Chapter 7

REMOTE SENSING FROM SPACE

Contents

List of Tables

List of Figures

Figure No. *Page*

Chapter 7

REMOTE SENSING FROM SPACE

INTRODUCTION

The value of viewing Earth from space to provide crucial resource and environmental information on the atmosphere, oceans, and land masses was recognized early in this Nation's development of space technology. It was an obvious extension of remote sensing by aircraft and balloons, technologies that were already well-established.[1] Two years after the National Aeronautics and Space Act was signed, the United States received its first images from space taken by the polar-orbiting[2] weather satellite called the Television and infrared Observation Satellite (TIROS).

This chapter describes the principal remote sensing systems that have been developed by the United States and other countries and those that are now under development. It draws heavily on a technical memorandum published in 1984 in connection with this assessments The chapter explores the primary issues connected with the generation, distribution, and application of remotely sensed data, and assesses various policy options for Congress to consider as it debates the need for remote-sensing technology for the atmosphere, land, and oceans.

[1] In general terms, remote sensing is the art of obtaining information about objects, areas or phenomena through analyzing data gathered by devices placed at a distance from the subjects of study. Remote sensing may refer to sensing over short distances, as in medical *or* laboratory research applications using lasers, or over long distances as in environmental monitoring from satellite platforms using advanced electro-optical instruments. Once the initial data are sensed, they must be analyzed and interpreted either visually or through sophisticated computer analysis.

[2] In a polar orbit the satellite is inclined nearly *90* degrees to the Equator. As the satellite orbits, the Earth turns beneath, making possible direct overhead observations of the entire Earth over a given period. The geostationary satellites, by contrast, provide continuous viewing but are limited to providing perpendicular viewing at only one longitude at the equator. All other points on Earth are sensed at some angle. They therefore "see" the polar regions at a highly oblique angle. The orbital elements of the meteorological TIROS satellites are so chosen to allow them to pass over every portion of Earth's surface twice every 24 hours, once passing from north to south, and once passing from south to north.

'*Remote Sensing and the Private Sector.. Issues for Discussion* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-TM-ISC-20, March 1984).

The Systems

The National Oceanic and Atmospheric Administration (NOAA)[4] operates two civilian systems (fig. 7-1) for making global meteorological observations: a geostationary system (Geostationary Orbiting Environmental Satellite–GOES) using two satellites that continuously monitor weather systems within their field of view (fig. 7-2);5 and a polar-orbiting meteorological system (Advanced Television and Infrared Observation Satellite–TIROS) that observes meteorological phenomena in more detail over the entire globe from two satellites (fig. 7-3).

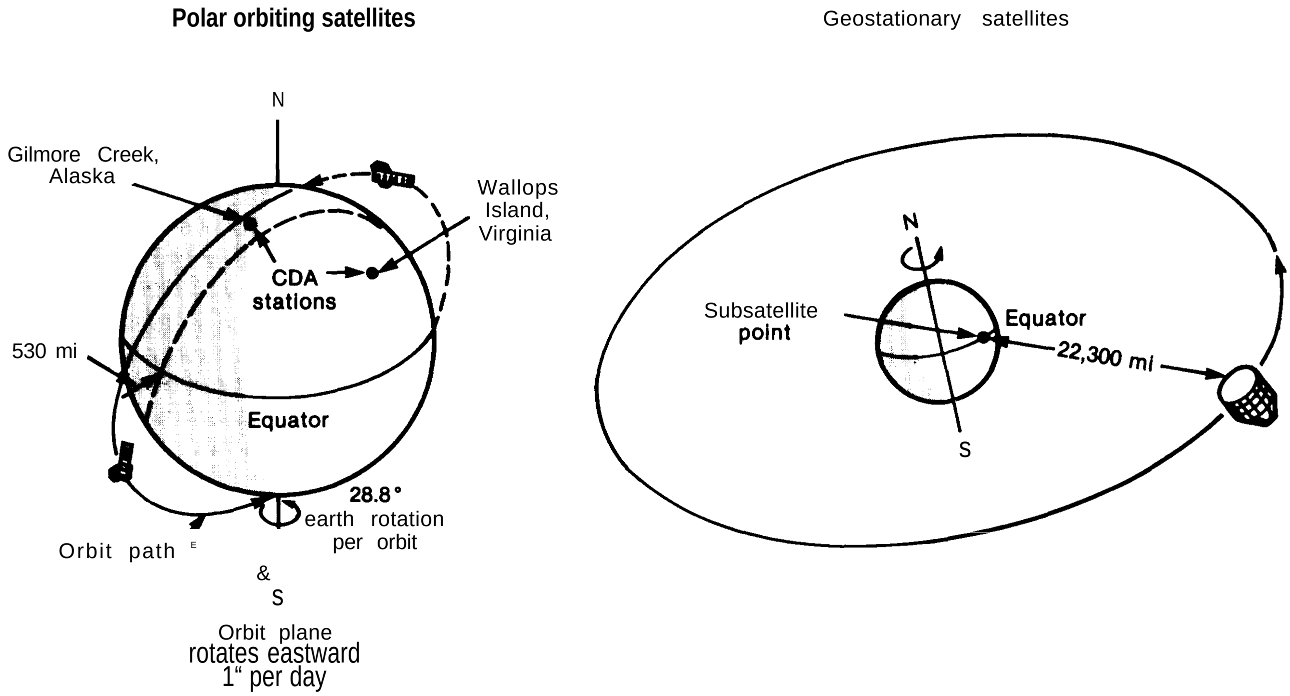
NOAA also operates the polar-orbiting U.S. Landsat system, which was developed by the National Aeronautics and Space Administration (NASA), to provide valuable data of high spatial and spectral resolution (fig. 7-4) of Earth's land resources. Data from the system support a variety of applications, including assessing and managing renewable and nonrenewable resources, mapping, and land-use planning. The Landsat system was transferred to NOAA in 1983 and is now managed as an operational system. The Department of Commerce is currently attempting to transfer the Landsat system to private ownership.

Ocean remote sensing systems are the least developed of remote sensing efforts. Although the results from such experimental ocean satellites as Seasat, Nimbus, and the Geodynamic Experi-

[4] The development of the weather satellite began in the DOD, but was transferred to NASA in 1959. In 1961 the Weather Bureau was placed in charge of providing an operational weather satellite system. Operational satellite services were moved to the Environmental Science Services Administration in 1965 and finally to NOAA in 1970. They now reside in the National Environmental Satellite Data and Information Service (N ESDIS), which is part of NOAA.

[5] On July 30, 1 g84, GOES-5 failed in orbit. This left the United States with only a single geostationary satellite (the western satellite, GOES-6) to provide data during the critical severe storm seasons of the summer and early fall. To make up (in part) for the loss of information that losing the eastern satellite entailed, NOAA moved GOES-6 to a central location. This meant reduced weather service for Alaska, Hawaii, and the Pacific Trust Territories. GOES-7, the replacement for the failed GOES-5, will not be available for launch until late in 1985 or early 1986.

Figure 7-1.—Polar-Orbiting and Geostationary Satellites



SOURCE: National Oceanic and Atmospheric Administration.

mental Ocean Satellite have created interest in developing remote sensing systems that will provide resource information from the oceans, no civilian operational U.S. system is planned.[6]

Remote sensing from space at present constitutes a small part of a larger array of mapping services provided by terrestrial and airborne devices.[7] The data acquired from space are now routinely integrated with other remotely sensed data (aircraft and balloons) and terrestrial, air, and water measurements, thus enhancing the value, and expanding the application of both data sets. As discussed in detail below, other countries either operate, or have under development, various remote sensing systems; a few complement U.S. efforts, others will compete with U.S. systems.

[6]The U.S. Navy is planning a system called Navy Remote Ocean Sensing System (N-ROSS) which may be launched in 1988 or 1989. Most data from this system will be available to civilian users through NOAA (see section on Ocean Remote Sensing).

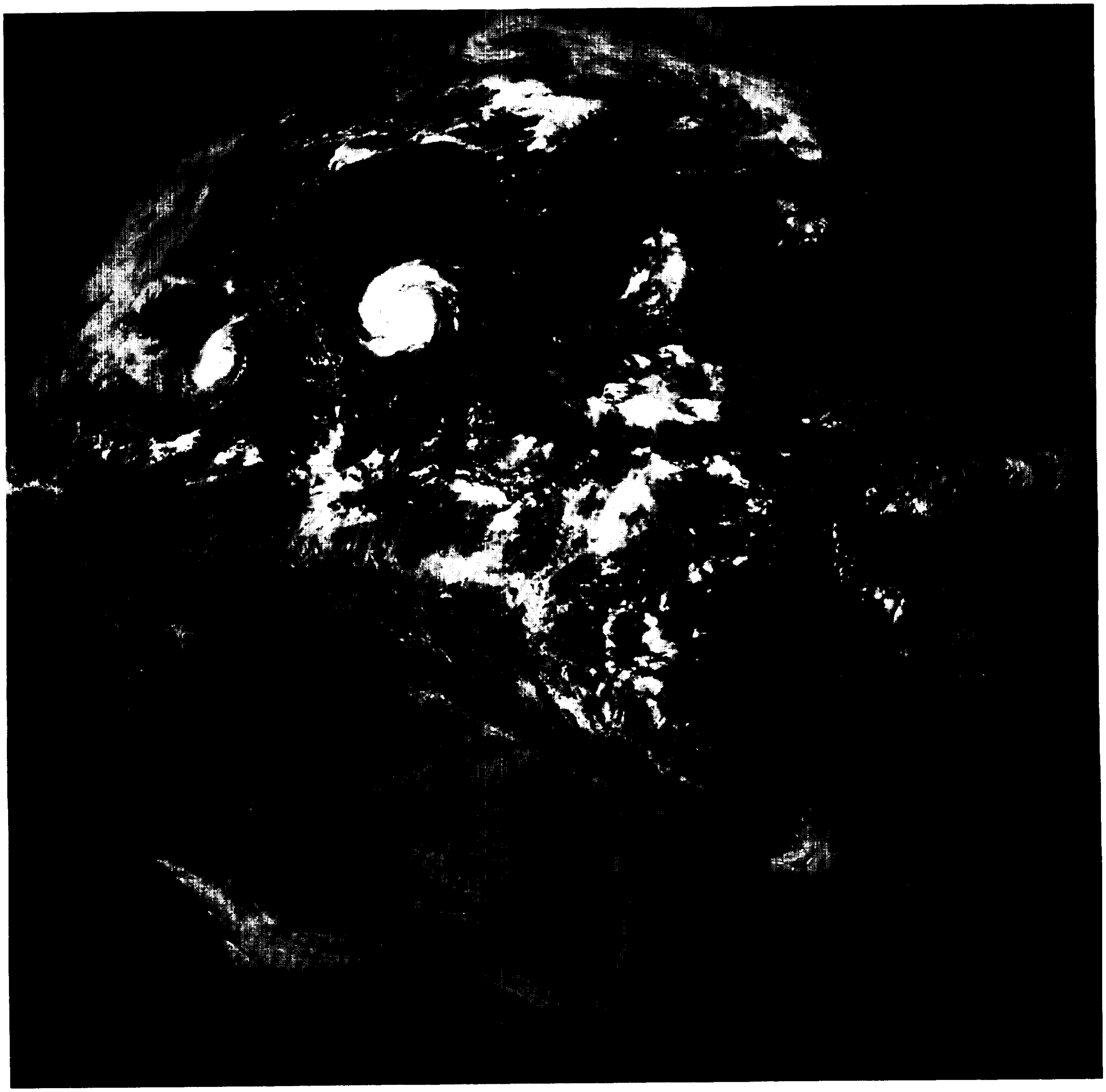
[7]In fiscal year 1984, sales of Landsat data made up 34 percent of the total sales of remotely sensed data from the EROS Data Center in Sioux Falls, SD. Private services also sense and sell aircraft data.

Remote Sensing Policy

Although the United States has led the world in the development and operation of civilian remote sensing systems, this year it will face competition from France for the sale of land remote sensing data products. There is little commercial market for data sales from meteorological systems, but opportunities do exist for broad multinational cooperation in providing meteorological data from space. The United States is exploring the prospect of joining with other Free World space-capable nations in building a cooperative polar-orbiting global meteorological satellite system. Such a venture could strongly enhance the level of service delivered by such systems.

In 1983, the Administration accelerated a process begun in the late 1970s intended to lead to the transfer of the Landsat system from the Federal Government to the private sector. The principal motivation for transferring the system to private hands is that the private sector excels both at innovation and at developing markets for goods and services. The 98th Congress passed the

Figure 7-2.—image of Earth, Received Aug. 8, 1980, by GOES Satellite



Two hurricanes are clearly visible: Allen in the Gulf of Mexico and Isis just west of Mexico.

SOURCE: National Oceanic and Atmospheric Administration.

F gu e 7 3 mage o Northeas Un ed S a es Taken n Feb uary 979 by he NOAA N Se es Po a Orb ng Sa e e

S w G

Figure 7-4.—image of New York City and Environs Taken by the Thematic Mapper (30-meter resolution)

The George Washington and Verrazano bridges are clearly visible.

Landsat Commercialization Act of 1984 (Public Law 98-365) that provides for a phased transfer of the Landsat system (see later section, Policy History of Land Remote Sensing) and authorizes a subsidy to fund part of the capital costs of building and launching a commercial system. As the Department of Commerce implements the provisions of Public Law 98-365, Congress is overseeing the transfer process. The question Congress now faces is whether additional legislation or other measures will be necessary to aid the commercialization process.

Transfer to the private sector raises several questions: 1) whether this course of action will enhance or impede U.S. competitiveness with other nations in this field, 2) whether private firms will eventually develop a self-sustaining business of providing land remote sensing from satellites, 3) how the Government might enhance that process, and 4) what transfer model best serves the needs of the United States? If the current transfer process fails to establish a viable commercial operation, Congress will be faced with deciding what to do about it.

A significant international effort has begun in remote sensing of the oceans. Both research and operational satellites are planned by the United States and other nations, making possible joint research and data distribution efforts. The United States is exploring ways in which to coordinate international efforts in ocean remote sensing.

Applications of Remotely Sensed Data

Data from satellite systems have been used for a variety of applications beyond the specific scientific objectives that guided their development. Specifications for meteorological satellites and sensors initially were set to address current and future needs of the National Weather Service for weather forecasting and warning. However, as the technology has evolved, the United States has used these systems to enhance its relations with other countries by integrating instruments provided by other nations into U.S. spacecraft, and by freely sharing data with member nations of the World Meteorological Organization (WMO), a specialized agency of the United Nations formed to coordinate weather services on a global basis. Though the Landsat system has a shorter history, the United States has also used it as an ambassador for U.S. space technology by selling data on a public, nondiscriminatory basis, and through arrangements for direct transmission of Landsat data (on a fee basis) to foreign-owned and foreign-operated ground stations.

Satellite remote sensing systems are also important to national security. Though the United States has consistently maintained separate civilian and military systems, the programs have been mutually supportive. In defense and civilian meteorological programs, mutual backup in case of system failures and free data exchange exemplify this support.

Government and civilian market potential vary considerably for the different remote sensing systems. Although the metsats have a long history of operation, these systems are just beginning to develop a commercial value-added data industry. The Federal Government is by far the largest user of meteorological data.[8] U.S. State and local

[8] "Transfer of the Civil Operational Earth Observation Satellites to the Private Sector," U.S. Department of Commerce, February 1983. p. B-24,

governments, foreign governments, universities, and commercial firms also use these data. Though new applications for meteorological data are being found **for assessing** crop conditions, scanning the ocean, and for mapping water resources, their potential for expanded use is limited by the need **for more complete computer models and by the availability of confirmatory data from higher resolution ocean and land satellite systems.**

The market for data from the Landsat system, which have always been sold to users, has remained undeveloped. The Government purchases nearly 50 percent of the Landsat data, but the commercial market for these data remains diffuse, unaggregated, and small.[9]

Although the potential for applying ocean remote sensing data to problems faced by ocean users is high, only short-term scientific satellite missions have been flown. Much more experimentation with actual data from operational satellite systems will be needed to assess the potential commercial market for data and data products.

[9]For example, total shipped sales (not counting special charges) for fiscal year 1984 amounted to only $3,812,128, 45 percent of which was purchased by Government agencies. Although the current market has historically been small (see table 7- I 4 and fig. 7-16 for the total Landsat data sales since 1972), these data have never been marketed commercially. Several analysts have predicted that given proper commercial marketing and a favorable Governmental attitude, the future market could be large. Their analysis is in part the basis for believing that land remote sensing could be effectively commercialized. See G. William Spann, statement before the Senate Subcommittee on Science, Technology, and Space of the Committee on Commerce, Science, and Transportation, S. Hrg. 98-747, Mar. 22, 1984.

METEOROLOGICAL REMOTE SENSING SYSTEMS

U.S. Systems[10]

NOAA manages two civilian environmental satellite (metsat) systems (see pp. 259, 260, and 261). The TIROS-N series of polar-orbiting satellites (fig. 7-5) provide systematic high resolution global weather observations, both day and night, to meet both U.S. and international data requirements for a global, immediate, and long-range weather forecasting system. The GOES series of geostationary satellites (fig. 7-6) provides continuous viewing of weather systems at visible and infrared wavelengths between 70°N latitude and 70°S latitude (fig. 7-7), and complements the data received by the TIROS-N series. The GOES satellites provide the weather images seen on television and in the newspapers. Both systems have the ability to collect and transmit data from Earth-based platforms. Both systems are necessary for providing adequate information about weather conditions directly related to U.S. needs.

Possible Future Directions

Continued R&D on new sensors will enhance the abilities of U.S. satellites to gather useful environmental data. Because much meteorological sensor technology is common to all national systems, new developments are applicable to both foreign and U.S. systems. Experience with microwave sounders'[11] on Nimbus satellites, as well as on the NOAA-N series, indicates that a new sounder capable of infrared sensing has promise for better soundings in cloudy areas, and better information on atmospheric water vapor and precipitation rates. The proposed 15-channei microwave instrument would give better vertical resolution, particularly in the stratosphere, and would be supplemented with additional channels for sounding water vapor. The United Kingdom, which now provides the microwave instrument on the TIROS-N spacecraft, has expressed interest in providing an advanced sounder with these improved characteristics.

[10]See *NOAA Satellite Programs Briefing,* U.S. Department of Commerce, August 1983.

[11]A device fo, measuring atmospheric parameters at different altitudes.

The Polar Orbiting Meteorligical Systems

The Advanced TIROS-N series first become operational with the launch of NOAA-8 in March 1983+* The spacecraft is a three-axis stabilized, box-like structure that carries four primary instrument systems for environmental data collection:

- **The Advanced Very-High Resolution Radiometer (AVHRR)** measures cloud coverage, moisture, and surface temperature at several different wavelengths. It is the only instrument returning images from the Metsat polar-orbiters. AVHRR data are transmitted at very high frequencies (VHF) to Automatic Picture Transmission (APT) stations, which have been in operation for many years, and by S-band to High-Resolution Picture Transmission (HRPT) stations. The latter are newer, more advanced, receivers capable of producing images from digital data at a resolution of 1.1 km. APT stations process analog transmission into imagery with a 4.0 km spatial resolution.
- **The TIROS Operational Vertical Sounder (TOVS)** is a set of three instruments for temperature/moisture profiles. The High-Resolution Infrared Sounder provides data for calculating temperature from the Earth's surface to the stratosphere, water vapor content at three levels of the troposphere, and total ozone content. The latter two are essential for deriving atmospheric temperature profiles. The Stratospheric Sounding Unit, provided at no cost to the United States by the Meteorological Office of the United Kingdom, senses energy in the part of the carbon dioxide absorption portion of the infrared spectrum to provide temperature information from the stratosphere. The Microwave Sounding Unit provides solid-state, microwave radiometer technology that meteorologists have long sought for making complete atmospheric soundings in the presence of clouds. Because of their wavelength, microwaves are not attenuated by nonprecipitating water droplets. Therefore, this instrument can record temperatures through and beneath most clouds to provide data that complement the other instruments of the TOVS.
- **The Space Environment Monitor (SEM)** monitors the state of solar activity. Its three sensors measure the energies and intensities of protons, electrons, and ions ejected from the Sun. These data, in conjunction with those obtained by the GOES system, are processed and forwarded to NOAA's Space Environment Laboratory in Boulder, CO, within an hour of spacecraft readout for monitoring of potential effects on terrestrial communications, communication satellite services, electrical power distribution, and high-flying aircraft.
- **The ARGOS Data Collection System (DCS).** Designed and contributed by the Centre National d'Études Spatiales (CNES) of France, the DCS is similar to the U.S. instrument maintained on its GOES system for collecting and relaying signals from a variety of remotely located terrestrial data platforms that monitor local environmental factors not obtainable by satellite systems alone. One such factor is water flow volume in streams or rivers. The ARGOS instrument differs from the GOES system by offering global and polar coverage along with the capacity to locate drifting platforms, such as balloons, through the use of a Doppler location technique. With ARGOS, new environmental data such as ocean current patterns, measured using drifting buoys, have become available on a global basis.
- **Search and Rescue Satellite System (COSPAS/SARSAT).** This additional instrument on the TIROS-N series was developed by NASA; it monitors emergency radiofrequencies for distress broadcasts from transmitters now carried by some 200,000 aircraft and 6,000 ships in the United States alone. With a planned turn-around time of 60 minutes after signal reception, ground forces can conduct rescue operations with minimal search. The United States, the Soviet Union, Canada, and France are currently participating in the program. Recently, Bulgaria, Norway, the United Kingdom, and Finland have agreed to participate. The value of a satellite monitor as part of a global system was proven with the location of a downed aircraft in September 1982 shortly after the launch of the Soviet COSPAS receiver. The Search and Rescue Satellite Receiver (SARSAT), the first U.S. complement of the search and rescue system receiver, was launched in March 1983 (on NOAA-8). Although a high false-alarm rate for received signals has plagued the Search and Rescue mission (95 percent of the total number of distress signals), about 400 persons have been rescued to date (app. A).

*NOAA-8 failed in July 1$S4 and was replaced in December 1984 by NOAA-9. NOAA-8 is now in partial operation again.

The Geostationary Environmental Satellite (GOES)

The GOES system consists of two geosynchronous satellite platforms located 36,000 km over the equator at 75°W and 135°W longitudes. They provide coverage of most of the western hemisphere, except for the polar regions (fig. 7-7). Partially functioning earlier satellites of the GOES series are also maintained in orbit to provide limited operational support for data collection, weather facsimile services, and data relay.

- **The Visible and Infrared Spin-Scan Radiometer (VISSR) Atmospheric Sounder (VAS)** is the principal instrument on the GOES series and provides not only imaging capability, but also the ability to take atmospheric soundings from geostationary orbit. The instrument contains a Ritchey-Chretien optical system for images and solid-state detectors for infrared sensing. Near-continuous cloud viewing with resolutions of 1 to 8 km in the visible and 8 km in the infrared wavelengths are provided at 30-minute intervals for full-Earth disc coverage or shorter intervals for partial-disc pictures. The VAS uses 12 infrared channels to derive vertical temperature and moisture profiles over desired areas. Experimental results from using geostationary atmospheric soundings for temperature and water vapor profiles have encouraged the development of ground system components to incorporate the data into weather analysis and forecasting programs.
- **The Data Collection System** is similar to the ARGOS system for collecting and relaying platform data except that it has no capacity to determine platform location because there is insufficient satellite motion to provide a Doppler frequency shift.
- **The Space Environment Monitor** system is comparable to one on the TIROS-N system. In addition, these satellites have the capacity to broadcast weather facsimile (WEFAX) images to a series of inexpensive ground stations in the Western Hemisphere and to retransmit satellite imagery and certain charts of the National Weather Service for use by marine and offshore facilities.

A second area for development involves increased use of the Visible Atmospheric Sounder (VAS) on geostationary satellites. Tests with the experimental system aboard the GOES satellites suggests the possibility of generating an index for severe weather.

An advanced Ocean Color Imager (OCI), similar to the Coastal Zone Color Scanner (CZCS) instrument flown on the NASA satellite, Nimbus-7, if placed on the polar-orbiters, would provide multispectral scanning of the ocean in the visible, and near-infrared spectral regions, for detection of such ocean phenomena as pigmentation chlorophyll content, and turbidity.

instruments on the TIROS-N satellites collect global data on the radiation processes of the Earth's surface and atmosphere for the Earth Radiation Budget Experiment (ERBE). [12] The exchange system involved in the absorption and reradiation of solar influx by Earth's surface is a major component of weather analysis. A Solar Backscatter Ultraviolet Radiometer (SBUR) will provide global sensings of the vertical distribution of ozone to assist determination of the effect of human activities on this essential protective shield and to further understanding of the relationship of ozone to weather changes,

Internationally, the principal technological thrust is toward devising more sensitive and stable sensors for polar-orbiting spacecraft, increasing the operational use of the microwave spectrum for atmospheric temperature and humidity measurements, and increasing the use of the Data Collection System for the international hydrological community.

[12] The ERBE experiment will consist of measurements of the total radiation received by Earth and radiation reemitted by Earth. Measurements are being made by a dedicated satellite, the Earth Radiation Budget Satellite (ERBS) which was launched Oct. 5, 1984, and by an Instrument on the NOAA-N series of satellites.

Foreign Systems

Other nations maintain operational satellite systems for both national purposes and as part of

Ground-Based Sensor Data

Remote sensors achieve greater value for weather analysis when combined with data from ground-based measurements. Ground-based sensors can provide data not now obtainable by a satellite-borne sensor, such as surface wind and pressure, rainfall amount, river levels, sea salinity, or subsurface oceanic temperatures. Because the ARGOS system can locate these surface platforms containing ground-based sensors, it is also possible to determine ocean currents and atmospheric winds. Ground-based observations also provide "ground truth" data valuable in verifying and correlating large-scale weather patterns predicted through analysis of satellite observations.

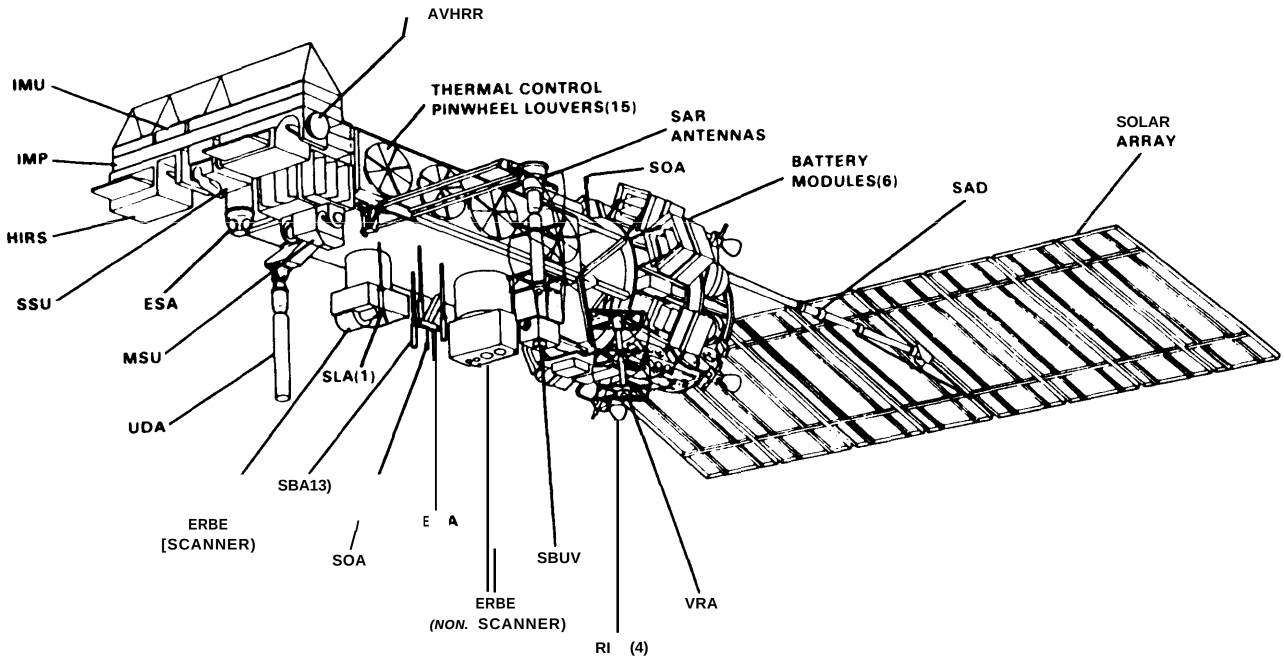
For their data to be useful for weather monitoring, moving platforms, such as ships or aircraft, must be capable of reporting their own position when reporting to geostationary satellites. Fixed platforms can be of three types: 1) self-timed, which report under control of an internal clock on a frequency and time assigned by an operator; 2) interrogated, in which a receiver replaces the clock to allow the satellite ground station to signal for a report on a flexible time schedule; and 3) alert, in which a special repmting frequency is allocated for a signal from the platform that some particular phenomenon has exceeded a preestablished threshold. The number of platforms that can be incorporated into the data collection service (DCS) is limited by the time required to interrogate, receive, and relay signals. Still, DCS capabilities have greatly expanded the availability of observations by obtaining data from remote areas not accessible to satellite sensors or ground telecommunication systems.

the international environmental data gathering community:

- European Space Agency (ESA)—Meteosat-2. The geostationary satellite, located at 0° longitude, provides raw imagery of European weather conditions to Europe as well as relaying processed imagery from U.S. geostationary weather satellites. It carries a visible and infrared scanning radiometer, a Data Collection System, and a weather facsimile service (WE FAX). An improved Meteosat is planned for launch in 1985.
- India—1nsat-1. This geostationary satellite provides both telecommunications and limited meteorological data. Visible and infrared images are available every 30 minutes from Insat 1's Very High Resolution Radiometer (VHRR). The spacecraft also has a data collection system. The satellite 1B, which replaced Insat-IA, was launched successfully by space shuttle Mission 8 in August 1983. The complete operational system will consist of two spacecraft, one at 74'E longitude and a second at 94°E longitude.
- Japan–Geostationary Meteorological Satellite, GMS-3 (Himawari or Sunflower 3). This was launched by Japan on a Japanese NII launcher in August 1984, and is the third in a series of geostationary meteorological satellites. Located at 140"E longitude, the satellite carries a visible and infrared radiometer, a space environment monitor, DCS, and WE FAX. The Japanese geostationary satellite is a crucial element in forecasting and warning of typhoon development and subsequent flooding.
- Peoples Republic of China. The Chinese are working on a polar-orbiting and a geostationary meteorological satellite; their launch dates are uncertain.
- The U.S.S.R. polar-orbiting meteorological program consists of two or three METEOR-2 series spacecraft that fly a near-polar orbit at a 900 km height with an orbital inclination of 810. The METEOR-2 carries five sensors: a scanning telephotometer that acquires imagery at visible wavelengths with a 2.0 km resolution; television-type scanner at the same wavelengths but with 1.0 km resolution; an infrared scanning radiometer; an 8-channel infrared scanning radiometer that senses the vertical temperature distribution in the atmosphere; and a radiometer that monitors high energy radiation influx from space.

Data available from these instruments provide analysis of the global distribution of clouds and snow and ice cover, global radiation temperature of the surface, cloud-top

Figure 7-5.—Advanced TIROS.N



SOURCE. Nat[onal Oceanic and Atmospheric Adm!nistratlon.

