Findings and Policy Options 1

Satellite systems supply information about Earth that assists federal, state, and local agencies with their legislatively mandated programs and that offers numerous additional benefits to commerce, science, and the public welfare. To provide these benefits, the U.S. government current] y operates or plans to develop five major civilian Earth sensing systems (table 1-1).

Three agencies—the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), and the Department of Defense (DOD)-currently operate remote sensing systems that collect unclassified data[1] about Earth.[2] These and other U.S. agencies make extensive use of the remotely sensed data that these systems generate. In addition, foreign countries and regional agencies have satellite programs that generate remotely sensed Earth data for national and global use (appendix B).[3]

Existing remote sensing satellite programs are characterized by having overlapping requirements and redundant instruments and spacecraft. This is the natural outgrowth of the way the United States divides responsibilities within the federal government and an authorization and appropriations process that has encouraged agencies to develop and acquire space-based remote

[1] This report is not concerned with any satellite system built exclusively for national security purposes, except for the Defense Meteorological Satellite Program (DMSP), whose data are available to civilians.

[2] Department of Energy (DOE) laboratories also develop sensors that are incorporated into operational and research satellites,

[3] Canada expects to join this group in 1995 with the launch of Radarsat, now under development.

TABLE 1-1: U.S Civilian Satellite Remote Sensing Systems[a]

Existing systems	Operator	Primary objective	status
Geostationary Operational Environmental Satellite System (GOES)	NOAA	Weather monitoring, severe-storm warning, and environmental data relay.	Two operational (one borrowed from Eumetsat); GOES-8 (GOES-Next) launched in April 1994; operational in October 1994.
Polar-orbiting Operational Environmental Satellite System (POES)	NOAA	Weather, climate observations; land, ocean observations; emergency rescue,	Two partially operational; two fully operational, launch as needed.
Defense Meteorological Satellite Program (DMSP)	Air Force, for DOD	Weather, climate observations.	One partially operational; two fully operational; launch as needed,
Landsat	EOSAT, NASA, NOAA, USGS[b]	Mapping, charting, geodesy; global change, environmental monitoring,	Landsat 4 and 5 operational; Landsat 7 under development—-planned launch date 1998.
Mission to Planet Earth	NASA		
Upper Atmosphere Research Satellite (UARS)	NASA	Research on upper-atmosphere chemical and dynamical processes,	Launched September 15, 1991; still operating.
TOPEX/Poseidon	NASA/CNES[c]	Research on ocean topography and circulation.	Launched in August 1992; still operating,
Earth Observing System (EOS)	NASA	Global change research,	EOS AM platform in advanced planning; launch in 1998; EOS PM in early planning; launch in 2000, CHEM in early planning, launch in 2002.
Earth Probes (focused process studies)	NASA	Global change research,	TOMS planned for launch in 1994; TRMM planned for launch in 1997; others being planned.

[a] The five major Earth sensing systems are GOES, POES, DMSP, Landsat, and EOS The United States also collects and archives Earth data for non-U S satellites

[b] EOSAT, a private corporation, operates Landsats 4 and 5 for the government Landsat 6, launched in September 1993, failed to achieve orbit when launched NASA, NOAA, and the U S Geological Survey will develop and operate a future Landsat 7.

[c] TOPEX/Poseidon is a joint project between NASA and the French Space Agency, Centre National of dÉEtudes Spatiales (CNES)

SOURCE U S Congress, Off Ice of Technology Assessment, 1994.

sensing systems uniquely suited to their particular needs. NOAA's two environmental satellite systems serve the needs of the National Weather Service and the general public. NOAA's data are also distributed free of charge to the larger international community. DOD's Defense Meteorological Satellite Program (DMSP) is designed to provide similar weather data to support the surveillance, war-fighting, and peacekeeping operations of U.S. military forces. As part of its Mission to Planet Earth program, NASA plans to build a series of satellites, including its Earth Observing System (EOS), to gather data in support of research to understand and predict the effects of human activities on the global environment. The Landsat system, developed by NASA and now operated by the private corporation EOSAT under contract to NOAA, provides multispectral data about Earth's surface for a wide variety of research and applied uses. Other countries and organizations have developed similar satellites with distinct, but often overlapping, capabilities.

The United States now spends about $1.5 billion per year to collect and archive remotely

BOX 1-1: What Is Satellite Remote Sensing?

Earth receives, and is heated by, energy in the form of electromagnetic radiation from the sun. Some incoming radiation is reflected by the atmosphere, most penetrates the atmosphere and is subsequently reradiated by atmospheric gas molecules, clouds, and the surface of Earth itself (including, for example, forests, mountains, oceans, ice sheets, and urbanized areas).

Remote sensors may be divided into passive sensors that observe reflected solar radiation and active sensors that provide their own illumination of the sensed object. Both types of sensors may provide images or simply collect the total amount of energy in the field of view.

Passive sensors collect reflected or emitted radiation. Types of passive sensors include:

- ***imaging radiometers***, which sense visible, infrared, near-infrared, and ultraviolet wavelengths and generate a picture of the object, and
- ***atmospheric sounders***, which collect energy emitted by atmospheric constitutents such as water vapor or carbon dioxide at infrared or microwave wavelengths and which are used to infer temperatures and humidity throughout the atmosphere.

Active sensors include:

- ***imaging radar***, which emits pulses of microwave radiation from a radar transmitter and collects the scattered radiation to generate a picture;
- ***scatterometers***, which emit microwave radiation and sense the amount of energy scattered back from the surface over a wide field of view and which can then be used to measure surface wind speeds and direction and to determine cloud content;
- ***radar altimeters***, which emit a narrow pulse of microwave energy toward the surface and time the return pulse reflected from the surface; and
- ***lidar altimeters***, which emit a narrow pulse of laser light toward the surface and time the return pulse reflected from the surface

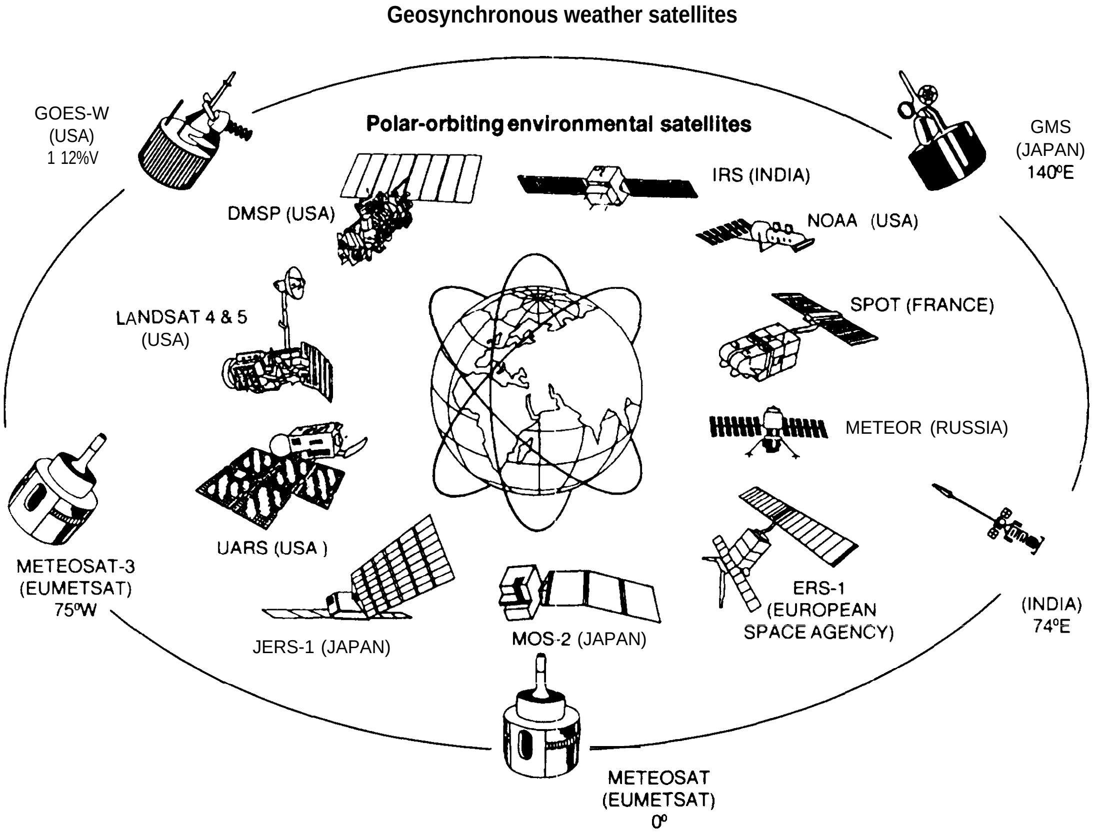
SOURCE Off Ice of Technology Assessment, 1994

sensed data. To maximize the nation return on its investment in remote sensing technologies (box l-l; figure l-l), to meet the needs of data users more effectively, and to take full advantage of the capabilities of other nations, Congress may wish to initiate the development of a long-term, comprehensive strategic plan for civilian satellite remote sensing.[4] **A national strategy for the development and operation of future remote sensing systems could help guide near-term decisions to ensure that future data needs will be satisfied. By harmonizing agency priorities with overall national priorities, a strategic plan would help ensure that agencies carry out programs that serve national data needs, not just the narrower interests of individual agencies.**

As envisioned in this report, a strategic plan for remote sensing would provide a general framework for meeting U.S. data needs for a diverse set of data users in the public and private sectors. A comprehensive strategic plan should remain flexible enough to respond effectively to changes in remote sensing technologies and institutional structures, and to improvements in scientific knowledge. However, developing such a plan carries certain risks. Without careful attention to the hazards that have jeopardized previous efforts to coordinate programs that affect many participants,

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

FIGURE 1-1: Existing Earth Observation Satellites



NOTE: Several countries operate satellites to monitor Earth and to collect environmental data. This figure depicts most of the satellites that are either in geosynchronous or polar/near-polar orbits.

SOURCE Off Ice of Technology Assessment, 1994

a comprehensive plan could result in a cumbersome management structure that is overly bureaucratic, rigid, and vulnerable to failure. It could also undermine existing operational programs that have met the needs of individual agencies.

This report, the last in a series of Office of Technology Assessment (OTA) reports and background papers about civilian Earth remote sensing systems (box 1-2), examines elements of a comprehensive long-term plan for U.S. satellite-based remote sensing. The assessment was requested by the House Committee on Science, Space, and Technology; the Senate Committee on Commerce, Science, and Transportation; the House and Senate Appropriations Subcommittees on Veterans Affairs, Housing and Urban Development, and Independent Agencies; and the House Permanent Select Committee on Intelligence.

This chapter outlines the elements that any strategic plan for satellite remote sensing must address and considers how the United States can best position itself to achieve its short-term and long-term goals for space-based remote sensing. It summarizes the assessment and analyzes policy options for congressional consideration.

