National Remote Sensing Needs and Capabilities 2

A comprehensive strategy for satellite remote sensing must take into account the specific features of remote sensing technologies and applications. Remote sensing satellite systems have historically been expensive to develop and operate, involving long time lines for planning, procurement, and integration into operations.[1] The process of developing, operating, and using the data from remote sensing satellites involves complicated and indirect linkages among many actors at many levels, including system contractors, commercial and government satellite operators, data managers, and the ultimate users of the derived information.

Remote sensing satellite systems serve a variety of purposes, depending on their specific design characteristics (box **2-1**). Systems designed for one purpose often differ markedly from those designed for other purposes. Thus, for example, land remote sensing systems are quite different from systems designed to gather meteorological data.

The requirements of different applications often overlap in complicated ways, so systems designed for one purpose can serve a range of other purposes, perhaps with some modifications. For example, the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration's (NOAA's) Polar-orbiting Operational Environmental Sat-

[1] Prospective private-sector suppliers of remotely sensed data are attempting to shorten the time taken to deliver a satellite to orbit. On June 8, 1994, the National Aeronautics and Space Administration (NASA) announced contract awards for two new Smallsat Earth observation satellites. NASA expects them to demonstrate advanced sensor technologies, cost less than $60 million each, and be developed, launched, and delivered on orbit in 24 months or less on a Pegasus launch vehicle

BOX 2-1: Design Characteristics of Remote Sensing Satellite Systems

Remote sensing satellites and their sensors differ in many characteristics:

- ***Type of sensor.*** Some sensors measure radiated and reflected light passively, and others transmit laser or microwave signals and measure the reflection.
- ***Spectral bands.*** Sensors measure electromagnetic radiation in radio, microwave, infrared, visible, and ultraviolet wavelengths.
- ***Radiometric resolution.*** Some sensors can make finer distinctions than others in the intensity of the observed radiation.
- ***Calibration.*** Sensors can be more or less highly calibrated with respect to how closely their output signal corresponds to the actual physical property being measured.
- ***Spatial resolution.*** Sensors may resolve or aggregate data on spatial scales that range from tens of kilometers to less than a meter.
- ***Spatial coverage.*** Sensors vary in the area they cover, from a few kilometers to thousands of kilometers.
- ***Revisit times.*** The time interval between satellite observations of a given location can range from less than a day to several weeks, depending on orbit and spatial coverage.
- ***Stereoscopic imaging.*** Some satellites can view the same scene at nearly the same time from more than one viewing angle.

Designing instruments and spacecraft involves complex tradeoffs among these characteristics, for example, among spatial resolution, spatial coverage, and revisit time, or between sensitivity and spectral resolution. Selected designs also involve tradeoffs among these technical characteristics, system costs, and technological risks.

The data provided by satellite sensors reveal information about the dynamics, chemistry, and biological activities on Earth's land and ocean surface and in the atmosphere. Widespread samplings of in situ data are often critical to the calibration, validation, and interpretation of satellite-based measurements. This information, in turn, supports a wide range of scientific and operational applications, each with its own distinct set of data requirements. For example, sensors used for global vegetation monitoring would not be much use for mapping.

SOURCE: Office of Technology Assessment, 1994.

ellite (POES), designed primarily to measure cloud cover and surface temperatures, can also monitor land vegetation on a global scale. The distinct but often synergistic requirements of remote sensing applications lead to complicated policy decisions, where choices made regarding a particular application of data have important effects on other potential applications.

This chapter begins with a discussion of the uses of remote sensing, including its use in existing operational and research programs. It then reviews the satellite programs of the agencies that develop and operate remote sensing systems. Finally, it describes the process for matching remote sensing capabilities to data needs and discusses possible improvements in that process.

NATIONAL USES OF REMOTE SENSING

As described in chapter 1, remote sensing programs serve a variety of national needs, including national security, technology development, and economic growth. This section concentrates on the direct application of civilian remote sensing systems to meet national needs for weather forecasting, scientific research, and other purposes. It describes the uses of satellites for these purposes and the federal agencies and other institutions responsible for them.

Monitoring Weather and Climate

Weather Forecasting

Satellites are used to observe and measure a wide range of atmospheric properties and processes to support increasingly sophisticated weather warning and forecasting activities. Imaging instruments provide detailed pictures of clouds and cloud motions, as well as measurements of sea-surface temperature. Sounders collect data in several infrared or microwave spectral bands that are processed to provide profiles of temperature and moisture as a function of altitude.[2] Radar altimeters, scatterometers, and imagers (synthetic aperture radar, or SAR) can measure ocean currents, sea-surface winds, and the structure of snow and ice cover.

Several federal agencies have distinct but overlapping mandates for monitoring and forecasting weather. The National Weather Service of NOAA has the primary responsibility for providing severe storm and flood warnings as well as short- and medium-range weather forecasts. The Federal Aviation Administration provides specialized forecasts and warnings for aircraft. The Defense Meteorological Satellite Program (DMSP) at the Department of Defense (DOD) supports the specialized needs of the military and intelligence services, which emphasize global capabilities to monitor clouds and visibility in support of combat and reconnaissance activities and to monitor sea-surface conditions in support of naval operations. Several private companies also provide both general and specialized weather forecast services commercially. NOAA, the Air Force, and the Navy share responsibility for processing the data from NOAA and DMSP satellites: NOAA for soundings, the Air Force for cloud imagery, and the Navy for ocean-surface data.

Global Change Research

Global change research aims to monitor and understand the processes of natural and anthropogenic changes[3] in Earth's physical, biological, and human environments. Satellites support this research by providing measurements of stratospheric ozone and ozone-depleting chemicals: by providing long-term scientific records of Earth's climate; by monitoring Earth's radiation balance and the concentrations of greenhouse gases and aerosols; by monitoring ocean temperatures, currents, and biological productivity; by monitoring the volume of ice sheets and glaciers; and by monitoring land use and vegetation. These variables provide critical information on the complex processes and interactions of global environmental change, including climate change.

The U.S. Global Change Research Program (USGCRP) was established as a Presidential Initiative and by congressional mandate in 1990 to encourage the development of a more complete scientific understanding of global environmental changes and to provide better information for policymakers in crafting responses to those changes (box 2-2). The USGCRP coordinates the activities of 11 federal agencies and organizations, although NASA, NOAA, the National Science Foundation, and the Department of Energy will contribute 91 percent of the funding in FY 1995. NASA alone is expected to contribute 68 percent of the total.

Long-Term Monitoring of Climate and Other Earth Systems

Scientists recognize the need for continuous, global, well-calibrated measurements of a broad range of critical environmental indicators over periods of several decades.

> The Earth undergoes major processes of change that are reckoned in scales of decades to millennia. Decades of continuous calibrated

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[2] Generally, the larger the number of channels, the better the vertical resolution of the sounder. Hence, the proposed Advanced Infrared Sounder (AIRS) has 2,300 channels compared with 20 channels in the High-Resolution Infrared Sounder (HIRS) it would replace.