MISSION: Collect global data on cloud cover, surface conditions such as Ice and snow. surface and afmosphenc temperatures. and atmospheric humldtty, measure solar particle flux, collect and relay informatlon from **hxad** and mowng **data platforms, prowde continuous data broadcasts**

ORBIT: 833- and 870-km ctrcular, 9889$ mclrratlon, 14-14 revsday

SENSORS AND FUNCTIONS:

. **Advanced very High Resolutlon Radiometer (AVHRW2)**
1 l-km resolution. ,2600-km **swath width**

Channels	Wavelengths (Km)	primary *Ueea*
1	058-068	Daytime cloud, surface mapping
2	0725-1 10	Surface water delineahon. Ice and snow melt
3	355-393	Sea surface temperature nighttlme cloud mappmg
4	1030-1130	**Sea surface** temperature, day and nighl cloud mappmg
5	1150-1250	**Sea** surface temperature. **day** and night cloud mappmg

•**TIROS Operational Vertlcal Sounder (TOVS):**
A 3-sensor atmospheric sounding system

(1) **High Resolution Infrared Radiatlon Sounder (HIRS/2) 17** 4-km resolution

Chennels	Waelengths (Pm)	Primary Uses
1-5	1495-1397	Temperature profiles, clouds
6-7	1364-1335	Carbon dloxlde & **water vapor bands**
8	11 11	Surface temperature, clouds
9	971	**Total 0, concentration**
10-12	**816-672**	Humldlty profiles, detection of thin cirrus clouds
13-17	457-424	Temperature profiles
18-20	400.069	Clouds surface temperatures under partly cloudy skies

(2) **Stretospharic Sounding Unit (SSU):** 147 3-km resolution

Channals	Wavelengths (vm)	Prtmary Uses
1-3	15	Temperature profiles

(3) **Microwave Sounding Unit (MSU):** 105-km resolution

Channela	Frequencies	Primary Uses
1	**5031 GHz**	
2	5373 GHz	Temperature soundings through clouds
3	5496 **(+iz**	
4	5795 CiHz	

. **Space Environment Monitor (SEM):** Measures solar particle flux at space**craft**

(1) Total Energy Detector (TED): Solar particle mtensty from 03- to 20-keV

(2) **Madlum Energy Proton and ElWron Detector (MEPED): Protons, electrons and lons m 30- to 60-keV range**

. **ARGOS Data Collection System (DCS) (French): Collectlon and relay of data from fixed or movmg automatic sensor platforms, determmes locatlon** of movmg platforms

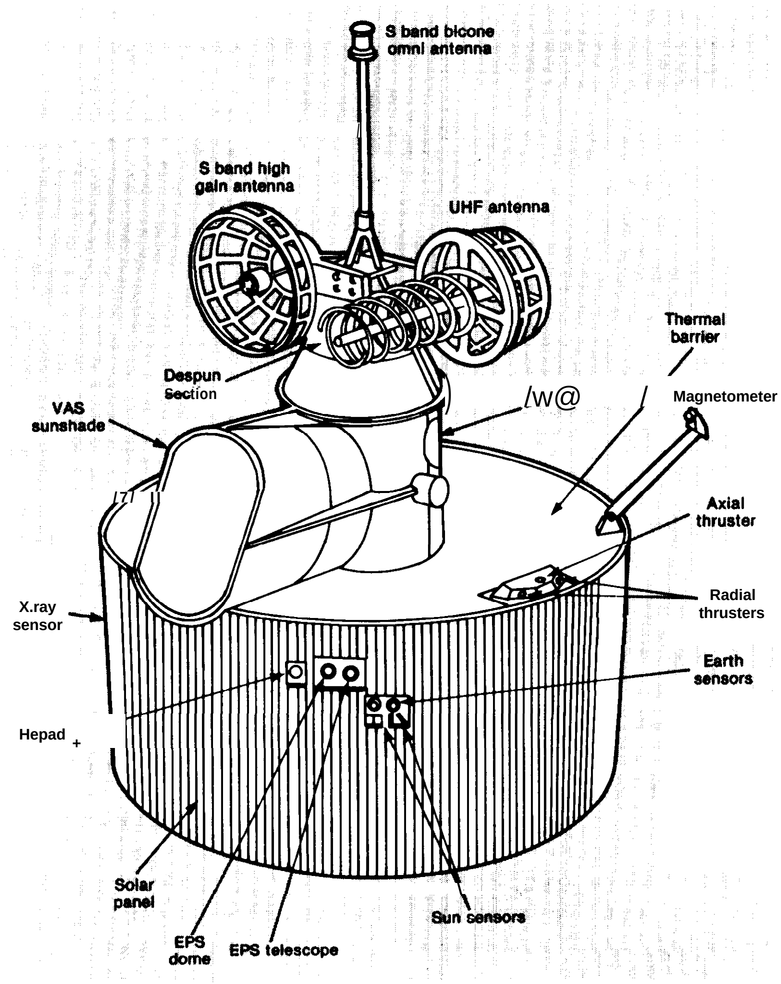
DIRECT BROADCAST: Contmuousdata broadcasts avadable to any recewmg station wthm range

•**Automatic Picture Transmlaaion (APT):** Vwble and Infrared Imagery at 4-km resolution VHF broadcasts at 13750 or 13762 MHz Basic ground equipment costs about $25.000 (U S) m 1981

0 **tllgh Resolution Picture Transmission (HRPT):** V!s!ble and Infrared data **at** 1 -km resolution S-band broadcasts at 16980 and 17070 MHz Basic ground equlpmer)t costs about $250000 **(U S) In** 1981

0 **Direct Sounder Broedca.t (DSB):** TOVS data Iransmftted for use In quantitative programs Broadcast at 13677 or 13777 MHz (Beacon Frequency) and In the HRPT data stream Conventional ground recelwng station required but specialized data processng IS necessary IO produce environmental In formation

Figure 7-6.—GOES Satellite



SOURCE: National Oceanic and Atmospheric Administration

MISSION: Repetttwe observations of the earth dsk and overlaying atmosphere (n the held of wew measurements of solar x-rays and the proximate space enwronment, collection and relay of data from platforms at or near the earths surface, broadcast of data and environmental informallon

ORBIT: 35,800-km geosynchronous **GOES East over equator at 75" W GOES West at 135W**

SENSORS AND FUNCTIONS:

- **Visible and Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (vAS):** The VAS is a visible and infrared radiometer capable of providing both multi-spectral imaging and dwell sounding data It possesses eight visible and six infrared detectors Positioning a filter wheel allows selections from among 12 **spectral bands with central wavelengths between 39 and 15 µm VAS scans west to east in conjunction with spacecraft rotation at 100 rpm a stepping** mirror provides **pole to pole scanning Resolutions** are 1-km in the visible and 7- or 14-km in the infrared depending upon the selection of IR detectors Visible imaging data are provided **routinely every** 30 minutes by each spacecraft during daylight and infrared (7-km) imaging data, **on the same schedule. are provided day and night**

- **Space Environment Monitor (SEM): Composed of 4 subsystems**
  - (1 i X-Ray Sensor Provides data on solar x-ray activity in two wavelength bands O 5-3 OA and 1-8A
  - (2) Energy Particle Sensor Determines intensity of charged particle flux in the following ranges

Protons	**-08 to 500 MeV, 7 log ranges**
Aiphas	**-32 to 400 MeV, 6 log ranges**
Electrons	**≥2 MeV, 1 range**

  - **(3) High Energy Proton and Alpha Detector (HEPAD) Protons in the** 379-keV **range, alpha particles in the 850-keV** range
  - (4) Magnetometer Monitors magnitude and direction of ambient magnetic field, parallel field (± 1200γ) and transverse field in 4 selectable ranges (± 50γ, ± 100γ, ± 200γ, or ± 400-Y)

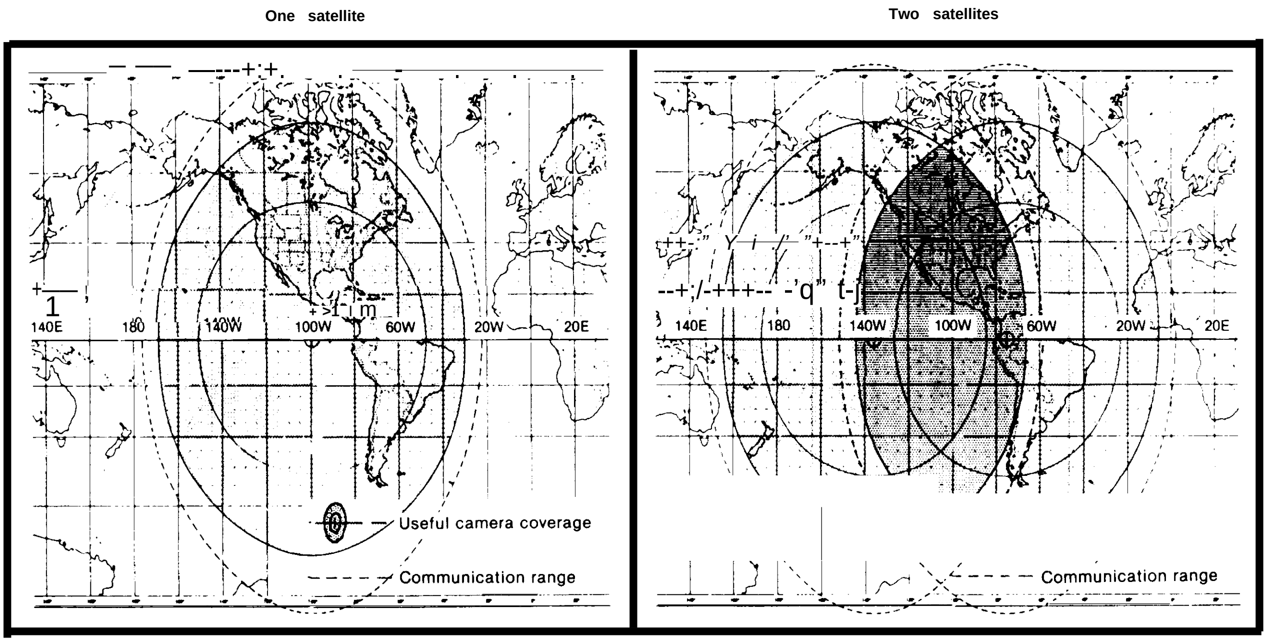
- **Data Collection System (DCS): Relays** UHF interrogations to and data from sensor platforms reporting environmental data

DIRECT BROADCAST: Broadcasts available to any ground station within range

- **WEFAX: Retransmission of processed data at 16910** MHz Along with meteorological charts, GOES imagery at 8-km resolution and NOAA Imagery al 8- to 12-km resolution are transmitted A daily operational message is transmitted that provides schedules and contents A basic ground capability costs about $8,000 (U S) in 1981

- **Stretched Sensor Data: A** retransmission at a reduced **rate, of the data burst that** occurs during the 20' angular sweep of VAS detectors **across** the earth The transmission is on S-band at 16871 MHz A basic ground **station that includes a** limited **product capability costs about $150 000 (U S) in 1981**

Figure 7-7.—GOES Geographic Coverage



SOURCE: National Oceanic and Atmospheric Administration.

heights; and vertical distribution of temperature. Only the United States and the Soviet Union operate polar-orbiting meteorological spacecraft.

The Soviet Union plans to launch a Geostationary Operational Meteorological Satellite (GOMS) this year, which will carry visible and infrared sensors. It will be stationed at 70°E longitude and will have a scanning radiometer operating at visible and infrared wavelengths, DCS, and WEFAX. Soviet designers are investigating the feasibility of operating a geosynchronous satellite inclined by 65° to the Equator.[13] The ground track of such a satellite would describe a figure-eight pattern (fig. 7-8) and have the dual advantage of spending some time over the Soviet Union, the northern reaches of which are inaccessible to a satellite positioned over the Equator, and also over the Indian Ocean where observations critical to certain Soviet military operations would be possible.

International Cooperation in Meteorological Satellite Systems

The United States has encouraged direct reception of data (at no cost) from its civilian meteorological satellites on an international basis for over **20 years. There are about 1,000 direct readout stations in over 125 countries (table 7-1). In addition, NOAA sells metsat data products** worldwide. Foreign sales of U.S. meteorological value-added data products were about 13 percent of product sales (provided at cost of reproduction) in fiscal year 1984.[14]

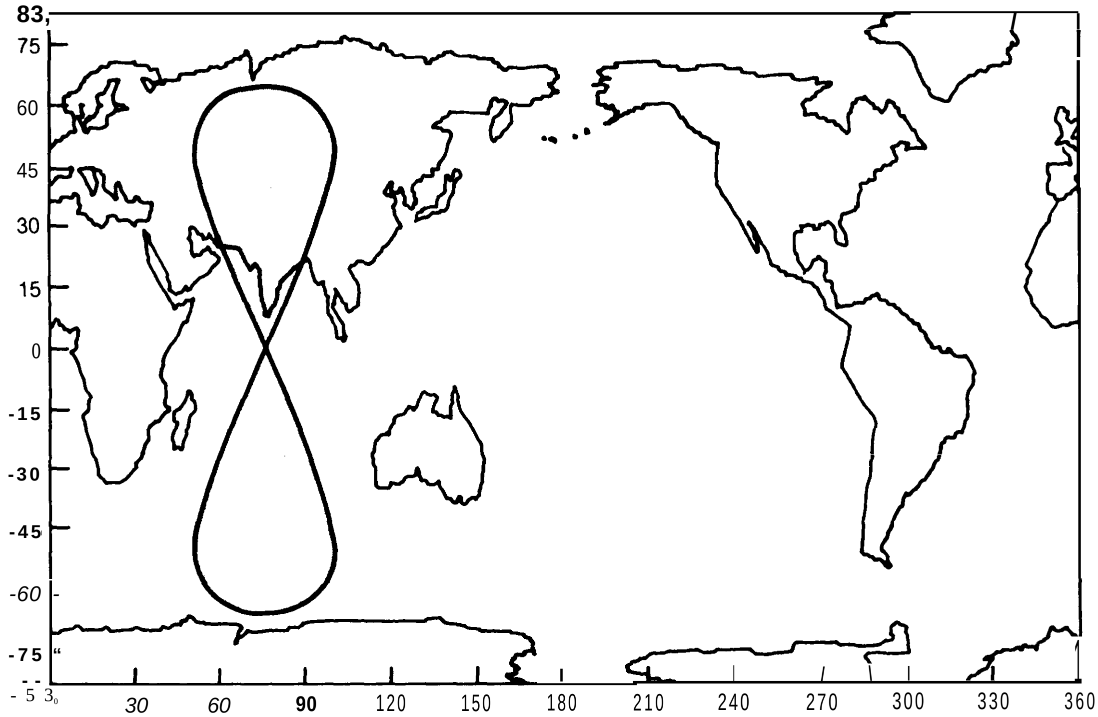
The United States cooperates with other nations through the World Meteorological Organization (WMO), a specialized agency of the United Nations whose purpose is to coordinate, standardize, and improve meteorological services throughout the world (see box, p. 268).

The United States has also reached bilateral and multilateral agreements in the form of Memoranda of Understanding with foreign governments

[13] Nicholas L. Johnson, "The Soviet Year in Space: 1983," Teledyne Brown Engineering, 1984, p. 24.

[14] Figure provided by National **Environmental Satellite, Data, and Information Service of NOAA.**

Figure 7-8. —Path of Geosynchronous Satellite in Inclined Orbit



NOTE: A geosynchronous satellite in an orbit inclined 65° to the Equator would trace out a daily figure eight pattern like the one Illustrated above

A geosynchronous satellite in an orbit inclined 65° to the Equator would trace out a daily figure-eight pattern like the one illustrated above.

SOURCE: N Johnson, "The Soviet Year in Space, 1983," Teledyne Brown Engineering, January 1984, p. 24.

concerning use of the U.S. Data Communications System. In order to be included in the system, foreign projects must be of interest to a U.S. Government agency and must meet certain technical criteria for system use. In some cases, data included in this system may be treated confidentially by the United States. However, all data in the system are available to NOAA.

As **mentioned earlier, the United Kingdom has provided the Stratospheric Sounding Unit for the U.S. TIROS-N polar orbiter. The French provide and operate the ARGOS data collection system for the NOAA polar orbiter. These arrangements make the polar-orbiting satellites much more capable than they would be otherwise.**

Finally, under an agreement among the United States, Canada, France, and the Soviet Union, the polar orbiting satellites are being used for search and rescue of downed aircraft in remote areas (COSPAS/SARSAT–see app. A).

Data Products and Service

This section summarizes the data products and services derived from meteorological satellite data that are routinely available through NOAA. All of these data products are available to users around the world either for free (through radio, TV, or telephone) or for purchase on a nondiscriminatory, cost-reimbursable basis from NOAA. Table 7-2 lists the categories of U.S. domestic users of such data. The categories of international users are similar.

Weather

Table 7-3 summarizes the major weather-related products provided by NOAA. In addition,

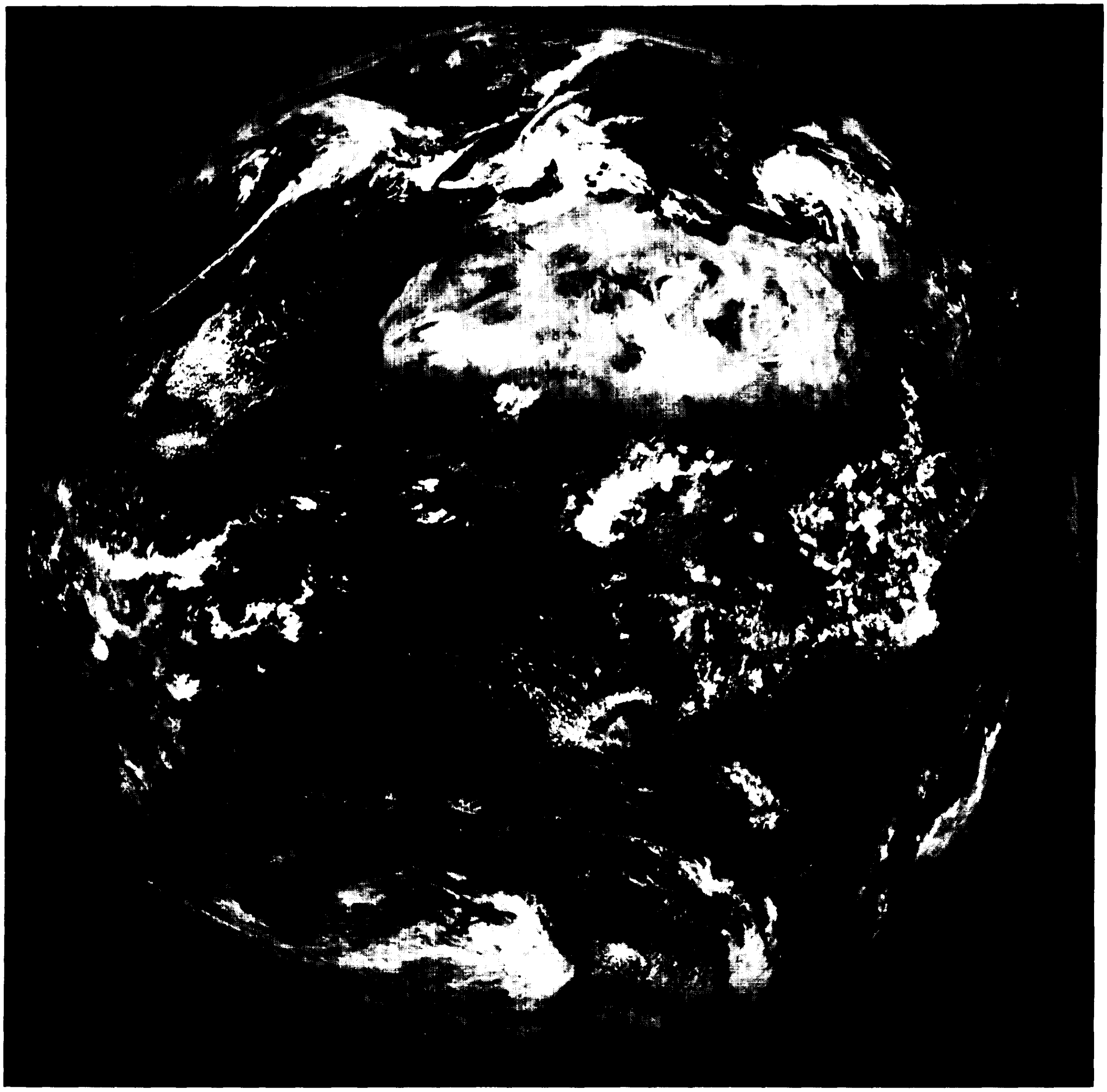


Photo credit: European Space Agency

Visible wavelength image of weather patterns on Earth, as taken by **Meteosat,** the European **geostationary** meteorological satellite. **Meteosat** was developed and built by the European Space Agency.

Table 7-1. Countries With APT/HRPT Reception Capabilities

Countries with APT facillties:
Afghanistan
Algeria
Angola (status unknown)
Antarctica (USN res.)
Argentina
Australia
Austria
Azores
Bahamas
Bahrain
Bangladesh
Barbados
Belgium
Bermuda
Bolivia
Brazil
Bulgaria
Burma
Cambodia (status unknown)
Cameroon
Canada
Canary Islands
Chile
Colombia
Costa Rica
Curacao
Czechoslovakia
Denmark
Dominican Republic
Ecuador
Egypt
El Salvador
Ethiopia
Fiji
Finland
France
French Guiana
Gambia
German Democratic Republic
Germany, Federal Republic of
Ghana
Greece
Greenland
Guadaloupe
Guatemala
Guyana
Honduras
Hong Kong
Hungary
Iceland
India
Indonesia
Iran
Iraq
Israel
Italy
Ivory Coast
Japan
Jordan
Kenya
Korea (South)
Kuwait
Madagascar
Malaysia
Mali
Malta
Martinique
Mauritania
Mauritius
Mexico
Mongolia
Morocco
Mozambique
Nepal
Netherlands
Netherlands Antilles
New Guinea
New Zealand
Nicaragua
Nigeria
Norway
Oman
Pakistan
Papua New Guinea
Paraguay
People's Republic of China
Peru
Philippines
Poland
Portugal
Romania
Saudi Arabia
Scotland
Senegal
Seychelles
Sierra Leone
Singapore
Somalia
South Africa
South Yemen
Spain
Sri Lanka
Sudan
Surinam
Sweden
Switzerland
Syria
Tahiti
Taiwan
Tanzania
Thailand
Trinidad and Tobago
Tunisia
Turkey
Union of Soviet Socialist Republics
United Arab Emirates
United Kingdom
United States
Upper Volta
Uruguay
Venezuela
Viet-Nam, Republic of (status unknown)
Yugoslavia
Zaire
Zambia
Zimbabwe

Countries with HRPT facilities:
Bangladesh
Belgium
Brazil
Canada
Czechoslovakia
Denmark
France
Germany, Federal Republic of
Greenland
India
Indonesia
Iran
Italy
Japan
Korea (South)
Malaysia
Mongolia
Netherlands
New Zealand
Norway
People's Republic of China
Saudi Arabia
Singapore
South Africa
Sweden
Switzerland
Taiwan
Thailand
Tunisia
Union of Soviet Socialist Republics
United Kingdom
United States
Yemen (South)

SOURCE” National Oceanic and Atmospheric Administration.

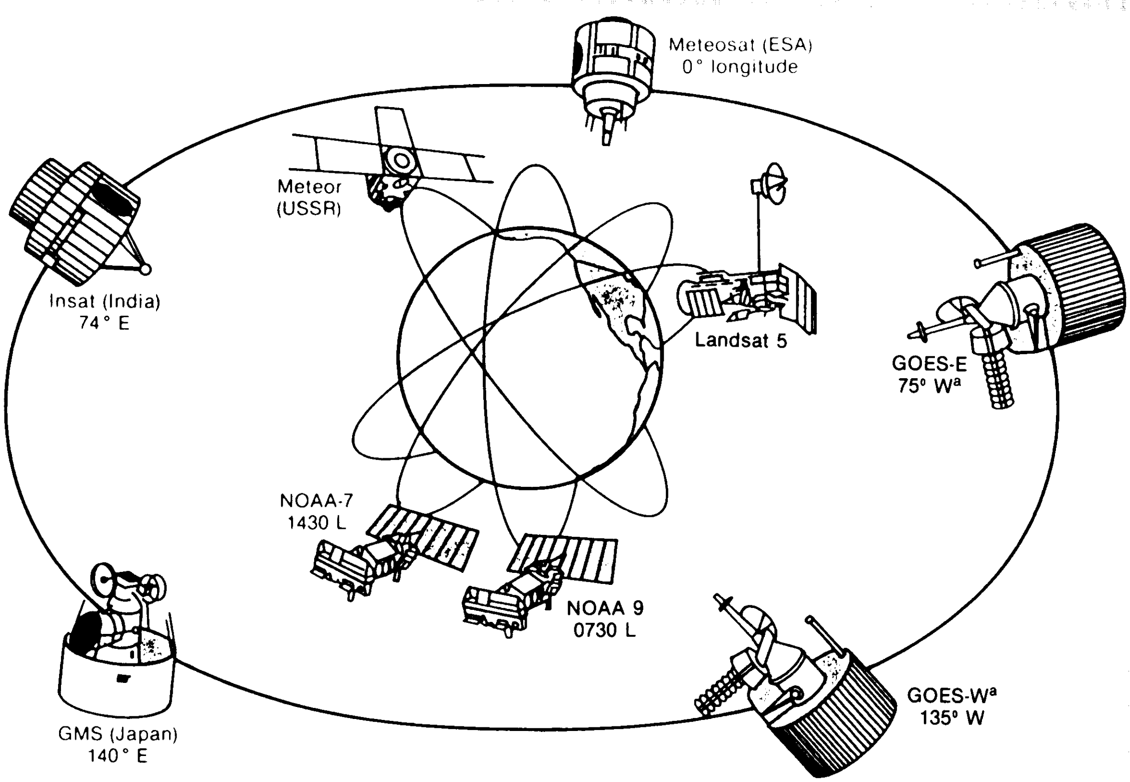
The World Meteorological Organization (WMO)

The WMO consists of more than 150 member countries and territories, each of which maintains its own meteorological services. Established under a 1947 international convention, the WMO has fostered international cooperation in meteorology. It has been the focus of free exchange of satellite weather data for the United States and other member nations. The WMO convention itself imposes no obligation for data exchange, but the free interchange of meteorological data from terrestrial stations and satellites has become an established custom of great utility to the participating countries. Since recognizing the potential value of meteorological measurements from artificial satellites in 1959, the WMO has pursued the coordination of national atmospheric satellite systems to "(a) increase the knowledge of climate forces and the possibility for large-scale weather modification, and (b) develop and make more effective existing weather forecasting capabilities through regional meteorological centers."* WMO's approach to this global sensing network was to establish the World Weather Watch which includes several world and regional centers and provides a means for collecting satellite data, integrating them with conventional data, and disseminating the resulting analyses and forecasts to member nations.

Geostationary and polar-orbiting meteorological satellites are part of the WMO's Global Observation system of the World Weather Watch. Though the geostationary satellites make regional observations, a complete international network of geostationary satellites with complementary and compatible instruments and data products will contribute significantly to continuous monitoring of global environmental data. Coordinated by the World Meteorological Organization (WMO), this network is virtually in place (fig. 7-8). Satellites from ESA, Japan and India, plus the U.S. satellites and the planned Soviet geostationary

*"U.N. Resolution 1721 (XVI), "International Cooperation in the Peaceful Uses of Outer Space" (Section C, Annex I).

Figure 7-8.—Operational Earth Observation Satellites



[a]As of May 1985, only one GOES satellite was in orbit (at 98° W longitude).

SOURCE: National Oceanic and Atmospheric Administration.

satellite, make up the heart of the World Weather Watch of the1. Metsat data received in the **United States support the National Weather Service, the Department of Defense, and international aviation. Most of the data on the Global Telecommunication & System come from countries other than the United States.****

In collaboration with the International Council of ~ie<ptl~~ LJaiO~$, the WMC) established the Global Atmospheric Research Program (GARP) to develop multinational projects for large-scale atmospheric data **gathering. The principal experiment of this** kind **was the F@tKb4RP Global Experiment (FGGE), held in the late 1970s, which prompted extensive nat[onal and [@emotional planning for development of meteorological systems. The WMO was assisted in this coa&?atlve effort** by an informal forum of **representatives of governments and organizations praposit&aU%mch geostationary meteorological satellites, the Coordination of Geostationary Meteoro!ogical Satellites (CGMS), This group was effective** in coordinating technical characteristics and operational pr@@qres ofsystems **as well as assuring similarity of data transmissions and platform data collection proc~+wes. The activities of these organizations led to support of the FGGE in 1978 and to the current glt@a'1 meteorological system.**

**"Satellite Systems in *Support of* WMO Programmes and Joint Programmes With Other International Organizations," prepared by the WMO for Unispace-82, Geneva, January 1982, pp. 20-21.

the **National Weather** Service (NWS) (table 7-4) **combines satellite data with other weather data** to develop weather forecasts designed to be useful to a variety of commercial interests, including aviators, farmers, fishermen, fruit growers, and

Table 7.2.—Domestic Users of Meteorological Satellite Data

- **NOAA**
  - **—National Weather Service Centers and Forecast Offices**
  - **—National Ocean Service**
  - **—Office of Research**
- **Department of the Interior**
  - **—Bureau of Land Management and Reclamation**
  - **—Water Resources Division**
- **Department of Agriculture**
  - **—Soil Conservation Service**
  - **—Forestry Service**
  - **—Foreign Agriculture Service**
- **NASA**
- **Department of Defense**
- Agency for International Development
- Department of Transportation
- National Science Foundation, National Academy of Science
- News media
- Commercial users
  - —Offshore drilling operations
  - —Ship routing
  - —Agricultural producers
  - —Commercial and general aviation
  - —Vessels at sea
  - —Fishing industry
- Universities
- Private individuals

Source: National Oceanic and Atmospheric Administration.

Table 7-3.—Derived Meteorological **Satellite Products**[a]

- Soundings —Temperature profiles from the surface through the stratosphere
- Sea Surface Temperature—Global and regional sea surface temperature and water mass analyses
- Ice—Ice analyses of the polar regions and Great Lakes
- Vegetation index — Measure of how "green" a target area appears.
- Rainfa'11" Estimates
- Hurricane Classification
- Cloud Motion Winds
- Satellite Interpretation Messages
- Tropical Storm Bulletins
- Cloud Top Height Data

aThese products are available in a variety of forms e g , charts, broadcast messages, and imagery

SOURCE: National Oceanic and Atmospheric Administration.

Table 7-4.—National Weather Service Hurricane, International Aviation, and Marine Forecast Programs

- Hurricane forecasts and warnings
- International aviation weather services
  - —Area forecasts
  - —Inflight advisories (hazardous weather)
  - —Computer flight planning forecasts
- High seas weather services
  - —Weather, waves, currents, and sea ice forecasts
  - —Navigation and operations support
  - —Forecasts and warnings for U.S. coastal and offshore waters
  - —Tsunami warnings and advisories

SOURCE: National Oceanic and Atmospheric Administration.

commercial shippers. The broadest category of weather data users are the millions of ordinary citizens who tune in to or read the daily forecast for guidance in preparing for work and recreation. NOAA and NWS also provide special warning of hurricane, tornado, and other severe weather conditions.

Land and Ocean

Meteorological remote sensing is not limited solely to weather applications, as the sensors can also measure important land and ocean phenomena throughout the world. Using data derived from channels 1 and 2 of the polar-orbiters' AVHRR to sense visible and near-infrared radiations, the U.S. Department of Agriculture, as well as the United Nations' Food and Agriculture Organization and private value-added corporations, are able to monitor and analyze global crop conditions (see later section on market for land remote sensing data). Identification of urban "heat islands" sensed by the High-Resolution Infrared Sounder assists planners in monitoring metropolitan industrial and population growth. NOAA provides analyses of meteorological satellite observations of snow and ice as both hydrological and oceanographic products.

Hydrological products using the AVHRR and GOES-VISSR instruments include the following at 1 km resolution: snow coverage observations of selected river basins; regional snow coverage analysis for selected regions of the world; and a northern hemisphere snow and ice chart. These products are valuable for assessing water runoff potential.

Products for oceanographic use include ice charts produced from AVHRR readings for the polar regions and a combination of AVHRR and geostationary VISSR imagery for the Great Lakes region, both to accuracies of 5 km. These analyses are particularly useful in forecasting the limits of the shipping season in particular regions and commercial ship routing, as well as for U.S. Navy and U.S. Coast Guard missions.

Global sea surface temperature (SST) observations are received daily from AVHRR infrared data and the High-Resolution Infrared Radiation Sounder (H IRS-2) data aboard the polar orbiters. Accuracies of 1.5o C are achieved over 70 percent of the oceans. Regional SST charts, distributed through NOAA Satellite Field Service Stations in Miami, Washington, DC, San Francisco, and Anchorage, are particularly useful to commercial fishermen for locating certain species of fish. Ocean current analyses include thermal front analysis of the waters off the west coast of the United States, which also benefits fishermen by identifying nutrient-rich ocean upwellings attractive to fish. Observations in the infrared using AVHRR can give an accuracy of 5 km for locating frontal zones. Ocean current navigation is assisted by analyses of polar-orbiter AVHRR infrared and GOES-VISSR imagery of the Gulf stream and "loop currents" in the Gulf of Mexico. The thermal boundaries of these currents and their eddies can be determined with an accuracy of 5 km, which allows fuel savings and reduces hazards for fishing and shipping interests. All of these data products are available for purchase on a nondiscriminatory cost-reimbursable basis from NOAA to users around the world.

Market for Metsat Equipment and Services

The market for civilian metsat equipment and services can be divided into three categories: the space component, ground station equipment, and various services related to reception and data distribution.

Satellite Manufacturers

The primary U.S. manufacturers are Hughes Aircraft Corp., which has built the U.S. (GOES) and most of the Japanese (GMS) geostationary satellites,[15] and RCA Astro-Electronics, which has built the NOAA-N series of polar orbiters.[16] The General Electric Corp. built the Nimbus series of research satellites for NASA.

The GOES satellites (4-6) cost approximately $15 million apiece and are designed to last about 5 years.[17] Replacement satellites (GOES-G and

[15] The GMS-2 and GMS-3 satellites were built by Hughes and Nippon Electric Corp.

[16] RCA also builds the DMSP satellites for DOD.

[17] However, GOES-5 lasted only 3 years. GOES-4 failed even sooner.

Photo credit: National Oceanic and Atmospheric Administration

Sixday normalized vegetative index composite made with data from instruments aboard the NOAA-N series polar orbiter.

GOES-H), built by Hughes, are expected to cost about $50 million and will be designed for a similar lifetime. Future satellites in the series, which will be much more capable, will likely cost about $100 million apiece. Two GOES satellites are necessary for complete coverage of the United States. The NOAA-N polar orbiters (H, 1, J) cost approximately $45 million but future models will cost about $100 million. Each polar orbiter is designed to last 3 years and two are normally orbiting at any one time.

The European (Meteosat) geostationary satellites, which constitute the satellite portion of Eumetsat, were built by a consortium headed by the French firm Aerospatiale.[18] Two Meteosat satellites have been launched since 1977. Although Europe has no polar-orbiting system, the United Kingdom and France contribute sensors to the U.S. polar orbiters.

Satellites

For several reasons, the overall market for meteorological satellites or for individual sensors is likely to remain small and competition highly limited. First, because the complete international geostationary system gives rather good coverage of the world as it is, no sales to countries that do not presently own a system are likely. * Second, because satellites are owned by national governments, countries will tend to purchase satellites from their own vendors.

- **The United States.** GOES G and H are planned for delivery in late 1985 and mid-l986 respectively. The GOES-Next series of advanced geostationary satellites (five are planned) will be needed in 1989 and beyond, but have not yet been ordered. NOAA-G is planned for launch in 1985. The Advanced NOAA series of polar-orbiting satellites are also planned but have not yet been ordered.
- **Japan.** It plans to launch three additional GMS satellites before the end of the century.[19] As noted, it purchased major portions of its previous geostationary satellites from Hughes Aircraft Corp. In the future it may attempt to build its own, or consider purchasing its next satellite from Europe.[20]
- **Europe.** The third Meteosat satellite is scheduled for launch in an Ariane 4 test flight in July 1986. Three more satellites and parts for building a backup satellite are now on order, and are scheduled for launch in August/September 1987, August 1988, and 1990. The market for Meteosat satellites, which are comparable to the GOES series, is essentially closed to U.S. suppliers.
- **International systems.** The Europeans and the Japanese may contribute to an international polar-orbiting system, in which case, individual countries will contribute instruments or other subsystems to the system (see section below on issues).

Ground Stations

The primary characteristic of the metsat ground equipment market is its relatively small size. Yearly international sales are extremely difficult to quantify, but representatives of several U.S. firms interviewed by OTA agreed that total yearly sales amount to less than $20 million, more than half from U.S. firms. Total worldwide investment in metsat ground receiving stations now equals at least $200 million.

Ground stations consist of the relatively inexpensive APT station (approximately $40,000 to $55,000), the more expensive HRPT station (approximately $0.5 million to $1 million) and any auxiliary data processing equipment. U.S. ground

[18] The other members of the consortium are Matra (France), IGG (United Kingdom), Marconi Space and Defense Systems (United Kingdom), Messerschmitt-Boelkow-Blohm (Federal Republic of Germany), ANT (Federal Republic of Germany), ETCA (Belgium), and Selenia (Italy).