Remotely sensed data provide the basis for unique kinds of information (box 1-3). Such ap-

BOX 1-2: OTA Publications on Satellite Remote Sensing

Reports

- *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications,* OTA-ISC-558 (Washington, DC: U.S. Government Printing Office, July 1993).
- *Remotely Sensed Data: Technology, Management, and Markets,* OTA-ISS-604 (Washington, DC: U.S. Government Printing Office, September 1994)
- *Civilian Satellite Remote Sensing: A Strategic Approach,* OTA-ISS-607 (Washington, DC: U.S. Government Printing Office, September 1994).

Background Papers

- *Remotely Sensed Data from Space: Distribution, Pricing, and Applications* (Washington, DC: International Security and Space Program, Office of Technology Assessment, July 1992).
- *Data Format Standards for Civilian Remote Sensing Satellites* (Washington, DC: International Security and Space Program, Office of Technology Assessment, April 1993).
- *The 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).

SOURCE: Office of Technology Assessment, 1994.

BOX 1-3: The Utility of Satellite Remote Sensing

Remote sensing from space provides scientific, industrial, military, and individual users with the capacity to gather data for a variety of useful tasks, including:

1. simultaneously observing key elements of an interactive Earth system;
2. monitoring clouds, atmospheric temperature, rainfall, wind speed, and direction;
3. monitoring ocean surface temperature and ocean currents;
4. tracking anthropogenic and natural changes to the environment and climate;
5. viewing remote or difficult-to-access terrain;
6. providing synoptic views of large portions of Earth's surface without being hindered by political boundaries;
7. allowing repetitive coverage over comparable viewing conditions;
8. identifying unique surface features; and
9. performing terrain analysis and measuring moisture levels in soil and plants.

SOURCE: 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), p. 9.

placations of remotely sensed data are mirrored around the world. **Chapter 2: National Remote Sensing Needs and Capabilities** introduces applications of remotely sensed data and summarizes the primary characteristics of the satellite systems that provide them. It also discusses the process for determining what data are needed by the federal government and other data users, and considers the potential role of the private sector in meeting data needs.

Chapter 3: Planning for Future Remote Sensing Systems provides an overview of institutional and organizational issues surrounding the development of operational environmental satellite remote sensing programs. In addition, the chapter discusses the potential for creating a stronger partnership than now exists between NASA as the developer of satellite research instruments and NOAA as the operational user. The chapter further explores the present and future status of the Landsat program, the involvement of the private sector in remote sensing, and the potential for operational ocean sensing.

Because Earth remote sensing already has a strong international component, a strategic plan must consider the role of international partners and competitors. **Chapter 4: International Cooperation and Competition** examines the part played by non-U.S. agencies and companies in gathering and applying remotely sensed data. It identifies the most important benefits and drawbacks of increased cooperation, including their impact on national security and the competitive position of the U.S. remote sensing industry. Finally, it analyzes a range of options for strengthening international cooperation in remote sensing, including a possible international agency or consortium for remote sensing.

NEED FOR A STRATEGIC PLAN

Several factors underscore the importance of improving the U.S. approach to its remote sensing efforts:

1. ***The expanding need for more and better data about Earth.*** The experimental remote sensing work of NASA, NOAA, and DOD in the 1960s and 1970s demonstrated that gathering environmental and other Earth data from space was both feasible and desirable (figure 1-2). NOAA's and DOD's experience with collecting data on an operational basis has led to ever more capable remote sensing systems and the development of a broad base of data users who need reliable and accurate data for a varied set of applications. Future long-term operational data needs include:
   - *Monitoring of weather and climate* for accurate weather forecasting, which will continue to be important to the U.S. economy and national security. In addition, the United States has a developing interest in monitoring the global climate.
   - *Monitoring of the land surface* to assist in global change research: management of natural resources; exploration for oil, gas, and minerals; mapping; detection of changes; urban planning; and national security activities.
   - *Monitoring of the oceans* to determine such properties as ocean productivity, extent of ice cover, sea-surface winds and waves, ocean currents and circulation, and ocean-surface temperatures. Ocean data have particular value to the fishing and shipping industries, as well as to the U.S. Coast Guard and Navy.

[5] Operational programs have an established community of data users who depend on a steady or continuous flow of data products, long-term stability in funding and management, a conservative philosophy toward the introduction of new technology, and stable data-reduction algorithms.

2. ***The increasing concern over regional and global environmental changes. The U.S.*** Global Change Research Program (USGCRP) and related international efforts grew out of a growing interest among scientists and the public over the potentially harmful effects of human-induced regional and global environmental change. Satellite data, combined with data gathered in situ, could provide the basis for a deeper understanding of the underlying processes of regional and global change, leading to useful predictions for the policy debate.

   Today, scientists understand too little about Earth's physical and chemical systems to make confident predictions about the effects of global change, particularly the effects on regional environments. Data from NOAA's and DOD's satellites systems will continue to be very useful to global change scientists, yet these data are not of sufficient breadth or quality to discern subtle changes in climate or other components of Earth's environment. As its contribution to the USGCRP, NASA has developed the EOS satellite program, which will provide more detailed, calibrated data about Earth over a 15-year period (appendix A). NASA designed the EOS program to improve scientists' understanding of the processes of global change by complementary airborne and ground-based measurements.

3. ***A growing consensus within the scientific community on the need for long-term, calibrated monitoring of the global environment.*** Although EOS is not structured to collect environmental data over the decadal time scales scientists believe are needed to monitor the health of the global environment, it would provide the basis for designing an observational satellite program capable of long-term, calibrated environmental observations. A long-term global monitoring program will also require a coordinated program of measurements taken by aircraft and ground-based facilities,[6] and the cooperation and involvement of other nations, both to collect critical environmental data and to share program costs.

FIGURE 1-2: GOES Image of Earth

AA

4. ***The increasing pressures, in the United States and abroad, to improve the cost-effectiveness of space systems.*** Congress and the Clinton Administration have reached consensus that to control so-called discretionary spending in the federal budget, funding for space systems must remain steady or decrease. As noted in an earlier OTA report, a declining NASA budget is likely to force the Administration and Congress to make difficult decisions about NASA's Mission to Planet Earth program, which competes for funding with other NASA programs such as the Space Station or the Shuttle.[7] NASA's

[6] U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, op. cit., pp. 4, 13

[7] U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., pp. 18-23.

FY 1995 proposed budget for Mission to Planet Earth is $1,238 million, compared with its FY 1994 budget of $1,024 million, an increase of 20 percent.

NOAA's funding for satellite programs is projected to remain between $410 million and $460 million (in current dollars) until the end of the decade. NOAA's budget is constrained by potential conflict with other agency programs, such as NEXRAD,[8] and by planned budget increases in other Department of Commerce programs, such as the National Institute of Standards and Technology (NIST). These pressures and declining defense budgets have led Congress and the Clinton Administration to propose consolidating the Polar-orbiting Operational Environmental Satellite System (POES) and the DMSP system as a way to reduce the costs of the nation's meteorological programs. The data gathered by DOD's DMSP and NOAA's POES are similar, and **the United States faces the challenge of making these programs more efficient without losing important capabilities that now exist or that are being developed.**

5. ***The increasing internationalization of civilian operational and experimental remote sensing programs.*** Budget pressures within most countries and the desire to improve the scope of national remote sensing programs have led to increased international interest in sharing satellite systems and data. This interest has increased U.S. opportunities to exploit foreign sources of satellite data and to develop new institutional arrangements. Non-U.S. instruments now fly on U.S. satellites, while European and Japanese satellites fly U.S. instruments. This pattern will continue in the future. In particular. NASA's Mission to Planet Earth, including its EOS program, has a major international component.[9] Participating countries share the data to support scientific research. NOAA has long pursued cooperative activities as a way to increase its capabilities of supplying environmental data. It is currently negotiating an agreement with Eumetsat to supply an operational polar-orbiter (METOP- 1) in the year 2000 that would allow NOAA to operate one satellite, rather than two.[10] Opportunities for further expansion of cooperative activities could increase as other countries gain experience in remote sensing and confidence in international cooperation.
6. ***The introduction of privately operated remote sensing systems to collect remotely sensed data on a commercial basis.*** Private firms have played a major role in the development of the remote sensing industry. They serve both as contractors for government-developeds systems and as service providers that process raw satellite data, turning them into useful information (i.e., the so-called value-added industry). First EOSAT and then SPOT Image have operated remote sensing systems developed by governments and have marketed the data worldwide.

Recently, U.S. firms have received government approval to operate privately financed satellite systems[11] and to market geospatial

8 The Next Generation Weather Radar, a network of advanced Doppler radar stations for measuring winds responsible for severe weather, It is a joint program funded by NOAA, the Federal Aviation Administration, and DOD.

9 For example, the first major EOS satellite, the so-called AM platform, will carry the Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). Instruments built by NASA and the French space agency, Centre National d'Etudes Spatiales (CNES), will fly on the Japanese Advanced Earth Observing System (ADEOS) satellite, developed by Japan's National Space Development Agency (NASDA) and its Ministry of International Trade and Industry (MITI).

10 Eumetsat's Meteorological Operational Satellite (METOP) would fly in a so-called morning orbit, crossing the equator at about 9:30 a.m. NOAA's POES satellite would fly in the afternoon orbit. The Clinton Administration's convergence plan assumes completion of this agreement.

11 U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, OTA-ISS-604 (Washington, DC: U.S. Government Printing Office, September 1994), ch. 4.

data[12] to government and industry customers around the world. If successful, they will change profoundly the international marketplace for remotely sensed data. Even now, international commerce in remotely sensed data shows signs of rapid change as foreign companies also begin to explore the potential for developing commercial remote sensing systems.[13]

7. ***The end of the Cold War era, which has forced reexamination of the role of space technologies in promoting national security and U.S. technological prowess.*** Much of the existing structure of U.S. space efforts grew out of the Cold War tensions between the United States and the former Soviet Union. The breakup of the Soviet Union has resulted in new opportunities for cooperation instead of competition with the former Soviet republics. The United States has now brought Russia into its partnership with Canada, Europe, and Japan in building an international space station. Other cooperative projects, including Earth observations, are likely to follow as well.[14]

   NASA was developed as an independent, civilian agency to separate civilian and military interests in the development of science and technology. Among other things, this separation allowed the military and intelligence agencies to pursue their space agendas largely out of the public view. As a result, NASA and DOD often developed similar technologies independent y. With the end of the Cold War and other changes in the political makeup of the world, the United States has eased many of its earlier restrictions on the civilian development and use of remote sensing technologies. As noted above, the United States has also undertaken the consolidation of DOD's DMSP system with NOAA's POES; similar efforts fell short in the past, in part as a result of national security considerations during the Cold War.[15]

STRUCTURAL ELEMENTS OF A STRATEGIC PLAN

The existing collection of satellite remote sensing systems, both nationally and internationally, has evolved in response to a variety of independent needs for data about Earth. Consequently, system capabilities may overlap, as they do in the polar-orbiting environmental satellites operated by DOD and NOAA. Some capabilities are also complementary. For example, both Europe and Japan operate synthetic aperture radar (SAR) satellites, but the United States has no civilian SAR system in operation.[16] Hence, for its SAR data, the United States now largely relies on Europe's and Japan's satellites.