[3] Changes caused by people

BOX 2-2: The U.S. Global Change Research Program

Global environmental and climate change issues have generated substantial international research. Increased data on climate change and heightened international concern convinced the U.S. government of the need to address global change in a systematic way. In 1989, the director of the Office of Science and Technology Policy, D. Allan Bromley, established the interagency U.S. Global Change Research Program (USGCRP) under the Committee on Earth and Environmental Sciences. Established as a Presidential Initiative in the FY 1990 budget, the goal of the program is to provide the scientific basis for the development of sound national and international policies related to global environmental problems. The USGCRP has seven main science elements:

- climate and hydrodynamic systems,
- biogeochemical dynamics,
- ecological systems and dynamics,
- Earth systems history,
- human interaction,
- solid Earth processes, and
- solar influences.

Participation in the USGCRP involves 11 government agencies and other organizations (including the Smithsonian Institution and the Tennessee Valley Authority). Research efforts coordinated through the USGCRP seek a better understanding of global change and the effects of a changing environment on our daily lives. Most research projects will rely on data from remote observations of atmosphere, oceans, and land. Coordination of research across agencies should eliminate duplication and increase cooperation, and at a minimum, will promote communication among agencies. The Committee on Environment and Natural Resources (CENR) of the National Science and Technology Council makes suggestions to federal agencies, and federal agencies can raise items for consideration through CENR. Although this process can be cumbersome, most researchers acknowledge that the program has brought a degree of coordination never before seen in federally sponsored research.

SOURCE: Committee on Environment and Natural Resources Research of the National Science and Technology Council, *Our Changing Planet, the FY 1995 U.S. Global Change Research Program* (Washington, DC: Coordination Office of the U.S. Global Change Research Program, 1994).

> global observations from space and at strategically located sites on the Earth's land and oceans will be required to document climate and ecosystem changes and for differentiating natural variability from human-induced changes.[4]

An operational satellite program is ideally suited to these purposes. Yet, NASA's Earth Observing System (EOS), the principal space-based component of the USGCRP, is scheduled to operate for only 15 years. EOS will gather data on climate and other environmental processes, which will help scientists determine which data are important for this long-term operational task. No federal agency has the combination of mission focus and resources needed to support long-term monitoring.

Land Remote Sensing

Mapping and Planning

The development of highly capable computer workstations and mapping software known as geographic information systems (GIS) has spurred

[4] U.S. Congress, Office of Technology Assessment, *U.S. Global Change Research Program and NASA's Earth Observing System*, OTA-BP-ISC-122 (Washington, DC: U.S. Government Printing Office, November 1993), p. 3.

much of the current interest in satellite remote sensing.[5] Within the federal government, the U.S. Geological Survey (USGS) of the Department of the Interior (DOI) has the primary responsibility for civilian mapping whereas other agencies use GIS for more specialized purposes, including military and intelligence applications. USGS also leads an interagency coordination effort through the Federal Geographic Data Committee to develop a National Spatial Data Infrastructure,[6] which would provide a consistent nationwide basis for geographic data and information.

The U.S. Department of Transportation and state and local transportation departments make use of remote] y sensed data from a aircraft and from SPOT (Système pour I 'Observation de la Terre) and Landsat to assist in planning major highways and other transportation routes. Pipeline companies use similar data sets to help plan pipeline routes and monitor development near pipelines.[7] State and local governments make extensive use of remotely sensed data for land-use planning and for general infrastructure development.

The Defense Mapping Agency (DMA) has the primary responsibility for creating maps used in military assessment and planning and for fighting wars. During the Persian Gulf Conflict, DMA generated maps of the Persian Gulf region based on SPOT and Landsat data. Because these maps were created using unclassified data, the U.S. military was able to share them with U.S. allies without fear of compromising classified data or the means of generating these data.

The Army Corps of Engineers makes extensive use of remotely sensed data and GIS to map project sites and assess the condition of dams, river channels, and levies in major watersheds. The Corps has projects throughout the world that make use of remotely sensed data.

Terrestrial Monitoring and Natural Resource Management

Remotely sensed land data support an extremely diverse set of natural resource monitoring and management applications.[8] This diversity reflects the diversity in natural, agricultural, residential, and other land-use types. It also leads to a diverse set of data requirements and data-processing techniques, making it difficult to develop a common set of requirements for a single land remote sensing sysem. As small, relatively inexpensive satellites increase in capability, they will be designed to target "niche" markets for satellite data.

Crop monitoring

Using data from two channels of NOAA's AVHRR sensor or from the Landsat sensors yields a vegetation index—roughly, "greenness' '—which provides information on the condition of vegetation. More detailed information can distinguish among various crop types. The Foreign Agricultural Service at the U.S. Department of Agriculture (USDA) combines the vegetation index with meteorological information to forecast crop production around the world. USDA's National Agricultural Statistics Service relies on aerial photography to provide higher-resolution information on domestic crops and to monitor compliance with agricultural land-use restrictions.[9]

[5] U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets,* OTA-ISS-604 (Washington, DC [J. S. Government Printing Office. September 1994), ch. 2.

[6] Recommendation DOI-3 in the National Performance *Review* (,4. Gore, *From Red Tape to Results: Creating a Government That Works Better and Costs Less*, report of the National Performance Review (Washington, DC: Office of the Vice president, Sept. 7, 1993)) and Executive Order 12906, Apr. I 1, I 994.

[7] For a discussion of the use of remotely sensed data for pipeline planning and management, see U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., app. B.

[8] Ibid., apps. B and C.

[9] The European Union uses data from France's SPOT satellite system for this purpose.

Managing federal lands

USDA and DOI use satellite data in managing federal lands. The Forest Service and the National Park Service each incorporate data from various land remote sensing systems and other sources into GIS to monitor forest harvests, natural habitats, and conditions that pose the risk of wildfires.[10] The Bureau of Land Management performs similar functions on other federal lands, including forests and range land. The Army Corps of Engineers uses satellite imagery to monitor inland and coastal waterways for flood control, flow management, and coastal erosion management.

Environmental regulation

Satellite monitoring can also support programs for regulating the use of private activities on public and private lands. The United States has programs for protecting wetlands, endangered species, and erodible farmlands administered by the Environmental Protection Agency (EPA), DOI, NOAA, the Army Corps of Engineers, and USDA. These programs rely on onsite monitoring as well as aerial and satellite remote sensing.

Geology and Mining

Satellite observations support a variety of geological observations. Moderate-resolution, multispectral land remote sensing systems can distinguish among mineral types based on their infrared reflectivity y and can observe large-scale geological features such as fault regions. These measurements are useful both scientifically and for mineral prospecting. The Laser Geodynamics Satellite (LAGEOS) and the Global Positioning System (GPS) satellites also provide precision measurements of position that can be used to monitor tectonic activity and earthquake risks.

Private Sector

Small private firms have provided processing and analytic data services since the beginning of satellite remote sensing. These so-called value-added companies take raw remotely sensed data and add other goespatial data to them to generate information of value to a wide selection of governmental and private customers. State and local governments have made significant use of the information provided by these firms, generally in the form of maps used for monitoring and planning. This small but rapidly growing sector of the U.S. economy has helped fuel the development and use of GIS and imaging-processing software.[11] The United States leads the world in the development of the remote sensing value-added industry.

Ocean Remote Sensing

In addition to providing greater understanding of ocean processes for global change research, the use of satellite data for ocean monitoring can support a variety of operational activities. Ocean-color sensors can observe coastal pollution and provide a measure of biological activity for fishing and for the management of fisheries. Measurements of sea-surface winds, waves, currents, and ice can be critical both for shipping and for weather forecasting. Monitoring the processes that underlie the El Niño-Southern Oscillation phenomenon could lead to greatly improved seasonal and interannual weather forecasts. NOAA and the U.S. Navy have the principal responsibility for the United States' operational ocean monitoring and rely primarily on in situ measurements from ground stations and radiosonde balloons and on sea-surface wind and temperature data from the NOAA and DMSP meteorological satellites.