*If China proceeds with its present plans to launch a geostationary and a polar-orbiting satellite, it will likely provide its own satellites as part of its effort to develop a capacity in space technology.

[19] According to current Space Council and NASDA plans, Japan will launch GMS-4 in fiscal year 1989, GMS-5 in fiscal year 1994, and GMS-6 in fiscal year 1999. However, production of none of these has been funded. See "Earth Sensors Further Japan's Efforts, " *Aviation Week and Space Technology,* June 25, 1984, pp. 151-57.

[20] Last year, European corporations offered to build a replacement satellite for the Japanese patterned after their own meteosat series. The price for the satellite, not including possible modifications to suit it for operation over Japan, is about $30 million. The offer included an additional $30 million to $32 million to launch it on an Ariane launcher. See "Europe Offers Weather Satellite to Japan," *Aviation Week and Space Technology,* July 2, 1984, pp. 21-22.

equipment manufacturers also supply receivers for a variety of applications, including civilian and military communications, military meteorological applications, intelligence, and command and control; supplying metsat stations and associated data processing equipment is a small part of their total business.

Foreign suppliers of ground station equipment include MacDonald Dettwiler Association, Inc., of Canada, SEP of France, MBB of West Germany, and NEC of Japan. They compete directly with U.S. firms abroad. U.S. firms compete well in the international market because of superior technology. In the past they have been supported in selling to the developing countries by the involvement of NASA, NOAA, and the U.S. Agency for International Development (AID) in extending the use of metsat technology.

There is little market in the United States for additional ground receivers because of easy access to processed data from the National Weather Service, Except for replacement items, most future market expansion will be in the developing world. However, developing countries already own a large number of installations and their future purchasing power is highly dependent on foreign aid programs, especially for the more expensive H RPTs. Technology transfer restrictions are not a problem, even for the high resolution equipment, because these receivers are not capable of conversion for use with military systems.

The foreign commercial market is dominated by foreign suppliers. Many of the purchases by Third World countries are sponsored by WMO through the World Weather Watch. In these instances, supplier selection is based on the usual purchase considerations, including lowest cost, best technology, and local and international politics. Where foreign aid is used, supplier selection will be heavily influenced by the donor country. The donor's influence can be felt either informally, through recommendations, or more formally, through specifications set to favor the donor country's technology. Selling to some foreign governments can be difficult because they often do not release enough information to allow a U.S. company to bid responsibly. Sometimes it is possible to obtain information through other U.S. firms that are successful bidders on another part of the project (e.g., the satellite builder).

Meteorological Satellite Issues

What Role Might the Private Sector Play in Enhancing the Utility of U.S. Meteorological Satellite Systems?

Suggestions a few years ago that the U.S. meteorological satellites might be transferred to private ownership raised a number of concerns about the domestic and international effects of such a policy. In March 1983, the Reagan Administration announced that it would seek to transfer both the meteorological and land remote sensing satellite systems to the private sector. This proposal was the result of an offer from COMSAT Corp. to purchase the Landsat system from the Government if the meteorological system was also included.[21] Although most aspects of this issue have been resolved in favor of continued Government operation of the metsat systems, the related principle of encouraging private sector involvement in space makes continued discussion of the issue appropriate. The following key concerns relate directly to the transfer proposal:

- **Data distribution policy.** In order to prepare for the eventuality that metsat data would be sold through a private corporation, the Administration began to explore the feasibility of charging for metsat data. Tentative and unofficial suggestions by U.S. officials in the spring and summer of 1983 that the United States might begin to charge other nations for these data were met with warnings from those countries[22] that the United States was tampering with well-established, long-term practices and that other countries might reciprocate in kind. These nations felt that such a change of policy would introduce an un-

[21] See statement of Joseph V. Charyk, of COMSAT before the Subcommittee on Space Science and Applications of the House Committee on Science and Technology and the Subcommittee on Science Technology, and Space of the Senate Committee on Commerce, Science, and Transportation July 23, 1985. COMSAT argued that if both systems were operated by a single entity, certain economies inherent in system operation, and sales of metsat data, would allow it to build the market for Landsat data while charging roughly what the Government was charging for Landsat data.

[22] "Satellite Storm Ahead," Nature, vol. 304, p, 202, 1983.

necessary and potentially destructive competitive element into a smooth functioning cooperative arrangement. Because the United States receives more data through membership in WMO than it supplies to the rest of the world, charging for metsat data would also result in a net cost to the United States. In part because of the outcry from U.S. users of foreign data (especially the Department of Defense (DOD)) as well as from Congress,[23] the Administration drew back and subsequently reaffirmed earlier commitments to supply meteorological data freely and free of charge to users throughout the world (except for certain special products that are priced at cost).

- **Contributions to and from the global system.** As noted earlier, the United States has been a member and strong supporter of the World Meteorological Organization since it was founded in 1947. Transfer of metsats to private ownership would have complicated U.S. arrangements with WMO and, in the absence of a formal organization such as INTELSAT or INMARSAT for managing a global meteorological satellite system, a U.S. **private firm might have found it extremely difficult to work with the meteorological agencies from other governments.**
- **Reduction of service.** In testimony before the Senate Subcommittee on Science, Technology, and Space in August 1983, representatives from several industries that depend heavily on weather data, including agriculture, aviation, forestry, and marine industries, expressed their reservations about the proposed transfer. They felt that the quality and quantity of service would suffer. Similar concerns were expressed to members of the House Subcommittee on Natural Resources, Agriculture Research, and Environment.
- **System hardware.** Although the specifications of the meteorological satellite systems are set by NOAA in response to Government and private sector needs, private firms have a major role in designing and building the systems' components. In the future, NOAA might be encouraged to make space available on its satellites (on a fee basis) for instruments that serve particular needs of the private sector and that would be provided by private firms for profit-making data services. In addition to serving domestic needs, such instruments would also be of interest to foreign customers.
- **Development of market for metsat data products.** In addition to their use in daily weather forecasts from the National Weather Service, data from meteorological satellites support a small, but growing industry devoted to converting data supplied by NOAA to information for a wide variety of public and private interests. These specialized value-added firms provide services as varied as predicting severe impending weather for the benefit of specialized groups, or predicting the best ocean routes for international shipping. Value-added firms have learned how to process metsat data conjointly with land remote sensing data to predict crop yields, both domestically and abroad.[24] Such information products are expected to be used by the value-added industry to expand the market for data sales from land remote sensing satellites. As the value of these services for metsat data becomes more widely known, this industry is likely to grow.

As a result of these and other considerations, Congress amended appropriations bill H.R. 3222, to prohibit the sale or transfer of the meteorological satellite systems to the private sector. On November 28, 1983, President Reagan signed this bill into law (Public Law 98-1 66), thereby reaffirming that the U.S. meteorological satellite systems would remain in the public sector.[25]

In order to provide appropriate service to data users, NOAA funds limited internal and university research to find new ways to utilize metsat

[23] Both House Concurrent Resolution 168, Sept. 19, 1983, and Senate Concurrent Resolution 67, Sept. 19, 1983; 98th Cong., 1st sess., expressed Congress' opposition to sale of metsat data.

[24] See, for example, *Remote Sensing and the Private Sector,* op. cit., app. D. The results of much of this work were reported at a NOAA-sponored conference, "NOAA's Environmental Satellites Come of Age," Mar. 26-28, 1984, Washington, DC.

[25] In addition, the Landsat Commercialization Act of 1984 (public Law 98-365) contains a provision that specifically prohibits sale of the meteorological systems. These actions reflect the strength of congressional opposition to the sale of any part of the meteorological satellite system.

data.[26] In addition, NOAA provides some specialized value-added services and products (e.g., fruit frost warnings or ocean surface temperatures charts) that might in time be provided profitably by private firms, using the initial satellite weather data as the input. As users gain more experience with using metsat data and linking them to other information sources, it will be important for the Government to avoid competing with the private sector in providing value-added data products, and to find ways to motivate the private sector to provide such services.

What Level of Service From the Polar-Orbiting Satellites Is Appropriate?

In its effort to reduce the costs of operating the meteorological satellites, the Administration has attempted to move to what is essentially a single polar-orbiting system, thereby saving some of the cost of the second satellite, and a percentage of the operating costs of the entire system. **Eliminating one of the polar orbiters** would reduce the coverage of the system from once every 6 hours to once every 12 hours for a particular spot on the Earth. For most of the continental United States, a reduction in service would not cause a serious decline in the ability to predict future severe weather. In those areas, conventional data collection systems and the geostationary satellites provide sufficient information. For the Pacific coast, Hawaii, Alaska, and the Pacific Trust Territories, the 6-hour repeat coverage that two polar-orbiting metsats supply is extremely important for timely warning of rapidly changing weather conditions (fig. 7-1 O). None of these areas has access to surface data for the predominately west-to-east weather patterns.[27]

As one observer noted,[28] having a second satellite for backup is also important. Experience with failures aboard Landsat 4 and metsats has demonstrated that even relatively simple satellite subsystems may fail in the harsh conditions imposed by launch or the environment of outer space. If only one polar orbiter were in service, and it failed, there would be no service for a period from the civilian satellite.[29] When NOAA's GOES-West failed in November 1982, well before it was scheduled to be replaced, NOAA was unable to replace it until June 1983. Only one GOES satellite is now in operation, the GOES-East satellite having failed in July 1984; its replacement cannot be launched before late 1985 or early 1986.

Operating only one polar orbiter would also reduce the data available to the military. Though it has its own system of meteorological satellites, the military makes extensive use of the NOAA system, both to provide data at different times of the day, and to act as an emergency backup to the military system. In the past, the military has had to depend from time to time on the civilian systems for critical weather information.

Although dropping one of the polar-orbiting satellites would not change the form of our cooperation with other nations, such a course of action would significantly reduce the amount and quality of data the United States can supply to other nations for predicting weather conditions. other nations that depend on these data and have purchased receiving stations have expressed dismay that the United States might operate only a single polar orbiter. Furthermore, the United States would not save much money because the cost of operating two polar satellites is very little more than the cost of operating one. NOAA estimates it would save between 10 and 20 percent of its yearly satellite operational costs by dropping one. In round numbers, each copy of the next series of NOAA polar-orbiting satellites, which are designed to last 5 years, is expected to cost about $100 million. so

[26] NOAA spends about $1.25 million, primarily internally, to develop new products that will use both Landsat and metsat data for agricultural and other renewable resource applications. In addition, it funds R&D (approximately $1 million) at about 6 universities to find new applications for metsat data in a variety of disciplines including severe storms, climate studies, and mesoscale meteorology.

[27] Because the primary weather flow i n the northern hemisphere is from west to east, information gathered to the west of a geographic area is especially important for weather predictions.

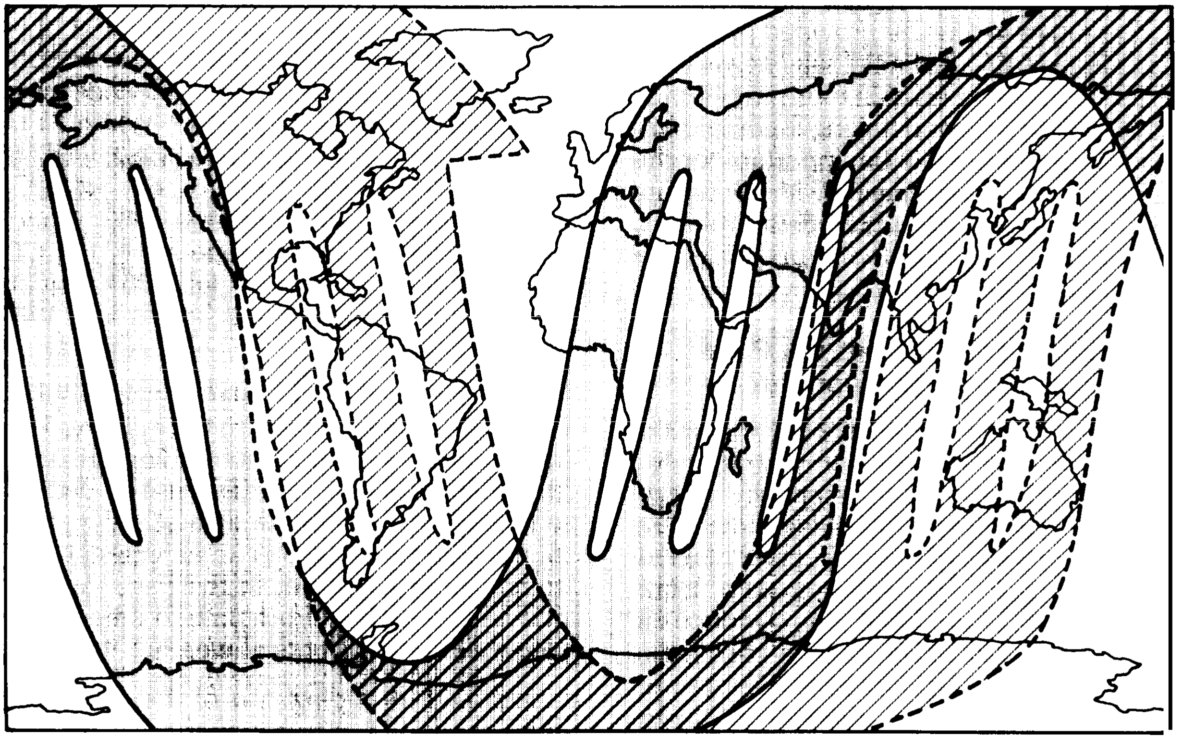
[28] Richard J. Reed, statement before the Subcommittee on Science, Technology and Space of the Senate Committee on Commerce, Science, and Transportation, August 1983.

[29] Presumably, some data could be provided by the DOD DMSP Satellites until a new civilian satellite was launched. However, the data from the two systems are not quite compatible. The quality of results from NOAA's forecasting models are reduced *accordingly.* Information from the GOES satellites cannot replace information from the polar orbiting satellites (see boxes A and B).

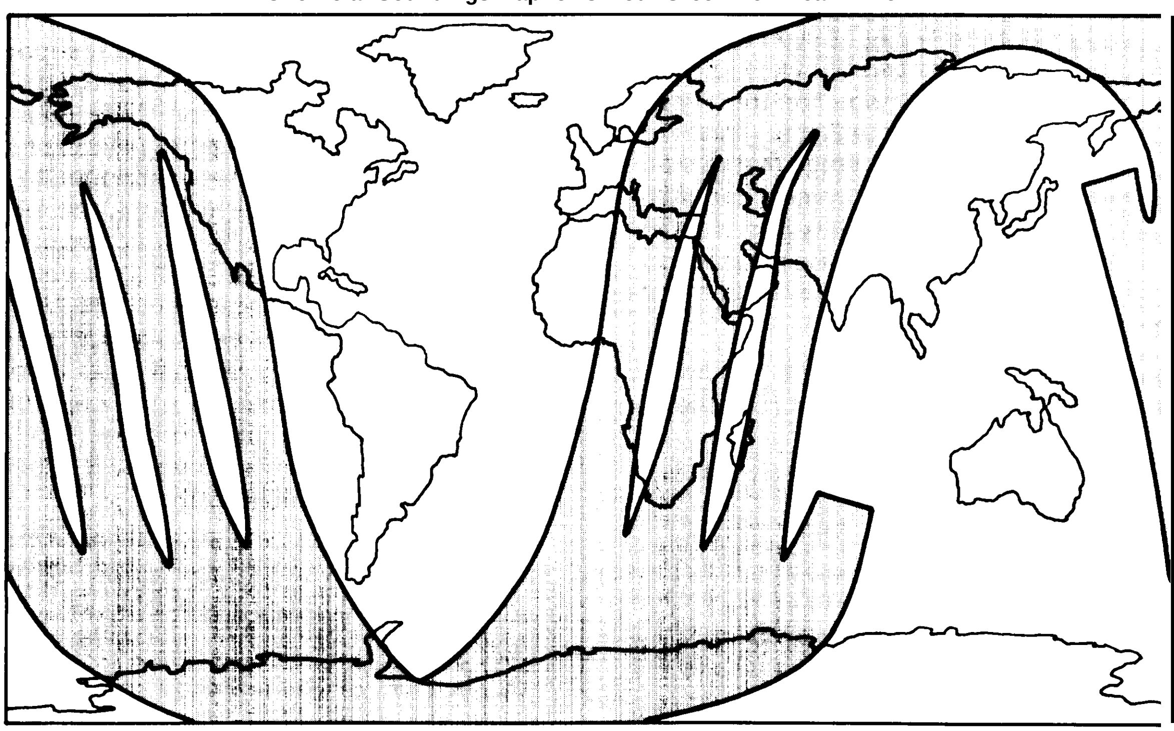
[30] The precise unit cost will depend on the total number of satellites purchased at one time, the delivery schedule, and their capability. If service is reduced to one satellite, each one will cost more than if two satellites were orbiting at all times.

Figure 7-10.—One. and Two-Polar Soundings

Two-Polar Soundings Map for O Hour Greenwich Mean Time



One-Polar Soundings Map for O Hour Greenwich Mean Time



The charts show satellite observational coverage for a 6-hour period centered at the synoptic observation time of O hour Greenwich mean time.

SOURCE: National Oceanic and Atmospheric Administration.

Reducing to one polar orbiter would also have had the effect of reducing our commitment to cooperation with Canada, France, and the Soviet Union in the COSPAS/SARSAT Search and Rescue Program (see app. A). The SARSAT receivers, built by France, are carried on the polar orbiters. The optimum system calls for a total of four instruments, one on each of two Soviet polar-orbiting metsats and one on each of two U.S. polar orbiters. Until recently this important international cooperative program was in jeopardy. In October 1984, after considerable debate over the implications of the decision, the United States signed an agreement with the three other primary participants to enter into operational phase of the project, which would extend through 1990.[31] The Administration was at first reluctant to sign the agreement because it means maintaining a two polar-orbiter system, or building another satellite to carry the emergency beacon. However, the system seems to have proved its worth, having contributed to saving nearly 400 lives since it began experimental operation in September 1982. Hence the Administration yielded to congressional and other pressure to maintain the program. Although the decision improves the chances for maintaining a two polar-orbiter system, it still does not mean its automatic continuation, because it would be possible (for a cost) to build and operate a dedicated satellite for the second beacon. This issue will require continual attention by Congress.

What Level of Cooperation With Other Nations Is Desirable?

In part because of the decrease in the quality of weather monitoring that would result from a reduction from two to one polar orbiters, and in part to share the costs of maintaining satellite weather service, the Administration is exploring the feasibility of establishing a formal cooperative arrangement with other nations. It has formally raised the question at two meetings of the Economic Summit of Industrialized Nations[32] and **has** received favorable responses (see policy discussion below). In addition to meeting daily needs for meteorological data and for sharing the operating costs of the system among its major users, a formal arrangement that would guarantee an internationally based two polar-orbiter system would increase each country's long-term ability to gather operational satellite data. It could also go far toward assuring continuity in spatial and temporal coverage and stimulating technological growth in member countries.[33] In short, the benefits of establishing a more formal cooperative arrangement seem to be high. Such cooperation could be a major step in improving the quantity and quality of weather-related information throughout the world. In addition, as the appendix on remote sensing in developing countries suggests, the greater use a country makes of meteorological satellite data, the more likely it is to develop uses for land remote sensing data as well.

Several drawbacks to a formal cooperative system exist:

- The United States would lose its unilateral control (through NOAA) over the management of the system. Thus, the U.S. military would lose its unilateral power to preempt civilian satellite operations in time of national emergency. Further, NOAA would also lose the power it now has to alter routine operations to follow particularly severe or dangerous weather developments in the United States. On the other hand, if the alternative is a single polar orbiter, U.S. access to crucial meteorological data (particularly for the military) would be lessened anyway.
- Some technology might be transferred from the United States to industrialized countries which could then use it in economic competition with the United States.
- An international organization might inadvertently become somewhat more cumbersome and require more personnel to operate the system than the current arrangement through WMO now requires.

[31] See "OMB **jeopardizes U.S.-Soviet Satellite Accord,** *science,* **Vol. 25, pp. 999-1000, 1984;** "Sarsat/Cospas **to Operate Through 1990,"** *Aviation Week and Space Technology, Nov. 12, 1984,* **p. 25.**

[32] For a discussion **of** various cooperative mechanisms, see "I nternational Meteorological Satellite **System: Issues and Options, " National Environmental Satellite, Data and Information Service, National Oceanic and Atmospheric Administration, Nov. 18, 1983.**

[33] **Department** of **Commerce news release,** NIC 84-132, Dec. 12, 1984.

The existence of INTELSAT and INMARSAT, both truly international organizations (see chs. 3 and 6), and the existence of Eumetsat, the European regional organization, suggest that the organizational problems can be solved within reasonable cost goals. Technology transfer also need not necessarily be a major threat. Most of the necessary technology is well understood and already well within the capacity of the industrialized countries. As these countries extend their capabilities, any technological gap is likely to shrink over time, making the problem moot. Nevertheless, all of these concerns would have to be weighed **in deciding whether formal cooperation is of overall benefit to the United States and,** if so, which form of cooperation would be most appropriate (see policy section).

LAND REMOTE SENSING SYSTEMS

Land remote sensing in the form of aerial photography is nearly as old as the photographic camera. Cameras have been flown on both balloons and aircraft. During World War II, aerial photography developed into a powerful and vital aid to tactical warfare. Well before the war, photographs taken from the special vantage point afforded by aircraft and balloons found use among such customers as agricultural and land-use planners, archaeologists, foresters, geologists, and geographers. By the early 1960s the interpretation of aerial photography had developed into a small, but highly useful, discipline. With the development of special-purpose photographic emulsions (e.g., infrared), advanced lenses, shutters, and other sensing devices (e.g., sidelooking radar) remote sensing analysts now provide a wider range of products for these customers.

Sensing from aircraft has limitations of coverage, high cost per unit area, as well as the difficulty of controlling lighting conditions. **It is not** suitable for developing a global data base. In contrast, remote sensing from space possesses several properties that permit the development of a unique global data base for resource inventory and monitoring over time:

- perspective over a range of selected spatial scales;
- selected combinations of spectral bands for categorizing and identifying surface features;
- repetitive coverage over comparable viewing conditions;
- direct measurement based on one set of solar illumination conditions for a wide surface area, data standardized from area to area and from day to day;
- signals suitable for digital storage and subsequent computer manipulation; and
- accessibility over remote and difficult terrain and across political divisions.

Although all of these characteristics contribute to the potential utility of remote sensing from space, the fact that data about Earth's surface arrive i n digital form suitable for routine computer manipulation is perhaps of greatest importance. Data from space can be routinely combined with other data to generate information products of great utility,

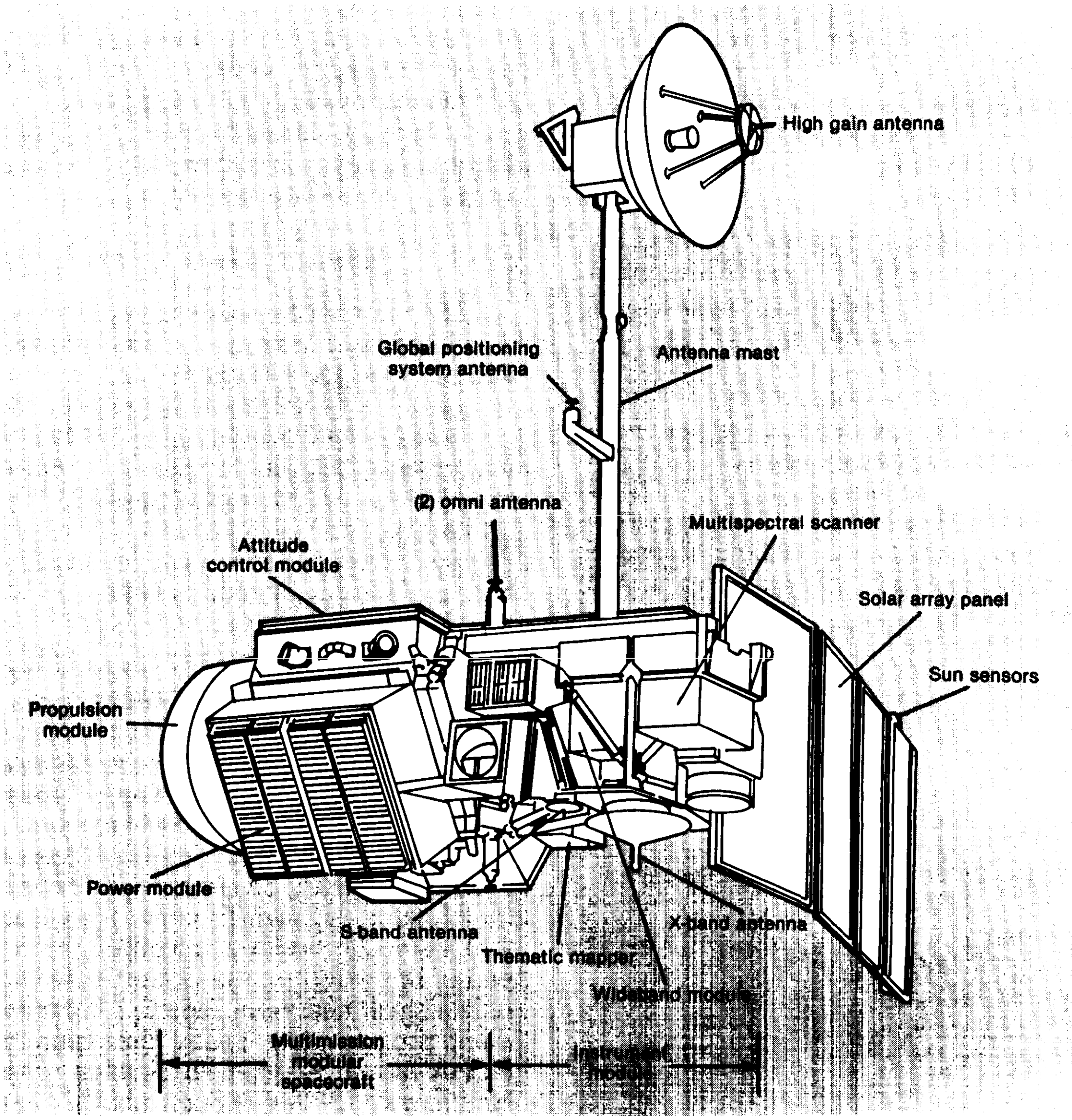
The U.S. Landsat System

Land remote sensing from space for civilian uses had its origins in a NASA program, begun in 1964.[34] After considerable theoretical study, and research and testing of multispectral scanners and other instruments in aircraft, NASA launched the first of five Landsat satellites in 1972.[35] These satellites follow a polar orbit that takes them over the same spot on Earth at the same time of day every 16 days. The latest in the series is Landsat 5, which was successfully launched on March 1, 1984, after Landsat 4 began to fail (fig. 7-11). In addition to other experi-

[34] For an early policy and institutional history of the Landsat system, see Pamela E. Mack, "Space Science for Applications: the History of Landsat," in *Space Science Comes of Age* (Washington, DC.: Smithsonian Institution Press, 1981).

[35] Landsat 1 was originally named Earth Resources Technology Satellite (ERTS-1).

Figure 7-11 .—Landsat.5 Spacecraft



SOURCE: National Oceanic and Atmospheric Administration.

MISSION: Collect remotely sensed multispectral land data broadcast data for receipt at ground stations operating under formal agreements

ORBIT: 705-km sun synchronous 16 day repeat cycle

SENSORS AND FUNCTIONS:

- **Multi-spectral Scanner (MSS):** The MSS is the specified operational sensor Swath width is 185-km resolution is 80-m

sensor Wavelengths (μm)	Primary Uses
05-06	Movement 01 sediment laden water delineation of shallow water areas
06-07	Cultural features
07-08	Vegetation boundary between land and water. landforms
08-1 1	Penetration of atmospheric haze vegetation boundary between land and water landforms

- **Thematic Mapper (TM):** The TM is a NASA experimental sensor It will come on-line operationally after it has been proven by NASA and an appropriate ground system has been constructed It is designed to provide 30-m resolution except for 120-m resolution in the thermal infrared band

sensor Wavelengths (μm)	Primary Uses
045 - 052	Coastal water mapping, soil vegetation differentiation deciduous coniferous differentiation
052 - 060	Green reflectance by healthy vegetation
063 - 069	Chlorophyll absorption for plant species differentiation
076 - 090	Biomass surveys, water body delineation
155 - 1 75	Vegetation moisture measurement
1040 -1250	Plant heal stress management, other thermal mapping
208 - 235	Hydrothermal mapping

DIRECT BROADCAST: Broadcasts are provided for ground stations which have entered into formal agreements covering the receipt and distribution of these data

38-797 0 - 85 - 10 : QL 3

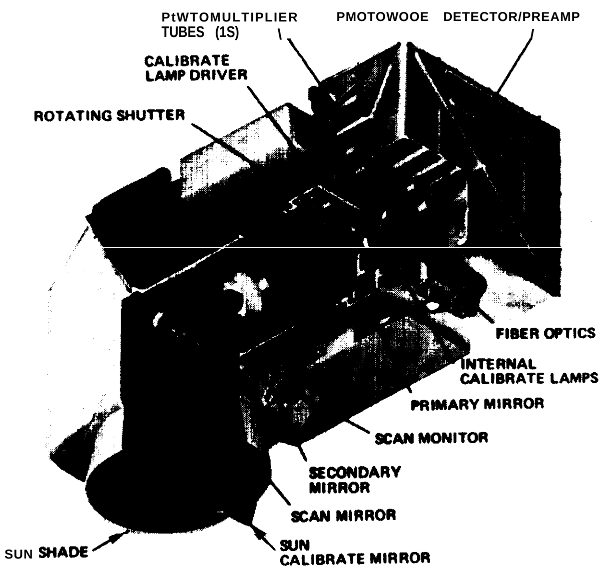
mental instruments, each Landsat spacecraft has carried a multispectral scanner (MSS), which has a spatial resolution of 80 meters and senses in four spectral bands (figs. 7-12 and 7-1 3). The Landsat 5 spacecraft carries an MSS and a thematic mapper (TM) sensor (fig. 7-13, which has a spatial resolution of 30 meters[36] and seven spectral bands (fig. 7-14).

The Landsat system is composed of the spacecraft and associated command and control telemetry, ground receiving stations, and processing, copying, storage, and distribution facilities. Landsat data are transmitted from the spacecraft in digital form to ground stations, collected on tape, corrected to remove radiometric and geometric distortions, and sold through the EROS Data Center (Department of the Interior) at Sioux Falls, SD. Data products are available in either image (photographic) form or on computer compatible tapes (CCTS) suitable for additional processing by large computers. Table 7-5 lists current and projected prices for Landsat data products.

In addition to providing data from the Landsat system to users around the world, NASA instituted a program in the mid-1970s to encourage wider experimentation with the data, and issued grants to a variety of State and local governments, to universities and private nonprofit institutions. As well as providing data free or at extremely low cost to these users and to other Federal agencies, the NASA program also developed computer software for processing the data.

[36] Except for the 10.4 to 12.5 micron wavelength band which has a spatial resolution of 120 meters.

Figure 7-12.–Cutaway View of the Multispectral Scanning System



SOURCE: National Aeronautics and Space Administration.

System Development

NASA has a small continuing program of sensor development for both optical and microwave (radar) sensors. Developmental models for these sensors are to be flown on the Shuttle. There are no plans for the Government to develop free-flying orbital systems in the near term. Both NASA and NOAA are exploring the possibility of a polar-orbiting platform as part of the U.S. effort in developing a permanently manned space station. Such a platform is a good candidate for international development.[37]

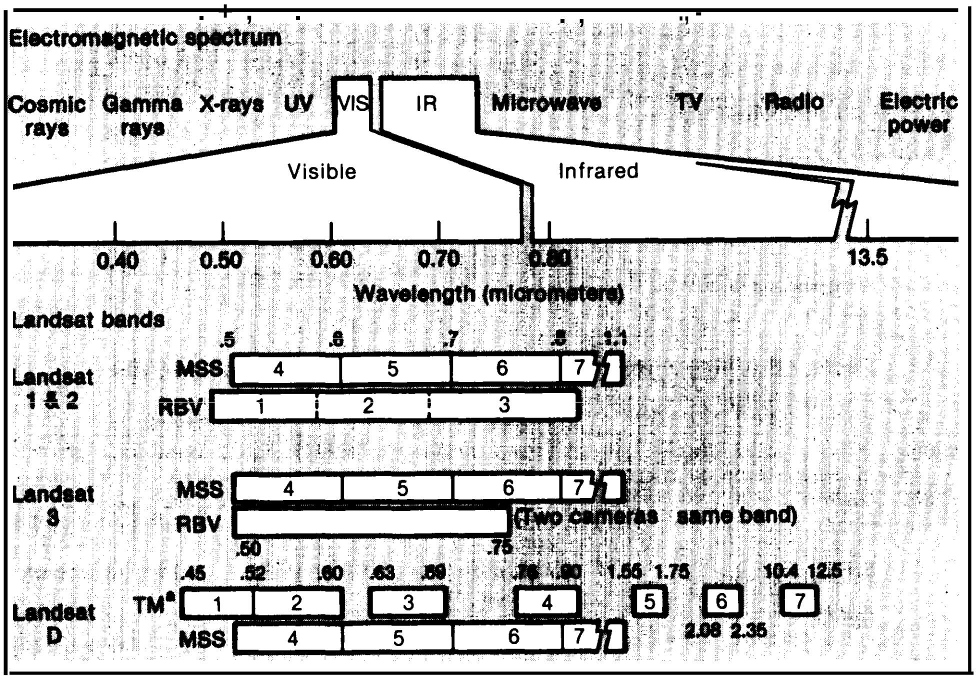
Table 7-6 lists the major sensors now under development by NASA. Until August 1984, NASA had a program to develop a multispectral linear array (MLA), similar to, but more capable than, the French SPOT sensor. However, under pressure from the Office of Management and Budget (OMB) to reduce overall spending, NASA decided to cut this program, on grounds that it was leading to an operational sensor rather than a research tool. Although NASA is attempting to reinstate part of this research, the United States now has only a small near-term remote sensor development program (see issues discussion below). NOAA has no program to develop sensors for land remote sensing, though it has a small effort in studying applications of metsat and Landsat data.

