Civilian Satellite Remote Sensing: A Strategic Approach

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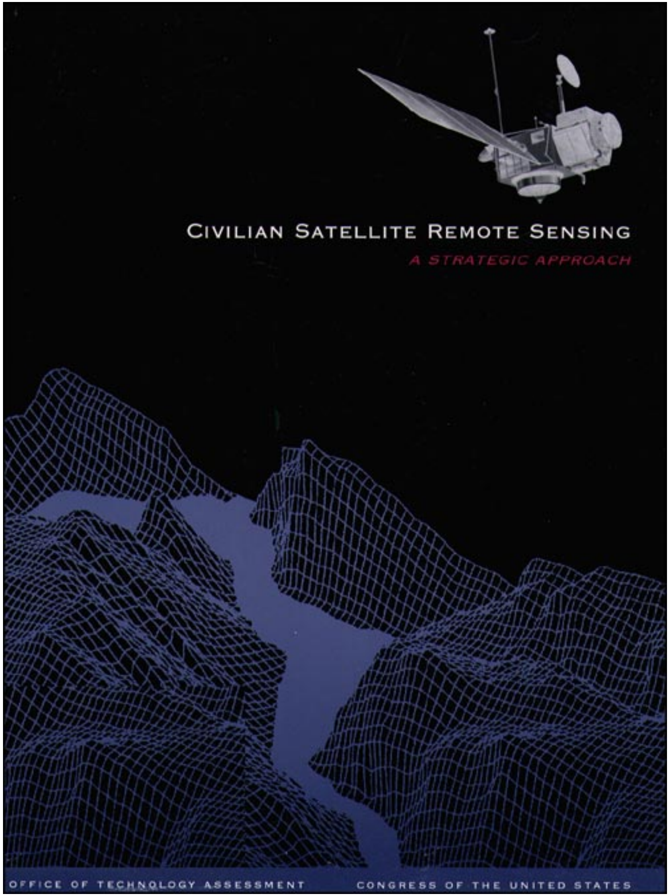

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Foreword

Over the next two decades, Earth observations from space promise to become increasingly important for predicting the weather, studying global change, and managing global resources. How the U.S. government responds to the political, economic, and technical challenges posed by the growing interest in satellite remote sensing could have a major impact on the use and management of global resources.

The United States and other countries now collect Earth data by means of several civilian remote sensing systems. These data assist federal and state agencies in carrying out their legislatively mandated programs and offer numerous additional benefits to commerce, science, and the public welfare. Existing U.S. and foreign satellite remote sensing programs often have overlapping requirements and redundant instruments and spacecraft. This report, the final one of the Office of Technology Assessment analysis of Earth Observations Systems, analyzes the case for developing a long-term, comprehensive strategic plan for civilian satellite remote sensing, and explores the elements of such a plan, if it were adopted. The report also enumerates many of the congressional decisions needed to ensure that future data needs will be satisfied.

In undertaking this effort, OTA sought the contributions of a wide spectrum of knowledgeable individuals and organizations. Some provided information; others reviewed drafts. OTA gratefully acknowledges their contributions of time and intellectual effort. OTA also appreciates the help and cooperation of officials with the Department of Defense, the National Aeronautics and Space Administration, and the National Oceanic and Atmospheric Administration.

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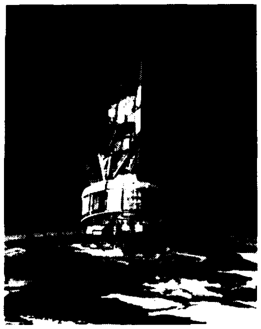
Contents

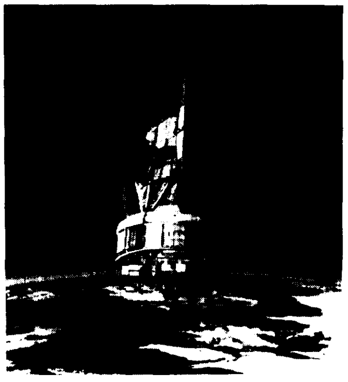


APPENDIXES

Executive Summary

Over the past two decades, data from Earth sensing satellites have become important in helping to predict the weather, improve public safety, map Earth's features and infrastructure, manage natural resources, and study environmental change. In the future, the United States and other countries are likely to increase their reliance on these systems to gather useful data about Earth.

U.S. and foreign satellite remote sensing systems often have overlapping requirements and redundant capabilities. **To improve the nation's return on its investment in remote sensing technologies, to meet the needs of data users more effectively, and to take full advantage of other nations' capabilities, Congress may wish to initiate a long-term, comprehensive plan for Earth observations.** 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 individual agency priorities in a framework of overall national priorities, a strategic plan would help ensure that agencies meet broad-based national data needs with improved efficiency and reduced cost.



ELEMENTS OF A STRATEGIC PLAN

A comprehensive strategic plan would endeavor to:

- incorporate the data needs of both government and nongovernment data users,
- improve the efficiency and reduce the costs of space and data-handling systems,
- involve private operators of remote sensing systems,
- incorporate international civilian operational and experimental remote sensing programs, and

- guide the development of new sensor and spacecraft technologies.

Meeting Data Requirements

To provide the foundation for a strategic plan, the federal government should aggregate and consider specific data needs from all major data users. Options for strengthening the process for setting data requirements include:

- developing methods to increase the interactions among users, designers, and operators of remote sensing systems,
- involving a broader range of users in discussions of requirements, and
- developing a formal process for revising agency satellite programs in response to emerging capabilities and needs from a broadened user base.