A strategic plan would consider the short-term and long-term needs of all major data users. As noted earlier, future data needs are likely to involve:

- ***collecting atmospheric data to support weather observations and forecasting,***
- ***monitoring the land surface,***
- ***monitoring the oceans,***
- ***collecting data to support research on global environmental change, and***

12 Geospatial data are data that are organized according to their location on Earth.

13 P. Seitz, "New Ventures Tempt European Space Firms," *Space News*, May 23-29, 1994, p. 3.

14 The United States and Russia are currently working together on a modest scale in Earth remote sensing. Russia flew a Total Ozone Mapping Spectrometer (TOMS) aboard one of its Meteor polar-orbiting satellites in 1991 and has agreed to do so again.

15 DOD and NOAA have collaborated in eight previous convergence studies, most of which contributed to operational improvements and closer cooperation between DOD and NOAA. However, attempts to meld the systems always failed on grounds that such a move would weaken U.S. national security without appreciably lowering overall system costs.

16 The United States has recently flown advanced SAR instruments, the Shuttle Imaging Radar (SIR-A, B, C), on the Space Shuttle, but these instruments do not provide continuous data collection. In 1978, NASA also orbited the experimental ocean remote sensing satellite, Seasat, which operated for only 3 months in 1978. See chapter 3.

- ***long-term monitoring of key indicators of global change and environmental quality.***

Programs for gathering needed data are discussed in later sections of this chapter. This section discusses structural and institutional issues that would affect the development of a strategic approach to remote sensing. For example, How can the United States most effectively identify and aggregate its data requirements? What role, if any, should private firms have in supplying data? How can the United States make the most effective use of the capabilities of other countries in meeting important data needs?

Plans for meeting national data needs will be developed within the context of other national priorities such as reducing the federal budget deficit by working more efficiently in space, defining the U.S. role in international cooperative activities, increasing U.S. competitiveness, improving scientific understanding of the global environment, improving the U.S. technology base, and maintaining U.S. national security.

Interagency Coordination and Collaboration

A strategic plan for Earth observations would weigh the potential contributions of every federal agency. NASA, NOAA, and DOD each fund the development and operation of satellite remote sensing systems in response to agency mission requirements for specific types of data. Yet, the data these systems provide have applications far beyond the needs of the agency generating them. Agencies also have overlapping interests in the collection and application of data. Further, each agency has developed certain areas of expertise. For example, NOAA and DOD have considerable expertise in providing operational satellite data. NASA has particular strength in developing new instrumentation and satellite platforms. To share their respective strengths, agencies develop mechanisms for coordinating and cooperating with each other on subjects of mutual interest. The collaborative USGCRP demonstrates such an interagency mechanism. Through it, agencies can tackle much larger problems than could any agency acting alone. However, such collaboration requires a certain accommodation to the needs of other agencies so that facilities and information can be shared efficiently.[17]

One of the benefits of developing a strategic plan for Earth observations is the opportunity to identify mutual interests and to strengthen cooperative relationships by sharing systems and data more effectively. The Clinton Administration's efforts to consolidate NOAA's and DOD's polar-orbiting satellite programs provide an important example of how one aspect of a strategic plan might function. By including NASA in the Integrated Program Office that will operate the combined polar-orbiting system, the Administration has the opportunity to use NASA's expertise in developing new sensors and spacecraft to enhance the collection of useful satellite data. The section "Monitoring Weather and Climate," later in this chapter, examines issues related to convergence of the polar-orbiting systems in more detail.

The convergence of polar-orbiting satellite systems is one important aspect of a strategic plan for U.S. remote sensing. Congress must also decide the future of U.S. efforts in land and ocean remote sensing and determine the U.S. role in long-term climate monitoring. The sections on land and ocean remote sensing in this chapter examine such issues. Congress will also be interested in NASA's and NOAA's plans for cooperating with international organizations and non-U.S. agencies in sharing costs and capabilities in remote sensing. Finally, Congress will also wish to understand what options it might have for assisting U.S. industry's efforts to supply remotely sensed data to a global marketplace in the face of national security concerns over the wide distribution of high-resolution geospatial data.

[17] For the USGCRP, the Subcommittee on Global Change Research of the Committee on Environment and Natural Resources Research of the National Science and Technology Council in the executive branch has provided oversight to assist collaboration.

Data Users and the Requirements Process

As noted earlier, the use of remotely sensed Earth data extends well beyond the federal government, to include state and local agencies as well as a variety of nongovernment users (box 1-4). Each data user has a range of requirements for satellite instruments and operations. To develop the foundation for a strategic plan, specific data needs will have to be aggregated and considered as part of a broad-based process.

Mechanisms for improving the process for developing data requirements process should be a central element of a national strategy for remote sensing. The federal government now has no established institutional means for considering overall needs for Earth observations. The current process for establishing requirements for these observations occurs mainly within individual agencies and involves specific groups of users who are responsible for those agencies' missions. This process can lead to inefficient decisions, as seen in a broad, national context, by limiting the ability to make tradeoffs between costs and requirements and excluding users outside the agencies. Chapter 2 discusses several options for strengthening the requirements process:

- ***Increasing the interaction among users, designers, and operators to improve the ability to make tradeoffs between requirements and costs.*** This can occur over time with successive generations of operational programs, but it is difficult to achieve with new programs.
- ***Including a broader range of users in discussions of requirements.*** This could involve establishing formal channels for seeking outside input into agency processes or formal interagency reviews of requirements.
- ***Developing a formal process for revising agency missions in response to emerging capabilities and needs.*** This could involve establishing an independent panel of experts to reexamine periodically agency capabilities and needs in the context of changing national priorities.

BOX 1-4: Major Elements of the U.S. Remote Sensing Community

Federal government civilian operators and data users

- Scientists
- Operational users (weather forecasters, resource managers, planners, geographers)

Military and intelligence users

Private industry

- Value-added companies
- Data suppliers
- Commercial data users

State and local governments

Nonprofit sector

- Universities
- Environmental organizations

SOURCE: Office of Technology Assessment, 1994.

The Private Sector

The activities and plans of private industry need to be considered in developing a strategic plan for Earth observations. The value-added sector of the remote sensing marketplace, which provides data processing and interpretation services, is relatively small ($300 million to $400 million per year) but growing rapidly as federal, state, and local government agencies and private firms discover the value of satellite data in a variety of applications.[18] U.S. companies developed most of the geographic information system (GIS) and other software used for processing geospatial data. They have been a major force in increasing the capability and reducing the costs of such software. U.S. industry, therefore, has a strong foothold in the development of the value-added industry; it supplies both software and information to a wide range of government and private customers. In setting requirements for future remote sensing

[18] U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management and Markets, op. cit.*, p. 107.

systems, the federal government may wish to take into account the needs of private data users because they are an important source of innovative applications of remotely sensed data.

Private firms could also play a substantial role in expanding overall U.S. remote sensing capabilities and in supplying data for government needs. As noted above, private U.S. firms are now developing land remote sensing systems with new capabilities. At least three private firms expect to be able to offer higher-resolution, more timely stereoscopic data[19] and to charge much less for such data than existing systems do. These firms have targeted international markets now served primarily by aircraft-imaging firms, especially in applications that require digital data for mapping, urban planning, military planning, and other uses. **If private systems succeed commercially, they are likely to change the nature and scope of the data market dramatically.**

The United States faces significant opportunities, challenges, and risks in assisting with the development of these systems. The federal government has the opportunity to facilitate the development of a robust U.S. remote sensing industry, one that provides high-quality, spatial data and information to customers throughout the world. If it decides to do so, it faces the challenge of devising the appropriate technological, financial, and institutional means to help this fledgling industry to compete with foreign governments and companies. Because the data from commercial systems would have significant military utility, however, the United States faces the risk that unfriendly nations might use the data to the detriment of the United States or its allies.

Current Administration policy (appendix F) allows for the licensing of U.S. companies to sell imagery with resolution as fine as 1 meter (m) and permits the companies to sell data worldwide, with several restrictions, including the possible limitation of data collection and/or distribution during times of crisis.

The policy also allows for the sale of “turnkey” systems to the governments of other countries, which would be able to gather whichever images they wish. However, Administration policy on such systems is much more restrictive than it is on U.S.-owned and -operated systems. The Administration will consider export of turnkey systems to other governments only on a case-by-case basis and under the terms of a government-to-govemment agreement.

NASA has recently contracted with TRW. Inc., and CTA, Inc., to build and operate two remote sensing systems under its Smallsat Program.[20] These represent two very different approaches to satellite remote sensing. The TRW system will carry a sensor capable of gathering data of 30-m resolution in 384 narrow spectral bands from the visible into the near-infrared. NASA will pay TRW $59 million for the satellite system, which will test a variety of new remote sensing technologies, including new materials, sensors, and spacecraft components. The data from this system will be of considerable interest to scientists working on global change research and to many current users of Landsat data, including farmers, foresters, and land managers.[21]

The CTA spacecraft, which will cost $49 million, will carry a sensor identical to the World-View Imaging Corporation sensor now in production for a 1995 launch. The CTA system will be capable of collecting land data of 3-m resolution (panchromatic). In contracting for these satellite systems, NASA is attempting to demonstrate its capacity to encourage the development of innovative, lightweight satellite technology, and to do it

19 Stereoscopic data make it possible for data analysts to generate topographic maps of a region directly from satellite data.

20 L. Tucci, "NASA Awards Smallsat Work," *Space News*, June 13-19, 1994, pp. 3,29.

21 If successful, the system should, among other things, generate data capable of distinguishing types of plants and trees from space by comparing responses from different spectral bands.

quickly and efficiently.[22] NASA officials emphasize their intent to stimulate the market for remotely sensed data.

Several private firms have argued that with regard to the CTA system, the market does not need such stimulation: private firms have already embarked on similar, competing systems. Further, these firms argue that NASA's entry into an endeavor so closely connected to ongoing commercial pursuits is already making it difficult for them to raise needed capital in the financial markets. The y complain that NASA is, in effect, competing with them.[23] NASA counters that the two satellites will test a range of new technologies that could contribute to the usefulness of remotely sensed data.

Although the two NASA satellites may improve the utility of remotely sensed data over the long term, in the short term, the CTA system, especially, could also inhibit the ability of firms to develop their own systems. Whether these systems help or harm markct development will depend in large part on the perceptions the venture capital market has regarding NASA's intentions and on NASA's plans for making the data available to customers. For example, if NASA makes these data available only for experimental purposes for a limited period of a few months, it could stimulate market interest. If, on the other hand, NASA makes the data available for longer periods. it would effectively compete with private efforts. Yet, if NASA limited the distribution of data from the CTA satellite to a few NASA users, Congress might well consider the $49 million cost of the satellite too high. For example, DOD would be a likely major user of data of 3-m resolution.[24] It is hard to see how NASA could limit DOD's use of data paid for by taxpayers. Congress may wish to monitor NASA's Small sat Program closely to ensure that both taxpayers and private satellite remote sensing firms are well served by its actions.