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[10] U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., app. C.

[11] Sales of remote sensing value-added firms totaled an estimated $300 million in 1992. They are growing at rates between 15 and 20 percent per year. See U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., ch. 4.

Other Needs

Public Safety

Severe storms, floods, fires, earthquakes, and volcanic eruptions can seriously disrupt the orderly flow of commerce and can cause displacement and great hardships in people's lives. In the United States. the Federal Emergency Management Agency (FEMA) has the responsibility for managing the federal responses to public emergencies. FEMA is beginning to use remotely sensed data from aircraft and from satellites to assess damage from natural disasters and to plan appropriate responses. GIS technologies have proved especially useful in creating geographic overlays that show the extent of damage, the locations of potential emergency centers, and the best routes for moving people and emergency supplies through affected areas. State and local governments feed into the development of the GIS by supplying data about the locations of state and local facilities. [2] For example, the Army Corps of Engineers, FEMA, and state agencies collaborated on assessing damage from the 1992 floods along the Missouri and Mississippi Rivers. Such assessments helped in determining which areas were most severely affected and how to allocate disaster-relief funding.

International Development Assistance

Information provided by satellites can be extremely useful in planning and administering international relief and development-assistance programs. The U.S. Agency for International Development (USAID) uses low-resolution vegetative-index data from satellites in its Famine Early Warning System (FEWS) program to monitor possible famine conditions in several regions of Africa. Information from FEWS helps in planning African food-assistance programs. Similarly, the African Emergency Locust/Grasshopper Assistance Program uses vegetative-index data to forecast the risk of insect infestations. USAID also provides technical assistance to developing countries in the use of remotely sensed data, particularly in GIS, and uses information from these systems to monitor the effectiveness of its programs. [14]

Research and Education

Universities have played a major part in conducting research on the use of remotely sensed data. Not only have university teams experimented with the characteristics of the data and determined their advantages and limitations, they have developed applications in a variety of disciplines such as archaeology, agriculture, forestry, geological exploration, mapping, and soil conservation. Universities have been the principal force behind providing a trained workforce for processing and analyzing remotely sensed data.

Public interest groups such as Ducks Unlimited, the World Wildlife Fund, World Resources Institute, and Conservation International have used remotely sensed data from aircraft, Landsat, and SPOT in their conservation efforts, both in the United States and abroad. The availability of relatively inexpensive software and hardware has made remote sensing data and techniques much more accessible in the 1990s than before, and it has helped public interest groups use the data. However, the work of universities and public interest groups has been inhibited by the relatively high cost of Landsat and SPOT data compared with what they can budget for the data. Such groups and universities look forward to much cheaper, more accessible data in the future. [5]

[12] See U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., app. B.

[13] Ibid., ch. 5.

[14] Ibid.. app. B.

[15] U. s. Congress, Office of *Technology Assessment,* International Security and Space Program, *Remotely Sensed Data from Space: Distribution, Pricing, and Applications*, background paper (Washington, DC: Office of Technology Assessment, July 1992), p. 17.

U.S. REMOTE SENSING CAPABILITIES

Several federal agencies and private firms are involved in developing and operating the satellites and managing the data systems necessary to meet the needs of users. In some cases, the operational agency is the same as the agency responsible for using the data, but for many applications, there is little or no overlap between the user and supplier agencies.

National Oceanic and Atmospheric Administration

NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) is responsible for managing the environmental satellite systems used to fulfill NOAA's missions in environmental forecasting and stewardship.[16] These systems consist of the Geostationary Operational Environmental Satellite (GOES) System and the Polar-orbiting Operational Environmental Satellite (POES) System,[17] both of which were developed by NASA, along with their associated data and information systems.

GOES consists of two operational satellites in geostationary orbits. One, called GOES-West, is stationed over the eastern Pacific Ocean and the other, GOES-East, is stationed over the Atlantic Ocean.[18] These two satellites provide continuous images of clouds over North and South America and the nearby oceans (box 2-3). GOES-8, launched in April 1994 and the first satellite in the upgraded GOES-Next series (figure 2-1), was designed to produce higher-resolution images, temperature measurements, and soundings. GOES-8 will replace the current GOES-East in early 1995 after extensive in-orbit testing and calibration.

POES consists of two polar-orbiting satellites (figure 2-2), each of which carries an imager for clouds and surface-temperature measurements and a pair of sounders for measuring the atmospheric temperature and moisture content, as well as other instruments (box 2-4). These satellites provide critical inputs to the National Weather Service's global weather forecast models.

NOAA also operates ground systems for processing, disseminating, and archiving meteorological data. It processes sounding data from both the NOAA and DMSP systems as part of the NOAA-DOD Shared Processing Network and makes the processed data available worldwide. NOAA's National Climatic Data Center, National Geophysical Data Center, and National Oceanographic Data Center serve as archives for environmental data from these and other satellite systems and make those data available worldwide.

Department of Defense

The Air Force developed and operates two DMSP satellites in polar orbits (figure 2-3), which provide DOD, the individual armed services, and the intelligence community with global information on clouds, visibility, and ocean conditions, in addition to weather forecast information (box 2-5). On the ground, the Air Force processes the visible, infrared, and cloud imagery; the Navy processes the sea-surface data; and NOAA archives the data.

The Navy developed and operated the Geodetic Satellite (Geosat) from 1985 to 1989 to provide detailed ocean altimetry and to map Earth's gravitational field for military purposes. Geosat data were initially classified, but some have since been made available to oceanographers for studies of

16 NOAA's strategic plan lists seven principal missions in two broad categories. For the environmental prediction, monitoring, and assessment category, NOAA has defined its missions as short-term environmental forecasting and warning, seasonal to interannual climate forecasting, and global change monitoring over periods of decades to centuries. The environmental protection category includes the environmental management of fisheries, endangered species, and coastal ecosystems, as well as navigation and positioning missions.

17 The POES satellites were known initially as Television Infrared Observing Satellites (TIROS) and are often referred to by that name.

18 After GOES-6 failed in 1989, Europe made Meteosat 3 available to NOAA in place of GOES-East.

19 For a description of the holdings of these archives, which also serve as World Data Centers of the International Council of Scientific Unions, see U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit.

BOX 2-3: The Geostationary Operational Environmental Satellite System

GOES satellites maintain orbital positions over the same Earth location along the equator at about 36,000 km (22,300 miles) above Earth, giving them the ability to make continuous observations of weather patterns over and near the United States. GOES satellites provide both visible-light and infrared images of cloud patterns, as well as "soundings," or indirect measurements, of the temperature and humidity throughout the atmosphere. NOAA has been operating GOES satellites since 1974. Data from these spacecraft provide input for the forecasting responsibilities of the National Weather Service. Among other applications, the GOES data assist in monitoring storms and provide advance warning of emerging severe weather. The vantage point of GOES satellites allows for the observation of large-scale weather events, which is required for forecasting small-scale events. Data from GOES satellites may be received free of charge directly from the satellite by individuals or organizations possessing a relatively inexpensive receiver.