Foreign Landsat Receiving Stations

As NASA developed the Landsat system, it encouraged other countries to use the system. Ten countries now own operational receiving stations (fig. 7-1 5). In return for a fee, these foreign sta-

[37] John H. McElroy and Stanley R. Schneider, "Utilization of the Polar Platform of NASA's Space Station Program for Operational Earth Observations," NOAA Technical Report, NESDIS 12, September 1984.

Figure 7-13.—Landsat Bands and Electromagnetic Spectrum Comparison



[a]Thematic mapper.

SOURCE: U.S. Geological Survey

Figure 7-14.—Thematic Mapper Sensor

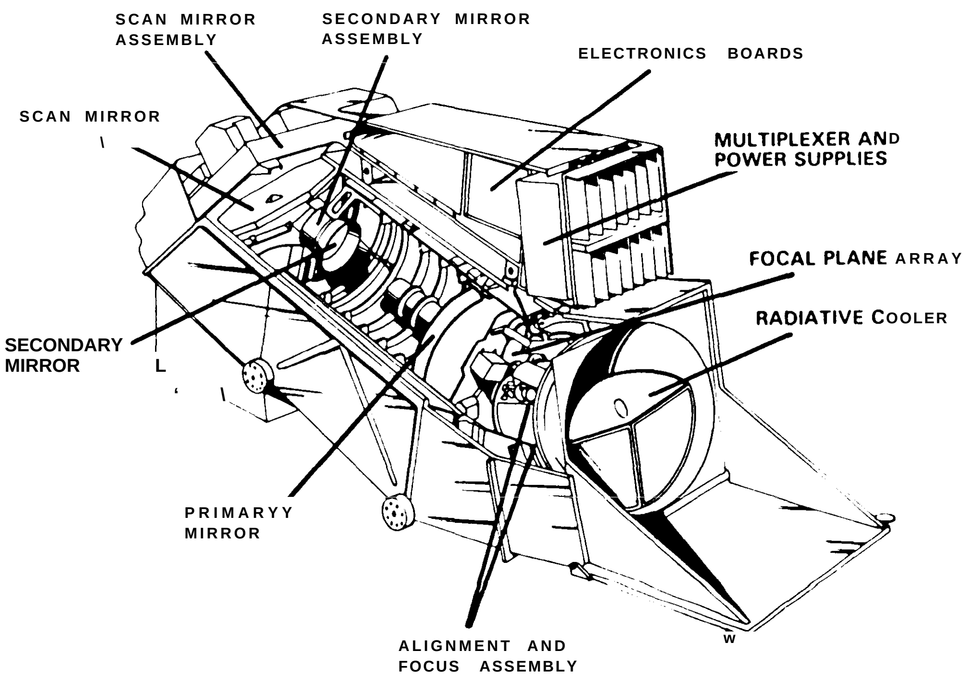


Table 7.5.—Costs for Some Landsat Data Products

	Cost			
Product	Until October 1981	October 1981—October 1983	October 1983—February 1985	February 1985—???
Multispectral scanner (MSS) computer-compatible tape (CCT)	$200	$ 650	$ 650	$ 730
Thematic mapper (TM) CTT	Not available	$2,800	$3,400	$4,400
TM CCT (quarterly)	Not available	$ 750	$ 925	$1,350
Color composite image (1:250,000 scale):				
MSS	$ 50	$ 175	$ 175	$ 195
TM	Not available	$ 235	$ 275	$ 290

SOURCE: National Oceanic and Atmospheric Administration.

Table 7-6.–Major Imaging Sensors Under Development by NASA

Sensor	Sensor type	Status	Notes
Large Format Camera	30.5 cm focal length camera; stereo capability	Flown on Shuttle flight 41-G, October 1984	Used for high-reolution mapping
Shuttle Imaging Radar (SIR)	Synthetic Aperture Radar		
	SIR-A	Flown on Shuttle, November 1981	L-Band microwave
	SIR-B	Flown on Shuttle flight 41-G, October 1984	L-Band microwave
	SIR-C	Under development	L-Band and C-Band microwave; NASA is negotiating with Germany to provide X-Band capability in a cooperative venture
Multispectral Linear Array Experiment	Pointing six-band focal plane sensor	Under development	Program terminated in August 1984; portions now reinstated
Shuttle Imaging Spectrometer	High spectral and spatial resolution spectrometer	Under development for Shuttle flight in 1989/90	Planned eventually for incorporation into space station polar-orbiting platform

tions receive Landsat data sensed over their region and sell or distribute them to local and foreign customers. Until fiscal year 1983, the yearly ground-station fee to NOAA was $200,000, but beginning on October 1, 1982, NOAA began to assess a $600,000 fee. In addition to the fee, each station pays a small distribution fee to NOAA for the data it sells or otherwise distributes. By signing the Memorandum of Understanding with NOAA, each station owner agrees to abide by the same nondiscriminatory data policy that NASA and NOAA have always followed and that is now mandated by the Landsat Commercialization Act of 1984.

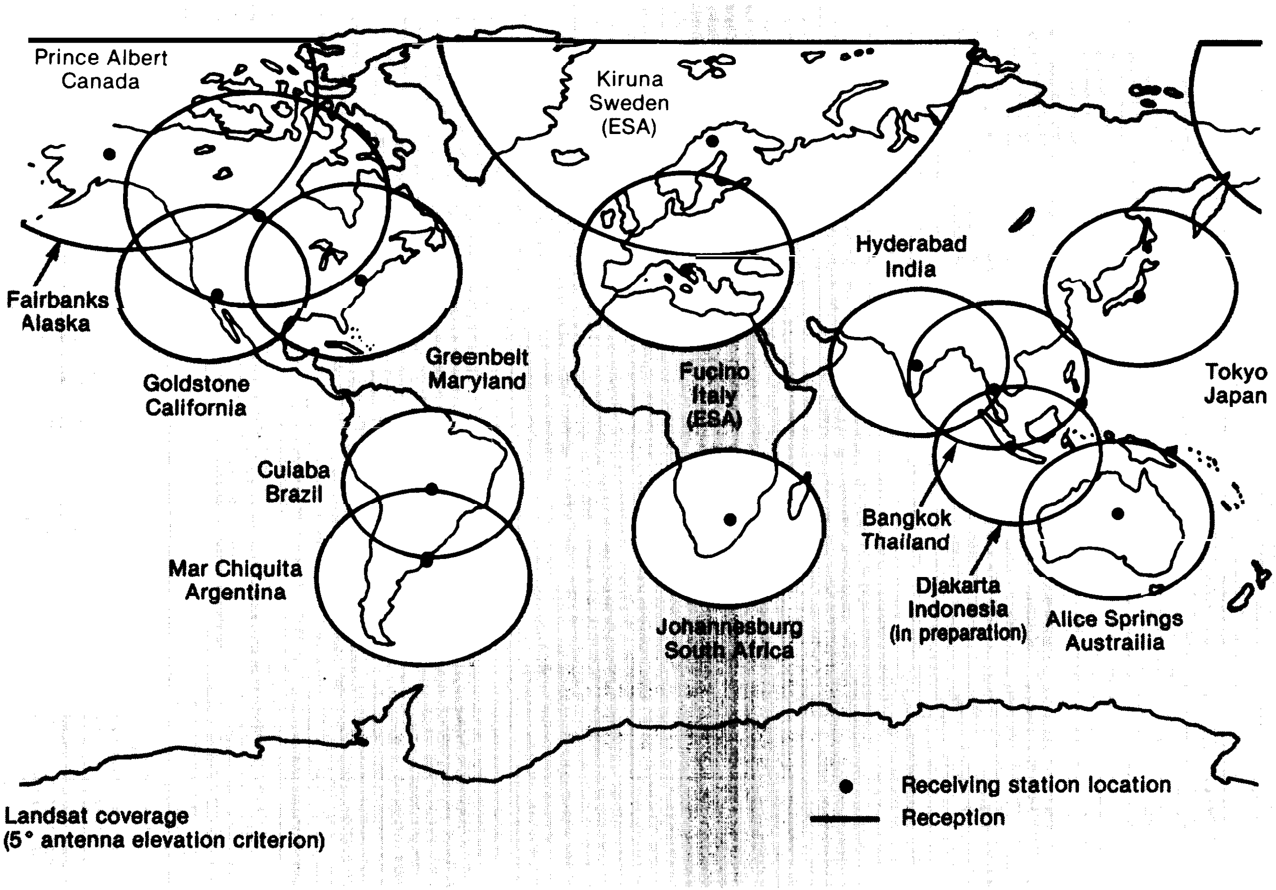
All Landsat receiving stations are capable of receiving MSS data. Some are also able to receive the more sophisticated TM data as well (table 7-7). Until the complete Tracking Data and Relay Satellite System (TDRSS) is in place and working,[38] foreign ground stations will be the predominant source of Landsat data for regions beyond the U.S. receivers.

Foreign Systems

As noted earlier, except for limited distribution of remotely sensed land data by the Soviet Union, the United States has been the sole supplier to the rest of the world. Other countries are now developing land remote sensing systems. These

[38] Unlike Landsats 2 and 3, Landsats 4 and 5 carry no tape recorders. They therefore depend on transmissions to ground stations as the satellites pass over, or to transmissions through the TDRSS satellites. Only one TDRSS satellite is currently in place and the demands on its time for other uses are great. The second TDRSS satellite is scheduled for launch on the Shuttle in late 1985 or early 1986 and will increase the capability of the Landsat 5 satellite to deliver TM data to users.

Figure 7-15.—Distribution by Foreign Ground Stations (as of Jan. 1, 1985)



SOURCE: National Oceanic and Atmospheric Administration.

foreign systems rely directly on experience and technology their designers have gained from U.S. R&D efforts as well as on indigenous capabilities. They are designed primarily to be operational, rather than R&D, systems. Some will be technically directly competitive with, but different from, the current Landsat system; some will exceed Landsat's capacity to return useful data.[39] The following summarizes briefly the characteristics of the foreign systems. In order of planned deployment, they are:

- **West Germany—Modular Optoekctronic Multispectral Scanner (MOMS) —1984/85). This instrument was flown on the Shuttle Pallet Satellite** (SPAS) developed by Messerschmitt-Boelkow-Blohm GmbH (MBB) aboard Shuttle flight 7. MBB and the Stenbeck Reassurance Co., Inc., together with the U.S. corporation, SPARX, wanted to market selected 20-meter resolution 2-color land remote sensing data collected on Shuttle flights beginning in 1985. However, they dropped such plans after NASA informed them that, according to public Law 98-365, the data must be sold on a nondiscriminatory basis. NASA and MBB are holding continuing discussions over a separate venture that would use the MOMS. The West Germans are developing a stereoscopic sensor and have already tested a limited synthetic aperture radar on Shuttle flight 9.
- **France—Systeme Probatoire d'Obsixvation de La Terre (SPOT) -1985.** Since 1978,

[39]For example, **the French SPOT system** will have higher resolution than is possible from the current Landsat system. It will also have the capacity to return quasi-stereo data to the user. It will, however, have fewer spectral bands, an important consideration in comparing the competitive capabilities of different systems.

Table 7-7.—Foreign Landsat Ground Stations

Country	Ground station location	Operating agency	Status of MOU	MSS data reception and processing	TM data reception and processing
Argentina	Mar Chiquita	Comision Nacional de Investigaciones Espaciales (CNIE)	signed	yes	no
Australia	Alice Springs	Division of National Mapping, Department of Resources and Energy (DRE)	signed	yes	no
Brazil	Cuiaba	Instituto de Pesquisas Espaciais (INPE)	signed	yes	yes
Canada	Prince Albert	Canada Centre for Remote Sensing (CCRS)	signed	yes	yes
European Space Agency	Fucino, Italy Kiruna, Sweden	European Space Agency (ESA)	signed	yes	yes
India	Hyderabad	National Remote Sensing Agency (NRSA)	signed	yes	yes
Indonesia[a]	Jakarta	Indonesian National Institute of Aeronautics and Space (LAPAN)	under negotiation	no (expected in 1985)	no
Japan	Tokyo	National Space Development Agency (NASDA)	signed	yes	yes
Pakistan	[under development]		signed	yes	yes
Peoples Republic of China[b]	Beijing	Chinese Academy of Science	signed	yes	yes
Saudia Arabia,	[under development]		signed	yes	yes
South Africa	Johannesburg	National Institute for Telecommunications, Council for Scientific and Industrial Research (CSIR)	signed	yes	no
Thailand	Bangkok	National Research Council of Thailand (NRCT)	under negotiation	yes	no

[a]Not currently operational.
[b]Expected to start operations, fall 1985.

France (through the French space agency CNES) has been planning the world's first commercial remote-sensing satellite service. It expects to fly a series of four satellites. Although the first satellite will not be launched until late 1985, it is currently preparing the sales market through a French company (government-owned in part), **SPOT IMAGE, S.A.** A Washington-based American subsidiary called SPOT Image Corp. is now developing the U.S. market for SPOT data. The U.S. corporation has flown a successful series of tests from high-altitude aircraft over the United States using sensors designed to simulate the data that will eventually flow from the SPOT system. Customers from U. S., private firms, State governments, and the Federal Government have purchased data sets from these flights. SPOT Image Corp. has an agreement with the Canada Centre for Remote Sensing to receive SPOT data from North America at two stations (Prince Albert and Ottawa).

The SPOT satellite will carry pointable multispectral linear-array sensors capable of resolving images at least as small as 20 meters in three wavelength bands. In addition, the satellite will be capable of 10-meter resolution operating in a panchromatic mode. These are higher resolutions than are possible on Landsat 5. Because the sensors are pointable, they are capable of producing quasi-stereo images. Although the system is a commercial effort, the French Government is spending a minimum of $400 million to $500 million to develop the system. CNES will pay for and build the second satellite in the series; SPOT Image will reimburse CNES from sales of SPOT data.

- **India-IRS-1985.** This low-resolution "semi-operational" land remote sensing satellite

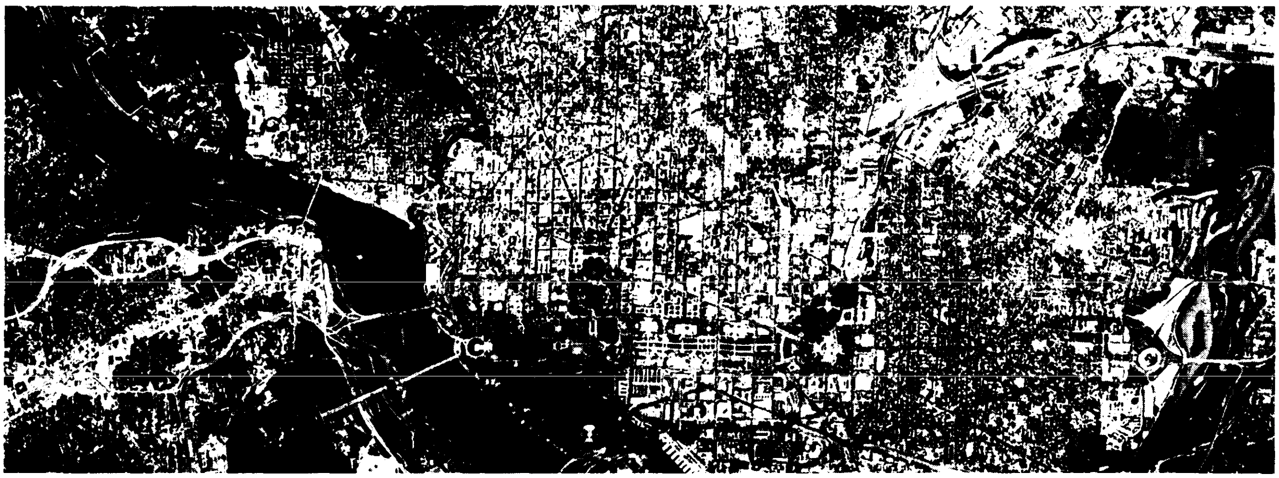


Photo credit: © 1983 SPOT Image Corp.

Panchromatic simulated SPOT image of Washington, DC (10 meters resolution), taken July 7, 1983, from an airplane. The SPOT satellite is expected to be launched in "late 1985.

will be built in India but launched by a Soviet launcher. It will carry solid-state sensors.

- **Japan Earth Resources Satellite (ERS-1)–1991.** Its primary mission will be to collect information on renewable and nonrenewable natural resources, including minerals, forests, and crops. ERS-1 will carry a synthetic aperature radar and an optical (visible and infrared) radiometer. It will be launched by an H-1 vehicle. Japan is also building a marine observation satellite (MOS-1) to be launched in 1986 by an N-11 vehicle.
- **Brazil.** Working on a moderate-resolution land-sensing salellite to be launched in the late 1980s.

Data Products and Uses

Land remote sensing data are put to a variety of uses for resource mapping, assessment, and management.[40] Table 7-8 lists the major categories of data users, table 7-9 lists the major customers for data. Figure 7-16 illustrates the broad categories of major users and their relative share of the data market. The EROS Data Center sells data either in digital format (computer compatible tapes, or CCTS) or photographic imagery in several sizes. For a special additional fee, customers may specify cloud-free scenes or other special attributes. As the section on issues points out, the largest potential market for land remote sensing data products is for information products generated by processing and adding information to the satellite data from other sources (so-called value--added products).

Table 7-8.—Categories of Foreign and Domestic Users

- *Agriculture* (Federal, State, and private): specific sampling areas chosen according to the crop; time-dependent data related to crop calenders and the weather patterns
- *Forestry* (Federal, State, and private): specific sampling areas; twice per year at preselected dates
- Geology *and nonrenewable resources* (Federal, State, and private): wide variety of areas; seasonal data in addition to one-time sampling
- Civil *engineering and /and use* (State and private): populated areas; repeat data required over scale of months or years to determine trends of land use
- *Cartography* (Federal, State, and private): all areas, repeat data as needed to update maps
- *Coastal zone management* (Federal and State): monitoring of all coastlands at selected dates depending on local seasons
- *Po//ution monitoring* (Federal and State): broad, selected areas; highly time-dependent needs both for routine monitoring and in response to emergencies

SOURCE: Off Ice of Technology Assessment.

[40] For an extended discussion of potential customers and their data needs see *Remote Sensing and the Private Sector,* chs. 4, 5, 6.

Table 7-9.—Domestic Distribution of Landsat Products

- Department of Agriculture
- Department of Defense
- Department of the Interior
- National Aeronautics and Space Administration
- Intelligence community
- Coast Guard
- State planning and resource management agencies
- Regional planning agencies
- Academic community
- Commercial users (e.g., foresters, mineral exploration geologists, engineering and consulting companies)
- Private individuals

SOURCE: Office of Technology Assessment.

Policy History of Land Remote Sensing

Although the potential utility of images gathered by satellite of atmospheric conditions and of the surface of the land and ocean were recognized by those conceiving the systems, until recently few considered operating the systems as commercial entities. However, as Federal, State, and local governments, universities, and industrial firms began to work with the data from the Landsat system, they realized that, at the prices charged,[41] these data were often a cost-effective substitute for older (aircraft) methods of gathering Earth resources data. The digital format, wide spatial coverage, and repeatability of the data made possible new applications that could eventually increase the value of the information these data provide. By the late 1970s, some observers postulated that the data might eventually have sufficient commercial value to attract private investment in a remote sensing system. However, it was also clear that the known barriers of high system cost, and technological and economic risk, would have to be drastically reduced if private investors were to be interested in providing a system comparable to Landsat, especially because the initial market for the data was thought to be quite small (see section on issues).

The history of the Landsat system illustrates the difficulties that may attend bringing a Government-developed applications system to operational status, let alone to commercial status. The current policy debate over land remote sensing had its genesis in an interagency controversy over who should develop and operate the Government system and what sensors it should contain. In 1966, while NASA and other agencies were experimenting with data derived from a variety of sensors carried in aircraft, the Department of Interior announced a program to fly its own operational satellite. NASA was convinced that considerable flight experimentation was needed with sensors that would be carried on Apollo and Skylab missions. The Interior Department, however, wanted to proceed more directly to operational use of data from a satellite and to shorten the lengthy process of research and development that NASA was contemplating. Yet its specifications for the appropriate sensor differed from those of the Department of Agriculture, which wanted greater spectral discrimination in order to detect crop stress and other agricultural characteristics. Both departments recognized the need to have NASA design and build the satellite, but as they would eventually derive the greatest use from the data generated by the Landsat system, they wanted control over the design of the system because they were aware that "the experimental program would inevitably shape any operational program."[42]

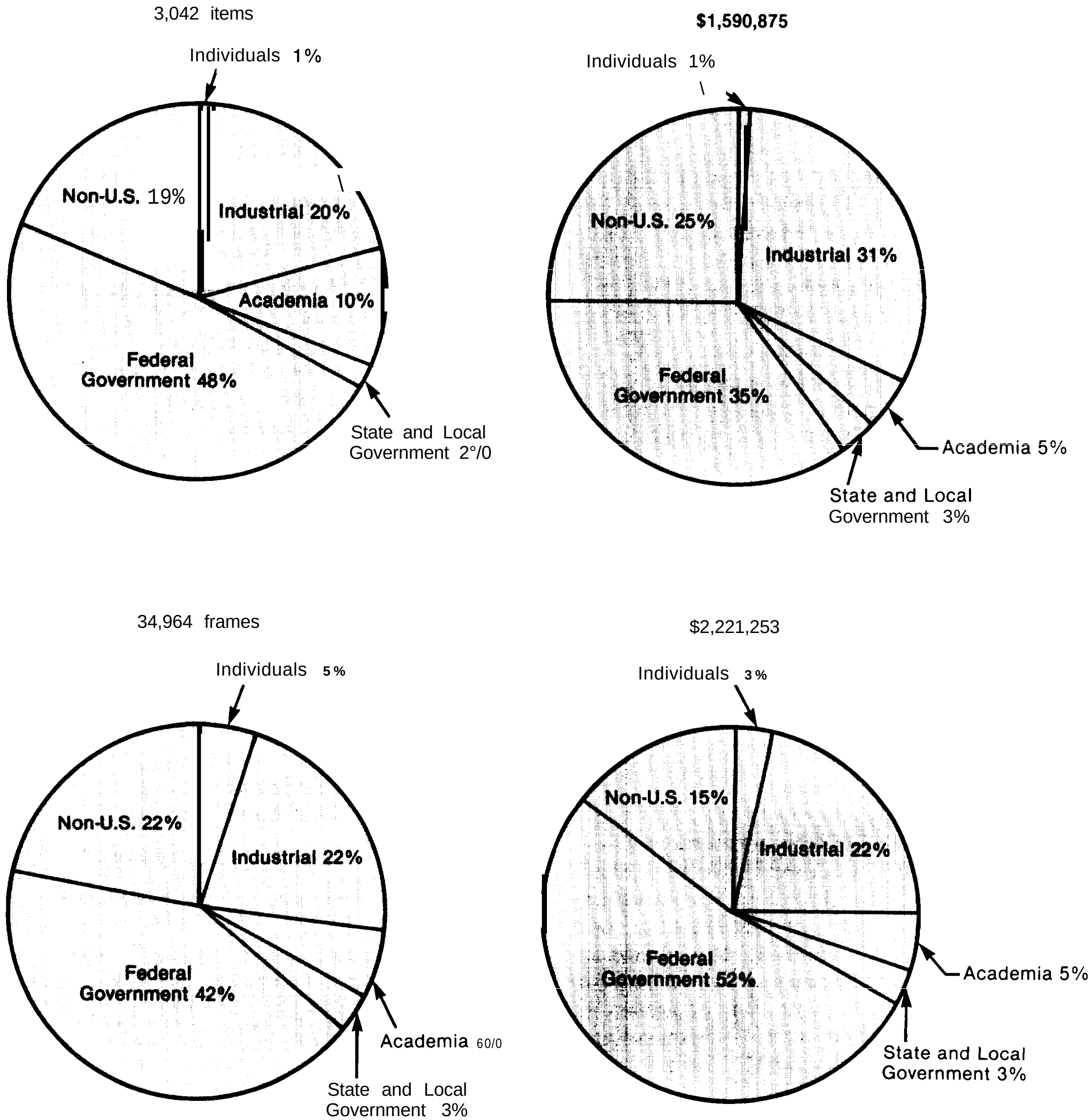
The Bureau of the Budget (BoB) was not convinced of the utility of the Landsat system compared to other data sources, and specified that NASA do only research and development. It also opposed purchase of equipment that would lead to operational use of the system. As the system was flight tested, NASA encouraged Federal, State, and local agencies and private groups to apply the data to their needs, in part to demonstrate to BoB that the data were beneficial. In spite of continued opposition from BoB and its successor, the Office of Management and Budget (OMB), NASA continued to involve data users, both domestic and foreign, in planning for follow-on satellites and sensors and to encourage the widespread use of the data. The result was a quasi-operational[43] system, which only partially met

[41] Landsat data prices have never reflected the cost of operating the system, much less the costs of developing the sensors in the first place.

[42] Pamela E. Mack, "Space Science for Applications . . . ," op. cit.

[43] *Civilian Space Policy and Applications,* OTA, p. 13. Article I also states: "The exploration and use of outer space . . . shall be carried out for the benefit and in the interest of all countries."

Figure 7-16.—Customer Profile of Landsat Digital and Imagery Products (shipped sales), Fiscal Year 1984



SOURCE: National Oceanic and Atmospheric Administration, the needs of users. Even though the system has now been transferred to NOAA, and is fully operational, it does not generate sufficient revenue from customers (i.e., a market) to enable the Landsat system to be transferred to the private sector or be commercialized without sizable subsidy.

Transfer of the Government's civilian land remote sensing system to private hands was first considered seriously by policy makers in the drafting of President Carter's 1979 policy statement on space, PD/NSC-54, which amplified the earlier policy directives, PD/NSC-37 and PD/NSC-42. It stated:

> Our goal is the eventual operation by the private sector of our civil land remote-sensing activities. Commerce will budget for further work in fiscal year 1981 to seek ways to enhance private sector opportunities.[44]

This statement left open the speed and the means of the transfer but, because it also committed the United States to provide continuity of the data flow from the Landsat system through the 1980s, most observers assumed that transfer to the private sector would take place about 1990. The first stage of that process was to transfer responsibility for operational management of the Landsat program to NOAA. Transfer of the meteorological satellite systems to private ownership was not envisioned by PDNSC-S4.

The Reagan Administration decided early in its tenure to hasten the process of transfer, and announced "the intent of transferring the responsibility [for Landsat] to the private sector as soon as possible."[45] That statement, too, made no mention of the meteorological systems. Later, in March 1983, the Administration proposed to transfer both the Landsat and the metsat systems to private hands.[46] Public Law 97-324 mandated (in Title 11) the Department of Commerce to commission studies and internal analyses to explore and examine the issues raised by transfer of remote sensing from space to the private sector.[47] None of these reports concluded that rapid transfer was in the best interest of the United States.[48]

In late 1983, however, the Administration began to draft a request for proposals designed to solicit proposals from private industry to own and operate the current Landsat system and any follow-on. Concurrently, the House Committee on Science and Technology drafted a bill authorizing a phased transfer of the system to the private sector, with the aim of eventually establishing a profit-making satellite land remote sensing industry. On January 3, 1984, the Department of Commerce released its request for proposal (RFP). Seven proposals were received on March 19, 1984.[49] It is significant that several of the proposers were partnerships or consortia. Few single firms have the breadth of experience and personnel to design, build, and operate a system as complex as the Landsat system. After evaluating all the proposals in an initial round, in June the Department of Commerce Source Evaluation Board (SEB) found three proposers, EOSAT, Kodak/Fairchild, and Space America, to be within the competitive range required by the RFP. After a second round of evaluation, the Secretary of Commerce selected Eastman Kodak and EOSAT for negotiations with the Department.

[44] "Presidential Directive NSC-54," Nov. 16, 1979.

[45] Statement of Joseph Wright, Deputy Secretary, Department of Commerce, to the Subcommittee on Space Science and Applications of the House Committee on Science and Technology, and the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce, Science, and Transportation, July 22 and 23, 1981.

[46] Statement of Malcolm Baldrige, Secretary of Commerce, to the Subcommittee on Natural Resources, Agricultural Research, and Environment of the House Committee on Science and Technology, Apr. 14, 1983. As discussed earlier, in November 1983, Congress passed, and the President signed, appropriations bill H.R. 3222 (Public Law 98-166), which contained a provision preventing sale of the Nation's meteorological satellite systems to private hands. The meteorological satellites will continue to be operated as a public service.

[47] "Space Remote Sensing and the Private Sector: An Essay," National Academy of Public Administration, March 1983, Department of Commerce contract No. NA-83-SAC-066; "Commercialization of the Land Remote Sensing System: An Examination of Mechanisms and Issues," ECON, Inc., April 1983, Department of Commerce contract No. NA-83-SAC-O0658; "A Study to Examine the Mechanisms to Carry Out the Transfer of Civil Land Remote Sensing Systems to the Private Sector," Earth Satellite Corp. and Abt Associates, Inc., Department of Commerce contract No. NA-83-SAC-O0679.

[48] The assumptions upon which these analyses were based included: 1) maintenance of data continuity, 2) maintenance of U.S. leadership, 3) Landsat-type technology, and 4) maintenance of international obligations.

[49] These were: Earth observing Satellite Co. (EOSAT—a new company to be formed by RCA and Hughes Aircraft); Eastman Kodak; Gee-Spectra Corp.; Miltope Corp. of Melville, NY.; Milton A. Schultz of Williston, ND; Space Access Corp. of Marina Del Rey; Space America Inc. See *Space Business News,* Mar. 26, 1984, p. 1.

A Guide to the Land Remote Sensing Commercialization Act of 1984

Title I—Declaration of Findings, Purposes, and Policies

This title presents the findings of Congress, and establishes the purposes, policies, and definitions of U.S. land remote sensing. It specifically states that the Act is to "maintain the United States' leadership in civil remote sensing, preserve its national security, and fulfill its international obligations." These purposes, and the following policies, serve as the general rationale for most of the provisions of the subsequent titles.

The Act (sec. 103) states that it shall be U.S. policy: a) "to preserve its right to acquire and disseminate unenhanced remote-sensing data," b) "that civilian unenhanced remote-sensing data be made available to all potential users on a nondiscriminatory basis and in a manner consistent with applicable anti-trust laws," and c) "to commercialize those remote-sensing space systems that properly lend themselves to private sector operation and to avoid competition by the Government with such commercial operations, while continuing to preserve our national security, to honor our international obligations, and to retain in the Government those remote-sensing functions that are essentially of a public service nature."

Title II—Operation and Data Marketing of Landsat System

This title calls for the Secretary of Commerce to contract for marketing of unenhanced data from the current, Government-owned, Landsat system. Its intent is to engage the private sector in aggressively marketing unenhanced Landsat data. Under its terms, "the contractor shall act as the agent of the Secretary by continuing to supply unenhanced data to foreign ground stations for the life, and according to the terms, of those agreements between foreign ground stations that are in force on the date of the commencement of the contract."

Title III—Provision of Data Continuity After the Landsat System

It is this title that constitutes the core of the transition of land remote sensing from Government to private ownership. Its aim (sec. 301) is to provide continuity of data delivery "for 6 years after the practical demise of the space segment of the Landsat system," by providing a subsidy to a private firm to construct and operate a follow-on system. Among the criteria by which a contractor is to be selected (sec. 303) are the contractor's ability to "maintain U.S. leadership in remote sensing," and its ability to develop a market for data.

The Terms of Contract (sec. 304) stipulate that the contractor must agree to sell data on a nondiscriminatory basis. Further, the Government "shall not provide a guarantee of data purchases from the contractor." In addition, the contractor may utilize (on a space-available, reimbursable basis) "a civilian U.S. Government satellite or vehicle" as an instrument platform.

Title IV—Licensing of Private Remote-Sensing Space Systems

This title essentially recognizes that although the follow-on to Landsat may be the first entity requiring a license, other systems should also be provided for. It requires that the owners or operators of the follow-on system and any other remote sensing system who are "subject to the jurisdiction or control of the United States" obtain a license from the Secretary of Commerce, certifying that the licensee complies with the provisions of the Act, including notifying "the Secretary of any 'value-added' activities (as defined by the Secretary) that will be conducted by the licensee or by a subsidiary or affiliate." The section provides for penalties for noncompliance. It explicitly recognizes the need (sec. 402 (b)) "to observe and implement the international obligations of the United States." Among these international obligations are the four treaties on outer space to which the United States is a party (see ch. 3).

Section 405(a) also specifically states "A private sector party may apply for a license to operate a private remote-sensing space system which utilizes on a space-available basis, a civilian United States Government satellite or vehicle as a platform for such a system."

Title V—Research and Development

This title directs the Administrator of NASA to provide continued Government research and development of remote sensing sensors, systems, and techniques. It further authorizes and encourages NASA to "conduct such research and development in cooperation with other Federal agencies and with public and private research entities . . ." The latter specifically includes international organizations.

The Act directs the Secretary of Commerce to conduct a continuing research program in applications, monitoring of Earth and its environment, and technology development for monitoring. It also authorizes and encourages other Federal agencies to conduct their own research programs in utilizing remote sensing.

Title VI—General Provisions

Section 601 reiterates the nondiscriminatory provisions mentioned earlier in the Act. The title further provides for archiving of data (sec. 602) and requires the system operator to make available data needed for a U.S. "basic data set." The system operator would retain rights to sell such data for a period not to exceed 10 years. Section 603 allows data to be sold "on the condition that such data will not be reproduced or disseminated by the purchaser," a provision that allows for copyright of the data.

Section 607 provides for consultation (sec. 607(a)) between the Secretary of Commerce and the Secretary of Defense concerning conditions that must be met for the national security, and (sec. 607(b)) for similar consultation between the Secretary of Commerce and the Secretary of State concerning international obligations and policies. It also authorizes and encourages appropriate Federal agencies "to provide remote-sensing data, technology, and training to developing nations as a component of programs of international aid. Finally, section 609 authorizes $75 million for fiscal year 1985 to begin the transfer process.

Title VII—Prohibition of Commercialization of Weather Satellites

This title prohibits the sale, lease, or transfer of the weather satellite systems (or any portion) operated by the Department of Commerce or any successor agency.