In the Office of Mission to Planet Earth, NASA has entered into a different contracting arrangement with Orbital Sciences Corporation (OSC) in which NASA has agreed to provide funding of $43.5 million up front in return for 5 years of data from OSC'S SeaStar satellite. SeaStar will carry the Sea-Viewing Wide Field Sensor (SeaWiFS) ocean-color sensor for gathering multispectral data about the surface of the ocean. NASA will use SeaStar data in its studies of global change. OSC will market data from SeaStar to fisheries and other ocean users, who will use them to locate the most productive ocean areas and assist in ship routing. The NASA-OSC "anchor tenant" agreement has allowed OSC to obtain additional funding from the financial markets to complete its project and will, if the satellite proves successful, deliver data of considerable interest to NASA scientists. **Congress may wish to consider encouraging NASA and other agencies to use the mechanism of data purchase to stimulate the market for data. Such a mechanism has the advantage of providing the government with needed data while assisting private firms in developing new Earth observation systems.**

■ international Cooperation and Competition

An effective strategic plan will also include consideration of how the United States cooperates and competes with other nations. Over the past decade, satellite remote sensing has become increasingly international: the European Space Agency (ES A), the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat), France, India, Japan, and Russia now operate

[22] K. Sawyer, "For NASA 'Smallsats,' a Commercial Role," *The Washington Post*, June 9, 1994. p. A7.

[23] L. Tucci, "NASA Refuses To Sell Clark. Industry Upset with Agency's Smallsat Imagery Advantage." *Space News*, June 27- July 3, 1994, pp. 3, 21

[24] Indeed, DOD is likely to be a major customer of data from WorldView, Space Imaging. Inc., and Eyeglass International. See chapter 3.

satellite systems; others, such as Australia, Brazil, Canada, China, Germany, Italy, South Africa, Sweden, and the United Kingdom, have developed considerable expertise in remote sensing instrumentation and the application of remotely sensed data but do not currently operate remote sensing systems.[25] Countries have become active in remote sensing to improve control over their information sources and applications, to obtain data not otherwise available, to develop capabilities in advanced information technologies, and to assist their national security forces.

International remote sensing activities have also become increasingly interactive: countries cooperate to expand their own access to remote sensing capabilities; they also compete for commercial advantage or technological prestige. In this new international environment, the United States, which once was the only supplier of remotely sensed data, no longer dominates the technology or the data markets. These circumstances require greater give-and-take in managing international cooperation and increased attention to the opportunities for maintaining and improving the U.S. competitive stance.

International Cooperation

Because remote sensing satellites pass over large portions of the Earth without regard to political boundaries, remote sensing is inherently international in scope. **Cooperation among countries offers the opportunity to reduce costs and improve the effectiveness of remote sensing programs.** International cooperation can reduce costs by eliminating unnecessary duplication among national programs. Cooperation can also improve the effectiveness of remote sensing by uniting the complementary strengths of national programs and eliminating data gaps that might otherwise occur. However, international cooperation carries certain risks because it entails some loss of control over the types and quality of available data. It also risks the loss of some data by relying on the contributions of other countries and poses additional burdens of meeting the requirements of other countries.

Data exchange is essential to international cooperation in remote sensing. The open exchange of data is particularly important for weather forecasting, global change research, ocean monitoring, and other applications that require data on a global scale. For this reason, the United States has had a long history of sharing remotely sensed data with other nations. Because some governments view data as a valuable commodity whereas the U.S. government and others treat them as public goods, the international remote sensing community faces a challenge in coordinating data access and pricing policies. Failure to coordinate and reach substantial commonality in policies on data access and exchange could greatly complicate access to data and undermine the effectiveness of remote sensing programs.[26] This is especially true for global change research, which requires large quantities of different kinds of data to develop and verify global environmental models.

Stronger institutional arrangements could enhance the benefits of international cooperation in remote sensing. Two questions will be critical. First, can countries share control over cooperative satellite programs in a way that meets their overlapping but distinct requirements? Second, can countries share the costs of these programs in a way that is fair and alleviates the pressures for cost recovery that can lead to restrictive data policies? Options for strengthening the institutions of international cooperation in remote sensing include the following:

- ***An international information cooperative,*** which is a set of institutional arrangements for the open sharing of data and information and

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25 Brazil, however, has an agreement with China to develop a polar-orbiting remote sensing satellite, and Canada will launch its Radarsat spacecraft in early 1995.

26 U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets,* op. cit., ch. 5.

the voluntary sharing of responsibility for data management. The prime example is the World Meteorological Organization (WMO), which has developed agreements for the open distribution of basic meteorological data, whether they come from satellites, ground stations, or other sources. The Committee on Earth Observations Satellites (CEOS) is a more informal organization,[27] which has pursued agreements on common principles for data exchange for global change research and environmental monitoring. Building on those agreements, CEOS could provide the basis for a broad information cooperative for sharing satellite data on the atmosphere, land, and oceans.

- ***A formal international division of labor.*** Countries already specialize to some degree in their remote sensing programs. Japan has devoted particular attention to ocean observations, whereas Europe focused initially on observations of atmosphere and land surface. In scaling back its initial plans for the Mission to Planet Earth, NASA has developed a program that complements these foreign efforts. A formal division of labor could allow countries to specialize further in the types of data they choose to collect without risking a loss of access to other types of data that are collected by other countries.

  In the future, such arrangements could be extended to make efficient use of the specialties developed within each country. For example, the United States has considerable expertise in weather and climate observations; Europe and Japan are developing strengths in ocean sensing and synthetic aperture radar (SAR) technology; Canada, which will soon launch its Radarsat, is focusing attention on SAR sensing of land and polar ice cover. Dividing up the tasks and labor among many countries would encourage those countries to make formal arrangements for sharing data from a wide variety of instruments in support of international monitoring efforts.

- ***An international remote sensing agency.*** Several experts have suggested that the United States should take the lead in establishing an international remote sensing agency to provide some global remote sensing needs.[28] An international remote sensing agency might focus on a narrow set of objectives, such as land remote sensing,[29] or it could deal with broad needs for data about the land, ocean, and atmosphere. Such an agency would allow countries to pool resources for a satellite system that meets their overlapping needs without the unnecessary duplication that characterizes current efforts. However, establishing such an agency would require great ingenuity in devising an efficient organizational structure that gives each member country a fair share of control. For the next several years, experience in working with CEOS and other international arrangements should provide insight into the ultimate workability of an international remote sensing agency.

Russia has a long and wide-ranging tradition of remote sensing and could be a strong international partner. The United States has a two-decade history of cooperation with the former Soviet Union, but Cold War tensions limited the scope of this cooperation. Current U.S.-Russian space activities involve cooperation in the use of data for Earth science and planned flights of U.S. instruments on Russian spacecraft. These activi-

[27] No formal intergovernmental agreements are involved. Government agencies and nongovemment organizations send representatives to its meetings.

[28] J.H. McElroy, "IN TELSAT, INMARSAT, and CEOS: Is ENVIROSAT Next?" In *Space Regimes for the Future*, G. MacDoald and S. Ride (eds.) (San Diego, CA: Institute on Global Conflict and Cooperation, University of California, 1993); J. McLucas and P.M. Maughan, "The Case for Envirosat," *Space Policy* 4(3):229-239, 1988.

[29] N. Helms and B. Edelson, "An International Organization for Remote Sensing," unpublished paper presented at the 42nd *Annual Meeting of (he International Astronautical Fe(/era/ion,* Montreal, October 1991 (IAF-9 1-112.)

ties could provide the basis for the future integration of Russia into international remote sensing programs. **Because of the potential benefits to the United States of cooperating with Russia on remote sensing programs, Congress may wish to urge NASA and NOAA to explore the potential for closer cooperation in operational programs.** In particular, the United States might explore the potential for including Russia in its cooperative program with Eumetsat in polar-orbiting satellites (see below, "Monitoring Weather and Climate' ').30 Ongoing cooperative activities on the international space station and other areas of space technology have given U.S. officials considerable insight into Russian capabilities and provide optimism that cooperative efforts would be highly beneficial for both countries. However, uncertainties in Russia's political relationships and the capacity to sustain its space programs argue for particular caution in undertaking cooperative programs with Russia. Projects should be well-defined, the benefits to both sides should be clearly articulated, and plans to handle contingencies should be developed.

International Competition

Despite the advantages of international cooperation noted above, commercial competition and national security considerations may limit the scope of intergovernmental cooperation in remote sensing. For example, commercial activity in land remote sensing will likely limit the development of intergovernmental cooperation. Yet, commercial firms and government agencies from various countries will likely cooperate on a variety of activities, including marketing data and developing technology and processing algorithms. The recent marketing agreement between EOSAT and the National Remote Sensing Agency of India provides an example of such cooperation.[31] Such strategic commercial alliances are likely to expand the global market for remotely sensed data.

The U.S. private sector has been a world leader in the development of sensors and spacecraft and is likely to maintain its dominant, competitive position for some time. However, the development and operation by other nations of rnultispectral and SAR satellite systems will give the private sectors of those countries considerable incentive to build their own systems and market data from them.

Experience with research and practical applications of data creates a strong synergy between the creation of a data market and the demand for the development of satellite systems. Such experience also extends to systems developed for national security needs. For example, several countries in Europe are cooperating in developing and operating the French-led HELIOS-1 surveillance satellite, which reportedly will be capable of l-m panchromatic ground resolution.[32] This experience will enhance the capabilities of non-U. S. government laboratories and private firms to field highly capable remote sensing systems and to use the data in a wide variety of civilian applications. If foreign private firms enter the marketplace with data from privately operated systems, they are likely to do so with the strong financial backing of their governments. **If Congress wishes to assist in maintaining U.S. competitiveness in remote sensing systems and data-management software, it has several options.** It could:

- direct U.S. agencies to purchase from private industry the multispectral data needed for operational purposes in monitoring the land and oceans,
- provide oversight to ensure that federal agencies do not compete with private firms in devel-

30 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., p. 31.

31 "EOSAT To Market Indian Data," *EOSAT Notes*, fall/winter 1993, pp. *4-5*.

32 France expects to launch HELIOS-1 *in 1995.* Germany has just announced its willingness 10 cooperate in the development of a follow-on system, HEL1OS-2. See "Germany Ready To Take Role in Helios Pro gram," *Space News*, May 23-29, 1994, p. 2.

oping software and in providing data processing and other value-added services,
- provide oversight to ensure that federal agencies do not compete with private firms in developing remote sensing systems, and
- fund the development of advanced sensors that would assist government remote sensing programs and private-sector needs.