To supply complete coverage of the continental United States, Alaska, and Hawaii, the GOES program requires two satellites, one nominally placed at 75° west longitude and one at 135° west longitude. The first GOES synchronous meteorological satellite (SMS/GOES) was placed in orbit in 1974. However, from 1984 to 1987 and from 1989 to the present time, as a result of sensor failures and a lack of replacements, only one GOES satellite has been available to provide coverage. GOES-7 is currently located at 112° west longitude, which provides important coverage for the eastern and central United States. GOES-7 was launched in 1987 and has already exceeded its 5-year design life. The United States has borrowed a Meteosat satellite from Europe to cover the East Coast and serve as a backup should GOES-7 fail. Meteosat-3 is now positioned at 75° west longitude. In April, NOAA launched GEOS-8, which will become operational in October and be placed at 75° west longitude by February 1995. NOAA will move GOES-7 to 135° west longitude and Meteosat to 70° west longitude.

SOURCE: National Oceanic and Atmospheric Administration, 1994.

ocean topography and dynamics. The Navy is developing a Geosat Follow-On (GFO) satellite for launch in 1996.

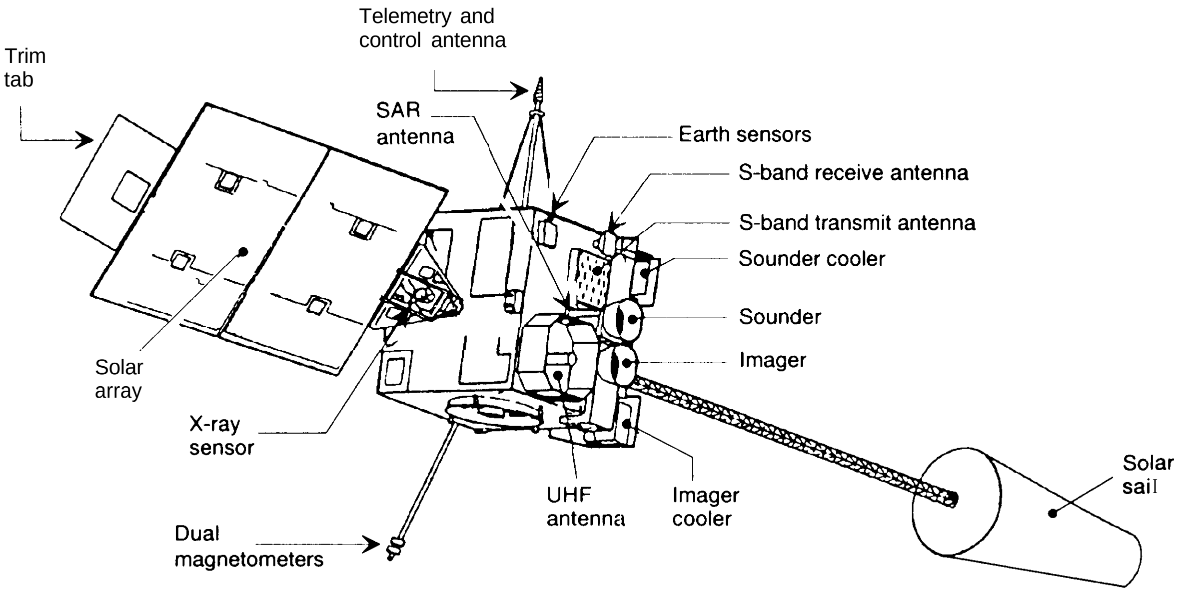
National Aeronautics and Space Administration

NASA's mission in remote sensing has traditionally focused on research and development. In the 1960s and 1970s, NASA developed NOAA's principal operational systems, TIROS (now POES) and GOES, as well as the NIMBUS, Landsat, and Seasat systems to demonstrate new capabilities in atmospheric, terrestrial, and oceanic remote sensing. However, NASA has no formal charter to operate these systems on a continuing basis.[20]

The Mission to Planet Earth (MTPE) forms the focus of NASA's current remote sensing activities. It includes the major EOS platforms (appendix A), scheduled for launch beginning in 1998, and several earlier observational projects. These include two ongoing projects: the Upper Atmospheric Research Satellite (UARS) for measuring stratospheric chemistry and ozone depletion and the U.S.-French TOPEX/Poseidon for measuring

[20] There is one exception to this rule. NASA has the mission of providing continuous global ozone data from the Total Ozone Mapping Spectrometer (TOMS).

FIGURE 2-1: Engineering Drawing of GOES-Next



NOTE: GOES-Next is the new generation of geostationary meteorological satellites developed for NOAA and built by Ford Aerospace

SOURCE: National Oceanic and Atmospheric Administration, 1994.

ocean topography and currents. A series of smaller Earth Probes will begin with the Total Ozone Mapping Spectrometer (TOMS) Earth Probe in late 1994.[21]

Recognizing the challenge of using the massive quantities of data to be produced by EOS, NASA has devoted a large fraction of the EOS budget to the EOS Data and Information System (EOSDIS).[22] EOSDIS is designed to provide ready data-access and data-processing capabilities to global change research scientists supported by NASA. It will also provide access for other users of remotely sensed data, including foreign researchers.

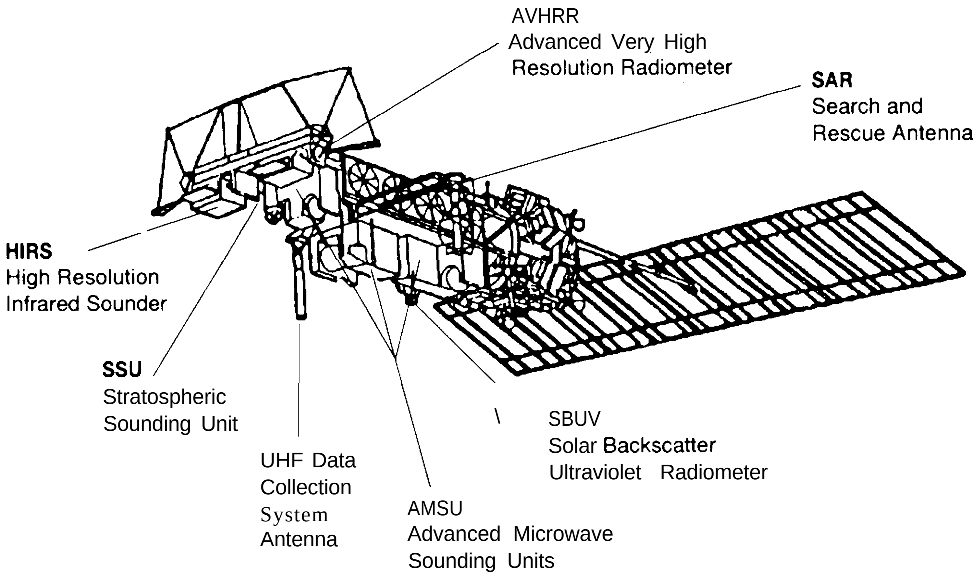
NASA also has a traditional role as the developer of new technologies for civil remote sensing, from the first TIROS weather satellite in 1960 and the first Landsat satellite in 1972 to the new systems being developed as part of MTPE. NOAA's environmental satellite systems reflect the legacy of NASA's technology-development efforts.