The initial proposals from EOSAT and Kodak/Fairchild included estimates of nearly $1 billion in Government subsidies over a 10-year period in order to take over marketing data from the current Landsat system and to build an advanced new satellite system. EOSAT was prepared to fly a refurbished Thematic Mapper on Landsat 6 and 7 and to develop and launch a more advanced multispectral linear array (MLA) sensor on Landsat 8 and 9. Kodak's proposal called for an entirely new design as a follow-on to Landsat 5 that would move directly to MLA technology. The Department of Commerce found both proposals acceptable technically, but unacceptable from a financial point of view. It invited drastically revised financial plans. Among other matters, the amount of financial risk the two companies were willing to accept was unacceptable.

During this process, H.R. 5155 was reported out of the House Committee on Science and Technology on April 3, 1984, and passed by the entire House April 10.[50] A similar bill (S. 51 55) was under consideration by the Senate Committee on Commerce, Science, and Transportation and passed the Senate May 8, 1984. After a conference and subsequent passage by both Houses, the Land Remote Sensing Commercialization Act of 1984 was signed into law (Public Law 98-365) by President Reagan on July 17, 1984.

In addition to authorizing the commercialization of the U.S. land remote sensing program, and providing for continuation of certain Government

[50] Committee Report 98-647 on the Land Remote-Sensing Commercialization Act of 1984, House Committee on Science and Technology.

functions, the Act is noteworthy for being the first piece of major legislation that attempts to set out the legal and regulatory framework for commercial space activity as required by the 1967 Outer Space Treaty (Articles VI and IX). The box summarizes the major provisions of Public Law 98-365. The complete Act is reproduced in appendix C.

The ultimate goal of the transfer of the results of Government R&D to the private sector is to create a self-sustaining business from all or part of the technology so transferred, with the private sector in full control (except for appropriate regulation) of further development and shaping of the system and products. Realization of this goal would constitute full commercialization of the Government-developed technology. intermediate steps along the way to this end could result in: 1) shared control of the technology by Government and the private sector; and/or 2) joint continued development of the technology and its products, through either subsidies, shared investment, or guaranteed Government purchase. Such intermediate steps, in which the system would receive significant Government subsidy, have often been referred to as "privatization. "

In passing Public Law 98-365, Congress decided to privatize the Landsat system by first authorizing the Secretary of Commerce to contract with a private firm to market Landsat data as the Government continues to operate the current system (Title I I). The Government will also provide a subsidy to enable a private operator to build a system that would provide data continuity for a total of 6 years after the demise of Landsat 5. Such legislation implicitly expects sufficient market for data to develop within 8 to 10 years to enable a private operation to be self-sufficient.

Among other provisions, Public Law 98-365 authorized up to $75 million for fiscal year 1985 as the first installment of a subsidy to aid the eventual commercialization of land remote sensing. The law does not specify the total amount of subsidy necessary, as this was left to the Department of Commerce to work out with a potential contractor. As these corporations were preparing to revise their proposals to respond to the SEB'S concerns, OMB informed the Department of Commerce a subsidy was inappropriate. After considerable debate within the Administration, the two agencies agreed on:

> 1) The run-out of Government cost for operating Landsats 4 and 5; plus 2) a maximum of $250 million of new budget authority for the commercial follow-on system .51

In August 1984, EOSAT submitted a revised proposal that included only two satellites, both using a Landsat-type sensor (TM), and which, among other things, assumed that the Government would continue its research program in advanced sensors, to support the transition to a more advanced system in the 199os. I n addition, EOSAT included an escape clause that allowed it to withdraw from the contract if sufficient market for data had not developed to support a commercial enterprise. Kodak Corp. declined to submit a revised proposal.

In mid-May 1985, the Department of Commerce announced that it had reached agreement with EOSAT to provide $250 million plus launch costs (a total subsidy of about $290 million). EOSAT agreed to build and launch two satellites whether or not the market has developed to support a profit-making business. An Administration request for $125 million ($75 million for fiscal year 1985 and $50 million for fiscal year 1986) to allow EOSAT to begin the process of building Landsat 6 has recently been sent to Congress for action .52

International Relevance of Landsat

Because the Landsat satellite travels in a polar orbit, which enables it to sense the entire surface of Earth, data from the system necessarily have international implications. Data from both the Landsat and metsat systems have served as constructive instruments of U.S. foreign relations, For example, these data have aided other countries to map, manage, and exploit their own resources; they have also raised the general level of awareness about growing environmental problems throughout the world.

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[51]" Report to the Congress (Public Law-98-365)," Department of Commerce, September 1984.

[52]EOSAT proposed an escape clause in the contract to allow for the possibility that, even with a vigorous marketing effort on its part, insufficient demand for data would develop.

Aircraft or balloons are clearly limited in overflight by national restrictions on sovereign airspace, but spacecraft have no overflight restrictions. According to international treaty, "Outer space . . . shall be free for exploration and use by all states."[53] This principle is understood by the United States and most other nations to mean that nations are free to place in orbit any satellite that does not violate other provisions of the 1967 Outer Space Treaty or other principles of international law. This understanding has been called the "open skies" principle; it is a fundamental principle of the U.S. space program. The United States supports this principle[54] in part by making civilian remote sensing data available on a nondiscriminatory basis to anyone who wishes to receive them. Through AID, NASA, and NOAA, the United States has been the principal force in setting up foreign regional and national centers capable of processing and interpreting Landsat data. By integrating these data with meteorological and/or ground data of all kinds, these centers aid developing countries coping with the enormous problems of environmental protection and resource management.

Although the private sector is technically capable (given adequate financial incentives) of providing the data promptly to meet the requirements of the Federal Government and other potential customers, commercial objectives may conflict with certain U.S. foreign policy objectives. **Constraints on a private firm that are sufficient to protect U.S. foreign policy objectives could well make such an enterprise unprofitable or require a large and continuing Government subsidy to make the enterprise viable.**

Equipment Market

In a manner similar to that for meteorological satellites, the market for land remote sensing equipment and services can be divided into three categories: the space component, ground station equipment, and services related to reception and data preprocessing (excluding the value-added industry discussed above).

Satellite Manufacturers

General Electric Corp. was the prime contractor for the Landsat 4 and 5 satellites, with Fairchild and Hughes Aircraft supplying significant components. If the transfer of the Landsat system to EOSAT is completed by appropriating the necessary subsidy, RCA and Hughes Aircraft Corp. (the two participants in EOSAT) will likely build most of the hardware (two satellites and associated system hardware), with other firms providing portions of it under contract.

The French firm Matra is the prime contractor for the SPOT satellite. Major subsystems and software are provided by Aerospatiale and SEP. The tape recorders are built by the U.S. corporation, Odetics, Inc.

Ground Stations and Receivers

Many of the same firms that manufacture components of ground stations and receivers for meteorological data reception also sell similar equipment for land remote sensing. The major differences are in the frequencies used for transmission and in the scale of investment for land remote sensing stations. There are now 12 operational Landsat receiving stations and 2 under construction. In addition, there are several SPOT receiving stations under construction. In the next 3 to 4 years, because of the advent of the SPOT system and the European ERS system (see section on ocean remote sensing) there could be as many as eight new receiving stations begun around the world. Several African countries, Iraq, Pakistan, and Saudia Arabia have expressed interest in building receiving stations. Each new station will cost between $10 million and $15 million. The balance of the market for ground stations, receivers, tape recorders, and the like will be in replacements and in upgrading some stations to receive X-Band transmissions from TM and from SPOT. For example, the Canadian Landsat receiving station in Prince Albert is being equipped to receive SPOT data. The Canadian firm MacDonald Dettwiler Association, inc. is providing the equipment for this station and the

[53] 1967 Outer Space Treaty. Because of the U.S. example, the nondiscriminatory data distribution policy is now of importance to other countries as well.

[54] John H. Gibbons, "International Implications of Transferring the Landsat System to the Private Sector, " hearing before the Subcommittee on Legislation and National Security of the Committee on Government Operations, Sept. 28, 1983.

SPOT receiving station in Ottawa. MBB of Germany and NEC of Japan also supply ground station equipment. Yearly international sales in ground receiving equipment may be as high as $30 million.

Issues

What International Issues Are Raised by Transfer to the Private Sector?

Congress and the Administration, in passing and signing into law Public Law 98-365, have agreed on the broad terms of transfer of the U.S. land remote sensing system to the private sector. Although the current attempts to effect such a transfer arose both from concern for reducing the Federal budget deficit and from the philosophical conviction that the private sector could provide those services more efficiently, the legislation also took into account the broader agenda of U.S. international relations. In general, the successful transfer of Government-developed technology to the private sector is a process that must take place over time, and with strong support from the potential foreign and domestic customers as well as from the policy makers.

As the process of transferring the Landsat system proceeds, it will be important to monitor the reactions of other countries to it, and to continue to approach each of the following issues with imagination and a sensitivity to the real or perceived concerns of other nations. Not only are the political sensitivities of other countries important to the United States, foreign customers are necessary to the financial viability of a private Landsat system.[55] In addition, the French SPOT system will soon offer customers an alternative choice of data sources.

The following discussion of international issues is summarized from the OTA Technical Memorandum, Remote Sensing *and the Private Sector: Issues for Discussion*:[56]

- **Data sales policies.** Landsat data have always been sold to all purchasers on a nondiscriminatory basis. In large part this policy was originally chosen to support the U.S. "open skies" policy and the use of space for peaceful purposes. In practice, selling data on a nondiscriminatory basis has helped to blunt criticism of other activities, such as the operation of classified surveillance satellites. It has also demonstrated U.S. adherence to the principle of the free flow of information. Although some private sector analysts* have argued that owners of remote sensing systems should be allowed to set their own data policies, Public Law 98-365 mandates the policy of nondiscriminatory sales, on the basis that **the open skies policy continues to be of importance to the United States.**
- **Value-added services.** Most of the revenue earned from space remote sensing will be earned by the companies that add value to the data by processing, analyzing, adding other information, and interpreting the primary data from space. The value-added companies constitute a small, but growing, specialized industry. The strength of commercial space remote sensing will depend on a strong value-added industry.[57] Most remote sensing system operators would want to participate in the value-added business.

  The availability of high resolution land remote sensing data *and the ability to analyze them* are potentially powerful tools for resource development. Many developing countries have expressed the concern that allowing the system operator to offer value-added services might give the seller too much power over the acquisition and distribution process. They are concerned that the company or favored customers could, by processing and interpreting these data before delivering them to others, obtain economic leverage over countries that lack their

[55] When projected foreign ground station fees are included in the estimates of future income from a land remote sensing system, foreign sales could constitute as much as 39 percent of the revenue from a U.S. system. See "Commercialization of the Land Remote Sensing System: An Examination of Mechanisms and Issues," ECON, Inc., Prepared for the U.S. Department of Commerce, contract No. NA-83-SAC-O0658.

[56] *Remote Sensing and the Private Sector: Issues for Discussion*, op. cit., ch. 3.

*Cf. Klaus Heiss, statement at hearing before the Subcommittee on Science, Technology, and Space of the Senate Committee on Commerce, Science, and Transportation, Mar. 22, 1984, pp. 83-88.

[57] Fred rick B. Henderson, II 1, "The Significance of a Strong Value-added Industry to the Successful Commercialization of Landsat," presented at the 21st Goddard Memorial Symposium, Mar. 24-25, 1983.

own facilities and personnel to interpret the data. **Therefore, in order to maintain good relations with developing countries, it may be appropriate for the United States to restrict the private data distributor from entering into the value-added business, or to regulate it closely to prevent such a company from exerting unfair economic leverage over others.** Here, foreign *perception* of economic harm may be as important as *actual* harm. As competition from foreign or other domestic systems grows, it would be possible to relax such restrictions.

Public Law 98-365 deals with this issue by requiring the firm to "notify the Secretary of any 'value-added' activities (as defined by the Secretary by regulation) that will be conducted by the licensee or by a subsidiary or affiliate" (Sec. 402(b)(6)). The terms of the Act assume that antitrust legislation is sufficient in most cases to deter the corporation from engaging in practices that would either inhibit competition from other U.S. firms or harm U.S. relationships with other nations. If additional legislation is required, as more experience is gained with private operation of land remote sensing, Congress could take remedial action.

- **U.S. cooperation with other countries.** The Landsat ground stations in 10 foreign countries constitute an eloquent statement of U.S. leadership in successfully applying high technology for the benefit of all mankind. The United States has also participated with industrialized and developing countries in research on applying Landsat data to critical resource and environmental needs. **It is essential for the continuing research and development of remote sensing technology, and the growth of the data market, for the United States to maintain its cooperative basic and applied research programs with other countries. [f the transfer is made, it will be particularly important to assure that appropriate Government funding is continued for imperative projects with developing countries.**
- **International legal issues.** Private ownership of the land remote sensing system could lead to suspicions that such data would be used to enable interests outside a sensed country to gain a competitive advantage in knowledge of minerals or other nonrenewable resources, or that information on crop conditions or military activities of states might be sold preferentially to political adversaries. Developing countries are particularly concerned about this possibility, because most lack the indigenous ability to analyze the data (see app. 7A). Some countries have maintained that they should have priority access to data derived from sensing their territory, while others have argued that their consent should be obtained before these data are transferred to third parties.

The United States has consistently opposed efforts to limit the distribution of Landsat data, arguing that remote sensing is a peaceful and beneficial use of space in which the restraints of national sovereignty have no valid application. Further, it has held that the free collection and dissemination of primary data and analyzed information is supported legally and encouraged by the 1967 Outer Space Treaty and article 19 of the U.N. Declaration of Human Rights. The U.S. policies of nondiscriminatory data sales and free flow of information have so far successfully deflected attempts to restrict the right to sense other countries and sell those data to third parties. Although attempts to restrict the flow of remotely sensed data and information are likely to continue in the U.N. and other international fora, the proliferation of civilian remote sensing systems will make it more difficult for such restrictions to gain ascendancy.

What Factors Are Most Important to Market Growth of Land Remote Sensing Data Products?

During its development, land remote sensing was treated as a technology that eventually "would create billions of dollars annually in benefits" to the public.[58] Actually, benefits of this magnitude have yet to materialize. To many, this departure from stated expectations suggests that

[58]"Commercialization of the Land Remote Sensing System: An Examination of Mechanics and Issues, " op. cit., p. 80,

the potential direct economic benefits of the Landsat program were oversold by some in its early days. In part, large public economic benefits have not followed from Landsat development because agencies have been slow to incorporate these data into their routine operations.[59] Government agencies have bought even less data in recent years than they did at first.

Clearly, although overall data sales have been low, the Landsat system still generates both public and private goods.[60] Data from the Landsat system have demonstrated to many domestic and foreign users, both inside and outside Government, that these data can be highly effective in meeting large-scale resource information needs.

As the policy section notes, transferring the Landsat system to the private sector may enhance this Nation's competitiveness in land remote sensing by employing industry's skills in marketing and innovation to increase the overall market for data and services. **However, without substantial Government subsidy for a land remote sensing enterprise, transfer in itself is not likely to result in a viable commercial business.**[61]

If the initial phase of the transfer process in which a private operator markets the data from Landsat 5 proves successful, it will still be necessary to evaluate progress toward a self-sustaining business. If Congress were to decide that sufficient progress had not been made, but the public good aspects were still high, it could still decide to operate a civilian system within the Government. **The most important single factor that will determine the viability of a commercial remote sensing enterprise is market growth.**

The development of the market for remote sensing data and services will depend on four major factors: the price, availability, utility of the data, and the ability of the information industry to develop cost-effective ways of processing and applying such data to the needs of users.

- **Data prices.** Even if it is possible to reduce dramatically the cost of the system's space segment, the costs of handling and correcting the raw data are likely to remain high in the near term because, with current data processing technology, labor costs are a significant proportion of the overall expense of producing corrected Landsat data. Technological advances in large-scale data processing, storage, and retrieval could reduce such costs. Customers for primary data complain that dramatic increases in data prices would reduce their ability to purchase data in the quantities that would be most effective.[62] Figures on data purchases from the EROS Data Center bear out their concerns. In October 1982, the beginning of fiscal year 1983, NOAA increased the price of data dramatically (table 7-5). For example, the price for an MSS computer compatible tape (CCT) increased 325 percent, from $200 to $650. Knowing the price increase was coming, customers purchased more data in the last half of 1982 than they would have otherwise (fig. 7-1 7). Although income from data sales increased in fiscal year 1983, the number of MSS scenes purchased fell to 33 percent of fiscal year 1982 sales (table 7-10). Sales figures for fiscal year 1984 confirm the overall downturn in data sales. Overall income from sales has increased dramatically, however, because OMB has required each agency to account for its data receipts,[63] and because NOAA has instituted special acquisition charges for cloud-free images or other nonstandard requests. In fiscal year 1983, special acquisition charges amounted to about $4 million, or 58 percent of the total income from data sales. In fiscal year 1984, special acquisition charges were $6,130,275 or 62 percent of total Landsat data income.
- **Availability of data.** Customers cite two concerns over-the availability of data: 1) data are

[59] See for example, *Remote Sensing and the Private Sector,* ch. 5.

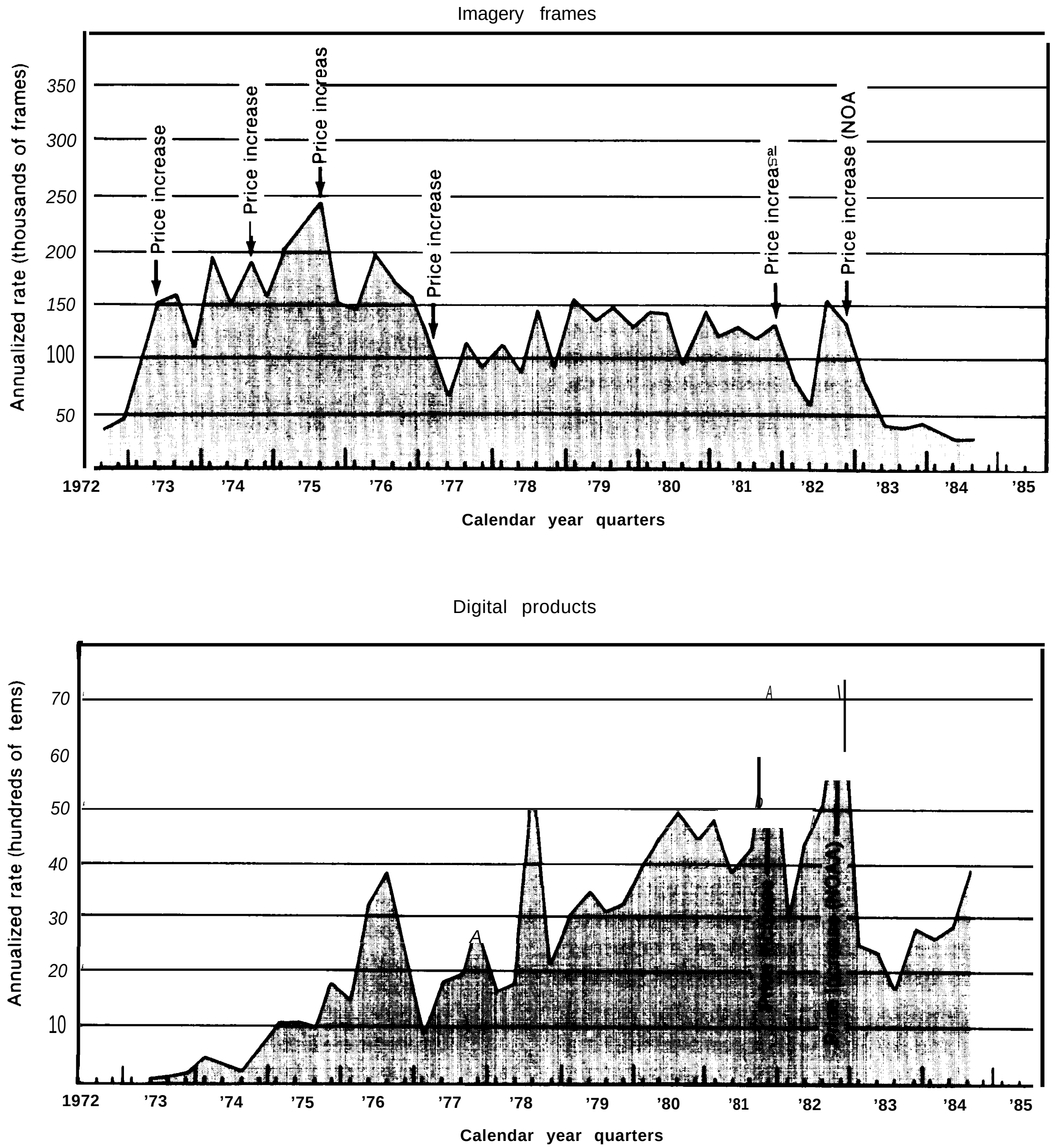
[60] *Remote Sensing and the Private Sector,* ch. 4.

[61] Although OTA has not done a detailed analysis of costs associated with developing a land remote sensing system, it appears that a subsidy (including launch costs) between $35o million and $500 million (depending on the financial risk the private firm is willing to assume) might be needed to reduce the risk of commercial failure to an acceptable level. See also *Remote Sensing and the Private Sector,* op. cit., ch. 1.

[62] See testimony in "Civil Land Remote Sensing Systems, " Joint Hearings before the House Subcommittee on Space Science and Applications of the Committee on Science and Technology, and the Senate Subcommittee on Science, Technology, and Space Committee on Commerce, Science, and Transportation, July 22, 23, 1981.

[63] The Foreign Agriculture] Service, for example, Was receiving data directly from NASA through a receiver in Houston.

Figure 7-17.—Sale of Landsat Imagery Frames and Digital Products (shipped sales)



SOURCE: National Oceanic and Atmospheric Administration.

Table 7=10.—Customer Profile of Landsat Total Data

Customer category	FY 1973[a]				FY 1974[a]				FY 1975			
	Items	Item (o/o)	Dollars	Dollar (o/o)	Items	Item (o/o)	Dollars	Dollar (o/o)	Items	Item (o/o)	Dollars	Dollar (o/o)
Federal Government (less N.1.'s)	21,780	27°~	62,756	270/o	28,493	180/0	87,156	160/0	34,346	17"!0	169,283	19 "/0
NASA investigators	—	—	—	—	—	—	—	—	5,456	3%	15,992	2%
State/local government	2,995	4%	10,639	5%	2,534	2%	10,920	2%	1,969	1%	16,988	2%
Academic	13,071	160/0	28,679	13 "/0	18,611	12 "/0	63,964	12 "/0	27,727	14 "/0	142,054	160/0
Industrial	24,430	30%0	67,360	30 "/0	35,890	230/o	114,140	22%0	45,671	230/o	219,704	240/o
Individuals	5,109	60/0	17,143	7%	17,266	11 "/0	67,127	13 "/0	18,643	9%	100,953	11 "/0
Non-U.S.	8,497	**11%**	28,154	12 "/0	37,038	230/o	120,499	230/o	47,174	240/o	174,659	19 "/0
Non-identified	5,189	6%	13,311	6%	17,346	11 "/0	64,708	12%	17,397	9%	69,376	7%
Total data	81.071	100 "/0	228,042	100 "/0	157,178	IOO%	528,514	100 "/0	198.383	IOO%	909,009	100 "/0

Customer category	FY 1976				TQ 1976				FY 1977			
	Items	Item (o/o)	Dollars	Dollar (o/o)	Items	Item (o/o)	Dollars	Dollar (o/o)	Items	Item (o/o)	Dollars	Dollar (o/o)
Federal Government (less N.1.'s)	31,645	13%	253,166	15 "/0	7,771	15%	73,436	16%	21,074	16%	269,825	19%
NASA investigators	63,329	250/o	341,056	21 "/0	5,730	11 "/0	48,111	**11 "/0**	9,827	7%	96,032	7%
State/local government	1,214	10%	8,191	00/0	149	0%	1,168	0%	1,360	1%	20,168	1 5
Academic	26,077	11 "/0	178,160	11 "/0	8,489	160/0	40,129	9%	14,063	**11 "/0**	141,077	10 "/0
Industrial	42,833	17 "/0	322,699	20 "/0	12,122	240/o	121,025	270/o	36,979	280/o	412,183	280/o
Individuals	18,052	7%	141,556	9%	3,755	7%	28,683	60/0	8,003	60/0	72,129	5%
Non-U.S.	65,100	26%	391,673	240/o	13,702	27%	138,632	31 "/0	40,632	31"!0	442,079	30%
Non-identified	488	0%	4,892	0%	96	0%	1,087	0%	49	0%	344	0%
Total data	248,738	1000/o	1,641,393	100 "/0	51,814	1000/o	452,271	100 "/0	131,271	100 "/0	1,453,837	100 "/0

Table 7-10.—Customer Profile of Landsat Total Data—Continued

Customer category	FY 1978 Items	Item (%)	Dollars	Dollar %	FY 1979 Items	Item (%)	Dollars	Dollar (%)	FY 1980 Items	Item (%)	Dollars	Dollar %
Federal Government (less N.I.'s)	28,020	25%	597,269	30%	3',692	24%	501,214	23%	25,919	19%	392,591	16%
NASA investigators	522	0%	13,431	1%	0	0%	0	0%	0	0%	0	0%
State/local government	1,515	1%	31,557	1%	968	0%	19,281	1%	4,225	3%	78,327	3%
Academic	10,222	9%	159,379	8%	14,742	11%	235,231	11%	12,977	10%	202,401	9%
Industrial	21,321	19%	469,924	24%	25,903	19%	508,792	24%	24,723	19%	614,400	26%
Individuals	5,537	5%	73,808	4%	9,247	7%	102,854	5%	8,147	6%	96,982	4%
Non-U.S.	46,409	41%	630,700	32%	53,912	39%	764,441	36%	56,581	43%	1,003,866	42%
Total data	113,576	100%	1,976,068	100%	137,464	100%	2,131,813	100%	132,572	100%	2,388,567	00%

Customer category	FY 1981 Items	Item (%)	Dollars	Dollar (%)	FY 198 Items	Item (%)	Dollars	Dollar (%)	FY 1983 Items	Item (%)	Dollars	Dollar (%)
Federal Government (less N.I.'s)	29,177	22%	481,067	19%	24,000	20%	571,807	20%	29,804[b]	47%	5,269,741[b]	75%
State/local governmer +	3,470	3%	107,667	4%	5,251	4%	146,897	5%	1,268	2%	70,263	1%
Academic	11,401	9%	198,611	8%	7,753	7%	201,577	7%	2,536	4%	210,790	3%
Industrial	29,821	22%	758,245	31%	23,078	19%	924,540	31%	6,341	10%	632,369	9%
Individuals	9,292	7%	117,642	5%	5,953	5%	126,565	4%	1,902	3%	70,263	1%
Non-U.S.	49,965	37%	832,036	33%	53,964	45%	969,893	33%	21,560	34%	772,895	11%
Total data	133,126	100%	2,495,268	[illegible]	9,999	100%	2,94 ,279	100%	63, 1	100%	7,026,895	100%

Customer category	FY 1984 Items	Item (%)	Dollars	Dollar (%)
Federal Government (less N.I.'s)	16,017	42%	1,696,710	45%
State/local government	1,222	3%	122,163	3%
Academic	2,578	7%	181,433	5%
Industry	8,213	22%	985,362	26%
Individual	1,848	5%	84,498	2%
Non-U.S.	8,128	21%	741,962	19%
Total data	38,006	100%	81 128	100%

for 1973 and 1974 (minimal data).

not delivered promptly, (the shortest period between acquisition and delivery from the EROS Data Center is about 2 weeks); and 2) the likelihood of a gap in delivery of data between the demise of Landsat 5 and the deployment of a follow-on satellite.[64] In part because the Landsat system was treated as an R&D system and declared operational only in 1983, insufficient funding and planning effort was devoted to assuring that customers received data in a timely, continuous manner. This has inhibited full development of those segments of the market (primarily agriculture and other nonrenewable resource management areas) that rely on rapid receipt of the data. Potential users have also been discouraged by the possibility that data from Landsat or a similar U.S. system may not be available in the future.

Until recently, the cost of manipulating data and adding value to them has been high because they have required large, expensive computers and peripheral equipment. Potential customers from all segments of the user community are reluctant to invest in the necessary sophisticated hardware and software as long as the data supply is uncertain.

- **Utility of data.** The value-added industry consists of a diverse set of service companies or departments of larger (discipline-oriented) industries (e. g., petroleum, mineral, or forestry firms) that take the corrected spacecraft data, manipulate them, and integrate them with other data to create useful sets of information, in the form of maps, tables, or graphs. They are properly considered part of the overall information industry.[65] Information derived from this process may, for example, indicate to the exploration geologist where ground tests for particular forms of minerals should be made, or to the agricultural planner what the extent of weather-related stress to a particular crop is likely to be. In addition to the profit-making enterprises that process land remote sensing data, a variety of nonprofit data users also process data for information content. These include universities, State and local governments, and several Federal agencies.

In order for the market for data to increase to the point that it will sustain a self-supporting business, potential customers will have to become convinced of the utility (based on price, availability, and convenience) of data for their needs. Although users in many different fields have experimented (with NASA's help) with the data and written much about their utility, the message has not yet reached the sort of customers needed to sustain a self-supporting business. Unlike most current users, who are conversant with manipulating data on mainframe computers and who have experimented with satellite data, potential customers are more interested in information and "services which directly address their information needs.[66] They are not customers for Landsat data per se, but for the information derived from linking Landsat data with other resource data. As such they are not unlike the majority of customers for personal computers—individuals who are uninterested in writing their own programs and will only purchase a computer if they can also purchase simple, "user--friendly" software that will meet their needs without modification and with little additional instruction.

For example, as one study has noted, the need to manage and exploit the world's renewable resources more effectively will require "more complete and timely information about soil conditions, crop acreage and yields, water availability, meteorology, and other factors that could benefit or deter resource production . . . the farmer, and the government official, and everyone in between is a potential customer for resource information."[67] At present, the primary customer for Landsat data related to agriculture is the Federal Government, which has a stake in U.S. agricultural productivity. How-

64 *Remote Sensing and the Private Sector,* ch. 4.

65 Donn C. Walklet, "Remote Sensing Commercialization: Views of the Investment Community, " ERIM Conference, May 9-13, 1983.

66 "Markets for Remote Sensing Data 1980-2000," Terra-Mar, Study for TRW Defense and Space Systems Group, contract No. M624770C2M, November 1982.

67 "Markets for Remote Sensing Data 1980-2000," op. cit.

ever, the agricultural industry also includes producers, processors, and merchandisers, banks, and brokers; only a few of these companies are now customers of land remote sensing data (table 7-11). As one report observed, the agricultural industry is highly competitive. Inexpensive and timely information about the status of crops would be well received[68] by all elements of that community. Unprocessed data will find little use by these potential customers.

Processing improvements. Inexpensive data processing is only one component in the list of factors that affect market growth, yet it could be more important than the price of data. The cost of adding value to a CCT* can today far exceed the price of a CCT. Typically, value-added services applied to a single CCT may range from 100 to 300 percent of the price of unprocessed data depending on the complexity of the service desired. If it is eventually possible to purchase particular portions of a CCT, rather than an entire scene,[69] the need for large computers to process these data will decrease. Already, it is possible to purchase a minicomputer system for processing Landsat data for about $50,000. In the near future, it will be possible for data users to make more effective use of microcomputers and thereby to decrease the cost of an in-house value-added system to the order of $20,000 to $25,000.[70] Although not as efficient as the mainframe computers, such systems put the price of using Landsat data for specific applications within the range of relatively small companies.

One of the reasons the market for Landsat data has not developed more quickly is that potential customers need primary data with a wide variety of different basic characteristics (spatial and spectral resolution, number of spectral bands, coverage area) delivered over widely different timeframes. Until the thematic mapper (TM) was developed, the data's spatial resolution and number of spectral bands were limited to the capabil-

[68] Ibid.
[69] Many data users find that they need only part of a given scene. As the data become more widely used by customers interested primarily in small geographical areas, the demand for smaller parts of a scene will likely increase. It is now possible to purchase quarter-scenes of TM data from EDC.
*Computer-compatible tape.

[70] Such a system would include at least a microcomputer with hard disk storage of 10 megabytes ($5,000 or less), an image processor and associated computer software ($1 5,000). Additional items, such as the software to work with a geographic information system, could raise the total to $25,0(X).

Table 7-il.—Agribusiness Industry Structure Analysis

Producers:	
Individual farmers	
Farm cooperatives:	***International Agribusiness Banks?***
Farmland Industries, Inc.	Bank of America[b]
	Citibank
Processors:	
Combined Function Companies:	***Agribusiness Brokers?***
Pillsbury	Merrill Lynch
Quaker	Conticommodity Services[c]
Ralston-Purina	
Merchandisers:	
International Grain Companies:[d]	
Cargill	
Bunge	
Dreyfus	
Continental Grain	

[a] Banks and brokers interact with all three industry segments.
[b] Bank of America consistently maintains the largest share of agribusiness lending in the world.
[c] Conticommodity is a subsidiary of Continental Grain.
[d] International grain trading is dominated by these four companies with Cargill representing by far the greatest influence within the industry,

SOURCE: Terra-Mar.

This table illustrates the variety of possible consumers of information from a single business area. Similar tables could be drawn for other business that depend on information about natural resources, whether renewable or nonrenewable.

ity of the MSS sensor. The speed of correcting and delivering the data has also been limited, If the market for primary data is to grow substantially, the system's owner will have to deliver data useful for a broad range of applications, and the value-added industry will have to develop a wide variety of inexpensive data products. At present, although some users can utilize the higher capabilities of the TM data, most cannot.[71] In other words, as argued above, the data will have to interest a broader category of users than they now do.

Issues for the Future

It is evident from the earlier summary of foreign systems that other countries, building on the experience gained from U.S. applications technology as well as on their own capabilities, see the development of the full range of remote-sensing satellites as an integral part of their entry into space. In addition to constructing systems that will be competitive with the U.S. Landsat system, they are also engaged in extensive research on how to apply the data.