LIMITATIONS OF A STRATEGIC PLAN

By linking different government environmental remote sensing programs, as well as private-sector developments, a national strategic plan for environmental satellite remote sensing might assist in the creation of an integrated remote sensing system that is less susceptible than current systems to single-point failure or changing priorities—a more "robust and resilent" system for Earth observations. If, on the other hand, it resulted in a large, single system, a comprehensive strategic plan might make Earth observation plans more susceptible to failure. NASA's initial, large EOS program, for example, was restructured twice to make it more resilient to technical failure and to lower funding expectations. The Space Station program has been cited as an example of the difficulties of funding and managing a large, single project incorporating several interest groups.[33] In addition, by forcing operating agencies to coordinate among themselves and with data users even more intensively than they now do, the process of developing and executing a national strategic plan for remote sensing has the potential to result in an overly bureaucratic approach to Earth observations. Furthermore, as noted in chapter 3, the Clinton Administration faces technical and programmatic risks in merging operational programs such as NOAA's POES and DOD's DMSP with research programs such as NASA's EOS.[34]

Integration of smaller programs into larger, comprehensive ones to accommodate research and development or operations goals tends to inhibit adaptation to external challenges because more groups have to be persuaded of a particular course of action. Further, although integration into larger systems tends to deter budget cuts, when cuts come they can undermine the entire program. By contrast, cuts in an isolated program may have few adverse effects beyond the program cut. Developing and executing a comprehensive strategic plan would be a major challenge because the existing institutional structure tends to resist change and integration into a larger whole. Each agency has developed a set of priorities for its programs, which then becomes incorporated into the work of the authorization and appropriations committees of the House and Senate. These committees thus have a stake in the development of new priorities and, therefore, may resist efforts to make changes that would reduce their influence over the agencies for which they are responsible.

Finally, as the experience with the USGCRP has demonstrated, the development of a well-coordinated plan within the executive branch does not necessarily mean that the program will be considered as a whole when the federal budget reaches Congress. Each committee has its own priorities and may either enhance or cut the budget of a given program, independent of the funding balance agreed upon by the Clinton Administration.[35] **In other words, the very structure of the U.S. government may make the development and execution of a strategic plan difficult.** The

33 R.D. Brunner and R, Byerly, Jr., "The Space Station Programme," *Space Policy* 6(2): 131-145, 1990.

34 On the other hand scientists have noted that data from the Advanced Very High Resolution Radiometer (AVHRR) sensor aboard NOAA's POES are extremely useful for certain aspects of global change research and that better calibration of the instrument would enhance their research. Hence, a mechanism for including research interests in operational systems would be beneficial.

35 In the case of the USGCRP, the programs of some agencies have been sharply cut and others enhanced as the result of congressional action. Appropriations subcommittees do not necessarily consider the effects of cuts or increases on the overall USGCRP program. See (-1, S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, op. cit., p. 9.

USGCRP has succeeded in increasing overall funding for global change research. It remains to be seen whether a coordinated plan devoted in part to increasing efficiency in Earth observations will function as well.

MONITORING WEATHER AND CLIMATE

NOAA's Polar-orbiting Operational Environmental Satellite (POES) System and DOD's Defense Meteorological Satellite Program (DMSP) have distinct but similar capabilities for gathering data on weather and climate. Since the 1970s, successive administrations have attempted, with only partial success, to merge these two systems.

Convergence

To reduce federal spending, Congress[36] and the Clinton Administration's National Performance Review recommended the consolidation of the "various current and proposed remote sensing programs."[37] The National Performance Review also recommended that NASA "assist in ongoing efforts to converge U.S. operational weather satellites, given the benefits of streamlining the collection of weather data across the government."[38] The Administration released its plan in May 1994 (appendix C). Administration officials will attempt to achieve total savings of up to *$300* million by the year 2000 and $1 billion over a decade by consolidating POES and DMSP (figure **1-3).**[39]

The proposals to consolidate the polar-orbiting programs arose from the desire to achieve cost savings and greater program efficiencies. **Nevertheless, the consolidation of** NOAA's, **DOD's, and NASA's satellite programs could have several benefits even if it achieved no cost savings. These** include the institutionalization of mechanisms to develop research instruments and move them into operational use, the potential for development of long-term (decadal-time-scale) environmental monitoring programs, and a potential strengthening of international partnerships that could facilitate new cooperative remote sensing programs.

Consolidation of DOD and NOAA **meteorological programs involves more than merging programs, spacecraft, and sensors. The** Clinton Administration's convergence plan calls for DOD, NOAA, and NASA to cooperate in setting up an Integrated Program Office (IPO) within NOAA to operate a converged polar-orbiting system. Each agency has different priorities, data requirements, user communities, perspectives, and protocols with respect to technology development, acquisition, and operations-differences they have developed during more than two decades of cooperative, but independent, operation. Therefore, consolidating space activities from DOD, NOAA, and NASA is as much a "cultural" and institutional challenge as a technical one.

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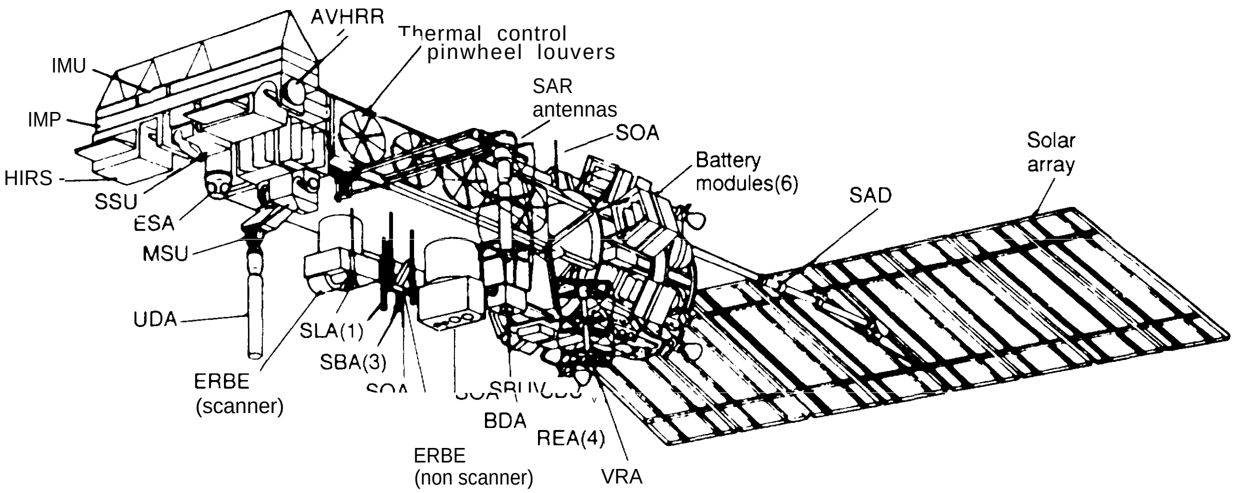
36 In 1993, tw₀ congressional committees requested a review of the NOAA and DOD polar-orbiting satellite programs to explore possible cost savings. See G.E. Brown, Chairman of the House Committee on Science, Space, and Technology, letter to D.J. Baker, Administrator of NOAA, Feb. 22, 1993; J.J. Exon, Chairman of the Senate Subcommittee on Nuclear Deterrence, Arms Control and Defense Intelligence, letter to R. Brown, Secretary of Commerce, June 2, 1993; OTA also suggested consolidation of the two programs as an option for reducing federal spending. See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., p. 16.

37 A. *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, September 1993), Department of Commerce Recommendation 12: Establish a Single Civilian Operational Environmental Polar Satellite Program.

38 of ffice of the Vice President, National Aeronautics and Space Administration, accompanying report of the National performance Review (Washington, DC: Office of the Viced President, September 1993): "By considering MTPE research activities in context with operational weather satellite programs, cost savings are possible through convergence of the current operational satellite fleets. Convergence of the National Oceanic and Atmospheric Administration (NOAA) Polar Metsat and NASA's EOS-PM (Earth Observing SystemAfternoon Crossing [Descending] Mission) will eliminate redundancy of measurements, enhance the capability of NOAA's data set and potentially result in cost savings. "

39 A. *Gore, From Red Tape t. Results: Creating a Government That Works Better and Costs Less*, op. cit.: "TO reduce duplication and save taxpayers a billion dollars over the next decade, various current and proposed polar satellite programs should be consolidated under NOAA."

FIGURE 1-3a: NOAA's Polar-orbiting Operational Environmental Satellite

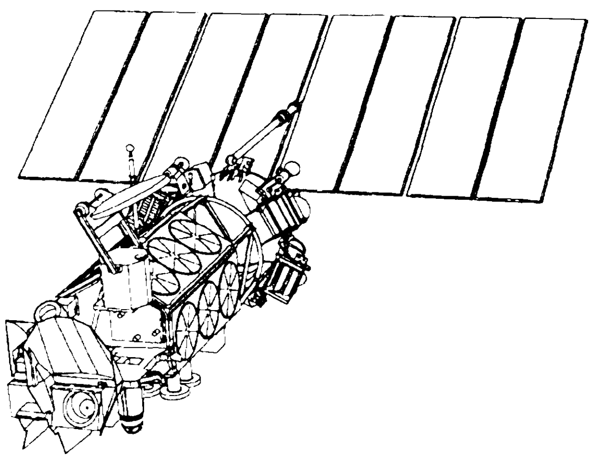


SOURCE: National Oceanic and Atmospheric Administration, 1993.

The principal challenge in converging the polar-orbiting satellite systems is likely to be the development of organizational and institutional mechanisms to ensure stable funding and stable management in programs that now involve multiple agencies and multiple congressional authorization and appropriation committees. The government has few examples of successful long-term, multiagency programs.[40] The recent failure of the joint NASA-DOD management of the Landsat system suggests that proposals to consolidate NOAA, NASA, or DOD programs should, at the very least, be viewed with great caution.

