of 1977 I was awarded a NASA/ASEE Summer Faculty Fellowship to work on remote sensing of the oceans with the Marine Applications Technology Branch at NASA/Langley. Because this was a new field for me I asked what I might read to learn what satellites existed with potential in remote sensing oceanography and what quantities their sensors measured. I was shocked to learn that no single document existed with such material. Furthermore, obtaining information on given satellites often proved quite difficut. As a result I spent much of the summer collecting and reading material from the many diverse sources just to get up-to-speed in the field. When I returned the following summer, again as a NASA/ASEE faculty fellow, I asked my NASA contact, Janet Campbell, whether or not I might begin putting together a document covering environmental satellites and their sensors. Dr. Campbell not only agreed to the idea but strongly encouraged it. We also agreed that one summer would not be sufficient to complete the task hence I would have to seek additional funding. I therefore spent the summer collecting and reading more material while at the same time putting together a proposal to NASA to continue with the task that fall. This proposal was rejected and work ceased on the project for a year. I submitted the proposal to Sea Grant the following year and this time it was funded. In the meantime I had learned that not only was obtaining technical information difficult but ordering data was next to impossible for the newcomer. Therefore, I decided to also include information with regard to data availability.

In the fall of 1979 I began working on the guide again. A number of facts quickly became apparent. First, those satellites and sensors of potential interest to the oceanographic community were also of interest to meteorologists, land use planners, forestry officials, etc.; i.e. the guide that I was assembling was of general interest. Second, different documents describing the same satellite or sensor often disagreed with one another. This increased significantly the labor required to generate a factual document. Third, most of the work done a year earlier had to be redone because of the rapid changes taking place. This problem became more and more apparent as time went on. Between the time that a draft was given to the typist and its return some satellites had ceased collecting data, new satellites had been launched, control of a satellite had ben transferred from one agency to another, etc. I therefore decided to (a) have the manuscript put on a word processor to allow for easy update and (b) to assemble the guide in a loose leaf format so that the users could modify their guides as changes occurred. In addition to the notebook format, the various satellite series in the guide have been tabbed to allow for easy access.

Putting all of the above together over a period of four years has led to this document. It is divided into two sections. The first provides an overview of environmental satellites, their sensors and in a general sense where their data are archived. The second section deals with each satellite and its sensors in detail, as well as how their data are ordered. Order forms, names, addresses, and telephone numbers have been included where appropriate. In an attempt to assure the accuracy of the included information, the guide has been sent out for review to a number of experts in the field and their many useful comments have been included.

Peter Cornillon
January, 1982

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CHAPTER I. INTRODUCTION

OVERVIEW

The first hurdle the potential user must overcome in order to begin working with remote-sensing data products is to determine what is available and how it is acquired. This notebook is directed primarily at these questions. The discussions will be limited to satellite borne sensors and their data products, as opposed to aircraft imagery. The desirability of satellite data products is due to their availability, relatively low cost and comparatively simple interpretation. Although more accurate in almost all respects, aircraft data are often more expensive to obtain. Generally, a tailor-made mission must be flown for the project, and the data are often more difficult to interpret, because of the large number of variables--sun angle, altitude, and speed, for instance--that must be known. These variables will vary during the mission and must be accurately determined. Of course, the professional can use the definition of these variables to advantage when flying a mission and obtain higher-resolution data products than is possible from satellite. Many coastal applications make use of aircraft data for just this reason.

Because the major objective of this document is to aid the potential user to identify and order satellite data products applicable to the user's problem, this chapter is devoted to a brief overview of satellite data dissemination in the United States as it exists today. The actual steps involved in obtaining the data are described in Section II, along with a detailed discussion of the satellites and relevant sensors. Satellite data is in general categorized and ordered by satellite rather than sensor type, so the descriptions contained in Section II are also organized by satellite. It is, however, important to understand the various sensors and their relationship to one another in order to make intelligent decisions about the appropriate data to order. For this reason, Chapter 2 has been included. It discusses in general terms the types of sensors borne on satellites and the variables they measure.

Chapter 3 provides a historical perspective of satellites with potential coastal and oceanographic applications. The organizational approach of United States environmental satellites followed in Section II is also developed in this chapter. Following Section II are two short reference sections. One presents a list of acronyms commonly used in remote sensing and a brief remote sensing dictionary, and the other is a bibliography of remote-sensing reference documents, books and newsletters.

ENVIRONMENTAL SATELLITE DATA AVAILABILITY IN THE UNITED STATES, FALL 1981

At present, data and imagery from United States environmental satellites are available from four sources, and these are briefly discussed below. However, the reader is cautioned that the situation is fluid and subject to change.

The source to which one wrote for data used to depend on which agency operated the satellite. In general, the data from meteorological satellites, operated by NOAA, were disseminated by the Environmental Data and Information Service (EDIS) of NOAA in Washington, D.C. Air Force meteorological satellite (DMSP) data were distributed by the University of Wisconsin, Space Science and Engineering Center for NOAA/EDIS. LANDSAT (the Earth Resources Satellite) data were obtained from the United States Geological Survey's EROS Data Center in Sioux Falls, South Dakota. Research data from many of the NASA launched experimental satellites were available from the National Space Science Data Center (NSSDC) of NASA, located at the Goddard Space Flight Center in Greenbelt, Maryland.

At present, one can still obtain DMSP data from the University of Wisconsin and civilian meteorological satellite data from NOAA in Washington. Although the operation of LANDSAT is now formally under the control of NOAA's National Earth Satellite Service, the EROS Data Center will continue to archive and distribute the actual data under a formal agreement with NOAA. EDIS in Washington has also been made the focal point for research satellite data such as that of SEASAT-1 and the NIMBUS-7 Coastal Zone Color Scanner. Table 1 summarizes current addresses and phone numbers of organizations from which data of each of the associated satellites may be obtained.

Table 1. Organizational Responsibility for the Archival and Dissemination of Satellite Data

	Organization	Acronym	Address	Satellites Covered
1.	Satellite Data Services Div/ National Climate Center/ Environmental Data Information Service/ National Ocean and Atmospheric Administration	SDSD NCC EDIS NOAA	SDSD/NOAA Room 100 World Weather Bldg. Washington, D.C. 20233 Tel: 301-763-8111 FTS: 763-8111	TIROS 1-X ESSA 1-9 ITOS-1 NOAA 1-5, 6-7 TIROS-M, -N SMS 1-2 GOES 1-5 GEOS 3 NIMBUS-7 (CZCS) SEASAT-1
2.	National Space Science Data Center/ National Aeronautics and Space Administration	NSSDC NASA	National Space Science Data Center Code 601 NASA/Goddard Space Flight Center Greenbelt, MD. 20771 Tel: 301-344-6695 FTS: 344-6695	HCCM NIMBUS 1-7 except CZCS
3.	EROS Data Center United States Geological Survey	USGS	EROS Data Center User Services Sioux Falls, S.D. 57198 Tel: 605-594-6511 Ext. 151 FTS: 784-7151	LANDSAT 1-3
4.	Space Science and Engineering Center/ University of Wisconsin	SSEC	DMSP Library Space Science & Engineering Center, University of Wisconsin, Madison, WI 53706	DMSP

CHAPTER 2. SENSORS: DESCRIPTION AND CLASSIFICATION

In the following sections, the satellite-borne sensors of interest to oceanography are considered in two separate groups. The first group deals with sensors operating in the visible, near infrared, and thermal infrared bands, the second with those operating in the microwave. The primary reason for this separation is that in general satellite borne sensors in the visible and infrared are passive--i.e., make use of reflected solar or emitted terrestrial radiation while, except for the SMMR (introduced briefly below), instruments operating in the microwave provide the source of radiation--as well as the detector. Active devices use the strength of the returned signal as well as its frequency and round-trip travel time to describe the target.

The sensors in these two groups can be subdivided into two broad categories: imaging and nonimaging. Imaging devices are those that tend to emphasize spatial information; i.e., they obtain a two-dimensional picture of either the color, temperature, or surface roughness of the area imaged, stressing the variability of these parameters over the area. The spatial dimensions range from several tens of meters (SEASAT, SAR) to about 10 kilometers (GOES, VISSR). Nonimaging devices stress temporal, spectral, or radiometric resolution with little consideration for spatial information; e.g., the altimeter which measures surface elevation and surface roughness only at the satellite suborbital (nadir) point, or the scatterometer which averages surface roughness over squares 50 km on a side or larger to estimate wind stress.

This distinction becomes important when considering data reception and processing. Although data from both systems often require significant processing to obtain the oceanographic variable of interest, those from an imaging device require a sophisticated display device, while standard line printer output is sufficient for those from the nonimaging sensors.

The sensors within both subcategories, imaging and nonimaging, are described in a generic sense, with the individual sensors more thoroughly detailed in Section II. It should be stressed that although these sensors are presented within the context of satellite remote sensing, the generic descriptions apply equally well to aircraft borne sensors. In fact, most of the satellite borne sensors are flight tested on aircraft prior to their implementation on board a satellite.

Electromagnetic Radiation--The Quantity Measured

Prior to presenting the subclassification of satellite-borne sensors, a discussion of the quantity measured is appropriate. All such sensors measure electromagnetic energy or the intensity of electromagnetic waves. Electromagnetic waves are composed of varying electric and magnetic fields and are defined by three properties: their wavelength, the amplitude or height of the waves, and their direction of propagation. (In the following, we assume the direction of propagation is toward the satellite, so only the wavelength and amplitude will be considered.) Electromagnetic waves may have any wavelength between zero and infinity, but, due to environmental and instrument constraints, only certain portions of the electromagnetic spectrum are useful in satellite remote sensing of Earth resources (Figure 1). Some of the more important constraints are atmospheric absorption, the size of the instrument's antenna, the relationship between the wavelength and the quantity observed, and the power available to operate the equipment (the last primarily for active devices). An additional and extremely important constraint is the data rate; i.e., the volume of data collected. This constraint is determined by the ability to (a) handle the data on the satellite, (b) send these data to Earth, and (c) process such data once they have been received on the ground.

Electromagnetic radiation of interest in remote sensing of Earth falls into three general regions: visible, infrared, and microwave. These are discussed below.

Visible Radiation—Light

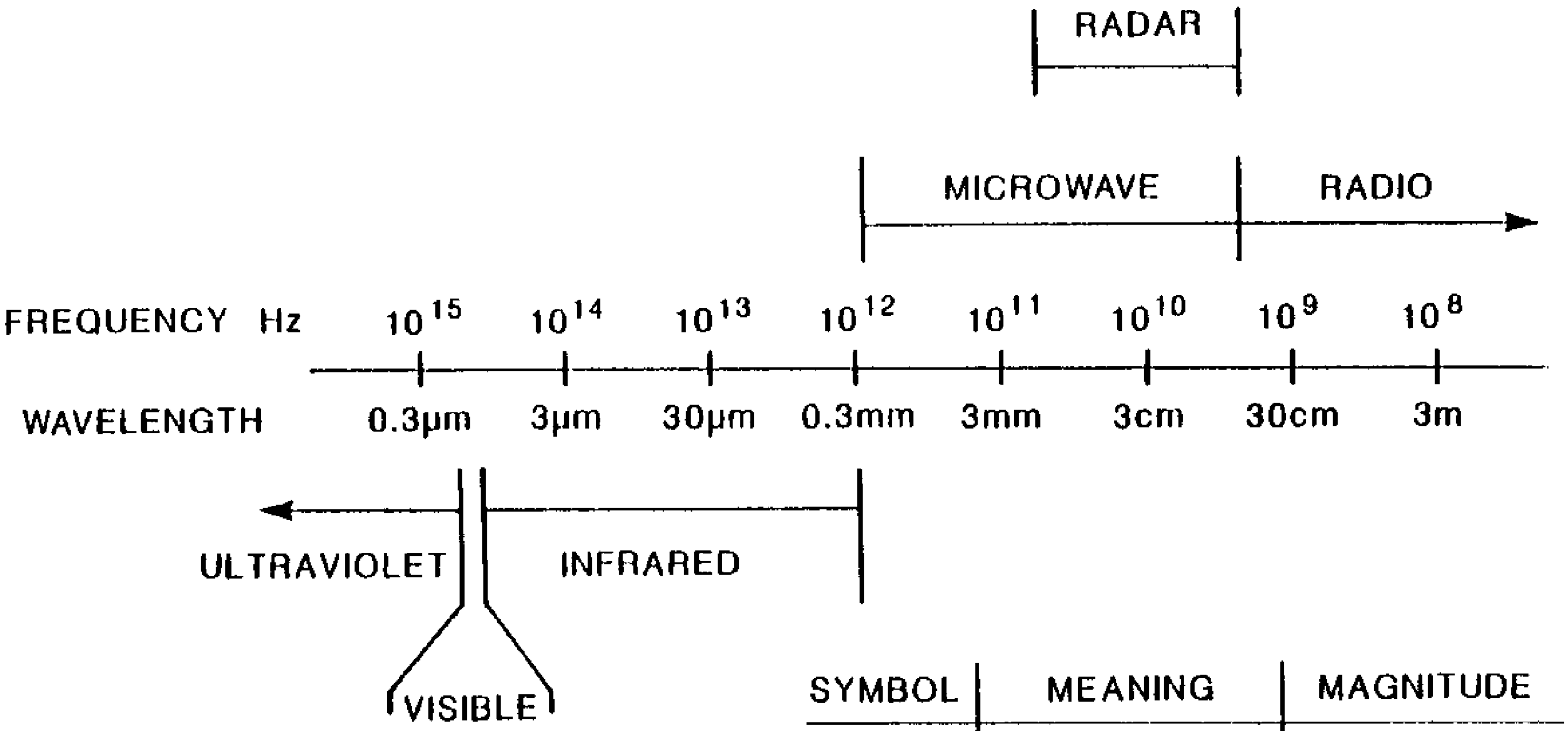
Light is one example of electromagnetic radiation (see Figure 1), the color of the light being determined by its wavelength. Red light, the longest wavelength light that we can see unaided, is composed of waves about 0.75×10^{-6} meters long (0.75 micrometers, written 0.75 μm), while blue light, the shortest wavelength we can see, is composed of waves about 0.4 um long. This portion of the eletromagnetic spectrum from blue to red light is called the visible portion because it is composed of only those wavelengths we can see without instrumentation.

The intensity of light, its brightness, is determined by the amplitude of the waves. Bright light will have relatively larger amplitude waves, while dim light will have relatively smaller ones.

Visible light will propagate through a clean, dry atmosphere with little disturbance and is therefore one of the more important bands of the spectrum for satellite sensing. In a clean, dry atmosphere we have good visibility: a "clear" day. On a hazy day there are a great deal more scatterers and absorbers in the atmosphere and the light can be substantially affected as it passes (propagates) through it.

Most visible radiation reaching a satellite from the Earth is reflected solar radiation; i.e., light from the sun that has been reflected from the Earth or its atmosphere toward the satellite. Note that this means that sensors in the visible can, in general, collect data only during daylight hours.

A final property of visible radiation that is important in oceanography is its ability to penetrate water. Of the three spectral regions of importance in remote sensing oceanography, light (especially blue light) penetrates water by far the best. Indeed, in the thermal and microwave portions of the spectrum, there is little (on the order of micrometers) to no penetration. Blue light, on the other hand, will propagate through tens of meters of clear ocean water before being significantly attenuated. Red light is sharply attenuated within the first few meters.



SYMBOL	MEANING	MAGNITUDE
μm	MICROMETERS	10^{-6} METERS
mm	MILLIMETERS	10^{-3} METERS
cm	CENTIMETERS	10^{-2} METERS
Hz	HERTZ or CYCLES/SEC.	

Figure 1. Electromagnetic Spectrum

Infrared Radiation

The second region of the spectrum important in remote sensing is the infrared, so called because it is "below" red, or beyond the visible red. We cannot see infrared radiation with the unaided eye; however, instruments can record this radiation either electronically or photographically. Once in this form, it is readily converted to an image we can see, or numbers we can interpret. The infrared portion of the spectrum is divided into several regions, of which the near infrared (near IR) and the thermal infrared (thermal IR) are the most important.

The near IR is important because it corresponds to the band of high reflectance for most vegetation; i.e., plants reflect a good deal more energy in the near IR than in the visible. Furthermore, the atmosphere, except for clouds, is transparent to near IR radiation. The wavelengths of interest here range from about 0.8 μm to about 1.5 μm. As in the case of visible radiation, most radiation leaving the Earth in this portion of the spectrum is reflected solar radiation.

Thermal IR radiation (> 4 μm) is important because it is dominated by radiation emitted by the Earth and atmosphere, not reflected solar radiation. The intensity of the emitted radiation depends on the temperature of the source (water, land, etc.) and a physical characteristic of the source, called the emissivity, which is generally sufficiently well known so that the temperature can be determined from an accurate measurement of the thermal IR radiation. The atmosphere is only transparent to thermal IR radiation within several narrow "windows." Two of the most important of these are the 3 μm to 5 μm band and the 9.5 μm to about 13.5 μm band. Outside these windows, almost all thermal IR radiation is absorbed by the atmosphere as it propagates toward the satellite. Within the 9.5 to 13.5 μm window, the radiation is greatly affected by atmospheric humidity, resulting in one of the most significant shortcomings of thermal IR sensors in determining sea surface temperatures (SST). Furthermore, thermal IR radiation does not penetrate clouds to any significant extent. However, because a significant fraction of the radiation is emitted by the Earth, data collection is not restricted to daylight hours.

Microwave Radiation

The third portion of the spectrum important in remote sensing of the Earth is the microwave region. Wavelengths of importance range from about 1 millimeter (1 millimeter = 10^{-3} meters) to several tens of centimeters (1 centimeter = 10^{-2} meters). The cutoff at the lower end is determined by atmospheric absorption while the cutoff at the upper end is more a function of instrument constraints as well as the reflective and emissive properties of the ground, atmosphere, and sea surface. There are several very important differences between sensing in the microwave compared to sensing in the visible and infrared.

First, most microwave radiation will penetrate clouds with little attenuation, or reduction of signal strength. This means that a substantial portion of the microwave spectrum may be used under all weather conditions (except for heavy rain).

Second, the intensities of radiation emitted by the Earth and solar radiation reflected by the Earth are very weak. This means that a passive sensor, depending on the Earth or the sun as its source of radiation, must be very sensitive to obtain useful information. On the other hand, active devices, those which provide the source of radiation and then measure the fraction reflected back toward the sensor, have little background radiation to confound the measurements.

Third, the wavelengths used are comparable to the size of many surface irregularities, sand grain size, capillary waves, etc. Therefore, the intensity of reflected radiation often carries information on the roughness of the surface, which is of particular value when studying oceanographic phenomena.

VISIBLE, NEAR INFRARED, AND THERMAL INFRARED SENSORS

The general classification scheme for sensors in the visible to thermal IR portion of the spectrum is shown in Figure 2. The first division is determined by the detector's operational modes. In the case of the photographic instrument, the recording medium is film. The detection process involves molecular alterations on the film, hence is not reversible; i.e., once a film has been exposed, it cannot be used again. In the case of the electro-optical sensors, the output of the detector is an electronic signal. This signal may then be used to expose a film (as is done by some thermal detectors), may be stored on magnetic storage devices, or displayed on a cathode ray tube (CRT). The detector is not destroyed in the process of detection. Furthermore, the recorded signal is in an appropriate form for transmission or digital processing. A second important difference between photographic and eletro-optical sensors is that the former are restricted to the visible and near infrared (up to about 1.2 μm) portion of the spectrum, while the latter can be made to cover any part of the visible to thermal IR region. Furthermore, the dynamic range available to electro-optical detectors is in general significantly greater than what is available to photographic ones. For many applications, probably the most important feature is that multispectral data (electromagnetic intensity separated into a number of different wavelength regions) is available simultaneously at each of the ground elements imaged by the sensor. Multispectral information is available from photographic devices--e.g., clusters of cameras or a number of lenses for the same frame--but registration of the resulting images is not easy. For the electro-optical device, on the other hand, registration is often inherent in the treatment of radiation by the instrument. A comparison of electro-optical detection and photographic detection is presented in Table 2. Understanding of photographic equipment by the reader is assumed (at least to the level required for an appreciation of Section II) and will not be dealt with further. The rest of this section will be devoted to electro-optical sensors, which are subdivided into imaging and nonimaging. Because the imaging device has as its basis the nonimaging sensor, the nonimaging sensor will be presented first.

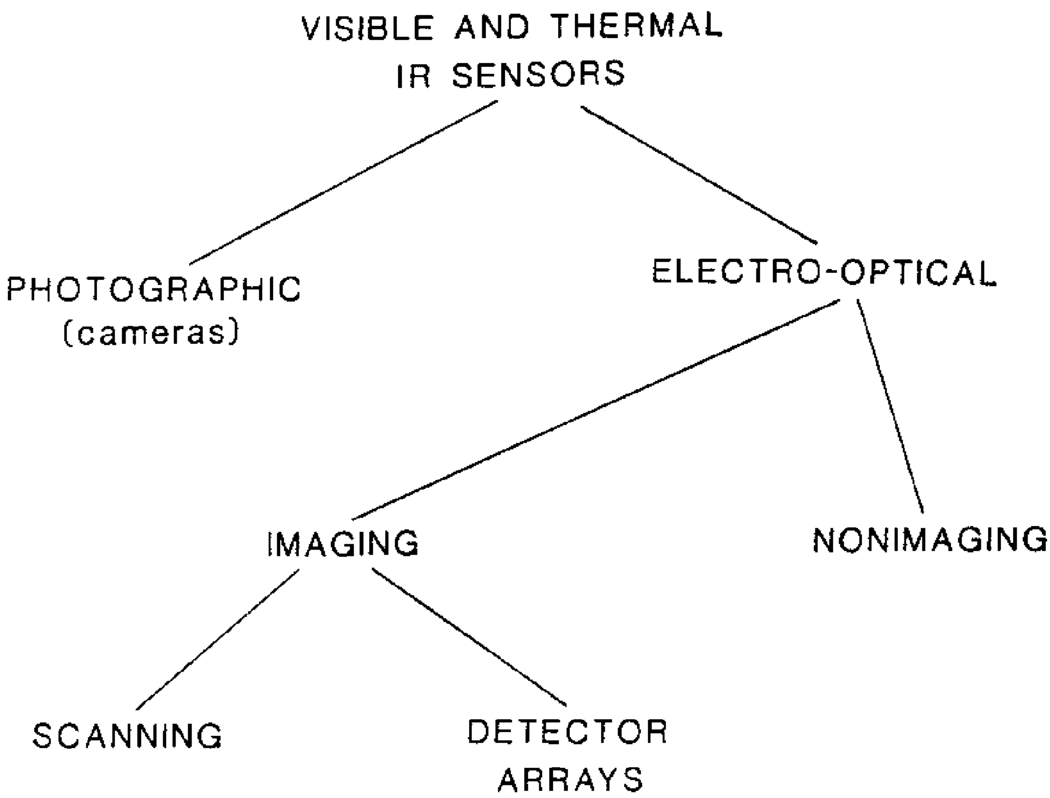


Figure 2. Classification Scheme for Sensors Covering the Visible and Thermal IR Portion of the Spectrum

TABLE 2. Electro-Optical Detection Versus Photographic Detection

Electro-Optical Advantages	Electro-Optical Disadvantages
- Can image beyond approximately 1.2 μm, the limit for photographic sensors	- In general, substantially more complex than a camera
- Output signal in electronic form may be: transmitted, recorded, digitally analyzed	- Data storage is not as efficient on magnetic tape as on film
	- Coarser spatial resolution
- Has a greater dynamic range	
- Capable of internal calibration	
- Multispectral data is coregistered	

Nonimaging Sensors

Radiometer/Photometer. The simplest of the nonimaging devices are radiometers or photometers. These instruments measure the intensity of all the electromagnetic radiation within their field-of-view and wavelength range. The field-of-view depends on the optics of the collector (mirror or lens), the field stop, and/or the geometry of the detector. There may, of course, be additional optical elements within the system which also act to determine the field-of-view. The wavelength range to which the sensor is responsive depends primarily on the optical elements through which the radiation must pass and on the design characteristics of the detector.

The distinction between the radiometer and photometer is based on the wavelength range over which they are sensitive. The radiometer operates at and beyond wavelengths in the infrared; i.e., at wavelengths greater than about one micrometer. The photometer operates at shorter wavelengths, the region of sensitivity corresponding approximately to that of photographic film.

Although the term radiometer is used in this section for detectors operating from 1 μm to radio wavelengths (meters), the primary emphasis is on detection in the thermal infrared. As mentioned previously, eletromagnetic energy in the thermal infrared portion of the spectrum is emitted primarily by objects in the 300°K (27°C or 80°F) range. This means that great care must be taken to cool the instrument so that the radiation observed is not that emitted by the sensor itself. In general, this requires that the instrument be equipped with an internal reference to calibrate the observed signal. Internal calibration is not required (although it may be used) for the photometer.

Spectometer. A spectrometer is a photometer or radiometer with a dispersing element. The dispersing element--e.g., a prism or ruled grating--spreads the incoming radiation spatially as a function of wavelength. The dispersed radiation is then detected either by a number of radiometers at different locations or by sweeping the dispersed beam past the same radiometer. The former method provides poorer spectral resolution but greater sensitivity by integrating longer in time. In the laboratory, this results in only a small advantage. In the field, where the incoming energy may be a function of time, this time constraint can be crucial.

Imaging Sensors

Photographic. As mentioned earlier, photographic equipment will not be covered in any detail here. The primary points have already been mentioned in the summary of Table 2.

Return Beam Vidicon Camera. The Return Beam Vidicon Camera, or RBV, is a television system which lies generically between photographic equipment and multispectral scanners, discussed in the next section. The device is similar to photographic equipment in that it images an entire scene at one instant. It is, however, similar to the electro-optical sensors in that the detected radiance is converted to an electronic signal. The RBV, therefore, has some of the disadvantages of photographic equipment (two dimensional distortion, lack of multispectral registration) and some of the advantages of the electro-optical sensors (electronic output, nondestructive detection, etc.). LANDSAT is currently the only environmental satellite with a television sensor aboard.

Scanners. Electro-optical scanners are devices which generate an image by scanning the scene of interest. This is generally done using a rotating mirror which reflects radiation from different parts of an area into the detection system. Usually the sensor is constructed so that the rotation of the mirror provides radiance data along a straight line. The second dimension of the image is then obtained by advancing the sensor perpendicular to the scanning direction. From the mirror back to the detector, the sensor resembles at least conceptually the simple radiometer or spectrometer discussed above.

All multispectral scanners on the various satellites (MSS on LANDSAT, CZCS on NIMBUS-7, VHRR and AVHRR on the TIROS-NOAA series, for instance) operate basically as described above, using the scanning motion of the mirror to provide the across track information and the motion of the satellite to provide the along track information. The only exception to this method of operation is the Visible Infrared Spin Scan Radiometer (VISSR) on GOES.

The VISSR operates differently because the GOES satellite on which it is flown does not advance relative to the ground. It is in what is referred to as a geostationary orbit, discussed in Chapter 3. For VISSR the scanning motion is achieved by rotating the entire satellite about an axis approximately perpendicular to the plane described by its orbit. The mirror inside the satellite is then stepped about the axis perpendicular to the earth-satellite vector and lying in the orbital plane of the satellite. One step is taken for each rotation of the satellite. The rotation of the satellite then provides the east-west information, while the stepping mirror provides the north-south information.

All of the visible/IR scanners on environmental satellites have at least two spectral channels.

MICROWAVE SENSORS

Because the intensity of emitted terrestrial radiation and reflected solar radiation is down several orders of magnitude in the microwave portion of the spectrum from what it is in the visible to IR portion of the spectrum, passive reception of such energy is quite difficult. Because of this--and because of their expected usefulness--active microwave sensors have received significant attention in the past several years. The ability to control the source of radiation in an active sensor permits the measurement of variables other than just the received radiance. In particular, active microwave sensors make use of the travel time of the emitted pulse to measure distance and the frequency of the returned pulse to measure the speed of the target relative to that of the sensor platform. The change in frequency due to relative motion is referred to as the doppler shift. These two variables, round trip travel time and doppler shift, may also be used to locate a signal geometrically. An active device can use any or all of the three variables outlined above as well as a fourth, polarization. The polarization is a measure of the plane in which the measured electromagnetic vector oscillates. Both active and passive devices measure the polarization. The emitted pulse of active devices may also be polarized.

Nonimaging Microwave Sensors

Radar Altimeter. A radar altimeter is an active device used to measure the distance from the spacecraft to the reflecting surface below with a high degree of accuracy. The primary variable observed, therefore, is the round trip travel time between the spacecraft and the sea surface. The sensor emits a traveling pulse straight down (it looks at nadir) and then looks for the return pulse. Altimeters have orbited on three spacecraft: Skylab, GEOS-3, and SEASAT-1. The vertical resolution of the instruments went from approximately one meter for Skylab to 30 cm for GEOS-3 and 10 cm for SEASAT-1. These resolutions were those obtained by averaging all returned pulses for one second (between 10 and 100 pulses) and correcting for atmospheric effects.

The radar altimeter has also been used quite successfully to determine sea state. This is done by comparing the shape of the returned pulse with that of the emitted pulse.

Scattermometer. Oceanographic applications of the scatterometer have been primarily directed toward the measurement of wind induced surface stress. This instrument responds to the intensity of reflected radiation at moderately large angles, 10^{o} to 80^{o}. The instrument is active and uses ranging, round trip travel time, to locate the reflected pulse spatially. In order to obtain directional information regarding wind stress, two antennae were used on SEASAT-1 to view the same location from different angles. One beam was emitted 45^{o} from the forward direction and the second 45^{o} from the aft direction. As the satellite advanced, the area covered by the aft-looking beam would cross whatever had been observed by the forward-looking beam. By this method, the direction of the wind stress was determined to point within 20^{o} of one of four directions. In some cases, the directional ambiguity was partially resolved, the stress being determined to lie within 20^{o} of one of two directions.

The electromagnetic pulses emitted by the spacecraft have wavelengths on the order of 3 cm. At this wavelength, capillary waves act as Bragg scatterers, hence the ability to measure wind stress, magnitude and direction. In order to meet the resolution requirements specified for wind stress, the area over which the reflected pulse must be averaged is large since capillary waves are weak scatterers. The scatterometer uses ranging to divide the region viewed into a number of large cells with length scales on the order of 50 km.

Scanning Microwave Radiometers. A number of scanning microwave radiometers have been orbited in recent years on various satellites; primarily, the SMMR on NIMBUS-7 and SEASAT-1, ESMR on NIMBUS-5 and NIMBUS-6, and SCAMS on NIMBUS-6. Two different techniques are used to scan the beam. The beam of electrically scanned radiometers (ESMR) is steered electrically using a phased array. There are no moving parts and the angle of the antenna is stepped across a scan line in discrete intervals. The second technique is to rotate a reflector in front of the antenna in much the same fashion as the visible/IR multispectral scanners described earlier. The primary difference is that the reflector is a metal sheet rather than a mirror. The SMMR reflector is rotated continuously, while the SCAMS reflector is rotated in discrete steps similar to the VISSR on GOES. In all cases, the scan direction provides spatial information normal to the satellite's suborbital track. All of these devices measure two polarizations as well as radiance in a number of channels.

Because the emitted terrestrial radiance or reflected solar radiance is many orders of magnitude lower at microwave frequencies than in the visible or thermal, the sensors must again average over a much larger area. This constraint is also imposed by the size and shape requirements for microwave antennae. For these reasons, the scanning microwave radiometers are included here as nonimaging devices all having resolutions coarser than 25 kilometers.

Imaging Microwave Sensors

Synthetic Aperature Radar. The only microwave imaging sensor orbited to date is the Synthetic Aperature Radar, or SAR, on SEASAT-1. The SAR is an active side-looking device which makes use of both ranging and doppler information to construct an image of the surface with a resolution on the order of 25 meters.

The term "synthetic" refers to the fact that the motion of the spacecraft allows the sensor to "synthesize" the signal normally seen with a much larger antenna system. This is accomplished by making use of all the information available from each target to generate the image. The radar emits many pulses each second, each pulse illuminating a fairly large area. Thus, each element of the sea surface is illuminated by the radar and reflects energy back to the spacecraft a number of times as the spacecraft passes. These multiple views of each target may be used to resolve features not visible to the radar using just ranging and doppler information.

CHAPTER 3. SATELLITE OVERVIEW

HISTORICAL PERSPECTIVE

In April 1960, only three and a half years after the first man-made satellite orbited the Earth, the United States began its environmental satellite program with the launch of TIROS-I (Television and Infrared Observation Satellite), the first in a series of ten satellites launched for the purpose of meteorological research. The TIROS satellites follow a near polar orbit. Such an orbit is generally circular, carrying the satellite to within ten degrees or so of the poles and allowing coverage of almost all the Earth. These orbits are further constrained in that the satellite passes overhead at approximately the same local sun time everywhere on the surface of the Earth. Such orbits are called sun-synchronous. The objective of the TIROS series was to determine through experimentation an acceptable configuration for a United States operational series of meteorological satellites. This task involved experimentation with the spacecraft, its sensors, and the satellite-to-ground communications link (called the "downlink").

TIROS-X, although included in most historical descriptions as the last research satellite in the TIROS series, actually served as the prototype for the first generation of operational, polar orbiting, meteorological satellites referred to as ESSA*. This series was inaugurated in February 1966 with the launch of ESSA-1. The ESSA series consisted of two satellites which collected data simultaneously. The odd-numbered satellites stored data which was then sent to the Wallops Island, Virginia, and the Fairbanks, Alaska, Command and Data Acquisition stations. The even-numbered satellites relayed the received data directly to ground via the Automatic Picture Transmission capability. The second ESSA satellite was launched in late February of 1966, and the last in the series, ESSA-9, was launched in February 1969. See Figure 3 for a chronological arrangement of United States meteorological satellites. It is of interest to note that ESSA-3, launched in October 1966, was also called TOS-1 (TIROS Operational Satellite or System). This alias is used interchangeably with the remainder of the ESSA series, ESSA-9 being TOS-7.

The NIMBUS ("cloud" in Latin) series, designed to carry on the research and development (R&D) function for the polar orbiting, meteorological satellites, was initiated with the launch of NIMBUS-1 in August 1964. (Note the overlap with the last R&D TIROS satellite.) In addition to the development and flight testing of advanced meteorological sensors, NIMBUS also played a research role in the exploration of natural resources and geophysical phenomena. This necessitated sensors capable of detecting various forms of air pollution, providing data on various oceanographic variables, etc. In particular, some of the more recent NIMBUS satellites have been

*From TIROS-X on, the prototype for each generation of operational, polar-orbiting, meteorological satellites has been called TIROS--TIROS-M for the second generation and TIROS-N for the third generation.

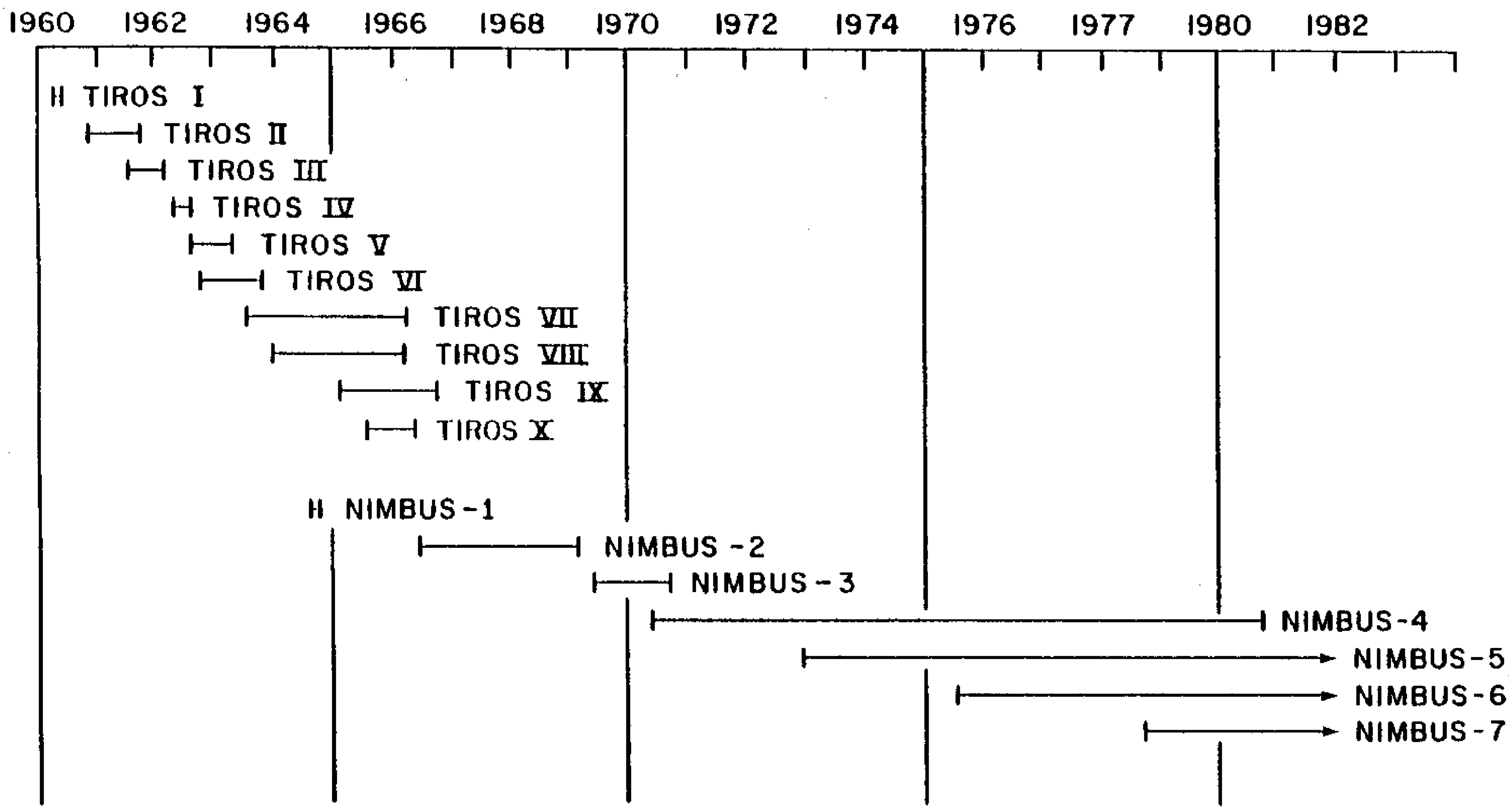
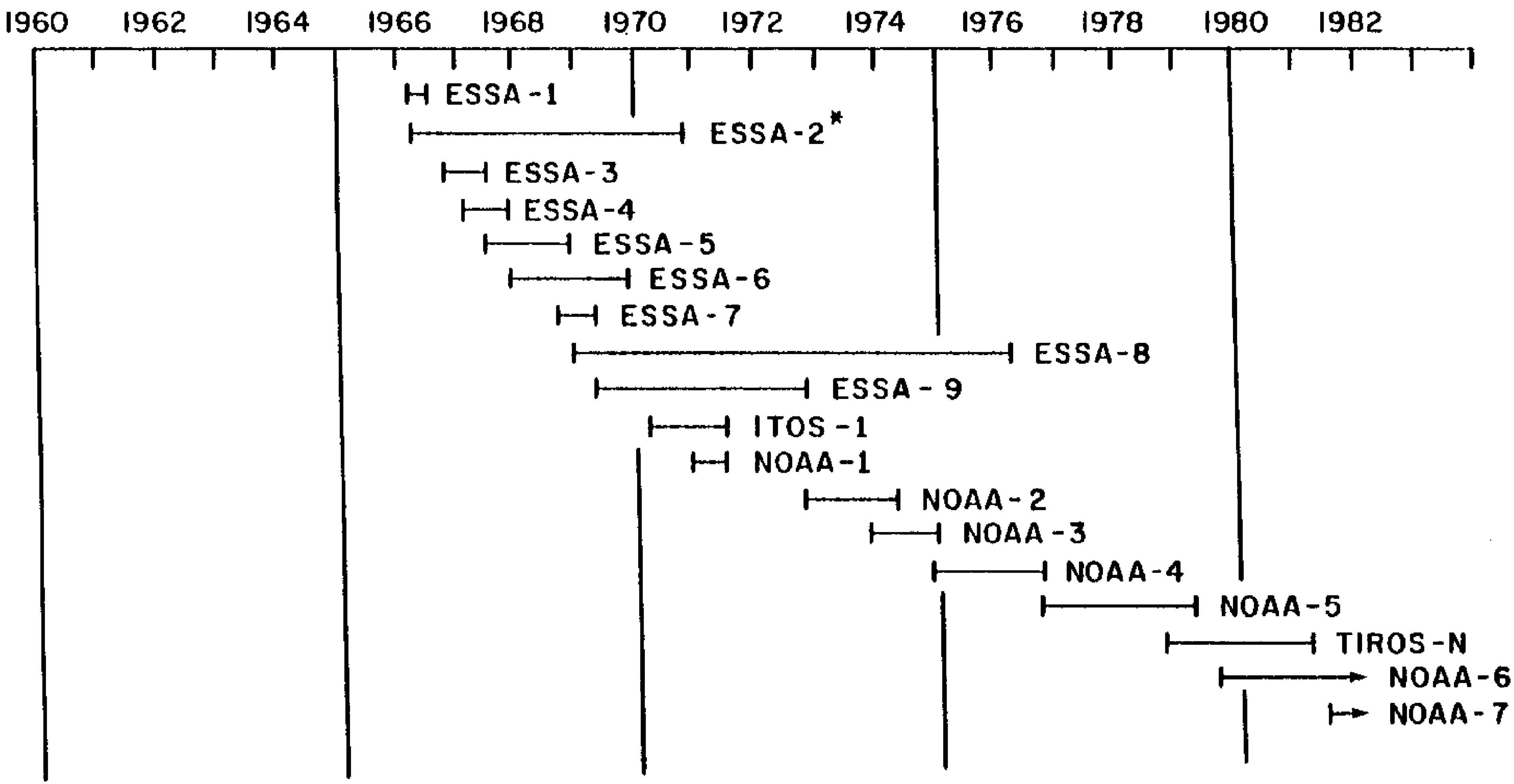


Figure 3a. Research Polar Orbiting Meteorological Satellites



*The ending date for odd numbered ESSA satellites corresponds to the date the satellite ceased operation. The ending date for the other satellites corresponds to the last day for which data exists in the NOAA archive.

Figure 3b. Operational Polar Orbiting Meteorological Satellites

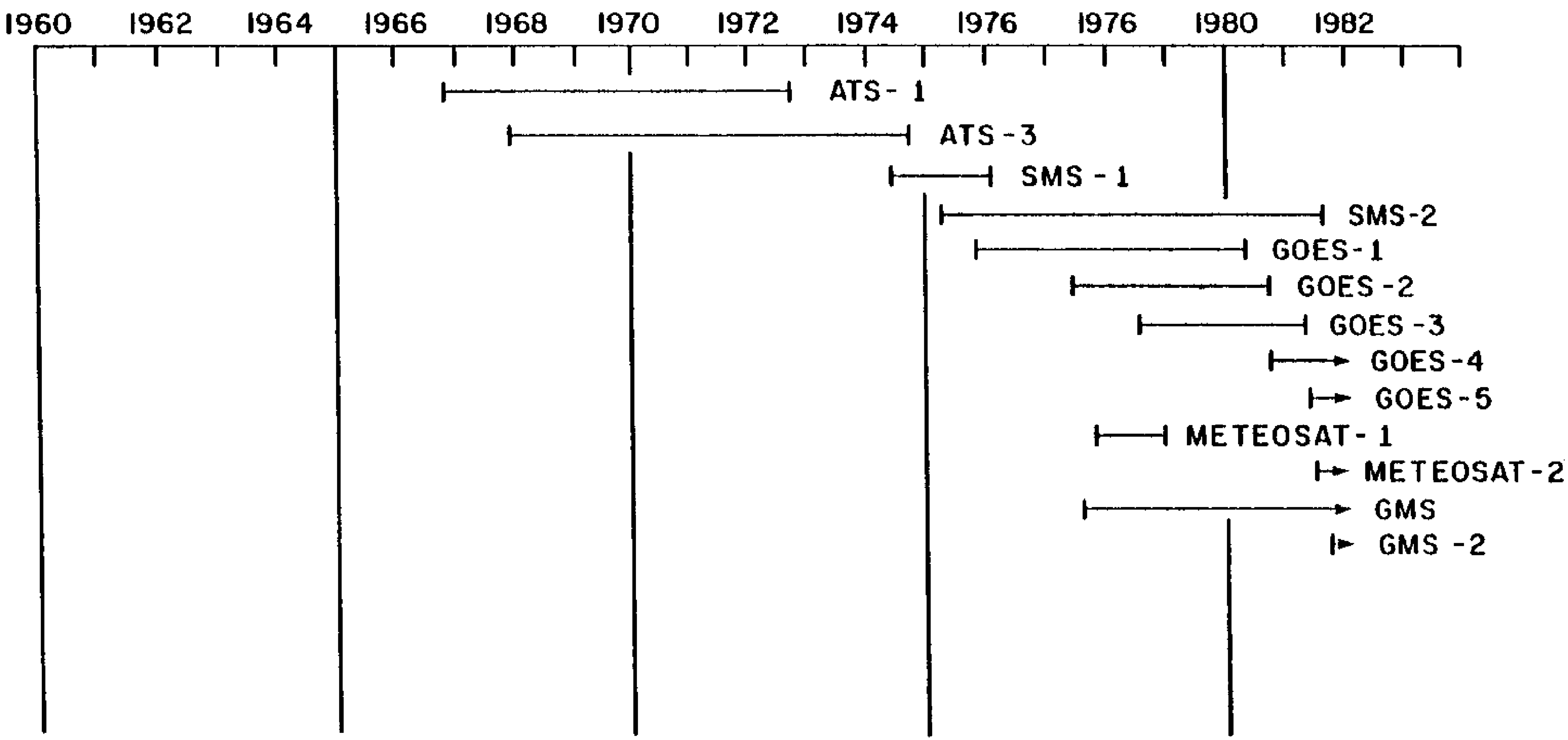


Figure 3c. Research and Operational Geosynchronous Meteorological Satellites

equipped with sensors dedicated to oceanographic studies. The last satellite in the series (NIMBUS-7) was launched in October 1978, and was still performing reliably at the time of this writing.

Advances made early in the NIMBUS program were incorporated on TIROS-M (launched in January, 1970), the prototype for the second generation of polar orbiting, meteorological series. TIROS-M was also known as ITOS-1, the Improved Tiros Operational Satellite. The first operational satellite in this series was designated NOAA-1 and launched in December 1970. This series included high resolution thermal IR sensors as well as visible sensors, and is discussed in more detail in Section II. The last satellite in this series, NOAA-5, was launched in July 1976.

TIROS-N, the prototype of the third generation, was launched in October 1978, and the first operational satellite in the third generation, NOAA-6, was orbited in June 1979. NOAA-6 was operational and providing useful oceanographic data at the writing of this report, TIROS-N having failed in the fall of 1980. NOAA-7 was launched in June 1981

Parallel to the development of the polar orbiting series, two other series also evolved. One of these, the Defense Meteorological Satellite Program (DMSP), developed by the military, is polar orbiting and collects much the same data as the NOAA satellites. The early development of the system was secret, hence little information is available from this period. The Air Force announced the existence of the series in February 1973, at which time DMSP data was made available to the public. Since the public announcement of the series, the early Block 5B/C satellites have been replaced with a newer generation called the Block 5D.

The other meteorological satellite series developed parallel to TIROS/ESSA/NIMBUS/NOAA was ATS/SMS/GOES. These satellites fly in a geosynchronous orbit rather than a polar orbit. A geosynchronous satellite orbits the Earth about the equator, one revolution taking 24 hours. In this fashion, the satellite will remain above the same point on the equator at all times. The advantage of such an orbit is that continuous coverage of an area is provided. However, the resolution is coarse, since a geosynchronous orbit requires the satellite to be much higher than the polar orbiters, 35,000 Km as opposed to 1,000 Km. Also, the satellites cannot monitor the poles because they are always over the equator; and they see only one section of the Earth. In order to capitalize on the advantages of both systems, the United States decided to deploy an operational geosynchronous series in addition to the polar orbiting series.

The Applications Technology Satellites (ATS), first launched in December 1966, served as the R&D series for the geosynchronous system, although this was not their primary mission. A number of spacecraft and sensor experiments were carried out on the early ATS satellites. SMS-1 (Synchronous Meteorological Satellites), the prototype of the operational geosynchronous meteorological series, was launched in May 1974. The third satellite in the series, SMS-C, was renamed GOES-1 (Geosynchronous Operational Environmental Satellite), and launched in October 1975. Two geosynchronous satellites are needed to cover the United States; hence GOES-2 was also launched. In addition to the GOES satellites, the Europeans have orbited a similar satellite, called METEOSAT, and the Japanese have one called GMS Geosynchronous Meterological Satellite. These two satellites cover those sections of the Earth of interest to the associated countries. (Coverage of these satellites is shown in Figure 6.3a of Section II.)

Following the early success of the meteorological satellites, as well as the promising results of numerous airborne missions, the United States embarked on its land-oriented satellite research program in July 1972. The first satellite in the series, ERTS-1 (Earth Resources Technology Satellite), carried two sensors spanning the visible and near infrared portion of the spectrum. The primary sensor was the Return Beam Vidicon (RBV) camera, actually a set of three television cameras sensing in the green, red, and near infrared. The secondary sensor was the multispectral scanner (MSS), an electro-optical sensor sensitive to radiation in four spectral bands. Shortly after the launch of ERTS-1, the RBV failed, and although it was included on ERTS-2, the second satellite in the series, it never saw much use. The MSS, however, included on ERTS-1 "at the last minute," has provided exceptional ground-cover data, and although ERTS was conceived as an R&D series, data dissemination as well as sensor continuity has been treated in an operational fashion. In 1975, after the launch of ERTS-2, the satellites were renamed LANDSAT-1 and 2. Since then LANDSAT-3 has been launched, with an improved RBV system and a thermal infrared channel on the MSS. A LANDSAT-D and D2 are planned for launch in the near future.

A second research satellite (manned in this case), from which a number of ground cover, oceanographic and meteorological experiments were carried out, was SKYLAB, launched in May 1973. Many of the experiments carried out on SKYLAB laid the groundwork for sensors launched on later satellites. For example, the results of the radar altimeter experiment were utilized in the design of the GEOS-3 (Geodetic Experimental Oceanographic Satellite) satellite (April 1975), whose primary sensor was a radar altimeter. GEOS-3 is included in most summaries as an oceanographic satellite because the radar altimeter, its primary instrument, collected data only over the oceans, providing data such as ocean topography and significant wave heights. There were two other satellites in the GEOS series, but their sensors provided data of little interest to oceanographic phenomena and will not be discussed here.

The last satellite launched to date with oceanographic data collection as its primary mission was SEASAT-1. Most of its sensors became operational on June 27, 1978, but after 99 days (October 10, 1978) of near flawless operation a major power failure incapacitated the spacecraft, terminating all data collection. This spacecraft and its sensors are discussed in detail in Section II. There was to be a SEASAT-2, but this project was dropped in favor of the proposed NOSS (National Oceanic Satellite System), which was scheduled for a 1986 launch. In the interim, no other civilian United States oceanographic satellites are planned. NOSS now also appears to have been dropped.

The only other satellite with potential application to remote sensing of the oceans that will be discussed is HCMM (Heat Capacity Mapping Mission), launched in April 1978. The mission of HCMM was to provide comprehensive, accurate, high-spatial-resolution thermal surveys of the Earth's surface. The objective of these measurements was to determine, from the observed thermal differences between day and night, the thermal inertia of the ground and thereby the geological structure. High-resolution thermal imagery is, however, also of interest in oceanographic studies.

SATELLITE CLASSIFICATION SCHEMES

Satellites can be classsifed in a variety of ways. An outline is therefore presented of some of the attributes of a satellite or satellite system that might be used for classification. Probably the most important is the satellite mission.

Application Areas--Satellite Mission

To date, satellites have been launched by the United States to address meteorological questions, observe the oceans, classify geological structures, determine the shape of the globe, and classify land cover, particularly agricultural cover. Future satellites are planned which will allow surface mapping, topographic feature extraction, ice cover analysis, and magnetic field strength determination. There also exist a variety of satellites with planetary, solar, and other astronomical missions; military satellites with classified missions; communications satellites; and navigational satellites. These, however, will not be discussed here as they do not fall within the group of environmental satellites and have no utility in remote sensing of the oceans.

For simplicity, we reduce the various application areas outlined above to the following three categories: meteorological (weather), oceanographic, and terrestrial (land oriented). Although our primary area of interest is the ocean, data from satellites in all three application groups have proven useful in oceanographic research.

Operational Mode

The second characteristic of a satellite or satellite system that can be used to classify it is its mode of operation. There exist in general three modes, although the distinction between them is sometimes nebulous. These operational modes are:

a. Research. The satellite is launched to study sensor characteristics, orbit alternatives, etc., and there is no guarantee that in the future the nation will support a similar satellite. Civilian research satellites are launched and operated by the National Atmospheric and Space Administration (NASA).

b. Prototype. This designation is used for the first satellite in a series of operational satellites. The satellite (civilian) is launched and operated at first by NASA. Control is eventually turned over to the National Oceanic and Atmospheric Administration (NOAA).

c. Operational. Such satellites come in series. The civilian ones are launched by NASA and operated by NOAA. In general, the country has made a commitment that the series as well as subsequent series will continue the observation program for a number of years into the future.

The word "civilian" has been used a number of times. These satellites are to be compared with a series of meteorological satellites, launched and operated by the military, the data of which is in the public domain. There is no commitment on the part of the military to supply meteorological data to the public in the future. Indeed, the military reserves the right to restrict their satellites to military use at any time. This military/nonmilitary dichotomy indicates another manner in which satellites may be categorized. This categorization will not be used here.

Satellite Orbit

The last characteristic to be considered is the satellite's orbit. It is convenient to consider three different types of orbits:

a. Sun-synchronous (sometimes called polar orbiting). The local sun time at the nadir point (the point directly beneath the satellite), on the sunlit side of the Earth, is approximately the same independent of latitude. Such orbits are important when reflected solar radiation dominates the observed radiance and of little consequence if the satellite's sensors are active, providing their own source of radiation. Such orbits are about 1,000 km above the Earth's surface.

b. Geostationary (Geosynchronous). These satellites orbit the equator at the rate at which the Earth rotates; hence, they always remain over the same point on the equator. These orbits are useful where repeat coverage at short time intervals is desired and spatial resolution is not as important. Their orbits are about 36,000 km above the Earth's surface.

c. General. This defines all possible orbits. Cases a and b above are special cases of the general or nonspecific orbit but are separated here because of their importance. The general orbit shall be used to define all orbits that are neither sun-synchronous nor geostationary.

In Table 3, existing satellite systems are categorized using the various categories outlined above. Across the top of the table is the mode of operation--research, prototype, and operational--while the columns are divided into application areas. Each application area is further subdivided by orbit where applicable.

Some peculiarities are evident in Table 3. NIMBUS appears in both the meteorology and oceanography application areas. The NIMBUS series was originally conceived as the research series for sun-synchronous, meteorological

TABLE 3. ENVIRONMENTAL SATELLITES OF THE UNITED STATES

APPLICATION AREA	ORBIT TYPE	RESEARCH	PROTOTYPE	OPERATIONAL
METEOROLOGY	SUN SYNCHRONOUS	TIROS I-X, NIMBUS	TIROS	ESSA, NOAA, DMSP
	GEO SYNCHRONOUS	ATS		SMS/GOES
	NON SPECIFIC			
LANDUSE	SUN SYNCHRONOUS	LANDSAT, HCMM		LANDSAT
	GEO SYNCHRONOUS			
	NON SPECIFIC			
OCEANOGRAPHIC	SUN SYNCHRONOUS	NIMBUS-7		
	GEO SYNCHRONOUS			
	NON SPECIFIC	SEASAT-1, GEOS-3		

applications. Recently, however, the NIMBUS platform has been used to test sensors, e.g.--the Coastal Zone Color Scanner (CZCS)--which have oceanographic applications.

A second point of confusion is the designation of TIROS as the prototype for the sun-synchronous meteorological satellites. This is only true for the more recent TIROS satellites. For example, TIROS-N is the prototype for the third generation, meteorological, polar-orbiting satellites. The confusion arises from the fact that the early TIROS satellites (from TIROS-I launched in 1960 to TIROS-X launched in 1965) served as research satellites, while the later ones are prototypes.

The designations of the various series of sun-synchronous, meteorological satellites can also be confusing. For example, the third satellite in the ESSA series was also named TOS-A (TIROS Operational Satellite). TIROS-M, the prototype of the second-generation, sun-synchronous series, is also known as ITOS-1 (Improved TIROS Operational Satellite). The number of aliases associated with a series often leads the casual observer to the conclusion that there are many more satellites than in fact exist. A final point to note here is that a satellite in a series generally has a letter designation prior to launch. If the launch is successful, the letter is converted to a number. For example, prior to launch, SEASAT-1 was referred to as SEASAT-A; after the launch its name was changed to SEASAT-1. This procedure, however, is not followed for the TIROS prototypes. TIROS-N remains TIROS-N. To add to the confusion, the first operational satellite in the third generation was designated NOAA-A prior to launch and NOAA-6 after launch. Because NOAA-B failed at launch, NOAA-C became NOAA-7.

There are several points concerning LANDSAT worth noting. First, the name of the series, originally ERTS, was changed to LANDSAT in 1975; hence, documents written prior to 1975 often use the acronym ERTS. Second, LANDSAT is included in both the research and operational categories. Although it has been quasi-operational for a number of years, it was not until late 1979 that control was transferred from NASA to NOAA, along with a long-term federal commitment to maintain such a satellite system. It is in this sense that it is included as an operational series.

The discussion of the satellites in Section II is organized by application area, as indicated in Tables 3, 4, and 5. The last two tables summarize the payloads of interest to coastal and oceanographic problems as well as the orbital characteristics.

Note that not all environmental satellites are discussed in Section II. Only those that have orbited or are currently active are included. Furthermore, some of the older satellites, the data of which are not available or are of very poor quality, are not discussed.

TABLE 4. SATELLITES WITH SENSORS APPLICABLE TO COASTAL AND OCEANOGRAPHIC PROBLEMS

Satellite	Application Area	Mode	Thermal IR	No. of Bands Visible Near IR	Altimeter	Data Collection System (DCS)
NIMBUS	Meteorology/ Oceanography	Research	X	5		
ITOS/NOAA	Meteorology	Operational	X	1		
TIROS-N	Meteorology	Prototype	X			X
DMSP	Meteorology	Operational	X	1		
SMS/GOES	Meteorology	Operational	X	1		X
GEOS-3	Oceanographic	Research			X	
SEASAT	Oceanographic	Research	X	1	X	
HCMM	Earth Resources	Research	X	1		X
LANDSAT	Earth Resources	Research/ Operational	X	4		X

TABLE 5. ORBITAL CHARACTERISTICS OF OPERATIONAL AND EXPERIMENTAL SATELLITES

Satellite	Application Area	Mode	Altitude (km)	Inclination	Period (min)	Orbit Type
NIMBUS	Meteorology/ Oceanography	Research	955	99.0°	104.1	Sun Sync
ITOS/NOAA	Meteorology	Operational	1470	101.9°	115.0	Sun Sync
TIROS-N	Meteorology	Prototype	833	98.7°	101.5	Sun Sync
DMSP	Meteorology	Operational	837	98.8°	101.6	Sun Sync
SMS/GOES	Meteorology	Operational	35790	1.0°	1436.0	Geostationary
GEOS-3	Oceanographic	Research	845	115.0°	101.8	General
SEASAT	Oceanographic	Research	755	108.0°	100.2	General
HCMM	Earth Resources	Research	620	97.8°	96.8	Sun Sync
LANDSAT	Earth Resources	Research/ Operational	910	99.1°	103.2	Sun Sync

Section II

Details of U.S. Environmental Satellites and Their Sensors

INTRODUCTION

This section represents the details associated with the satellites listed in Table 3 of Chapter III. The organization of the appendix will follow that of Table 3. Specifically, meteorological satellites are discussed first beginning with the civilian research meteorological satellites, then the civilian operational polar-orbiting series, the military operational polar-orbiting series, and the operational geosynchronous series. Following the discussion of the meteorological satellites, the oceanographic satellites are covered. Satellites in the third application area, "terrestrial orientation," are discussed last.

The descriptions for each of the series follows the same basic format. First the objective of the series as abstracted from NOAA or NASA literature is presented. Following the objectives is a general description of the series. The third section covers some of the details associated with the orbital characteristics of the various platforms as well as their attitudinal control. For most series, there is little change from one satellite to another in the general nature of the orbit. Where the changes are significant, they will be noted.