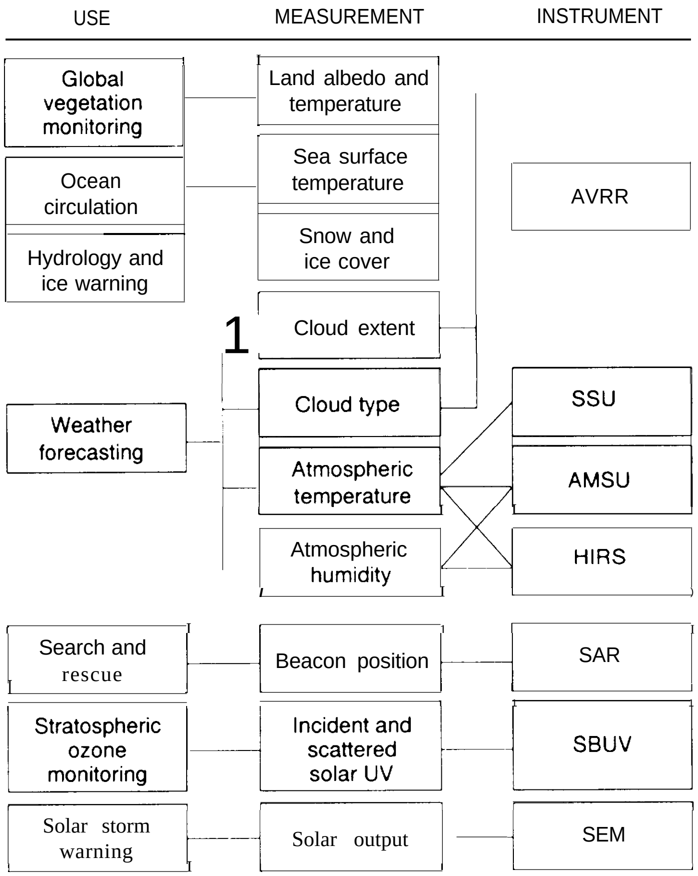
NASA has two programs that support the development of commercial remote sensing applications. The Centers for the Commercial Development of Space include the Space Remote Sensing Center located at the Stennis Space Center in Mississippi, which is developing commercial applications for agriculture and environmental monitor-

21 The launch of the TOMS Earth Probe has been delayed pending review of a recent failure of its Pegasus launch vehicle.

22 U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets,* op. cit., ch. 3; National Aeronautics and Space Administration, Office of Mission to Planet Earth, *EOSDIS: EOS Data and Information System* (Washington, DC: National Aeronautics and Space Administration, 1992); National Research Council, Space Studies Board, *Panel to Review EOSDIS Plans, Final Report* (Washington, DC: National Academy Press, 1994).

FIGURE 2-2: NOAA's Polar-orbiting Operational Environmental Satellite





SOURCE Martin Marietta Astrospace 1993

BOX 2-4: The Polar-orbiting Operational Environmental Satellite System

The POES satellites follow orbits that pass close to the north and south poles as Earth rotates beneath them. They orbit at about 840 km altitude, providing continuous, global coverage of the state of Earth's atmosphere, including such essential information as atmospheric temperature, humidity, cloud cover, ozone concentration, and Earth's energy budget, as well as important surface data such as sea-ice and sea-surface temperature and snow and ice coverage. All current and near-future POES satellites carry five primary instruments:

1 The ***Advanced Very High Resolution Radiometer/2 (AVHRR/2),*** which determines cloud cover and Earth's surface temperature. This scanning radiometer uses five detectors to create surface images in five spectral bands, allowing multispectral analysis of vegetation, clouds, lakes, shorelines, snow, and ice.

2 The ***High Resolution Infrared Radiation Sounder (HIRS/2),*** which measures energy emitted by the atmosphere in 19 spectral bands in the infrared region of the spectrum, and one spectral band at the far-red end of the visible spectrum. HIRS data are used to estimate temperature in a vertical column of the atmosphere to 40 km above the surface. Data from this instrument can also be used to estimate pressure, water vapor, precipitable water, and ozone in a vertical column of the atmosphere.

3 The ***Microwave Sounding Unit (MSU),*** which detects energy in the troposphere in four areas of the microwave region of the spectrum. These data are used to estimate atmospheric temperature in a vertical column up to 20 km high. Because MSU data are not seriously affected by clouds, they are used in conjunction with HIRS/2 to remove measurement ambiguity when clouds are present.

4 The ***Space Environment Monitor (SEM),*** a multichannel charged-particle spectrometer that measures the flux density, energy spectrum, and total energy deposition of solar protons, alpha particles, and electrons. These data provide estimates of the energy deposited by solar particles in the upper atmosphere and a "solar warning system" on the influence of solar fluctuations on the Earth system.

5 The ***ARGOS Data Collection System (DCS),*** which consists of approximately 2,000 platforms (buoys, free-floating balloons, remote weather stations, and even animal collars) that transmit temperature, pressure, and altitude data to the POES satellite. The on-board DCS instrument tracks the frequency and timing of each incoming signal and retransmits these data to a central processing facility.

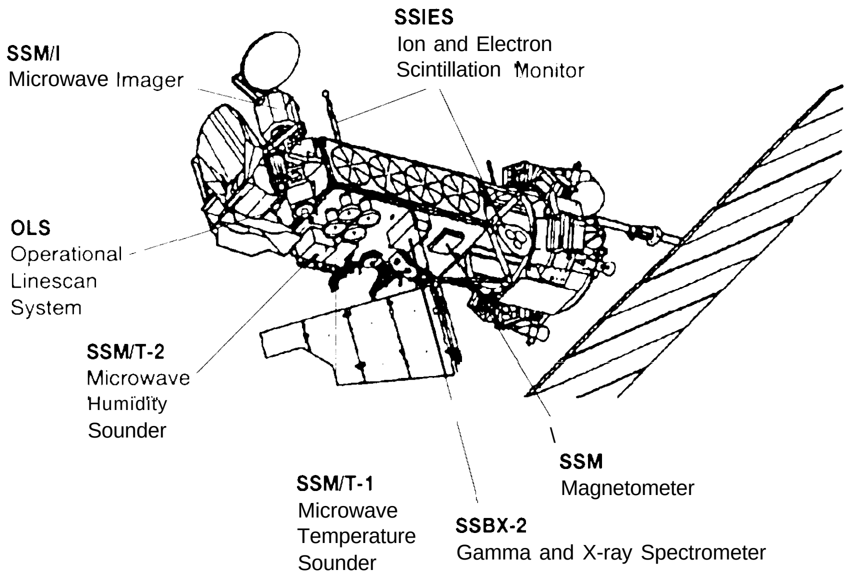
Instruments that fly on some POES satellites include:[1]

- The ***Stratospheric Sounding Unit (SSU),*** a three-channel instrument that has flown on all NOAA POES satellites except NOAA-12. It measures the intensity of electromagnetic radiation emitted from carbon dioxide at the top of the atmosphere, providing scientists with the necessary data to estimate temperatures through the stratosphere. The SSU is used in conjunction with HIRS/2 and MSU as part of the Television Infrared Observing Satellite (TIROS) Operational Vertical Sounder System.
- The ***Solar Backscatter Ultraviolet Radiometer/2 (SBUV/2),*** which measures concentrations of ozone at various levels in the atmosphere and total ozone concentration. This is achieved by measuring the spectral radiance of solar ultraviolet radiation "backscattered" from the ozone absorption band in the atmosphere, while also measuring the direct solar spectral irradiance. The SBUV is flown on POES PM orbiters only.
- The ***Search and Rescue Satellite Aided Tracking System (SARSAT, or S&R),*** which locates signals from emergency-location transponders on board ships and aircraft in distress and relays these data to ground receiving stations that analyze the data and transmit information to rescue teams in the area.
- The ***Earth Radiation Budget Experiment (ERBE),*** which was flown only on NOAA-9 and NOAA-10. This research instrument consists of a nonscanning radiometer with both medium and wide fields of view, operating in four channels that view Earth and one channel that views the sun, and a narrow-field-of-view scanning radiometer with three channels that scan Earth from horizon to horizon. ERBE measures the monthly average radiation budget on regional to global scales and determines the average daily variations in the radiation budget.