Under the IPO set out in the Clinton Administration's plan (figure 1-4), each agency would take the lead on one aspect of the operational system—technology development, procurement, and operations—but each functional office would include representatives of all agencies. The converged system would be funded by the three

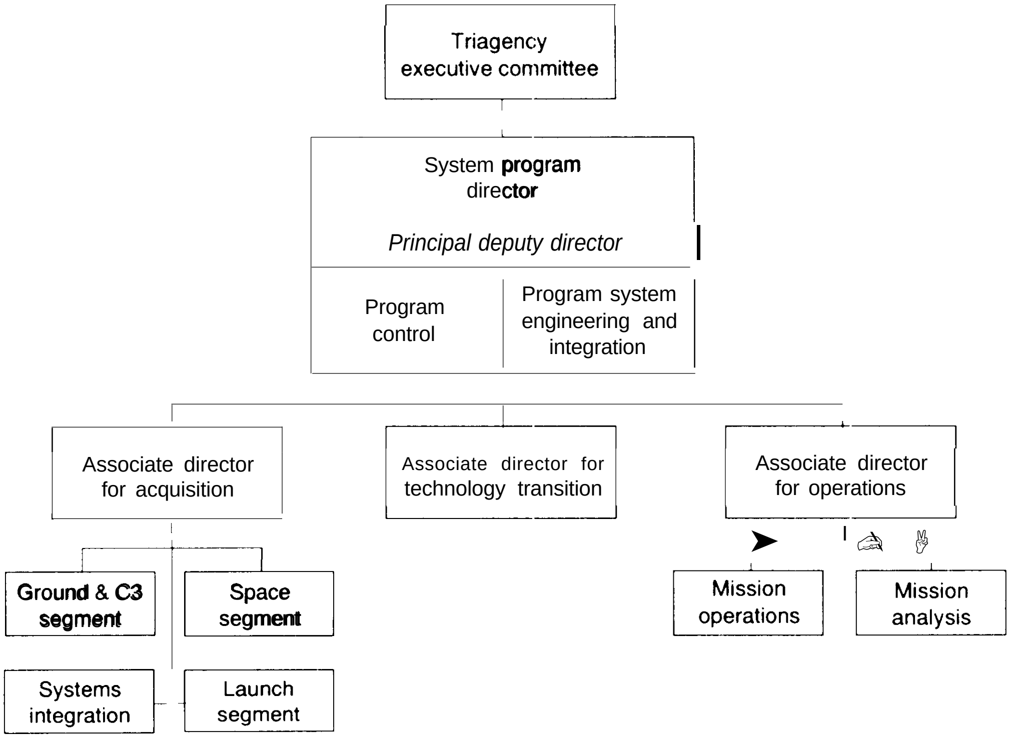
FIGURE 1–3b: DOD's Defense Meteorological Satellite Program Satellite



SOURCE: Department of Defense, 1993

[40] NEXRAD, a program funded jointly by NOAA, the Federal Aviation Administration (FAA), and DOD, has functioned relatively well. However, unlike the converged polar-orbiting system, the components of NEXRAD are relatively severable. If one agency proves unable to fund its portion, the program can still proceed at a reduced level.

FIGURE 1-4: The Integrated Program Office



NOTE: The Integrated Program Office set out in the Clinton Administration's convergence plan will be funded by NASA, NOAA, and DOD. Each agency will take the lead on one aspect of the operational system—technology development (NASA), procurement (DOD), and operations (NOAA)—but each functional office would include representatives of all agencies. This arrangement is designed to institutionalize each agency's incentive to support the overall system.

SOURCE: Presidential Decision Directive NSTC-2, May 5, 1994

agencies. Such an arrangement ensures that each agency has a role and a stake in ensuring system success. On the other hand, it suffers from the weakness of depending on three different sources of funding to support the system. Within the Office of Management and Budget (OMB), the budgets of each agency are handled by different examiners, who must perform a budget crosscut to ensure that the total funding for the IPO is appropriate. Within Congress, the programs and budgets of each agency receive oversight by two committees in each chamber; three subcommittees of the House and Senate appropriations committees appropriate funds.

Although the planning for convergence has already begun, a converged system will not be fully operational until 2005 or later. Near-term savings are, therefore, likely to be modest. The Administration estimates savings of up to $300 million from a total projected outlay of about $2.2 billion between FY 1996 and FY 2000. If implemented successfully, convergence could eventually lead to greater savings. It might also lead to more effective programs as talent and resources are pooled. **Perhaps as important as cost savings, however, would be the opportunity to strengthen the relationship between NASA and NOAA in de-**

veloping the technology that will be needed for future operational spacecraft. Before the mid- 1980s, NASA funded the Operational Satellite Improvement Program (OSIP), which developed technology and flight-worthy instruments for NOAA's operational systems.[41] During the Reagan Administration, NASA sharply reduced its support for OSIP.[42] Currently, NOAA has the lead role in managing operational programs, but it lacks the funds and in-house expertise to develop the instruments it will need to carry out potential new Earth observation programs, such as ocean monitoring and long-term monitoring of Earth's climate.

Once the Integrated Program Office is organized and staffed in October 1994, it will need to address many technical and programmatic issues, including program synchronization and the development of new sensors and spacecraft.

- ***Synchronizing programs.*** To maintain the operational status of their systems, both NOAA and DOD have satellites in storage and in various stages of construction. Before the Clinton Administration's convergence proposal was announced, both systems had been scheduled for so-called block changes, or major redesigns of new sensors and satellites, by about 2006. The Administration now plans to prepare a single spacecraft design by 2005 or 2006 that will satisfy the requirements of both NOAA and DOD. This approach could require the development of new sensors and a new spacecraft. The timing of the spacecraft might enable the converged system to use sensors and/or the spacecraft adapted from the NASA EOS-PM satellite, which NASA is developing to support its two-decade study of global change (appendix A).[43] The first satellite in this series, PM-1, is too far into development for modification to be cost-effective. The second, PM-2, is scheduled for launch in approximately 2005; therefore, it and PM-3, which might be launched in 2010, are the most likely candidates for inclusion in a combined research-operational satellite program.
- ***Sensor and spacecraft convergence.*** A converged meteorological satellite would have to satisfy DOD needs for advanced imagery sensors and NOAA's requirements for highly calibrated sounders. For example, NOAA and DOD may find designing an optical imager suitable for the needs of both agencies particularly difficult technically. Existing NOAA and DOD optical scanners generate images differently and differ in their capabilities to operate at low light levels.[44] Accommodating NASA's science research agenda in an operational program would add further technical and financial challenges.
- ***The transition from research to operational systems. The*** possibility of implementing a combined DOD and NOAA operational program with NASA's EOS-PM science research program adds both opportunities and complications to instrument and spacecraft design. A tri - agency research-operational satellite program

41 See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., pp. 38-39.

42 Throughout the *1970s*, NASA helped develop NOAA's operational satellites through the NASA OSIP. For example, NASA built and paid for the launch of the first two geostationary operational satellites, which NOAA operated. OSIP ended in the early 1980s as NASA placed its emphases elsewhere and may have contributed to the subsequent difficulties NOAA experienced in the development of "GOES-N ext," an advanced geostationary satellite that suffered schedule delays and cost overruns. The first GOES-Next was launched in April 1994 and will go into operation in October 1994. See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., pp. 38-39, for a discussion of the GOES-Next program.

43 EOS-PM carries instruments &Signed to collect data on weather and climate. *See* chapter 3.

44 The DOD operational Linescan System, for example, generates images with approximately constant resolution across the field of view. Images from NOAA's AVHRR degrade in resolution toward the edges of the field of view. Both characteristics are the result of tradeoffs between achieving data of particular interest to the missions of each agency and added cost and complexity.

would present challenges that include the need to:

- satisfy operational needs with relatively unproven instruments,
- accommodate the different production standards and data and communication protocols that, so far, have distinguished operational and research instruments,
- develop advanced instruments that meet NASA's research needs but are affordable to NOAA and DOD,
- develop instruments that meet the more limited space and volume requirements of the smaller, cheaper launch vehicles used in operational programs, and
- accommodate demonstrations of new technology and prototyping of spacecraft that are being used for operational programs.

Operational systems require a predictable, steady supply of data. **Historically, the transition from research instrumentation to operational instrumentation has been successful when it has been managed with a disciplined, conservative approach toward the introduction of new technology.** In addition to minimizing technical risk, minimizing cost has been an important factor in the success of operational programs, especially for NOAA.

Convergence provides an opportunity to restore a successful partnership between NASA and NOAA in the development of operational environmental satellites, expanding that partnership to include DOD operational requirements. However, even with convergence, tensions could arise, as both NOAA and NASA face difficulties in reconciling the inevitable differences in risk and cost between instruments designed for research and instruments designed for routine, long-term measurements. For example, the Moderate-Resolution Imaging Spectroradiometer (MODIS), a key EOS instrument, could eventually replace NOAA's AVHRR. Yet, as currently designed, MODIS is unlikely to fit within NOAA's budget and would produce data that would tax the processing capabilities of operational users. NASA and NOAA would likely have to redesign MODIS to make its characteristics more compatible with NOAA's needs. NASA designed its EOS program to provide data for the research and policymaking communities rather than to serve as a test bed for advanced technology. With or without convergence, NASA, NOAA, and DOD would find many challenges in adapting EOS instruments to serve both research and operational needs.

The Clinton Administration's convergence plan maintains and could even strengthen U.S. cooperative relationships with Eumetsat, which plans to operate the METOP-1 polar-orbiting meteorological satellite system beginning in 2000. At the same time, the plan increases U.S. dependence on Europe for meteorological data. As the IPO develops its detailed plans for convergence, it will have to address certain questions, including the following:

- ***What arrangements can the United States and Eumetsat make to prevent its adversaries from using these meteorological data during times of crisis? Who determines when such times exist and how?*** Previous efforts at convergence failed in part because DOD wished to control its source and distribution of weather data, especially in times of crisis. Current plans call for Eumetsat to include three U.S. sensors on METOP.[45] DOD has argued that it needs the capability to deny useful weather data to adversaries in times of crisis. During such times, DOD proposes to encrypt data from U.S. sensors. It would release the data a few hours later, when they could no longer be used to assist adversaries' war-fighting capabilities.

  Even if control over data is achieved, the growing capabilities of other countries to acquire sophisticated weather data and information may reduce the advantage DOD would

[45] AVHRR, the High-Resolution Infrared Sounder (HIRS), and the Advanced Microwave Sounding Unit (AMSU).

have in controlling weather data.[46] Eumetsat is dubious of such data control because it would sharply reduce the capability of the METOP system to supply data to Eumetsat's contributing partners, the weather bureaus of each country. Eumetsat has linked this issue to "the open issues between NOAA and Eumetsat regarding data policy for both geostationary and polar satellites."[47] Before disclosing the plans for convergence on May 6, 1994, the United States opposed the encryption of data on either the geostationary or the polar-orbiting satellites on grounds that such data should be available to all users.

- ***How will the United States reconcile European desires for self-sufficiency in sensors and spacecraft with U.S. needs for consistency of data among spacecraft?*** Although three U.S. sensors will fly on METOP-1 and METOP-2, Europe plans to develop its own sensors for future METOP spacecraft. Data users require consistency in format and calibration. To maintain consistent data, IPO officials will have to coordinate closely with Eumetsat and European Space Agency officials concerning the technical characteristics of new sensors.
- ***What contingency plans are necessary should delays occur in the launch of METOP or should it fail at launch or on orbit?*** As the U.S. and European experience has demonstrated, space operations risk occasional delays and failures. Hence, the United States and Eumetsat will have to work out a detailed contingency plan to ensure full operational status. Previous NOAA-Eumetsat experience in providing backup satellites and services for each other in times of need will provide important guides for future plans.