- **Private sector efforts.** The success of the private sector in developing a competitive remote sensing system may well depend on the strength and longevity of Government support. Such support could consist of one or more of the following: a direct subsidy, such as has been authorized in Public Law 98-365, support in the form of a guaranteed annual Government purchase of data (specifically prohibited in Public Law 98-365), tax benefits, and/or in continued Government research. Although NASA has a program to develop a variety of advanced sensors that would be tested on the relatively short Shuttle missions, the Government has announced no plans to develop civilian operational systems that would provide data over the long term with repeat coverage. It will rely primarily on the private sector to develop and maintain a land remote sensing system. Thus, to obtain certain important civilian data, the Government may have to rely on foreign systems. In the absence of strong Government support for a private system, the private sector would be left to compete directly with foreign government-funded enterprises to sell data.
- **Remote sensing research.** An important aspect of maintaining leadership in land remote sensing is the continuation of research on applying remotely sensed data to resource discovery, analysis, and management. University land remote sensing research is at a low ebb in this country,[72] in large part because Federal research funds have dried up prematurely. If the market for land remote sensing data were strong, research funding for applications would likely be forthcoming from the private sector in support of its needs. However, the lack of high demand for data, caused in part by the uncertainty over whether land remote sensing activities will continue, has led to reduced private funding for applications research. Neither NASA nor NOAA now have strong land remote sensing research programs, although the Land Remote Sensing Commercialization Act of 1984 authorizes both agencies to continue such research. It is clear, however, that successful commercialization will depend on developing a large variety of methods to turn remotely sensed data, especially the high-resolution TM data, into useful information. The decline in U.S. research has taken place at the same time that other nations are developing new remote sensing systems and increasing their research funding on remote-sensing applications. These nations are building on the substantial investment that the United States has already made in remote sensing applications.

[71] For a discussion of using TM data effectively, see *Remote Sensing and the Private Sector,* op. cit., pp. 62-65.

[72] See, for example, *Remote Sensing and the Private Sector,* op. cit., pp. 60-61, app. C.

OCEAN REMOTE SENSING

Observations from space devoted specifically to understanding ocean phenomena were first made visually and photographically by the Mercury program astronauts in the 1960s. Later, infrared radiometers incorporated on the meteorological satellites provided considerable ocean data that were later supplemented by data from a microwave instrument aboard Skylab in 1973. In 1978, NASA launched Seasat, the first dedicated ocean remote sensing satellite, which demonstrated the feasibility of using microwave sensors aboard a spacecraft. Although it failed prematurely, the experimental Seasat returned massive amounts of highly useful data to scientists (table 7-1 2) and demonstrated that a dedicated oceanographic satellite would serve the needs of commercial and scientific interests and Government agencies.

Because the ocean environment is constantly changing and potentially dangerous, its behavior is of considerable importance to all countries that border on the oceans, and especially to those that maintain large commercial or military fleets. Whether they are primarily concerned about activities within the 200-mile economic zones or have a wider interest in the oceans, all of these countries would benefit from data derived from space-based ocean observations delivered promptly and continuously.

A few countries, notably Canada, Japan, and the European nations (under the auspices of the European Space Agency) are now planning civilian satellite systems specifically dedicated to ocean observations. The Soviet Union has flown several dedicated civilian-military oceanographic satellites. In the United States a joint civilian-military National Oceanic Satellite System (NOSS) was proposed for launch in 1986[73] but was canceled when projected program costs rose to more

[73] *Technology and oceanography,* **U.S.** Congress, Office of Technology Assessment (Washington, DC: OTA-O-1 **41, June 1981).**

Table 7=12.—Geophysical Oceanographic Measurement Design Capabilities for Seasat-A

	Measurement	Sensor	Range	Precision /accuracy	Resolution, km
Topography	Geoid	Altimeter	5cm-200m	* 20cm	1.6-12
	Currents, surges, etc.		IOcm-10m		
Surface winds	Amplitude	Microwave radiometer	7-50mls	~ 2m/s OR A 10°/0	*50*
		Scatterometer	3-25m's	* 2m/s OH 1070	*50*
	Direction		0-360°	* 2(30	
Gravity waves	**Height**	**Altimeter**	**0.5-25m**	**& 0.5 TO 1.Om OR& lo~o**	**1.6-12**
	Length	**Imaging radar**	**50-100m**	*** 100/0**	**50m**
	Direct Ion		**0-360°**	*** 15%**	
Surface temperature	Relative	V & IR radiometer	-2-35° C	1 .5°	- 5
	Absolute		Clear weather	2°	
	Relative	Microwave radiometer	-2-35° C	1°	100
	Absolute		All weather	1.5°	
Sea ice	Extent	V & IR radiometer		- 5km	- 5
		Microwave radiometer		10-1 5km	10-15
		Imaging radar		* 25m	25m
	Leads		50m	* 25m	25m
	Icebergs		25m	* 25m	25m
Ocean features	Shores, clouds islands	V & IR radiometer		7 !jkm	- 5
	Shoals, currents	Imaging radar		* 25m	25m
Atmospheric corrections	Water vapor & liquid	Microwave radiometer		~ 25m	50

SOURCE: National Oceanic and Atmospheric Administration than three-quarters of a billion dollars. No civilian operational ocean satellite is now planned, but the U.S. Navy is developing the Navy Remote Ocean Sensing Satellite (N-ROSS) for Jaunch in 1989. NASA is planning a research satellite (TOPEX/POSEIDON), with French participation, to measure ocean topography.

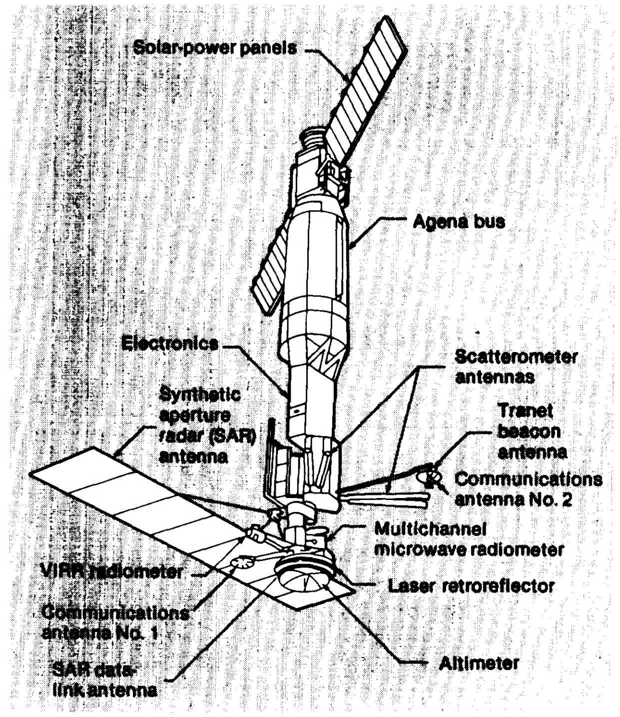
This section briefly summarizes the status of ocean observations from space and explores the international issues related to ocean remote sensing.

U.S. Oceanographic Systems

The technologies necessary for the complement of instruments required for an operational ocean remote sensing system are available and have been tested on a variety of U.S. satellites.

- **Seasat—1978.** Built by NASA to explore the utility of a satellite devoted to measuring ocean dynamics and topography, Seasat (fig. 7-1 8) lasted only 3 months. However, it returned data of considerable scientific and operational use.
- **Nimbus—1%4-85.** The Nimbus series of research satellites were designed by NASA to test new sensors for generating ocean and meteorological data and to collect data of scientific interest. Nimbus-7, the latest in the series, which was launched in 1978, is still operating. It carries a Scanning Multichannel Microwave Radiometer (SMMR) that provides measurements of sea surface temperatures, and a Coastal Zone Color Scanner (CZCS) that provides a measure of biological productivity of the ocean.
- TOPEX/POSEI DON —1990. NASA has proposed to operate, in a joint U.S./French project, a research satellite devoted primarily to highly accurate measurements (to an accuracy of about 2.0 centimeters) of the height of the oceans. The satellite would also carry a microwave radiometer in order to correct for the effects of water vapor in the atmosphere, France would supply a solid-state altimeter and a radiometric tracking system. The altitude of the ocean is crucial to understanding patterns of ocean circulation. The satellite's orbit would allow determination of ocean topography from latitudes 630 north to 630 south. Accurate altitude measurements could lead to better understanding of ocean topography and dynamics, tides, sea ice position, climate and seafloor topography, among other ocean-related qualities.[74] TOPEX is planned as a new start for fiscal year 1987 and would be in orbit from 1990 to 1993 or later. This schedule would allow altitude data to be gathered at the same time N-ROSS (U.S. Navy) and ERS-1 (ESA), which would fly similar orbits, would be sensing data on other ocean parameters. ERS-1 would generate topography data of lower accuracy but it would reach higher latitudes than TOPEX. Together, data from the two satellites would provide considerably more information on ocean topography than either satellite could alone.

Figure 7-18.—The Seasat-A Spacecraft



SOURCE: National Aeronautics and Space Administration.

[74]" Satellite Altimetric Measurements of the Ocean," Report of the TOPEX Science Working Group, NASA, JPL 1981; Richard Fifield, "The Shape of Earth from Space, " New *Scientist,* Nov. 15, 1984, pp. 46-50.

[page omitted]

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- **Metsats.** The operational meteorological satellites, including the DOD DMSP satellites, have carried instruments that measure ocean parameters of interest to those who study, use, explore, and exploit the oceans' resources. Table 7-13 lists the measurements from satellites that are of particular utility to oceanic concerns.
- Navy Remote **Ocean Sensing System (N-ROSS).** N-ROSS is under development by the Navy; as currently configured, the system would employ one satellite (fig. 7-19) deployed in polar orbit, having a design life of 3 to 4 years. Although it is designed to sense parameters of direct interest to the operational needs of the Navy (tables *7-14* and 7-1 5), the data it returns will also benefit civilian users of the ocean. NOAA plans to collect and distribute these data (except for certain classified information) to the civilian community.

Foreign Systems

- **Japan Marine Observation Satellite-1 (MOS-1)-1986.** MOS-1 will carry sensors capable of resolving objects 50 meters across in three visible and one infrared (IR) wavelength bands. It will also carry a microwave scanning radiometer and a variable-resolution radiometer (900 to 2,700 meters) with one visible and three thermal IR bands. Although this satellite is being developed primarily for ocean sensing of wave heights, ocean color, and temperature, these data will also be useful for land remote sensing. Japan is also planning a land remote-sensing satellite (ERS-1), which it expects to launch by 1990. It will carry a synthetic aperture radar. It has not yet announced plans for distributing or selling data from MOS-1 or ERS-1.
- **European Space Agency (ESA) Remote Sensing Satellite (E RS-l)—1987/88.**[75] This satellite is planned primarily for passive microwave sensing of the coastal oceans and weather over the oceans. In addition, it will carry a synthetic aperture radar for active microwave sensing of ice topography or land masses through any cloud cover. However, because of inherent limits of available power aboard the spacecraft, its use over the Arctic regions

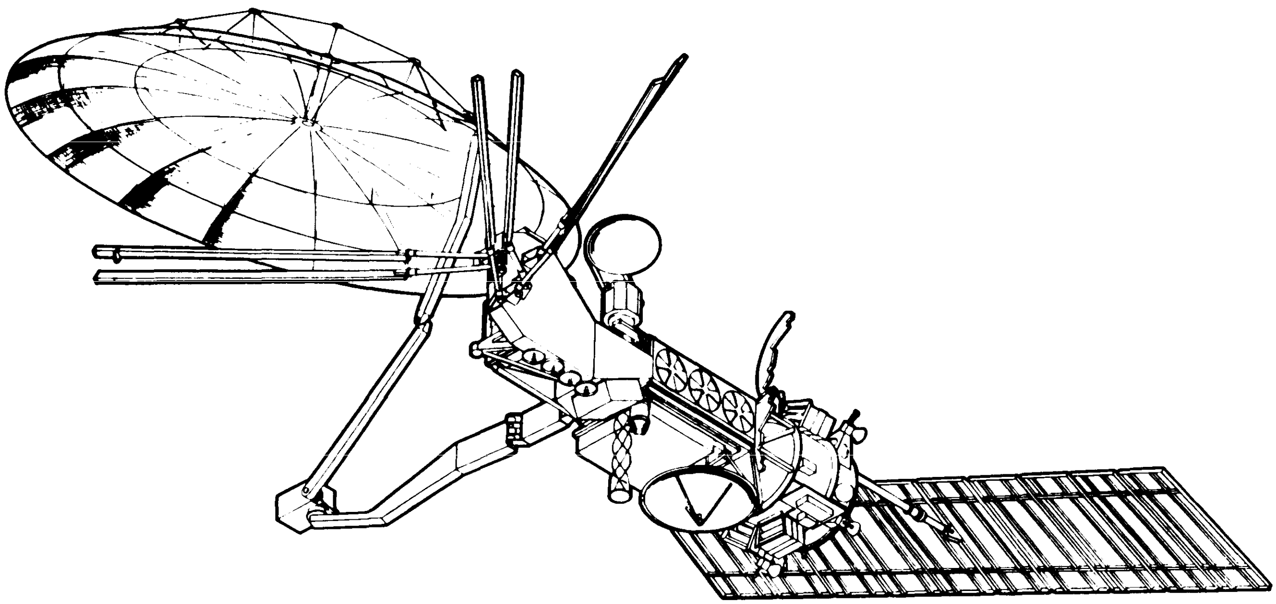
[75] A. Haskell, "The ERS-1 Programme of the European Space Agency," *ESA Journal, vol. 7, 1983,* pp. 1-14.

Table 7-13.—Measurement Needs for Oceanographic Satellites

Measurement			Range	Precision accuracy	Resolution	Spacial grid	Temporal grid
Topography	Geoid		5cm-200m	* 10 cm	IOkm	—	Weekly to monthly
	Currents, surges, etc.		IOcm-10m 5-500cm/s	Y 1 Ocm a 5cm/s	10-1 OOOm	IOkm	Twice a day to weekly
Surface winds	Amplitude	Open ocean	3-50mLs	& 1 TO 2m/s OR A 10%	10-50km	50-100km	2-81d
		Closed sea			5-25km	25km	
		Coastal			I-5km	5km	Hourly
	Direction		0-360°	~ 1 ().200	—	—	—
Gravity waves	Height		0.5-20m	& 0.5m	20km	50km	2-81d
	Length		6-1 ,000m	OR ~ 1o.25y0 ~ 10.250/o	3-50m		2-4/d
	Direction		0-360°	* 10-300			
Surface temperature	Open sea		–2-35°C	0.1-2 'relative 3.5-2° absolute	25-100km	IOOkm	Daily to weekly with spectrum of times of day and times of year
	Closed sea				5-25km	25km	
	Coastal				0.1-5km	5km	
Sea ice	Extent and age		6 me.— yrs.	I-5km	I-5km	I-5km	weekly
	Leads		50cm	25m	25m	25m	2-4/d
	Icebergs		IOcm	I-50m	I-50m	25m	—

SOURCE National Ocean(c and Atmospheric Admlnlstratlon

Figure 7-19.—Navy Remote Ocean Sensing Satellite (N-Ross)



SOURCE: U.S. Navy.

Table 7-14 N-ROSS Sensor Capabilities

Sensor	Parameter measured	Capability	Heritage
Scatterometer	Wind speed Wind direction	1.3 M/S (range 4-26 MIS) 16°	Modified from Seasat; improved wind direction
Altimeter	Altitude Significant waveheight (H 1/3) Wind speed	8 cm (when H 1/3 s5M) 0.5 m 2 MIS	Same as GEOSAT altimeter
Microwave Imager (SSM/I)[b].	Surface wind speed	*2 MIS (25 km resolution)	DMSP instrument; high frequency for ice
	Ice edge	t 12.5 km (25 km resolution)	Edge better than Seasat
	Precipitation	*5 mmlhr (25 km resolution)	SMMR
Low Frequency Microwave Radiometer (LFMR)[c d].	Sea surface temperature	1.0" 2.5 km resolution	New device with higher resolution than SMMR

[a]Seasat type sensor.
bAFlpJavy DMSP sensor.
[c]New sensor.
dD ua j Frequency Sensor (5 and 10 GHz) to be flown as a companion sensor to the SSM/I.

SOURCE: RCA Astro-Electronics.

may be limited. It is the first of a planned series of three satellites to be launched by ESA. It is not yet clear how data from this satellite are to be distributed to other countries (see issues section below).

Canada Radarsat—1990. Under development by Canada for routine observations of polar sea ice, as well as assessments of Canada's natural resources, the satellite will provide C-band radar images of Earth's surface. Its primary sensor will be capable of being pointed and will have a spatial resolution of about 30 meters. Because it will operate at microwave frequencies, it will be able to gather information on the surface of Earth through cloud cover. Data from this satel-

Table 7-15.—Oceanographic Data Tactical Operations

Data/Instrument	Oceanographic Product	Fleet Tactical Applications
Sea Surface Winds/(Scatterometer, Altimeter, Microwave Imager)	Sea Surface Wind Field Analysis	Flight Forecasting Ship Routing Wave and Surf Forecasting: • Amphibious Operations • Swimmer OPS • Underway Replenishment Cruise Missile Support Surface Ambient Noise (ASW) Radar and ECM Range Predictions
Sea Surface Temp.l(Low frequency microwave radiometer)	Ocean Thermal Structure Analysis Map of Fronts and Eddies	Location of Potential Hiding Places For Submarines (Friendly and Unfriendly) ASW Suppo~: c Sonar Range Predictions • Weapons Settings Q Sonobuoy Spacing • Sonar Tow Depths Acoustic Routing of Surface Ships and Submarine
Ice/(Microwave Imager)	Polar Ice Field Analysis	Submarine Surfacing information Navigation Information

SOURCE' RCA Astro-Electronics.

lite will be available for direct sale or by arrangement through offset programs. In order to reduce its costs, Canada is seeking partners in this venture. The spacecraft will also carry a NASA scatterometer and an optical sensor built either in the United States or Europe.

- U.S.S.R. Oceanographic Satellites Kosmos 1500 (1983) and Kosmos 1602 (1984).[76] In addition to a low-resolution scanner and a microwave radiometer, Kosmos 1500 carried a side-looking radar that was used to assist Soviet merchant ships trapped in the ice in the Chukchi and East Siberian Seas.[77] Kosmos 1602 presumably carries a similar complement of instruments. Analysis of data received from these satellites indicates quality comparable to that of the U.S. Seasat.

Major Ocean Parameters of Interest for Scientific and Applied Uses

A satellite specifically designed for ocean applications should produce timely, synoptic data of extreme usefulness to researchers, to private enterprise, and to governments.

The following selection of major ocean attributes indicates some parameters that satellites could measure successfully.

Sea Surface Temperature

Data on sea surface temperatures, gathered by the infrared radiometers aboard the meteorological spacecraft, have been available for two decades. The maps of sea surface temperatures produced from these data demonstrate complex surface temperature patterns that have led to considerable speculation about the physical processes that might cause such patterns. Because they reflect only surface effects (1 millimeter or less) these data alone are of limited use in understanding the physical processes of the deeper layers of the ocean. Yet, higher resolution meas-

[76] Nicholas L. Johnson, "The Soviet Year in Space: 1984, " Teledyne Brown Engineering, 1985, p. 28.
[77] V. Shmyganoviskiy, "A Space Pilot for the Nuclear-Powered Icebreakers, " *Izvestiya,* Moscow, Nov. 6, 1983, p. 6; *TASS,* Moscow, 23 Jan. 1984; "Soviet Cosmos Spacecraft Providing Lane, Sea Imagery,'' *Aviation Week and Space Technology, Nov.* 12, 1984, pp. 212-213.

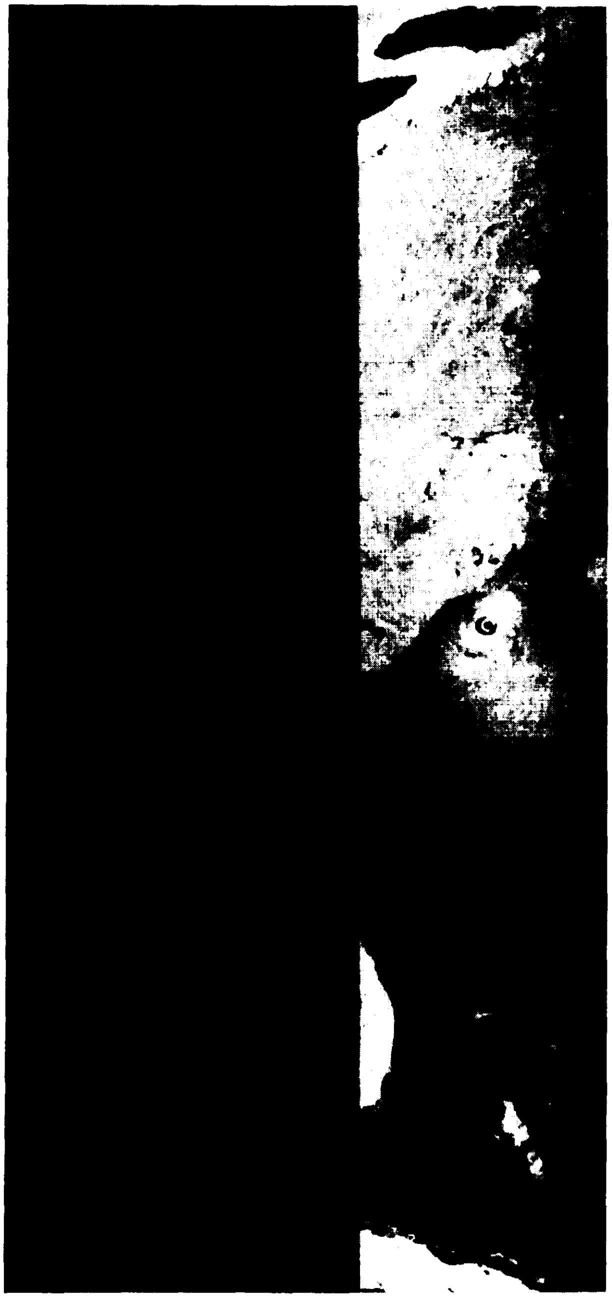


Photo credit: U.S.S.R. Hydromet Office

Images of hurricane Diane off the coast of North Carolina received from the Soviet Cosmos-1500 satellite (Sept. 11, 1984). The lefthand image is from a multichannel scanner. The righthand one is from a side-looking radar operating at 3 cm wavelength. They were given to NESDIS by engineers at Hydomet in Moscow.

urements of water temperatures at the surface, coupled with observations of surface winds and estimates of evaporation and rainfall, would provide better information on heat transport of the oceans.[78] In addition to their scientific interest for climatological studies, many of these physical processes are of interest to the users of the ocean.

Ocean Color

The polar-orbiting satellite Nimbus-7, launched in 1978, carries a Coastal Zone Color Scanner (CZCS), which measures spectral radiance from ocean waters in thermal, near-infrared, and four visible wavelength bands. Among other considerations, the optical bands were selected according to the optical properties of chlorophyll. The infrared bands provide data on coastal and ocean current temperature. Although no operational sensor is now funded, experiments with the CZCS aboard Nimbus-7 have demonstrated[79] that the data from such a sensor are potentially of considerable utility in locating areas of fish abundance, A recent report[80] urged the development of an Ocean Color Imager to start in fiscal year 1987. Such a satellite would yield important scientific information on understanding biological productivity in the oceans.

Sea Ice

Whether from concern for locating and tracking icebergs as they cross shipping lanes, or from desire to understand the direction of ice type, extent, and drift in polar regions, interest in the distribution and condition of sea ice has increased in recent years (table 7-16).[81] Visual observations of sea ice are now collected by the Multispectral Scanner (MSS) and Thematic Mapper (TM) sensors aboard Landsat 5 and by the Very High

[78] Brethaton Francis P., "Climate, the Oceans and Remote Sensing," *Oceans 24, No. 3,* pp. 48-55, 1981.

[79] "The Marine Resources Experiment Program, (MAREX)," Report of the Ocean Color Science Working Group, NASA-Goddard Space Flight Center, December 1982.

[80] "Oceanography From Space: A Research Strategy for the Decade 1985-1 995, " Report of the Joint Oceanographic Institutions, Washington, DC. 1984.

[81] W. F. Weeks, "Sea Ice: The Potential of Remote Sensing," *Oceanus 24, No. 3,* pp. 39-47, 1981.

Table 7-16.—Ice Parameters of Importance in Different Operations and Research Areas

Area of interest	Pertinent ice parameters[a]
Offshore operations. . . .	Extent, type, thickness, drift velocity, internal stress, properties (air temperature, atmospheric pressure, wind velocity, current velocity)
Climate	Extent, thickness
Albedo ... , ...	Extent, type, snow cover
Insulation	Type, thickness, *snow* cover (air temperature, wind veloclty)
Latent heat export . . .	Thickness, drift velocity
Surface stress	Drift velocity, top and bottom ice roughness (wind velocity, current velocity)
Ocean mixed layer. ... ,	Ice growth and ablatlon rates, drift velocity (current veloclty, water-column stabllity)

[a]The parameters In parentheses are also important, although they are not directly related to Ice.

SOURCE: W. F. Weeks, "Sea Ice: The Potential of Remote Sensing," Oceanus 24, No. 3, 19S1, p. 41.

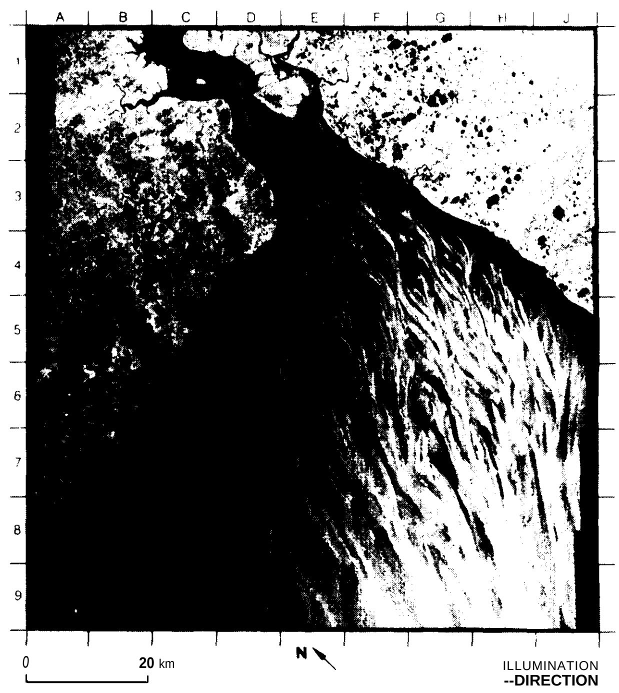
Resolution Radiometer (VHRR) on the NOAA-N series satellites. Although highly useful for determining the extent of ice cover and ice flow, these data are limited by cloud cover and by darkness (at those times of year when the Sun is not visible at high latitudes). Further, the Landsat data are limited by lack of daily coverage, and the NOAA-N data are limited in spatial resolution.

Thermal infrared measurements made by the VHRR infrared sensor on the NOAA-N satellites have some usefulness for determining sea-ice thickness. Although the instrument is limited by cloud cover, it is not limited by lack of sunlight; it is highly useful for low resolution, large-scale measurements of ice movement and extent.

Microwave systems have the advantage that the frequencies at which they operate are limited by neither clouds nor darkness. Both passive and active (radar) systems can be used for mapping and monitoring sea ice, but the passive system suffers from the highly limited resolution available from the relatively small antennas that can be carried aboard a satellite. Nimbus-5 and Nimbus-7 carried passive microwave radiometers. No microwave measurements of sea ice are now being taken by the United States.

An active system based on the synthetic aperture radar principle could overcome the problem of low resolution at the price of having to handle high volumes of data. A Synthetic Aperture Radar (SAR) would achieve relatively high resolution along the line of sight at an angle to the nadir by using the satellite motion coupled with digital signal processing techniques to create a synthetic image of Earth's surface. Such systems are an outgrowth of aircraft side-looking aperture radar systems; an L-band SAR was demonstrated on Seasat (fig. 7-20). However, before such an instrument could become operational, methods

Figure 7-20.—Radar Image of Kuskokwim Bay in Alaska



As the Kuskokwim River flows into the Bering Sea, it forms large sediment deposits in Kuskokwim Bay, which are visible as small dark areas separated by channels (bright areas).

SOURCE: Lee-Lueng Fu and Benjamin Holt, "Seasat Views Oceans and Sea Ice With Synthetic-Aperture Radar," NASA Jet Propulsion Laboratory Publication 81-120, Feb. 15, 1982, p. 98.

would have to be developed to process the data rapidly and turn them into useful products. As noted, Canada and ESA will include an SAR instrument on their satellites, Radarsat, and ERS-1.

A satellite altimeter and a scatterometer are two other examples of active radar systems that could be used to measure ice parameters. An altimeter (e.g., that planned for TOPEX/POSEIDON) could measure the height of the ice with a precision of a few centimeters. Data from a scatterometer would be used to determine ice roughness and the position of sea-ice boundaries.

Wave Heights

Knowledge of wave height and general wave conditions at a variety of ocean locations is crucial for the safety of ships at sea, and for ocean platforms. Data on waves are also important for understanding and modeling ocean dynamics. Because winds create waves, measurements of wind speed and direction over wide areas can lead to estimates of wave height and condition.

Applications of Ocean Remote Sensing

Data from satellite remote sensing of the oceans have the potential for providing information for several important applications (table 7-17; table 7-18). The following examples illustrate the potential importance of these data.

Weather and Climate

The world's climate system is dominated by the behavior of the oceans. Understanding and predicting climate depends directly on understanding ocean temperatures, currents, wave heights, sea level, and sea surface winds, as well as other characteristics. Obtaining comprehensive, periodic, synoptic measurements requires a spaceborne system. Although daily measurements from ships crossing the oceans or from ocean buoys are available to climatologists, such measurements are primarily limited to the major shipping routes or to the coastal areas. The climate-related parameters of vast areas of the ocean remain unobserved except on a sporadic basis.

Marine Transportation

In ship routing, the most critical parameter to measure is sea state (wave heights). However, winds, currents, fog, rain, etc., are also important. One report suggested that reliable data and analysis of sea state "can reduce ship transit time and therefore save a significant amount of fuel."[82]

The experimental Seasat was used by a U.S. ship routing company in studies that indicated:

> . . . that the use of satellite-derived wind observations can be useful in more accurately locating low-pressure storm centers. This knowledge could reduce vessel transit distances and times.[83]

Offshore Mining: Oil and Gas Exploration and Extraction

Offshore mining firms could make considerable use of ocean satellites because many of the areas with the richest resource potential are not located in the major shipping lanes and thus are the most poorly observed by conventional means. The deep-ocean-mining industry now is using wind and wave measurements from ship reports in designing equipment and formulating operating plans and schedules.[84] Various experimenters have suggested that a better climatological information base, which could be provided by satellite, would be put to good use in planning for and operating deep ocean mining projects.

Oil and gas exploration and extraction companies could also use an improved ocean climatological data base for selecting equipment, such as drilling rigs and supply vessels, and in planning offshore operations. * Perhaps the most important use of the satellite data is for improved weather warnings and status of ice information. as

[82] Donald Montgomery, "Commercial Applications of Satellite Oceanography," *Oceanus 24, No. 3,* p. 58, 1981.

[83] 1 bid., p. 59.

[84] 1 bid., p. 59.

**Oil and Gas Technologies for the Arctic and Deepwater* (Washington, DC: U.S. Congress, Office of Technology Assessment, OTA-0-270, May 1985).

[85] Ibid., p. 60.

Table 7-17.—Possible Oceanographic Satellite Applications

Activity	Application
Offshore oil and gas:	*Increased ocean forecast accuracy*
	Exploration operations
	Seismic surveys
	Drill ships
	Towout operations
	Production operations
	Crew scheduling
	Platform and crew safety
	Ice observations
	Ice dynamics for platform design criteria
	Ice movement for platform and crew safety
	Environmental data
	Replace platform instrumentation
	Subsurface and seabed dynamics
	Gas pipeline and applications
Environmental forecasting:	*Increased observations (particularly in Southern Hemisphere)*
	Consistent observations
	Wave-height measurements
	Wind averages
Marine transportation:	*Increased ocean forecast accuracy*
	Optimum routing
	Port scheduling
	Ice observations
	Arctic resupply
	Vessel/personal safety
Deep-ocean mining:	*Increased ocean forecast accuracy*
	Mining operations
	Improved tropical storm, storm-track prediction
	Mining operations and safety
	Historical data base
	Unbiased climatology
	Mining equipment design
	Operational criteria
Marine fisheries:	*Increased ocean forecast accuracy*
	Efficient search efforts
	Efficient gear operations
	Reduced gear losses
	Crew and vessel safety
	Ice observations/forecasts
	Gear losses
	Crew and vessel safety

SOURCE D R Montgomery, "Commercial Applications of Satellite Oceanography," *Oceanus* 24, 1981, pp. 57-65.

Table 7-18.—Impacts of Observed Parameters on Commercial Benefits

	Measurement Parameter			
Application	Wind	Waves	Sea Surface Temperature	Ice
Ocean Fishing	High	High	High	Low
Marine Transportation	High	High	Low[a]	Low[b]
Oil and Gas Exploration and Development	High	High	Low	High[c]
Arctic Operations	High	High	Low	High

[a]High in regions where sharp temperature gradients indicate currents.
[b]Dependency low for present trade routes; will Increase with the movements of arctic resources using Ice breakers.
[c]High only In ice prevalent regions.

SOURCE RCA Astro-Electronics

Surveillance and Enforcement

With the recent extension of coastal economic zones to 200 miles, all coastal countries, and especially developing ones, would benefit from better surveillance and enforcement programs. Surveillance of cooperative targets–the monitoring of boats legally within a country's 200-mile economic zone–could be done using the ARGOS system on TIROS-N, This system could monitor cooperative vessels (i. e., those with an appropriate transmitter aboard) and enable a host government to supervise their fishing activities. An uncooperative or illegal foreign fishing vessel, however, must still be apprehended by aircraft or ocean patrol.[8b]

Fisheries

Indirect measurements of environmental factors which affect the distribution and abundance of the resource, both temporally and spatially, can be used to indicate areas of high yield. However, using satellite data for commercial fisheries requires that two links be made: 1) fish availability must first be correlated with environmental and/or ocean attributes, then, 2) environmental and/or attributes detected from the satellite must lead to information about the potential available food supply.