The orbital description completes the introductory remarks associated with a series. The sections following the introductory remarks deal with those satellites thought to be of interest in oceanographic research. The discussion of each satellite follows the same format beginning with general remarks, followed by detailed descriptions of sensors of potential interest in oceanography and ending with a summary of documentation and data availability. The data availability section includes the instructions required to order data. The user is, however, cautioned that both the availability and the ordering information may change with time. This document should be current as of January, 1981

The reader will note that many of the pages describing sensors are largely blank. This is done in keeping with the preparation of this as a reference document, easy to use and easy to update.

Description of Tables

There are two basic tables that occur in this chapter, one describing satellite orbital parameters, the other outlining the characteristics of those sensors discussed. An attempt has been made to force all satellites and sensors into the format of these tables. In most cases, this provides an adequate description, thus, given the uniformity, a handy reference, especially in the case of the orbital parameters. For the tables outlining the sensors, cases do arise in which the tabulation is somewhat contrived. The user is, therefore, encouraged to read the accompanying descriptions. This is especially true of the microwave sensors. Finally, the included material only touches on each sensor and is meant as a brief guide to what is available. When actually using the data from a sensor, the reader is encouraged to seek out the original source for a description of the instrument and its operation.

Now both of the table types are described.

Satellite Orbital Parameters

This table is divided into eight columns. The first gives the satellite name as well as its most common alias, the latter in parenthesis. The next two columns contain the satellites launch date and in most cases the date of the last data included in the archive.* The fourth column is the orbital period in minutes. This is followed by the periapsis (distance from the satellite to the earth's surface at the point of nearest approach) and the apoapsis (the greatest distance between the satellite and the earth's surface), both in kilometers. The inclination (in degrees) of the orbit occupies the seventh column. This is the angle that the satellite's orbital plane makes with the equatorial plane. This angle is measured from the east counterclockwise to the orbital plane at the ascending crossing. The last column gives the local sun time for the equatorial crossing of the descending node (north to south). The local sun time is defined such that local noon occurs at the instant that the sun reaches its highest point in the sky for that day.

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* This date was selected as being the most useful one to the reader of this guide. There are actually a number of different criteria used to describe the "end" of a satellite, these criteria depending on the interests of the organization providing the information. Often documents present a termination date without specifying what it refers to, so different documents list different dates for what is apparently the same occurrence. The primary occurrences associated with the termination of satelite activities are:

a) Last date for which data was collected. This could be from all sensors or from the primary sensors.

b) Formal deactivation by NASA. In general this date is followed by a month or so of engineering analysis often leading to the destruction of components of the spacecraft. Environmental data may continue to be collected during this period.

c) Termination of tracking. This means that communication with the satellite has been terminated and no more environmental data will be collected after this.

d) Reentry of the spacecraft into the atmosphere. This involves the physical destruction of the satellite.

Sensor Parameters

The tables of sensor characteristics will in general contain redundant information. For example, the sample rate and the satellite altitude define the pixel separation at nadir. When available, both descriptions will be included but under no circumstances does the author make the indicated calculations if the information does not exist in the source material--the corresponding entry is simply left blank. The reader is, of course, free to make the calculation.

The various parameters in the table have been grouped into classes covering similar material. The first group has just one element. The spectral range of the various channels. For sensors operating in the visible and infrared portions of the spectrum, the units of this entry are micrometers (μm). For channels in the microwave, the units are gigahertz (GHz). The second group consists of those variables related to the spatial resolution of each channel of the sensor. The first of these, IFOV defines the instantaneous field of view. It is generally assumed to be square and for the visible and most IR channels is given in milliradians (mr). For some IR channels and most microwave channels, the units are degrees. The altitude of the satellite and IFOV define the size of a ground resolution element. This size will, of course, vary with the nadir angle. The symbol '@ nadir' in the third row refers to the pixel directly beneath the satellite while '@ swath edge', the fourth entry, refers to the size of a pixel at the furthest extreme at which the sensor collects data.

The next group of variables relates to the spacing of the scan lines. Since most scanners make use of a rotating reflector, the rotation rate in revolutions per minute (rpm) is given. This is followed by the separation in kilometers of scan lines at nadir. In some cases, the reference material states that adjacent pixels were contiguous rather than giving an actual separation. They are reported that way here also. Neglecting the curvature of the earth which introduces only very small deviations, the scan lines will be separated by the same amount along their entire length. This is, of course, only true for sensors that scan through the nadir position.

The sample rate defines the separation of adjacent pixels along the scan line. This is given either in inverse seconds (so many samples per second) or in angular units, a sample every so many milliradians of scanner rotation.

The last group deals with the width over which the sensor collects data for one pass. The total field of view in degrees defines this swath width.

Numbering Scheme for Section II

The sections describing the various satellites are numbered in the rather sterile but easily interpreted fashion of nested numbers (e.g., 3.1.6.4.). The first number defines the satellite series.

This number assumes the following meaning:

1. NIMBUS - 2nd generation, civilian, polar orbiting, research meteorological satellites.
2. TIROS-M - 2nd generation, civilian, polar orbiting, operational meteorological satellites.
3. TIROS-N - 3rd gneration, civilian, polar orbiting, operational meteorological satellites.
4. DMSP - Block 5B/C military, polar orbiting, operational meteorological satellites.
5. DMSP - Block 5D the next generation, military, polar orbiting, operational meteorological satellites.

6. SMS/GOES - 1st generation, civilian, geosynchronous, operational meteorological satellites.
7. GEOS - Geodynamics Experimental Ocean Satellites.
8. SEASAT - 1st generation, research oceanographic satellite.
9. LANDSAT - 1st generation, research (and now operational) terrestrial satellites.
10. Applications Explorer Mission - a series of small mission oriented satellites.

The second number separates the satellites within the series as well as some of the series related discussions. The numbers have the following meaning:

1. series objectives
2. general overview of series
3. orbital characteristics
4. first satellite dealt with in this report
5. second satellite dealt with in this report

- etc. -

The third number repeats as follows for each satellite:

1. for the sensors
2. for the documentation
3. for data availability

Finally the fourth level is used for the individual sensors, each sensor being assigned a number.

Putting all this together, the description of, for example, the Selective Chopper Radiometer of NIMBUS-5, the first satellite in the NIMBUS series discussed in this document would occur in section 1.4.1.5.

The tables in a given section are given the same number as the section prefixed with a "T" and followed with an "a" for the first table, a "b" for the second one, etc. (e.g., T.1.4.1.5.a). The figures are numbered the same way except they are prefixed with an F.

CIVILIAN RESEARCH METEOROLOGICAL SATELLITES

As outlined in Chapter III, there have been three series of Research and Development (R&D) satellites devoted to meteorology, two for the polar orbiting platforms and one for the geosynchronous platforms. The satellites in each of these series along with their orbital parameters are presented in Table II.1. These orbital parameters are only approximate values, not to be used for detailed satellite navigation, but rather as a general indication of the orbit. Only the NIMBUS series will be discussed in this report, the others being omitted because their data is old, of poor quality or difficult to obtain, hence, in general only of historical interest.

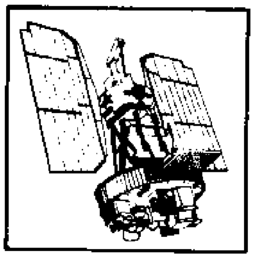
Table II.1 Research Meteorological Satellites (Civilian)

Satellite Name (alias)	Launch Date	Limit of Data Archive Date	Period Min	Periapsis km	Apoapsis km	Inclination Degrees	Descending Node LST
1st generation polar orbiting							
TIROS-I	4/1/60	6/14/60	99.16	693	750	48.4°	
II	11/23/60	9/27/61	98.27	533	626	48.5°	
III	7/12/61	1/23/62	100.4	631	702	47.9°	
IV	2/8/62	6/18/62	100.4	609	724	48.3°	
V	6/19/62	5/14/63	100.4	588	974	58.0°	
VI	9/18/62	10/21/63	98.73	686	713	58.3°	
VII	6/19/63	2/26/66	97.42	621	649	58.2°	
VIII	12/21/63	2/12/66	99.33	691	765	58.5°	
IX	1/22/65	9/9/66	119.2	705	2582	96.4°	
X	7/2/65	4/12/66	100.7	751	837	98.7°	
2nd generation polar orbiting							
NIMBUS-1	8/28/64	9/22/64	103.4	423	932	98.7°	
2	5/15/66	1/17/69	108.0	1109	1179	100.3°	
3 (B2)	4/14/69	9/25/70	107.3	1071	1132	99.9°	
4 (D)	4/8/70	9/30/80	107.2	1092	1108	80.1°	

Table II.1 Research (Meteorological Satellites (Civilian) (Cont'd)

Satellite Name (alias)	Launch Date	Limit of Data Archive Date	Period Min	Periapsis km	Apoapsis km	Inclination Degrees	Descending Node LST
5 (E)	12/12/72	#	107.2	1089	1101	99.9°	Midnight
6 (F)	6/12/75	#	107.3	1093	1101	100.0°	Midnight
7	10/24/78	present	104.0	938	953	99.3°	Midnight
geo synchronous							
ATS-1 (B)	12/7/66	10/16/72	1466.0	35852	36887	.23°	Not applicable
2 (A)	4/6/67	No useful data	219.7	186	11180†	28.3°	" "
3 (C)	11/5/67	9/2/74	1422.0	35330	35705	.54°	" "
4 (D)	8/10/68	*	93.9	218	726	29.1°	" "
5 (E)	8/12/69	*	1435.9	35777	35790	2.5°	" "
6 (F)	5/30/79	*	1436.3	35763	35818	1.8°	" "

Some sensors still collecting data.
* No environmental data collected.
† Not planned.



1. NIMBUS Series

1.1 Objectives

i. To develop and flight-test advanced sensors and general technology for the study of the atmosphere and other application areas.

ii. To provide data for meteorological research.

1.2 General

The NIMBUS series was conceived primarily as the second generation R&D polar orbiting series for meteorological research. There were, however, research missions in other areas of the earth sciences planned and carried out on the series' seven satellites. Data from the Coastal Zone Color Scanner (CZCS) and the Scanning Multichannel Microwave Radiometer (SMMR), two of the most promising for oceanographic applications of these "other" sensors are just now becoming available. These two sensors along with a number of others are discussed in more detail below. These discussions will, however, be limited to NIMBUS-5 to NIMBUS-7.

1.3 Orbital Characteristics

All of the NIMBUS satellites were launched into sun-synchronous orbits. The NIMBUS satellites of interest here, 5 to 7, orbited at altitudes ranging from about 950 km to about 1100 km. (See Table II.1). As described earlier, the defining characteristic of the sun-synchronous orbit is that it passes over every point on the sunlit side of the earth at approximately the same local sun time. In the case of NIMBUS-5 to 7 the ascending node of the satellite occurs at local noon. This means that the satellite crosses the equator moving from south to north when the sun has reached its highest point in the sky. The descending node, equatorial crossing from north to south, occurs at local midnight. Two points worth underscoring with respect to NIMBUS sun-synchronous orbits are:

i. the importance of solar elevation in determining reflectance, solar elevation being a function of the local sun time, the latitude and the time of year;

ii. the satellite passes overhead at the same local sun time <u>only</u> for the nadir point. There is a difference of about one half of an hour in local sun time between the nadir point and a point on the edge of the swath for some of the sensors. This means that those sensors which see the same ground point more than twice during daylight hours do not see these points at the same local sun time.

Successive equatorial crossings of the NIMBUS satellites range from 26^{o} to 27^{o} longitude; i.e., if the satellite crosses the equator south to north at 70^{o} west, its next south to north equatorial crossing will be at about 97^{o} west. This 26^{o} to 27^{o} separation corresponds to between 2800 km and 2900 km (1^{o} longitude at the equator corresponding to about 110 km). At higher latitudes the separation of successive orbits is, of course, smaller.

The satellites take approximately 105 minutes for one revolution of the Earth or about 14 revolutions per day. It is important to note that there are not exactly 14 revolutions per day, i.e., the nadir track of the satellite does not repeat every day. This is also apparent from the fact that successive equatorial crossings are separated by between 26^{o} and 27^{o}.

The attitude control on NIMBUS-5 stabilized the spacecraft to $\pm$ 0.5^{o} in roll and yaw and $\pm$ 1.0^{o} in pitch. NIMBUS-6 provided stabilization to $\pm$ 1.0^{o} in yaw and $\pm$ 0.5^{o} in roll and pitch although there existed for this spacecraft a permanent bias of + 0.6° in pitch to reduce contol systems pneumatic consumption. Finally, NIMBUS-7 is stabilized to ± .7° in pitch and ± 1.0° in yaw and roll.

1.4 NIMBUS-5 Satellite

NIMBUS-5 was the fifth in a series of R&D satellites directed primarily at meteorological applications. In addition to improved and additional sensors this spacecraft was equipped with an improved attitude control system maintaining the pitch to within $\pm$ 1.0° and the roll and yaw to within $\pm$ .5°. This improvement provided better pointing accuracy for the satellite's sensors compared to previous NIMBUS satellites. The specific objectives of this satellite were:

i. To observe atmospheric conditions and processes whose bearing on weather prediction was at the time of the launch of the satellite not fully understood.

ii. To develop techniques for measuring on a global scale those parameters required for the mathematical modeling of atmospheric circulation.

1.4.1 NIMBUS-5 Sensor Objectives

THIR (Temperature-Humidity Infrared Radiometer) Section 1.4.1.1

- To provide day/night cloud top or surface temperatures.
- To give information on the moisture content of the upper troposphere and stratosphere and the location of jet streams and frontal systems.

SCMR (Surface Composition Mapping Radiometer) Section 1.4.1.2

- To distinguish acidic from basic rock.
- To map surface temperatures.
- To map surface features.

ESMR (Electrically Scanning Microwave Radiometer) Section 1.4.1.3

- To derive the liquid water content of clouds.
- To observe differences between sea ice and the open sea over the polar caps.
- To test the feasibility of inferring surface composition and soil moisture.

ITPR (Infrared Temperature Profile Radiometer) Section 1.4.1.4

- To test the feasibility and operational applications of a remote sounding technique to determine temperature profiles and total water vapor content in the troposphere and lower stratosphere.

SCR (Selective Chopper Radiometer) Section 1.4.1.5

- To observe the global temperature structure of the atmosphere up to 50 km.
- To make supporting observations of water vapor distribution.
- To determine the density of ice particles in cirrus clouds.

NEMS (Nimbus-E Microwave Spectrometer) Section 1.4.1.6

- To demonstrate the capabilities and limitations of microwave sensors for measuring tropospheric temperature profiles, water vapor abundances, cloud liquid water content, and earth surface temperatures.

1.4.1.1 The Temperature-Humidity Infrared Radiometer (THIR)

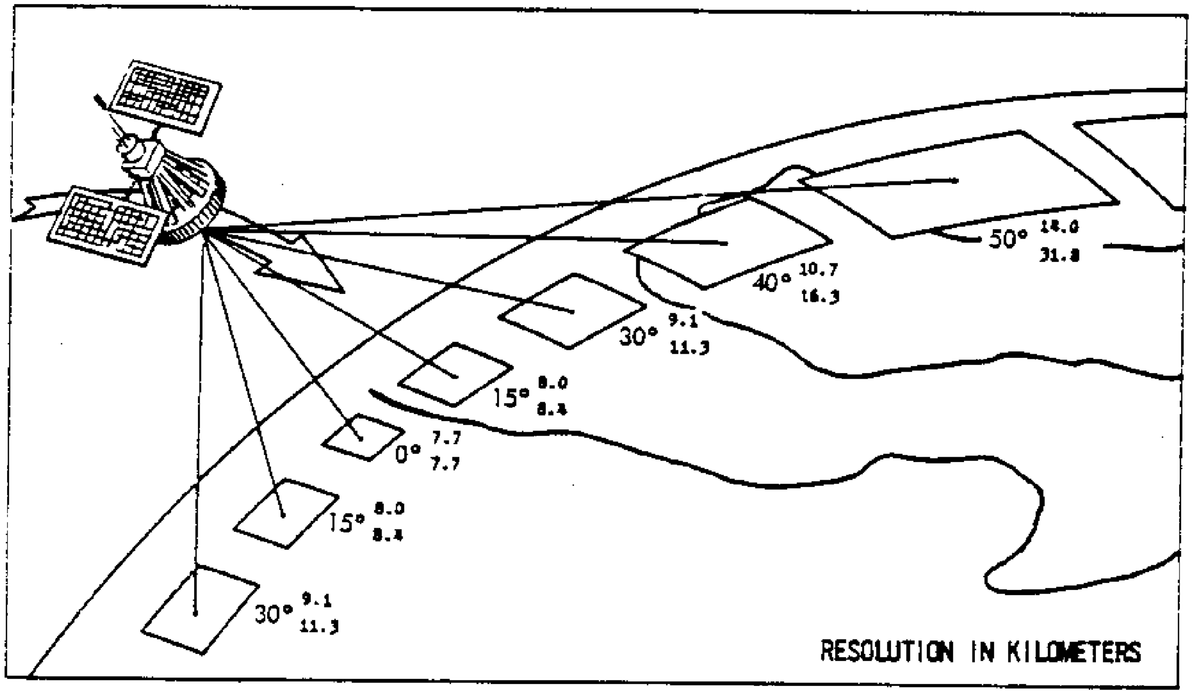
The THIR was a two channel scanning radiometer (see Chapter II for a brief generic description of a scanning radiometer) designed to measure cloud top and surface temperature day and night to provide information on the location of water vapor in the atmosphere. The first objective was met by the thermal channel in the 10.5 to 12.5 μm range with a nadir resolution of 8 km. The second objective, water vapor measurement, was met by a channel in the 6.5 to 7.0 μm range with a 22 km nadir resolution. Another way of representing the resolution is by the channel's instantaneous field of view (IFOV). For the thermal channel this was 7 milliradians (mr) while for the water vapor channel it was about 21 mr. (See Table T.1.4.1.1.a and Figure F.1.4.1.1.a)

The scanning mirror of the instrument rotated at 48 rpm or 1.25 seconds per revolution. In that time the satellite advanced approximately 8 km, thus oversampling the 6.5 to 7.0 μm channel. The detector viewed the in flight black box calibration during part of each scan, i.e., as the mirror rotated it viewed the Earth, then outer space, then the in-flight calibration (built into the instrument housing), outer space and then the Earth again, etc. This provided a calibration signal on each scan.

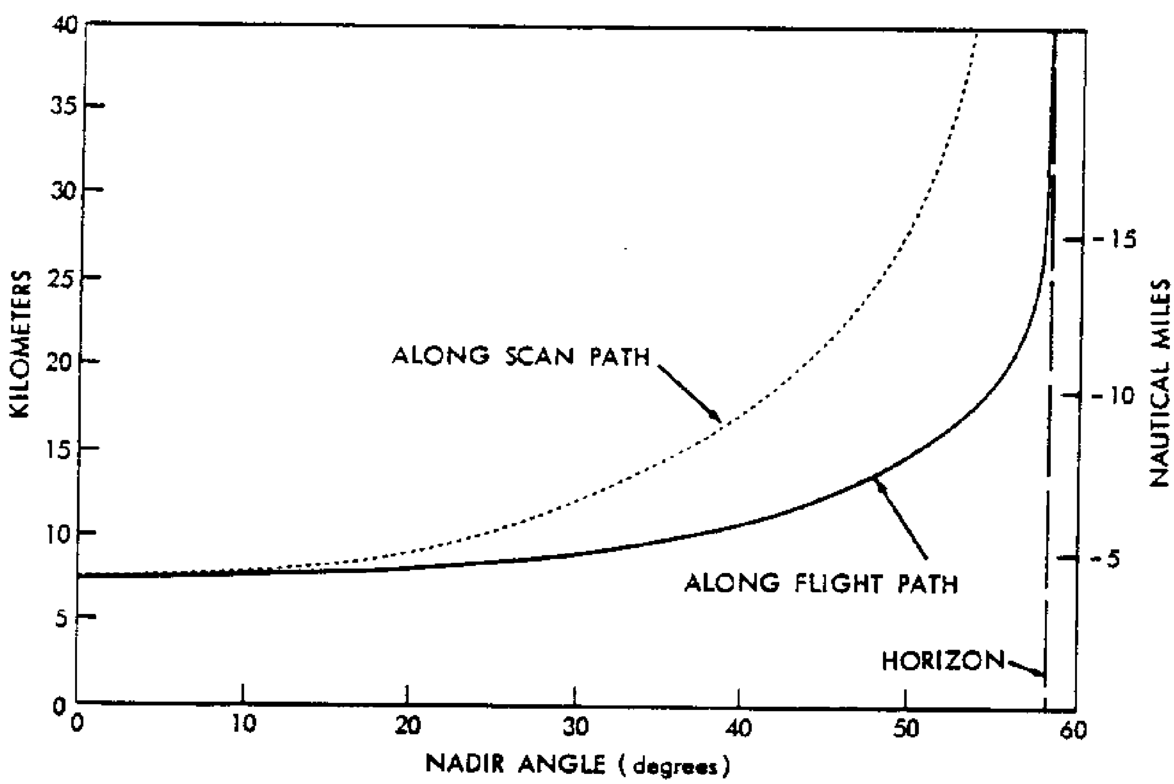
Some data from the THIR are available in digital form while all the data are available in photo-facisimili form.

Table T.1.4.1.1.a Characteristics of the NIMBUS-5 Temperature-Humidity Infrared Radiometer (THIR)

Spectral Range (micrometers)	6.5 - 7.0	10.5 - 12.5
IFOV (milliradians)	21.	7.
Ground Resolution @ Nadir (kilometers)	22.6	7.7
Ground Resolution @ $\pm$ 50° (kilometers)	93.5 x 41.1	31.8 x 14.0
Rotation Rate (rpm)	48	48
Scan Line Separation @ Nadir (meters)		contiguous
Sample Rate $(\text{seconds})^{-1}$		
Pixel Separation @ Nadir (meters)		
FOV (degrees)	117	117
Swath width (kilometers)		



(a)



(b)

Figure F.1.4.1.1.a . Relationship between Nadir Angle and Ground Resolution for the THIR 11.5 μm Channel at 1100 km (a) Pictorial (b) Graphical*

*From The NIMBUS-5 User's Guide, Page 20

1.4.1.2 Surface Composition Mapping Radiometer (SCMR)

This was a three channel instrument (see Table T.1.4.1.2.a), operating in the visible to thermal infrared region. Two of the channels were designed to sense emitted terrestrial radiation between 8.3 and 9.3 μm and between 10.2 to 11.2 μm. The third channel was designed to view the .8 to 1.1 μm interval. During night time only the two channels in the thermal infrared region were used. During daylight hours any two of the three channels could be used, the actual selection being made in real time.

Two dimensional coverage of the ground was achieved by a rotating mirror scanning across the satellite suborbital track as discussed in Chapter II. The spatial resolution of each channel of the instrument was on the order of 660 x 660 meters or .6 x .6 milliradians. The rotation rate of the mirror was 600 rpm and the total useful field of view extended approximately 400 km to each side of the nadir track for a total swath width of 800 km.

The 8.3 to 9.3 μm channel was selected for geological reasons primarily to separate acidic from basic rocks.

Table T.1.4.1.2.a Characteristics of the NIMBUS-5 Surface Composition Mapping Radiometer (SCMR)

Spectral Range (micrometers)	.8 - 1.1	8.3 - 9.3	10.2 - 11.2
IFOV (milliradians)	.6	------------------------>	
Ground Resolution @ Nadir (meters)	660	------------------------>	
Ground Resolution @ Swatch Edge (meters)			
Rotation Rate (rpm)	600	------------------------>	
Scan Line Separation @ Nadir (meters)	contiguous	------------------------>	
Sample Rate $(\text{seconds})^{-1}$			
Pixel Separation @ Nadir (meters)			
FOV (degrees)			
Swath Width (kilometers)	800	------------------------>	

1.4.1.3 Electrically Scanning Microwave Radiometer (ESMR)

Most radiometers are mechanically scanned, a rotating reflector directing the received radiance onto the detectors. ESMR operated differently. In this case, scanning was performed electronically. The receiving microwave antenna consisted of 103 wave guide elements. The output of each wave guide was phase shifted, thus altering the effective path length from the source to the given antenna element. This had the effect of defining the direction in which the antenna looked without altering the position of the antenna. In the case of ESMR, the relative phase shifts were adjusted in discrete steps by computer, thus steering the beam position. The beam was steered in 78 discrete steps from 50° off nadir on one side of the spacecraft to 50° off nadir on the other side. One scan was repeated every 4 seconds. At nadir the beam spot was approximately 1.4° x 1.4° while at the swath edge it was about 2.2° x 1.4°, the longer dimension being across track. These angular dimensions correspond to about 25 km x 25 km at nadir and 160 km x 45 km at swath edge. (See Tables T.1.4.1.3.a and T.1.4.1.3.b).

The microwave receiver was sensitive to a center frequency of about 19.4 GHz or a wavelength of about 1.6 cm. The instrument was passive in nature.

Table T.1.4.1.3.a Characteristics of the NIMBUS-5 Electrically Scanning Microwave Radiometer (ESMR)

Spectral Range (GHz)	19.225 - 19.475
IFOV (degrees)	1.4
Ground Resolution @ Nadir (kilometers)	25
Ground Resolution @ Swath Edge (kilometers)	160 x 45
Time for one Scan (seconds)	4
Scan Line Separation @ Nadir (meters)	
Sample Rate $(\text{seconds})^{-1}$	.05
Pixel Separation @ Nadir (degrees)	1.28
FOV (degrees)	100^{o}
Swath Width (kilometers)	

Table T.1.4.1.3.b NIMBUS-5 ESMR Flight Model Parameters*

Antenna	
Aperture Size (Linear Array Dimension)	83.3 cm (32.80 in.)
Aperture Size (Feed Array Dimension)	85.5 cm (33.66 in.)
Number of Linear Elements	103
Number of Slots per Element	81
Amplitude Distribution (Linear Array)	−40 db sidelobe Taylor distribution
Amplitude Distribution (Feed Array)	−35 db sidelobe Taylor distribution
Broadside Half Power Beamwidth	1.4°
Number of Beam Positions	78
Antenna Beam Efficiency	90 to 92.7%
Beam Scan Angle	±50°
Antenna Loss	1.7 db
Beam Squint Angle	−3.2° nominal
Polarization	Linear E vector (parallel to flight direction)
Cross Polarization	−25 to −36 db
Failsafe Angle (Non-Scanning Mode)	−13.7°
VSWR	<1.15

Radiometer	
Center Frequency	19.35 GHz
Bandwidth IF (Nominal)	50 − 150 MHz
Bandwidth RF (Nominal)	300 MHz
Local Oscillator	19.35 GHz
Mixer Noise Figure	6.5 db
T_{rms}/47 ms.	1.5K
Absolute Accuracy	2°K
Dynamic Range	50 − 330°K
Calibration:	
Dicke Load	338 ±0.1°K
Ambient Load	Local ambient
Sky Horn	<3°K

*From The NIMBUS-5 User's Guide, page 95

1.4.1.4 The Infrared Temperature Profile Radiometer (ITPR)

ITPR was a scanning radiometer with seven spectral channels spread over the infrared portion of the spectrum. The objective of this radiometer was to provide three dimensional information on the earth's atmosphere. The field of view, scanning 35.1° to each side of nadir with ground resolution ranging upward from 35 km, provided coarse resolution of atmospheric radiance on a global scale at least once every 24 hours. Scanning was achieved by a stepping mirror, making 140 1.8° steps. The actual construction and operation of the instrument was quite complex with six Cassagranian arc telescopes operating on three different grids.

Tables T.1.4.1.4.a and T.1.4.1.4.b and Figure F.1.4.1.4.a summarize the attributes of this sensor. The reader, however, is cautioned that these numbers are presented here only to guide him in the approximate characteristics of this complex instrument.

The ITPR was calibrated by an internal reference controlled at 37.8° ± 0.2°C. The spectral channels chosen to map the three dimensional temperature distribution were comprised of two channels in two atmospheric windows, one at 3.7 μm, the other at 11 μm, four channels in the carbon dioxide band near 15 μm and one channel in the rotational water vapor absorption band near 20 μm.

Table T.1.4.1.4.a Characteristics of the NIMBUS-
Infrared Temperature Profile Radiometer (ITPR)

Spectral Range (micrometers)	.321 - .44	10.7 - 11.6	13.1 - 13.7	13.7 - 14.4
IFOV (degrees)	1.45	------------>	------------>	------------>
Ground Resolution @ Nadir (kilometers)	34.8	------------>	------------>	------------>
Ground Resolution @ Swath Edge (meters)				
Rotation Rate (rpm)				
Scan Line Separation @ Nadir (kilometers)	39.4	------------>	------------>	------------>
Sample Rate $(\text{seconds})^{-1}$	.4	------------>	------------>	------------>
Pixel Separation (degrees)	1.8	------------>	------------>	------------>
FOV (degrees)	70.2	------------>	------------>	------------>
Swath Width (kilometers)	1690	------------>	------------>	------------>

Table T.1.4.1.4.a (Continued) Characteristics of the NIMBUS-5 Infrared Temperature Profile Radiometer (ITPR)

Spectral Range (micrometers)	14.2 - 14.8	14.8 - 15.1	16.9 - 23.6
IFOV (degrees)	1.45 ------------------------------------>		
Ground Resolution @ Nadir (kilometers)	34.8 ------------------------------------>		
Ground Resolution @ Swath Edge (meters)			
Rotation Rate (rpm)			
Scan Line Separation @ Nadir (kilometers)	39.4 ------------------------------------>		
Sample Rate $(seconds)^{-1}$	.4 ------------------------------------>		
Pixel Separation @ Nadir (kilometers)	1.8 ------------------------------------>		
FOV Degrees)	70.2 ------------------------------------>		
Swath Width (kilometers)	1690 ------------------------------------>		

Table T.1.4.1.4.b NIMBUS-5 ITPR Optical Unit Design Summary*

Type of Instrument:	Multi-channel filter radiometer Cassegrainian before optics and refractive after optics.
Field of View:	Circular half power 1.45°, Circular 97% 1.84°; scans 35.1° each side of nadir.
Optical Design Summary:	Programmed object scan mirror 25 Hz earth-chopper reference reflective chopper. Cassegrainian fore optics, refractive aft optics. TGS pyro-electric detectors. Approximately 19.8 inches long, 10.25 inches wide and 10.75 inches high, not including sun shields. Weight of 20 pounds.
Calibration:	Internal ambient blackbody reference surfaces and space.

ITPR Spectral Characteristics

Channel	Central Wave No. (cm^{-1})	Half Bandwidth (cm^{-1})	NEN (mw/m^2 sr cm^{-1})
1	2683	430	0.004
2	899.0	39.5	0.192
3	747.0	17.2	0.192
4	713.8	17.0	0.192
5	689.5	15.2	0.187
6	668.3	5.3	0.500
7	507.3	84	0.195

*From The NIMBUS-5 User's Guide, page 109

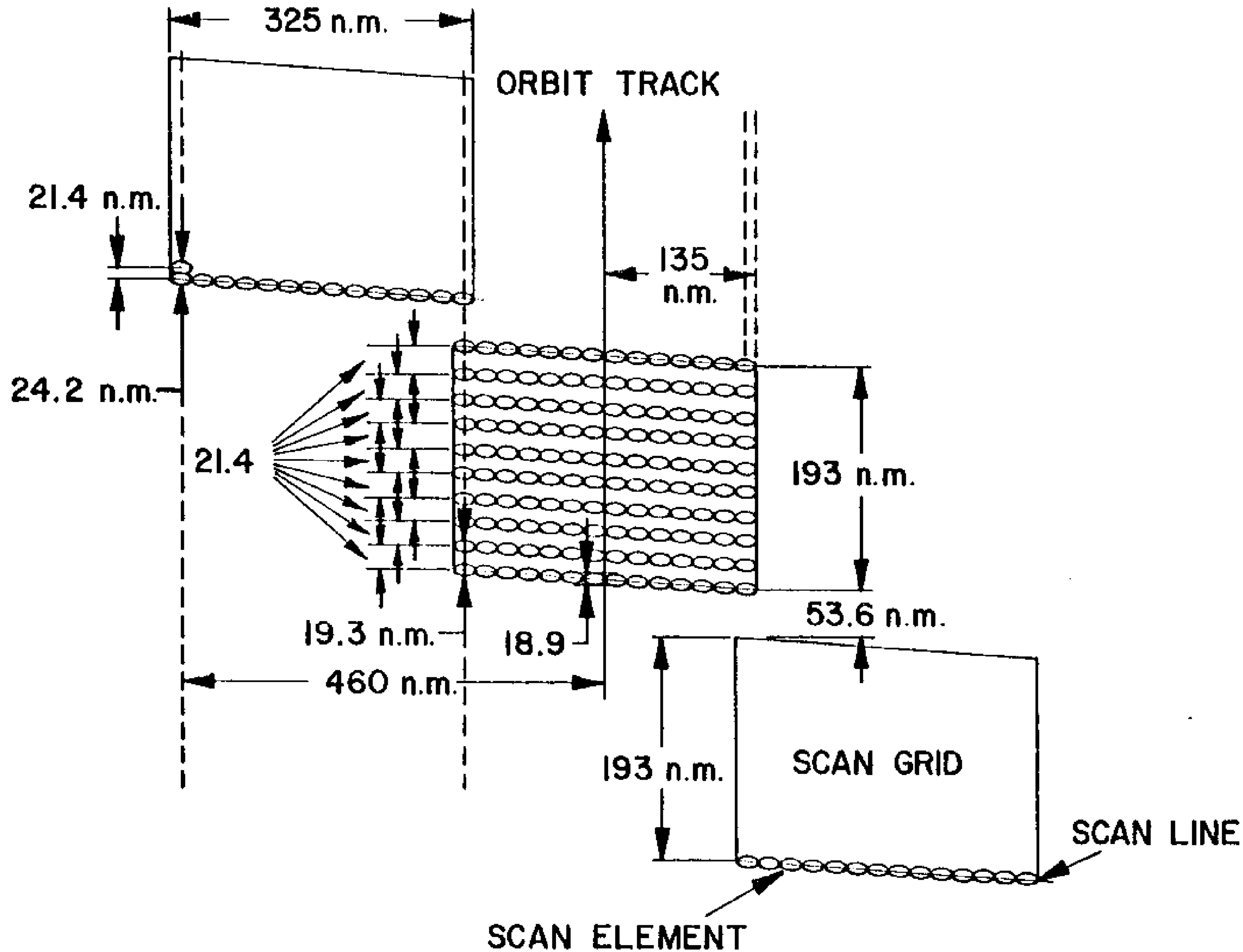


Figure F.1.4.1.4.a . The ITPR Scan-Grid Pattern*

*From The NIMBUS 5 User's Guide Page [illegible]

1.4.1.5 The Selective Chopper Radiometer (SCR)

The Selective Chopper Radiometer was a nonimaging instrument with 16 spectral bands in the infrared portion of the spectrum (See Tables T.1.4.1.5.a and T.1.4.1.5.b). The radiometer was, as are most radiometers in the infrared, self calibrating, i.e., the instrument contained an internal reference as well as being designed to permit views of deep space. Eight of the channels were within the 15 μm carbon dioxide band, three channels were situated in three window regions, 11.6 μm, 3.6 μm and 3.3 μm. Of the remaining 4 channels, 3 were at longer wave lengths ranging from about 18 μm to 90 μm while one defined a spectral band at shorter wave lengths. The thermal resolution of the detectors themselves were in the .1° K range.

All 16 channels viewed the same vertical column of atmosphere but at slightly different times. This was made possible by a reflecting mirror which was tilted backward as each new radiometer recorded data and then the mirror took a giant step forward and the process was repeated. Actually the filter wheel included in the sensor made the action a little more complicated than this. The time between successive "scans" was four seconds. The sensor viewed the atmosphere only along the nadir track with a spatial resolution upwards of 23 km.

Table T.1.4.1.5.a Characteristics of the NIMBUS-5 Selective Chopper Radiometer (SCR)

	Channel 1	2	3	4	5 - 8
Spectral Range (micrometers)	14.8-15.2	14.3-14.7	14.0-14.3	13.5-14.0	14.9-15.0
IFOV (degrees)	1.5	------------>			
Ground Resolution @ Nadir (meters)					
Ground Resolution @ Swath Edge (meters)	Approximately Nadir looking ------------>				
Rotation Rate (rpm)					
Scan Line Separation @ Nadir (meters)					
Sample Rate (seconds)$^{-1}$	.25	------------>			
Pixel Separation @ Nadir (meters)					
FOV (degrees)					
Swath Width (kilometers)					

Table T.1.4.1.5.a (continued) Characteristics of the NIMBUS-5 Selective Chopper Radiometer

	Channel			
	9	10	11	12
Spectral Range (micrometers)	<90.9	45.5-54.3	18.2-19.1	10.5-13.0
IFOV (degrees)	1.5	------------------------>		
Ground Resolution @ Nadir (meters)				
Ground Resolution @ Swath Edge (meters)	Approximately Nadir looking ------>			
Rotation Rate (rpm)				
Scan Line Separation @ Nadir (meters)				
Sample Rate $(\text{seconds})^{-1}$	.25	------------------------>		
Pixel Separation @ Nadir (meters)				
FOV (degrees)				
Swath Width (kilometers)				

Table T.1.4.1.5.a (continued) Characteristics of the NIMBUS-5 Selective Chopper Radiometer

	Channel			
	13	14	15	16
Spectral Range (micrometers)	2.6-2.7	2.6-2.7	2.3>	3.5-3.6
IFOV (degrees)	2.2	------------------------>		
Ground Resolution @ Nadir (meters)				
Ground Resolution @ Swath Edge (meters)	Approximately	Nadir	looking	-------->
Rotation Rate (rpm)				
Scan Line Separation @ Nadir (meters)				
Sample Rate $(seconds)^{-1}$	.25	------------------------>		
Pixel Separation @ Nadir (meters)				
FOV (degrees)				
Swath Width (kilometers)				

Table T.1.4.1.5.b

Channel Characteristics of SCR Flight Instrument†

Channel Designation	Center cm^{-1}	Width at half transmission cm^{-1}	Filter type	path length mm	pressure CO_2 mb	Total pressure including He mb	*** f	Typical op for 21°C counts	rms noise	
									counts	(ΔT_n) °K **
A1	668.5	9.0	DHW					950	1.2	0.15
A2	688.5	9.0	DHW					741	0.7	0.11
A3	707.4	9.3	DHW					634	0.5	0.08
A4	726.5	12.6	DHW					626	1.2	0.2
B1	668.2	3.4	FP	3	0	13	1	447	1.2	0.3
B2	668.2	3.4	FP	3	40	49	0.89	442	1.0	0.2
B3	668.2	3.4	FP	3	95	103	0.81	483	1.4	0.3
B4	668.2	3.4	FP	3	310	325	0.64	390	1.4	0.4
C1	110*		MESH					686	1.8	0.6
C2	202	18	2nd order FP MESH					295	1.9	1.2
C3	536.4	13.3	DHW					895	0.7	0.1
C4	859	89	DHW					1232	TELEMETRY LIMITED	0.1
D1	3710	72	DHW					414	9	0.4
D2	3805	100	DHW					330	9	0.5
D3	4260(*10%)							113	9	1.5
D4	2817	50	DHW					283	9	0.7

* edge filter: number is position of edge.

** defined so that the rms noise at the output is equivalent to change in signal which would occur from a blackbody source near 250°K (channels A, B, C) or 291°K (channel D) if its temperature changed by ΔT_n K.

*** defined by equation (2).

† From The NIMBUS-5 User's Guide, Page 132

1.4.1.6 NIMBUS-E Microwave Spectrometer (NEMS)

NEMS was a nadir viewing, nonimaging microwave spectrometer with a spatial resolution of about 180 km. The objective of the sensor was to provide information about atmospheric humidity and cloud water content over oceans, snow cover, ice type, soil moisture, etc.

NEMS integrated the radiation in each of 3 spectral bands near the 5mm oxygen resonance and two bands near the 1.35 cm water vapor resonance (See Tables T.1.4.1.6.a and T.1.4.1.6.b). The first set of three bands were designed primarily to measure atmospheric temperature while the last two to measure water vapor and liquid water. The location of the 5 mm bands was such that each had an associated weighting function that peaked at a different altitude in the atmosphere, thus allowing for some vertical resolution of the temperature profile. The accuracy of the temperature measurements after calibration was in the 1° K range. The water vapor measurements were made to an accuracy of approximately .1 gm/cm^2 and clouds with approximately .04 gm/cm^2.

Table T.1.4.1.6.a Characteristics of the NIMBUS-5 NIMBUS-E Microwave Spectrometer (NEMS)

	Channel				
	1	2	3	4	5
Spectral Range (GHz)	22.235	31.4	53.65	54.9	58.8
IFOV (degrees)	10	-->			
Ground Resolution @ Nadir (kilometers)	180	-->			
Ground Resolution @ Swath Edge (meters)	------------ Nadir viewing only ---------------->				
Rotation Rate (rpm)	------------ Nadir viewing only ---------------->				
Scan Line Separation @ Nadir (meters)					
Sample Rate (seconds)$^{-1}$	.5	-->			
Pixel Separation @ Nadir (meters)					
FOV (degrees)	10	-->			
Swath Width (kilometers)	180	-->			

Table T.1.4.1.6.b

NEMS Characteristics as of June, 1972*

	SPEC	R 1	R 2	R 3	R 4	R 5
Frequency (MHz) (to be updated)	±5	22,235	31,400	53,650	54,900	58,800
RF Bandwidth (MHz)	220	250	250	250	250	250
Integration Time (sec)	> 1.9	1.9962	1.9962	1.9962	1.9962	1.9962
ΔT_{rms} (°K) (outside antenna)	< 1.0/1.5	0.24	0.23	0.29	0.29	0.24
Dynamic Range, Linearity (50-400°K) %	100-325°K < 0.1	< 0.05	< 0.05	< 0.05	< 0.05	< 0.05
Absolute Accuracy (°K_{rms}) Long Term	< 2.0	1 E	1 E	2 E	1 E	2 E
IF Frequency Range (MHz)	10-110	10-110	10-110	10-110	10-110	10-110
Antenna Beamwidth (deg)	10	10	10	10	10	10
Antenna Beam Efficiency, within 14° (%)	> 90	95	94	94	93	95
Cal Temperature Below Ambient (°C)	>80/60	81-92	81-92	73-87	73-87	73-87

E = Estimated

*From The NIMBUS-5 User's Guide, Page 149

1.4.2 Additional Information for NIMBUS-5

A user's guide for the NIMBUS-5 spacecraft is available from:

National Space Sciences Data Center
Code 601
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

The document is called:

THE NIMBUS 5 USER'S GUIDE. Edited by Romeo R. Sabatini. Published by the ERTS/NIMBUS Project. Goddard Space Flight Center, NASA, Greenbelt, Maryland

1.4.3 Data Availability

The following description of NIMBUS-5 data archival and dissemination has been abstracted from the NIMBUS-5 USER'S GUIDE, pages 9 and 10. It should be kept in mind that this description was written prior to the launch of NIMBUS-5, hence may have been modified when the data actually became available. Furthermore most of these data were collected in the mid 70's and may no longer be stored in the same format or available in the same fashion. The primary reason for including this here is to provide a starting point for the user who may be interested in these data.

Archival and Dissemination of NIMBUS-5 Data

The nature and format of the data to be available from each experiment are explained in detail in the respective sections of this guide. The data will be archived and available as described below:

- Photographic data from THIR and ESMR will be archived and available through the National Space Science Data Center (NSSDC), Goddard Space Flight Center, Code 601, Greenbelt, Maryland 20771.

- Digital data tapes from THIR, SCR, ESMR and NEMS will be archived and available through the NSSDC.
- Availability of photographic and digital SCMR data will be through the experimenter, Dr. Warren Hovis, Code 652, Goddard
- Space Flight Center, Greenbelt, Maryland 20771. ITPR digital data tapes will be available in three different formats from three different agencies:

  i) Archival tapes containing the calibrated, located radiances, and a minimum of auxiliary information will be available from NSSDC.

  ii) Archival tapes containing atmospheric temperature profiles and the corresponding radiances and earth locations will be at the National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite Service (NESS), FOB4, Suitland, Maryland 20023.

  iii) Archival tapes containing the ITPR derived temperature profiles used in the National Meterorological Center's (NMC) operational forecasts will be available from the National Climatic Center (NCC), NOAA, Federal Building, Asheville, North Carolina 28801.

ITPR data will be available from the NCC at cost. Limited quantities of all other data will be furnished to qualified investigators, by the NSSDC, without charge. A charge for production and dissemination costs may be established by NSSDC if a large volume of data is requested. Whenever it is determined that a charge is required, a cost estimate will be provided to the user prior to filling his data request.

All requests from foreign researchers for Nimbus-5 data archived and available through NSSDC must be specifically addressed to:

Director, World Data Center A for Rockets and Satellites
Code 601, Goddard Space Flight Center
Greenbelt, Maryland 20771, U.S.A.

When ordering data from either the NSSDC or the World Data Center, a user should specify why the data are needed, the subject of his work, the name of the organization with which he is connected, and any government contracts he may have for performing his study.

When a user requests data on magnetic tapes, he should provide additional information concerning his plans for using the data, e.g., what computers and operating systems will be used. In this context, the NSSDC can provide data tapes with physical characteristics which are appropriate for the user's computer. NSSDC will provide, upon request, information concerning its services.

When requesting data on magnetic tape, the user must specify whether he will:

- Supply new tapes prior to the processing, or
- Return the original NSSDC tapes after the data have been copied

1.5 NIMBUS-6 Satellite

The objectives of the NIMBUS-6 mission are conveniently divided into three primary groups: a) meteorological research; b) earth radiation budget observations; and c) communications and tracking. The last two are of little interest in remote sensing of the oceans. The first group is of interest in two areas of research related to oceanography; a) the atmosphere/ocean relationship and b) the effect that the atmosphere has on measurements of the oceans made from spacecraft. For these reasons those sensors that have atmospheric applications will be discussed in more detail here. It should be noted at the outset that the experimental nature of these sensors means that a) their resolution is often quite coarse, b) there may not be a similar sensor flown on a later spacecraft and c) the data may be difficult to obtain or to read once obtained, if in digital form.

The specific objectives of this satellite were to:

i) Achieve a major milestone in the global atmospheric research program.

ii) Develop and demonstrate techniques for environmental monitoring.

iii) Extend vertical sounding capability to the upper stratosphere and to develop new sounding techniques.

iv) Measure large scale atmospheric motion.

v) Measure sea ice, snow cover, surface roughness, moisture and liquid water content of clouds.

vi) Measure the synoptic and planetary earth radiation budget.

vii) Develop new technology in the field of low-orbiting satellite communication and tracking.

1.5.1 NUMBUS-6 Sensor Objectives

THIR (Temperature-Humidity Infrared Radiometer) Section 1.4.1.1

- To provide day/night cloud top or surface temperatures
- To give information on the moisture content of the upper troposphere and stratosphere and the location of jet streams and frontal systems.

ESMR (Electrically Scanning Microwave Radiometer) Section 1.5.1.1

- To derive the liquid water content of clouds
- To observe differences between sea ice and the open sea over the polar caps.

HIRS (High Resolution Infrared Radiation Sounder) Section 1.5.1.2

- To provide vertical temperature profiles twice daily on a global basis to an altitude of 40 km.
- To provide information on the water vapor distribution in the troposphere

SCAMS (Sounding Microwave Spectrometer) Section 1.5.1.3

- To map topospheric temperature profiles, water vapor abundance and cloud water content, to be used for weather prediction purposes.

LRIR (Limb Radiance Inversion Radiometer) Not covered here

- To provide calibrated radiance versus altitude profiles used to calculate global temperature and water vapor profiles in the stratosphere and lower mesosphere.

PMR (Pressure Modulated Radiometer) Not covered here

- To determine the temperature structure of the upper stratosphere and lower mesosphere

ERB (Earth Radiation Budget) Not covered here

- To measure reflected and emitted terrestrial radiation fluxes in conjunction with solar radiation. From these measurements the following are deduced: Earth radiation budget

  Angular dependence of terrestrial radiation

TWERLE (Tropical Wind Energy Conversion and Reference Level Experiment) Not covered here

- To measure upper atmospheric winds over Remote Regions
- To study the relative air motion along isobaric surfaces
- To provide direct measurements of various meteorological parameters

T&DRE (Tracking and Data Relay) Not covered here

- To gain information on the use of a satellite, ATS, ground link for range and rate communications.

1.5.1.1 Electrically Scanning Microwave Radiometer (ESMR)

Most radiometers are mechanically scanned, a rotating reflector directing the received radiance onto the detectors. ESMR operated differently. In this case, scanning was done electronically. The receiving microwave antenna consisted of 103 wave guide elements. The output of each wave guide was phase shifted, thus altering the effective path length from the source to the given antenna element. This had the effect of defining the direction in which the antenna looked without altering the position of the antenna. In the case of ESMR, the relative phase shifts were adjusted in discrete steps by computer, thus steering the beam position. The beam was steered along a conical surface making a 45^{o} angle with nadir in 71 discrete steps. This scan was performed in azimuth $\pm$ 35^{o} from the forward direction from nadir. One scan was repeated every $5^{1}/3$ seconds. In azimuth the angular resolution varied from $.95^{o}$ where the beam crossed the satellite subtrack to 1.17^{o} at the ends of the scan. The angular resolution in elevation ranged from 1.0^{o} at the satellite subtrack to $.84^{o}$ at the swath edge. These angular ranges gave a spatial resolution at the surface of approximately 20x50 km (cross track and down track).

The microwave receiver was sensitive to a center frequency of about 37 GHz or a wavelength of about 0.81 cm with a bandwidth of 250 MHz. The instrument was passive. (See Table T.1.5.1.1.a)

One will note some similarities and several significant diferences when comparing the NIMBUS-6 with the NIMBUS-5 ESMR (Section 1.4.1.3). The primary difference was the frequency to which the sensor responded. The change in frequency was designed to increase the sensitivity of the ESMR to water droplets, the NIMBUS-6 sensor being approximately three times as sensitive as the one on NIMBUS-5. The scanning geometry was also quite different.

Table T.1.5.1.1.a Characteristics of the NIMBUS-6 Electrically Scanning Microwave Radiometer (ESMR)

	Channel 1
Spectral Range GHz	37.±.125
IFOV (degrees)	1
Ground Resolution along subtrack (kilometers)	20 x 50
Ground Resolution @ Swath Edge (kilometers)	20 x 50
Scan Lines Per Minute	11.3
Scan Line Separation @ Nadir (meters)	
Sample Rate $(seconds)^{-1}$	13.3
Pixel Separation @ Nadir (meters)	
FOV (degrees)	
Swath Width (kilometers)	1200

1.5.1.2 High Resolution Infrared Radiation Sounder (HIRS)

HIRS was an improved version of the NIMBUS-5 ITPR (see section 1.4.1.4). The spectral channels of the HIRS were designed to obtain vertical temperature profiles, surface temperatures, water vapor profiles and cloud coverage. The channel wave lengths, principal absorbing constituents, and purpose of observation for each of the channels is summarized in Tables T.1.5.1.2.a to T.1.5.1.2.c. The spatial resolution in the horizontal was on the order of 25 km at nadir. The instrument scanned in 42 discrete steps perpendicular to the nadir track, 21 steps to each side of nadir. Each location was observed for 71 ms. As with most sensors viewing in the infrared region, this sensor was calibrated in flight both with an internal reference and views of space.

Table T.1.5.1.2.a Characteristics of the NIMBUS-6 High Resolution Infrared Radiation Sounder (HIRS)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	14.6-15.3	14.4-15.1	13.4-14.8	14.0-14.5	13.7-14.2
IFOV (degrees)	1.24	----------->			
Ground Resolution @ Nadir (kilometers)	23.8x23.8	----------->			
Ground Resolution @ Swath Edge (kilometers)	31.3x44.8	----------->			
Rotation Rate (rpm)					
Scan Line Separation @ Nadir (kilometers)	30.6	----------->			
Sample Rate (seconds)$^{-1}$	9.4	----------->			
Pixel Separation @ Nadir (degrees)	1.8	----------->			
FOV (degrees)	75.3	----------->			
Swath Width (kilometers)	1821	----------->			

Table T.1.5.1.2.a (continued) Characteristics of the NIMBUS-6 High Resolution Infrared Radiation Sounder (HIRS)

	Channel 6	7	8	9	10
Spectral Range (micrometers)	13.4-13.9	13.1-13.6	11.0-11.2	8.12-8.23	6.66-6.71
IFOV (degrees)	1.24	------------------------------------>			
Ground Resolution @ Nadir (kilometers)	23.8x23.8	------------------------------------>			
Ground Resolution @ Swath Edge (kilometers)	31.3x44.3	------------------------------------>			
Rotation Rate (rpm)					
Scan Line Separation @ Nadir (kilometers)	30.6	------------------------------------>			
Sample Rate $(seconds)^{-1}$	9.4	------------------------------------>			
Pixel Separation @ Nadir (degrees)	1.8	------------------------------------>			
FOV (degrees)	75.3	------------------------------------>			
Swath Width (kilometers)	1821	------------------------------------>			

Table T.1.5.1.2.a (continued) Characteristics of the NIMBUS-6 High Resolution Infrared Radiation Sounder (HIRS)

	Channel 11	12	13	14	15
Spectral Range (micrometers)	4.56-4.58	4.51-4.53	4.45-4.47	4.37-4.40	4.24-4.25
IFOV (degrees)	1.24	--------------------------------------->			
Ground Resolution @ Nadir (kilometers)	23.8x23.8	--------------------------------------->			
Ground Resolution @ Swath Edge (kilometers)	31.3x44.8	--------------------------------------->			
Rotation Rate (rpm)					
Scan Line Separation @ Nadir (kilometers)	30.6	--------------------------------------->			
Sample Rate $(seconds)^{-1}$	9.4	--------------------------------------->			
Pixel Separation @ Nadir (degrees)	1.8	--------------------------------------->			
FOV (degrees)	75.3	--------------------------------------->			
Swath Width (kilometers)	1821	--------------------------------------->			

Table T.1.5.1.2.a (continued) Characteristics of the NIMBUS-6 High Resolution Infrared Radiation Sounder (HIRS)

	Channel 16	Channel 17
Spectral Range (micrometers)	3.71-3.72	.6927-.6924
IFOV (degrees)	1.24	-------->
Ground Resolution @ Nadir (kilometers)	23.8x23.8	-------->
Ground Resolution @ Swath Edge (kilometers)	31.3x44.8	-------->
Rotation Rate (rpm)		
Scan Line Separation @ Nadir (kilometers)	30.6	-------->
Sample Rate $(\text{seconds})^{-1}$	9.4	-------->
Pixel Separation @ Nadir (degrees)	1.8	-------->
FOV (degrees)	75.3	-------->
Swath Width (kilometers)	1821	-------->

Table T.1.5.1.2.b

Functions of the HIRS Channels*

Channel Number	Channel Central Wave-number	Central Wavelength (μm)	Principal Absorbing Constit-uents	Level of Peak Energy Contri-bution	Purpose of the Radiance Observation
1 2 3 4 5 6 7	668 679 690 702 716 733 749	15.0 14.7 14.4 14.2 14.0 13.6 13.4	CO_2 CO_2 CO_2 CO_2 CO_2 CO_2/H_2O CO_2/H_2O	30 mb 60 mb 100 mb 250 mb 500 mb 750 mb 900 mb	Temperature Sounding. The 15 μm band channels provide better sensitivity to the temperature of relatively cold regions of the atmosphere than can be achieved with the 4.3 μm band channels. Radiances in Channels 5, 6, and 7 are also used to calculate the heights and amounts of cloud within the HIRS field of view.
8	900	11.0	Window	Surface	Surface Temperature and cloud detection.
9 10	1224 1496	8.2 6.7	H_2O H_2O	900 mb 400 mb	Water Vapor Sounding. Provide water vapor corrections for CO_2 and window channels. The 6.7 μm channel is also used to detect thin cirrus cloud.
11 12 13 14 15	2190 2212 2242 2275 2357	4.57 4.52 4.46 4.40 4.24	N_2O N_2O CO_2/N_2O CO_2/N_2O CO_2	950 mb 850 mb 700 mb 600 mb 5 mb	Temperature Sounding. The 4.3 μm band channels provide better sensitivity to the temperature of relatively warm regions of the atmosphere than can be achieved with the 15 μm band channels. Also, the short-wavelength radiances are less sensitive to clouds than those for the 15 μm region.
16	2692	3.71	Window	Surface	Surface Temperature. Much less sensitive to clouds and H_2O than 11 μm window. Used with 11 μm channel to detect cloud contamination and derive surface temperature under partly cloudy sky conditions.
17	14,443	0.69	Window	Cloud	Cloud Detection. Used during the day with 3.7 μm and 11 μm window channels to define clear fields of view and to specify any reflected solar contributions to the 3.7 μm channel.

*From The NIMBUS-6 User's Guide, Page 39

Table T.1.5.1.2.c

Summary of HIRS Optical Parameters*

Type of Instrument	Multi-channel filter radiometer, Cassegrainian telescope before the filter wheel/chopper assembly. Dichroic and refractive elements between this point and the detectors.
Detector summary	Two cooled detectors at 120°K: LnSe for six short wave IR channels, HgCdTe for ten long wave IR channels. One (300°K) Si detector for the visible channel.
Signal treatment	The signal through each filter is sampled for an integral number of cycles (between 1 and 7 cycles depending on the filter). The rectified signal is integrated over the integral number of cycles, beginning and ending at a positive peak in signal amplitude. The output voltage is digitized to 12 bits, plus a sign bit and a parity bit. Thus the maximum digital range of the output is ±4095 bits in all channels.
Commands	There are 9 bits available for command status.
Field of View	Circular, half amplitude separation 1.24 degrees. Scans to 36.9 degrees from nadir across the point tract, with 21 steps along a scan line on each side of nadir (42 total).
Calibration	Two internal blackbody sources (at 270°K and 300°K), and space. Calibration approximately every 90 seconds (every twenty scan lines).

Channel	Characteristics					
Channel Number	Central Wave Number (cm^{-1})	Interval Between 50% Response Points (cm^{-1})	Noise Equivalent Radiance ($mw/m^{-2} ster\ cm^{-1}$)		Noise Equivalent Temperature (NEΔT) Source Temp. = 290°K	
			T_D = 118°K	T_D = 124°K	T_D = 118°K	T_D = 124°K
1	668	2.8	3.0	6.0	1.90	3.80
2	679	13.7	0.66	1.5	0.41	0.94
3	690	12.6	0.45	0.75	0.28	0.47
4	702	15.9	0.27	0.44	0.17	0.27
5	716	17.5	0.52	0.85	0.32	0.52
6	733	17.6	0.23	0.38	0.14	0.23
7	749	18.4	0.27	0.42	0.16	0.26
8	900	34.6	0.19	0.30	0.12	0.19
9	1224	63.4	0.15	0.24	0.14	0.23
10	1496	87.6	0.13	0.19	0.21	0.31
11	2190	20.6	0.012	0.012	0.13	0.13
12	2212	22.5	0.003	0.003	0.04	0.04
13	2242	21.6	0.006	0.006	0.08	0.08
14	2275	35.2	0.002	0.002	0.03	0.03
15	2357	23.0	0.003	0.003	0.06	0.06
16	2692	296.9	0.001	0.001	0.06	0.06
17	14,443	892.2	–	–	–	–

*From The NIMBUS-6 User's Guide, Page 40

1.5.1.3 The Scanning Microwave Spectrometer (SCAMS)

SCAMS was an advanced version of the NIMBUS-5 NEMS (Section 1.4.1.6), the main difference being that SCAMS scanned perpendicularly to the suborbital track while NEMS observed only at nadir. SCAMS provided global maps of tropospheric temperature profiles and, over oceans, liquid water and water vapor in the atmosphere every 12 hours. The spatial resolution for such coverage was necessarily coarse, 144 km near nadir and 212x361 km at the scan edge. (See Figure F.1.5.1.3.a)

The instruments' five spectral channels were located near the water vapor line at 22 GHz (1.36 cm), near the atmospheric window at 32 GHz (1 cm) and near the oxygen band at 54 GHz (5 mm). (See Tables T.1.5.1.3.a and T.1.5.1.3.b). The scanning mechanism was similar to that of most other scanners, a reflector in front of each antenna stepped across the scene as the satellite advanced. Data were recorded from 43° on one side of nadir to 43° on the other side of nadir in 13 steps, each separated by 7.2°. The instrument was calibrated once for each scan line using an internal reference and outer space.