In the future, the United States may wish to consider expanding its international cooperation on weather satellites. It already cooperates closely with Japan and with Eumetsat on supplying data from the geostationary weather satellites. Recently, officials from both Japan and Russia have inquired informally about the possibility of broadening the arrangement for the polar-orbiting systems.[48] Japan has a very active remote sensing program in support of operational applications and scientific research, cooperating closely with the United States on global change research.[49] Japan does not currently operate polar-orbiting weather satellites, but it is interested in the long-term operation of ocean monitoring satellites. Japan currently depends on data from the U.S. polar orbiters. Russia operates the Meteor series of polar-orbiting weather satellites that provide data similar to the U.S. POES. One of the Meteor satellites now carries a Total Ozone Mapping Spectrometer (TOMS) instrument, provided by NASA. to assist in monitoring atmospheric concentrations of ozone. **In the next few years, Congress may wish to explore the opportunities for expanded international cooperation in the polar-orbiting program in an effort to improve the gathering and distribution of Earth observation data. Other countries could supply sensors, spacecraft, or both.**

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46 National security restrictions on technical capabilities of land remote sensing systems have relaxed considerably since the 1970s, in large part because other countries have gained capabilities once controlled only by the United States and the former Soviet Union. France, for example, currently operates the SPOT Image satellite system, which collects data of much higher ground resolution than the comparable U.S. Landsat system. As noted earlier in this chapter, the French HELIOS surveillance satellite reportedly will achieve 1 -m ground resolution. Other countries are steadily improving their weather monitoring systems as well.

47 J, Morgan Director of Eumetsat, letter to E.F. Hollings, Chairman of the Committee on Commerce, Science, and Transportation. U.S. Senate, Washington, DC, June 10, 1994.

48 D.J. Baker, Under Secretary of Commerce for Oceans and Atmosphere, National Oceanic and Atmospheric Administration. testimony presented at hearing son convergence before the Committee on Commerce, Science, and Transportation, U.S. Senate, Washington. DC, June 14, 1994.

49 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, *Op.* cit., pp. *177-178.*

Long-Term Options

If the federal government were structuring an institution to develop and operate environmental satellites de novo, it would probably not create as complicated an administrative arrangement as the Integrated Program Office. However, the Administration is attempting to bring two satellite systems, each with its own requirements, objectives, and procedures, under a single institutional structure. By including NASA in the structure, it is also attempting to increase the success of incorporating instruments from EOS satellites in future polar-orbiting spacecraft. This arrangement could also benefit NASA's EOS program by tying it more closely to an operational program.

Experience with the Administration's plan, which provides near-term direction for convergence, will guide future long-term plans. For example, experience with the IPO arrangement may demonstrate that DOD's needs for timely meteorological data can be met with a civilian-operated system. In addition, the international proliferation of environmental satellite systems may increase the sources of high-quality weather data, thereby reducing the need for a strong DOD presence in the operational system. Thus, **over the long term, Congress may wish to consider eventually placing the development, acquisition, and operation of the nation's polar-orbiting environmental satellite system entirely within a single civilian agency.** Long-term options for this shift of responsibility include (see box 1-5):

- ***incorporate the Integrated Program Office into a NOAA office,***
- ***integrate NOAA's operational satellite services into NASA,***
- ***develop an independent agency focused on Earth observations, or***
- ***incorporate Earth remote sensing efforts into a Department of the Environment.***

Each of these options would streamline the congressional authorization and appropriations process. The last three might lead to greater funding stability for a global environmental monitoring system. None would undercut efforts to increase international participation in such a system. As the United States gains experience with the near-term arrangement as outlined in the Administration plan, arrangements more suitable for the long term can be considered. Experience may also show that none of these options is able to give sufficient attention to DOD's needs for data that support its missions. The Administration's near-term plan gives heavy emphasis to DOD's data requirements and adopts many elements of DOD's process for determining data requirements. Decisions about a long-term plan do not need to be made for several years; in the meantime, Congress will have ample opportunity to assess the progress made in bringing these programs together.

LAND REMOTE SENSING

U.S. government efforts to develop operational, civilian, space-based land remote sensing systems have proved technically successful but chaotic in terms of policy. Since 1972, first NASA, then NOAA, and now EOSAT have operated the Landsat system—the U.S. satellite system for collecting multispectral data (figure 1 -5) about the surface of Earth (appendix D). NASA, NOAA, and the U.S. Geological Survey (USGS) are now collaborating on procuring and operating the newest Landsat system, Landsat 7. Because Landsat data constitute the longest continuous record of the state of the world's land and coastal areas, they are extremely important in monitoring regional and global change. Many federal and state agencies now depend on Landsat data to carry out their legislatively mandated programs. Hence, **maintaining the continuity of data from Landsat should continue to be a priority for the United**

BOX 1-5: Long-Term Options for a Converged Satellite System

- ***Incorporate the Integrated Program Office into a NOAA Office.*** Under this option, the Integrated Program Office would eventually become solely a NOAA function, and NOAA would assume responsibility for providing data for both civilian and national security needs. Such a transition would require enhancing NOAA's budget to pay for the personnel required to provide the three office functions of acquisition, technology transition, and operations. In addition, the new office within NOAA would still have to maintain close connections with NASA to take advantage of NASA's institutional capabilities in developing new sensors and spacecraft. It would also have to maintain similar ties with the DOD laboratories that have developed DMSP instrumentation in order to ensure sufficient attention to DOD data needs.
- ***Integrate NOAA's operational satellite services into NASA.*** NASA has the largest civilian budget for space technology development and operations, and a future operational program could develop from elements of NASA's Earth Observing System. However, NASA has relatively little experience in running an operational program. Its institutional culture is more suited to conducting R&D in support of operational programs than to conducting operational programs. [1]In addition, NASA might not be as attentive to the needs of the National Weather Service or other data users as NOAA is now.
- ***Develop an independent agency focused on Earth observations.*** Such an agency would incorporate NASA's Office of Mission to Planet Earth, NOAA's National Environmental Satellite Data and Information Service (NESDIS), and some elements of DOD's DMSP Office. This agency would benefit from a focus on environmental issues. It would pursue research on the global environment and operate the nation's environmental satellite programs. However, part of NASA's broad expertise with space systems might be lost. In addition, such an agency would compete with large agencies and might have difficulty maintaining a budget large enough to provide effective operational service.
- ***Incorporate Earth remote sensing efforts into a Department of the Environment.*** In recent years, several groups have suggested developing a Department of the Environment to consolidate environmental programs now located in other agencies. A Department of the Environment could include the Environmental Protection Agency (EPA), NOAA, and parts of the Department of the Interior and the Department of Energy. It might also include NASA's Office of Mission to Planet Earth, or its successor. Such an agency would have the advantage of bringing together programs and staff with similar interests in understanding and preserving the national and global environment. For environmental remote sensing, such an institutional arrangement might assist in consolidating data requirements and give a much firmer base to funding satellite programs. The political cost of reorganization, including the rearrangement of congressional authority, would impede efforts to establish such an office. Any effort to consolidate environmental programs under the management of a single agency would be derived primarily from concerns over giving more focused national attention to environmental issues. Finding a better institutional setting for the polar-orbiting satellite programs would be one of many such concerns.

[1] U.S. Congress, Office of Technology Assessment, *Civilian Space Policy and Applications*, OTA-STI-177 (Washington, DC: U.S. Government Printing Office, June 1982), ch. 9.

SOURCE: U.S. Congress, Office of Technology, 1994.

FIGURE 1-5: 1993 Landsat Image of Miami, Florida

SOURCE © 1993 by EOSAT

States.[50] If the United States is to maintain the future continuity of data delivery from Landsat, it will have to develop an operational system. However, **despite significant advances in remote sensing technology and the steady growth of a market for data, the United States lacks a coherent, long-term plan for a fully operational land remote sensing system.**

The Future of the Landsat Program

As currently structured, the Landsat program is vulnerable to a launch-vehicle or spacecraft failure. The Landsat program has also suffered from instability in management and funding. Indeed, the Landsat program still bears more resemblance to an experimental program than an operational one. As a result of the loss of Landsat 6 and the lack of a backup satellite, the United States now faces the prospect of losing data continuity before Landsat 7 can be built and launched in late 1998. In addition, as demonstrated by its policy history, the Landsat program is highly vulnerable to the breakdown of institutional relationships. Responsibility for satellite procurement, operation, and data distribution is currently split among three agencies—NASA, NOAA, and USGS. Thus, the Landsat program could be in jeopardy should differences of opinion about its value arise within NASA, the Department of Commerce, or the Department of the Interior, or within the appropriations subcommittees of the House and Senate.[51] Indeed, the report of the Senate Appropriations Committee for NASA's FY 1995 appropriations expresses concern over whether NOAA will have sufficient funding to support the operations of Landsat 7.[52] Ensuring the future of the Landsat program will require close cooperation among NASA, the Department of Commerce, the Department of the Interior, and the six appropriations subcommittees of the House of Representatives and the Senate.

The United States has a few short-term options for improving Landsat program resiliency. As one option, the United States could also

50 The Land Remote Sensing Policy Act of 1992 (P.L. 102-555, 106 Stat. 4163-41 80; 15 USC 5601, sec. 2. Findings) strongly supports the "continuous collection and utilization of land remote sensing data from space" in the belief that such data are of "major benefit in studying and understanding human impacts on the global environment, in managing the Earth natural resources, in carrying out national security functions, and in planning and conducting many other activities of scientific, economic, and social importance."

51 NASA's appropriations originate in the Subcommittee on Appropriations for the Veterans Administration, Housing and Urban Development, and Independent Agencies; NOAA's originate in the Subcommittee on Commerce, Justice, State, and the Judiciary; and USGS's originate in the Subcommittee on Interior and Related Agencies.

52 The Committee recommended removing "$10 million from program reserves for Landsat. In the operating plan, NASA should indicate whether sufficient support exists in NOAA's committees of jurisdiction in the Congress to support NOAA funds for Landsat 7. Without such assurances, the viability of Landsat 7 as a joint project is questionable." Report 103-31 I of the Senate Subcommittee on Appropriations for the Veterans Administration, Housing and Urban Development, and Independent Agencies for FY 1995, p. 126.

rely on non-U. S. sources of data. Land remote sensing became broadly international in the 1980s with the development of the French SPOT, the Russian Resurs-F, and the Indian Remote Sensing Satellite (IRS) systems. Some data users would be able to substitute digital data from the French SPOT system or from the Indian IRS system, which EOSAT now distributes worldwide. SPOT data are already in wide use in the remote sensing community. However, SPOT data do not have the spectral or spatial range of Landsat. Few users have experience with IRS data, which nearly duplicate the resolution and spectral response of the first four spectral bands of Landsat TM data. To determine whether IRS data could serve as backup to the Landsat system, data users will have to experiment with the data in their specific application. NASA, USGS, and other U.S. agencies could assist such users by carrying out a series of experiments with the IRS data to determine how well they would function as backups to Landsat data.

Alternatively, if the Thematic Mapper (TM) sensors or the X-band data transmitters aboard Landsats 4 and 5 fail, before the launch of Landsat 7 in 1998, it will still be possible to collect data from the low-resolution Multispectral Scanner (MSS) sensor, which could likely be reactivated.[53] Such data would still be useful for certain global change studies and other applications where fineness of resolution is not a major concern.