The following environmental parameters relate to the distribution and abundance of ocean fish:

- **Sea surface temperature.** Sea surface temperature may be directly related to the distribution and abundance of marine organisms. For instance, studies of Pacific tuna have demonstrated strong correlations between tuna catch and water temperature. Also, strong temperature gradients may indicate the edges of warm and cold water systems. These edges or boundaries usually define currents and mark areas of increased pelagic fish productivity.
- **Sea surface salinity.** Although sea surface salinity cannot be measured by satellite, measurements of salinity help indicate the distribution and abundance of certain kinds of marine organisms, especially those that spend some portion of their life cycle in the estuarine areas.
- **Sea state (wave heights).** Sea state becomes an important indicator for current systems when temperature, salinity, and other property gradients are negligible. Because current systems delineate areas of more or less fish productivity and may also possess different sea states, the measurement of sea state may correlate with fish catch.
- **Water color and chlorophyll concentrations.** Water color variations indicate the boundaries of major current systems. More important, water color has long been used indirectly as an indicator of biological productivity. Detection of water color is primarily used to detect shifts of marine organisms, especially those that spend some portion of their life cycle in the estuarine areas.
- **Pollution.** Pollution may be considered as an indicator of areas in which fish are not present. it may also indicate where fish and their environment might be endangered. Slicks, foam, and debris lines may also indicate current convergence zones, which may be areas of high productivity.
- **Surface objects.** Surface objects of interest that may be detected include vessels, buoys, offshore oil platforms, weed-debris lines, marine mammals (whales, porpoises), bioluminescence, and fish schools on or near the surface.
- **Other factors.** Other environmental data are important, including water clarity and current patterns, but these are usually inferred from the parameters listed above.

Issues in Ocean Remote Sensing

What Are the Research Needs for Ocean Remote Sensing?

There is a strong continuing need for research into ocean phenomena, both to support ocean users (e.g., the maritime industries), and to increase our basic understanding of fundamental ocean processes. Although humans have traveled and studied the oceans since before recorded his-

[86] Resources Development **Associates,** *Feasibility of Surveillance and Monitoring of Fishing Vessels in Papua New Guinea* **(Los Altos, CA: RDA, January 1980).**

tory, our ability to predict future ocean behavior is severely limited by lack of knowledge of how the ocean works and how to model its behavior. Understanding the oceans more thoroughly will also require the collection and processing of vast amounts of data, both from surface observations and from satellites.

The problems of understanding the dynamics of the ocean are similar to those of understanding the dynamics of the atmosphere. The oceans and the atmosphere are both fluids that are heated and cooled by complicated processes and strongly affected by thermal flows from the land masses. Major changes may occur over scales of hours, days, weeks, or even years. The ability to predict future behavior of the oceans requires knowledge of the ocean as it is at any given moment, and how it changes over time. predictions also require the ability to model ocean behavior in large computers and compare those results with observations. Satellites are particularly useful for gathering much of the necessary data because they provide a synoptic view of the oceans at predictable repeat intervals. Observations from ships, although extremely important in verifying satellite records, are scattered both in time and space, and provide poor data sets for modeling ocean behavior. Ocean buoys, though useful for collecting important data, are necessarily few in number and widely scattered throughout the oceans.

How Can We Make the Best Use of the Space Assets of the United States and of Other Countries to Increase Our Knowledge of the Oceans?

As noted earlier in this section, Canada, Japan, and the European Space Agency are designing or building ocean-related satellite systems that are expected to be operational within the next s years. The Navy N-ROSS system, the data from which will be distributed to the civilian community through NOAA, is likely to be operational in the same time period. This is one area in which the increased ability of other countries to compete with the United States technologically by building space systems can lead to closer cooperation. Close cooperation and coordination among countries could provide timely and continuous access to the data from these systems. Most important, substantial cooperation could assure that the data the systems provide are useful to the worldwide community of users. The result of cooperation and coordination could be a system that is of far greater utility than any one nation could provide on its own. NOAA is expending considerable energy to increase cooperation, not least because cooperation may enable the United States to spend lesson its own data collection systems.

Opportunities for cooperation occur in the following areas:

- **Coordination of Equator crossing times and repeat cycles.** N-ROSS is designed to have a 2-day repeat cycle for measurements. ERS-1 will also pass over the same locations every 2 days. If the orbital parameters of both satellites could be properly coordinated, because the sensor complement of the satellites overlaps to a considerable extent, it would be possible to achieve daily global ocean coverage. Such coordination would affect neither the cost nor the national objectives of either satellite system, but could nearly double their value to the participants, if all the data are shared freely .87

  As future systems are designed, coordination of the Equator crossing times for satellites could also lead to similar benefits. For example, measurements of ocean color, solar radiation, and ozone content require high Sun angles, and are therefore best taken near noon.
- **Cooperation on future satellite missions.** As experience is gained with the planned operational and research satellites, potential cooperative missions will begin to suggest themselves. It appears to be in the best interest of the United States to continue a variety of cooperative programs in order to: 1) save money on building research and applications systems, and 2) increase the available scientific and operational knowledge base about ocean processes.

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[87] " Utilization of the Polar Platform of NASA's Space Station Program for operational Earth Observations, " op. cit. (fn 37).

- **Building an international polar-orbiting platform.** The Europeans have shown considerable interest in providing instruments or funding for an international system of meteorological satellites (see metsat issues above). They and the Japanese have also indicated interest in supplying some part of a space station. Polar-orbiting platforms that could provide a variety of atmospheric, land, and ocean measurements would seem to provide fertile ground for future international cooperation in remote sensing.[88]

What Needs Are There for Collecting, Processing, and Distributing the Primary Data From Satellites?

The ground receiving station, and the data ordering, processing, and distribution facilities are as important to the user of satellite data as are the satellites that gather the data. Therefore, when the funding for ocean remote sensing systems is considered, it is extremely important to include sufficient funds for these ground-based functions, because NOAA must be capable of supplying unenhanced data reliably and efficiently to the user. Some data, such as the position and strength of a large ocean storm, are highly time-dependent and are of no use to the operational user unless supplied immediately after being gathered. Others, relating for example to sea ice position, may change more slowly and allow a time lag of several hours or even days for distribution.

The need for timely delivery of data is as important for research scientists as it is for commercial or Government applications. Sensor characteristics change with time and require recalibration if the data collected are to be of use to the researcher. Data stored for long periods before their intended use may well be unusable because the user was unaware soon enough of small changes in sensor characteristics.

Large-scale experimental programs such as the World Climate Research Program, components of which include the Tropical Ocean Global Atmosphere Program and the World Ocean-Circulation Experiment,[89] or the International Geosphere-Biosphere Program (IGBP),[90] will generate large amounts of data from space that must be sifted, analyzed, and integrated with related data gathered at the surface, before being used in experimental models of the oceans and the atmosphere. This process will require sufficient archiving of corrected historical data, and the ability to access them efficiently.

[88] Ibid

[89] "Oceanography From Space: A Research Strategy for the Decade 1984-1 995, " op. cit.

[90] " Toward an International Geosphere-Biosphere Program: A Study of Global Change," Report of a National Research Council Workshop, Woods Hole (Washington, DC: National Academy Press, July 25-29, 1983).

REMOTE SENSING POLICY

The treatment of current U.S. systems for remote sensing from space presents a particular challenge to policy makers. Although land, ocean, and meteorological remote sensing use related technologies to produce data, for the most part they still serve different constituencies. Consequently each requires a different policy treatment. Further, the three systems have different economic, political, and social characteristics, As the data from these systems find greater use, and their applications increasingly overlap it may be possible to integrate the systems, perhaps on an astronaut-tended polar-orbiting platform.[91] However, analysis of such an integrated approach is beyond the scope of this report.

Policy options for guiding the direction of U.S. meteorological satellite systems exist primarily in the context of cooperative ventures in space, because these spacecraft sense large-scale conditions that generally transcend political boundaries. Small-scale surface features and most signs of human activity do not appear in images produced by metsat sensors. Economic value lies primarily in the data's use in predicting severe weather and climate trends.[92] Earth resources re-

[91] See, for example, the discussion in "Utilization of the Polar Platform of NASA's Space Station Program for Operational Earth Observations, " op. cit. (fn 37),

[92] See, for example, the discussion of "El Nino in the Southern Hemisphere and Its Effects on the Northern Hemisphere, " Remote *Sensing and the Private Sector,* op. cit, App. 1.

mote sensing systems, whether for land, coastal regions, or the oceans, are specifically designed to be used for assessing, managing, and exploiting renewable and nonrenewable resources. The data collected therefore have direct economic consequences for the sensed country. Consequently, the following policy treatment discusses each system independently.

Meteorological Remote Sensing Policy

Because weather data collected in one region of the globe are of interest to other regions, the nations of the world, even in time of war, have at least since 1853 treated the gathering and distribution of weather data as a cooperative venture. The primary means of cooperation among nations with respect to meteorological satellite systems has been the sharing of data.

Cooperation

Four primary policy options are possible: 1) maintain the status quo in polar-orbiting systems and continue to cooperate in providing data to the global meteorological data exchange; 2) maintain the form of our cooperation, but reduce the quantity and quality of data supplied to other countries by operating only one polar orbiter;[93] 3) increase our cooperation with other countries by engaging in additional cooperative projects; and 4) increase the sharing of data from the geostationary satellites with our Western Hemisphere partners.

Maintain Status Quo

The United States normally operates two civilian polar orbiters and two geostationary satellites.[94] It could continue to operate both systems and cooperate as in the past by supplying data to U.S. citizens and other nations at no cost (or at cost of reproduction), while continuing to fly sensors of other countries. The two systems cost about $7.4 million in fiscal year 1984 to operate. Each new polar-orbiting satellite will cost about $100 million to build and $30 million to $50 million to launch.[95]

As argued in the next option, this course of action would have the advantage that it would maintain the same data flow that the United States and other countries have experienced in the past, with the consequent benefits that flow from access to such data. It would have the disadvantage of not contributing to a reduction of the budget deficit.

Operate Only One Polar Orbiter

In its effort to reduce the Government's budget deficit, the Administration has repeatedly tried to reduce the number of polar orbiters from two to one. Eliminating one of the polar orbiters would reduce the coverage of the system from once every 6 hours to once every 12 hours for a particular spot on the Earth. For most of the United States, a reduction in service would not cause a serious decline in the ability to predict severe weather. Conventional data collection systems and the geostationary satellites provide sufficient information. For Hawaii, Alaska, American Samoa, Guam, and the Pacific Trust Territories, however, the 6-hour repeat coverage that two polar-orbiting metsats supply is extremely important for timely warning of rapidly changing weather conditions. None of these areas has access to surface data for the predominantly west-to-east weather patterns.[96]

Operating only one civilian polar orbiter would reduce the data available to DOD. Though it has its own system of meteorological satellites (Defense Meteorological Satellite Program or DMSP), DOD makes extensive use of the civilian system, both to provide data at different times of the day,

[93] A fifth potential option of reducing our cooperative efforts in meteorology by reducing our participation in the WMO is infeasible because the United States would therefore likely lose access to some data it now receives from foreign surface stations.

[94] Note that only one geostationary Satellite is now operating. NOAA plans to launch a replacement for the failed GOES-5 in late 1985 or early 1986. See W. Mitchell Waldrop, "A Silver Lining for the Weather Satellites?" Science, vol. 226, pp. 1289-1291, for a summary of the state of technological and political affairs of the U.S. meteorological satellite systems.

[95] These figures are approximate and depend highly on the number of satellites contracted for in a single purchase agreement, the number and type of new sensors that are *flown, inflation, and future* launch prices.

[96] Because th. primary weather flow in the Northern *Hemisphere* is from west to east, information gathered to the west of a geographic area is especially important for weather predictions.

and to act as an emergency backup to the military system. The DMSP can provide a backup of sorts for the civilian satellite. However, because the characteristics of the data from the DMSP are somewhat different from those supplied from the civilian system, its data cannot be used directly in forecasting models.

Nations that depend on metsat data and have purchased receiving stations have expressed their dismay that the United States might operate only a single polar orbiter. Such a course of action would save less money than it might appear because the cost of purchasing and operating two polar satellites is much less than twice the cost of operating one. NOAA estimates it would save less than $25 million yearly.

The U.S. polar orbiters carry the emergency beacons used in the COSPAS/SARSAT cooperative program with Canada, France, and the U.S.S.R. Until October 1984, the system had been operated as a demonstration program. However, in October 1984, the Administration signed an agreement with the participating countries to continue the program on an operational basis, therefore committing the United States for the immediate future to maintain two polar-orbiting metsats for the COSPAS/SARSAT program. The SARSAT receiver could be flown on a separate small satellite (at an unknown cost), so this agreement does not guarantee continuation of two polar-orbiting metsats.

Joint International System for Polar Orbiters

The only other nation to operate a polar-orbiting meteorological satellite is the Soviet Union. The two U.S. polar-orbiting satellites provide total global coverage and are the principal source of meteorological data from 80 percent of the globe. They also provide coverage for the high latitude regions, which are not covered by the geostationary satellites,[97] and for which conventional measurements are particularly sparse. The two-orbiter system benefits all the countries of the world because of its frequent coverage. A single polar orbiter would result in markedly reduced weather coverage (fig. 7-10).

The United States has suggested to the other OECD nations that:

> unlike the situation that existed when the United States initiated the meteorological satellite system, it is now possible for subsystems, systems, and entire satellites to be built, launched, and operated by numerous organizations in many countries. The satellites and instruments are well understood. The data standards that are necessary for worldwide distribution and use of satellite data are in place and thoroughly developed. Interoperability of space systems or subsystems can be readily achieved through procedures that many countries have applied.[98]

NOAA representatives have briefed representatives of other nations about U.S. views on the desirability of jointly providing the second polar orbiter. A joint program would reduce U.S. operating costs and increase U.S. cooperation with other countries.

At the June 1984 Versailles Economic Summit, delegates agreed to discuss cooperating in satellite remote sensing and established the international polar-Orbiting Meteorological Satellite group (IPOMS), the members of which unanimously agreed on the need for two polar orbiters.[99] Foreign participants were willing to accept more of the financial burden of an advanced polar-orbiting system and to fund new instruments for it.

An agreement to cooperate in building and maintaining a multinational polar-orbiting system would constitute a marked change in the form of international cooperation in meteorological systems. Heretofore, with the exception of two foreign sensors flown on U.S. polar orbiters, data, not sensors, have been shared.

[97] Although the geostationary satellites can image the full disk of the Earth, their ability to make quantitative measurements of extreme north and south latitudes is limited by the oblique angle at which they sense Earth's surface at these latitudes.

[98] "International Cooperation in Polar-Orbiting Meteorological satellites," NOAA, Apr. 19, 1983.

[99] "Dual Polar Satellites Draw International Support," *Aviation Week and Space Technology,* Dec. 10, 1984, p. 27. Members of this group include representatives from Australia, Canada, France, Federal Republic of Germany, Italy, Japan, Norway, the Commission of the European Communities, the European Space Agency, the United Kingdom, as well as the United States (NASA, NOAA, and the Department of State).

U.S. spacecraft manufacturing firms might lose some business as a result of such cooperation. On the other hand, if the choice were between international cooperation on a two polar-orbiting system and a domestic system of only one polar-orbiting satellite, they could well do more business with an international system.

Although the nations that might participate are able to contribute to this effort, the United States could face a question of undesirable technology transfer. For certain advanced new sensors and data processing technology, it would be important to structure the agreement so that no technology vital to national security interests be transferred to other countries. Part of this concern could be met by structuring the system in such a way that each country provided its own independently developed sensors in accordance with mutually agreed-upon specifications.

Sharing the Data From Geostationary Satellites

The U.S. geostationary satellites are in a different category from the polar orbiters because they remain stationary over regions centered on the Equator. The data from these satellites, like those

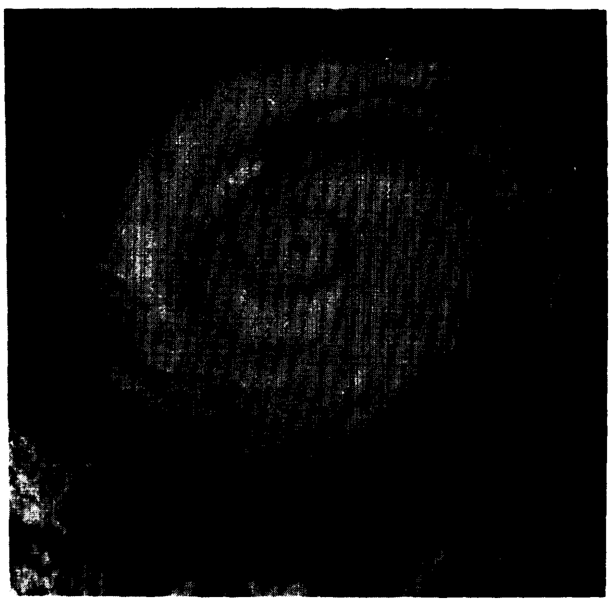

Photo credit: National *Oceanic* and *Atmospheric Administration*

Image of Hurricane Allen centered over the Gulf of Mexico received from the GOES satellite stationed at 75° W longitude, Aug. 8, 1980.

from the polar orbiters, are already shared with the countries of the world. However, unlike the data from the polar orbiters, their data benefit primarily the countries of the Western Hemisphere. Thus, in order to provide development assistance to many of these countries, and further Western Hemisphere relations, it may be in the long-term interest of the United States to support bilateral or multilateral programs to make better use of the data from these satellites. Such programs could take the form of joint research projects to investigate the effects of El Nino and other large-scale weather patterns that affect the Western Hemisphere.

Competition

There is no market for sales of primary metsat data because, except for reproduction changes, they are shared freely among nations.[100] What competition exists for meteorological satellite technology is for ground equipment, but that market is extremely small and is likely to remain so in the future.

Competition for value-added services also exists, but here again the total market is now extremely small. The United States leads in processing metsat data. The value-added market will remain relatively small in the near future, but is likely to continue to develop as techniques for using land and meteorological data for agricultural and hydrological purposes improve.[101] in time, meteorological sensors will provide more wavelength bands, and have higher resolution; the value-added companies will become more sophisticated in their applications of the data. As a result, processed meteorological data may begin to compete with the use of certain land and ocean remote sensing data both in the United States and abroad.[102] This could bean important step toward an integrated U.S. remote sensing

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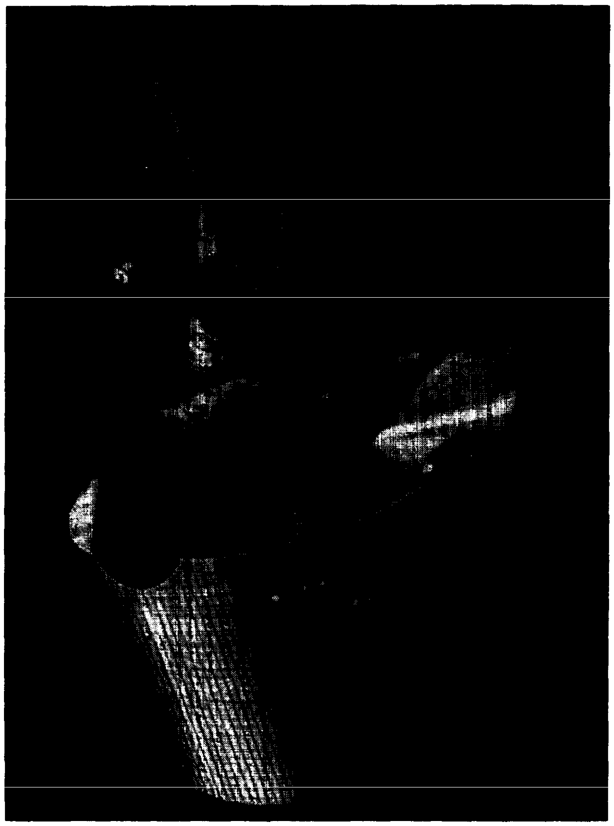
[100] Country satellite services organizations generally charge (at cost) for data that requires special processing, or for derived products.

[101] See, for example, discussion at the NOAA-sponsored conference, NOAA's Environmental Satellites Come of Age, Mar. 26-28, 1984. Participants there shared techniques used to utilize environmental satellite data for a variety of tasks once reserved for high resolution data. See also "Metsats Seen Competing with Landsats," *Space Business News,* May 21, 1984, p. 3.

[102] "Metsats Seen Competing With Landsats," *Space Business News,* May 21, 1984, p. 3.



G ry O E m S
GOES

Photo credits: National Oceanic and Atmospheric Administration

NOAA-N series polar-orbiting environmental satellite, artist's conception.

system that would enhance the U.S. competitive position in remote sensing.

Land Remote Sensing Policy

The feature that most distinguishes Earth resources remote sensing from meteorological remote sensing is its potential for immediate use in assessing, managing, and exploiting Earth's resources. The potential economic value of the data these systems supply has recently made them a primary subject of competition between nations. Cooperative efforts, though potentially serving an important role, have lessened in importance with the development of competitive foreign systems.

Competition

The previous analysis in this chapter has shown that the greatest current demand (in volume) for land remote sensing data is for low-cost moderate-resolution (80-meter) MSS data delivered promptly and continuously. The current demand for expensive data is smaller.[103] Most customers today have neither the experience with high resolution (30-meter) thematic mapper (TM) data nor the processing equipment. In addition, it is not clear that TM data or their equivalent will be cost effective for many tasks. Except for the mineral exploration companies, which can make cost-effective use now of the more expensive TM data, relatively few users are willing or able to purchase them. This situation is likely to continue until: 1) customers gain confidence that TM or comparable data would be cost effective; and 2) they also gain confidence that the data will be available on a continuous, long-term basis.

Land remote sensing policy is at an important crossroad. As discussed earlier, by creating Public Law 98-365, the Administration and Congress committed the United States to transferring this technology to the private sector. Proponents of transfer hope that the private sector will eventually develop the technology into a self-supporting, commercial operation. However, it is unclear: 1) how much subsidy might eventually be needed, 2) how future research and development needs will be met, and 3) whether sufficient demand for data will develop to build a viable market.

Opponents of transfer generally believe the system should continue to be operated in the public interest. They argue that the costs of continuing to provide data are relatively small compared to the cost of putting the system in place. A few observers believe that it is possible to operate a complete land remote sensing system without Government subsidy.[104] However, they also point out that this could not be done in competition with a Government-subsidized operation.

The following discussion views each policy option from the point of view of how it would serve the overall public interest. The disposition of the Landsat system is likely to affect overall U.S. competitiveness in space, international relations, and the development of the international market for land remote sensing data.

Options for Continued Financial Support

The Administration and Congress have decided that the public interest will be served by a phased transfer of the Landsat system to private ownership. Although the Department of Commerce has chosen the EOSAT Corp. to operate the current Landsat system and to build two follow-on satel-

[103] In the first half of fiscal year 1985, Thematic Mapper data generated about 49 percent of the total income of Landsat data sales from the EROS Data Center.

[104] Most notable among these is Space America, Inc., which was one of the bidders to take over operation of the Landsat program. Space America's approach to land remote sensing is radically different from either EOSAT or Kodak. It has proposed building a system that would be less technically sophisticated than the current Landsat 5, but would be considerably cheaper and directly responsive to customers' data needs. Operating at 40 meters resolution in 4 wavelength bands and providing stereoscopic data, its proposed MLA-based satellite would be comparatively light and require little advanced technology development. It would also require relatively little or no Government subsidy. Space America is also developing a data processing system that would integrate satellite aircraft and ground-based data to produce new information products. In proposing such a satellite system, Space America is relying on the premise that the largest market for data will be for inexpensive, moderate resolution data targeted to customers' needs and combined with ground-based data. Its proposed system has been criticized on the grounds that it does not maintain the U.S. technological leadership in remote sensing. However, Space America is convinced that the greatest immediate need is to build a market for the data before moving to more advanced sensors that will generate expensive data. See Diane Josephson, statement at hearing before the Subcommittee on Science and Technology, of the Senate Committee on Commerce, Science, and Transportation, Mar. 22, 1984, S. Hrg. 98-747, pp. 78-82.

lites, and has reached agreement on the contract terms (including amount of subsidy), it will still be necessary for Congress to monitor the process of transfer over the long term.

If EOSAT is able to operate the current system for a period long enough to inspire customer confidence, to provide data promptly at reasonable costs, and to establish a strong market for data, then the transfer has a reasonable chance of succeeding.[105] However, the subsidy cap of $250 million plus launch costs OMB has imposed may limit the ability of EOSAT to establish a self-sustaining corporation within the 10 years of the centract.

This attempt to commercialize land remote sensing is an experiment that has no exact precedent. It may be necessary or desirable to institute additional legislative measures, or to appropriate additional funds for the transfer in later years (beyond that committed in the current contract). Therefore, Congress may wish to pursue one of the following options:

Maintain a High Level of Direct Support for Commercial Land Remote Sensing

Although the Administration has set a cap on the total subsidy to be paid, Congress might later decide to appropriate an additional subsidy (perhaps $100 million to $150 million), on the basis that a $250 million subsidy allows little margin for maintaining U.S. technological and marketing leadership. The contract with EOSAT has several vulnerabilities that could adversely affect the company's ability to compete effectively. EOSAT will attempt to use high-capacity tape recorders on Landsat 6 and 7 to gather and store data from areas that are not covered by ground receiving stations. However, tape recorders have proven particularly vulnerable to malfunctions in the past (e.g., on Landsats 2 and 3). In addition, MSS-type data will be generated by summing appropriate elements of the TM instrument on board the spacecraft. Not only is this an untried technique, but because there will be no separate MSS instrument, there will be no backup should the TM itself fail. (On Landsat 4, when the antenna for the TM failed, it was still possible to receive MSS data through an entirely separate system.) Finally, the rate of data processing planned for the facility at Goddard Space Flight Center has never been reached for the extended periods of time necessary for developing a high-volume market.

Additional funding could allow redundant systems to be built that would reduce the amount of risk posed by these system vulnerabilities. Proponents of additional subsidy argue that the benefits derived from land remote sensing are such that the system should be maintained even if there is a relatively low demand for data. They further offer that Government needs for data to use in monitoring the Nation's renewable and nonrenewable resources and the environment, in the public interest, are great and that more time and funds are needed to learn how to integrate these data into existing programs.[106]

Moderate Additional Subsidy

The difference between this and the previous option is the level of extra support that is deemed necessary to assure near-term privatization and eventual commercialization of land remote sensing. proponents of this alternative policy would argue that some additional subsidy is appropriate to provide an additional margin of safety for the transfer, but that it should not exceed, say, $50 million over the life of the current contract between the private firm and the Government. They further support the need for the private corporation to assume a higher level of financial risk than might be implied in the first option.

No Extra Subsidy

Such a policy would follow from OMB'S conviction that $250 million (plus launch costs) is about the right amount to extend to a private corporation for the first steps of the commercialization process and that holding out the possibility of any greater future subsidy would undermine the creative energies of a corporation that was risking its own capital to build sufficient market for remotely sensed data. Further, it could be

[105] As noted in the discussion of issues, a strong market for data would imply sufficient revenues to build follow-on satellites beyond Landsat 6 and 7.

[106] For a detailed discussion of Government requirements, see *Remote Sensing and the Private Sector,* op. cit., ch. 5, app. G, H, 1.

argued that if sufficient demand for remote sensing products fails to develop, the field should be left to other nations and the United States should devote its energies to maintaining leadership in other technologies.

Additional Policy Options

Several other options for promoting U.S. competition in satellite land remote sensing are possible. They are primarily designed to promote the development of a market for the data. As the earlier analysis has shown, the most important factors contributing to the development of demand for remotely sensed data are: 1) continuity and timeliness of data delivery; 2) a strong value--added industry; and 3) continued research and development, both on sensors and other system elements, and on effective application of the data. The last factor is also the major element in contributing to U.S. technological leadership.

Reinstate a Strong Remote Sensing Research Program

The Remote Sensing Commercialization Act of 1984 calls for both NASA and NOAA to continue research in advanced sensors and in the use of remotely sensed data.[107] Until about 1982, primarily within NASA, the United States maintained a strong remote sensing research program both for applications of the data, and in sensor development. As the Landsat system began the transition to operational status, NASA began to cut back on its research effort in the expectation that NOAA would be the lead agency in operational land remote sensing. However, NOAA has only a small research program. NASA continued to work on a multispectral linear array to be tested on a future satellite. As discussed earlier (see issues section), NASA terminated fiscal year 1985 research in order to concentrate on developing a much more advanced sensor system. Some Members of Congress and representatives of the industry are concerned that NASA's decision, which was driven by the desire to cut some programs in order to reduce its operating budget, left NASA providing very little research effort for supporting the U.S. competitive stance in land remote sensing. NASA officials argue that NASA's role is to continue research on advanced sensors, not to develop sensors that would be used for commercial operations. NASA is now attempting to reinstate part of this research. However, the question of what level of effort is appropriate remains.

In spite of the mandate of Public Law 98-365 for continuing research in land remote sensing, the fiscal year 1985 NOAA budget contains no support for research on operational sensors or on utilization of the data. if the United States is to support the development of a market for the data, maintain its technological lead in civilian applications of remote sensing technology, and promote national prestige in the face of competition from France and other countries, continued research on advanced civilian sensors will be necessary. Some technology developed for reconnaissance satellites might eventually be transferred to civilian use, but as discussed in a previous OTA report,[108] the steps from military or intelligence use of part or all of a space system to civilian use are long and difficult.

Encourage the Growth of the Value-Added Business

There is no straightforward process for transferring complex new technologies from Government laboratories to private industry. Indeed, the experience with Landsat has demonstrated that it can be highly complex and difficult. The biggest impediment to private ownership of land remote sensing is the small market for data from the system.

Gathering land data from space is a major innovation in the remote sensing business; it will take yet more time, money, and considerable attention to building sufficient demand for data to support a self-sufficient private sector operation.

One key to developing a sufficient market is the small value-added industry.[109] One reason it remains small is that the Government, in certain

[107] See Public Law 9-365, Title V—Research and Development.

[108] *Civilian Space Policy and Applications*, op. cit., ch. 6.

[109] It is difficult to estimate how much income the value-added industry generates because many larger firms, such as the oil and gas firms, maintain their own computer processing facilities for converting the data to useful information.

areas, in effect competes with it by maintaining its own data processing and value-added capacity. This may be appropriate in the research and development phase, but inappropriate when the system is to be transferred to private hands and operated as a profitmaking entity. If a strong land remote sensing industry is desired, it will be essential for the Government to reduce its involvement in value-added services and contract for those services that can be supplied by private companies.

Repair Landsat 4

The virtual certainty of a gap in data delivery between the demise of Landsat 5 and the launch of a private follow-on satellite deeply concerns data users. Some have suggested that it might be possible to eliminate or shorten such a data gap by repairing Landsat 4, which is still operating, though at sharply reduced capacity. NASA has investigated the feasibility of repairing the Landsat 4 satellite in orbit, as was done with the Solar Maximum Mission repair in April 1984,[110] or bringing it back to Earth, as was done with two communications satellites. However, unlike the Solar Maximum Mission, which operates at altitudes that are accessible to the Shuttle, Landsat 4 would require special efforts to retrieve it and bring it back for repair.[111] In addition, it does not seem cost effective to repair the satellite.[112]

Because the Landsat satellites follow a near-polar orbit, a Landsat repair mission would have to wait until the Western Test Range at Vandenberg Air Force Base in California is able to accommodate the Shuttle (i.e., in 1986). NASA has no such plans.

Cooperation

Although competition plays a major role in land remote sensing policy, there is ample opportunity for cooperative efforts as well. These range from coordination of individual country efforts to the possibility of establishing a multilateral consortium to build and operate a system from which remotely sensed data are sold.

Future International Coordination

The United States participates (through NOAA) in the deliberations of the Landsat Ground Station Operators Working Group and the Committee on Earth Observation Satellites,[113] organizations that coordinate standards for land remote sensing systems and serve as fora for exchanging technical and other remote sensing information. Such coordination will still be important after the Landsat system is transferred to the private sector. If the transfer process continues as planned, it will be important to spell out how private firms would have to interact with the agencies that represent the United States in these organizations. At present, NOAA's plan is to continue to take the lead, with major input from the corporation, and from representatives of the value-added industry.

Multilateral Consortium

Although the idea has received relatively little attention since it was recommended in a 1977 National Academy of Sciences study,[114] one feasible option is to establish a land (and ocean) satellite remote sensing system owned and operated by a multinational consortium. One possible form of this option is discussed in detail in an earlier OTA report.[115] Under such an arrangement, a single management authority with multinational par-

[110] "Orbiter Crew Restores Solar Max," *Aviation Week and Space Technology*, Apr. 16, 1984, pp. 18-20. See "Astronauts Deploy, Retrieve Satellite," *Aviation Week and Space Technology*, Nov. 26, 1984, pp. 20-22.

[111] The satellite is designed to operate at an orbit of 380 nautical miles. The shuttle can only reach to about 285 nautical miles above Earth.

[112] According to NASA, estimates for the cost of retrieval and repair, range up to $250 million, depending on how extensive refurbishment of Landsat 4 might be.

[113] This group met for the first time in September 1984. It was formed from the Coordination on Land Observing Satellites and the Coordination on Ocean Remote Sensing Satellites, as a result of a recommendation from the Economic Summit panel of experts on remote sensing. It includes entities from the free world that have land or ocean remote sensing systems or plans for building them.

[114] *Resources Sensing From Space: Prospects fOr Developing Countries* (Washington, DC: National Academy of Sciences 1977); see also Ray A. Williamson, "Commentry on Land, Sea, and Air: Global Implications of the View from Space," *Global Implications of Space Activities*, AIAAAerospace Assessment Series, vol. 9, 1982; and John L. McLucas, "Whither Landsat," *Aerospace America*, January 1985, p. 6.

[115] *Civilian Space Policy and Applications*, pp. 298-300; A similar option has also been discussed at recent meetings of the U.N. Committee on the Peaceful Uses of Outer Space, though the United States took little part in these deliberations.

ticipation would assume responsibility for global operation of the system, including establishing technical specifications, procuring and operating satellites, and receiving and preprocessing satellite data. This approach would spread the investment risk, as well as encourage other nations to be more aggressive in developing their own internal markets for satellite data. It would also aid the developing countries in establishing their own ability to use remotely sensed data for resource development and help allay their fears of domination of this technology by industrialized countries. A multinational remote sensing corporation could also guarantee that data would continue to be accessible to all countries on a nondiscriminatory basis.

Given the current climate in the U.N. toward remote sensing, and the more important fact that the U.N. is not organized for operational functions, a U.N. consortium seems inappropriate. It would in principle be more feasible to establish a limited consortium among those nations with substantial expertise in remote sensing, similar in form, perhaps, to the INMARSAT structure. Overtures for other countries to cooperate in remote sensing have been made in the past. Now, because France, Japan, and Canada are well along in their planning process for either land or ocean remote sensing satellite systems, their commitment to national systems might make it difficult to interest them in such a multinational system, particularly if it were dominated by the United States. Nevertheless, a multinational system might eventually emerge from the current cooperative arrangements for coordinating and setting system standards.