Table T.1.5.1.3.a Characteristics of the NIMBUS-6 Scanning Microwave Spectrometer (SCAMS)

	Channel 1	2	3	4	5
Spectral Range (GHz)	22.231	31.650	52.863	53.845	55.445
IFOV (degrees)	7.5	------------------------------------>			
Ground Resolution @ Nadir (kilometers)	144	------------------------------------>			
Ground Resolution @ Swath Edge (kilometers)	211x361	------------------------------------>			
Scan Lines per Minute	3.75	------------------------------------>			
Scan Line Separation @ Nadir (meters)					
Sample Rate $(seconds)^{-1}$					
Pixel Separation (degrees)	7.2	------------------------------------>			
FOV (degrees)	93.9	------------------------------------>			
Swath Width (kilometers)	2618	------------------------------------>			

Table T.1.5.1.3.b NIMBUS-6
SCAMS Flight Model Performance Characteristics*

Characteristics	Tolerance	Channel 1	2	3	4	5
Frequency (GHz)	+5	22.235	31.650	52.350	53.850	55.450
	Measured	22.231	31.650	52.863	53.845	55.445
RF Bandwidth (MHz)	+30, -10	220	220	220	220	220
Integration Time (ms)	±5	950	950	950	950	950
T_{rms} (°k/sec) (including antenna loss)	Max	1.0	1.0	1.5	1.5	1.5
	Measured	0.2	0.2	0.6	0.5	0.5
Dynamic Range (°K)	±20	0-350	0-350	0-350	0-350	0-350
Absolute Accuracy (°K rms) (Long Term)	Max	2.0	2.0	2.0	2.0	2.0
IF Frequency Range (MHz)	±10	10-110	10-110	10-110	10-110	10-110
	Measured	6-117	7-114	8-118	7-120	7-122
Antenna Beamwidth(deg)	±0.2	7.5	7.5	7.5	7.5	7.5
	Measured	7.5	7.5	7.6	7.5	7.4
Antenna Beam Efficiency (%)(within 10 deg. of center)	Measured	97.3	97.3	96.9	97.1	97.4

*From The NIMBUS-6 User's Guide, pages 60-61

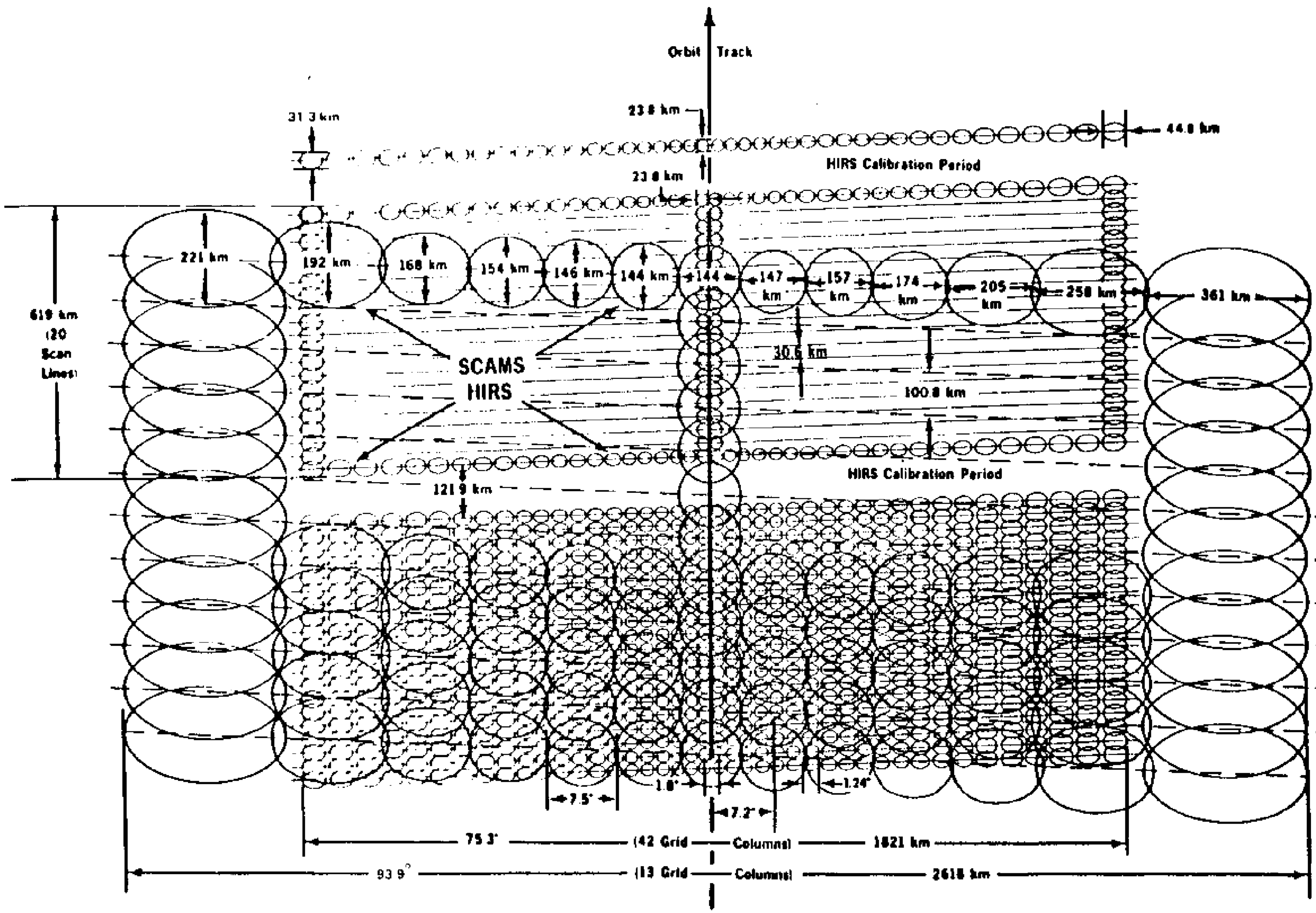


Figure F.1.5.1.3.a • Scan Grid Patterns for HIRS and SCAMS*

*From The NIMBUS-6 User's Guide, Page 44

1.5.2 Additional Information for NIMBUS-6

A user's guide for the NIMBUS-6 spacecraft is available from:

National Space Sciences Data Center
Code 601
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

The document is called:

The NIMBUS-6 USER'S GUIDE, Edited by John E. Sissala, Published by the ERTS/NIMBUS Project, Goddard Space Flight Center, NASA Greenbelt, Maryland

1.5.3 Data Availability

The following description of NIMBUS-6 data archival and dissemination has been abstracted from the NIMBUS 6 USER'S GUIDE, pages 7 to 9. It should be kept in mind that this description was written prior to the launch of NIMBUS-6, hence may have been modified when the data actually became available. Furthermore, most of these data were collected in the mid 70's and may no longer be stored in the same format or available in the same fashion.

Archival and Dissemination of NIMBUS-6 Data

Each experimenter is responsible for setting up a procedure to process the data from his experiment and produce archival products. As data are archived they are delivered to the NSSDC where they are used as the source for generating Nimbus-6 user products. Each Nimbus-6 Data Catalog will announce the quantity of data from each experiment archived and available at the NSSDC. This data availability list will be updated to the time of each catalog's publication date.

The nature and format of the data to be available from each experiment are explained in detail in the respective section of this guide.* The data will be archived and available as described below:

*This guide refers to the NIMBUS-6 USER'S GUIDE.

- Photographic data from ESMR, HIRS, SCAMS, and THIR will be archived and available through the National Space Science Data Center (NSSDC), Code 601, Goddard Space Flight Center, Greenbelt, Maryland 20771.

- Digital data tapes from ERB, ESMR, HIRS, LRIR, PMR, SCAMS, and THIR will be archived and available through NSSDC. Archival tapes of ERB and HIRS data also will be available through the National Oceanic and Atmospheric Administration (NOAA), National Environmental Satellite Service (NESS), World Weather Building, 5200 Auth Road, Marlow Heights, Maryland 20023, Attention Dr. W.L. Smith.

- Archived LRIR tapes also will be available through the National Center for Atmospheric Research, P.O. Box 3000, Boulder, Colorado 80303, Attention Dr. John C. Gille.

- TWERLE balloon data will be available through the above NCAR address, Attention Dr. Paul R. Julian. Users who desire other TWERLE information or data should write directly to the appropriate experimenter listed in Table 9-2 of this guide*.

- Since T&DRE is not a data gathering experiment but an experiment of a new method of relaying data, nothing is archived at the NSSDC. The divisions of GSFC processing and evaluating the data also store these data. Users who desire more information or data from the T&DRE should write to: Mr. Bernard J. Trudell, Tracking and Data Relay Experiment Manager, Code 953, Goddard Space Flight Center, Greenbelt, Maryland 20771.

The NSSDC will furnish limited quantitites of data to qualified investigators without charge. The NSSDC may establish a charge for production and dissemination if a large volume of data is requested. Whenever a charge is required, a cost estimate will be provided to the user prior to filling his data request.

All requests from foreign researchers for NIMBUS-6 data archived and available through NSSDC must be specifically addressed to:

Director, World Data Center A for Rockets and Satellites
Code 601, Goddard Space Flight Center
Greenbelt, Maryland 20771, U.S.A.

When ordering data from either the NSSDC or the World Data Center, a user should specify why the data are needed, the subject of his work, the name of the organization with which he is connected, and any government contracts he may have for performing his study. Of course, each request should specify the experiment data desired, the day and area of interest, plus any other information that would facilitate the handling of the data request.

A user requesting data on magnetic tapes should provide additional information concerning his plans for using the data, e.g., what computers and operating systems will be used. In this context, the NSSDC can provide data tapes with physical characteristics which are appropriate for the user's computer. NSSDC will provide, upon request, information concerning its services.

When requesting data on magnetic tape, the user must specify whether he will supply new tapes prior to the processing, or return the original NSSDC tapes after the data have been copied.

1.6 NIMBUS-7 Satellite

NIMBUS-7 is of particular interest to oceanographers because two of its sensors, SMMR and CZCS, are devoted to observing oceanographic parameters. In particular, the CZCS, data of which is just now becoming available, is the only satellite borne sensor designed to measure upwelling radiance from the water in the visible portion of the spectrum. SMMR is similarly designed to measure upwelling radiance from the water, but in the microwave. The SEASAT-1 spacecraft carried an identical SMMR. Both the SMMR and CZCS were functional at the writing of this document.

NIMBUS-7 is in a six-day repeat cycle for world coverage.

1.6.1 NIMBUS-7 Sensor Objectives

THIR (Temperature-Humidity Infrared Radiometer) Section 1.6.1.1

- To measure the infrared radiation from the earth in two spectral bands day and night for:

  Cloud cover

  3-d maps of cloud cover

  Temperature mappings of cloud, land and ocean surfaces

  Cirrus cloud content, contamination and relative humidity.

CZCS (Coastal Zone Color Scanner) Section 1.6.1.2

- To map chlorophyll concentrations, sediment distribution, gelbstoffe (as a salinity indicator) and temperature.

SMMR (Scanning Multichannel Microwave Radiometer) Section 1.6.1.3

- To obtain ocean momentum and energy transfer parameters on a nearly all-weather operational basis.

ERB (Earth Radiation Budget) Not covered here

- To determine over a period of a year the earth radiation budget on both synoptic and planetary scales.

LIMS (Limb Infrared Monitor of the Stratosphere) Not covered here

- To survey on a global scale selected gases which may affect the earth's environment.

SAMS (Stratospheric And Mesospheric Sounder) Not covered here

- To measure the vertical concentration of H_2O, N_2O, CH_4, CO and NO in the stratosphere and mesosphere.
- To measure the temperature to 90 km.

SAM II (Stratospheric Aerosol Measurement II) Not covered here

- To map concentration and optical properties of stratospheric aerosols as a function of altitude, latitude and longitude.

SBUV/TOMS (Solar Backscatter Ultraviolet and Total Ozone Mapping Spectrometer) Not covered here

- To measure the incident solar UV radiation and the UV radiation backscatter from the earth.
- To examine the extraterrestrial solar spectrum and the earth radiance spectrum.

1.6.1.1 The Temperature-Humidity Infrared Radiometer (THIR)

The NIMBUS-7 THIR is a two channel scanning radiometer (see Chapter II for a brief generic description of a scanning radiometer) designed to measure cloud top and surface temperatures day and night and to provide information on the location of water vapor in the atmosphere. The instrument design is identical to that of the NIMBUS-5 (Section 1.4.1.1) and NIMBUS-6 THIR. The discussion of the operation of this instrument is repeated here because of additional information in the NIMBUS-7 User's Guide. The sensor's first objective is met by the thermal channel in the 10.5 to 12.5 µm range with a nadir resolution of 7 km. The second objective, water vapor measurements, is met by a channel in the 6.5 to 7.0 µm range with a 20 km nadir resolution. (See Figure F.1.6.1.1.a). Another way of representing the resolution is by the channel's instantaneous field of view, IFOV. For the thermal channel this is 7 milliradians (mr) while for the water vapor channel it is about 20 mr. (See Tables T.1.6.1.1.a and T.1.6.1.1.b).

The scanning mirror of the instrument rotates at 48 rpm or 1.25 seconds per revolution. In that time the satellite advances approximately 8 km thus oversampling the 6.5 to 7.0 µm channel. The detector views the in-flight black box calibration during the back part of each scan, i.e., as the mirror rotates it views the earth, then outer space, then the in-flight calibration (built into the instrument housing), outer space and then the earth again, etc. This provides a calibration signal on each scan.

Some data from the THIR are available in digital form while all the data are available in photo-facisimili form.

Table T.1.6.1.1.a Characeristics of the NIMBUS-7 Temperature-Humidity Infrared Radiometer (THIR)

	Channel 1	Channel 2
Spectral Range (micrometers)	6.5-7.0	10.5-12.5
IFOV (milliradians)	20	7
Ground Resolution @ Nadir (kilometers)	20x20	6.7x6.7
Ground Resolution @ 50° (kilometers)	36x75	12.4x23.9
Rotation Rate (rpm)	48	48
Scan Line Separation @ Nadir (kilometers)		8
Sample Rate $(\text{seconds})^{-1}$		850
Pixel Separation (degrees)		.34
FOV (degrees)	118.2	118.2
Swath Width @ ± 50° (kilometers)	2610	2610

Table T.1.6.1.1.b

THIR Subsystem Specifications*

Design Parameter	Channel 1	Channel 2
Wavelength Band of Operation (Half Power Points (microns))	6.5 to 7.0	10.5 to 12.5
Field-of-View (mrad)	20	7
Ground Resolution (Subsatellite Point at 955 Km) (Km)	20	6.7
Collecting Aperture (cm^2)	110	110
Detector (Immersed Bolometer)		
Size (mm)	0.67 x 0.67	0.22 x 0.22
Time Constant (msec)	2.7	1.8
Scan Rate (rps)	0.8	0.8
Dwell Time (msec)	4.2	1.4
Information Bandwidth (Hz)	115	345
Dynamic Range (Target Temperature) (°K)	0 to 270	0 to 330
Performance Characteristics	**Channel 1**	**Channel 2**
Noise Equivalent Irradiance (NEI) ($watts/cm^2$)	4.35×10^{-10}	3.0×10^{-10}
Noise Equivalent Temperature Differential (NETD) at Indicated Scene Temperature	5.0°K @ 185°K 0.26°K @ 300°K	1.5°K @ 185°K 0.28°K @ 300°K
S/N Ratio at Indicated Scene Temperature	3.8:1 @ 185°K 110:1 @ 270°K	19:1 @ 185°K 375:1 @ 330°K
Physical Characteristics	**Scanner**	**Electronics Module**
Weight (lbs)	14.0	6.0
Size (in.)	7.5 x 7.1 x 15.7 (Excluding sunshield)	7.0 x 6.8 x 6.0
Power Requirements	**Scanner**	**Electronics**
-24.5 vdc (watts)	1.8	5.8
100-Hz Two-Phase Square Wave 5.25 V (watts/phase)	0.1	
Operating Temperature Range	0° to 45°C	

*From The NIMBUS-7 User's Guide, Page 249

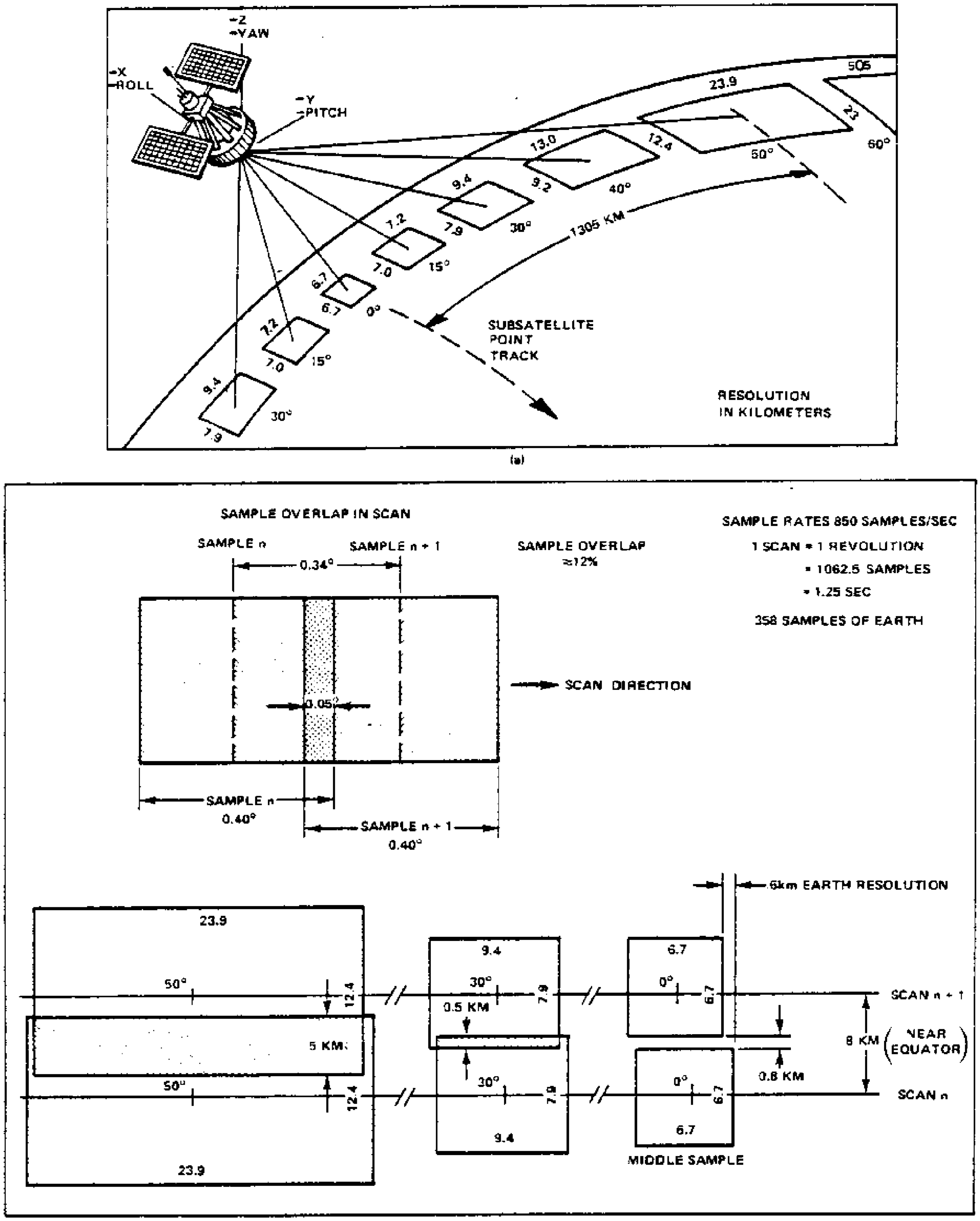


Figure F.1.6.1.1.a Relationship Between Ground Resolution and a Scan Sample with a 0.40° x 0.40° FOV for the THIR 11.5 μm Channel at 955 Km*

*From The NIMBUS-6 User's Guide, Page 256

1.6.1.2 Coastal Zone Color Scanner (CZCS)

The NIMBUS-7 Coastal Zone Color Scanner has as its primary mission the quantification of the chlorophyll concentration in the near-surface waters. It is with this major objective in mind that five visible spectral bands were selected. (Tables T.1.6.1.2.a and T.1.6.1.2.b). In addition to these bands there is one thermal IR band coregistered with the visible bands, i.e., the same optical system is used to collect the upwelling radiation. Mechanically this scanner is quite similar to scanners described previously, making use of a rotating plane mirror at a 45^o angle to the optical axis. The total field of view is $\pm$ 40^o or 80^o, i.e., the mirror reflects radiation onto the radiometer for angles less than 40^o to either side of nadir. This covers a ground swath of about 783 km on each side of the satellite suborbit when the tilt angle is set to 0^o (Figure F.1.6.1.2.a).

Because NIMBUS-7 is an R&D satellite with many experiments aboard there is not sufficient power to run all of these experiments simultaneously. For this reason the CZCS operates approximately two hours per day in two minute segments. The areas over which the scanner collects data is determined by the NIMBUS Experiment Team (NET) and depends on the relevant importance of the area, supporting ground truth measurements, etc. The visible channels only collect data during daylight while the thermal IR channel is able to collect data day and night.

Unlike most other multispectral scanners, the CZCS has the additional feature of a ground controlled tilt of the instrument axis relative to nadir. This tilt is possible only in the plane of the orbit, i.e., either forward or backward relative to the spacecraft line of flight. The tilt angle can be as much as 20^o in either direction the increment being 2^o.

The primary purpose of the tilt is to allow the sensor to avoid sun glint as its objective is to "see" into the water column.

Each of the first four spectral bands also has separate (ground controlled) gain settings. This feature is present to allow for the compensation of varying solar illuminations as the satellite circles the globe.

Some of the other special features of the scanner worth noting are:

i) The very narrow spectral range of the visible channels

ii) Thermal resolution .25°C - this mainly because of the limited thermal range

iii) DC offset control for the radiometers

iv) Change in swath from 1577 km (full swath) to 700 km (narrow swath).

Given the flexibility of the instrument and the fact that the parameters described in the previous two paragraphs are ground controlled the user must exercise great caution in dealing with these data. In addition to the complications associated with these settings the user is also advised that the numbers for tilt, for example, supplied with the data are only approximations, i.e., a given tilt of 20° may have a bias associated with it yielding a tilt actually corresponding to 20.5°.

Table T.1.6.1.2.a Characteristics of the NIMBUS-7 Coastal Zone Color Scanner (CZCS)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	.433-.453	.510-.530	.540-.560	.660-.680	.700-.800
IFOV (milliradians)	.865	-->			
Ground Resolution+ @ Nadir (kilometers)	.825	-->			
Ground Resolution @ Swath Edge (meters)					
Rotation Rate (rpm)					
Scan Line Separation @ Nadir (kilometers)	.617	-->			
Sample Rate $(\text{seconds})^{-1}$					
Pixel Separation @ Nadir (meters)					
FOV (degrees)	78.68	-->			
Swath Width (kilometers)	1566	-->			

+ for zero tilt of the scan mirror

Table T.1.6.1.2.a (continued) Characteristics of the NIMBUS-7 Coastal Zone Color Scanner (CZCS)

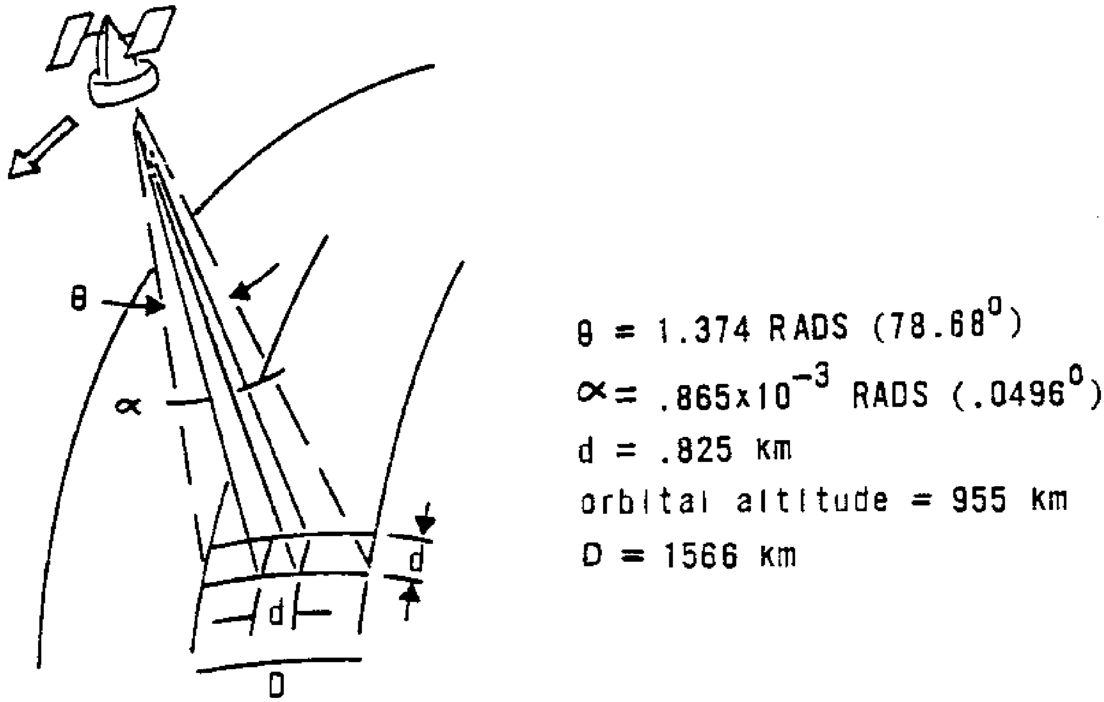
	Channel 6
Spectral Range (micrometers)	10.5-12.5
IFOV (milliradians	.865
Ground Resolution @ Nadir (kilometers)	.825
Ground Resolution @ Swath Edge (meters)	
Rotation Rate (rpm)	
Scan Line Separation @ Nadir (kilometers)	.617
Sample Rate $(seconds)^{-1}$	
Pixel Separation @ Nadir (meters)	
FOV (degrees)	78.68
Swath Width (kilometers)	1566

Table T.1.6.1.2.b

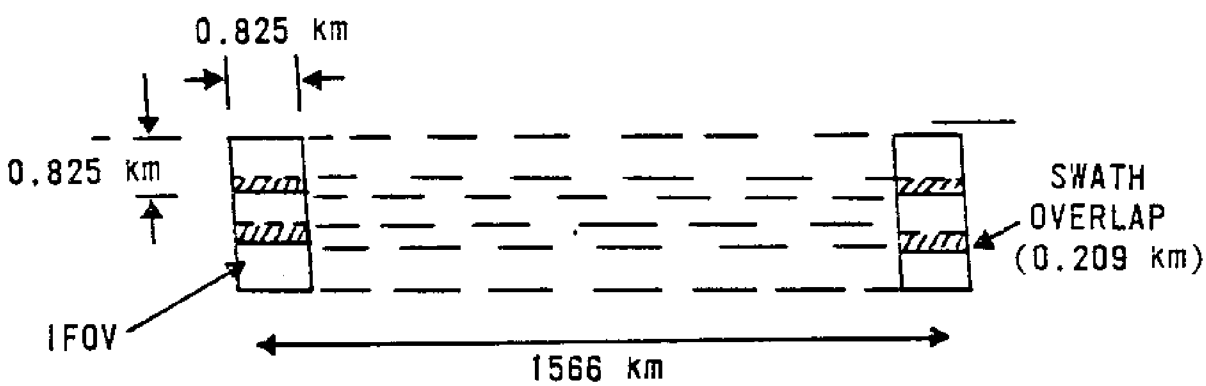
CZCS Performance Parameters*

Performance Parameters	Channels					
	1	2	3	4	5	6
Scientific Observation	Chlorophyll Absorption	Chlorophyll Correlation	Yellow Stuff	Chlorophyll Absorption	Surface Vegetation	Surface Temperature
Center Wavelength λ Micrometers	0.443 (blue)	0.520 (green)	0.550 (yellow)	0.670 (red)	0.750 (far red)	11.5 (infrared)
Spectral Bandwidth Δλ Micrometers	0.433 – 0.453	0.510 – 0.530	0.540 – 0.560	0.660 – 0.680	0.700 – 0.800	10.5 – 12.5
Instantaneous Field of View (IFOV)	← 0.865 x 0.865 Milliradians (0.825 x 0.825 km at sea level) →					
Co-registration at NADIR	<0.15 Milliradians					
Accuracy of Viewing Position Information at NADIR	<2.0 Milliradians					
Signal to Noise Ratio (min.) at Radiance Input N < (mW/cm^2 · STER · μm)	>150 at 5.41	>140 at 3.50	>125 at 2.86	>100 at 1.34	>100 at 10.8	NETD of 0.220°K at 270°K
Consecutive Scan Overlap	25%					
Modulation Transfer Function (MTF)	1 at 150 km target size, 0.35 min. at 0.825 km target size					

*From The NIMBUS-7 User's Guide, Page 24



CZCS SCANNING ARRANGEMENT



ACTIVE SCAN ANGLE = 78.68°

Figure F.1.6.1.2.a CZCS Viewing Geometry and Earth Scan Pattern*

*From The NIMBUS-7 User's Guide Page 22

1.6.1.3 Scanning Multichannel Microwave Radiometer (SMMR)

The SMMR was designed to provide sea surface temperature and near-surface winds over the world's oceans on a daily basis. Because it is a microwave instrument it is capable of sensing these parameters in all but the most severe weather.

SMMR has no direct spaceborne predecessor although in some respects it resembles the NIMBUS-6 SCAMS. Also, an identical instrument was flown on SEASAT-1. It is a 10 channel passive microwave instrument, the ten channels consisting of two polarization components at each of five wavelengths. Scanning is achieved by rotating a microwave reflector in front of the receiving antenna. Unlike many other mechanical scanning instruments the axis about which the reflector is rotated is aligned with the vertical. In this fashion the sensor "looks" at the earth's surface with approximately the same angle of incidence, about 50°, at all points along the scan, i.e., the instrument scans along a conical surface. This means that the spatial resolution of the scanner is roughly independent of position along the scan.

The spatial resolution of the SMMR following processing into geophysical parameters ranges from squares about 150 km on a side for the 4.6 cm (6.6 GHz) channels to squares approximately 30 km on a side for the .81 cm (37 GHz) channels. The temperature resolution ranges from about .9° C for the channels at 4.6 cm to about 1.5° C for the .81 cm channels.

There is an operational restriction on SMMR similar to the one on the CZCS, again resulting from spacecraft power limitations. In this case the instrument is constrained to a 50% duty cycle, operating every other day. This provides for global coverage every six days.

Table T.1.6.1.3.a Characteristics of the NIMBUS-7 Scanning Multichannel Microwave Radiometer (SMMR)

	Channel 1	2	3	4	5
Spectral Range (GHz)	6.6±.12	10.69±.12	18.0±.12	21.0±.12	37.0±.12
IFOV (degrees)	4.2	2.6	1.6	1.4	.8
Ground Resolution* (kilometers)	97.5	97.5	60	60	30
Ground Resolution @ Swath Edge		Conical scan same everywhere			
Rotation Rate (rpm)	14.64	-->			
Scan Line Separation @ Nadir	overlap	-->			
Sample Rate $(seconds)^{-1}$					
Pixel Separation @ Nadir (meters)					
FOV (degrees)					
Swath Width (kilometers)					

* Ground Resolution after processing by NASA

Table T.1.6.1.3.b

SMMR Performance Characteristics†

Parameter	Channel				
	1	2	3	4	5
Wavelength (cm)	4.54	2.8	1.66	1.36	0.81
Frequency (GHz)	6.6	10.69	18.00	21.00	37.00
R-F Bandwidth (MHz)	250	250	250	250	250
Integration Time (ms) (approximate)	126	62	62	62	30
I-F Frequency Range (MHz)	10-110	10-110	10-110	10-110	10-110
Dynamic Range (°K)	10-330	10-330	10-330	10-330	10-330
Absolute Accuracy (°K rms)	<2.0	<2.0	<2.0	<2.0	<2.0
Temperature Resolution, ΔTrms (°K) (per IFOV)*	0.9	0.9	1.2	1.5	1.5
Antenna Beam Width (±0.2°)	4.2	2.6	1.6	1.4	0.8
Antenna Beam Efficiency (percent)	87.0	87.0	87.0	87.0	87.0
Scan Cycle ±0.4 rad (±25°)/second**	4.096	4.096	4.096	4.096	4.096
Double Sideband Noise (dB) (maximum)	5.0	5.0	5.0	5.0	5.0

*IFOV are remapped to form equal sized cells (150, 90, 50km) across the swath prior to retrieval of geophysical parameters; the ΔT rms's are correspondingly lower.

**Add 2 ms (used for integer dump) for complete IFOV cycle time.

†From The NIMBUS-7 User's Guide, Page 215

1.6.2 Additional Information for NIMBUS-7

As with the previous NIMBUS satellites, a user's guide for NIMBUS-7 has been written. This user's guide is available from the:

National Space Sciences Data Center
Code 601
NASA/Goddard Space Flight Center
Greenbelt, Maryland 20771

The document is called:

The NIMBUS-7 USERS' GUIDE, Edited by Charles R. Madrid, Published by Landsat/Nimbus Project, Goddard Space Flight Center, NASA, Greenbelt, Md.

1.6.3 Data Availability

The following description of data archival and dissemination of NIMBUS-7 data has been abstracted from pages 15 to 17 of the NIMBUS-7 USERS' GUIDE. The table numbering scheme has been altered to agree with that of this document. Furthermore the user is advised that much of the data are just now becoming available, well after the two to six months quoted below.

Data Archiving

The NIMBUS-7 archival data products distribution is accomplished after the individual Nimbus Experiment Teams have validated the data. [This validation process is expected to take from two to six months after launch, depending on the experiment and the type of anomalies that may arise during the initial checkout phase.]

Listed in Table T.1.6.3.a are the film data products available to all users. Table T.1.6.3.b provides the same information for tape data products. All products except for CZCS, are

* The expression in brackets has proven to be false but is included here as part of the original quote.

Table T.1.6.3.a

Film Data Products Available Through EDIS and NSSDC.*

Archival Data Center	Sensor	Reproducible Copy Is:	User Copy Will Be:
EDIS	CZCS	2nd generation 241 mm (9.5") black and white negative transparency.	a. 241 mm black and white positive or negative transparency. b. 241 mm black and white positive print.
NSSDC	ERB, SAM II, LIMS, SBUV/ TOMS, SAMS	2nd generation 16 mm negative (black background) transparency.	a. 16 mm positive transparency. b. 241 mm hard copy (in limited quantity).
	TOMS (montage)	2nd generation 241 mm black and white negative transparency.	a. 241 mm black and white positive or negative transparency. b. 241 mm black and white positive print.
	SMRR (all data)	2nd generation 35 mm color positive transparency.	a. 35 mm color slide. b. color prints – maximum size 203 mm x 254 mm (8" x 10").
	THIR (montage)	2nd generation 241 mm black and white negative transparency.	a. 241 mm black and white positive or negative transparency.

*From The NIMBUS-7 User's Guide, Page 16

Table T.1.6.3.b

Tape Types Available Through EDIS and NSSDC*

Archival Data Center	Sensor	Tape Name	Tape Quantity per Year	PDFC	Tape Spec. No.
EDIS	CZCS	CRCST	5500	ZB	T749021
		CAT	12	ZC	T749031
NSSDC	ERB	MATRIX	12	AA	T134031
		MAT	365	AC	T134081
		SEFDT	12	AD	T134021
		ZMT	2	AE	T134091
	LIMS	MATRIX-M	14	EA	T564041
		MATRIX-C	14	EB	T564081
		PROFILE-R	7	EC	T564111
		PROFILE-I	21	ED	T564071
		RAT	210	EE	T564011
		IPAT	105	EF	T564021
		MAT	70	EG	T564051
		CAT	70	EH	T564091
		SMAT	7	EI	T564101
		SCAT	7	EM	T564121
	SAMS	MATRIX	24	HA	T884011
		RAT	180	HC	T884041
	SAM II	MATRIX	4	DA	T454021
		PROFILE	12	DB	T454011
		RDAT	12	DC	T454041
		BANAT	12	DD	T454051
	SBUV/TOMS	MATRIX	24	FA	T634071
		MONTAGE	52	FC	T634081
		RUT-S	26	FD	T634111
		OZONE-S	12	FE	T634041
		OZONE-T	180	FF	T634091
		ZMT	2	FH	T634061
		RUT-T	120	FJ	T634121
	SMMR	MAP-30	12	BD	T234051
		MAP-LO	12	BE	T234101
		MAP-SS	12	BF	T234111
		PARM-30	60	BG	T234041
		PARM-LO	30	BH	T234121
		PARM-SS	30	BI	T234131
		TAT	183	BJ	T234021
		CELL-ALL	61	BK	T234071
	THIR	CLDT	730	ID	T344011
		CLE	53	IE	T343031
		CLT	104	IF	T343041

*From The NIMBUS-7 User's Guide, Page 17

CZCS, are archived by the National Space Science Data Center (NSSDC). CZCS data are archived by the Environmental Data and Information Service (EDIS). The addresses of these agencies are:

- Satellite Data Services Division/
  Environmental Data and Information Service
  World Weather Building
  Room 100
  Washington, D.C. 20233

- National Space Science Data Center
  Goddard Space Flight Center
  Code 601
  Greenbelt Maryland 20771

In addition to the film and tape data products, EDIS will publish a CZCS catalog listing all available CZCS data. NSSDC will publish a meteorological catalog listing data from all meteorological satellites including tape and film output products from NIMBUS-7. To obtain copies of these catalogs, write to NSSDC or EDIS.

All requests from foreign researchers for NIMBUS-7 data archived and available through NSSDC must be specifically addressed to:

Director, World Data Center A for Rockets and
and Satellites
Code 601, Goddard Space Flight Center
Greenbelt, Maryland 20771, U.S.A.

When ordering data from either the NSSDC or the World Data Center, a user should specify why the data are needed, the subject of his work, the name of the organization with which he is connected, and any government contracts he may have for performing his study. Of course, each request should specify the experiment data desired, the day and area of interest, plus any other information that would facilitate the handling of the data request. Requests for specific tape types, as listed in Table T.1.6.3.b should specify the tape specification (last column in Table T.1.6.3.b). This number references a tape specification document describing the record and file content and word format of each tape type. A user receives a tape specification document for each requested tape type.

A user requesting data on magnetic tapes should provide additional information concerning his plans for using the data, e.g., what computers and operating systems will be used. In this context, the NSSDC can provide data tapes with physical characteristics which are appropriate for the user's computer. NSSDC will provide, upon request, information concerning its services.

When requesting data on magnetic tape, the user must specify whether he will supply new tapes prior to the processing, or return the original NSSDC tapes after the data have been copied.

CIVILIAN OPERATIONAL SUN-SYNCHRONOUS METEOROLOGICAL SATELLITES

The sun-synchronous or polar orbiting meteorological satellite has been the mainstay of the United States' satellite meteorological program since the early 1960's. Currently the third generation operational series is in use. In the early years of the program these were the only satellites used routinely for weather prediction. In the early 1970's, however, it became apparent that geostationary satellites could provide the increased temporal resolution required for weather prediction while the polar orbiting spacecraft could continue providing the higher resolution (both thermal and spatial) data. For this reason the National Environmental Satellite System was expanded in 1975 to include a second component, the operational geostationary satellite series, GOES. The first component of this system was the polar orbiting satellites. The objectives of the national environmental satellite system are "to provide global data on the Earth's environment regularly and reliably each day." The data consist primarily of cloud top temperature information as well as thermal profiles of the atmosphere. Oceanographic applications are gaining importance, however, with channels being added to the sensors to provide for better sea surface temperature definition; e.g., the 3.8 μm window on the TIROS-N series. Indeed, the NOAA's National Weather Service (NWS) and the National Earth Satellite Service (NESS) provide oceanographic analysis charts off the northeastern and western United States on a reglar basis using both polar orbiting and geostationary satellite data.

The orbital parameters for all of the operational sun-synchronous meteorological satellites flown to date are included in Table II.2. These orbital parameters are only approximate values not to be used for detailed satellite navigation, but rather as a general indication of the orbit.

Because their data are difficult to impossible to use in a quantitative fashion and because they date back to the 1960's, the first generation satellites, ESSA-1 to ESSA-9 will not be discussed. The TIROS-M or early NOAA (NOAA-1 to NOAA-5) series, the second generation, and the TIROS-N series, the third generation, will be discussed in detail.

Table II.2

OPERATIONAL METEOROLOGICAL SATELLITES (Civilian)

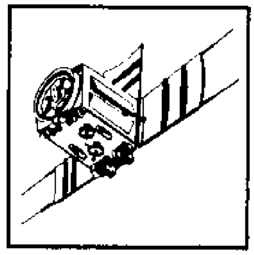
(Sun-Synchronous)

Satellite Name (alias)	Launch (Date)	Limit of Data Archive (Date)	Period (minutes)	Periopsis (km)	Apoapsis (km)	Inclination (Degrees)	Descending Node (Local Sun Time)
ESSA 1	2/3/66	6/6/66	100.3	800	965	97.9°	
2	2/28/66	†	113.5	1561	1639	101.0°	
3 (TOS-A)	10/2/66	6/1/67	114.5	1593	1709	101.0°	
4 (TOS-B)	1/26/67	†	113.4	1522	1656	102.0°	
5 (TOS-C)	4/20/67	12/3/68	113.6	1556	1635	102.0°	
6 (TOS-D)	11/10/67	†	114.8	1622	1713	102.1°	
7 (TOS-E)	8/16/68	3/31/69	114.9	1646	1691	101.8°	
8 (TOS-F)	12/15/68	†	114.6	1622	1682	101.4°	
9 (TOS-G)	2/26/69	11/15/72	115.2	1637	1730	101.8°	0343
ITOS-1 (TIROS-M)	1/23/70	6/17/71	115.0	1648	1700	102.0°	0349
NOAA-1 (ITOS-A)	12/11/70	6/20/71	114.8	1423	1472	101.9°	0308
Reconfigured TIROS-M							
NOAA-2 (ITOS-D)	10/15/72	3/19/74	114.9	1448	1454	101.7°	0844
3 (ITOS-F)	11/6/73	12/17/74	116.1	1500	1509	102.1°	0827
4 (ITOS-G)	11/15/74	9/15/76	114.9	1443	1457	101.7°	0835
5 (ITOS-H)	7/29/76	3/1/79	116.2	1502	1520	102.1°	0836

Table II.2 (cont'd)

Satellite Name (alias)	Launch (Date)	Limit of Data Archive (Date)	Period (minutes)	Periopsis (km)	Apoapsis (km)	Inclination (Degrees)	Descending Node (Local Sun Time)
TIROS-N	10/13/78	2/17/81	102.3	846	862	98.9°	0300
NOAA-6	6/27/79	present	101.5	833	833	98.7°	0730
NOAA-7	6/23/81	present	102.0	845	863	98.9°	0230

†ESSA -2, -4, -6 and -8 were Automatic Picture Transmission (APT) satellites; hence no negatives were archived.



2. The ITOS/NOAA Satellite Series - Second Generation, Civilian, Operational, Sun-Synchronous Meteorological Satellites

2.1 Objectives

i) To provide improved operational IR and visual observations of Earth cloud cover for use in weather analysis and forecasting.

ii) To provide both solar proton and global heat data on a regular daily basis.

2.2 General

The second generation, operational, sun-synchronous (polar-orbiting) meteorological satellite series has a number of different aliases. The prototype for the series was called TIROS-M. Therefore, some refer to the series as the TIROS-M series, more so recently with the launch of TIROS-N, the prototype of the third generation. The official designation for the series was the Improved TIROS-Operational Series or ITOS. The most commonly used names for the satellites in the series are, however, NOAA-1 to NOAA-5.

In addition to the various aliases, one is cautioned that not all the satellites in the series are identical. Twice during its approximate eight years of operational use, sensors were added, removed or modified. In particular:

ITOS-1 (TIROS-M) was the prototype for the second generation operational sun-synchronous meteorological spacecraft.

NOAA-1, the second in the ITOS series.

NOAA-2, a reconfigured ITOS spacecraft with additional sensors as well as missing some of the sensors on ITOS-1 and NOAA-1.

NOAA-3 to NOAA-5 are identical to NOAA-2 in terms of the type of instruments carried. Some of the instruments have been modified or improved as shown in Table T.2.2.a.

The NOAA polar orbiting satellites form one component of the NOAA polar satellite system. The components of this system are:

a. a single polar orbiting NOAA satellite.

b. an operating system that includes: Satellite Operations Control Center (SOCC), two Command and Data Acquisition (CDA) stations, a communications network, and a Central Processing Facility (DAPAF).

c. a direct broadcast service that transmits raw environmental data to local users within radio range of the satellite, and

d. a central service to transmit products derived from satellite data to the users.

Although an understanding of all components and how they interrelate is useful when ordering and dealing with the data, only the first, the satellites and their sensors, will be discussed here.

2.3 Orbital Characteristics for the ITOS/NOAA Series

The ITOS/NOAA satellites are in a near-polar, sun-synchronous orbit. A sun-synchronous orbit is one for which the orbit of the satellite "appears" to rotate around the earth at the same rate as the sun. The satellites are placed in one of two different orbital configurations: one with an ascending node (the time at which the satellite crosses the equator moving from south to north) at 1500, i.e., 3:00 PM, the other with a descending node at 0900 local suntime. The orbital plane is inclined at 101° to the equatorial plane in order to give the spacecraft the appropriate rate of precession to maintain a sun-synchronous orbit for an altitude of approximatley 1450 km. Each orbit crosses the equator approximately 28.8^{o} in longitude (about 3200 km) to the west of the previous orbit. At higher latitudes the spacing between successive passes decreases hence providing more frequent coverage from the same sensor.

Table T.2.2.a Instruments Flown On ITOS/NOAA Series

	Sensor Acronym						
Satellite Name	FPR	*SR	AVCS	APT	SPM	*VHRR	VTPR
ITOS-1 (TIROS-M)	1†	1	1	1			
NOAA 1 (ITOS-A)	1	1	1	1			
2 (ITOS-D)		1		1	1	1	1
3 (ITOS-F)		2†		1	1	1	1
4 (ITOS-G)		2		1	1	1	1
5 (ITOS-H)		2		1	2	2	1

Acronym	Definition
FPR	Flat Plate Radiometer
*SR	Scanning Radiometer
AVCS	Advanced Vidicon Camera System
APT	Automatic Picture Transmission
SPM	Solar Proton Monitor
*VHRR	Very High Resolution Radiometer
VTPR	Vertical Temperature Profile Radiometer

*Sensor of potential application to oceanographic or coastal problems. Described in greater detail in this paper.

†The numbers in the table represent the version of the sensor. A 1 indicates the first version flown on the TIROS-M series, and a 2 indicates a modified sensor.

2.4 TIROS-M (ITOS-1)

TIROS-M was the prototype for the second generation polar orbiting series satellites. Because it was operational in the early 70's, its data have not been saved in digital form and its sensors were of coarse spatial resolution. It will therefore not be discussed here.

2.5 NOAA-1 (ITOS-A)

This satellite was a duplicate of TIROS-M launched approximately 12 months after the prototype. It will not be discussed here for the same reasons that TIROS-M is not discussed.

2.6 NOAA-2 (ITOS-D)

NOAA-2, the third in the TIROS-M series, was made up of a substantially different suite of sensors compared to its predecessors. To begin with, two of the sensors flown on the first spacecraft were eliminated. But of more importance the Very High Resolution Radiometer (VHRR) was for the first time included on NOAA-2.

NOAA-2 was launched into a sun-synchronous orbit with an ascending node (south-to-north) equatorial crossing of 2100 local sun time.

2.6.1 NOAA-2 Instrument Objectives (see Table T.2.2.a)

SR (Scanning Radiometer) Section 2.6.1.1

- To determine surface temperatures of the ground, the sea and cloud tops.

VHRR (Very High Resolution Radiometer) Section 2.6.1.2

- To continuously measure surface temperatures of the earth, sea and cloud tops in daylight, as well as at night, and to transmit the temperature data in real time to Command and Data Acquisition (CDA) stations throughout the world for use in local weather forecasting.

VTPR (Vertical Temperataure Profile Radiometer) Section 2.6.1.3

- To measure the radiated energy from atmospheric CO_2, gross water content and surface cloud top temperatures. These measurments were to be used to compute the temperature - pressure profiles in the atmosphere to altitudes of 30 km.

SPM (Solar Proton Monitor) Not covered here

- To monitor the omnidirectional fluxes of solar protons and the directional fluxes of protons and alpha particles.

APT (Automatic Picture Transmission) Not covered here

- To automatically take wide-angle, slow scan TV pictures of the earth and its cloud cover.

2.6.1.1 NOAA-2 Scanning Radiometer (SR)

The NOAA-2 scanning radiometer was a two channel device, one channel covering the visible portion of the specturm from .5 to .7 μm and the other covering the thermal IR portion from 10.5 to 12.5 μm. (See Table T.2.6.1.1.a)

The Instantaneous Field of View (IFOV) in the thermal IR was 5.3 milliradians (mr) which at a nominal altitude of 1470 km yielded for the resolution of a ground element (pixel) at nadir (directly below the spacecraft) about 8.0 km. The separation at nadir of adjacent scan lines was approximately 6.4 km leading to a slight overlap of the 8 km pixels. Pixels near the swath edge (at 1450 km from nadir) measured 19.3 km by 12.9 km and significantly overlapped corresponding pixels in adjacent scan lines.

The IFOV for the visible detector was 2.8 mr, i.e., a ground resolution of about 3.2 km at nadir. Nadir pixels of the visible channel on adjacent scan lines were separated by 3.2 km. At approximately 1208 km from nadir the pixels touched and further from nadir they overlapped.

The SR scanned from horizon to horizon yielding a total field of view of approximately 120° or 2900 km. This provided for near continuous coverage at the equator where consecutive passes of the satellite were separated by 28.8° or about 3100 km. The sensor provided complete global coverage twice daily in the thermal IR and once daily in the visible.

Table T.2.6.1.1.a Characteristics of the NOAA-2

Scanning Radiometer (SR)

	Channel 1	Channel 2
Spectral Range (micrometers)	.5 - .7	10.5 - 12.5
IFOV (milliradians)	2.8	5.3
Ground Resolution @ Nadir (Kilometers)	3.2	7.4
Ground Resolution $\pm$ 60° (Kilometers)	6.4 x 12.9	12.9 x 19.3
Rotation Rate (rpm)	48	48
Scan Line Separation @ Nadir (Kilometers)	6.4	contiguous
Sample Rate (seconds)$^{-1}$		
Pixel Separation @ Nadir (meters)		
FOV (degrees)	120*	120
Swath Width (kilometers)	2900	2900

* Actually the FOV is somewhat greater than this. This range represents that required for contiguous coverage by successive orbits at the equator.

2.6.1.2 NOAA-2 Very High Resolution Radiometer (VHRR)

The VHRR (Table T.2.6.1.2.a), was a two channel scanning radiometer. Channel 1, the visible channel, responded to radiance with wavelengths ranging from .6 to .7 μm. The thermal IR channel covered most of the thermal IR window, 10.5 to 11.5 μm.

The instantaneous field of view, IFOV, was .6 mr in both channels yielding a pixel resolution of .8 km at nadir. Like most other scanners, the scanning mechanism was provided by a rotating mirror set at 45° to the scan axis.

The scanning mirror rotated at 400 rpm, which at the satellite ground speed of 5.8 km/sec, provided for a scan line separation of .8 km i.e., there was no overlap or underlap in the along track direction at nadir and the ground coverage was complete.

The thermal channel was reset to zero on each scan while viewing outer space. The output of this radiometer for the ground viewing portion of the scan was then equal to the difference in energy received from outer space and the scene below. The noise equivalent differential temperature of this instrument was about .5° C at 27° C and degraded to 2° C at -88° C.

Calibration for the visible channel was provided once per orbit when the satellite reached the polar region. At this point (on the sun-side horizon) the visible detector viewed a solar illuminated target.

For users interested in using the visible and thermal channels together it is important to note that the data from these detectors was 180° out of phase. This results from the fact that data from one channel, say the IR, was collected and sent to the ground while the other detector viewed the instrument housing. While the IR detector viewed the instrument housing, the visible detector viewed the ground.

Table T.2.6.1.2.a Characteristics of the NOAA-2 Very High Resolution Radiometer (VHRR)

	Channel 1	Channel 2
Spectral Range (micrometers)	.6 - .7	10.5 - 12.5
IFOV (milliradians)	.6	.6
Ground Resolution @ Nadir (Kilometers)	.87	.87
Ground Resolution $\pm 60^{o}$ (Kilometers)		
Rotation Rate (rpm)	400	400
Scan Line Separation @ Nadir (Kilometers)		
Sample Rate $(seconds)^{-1}$		
Pixel Separation @ Nadir (meters)		
FOV (degrees)		
Swath Width (kilometers)	2580	2580

2.6.1.3 NOAA-2 Vertical Temperature Profile Radiometer (VTPR)

The VTPR was a scanning radiometer providing estimates of atmospheric temperature from the earth's surface to about 30,500 m. The instrument measured energy in eight spectral channels in the infrared portion of the spectrum. Six of these channels were clustered near the 15 μm carbon dioxide absorption band, one at the 11 μm water vapor window and one at the 18 μm water vapor absorption band.

The sensor had one optical system and detector. Selection of the spectral regions was performed by a rotating filter wheel. Each channel viewed the ground for 62.5 milliseconds, a complete atmospheric profile being obtained in .5 seconds.

Scanning was achieved by a stepping mirror, 23 equal angle steps being made over an angular distance of 62.9° centered on the nadir track in 11.5 seconds. The mirror then took one second to return to the first element. During this time the satellite advanced about 70 km. The instrument's field of view was 2.235° x 2.235° corresponding to a ground resolution of about 60 x 60 km at nadir. This means that near continuous ground coverage was obtained along the nadir track. (see Table T.2.6.1.3.a)

The instrument was calibrated using both an internal target at 285° K, and outer space, at 4° K. Absolute accuracy of the sensor was designed to be .5% with a relative accuracy of .125%.

Table T.2.6.1.3.a Characteristics of the NOAA-3 Vertical Temperature Profile Radiometer (VTPR)

	Channel 1 - 6	7	8
Spectral Range (micrometers)	15	11	18
IFOV (degrees)	2.235	——————>	
Ground Resolution @ Nadir (Kilometers)	59	——————>	
Ground Resolution @ Swath Edge (meters)			
Scan lines per (minute)	4.8	——————>	
Scan Line Separation @ Nadir (meters)			
Sample Rate $(\text{seconds})^{-1}$			
Pixel Separation (degrees)	2.73	——————>	
FOV (degrees)	62.9	——————>	
Swath Width (kilometers)	1364	——————>	

2.6.2 Additional Information for NOAA-2

For more information on NOAA-2 see:

"The Operation of the NOAA Polar Satellite System," by J.J. Fortuna and L.N. Hambrick, NOAA Technical Memorandum NESS 60, 1974.

available from:

Environmental Science Information Center (D822)
Environmental Data Service
NOAA
Department of Commerce
6009 Executive Boulevard
Rockville, Maryland 20852

2.6.3 Data Availability for NOAA-2

The Satellite Data Services Division (SDSD) of the Environmental Data and Information Service (EDIS/NOAA) has the responsibility for the archival and dissemination of all civilian operational meteorological satellite data products. (See Appendix II for instructions on ordering these data.) A number of derived data products from the Scanning Radiometer (SR) and the Very High Resolution Radiometer (VHRR) are produced. Appendix III contains a description of these as abstracted from the Satellite Data User's Bulletin. For NOAA-2 some of these data products are available for the period from 11/16/72 to 3/19/74. Unfortunately the VHRR data were not retained from this spacecraft in full resolution digital form.

2.7 NOAA-3 (ITOS-F)

NOAA-3 was the fourth of the TIROS-M series. Except for slight modification of the scanning radiometer, NOAA-3 was identical to NOAA-2. Like NOAA-2 it also was placed in an orbit with a descending node at 900 local sun time.

2.7.1 NOAA-3 Instrument Objectives (see Table T.2.2.a)

SR (Scanning Radiometer) Section 2.7.1.1

- To determine surface temperatures of the ground, the sea and cloud tops.

VHRR (Very High Resolution Radiometer) Section 2.6.1.2

- To continuously measure surface temperatures of the earth, sea and cloud tops in daylight, as well as at night, and to transmit the temperature data in real time to Command and Data Acquisition (CDA) stations throughout the world for use in local weather forecasting.

VTPR (Vertical Temperature Profile Radiometer) Section 2.6.1.3

- To make measurements of radiated energy from atmospheric CO_2, gross water content and surface cloud top temperatures. These measurements are used to compute the temperature-pressure profiles in the atmosphere to altitudes of 30 km.

SPM (Solar Proton Monitor) Not covered here

- To monitor the omnidirectional fluxes of solar protons and the directional fluxes of protons and alpha particles.

APT (Automatic Picture Transmission) Not covered here

- To automatically take wide-angle, slow scan TV pictures of the earth and its cloud cover.

2.7.1.1 NOAA-3 Scanning Radiometer (SR)

The NOAA-3 scanning radiometer (SR) was similar to that on NOAA-2, the only difference being in the spectral range covered by the visible detector (see Table T.2.7.1.1.a). On NOAA-3 this detector responded to some ultraviolet radiation as well as most of the near IR portion of the spectrum in addition to the entire visible portion, specifically from .4 μm to 1.1 μm.

The Instantaneous Field of View (IFOV) in the thermal IR was 5.3 milliradians (mr) which yielded for the resolution of a ground element (pixel) at nadir (directly below the spacecraft) about 8.0 km at a nominal altitude of 1470 km. The separation at nadir of adjacent scan lines was approximately 6.4 km leading to a slight overlap of the 8 km pixels. Pixels near the swath edge (at 1450 km from nadir) measured 19.3 km by 12.9 km and significantly overlapped corresponding pixels in adjacent scan lines.

The IFOV for the visible detector was 2.8 mr, i.e., a ground resolution of about 3.2 km at nadir. Nadir pixels of the visible channel on adjacent scan lines were separated by 3.2 km. At approximately 1208 km from nadir the pixels touched and further from nadir they overlapped.

The SR scanned from horizon to horizon yielding a total field of view of approximately 120° or 2900 km. This provided for near contiguous coverage at the equator where consecutive passes of the satellite were separated by 28.8° or about 3100 km. The sensor provided complete global coverage twice daily in the thermal IR and once daily in the visible.

Table T.2.7.1.1.a Characteristics of the NOAA-3 Scanning Radiometer (SR)

	Channel 1	Channel 2
Spectral Range (micrometers)	.4 - 1.1	10.5 - 12.5
IFOV (milliradians)	2.8	5.3
Ground Resolution @ Nadir (Kilometers)	3.2	7.4
Ground Resolution @ Swath Edge (Kilometers)	6.4 x 12.9	12.9 x 19.3
Rotation Rate (rpm)	48	48
Scan Line Separation @ Nadir (meters)	6.4	contiguous
Sample Rate $(\text{seconds})^{-1}$		
Pixel Separation @ Nadir (meters)		
FOV (degrees)	120*	120
Swath Width (kilometers)	2900	2900

*Actually the FOV is somewhat greater than this. This range represents that required for contiguous coverage by successive orbits at the equator.

2.7.2 Additional Information for NOAA-3

For more information on NOAA-3 see:

"The Operation of the NOAA Polar Satellite System," by J.J. Fortuna and L.N. Hambrick, NOAA Technical Memorandum NESS 60, 1974.

available from:

Environmental Science Information Center (D822)
Environmental Data Service
NOAA
Department of Commerce
6009 Executive Boulevard
Rockville, Maryland 20852

2.7.3 Data Availability for NOAA-3

The Satellite Data Services Division (SDSD) of the Environmental Data and Information Service (EDIS/NOAA) has the responsibility for the archival and dissemination of all civilian operational meteorological satellite data products. (See Appendix II for instructions on ordering these data.) A number of derived data products from the Scanning Radiometer (SR) and the Very High Resolution Radiometer (VHRR) are available. Appendix III contains a description of these as abstracted from the Satellite Data User's Bulletin. For NOAA-3 some of these data products are available for the period from 3/26/74 to 12/17/74. Unfortunately the VHRR data were not retained from this spacecraft in full resolution digital form.

2.8 NOAA-4 (ITOS-G)

NOAA-4 was identical to NOAA-3 in all respects so none of the discussions will be repeated here. See Section 2.7 for detailed descriptions.

With regard to data availability all of the comments pertinent to NOAA-3 (Section 2.7.3) apply here except for the period for which data are available. For NOAA-4 this period is from 12/17/74 to 9/15/76.

2.9 NOAA-5 (ITOS-H)

NOAA-5 was the last of the TIROS-M series (second generation, polar orbiting, civilian meteorological satellite). It differs from the previous NOAA satellites in two respects: it carried an improved SPM, and some of the VHRR digital data have been retained by EDIS.

NOAA-5 was launched on July 29, 1976. It was on operational status from September 5, 1976 to March 1, 1979 when it was placed on standby. This is the last date for which data was archived at the SDSD. One of the low resolution scanning radiometers failed on February 24, 1978 and the second one failed on March 16, 1978. The satellite was deactivated on July 16, 1979.

2.9.1. NOAA-5 Instrument Objectives (see Table T.2.2.a)

SR (Scanning Radiometer) Section 2.7.1.1

- To determine surface temperatures of the ground, the sea and cloud tops.