[1] The SSU is contributed by the United Kingdom; ARGOS is a contribution of the French Space Agency Centre National d'Études Spatiales (CNES); and the SARSAT instrument is a joint project of Canada and France.

SOURCE: National Oceanic and Atmospheric Administration, 1994.

FIGURE 2-3: DOD's Defense Meteorological Satellite Program Satellite



USE	MEASUREMENT	INSTRUMENT
Weather and sea state forecasting	Cloud extent	OLS
	Atmospheric temperature	SSM/T-1
	Atmospheric humidity	SSM/T-2
	Ice and snow extent	SSM/I
	Wind speed at sea surface	
	Precipitation rate	
Global magnetospheric model	Earth's magnetic field	SSM
Characterize aurora	Flux and energies of electrons and ions	SSJ
Monitor nuclear events	Energy spectrum of nuclear denotation	SSBX-2
Long-haul communications; OTH radars	Space plasma above ionospheric F region	SSIES

SOURCE Martin Marietta Astrospace 1993

BOX 2-5: The Defense Meteorological Satellite Program

The DMSP program collects and disseminates global environmental information for the U.S. Department of Defense. The space segment of DMSP consists of two polar-orbiting satellites, each of which orbits Earth at an altitude of 832 km (516 miles). The satellites are capable of storing up to 2 days' worth of data before downloading to ground stations located at Fairchild Air Force Base, Washington, and Kaena Point, Hawaii. Sensors on DMSP view most of Earth twice per day. The primary sensor aboard DMSP satellites is a visible and infrared imager. Data from this sensor are also supplemented with atmospheric and oceanographic data. As discussed in chapter 3, the current Block 5D-2 satellites are being replaced with upgraded 5D-3 satellites. However, plans for a major upgrade (Block 6) have been deferred because—DOD and NOAA plan to develop a joint meteorological satellite.

The instruments on the current Block 5D-2 satellite are:

1. The ***Operational Linescan System (OLS),*** a visible and infrared imager that monitors cloud cover, has three spectral bands. OLS operates at high spatial resolution (0.6 km) about 25 percent of the time. The OLS uses photomultipliers to make observations at very low light levels and is capable of monitoring biomass burning. OLS generates images across its nearly 3,000-km ground swath width with nearly constant spatial resolution. This is an important feature that distinguishes the OLS from NOAA's Advanced Very High Resolution Radiometer (AVHRR).
2. The ***Special Sensor Microwave/ Imager (SSM/I),*** a radiometer used for determining soil moisture, precipitation, and ice cover, has four channels and a spatial resolution of 25 to 50 km. It also measures sea-surface wind speed, but not direction, through scatterometry and droplet size.
3. The ***Special Sensor Microwave/Temperature Sounder (SSM/T1),*** used for vertical temperature sensing, has seven channels.
4. The ***Special Sensor Microwave/Water Vapor Sounder (SSM/T2),*** used for determining humidity through the atmosphere, has five channels and spatial resolution of 40 to 120 km.
5. ***Space Environment Sensors: SSB/X-2,*** a gamma- and X-ray spectrometer; ***SSM,*** a magnetometer; ***SSJ/4,*** a precipitating charged particle spectrometer; and **SSI/ES-2,** a plasma and ion/electron scintillation monitor. Information from these sensors is used to predict and plan for the impact of the space environment on DOD systems. This includes, for example, the effect of the space environment on satellite lifetimes and the effect of the space environment on over-the-horizon radio communications.

The importance of DMSP to defense operations was illustrated most recently during the Desert Storm campaign. Allied forces received DMSP imagery data directly in the field, and additional environmental data products were forwarded to field commanders after detailed analysis at strategic processing centers. Data from DMSP were used to support mission planning, including target and weapon selection.

SOURCES: Department of Defense fact sheets on DMSP, 1992; Office of Technology Assessment, 1994.

ing, and the Center for Mapping at Ohio State University.[23] The Earth Observation Commercial Applications Program (EOCAP) provides matching federal funds for privately proposed projects designed to demonstrate the commercial application of remotely sensed data.[24] Through its Small Satellite Technology Initiative (SSTI) in the Office of Advanced Concepts and Technology, NASA has awarded two contracts to develop small remote sensing satellites. These satellites are to demonstrate technologies that could be used in future commercial projects.[25]

Landsat

Since the launch of Landsat 1 in 1972, the Landsat system has provided a continuous record of multispectral, moderate-resolution land-surface data. Throughout its history, the continuation of the Landsat system has been uncertain, as NASA, NOAA, DOD, USGS, and the private company EOSAT have at various times had responsibility for system development, operations, and data management and distribution (appendix D). Under current plans, NASA is responsible for the development of Land sat 7, NOAA for ground operations, and USGS for data-archive management (see chapter 3).

The Advanced Research Projects Agency and the Defense Laboratories

The Advanced Research Projects Agency (ARPA) is charged with assisting the development of new defense-related technologies that might not be undertaken by the private sector without government assistance. For example, ARPA helped develop Orbital Sciences Corporation's Pegasus launch vehicle by agreeing to purchase a specified number of launches on the new vehicle. ARPA has been attempting to develop a new, common small spacecraft that could be used in a variety of applications, including for remote sensing.[26]

Several DOD and Department of Energy laboratories have a long history of developing sensors and spacecraft for defense purposes. For example, Los Alamos National Laboratory developed the Alexis satellite system for detecting charged particles and for observing other characteristics of the near-Earth space environment. Lawrence Livermore National Laboratory has created sensors for detecting the launch of missiles. Derivatives of these sensors, developed for the Strategic Defense Initiative, found their way into the highly successful Clementine satellite that recently mapped the moon in 11 spectral bands.[27] The sensor developed for the WorldView commercial remote sensing satellite now under development grew out of sensor research carried out at Livermore.

Private Sector

Private firms have long served as contractors to the federal government, designing and building sensors, communications packages, and spacecraft for both civilian and national security government remote sensing programs. Hence, they have developed considerable expertise in spacecraft and instrument design.

In recent years, private firms have begun to explore the market potential for building and operating their own remote sensing systems (see box 3-7). Orbital Sciences Corporation, WorldView Imaging Corporation, Space Imaging, Inc., and

23 "Commercial Development: NASA Centers for the Commercial Development of Space." Space *Technology Innovation*, May-June, 1994, p. 14.

24 For example, NASA is sponsoring the Cropix program to demonstrate the use of satellite data to manage individual farms. See U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., app. B; and "Remote Sensing Program Offer\ Partnership Advantages," *Space Technology Innovation*, May-June 1994, pp. 8-9.