In the long term, the United States may wish to develop a fully operational system that provides for continuous operation and a backup satellite in the event of system failure. In the past, high system costs have prevented the U.S. government from making such a commitment. If system costs can be sharply reduced by inserting new, more cost-effective technology or by sharing costs with other entities, the government might be able to maintain the continuity of delivery of Landsat-type data.

As noted earlier, several firms plan to build and operate commercial remote sensing systems.[54] **Because these firms focus on providing data of comparatively high resolution, only a few or no spectral bands, and limited spatial coverage, these systems cannot substitute for the Landsat system, which collects calibrated multispectral data over a large field of view.** However, these systems are likely to provide data that would complement data from Landsat and similar systems. Ultimately, the United States may wish to develop a new system concept for Landsat, one that incorporates both wide-field multispectral observations and narrow-field, stereo panchromatic observations.

■ Options for Reducing the Costs of Federal Land Remote Sensing

One way to cut costs in land remote sensing would be to enter into partnership with a U.S. private firm or firms. Four broad options are possible:

1. ***Contract with a private firm to operate a system,*** paid for by the federal government, that distributes the data at the cost of fulfilling user requests.[55]
2. ***Return to an EOSAT-like arrangement*** in which government supplies a subsidy and specifies the sensor and spacecraft but allows the firm to market the data, setting its own prices according to market forces.
3. ***Make a data-purchase arrangement*** in which the government purchases data of specified character and quality from a private-sector supplier.

[53] EOSAT has deactivated the MSS sensor, MSS data could be collected again if the MSS sensor and the S-band transmitter that transmits MSS data continue to operate properly. EOSAT stopped collecting data from these sensors in December 1992 because demand for these relatively low-resolution data was low.

[54] See "The Private Sector" section.

[55] In other words, according to the guidance of OMB Circular A-130.

4. ***Create a public-private joint venture*** in which the government and one or more private firms cooperate in developing a land remote sensing system.

The U.S. government could also enter into partnership with one or more foreign governments.[56] Interest in enhancing national prestige and the prospect of being able to make remote sensing a commercially viable service have heretofore prevented the United States and other countries from developing cooperative land remote sensing systems. Yet, systems such as Landsat that produce calibrated multispectral data of moderate resolution may never be commercially viable,[57] even though the data are of great interest to global change scientists and other users who require coverage of relatively large areas. Hence, cooperation on systems that primarily serve the public good may eventually be in the best interests of several countries. Possible candidates include Canada, which is developing Radarsat; France, which is operating the SPOT system; Germany, which has developed several sensors but has no satellite system; India, which now operates IRS-1; Japan, which operates Japan Earth Resources Satellite- 1 (JERS-1) and Marine Observation Satellite-2 (MOS-2); and Russia, which has a long history of using photographic remote sensing systems but whose multispectral digital systems have yet to prove themselves. Alternatively, a system might be provided by a consortium of several countries.

In addition to paying greater attention to improving organizational efficiencies and reducing costs, the United States may wish to institute a focused program to develop remote sensing technologies. **If the United States wishes to maintain and improve its capabilities in remote sensing technology as called for in the Land Remote-Sensing Policy Act of 1992 (P.L. 102-555, Title III), it should continue to develop new technology for the Landsat program as well as for EOS and other programs.**

OCEAN REMOTE SENSING

The oceans cover about 70 percent of Earth's surface and, therefore, make a significant contribution to Earth's weather and climate. The oceans interact with the atmosphere, land, and ice packs, constantly exchanging heat and moisture with them. Yet Earth's oceans remain much more of a mystery than its atmosphere. Scientists know very little about the details of the oceans' effects on weather and climate, in part because the oceans are monitored only coarsely by satellites, ships, and buoys. Sea ice covers about 13 percent of the world oceans and has a marked effect on weather and climate. Measurements of the thickness, extent, and composition of sea ice help scientists understand and predict global trends in weather and climate. More detailed geographic coverage and more timely delivery of ocean and ice data would significantly enrich scientists' understanding of both realms.

Improving the safety of people at sea and managing the seas' vast natural resources also depend on receiving better and more timely data on ocean and sea-ice phenomena. For example, until satellite measurements became available, the difficulties of monitoring characteristics of the ice packs from ground- or aircraft-based observations were major impediments to understanding the behavior of sea ice, especially its seasonal and yearly variations. Table 1-2 summarizes some of the data that ocean-ice satellite sensors can provide.

56 N. Helms and B. Edelson, Op. cit.

57 M. C. Trichel, ERIM, has suggested that although Landsat as currently conceived may not be a candidate for commercialization because of its 16-day revisit period and its 1970s technology, a Landsat replacement using lightweight advanced technology might be commercially successful (personal communication, 1994). NASA's experience with the data from a hyperspectral smallsat built by TRW may help determine whether the market would support such a system.

TABLE 1-2: Ocean and Ice Data

Sensor	Data	Science question	Application
Ocean-color sensor	Ocean color.	Phytoplankton concentration, ocean currents, ocean surface temperature; pollution and sedimentation	Fishing productivity, ship routing, monitoring coastal pollution.
Scatterometer	Wind speed, wind direction	Wave structure, currents, wind patterns.	Ocean waves; ship routing, currents, ship, platform safety
Altimeter	Altitude of ocean surface, wave height, wind speed.	El Niño onset and structure	Wave and current fore-casting.
Microwave Imager	Surface wind speed, ice edge, precipitation	Thickness, extent of ice cover; internal stress of ice; ice growth and ablation rates	Navigation information, ship routing, wave and surf forecasting
Microwave radiometer	Sea-surface temperature.	Ocean-air interactions.	Weather forecasting

SOURCE U S Congress Office of Technology Assessment, 1994

Operational Monitoring of the Oceans and Ice

The development and operation of NASA's Seasat system, the first satellite devoted solely to measurements of ocean-ice phenomena, demonstrated the utility of continuous ocean observations, not only for scientific use, but also for navigating the world's oceans and exploiting ocean resources. Seasat failed after only 3 months. Nevertheless, its operation convinced many that an operational ocean remote sensing satellite would provide significant benefits.[58] Although the capabilities of land and ocean sensing systems are not entirely separable,[59] agencies have developed satellite systems with specialized applications in order to optimize the sensors and spacecraft.

In the long term, the United States may wish to provide ocean-ice data on an operational basis. Not only do NOAA and DOD have applications for data in an operational mode (i.e., where continuity of data over time is ensured and the data formats change only slowly), but so also do private shipping firms and operators of ocean platforms. Knowledge of currents, wind speeds, wave heights, and general wave conditions at a variety of ocean locations is crucial for enhancing the safety of ocean platforms and ships at sea. Such data could also decrease costs by allowing ship owners to predict the shortest, safest sea routes. Information about ocean biological productivity would help guide commercial fishing to promising fishing grounds and assist in maintaining fisheries yields.

Despite repeated proposals for operational ocean satellites, the United States has not yet made the commitment to ocean monitoring outside of meteorological applications.[60] In the meantime, other entities, such as ESA, Japan, and Canada, are emerging as primary sources of ocean data for research and operational purposes (figure

[58] D. Montgomery}. "Commercial Applications of Satellite Oceanography," *Oceanus* 24(3), 198 I: Joint Oceanographic Institutions, "Oceanography) from Space: A Research Strategy for the Decade 1985- 1995"' (Washington, DC: Joint Oceanographic Institutions, 1984).

[59] Most sensors provide some data about both land and the oceans.

[60] The National Oceanographic Satellite System (NOSS), developed in the late 1970s by NASA, NOAA, and the Navy, was canceled in 1981 in part because of its cost. A similar fate befell the Navy Remote Ocean Sensing Satellite (N-ROSS) in 1988.

FIGURE 1-6: European Space Agency ERS-1 Image of the Bay of Naples

SOURCE: © 1992 by ESA.

1-6). Growing experience with these data for operational uses and for global change research could increase U.S. interest in ocean monitoring and could build confidence in relying on these (and other) foreign services. In addition, growing experience with land remote sensing has demonstrated to a wider set of users the utility of remote sensing for operational purposes.

Options for Operational Ocean Monitoring

If Congress wishes to support a U.S. commitment to civilian operational ocean monitoring, it could:

- ***Expand the mandate of the IPO to include an ocean and ice monitoring capability.*** Although the POES and DMSP satellites collect data about the surface of the ice and oceans, these capabilities could be expanded to include additional useful data about ocean-surface wind speeds and currents, and more precise characterization of the boundaries and thickness of sea ice. The IPO could increase its capabilities for collecting such data incrementally by improving existing instruments and by adding additional ones as needs arise.
- ***Develop a comprehensive national ocean observation system,*** which would be the most costly option because it would require the U.S. government to develop instruments and a spacecraft that it does not now possess. However, a national system would allow the greatest independence in developing programs to meet U.S. national needs. The United States has started out on this course twice in the past,[61] only to step back as the costs mounted.
- ***Take part in an international ocean monitoring system,*** which would be much less expensive than creating a national system because the U.S. government would share the burden of satellite systems with other countries. For example, the United States could deploy satellites for ocean color, scatterometry, and wave altimetry while relying on other countries for SAR data on sea ice. This type of approach would build on existing mechanisms for international data exchange to provide data from various types of sensors to all participants, but it would require expanding the capacity for data processing and transmission, both domestically and internationally.
- ***Purchase data from commercial satellite operators,*** which might reduce costs and strengthen the U.S. private sector. However, to reduce the risk to potential contractors, this option would require a long-term commitment from the government to acquire specified types and quantities of data. The novel arrangement between NASA and Orbital Sciences Corpora-

61 For example, with [he proposed joint civilian-military NOSS and with the Navy's N-ROSS.

(ion for the development of the SeaStar system will provide a test of this approach.

- ***Rely primarily on data exchanges with other countries,*** which means that the United States could also continue to forego any major commitment of resources to satellite ocean monitoring beyond existing meteorological programs. This approach offers the lowest up-front cost, but it also provides the United States with the least influence over the future of ocean monitoring programs and related data-exchange policies unless it is tied to other activities with these same countries. The eventual cost in limited data access or high data prices might surpass the initially low costs.

Whichever path Congress chooses for the future of U.S. ocean monitoring activities, **the most important question is whether the United States will make a long-term commitment to ocean monitoring.** Cost has been a critical factor in the inability to maintain past proposed programs, which may have been overly ambitious. The emergence of satellite ocean observation programs in other countries presents the opportunity to develop a less expensive strategy for ocean monitoring. Experience with data from the European Remote-Sensing Satellite-1 (ERS-1), JERS-1, MOS, and Radarsat, as well as from the U.S. SIR-C synthetic aperture radar flown on the Space Shuttle,[62] will provide additional information regarding the desirability of an operational system. That information, when considered in light of overall U.S. goals for Earth observations, could provide the basis for deciding whether or not to pursue an operational ocean-ice monitoring program.

62 SIR-C flew for the first time on the Space Shuttle in April 1994. 1(s second flight is scheduled for December 1994.