VHRR (Very High Resolution Radiometer) Section 2.6.1.2

- To continuously measure surface temperatures of the earth, sea and cloud tops in daylight, as well as at night, and to transmit the temperature data in real time to Command and Data Acquisition (CDA) stations throughout the world for use in local weather forecasting.

VTPR (Vertical Temperature Profile Radiometer) Section 2.6.1.3

- Makes measurements of radiated energy from atmospheric CO_2, gross water content and surface cloud top temperatures. These measurements are used to compute the temperature-pressure profiles in the atmosphere to altitudes of 30 km.

SPM (Solar Proton Monitor) Not covered here

- To monitor the omnidirectional fluxes of solar protons and the directional fluxes of protons and alpha particles.

APT (Automatic Picture Transmission) Not covered here

- To automatically take wide-angle, slow scan TV pictures of the earth and its cloud cover.

2.9.2 Additional Information for NOAA-5

Although written for NOAA-2 and NOAA-3, the NOAA publication NESS-60 is still a useful document describing in general the spacecraft and its sensors.

"The Operation of the NOAA Polar Satellite System," by
J.J. Fortuna and L.N. Hambrick, NOAA Technical Memorandum
NESS 60, 1974.

available from:

Environmental Science Information Center (D822)
Environmental Data Service
NOAA
Department of Commerce
6009 Executive Boulevard
Rockville, Maryland 20852

2.9.3 Data Availability for NOAA-5

The Satellite Data Services Division (SDSD) of the Environmental Data and Information Service (EDIS/NOAA) has the responsiblity for the archival and dissemination of all civilian operational meteorological satellite data products. (See Appendix II for instructions on ordering these data.) A number of derived data products from the Scanning Radiometer (SR) and the Very High Resolution Radiometer (VHRR) are produced. Appendix III contains a description of these as abstracted from the Satellite Data User's Bulletin. For NOAA-5 some of these data products are available for the period from 9/15/76 to 2/7/79.

As indicated in the introduction, some of the NOAA-5 VHRR digital data exist in the SDSD archive. Starting on January 1, 1977, the SDSD maintained a 90 day rotating archive of VHRR digital data. That is, data was retained for 90 days from the day of acquisition. After 90 days, they were overwritten. The last 90 days of this archive were retained by the SDSD; i.e., VHRR digital data from each of the three readout stations are available for the period from about 12/15/77 to 3/16/78, with some gaps. The three readout stations are:

i) Gilmore Creek near Fairbanks, Alaska

ii) Wallops Station, Virginia

iii) Redwood City, California

The Gilmore Creek station receives data covering most of the North Pacific from about 40° north. Redwood City receives data covering much of the northwestern Pacific from Hawaii to the west coast of the U.S. Wallops Island receives data covering the northwestern Atlantic from Cuba to New Foundland. See Figure F.2.9.3.a.

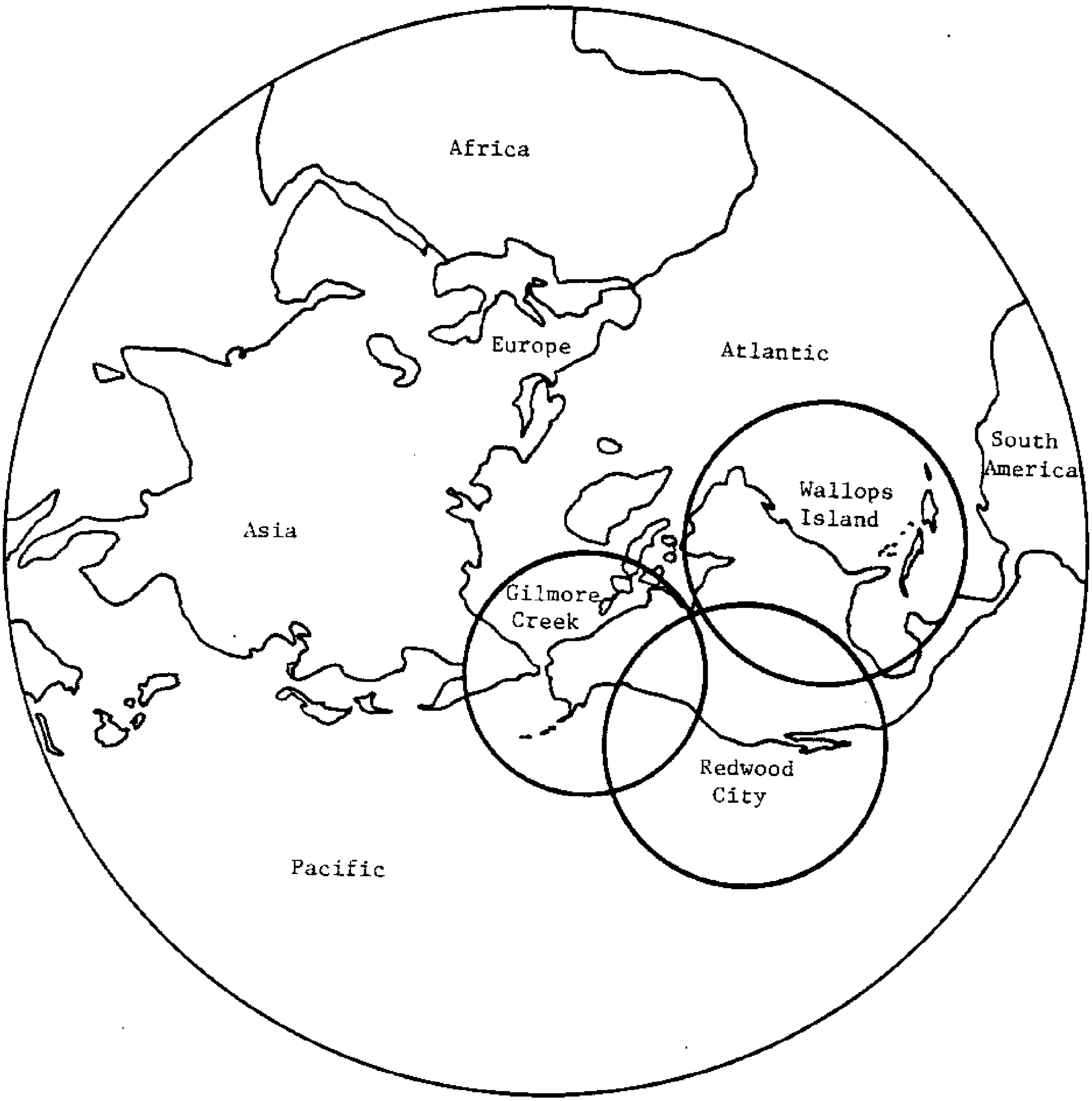
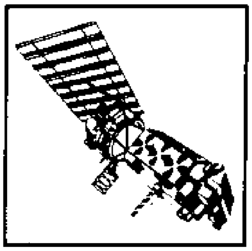


Figure F.2.9.3.a Coverage of the NESS Readout Stations, Northern Hemisphere



3. The TIROS-N Satellite Series - Third Generation, Civilian, Operational, Sun-Synchronous Meteorological Satellites.

3.1 Objectives: To measure the Earth's

i) Atmosphere

ii) Surface and cloud cover

iii) Near surface environment.

3.2 General

The third generation, sun-synchronous (polar-orbiting), operational, meteorological satellite series was introduced into the U.S. meteorological program with the launch of TIROS-N in October of 1978. This generation has for all practical purposes the same objectives as the previous generation, the TIROS-M series. One major difference between the TIROS-N series and the previous series is that provisions have been made to include two satellites in orbit recording data simultaneously. One of these has a descending node at 0330 local sun time (LST) while the second has a descending node of 0730 LST. Although this was the original intent, to date it has been rare that two of the satellites have operated simultaneously.

All of the data acquired by the readout stations is to be put on permanent archive.

3.3 Orbital Characteristics of the TIROS-N Series

The orbit of the TIROS-N series differs from that of the previous TIROS-M satellites in several important respects. First the orbital altitude is normally 850 km as opposed to the 1450 km TIROS-M altitude. This means the satellite moves faster, about 6.6 km/sec as opposed to 5.8 km/sec. Also it means that the orbital inclination must be different to maintain a sun-synchronous trajectory. For TIROS-N the ascending node is at 1500 local sun time while the descending node is at 0300 local sun time. For NOAA-6 the ascending and descending nodes occur at 1930 and 0730 respectively.

Finally, the attitude stabilization system on the TIROS-N satellites is designed to maintain the pointing accuracy of the sensors to within $\pm .2^{o}$ of the local geographic reference. In general, the pointing accuracy is thought to rarely deviate by more than $.15^{o}$ in any direction (roll or pitch). Furthermore, data provided by the satellite allows for roll, pitch and yaw estimates to within $.1^{o}$.

3.4 TIROS-N

TIROS-N was the prototype for the third generation polar orbiting series satellites. Its sensors showed marked improvements over those of the second generation. But of more importance from the oceanographic perspective, this series marked the first of the polar orbiting meteorological satellites for which the high resolution infrared digital data has been archived continuously. This satellite was launched in October of 1978 but archival of most of its data did not begin until January of 1979. TIROS-N ceased collecting data in the fall of 1980. There also existed a period, the spring of 1980, for which no data were archived.

3.4.1 TIROS-N Instrument Objectives

AVHRR (Advanced Very High Resolution Radiometer) Section 3.4.1.1

- to measure cloud top and sea surface temperatures

TOVS (TIROS Operational Vertical Sounder) An instrument package with the following components

a. High Resolution Infrared Sounder (HIRS/2) Section 3.4.1.2

   To measure:

   - the temperature profile from the surface to 10 millibar;
   - water vapor content in three layers;
   - total ozone content.

b. Stratospheric Sounding Unit (SSU) Section 3.4.1.3

   - to measure upper atmosphere weighting functions

c. Microwave Sounding Unit (MSU) Section 3.4.1.4

   - to measure the temperature profile under cloud covered conditions.

DCS (Data Collection System) Section 3.4.1.5

- to acquire data from fixed and free-floating terrestrial and atmospheric platforms.

SEM (Space Environment Monitor) An instrument package with the following components

a. Total Energy Detector (TED) Not covered here

   - To measure energetic particles in the .3 to 20 Kev range.

b. Medium Energy Proton and Electron Detectors (MEPED) Not covered here

   - To sense protons, electrons and ions with energies from 30 Kev to several tens of Mev.

c. High Energy Proton Alpha Detector (HEPAD) Not covered here

   - To sense protons and alphas from a few hundred Mev to .884 Gev.

3.4.1.1 TIROS-N Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR was a four channel instrument: two channels in the visible and near infrared, .55 - .90 μm and .725 - 1.10 μm; one in the IR window region at 4 μm, 3.55 - 3.93 μm; and one in the thermal IR window at 11 μm, 10.5-11.5 μm. (See Table T.3.4.1.1.a - T.3.4.1.1.c) On TIROS-N and NOAA-6 the thermal IR channels are redundant covering the same spectral region. On later versions of this series a second channel will be added in the 11 μm window, at 11.5-12.5 μm.

Scanning was accomplished by a mirror at 45° to the scan axis rotating at 360 rpm. The IFOV of all channels was 1.4 ± 0.1 milliradians (mr) corresponding to a ground resolution of about 1.1 kilometers (km) at nadir. (Notice the slightly coarser resolution than that of the earlier NOAA high resolution scanners, VHRR). This provided for continuous coverage at nadir by adjacent scan lines which were separated by about 1.1 km. The sample rate of about 40 kilohertz (kHz) per channel yielded a pixel separation of 1.03 mr or about .81 km at nadir. Given the approximate pixel size of 1.1 km at nadir this corresponded to substantial oversampling in the along scan direction.

The visible and near IR channels yielded a better than 3:1 signal-to-noise ratio. Both the 3.8 μm and 11 μm channels were to provide noise equivalent temperature differences of about .12° K on a 300° K scene. Unfortunately, however, the 3.8 μm channel on TIROS-N picked up electronic noise from within the satellite which rendered this channel almost useless. This problem was corrected for NOAA-6. As on the TIROS-M (ITOS) series VHRR, each scan line was reset to zero using outer space as a reference. The resulting output being the difference in detector response to the ground scene and outer space. The thermal channels also viewed a calibration target in the instrument housing at 290°K, thus providing the second point required for calibration. The response of these sensors to incoming radiation was approximately linear.

Table T.3.4.1.1.a Characteristics of the TIROS-N Advanced Very High Resolution Radiometer (AVHRR)

	Channel 1	Channel 2	Channel 3	Channel 4
Spectral Range (micrometers)	.55-.9	.725-1.1	3.55-3.93	10.5-11.5
IFOV (milliradians)	1.39	1.41	1.51	1.41
Ground Resolution @ Nadir (kilometers)	1.1	--------------------------->		
Ground Resolution @ Swath Edge (meters)				
Rotation Rate (rpm)	360	--------------------------->		
Scan Line Separation @ Nadir (meters)				
Sample Rate $(\text{seconds})^{-1}$	39936	--------------------------->		
Pixel Separation @ Nadir (kilometers)	.81	--------------------------->		
FOV (degrees)	110.8	--------------------------->		
Swath Width (kilometers)				

Table T.3.4.1.1.b Spectral characteristics of the TIROS-N/NOAA AVHRR† instruments

		Four-channel AVHRR, TIROS-N		
Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
0.55–0.9 μm	0.725–1.1 μm	3.55–3.93 μm	10.5–11.5 μm	Data from Ch 4 repeated
		Four-channel AVHRR - NOAA-6		
Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
0.58–0.68 μm	0.725–1.1 μm	3.55–3.93 μm	10.5–11.5 μm	Data from Ch 4 repeated
		Five-channel AVHRR, NOAA-7		
Ch 1	Ch 2	Ch 3	Ch 4	Ch 5
0.58–0.68 μm	0.725–1.1 μm	3.55–3.93 μm	10.3–11.3 μm	11.5–12.5 μm

Table T.3.4.1.1.c AVHRR instrument parameters†

Parameter	Value
Calibration	Stable blackbody and space for IR channels. No inflight visible channel calibration other than space.
Cross track scan	$\pm 55.4^{\circ}$ from nadir
Line rate	360 lines per minute
Optical field of view	1.3 milliradians
Ground resolution (IFOV)(1	1.1 km @ nadir
Infrared channel NEΔT(2	<0.12°K at 300°K
Visible channel S/N(3	3:1 @ 0.5% albedo

1) Instantaneous field of view
2) NEΔT - Noise equivalent differential temperature
3) Signal-to-noise ratio

† From NESS 107, page 3

*The designation of the satellites has been changed from that of the NESS publication 107 to correspond to the actual designation used for the satellite today.

3.4.1.2 TIROS-N High Resolution Infrared Radiation Sounder (HIRS/2)

HIRS/2 was a slightly modified version of HIRS/1 flown on NIMBUS-6 (see section 1.5.1.2. This instrument measured upwelling radiance in 20 spectral bands as compared to the 17 of HIRS/1. All of the spectral bands were in the visible and thermal infrared portion of the spectrum. (See Table T.3.4.1.2.a - T.3.4.1.2.c)

The IFOV of 1.25° (identical in all channels), about 20 km at nadir, was scanned across the earth's surface by a stepping mirror. (Figure F.3.4.1.2.a). The mirror performed 56 steps each in 1.8° increments for a total field of view of 99° or about 2240 km. Each scan line required 6.4 seconds. Adjacent pixel centers were separated by about 30 km at nadir in the across track direction and 42 km in the along track direction.

Calibration was performed on command. When in auto calibrate, a calibration was made every 256 seconds. During calibration the mirror alternately viewed outer space, a cold calibration target and a warm calibration target. Each of the 20 channels viewed each of these three calibration points.

Table T.3.4.1.2.a Characteristics of the TIROS-N High Resolution Infrared Radiation Sounder (HIRS/2)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	14.9-15.0	14.6-14.8	14.4-14.6	14.1-14.4	13.8-14.1
IFOV (degrees)	1.25	——————————>			
Ground Resolution @ Nadir (kilometers)	17.4	——————————>			
Ground Resolution @ Swath Edge (kilometers)	29.9x58.5	——————————>			
Scan lines per minute	9.4	——————————>			
Scan Line Separation @ Nadir (kilometers)	42	——————————>			
Sample Rate $(\text{seconds})^{-1}$	10	——————————>			
Pixel Separation (degrees)	1.8	——————————>			
FOV (degrees)	99	——————————>			
Swath Width (kilometers)	2240	——————————>			

Table T.3.4.1.2.a (continued) Characteristics of the TIROS-N High Resolution Infrared Radiation Sounder

	Channel 6	7	8	9	10
Spectral Range (micrometers)	13.5-13.8	13.2-13.5	10.9-11.3	9.59-9.83	7.97-8.37
IFOV (degrees)	1.25	--------------------------------->			
Ground Resolution @ Nadir (kilometers)	17.4	--------------------------------->			
Ground Resolution @ Swath Edge (kilometers)	29.9x58.5	--------------------------------->			
Scan lines per minute	9.4	--------------------------------->			
Scan Line Separation @ Nadir (kilometers)	42	--------------------------------->			
Sample Rate $(\text{seconds})^{-1}$	10	--------------------------------->			
Pixel Separation (degrees)	1.8	--------------------------------->			
FOV (degrees)	99	--------------------------------->			
Swath Width (kilometers)	2240	--------------------------------->			

Table T.3.4.1.2.a (continued) Characteristics of the TIROS-N High Resolution Infrared Radiation Sounder

	Channel 11	12	13	14	15
Spectral Range (micrometers)	7.22-7.43	6.54-6.91	4.54-4.59	4.50-4.55	4.44-4.49
IFOV (degrees)	1.25	———————————————>			
Ground Resolution @ Nadir (kilometers)	17.4	———————————————>			
Ground Resolution @ Swath Edge (kilometers)	29.9x58.5	———————————————>			
Scan lines per minute	9.4	———————————————>			
Scan Line Separation @ Nadir (kilometers)	42	———————————————>			
Sample Rate $(\text{seconds})^{-1}$	10	———————————————>			
Pixel Separation (degrees)	1.8	———————————————>			
FOV (degrees)	99	———————————————>			
Swath Width (kilometers)	2240	———————————————>			

Table T.3.4.1.2.a (continued) Characteristics of the TIROS-N High Resolution Infrared Radiation Sounder

	Channel 16	17	18	19	20
Spectral Range (micrometers)	4.38-4.43	4.22-4.26	3.95-4.00	3.69-3.83	.667-.714
IFOV (degrees)	1.25	——————————————————→			
Ground Resolution @ Nadir (kilometers)	17.4	——————————————————→			
Ground Resolution @ Swath Edge (kilometers)	29.9x58.5	——————————————————→			
Scan lines per minute	9.4	——————————————————→			
Scan Line Separation @ Nadir (kilometers)	42	——————————————————→			
Sample Rate $(\text{seconds})^{-1}$	10	——————————————————→			
Pixel Separation (degrees)	1.8	——————————————————→			
FOV (degrees)	99	——————————————————→			
Swath Width (kilometers)	2240	——————————————————→			

Table T.3.4.1.2.b HIRS/2 system parameters*

Parameter	Value
Calibration	Stable blackbodies (2) and space background
Cross-track scan	$\pm 49.5^{o}$ (± 1120 km)
Scan time	6.4 seconds
Number of steps	56
Optical FOV	1.25^{o}
Step angle	1.8^{o}
Step time	100 milliseconds
Ground IFOV (nadir)	17.4 km diameter
Ground IFOV (end of scan)	58.5 km cross-track by 29.9 km along-track
Distance between IFOV's	42 km along-track
Data rate	2880 bits/second

* From: NESS 95, page 27

Table 3.4.1.2.c HIRS/2 instrument specifications†

Channel	Central Wave No.† cm^{-1}	Half Power Bandwidth cm^{-1}	Wavelength m	Specified NE N mw/m^2-sr cm^{-1}
1	668.00	$3.0^{+1}_{-0.5}$	14.97	0.80*
2	679.23	10.0^{+4}_{-1}	14.72	0.27
3	691.12	12.0^{+6}_{-0}	14.46	0.27
4	703.56	16.0^{+4}_{-2}	14.21	0.22
5	716.05	16.0^{+4}_{-2}	13.97	0.22
6	732.38	16.0^{+4}_{-2}	13.65	0.22
7	748.27	16.0^{+4}_{-2}	13.36	0.22
8	897.71	35.0 ± 5	11.14	0.11
9	1027.87	25.0 ± 3	9.73	0.16
10	1217.10	60.0^{+10}_{-3}	8.22	0.16
11	1363.69	40.0 ± 5	7.33	0.22
12	1484.35	80.0^{+15}_{-4}	6.74	0.11
13	2190.43	23.0 ± 3	4.57	0.002
14	2212.65	23.0 ± 3	4.52	0.002
15	2240.15	23.0 ± 3	4.46	0.002
16	2276.27	23.0 ± 3	4.39	0.002
17	2360.63	23.0 ± 3	4.24	0.002

Table 3.4.1.2.c (continued)

Channel	Central Wave No.† cm^{-1}	Half Power Bandwidth cm^{-1}	Wavelength μm	Specified NEΔN mw/m^2-sr cm^{-1}
18	2511.95	35.0 ± 5	3.98	0.002
19	2671.18	100.0 ± 15	3.74	0.001
20	14367.0	1000.0 ± 15	0.69	0.1% Albedo

*1.70 most likely achievable

†From: NESS 95, page 31

‡These values have been updated with the values from Table 2.4-1 of the NOAA Polar Orbiter Data (TIROS-N and NOAA-6) User's Guide.

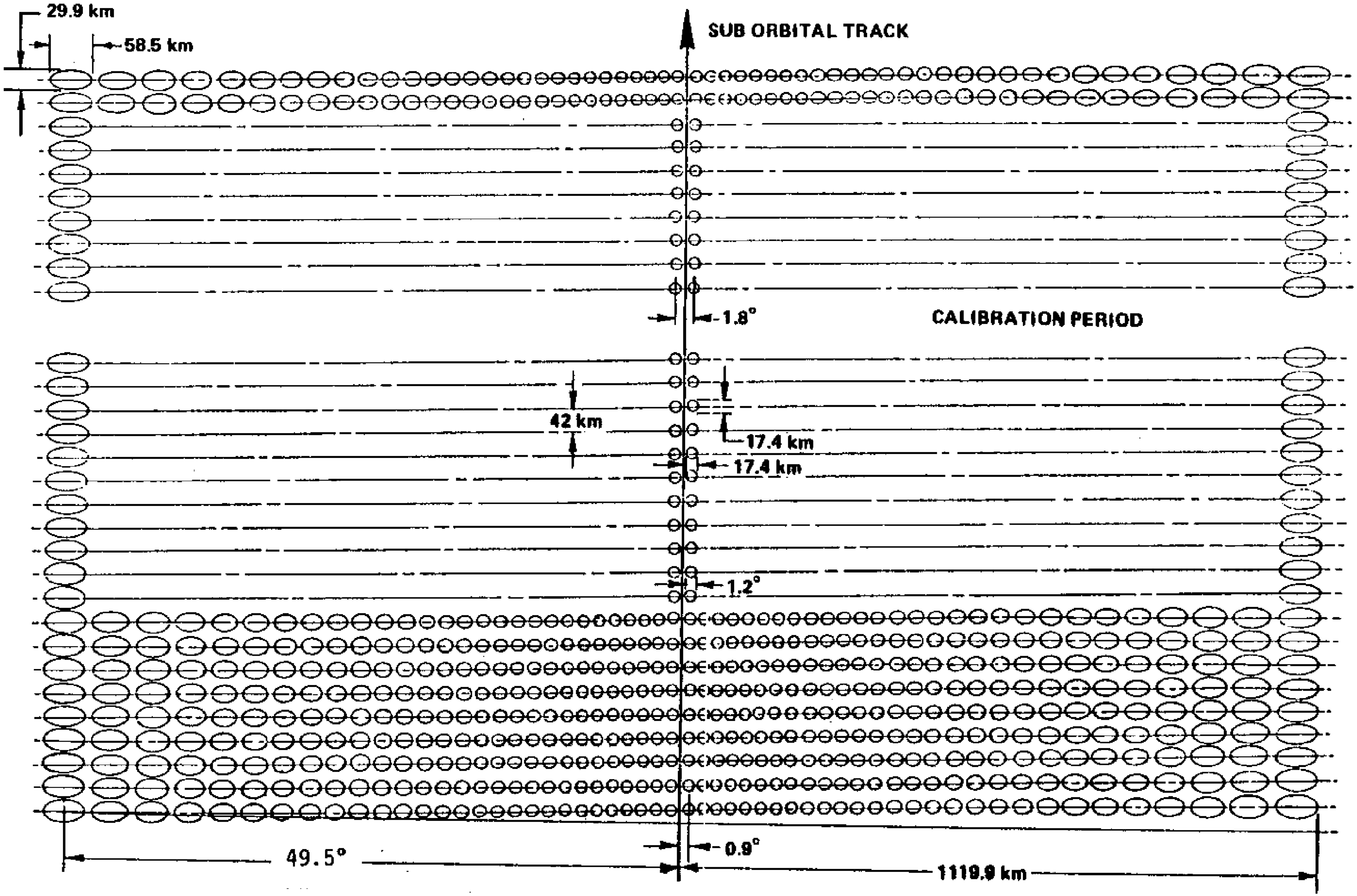


Figure F.3.4.1.2.a --TIROS Operational Vertical Sounder HIRS/2 Scan Pattern Projected on Earth*

*From NESS 95, Page 28

3.4.1.3 TIROS-N Stratospheric Sounding Unit (SSU)

The SSU designed and built by the United Kingdom Meteorological Office was based on the Pressure Modulator Radiometer of NIMBUS-6. It was a three channel scanning instrument operating in the far infrared at the 15 μm carbon dioxide emission peak. (See Tables T.3.4.1.3.a and T.3.4.1.3.b)

The sensor used the pressure modulation technique to determine weighting functions. The weighting function peaks occur near 29 km, 37 km and 45 km, hence, this instrument provided information primarily about the upper atmosphere.

The IFOV of the instrument was 10^{o}, providing a spatial resolution at nadir of about 150 km. (See Figure F.3.4.1.3.a). A mirror stepped through 8 discrete values covering a total field of view of 80^{o} centered on the nadir track. One scan consumed about 32 seconds.

Calibration was performed synchronously with HIRS/2, every 250 seconds when in the auto calibration mode. When calibrating, outer space and an internal black body target were used.

Table T.3.4.1.3.a Characteristics of the TIROS-N Stratospheric Sounding Unit (SSU)

	Channel 1	Channel 2	Channel 3
Spectral Range (micrometers)	14.925	14.934	14.940
IFOV (degrees)	10	——————>	
Ground Resolution @ Nadir (kilometers)	147	——————>	
Ground Resolution @ Swath Edge (kilometers)	186x244	——————>	
Scan lines per minute	1.875	——————>	
Scan Line Separation @ Nadir (kilometers)	210	——————>	
Sample Rate $(\text{seconds})^{-1}$	.25	——————>	
Pixel Separation (degrees)	10	——————>	
FOV (degrees)	80	——————>	
Swath Width (kilometers)	1473	——————>	

Table 3.4.1.3.b SSU characteristics*

Channel Number	Central† Wave No. (cm^{-1})	Cell Pressure (mb)	Pressure of weighting function peak mb	km
1	669.998	100	15	29
2	669.628	35	5	37
3	669.357	10	1.5	45

Calibration	Stable blackbody and space
Angular field-of-view	10°
Number of Earth views/line	3
Time interval between steps	4 seconds
Total scan angle	$\pm 40^{\circ}$ from nadir
Scan time	32 seconds
Data rate	480 bits/second

*From: NESS-95, page 36

†These values have been updated with those of Table 2.4-1 of the Polar Orbiter Data (Tiros-N and NOAA-6) User's Guide.

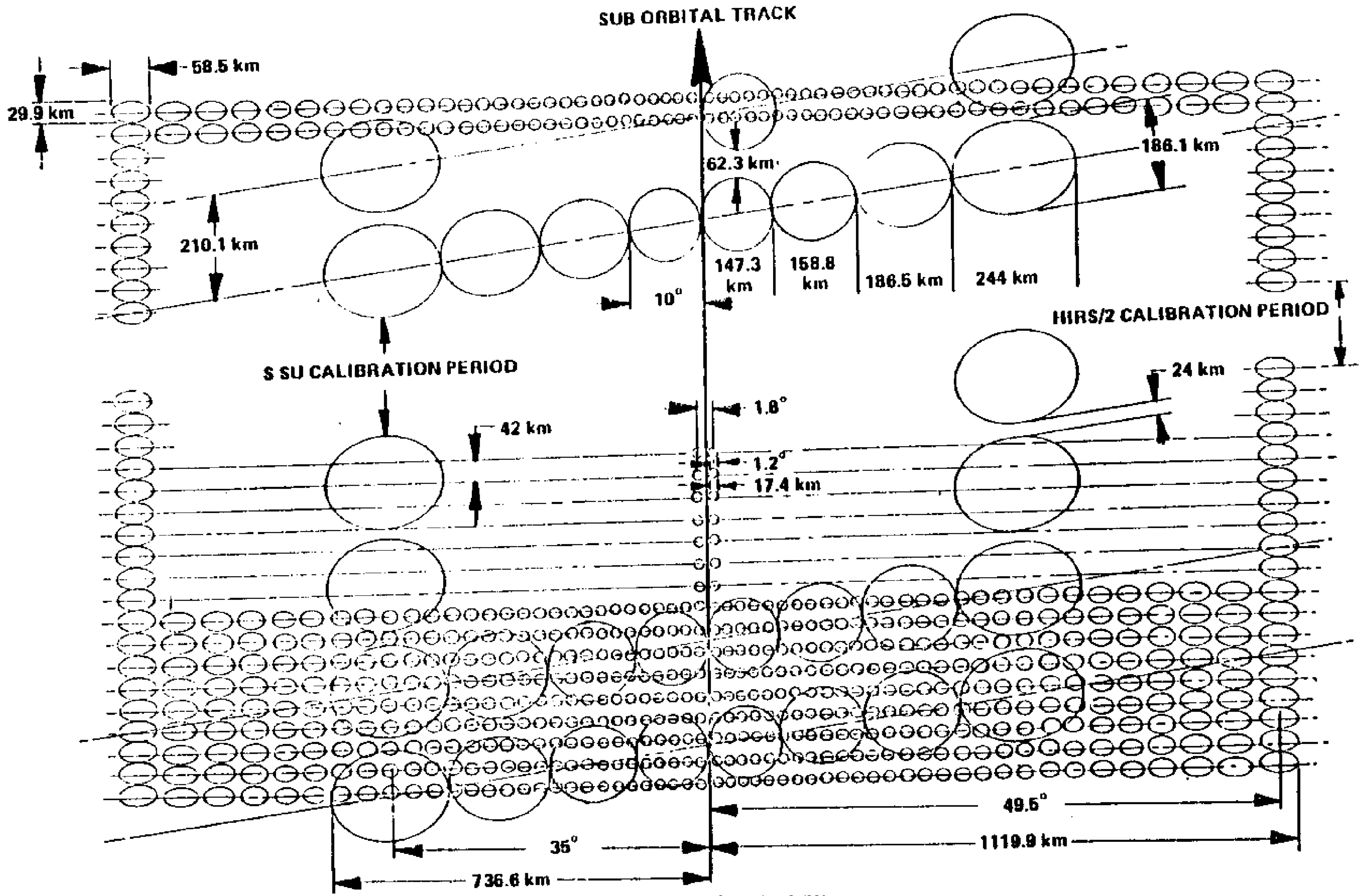


Figure F.3.4.1.3.?.--TIROS Operational Vertical Sounder HIRS/2 and Stratospheric Sounding Unit scan patterns projected on earth*

*From NESS 95, Page 35

3.4.1.4 TIROS-N Microwave Sounding Unit (MSU)

The MSU was a modified version of SCAMS flown on NIMBUS-6 (Section 1.5.1.3). It was a four channel passive microwave scanning Dicke radiometer. (Tables T.3.4.1.4.a and T.3.4.1.4.b) The four channels made measurements in the 5.5 mm oxygen region at 50.3 gigahertz (GHz), 53.74 GHz, 54.96 GHz and 57.05 GHZ. The NEΔT of these channels is less than .3° K. The instrument operating in the microwave provided useful data under all but the most severe weather conditions.

Scanning was achieved with this sensor by rotating reflectors in front of the fixed corrugated horns. The total field of view of the sensor was 94.7° or about 2350 km. (See Figure F.3.4.1.4.a). The reflectors made 10 equal angle steps over this distance, in 25.6 seconds, each step being 9.4° and separated in time by 1.84 seconds. The IFOV (angular resolution or angular separation of half power points) was 7.5° corresponding to a gound resolution of about 110 km at nadir. Consecutive scan lines were separated by 168 km.

Table T.3.4.1.4.a Characteristics of the TIROS-N Microwave Sounding Unit (MSU)

	Channel 1	2	3	4
Spectral Range (GHz)	50.3±.1	53.74±.1	54.96±.1	57.95±.1
IFOV (degrees)	7.5	----------------------->		
Ground Resolution @ Nadir (kilometers)	109.3	----------------------->		
Ground Resolution @ Swath Edge (kilometers)	178.8x323.1	----------------------->		
Scan lines per minute	2.34	----------------------->		
Scan Line Separation @ Nadir (kilometers)	168.1	----------------------->		
Sample Rate $(seconds)^{-1}$	.54	----------------------->		
Pixel Separation (degrees)	9.47	----------------------->		
FOV (degrees)	94.7	----------------------->		
Swath Width (kilometers)	2347.2	----------------------->		

Table T.3.4.1.4.b MSU instrument parameters†

Characteristics	Value				Tolerance
	CH 1	CH 2	CH 3	CH 4	
Frequency (GHz)	50.3	53.74	54.96	57.05	±20 MHz
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)
Data Rate	320 Bps

*>95% expected

†From: NESS 95, page 38

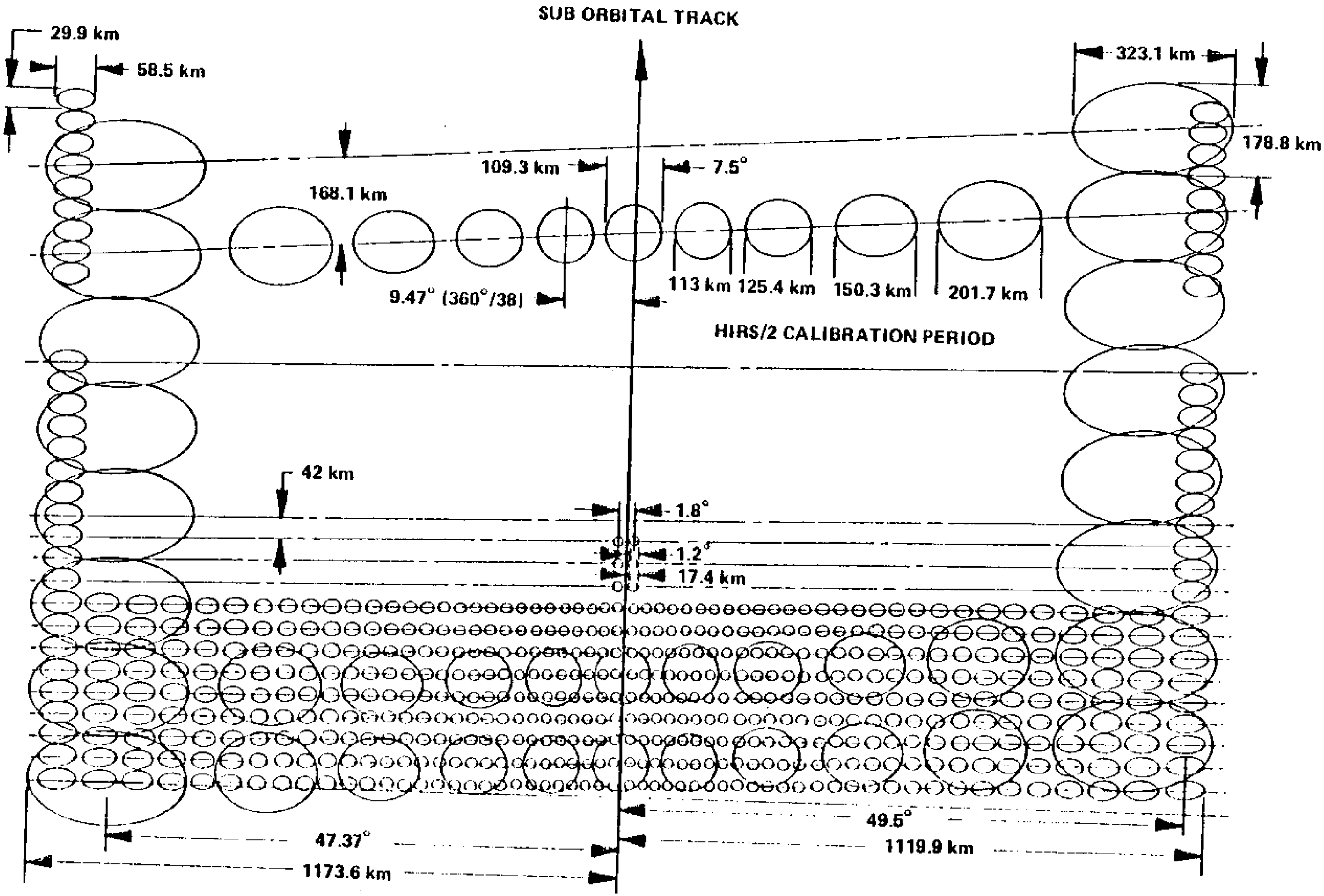


Figure F.3.4.1.4.a --TIROS Operational Vertical Sounder HIRS/2 and MSU scan patterns projected on earth*

*From NESS 95, Page 39

3.4.1.5 TIROS-N Data Collection System (DCS)

The Data Collection and Location System, DCS, was designed as a means of obtaining environmental data from remote, difficult to service or moving platforms. The system is referred to as ARGOS and was built and operated by the French. It consisted of three parts: the data receiving and transmitting segment on the satellite; the data collection platforms; and the processing of the relayed data.

Platforms may be designed and built by the user as long as they meet certain interface criteria. The French also built oceanographic platforms which may be purchased by the potential user.

The platform sent messages in lengths from 360 ms to 920 ms to the TIROS spacecraft. The carrier frequency used was 401.650 megahertz (MHz). The French will process the TIROS data using differential doppler techniques if locational information is desired. Position determination was designed for an accuracy of better than 5 kms. Velocity determination was to be better than 1.5 meters per second.

3.4.2 Additional Information for TIROS-N

There are several documents which describe the TIROS-N series, its sensors and the form of its data. Three of these documents are listed below in order of detail. The first provides a general overview of the series, the second a slightly more technical description and the third a detailed description of the digital data.

1. The TIROS-N/NOAA A-G Satellite Series
   Arthur Schwalb March, 1978
   NOAA Technical Memorandum NESS 95

2. Data Extraction and Calibration of TIROS-N/NOAA Radiometer
   Levin Lauisston, Gary J. Nelson and Frank W. Porto
   November, 1979
   NOAA Technical Memorandum NESS 107

3. NOAA Polar Orbiter Data
   (TIROS-N and NOAA-6)
   User's Guide
   Katherine B. Kidwell March 1981

All three of the documents are available from:

NOAA/EDIS/SDSD
Room 100, World Weather Bldg.
Washington, D.C. 20233

Telephone: 301-763-8111

3.4.3 Data Availability for TIROS-N

All archived TIROS-N data is obtained from the Satellite Data Services Division (SDSD) of NOAA/EDIS. Ordering procedures are outlined in Appendix II and data product costs are summarized in Appendix I. All TIROS-N data which arrived at EDIS in Washington has been archived in digital form on the Tera-Bit Memory (TBM). This includes most data collected by the three read-out stations: Wallops Island, Va; Gilmore Creek, Alaska; and, Goldstone, California, starting in January of 1979 with continuous coverage to January of 1980. At that time because of problems on TIROS-N, NOAA-6 was made the primary satellite in the series. Because NESS was not prepared to send data from both satellites to Washington from the readout stations, archival of TIROS-N data ceased. TIROS-N data was, however, still received at the readout station and may have been saved under special circumstances by individual researchers. Archival of TIROS-N digital data resumed in May of 1980 and continued until November of 1980 when the satellite failed.

The user is cautioned that only data received at the readout station and relayed to EDIS was archived. This means that in general the only high resolution imagery (AVHRR) archived was that collected by the satellite while in view of the readout station. For Wallops Island this means the western Atlantic from Greenland south to Cuba; for Gilmore Creek, most of the north Pacific; and, for Goldstone, the north Pacific west of Hawaii. On special occasions a maximum of 10 minutes per orbit of high resolution imagery was tape recorded, readout by the stations and sent to EDIS. Finally, degraded resolution AVHRR data called GAC for Global Area Coverage or GHRR (Global High Resolution Radiometry) is available for the entire earth's surface.

All Argos related data is available from:

Service Argos
Centre Spatial De Toulouse
18, Avenue Edward Belin
31055 Toulouse Cedex
FRANCE

All AVHRR and TOVS (HIRS/2, MSU and SSU) data are availabe from SDSD.

3.5 NOAA-6

NOAA-6 is the first operational satellite in the 3rd generation, TIROS-N being the prototype for the series. This satellite is identical to TIROS-N except that the problem giving rise to noise in the 3.5 μm channel of the AVHRR was corrected prior to its launch and the .6 μm channel is somewhat narrower than on TIROS-N. The satellite was launched and began collecting good data in late June of 1979.

3.5.1 NOAA-6 Instrument Objectives

AVHRR (Advanced Very High Resolution Radiometer) Section 3.5.1.1

- to measure cloud top temperatures

TOVS (TIROS Operational Vertical Sounder) An instrument package with the following components

a. High Resolution Infrared Sounder (HIRS/2) Section 3.4.1.2

   To measure:

   - the temperature profile from the surface to 10 mb
   - water vapor content in three layers
   - total ozone content

b. Stratospheric Sounding Unit (SSU) Section 3.4.1.3

   To measure upper atmosphere weighting functions

c. Microwave Sounding Unit (MSU) Section 3.4.1.4

   To measure the temperature profile under cloud covered conditions

DCS (Data Collection System) Section 3.4.1.5

- to acquire data from fixed and free-floating terrestrial and atmospheric platforms.

SEM (Space Environment Monitor) An instrument package with the following components.

a. Total Energy Detector (TED)

   To measure energetic particles in the .3 to 20 Kev range

b. Medium Energy Proton and Electron Detectors (MEPED)

   To sense protons, electrons and ions with energies from 30 Kev to several tens of Mev.

c. High Energy Proton Alpha Detector (HEPAD)

   To sense protons and alphas from a few hundred Mev to .34 Gev.

3.5.1.1 NOAA-6 Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR is a four channel instrument: two channels in the visible and near infrared, .58 - .68 µm and .725 - 1.10 µm; one in the IR window region at 4 µm, 3.55 - 3.93 µm, and one in the thermal IR window at 11 µm, 10.5-11.5 µm. (See Table T.3.5.1.1.a and T.3.4.1.1.b)

Scanning is accomplished by a mirror at 45° to the scan axis rotating at 360 rpm. The IFOV of all channels is 1.4± 0.1 milliradians (mr) corresponding to a ground resolution of about 1.1 kilometers (km) at nadir. (Notice the slightly coarser resolution than that of the earlier NOAA high resolution scanners, VHRR). This provides for continuous coverage at nadir by adjacent scan lines which are separated by about 1.1 km. The sample rate of 40 kilohertz (kHz) per channel yields a pixel separation of 1.03 mr or about .31 km at nadir. Given the approximate pixel size of 1.1 km at nadir this corresponds to substantial oversampling in the along scan direction.

The visible and near IR channels yield a better than 3:1 signal-to-noise ratio. Both the 3.8 µm and 11 µm channels were to provide noise equivalent temperature differences of about .12° K on a 300° K scene. As on the TIROS-M (ITOS) series VHRR, each scan line is reset to zero using outer space as a reference. The resulting output being the difference in detector response to the ground scene and outer space. The thermal channels also view a calibration target in the instrument housing at 290° K, thus providing the second point required for calibration. The response of these sensors to incoming radiation is approximately linear.

Table T.3.5.1.1.a Characteristics of the NOAA-6 Advanced Very High Resolution Radiometer (AVHRR)

	Channel 1	Channel 2	Channel 3	Channel 4
Spectral Range (micrometers)	.58-.68	.725-1.1	3.55-3.93	10.5-11.5
IFOV (milliradians)	1.4	---------------------->		
Ground Resolution @ Nadir (kilometers)	1.1	---------------------->		
Ground Resolution @ Swath Edge (meters)				
Rotation Rate (rpm)	360	---------------------->		
Scan Line Separation @ Nadir (meters)				
Sample Rate $(\text{seconds})^{-1}$	39936	---------------------->		
Pixel Separation @ Nadir (kilometers)	.31	---------------------->		
FOV (degrees)	110.8	---------------------->		
Swath Width (kilometers)	2240	---------------------->		

3.5.2 Additional Information for NOAA-6

Information sources for NOAA-6 regarding the satellites, its sensors and resulting data is identical to that for TIROS-N. The reader is referred to section 3.4.2.

3.5.3 Data Availability for NOAA-6

Like TIROS-N all NOAA-6 data are archived at EDIS. See Appendix II for instructions on ordering these data and Appendix I for costs.

Although launched in June of 1979 NOAA-6 did not become the designated operational satellite until January, 1980. Until then the satellite was operated in the backup mode. In January of 1980 archival of data acquired at the three readout stations (Wallops Island, Virginia; Gilmore Creek, Alaska; and Goldstone, California) began.

For the availability of Argos data see section 3.4.3.

3.6 NOAA-7

NOAA-7 is the second operational satellite in the TIROS-N series. Between the successful launch of NOAA-6 (NOAA-A prior to launch) on June 27, 1979 and NOAA-7 (NOAA-C prior to launch) on June 23, 1981 there was an attempt on May 29, 1980 to launch NOAA-B. This launch failed and the NOAA-B satellite that was to have become NOAA-7 was destroyed. It is for this reason that the prelaunch designations NOAA-A, -B, -C, etc. no longer correspond to the originally planned post launch designations NOAA-6, -7, -8, etc. but rather to the new sequence NOAA-6, - , -7, etc.

In addition to this change, the four channel AVHRR originally scheduled for NOAA-C was replaced with the five channel AVHRR originally scheduled for NOAA-D, -F and -G. See section 3.6.1.1 for a description of the five channel instrument.

3.6.1 NOAA-7 Instrument Objectives

AVHRR (Advanced Very High Resolution Radiometer) Section 3.6.1.1

- to measure cloud top temperatures

TOVS (TIROS Operational Vertical Sounder) An instrument package with the following components

a. High Resolution Infrared Sounder (HIRS/2) Section 3.4.1.2

   To measure:

   - the temperature profile from the surface to 10 mb
   - water vapor content in three layers
   - total ozone content

b. Stratospheric Sounding Unit (SSU) Section 3.4.1.3

   To measure upper atmosphere weighting functions

c. Microwave Sounding Unit (MSU) Section 3.4.1.4

   To measure the temperature profile under cloud covered conditions

DCS (Data Collection System) Section 3.4.1.5

- to acquire data from fixed and free-floating terrestrial and atmospheric platforms.

SEM (Space Environment Monitor) An instrument package with the following components.

a. Total Energy Detector (TED)

   To measure energetic particles in the .3 to 20 Kev range

b. Medium Energy Proton and Electron Detectors (MEPED)

   To sense protons, electrons and ions with energies from 30 Kev to several tens of Mev.

c. High Energy Proton Alpha Detector (HEPAD)

   To sense protons and alphas from a few hundred Mev to .84 Gev.

3.6.1.1 NOAA-7 Advanced Very High Resolution Radiometer (AVHRR)

The NOAA-7 AVHRR is a five channel instrument: two channel in the visible and near infrared, .58 - .68 μm and .725 - 1.10 μm; one in the IR window region at 4 μm, 3.55 - 3.93 μm and two in the thermal IR window at 11 μm, 10.5-11.3 μm and 11.5-12.5 μm. (See Table 3.6.1.1.a and T.3.4.1.1.b)

Scanning is accomplished by a mirror at 45° to the scan axis rotating at 360 rpm. The IFOV of all channels is 1.4$\pm$ 0.1 milliradians (mr) corresponding to a ground resolution of about 1.1 kilometers (km) at nadir. (Notice the slightly coarser resolution than that of the earlier NOAA high resolution scanners, VHRR). This provides for continuous coverage at nadir by adjacent scan lines which are separated by about 1.1 km. The sample rate of 40 kilohertz (kHz) per channel yields a pixel separation of 1.03 mr or about .31 km at nadir. Given the approximate pixel size of 1.1 km at nadir this corresponds to substantial oversampling in the along scan direction.

The visible and near IR channels yield a better than 3:1 signal-to-noise ratio. Both the 3.8 μm and 11 μm channels were to provide noise equivalent temperature differences of about .12° K on a 300°K scene. As on the TIROS-M (ITOS) series VHRR, each scan line is reset to zero using outer space as a reference. The resulting output is the difference in detector response to the ground scene and outer space. The thermal channels also view a calibration target in the instrument housing at 290° K, thus providing the second point required for calibration. The response of these sensors to incoming radiation is approximately linear.

Table T.3.6.1.1.a Characteristics of the NOAA-6 Advanced Very High Resolution Radiometer (AVHRR)

	Channel				
	1	2	3	4	5
Spectral Range (micrometers)	.58-.68	.725-1.1	3.55-3.93	10.5-11.3	11.5-12.5
IFOV (milliradians)	1.4	-->			
Ground Resolution @ Nadir (kilometers)	1.1	-->			
Ground Resolution @ Swath Edge (meters)					
Rotation Rate (rpm)	360	-->			
Scan Line Separation @ Nadir (meters)					
Sample Rate $(seconds)^{-1}$	39936	-->			
Pixel Separation @ Nadir (kilometers)	.81	-->			
FOV (degrees)	110.8	-->			
Swath Width (kilometers)	2240	-->			

3.6.2 Additional Information for NOAA-7

Information sources for NOAA-7 regarding the satellites, its sensors and resulting data is identical to that for TIROS-N. The reader is referred to section 3.4.2.

3.6.3 Data Availability for NOAA-7

Like TIROS-N all NOAA-7 data are archived at EDIS. See Appendix II for instructions on ordering these data and Appendix I for costs.

For the availability of Argos data see section 3.4.3.

MILITARY OPERATIONAL SUN-SYNCHRONOUS METEOROLOGICAL SATELLITES

In 1973 the United States Air Force announced the existence of a previously secret series of meteorological satellites. This was the Block 5 B/C series of the Defense Meteorological Satellite Program (DMSP). This series was upgraded by the Block 5D series in 1977. The orbital characteristics of the satellites in these two series are shown in Table II.3.

The two series 5B/C and 5D were similiar in nature and objectives to the civilian run polar orbiting series ITOS/NOAA and TIROS-N. The main differences were in the capabilities of the primary sensors and, more importantly, in the availability and format of their data.

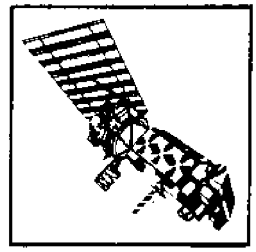
Table II.3 OPERATIONAL METEOROLOGICAL SATELLITES (Military)

(Sun-Synchronous)

Satellite Name (alias)		Launch (Date)	Limit of Data Archive (Date)	Period (min)	Periopsis (km)	Apoapsis (km)	Inclination (Degrees)	Equatorial Crossing Descending Node (Local Sun Time)
DMSP								
	P		6/21/73					
	Q		2/23/74					
Block 5B/C	R	8/17/73	12/9/76	101.4	808	854	98.8	
	S	3/16/74	5/14/76	101.5	780	879	98.9	
	T	8/9/74	11/27/74	101.7	803	872	98.9	
	Y	5/24/75	7/14/77	101.8	801	896	98.9	
Block 5D	F1	9/11/76	9/16/79	101.6	818	848	98.7	2400
	F2	6/24/77	3/79*	101.7	811	869	99.0	~ 1800†
	F3	5/1/78	Present*	96.9	564	653	97.6	~ 1800
	F4	6/6/79	8/80*	101.4	817	839	98.7	~ 1000

* The status of operational DMSP satellites is not in the public domain. At this time the DMSP library is receiving imagery from F3 only, albeit of poor quality. The Air Force's Office of Public Affairs however indicates that some data is still being received from F2, F3 and F4.

† The tild symbol means approximately. The actual time is not available to the public.



4 The DMSP Block 5B/C Satellite Series

4.1 Objectives

1. To provide globally recorded visual and infrared cloud cover and other specialized environmental data to the Air Force Global Weather Central (AFGWC).
2. To provide real time direct readout of local area environmental data to mobile receiving terminals at key locations throughout the world.
3. To continue the advancement of environmental satellite technology to meet Department of Defense requirements.

4.2 General

Until February, 1973, data from the DMSP (Defense Meteorological Satellite Program previously referred to as DAPP, Data Acquisition and Processing Program) satellites were not available to the public. The series, announced in February, 1973, is known as the DMSP Block 5B/C series. The DMSP system is comprised of two polar orbiting spacecraft in sun-synchronous orbits, much like the civilian polar orbiting meteorolgical system. Also like the NOAA satellites the primary sensor of the DMSP is the multispectral scanner with a channel in the thermal IR and one in the visible. The primary differences between the two systems are: the actual design of the primary sensor; the availability (or lack thereof) of the data; and, the equatorial crossing times.

In general, each spacecraft in the Block 5B/C series also carried two supplementary sensors measuring such quantities as rain rate, lightning, vertical temperature profile, etc. The two particular sensors were selected from a suite of four associated with the series, the particular choice depending on the time of orbit of the spacecraft and the condition of the supplementary sensors on previous spacecraft.

4.3 Orbital Characteristics of the DMSP Series

The DMSP satellites, like the NOAA satellites, were in a near-polar, sun-synchronous orbit (see Table II.3). They flew approximately 850 km above the surface of the earth with an orbital period of about 102 minutes. There were generally two satellites in the series collecting data simultaneously, one at about noon (ascending) and midnight (descending) and the other at about dawn (ascending) and dusk (descending). The sensors were configured to collect data over the entire earth four times a day, at each of the times listed above. The inclination of the orbit required to maintain the sun-synchronous relationship was 98.7°. The inclination defines the northernmost and southernmost satellite subpoint, which for DMSP was 81.3° N/S.

During the orbital period of 102 minutes the earth rotated under the satellite and the orbit of the satellite precessed slightly. The result was that each ascending node of the satellite was 25.4° west of the previous one. Since the satellite did not make an integer number of orbits in one day, the ground tracks did not repeat from one day to the next. In the case of DMSP there were about 14.2 orbits per day. Another way of looking at this is that consecutive sets of 14 orbits were offset by 4.54°, each set being this distance east of the previous set.

4.4 DMSP Block 5B/C Satellites (R, S, T and Y)

Because the author knows little about the individual satellites in the Block 5B/C series they will all be considered together here. There were six Block 5B/C satellites described to the public. The designation of these is different from that of the civilian satellites in that each satellite was given a letter which it retained after launch. In the 5B/C series the satellites were P, Q, R, S, T and Y. All have ceased to function.

4.4.1 DMSP Block 5B/C Sensor Objectives

SAP - Sensor AVE (Aerospace Vehicle Electronics) Package (Section 4.4.1.1)

To provide global day and night cloud cover information.

SEE - Special Sensor E (Not covered here)

To provide global radiance data, from which vertical temperature profiles are obtained.

SSJ - Special Sensor J (Not covered here)

To detect energetic electrons over a range of energies associated with the visible aurora.

SSJ/2 - Special Sensor J, second generation (Not covered here)

To detect energetic electrons over a range of energies associated with the visible aurora.

SSL - Special L (Not covered here)

To detect lightning flashes during the night.

4.4.1.1 DMSP 5B/C Series Sensor AVE Package (SAP)

The SAP consisted of two scanning radiometers (Table T.4.4.1.1.a) mechanically coupled, i.e., one scanning mirror was driven by the other through a geared assembly. One of the scanning radiometers was a high resolution two channel device collecting data in the visible .4 to 1.1 μm and in the thermal IR 8 to 13 μm. The spatial resolution at nadir for the visible band was about 3.7 km and for the thermal IR band was about 4.4 km. The resolution for both channels deteriorated with the off-nadir angle.

The second scanning radiometer was a very high resolution two channel device covering the same spectral ranges as the high resolution radiometer. The ground resolution at nadir for both channels was about .6 km and deteriorated with off-nadir angle.

The very high resolution visible channel is referred to as VHR, Very High Resolution, and the thermal IR very high resolution channel as WHR. The high resolution visible channel is referred to as HR, High Resolution, and the thermal IR channel referred to interchangeably as IR or MI (mode infrared.).

The high resolution visible channel was sufficiently sensitive to respond to a moonlit scene and city lights at night, hence data from this band as well as the high resolution thermal IR band were collected and transmitted day and night.

The very high resolution radiometer collected more data than the satellite could process and transmit. In addition the visible band was not sufficiently sensitive to respond at night. For these reasons VHR data were generally collected and transmitted during the day and WHR data during the night. However, this schedule was altered under special conditions.

Table T.4.4.1.1.a Characteristics of the DMSP Block 5B/C

Sensor AVE Package (SAP)

	Channel			
	HR	MI	VHR	WHR
Spectral Range (micrometers)	.4 - 1.1	8 - 13	.4 - 1.1	8 - 13
IFOV (milliradians)	4.56	5.33	.766	.766
Ground Resolution @ Nadir (kilometers)	3.7	4.4	.60	.60
Ground Resolution @ Swath Edge (kilometers)				
Rotation Rate (rpm)	106.8	106.8	320.4	320.4
Scan Line Separation @ Nadir (meters)				
Sample Rate $(seconds)^{-1}$				
Pixel Separation @ Nadir (meters)				
FOV (degrees)	112.5	------------------------------>		
Swath Width (kilometers)	3025	------------------------------>		

The length of the scan line for both sensors, high resolution and very high resolution, was about 1600 km.

HR sensor data proves difficult to interpret because the gain could be and was varied along the scan line. The reason for adding this degree of control was that as the satellite crossed the terminator (the line separating the sunlit part of the Earth from the dark side), the upwelling radiation changed substantially. To compensate for this, the gain was increased as the ground scene became progressively darker. In addition, the gain along the entire scan line for the sensor could be increased to permit data collection at night.

Finally the DMSP system included a data processor called the DDS, Data Display Segment, for image generation from the digital data output by the two scanners that arrived at the ground station. This system corrected for orbital anomalies and foreshortening, and provided the capability of selecting segments of the data for display. This system, which includes several sets of enhancement modes, is described in detail in the <u>DMSP User's Manual</u>. Data which have been archived may have been processed in any one of the optional modes and will be available <u>only</u> in that mode.

4.4.2 Additional Information for DMSP Block 5 B/C

Documentation:

The most descriptive document for DMSP is the user's guide written for the Block 5B/C series.

Defense Meteorological Satellite Program (DMSP) User's Guide, Dickinson, L.G., S.E. Boselly, III, and W.S. Burgmann, Air Weather Service (MAC), United States Air Force, AWS-TR-74-250, December, 1974.