25 K. Sawyer, "For NASA 'Smallsats,' a Commercial Role," *The Washing/on Post*, June 9, 1994, p. A7.

26 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, OTA-ISC-558 (Washington, DC: U.S. Government Printing Office, July 1993), app. B.

27 The Naval Research Laboratory built the Clementine satellite.

Eyeglass International, Inc., have all received licenses from the Department of Commerce to operate remote sensing systems. These new business ventures, formed largely from companies with previous experience building systems for the government, expect to orbit highly capable spacecraft in the next few years and to sell data from these systems in the global data market. If they succeed commercially, these companies are likely to revolutionize the delivery and use of remotely sensed data from space (see chapter 3).

MATCHING CAPABILITIES TO NEEDS

The array of uses of satellite remote sensing systems matches only imperfectly the missions of the agencies that develop and operate those systems. Matching the requirements of data users with the capabilities of satellite systems presents an extremely important challenge. **OTA finds that mechanisms for improving the requirements process should be a central element of a national strategy for remote sensing.**

The Requirements Process

The United States currently has no national process for developing remote sensing satellite requirements. Instead, each agency has developed its own mechanism for matching its individual missions with programmatic resources to determine data requirements and satellite-design specifications. The development of systems to collect needed data depends in turn on the legislative and administrative processes for developing and refining agency missions and on the budgetary process for allocating resources. The Office of Management and Budget has initiated occasional budget reviews for specific policy issues concerning land remote sensing, the convergence of polar-orbiting meteorological satellites, and global change research. Congress has also weighed in on these issues, but there have been few formal, comprehensive reviews of Earth observations needs.

The current system has important strengths. For critical national needs, it is simpler and more efficient to assign each mission to a single agency with the resources and authority to carry it out. This arrangement also meshes well with the congressional authorization and appropriations process, by allowing a single authorizing committee or appropriations subcommittee in each house to deal with the missions assigned to a given agency.

Through their experience in continuous satellite operations and repeated system upgrades, the agencies with operational remote sensing missions have developed disciplined processes for developing and refining requirements. These processes rely on the accumulated knowledge of data users as well as the availability of proven satellite technologies.

The requirements processes for NOAA and the Defense Meteorological Satellite Program are now being merged. Before the current convergence effort began, NOAA's requirements process would begin with requests for each NOAA line and program office to define its needs for data. NOAA would then analyze these requirements for technical feasibility and cost before a review that established mission priorities. Weather forecasting has the highest priority because of its importance for public safety. NOAA's offices are also expected to represent the interests of the many outside users who rely on data from the agency's environmental satellite systems, but NOAA has no formal mechanism for gathering information on outside needs.

The requirements process for DMSP has been more formalized than NOAA's: the Air Fore'e initiates the process of generating an Operational Requirements Document (ORD), which then passes it to the Army and Navy for comment before final review by the Air Force Space Command and the Air Staff. This process went through three stages at increasing levels of detail (ORD- 1. -2, and -3)-corresponding to major development milestones—for assessing cost, feasibility, and priority. At each stage, requirements had to be formally validated as essential to support established military missions. This interservice process could provide a model for interagency coordination, although its hierarchical structure has had the effect of separating users from designers.

The requirements processes for NASA's Mission to Planet Earth derive not from operational experience but from mission priorities established through the U.S. Global Change Research Program. NASA uses a variety of mechanisms, including scientific conferences, technical workshops, and internal and external review panels, to refine these into scientific priorities and requirements. The agency then solicits proposals for instruments that will meet these requirements and selects proposals according to feasibility, cost, and mission priority. NASA also makes effective use of science teams that combine observational users with engineering designers during the design and development process.

Despite its strengths, the current agency-centered approach to requirements has several weaknesses that affect the processes of reaching agreement on high-level requirements[28] and of linking those requirements to design specifications.

- ***Insufficient weight given to the requirements of outside users.*** An instrument designed for one purpose often produces data that can serve other purposes, though doing so may require some modifications in its design or in its associated data systems. As noted above, AVHRR data from NOAA's POES platforms can provide a measure of vegetative condition through a vegetative index.[29] Although the index was not a primary goal of AVHRR development, several programs, including the Foreign Agricultural Service and the USGCRP, now use it for global vegetation monitoring. NOAA has accommodated this application by making minor modifications of the spectral bands for the next-generation AVHRR/3, though not with the improved radiometric calibration some users need. In general, however, the requirements process is geared to a specific group of users and will give a higher priority to the needs of those users. NOAA uses sounding data primarily as input to weather forecast models and is reluctant to undertake the long-term commitment of meeting the more refined requirements of climate monitoring without additional funding.
- ***Inefficiencies from overlapping capabilities.*** For example, the POES and DMSP satellites serve primarily the purposes of operational weather forecasting, and the EOS-PM platforms will collect more refined atmospheric data for research purposes. A coordinated program to meet the combined mission requirements should be cheaper over the long run than three separate systems. This is the impetus for the convergence proposal, discussed in chapter 3.
- ***Inability to aggregate diffuse requirements.*** This happens when several agencies or other users have requirements for similar data, but none of those agencies can afford the satellite system needed to acquire those data. The difficulties in funding the Landsat system provide a clear example. Although many agencies use Landsat data, historically, no single agency has found its data needs compelling enough to fund a satellite system of its own. Because of this, responsibility for the Landsat program has shifted from agency to agency and still lacks the robustness that operational users need (chapter 3).
- ***Inefficiency in making tradeoffs between costs and requirements.*** The current requirements process often separates the phase of drawing up user requirements from the phase of engineering design. This separation makes it difficult for users and designers to discuss tradeoffs between requirements and costs. For example, a slight adjustment in requirements

[28] High-level requirements are intermediate between broad mission statements and the detailed requirements used in instrument design. For the broad mission of climate monitoring, for example, the high-level requirements would be to improve the accuracy of temper-ature sounding data to a few tenths of a degree, whereas the engineering requirements would be to describe the radiometric calibration and spectral bands of the sounding instrument.

[29] The Normalized Difference Vegetative Index was originally derived from two spectral bands of Landsat's Multispectral Scanner (MSS), but it applies to other sensors with similar bands, such as AVHRR. The difference in intensities in the green and red bands, normalized by the total intensity, provides a rough index of plant "greenness."

could result in a major reduction in cost, or a substantial improvement in capabilities could be accomplished at modest additional cost. Private industry has used this process of concurrent engineering to meet market demands more efficiently.[30] These tradeoffs can occur in operational programs through many iterations of the process of developing and refining requirements for successive generations of satellites but are harder to accomplish for new satellite systems. Several systems under development were later canceled because stated requirements led to unaffordable costs.[31]

- ***Difficulty in establishing national priorities. The*** current institutional arrangement for meeting national priorities allows each agency to make tradeoffs among its own missions and budget constraints but provides no mechanism for establishing priorities and making tradeoffs among the programs of several agencies. The problem is especially acute when an agency is attempting to establish new missions and the budgets to carry them out. For example, NOAA may be the appropriate agency to pursue long-term monitoring of global change, but it currently lacks the budget to carry out that mission. Conversely, NASA has a substantial budget for research and development but no charter for long-term operational missions.
- ***Lack of agency expertise. The*** agency responsible for operating a satellite system may lack experience and expertise in the design of satellite systems. This has been true for NOAA, which relies on NASA for the development of new instruments. Partly for this reason, the ambitious requirements for GOES-Next led to significant delays and cost overruns that threatened the continuity of the GOES program.[32]

Coordination Mechanisms

There are several options for improving the requirements process and limiting the drawbacks of the current agency-led approach, without altering the organizational structure of the agencies. Some of these mechanisms are already in place for global change research through the USGCRP and could be expanded; others could be implemented at the agency level. For example, the Committee on the Environment and Natural Resources (CENR)[33] could expand its purview to include oversight and coordination of agency-based remote sensing programs.