One major disadvantage of a multinational system is that the United States would no longer be in complete control of its own civilian system. In addition, U.S. suppliers of space system equipment would face certain competition from industries in other countries. Yet, U.S. industry currently possesses a competitive advantage in these areas, which transfer of the Landsat system to the private sector will support. In addition, because the value-added component of the remote sensing industry is projected to be the major revenue source, and the United States is in a relatively strong competitive position in that market too, a cooperative satellite system in which costs were shared could be of overall benefit to the United States.

Development Assistance

The United States could continue to provide technical assistance to developing countries in the applications of remotely sensed data, even after the Landsat system has been transferred to private hands.

As explained in appendix 7A of this chapter, developing countries face two major barriers to expanding their applications of remotely sensed data: lack of supportive institutions, and lack of training. The United States has attempted to reduce some of these barriers by offering developing countries substantial assistance in applying remotely sensed data to their resource problems. It has set up training programs, regional centers, and has assisted in purchasing data processing equipment.

The U.S. technical assistance programs are largely responsible for the emergence of the international user community. To the extent that an international market exists for satellite remote sensing data, it developed as a result of U.S. aid. Discontinuing such aid would slow the growth of an international market for the data and impede the spread of land remote sensing technology.

Ocean Remote Sensing Policy

International interest in ocean remote sensing from space in this decade is high and reflects a sense that such systems can serve as useful research tools and provide important operational data for ocean users. Ocean remote sensing, because it is about to pass from research to operational status, presents a substantial opportunity for all nations to gain from cooperative arrangements. The following presents possible policy options for Congress to consider vis-a-vis ocean remote sensing.

Take the lead in organizing and coordinating an international program for collecting and distributing ocean data from space.

International prospects for ocean remote sensing from space present the United States with an excellent opportunity to lead the coordination of global efforts. Although the U.S. system is a Navy one (N-ROSS), under arrangements now planned, NOAA will distribute most of the data to the civilian community in the United States and abroad.

NOAA has embarked on an effort to coordinate not only the distribution of data gathered from N-ROSS and other ocean satellites, but also the orbital parameters of the satellites. For example, coordination of the satellite crossing times of N-ROSS with ESA'S ERS-1, if successful, could result in a data set much more useful to the United States and other nations than either ESA or NOAA could accomplish alone.[116] This appears to be a least-cost approach to obtaining data important to research scientists and to ocean industries. Congress may wish to encourage this effort by specifically directing NOAA to take the lead in organizing and coordinating an international program for collecting and distributing ocean data from space. If it decides to do so, Congress must also authorize and appropriate adequate funds to support acquisition, processing, archiving, and distribution of the data from the various sytems.

Support continued research for advanced ocean sensors and applications.

In the next decade, NASA plans several major ocean sensing experiments and contemplates many more.[117] These will contribute vital information to our general knowledge of the oceans. As these experiments proceed, it will be important to examine them for opportunities to develop operational sensors that would serve users of ocean data. Such sensors could be flown on a variety of platforms. For example, it may be appropriate for the Government to fund part or all of the ocean sensors that would be flown on a private land remote sensing satellite. Alternatively, the private sector may wish to build sensors for obtaining certain specialized ocean data that would be flown on a Government satellite. Finally, as the planning for the space station proceeds, it will be especially important for NASA and NOAA to consider operational sensors appropriate for a polar-orbiting platform, one of the planned elements of the international space station program.

As work on the sensors proceeds, it is just as important to continue research on how to apply the data from research and operational sensors for ocean-related problems. World maritime industries generate billions of dollars of revenue each year. Information about ocean parameters can increase industry productivity and reduce the danger to lives at sea.[118] One component of this research should be the development of techniques to utilize meteorological data more effectively in understanding and predicting ocean dynamics. Developing U.S. capability to use ocean data from satellites effectively would help maintain U.S. technological leadership and contribute to the efforts of U.S. value-added firms to generate useful information products for the international maritime market.

Develop a dedicated civilian ocean satellite.

Through its flights of Seasat in 1978 and the Nimbus series of satellites the United States has demonstrated the utility of ocean remote sensing. In the future it may be appropriate for the United States to operate a dedicated civilian ocean remote sensing satellite. If current attempts to coordinate ocean remote sensing with other nations prove successful, it may be possible to develop an international polar-orbiting platform carrying some sensors dedicated to ocean sensing, or to build a U.S. platform that contains a set of instruments complementary to those of a platform built by other nations. In the latter case, it would be essential to select the orbital parameters of each to allow the satellite to sense Earth at complementary times as well.

[116] "Utilization of the Polar Plaform of NASA's Space Platform Program for Operational Earth Observation," op. cit.

[117] "Oceanography From Space: A Research Strategy for the Decade 1985-1 995, " Report of the Joint Oceanographic Institutions, 1984.

[118] "Oceanography From Space: A Research Strategy for the Decade 1985-1 995, " op. cit.

APPENDIX 7A.–SATELLITE REMOTE SENSING IN DEVELOPING COUNTRIES

Developing countries have made limited use of remote sensing from aircraft for mapmaking or for resource development and management since the 1930s and 194os. When meteorological data from satellites became available in the mid-1960s, developing countries began to take advantage of the opportunity these systems afforded to gather information on current and impending weather conditions.

By contrast, satellite remote sensing for the purposes of resource development, on land or in the ocean, has seen relatively little application in developing countries, primarily because the level of technical sophistication needed to process the data is very high and the hardware and special training costly.

This section decribes the current use of remote sensing data in selected developing countries and investigates the potential these data provide for locating and managing renewable and nonrenewable resources. It identifies the factors that might contribute to the growth of a market for remotely sensed data and data products and suggests ways in which U.S. policies could be improved to the mutual benefit of both the developing countries and the United States.[1]

The Experience of Developing Countries

As the UNISPACE '82 report notes, "The synoptic view and the possibility of frequent repetitive coverage of large and even inaccessible areas make, for the first time, regional and global monitoring of renewable natural resources and changing environmental phenomena technically feasible and economically attractive. "[2] This statement is as true for the developing countries as it is for those industrialized countries that already possess a well-developed industrial and information infrastructure. The problems lie in the ability of developing countries to take advantage of remotely sensed data from space,

Weather and Climate

Developing countries have made significant use of the availability of weather data supplied by satellite. Synoptic, timely, weather data are of general use to all countries, and are particularly useful in development projects. Beyond their use in warning of particulady stressful conditions, such as severe storms or radical short-term climatic changes, they can also be employed predictively in crop yield models to signal potential crop failure.[3] Most satellite weather data are readily and routinely available via direct readout to any government agency, nongovernment agency, institution, or individual anywhere in the world within range of the satellites. One need only acquire the proper ground receiving equipment. Neither permission, consent, nor payment is required. Because ground receiving equipment is relatively inexpensive, the meteorological system is highly accessible to most countries of the world. Nearly 100 developing or newly industrialized countries now own APT receiving stations. A few own High Resolution Picture Transmission Stations (H RPT). Many of these countries acquired the stations through the voluntary assistance program initiated by the WMO as part of its traditional effort to aid developing countries in learning to gather and analyze weather data.

Earth Resources

Few developing countries have made much use of Earth resources data from satellites, in spite of the fact that these data could directly serve their development. The objectives of collecting Earth resources information are to:[4]

1. locate resources;
2. aid in *evacuating* resource investment;
3. provide information to be used for improving current management of natural resources; and
4. aid in the performance of certain ***government/*** activities (particularly administerig land taxes, etc.).

Although the resource information needs of developing countries are similar to those of the industrialized countries, their experience in attempting to develop an adequate information base is different. Whereas in most industrialized countries detailed maps of all kinds (e.g., political, geologic, hydrologic, agricultural) already exist to provide baseline data for a resource survey, s many developing countries have not even been mapped on the coarsest scale for any

[1] For a related discussion of the potential effects of transfer of the Landsat system to private hands, see *Remote Sensing and the Private sector,* op. cit., app. A.

[2] Report of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space, A/CON F.101/10, 1982, para. 168

[3] See disscussion in section on meteorological remote sensing also, *Remote Sensing and the Private Sector,* op. cit., app. D.

[4] Orris Herfindel, Natural Resource Information for Economic Development. Resources for the Future, Washington, DC, John Hopkins Press, Baltimore, MD, 1969, pp. 20-21.

[5] In the United States, for example, even the average citizen may purchase topographic maps from the U.S Geological Survey at scales as detailed as 1:50,000. In addition, State, county, and local maps are readily available, as well as direct aerial survey photographs,

reason. Because they lack useful maps, many developing countries can often use the coarse-scale mapping available from Landsat MSS imagery effectively for initial survey of a resource problem. Map scales of 1 :200,000 are possible with the 80-meter resolution of the MSS sensors aboard Landsat. Application of this minimal record could help define the boundaries of particular resource problems, and identify specific needs for more detailed information. At that stage, aerial photography and ground survey become important.

Data needs are generally divided into two categories of renewable and nonrenewable resources:

- **Renewable resources.** Some 25 developing countries have used Landsat data together with aerial photographs to gather information on crop or forest statistics.[6] Because the agricultural production and distribution system reacts slowly to emergency conditions, advance warning of drastic changes in predicted crop production is necessary to prevent either famine or oversupply. For this purpose, the synoptic view of satellites is especially advantageous. These same countries have also used Landsat imagery to monitor water availability and to create maps delineating the uses to which the land is now put, and to assess the renewable natural resources that are available. Most of them feel that as land use intensifies, they will need to put more effort into both short- and long-term planning based on satellite remote sensing.
- **Nonrenewable resources.** In sharp contrast to the case for renewable resources, large national and multinational firms have led the efforts to integrate Landsat data with aircraft and ground data in the search for valuable minerals in the developing countries.[7] Efforts to date have resulted primarily in locating oil. Although these firms are willing to search for minerals in various developing countries, they are uninterested in sharing the use of data processing technology because many of their techniques are proprietary.

Most developing countries have received their knowledge and training in the application of remotely sensed data through programs instituted by AID, NASA, and NOAA. Table 7A-1 lists the developing countries that have received aid directly from the United States for satellite land remote sensing and meteorological projects. Other industrialized countries and several multilateral organizations have also been active in supplying similar aid.

[6] C. K. Paul, "Land Remote Sensing, " *Science,* 1981.
[7] 1 bid.

Table 7A.1.—Agency for International Development Remote Sensing Grants and Projects, 1971.85

Bangladesh	Kenya	Thailand
Bolivia	Lesotho	Tunisia
Costa Rica	Mali	Upper Volta
Cameroon	Morocco	Yemen
Cape Verde	Niger	Zaire
Chile	Pakistan	*Regiona/ Aid:*
Ecuador	Peru	Asia
Egypt	Philippines	East Africa
The Gambia	Senegal	West Africa
Haiti	Somalia	Sahel Regional Program
Indonesia	Sri Lanka	
Jamaica	Switzerland	

Gathering Information for Development

Although developing countries face the same general needs for resource information to aid their development process, the stated needs of individual countries can vary widely. The following programs illustrate the variety of information needs that can be met by using information derived from satellites. They were chosen to be illustrative and are not comprehensive.

TANZANIA

Much of Tanzania's economic development effort is directed toward agriculture and animal husbandry. Its strongest data requirements include:

- current land use-and land suitability (distribution of vegetation and soil types);
- geologic and groundwater information to help locate additional water sources, increase the efficiency of schemes for well-digging and water impoundment, and to help in siting new villages;
- vegetative cover information for monitoring land and range stress (drought and overgrazing are primary concerns).[8]

VENEZUELA

Venezuela plans to tap its natural hydroelectric potential in order to develop nonpetroleum energy sources. The planning effort requires extensive surveys to locate potential dam sites. Data required include:

- reconnaissance level maps over an entire region to delineate drainage, watersheds, soils, vegetation and geologic structure;
- detailed maps of target areas to determine appropriate dam heights, flow rates, the commercial potential of resources, and detrimental environmental effects.[9]

[8] National Academy of Sciences, *Remote Sensing From Space: Projects for Developing Countries,* (Washington, DC: NAS, 1977), p. 29.
[9] Robert W. Campbell, Jule A. Caylor, and Matthew R. Willard, "Rio Caura Resource Inventory" (Diamond Springs, CA:RDA, 1982).

COSTA RICA

Costa Rica's growing industrial and economic base places increasing pressures on agricultural and range land, and in turn, upon the nation's forests. The result is that prime agricultural areas are threatened by urban expansion at the same time that areas predominantly suited to forestry are being converted to marginally productive range and agricultural uses. Costa Rica has expressed a need to monitor and control these changes.[10]

SRI LANKA

In the mid-1970s Sri Lankan development planners began a program to develop new agricultural land in order to become self-sufficient in agricultural production. Program goals include:

- crop breeding;
- multiple cropping;
- soil conservation;
- improved management of agricultural lands.

Sri Lanka began an agricultural base mapping program to provide information on soils, present vegetation, land use for siting new agricultural areas, and topography for assisting irrigation planning and watershed management. Although earlier maps existed they had not been updated since the early 1960s and they were incomplete. "

PERU

In Peru, the Officina Nacional de Evaluation de Recoursos Naturales (ONERN) is to provide the Peruvian Government with inventory and evaluation of Peru's natural resources as well as an assessment of the state of the environment and recommendations for its protection. ON ERN'S objectives require extensive resource information:

- natural resources inventories oriented to Peru's development and resource management needs;
- natural resources inventories for conservation policy planning;
- studies of the interactions of human and other natural resources, with an emphasis on use and preservation .12

BANGLADESH

Among other things, Bangladesh's development goals include disaster warning to prevent damage and loss of life from severe storms, as well as increased agricultural production and monitoring of crop production. These two areas generate a need for the following types of resource information:

- cloud patterns and storm warning on a real-time basis;
- data on rainfall, soil moisture, hours of sunshine, and crop stress, in order to monitor crop growth and crop conditions;
- data on land use and land use change to plan better agricultural development and irrigation;
- flood patterns and water levels to plan better cropping patterns. [13]

DOMINICAN REPUBLIC

Forests represent one of the Dominican Republic's primary natural resources. Before an aerial photographic survey in 1965 and 1966, the Government of the Dominican Republic believed that 40 percent of its total land area was forested, 750,000 hectares in high-quality pine. The survey showed that less than 11.5 percent of the land was actually in forest, and only 215,000 hectares in pine. This information profoundly affected its previous planning estimates.1[4] Continued observation using satellite data could help the country survey their forest resources on a regular basis.

Potential Fishery Applications

To date, very little work has been done in developing countries with respect to fisheries development. However, "new developments in marine-related remote sensing, such as synthetic aperture radar for wave studies, microwave radiometers for salinity measurements, and multispectral scanners for chlorophyll mapping"Is present new opportunities for the use of satellites in fisheries development throughout the world.

Although U.S. research on using satellite remote sensing for fisheries is in its infant stages, it has not begun in developing countries. Generally, Landsat's

[10] T. K. Cannon, et al., "Application of Remote Sensing Techniques to Forest Vegetation Surveys in Tropical Areas and Urban Fringe Land Use Problems in Coasta Rica," m *Proceedings of the Twelfth International Symposium of Remote Sensing of Environment,* (Ann Arbor, Ml: Environmental Research Institute of Michigan, 1978), p. 2081.

[11] Resources Development Associates, "Agricultural Resource Inventory and Base Mapping in Sri Lanka, A Program Evaluation and Assessment, " Los Altos, CA Nov., 1976.

[12] Robert Campbell, et al., *Land Use Inventory and Environmental planning Project: Peru* (Los Altos, CA: RDA, April 1980).

[13] Harvey Newton, et al., *Early warning Crop Yield Modelling in Bangladesh* (Diamond Springs, CA: RDA, April 1982).

'Organization of American States, "An Exploratory Survey of the Dominican Republic, " in *Physical Resources Investigations for Economic Development, A Casebook of OAS Field Experience in Latin America,* General Secretariat, Washington, DC, 1969, pp. 212-214.

[15] Vic Klemas, "Technology Transfer to Developing Countries: Future Use of Remote Sensing in Biological Marine Resource Development, " Background paper for Ocean Policy Committee, National Academy of Sciences Workshop on Future of International Cooperation in Marine Technology, Science, and Fisheries, La Jolla, CA, Jan. 18-22, 1981.

sensors have very limited application to marine studies; thermal infrared and microwave sensors have shown good potential. While some developing countries receive low-resolution thermal infrared imagery from the GOES satellites, they would not be able to receive and analyze thermal infrared or microwave data of high resolution from ocean satellites if they were flying because they do not possess the high capacity computers needed to process such data. However, these kinds of data are necessary to pursue useful analyses of the coasts and oceans. In addition, as the previous section on ocean remote sensing emphasized, those applications require more research and efforts to demonstrate whether they will work or be cost effective.

The importance of accurate information about natural resources is clear, particularly as developing countries strive for self-sufficiency. Economic development requires discovering what resources are available and then organizing the information so that informed decisions can be made about the development and exploitation of natural resources. The key is the information base. Most developing countries lack a consistent, homogeneous, and complete data base from which to work. They also lack the means to acquire, sift, and analyze the new data they need. The preliminary surveys and maps they have made, largely with the help of the United States and the European countries, represent only the beginning of the long and difficult process of information management.[16]

Institutional Factors Influencing the Use of Satellite Remote Sensing

A variety of nontechnical factors, including institutional and political ones, affect the use of satellites in developing countries.

Domestic Institutional Factors

It is in the routine use of data, not its initial collection, that the operational use of remote sensing data meets its toughest test. ' Therefore, in order to determine what type of interpretation and analysis procedures will best serve a developing country's needs, it is necessary to understand what internal institutional and technological capabilities already exist in a given country,

As one report[18] suggests, prior to the development of self-supporting satellite data users in developing countries, an institutional framework to support the use of that data and a capacity for internal problem solving are essential. In the absence of this homework, transferring or selling technology to end-users does little to help them achieve any of their objectives with remote sensing data. Unfortunately, many international technology transfer projects have overemphasized the immediate use of equipment and technologies and have failed to aid in building an infrastructure or internal organization to support continued use of the data. The Wallender study[19] concluded that efforts to build the technical capabilities associated with later stages of development will fail unless the objectives of earlier stages have been realized.

Because satellite data is likely to be used by many interested parties, including hydrologists, geologists, soils scientists, agricultural specialists, physical planners, or geographers, economies of scale can be realized by promoting multiple uses of satellite data. In other words, "the more numerous and diversified the users of remote sensing are, the more economically feasible it is for a country to sustain a national analysis capability."[20] In addition, given limited manpower and budgetary resources, a focused resource and environmental information effort is also needed. Many ways of coordinating such activity are possible, depending on the country involved, its needs, resources, and political situation. The transfer agent, whether USAID or some private consulting firm, will not succeed until the developing country has developed an internal organization that can decide on its own to use satellite products and satellite technology. Foreign aid spent on transferring technology (hardware) might be better spent in developing an institutional and organizational infrastructure conducive to using remote sensing data.

The Training Constraint

Closely related to the development of an effective organizational context is the need to familiarize thoroughly the users of the technology with the technology itself and its value for helping them perform their work. This primarily means training people and coordinating manpower and equipment.

As a review of AID projects in the Sahel pointed out:

> [the] factors which impeded the maximum transfer"of technical expertise to the counterparts and the application of results to development programs were: the scant availability of appropriately trained counterpart resource analysts; and the lack of an extended period of practical training and technical assistance after inventory completion, during which expatriate analysts

[16] See, for example, "Satellite Remote Sensing for Developing Countries," Proceedings of an EARSel-ESA Symposium, Igls, Austria, Apr. 20-21, 1982 (ESA- SP-1 75).

[17] NAS Study, op. cit., p. 117.

[18] Harvey Wallender, et al., *Technology Transfer and Management in Developing Countries* (Cambridge, MA: Ballinger Publishing Co., 1979), ch. 3.

[19] Ibid.

[20] *Remote Sensing From Space*, op. cit., p. 125.

could gradually withdraw as the host country personnel gained self-sufficiency in the implementation process. **These** are issues which can and should be accounted for in future resource inventories in Africa. They must be considered in the preliminary stages of project design by the funding agency and the host country, so that adequate time and resources for them are allocated .[21]

In developing countries where trained personnel do not exist, training is critical, not only in resource survey and map interpretation and mapmaking techniques, but also in equipment operation and upkeep. Where a country does not have the personnel or tools to provide upkeep on electronic equipment, it quickly becomes useless.

Training in both general topics and specific subjects is needed. General training includes educating scientists and policy makers about the technology and its limitations and advantages. Such exposure is essential to starting a country on a road toward the adoption of the technology.

Specific training involves coupling the training of specialists in the fields to be explored (e.g., weather, climate, water resources, geology) with training in the interpretation of remotely sensed data. This process may be extensive and take several years. Such training may well consist of courses in the United States, on-the-job training either in the United States or in the host country, and day-to-day interactions between foreign and host country participants.

Training programs of even the best quality may not be successful, however, unless developing countries are able to commit professional personnel on a long-term basis:

In most VVest African countries, the supply of educated scientists and planners is extremely limited. The few specialists who do exist are often quickly cycled through government hierarchies and do not remain in positions where their project experience can be technically or managerially utilized. The shortage of scientists sometimes necessitates that government administrators be given assignments that would be more appropriately filled by people trained in the earth sciences. This was the case in the Volta Basin project where three of the seven counterparts were government administrators or department heads who already had full-time administrative positions and corresponding responsibi lities.[22]

These administrators usually return to their old duties and are unable to continue supporting the use of remote sensing:

program success also requires the full commitment of scientifically trained counterparts for an extended period immediately *following* the inventory, during which resource development programs are initiated. The inclusion and funding of this extended implementation period is a critical element of any natural resource inventory. It is also one which has often been overlooked by sponsor agencies in project design. The result is that priorities are shifted, counterparts resume, or are reassigned to other duties, and inventory products are shelved. Development projects may then continue on an ad hoc basis, without the benefit of the management resource.[23]

To develop self-supporting users who can generally solve their own problems, it will be essential to construct long-term, intensive training programs. If training is treated haphazardly, the potential for satellite applications in developing countries will be severely hampered.

In sum, the development of satellite remote sensing users in developing countries will rely on effective technology transfer that encourages these countries permanently to adopt satellite technology. Such technology transfer will be successful only if it assists in the development of an effective organizational context. However, the adoption of satellite technology in developing countries also depends on political factors.

Political Constraints

During the last decade, the control of information has emerged as a critical component of the North-South debate over a New International Order. In particular, information that is carried across national boundaries without the consent of all parties has been seen by some countries as a threat to their national sovereignty and their "sovereign right" to control information about themselves and their resources (including resources within a 200-mile Extended Economic Zone). Earth resource sensing satellites pose a unique problem because they *collect* information about one country and disseminate it to many other countries .24

Sovereignty issues have been discussed and debated throughout the legal and political debate in the U. N., focusing on the development of an international regime for Earth resource sensing satellites. The sovereignty debate has centered on the desire of some countries to control the dissemination of data obtained about their country from space. This issue is the heart of the argument in the U.S. debate; a prohibition against open dissemination without consent is contained in an early Argentine-Brazilian draft treaty, and

[21] Lynda Hall, "Factors in the Effective Utilization of a Landsat Related Inventory in West Africa" (Baltimore, MD: National Conference on Energy Resource Management, 1982), p. 4.
[22] Ibid , p. 5

[23] Ibid., p. 6.
[24] See discussion on this and similar issues in *UNISPACE '82: A Context for International Cooperation and Competition,* op. cit., pp. 24-28,

also in an early French-Russian set of draft principles regarding control of remote sensing from space.[25]

The issue stems from a basic disagreement over control of information. Whereas the United States admits to a nation's sovereignty over its natural resources, it does not agree to a nation's sovereignty over information about those resources, Developing countries fear being exploited by other countries and especially by multinational corporations. The importance of information is dramatically evident in the search for new forms of mutually agreeable relations–new contracts-between multinational corporations and developing countries. Differential access to information and the ability to apply it are crucial elements in bargaining power between multinational corporations and the developing countries.

The United States questions developing countries' concerns over economic exploitation on three grounds:

> First, developing countries are entering into mature, mutually beneficial resource exploitation relationships with foreign interests, without forswearing their rights to such ultimate sanctions as nationalization andlor expropriation. Second, the physical control of resources and of access to resource sites are the trump cards, not possession of tentative and unverified data. Third, as developing countries acquire their own remote sensing expertise, whether indigenous or procured from outside consultants, the margin of information disadvantage can lose a good measure of its significance.[26]

The United States further suggests that imposition of some form of restrictive data dissemination regime would create two "classes" of countries; those with data acquisition capabilities and those without. It has argued that this would create more inequality than a regime of open dissemination.

Such a point of view suggests that developing countries should emphasize efforts to develop capabilities to use technology and data relevant to their capacities while working to maintain equal access to worldwide data and information networks. There is, however, a serious tradeoff involved here. If developing countries make:

> . . . vigorous attempts to be integrated into the international data market, many of them may face the prospects of increased dependence on imported technology and equipment; on the other hand, if they stand aloof, they may have the problems associated with a very limited access to the rapidly expanding pool of machine-readable data.[27]

The avoidance of this tradeoff will be extremely difficult. It is important, though, that information asymmetries (either real or imagined) be dealt with, because it is likely that an increase in the knowledge and capabilities of developing countries would lead to smoother international negotiations. At present, international negotiations over access to data and information may be clouded with political rhetoric from countries that feel they are at an information disadvantage; perceiving asymmetries in access to information, they tend to block agreement.

Cruise O'Brien and Helleiner suggest that "the consequences of imperfect information are nowhere more dramatic than in the resource sector."[28] Private users, with greater information in early stages of resource exploitation, usually strike what appears to be a good bargain. As exploration proceeds and the host government learns more, it may find that it gave away too much early on. This leads to what is known as the "ob solescing bargain." When this occurs, host countries push for renegotiation and, in fact, a great deal of renegotiation has occurred in recent years.[29] As a result, an impasse "has developed between host governments in developing countries and the resource transnationals (multinationals) which has produced a marked decline in resource exploration and development in the Third World in recent years which is in the interests of neither.[30]

The elimination of information asymmetries might provide a common knowledge base and common ground for negotiation. Increased knowledge in developing countries would enable them to bargain more effectively and efficiently.

The issue of dependence cannot be easily dismissed. Developing countries do not want, for political and practical reasons, to become dependent on one source of resource information vital to their national planning–particularly a source over which they have no control. As dependence increases, the demand for a voice in the planning of the system will grow.

It should be noted that U.S. policies to make data and technology available have to a great extent mitigated the most serious concerns of developed and de-

[25] See U.N. Document A/AC,1/1047 (Oct. 15, 1974), Article IX of Latin America Draft Treaty. Although positions on this issue have shifted, it is still a major point for debate.

[26] *Remote Sensing from Space,* op. cit., pp. 147-148.

[27] "Transnational Corporations and Transborder Data Flows: A Technical Paper," U.N. Centre of Transnational Corporations, ST/CTC/23, New York, 1982.

[28] Rita Cruise O' Brien and Gerald Helleiner, "The Political Economy of Information in a Changing International Economic Order," in *International Organization* 34:4, Autumn 1980, p. 457.

[29] U.N. Commission on Transnational Corporations, "Transnational Corporations in World Development: A Re-Examination," U.N. Economic and Social Council E/C10/28, Mar. 20, 1978.

[30] J. Favre and H. La Lauch, "Natural Resources Forum," vol. 5, No. 4 (Boston, MA: D. Ridel Pub. Co., October 1981), pp. 327-347.

veloping countries who, despite their U.N. posturing, have taken to building satellite remote sensing programs based on Landsat technology. One can see this not only in the French and Japanese remote sensing programs, which will fly Landsat compatible sensors, but also in the developing countries which focus their space activities around remote sensing. The effect of the Landsat system and Landsat policy has been to generate expectations of data continuity. Developing countries are now extremely worried about a cut-off in available data should the Landsat program be terminated.[31]

j! Second U N ISPACE Conference, *Draft Report of the Conference,* A/CONF.101/3, Mar. 20, 1982., p. 77.

APPENDIX 7B.–U.S. ENVIRONMENTAL SATELLITES, 1960-85

Satellite	Purpose(l)	Launch	Average(*) Altitude (km)	Ceased Operation	Remarks(3)
TIROS I	R	04/01 /60	720	06/19/60	First weather satellite providing cloud cover photography.
TIROS 2	R	11 /23/60	672	02/01 /61	
TIROS 3	R	07/12/61	760	10/30/61	
TIROS 4	R	02/08/62	773	“06/12/62	
TIROS 5	R	06/19/62	694	10/1 1 /63	
TIROS 6	R	09/ 18/62	694	10/ 11 /63	
TIROS 7	R	06/19/63	645	02/03/66	
TIROS 8	R	12/21 /63	749	01 /22/66	First APT satellite.
Nimbus 1	R	08/28/64	S/677	09/23/64	Carried AVCS, APT,and High Resolution Infrared Radiometer for night pictures.
TIROS 9	R	01/22/65	S11630	02/15/67	First TIROS satellite in Sun-synchronous orbit.
TIROS 10	O	07/01 /65	S1792	07/03/66	
ESSA 1	0	02/03/66	S/765	05/08/67	First satellite in the operational system; carried 2 wide-angle TV cameras.
ESSA 2	0	02/28/66	S/1376	10/16/70	Carried APT cameras. APT carried onall even-numbered ESSA satellites
Nimbus 2	R	05/15/66	S/1 136	01/18/69	
ESSA 3	o	10/02/66	S/1427	10/09/68	Carried first AVCS cameras. ABCS carried on all odd-numbered ESSA satellites.
ATS 1	R	12/06/66	G135,765	10/16/72 (pictures)	WEFAX discontinued December 31, 1978.
ESSA 4	o	01 /26/67	s/1373	10/06/67	
ATS 2	R	04/05/67	—	—	Unstable attitude-data not useful.
ESSA 5	o	04/20/67	S11379	02/20/70	
ATS 3	R	11 /05/67	G135,815	10/30/75 (pictures)	WEFAX discontinued December 31, 1978.
ESSA 6	o	11 /10/67	SI1437	11/04/69	

Satellite	Purpose(l)	Launch	Average Altitude (km)[2]	Ceased Operation	Remarks[3]
ESSA 7	0	08/16/68	s/1440	07/19/69	
ESSSA 8	0	12/ 15/68	S/1429	03/12/76	
ESSA 9	0	02/26/69	S/1456	11/15/73	
Nimbus 3	R	04/ 14/69	S/II00	01/22/72	Provided first vertical temperature profile data of the atmosphere on a global basis.
ITOS 1	R/O	01 /23/70	S/1456	06/17/71	Second generation prototype.
Nimbus 4	R	04/08/70	S/1108	09/30/80	
NOAA 1	0	12/1 1 /70	S/1438	08/19/71	First NOAA funded second generation satellite.
ITOS B	0	10/21 /71	—	—	Failed to orbit.
Landsat 1	R	07/23/72	S/918	01/16/78	
NOAA 2	0	10/15/72	S/1460	01/30/75	First operational satellite to carryall scanning radiometer.
Nimbus 5	R	12/12/72	S/IIIO	03/29/83	
ITOS E	0	07/16/73	—	—	Failed orbit.
NOAA 3	_0-	11/06/73	s/1510	08/31/76	First operational satellite to permi(t direct broadcast of VTPR data.
SMS 1	RIO	05/17/74	G/35,788	01/29/81	Deactivated. Boosted out of geosynchronous orbit,
NOAA 4	0	11/15/74	S/1460	11/18/78	Deactivated.
Landsat 2	R	01/22/75	S/918	03/31/83	On Standby.
SMS 2	R/O	02/06/75	G/35,800	08/05/82	Deactivated. Boosted out of geosynchronous orbit.
Nimbus 6	R	06/12/75	s/IIIO	03/29/83	
GOES 1	0	10/16/75	G/35,796	—	First NOAA operational geostationary satellite; 130°W on standby.
NOAA 5	0	07/29/76	s/1511	07/16/79	Deactivated.
GOES 2	0	06/16/77	G/35,787	—	Second NOAA operational geostationary satellite; 113°W supporting Central WEFAX.

Satellite	Purpose[l)	Launch	Average[2] Altitude (km)	Ceased Operation	Remarks[3]
Landsat 3	R	03/05/78	S/918	03/31 /83	First Landsat with infrared capability. Now on standby.
GOES 3	o	06/16/78	G/35,784	—	On standby. Moving to 135°W.
Seasat 1	R	06/26/78	850	10/10/78	Electrical failure.
TIROS-N	RIO	10/13/78	S/850	02/27/81	Deactivated.
Nimbus 7	R	10/24/78	S/954	—	Carrying Coastal Zone Color Scanner.
NOAA 6	o	06/27/79	S/807	—	First NOAA funded TIROS-N system satellite.
NOAA B	0	05/30/80	-	—	Failed to achieve an operational orbit.
GOES 4	0	09/09/80	G/35,782	—	First geostationary satellite to carry the VISSR Atmospheric Sounder (VAS) which has now failed. At 139°W. Provides west, WEFAX, and DCS.
GOES 5	0	05/22/81	G/35,785	–	At 75°W; also carried VAS. Now failed. Provides east DCS, WEFAX, and relay of GOES 6 imagery.
NOAA 7	0	06/23/81	S/847	–	Second NOAA funded TIROS-N system satellite.
Landsat 4	0	07/ 16/82	S/7oo	–	Carries MSS and TM.
NOAA 8“	0	03/28/83	S/815	06/12/84	Had search and rescue capability.
GOES 6	0	04/28/83	G/35,791	–	Alternates between 98°W and 108°W. Only spacecraft with operating VAS.
NOAA 9	0	12/12/84	S/815	–	Has search and rescue capability and sensors for ozone and earth radiation budget.

(l) R. **Research; O-Operations;** R/O-Operational **Prototype.**

(2) **S-Sun-Synchronous;** G-Geosynchronous,

~) **APT-Automatic** picture Transmission; **AVCS-Advanced** Vidicon Camera System; WEFAX-Weather Facsimile; **VTPR-**Vertical Temperature **Profie** Radiometer; **VISSR-Visible** Infrared Spin-Scan Radiometer; **VAS-VISSR** Atmospheric Sounder; **MSS-Multi** Spectral Scanner; TM-Thematic Mapper; **DCS-Data** Collection System

● NOAA 8 is once again in operation.