This document may be obtained from:

National Technical Information Service (NTIS)
Springfield, Virginia 22161
Order No.: AD-A007673
Cost: $6.50

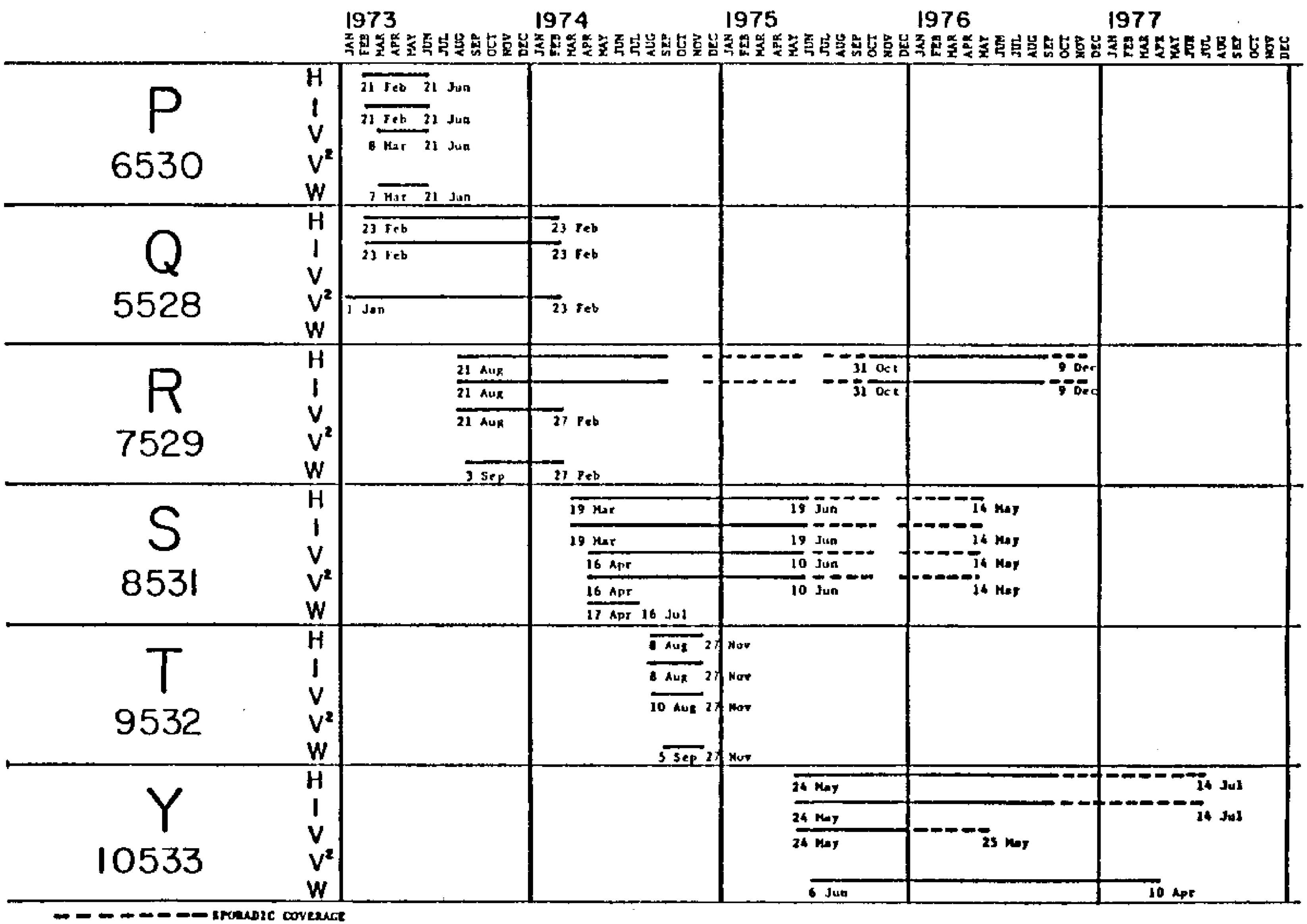
4.4.3 DMSP Block 5B/C Data Availability

DMSP data are stored in image form at the Space Science Engineering Center (SSEC) of the University of Wisconsin under contract to NOAA/EDIS. Digital DMSP data is in general not available. Several users have obtained the raw data tapes by special arrangement with the Air Force while the system was in operation. (None of the block 5 B/C DMSP satellites are currently operational.) Figure F.4.4.3.a shows that data held in the SSEC DMSP archive.

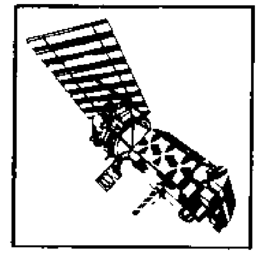
The SSEC receives positive transparent film from the Air Force in lengths varying from one to eight feet. The film is 9 1/2 inches wide. See Appendix VII for a description of DMSP data products available from the Space Science Engineering Center at the University of Wisconsin and a description of the procedure by which such data are ordered.

Figure 4.4.3.a

DMSP C SERIES ARCHIVE COVERAGE*



*From The Space Sciences Engineering Center, University of Wisconsin



5 The DMSP Block 5D Satellite Series

5.1 Objectives

- To provide globally recorded visual and infrared cloud cover and other specialized environmental data to the Air Force Global Weather Central (AFGWC).
- To provide real time direct readout of local area environmental data to mobile receiving terminals at key locations throughout the world.
- To continue the advancement of environmental satellite technology to meet Department of Defense requirements.

5.2 General

The Block 5D series was introduced in September, 1976, as a follow-on to the Block 5B/C series. As with the Block 5B/C satellites, the primary sensor was a line scanner with visible and thermal IR channels. However the operation of this sensor was quite different. Like the 5B/C series this series also flew supplementary sensors designed to measure additional atmospheric phenomena.

5.3 Orbital Characteristics of the DMSP Series

Like the DMSP satellites, the NOAA series satellites are in a near-polar, sun-synchronous orbit (see Table II.3). They fly approximately 820 km above the surface of the earth with an orbital period of about 102 minutes. There were generally two satellites in the series collecting data simultaneously, one at about noon (ascending) and midnight (descending) and the other at about dawn (ascending) and dusk (descending). The F4 spacecraft did not fit into this scheme, having a mid evening, 2200 local suntime, ascending node and a mid morning, 1000 local sun time, descending node. The sensors were configured to collect data over the entire earth four times a day, at each of the times listed above. The inclination of the orbit required to maintain the sun-synchronous relationship was 98.7°. The inclination defines the northernmost and southernmost satellite subpoint which for DMSP was 81.3° N/S.

During the orbital period of 102 minutes the earth rotated under the satellite and the orbit of the satellite precessed slightly. The result was that each ascending node of the satellite was 25.4° west of the previous one. Since the satellite did not make an integer number of orbits in one day, the ground tracks did not repeat from one day to the next. In the case of DMSP there were about 14.2 orbits per day. Another way of looking at this is that consecutive sets of 14 orbits were offset by 4.54°, each set being this distance east of the previous set.

Three-axis attitude stabilization was achieved with automatic momentum exchange between the three momentum flywheels. The attitude determination and control subsystem stabilized the spacecraft to .01° (3 sigma) with a maximum rate of .03°/second (3 sigma). Should this system have failed, a backup system existed which maintained spacecraft attitude to .1°.

5.4 DMSP Block 5D Satellites F1, F2, F3 and F4

As was done with the Block 5B/C series all spacecraft in the 5D series are discussed collectively. The distribution of Block 5D sensors is indicated in Table T.5.4.a.

Table T.5.4.a DMSP Block 5D Sensor Distribution

Satellite	OLS	SSH	SSM/T	SSC	SSD
F1	1	0	0	0	0
F2	1	1	0	0	0
F3	1	1	0	0	0
F4	1	1	1	1	1

1 - Sensor present

0 - Sensor absent

5.4.1 DMSP Block 5D Sensor Objectives

OLS - Operational Linescan System (Section 5.4.1.1)

- To provide global, day/night observations of cloud cover and temperature to support Department of Defense requirements for operational weather analysis and forecasting.

SSH - Special Sensor H, also Vertical Temperature Profile Radiometer (Section 5.4.1.2)

- To obtain vertical temperature, water vapors and ozone profiles.

SSM/T - Microwave Temperature Sounder (Not covered here)

- To provide for vertical temperatures from the earth's surface to above 30 km.

SSC - Special Sensor C also Snow/Cloud Discriminator

- To, in conjunction with the OLS, discriminate between snow cover and clouds.

SSD - Special Sensor D also Atmospheric Density Sensor

- To measure day-glow emissions from Oxygen (O) and Nitrogen (N_2).

Plus other sensors designed to measure electrons, gamma rays, ionospheric plasma, X-rays, etc.

5.4.1.1 DMSP Block 5D Operational Linescan System (OLS)

This was an improved version of the SAP flown on the Block 5B/C series. See Table T.5.4.1.1.a for a listing of the sensor characteristics. The operation of this scanner was somewhat different from that of the other meteorological satellites in that the mirror oscillated rather than rotated. This means that consecutive scans were performed in opposite directions. One of the improvements was the near-constant resolution across a scanline, with optical compensation for image motion. Another feature of the OLS was compensation for large variations in the level of reflected light as the satellite crossed the terminator. The terminator is the circle around the earth which separates night from day. Another way of stating this is that it is the circle defined by the intersection of the earth's surface and a plane normal to the Earth-Sun vector. As the instrument scanned from one side of the terminator to the other, the amount of reflected light changed quite rapidly. The gain of the sensor was adjusted in steps along the scan line to compensate for this. The gain was also adjusted from one scan line to the next to compensate for changes in received light as the satellite advanced.

The very high resolution data .6 km were collected in the thermal IR day and night, and in the visible during the day. The data could be smoothed to 2.8 km by an onboard processor for storage when the satellite was out of range of a receiver. These data were then transmitted when the satellite flew over a receiving station.

A photomultiplier tube was used to collect reflected and emitted visible radiation during the night, down to an illumination corresponding to a quarter moon.

Table T.5.4.1.1.a Characteristics of the DMSP Block 5D Operational Linescan System (OLS)

	Channel 1	Channel 2	Channel Photomultiplier
Spectral Range (micrometers)	.4 - 1.1	8.0-13.0	
IFOV (milliradians)	.66	.66	3.33
Ground Resolution @ Nadir (Kilometers)	.60	.60	2.8
Ground Resolution @ Swath Edge (kilometers)	.60		
Scan lines per minute	712.8	--------->	
Scan Line Separation @ Nadir (kilometers)	.60	--------->	
Sample Rate (seconds)$^{-1}$			
Pixel Separation @ Nadir (meters)			
FOV (degrees)	112.5	--------->	
Swath Width (kilometers)	3012	--------->	

5.4.1.2 DMSP Block 5D Special Sensor H (SSH)

This sensor also known as the Vertical Temperature Profile Radiometer was a cross-track scanning, multi-channel filter radiometer similar to the TIROS-N HIRS/2 described in Section 3.4.1.2. The sensor was introduced on the second Block 5D spacecraft, F2, and included on the remaining two, F3 and F4. The SSH provided 16 radiance measurements in the infrared region of the electromagnetic spectrum: six in the 15 μm carbon dioxide band; one in the 10 μm ozone band; one in the 12 μm window; and eight in the rotational water vapor band between 18 μm and 30 μm. See Tables T.5.4.1.2.a and T.5.4.1.2.b.

Like the TIROS-N HIRS-2, scanning was achieved by stepping the field of view across the scan line. For the SSH there were twenty-five 4^o steps over a 96^o range centered on nadir. See Figure F.5.4.1.2.a. The instantaneous field of view of 2.5^o provided for approximately 38 km resolution at nadir and 63x117 km resolution at the swath edge approximately 1000 km from nadir. The pixel separation was 60 km along the scan line at nadir and 153 km at the swath edge. The along track separation of scan lines (or pixels) was about 203 km.

In flight calibration was accomplished once every scan line (once every 32 seconds) by exposing all sixteen channels to a cold source (space) and a warm source (an internal black body). The calibration values were also returned in the data stream.

Table T.5.4.1.2.a Characteristics of the DMSP Block 5D Special Sensor H (SSH)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	9.67-9.91	11.9-12.1	13.2-13.6	13.6-14.0	13.9-14.3
IFOV (degrees)	2.7	----------------------------------->			
Ground Resolution @ Nadir (kilometers)	38	----------------------------------->			
Ground Resolution @ Swath Edge (kilometers)	117x63	----------------------------------->			
Scan lines per minute	1.375	----------------------------------->			
Scan Line Separation @ Nadir (kilometers)	203	----------------------------------->			
Sample Rate $(\text{seconds})^{-1}$	1	----------------------------------->			
Pixel Separation @ Nadir (kilometers)	60	----------------------------------->			
FOV (degrees)	96	----------------------------------->			
Swath Width (kilometers)	1993	----------------------------------->			

Table T.5.4.1.2.a (Cont'd) Characteristics of the DMSP Block 5D Special Sensor H (SSH)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	14.2-14.6	14.6-15.0	14.39-15.05	18.2-19.3	23.8-25.2
IFOV (degrees)	2.7	----->			
Ground Resolution @ Nadir (kilometers)	38	----->			
Ground Resolution @ Swath Edge (kilometers)	117 x 63	----->			
Scan lines per minute	1.375	----->			
Scan Line Separation @ Nadir (kilometers)	203	----->			
Sample Rate (seconds)$^{-1}$	1	----->			
Pixel Separation @ Nadir (kilometers)	60	----->			
FOV (degrees)	96	----->			
Swath Width (kilometers)	1993	----->			

Table T.5.4.1.2.a (Cont'd) Characterics of the DMSP Block 5D Special Sensor H (SSH)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	21.8–23.6	22.7–25.0	25.9–27.6	24.5–25.8	27.0–29.4
IFOV (degrees)	2.7	---------->			
Ground Resolution @ Nadir (kilometers)	38	---------->			
Ground Resolution @ Swath Edge (kilometers)	117 x 63	---------->			
Scan lines per minute	1.875	---------->			
Scan Line Separation @ Nadir (kilometers)	203	---------->			
Sample Rate $(seconds)^{-1}$	1	---------->			
Pixel Separation @ Nadir (kilometers)	60	---------->			
FOV (degrees)	96	---------->			
Swath Width (kilometers)	1993	---------->			

Table T.5.4.1.2.a (Cont'd) Characteristics of the DMSP Block 5D Special Sensor H (SSM)

	Channel 1	2	3	4	5
Spectral Range (micrometers)	27.4-29.2				
IFOV (degrees)	2.7				
Ground Resolution @ Nadir (kilometers)	38				
Ground Resolution @ Swath Edge (kilometers)	117 x 63				
Scan lines per minute	1.875				
Scan Line Separation @ Nadir (kilometers)	203				
Sample Rate $(seconds)^{-1}$	1				
Pixel Separation @ Nadir (kilometers)	60				
FOV (degrees)	96				
Swath Width (kilometers)	1993				

Table T.5.4.1.2.b Special Sensor H Parameters†

Center µm	Center cm^{-1}	Width cm^{-1}	Species	Absorption	NESR*	Number
9.8	1022	12.5	O_3	-----	0.05	Z1
12.0	835	8	Window		0.11	E8
13.4	747	10	CO_2	least	0.12	E6
13.8	725	10	CO_2	↓	0.11	E5
14.1	708	10	CO_2	↓	0.11	E4
14.4	695	10	CO_2	↓	0.11	E3
14.8	677	10	CO_2	↓	0.09	E2
15.0	668	3.5	CO_2	most	0.30	E1
18.7	535	16	H_2O	least	0.15	E7
24.5	408.5	12	H_2O	↓	0.14	F6
22.7	441.5	18	H_2O	↓	0.09	F4
23.9	420	20	H_2O	↓	0.12	F3
26.7	374	12	H_2O	↓	0.18	F7
25.2	397.5	10	H_2O	↓	0.16	F2
28.2	355	15	H_2O	↓	0.25	F1
28.3	353.5	11	H_2O	most	0.33	F8

*NESR = Noise Equivalent Spectral Radiance in ergs/sec - cm^2-ster-cm^{-1}

†From the DMSP Special Sensor H (SSH) Users' Guide Page 2

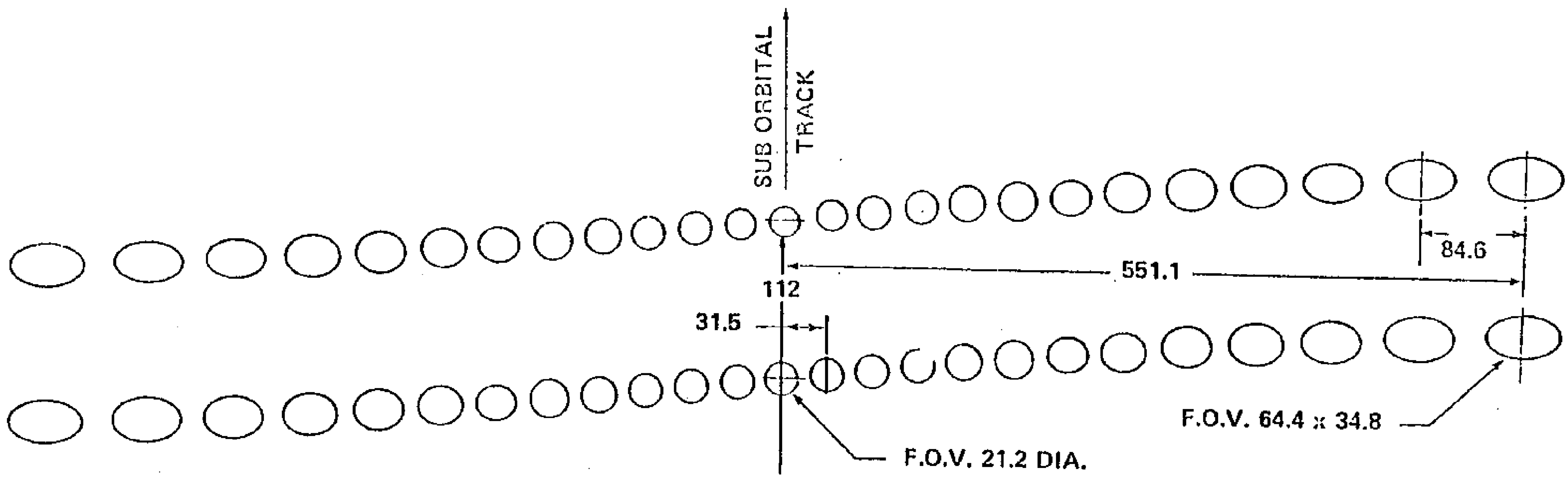


Figure F.5.4.1.2.a SSH Scan Pattern-Earth Projection†

†From the DMSP Special Sensor H (SSH) Users' Guide Page 4

5.4.2 Additional Information

An excellent general description of the DMSP system, with emphasis on the 5D series, is available in a special issue of Optical Engineering, Vol. 14, #4, July/August, 1975.

1. "The Defense Meteorological Satellite Program," by David A. Nichols, pp. 273-278.

2. "Primary Optical Subsystem for DMSP Block 5D," by David A. Nichols, pp. 279-283.

3. "DMSP Block 5D Special Meteorological Sensor H, Optical Subsystem," by David A. Nichols, pp. 284-288.

The SDSD will send on request a copy of the SSH user's guide.

"DMSP Special Sensor H Users' Guide"
National Climatic Center
Satellite Data Services Division
Applications Branch, June 1979

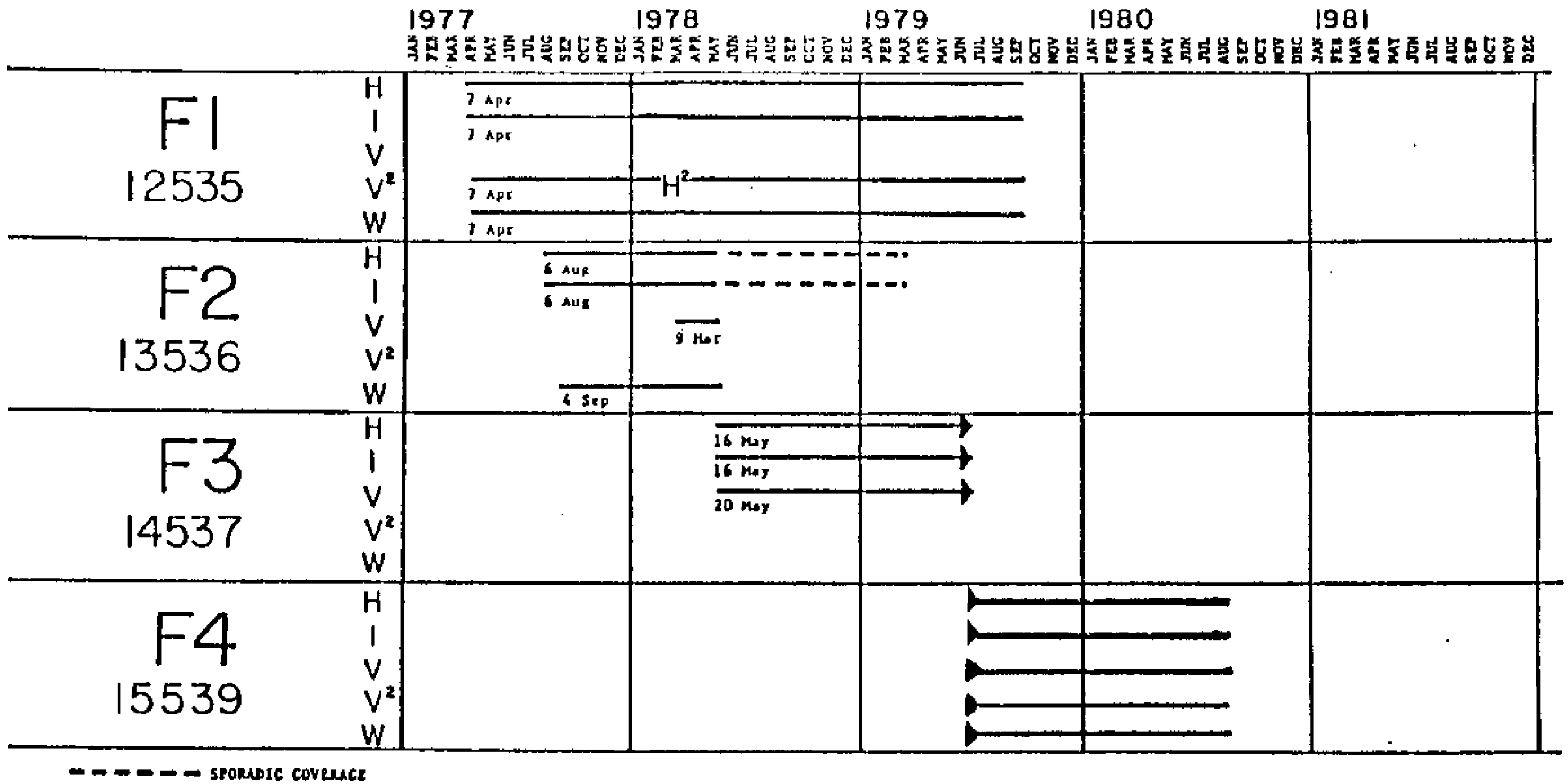
5.4.3 Data Availability

As with the Block 5B/C series, all archived Block 5D linescan imagery available to the public is stored at the DMSP library of the Space Sciences Engineering Center (SSEC), University of Wisconsin. See section 4.4.3 and Appendix VII for a description of the type of imagery archived. To order Block 5D imagery the user is also referred to Appendix VII. Figure F.5.4.3.a shows those periods for which Block 5D imagery has been archived at the SSEC.

Special Sensor H (SSH), digital data are available from the SDSD. See Appendix I for cost information of digital data provided by the SDSD and Appendix II for instructions on ordering from the SDSD.

Figure F.5.4.3.a

DMSP D SERIES ARCHIVE COVERAGE*



*From The Space Sciences Engineering Center, University of Wisconsin

OPERATIONAL GEOSYNCHRONOUS METEOROLOGICAL SATELLITES

The SMS/GOES series forms the second component of NOAA's two component meteorological satellite system. These satellites being geostationary provide near continuous (every half hour) coverage of the weather over the United States and adjacent waters. Of course, they also view much of the southern hemisphere. Because of the orbital altitude required to maintain a geostationary orbit the data is of lower spatial and radiometric resolution than that of the polar orbiting satellites, the other component. Also because the satellites orbit the equator, coverage of the poles is not possible. In recent years other countries have launched geostationary meteorological satellites to cover other regions of the world thus complementing the two United States satellites. (See Table II-4 and Figure F.6.3.a.)

Geostationary satellites generally survive longer than their polar orbiting counterparts for several reasons. First, the satellites are always within range of data receiving stations, therefore, there is no need to rely on on-board tape recorders (often the first piece of equipment to fail) to save data collected when the satellite is out of range. Second, the environment of the geostationary satellite is less hostile, containing less particles, lacking the dramatic fluctuations on a daily basis of solar radiation, etc., than that of the polar orbiters. Finally, geoidal perturbations on the orbit, atmospheric drag, etc., are much less pronounced so less fuel is required to maintain the proper orbit. For these reasons all five of the United States launched geostationary satellites were still partially operational as of the writing of this document.

The SMS/GOES satellites were preceeded by a series of geostationay research satellites referred to as the Applications Technology Satellites (ATS). Although these satellites were used primarily to demonstrate satellite communications technology, they did carry high resolution cameras for atmospheric observations.

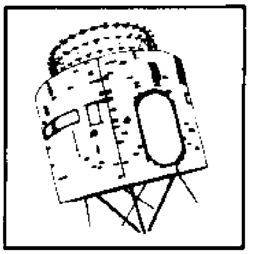
The ATS series will not be discussed here, their data existing only on imagery and being of comparatively low quality compared to the SMS/GOES VISSR data.

Table II-4

OPERATIONAL METEOROLOGICAL SATELLITES (CIVILIAN)

(Geostationary)

Satellite Name (Alias)	Launch (Date)	Limit of Data Archive (Date)	Period (Minutes)	Periapsis (km)	Apoapsis (km)	Inclination (Degrees)
SMS 1	5/17/74	1/7/76	1340	32345	35439	1.9°
SMS 2	2/6/75	8/4/81	1436	35778	35799	1.0°
GOES 1 (SMS-C)	10/16/75	3/15/80	1412	34165	36458	1.0°
2	6/16/77	9/15/80	1436	35266	36304	.9°
3	6/16/78	3/5/81	1451	35469	36679	1.7°
4	9/9/80	present	1440	35786	35786	1.0°
5	5/15/81	present	1440	35786	35786	1.0°
METEOSAT 1	11/23/77	11/25/78	1411	34913	35692	.7°
METEOSAT 2	6/19/81	present	1440	35600	35600	0.0°
GMS	7/14/77	present	1429	35531	35779	0.0°
GMS-2	8/10/81	present	1440	36000	36000	29.0°



6 The SMS/GOES Satellite Series

6.1 Objectives

1. To provide high quality day/night cloud cover data and to make radiance temperature measurements of the earth/atmosphere system.
2. To relay weather information from a central facility to small APT (automatic picture transmission) equipped regional stations.
3. To collect and retransmit data from remotely located Earth-based platforms.
4. To measure proton, electron and solar x-ray fluxes as well as magnetic fields.

6.2 General

See the introduction to this section on Operational Geosynchronous Meteorological Satellites.

6.3 Orbital Characteristics for the SMS/GOES Series

The SMS/GOES satellites are in a geosynchronous equatorial orbit. This is an orbit for which the satellite circles the earth's equator at the same rate at which the earth rotates. In this fashion the satellite appears to remain stationary above a given point on the earth. These orbits put the satellite approximately 35,800 km above the earth's surface and thus permit a view of a large portion of the earth's surface at one time. Data for the edges of the image are, however, not useable because of foreshortening. Tables in subsequent sections indicate the approximate location of the various satellites as a function of time. These positions are changed from time to time to meet specific objectives, i.e., a given satellite may be moved forward or backward in its orbit to a new location to replace one that is failing or to supplement the data collection effort of a given program.

For example, SMS-1 was stationed at 45°W from the fall of 1974 to early 1976 in support of the Global Atmospheric Research Program (GARP) Atlantic Tropical Experiment (GATE). In February of 1976 SMS-1 was moved to 105° W and placed in standby mode as backup to either SMS-2 or GOES-1. Because the various satellites are moved around in this fashion, the terms GOES-EAST and GOES-WEST are now used for the satellites at 75° W and 135° W, respectively, rather than the name of the specific satellite. The areas of coverage for the GOES satellites as well as the other geosynchronous meteorological satellites in the global system are shown in Figure F.6.3.a. The Soviet satellite in the system has not yet been launched.

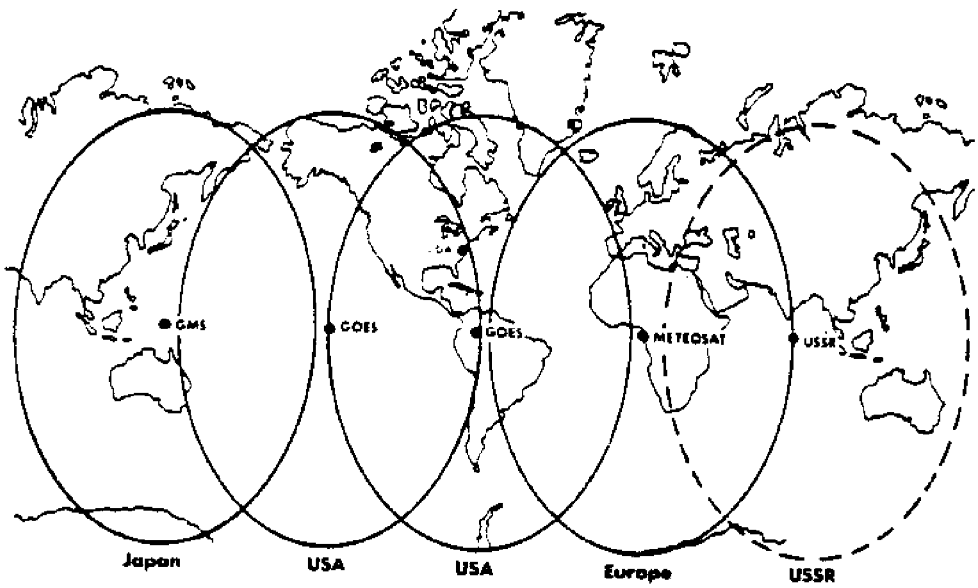


Figure F.6.3.a POSITIONS OF GEOSTATIONARY SATELLITES *

*From The Satellite Data User's Guide, Vol. I, #2, Page 34

6.4 SMS-1

SMS-1 was the first prototype for the geosynchronous series of meteorological satellites. It was launched on May 14, 1974 and until it was placed in standby mode in January of 1976 it occupied a number of positions. This history is summarized in Table T.6.4.a. The alternate designation for SMS-1 during the period that it occupied the location at 75° West was GOES-EAST. This was because of its position near the east coast of the continental U.S.

Table T.6.4.a SMS-1 History

Date or Period	Comment
5/17/74	Launch
6/7/74	Arrives on station at 45° West
6/27/74 - 9/21/74	Operational at 45° West
9/21/74 - 11/15/74	Moved to 75° West
11/15/74 - 1/8/76	Operational at 75° West as GOES-EAST
2/16/76 - 1/9/79	On Standby at 92° West
1/9/79 - 1/26/79	Moved to 75° West
1/26/79 - 4/19/79	Operational at 75° West as GOES-EAST
3/19/81	Operational support terminated

6.4.1 SMS-1 Sensor Objectives

VISSR - Visible Infrared Spin Scan Radiometer (Section 6.4.1.1)

To provide day/night observations of cloud cover and Earth/cloud radiance temperature measurements.

DCS - Data Collection System (Section 6.4.1.2)

To receive, process and transmit meteorological data collected from remotely located Earth-based collection platforms.

SEM - Space Environment Monitor (Not covered here)

To measure particle type and energy for protons, electrons and alpha particles; to measure solar x-rays; and, to measure the earth's magnetic fields.

6.4.1.1 The SMS-1 Visible Infrared Spin Scan Radiometer (VISSR)

The VISSR (Table T.6.4.1.1.a) consisted of a set of eight radiometers in the visible (.55 to .70 μm) which collected data along adjacent scan lines as the satellite rotated. For each revolution of the satellite the collecting mirror was stepped one increment so that the data collected were adjacent to the previous set of eight scan lines. The thermal IR channel (10.5 to 12.6 μm) had two redundant radiometers which covered the same area for each scan. The fact that only one scan line was performed per revolution of the satellite covering the same width as the eight visible scan lines means that the spatial resolution in the thermal IR was much lower, 7 km at nadir, compared to .8 km by .8 km for the visible. The sampling rate of the scanner was such that the width of a pixel for the IR channel was 4 km.

The collecting mirror performed 1821 steps from north to south resulting in 14568 scan lines in the visible and 1821 in the thermal IR. Because the satellite rotated at 100 rpm it took 18.2 minutes to collect these data. A complete Earth disk of data was collected and transmitted every 30 minutes.

If the data for one region North/South were desired more frequently, e.g. to follow a hurricane, the mode could be changed to allow for this. Less data would then be collected, e.g. 910 scan lines but twice as often (every 15 minutes). The maximum rapid scan capability is every three minutes.

Table T.6.4.1.1.a Characteristics of the SMS-1 Visible Infrared Spin Scan Radiometer

	Channel 1	Channel 2
Spectral Range (micrometers)	.55-.70	10.5-12.6
IFOV (milliradians)	.021x.021	.192x.084
Ground Resolution @ Nadir (kilometers)	.78x.78	7x3
Ground Resolution @ Swath Edge (meters)		
Rotation Rate (rpm)	100 ------------->	
Scan Line Separation @ Nadir (kilometers)	.78	8
Sample Rate (seconds)$^{-1}$		
Pixel Separation @ Nadir (kilometers)	.78	3
FOV (degrees)	18 ------------>	
Swath Width (kilometers)	Earth Disc ------------>	

6.4.1.2 The SMS/GOES Data Collection System

The Data Collection System was to used to

- Collect and distribute environmental data measured on remotely located, attended and unattended data collection platforms (DCP) located on land, at sea, or in the atmosphere.

- Collect all data on a scheduled or on a request basis.

- Collect data from a minimum of 10,000 DCP's.

The DCP's were environmental sensing devices with radio transmission and reception capabilities. The uses of such platforms for the ocean consisted of buoys that drifted with the current or that collected environmental data which could be used for sea truth in other remote sensing experiments. NOAA (NESS) operated these buoys in conjunction with other organizations, agencies and institutions.

6.4.2 Additional Information

For more information on the SMS/GOES series see:

"The GOES/SMS User's Guide,"
R.P. Corbell, C.J. Callahan and W.J. Katsch
NOAA/NESS and NASA, 1976.

"VISSR Digital Arcive User's Guide,"
NOAA/EDIS/NCC, November 1978.

These documents may be ordered from:

Satellite Data Services Division
National Oceanic and Atmospheric Administration
Room 100, World Weather Bldg.
Washington, D.C. 20233

A detailed description of the Data Collection System of GOES is available in:

"Geostationary Operational Environmental
Satellite/Data Collection System,"
Office of System Engineering,
NOAA Technical Report NESS 78, July 1979.

National Technical Information Service (NTSI)
U.S. Department of Commerce
Sills Bulding
5285 Port Royal Road
Springfield, VA 22161

6.4.3 Data Availability

Data from the SMS/GOES series are available from the Satellite Data Service Division of NOAA. In some cases the digital data will be acquired from the Space Science Engineering Center of the University of Wisconsin by SDSD. The SDSD has archived all SMS/GOES imagery (film positives and negatives). Neither the SDSD nor the SSEC has archived all of the full resolution digital data.

The cost of data available from SDSD is summarized in Appendix I. Of course these costs are subject to change. Users should contact SDSD direction for current prices or quotations. In addition, special products such as the 15 day coverage discussed above have their own costs.

To order SMS or GOES data from SDSD the user is referred to Appendix II. Appendix IV describes the form of data that is transferred from the Space Science and Engineering Center at the University of Wisconsin. In particular, Appendix IV provides added insight into the general organization of GOES data at SSEC.

6.4.3.1 Holdings of Satellite Data Services Division of NOAA

The holdings of the SDSD are described in the paragraph below, abstracted from page 8 of the SDSD's Satellite Data User's Bulletin, Volume 1, Number 2, August, 1979. The table numbers have been changed to correspond to the numbering system used in this report.

> Table T.6.4.3.1a lists the known positions of the various SMS/GOES satellites from launch to the present and the date of data from each satellite on archive at SDSD. Table T.6.4.3.1.b lists the SMS/GOES still imagery products routinely available from SDSD as prints, negatives, or positive transparencies. In addition to these data products, since August 9, 1976, one Visible and five Infrared images from GOES-East and one Visible and five Infrared images from GOES-West have been placed on CCT's in digital format (9-track, 1600-bpi). Resolution of both the Infrared and Visible images is approximately 8 km at nadir. One tape per day for each satellite is archived. Only 89° of latitude, starting at 50°N, and 99° longitude, centered at the satellite sub-points, are included in each image. Some gaps in the period of record are evident because of mechanical and operational difficulties. Since September 6, 1978 3 CCT's per day, data every three hours from each satelite have been archived. The contents of these tapes are listed in Tables T.6.4.3.1.c and T.6.4.3.1.d.

For those interested in imagery (as opposed to digital data) a more complete description of the state of the SDSD archive in June, 1980, is contained in the paragraphs below, taken from pages 4 and 5 of the SDSD's Satellite Data Users Bulletin, Volume 2, Number 1, June 1980. References to figures showing the sectors and full disk images have been removed in the interest of economy, as have been the figures.

Previous to June 1979, a wet photographic process was used to reproduce these sectors, and the original negatives were available for archiving at the SDSD. However, commencing in June 1979 there has been widespread conversion from wet process to a dry facsimile process (Unifax), producing only a single paper positive without the intermediate negative. At this time, only a small selection of all available Sectors are being wet processed at the central Washington complex, with only these negatives being archived. (No Sectors are being archived from the other SFSS's.)

The only complete imagery record now being archived each day is the 4-mile (8-km) resolution Infrared, full disk image from both satellites, the 2-mile (4-km) Visible full disk image, and 1-mile (2-km) WB-1 Sector of North and Central America during daylight hours. Potential users of Sectors should first contact the SDSD to determine actual availability before placing an order. Also, the sectorizing process did not begin until the launch of SMS-1 in mid-1974, and are not available for the previous ATS-series satellites.

To overcome the problems of diminishing availability of Sectors by the conversion of the Satellite Field Service Stations (SFSS) to dry process reproduction, it is planned in the future that the SDSD will have a capability to produce Sectors upon customer demand, on its own dedicated equipment. This would be accomplished by the SDSD archiving the full resolution Visible and Infrared full disk imagery on magnetic tape. Upon receiving a customer request for a Sector at a given resolution and over a particular area, this would be produced on a dedicated Sectorizer from the archived full resolution tape. This capability will become available in early 1982. Users will be kept informed through this publication.

The positive paper prints from the Satellite Field Service Stations are not included in the SDSD Archive because of the large number involved. However, after a mandatory retention period at the Receiving Stations, the pictures are deposited at a local university within the region covered by the images, where they are available for use in a library mode. Present depositories are:

SFSS	COVERAGE	UNIVERSITY
San Francisco	Western U.S.	California State U. @ San Jose
Kansas City	Central U.S.	Texas A&M University
Washington	Eastern U.S.	University of Maryland
Miami	Florida, Gulf of Mexico, Caribbean	Miami-Dade County Community College
Honolulu	Central Pacific, Hawaii	University of Hawaii

TABLE T.6.4.3.1.a

SMS/GOES DATA

SATELLITE	POSITIONS	DATES OF DATA
SMS-1	45°W	6/27/74 - 9/21/74
SMS-1	75°W	9/21/74 - 1/ 7/76
SMS-2	115°W	3/10/75 - 12/ 9/75
SMS-2	(In Transit)	12/ 9/75 - 12/19/75
SMS-2	135°W	12/19/75 - 7/13/78
GOES-1	75°W	1/ 8/76 - 8/15/77
GOES-2	75°W	8/15/77 - 7/9/81
GOES-3	135°W	7/13/78 - 3/5/81
GOES-4	135°W	3/5/81 - present
GOES-5	75°W	7/9/81 - present

TABLE T.6.4.3.1.b

SMS/GOES STILL IMAGERY PRODUCTS

PRODUCT	RESOLUTION	AREA	QUANTITY PER SATELLITE PER DAY	-	QUANTITY PER SATELLITE PER YEAR
IR	3 km	Full Disc	45	-	16,425
VIS	4 km	Full Disc	32	-	11,680
VIS	2 km	1/4 Disc	32	-	11,680
VIS	1 & 2 km	Variable Sectors	180	-	102,200

TABLE T.6.4.3.1.c
CONTENTS OF GOES-EAST DIGITAL ARCHIVE

TAPE ID #	TIMES (GMT)	IR/VIS	DATES ON ARCHIVE
	0930	IR	August 9, 1976 to Present
	1000	IR	August 9, 1976 to Present
	1600	IR	August 9, 1976 to Present
(VDBAR-1)	1600	VIS	August 9, 1976 to Present
	2130	IR	August 9, 1976 to Present
	2200	IR	August 9, 1976 to Present
	0000	IR	September 6, 1978 to Present
	0000	VIS	September 6, 1978 to Present
	0300	IR	September 6, 1978 to Present
(VDBAR-3)	0600	IR	September 6, 1978 to Present
	0900	IR	September 6, 1978 to Present
	1200	IR	September 6, 1978 to Present
	1500	IR	September 6, 1978 to Present
	1500	VIS	September 6, 1978 to Present
	1800	IR	September 6, 1978 to Present
(VDBAR-4)	1800	VIS	September 6, 1978 to Present
	2100	IR	September 6, 1978 to Present
	2100	VIS	September 6, 1978 to Present

TABLE T.6.4.3.1.d
CONTENTS OF GOES-WEST DIGITAL ARCVHIVE

TAPE ID #	TIMES (GMT)	IR/VIS	DATES ON ARCHIVE
	1015	IR	August 9, 1976 to Present
	1045	IR	August 9, 1976 to Present
	1515	IR	August 9, 1976 to Present
(VDBAR-2)	1545	IR	August 9, 1976 to Present
	2145	IR	August 9, 1976 to Present
	2145	VIS	August 9, 1976 to Present
	2345	IR	September 6, 1978 to Present
	2345	VIS	September 6, 1978 to Present
	0245	IR	September 6, 1978 to Present
(VDBAR-5)	0545	IR	September 6, 1978 to Present
	0845	IR	September 6, 1978 to Present
	1145	IR	September 6, 1978 to Present
	1445	IR	September 6, 1978 to Present
	1445	VIS	September 6, 1978 to Present
	1745	IR	September 6, 1978 to Present
(VDBAR-6)	1745	VIS	September 6, 1978 to Present
	2045	IR	September 6, 1978 to Present
	2045	VIS	September 6, 1978 to Present

MICROFILM ARCHIVE

The SDSD is currently in the process of reducing to microfilm hourly full disk IR and Visible GOES/EAST imagery from the period September 1974 to July 15, 1979. Fifteen days of data are contained on a single 100-foot 35mm film reel. When this period is complete, SDSD plans to continue with the reduction on a continuing basis, and will also do this for the GOES/WEST Satellite. Currently GOES-WEST microfilm are available from March, 1975 through July 1, 1980. Each 15-day period is available in positive or negative 35mm copies for $23.50 each.

6.4.3.2 Holdings of the Space Science and Engineering Center, University of Wisconsin

The digital archive at the SSEC of SMS/GOES data is shown in Table T.6.4.3.2.a. The reader is referred to Appendix IV for a detailed discussion of the two tape formats available. This information should aid the user in determining what is required when placing an order. Remember these data must be ordered through the SDSD. The SSEC is currently preparing a manual describing the SMS/GOES digital data tape format. This manual should be available in "late 1981."

Table T.6.4.3.2.a

SSEC VISSR Holdings

Satellite	Period of data
GOES-EAST	March, 1978 to present
GOES-WEST	November, 1978 to present
GOES Indian Ocean	December 1, 1978 to November 30, 1979
GMS (Japanese Satellite)	December 1, 1978 to November 30, 1979

Note: These data all exist at full resolution in digital form from when the VISSR was operational.

6.5 SMS-2

SMS-2 was the second prototype for the geosynchronous series of meteorological satellites. It was launched on February 6, 1975 and, except for its location, it was identical to SMS-1 in all respects. Table T.6.5.a summarizes its position as well as other important dates of its history. The user is referred to the discussion of SMS-1 section 6.4 for all other particulars of the satellite and its sensors.

Table T.6.5.a SMS-2 History

Date or Period	Comments
2/6/75	Launch
2/22/75	On station at 115° West
3/10/75 - 12/9/75	Operational at 115° West as GOES-WEST
12/9/75 - 12/19/75	Moved to 135° West
12/19/75 - 7/13/78	Operational at 135° West as GOES-WEST
4/19/79	Replaced SMS-1 as GOES-EAST

6.6 GOES-1

GOES-1 was the first operational satellite in the geosynchronous series and it was designed and built as an exact duplicate of the two prototypes SMS-1 and SMS-2. It was launched on October 16, 1975 and operated as GOES-EAST at 75° West (Table T.6.6.a), replacing SMS-1. In November of 1978, it was moved to 59° East. This is the approximate location that the Soviet geosynchronous meteorological satellite was to have occupied. While in this location it was operated by the ESA, the European Space Ageney.

For details regarding the satellite, its sensor or documentation and data availability, the user is referred to the discussion on SMS-1, section 6.4 .

Table T.6.6.a GOES-1 History

Date or Period	Comments
10/16/75	Launch
12/18/75	On station at 75° West
1/8/75 - 8/15/77	Operational at 75° West as GOES-EAST
11/29/78	Operational at 59° East operated by the European Space Agency.

6.7 GOES-2

GOES-2, identical in all respects except for satellite location to SMS-1, SMS-2 and GOES-1, replaced GOES-1 as GOES-EAST in August of 1977. Its history is summarized in Table T.6.7.a.

For all other information the user is referred to section 6.4.

Table T.6.7.a GOES History

Date or Period	Comments
6/16/77	Launch
8/15/77 - 1/26/79	Operational at 75° West as GEOS-EAST

6.8 GOES-3

Like GOES-1 and GOES-2, GOES-3 is a duplicate of the prototypes SMS-1 and SMS-2. GOES-3 replaced SMS-2 as GOES-WEST in July of 1978 as summarized in Table T.6.8.a.

For all details related to GOES-3 the reader is referred to section 6.4.

Table T.6.8.a GOES-3 History

Date or Period	Comments
6/16/78	Launch
7/13/78	Operational at 135° West as GOES-WEST

6.9 GOES-4

The first five geosynchronous meteorological satellites (SMS-1 to GOES-3) were for all practical purposes identical in design and construction. GOES-4, launched in September 1980, however, showed substantial modifications. In particular, the primary sensor, VISSR, included a numer of new channels (see Section 6.9.1.1). Because of these design changes, GOES-4 is viewed by some as the first satellite in the second generation, operation, geosynchronous meteorological satellite series. In this document GOES-4, with the same basic platform as the previuos satellites and similar orbital characteristics, is considered as the same generation but with an improved primary sensor.

Engineering checkout at 100°W longitude lasted through October 1980. Problems at the Wallops Island ground station were rectified in this time frame. Useful data gathering began October 11, 1980 and continued on and off until GOES-4 replaced GOES-3 at 135°W longitude as the operational VISSR on March 5, 1981.

6.9.1 GOES-4 Sensor Objectives

VAS - Visible Infrared Spin-Scan Radiometer Atmospheric Sounder (Section 6.9.1.1).

To provide high-quality day/night cloud cover data.

To take radiance temperatures of the earth/atmosphere system.

To determine atmospheric temperature and water content at various levels.

Meteorological Data Collection and Transmission System (Section 6.4.1.2).

To relay processed data from central weather facilities to small Automatic Picture Transmission (APT) equipped regional stations.

To collect and retransmit data from remotely located earth-based platforms.

SEM - Space Environment Monitor (not covered here)

To measure particle type and energy for protons, electrons and alpha particles.

To measure solar x-rays.

To measure the earth's magnetic field.

6.9.1.1 Visible Infrared Spin-Scan Radiometer Atmospheric Sounder (VAS)

The VAS is an improved version of the VISSR flown on the SMS and early GOES satellites. The improvements consist of the addition of several infrared detectors, the addition of an infrared filter wheel in the optical train and the capability of operating the instrument in several different modes. The filter wheel consists of twelve filters (see Table T.6.9.1.1.b for a listing of the spectral bands) anyone of which may be placed in the optical path. A filter is selected for an entire scan line (one rotation of the satellite), i.e. the wheel is not rotated while the earth is being viewed. Scanning is achieved as for the earlier GOES satellites by the rotation of the satellite. See section 6.4.1.1 for a more detailed description of this process. The filtered radiation is then directed to one of the three pairs of infrared detectors. The basic characteristics of the detectors are summarized in Figure F.6.9.1.1.a and Table F.6.9.1.1.a. The actual pair of detectors used is a function of the mode in which the instrument is operating as well as which filter on the filter wheel is being used. For example, the large indium antimonide (InSb) detectors are used only with filters 6,11 and 12, the small mercury-cadmium-telluride (HgDcTe) detectors are used only with filters 3,4,5,7,8,9 and 10, while the large HgDcTe detectors are used with all but filters 6,11 and 12. (See table T.6.9.1.1.b for the correspondence between the filter numbers used above and the filter characteristics.)

The instrument may be operated in one of three modes. For the time being the mode in use most of the time is the VISSR mode. In this mode the data collected is similar to that of the earlier GOES

VISSR instruments. The visible data covers the same spectral range and provides the same spatial resolution. (See section 6.4.1.1 for more details.) For the infrared data the small HgCdTe detectors are used with filter 8. The spatial resolution of this detector is somewhat finer than with the previous GOES providing approximately 7 km resolution compared to 8 km.

The second mode, the multispectral imaging (MSI) mode, is to be the primary one in which the sensor will operate, the VISSR mode being a fall back one to be used when power becomes a problem (as the satellites age.) As indicated above, this is not the mode in current use now. This is because the down link for MSI mode data is different than that for VISSR mode data and only Goddard and the University of Wisconsin are capable of receiving these data. In the MSI mode every other scan line is used to provide the infrared portion of the normal VISSR mode data, the two small HgCdTe detectors scanning adjacent lines simultaneously. The alternate scan lines are then used with the large detectors to provide data on radiation at other wavelengths with a coarser resolution of 13.8 km.

The third mode in which the sensor may operate is the sounding mode, referred to as the dwell mode. In this mode of operation the sensor may dwell on one scan line for a number of satellite revolutions. During this time as many as 12 filters may view the scan line with different combinations of detectors. In addition, any filter/detector combination may view the same scan line several times to obtain a better signal-to-noise ratio. Typically, 50 scans (satellite rotations) of one line are required to obtain the desired sounding data. Note that when using the sounding mode complete earth coverage at 7 km is no longer possible.

Because the VAS is a new instrument with a number of options in terms of its mode of operation, firm decisions have not yet been made as to how it will operate in the future.

Table T.6.9.1.1.a Characteristics of the GOES-4 Visible Infrared Spin-Scan Radiometer Atmospheric Sounder (VAS)

	Channel 1	2	3	4	5
Spectral Range* (micrometers)	.55-.72	6.7-14.7	6.7-14.7	3.9-4.5	3.9-4.5
IFOV (milliradians)	.025x.021	.192x.192	------>	.384x.384	------>
Ground Resolution @ Nadir (kilometers)		6.9 x 6.9	------>	13.8x13.8	------>
Ground Resolution @ Swath Edge (meters)					
Rotation Rate (rpm)	100	------------------------------------>			
Scan Line Separation @ Nadir (meters)					
Sample Rate $(seconds)^{-1}$					
Pixel Separation @ Nadir (meters)					
FOV (degrees)	20	------------------------------------>			
Swath Width (kilometers)	Earth Disc	------------------------------------>			

*The spectral range given here denotes that of the detectors. As discussed in the text a filter wheel which further restricts the sspectral range is included in the optical train. The spectral characteristics of the filters on the wheel are summarized in Table T.6.9.1.1.b.

Table T.6.9.1.1.a (Cont'd) Characteristics of the GOES-4 Visible Infrared Spin-Scan Radiometer Atmospheric Sounder (VAS)

	Channel 6	Channel 7
Spectral Range (micrometers)	6.7-14.7	6.7-14.7
IFOV (milliradians)	.384x.384	------->
Ground Resolution @ Nadir (kilometers)	13.8x13.8	------->
Ground Resolution @ Swath Edge (meters)		
Rotation Rate (rpm)	100 ----------->	
Scan Line Separation @ Nadir (meters)		
Sample Rate (seconds)$^{-1}$		
Pixel Separation @ Nadir (meters)		
FOV (degrees)	20 --------->	
Swath Width (kilometers)	Earth Disc ----------->	

Table T.6.9.1.1.b†

VAS Infrared Spectral Bands

Spectral Band	Atmos Press. (mb)	ν (cm^{-1})	λ (μm)	$\Delta\nu$ (cm^{-1})	Single Sample S/N for 320°K Scene Temperature		Remarks	
					0.192 mr IGFOV	0.384 mr IFGOV	Band	Detector Type
1	65	678.7	14.73	10	N/A	37.4	CO_2	HGCDTE
2	100	690.6	14.48	16	N/A	92.3	CO_2	HGCDTE
3	325	701.6	14.25	16	50.4	100.8	CO_2	HGCDTE
4	450	713.6	14.01	20	65.3	130.6	CO_2	HGCDTE
5	Surf.	750	13.33	20	64.1	128.3	CO_2	HGCDTE
6	700	2210	4.525	45	N/A	108.9	CO_2	IN SB
7	Surf.	790	12.66	20	60.7	121.4	H_2O	HGCDTE
8	Surf.	895	11.17	140	607.1*	953.5	Window	HGCDTE
9	375	1377.2	7.261	40	24.2	48.5	H_2O	HGCDTE
10	330	1487	6.725	150	73.7	147.4	H_2O	HGCDTE
11	280	2250	4.444	40	N/A	83.7	CO_2	IN SB
12	Surf.	2535	3.945	140	N/A	111.1	Window	IN SB

*For 340°K scene temperature

†From Execution Phase Project Plan for Operational Satellite Improvement Program Plan VISSR Atmospheric Sounder (VAS) Demonstration March. 1980 page A-2

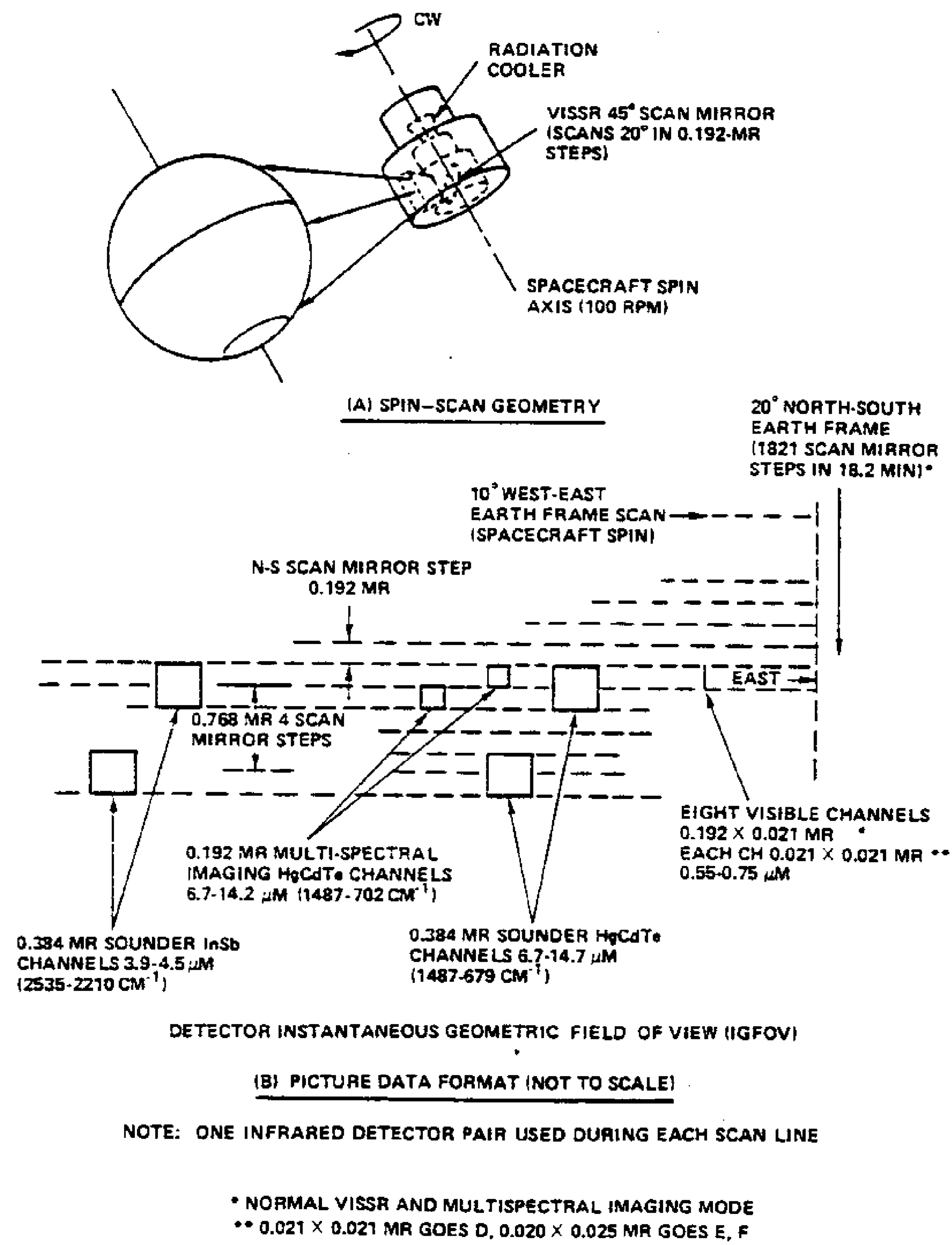


Figure F.6.9.1.1.a VAS/Spacecraft Spin-Scan Geometry and Image Data Format Arrangement†

†From Execution Phase Project Plan for Operational Satellite Improvement Program Plan VISSR Atmospheric Sounder (VAS) Demonstration March 1980 page A-3

6.9.2 Additional Information for GOES-4

The VAS system is discussed in Appendix A of:

> Execution Phase Project Plan
> for
> Operation Satellite Improvement
> Program Plan
> VISSR Atmospheric Sounder (VAS)
> Demonstration
> Goddard Space Flight Center
> Greenbelt, Maryland, 1980

For information regarding the current status of the VAS project the reader is referred to:

> Paul Menzel Tel: 608-262-6361
> Space Science and Engineering Center
> University of Wisconsin, Madison
> 1225 West Dayton St
> Madison, Wisconsin 53706

6.9.3 Data Availability

Data from the SMS/GOES series are acquired from The Satellite Data Services Division (SDSD) of NOAA. Cost of these data are summarized in Appendix I while instructions for ordering the data are contained in Appendix II. Appendix IV describes the form of data that is transferred from The Space Science and Engineering Center of The University of Wisconsin to the SDSD.

6.10 GOES-5

GOES-5 carrying VAS-E was launched in May 1981. Daily data gathering from 85°W continued until August 5, 1981 at which time GOES-5 became the operational east VISSR at 75°W. During the late summer and fall of 1981 VAS data was intermittently received on a number of days in order to permit coverage of hurricanes Emily, Floyd, Gert, Harvey, Irene, and Jose. On these days every sixth VISSR image was cancelled to enable a VAS dwell sounding. The last two weeks of July are especially data rich over the continental US, and the sounding coverage of Harvey is nearly complete.

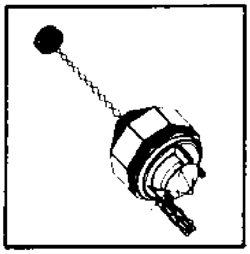
GOES-5 is similar to GOES-4. The reader is therefore referred to section 6.9 for more detailed discussion of the satellite and its sensors.

OCEANOGRAPHIC SATELLITES

To date there have been only two satellite series (see Table II-5), the missions of which have been oceanographic in nature. These are GEOS (Geodynamics Experimental Ocean Satellites, not to be confused with GOES) and SEASAT. The GEOS series included three satellites which were designed primarily for missions relating to geoidal measurements. The only instrument of interest here is the altimeter flown on GEOS-3. This instrument provided much useful scientific data as well as engineering data used for the design of the SEASAT altimeter. The other oceanographic series, SEASAT, consisted of only one satellite. Origially there was to be a second satellite in the series, SEASAT-B, but it was dropped in favor of NOSS (National Oceanic Satellite System) which has also recently been dropped. SEASAT-1, incapacitated after about 100 days of operation, provided a wealth of useful data.

Table II-5 Oceanographic Satellites

Satellite Name (alias)	Launch (Date)	Limit of Data Archive (Date)	Period (Minutes)	Periapsis (km)	Apoapsis (km)	Inclination (Degrees)
GEOS-1	1965		---	---	---	---
GEOS-2	1/11/78		112.2	1083	1577	105.4°
GEOS-3	4/9/79	12/1/78	101.8	839	853	114.9°
SEASAT-1	6/27/78	10/9/78	100.7	769	799	108.0°



7 Geodynamics Experimental Ocean Satellites

7.1 Objectives

a. To perform an in-orbit satellite altimeter experiment to determine the feasibility and utility of a spaceborne radar altimeter to map the topography of the ocean surface, measure the deflection of the vertical at sea, measure wave height, and contribute to the technology leading to a future operational altimeter-satellite system with a 10-cm measurement capability.

b. To further support the calibration of NASA and other agencies' ground C-band radar systems.

c. To perform a satellite-to-satellite tracking experiment with the ATS-6 satellite.

d. To further support the intercomparison of new and established geodetic and geophysical measuring systems.

e. To investigate solid-earth dynamic phenomena such as polar motion, fault motion, Earth rotation, Earth tides, and continental drift theory.

f. To further refine orbit-determination techniques.

g. To support the calibration of the Unified S-Band (USB) sites in the STDN.

7.2 General

The GEOS series was part of the National Geodetic Satellite Program (NGSP) which had as its major objectives:

- To generate a unified world datum with an accuracy of 10 m.

- To establish the coefficients required for mathematically describing the gravitational field of the earth in spherical harmonics of a prescribed accuracy through fifteen degrees and order.