- ***Improve mechanisms for communicating requirements of outside users.*** The agency responsible for operating a satellite could solicit data requirements from users or from art advisory committee on data requirements. Either process would give the agency information on the data needs of other agencies and of users outside the federal government. The agency could undertake this process on its own initiative, or CENR or Congress could mandate that it do so. Even with information on the requirements of outside users, however, operating agencies generally give a higher priority to their own data needs than to the needs of outside users.
- ***Improve interactions between the setting and implementation of requirements.*** A more direct channel of communication between data

30 The Boeing Company recently made effective use of concurrent engineering and computer-aided design in designing and building its Boeing 777 aircraft. See P. Proctor, "Boeing Rolls Out 777 to Tentative Market," *Aviation Week*, Apr. 11, 1994, pp. 36-37.

31 The High Resolution Multispectral Imager (HRMSI) originally planned for Landsat 7 was one of these, as were two past programs for developing operational ocean observing satellites, the National Ocean Satellite System (NOSS) and the Naval Remote Ocean Satellite System (N-ROSS).

32 For a summary of the history of GOES-Next, see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, op. cit., pp. 38-39.

33 CENR, part of the National Science and Technology Council (NSTC), is the descendant of the Committee on Earth and Environmental Sciences (CEES), established under the Federal Coordinating Committee for Science, Education, and Technology (FCCSET), the predecessor to NSTC. CENR already oversees the USGCRP.

users and satellite engineers could improve cost-effectiveness by permitting tradeoffs between system costs and capabilities to occur early in the design process. For example, satellite engineers could play a formal role in the process of defining requirements, and data users could be involved in the major engineering-design milestone reviews. This concurrent engineering process provides away for the data users and the satellite designers to understand and respond to each other's perspective on satellite design and operations. When pursued early in the development process, such interactions can lead to more effective satellite design.

- ***Institute a formal interagency process for setting and implementing requirements.*** The coordination processes of CENR or the USGCRP would function most effectively for setting high-level requirements. However, the detailed implementation of high-level requirements depends on the cooperation of the agency or agencies involved. The history of efforts to converge civil and military meteorological satellites demonstrates how difficult it can be to achieve this cooperation (see chapter 3).
- ***Improve mechanisms for assigning and updating agency missions.*** USGCRP and CENR can address these issues on an interagency basis, but where agencies fail to reach consensus, they may require decisionmaking at" a higher level. Congress could assist this process through authorizing legislation that specifies agency roles in meeting new national missions for environmental data collection.

Each of these options has the advantage of making the requirements process more responsive to a broader set of needs, but the options also risk undermining established operational programs by diluting the role of agency missions in the iterative process of establishing and refining system capabilities. Defining **a baseline set of requirements that are essential to each operational mission could protect operational programs from the risk of having their missions diluted or eroded.**[34] **These** baseline requirements will generally arise from each agency's operational missions but may require high-level policy input if interagency negotiations do not lead to agreements to protect those requirements.

Beyond revising the requirements process, a national strategy for remote sensing could include new agencies or interagency programs. The long-term stability of interagency programs depends on continuing political commitments from the participating agencies, which in turn rest on the agencies' abilities to meet their essential requirements. The Integrated Program Office proposed for a converged meteorological satellite program provides an example of how this might work (see chapter 3).

Market-Oriented Options

As mentioned above, budgetary processes underlie many of the inefficiencies of the agency-oriented requirements process. Unless they receive funding to do so, agencies are unwilling to meet requirements that go beyond their established missions. Market-oriented financing mechanisms would allow users to pay a part of satellite system costs, either directly or through data purchases. This could give users some leverage over the design and operation of satellite systems, provided the users clearly indicate their requirements and their willingness to pay for meeting them.

- ***Facilitate interagency payments by data users.*** This would provide a way to aggregate resources and to give the agencies using the data some financial leverage for influencing the development of system requirements and capabilities. So far, using interagency payments has not been a common practice in the federal budget process. In the late 1980s, the Office of Management and Budget attempted to convince agencies that use significant quantities of

34 The Clinton Administration's convergence proposal assigns each requirement one of three levels of priority. Baseline requirements essential to each agency mission are called "key" requirements, whereas lower-priority requirements are labeled "threshold" and "objective."

Landsat data to help pay for a next-generation Landsat satellite, but even agencies that routinely purchase Landsat data commercially were unwilling to make a such a financial commitment in advance.[35]

- ***Allow commercial data sales by federal agencies.*** Other countries, particularly in Europe, have developed commercial data-access policies that allow government agencies to recover some of the costs of satellite systems through data sales (see chapter 4 for a discussion of international data policies). These data-access policies give those agencies an incentive to meet commercial data requirements. This option would be difficult to institute in the United States because of long-standing policies[36] and traditions that forbid commercial data sales by federal agencies; U.S. agencies can charge data users, but only for their marginal costs of fulfilling user requests for data. Data collected by government agencies are considered to be in the public domain (that is, they may be freely reproduced and transmitted to third parties) and are made available as a public good.
- ***Encourage federal agencies to purchase data from commercial suppliers.*** This may be much easier for federal agencies than attempting to sell data commercially.[37] Furthermore, it may be easier for the private sector than for government agencies to respond to market forces as it designs systems to meet user needs. Users of land data already do this on a small scale, but NASA's arrangement to purchase SeaWiFS data from the Orbital Sciences Corporation would be the largest data purchase yet and the first to cover the capital costs of satellite development and launch.

Government data-purchase arrangements raise the question of data access for third parties, which affects whether the supplier can also sell data commercially. In the case of SeaWiFS, Orbital Sciences expects to make a profit by selling timely operational data to commercial fishing operations while NASA uses the same data on a longer time scale for global change research. For terrestrial data, timeliness of data access does not distinguish as clearly between commercial and governmental data needs, so the question of whether third parties may have access to data purchased by the government becomes an important subject for negotiation between the government and the commercial data suppliers.

Market mechanisms also pose several problems. Increased data costs for commercial users in the short run could hold down the demand for data and impede the development of the information market. Furthermore, government agencies will continue to be the largest users of remotely sensed data. Budget and policy constraints may prevent agencies from paying more for the data they use, even if the national need for their use of the data continues or grows. Finally, data-purchase arrangements pose anew set of risks to agencies and contractors: for agencies, the loss of control over data supply, and for contractors, uncertainties in the long-term continuity of data demand. Chapter 3 addresses these issues in greater detail.

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35 In FY1989, several user agencies did contribute funds to pay for continued operation of Landsats 4 and 5. For a more detailed account of the history of Landsat, see U.S. Congress, Congressional Research Service, *The Future of Land Remote Sensing Satellite System (Landsat)*, *91-685* SPR (Washington, DC: The Library of Congress, Sept. 16, 1991).

36 This policy is outlined in OMB Circular A-130 and reaffirmed in the Global Change Data Exchange principles.

37 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, op. cit., ch. 6.