In order to achieve these objectives a number of other satellites (Explorer 22, Explorer 27, etc.) were also used. These other satellites, as well as GEOS-1 and GEOS-2, are of little interest in remote sensing oceanography and are not discussed in this notebook. Because only GEOS-3 is covered here the objectives outlined above (section 7.1) are those specific to GEOS-3 and not to the three satellite GEOS project. It is important to note that GEOS-3 was viewed as an interim step between the nearly completed NGSP and the beginning NASA Earth and Ocean Physics Applications Program (EOPAP).

7.3 Orbital Characteristics of GEOS-3

Because none of the sensors on GEOS-3 depended on solar illumination or earth radiation, a sun-synchronous orbit was not required. For this reason the orbit followed by this satellite falls into the category labeled "general orbit" in Chapter III, i.e., neither sun-synchronous nor geostationary. The orbit was nearly circular at 843 km with an inclination of 115° and a period of 101.8 minutes. The ground coverage of such an orbit is difficult to describe as it criss-crosses any given area, very rarely repeating the same path. The radar altimeter provided fairly uniform coverage of a 1° x 1° square in about one month.

The spacecraft's gravity gradient boom with accompanying angular momentum wheels kept the spacecraft, hence the altimeter, aligned to within ± .5° of nadir 98% of the time. The various tracking systems used were capable of locating the satellite to $\pm$ 5 m in the vertical, $\pm$ 10 m in the along-track direction and $\pm$ 50 m in the across-track direction.

7.4 GEOS-3

The specific objectives of GEOS-3 are outlined in section 7.1 while its orbital characteristics are discussed in section 7.3. The primary sensor on the satellite, the radar altimeter (section 7.4.1.1) performed very well for approximately four years from April, 1975, to July of 1979. Its operation was terminated on July 1, 1979, because of serious degradation of the High Intensity Mode (3.8 km resolution) in late 1978. From late 1978 to July, 1979, the altimeter operated primarily in Global Mode (14.3 km resolution).

7.4.1 GEOS-3 Sensor Objectives

1. Radar Altimeter System (Section 7.4.1.1)

   - to determine the feasibility and utility of a spaceborne radar altimeter for mapping the topography of the ocean surface.

2. U. S. Navy Doppler System (Not covered here)

   - to aid in determining the structure of the Earth's magnetic field.

3. Satellite-to-Satellite Tracking (Not covered here)

   - to determine the accuracy of the method and the application of the data to gravity field refinement.

4. C-Band System (Not covered here)

   - range, range-rate and angle measurements.

5. S-Band Tracking System (Not covered here)

   - to provide metric range and range-rate tracking, both satellite-to-satellite and satellite-to-ground.

6. Laser Cube System (Not covered here)

   - to obtain precise satellite tracking information.

7.4.1.1 GEOS-3 Radar Altimeter System

A radar altimeter is an active device (i.e., provides the source of radiation as well as the detection of the returned signal) used to measure the height of the sensor above the underlying surface. This is done by measuring the round trip travel time for a signal sent from the spacecraft to the earth below. The GEOS-3 radar altimeter operated in one of two data gathering modes. In the short pulse mode or High Intensity Mode, six pulses per second were read by the altimeter. The input power of the altimeter was 100 watts for this mode. In the global or long pulse mode two pulses per second were read and the input power was 50 watts. In both cases the same antenna was used and the pulse carrier frequency was 13.9 GHz. The pulse was 12.5 ns wide. In the short pulse mode the range precision for a one second average (100 pulses) was $\pm$ 30 cm. This average is performed over an area on the ground or ocean approximately 3.6 km wide and 11 km long. The actual area viewed depended in general on sea state, increasing as the sea state increased.

In addition to knowing the width of the pulse, the slope of the front edge (rise time) was also known. Distortions of the front edge provided information regarding sea state, which was provided to shipping interests on an operational basis during the last years of its life.

Table T.7.4.1.1.a Characteristics of the GEOS-3 Radar Altimeter

	Short	Long
Spectral Range (GHz)	13.9	13.9
IFOV (milliradians)		
Ground Resolution @ Nadir (kilometers)	3.6	3.6
Ground Resolution @ Swatch Edge (meters)	nadir looking	
Rotation Rate (rpm)	not relevant	
Scan Line Separation @ Nadir (meters)		
Sample Rate $(seconds)^{-1}$	100	10
Pixel Separation @ Nadir (metes)		
FOV (degrees)		
Swath Width (kilometers)	3.6	3.6

7.4.2 Additional Information

Descriptions of the mission plan and the spacecraft are available in:

GEOS-C Mission Plan, NASA, Wallops Flight Center Report TK-6349-001

and

GEOS-C Spacecraft Description, 1975, APL/JHU Report SDO-4156

An excellent review of the mission and its application is available in a special issue of the Journal of Geophysical Research:

Journal of Geophysical Research, July 30, 1979, Volume 84, Number B8.

7.4.3 Data availability:

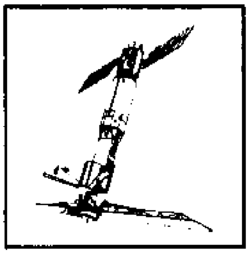
All GEOS altimeter data tapes have recently been transferred from NASA to the Satellite Data Services Division (SDSD) of NOAA. Included below are paragraphs extracted from the Satellite Data User's Bulletin describing GEOS-3 data as it exists at SDSD:

> Mission data collection began on April 21, 1975, and continued through December 8, 1978.
>
> The "G-Tape" contains only products of the mission (i.e., smoothed sea-surface height at once per 1.024 seconds and all oceanographic parameters derived during the mission).
>
> The "I-Tape" contains all the "G-Tape" information plus the calibrated data used to produce the cited products. In addition, the "I-Tape" contains smoothed sea-surface height at a rate of ten per 1.024 seconds.
>
> The "M-Tape" contains additional data such as system temperatures that were used to calibrate functional parameters and, in high data rate records, instantaneous samples of the

Altimeter PRF rate records, instantaneous samples of the Altimeter PRF rate of 16 waveform gates, the plateau gate, and the range serve error signal.

Only the "G-" and "I-Tapes" are archived at SDSD. The "M-Tapes" will be retained by NASA/Wallops.

For additional information on ordering data from SDSD, see Appendix II.



8 SEASAT Satellite

8.1 Objective

To provide an evaluation of sensor capabilities to measure:

Wave heights

Wave length and direction

Surface wind speed and direction

Ocean surface temperature

Atmospheric water content

Sea ice morphology and dynamics

Icebergs

8.2 General

SEASAT-1 was the first satellite devoted entirely to sensing the ocean. It is what is generally known as a "proof-of-concept mission," one whose major objective is to acceess the merit of a new concept, in this case microwave sensing of the ocean. The HCMM is also a proof-of-concept mission as was ERTS-1, since renamed LANDSAT-1. SEASAT-1 was launched on 6/6/78 and began collecting data almost immediately. Unfortunately, the main power supply on the satellite failed on October 10, 1978, after about 100 days of operation and no further data was collected. All of the sensors operated within specifications during the 100 days except for the visible and infrared radiometer.

Originally there was to be a SEASAT-B (or 2) to follow SEASAT-1. It was decided, however, to drop SEASAT-B in favor of the planned NOSS (National Oceanic Satellite System). At the writing of this document it appears that NOSS has also been abandoned.

8.3 Orbital Characteristics of SEASAT

Because SEASAT-1 was the only satellite in the series, its orbit is described here. SEASAT-1 was launched into a near-circular orbit of altitude approximately 800 km on June 27, 1978. (See Table II-5) This orbit was inclined at 108° to the equator, hence, not sun-synchronous. As in the case of GEOS-3, most of SEASAT-1's sensors were active, not depending on reflected solar radiation, hence, the orbit was optimized with other parameters in mind. One complete SEASAT orbit took approximately 100 minutes and crossed the equator south to north about 25° to the west of the previous orbit. The orbit was designed to precess through a day/night cycle in approximately four and one-half months. This was the orbit used for the first two months. During the last month, September and early October of 1978, the satellite was in a "temporary" orbit for engineering evaluation. This orbit repeated itself precisely once every three days and was designed to pass over the Bermuda tracking station. Consecutive ascending nodes were separated by 50° during this phase.

Satellite stabilization was achieved by gravity gradient-momentum bias and maintained the roll, pitch and yaw to within .5°.

8.4 SEASAT-1

8.4.1 SEASAT-1 Sensor Objectives

ALT - Radar Altimeter (Section 8.4.1.1)

- To measure altitude to ±10 cm RMS from which the geoid is to be refined and currents, tides, wind speed, etc., to be determined.
- To measure significant wave height to ±.5 meters or 10% in the 1 to 20 meter range.

SASS - SEASAT-A Scatterometer Sensor (Section 8.4.1.2)

- To measure ocean surface wind velocity from 4 m/s to 26 m/s to within ±2 m/s or 10% and to within 20°.

SMMR - Scanning Multispectral Microwave Radiometer (Section 8.4.1.3)

- To determine sea surface temperature to ±2°C.
- To determine ocean surface wind speed to ± 2 m/s in the 0 to 50 m/s range.
- To measure integrated liquid water content and water vapor content in the atmosphere.
- To determine the rain rate.
- To detect ice coverage, extent, concentration and dynamics.

VIRR - Visible and InfraRed Radiometer (Section 8.4.1.4)

- To image ocean and coastal features and clouds and to measure the sea surface temperature.

SAR - Synthetic Aperture Radar (Section 8.4.1.5)

- To measure ocean wave spectra (direction and wavelength)
- To detect slicks, icebergs, ice coverage, etc.

8.4.1.1 SEASAT-1 Radar Altimeter

The SEASAT-1 radar altimeter operated in much the same fashion as the GEOS-3 altimeter (Section 7.4.1.1) except that it was significantly more accurate. As for the GEOS-3 altimeter, the SEASAT-1 device sent a narrow pulse (3 μsec in this case) to the sea surface and measured the time for the pulse to return. The frequency used was the same as that for GEOS-3, 13.5 GHz. From knowledge of the satellite location relative to the local geoid and the time of flight measurement of the pulse, the level of the sea surface relative to the local geoid was determined.

The spot size of a radar altimeter pulse on the water surface depends on sea state. This is due to the fact that at a given distance from nadir the probability of a wave having facets which reflect radiation back to the satellite increases with sea state. The area actually illuminated by the altimeter is the same, it is the area from which reflected radiation is returned to the device that varies with sea state. In addition the shape of the leading edge of the pulse varies with sea, the slope decreasing as sea state increases. Again this is simply a consequence of the change in the reflecting geometry of the sea surface. For a low sea state the spot size for the SEASAT altimeter was about 1.6 km. For larger sea states the pulse was broader and the spot size increased up to 12 km. The ability to measure the change in pulse shape was expected to provide an estimate of sea state to ±.5 meters or ±10% in the 1 to 20 meter range. The rms error on the altitude determination for the SEASAT-1 radar altimeter is better than ± 10 cm. It should be stressed that this is the accuracy of the measurement of the satellite to sea surface distance, and not of the sea surface relative to an arbitrary datum. The difficulty is that the location of the satellite relative to a reference ellipsoid is not known to better than one meter. In addition the geoid required to derive dynamic oceanographic parameters from the altimeter measurements is often in error by several tens of centimeters.

3.4.1.2 SEASAT-A Scatterometer Sensor (SASS)

The SEASAT scatterometer was an active radar system that operated in the 14.595 GHz range. As with all radar devices it was the reflected signal that was important for the SASS device. In this case the reflected signal of interest was that from capillary waves. There were four antennae, two radiating $\pm 45^{\circ}$ aft of the spacecraft and two radiating $\pm 45^{\circ}$ forward. Two separate antennae are needed to resolve the wind into u and v components. Actually, these measurements are not sufficient to completely resolve the wind vector. A fourfold ambiguity remains in most cases, while under special conditions a twofold ambiguity remains following the SASS measurement. Because the technique requires back scattering from a grazing beam (centered at 42° to the vertical for SASS) one pair of antennae cover only one side of the spacecraft (in the band between 200 km and 700 km from nadir). For this reason a second pair of antennae was used to obtain these measurements for the other side. There was a 400 km wide swath directly below the spacecraft where no measurements were made.

Global measurements of the surface wind velocity over the seas were obtained from this sensor at least once every 36 hours with the high latitudes being covered more frequently. The resolution of the instrument was 50 km and the grid spacing of the output data product, 100 km.

8.4.1.3 Scanning Multifrequency Microwave Radiometer (SMMR)

This was a passive device with a scanning dish antenna similar in principle to the multispectral scanner with a rotating mirror. The device had 5 spectral bands of varying spot size (from 16 x 25 km to 87 x 144 km). (See Table T.8.4.1.3.a) Its main function was to obtain information regarding the atmosphere above the ocean. In addition to atmospheric information, sea surface temperature was also determined in coarse cells. The advantage of this measurement over the thermal IR sea surface temperature measurements is that they were obtained under all weather conditions.

The swath width was 600 km off nadir, i.e., 560 km to one side of nadir and 40 km to the other. This instrument made use of a conical scan 45° forward of the spacecraft. As for the SASS the repeat coverage time was at most 36 hours.

The SEASAT SMMR was identical to the SMMR flown on NIMBUS- 7 (see Section 1.6.1.3).

Table T.8.4.1.3.a Characteristics of the SEASAT-1 Scanning Multifrequency Microwave Radiometer (SMMR)

	Channel				
	1	2	3	4	5
Spectral Range (GHz)	6.6	10.7	18.0	21.0	37.0
IFOV (milliradians)					
Ground Resolution @ Nadir (kilometer)	87 x 144	58 x 89	31 x 53	27 x 42	16 x 25
Ground Resolution @ Swath Edge (meters)					
Rotation Rate (rpm)					
Scan Line Separation @ Nadir (meters)					
Sample Rate $(seconds)^{-1}$					
Pixel Separation @ Nadir (meters)					
FOV (degrees)					
Swath Width (kilometers)	600				

8.4.1.4 SEASAT-1 Visible/Infrared Radiometer (VIRR)

This scanner was similar to that flown on the ITOS/NOAA series satellites (see Section 2.6.1.2). Its characteristics are summarized in Table T.8.4.1.4.a. The entire globe was covered at least every 36 hours with this instrument. The sensor had fairly coarse spatial and temporal resolution when compared with many of the other satellies listed in this manual. The primary reason for including it on SEASAT was to collect data in conjunction with the other sensors. Also when comparing the SEASAT-1 VIRR with the ITOS scanner (the same instrument) the lower SEASAT altitude must be kept in mind. A lower altitude results in improved spatial resolution on the SEASAT-1 device but a smaller swath width. The instrument operated poorly during the mission and most of its data are useless.

Table T.3.4.1.4.a Characteristics of the SEASAT-1 Visible/Infrared Radiometer

	Channel 1	Channel 2
Spectral Range (Micrometers)	.49 - .94	10.5 - 12.5
IFOV (milliradians)		
Ground Resolution @ Nadir (kilometers)	3	5
Ground Resolution @ Swath Edge (meters)		
Rotation Rate (rpm)		
Scan Line Separation @ Nadir (meters)		
Sample Rate $(\text{seconds})^{-1}$		
Pixel Separation @ Nadir (meters)		
FOV (degrees)		
Swath Width (kilometers)	1500	

8.4.1.5 SEASAT-1 Synthetic Aperture Radar (SAR)

The SAR was an active device capable of 25 m resolution (see Chapter II for a description of the synthetic aperture radar). The high resolution resulted from the fashion in which the collected data is processed. Like other radar devices, the SAR data recorded the reflected signal as a function of time. Because of the width of the beam and the pulse rate a given object on the gound was seen in several consecutive radar pulses. This fact is used when processing the data to artificially improve the resolution of the sensor.

The SAR swath width was 100 km centered 300 km off nadir. The very high resolution over this 100 km wide region means that large quantities of data were collected. There was not sufficient storage capability to store these data for an entire orbit. For this reason the sensor was only operated in real time, when in range of a high-data-rate ground station. Even when in range of such stations the sensor was not necessarily turned on.

8.4.2 Additional Information

A number of documents describing SEASAT-1 are available. A fairly nontechnical description of the satellite, its mission and its sensors is:

SEASAT: Global Ocean Monitoring System, NASA, 1978

This document is available from:

Office of Application: Special Programs
National Aeronautics and Space Administration
Washington, DC 20546

More technical information such as Project Plan for SEASAT-A 1978 Mission is available from:

The Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91103

Finally, NOAA/EDIS distributes documentation describing the sensor and data format with data orders.

8.4.3 Data Availability

All SEASAT data are eventually to be archived by the Satellite Data Services Division (SDSD) of NOAA/EDIS. Instructions on ordering data from SDSD are included in Appendix II. Below, several paragraphs describing the SDSD SEASAT-1 holdings as of June, 1981, are included. These paragraphs were provided by Bruce Needham of SDSD.

During the period since the distribution of our last issue of the Bulletin in June 1980, our archive of SEASAT data has increased dramatically. Table T.8.4.3.a lists the contents of each type of File/Record, and Table T.8.4.3.b summarizes the sensors and dates of data availability.

ALTIMETER (ALT)

The Final Geophysical Data Records (GDRs) from the Altimeter are completed. Those files are divided into two types: The Geophysical File (G.F.) and the Sensor File (S.F.). Data tapes are currently available for the periods listed below. Each ALT GDR-GF tape contains global data for approximately six days. Each ALT GDR-SF tape contains

FILE RECORD TYPE	SENSOR: ALT	SASS	SMMR	VIRR
Basic Geophysical Record	.One Point .Time/Lat/Long .Fully Corrected h, $H_{1/3}$ and Tidal Height .Steric Anomalies .Corrected SS Height above Ellipsoid .Atm. Press. Effect .Ionosphere Correction .WET/DRY Tropo. Corr. .Surface Pressure	.Mean Time/Lat/Long .Wind Stress Magnitude and σ .Wind Stress Direction and σ .Mag/Dir Correlation .120 Wind Vector Solutions with Aliases .(Ambiguity in Direction will not be Removed)	.Mean Time/Lat/Long .SST, SSW, Rain Rate .Atm. Liq. Water/ Water Vapor .Path Length Corr. .600km x 600km area .90 Seconds of Data	
Supplemental Geophysical		.Time/Lat/Long .Fully Corrected Backscatter Coefficient (σ^0) .Individual SMMR Channel Temps (Int. over Area for each of 15 Cells/Fan Beam .1.89 Seconds		
Basic Sensor Record	.One Point .Time/Lat/Long .Instrument Corr. h .Fully Corr. $H_{1/3}$	.Time/Lat/Long .Instr.Corr.Back.Coeff.(σ^0) .Corner Lat/Long .S/N Ratio .σ^0 Corrections .1.89 Seconds	.Mean Time/Lat/Long .Individual Channel Brightness Temps and T .Same Area as above	.Start Time of Scan Line .Lat/Long of Start-Middle-End .VIS Brightness/IR .One Scan Line - 1.25 Sec.
Temp.				
Supplemental Sensor	.Time .Δ h .One minute .Calibration Mode	.Time .7.6 Min.Cal.Sequence .Noise .Calibration Mode	.Start/Time/Nadir Lat/Long .Cone-Clock Angle .Indiv.Chan.HOT/COLD Cal. Mean and σ .Ant. Temp. .Footprint Lat/Long for 30 Footprint Locations .One 4.096 Sec.Scan Line .Calibration Data	.Start Time .Nadir Lat/Long .Altitude .IR/VIS HOT/COLD Cal. .Calibration Mode

Table T.8.4.3.a SEASAT FINAL GEOPHYSICAL D[illegible] RECORD CONTENT DEFINITION

TABLE T.8.4.3.b
SEASAT DATA PRODUCTS

SENSOR	PRODUCT DESCRIPTION	GEOGRAPHIC AREA AND DATES OF DATA
Scanning Multi-Channel Microwave Radiometer (SMMR)	Computer Tapes containing latitude longitude and time located data of surface wind-speed (no direction), sea surface temperatures, integrated air column liquid water and water vapor, rain rate, atmospheric path length correction, and individual channel brightness temperatures.	Global Coverage 7/7/78 - 10/10/78
SEASAT Scattermeter System (SASS)	Computer Tapes containing latitude, longitude, and time located geophysical data of surface wind velocity and fully corrected backscatter coefficient.	Global Coverage 7/7/78 - 10/10/78
Radar Altimeter (ALT)	Computer Tapes containing latitude, longitude, and time located geophysical data every 13km along the spacecraft track of the displacement of the spacecraft from the ocean surface, significant wave heights, atmospheric pressure effect, ionospheric correction, and surface pressure.	Global Coverage 7/7/78 - 7/17/78; 7/24/78 - 8/28/78; 9/1/78; 9/6 - 7/78; 9/10/78; 9/13/78; 9/15/78 - 10/10/78
Visible and Infrared Radiometer (VIRR)	A limited number of photographic imagery containing oceanic radiance values.	JASIN 7/15/78 - 8/27/78
Synthetic Aperture Radar (SAR)	Approximately 478 passes of optically correlated radar imagery are available as 70mm film products. A more limited amount (250) of digital correlated film products and tapes are also available.	North & Central America, and Western Europe 7/7/78 - 10/10/78

* NOTE: SMMR data products are not currently available through SDSD, but should be soon

global data for approximately three days. SDSD has the capability to selectively extract specific geographic regions and/or time periods from these tapes, thereby providing the user with only those data points required at a considerable cost savings.

DATA TYPE	PERIOD COVERED
Geophysical File	7/7-7/17, 7/24-8/28, 9/1, 9/6, 9/7, 9/10, 9/13, and 9/15 through 10.10/78
Sensor File	7/7-7/17, 7/24-8/28, 9/1, 9/6, 9/7, 9/10, 9/13, and 9/15 through 10/10/78

NOTE: No ALT data are available for the periods 7/4-7/6, 7/18-7/23, 8/29-8/31, 9/2-9/5, 9/8-9/9, 9/11-9/12, and 9/14/78. The sensor was not turned on to collect data for these periods.

SCATTEROMETER (SASS)

The final SASS GDRs are nearly completed. These data are contained in three data sets. The first contains both the complete Geophysical and Sensor Files on the same tape. Each tape contains approximately six hours of continuous global SASS data and cover the time periods from 7/7-10/10/78. The second set contains only the Basic Geophysical Record. Each tape contains approximately 48 hours of continuous, global SASS data and cover the two periods from 7/7-10/10/78. The third and last set of SASS data contains both the Basic and Supplemental Geophysical Records, contains 24 hours of global SASS data per tape and covers the period from 7/7-10/10/78.

MICROWAVE RADIOMETER (SMMR)

SDSD has finally started to receive the final SMMR GDR data tapes. These data products contains 6 hr of global SASS data per tape for the entire mission.

SDSD is still receiving both the optically-correlated 70 mm SAR imagery, and the more limited number of digitally-correlated tapes and film. Currently, SDSD has 432 sets of 70mm data and 270 digitally processed images. Since SDSD continues to receive additional SAR data every month, users should contact SDSD directly for up-to-date listings.

NEW SAR PRODUCTS AVAILABLE

The SAR digitally correlated data now available have been produced by JPL through funding provided by the NOAA/NASA SEASAT Project. Effective recently, SDSD has entered into a working agreement with JPL to produce, on request, SAR digitally-correlated data for users throughout the world for areas not being processed by the SEASAT Project. This agreement between SDSD and JPL will continue through September 30, 1982 and will provide for up to 65 additional scenes of 100 x 100-km areas to be processed.

Users interested in such data should contact SDSD to first verify that such digitally processed data coverage does not already exist, and second to verify that the instrument collected data for the area and/or time of interest. Users should provide SDSD with geographic coordinates, time period, and specific look angle (ascending or descending pass, if important). SDSD personnel will verify existence of already processed digital data, or existence of coverage by SAR.

If approved, SDSD will initiate a Work Request through JPL to have a special data set produced. Because of the price associated with processing each 100 x 100-km scene, SDSD will require payment in advance for each order. Each user will be supplied with one 9-track/1600-BPI tape, one 10 x 10 inch duplicate negative, and one 10 x 10 inch print of the area processed. Each order will cost the user $1,650.00. Other SAR digital tapes already in the archive at SDSD still only cost $72 per copy.

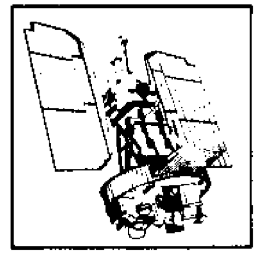
TERRESTRIAL SATELLITES

In this notebook we consider two different satellites dedicated to the study of terrestrial resources (see Table II-6). The first is a series, the LANDSATs, which has been providing high resolution (spatial), multispectral data since 1972. These data have been used for a number of resource management tasks and there is every indication that, due to the success of the series, it or similar satellites will continue collecting data indefinitely. In addition to U.S. plans for new LANDSATS, the French and the Japanese also plan LANDSAT-like satellites for the mid-'80's.

The second satellite included in the Earth Resources category is HCMM, the Heat Capacity Mapping Mission. HCMM was a member of a series of satellites each dedicated to a specific mission. The missions from one satellite to the next in this series differ markedly, HCMM being the only one of interest to ocean or coastal problems. HCMM was used to investigate the geology of the earth's surface by measuring the heat capacity of terrestrial regions. Its high resolution (spatial and radiometric) sensor does, however, provide data of significant interest to oceanography especially given the fact that it was the only U.S. satellite that collected high resolution thermal data during the SEASAT mission.

Table 11-6 EARTH RESOURCES SATELLITES - Land Oriented

Satellite Name (alias)	Launch (Date)	Limit of Data Archive (Date)	Period (minutes)	Periopsis (km)	Apoapsis (km)	Inclination (Degrees)
LANDSAT-1 (ERTS-A)	7/23/72	1/6/78	103.1	897	917	99.9°
-2 (ERTS-B)	1/22/75	present	103.2	907	918	99.2°
-3	3/5/78	present	103.1	897	914	99.1°
HCMM (AEM-A)	4/26/78	10/1/80	98.8	620	620	98.8°
SAGE (AEM-B)	2/18/79		96.8	548	660	54.9°
MAGSAT (AEM-C	10/30/79		93.9	352	578	96.8°



9 LANDSAT Satellites

9.1 Objective

To provide for the repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis.

9.2 General

Thus far there have been three satellites launched in the series with nearly identical sensors, the MultiSpectral Scanner (MSS) and the Return Beam Vidicon (RBV), providing continuous coverage of the United States and coastal waters since 1975. The next LANDSAT satellites, -D and -D1 will, in addition to the MSS, carry some new sensors. LANDSAT-D is scheduled for launch in March of 1982 and LANDSAT-D1 for 1983.

LANDSAT, like many other polar orbiting spacecraft includes high density tape recorders to permit the storage of information gathered over parts of the earth for which direct transmission of the received data is not possible. Originally only ground stations capable of direct readout existed in the United States. Over the years, however, a number of other countries have installed ground receiving stations, greatly increasing the coverage as dependence on onboard tape recorders decreased.

In the fall of 1979 operational control of the LANDSAT series was transferred from NASA to NOAA/NESS. In 1982 NOAA expects to assume full control of data dissemination for the LANDSAT series.

9.3 Orbital Characteristics of the LANDSAT Series

The LANDSAT satellites have been launched into near-polar, sun-synchronous, circular orbits 920 km above the earth's surface. The orbits have been adjusted so that they repeat exactly once every 18 days. LANDSAT-2 was launched into an orbit nine days out-of-sync with LANDSAT-1. This means that while both were operating properly the entire earth was covered every nine days. Slight differences between the LANDSAT-1 and two orbits, however, led to a continuous drift of one relative to the other. By July, 1977, this drift led to a six-day lag of LANDSAT-1 behind LANDSAT-2 rather than the planned nine days. Several months after LANDSAT-1 became inoperable, LANDSAT-3 was launched into an orbit similar to that of LANDSAT-1 continuing the approximate nine day coverage of the Earth. The local sun time for the descending equatorial crossing of LANDSAT-1 is 8:50 AM, of LANDSAT-2 is 9:08 AM and of LANDSAT-3 is 9:31 AM

Successive orbits are separated by 25.5^{o} at the equator, each orbit being to the west of the previous one. Each orbit is 1.43^{o}(159 km) to the west of the same orbit on the previous day. This separation results in a 14% overlap at the equator of images resulting from the same orbit on successive days. This overlap increases to 19.1% at 20^{o}, 34.1% at 40^{o}. 57% at 60^{o} and 85% at 80^{o}.

The satellite nadir velocity is 6.456 km/sec.

9.4 LANDSAT-1

LANDSAT-1, originally named ERTS-1, was launched on July 23, 1972, and collected useful data for over four years, well beyond its designed one year life. The satellite included two sensors, the Return Beam Vidicon (RBV, a TV system) and the Multispectral Scanner (MSS, an electro-optical scanner). The RBV was to be the primary instrument, the MSS being included at the "last minute." Very quickly, however, it became apparent that the real sensor of value was the MSS which has become a mainstay of the LANDSAT series.

9.4.1 LANDSAT-1 Instrument Objectives

MSS - MultiSpectral Scanner (Section 9.4.1.1)

To provide for the repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis.

RBV - Return Beam Vidicon camera (Section 9.4.1.2)

To obtain high resolution television pictures of the earth.

DCS - Data Collection System (Section 9.4.1.3)

To collect and disseminate data from remotely located earth sensors.

9.4.1.1 LANDSAT-1 Multispectral Scanner (MSS)

The LANDSAT-1 multispectral scanner was a high resolution four channel (two visible and two near IR) instrument. It consisted of six adjacent radiometers for each of the four spectral bands. The scan lines were adjacent at nadir and overlapped slightly on the edges of the image (see Table T.9.4.1.1.a). The swath width was 185 km for a total FOV (field of view) of about 11^{o}. This small FOV, compared to the 110^{o} FOV of the DMSP series satellites, for example, lead to little foreshortening (distortion on the edges). The pixel size on the swath edge was about 6% larger than at nadir.

The sensor in the visible bands collected radiation from a 79 x 79 meter area. The pixels overlapped, however, along the scan line, their centers separated by 56 m. This leads to what is referred to as an "effective" resolution of 56 x 79 m.

Swaths on successive days overlapped by about 30% at 40^{o} North with this overlap increasing as the poles were approached and decreasing as the equator was approached. The overlap at the equator was approximately 15%. This overlap (coverage on two consecutive days) may be used to advantage when studying short term phenomena, such as oil spills.

The visible data from the MSS was collected only during the day.

Table T.9.4.1.1.a Characteristics of the LANDSAT-1 Multispectral Scanner (MSS)

	Channel 1	Channel 2	Channel 3	Channel 4
Spectral Range (micrometers)	.5 - .6	.6 - .7	.7 - .8	.8 - 1.1
IFOV (milliradians)				
Ground Resolution @ Nadir (meters)	79 x 79	------------------------------------>		
Ground Resolution @ Swath Edge (meters)				
Rotation Rate (rpm)	317.2	------------------------------------>		
Scan Line Separation @ Nadir (meters)	79	------------------------------------>		
Sample Rate $(seconds)^{-1}$	100422	------------------------------------>		
Pixel Separation @ Nadir (meters)	56	------------------------------------>		
FOV (degrees)	11	------------------------------------>		
Swath Width (kilometers)	185.3	------------------------------------>		

9.4.1.2 LANDSAT-1 Return Beam Vidicon Camera (RBV)

On LANDSAT-1 there were three RBV cameras: one to measure in the blue-green, .475 to .575 μm; one in the orange-red, .580 - .680 μm; and, one in the red-near IR, .690 to .830 μm (Table T.9.4.1.2a and T.9.4.1.2.b). These three cameras were aligned to view the same region on the ground, a 185 x 185 km square.

As indicated earlier, the RBV was to be the primary instrument on the LANDSAT series, but it proved not as valuable as the MSS (Section 9.4.1.1) and has been used rarely. Some of the problems with the RBV have to do with its mode of operation (see Chapter II). First, the various spectral channels are not coregistered, the data being collected by three separate cameras. Second, the RBV collected data in two dimensions. The scene was imaged on a photosensitive surface when the camera was shuttered, then the photosensitive surface was read out, the readout taking 3.3 seconds per camera (or channel). This means that the optical system focused the up-welling radiation in two dimensions rather than along a line as with the MSS. This resulted in two dimensional distortion, much more difficult to correct than the linear distortion of the MSS.

Table T.9.4.1.2.a Characteristics of the LANDSAT-1 Return Beam Vidicon Camera (RBV)

	Channel 1	2	3	4	5
Spectral Range (GHz)	.475-.575	.580-.680	.790-.830		
IFOV (milliradians)					
Ground Resolution @ Nadir (kilometers)	30 x 80				
Ground Resolution @ Swath Edge (meters)					
Rotation Rate (rpm)		N O T			
Scan Line Separation @ Nadir (meters)	R E L E V A N T				
Sample Rate $(seconds)^{-1}$					
Pixel Separation @ Nadir (meters)					
FOV (degrees)					
Swath Width (kilometers)	185				

Table 9.4.1.2.b Landsats 1 and 2 RBV Camera Parameters*

Parameter	Performance Requirements Camera 1	Camera	Camera 3
Spectral Bandpass (nm)	475 to 575 blue-green	580 to 680 orange-red	690 to 830 red-near IR
Video Bandwidth (MHz)	3.2	3.2	3.2
Peak Signal/rms Noise (dB)	33	33	31
Relative Aperture	f/2.66	f/2.66	f/2.66
Full Field Angle (deg)	16.2	16.2	16.2
Effective Focal Length (mm)	125.98+0.27 -0.98	125.98+0.27 -0.98	125.98+0.27 -0.98
Highlight Brightness (MJ/cm^2)	0.78	0.78	1.2
Shading - inside 1 in. circle	<15%	<15%	<15%
Shading - outside 1 in. circle	<25%	<25%	<25%
Edge Resolution (% of center)	80%	80%	80%
Image Distortion	< 1%	< 1%	< 1%
Skew	$\leq\pm$0.5%	$\leq\pm$0.5%	$\leq\pm$0.5%
Size and Centering	$\leq\pm$2%	$\leq\pm$2%	$\leq\pm$2%
Read Horizontal Rate (lines/sec)	1,250	1,250	1,250
Active Horizontal Lines	4,125	4,125	4,125
Readout Frame Time (sec)	3.5 (3.3 active)	3.5 (3.3 active)	3.5 (3.3 active)
Readout Sequence	3	2	1
Three-Camera Cycle Rate (sec)	25	25	25
Exposure Time Matrix (msec)			
Expose 1	4.0	4.8	6.4
Expose 2	5.6	6.4	7.2
Expose 3	8.0	8.8	8.8
Expose 4	12.0	12.0	12.0
Expose 5	16.0	16.0	16.0

*From The LANDSAT Data User's Handbook, pages 4-8.

9.4.1.3 LANDSAT Data Collection System

The DCS received and retransmitted data from remotely located environmental data collection platforms. The satellite interrogated every platform at least once every twelve hours. The platforms sent a burst of data every three minutes. It was therefore possible to see a platform as many as three times during the nine minute interval during which the satellite was within range during a pass.

Each data collection platform sampled up to eight analog 64 bit words.

9.4.2 Additional Information

Detailed information on LANDSAT and how to make use of LANDSAT data products are available in:

LANDSAT Data Users Handbook
Published by the General Electric Company

This book may be purchased for $11.00 from:

Branch of Distribution
U.S. Geological Survey
1200 South Eads Street
Arlington, VA 22202

Along with the User's Handbook comes a subscription to the "LANDSAT Data User's Notes," a bimonthly publication dealing with the LANDSAT satellites, their data, other satellites of interest, meetings, etc.

A second newsletter dealing with LANDSAT related issues is the:

LANDSAT Newsletter

put out when needed by the Missions Utilization Office of the Goddard Space Flight Center. This newsletter deals more with the operational aspects of LANDSAT than its data. It also contains useful information on other satellites. Information regarding the newsletter is available from:

LANDSAT Newsletter
Missions Utilization Office
Code 902, NASA-GSFC
Greenbelt, MD 20771
301/344-3826

9.4.3 Data Availability

All digital and photographic LANDSAT data of the Unites States are archived at the EROS Data Center in Sioux Falls, South Dakota. This facility was run by the United States Geological Survey of the Department of the Interior while the satellites were operated by NASA. In late 1979, control of LANDSAT was turned over to NOAA/NESS. Plans are to retain the data archive at Sioux Falls and until 1982, products will be ordered from Sioux Falls as they have been in the past. Appendix V provides the requisite details to order these data products. In addition to the extensive data archive, the EROS data center will also perform computer searches of their holdings on request. The information required to initiate such a search is also included in Appendix V.

Because of the large volumes of data available from LANDSAT the MSS is not turned on automatically when over the United States. Instead a decision is made a day in advance whether or not to turn the sensor on, the criteria being related to the forecast cloud cover. In general, if a region is forecast to be cloud covered the sensor will not be turned on. The user is also cautioned that due to deterioration of the high density digital tapes many of the early scenes, although recorded, are now irretrievable.

LANDSAT-1 began collecting good data shortly after its launch in July of 1972. Except for short periods it collected multispectral scanner data fairly routinely until March 3, 1977, when the .5 to .6 μm band failed. The MSS operated with the remaining three channels until a variety of problems led to the termination of operations on January 6, 1978.

The EROS archive contains data from other regions of the earth, data that have been recorded on board and transmitted later when over a receiving station. Recently a number of receiving stations have been set up and are being run by other countries around the earth. These stations may archive data for their area. (All such scenes are listed in the EROS Main Image File.) The interested user is advised to write directly to these stations for more information:

Brazil:
Instituto de Pesquisas Espaciais
Rodovia Presidente Dutra KM. 210
Caixa Postal 01
CEP 12,630
Cochoeira Paulista
Sao Paulo, Brazil
Telefone: (0125)61-1377
Telex: 0122160

Italy: European Space Agency (ESA)
ESRIN
Via Galileo Galilei
00044 Frascati
Italy
Tel: 06-9424116
TWX: 61637

Canada: Canada Centre for Remote Sensing
(CCRS)
2464 Sheffield Rad
Ottawa
Ontario K1A OY7
Canada
Telephone: (613)993-0121

Japan: Remote Sensing Technology Center of Japan
(RESTEC)
Uni-Roppongi Bldg.
7-15-17, Roppongi, Minatoku
Tokyo 106
Japan
Tel: Tokyo (403) 1761

9.5 LANDSAT - 2

The LANDSAT-2 satellite is identical to the LANDSAT-1 satellite in most respects. The user is referred to Section 9.4 for a description of LANDSAT-1.

9.5.1 LANDSAT-2 Sensor Objects

MSS - Multispectral Scanner (Section 9.4.1.1)

To provide for the repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis.

RBV - Return Beam Vidicon camera (Section 9.4.2)

To obtain high resolution television pictures of the earth.

DCS - Data Collection System (Section 9.4.1.3)

To collect and disseminate data from remotely located earth sensors.

9.5.2 Additional Information

The documentaion for LANDSAT-2 is the same as that of LANDSAT-1. See Section 9.4.2.

9.5.3 Data Availability

The source, ordering information, prices, etc., for LANDSAT-2 data are the same as for LANDSAT-1. See Section 9.4.3

LANDSAT-2 data collection began shortly after its launch in January of 1975 and continued on a fairly regular basis until November 5, 1979. At that time data acquisition was reduced to five or six orbits per day rather than the regular 14, this to conserve the gas used in the attitude control system. The satellite was officially retired on January 22, 1980, following the failure of the fly wheel used to control satellite yaw. This flywheel began working again on May 27, 1980 and the satellite was reactivated at that time.

9.6 LANDSAT-3

The LANDSAT-3 satellite included some modifications which makes it different from LANDSAT's-1 and 2. Both the RBV and MSS systems have been modified, the RBV consisting of four monochromatic cameras providing 40 m resolution, and the MSS including a thermal IR channel.

9.6.1 LANDSAT-3 Sensor Objectives

MMS - MultiSpectral Scanner (Section 9.6.1.1)

To provide for the repetitive acquisition of high resolution multispectral data of the earth's surface on a global basis.

RBV - Return Beam Vidicon camera (Section 9.6.1.2)

To obtain high resolution television pictures of the Earth.

DCS - Data Collection System (Section 9.4.1.3)

To collect and disseminate data from remotely located earth sensors.

9.6.1.1 LANDSAT-3 Multispectral Scanner(MSS)

The LANDSAT-3 multispectral scanner is a high resolution five channel (two visible, two near IR and one thermal IR) instrument. It consists of six adjacent radiometers for each of the four spectral bands and two radiometers for the thermal IR band. The scan lines are adjacent at nadir overlapping slightly on the edges of the image (see Table T.9.6.1.1.a). The swath width is 185 km for a total FOV (field of view) of about 11°. This small FOV, compared to the 110° FOV of the DMSP series satellites, for example, leads to little foreshortening (distortion on the edges). The pixel size on the swath edge is about 6% larger than at nadir.

The sensor in the visible bands collects radiation from a 79 x 79 meter area. The pixels overlap, however, along the scan line with their centers separated by 56 m. This leads to what is referred to as an "effective" resolution of 56 x 79 m.

Swaths on successive days overlap by about 30% at 40° North with this overlap increasing as the poles are approached and decreasing as the equator is approached. The overlap at the equator is approximately 15%. This overlap (coverage on two consecutive days) may be used to advantage when studying short term phenomena, such as oil spills.

The visible data from the MSS is collected only during the day. The thermal IR data were collected for both the day and the night thus covering every point on the globe at least twice within 18 days, once during the day and once at night.

The thermal IR channel proved to be very noisy and has seen little use.

Table T.9.6.1.1.a Characteristics of the LANDSAT-3 Multispectral Scanner (MSS)

	Channel				
	1	2	3	4	5
Spectral Range (micrometers)	.5 - .6	.6 - .7	.7 - .8	.8 - 1.1	10.4 - 12.6
IFOV (milliradians)					
Ground Resolution @ Nadir (meters)	79 x 79	----------------->			237 x 237
Ground Resolution @ Swath Edge (meters)					
Rotation Rate (rpm)	817.2	----------------->			272.40
Scan Line Separation @ Nadir (meters)	79	----------------->			237
Sample Rate $(seconds)^{-1}$	100422	----------------->			33000
Pixel Separation @ Nadir (meters)	56	----------------->			
FOV (degrees)	11	----------------->			----->
Swath Width (kilometers)	185.3	----------------->			----->

9.6.1.2 LANDSAT-3 Return Beam Vidicon Camera (RBV)

The LANDSAT-3 Return Beam Vidicon camera system is quite different from the RBV systems on LANDSAT-1 and 2. Two cameras were used to image an MSS scene defined as a 185 x 185 km region. Note that for the MSS this definition is somewhat arbitrary because the MSS collects data in a continuous strip. In the case of the RBV the concept of a scene is well-defined because the sensor images the entire area of one instant in time. Each RBV camera on LANDSAT-3 images a square area 99 x 99 km. Each RBV camera overlaps a small portion of the area imaged by the other. For the adjacent camera this overlap corresponds to a strip approximately 17 Km wide (17%). The spatial resolution of this RBV is approximately 40 x 40 meters. These data are summarized in Tables T.9.6.1.2.a and T.9.6.1.2.b.

The two camera system on LANDSAT-3 images the scene in one quite broad spectral band, 505 to 750 nanometers, covering most of the visible portion of the spectrum.

Table T.9.6.1.2.a Characteristics of the LANDSAT-3

Return Beam Vidicon Camera

	Channel 1	2	3	4	5
Spectral Range (micrometers)	.505-.750				
IFOV (milliradians)					
Ground Resolution @ Nadir (meters)	40				
Ground Resolution @ Swath Edge (meters)					
Scan Lines per minute (rpm)		NOT RELEVANT			
Scan Line Separation @ Nadir (meters)					
Sample Rate (seconds)$^{-1}$					
Pixel Separation @ Nadir (meters)					
FOV (degrees)					
Swath Width (kilometers)	99				

Table T.9.6.1.2.b Landsat 3 RBV Camera parameters†

Parameter	Performance Objective
Spectral Bandpass	505 to 750 nanometers*
Video Bandwith	3.2 MHz
Peak Signal/rms Noise	33 dB
Lens, Effective Focal Length	236mm (nominal)*
Highlight Irradiance	2.013mW/cm^2-SR*
Shading	<15% within 1 in circle
	<25% elsewhere
Image Distortion	<1%
Skew	<+0.5
Size and Centering	<+2%
Read Horizontal Rate	1,250 lines/sec
Active Horizontal Lines	4,125 per frame
Readout Frame Time	3.5 sec (3.3 active)
Two-Camera Cycle Rate	12.5 sec*

*Denotes change from Landsat 1 and 2

†From The LANDSAT Data User's Handbook, page 4-13

9.6.2 Additional Information

LANDSAT-3 documentation is available from the same source as that for LANDSAT-1 and 2. See section 9.4.2.

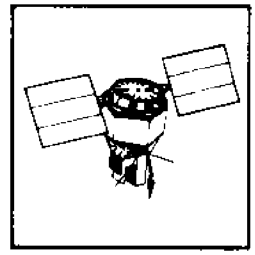
9.6.3 Data Availability

LANDSAT-3 data are available from the same source as LANDSAT-1 and 2. See section 9.4.3 for a description of this.

LANDSAT-3 data collection began on March 13, 1978, for all sensors except the MSS thermal band which required time for outgassing. Routine collection of thermal data began on April 4. These data were, however, quite noisy. On July 11, 1978, one of the two channels of the thermal band failed. Data collection continued with the other channel but the signal-to-noise ratio in this channel decreased steadily with time. Thermal data collection was terminated several months later. The processing of MSS thermal data was quite erratic and the interested user is advised to consult the LANDSAT Newsletter, No. 25 or the EROS data center for a more detailed discussion.

On August 27, 1978, the MSS began experiencing intermittent line start problems. This resulted in the loss of the first quarter of the effected scan lines. This problem continued on and off into 1980. Most of the data collected during this period does not show the problem.

LANDSAT-3 was still operational at the writing of this document.



10 Applications Explorer Missions (AEM)

10.1 Objectives

HCMM - to provide comprehensive, accurate, high spatial resolution thermal surveys of the surface of the earth.

SAGE - to determine the spatial distribution of stratospheric aerosols and ozone on a global scale.

MAGSAT - to measure near-Earth magnetic fields on a global basis.

10.2 General

The Applications Explorer Missions is a series of low-cost, modular designed spacecraft in special orbits designed to satisfy mission-unique data acquisition requirements. In keeping with this philosophy each of the AEM satellites launched to date (Table II-6): HCMM (Heat Capacity Mapping Mission); SAGE (the Stratospheric Aerosol and Gas Experiment); and MAGSAT, has carried only one sensor designed for a specific purpose. The only AEM satellite that will be discussed here, however, is the Heat Capacity Mapping Mission (HCMM) as it is the only one judged to have direct application to the marine related sciences.

10.3 Orbital Characteristics of HCMM

Because HCMM is the only AEM satellite in the series to be dealt with in any detail in this document, and because the orbits of each of the satellites is so different, only the HCMM orbit will be discussed here.

In order to study the thermal inertia of various parts of the globe in a consistent, meaningful fashion the obvious orbit for this satellite is a sun-synchronous one. Furthermore, the orbit should be one which views the earth's surface at the time when it is the warmest and the coolest. To satisfy these requirements the satellite was launched into an orbit with an inclination of 97.8° at an altitude of 620 km and a period of 96.8 minutes (a sun-synchronous orbit). The ascending (south to north) equatorial crossing time was 2:00 PM. This provided for 1:30 PM and 2:30 AM local time coverage of the northern mid-latitudes. The repeat time for this satellite was 16 days but mid-latitudes will receive coverage approximatley every five days.

The attitude control system provided for three axis stabilization via momentum wheels. The specifications for attitude control required roll to within ± 0.7°. pitch to within ± 0.5° and yaw to within ± 2°. Angular velocities of the satellite about its center of gravity were to be ± 0.01°/second. All of these specifications were met by the satellite.

10.4 Heat Capacity Mapping Mission (HCMM)

HCMM was the first satellite launched in the AEM series. It was designed to estimate the feasibility of acquiring thermal infrared remote-sensor derived temperature measurements of the Earth's surface with a 12 hour interval at times when the temperature variation is at its maximum. These measurements are then used to determine the thermal inertia, that property of material which resists temperature changes, as incident energy varies.

Satellite operations were officially terminated on September 30, 1980, due to increasing operational difficulties. The primary source of these difficulties resulted from a deterioration of the batteries. This condition was "worked-around" for over a year by taking power conservation measures, including a reduction in data passes over several ground stations.

10.4.1 HCMM Sensors

10.4.1.1 HCMM - Scanning Radiometer

The two channel scanning radiometer, Tables T.10.4.1.1.a and T.10.4.1.1.b, was the only data collection instrument aboard the HCMM. One channel was in the visible and near IR between .5 to 1.1 μm and was used primarily to align the thermal data. The thermal infrared channel sensed radiation in the 10.5 to 12.5 μm range. The nominal thermal accuracy of the 10.5 to 12.5 μm channel was .5°C at 8°C and the spatial resolution in both channels was 600 x 600 m at nadir. The registration between channels was .2 resolution elements at nadir, i.e., the separation between the centers of a given pixel in the thermal and the corresponding pixel in the visible was at most .2 pixels. The ground swath was 700 km with a repeat time of 16 days between 85° North and 95° South. For regions between 20°N to 20°S; 32°N to 95°N and 32°S to 35°S a nighttime pass followed a daytime pass by 12 hours. For the region from 20°N to 32°N and 20°S to 32°S a nighttime pass followed the daytime pass by 36 hours.

Table T.10.4.1.1.a Characteristics of the HCMM Scanning Radiometer

	Channel 1	Channel 2
Spectral Range (micrometers)	.5 - 1.1	10.5 - 12.5
IFOV (milliradians)	.83	.83
Ground Resolution @ Nadir (kilometers)	.5 x .5	.6 x .6
Ground Resolution @ Swath Edge (kilometers)		
Rotation Rate (rpm)	840	840
Scan Line Separation @ Nadir (meters)		
Sample Rate $(seconds)^{-1}$	108696	108686
Pixel Separation @ Nadir (kilometers)	.42	.5
FOV (degrees)	60	60
Swath Width (kilometers)	716	716

Table T.10.4.1.1.b Heat Capacity Mapping Radiometer

Summary Data Sheet*

Orbital altitude = 620 kilometers

Angular resolution = 0.83 milliradians

Resolution = 0.6 km x 0.6 km at nadir (infrared)

0.5 km x 0.5 km at nadir (visible)

Scan angle = 60 degrees (full angle)

Scan rate = 14 revolutions/second

Sample rate = 1.19 samples/resolution element at nadir

Sampling interval = 9.2 microseconds

Swath width = 716 kilometers

Information bandwidth = 53 KHz/channel

Thermal channel = 10.5 to 12.5 micrometers; NEDT = 0.4°K at 280°K

Usable range = 260° to 340°K

Visible channel = 0.55 to 1.1 micrometers; SNR 10 at 1% albedo

Dynamic range = 0 to 100% albedo

Scan mirror = 45 degree elliptical flat

Nominal telescope optics diameter = 20 cm

Calibration = Infrared: View of space, seven-step staircase electronic calibration, and blackbody calibration once each scan.

Visible: Pre-flight calibration assumed valid.

*from the Heat Capacity Mapping Mission User's Guide, page 18

10.4.2 Additional Information

A manual for the use of HCMM data describing the satellite, sensor, etc., has been prepared by the NASA Goddard Space Flight Center:

Heat Capacity Mapping Mission User's Guide

and is available from:

National Space Science Data Center
Code 601
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
Tel: 301-344-6695

The Missions Utilization Office of the NASA/Goddard Space Flight Center also issued a Heat Capacity Mapping Mission Data User's Bulletin during the operation of the satellite. Information regarding this bulletin may be obtained from:

HCMM Data User's Bulletin
Missions Utilization Office
Code 902
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
Tel: 301-344-8826

10.4.3 Data Availability

All HCMM data have been archived at the National Space Science Data Center (NSSDC). A catalog of these data are available on Microfiche from NSSDC at the address listed above. Appendix VI is a copy of Section VI of the HCMM User's Guide detailing the steps involved in ordering data from this source. Data exists for most of the period from 4/27/78 to 9/30/80. The user is cautioned that the availability of data decreases during the last year of the mission due to the increasing operational problems discussed in Section 10.4.

Appendix I. Satellite Data Services Division (SDSD) of NOAA/EDIS Data Product Costs

Satellite data come either as imagery (photographs, negatives, etc.) or in digital form (computer tapes-CCT's). The price of imagery and digital data are indicated in Table A-I-1 (Current as of July 1981).

Note that the cost of digital data is a function of the number of digital data tapes handled. The cost of an order is calculated in two fashions and the maximum is selected. One method charges $50.00 per input tape, SDSD tapes from which the data are copied. The other method charges $72.00 per 9 trk 1600 BPI output tape, the tape sent to the customer. For example, an order with many small scenes, say 10, from a number of different orbits and/or satellites, might only occupy one output tape. It would cost $500.00 (10 input tapes x $50./tape). A second order might consist of all the TIROS-N data from a 20 minute period. These data might be contained on one input tape and two output tapes hence cost $144.00. Therefore it is required that the user know about how much data (how many minutes of satellite data) can fit on a tape or that s/he contact SDSD to arrive at an estimate of the approximate cost. Table A-I-2 taken from the NOAA Polar Orbit Data (TIROS-N and NOAA-6 Users Guide pages 3.1-5 to 3.1-9), provides such information for the TIROS-N series.

The user is advised that all of these prices can change with time (unfortunately, increasing in most cases). Also, special products will have special prices. The costs presented in this section are included to serve as a guide only.

Table A-I-1

UNITED STATES DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
ENVIRONMENTAL DATA AND INFORMATION SERVICE
NATIONAL CLIMATIC CENTER
SATELLITE DATA SERVICES DIVISION
WORLD WEATHER BUILDING, ROOM 100
WASHINGTON, D.C. 20233
(301) 763-8111 Commercial or FTS 763-8111

SATELLITE DATA PRODUCT PRICE LIST FY82
(subject to change without notice)

I. STANDARD PHOTOGRAPHIC PRODUCTS (BLACK & WHITE)

ITEM#	DESCRIPTION	UNIT PRICE
1	8 In. x 10 In. Contact Paper Print	$ 8.50
2	10 In. x 10 In. Contact Paper Print	$ 8.50
3	10 In. x 10 In. Paper Print Enlargement	$ 14.00
4	16 In. x 20 In. Paper Print Enlargement	$ 15.00
5	20 In. x 20 In. Paper Print Enlargement	$ 16.00
6	30 In. x 30 In. Paper Print Enlargement	$ 18.00
7	10 In. x 10 In. Contact Dupe Negative from Positive	$ 10.75
8	10 In. x 10 In. Contact Positive Transparency from Negative	$ 10.75
9	10 In. x 10 In. Contact Negative from Negative	$ 14.50
10	Duplicate 35mm Slide from a Slide	$ 2.75
11	35mm Slide from Transparency, Print or Art	$ 11.00
12	35mm Slide from Negative	$ 13.50
13	Duplicate 16mm Operation Film Loop (Positive or Negative)	$ 14.75
14	Duplicate 16mm TV Movie (50 Ft.strip)(Positive or Negative)	$ 14.75
15	Duplicate 16 mm Huricane/Seasonal Movie	$ 75.00
16	Construct Original 16mm Movie Loop (6 Hrs. of Data)	$ 55.00
17	Construct Original 16mm Movie Loop (12 Hrs. of Data)	$ 76.00
18	Construct Original 16mm Movie Loop (24 Hrs. of Data)	$147.00
19	Duplicate 35mm microfilm, 100-Ft. (Positive or Negative)	$ 23.50
20	Duplicate Transparent Grid Overlays (GOES)	$ 10.75
21	Duplicate Transparent Grid Overlay (AVHRR)	$ 10.75
22	Geographic Gridding on GOES Imagery	$ 1.00

II. SPECIAL PHOTOGRAPHIC PRODUCTS (BLACK & WHITE)

A. SEASAT SYNTHETIC APERATURE RADAR (SAR) DIGITALLY PROCESSED DATA

ITEM#	DESCRIPTION	UNIT PRICE
23	10 In. x 10 In. Paper Print Enlargement	$ 14.00
24	10 In. x 10 In. Positive Transparency Enlargement	$ 25.00
25	10 In. x 10 In. Duplicate Negative Enlargement	$ 30.00

B. SAR 70 mm OPTICALLY PROCESSED DATA (Reproduced from original 70 mm negative strips of various lengths up to 200 feet. Requires four sub-swaths for entire 100 km swath width. Sample prices for one 5-Ft. 1/4 swath image are shown below. Contact SDSD directly for specific price quotations).

ITEM#	DESCRIPTION	UNIT PRICE
26	70mm Contact Paper Pring (5-Ft. length, 1/4 swath)	$ 30.00
27	70mm Positive Transparency (5-Ft. length, 1/4 swath)	$ 35.00
28	70mm Duplicate Negative (5-Ft. length, 1/4 swath)	$ 60.00

C. BRIEFING AIDS

ENVIRONMENTAL SATELLITES: Systems, Data Interpretation and Application. October 1976, 66 pages.

ITEM#	DESCRIPTION	
29	Illustrated Document plus set of 43 slides (35mm)	$ 20.00
30	Document plus B/W Film Strip of Illustrations	$ 9.50
31	Document Only	$ 2.00

D. SATELLITE DATA ANALYSIS CHARTS (paper copy)

ITEM#	DESCRIPTION	UNIT PRICE
32	Weekly GOSSTCOMP (1 of 24) (Quarterly Subscription)	$ 3.50
33	Weekly GOSSTCOMP (1 of 24) (Annual Subscription)	$ 12.50
34	Weekly Regional SST (1 of 10) (Quarterly Subscription)	$ 3.50
35	Weekly Regional SST (1 of 10) (Annual Subscription)	$ 12.50
36	Monthly Mean GOSSTCOMP (1 of 18) (Semi-Annual Subscription)	$ 1.75
37	Monthly Mean GOSSTCOMP (1 of 18) (Annual Subscription)	$ 3.00
38	Gulf Stream (Oceanographic) Analysis (1 North & 1 South/Week) (Semi-Annual)	$ 7.00
39	Gulf Stream (Oceanographic) Analysis (1 North & 1 South/Week) (Annual)	$ 12.00
40	Gulf Stream (Oceanographic) Analysis (3 North & 2 South/Week) (Semi-Annual)	$ 21.00
41	Gulf Stream (Oceanographic) Analysis (3 North & 2 South/Week) (Annual)	$ 37.50
42	Great Lakes Ice & SST Charts (2 Charts/Week) (Semi-Annual)	$ 7.00
43	Great Lakes Ice & SST Charts (2 Charts/Week) (Annual)	$ 12.50
44	Northern Hemisphere Snow & Ice Charts (1 per week)	$ .30
45	NAVY-NOAA Joint Ice Boundary Charts (1 per week)	$ .30
46	River Basin Snow Coverage Charts (1 of 23) (1 per week)	$ .30
47	Single Copy of any of above (not subscription)	$ .30

(NOTE: MINIMUM CHARGE FOR ANY NON-SUBSCRIPTION ORDER IS $5.00)

III. DIGITAL TAPE PRODUCTS

A. DIRECT ONE-FOR-ONE TAPE COPY (CCT TO CCT)

ITEM#	DESCRIPTION	UNIT PRICE
48	7-track, 200, 566 or 800 bpi	$ 72.00 (per output tape)
49	9-track, 800 or 1600 bpi	$ 72.00 (per output tape)
50	9-track, 6250 bpi	$112.00 (per output tape)

B. SELECTIVE EXTRACTION (CCT TO CCT)

ITEM#	DESCRIPTION	UNIT PRICE
51	9-track, 800 or 1600 bpi	$ 20.00 per input tape plus $72 per output tape
52	9-track, 6250 bpi	$ 20.00 per input tape plus $112 per output tape

C. AVHRR DATA SETS (TBM TO CCT)

ITEM#	DESCRIPTION	UNIT PRICE
53	9-track, 800 or 1600 bpi	$ 50.00 per input data set or $72 per output tape whichever is greater.
54	9-track, 6250 bpi	$ 50.00 per input data set or $112 per output tape, whichever is greater.

D. TOVS DATA SETS (TBM TO CCT)

ITEM#	DESCRIPTION	UNIT PRICE
55	9-track, 800 or 1600 bpi	$ 10.00 per input data set or $72, per output tape, whichever is greater.
56	9-track, 6250 bpi	$ 10.00 per input data set or $112 per output tape whichever is greater.

E. GOES FULL RESOLUTION DATA SETS (CASSETTE TO CCT)

ITEM#	DESCRIPTION	UNIT PRICE
57	9-track, 800 or 1600 bpi (ODIS TAPE FORMAT)	$ 30.00 per sector or $75 per output tape whichever is greater.
58	9-track, 800 or 1600 bpi (SAVE TAPE FORMAT)	$ 35.00 per sector or $75 per output tape whichever is greater.

Table A-I-2.a GAC DATA VOLUME*
(2 scans/record, 120 scans/minute)

	Number of Channels Selected 1	2	Full Copy (5 ch.)
Documentation bytes including spares per scan	448	448	492
Data bytes/scan	820	1636	2728
Total (bytes/scan)	1268	2084	3220
Record length (bytes)	2536	4168	6440
Records needed	1	1	1
Physical record length (inches) @ 1600 BPI	1.58	2.60	4.02
Record Gap	.60	.60	.60
Total (inches/record)	2.18	3.20	4.62
Total feet/scan	.09	.13	.19
Feet/minute	10.92	16.2	23.1
Minutes/2200 foot tape	201.4	135.8	95.2

*From: <u>NOAA Polar Orbiter Data (TIROS-N and NOAA-6) User's Guide</u>

Table A-1-2.b LAC/HRPT DATA VOLUME
(360 scans/minute, 2 records/scan)

	Number of Channels Selected		
	1	2	Full Copy (5 ch.)
Documentation and Spare bytes/scan	448	448	1144
Data bytes/scan	4096	8192	13656
Total (bytes/scan)	4544	8640	14800
Records needed	2	2	2
Record length (bytes)	2272	4320	7400
Physical record length (inches) @ 1600 BPI	1.42	2.70	4.62
Record Gap	.60	.60	.60
Total (inches/record)	2.02	3.30	5.22
Total inches/scan	4.04	6.60	10.44
Total feet/scan	.33	.55	.87
Feet/minute	118.82	198.0	313.2
Minutes/2200 foot tape	18.5	11.1	7.0

Table A-I-2.c HIRS/2 DATA VOLUME
(1 record/scan, 9.4 scans/minute)

	Number of Channels Selected			
	1	2	3	Full Copy (20 Ch.)
Documentation and spare bytes/scan	1012	996	980	1440
Data bytes/scan	480	608	736	2816
Total (bytes/scan)	1492	1604	1716	4256
Records needed	1	1	1	1
Record length (bytes)	1492	1604	1716	4256
Physical record length (inches) @ 1600 BPI	.93	1.00	1.07	2.66
Record gap (inches)	.60	.60	.60	.60
Total (inches/record)	1.53	1.60	1.67	3.26
Total feet/scan	.13	.13	.14	.27
Feet/minute	1.20	1.25	1.31	2.44
Minutes/2200 foot tape	1835.6	1755.3	1681.7	861.5

Table A-I-2.d SSU DATA VOLUME
(1 record/scan, 1.9 scans/minute)

	Number of Channels Selected		
	1	2	Full Copy (3 ch.)
Documentation and Spare bytes/scan	180	180	580
Data bytes/scan	128	256	1920
Total	308	436	2500
Physical record length (inches) @ 1600 BPI	.19	.27	1.56
Record Gap (inches)	.60	.60	.60
Total	.79	.87	2.16
Total feet/scan	.06	.07	.18
Feet/minute	.12	.14	.34
Minutes/2200 foot tape	17,532.8	15,925.2	6,425.3

Table A-I-2.e MSU DATA VOLUME
(1 record/scan, 2.3 scans/minute)

	Number of Channels Selected			
	1	2	3	Full Copy (4 Ch.)
Documentation and spare bytes/scan	178	176	178	216
Data bytes/scan	26	52	78	224
Total (bytes/scan)	204	228	256	440
Records needed	1	1	1	1
Record length (bytes)	204	228	256	440
Physical record length (inches) @ 1600 BPI	.13	.14	.16	.27
Record gap (inches)	.60	.60	.60	.60
Total (inches/record)	.73	.74	.76	.87
Total feet/scan	.06	.06	.06	.07
Feet/minute	.14	.14	.14	.16
Minutes/2200 foot tape	15,777.7	15,458.9	15,103.0	13,118.0

Appendix II. Ordering Data from the Satellite Data Services Division of NOAA/EDIS

The following is taken directly from the "Satellite Data User's Bulletin", Volume 2, Number 1, June 1980, Pages 8 and 9. This document is prepared and distributed by the Satellite Data Services Division of NOAA/EDIS.

"Users requesting satellite data from the Satellite Data Services Division (SDSD) should make every effort to supply as complete information as possible concerning their needs. Frequently orders contain incomplete or ambiguous information which results in delays or improper filling of orders. The following points should be considered and information furnished in preparing orders for data to assure timely, correct completion.

PHOTOGRAPHIC PRODUCTS

After identifying a particular image or set of images, the final product supplied to the requester can be in several forms. Specify as much as possible of the following:

- -Date(s) of Interest
- -Time(s) in GMT
- -Type of Product: HRPT Frame, Mercator Mosaic, Pass-by-Pass Swath, etc.
- -Geographic Area
- -Satellite (if known)
- -Orbit Number (if known)
- -Visual and/or Infrared Sensor
- -Special Physical Features to be shown in Imagery
- -Geographical Gridding Desired or Not
- -Final Product Format: Print, Transparency, Negative, Slide, Microfilm, etc.
- -Final Product Size
- -Finish of Photographic Prints: Matte or Glossy
- -Minimum Acceptable Size or Resolution

COMPUTER TAPE PRODUCTS

Proper identification of desired data on magnetic tapes becomes even more important because of the high data densities frequently encountered and large tape volumes. Specify as much as possible of the following:

- -Date(s) of Interest
- -Time(s) in GMT
- -Geographic Area and Coordinates

- -Type of Data Products: HRPT, Sea Surface Temperature, TOVS, etc.
- -Satellite (if known)
- -Orbit Number (if known)
- -Sensor Instrument
- -Channel Type or Numbers, if Channel Select Option is Available or Desired

ORDERING PROCEDURES, SHIPMENTS, AND PAYMENTS

Mail orders for data should be addressed:

EDIS/SDSD
Room 100 World Weather Building
Washington, D.C. 20233

Telephone orders and inquiries can be taken by a Data Service representative from approximately 0730 to 1700 Eastern Time Monday through Friday (except holidays) at (301) 763-8111 or FTS 763-8111. International inquiries, where time is critical, can be sent via International Telex specifying delivery to "Satellite Data Services Division, Room 100, World Weather Building". Our cable address is "NOAA, Washington, D.C."; the International Telex numbers are RCA 248376 or ITT 440108.

Telephone orders will not be accepted for photographic products totalling more than $100 or digital products totalling more than $250 without written confirmation specifying the exact contents of the order. Any order regardless of price which is particularly lengthy or very detailed should be submitted originally or followed up in writing.

Users associated with colleges and universitites are required to furnish a Purchase Order with each request. U.S. Federal agencies and contractors must also supply a Purchase Order or MIPR. Industrial buyers should follow their usual purchasing procedures. Cost estimates will be provided upon request.

Prepaid orders should have checks made payable to "COMMERCE/NOAA/NCC".

Specify if shipping and billing addresses are different.

Completed orders are sent via regular mail and via Air Mail to overseas customers; orders valued more than $250 are sent Registered or Certified. We also have the capability to deliver orders to most areas of the U.S. (and some Canadian locations) overnight by private air courier (Federal Express, Inc.) or by United Parcel Service (UPS). If Federal Express, UPS, or Special Delivery is requrested, the customer will assume all delivery charges.

DELIVERY TO FOREIGN NATIONS

In the past, SDSD has experienced difficulties in delivering data packages to non-US users. Although we make every effort to conform to U.S. and any local customs requirements, some shipments have been delayed for extended periods at their destination or have been completely lost. Attempts to trace such lost deliveries can take several months.

SDSD will fill out appropriate customs forms for any nation, if provided by the user, along with a sample appropriately completed. Deliveries can also be sent via Air Freight Collect with the user paying all shipping fees. SDSD has, for several nations, been able to forward data shipments to the destination through each nation's Scientific Attache located at their Embassy in Washington, D.C. Such formal arrangements should be requested by the user directly through the Scientific Attache. With their approval, all future shipments can be delivered in such a manner.

CANCELLATIONS OR ALTERATIONS TO ORDERS

Once a request for data has been received at SDSD, all attempts will be made to complete it and mail it to the user as quickly as possible. Such orders, once initiated, cannot be routinely cancelled or changed. If a user, prior to receipt of the data he has requested, decides to cancel that particular order or to change the contents, all attempts will be made to comply. However, if the order has already been mailed, the user must accept and pay all fees. If the order has not been completely finished, but processing has started, the user is responsible for all fees associated up to that point in the processing.

CERTIFIED SATELLITE PHOTOPRINTS

Under certain circumstances, particularly in legal proceedings, it is desirable that satellite photoghraphs depicting certain meteorological events be certified as "True Copies" of materials held by the Satellite Data Services Division. There are three types of certifications provided:

1. Individual Certification. Copies of photographs can be individually certified as true copies of originals on file at SDSD. This type of certification consists of the appropriate statement stamped on each photograph and signed by the Certifying Officer. A charge of $5 is made for each signature, in addition to the actual cost of the image(s).

2. Group Certification (Attached Certification Statement). A certificate without seal can be provided as a cover to multiple numbers of photographs (Group Certification). This consists of an appropriate statement signed by the Certifying Officer and affixed to manageable collections of assembled photographs. There is a charge of $5 per group of records, plus the price of the image(s).

3. DOC Certification (Authenticated Certification Under the Seal of the Department of Commerce). This two-part certificate (certification and authentication) can be furnished when required. Authenticated Certification can be applied to individual items or groups of items. For DOC certification and authentication, the charge is $9 per certification, plus the price of the image(s).

Some entries on the legends of satellite photographs may be in code form (digits and letters) not known to non-meteorologists. Qualified SDSD employees will prepare a plain language description of the codes if necessary and have it certified.

SDSD personnel cannot provide a description and interpretation of what a particular photograph depicts which may be certified and/or entered into litigation. Such requests will be referred to an appropriate official in NESS on a case-by-case basis or, if desired, the user may request the services of a private Consulting Meteorologist. Lists of such individuals may be obtained from:

American Meteorological Society
45 Beacon Street
Boston, MA 02108
(617) 227-2425

GOES DIGITAL DATA

Although GOES digital data is now ordered from the SDSD it should be considered somewhat separately from other SDSD digital data orders (TIROS-N, NOAA-5, SEASAT, etc) because in some instances it is actually filled by the Space Science and Engineering Center (SSEC) of the University of Wisconsin. All of the digital data collected by the GOES satellite series after 1978 has been archived by the SSEC. When the SDSD receives an order for GOES digital data this order is forwarded to the SSEC. For this reason a description of the GOES data tapes produced by the SSEC as well as the information they require is included here. First, the minimum information required in an order is as follows:

1. Time and Date: GOES-East records, an image every half hour starting on the hour and half hour. GOES-West also records one every half hour starting 15 minutes after the hour and 45 minutes after the hour. The time should be specified as Greenwich Mean Time to avoid confusion arising from local time changes.

2. The Satellite: GOES-East centered at 75°W or GOES-West centered at 135° W.

3. The resolution: the data available from SSEC are produced at a number of different resolutions. Actually this means that the visible data are averaged to degrade their spatial resolution or IR data pixels are doubled to give an apparent increase in resolution. See Appendix IV for a description of the SSEC GOES data types.

4. The area of interest: the user may specify an area by longitude and latitude or by scan line and element. When using the former method caution is advised because of curvature of longitude and latitude which can be quite deceptive in the geostationary satellite projection. When specifying these the

minimum and maximum position of the scan elements corresponding to the left-most and right-most longitudes respectively will be calculated at the reference latitudes.

The time required to fill an order will in general depend on its size. For example an order of 20 sectors in ODIS format (requiring 3 ODIS tapes) made by mail directly to the SSEC prior to the switch off to the SDSD on July 31, 1980 was received on August 25, 1980. This order is included with other sample orders in the next section.

The meaning of some of the required parameters outlined above will become more clear with the following description of the GOES digital data tapes produced at the SSEC. This description was provided on request by the SSEC and is included in Appendix IV.

Appendix III. NOAA Series Standard Products Available from SDSD

The material in this appendix describes standard products for the NOAA satellites available from the Satellite Data Services Division (SDSD) of NOAA. Instructions on ordering these products is available in Appendix II. This material has been abstracted from the Satellite Data User's Bulletin Volume 1 Number 2 August 1979, pages 11 and 12.

STANDARD PRODUCTS

1. ORBITAL SWATH IMAGES. Orbital swath images are available in the form of 35mm microfilm or photographic prints. Data coverage is essentially from November 1972 to March 15, 1978 and January 15, 1979 to present.

2. MAPPED MOSAICS. Northern and Southern Hemispheric Polar-Stereographic Projections and a Tropical (40°N-40°S) Mercator Projection of SR Visible, SR Daytime IR, and SR Nighttime IR data are archived for each day on 25 x 25 cm negatives. On September 15, 1976, the format for the Hemispheric Mosaics changed from using 2048 grids to a 1024-grid structure. Simultaneously, both Hemispheric Mosaics were placed on one 25 x 25 cm negative. These data are available on 35mm microfilm or photographic prints for data from November, 1972 to March, 1978. Polar-Stereographic Mosaics, Northern and Southern Hemispheres, are also available on computer-compatible tape for data from May, 1974 to March, 1978.

3. SEA-SURFACE TEMPERATURE PRODUCTS. Quantitative data from the SR Infrared channel, together with information from the VTPR, are used to compute sea-surface temperature values for grid points at roughly 100-km intervals over the world's oceans. Temperature values are computed daily for grid points where the sea surface is not obscured by clouds. Where clouds interfere, values from the most recent day without cloud interference are retained to complete the daily data field. A magnetic tape containing temperatue values, the age of the computed value in days, and other related statistical parameters at each grid point is prepared each day. The data may be reproduced in a number of display products for specialized applications. Daily Sea-Surface Temperature data are archived and available on CCT's at SDSD.

a. CCT's containing global Sea-Surface Temperature (SST) observations for each day and a summary of the orbital passes processed are available. The coverage of these data is from December 1972 to the present, with each tape containing one month's data.

b. Negatives (25x25 cm) are available which display the latest available Sea-Surface Temperature observations, and the "age" of the observation at each data point for both Northern and Southern Hemispheres. Primary use of this product is internal to the National Environmental Satellite Service (NESS) for daily monitoring of SST processing. The coverage of these data is from November 1972 to the present.

c. SST 10-Day Analyzed Field Tapes: Once per day, all satellite SST observations are merged into a polar-stereographic field. In addition to SSTs, this "analyzed field" contains land-sea tags, climatology temperatures, SST gradients, data age information, and verification temperatures. Ten analyzed fields from ten successive days are written to tape. With a few exceptions, these tapes are available for every day since May 10, 1973.

d. Global Ocean Sea-Surface Temperature Computations (GOSSTCOMP) Isoline Charts: Contour displays of analyzed SST fields are available in paper copies. Contours are labelled in °C with a one-degree contour interval. Sections of the globe (50° x 50° increments) are enlarged in Mercator Projection (Arctic and Antarctic regions in Polar-Stereographic Projection). These charts are available weekly beginning with April 1976 to the present (June 1976 missing).

Appendix IV GOES Data Tapes Produced by SSEC

INTRODUCTION

The Off-line Data Ingest System (ODIS) receives real-time or archive GOES image data, visible and IR; and records selected segments of these data on conventional, computer-compatible magnetic tape (9-track, 800/1600 BPI, NRZI). The segments of interest are specified by operator's commands entered on a keyboard on the off-line system or through a communications line from a large computer facility (McIDAS).

DATA SEGMENTS

A segement is described as follows:

1. The nominal start time of the image from which the segment will be taken
2. The first scan to be included in the segment
3. The last scan to be included in the segment
4. The data resolution of interest
5. The extent of the horizontal coverage
6. The left-most picture element to be included in the segment.

Note that the segment is defined down to one satellite scan, not to one visible sensor line. (There are eight scan lines in the visible for every rotation of the satellite.) This problem is easily solved by requesting slightly more data than needed. Several segments may be taken from one image, but only one segment can be recorded at a time and, therefore, overlap between segments will require multiple recordings.

Each segment put on a tape is preceded by a unique header record containing the descriptors of the segment for identification puposes. In addition, the first 128 bytes of the IR data (the documentation block) are output for each scan in a segment, regardless of the resolution or extent requested. The segment header record and IR documentation together identify the data adequately for all subsequent processing.

Several data resolutions are available in the system. For each resolution there are differences in the possible coverage. These limitations are imposed by the transfer rate of the 9-track tape unit which is writing the data.

Available options are:

1. Full resolution (half mile) visible data. For this option horizontal coverage is fixed at 1008 elements. IR data cannot be recorded with full resolution visible data.
2. Infrared only. Coverage is possible from 256 pixels minimum to the entire data line in increments listed below under "Permissable Horizontal Coverage Codes."
3. Infrared and averaged visible data combined data sets. One, two, or three mile visible data averages are available, corresponding to the average of 2, 4, or 6 visible elements. Coverage is possible up to 2,048 pixels for 1 mile visible and for the whole line at 2 or 3 miles.

The vertical extent of a segment is limited only in that it must remain inside of one image, and the total amount of data on a tape is controlled by the length of the tape and the limitation of not more than 15 segments per tape regardless of segment length.

The total amount of data which can be put on a given length of tape can be determined from the following:

1. Data are divided into records as follows:

   IR - one record per satellite revolution (scan) 3840 data bytes (max) + 129 documentation bytes per record.

1/2 nmi (nautical miles) Visible - one record per scan (no IR) 1008 data bytes (pixels) per line x 8 lines + 129 documentation bytes = 8193 bytes (max) per record

1 nmi Visible - five records per scan (one is IR data) 2048 bytes per visible data record (max) + 129 documentation bytes in the IR record

2 and 3 nmi Visible - three records per scan (one is IR data) 3840 bytes per visible data record (max) + 129 documentation bytes in the IR record

2. Data are recorded at 800 or 1600 bytes (pixels) per inch plus 3/4 inch gap between records.

3. Additional detail on the ODIS tape format is provided below.

DATA FORMATS

When recorded on ODIS, IR and visible data records are intermixed on the tape. SSEC can reformat data to separate records and simplify the programming effort for other users. This is called the save-tape format. If the data user will be processing a large amount of SMS/GOES data it is much more economical to use the tape as it comes from ODIS and to put the reformatting and header generation software in his own computer. Details of the save-tape format are provided below.

ODIS TAPE FORMAT

Data Block Header

A single 64 byte record is written for each area of data recorded, before any satellite data for the area is written. This record has the following format:

Byte 0: 55 (Hex, inverted ASCII for '*')

Bytes 1-2: Undefined

Bytes 3-63: A copy of the command line for the block to follow. Byte 3 contains the first character of the time field; the rest of the command line appears exactly as typed. All characters of the line are represented in inverted (complemented ASCII, with bit 7 set to zero.

Mode 0 - IR Only Sectors

One data record is written for each rotation of the satellite. Its length is equal to 256 times the horizontal coverage code which is contained in the command line. (See below for list of permissible horizontal coverage codes.) The format of the record is:

Byte 0: 00

Bytes 1-128: IR Documentation

Bytes 129+: IR Data.

Mode 1-2 Mile IR, 1 Mile Visible Sectors

One IR record is written, followed by four visible records for each satellite rotation. The IR record has the same format as the mode 0 IR record. The visible records have a length of 256 times the horizontal coverage code. Their format is:

Byte 0: 02 (the averaging number)

Bytes 1-2: Starting pixel number + 512 (in binary, low order byte first)

Byte 3+: Visible data.

Modes 2 and 3 - 2 Mile IR and 2 Mile Visible or 2 Mile IR and 3 Mile Visible Sectors

One IR record, followed by two visible records are written for each scan. The IR records have the same format as the Mode 1 visible records except byte 0 is 04 for Mode 2 and is 06 for Mode 3.

Mode H - 1/2 Mile Visible Only Sectors

One 8193 byte record is written per satellite rotation. Horizontal coverage is fixed at 1008 pixels and no other coverage is available at 1/2 nmi resolution. Each record has the following format:

Byte 0:	01
Bytes 1-128:	IR Documentation
Bytes 129-1136:	Visible Data, Line 1
Bytes 1137-2144:	Visible Data, Line 2
Bytes 2145-3152:	Visible Data, Line 3
Bytes 3153-4160:	Visible Data, Line 4
Bytes 4161-5168:	Visible Data, Line 5
Bytes 5169-6176:	Visible Data, Line 6
Bytes 6177-7184:	Visible Data, Line 7
Bytes 7185-8192:	Visible Data, Line 8

Permissible Horizontal Coverage Codes (in Pixels at Specified Resolution)

Coverage Number	Width in Pixels	
	IR	Visible
2	383	509
3	639	765
4	895	1021
5	1151	1277
6	1407	1533
7	1663	1789

8	1919	2045
9	2175	2301
A	2431	2557
B	2687	2813
C	2943	3069
D	3199	3325
E	3455	3581
F	3711	3938

SAVE-TAPE FORMAT

A McIDAS image save-tape contains two dimensional digital image sectors prepared on the McIDAS system from a variety of image sources. The first record on a save-tape is an image directory (header record) containing descriptors necessary to the definition of each of the image sectors contained on the tape. Following the directory record are up to 16 image sectors in a blocked format. The image sectors are composed of 8 bit samples (0-225). There are no END-OF-FILES between the image sectors. The tape mode is 9 track - binary (odd parity) with 800 or 1600 bit per inch (BPI) packing density. McIDAS save-tapes are generated by a Harris /5 computer which uses a 24-bit word size. The following tape format is therefore described in terms of 24 bit words.

Directory Record (225 words)

There are 16 sets of descriptors in the directory record, each composed of 14 parameters; the first 14 words for the first sector; the second 14 words for the second sector; etc. This gives a total of 224 words for the descriptor sets. An additional word containing an operator assigned tape label number makes the directory record 225 words long. If there are N image sectors on the save tape where ($1 \leq N \leq 16$), there are N sets of descriptors defined. The last M sets of descriptors parameters where (M = 16 - N) are set to -1. A directory record can now be defined as follows:

Words	Contents
1-14	Descriptor set 1
15-28	Descriptor set 2
.	.
.	.
.	.
209-224	Descriptor set 16
225	Tape Number

A Descriptor Set contains the following parameters:

Word	Parameter (All Integers)
1	SSYYDD (source-year-day of image) SS = source YY = last two digits of year DDD = day number
2	HHMMSS (Greenwich time of image) HH = hour MM = minute SS = second
3	ULIN (line coordinate of upper left hand corner of image)
4	UELE (element coordinate of upper left hand corner of image)

5	MMRR (data scale and resolution in the line direction)
	MM = magnification or repetition factor*
	RR = sampling format*
6	MMRR (data scale and resolution in the element direction)
	MM = magnification or repetition factor*
	RR = sampling factor*
7	KKKKKKK (image massaging codes)
8	SRI (source-reel identifier)
	The SRI is the McIDAS serial number of original source tape from which the image sector was derived.
9	Set to 0 (unused)
10	Set to 1 (unused)
11	NUMLIN (number of rows in image sector)
12	NUMELE (number of columns in image sector)
13	YYDDD (year-day when image sector was produced on McIDAS)
14	HHMMSS (hour-minute-second when image sector was generated on McIDAS-Central Standard Time)

* If this parameter is set to 0, it is assumed to be 1.

Image Sectors

1. There are 6723 8-bit bytes per record (2241 words).

2. 6720 bytes per record are used for data. The last 3 bytes (1 word) contain a record sequence counter which may be used to aid in detecting or recovering from tape read errors.

3. The number of columns (NUMELE) in an image sector (referred to as a "digital area" on McIDAS) is always an integer multiple of 336. The maximum allowed is 3360.

4. Rows are not split between records. The maximum number of whole image sector rows that can be stored in 6720 bytes will be written in one record, with any remainder of the 6720 byte record left undefined.

5. The number of rows (NUMLIN) in an image sector is always an integer multiple of the number of rows per tape record.

Example 1

500 rows by 672 column (standard McIDAS image sctor size)

6720/672 = 10; therefore each tape record will contain 10 rows.

The entire image sector will be recorded on 500/10 = 50 tape records.

Example 2

1002 rows by 1008 columns

6720/1008 = 6 2/3; therefore each tape record will contain 6 rows.

The entire image sector will be recorded on 1002/6 = 167 tape records.

Image Source Codes (Octal)

SS	Image Type
16	SMS-1 Visible
17	SMS-1 IR
20	GOES-1 Visible
21	GOES-1 Infrared

22	GOES-2 Visible
23	GOES-2 Infrared
24	GOES-3 Visible
25	GOES-3 Infrared

Image Messaging Codes

K	Data Operator
0	Denotes no operator
1	Left earth edge correction
2	Right earth edge correction
3	Both earth edge correction
4	Low pass filter
5	High pass filter
6	Dynamic range stretch
7	Laplacian applied
8	Gradient applied
9	Enhancement applied

NOTE: In the image massaging descriptor word, the order of the operator flags (right to left) designates the order in which the operators were applied

Appendix V. Ordering Data from the EROS Data Center

The EROS Data Center archives and disseminates all LANDSAT data received at U.S. operated ground stations. This includes all data of the U.S. as well as some data from other regions of the earth. The EROS Main Image File used to catalog LANDSAT imagery references all these images and all images acquired by foreign stations. Therefore, in principal, a search of the EROS data directory will point to all images archived at all data centers for the region and time specified.

The EROS Data Center also archives aircraft data from selected government missions.

The remainder of this section contains section 8 and Appendix A of the LANDSAT Data User's Handbook describing the ordering of data and providing samples of ordering forms.

AVAILABILITY AND ORDERING OF LANDSAT DATA

Availability of Data

The availability of Landsat data over a specific area of interest may be determined by several methods. The scene identification number can be obtained by consulting a catalog, obtaining a computer listing, or using other accession aids. A computer listing (fig. 8–1) of the scene identification number(s) may be obtained from the EROS Data Center after specifying the area of interest. The primary method of indicating the area of interest is to use geographic coordinates specifying or delimiting the area. These coordinates can be either a single point, the corners of a rectangle or square, or a polygon (for a polygon, up to eight corner points may be used).

A second manner of indicating an area of interest is to use path and row numbers obtained from the Worldwide Reference System (page 5–9 to 5–31).

Another acceptable manner of inquiry is to furnish a map showing the respective area of interest. This map must contain sufficient information (latitude and longitude, place names, political boundaries) to enable the customer-service representative to determine the geographic coordinates of the area of interest.

Extreme care should be taken by the requestor to identify his specific area of interest and to provide information on acceptable cloud cover and quality (see inquiry form 9–1936, Appendix A).

User Services

User Services provides customer assistance and ordering information for all users of EROS Data Center products. Its primary function is to respond to requests for information on availability of Landsat (and other) data and process orders from the EROS Data Center's photographic and (or) magnetic tape holdings. Requests for information are received at the User Services Section by letter, telephone, telegraph/telex, and in person at the Visitor Assistance Unit (p. 8–12), and also at offices of U.S. Geological Survey National Cartographic Information Center (NCIC), which works closely with EDC. Orders may be placed in person or by mail (see p. 8–10 to 8–12). Information about available Landsat data is provided to NCIC offices through computer terminals and (or) by telephone; in turn, NCIC offices accept orders from the public and process them through the EDC computer. NCIC offices where information may be obtained and orders placed are as follows:

U.S. Geological Survey Eastern Mapping Center
Room 1C105, National Center, Stop 536
Reston, Virginia 22092
(703) 860–6336, FTS 928–6336

U.S. Geological Survey Mid-Continent Mapping Center
1400 Independence Road, Rm 231
Rolla, Missouri 65401
(314) 364–3680, ext. 107, FTS 276–9107

National Space Technology Laboratories, Building 1100, Room 218
Located at: Bay St. Louis, Mississippi
mailing address: NSTL Station, Mississippi 39529
(601) 688–3544, FTS 494–3544

U.S. Geological Survey Rocky Mountain Mapping Center
Room H–2206, Building 25, Denver Federal Center
mailing address: Stop 504, Box 25046, Federal Center
Denver, Colorado 80255
(303) 234–2326, FTS 234–2326

U.S. Geological Survey Western Mapping Center

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                                        EROS DATA CENTER                                          REPORT NO. DL001-1
                                   SIOUX FALLS, SOUTH DAKOTA  57198                               DATE       06/12/78
          PHONE 605-594-6511   FEDERAL TELECOMMUNICATIONS SYSTEM PHONES USE 784-7151              TIME       15:40
                                                                                                  PAGE           1
                         CONTACT NUMBER 0004309121          TERMINAL T83A61

 9 ACCESSIONS                              POINT REFERENCE  RETRIEVAL

 PATH  ROW    PATH  ROW     PATH  ROW    PATH  ROW        EXPOSURE DATES QUALITY CLOUD COVER  RECORDING-TECH
  016  033                                                 GE 770701          5        10%        VERTICAL

                                              DATA TYPE  LANDSAT

                                                                                                                    BIP2
 IMAGERY-TYPE       SCENE  ID      FILM SOURCE QUALITY CLOUD EXPO DATE   SCENE-CENTER-POINT    SCENE-SCALE   MICROFORM  COL CCT
PATH= 16  ROW= 33  LANDSAT
 LANDSAT-2 (MSS)     8211201439IX0    B&W-02.1"    8888*   10%  02/15/78  N38D46M08S W076D49M12S  1:3,369,000  *0000000000  P   N
  CORNER POINT COORDINATES=#1:N39D18M57S W075D37M40S,#2:N39D37M15S W077D31M48S,#3:N38D13M19S W077D59M39S,#4:N37D55M02S W076D07M37S

 LANDSAT-2 (MSS)     8211021438IX0    B&W 02.1"    8888*   10%  01/28/78  N38D46M08S W076D49M08S  1:3,369,000  *0000000000  P   N
  CORNER POINT COORDINATES=#1:N39D18M57S W075D37M36S,#2:N39D37M15S W077D31M44S,#3:N38D13M19S W077D59M35S,#4:N37D55M02S W076D07M33S

 LANDSAT-1 (MSS)     8598513410500    B&W 02.1"    M55B*   10%  12/29/77  N38D57M00S W077D00M00S  1:3,369,000  *0000000000  P   N
  CORNER POINT COORDINATES=#1:N39D33M05S W075D42M02S,#2:N39D51M16S W077D46M03S,#3:N38D20M06S W078D16M42S,#4:N38D02M26S W076D15M13S

 LANDSAT-2 (MSS)     8301214394500    B&W-02.1"    5888*   00%  10/30/77  N38D52M00S W076D58M00S  1:3,369,000  *0000000000  7   N
  CORNER POINT COORDINATES=#1:N39D27M37S W075D39M44S,#2:N39D46M34S W077D43M25S,#3:N38D15M34S W078D15M01S,#4:N37D57M07S W076D13M49S

 LANDSAT-1 (MSS)     8591313490500    B&W 02.1"    M85B*   10%  10/18/77  N38D54M00S W077D05M00S  1:3,369,000  81100640024  P   N
  CORNER POINT COORDINATES=#1:N39D30M20S W075D47M10S,#2:N39D48M11S W077D51M18S,#3:N38D16M52S W078D21M34S,#4:N37D59M30S W076D19M57S

 LANDSAT-1 (MSS)     8587713525500    B&W 02.1"    M580*   00%  09/12/77  N38D55M00S W077D06M00S  1:3,369,000  81100620651  P   N
  CORNER POINT COORDINATES=#1:N39D31M04S W075D48M32S,#2:N39D48M54S W077D51M57S,#3:N38D18M00S W078D22M12S,#4:N38D00M47S W076D21M17S

 LANDSAT-1 (MSS)     8585913545500    B&W 02.1"    M885*   10%  08/25/77  N38D55M00S W077D08M00S  1:3,369,000  81100620288  P   N
  CORNER POINT COORDINATES=#1:N39D31M16S W075D50M21S,#2:N39D49M02S W077D54M14S,#3:N38D17M55S W078D24M22S,#4:N38D00M39S W076D23M01S

 LANDSAT-2 (MSS)     8290414455500    B&W 02.1"    8588*   10%  07/14/77  N38D48M00S W076D58M00S  1:3,369,000  82100321205  P   N
  CORNER POINT COORDINATES=#1:N39D23M43S W075D38M49S,#2:N39D43M16S W077D43M33S,#3:N38D11M27S W078D15M55S,#4:N37D52M25S W076D13M43S

 LANDSAT-1 (MSS)     8500514003500    B&W 02.1"    M888*   10%  07/02/77  N38D53M00S W077D11M00S  1:3,369,000  81100600340  P   N
  CORNER POINT COORDINATES=#1:N39D29M30S W075D52M41S,#2:N39D47M32S W077D57M32S,#3:N38D15M40S W078D28M02S,#4:N37D56M08S W076D25M43S
**************************************************************   DONE   ****************************************************************
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FIGURE 8–1.—*Example of a computer-printout listing of Landsat scenes.*

Room 122, Building 3
345 Middlefield Road
Menlo Park, California 94025
(415) 323–8111, ext. 2427, FTS 467–2427

Main Image File

Information on the over 250,000 Landsat scenes (and over five million frames of aerial and other space photography and imagery) is stored in the EDC computer. This data base of photography and imagery is known as the EDC Main Image File (MIF). The Landsat portion of the MIF contains information for every Landsat scene [1] stored at the EROS Data Center. This information includes the following items:

scene identification number [2]
geographic coordinates
cloud cover indicator
quality for each individual band
date of exposure
image type
path-row indicator
microfilm location of image
accession format
storage location at EDC
digitized format availability.

A user inquiry can specify a geographic point, a point and radius, a rectangle described by latitude and longitude limits, or a polygon of up to eight sides. In addition, the user can specify images with a maximum cloud cover, minimum quality, and (or) date(s) of coverage.

From the accession data displayed, the user may obtain microfiche or microfilm of the desired scene and visually select the imagery best suited to the application.

Terminal requests may be processed immediately or, as an option, delayed for overnight processing. Standing requests are entered and processed in batch mode and compared to Landsat data acquisition for a given period. Accessions of interest will be listed and sent to the requestor.

Upon completion of an inquiry resulting in identification of accessions of interest, an order can be placed through the User Services Section at EDC or at an NCIC office if deemed more advantageous. In addition, an order can be automatically processed as an option of the Standing Request System (SRS).

Landsat Micrographic Accession Aids System

The EROS Data Center (EDC) has developed an inexpensive, user-oriented geographic accession aid system in which the descriptions of all Landsat accessions are stored on microfiche film records. This system is based on the Worldwide Reference System (WRS) (p. 5–9 to 5–31), a network of intersecting paths and rows whose junctions define the nominal scene centers of Landsat scenes. The zone, path, and row notation is the primary storage and retrieval key for the microfiche records. Each microfiche record shows the accession descriptions, for as many as 60 Landsat nominal scene centers, as computer listings. Users of the Landsat accession aids system will need WRS maps of their regions of interest to identify the path-row points for which data are desired. To use a WRS index map, it is necessary only to locate a point on the ground and then determine which is the closest path-row intersection. For example, the intersection nearest to Washington, D.C. is Path 16, Row 33.

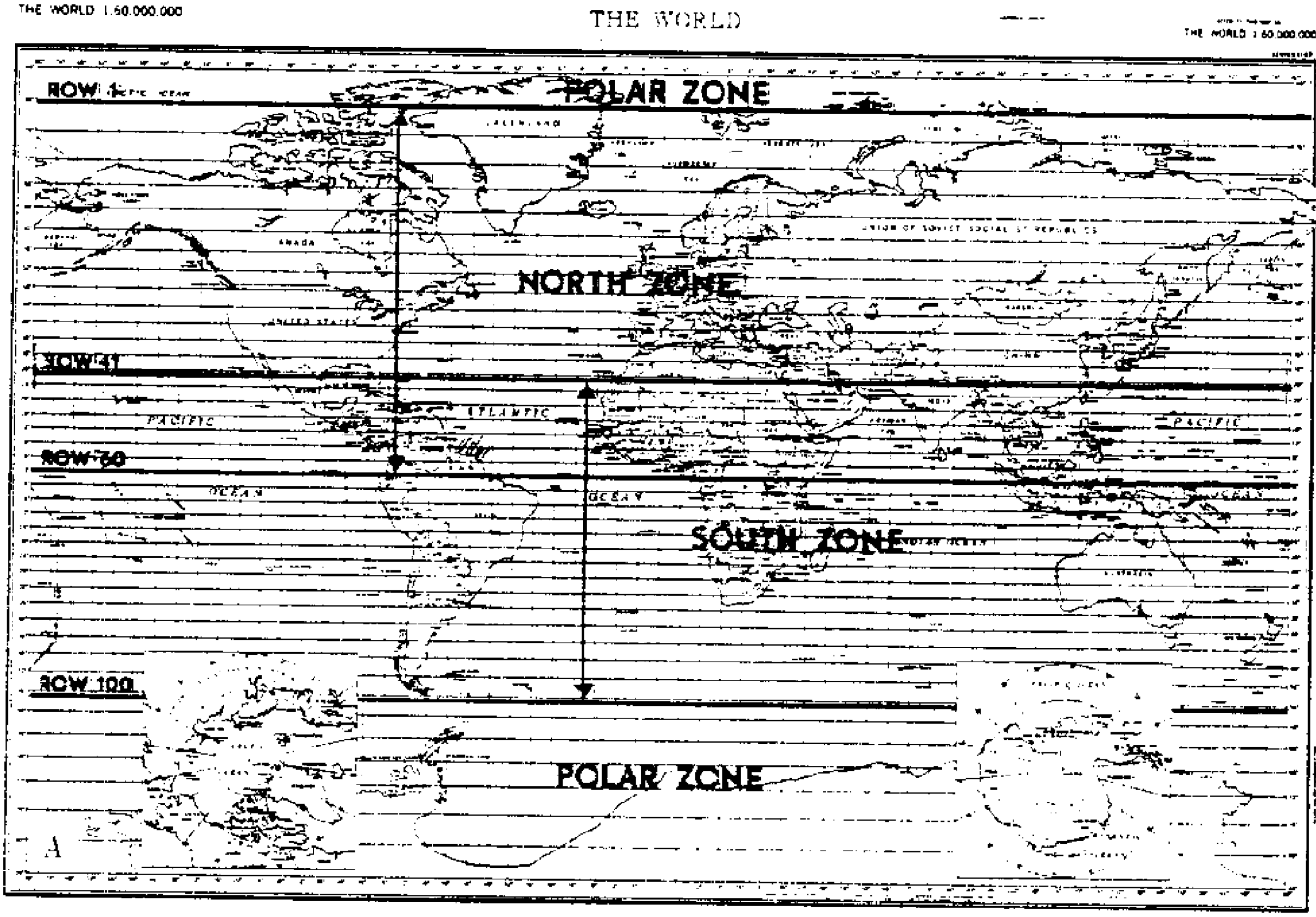
Zones Within the Worldwide Reference System

The Worldwide Reference System has been divided into three zones. Each zone represents a group of as many as 60 WRS rows (fig. 8–2 for descending node). These zones are:

Zone	Node	Rows
North	Descending	1–40
	Ascending	184–243
South	Descending	41–100
	Ascending	144–203
Polar (combined)	Descending }	101–143
	Ascending }	244–248

[1] A Landsat scene is herein defined as the single MSS band 8 image (Landsat 3, ascending node), the four MSS images (Landsats 1 and 2), the five MSS images (Landsat 3, descending node), the 3 RBV images (Landsat 1 and 2), or the 4 RBV subscenes (Landsat 3).

[2] The 9- or 10-character scene (frame) identification number for Landsats 1, 2, and 3 indicates by which satellite the data were acquired, days after launch, and time of exposure in hours, minutes, and tens of seconds Greenwich mean time. (See figure AE–11, p. AE–10, for explanation of the scene i.e., frame, identification number).



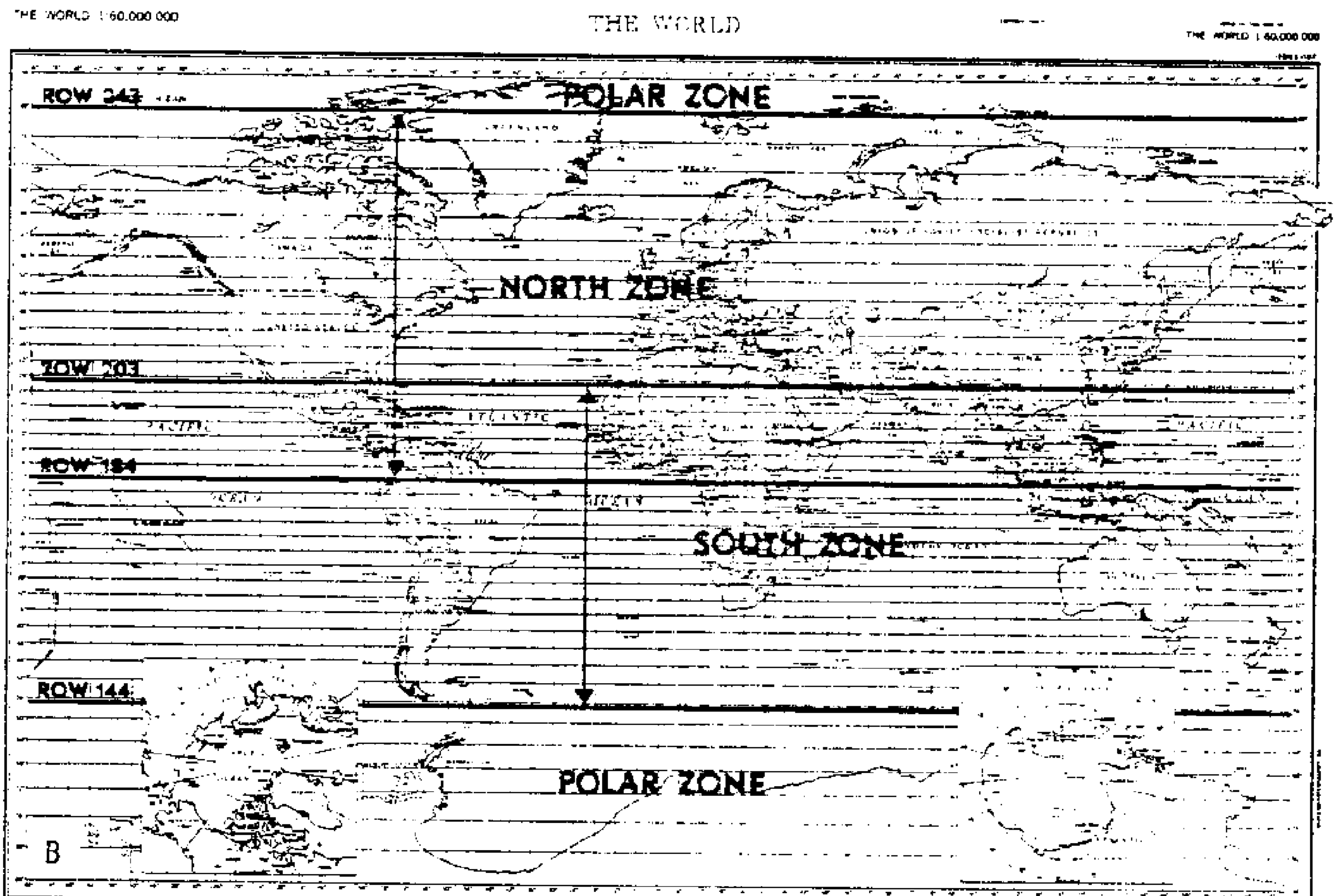


FIGURE 8–2.—*Landsat microfiche systems index, showing representative paths (orbits), selected rows, and zones (row groupings) in descending node.*

A 20-row overlap has been made between the North and South zones. Each microfiche represents the Landsat data for one path in one zone, and the overlap enables users to confine their microfiche collection to one zone for any country.

Landsat Catalog Microfiche

Each microfiche is a single film chip, measuring 105 mm by 148 mm, containing an eye-readable header section, and microimages (24 × reductions) of computer listings of as many as 60 Landsat WRS scene descriptions.

A diagram of the microfiche layout is shown in figure 8–3. The narrow band of data at the top of the record is the header and shows path number, row numbers, zone designation, date range, accession types, and an indicator of daytime or nighttime coverage. Almost all Landsats 1 and 2 scenes were acquired during daytime passes.[3]

The microimages of the computer listings are presented in a 10-row by 6-column matrix, which accommodates the 60 potential path/row positions. Each microimage position is allocated to a unique row number within each zone. Position No. 1 (upper left-hand corner) is reserved for rows 1, 41, or 101, respectively, for North, South, or Polar Zones.

[3] A very few nighttime scenes were acquired, for special studies; as the indexing system in use prior to Landsat 3 could not accommodate these nighttime scenes, they were not entered into the computerized listing.

Landsat Listings

Each microimage of a computer listing for a dedicated path and row intersection is formatted as shown in figure 8–4. The computer listing is explained in table 8–1. Path/row scene centers for which no Landsat scenes exist will show a "NO ACCESSIONS" display.

System Organization

The key to organizing Landsat microfiche is given in the header. The primary subdivision is by path, the secondary subdivision is by zone (implying specific row groupings), and the third is by date.

A geographic filing system may be based on the paths crossing and bordering a user's area of interest. Normally, a region will fall within one of the three zones. The United States, for example, is covered by Paths 11–51, which are enclosed entirely within the North Zone. All current accessions can be listed within five date ranges: 1972–74, 1975, 1976, 1977 and 1978–present. The total microfiche file for any specific area can be determined by multiplying the number of paths by the number of date

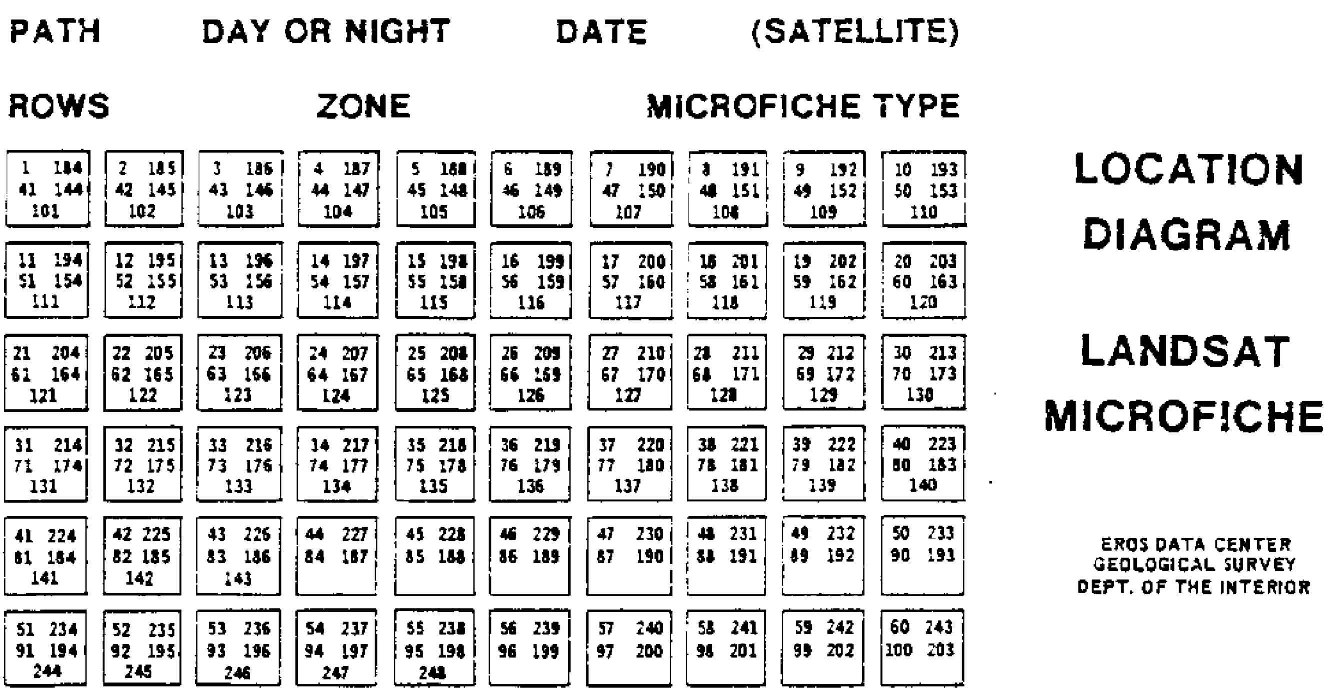


FIGURE 8–3.—*Format of the Landsat microfiche record.*

LANDSAT UNIT RECORD
MICROGRAPHIC ACCESSION AIDS SYSTEM
WRS DATA LISTINGS - Phase I and II

PATH 020 ROW 036 LANDSAT

Phase I Microfiche

DATE	SAT	SEN	IMAGE QUAL 45678	CLD COV	COL	MICROFILM	CCT	CENTER	COORDINATES	SCENE ID	SP
05/21/76	1	MSS	8888	10%		1100510441		N34033M595	W084015M00S	854521456050000	
07/14/76	1	MSS	5888	10%		1100500013		N34033M595	W084015M00S	853981500050000	
08/10/76	2	MSS	8888	10%		2100210812		N34037M595	W084000M00S	825661524150000	

PATH 020 ROW 036 LANDSAT

Phase II Microfiche

DATE	SAT	SEN	IMAGE QUAL 45678	CLS COV	COL	MICROFILM	CCT	DIGIT QUAL 45678	CENTER	COORDINATES	SEN	CLOUD COVER/IMAGE QUAL A	B	C	D	DIG QUAL ABCD	SCENE ID	SP
09/30/78	3	MSS	58888	10%		3100210830	Y	88888	N34035M00S	W084010M00S	RBV	10%/8	10%/8	00%/8	10%/8	8888	834531524150000	
10/18/78	3	MSS	55555	20%	7	3100220633	Y	77777	N34030M59S	W084000M59S	RBV	10%/8	20%/8	20%/8	10%/8	8888	835621522450000	
11/13/78	3	MSS	58558	10%		3100230438	Y	88888	N34020M00S	W084015M00S	RBV	10%/8	10%/7	10%/7	10%/8	8888	835661456050000	
12/01/78	3	MSS	85888	00%		3100240520	Y	88888	N34033M00S	W084015M00S	RBV	00%/7	00%/5	00%/7	00%/5	8788	835691500050000	

FIGURE 8–4.—*Format of computer listing for a dedicated path and row as shown on microfiche: Phase I, prior to implementation of IPF/EDIPS; Phase II, after implementation of IPF/EDIPS.*

TABLE 8–1.—*Computer listing key*

1. DATE.—Indicates the month, day, and year that the images were taken. Dates are listed sequentially, with earliest date first and most recent date last.
2. SAT (Satellite.)—1, 2, or 3 for Landsats 1, 2, or 3, respectively.
3. SEN (Sensor).—MSS for Multispectral Scanner. RBV for Return Beam Vidicon.
4. IMAGE QUAL (Quality).—Each black-and-white band is rated in sequence by a 2 (Poor), 5 (Fair), or 8 (Good). O or M indicates a missing band. Color composites are rated on a 0–9 scale with 9 indicating excellent quality.
5. CLD CLV (Cloud Cover).—Percentage of image obscured by clouds and cloud shadows.
6. COL (Color Composite).—If a color composite has been made from the black-and-white images, its quality designator is shown.
7. MICROFILM.—Indicates (or "shows") the cassette and frame number (for Landsat images acquired prior to the conversion to microfiche records).
8. CCT (Computer Compatible Tape).—Indicates the availability of a CCT by one of the three categories:
   N, scene cannot be processed and will never be available
   Y, scene has been processed and can be ordered
   P, scene has not yet been processed; may or may not be processable
9. CENTER COORDINATES.—The latitude and longitude of the scene center in degrees, minutes, and seconds.
10. SCENE ID.—A 13-character identification number unique to each Landsat scene which is used for product ordering.
11. SP (Special).—Denotes a non-standard product associated with the specific accession, e.g., digital enhanced version available, nonstandard bands used in color composite, and so forth (see STA). Suggest contact with EROS Data Center prior to ordering products.

blocks. Therefore, the U.S. file will total 205 microfiche (41 paths × 5 date blocks). Foreign coverage obtained from non-U.S. ground receiving stations [1] (table 8–2) may be organized in a similar manner.

System Use

Using the Landsat micrographics accession aids system requires only the appropriate WRS maps, a microfiche reader (24 × magnification is recommended), and the microfiche ac-

[1] Several Landsat data reception and processing stations are operated by Government or Government-subsidized organizations or agencies in other countries under agreements with the National Aeronautics and Space Administration. These stations are capable of directly receiving Landsat data acquired over a circular area with a radius of about 3,000 km from the station.

TABLE 8–2.—*International Landsat ground stations in operation, December 1977*

Country	Location of Receiving Station	Address Inquiries to
Canada	Prince Albert Saskatchewan	User Assistance Canada Centre for Remote Sensing
	St. John's, Newfoundland	Department of Energy, Mines and Resources 717 Belfast Road Ottawa, Ontario, K1A0Y7 Canada
Brazil	Cuiaba, Mato Grosso	Instituto de Pesquisas Espaciais (INPE) Attn: Divisao de Banco de Dados Av. Dos Astronautas, 1758—Caixa Postal 515 12.200—Sao Jose dos Campos S.P.–Brasil
Italy	Fucino	Telespazio S.P.A. Per Le Communicazioni Spaziali Corso d'Italia 42 00198 Roma, Italy Attn: Mrs. G. Calabresi

cession aids. The following procedure is suggested:

a. Select the proper WRS map, and locate your area of interest.
b. Define the WRS paths crossing and bounding the selected area.
c. Note the zone(s): North, South, and (or) Polar.
d. Choose the date range of interest: 1972–74, 1975, 1976, 1977, 1978–present (North America date range breakdown).
e. Extract the appropriate microfiche (path, zone, and date dependent) from the file and insert in the reader.
f. Move microfiche holder so that images (rows) of interest can be viewed.
g. Note selected accessions for ordering imagery or viewing on microfilm.
h. Continue for their paths and rows until all scene information is obtained.

Landsat Data Products

A wide variety of Landsat data products are available from the EROS Data Center. These include black-and-white and color photographs, in nominal image sizes ranging from 56 mm to 100 cm, and several kinds of digital tapes (table 8–3). The ways in which these products are made are described in the section on "Landsat Data Handling and Processing"; the products are described in detail in Appendixes E (Photographic Products), F (Computer-Compatible Tapes), and H through K (High-Density Digital Tapes).

Photographic Products

Black and White

Black-and-white products ranging in nominal image size from 56 mm (1:3,369,000 scale) to 740 mm (1:250,000 scale) are available as standard products from the EROS Data Center. The specific products are listed in table A–3 and described in detail in Appendix E.

Black-and-white products produced and distributed by the EROS Data Center come from two basic sources: 56 mm (1:3,369,000 scale) second-generation negatives (N–2)[*] provided by the NASA Goddard Space Flight Center Processing Facility (NDPF), and 185 mm (1:1,000,000 MSS) and 198 mm (1:50,000 RBV) first generation negatives produced by the EROS digital image processing system (EDIPS). The NDPF negatives are produced from postive transparencies exposed by an electron beam recorder; the EDIPS negatives are exposed by a laser beam recorder from digital tapes provided by the NASA GSFC Image Processing Facility (IPF). A limited number of Landsat 1 and 2 scenes were processed from October 1976 through March 1978 by the EDIPS pilot system, known as EDIES (for *E*ROS Data Center *d*igital *i*mage *e*nhancement *s*ystem). The characteristics of the EDIES products are similar to those from the production system (EDIPS); EDIES photographic products are available from EDC.

Color

False-color composites are available as positive transparencies at a scale of 1:1,000,000

[*] N, negative; P, positive; number following, generation, commencing with 1 for the initial exposed film, either positive or negative, and increasing by one generation for each succeeding product (for example, the negative produced by GSFC from their 1st generation positive exposed by the electron-beam recorder, and furnished to the EROS Data Center, is second generation [N–2]; positive prints made from the N–2 are P–3, and so on).

TABLE 8-3.—*Landsat data products*

Basic Sources	Black and white	False-Color Composites	Digital Magnetic Tapes
56 mm[1] N–2[2] black and white negatives (NDPF)[3]	56 mm P–3 transparencies 56 mm N–4 transparencies 185 mm P–3 transparencies 185 mm N–4 transparencies 185 mm P–3 prints 1:1,000,000 scale 370 mm P–3 prints 1:500,000 scale 940 mm P–3 prints 1:250,000 scale standard products 100 cm up to 1:100,000 scale custom product	185 mm P–6 transparencies	
185 mm N–1 black and white negatives (EDIPS)[4]	56 mm P–2 transparencies 185 mm P–2 transparencies 185 mm N–3 negatives 185 mm P–2 prints 370 mm P–2 prints 940 mm P–2 prints up to 1:100,000 scale custom	185 mm P–3 transparencies	
185 mm P–3 or P–6 false-color composite trans- parencies	185 mm P–7 or P–4 prints 370 mm 940 mm	185 mm P–7 or P–4 transparencies 185 mm P–7 or P–4 prints 370 mm P–7 or P–4 prints 740 mm	
CCT_{NDPF} (NDPF) HDT (IPF)[5]			CCT_{NDPF} HDT CCT_{EDIPS}

[1] Nominal image size.

[2] N, negative; P, positive; number following, generation; commencing with 1 for the initial exposed film, either positive or negative, and increasing by one generation for each succeeding product (for example, the negative produced by GSFC from their 1st generation positive exposed by the electron-beam recorder, and furnished to the EROS Data Center, is second generation [N–2]; positive prints made from the N–2 are P–3, and so on.

[3] NASA—Goddard Space Flight Center, Data Processing Facility (initial facility in use until summer 1978).

[4] EROS Digital Image Processing System.

[5] NASA—Goddard Space Flight Center, Image Processing Facility (revamped facility in use after summer 1978).

(185 mm) and as positive prints at scales 1:1,000,000 (185 mm), 1:500,000 (340 mm), and 1:250,000 (740 mm). The master reproducible color composite positive transparencies from which the color products are reproduced were composited either at the NDPF or EDC. For Landsats 1 and 2, until June 1978 the source for the NDPF composites were black-and-white 185 mm N–2's made from 56 mm P–1 transparencies; for the EDC composites the basic source was black-and-white 56 mm N–2's made from a 56 mm P–1. With the implementation of EDIPS, the basic source for Landsats 2 and 3 is 185 mm (1:1,000,000 scale) N–1's. A limited number of false-color composites were made from the pilot image processing system (EDIES), and are available from EDC. However, for all false-color composites, whether produced at NDPF or EDC, three black-and-white 185 mm positive transparencies are "composited"; the manner in which this is done, and the types of color products available are described in detail in Appendix E.

Digital Magnetic Tapes

Landsat sensor data are available from the EROS Data Center in two digital forms: high-density tape (HDT) and computer-compatible tape (CCT). These digital data may be obtained for either the RBV or MSS sensor as only radiometrically corrected, referred to as "partially processed," or as both radiometrically and geometrically corrected, referred to as "fully processed." Digital scenes include all bands available. Radiometric correction includes data decompression to a dynamic pixel range of 0–127 and compensation for MSS detector gain and offset changes. Geometric correction includes compensation for distortions caused by the sensor, spacecraft attitude and altitude variations, and Earth rotation. Also, during geometric correction, ground control point detection and map projection transformation are performed on the image data. Hotine Oblique Mercator (HOM)[a] projection will be the standard projection on which the processed HDT's and CCT's are cast initially; Space Oblique Mercator (SOM) projection will replace the HOM when the formulae and computer programs are worked out. Either Universal Transverse Mercator (UTM), for latitudes between 65° N and 65° S, or Polar Stereographic (PS), for latitudes above 65° N and below 65° S, may be specified at extra cost. Partially processed tapes contain the data necessary to process the data to the two projections, HOM and either UTM or PS, depending on latitude, as discussed above.

[a] The difference between the HOM and SOM are very small, and will only be either apparent or of concern to users with elaborate and precise computer programs (A.P. Colvocoresses, written communication, 1978).

High-Density Tapes

The digital data are transferred from the NASA Goddard Space Flight Center Image Processing Facility to the EROS Data Center in the form of HDT's. The data content is substantially the same as that on the CCT. The HDT is 14-track 1-inch magnetic tape with data encoded at 20,000 bits per linear track-inch. One track contains a standard telemetry IRIG–A time code, 10 tracks contain the data, and three tracks are unused. The HDT can be one of four types; HDT–PM, HDT–AM, HDT–PR, OR HDT–AR. The "M" and "R" refer to the sensor that provided the data on the tape, MSS or RBV. The "P" and "A" refer to the data as being "fully processed" (radiometrically and geometrically corrected) or "partially processed" (only radiometrically corrected), respectively. Once at EDC, an HDT–P is used to produce all the standard products available. Detailed descriptions of HDT's are given in Appendixes I (HDT–PM), H (HDT–AM), K (HDT–PR), and J (HDT–AR). The complete appendixes are not routinely included in the Landsat Data User Handbook, Revised, because of their length and expected limited demand, but they may be obtained upon request to User Services, EROS Data Center, Sioux Falls, South Dakota 57198.

Computer-Compatible Tapes

A computer-compatible tape (CCT) is a standard 2400 foot reel of ½ inch magnetic tape. A CCT can be requested in either 9-track, 800-bpi, or 9-track, 1600-bpi (bpi, bits per inch) format. A CCT set is the equivalent of one MSS scene or one RBV subscene. The MSS scene CCT can contain data for 1, 4, or 5 bands, depending on whether it is for descending or ascending node coverage. Landsats 1 and 2 have four MSS bands. Landsat 3 has five MSS bands, but only one, band 8, the thermal infrared band, will ordinarily be used for nighttime coverage. The MSS CCT set can include from one to three physical reels of magnetic tape depending on the sensor, bpi, and number of bands. A Landsat 3 RBV scene[7] is composed of four subscenes, each of which is a separate entity recorded on one magnetic tape set. A complete description of the CCT's produced by the GSFC NDPF is given in Thomas (1975; 1977), and CCT's produced by the EDIPS are described in Appendix F.

Each CCT set contains the following three data files: (1) the header, ancillary, and annotation file; (2) the image data file; and (3) the trailer file.

Ordering of Data

Orders may be placed with the EROS Data Center by personal visit, telephone, telegraph/telex, or mail. Orders also may be placed at any of the National Cartographic Information Center (NCIC) offices located at various places throughout the United States (see p. 3). Orders for available Landsat data can be processed only when all of the necessary information (scene identification number, specification of product[s]) has been obtained from the customer and payment has been received.

Each order received is checked to verify that the scene identification number is valid, that sufficient information about the product(s) and shipping instructions have been provided, and that payment has been received. When it has been determined that the order is correct and complete, it is processed through the computer system, which results in a work order to the section responsible for product reproduction. Each item of an order requires separate reproduction from master reproducibles.

Each customer is assigned an account number, to which reference should be made whenever applicable.

Specification of Desired Product

Three methods of specifying a desired Landsat product may be used. In two of these, the "Selected Landsat Coverage" (of the conterminous United States) and "Major U.S. Metropolitan Areas," the customer orders the representative scene(s) selected by the EROS Data Center of the area(s) of interest. In the third, "Standard Landsat Products," the customer may order any available scene and product.

[7] Landsats 1 and 2 RBV scenes are not available on CCT's.

Selected Landsat Coverage

For photographic products of the single Landsat scene selected by the EROS Data Center as the best one for each of the nominal scene centers within the conterminous United States, the "Selected Landsat Coverage" order form, 9–1493 (Appendix A) may be used. The scene is specified by path and row. When using this method, only certain products may be ordered: black-and-white paper prints of band 5 at scales of 1:1,000,000 (185 mm nominal image size), 1:500,000 (370 mm nominal image size) and 1:250,000 (740 mm nominal image size); false-color film positives at a scale of 1:1,000,000; and false-color composite paper prints at scales of 1:1,000,000, 1:500,000, and 1:250,000.

Major Metropolitan Areas

Landsat false-color composites that are available for 101 major U.S. metropolitan areas may be ordered by using Order Form 9–1492 (Appendix A). A representative scene has been chosen for each of the areas, which are listed on the back of the order form. Available products are film positives at a scale of 1:1,000,000 and prints at scales of 1:1,000,000, 1:500,000, and 1:250,000.

Standard Products

Photographic products and CCT's of any available scene, anywhere in the World, whose master reproducible is stored at the EROS Data Center or is available from the Goddard Space Flight Center, are ordered on form 9–1938 (Appendix A). The scene identification number, type of product, and bands (for black-and-white photographic products) must be specified.

Four types of photographic products and two types of CCT's are available. The "standard" photographic products include black-and-white and false-color film transparencies and prints produced from:

1. NDPF/EBR
2. EDIES/HRFR
3. IPF/EDIPS
4. Specially processed (enhanced) IPF/EDIPS products.

The two types of CCT's are those produced by:

1. NDPF, called "X–format"
2. IPF/EDIPS, called "A and P formats" (Appendix F).

Prepayment

All orders for reproduction of data must be accompanied by cash, check, money order, purchase order, or authorized account identification. Checks, money orders, purchase orders, and other instruments must be made payable to the "U.S. Geological Survey." Currency should not be sent but may be used to pay for products ordered during a personal visit to the EROS Data Center or one of the facilities authorized to place orders and receive payment.

Standing or open accounts may be established by users having a need for repetitive and continuing orders. A standing account may be opened by advance deposit of funds with the EROS Data Center. The user will be given an account number against which to place all subsequent orders. Status of standing order accounts will be provided by a monthly statement. Accounts may be added to, or a refund of the unused portion obtained, at any time.

Checks drawn on foreign banks will not be accepted due to conversion charges and international documentation requirements; payment should be processed through a U.S. Federal Reserve bank, which will send the draft (payable to the U.S. Geological Survey) to the EROS Data Center.

Standing Request System

The EROS Data Center *Standing Request System* is intended to provide Landsat data users with several options for obtaining data or information on a regular and timely basis.

The two basic options within the system are:

1. Automatic reproduction of data of an area. This option provides the most expeditious method for acquiring data that meets the customer's criteria over a specified area of interest. A standing account must be established and maintained to satisfy the prepayment requirement for orders.
2. Routine provision of information about the data acquired over the area(s) of interest. This option allows the customer to select and order specific scenes of area(s) of interest; unlike Option (1), however, the customer must place an order, in the normal manner, each time data are desired.

Custom Products

Custom processing of Landsat data to unique scales and (or) formats is available. This service normally takes longer to perform and costs three times as much as standard products of similar types and sizes.

Custom processing must be specified on the order form, and the requirements explicitly identified.

Priority Service

A priority system for rapid delivery of *Standard Products* is available. When a priority order is specified, products will be shipped to the user within five working days after the order is received and the items requested are verified. Certain requirements must be met to qualify for priority service: only a standard product may be ordered, the product must be exactly identified, and payment must accompany the order (or sufficient funds must be available in the standing account). Further, the master reproducible must be available at the EROS Data Center. An item produced on a priority order costs three times the standard price for that product. The submitted order form must be clearly marked "PRIORITY." If an order cannot be filled on a priority basis, the customer will be notified and, if the customer desires, the order will be filled routinely at the standard price. In that event, the excess payment will be refunded (or not withdrawn from a standing account).

Visitor Assistance

The Visitor Assistance Unit contains reference materials for Landsat and other data; microform (microfilm or microfiche) copies of data are available for viewing, and assistance in inquiring and ordering is provided. Computer listings ordinarily may be obtained during a visit.

ORDER FORMS AND PRICE LISTS FOR LANDSAT DATA PRODUCTS

This appendix includes illustrations of the form to request a computer search of Landsat imagery and of forms to order (1) standard products, (2) selected Landsat coverage of the U.S. (by path and row), and (3) major metropolitan areas in the United States. These forms may be obtained from the EROS Data Center, User Services, Sioux Falls, South Dakota 57198 [telephone: (605) 594–6511, extension 151; Federal Telecommunications System, 784–7151].

INQUIRY FORM

GEOGRAPHIC COMPUTER SEARCH

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Return Completed Form To:

U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
FTS: 784-7151
Comm: 605/594-6511

DATE ____________

NAME MR / MS ____________ (FIRST) ____________ (INITIAL) ____________ (LAST)

COMPUTER ACCOUNT NO. ____________ (IF KNOWN)

COMPANY ____________ (IF BUSINESS ASSOCIATED)

PHONE (Bus.) ____________

ADDRESS ____________

PHONE (Home) ____________

CITY ____________ STATE ____________ ZIP ____________

YOUR REF. NO. ____________ (P.O. GOV'T ACCT. OR OTHER)

TO INITIATE AN INQUIRY AND COMPUTER GEOSEARCH COMPLETE THE FOLLOWING

POINT SEARCH

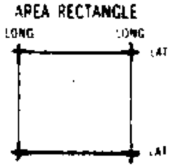
Imagery with any coverage over the selected point will be included.

	POINT #1	POINT #2	POINT #3
Latitude	___° ___' N or S	___° ___' N or S	___° ___' N or S
Longitude	___° ___' E or W	___° ___' E or W	___° ___' E or W

Landsat Only (Worldwide Reference System)

Path ____	Path ____	Path ____	Path ____	Path ____
Row ____	Row ____	Row ____	Row ____	Row ____

AREA RECTANGLE



Imagery with any coverage over the selected area will be included.

AREA #1	AREA #2	AREA #3
Lat. ___° ___' N or S to	Lat. ___° ___' N or S to	Lat. ___° ___' N or S to
Lat. ___° ___' N or S	Lat. ___° ___' N or S	Lat. ___° ___' N or S
Long. ___° ___' E or W to	Long. ___° ___' E or W to	Long. ___° ___' E or W to
Long. ___° ___' E or W	Long. ___° ___' E or W	Long. ___° ___' E or W

If the above geographic coordinates cannot be supplied, please specify area by GEOGRAPHIC NAME AND LOCATION (include a map if possible.)

PREFERRED TYPE OF COVERAGE

	Black & White	Color or Color Infrared
☐ Landsat	☐	☐
☐ Skylab	☐	☐
☐ Nasa Aircraft	☐	☐
☐ Aerial Mapping Photography (Minimum color available)		

PREFERRED TIME OF YEAR

Check maximum of three

- ☐ JAN-MAR
- ☐ APR-JUNE
- ☐ JULY-SEPT
- ☐ OCT-DEC
- ☐ All coverage
- ☐ Latest coverage
- ☐ SPECIFIC DATES ____________

NOTE: Seasonal coverage normally applies only to Landsat coverage.

MINIMUM QUALITY RATING ACCEPTABLE

☐ 0-2 (VERY POOR) ☐ 3-4 (POOR) ☐ 5-6 (FAIR) ☐ 7-9 (GOOD)

MAXIMUM CLOUD COVER ACCEPTABLE

☐ 10% ☐ 30% ☐ 50% ☐ 70% ☐ 90%

NOTE: Classification of percent of cloud cover is subjective and is relative to the amount of clouds appearing on the imagery and not to their location.

APPLICATION AND INTENDED USE ____________

FORM 9-1936
(April 1978)

For Additional Information or Assistance Please Contact One of the Following Offices of the National Cartographic Information Center (NCIC).

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092
FTS: 928-6045
Comm: 703/860-6045

U.S. Geological Survey
Eastern Mapping Center
National Cartographic Information Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: 314/364-3680

U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

U.S. Geological Survey
National Cartographic Information Center
National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

PLEASE CONTACT THE NEAREST NCIC OFFICE FOR INFORMATION CONCERNING THE AVAILABILITY OF CARTOGRAPHIC PRODUCTS OTHER THAN IMAGERY.

FIGURE AA-1

HOW TO REQUEST A GEOGRAPHIC SEARCH

This form is used to request a computer search for imagery over a point or area of interest.

Data from this inquiry sheet will be used to initiate a computer Geosearch. The results will be returned on a computer listing along with a decoding sheet, from which imagery can be selected and ordered.

Complete the form as follows:

A. Enter your NAME, ADDRESS, and ZIP CODE clearly. If you have had previous contact with that facility, include your COMPUTER ACCOUNT number. Enter a PHONE number where you can be reached during business hours.

B. Complete the required information for either the POINT SEARCH, or AREA RECTANGLE inquiry, which includes the geographic LATITUDE and LONGITUDE coordinates. If coordinates are not available, please supply the GEOGRAPHIC NAME AND LOCATION or a map with the area of interest identified. It is beneficial that you minimize your area of interest, thereby allowing for a faster and more critical retrieval of information.

C. Complete all other information.

D. Complete the APPLICATION AND INTENDED USE portion of the inquiry. e.g. Will it be used for identifying buildings or will it be framed and placed on a wall. This information will assist our technicians in determining whether the products available will satisfy your requirements.

E. Return completed form to the EROS DATA CENTER.

NOTE: If an inquiry is made for Landsat Data, and the Worldwide Reference of PATH and ROW numbers are available, please insert them in the appropriate locations. Otherwise, geographic coordinates will suffice.

FIGURE AA–1—Continued

ORDER FORM
LANDSAT STANDARD PRODUCTS
U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

NAME MR / MS ____________ (FIRST) (INITIAL) (LAST) DATE ____________

COMPANY ____________ (IF BUSINESS ASSOCIATED) COMPUTER ACCOUNT NO (IF KNOWN) ____________

ADDRESS ____________ PHONE (Bus.) ____________

CITY ____________ STATE ________ ZIP ________

PHONE (Home) ____________

SHIP TO ____________

YOUR REF NO. ____________ (P.O. GOV'T ACCT OR OTHER)

PLEASE TYPE OR PRINT PLAINLY

SCENE IDENTIFICATION NUMBER	PRODUCT CODE	PHOTOGRAPHS ONLY: MSS BANDS 4	5	6	7	8	NO. OF EACH	QTY	UNIT PRICE	TOTAL PRICE

TOTAL ABOVE	A	
TOTAL FROM PREVIOUS SHEETS	B	
TOTAL COST	C	

STANDARD PRODUCTS TABLE

BLACK AND WHITE PRODUCTS

NOMINAL IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	PRICE
[illegible]	Film Positive	[illegible]	$ 4.00
55.5mm (2.2 in.)	Film Negative	01	10.00
18.5cm (7.3 in.)	Paper	03	8.00
18.5cm (7.3 in.)	Film Positive	13	10.00
18.5cm (7.3 in.)	Film Negative	73	10.00
37.1cm (14.6 in.)	Paper	04	12.00
74.2cm (29.2 in.)	Paper	26	20.00

FALSE COLOR COMPOSITE PRODUCTS

NOMINAL IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	PRICE
18.5cm (7.3 in.)	Paper	63	$12.00
18.5cm (7.3 in.)	Film Positive	53	15.00
37.1cm (14.6 in.)	Paper	64	25.00
74.2cm (29.2 in.)	Paper	66	50.00

PRICES SUBJECT TO CHANGE.

COLOR COMPOSITE GENERATION

NOMINAL IMAGE SIZE	PRODUCT MATERIAL	PRODUCT CODE	PRICE
18.5cm (7.3 in.)	Printing Master	59	$50.00

NOTE. Not applicable for MSS Band 8 nor RBV Subscenes. Printing Master is retained by EDC. Cost of products from this composite must be added to total costs.

COMPUTER COMPATIBLE TAPES (CCT)

TRACKS	BPI	FORMAT	MSS All Bands Available: PRODUCT CODE	PRICE	RBV Single Subscene: PRODUCT CODE	PRICE	Set of Four RBV Subscenes: PRODUCT CODE	PRICE
9	800	TAPE SET	183-B	$200.00	183-C	$200.00	183-D	$400.00
9	1600	TAPE SET	184-B	200.00	184-C	200.00	184-D	400.00

PAYMENT MADE BY:

CHECK, MONEY ORDER ☐

PURCHASE ORDER ☐

GOVT ACCOUNT ☐

COMMENTS: ____________

FORM 9-1938 (August 1979)

Return Completed Form To:
U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
FTS: 784-7151
Comm: 605/594-6511
TWX: 910-668-0310

For Additional Information or Assistance Please Contact One of the Following Offices of the National Cartographic Information Center (NCIC).

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092
FTS: 928-6045
Comm: 703/860-6045

U.S. Geological Survey
Eastern Mapping Center
National Cartographic Information Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: 314/364-3680

U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

U.S. Geological Survey
National Cartographic Information Center
National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

PLEASE CONTACT THE NEAREST NCIC OFFICE FOR INFORMATION CONCERNING THE AVAILABILITY OF CARTOGRAPHIC PRODUCTS OTHER THAN IMAGERY

FIGURE AA-2

HOW TO ORDER STANDARD LANDSAT DATA

This order form is used to order all standard Landsat data. Necessary order information can normally be extracted from a computer listing of available data or from other Landsat references.

Please provide the following information in the indicated areas of the order form:

A. List your complete NAME, ADDRESS, ZIP CODE, and name of your COMPANY if applicable.

B. If you desire to have the products mailed to an address or individual other than yourself, please complete the "SHIP TO" address.

C. List a PHONE NUMBER where you can be contacted during business hours.

D. If you have had previous business with the EROS DATA CENTER, please list your COMPUTER ACCOUNT NUMBER if known.

E. Enter the complete SCENE IDENTIFICATION NUMBER. This number can be transcribed directly from the COMPUTER LISTING. If the source of information is from other than a computer listing, please specify the date and the time (GMT) that the scene was recorded.

F. Review the STANDARD PRODUCTS TABLE on the ORDER FORM and determine the type of product desired.

G. Enter the PRODUCT CODE of the type product being ordered from the STANDARD PRODUCTS TABLE.

H. Enter an indicator for the band(s) desired. Not required for RBV Subscenes.

I. The COMMENTS portion is completed only when a CUSTOM PRODUCT is desired and you want to specify the parameters. Cost determination is normally based on three times the standard cost.

J. Enter the Total Number of Bands ordered.

K. Multiply the total bands ordered by the number of copies desired and enter the result in the QUANTITY column.

L. Enter the UNIT PRICE of the type product as reflected in the STANDARD PRODUCTS TABLE.

M. Multiply the figure in the QUANTITY column by the UNIT PRICE and enter the result in the TOTAL PRICE column.

N. Repeat the above for each product ordered.

O. TOTAL the costs of all products ordered on this order form and enter the net result in BLOCK A. (TOTAL ABOVE).

P. If more than one order form is required, enter the sum of the figures in BLOCKS A in BLOCK B of the last order form.

Q. Enter the SUM of BLOCK A and BLOCK B in BLOCK C. (TOTAL COST).

R. Indicate the TYPE of payment being made with a CHECK MARK. Make all drafts payable to U.S. GEOLOGICAL SURVEY. DO NOT SEND CASH.

S. Mail ORDER FORM(S) and PRE-PAYMENT to the EROS DATA CENTER. IF PAYMENT HAS BEEN PREVIOUSLY FORWARDED TO ANOTHER FACILITY, PLEASE FORWARD THIS ORDER TO THAT FACILITY FOR PROCESSING.

FIGURE AA-2—Continued

ORDER FORM

SELECTED LANDSAT COVERAGE

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

Return Completed Form To:

U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
FTS: 784-7151
Comm: 605/594-6511

NAME MR MS ______________________ (FIRST) (INITIAL) (LAST) DATE ____________

COMPANY ______________________ (IF BUSINESS ASSOCIATED) COMPUTER ACCOUNT NO. (IF KNOWN) ____________

ADDRESS ______________________ PHONE (Bus.) ____________

CITY ____________ STATE ________ ZIP ________

PHONE (Home) ____________

SHIP TO ______________________

YOUR REF. NO. (P.O. GOV'T ACCT OR OTHER) ____________

PLEASE TYPE OR PRINT PLAINLY

MAP REFERENCE NUMBER PATH	ROW	PRODUCT CODE	QTY	UNIT PRICE	TOTAL PRICE

TOTAL ABOVE	A
TOTAL FROM PREVIOUS SHEETS	B
TOTAL COST	C

STANDARD PRODUCTS

BLACK AND WHITE

IMAGE SIZE	PRODUCT MATERIAL	CODE	UNIT PRICE
18.5cm (7.3 in.)	PAPER	23	$ 8.00
37.1cm (14.6 in.)	PAPER	24	$12.00
74.2cm (29.2 in.)	PAPER	26	$20.00

FALSE COLOR COMPOSITE

IMAGE SIZE	PRODUCT MATERIAL	CODE	UNIT PRICE
35mm SLIDE	FILM POSITIVE	50	$ 1.00
18.5cm (7.3 in.)	PAPER	63	$12.00
37.1cm (14.6 in.)	PAPER	64	$25.00
74.2cm (29.2 in.)	PAPER	66	$50.00

PAYMENT MADE BY:

- CHECK (MONEY ORDER) ☐
- PURCHASE ORDER ☐
- GOVERNMENT ACCT. ☐

*Refer to item "O" on reverse side.

UNIT PRICES SUBJECT TO CHANGE

COMMENTS: ______________________

FORM 9-1943 April 1978

For Additional Information or Assistance Please Contact One of the Following Offices of the National Cartographic Information Center (NCIC).

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092
FTS: 928-6045
Comm: 703/860-6045

U.S. Geological Survey
Eastern Mapping Center
National Cartographic Information Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: 314/364-3680

U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

U.S. Geological Survey
National Cartographic Information Center
National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

PLEASE CONTACT THE NEAREST NCIC OFFICE FOR INFORMATION CONCERNING THE AVAILABILITY OF CARTOGRAPHIC PRODUCTS OTHER THAN IMAGERY.

FIGURE AA-3

HOW TO ORDER SELECTED LANDSAT COVERAGE DATA

This order form is used to order only SELECTED LANDSAT COVERAGE DATA over the Conterminous United States

Please provide the following information in the indicated areas of the order form.

A. List your complete NAME, ADDRESS, ZIP CODE, and name of your COMPANY if applicable.

B. If you desire to have the products mailed to an address or individual other than yourself, please complete the "SHIP TO" address.

C. List a PHONE NUMBER where you can be contacted during business hours.

D. If you have had previous business with the EROS DATA CENTER, please list your COMPUTER ACCOUNT NUMBER if known

E. Enter the MAP REFERENCE NUMBER

Refer to the SELECTED LANDSAT COVERAGE MAP foldout.

Identify your area of interest on the map. It may require that you reference a road map or atlas in locating the area on the map.

Trace the small coverage outline from the lower left corner of the map onto a sheet of thin paper. This outline portrays the ground coverage of a LANDSAT image on that map.

Center the coverage trace over the numbered dot nearest your area of interest on the map, aligning the extended dashed line through the dots above and below. (See example of template in use - lower left on map.) Dots should fall in sequence, i.e. if your center dot is 35 - 27 the dots to align with will be 35 - 26 and 35 - 28. You may find that a photo centered over adjoining dots will also cover your area of interest. Select the framing you most prefer.

Transcribe the PATH number from the map to the first column of the Map Reference Number. Transcribe the ROW number from the map to the second column of the Map Reference Number.

NOTE: ROW numbers are identified on every FIFTH PATH.

F. Enter the PRODUCT CODE of the type product being ordered from the STANDARD PRODUCTS TABLE. If your order is for Black and White imagery and a spectral band other than band 5 is desired, please so indicate in the comments section.

G. Enter the number of COPIES of that product which you desire in the QUANTITY column.

H. Enter the UNIT PRICE of the type product as reflected in the STANDARD PRODUCTS TABLE.

I. Multiply the figure in the QUANTITY column by the UNIT PRICE and enter the result in the TOTAL PRICE column

J. Repeat the above for each product ordered.

K. TOTAL the costs of all products ordered on that order form and enter the net result in BLOCK A (TOTAL ABOVE.)

L. If more than one order form is required, enter the sum of the figures in BLOCKS A in BLOCK B on the last order form

M. Enter the SUM of BLOCK A and BLOCK B in BLOCK C. (TOTAL COST.)

N. Indicate the TYPE of payment being made with a CHECK MARK. Make all drafts payable to U. S. GEOLOGICAL SURVEY DO NOT SEND CASH.

O. Mail ORDER FORM(S) and PAYMENT to the EROS DATA CENTER. IF PRE-PAYMENT HAS BEEN PREVIOUSLY FORWARDED TO ANOTHER FACILITY, PLEASE FORWARD THIS ORDER TO THAT FACILITY FOR PROCESSING.

FIGURE AA-3—Continued

ORDER FORM
MAJOR U. S. METROPOLITAN AREAS

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

NAME MR. MS. ________ (FIRST) (INITIAL) (LAST) DATE ________

COMPANY ________ (IF BUSINESS ASSOCIATED) COMPUTER ACCOUNT NO. (IF KNOWN) ________

ADDRESS ________ PHONE (Bus.) ________

CITY ________ STATE ________ ZIP ________ PHONE (Home) ________

SHIP TO ________ * YOUR REF. NO. ________ (P.O. GOV'T ACCT OR OTHER)

PLEASE TYPE OR PRINT PLAINLY

METROPOLITAN AREA	PRODUCT CODE	Landsat/Skylab/NASA Aircraft	QTY.	UNIT PRICE	TOTAL PRICE

TOTAL ABOVE A

TOTAL FROM PREVIOUS SHEETS B

TOTAL COST C

STANDARD COLOR PRODUCTS

Image Size	PRODUCT MATERIAL	PRODUCT CODE	Unit Price
LANDSAT DATA			
35mm slide	Film Positive	50	$ 1.00
18.5cm (7.3 in.)	Film Positive	53	$15.00
18.5cm (7.3 in.)	Paper Print	63	$12.00
37.1cm (14.6 in.)	Paper Print	64	$25.00
74.2cm (29.2 in.)	Paper Print	66	$50.00
SKYLAB DATA			
11.4cm (4.5 in.)	Film Positive	52	$12.00
11.4cm (4.5 in.)	Paper Print	62	$ 8.00
21.8cm (8.6 in.)	Paper Print	63	$12.00
43.4cm (17.1 in.)	Paper Print	64	$25.00
36.9cm (34.2 in.)	Paper Print	66	$50.00
NASA AIRCRAFT DATA			
22.9cm (9.0 in.)	Film Positive	53	$15.00
22.9cm (9.0 in.)	Paper Print	63	$ 7.00
45.7cm (18.0 in.)	Paper Print	64	$25.00
68.6cm (27.0 in.)	Paper Print	65	$30.00
91.4cm (36.0 in.)	Paper Print	66	$50.00

TURN TO REVERSE SIDE FOR LIST OF AVAILABLE PHOTOGRAPHY.

PAYMENT MADE BY:

- CHECK, MONEY ORDER ☐
- PURCHASE ORDER ☐
- GOVERNMENT ACCT. ☐

*Refer to "NOTE" on reverse side.

UNIT PRICES SUBJECT TO CHANGE

FORM: 9-1942 (April 1978)

Return Completed Form To:

U.S. Geological Survey
EROS Data Center
Sioux Falls, SD 57198
FTS: 784-7151
Comm: 605/594-6511

For Additional Information or Assistance Please Contact One of the Following Offices of the National Cartographic Information Center (NCIC).

U.S. Geological Survey
National Cartographic Information Center
507 National Center
Reston, VA 22092
FTS: 928-6045
Comm: 703/860-6045

U.S. Geological Survey
Eastern Mapping Center
National Cartographic Information Center
536 National Center
Reston, VA 22092
FTS: 928-6336
Comm: 703/860-6336

U.S. Geological Survey
Mid-Continent Mapping Center
National Cartographic Information Center
1400 Independence Road
Rolla, MO 65401
FTS: 276-9107
Comm: 314/364-3680

U.S. Geological Survey
Rocky Mountain Mapping Center
National Cartographic Information Center
Stop 504, Denver Federal Center
Denver, CO 80225
FTS: 234-2326
Comm: 303/234-2326

U.S. Geological Survey
Western Mapping Center
National Cartographic Information Center
345 Middlefield Road
Menlo Park, CA 94025
FTS: 467-2426
Comm: 415/323-8111

U.S. Geological Survey
National Cartographic Information Center
National Space Technology Laboratories
NSTL Station, MS 39529
FTS: 494-3541
Comm: 601/688-3544

PLEASE CONTACT THE NEAREST NCIC OFFICE FOR INFORMATION CONCERNING THE AVAILABILITY OF CARTOGRAPHIC PRODUCTS OTHER THAN IMAGERY.

FIGURE AA–4

The following list includes the Major Metropolitan Areas and the coverage types available:

X = COVERAGE AVAILABLE

	NASA Aircraft	Skylab	Landsat
Albany, NY	X		X
Albuquerque, NM	X		X
Akron, OH	X	X	X
Anaheim, CA	X		X
Atlanta, GA	X		X
Baltimore, MD	X	X	X
Baton Rouge, LA	X	X	X
Beaumont, TX	X		X
Bethlehem/ Allentown, PA	X	X	X
Birmingham, AL	X	X	X
Boston, MA	X	X	X
Bridgeport, CT	X	X	X
Buffalo, NY	X		X
Canton, OH	X		X
Charleston, SC	X		X
Charlotte, NC			X
Chattanooga, TN	X		X
Chicago, IL	X	X	X
Cincinnati, OH	X		X
Cleveland, OH	X	X	X
Columbus, OH	X		X
Dallas, TX	X		X
Davenport, IA	X		X
Dayton, OH			X
Denver, CO	X		X
Detroit, MI	X	X	X
El Paso, TX	X	X	X
Flint, MI	X	X	X
Fresno, CA	X	X	X
Ft. Lauderdale, FL	X		X
Ft. Wayne, IN			X
Ft. Worth, TX	X		X
Gary, IN	X	X	X
Grand Rapids, MI	X	X	X
Greensboro, NC	X		X
Greenville, SC			X
Harrisburg, PA	X	X	X
Hartford, CT	X	X	X
Honolulu, HI	X		
Houston, TX	X		X
Indianapolis, IN	X		X
Jacksonville, FL			X
Jersey City, NJ	X	X	X
Kansas City, MO	X		X
Knoxville, TN	X	X	X
Lansing, MI	X	X	X
Long Branch, NJ	X		X
Los Angeles, CA	X		X
Louisville, KY	X	X	X
Memphis, TN	X		X
Miami, FL	X		X
Milwaukee, WI	X		X
Minneapolis/ St. Paul, MN	X	X	X
Mobile, AL	X	X	X
Nashville, TN		X	X
Nassau/Suffolk (Long Island), NY	X		X
New Brunswick, NJ	X	X	X
New Haven, CT	X	X	X
New Orleans, LA	X		X
New York City, NY	X	X	X
Newark, NJ	X	X	X
Norfolk, VA	X		X
Northeast (Scranton), PA	X		X
Oklahoma City, OK	X		X
Omaha, NE		X	X
Orlando, FL	X		X
Oxnard/SimiValley, CA	X		X
Patterson, NJ	X	X	X
Peoria, IL	X	X	X
Philadelphia, PA	X		X
Phoenix, AZ	X	X	X
Pittsburgh, PA	X	X	X
Portland, OR	X		X
Providence, RI	X		X
Raleigh/Durham, NC	X		X
Richmond, VA	X		X
Rochester, NY	X		X
Sacramento, CA	X		X
Salt Lake City, UT	X	X	X
San Antonio, TX			X
San Bernadino, CA	X		X
San Diego, CA	X	X	
San Francisco, CA	X	X	X
San Jose, CA	X	X	X
Seattle, WA	X		X
Shreveport, LA	X		X
Sioux Falls, SD	X	X	X
Springfield, MA	X	X	X
St. Louis, MO	X	X	X
St. Petersburg, FL	X		X
Syracuse, NY	X	X	X
Tacoma, WA	X		X
Tampa, FL	X		X
Toledo, OH	X		X
Tulsa, OK	X	X	X
Tucson, AZ	X		X
Utica/Rome, NY	X		X
Washington, DC	X	X	X
West Palm Beach, FL	X		X
Wichita, KS			X
Wilmington, DE	X		X
Worcester, MA	X	X	X
Youngstown, OH		X	X

PLEASE REFER TO THE REVERSE SIDE OF THE INFORMATION LETTER FOR INSTRUCTIONS ON ORDERING PHOTOGRAPHS OVER THE MAJOR METROPOLITAN AREAS

NOTE

Coverage is available only for those areas annotated with an X and does not mean that the entire metropolitan area will be covered in that photograph.

Mail ORDER FORM(S) and PAYMENT to the EROS DATA CENTER. IF PRE-PAYMENT HAS BEEN PREVIOUSLY FORWARDED TO ANOTHER FACILITY, PLEASE FORWARD THIS ORDER TO THAT FACILITY FOR PROCESSING.

FIGURE AA–4—Continued

APPENDIX VI. HCMM Data Availability and Cost

VI-1 Data Catalogs

The IPF (Image Processing Facility) produces monthly catalogs of available HCMM imagery. Information is listed chronologically by scene ID. The format of the catalog is shown in Figure VI-1. Accompanying explanatory notes are contained in Table VI-1.

VI-2 National Space Science Data Center (NSSDC)

HCMM data and catalogs generated by the GSFC IPF are archived and available from NSSDC. The NSSDC will furnish limited quantities of data to qualified users without charge. The NSSDC may establish a nominal charge for production and dissemination if a large volume of data is requested. Whenever a charge is required, a cost estimate will be provided to the user prior to filling the data request.

Domestic requests for HCMM data should be addressed to:

National Space Science Data Center
Code 601
NASA/Goddard Space Flight Center
Greenbelt, MD 20771

All requests from foreign researchers for HCMM data archived and available through NSSDC must be specifically addressed to:

Director, World Data Center A for Rockets and Satellites
Code 601
NASA/Goddard Space Flight Center
Greenbelt, MD 20771 USA

When ordering data from either NSSDC or the World Data Center, a user should specify why the data are needed, the subject of his work, the name of the organization with which he is connected, and any government contracts he may

AEM-A

IMAGE CATALOG

SORTED BY LONGITUDE/LATITUDE

LONGITUDE	LATITUDE	CC%	V	IR	SCENE ID	SUN/AZM	SUN ELEV	ORBIT NUMBER
E000-10	N17-07	50		G	AA026801340			3965
E000-09	N19-42	40	J2	J2	AA025513150	229.69	43.36	3780
E000-33	N20-05	10	G	P	AA015913290	248.46	56.12	2358
E000-17	N20-31	50		G	AA014001530			2069
E000-00	N20-40	30	F	F	AA019113220	239.96	46.15	2832
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)

Figure VI-1. HCMM Image Catalog--Format

Table VI-1. HCMM Image Catalog-Explanatory Notes

(1) Longitude (of scene center)
dDDD-MM)

where d - direction ("E" or "W")
DDD - degrees
MM - minutes

(2) Latitude (of scene center)
dDD-MM

where d - direction ("N" or "S")
DD - degrees
MM - minutes

(3) Cloud cover percentage
0-99 in 10% increments:
(0, 10, 20, ... , 90, 99)

(4) Quality of the Visible band

G - good
F - fair
P - poor
M - missing
J0-J9 - rejected

(5) Quality of the infrared band

G - good
F - fair
P - poor
M - missing
J0-J9 - rejected

(6) Scene ID
AADDDDHHMMO

where AA - mission code ("AA" for AEM-A)
DDDD - days since launch
HH - hours
MM - minutes
O - fill; 1-second processing of the same pass starting at the same time.

(7) Sun azimuth
DDD.XX

where DDD - degrees
XX - hundredth of degrees

(8) Sun elevation
DD.XX

where DD - degrees
XX - hundredths of degrees

(9) Orbit Number

Number of ascending equator crossings since launch.

have for performing his study. Of course, each request should specify the experiment data desired, the day and area of interest (i.e., latitude and longitude) plus any other information that would facilitate the handling of the data request.

A user requesting data on magnetic tapes should provide additional information concerning the plans for using the data, i.e., what computers and operating systems will be used. In this context, the NSSDC can provide data tapes with physical characteristics that are appropraite for the user's computer. NSSDC will provide, upon request, information concerning its services.

When requesting data on magnetic tape, the user must specify whether he will supply new tapes prior to the processing, or return the original NSSDC tapes after the data have been copied.

A HCMM data product order form follows along with instructions for completing the form. Additional forms may be obtained from NSSDC/World Data Center-A.

VI-3 European Space Agency

HDMM data acquired at Lannion, France, may be ordered from:

Earthnet User Services
Via Galileo Balilei
C.P. 64
00044 Frascati
Italy

Data products generally are in agreement with NASA specifications. The quality of recordings is generally very good.

ORDER FORM

HCMM SATELLITE PRODUCTS

National Space Science Data Center
World Data Center A for Satellites and Rockets

(1)

Name ______________________________ Date ____________

Address ____

City ____________________ State ______________ Zip __________

(2) Scene ID LON / LAT	(3) Associate Scene ID Associate LON/ LAT	(4) Product Code	(5) Quantity	(6) Unit Price	(7) Total Price
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				
/	/				

(9) TOTAL COST ________

(8) Product Code & Unit Price		+ Trans	- Trans	+ Print	- Print	CCTs
Day Visible	Code	10	20	30	40	50
	Cost					
Day IR	Code	11	21	31	41	51
	Cost					
Night IR	Code	12	22	32	42	52
	Cost					
Temp. Diff.	Code	13	23	33	43	53
	Cost					
Thermal Inertia	Code	14	24	34	44	54
	Cost					

(10) Mail To:

NSSDC/WDC - A
NASA/Goddard Space Flight Center
Greenbelt, MD 20771
Tel: (301) 344-6695

Note: If order is not received within eight weeks after date of order please contact the above office.

HOW TO ORDER HEAT CAPACITY MAPPING MISSION (HCMM) DATA PRODUCTS

1. List name, address and date.
2. List scene ID. Longitude (LON) and latitude (LAT) should be listed in the event of two or more identical scene IDs (the full orbit should be scanned to ascertain the presence of identical scene IDs).
3. Use this block only when ordering temperature difference and thermal inertia data products which require the registration of two scenes.
4. List product code. (From block 8).
5. Indicate quantity.
6. List unit price. (From block 8).
7. Figure total price.
8. Table of product codes and unit prices.
9. Figure total cost.
10. Mail order and payment to address shown.

APPENDIX VII. Ordering DMSP Data from SSEC

This appendix describes what DMSP data products are available from The Space Science Engineering Center of the University of Wisconsin, the DMSP library and how it operates, and finally, how one orders DMSP imagery. The following paragraphs describing imagery production and film density control, have been taken verbatum from a description sent out by the SSEC.

IMAGERY PRODUCTION

Scale:

Imagery is produced by the ground equipment in a scale of 1 to 15 million (normal mode) or 1 to 7.5 million (expanded mode). Either the left half, right half or middle half of the data swath may be so expanded.

The image is corrected to remove apparent compression at the edges of the strip: that is, the image is automatically reformatted to appear as a strip of flat earth with nearly true horizontal dimensions. The field of view of the sensor is not constant across the swath and the resultant loss of resolution at the edges cannot be corrected.

Some of the DMSP satellites are programmed so that the H channel gain changes rapidly as the sensor scans across the terminator from night to day. The image signal gain is stepped through several orders of magnitude and the steps are readily apparent; however, it is possible to distinguish clouds continuously across the terminator in these pictures.

FILM DENSITY CONTROL

Visual Enhancement:

H and V data film density is linearly proportional to scene reflectivity (in daylight) or to scene radiance (nighttime) unless enhancement is added. Low enhancement allocates more of the 16 discernable grey shades to the low reflectivity (low radiance portion of the scene, at the expense of high reflectivity areas. High enhancement allocates more of the 16 discernable grey shades to the high reflectivity (high radiance) portion of the scene, at the expense of low reflectivity areas. High-low enhancement allocates 16 grey shades to the extremes of the signal, i.e., most of the scene is reduced to monotone grey. GWC (Global Weather Central) visual data is usually not enhanced and the products are not labelled in terms of enhancement when received at the archive. Images received from transterms (these are the remote or tactical sites, generally mobile) are often enhanced and are usually labelled appropriately.

Infrared Density Control:

Film density is directly, linearly proportional to scene black body temperature over a 100° range (x1), a 50° range (x2), or a 25° range (x4). Most GWC infrared data is in the 100° range, between 210° K and 310°K. Again transterm products vary in range and are labelled appropriately.
Threshold Mode:

The three temperatures, T_1 T_2 T_3 may be set on the image producer to render all temperatures less than T_1 as white, between T_1 and T_2 as light grey, between T_2 and T_3 as dark grey, and greater than T_3 as black. This convention may be reversed. Thresholded data is more frequently produced by transterm sites than by GWC.

Figure VII-A-1 is a sample order form. Figure VII-A-2 is the current price list. There is no charge for the positive transparencies which are loaned to the user. The user is expected to return these within an appropriate period in good condition. There is a handling and mailing charge, however, if films are borrowed.

All requests for DMSP data should be made to:

DMSP Satellite Data Library
Space Science and Engineering Center
The University of Wisconsin
1225 W. Dayton Street
Madison, Wisconsin 53706
608/262-5335

A BRIEF DESCRIPTION OF DMSP LIBRARY SERVICES†

The Defense Meteorological Satellite Program (DMSP) is operated by the United States Air Force. Data are archived and distributed by the University of Wisconsin under sponsorship of the National Oceanic and Atmospheric Administration (NOAA). DMSP data holdings at the University of Wisconsin date from March 1973. The images are in the form of positive transparencies which are received from the USAF Global Weather Central (GWC) at Offutt Air Force Base, Nebraska, and fourteen direct readout sites around the world. GWC coverage is nearly global; coverage at each direct readout site is about 50^{o} in diameter. The width of each GWC pass is about 1400 nautical miles. The format of all DMSP data is positive transparent film strips 9 1/2 inches wide, from 1 to 6 feet long.

At the present time, both a dawn-dusk and noon-midnight satellite are operating.* During each of the fourteen daily orbits of the satellite, it is either noon or midnight, or dawn or dusk at the equator. The satellites produce both infrared and visual imagery, both day and night. Most data has 1.5 nm (about 2.7 kilometer) resolution. We receive a limited amount of data with a resolution of 1/3 nm, which we supply when availabe.

The transparencies can be reproduced as slides or glossy or matte prints, with negatives available. We charge only for the cost of reproduction, for labor over one hour and for mailing. The originals are available for research purposes on a three-week loan. Extensions may be granted when justified.

The film strips can be kept in archival condition if treated with care. For example, tape should never be affixed to the surface, liquid must never be spilled on it and it ought not be written upon.

It will help us fill your request if you can be quite specific when completing our request form. Emphasize details that are most important to you, such as geographic coordinates, time (local or GMT), weather features, whether very high resolution is needed, etc.

† This description is distributed by the DMSP library of the University of Wisconsin and was current as of the summer of 1980.

* This statement is no longer valid.

REQUEST FOR DMSP IMAGERY

SSEC

SPACE SCIENCE AND ENGINEERING CENTER

THIS IS NOT AN INVOICE!

UNIVERSITY of WISCONSIN - MADISON
1225 West Dayton Street
Madison, Wisconsin 53706
TWX (910) 286-2771

REQUEST NO. ______________

ORDER NO. ______________

INVOICED ON NO. ______________

USER OR SHIPPING ADDRESS

Telephone #

BILLING ADDRESS

GEOGRAPHIC AREA

DATES

Dates

Time
(day)
(night)

Local or GMT

Night of

SPECIAL FEATURES

DMSP FORMAT

H
I
V_2
V^2
W
T

FORMAT REQUESTED

Original
8x10 print
8x10 contact print
B&W slide
Three Week Loan

SUPPLEMENTARY INFORMATION

ephemeris data
grids: 9.5 Ramstein
info: sensors gridding
GWC coverage direct read-
out coverage prices
handling

STATISTICS

Units and format | discipline | specific use

COSTS

Photoreproduction | labor | mailing

DATE OF REQUEST ______________

DATE FILLED ______________

DATE RETURNED ______________

KEY TO DMSP IMAGERY

Data types: (DMSP Format)

H - low resolution visual. Resolution is 1.5 nm with current satellites, 2.0 nm for satellites operating prior to April 1977. Both day and night imagery is generally available.

I - low resolution infrared. Thermal pictures. Resolution and availability same as for 'H'.

V - high resolution visual, 1/3 nm. Limited amount of data available for many different geographic areas and times.

V2 - expanded high resolution visual. Picture is twice the normal width. Resolution is 1/3 nm. Limited geographic coverage.

W - high resolution infrared. Same resolution and availability as V.

T - threshold. Used in meteorological research. Limited availability.

H2 - expanded visual. Same resolution as H. Limited availability.

High resolution data is supplied when available.

1 nm = 1.1 miles = 1.85 kilometers

For a more comprehensive description of DMSP imagery, a user's guide is available on loan.

DMSP COST SCHEDULE*

Labor and Shipping:

Labor required greater than 1 hour per request will be billed at. $6.75/hour

Postage will be billed if request exceeds $5.00

Photocopies:

Negative (35mm, 4 x 5.	$2.00
8 x 10 glossy print.	$1.70
8 x 10 matte print	$1.70
11 x 14 glossy print	$3.55
11 x 14 matte print.	$3.55
16 x 20 glossy print	$5.55
16 x 20 matte print.	$5.55
35mm Black and White Slide (2 x 2)	$2.00
8 x 10 negative by contact	$2.80
8 x 10 contact print (glossy).	$1.30
8 x 10 contact print (matte)	$1.30
United States mosaic (or any continent mosaic)	
8 x 10 print	$3.00
11 x 14 print.	$5.00
(Exception: Australia $2.50, $3.50)	

Negatives requiring excessive photographer time will be charged proportionately.

Rev. 8-1-81

* This price schedule was current as of August 1, 1981. Because the prices change periodically, the user should check with the library for current prices before ordering.

Figure VII-A-2. DMSP Cost Schedule.

GLOSSARY

The glossary consists of two parts: a list of terms and a list of "acronyms." The list of acronyms contains many items that are not "acronyms" per se ("a word [such as radar, snafu] formed from the initial letter or letters of each of the successive parts or major parts of a compound term" [Webster's Seventh New Collegiate Dictionary, p. 9]); many are not words but only a group of initials.

TERMS

Absorption. The process by which electromagnetic radiation (EMR) is assimilated and converted into other forms(s) of energy, primarily heat. Absorption takes place only on the EMR that enters a medium, and not on EMR incident on the medium but reflected at its surface. A substance that absorbs EMR may also be a medium of refraction, diffraction, or scattering; however, these processes involve no energy retention or transformation and are distinct from absorption.

Absorption band. A range of wavelengths (or frequencies) of EMR that is assimilated by a substance.

Albedo. (1) The ratio between the amount of EMR reflected by a body and that incident upon it, often expressed as a percentage, as, the albedo of the earth is 34 percent. (2) The reflectivity of a body as compared to that of a perfectly diffusing surface at the same distance from the Sun, and normal to the incident radiation. Albedo is sometimes used to mean the flux of the reflected radiation, as, the earth's albedo is 0.64 calorie per square centimeter, but this usage is improper and should be discouraged. Albedo may refer to the entire solar spectrum or merely to the visible portion.

Algorithm (computing terminology). A statement of predefined steps to be followed in the solution of a problem.

Attenuation. The reduction of electromagnetic signal strength as the signal propagates through a medium such as the atmosphere or the water.

Attitude. (1, photogrammetry). The angular orientation of a camera, or the photograph taken with that camera, with respect to some external reference system. Usually expressed as tilt, swing, and azimuth; or roll, pitch, and yaw. (2, platforms). The angular orientation of an aerial or space vehicle with respect to a reference system. Usually, "x" is used for the axis that defines the direction of flight, "y" for the "cross-track" axis, perpendicular to the direction of flight, and "z" for the vertical axis. "Roll" is the deviation from the vertical (the angle between the z-axis of the vehicle and the vertical axis, or angular rotation around the x-axis). "Pitch" is the angular rotation around the y-axis. "Yaw" is rotation around the z-axis.

Background. Any effect in a sensor or other apparatus or system above which the phenomenon of interest must manifest itself before it can be observed. See background noise.

Background noise. (1) In recording and reproducing, the total unwanted disturbance within a useful frequency band, independent of whether or not a signal is present. The signal is not to be included as part of the disturbance. (2) In receivers, the random oscillation in the absence of signal modulation on the carrier. Ambient oscillations detected, measured, or recorded with the signal become part of the background noise. Included in this definition is the interference resulting from primary power supplies, that is commonly described as hum.

Band, spectral. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

Beam width. A measure of the concentration of power of a directional antenna. It is the angle in degree subtended at the antenna by arbitrary power-level points across the axis of the beam. This power level is usually the point where the power density is one-half that which is present in the axis of the beam at the same distance from the antenna (half-power points). Also called the beam angle.

Bit. (1) An abbreviation of binary digit. (2) A unit of memory corresponding to the ability to store the result of a choice between two alternatives, used especially in connection with digital computing devices.

Cell. In remote sensing, an area on the ground from which EMR is emitted or reflected. See instantaneous field-of-view.

Contrast. The difference in light intensity between the brightest highlights and the deepest shadow.

Digital computer. A computer in which descrete representation of data is mainly used. In general, any device that performs arithmetic, logical, and comparative functions upon information represented in digital forms, and operates under the control of an internal program.

Distortion. (1) Any shift in the position of an image on a photograph that alters the perspective charateristics of the photograph. Causes of image distortion include lens aberration, differential shrinkage of film or paper, and motion of the film or camera. (2, linear scale) Compression or expansion of the scale of the imagery in the azimuth direction. It may be caused by an incorrect film speed. (3, non-linear) Change in scale from one part of the imagery to another.

Electromagnetic radiation (EMR). Energy emitted as a result of changes in atomic and molecular energy states and propagated through space at the speed of light. The term radiation, alone, is used commonly for this type of energy, although it actually has a broader meaning. Also called electromagnetic energy. See electromagnetic spectrum.

Electromagnetic spectrum. (1) A system that classifies, according to wavelength, all energy that moves, harmonically, at the constant velocity of light. (2) A continuum that is conventionally broken into arbitrary segments (as ultraviolet, visible, radio).

Emmissivity. (symbol ϵ). A special case of exitance, a fundamental property of a material that has a specular surface and is sufficiently thick to be opaque. One may further qualify it as spectral emmissivity in reference to a specific band pass. The suffix -ity implies a property intrinsic with a given material, a limiting value.

Ephemeris. Any tabular statement of the assigned places of a celestial body for regular intervals.

Exitance. The radiant flux per unit area emitted by a body or surface.

Field-of-view. The solid angle through which an instrument is sensitive to radiation. Due to various effects, diffraction, and so forth. The edges are not sharp, and in practice they are defined as the "hold-power" points (the angle outwards from the optical axis) at which the energy sensed by the radiometer drops to half its on-axis value. See instantaneous field or view, resolution.

Gyroscopic stabilization. Equilibrium in the attitude and (or) course of a ship or airborne vehicle maintained by the gyroscopes.

Image. (1) The recorded represenation of an object produced by optical, electro optical, optical mechanical, or electronic means. It is the term generally used when the EMR emitted or reflected from a scene is not directly recorded on film. (2) The optical counterpart of an object, produced by a lens, mirror, or other optical system.

Image enhancement. Any of several processes to improve the interpretability of an image. These include contrast enhancement, ratioing, spatial filtering, and so on.

Infrared (IR). Pertaining to or designating the portion of the EM spectrum with wavelengths from the red end of the visible spectrum to the microwave portion of the spectrum, or from 0.7 μm to 1 mm.

Instantaneous field-of-view (IFOV). (1) A term specifically denoting the narrow field of view designed into scanning radiometer systems, so that, while about 120° may be under scan, at any one instant only EMR from a small area is being recorded. (2) The field of view of a scanning radiometer with the scan motion stopped. See field-of-view, cell.

Kilobyte. In computer terminology, refers to 1024 bytes of core memorary storage.

Multispectral. Generally used for remote sensing in two or more spectral bands, such as visible and IR.

Multispectral (line) scanner (MSS). For Landsats 1 and 2; a line scanning device that used an oscillating mirror to continuously scan perpendicular to the spacecraft trajectory. Radiation is sensed simultaneously by an array of six detectors in each of four spectral bands from 0.5 μm to 1.1 μm. The MSS for Landsat 3 is essentially the same except for the addition of a fifth sensor operating in the spectral range of 10.4 μm to 12.6 μm. This sensor utilizes two detectors as opposed to the six used on the other four bands. See scanning radiometer.

Multispectral sensing. Employment of one or more sensors to obtain imagery from different portions (bands) of the electromagnetic spectrum.

Nadir. (1) That point on the celestial sphere vertically below the observer, or 180° from the zenith. (2) That point on the ground vertically beneath the perspective center of the camera lens.

Near infrared. The preferred term for the shorter wavelengths in the infrared region extending from about 0.7 micrometers (visible red) to about three micrometers. The longer wavelength end grades into the middle infrared. The term really emphaizes the radiation reflected from plant materials, which peaks around 0.85 micrometers. It is also called solar infrared, as it is only available for use during the daylight hours.

Overlap (photography). Amount by which one photograph overlaps the area covered by another, customarily expressed as a percentage. The overlap between aerial photographs in the same flight is distinguished as the endlap, and the overlap between photographs in adjacent parallel flights is called the sidelap.

Panchromatic. Used for films that are sensitive to broad band (the entire visible part of spectrum) EMR, and for broadband photographs.

Picture element (pixel). A unit whose first member is a resolution cell and whose second member is the gray shade assigned by a digital count to that resolution cell.

Pitch. (1, air navigation) A rotation of an aircraft about the horizontal axis normal to its longitudinal axis so as to cause a nose-up or nose-down attitude. (2, photogrammetry) A rotation of the camera or of the photograph-coordinate system, about either the photograph axis or the exterior Y; tip or longitudinal tilt.

Pixel. Abbreviation of picture element, also pictel. A unit whose first member is a resolution cell and whose second member is the gray shade assigned by a digital count to that resolution cell.

Range, dynamic. The difference between maximum measurable signal and minimum detectable signal. The upper limit usually is set by saturation and the lower limit by noise.

Reflection (EMR theory). EMR neither absorbed nor transmitted is reflected. Reflection may be diffuse, when the incident radiation is scattered upon being reflected from the surface, or specular, when all or most of the EMR is reflected at an angle equal to the angle of incidence.

Remote sensing. In the broadest sense, the measurement or acquisition of information of some property of an object or phenomenon, by a recording device that is not in physical or intimate contact with the object or phenomenon under study; for instance, the utilization at a distance (as from aircraft, spacecraft, or ship) of any instrument and its attendant recording and display devices for gathering information pertinent to the environment, such as measurements of force fields, electromagnetic radiation, or acoustic energy. The technique employs such devices as the camera, lasers, and radio frequency receivers, radar systems, sonar, seismographs, gravimeters, magnetometers, multispectral scanners, and scintilation counters.

Resolution. The ability of the entire photographic system, including lens, exposure, processing, and other factors, to render a sharply defined image. It is expressed in terms of lines per millimeter recorded by a particular film under specified conditions. Strictly speaking, should not be used for scanning systems. See instantaneous field-of-view.

Return-beam vidicon (RBV). For Landsats 1 and 2; a camera system which operates by shuttering three independent cameras simultaneously, each sensing a different spectral band in the range of 0.48 μm to 0.83 μm. The RBV system for Landsat 3 contains two identical cameras which operate in the spectral band from 0.51 μm to 0.75 μm. The cameras are aligned to view adjacent nominal 99 km by 99 km square ground scenes with a 15 km sidelap yielding 183 km by 99 km scene pair. Two successive scene pairs will nominally overlap each MSS scene.

Roll. A rotation of the spacecraft or aircraft about its longitudinal axis, the axis defined by the velocity vector of the craft.

Saturation. Degree of intensity difference between a color and an achromatic light-source color of the same brightness.

Scanners. The sweep of a mirror, prism, antenna, or other element across the track (direction of flight); may be straight, circular, or other shape.

Scanning radiometer. A radiometer, which by the use of a rotating or oscillating plane mirror, can scan a path normal to the movement of the radiometer or an arc or circle around the radiometer. The mirror directs the incoming radiation to a detector, which converts it into a electrical signal. This signal is amplified to stimulate a device such as a tape recorder, or glow tube or CRT that can be photographed to produce a picture. When the system is moved forward at velocity V and at altitude H, a suitable V/H ratio may be established, so that consecutive scans are just touching. This is often called an IR-imager, but is only so restricted because of the optical materials used, all-reflective optics being as useful in the UV and visible regions. They may be single- or multi-band.

Scattering. (1) The process by which small particles suspended in a medium of a different index of refraction diffuse a portion of the incident radiation in all directions. (2) The process by which a rough surface reradiates EMR incident upon it.

Scene, Landsat. The ground depicted on the three RBV's or the four MSS images on Landsats 1 and 2, or the four daytime MSS images or the one nighttime MSS image or the four RBV subscenes on Landsat 3.

Sensor. Any device which gathers energy and presents it in a form suitable for obtaining information about the environment. Passive sensors, such as thermal infrared and microwave, utilize EMR produced by the surface or object being sensed. Active sensors, such as radar, supply their own energy source. Aerial cameras use natural or artifically produced EMR external to the object or surface being sensed.

Signature. Any characteristic or series of characteristics by which a material may be recognized. Used in the sense of spectral signature, as in photographic color reflectance. A category is said to have a signature only if the characteristic pattern is highly representative of all units of that category.

Spectral band. An interval in the electromagnetic spectrum defined by two wavelengths, frequencies, or wave numbers.

Spectral interval. The width, expressed either in wavelength or frequency, of a particular portion of the electromagnetic spectrum. A given sensor, such as radiometer detector or camera film, may be designed to measure or be sensitive to energy from a particular spectral interval. Also termed spectral band, which see.

Specular surface. A surface that is smooth with respect to the wavelength of EMR incident upon it; reflects like a mirror.

Sun angle. The angle of the Sun above the horizon. Both the quantity (lumes) and spectral quality of light being reflected to the aerial camera or sensor are influenced by Sun angle. Also called Sun elevation, Sun elevation angle.

Sun-synchronous. An Earth satellite orbit in which the orbital plane and altitude are such that the satellite track is at constant local Sun time.

Telemeter. To transmit the measurement data obtained from sensors by electronic (radio) means. The transmitting of measurement data by radio to a distant station.

Thermal band. A general term for intermediate and long wavelength infrared-emitted radiation, as contrasted to short wavelength reflected (solar) infrared radiation. In practice, generally refers to infrared radiation emitted in the 3- to 5- and 8- to 14-micrometer atmospheric windows.

Thermal infrared. The preferred term for the middle wavelength ranges of the IR region extending roughly from 3 micrometers at the end of the near infrared, to about 15 or 20 micrometers where the far infrared commences. In practice the limits represent the envelope of energy emitted by the Earth behaving as a greybody with a surface temperature around 290°K (27°C). Seen from any appreciable distance, the radiance envelope has several brighter bands corresponding to windows in the atmospheric absorption bands. The thermal band most used in remote sensing extends from 8 to 14 micrometers.

Tilt, x- and y-. Tilt expressed as resultant rotations about each of two stationary rectangular axes lying in a horizontal plane, and the x-tilt being the resultant rotation about the y-axis.

Ultraviolet radiation. EMR of shorter wavelength than visible radiation but longer than X-Rays; roughly, radiation in the wavelength interval between 10 and 4000 Angstroms.

Vidicon. (1) A storage-type, electonically-scanned, photoconductive, television camera tube, which often has a response to radiations beyond the limits of the visible region. Particularly useful in space applications, as no film is required. (2) An image-plane scanning device. See return beam vidicon.

Visible radiation. EMR of the wavelength interval to which the human eye is sensitive, the spectral interval from approximately 0.4 to 0.7 μm (4000 to 7000 Angstroms).

Wavelength (symbol λ). Wavelength =1/frequency. In general, the mean distance between maximums (or minimums) of roughly periodic pattern. Specifically, the shortest distance between particles moving in the same phase of oscillation in a wave disturbance. Optical and IR wavelengths are measured in nanometers (10^{-9}m), micrometers (10^{-6}m) and Angstroms (10^{-10}m).

Yaw. (air navigation) The rotation of an aircraft about its vertical axis so as to cause the aircraft's longitudinal axis to deviate from the flight line.

Zenith. The point in the celestial sphere that is exactly overhead: opposed to nadir.

ACRONYMS AND ABBREVIATIONS

ACS	Attitude control subsystem
A/D	Analog to digital
ADP	Automatic data processing (system)
AEM	Applications Explorer Mission
AGC	Automatic gain control
AMS	Attitude measurement sensor
ANSI	American National Standards for Information Interchange
ASCII	American Standard Code for Information Interchange
bpi	Bits per linear inch
bps	Bits per second

°C	degrees Celsius (centigrade)
cm	centimeter
CRT	Cathode ray tube
D/A	Digital to analog
db	decibel
DCS	Data collection system
EBCDIC	Extended binary coded decimal interchange code
EBR	Electron beam recorder
EROS	Earth Resources Observation Systems (DOI)
ERTS	Earth Resources Technology Satellite, now Landsat
FM	Frequency modulation
FOV	Field of view
ft	feet
gm	gram
GMT	Greenwich mean time
GSFC	Goddard Space Flight Center
HCMM	Heat capacity mapping mission
HCMR	Heat capacity mapping radiometer
HOM	Hotline oblique mercator
hrs	hours
Hz	Hertz (cycles per second)
IFOV	Instantaneous field of view
IPF	Image Processing Facility (GSFC)
IR	Infrared
°K	degrees Kelvin
kbps	Kilobits per second
KHz	kilohertz
Kg	kilogram
Km	kilometer
mm	millimeter
mW	milliwatt
μm	micrometer
NESS	National Earth Satellite Service
NCIC	National Cartographic Information Center
NOAA	National Oceanic and Atmospheric Administration
NSSDC	National Space Science Data Center
pixel	Picture element
RBV	Return-beam vidicon
RF	Radio frequency
rms	Root mean square
sec	second
SDSD	Satellite Data Services Division (NOAA)
SIAT	Special image annotation tape

S/N	Signal-to-noise ratio
SOM	Space Oblique Mercator (map projection)
SRS	Statistical Reporting Service (USDA)
STDN	Space Tracking and Data Network (NASA)
UHF	Ultra-high frequency
USDA	United States Department of Agriculture
USGS	United States Geological Survey (DOI)
UTM	Universal Transverse Mercator (map projection)
VHF	Very high frequency

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