Primary Elements of the U.S. Remote Sensing Community

Federal government civilian operators and data users
- *Scientists*
- *Operational users (e.g., 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*

Private Sector

A strategic plan for Earth observations should capitalize on the expertise resident in private industry. The collection of private firms that supply data-processing and -interpretation services is small but growing rapidly. In setting requirements for future remote sensing systems, the federal government may wish to take into account the needs of private-sector data users, who provide an important source of innovative applications of remotely sensed data.

U.S. firms are now developing land and ocean sensing systems with new capabilities. **If private systems succeed commercially, they are likely to change the nature and scope of the data market dramatically.** Congress could assist the remote sensing industry and enhance its international competitiveness by:

- directing federal agencies to purchase data rather than systems from private industry.
- providing oversight to ensure that federal agencies do not compete with industry in developing software, providing analytic services, and developing remote sensing systems, and
- supporting the development of advanced technologies to assist government remote sensing programs and private-sector needs.

International Cooperation

To reduce costs and improve the effectiveness of remote sensing programs, a strategic plan should include mechanisms for exploiting international capabilities. The open exchange of data is essential to international cooperation in remote sensing, especially for weather forecasting, global change research, ocean monitoring, and other applications that require data on a global scale. To enhance the benefits of international cooperation in remote sensing, the United States could consider pursuing one or more of the following:

- increase U.S. efforts to promote sharing of data gathered from national systems,
- participate in a formal international division of labor, which would allow countries to specialize in the types of data they collect, and
- support development of an international remote sensing agency, to which each participating nation would contribute funding to develop an international satellite system.

Countries and Organizations with Significant Remote Sensing Programs
Canada
European Space Agency (ESA)
European Organisation for the Exploration of Meteorological Satellites (Eumetsat) (ESA)
France
Germany
Japan
Russia
United States

DATA COLLECTION

As part of its strategic plan, the United St ates needs to improve its programs for:

- collecting atmospheric data to support weather forecasting and severe-weather warning,
- monitoring the land surface,
- monitoring the oceans and ice caps,
- collecting data to support research on global environmental change, and
- monitoring key indicators of global change and environmental quality over decades.

Converging the Polar-Orbiting Meteorological Satellite Systems

The Clinton Administration's plan to consolidate the two polar-orbiting systems operated by the National Oceanic and Atmospheric Administration (NOAA) and the Department of Defense (DOD) is one important component of a broader strategic plan. DOD, NOAA, and NASA will contribute personnel and funding to an Integrated Program Office within NOAA, which will operate the converged polar-orbiting system.

This proposal arose from the desire to reduce program redundancy and costs. Yet, convergence of the agencies' satellite programs into a single program could have several benefits even if it achieved no cost savings. These include the institutionalization of mechanisms for moving research instruments into operational use, the development of long-term environmental monitoring programs, and the strengthening of international partnerships.

The convergence plan would continue U.S. cooperative relationships with Europe through Eumetsat, which plans to operate the METOP-1 polar-orbiting meteorological satellite system beginning in 2000. The plan also increases U.S. dependence on Europe for meteorological data. DOD's desire to control the flow of data from U.S. sensors aboard the Eumetsat METOP during times of crisis may impede the completion of a U.S.-Eumetsat agreement. In the future, the United States and Eumetsat may wish to expand their cooperative satellite program by including Japan and/or Russia as partners.

The U.S. government has few examples of successful long-term, multiagency programs. Ensuring stable funding and stable management in programs that now involve multiple agencies and multiple congressional authorization and appropriations committees will challenge Congress and the Administration. Nevertheless, convergence of the polar-orbiting programs could serve as an important experiment in determining the feasibility of developing and executing a long-term strategic plan for Earth observations.

Land Remote Sensing

Despite significant advances in remote sensing technology and the steady growth of a market for data, the United States continues to approach the Landsat program more as a research effort than a fully operational one. As currently structured, the Landsat program is vulnerable to a launch-vehicle or spacecraft failure. It has also suffered from instability in management and funding. The current management arrangement, in which responsibility for satellite procurement, operation, and data distribution is split among NASA, NOAA, and the U.S. Geological Survey, risks failure should differences of opinion about the value of Landsat arise among these agencies or the appropriations committees of the House and Senate.

High system costs have prevented the U.S. government from committing to a fully operational land remote sensing system. To reduce taxpayer costs, the government could:

- return to an EOSAT-like arrangement, in which the government supplies a system subsidy but allows the firm to sell the data at market prices,
- contract with industry suppliers to provide data of specified character and quality,
- create a public-private joint venture in which the government and one or more private firms cooperate in developing a land remote sensing system, and/or
- lead the development of an international land remote sensing system with one or more foreign partners.

Ocean and Ice Remote Sensing

The United States may eventually wish to provide ocean and ice data on an operational basis. Not only do NASA, NOAA, and DOD have applications for scientific and operational data, but so also do ocean fishing companies, private shipping firms, and operators of ocean platforms. Europe, Japan, and Canada are emerging as primary sources of ocean and ice data for research and operational purposes. If Congress wishes to support a U.S. commitment to civilian operational ocean and ice monitoring, it could direct NASA, NOAA, and DOD to:

- broaden their scope for monitoring ocean and ice on existing systems,
- develop a comprehensive national ocean observation system,
- take part in developing an international ocean monitoring system,
- purchase data from commercial satellite operators, or
- rely primarily on data exchanges with other countries.

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

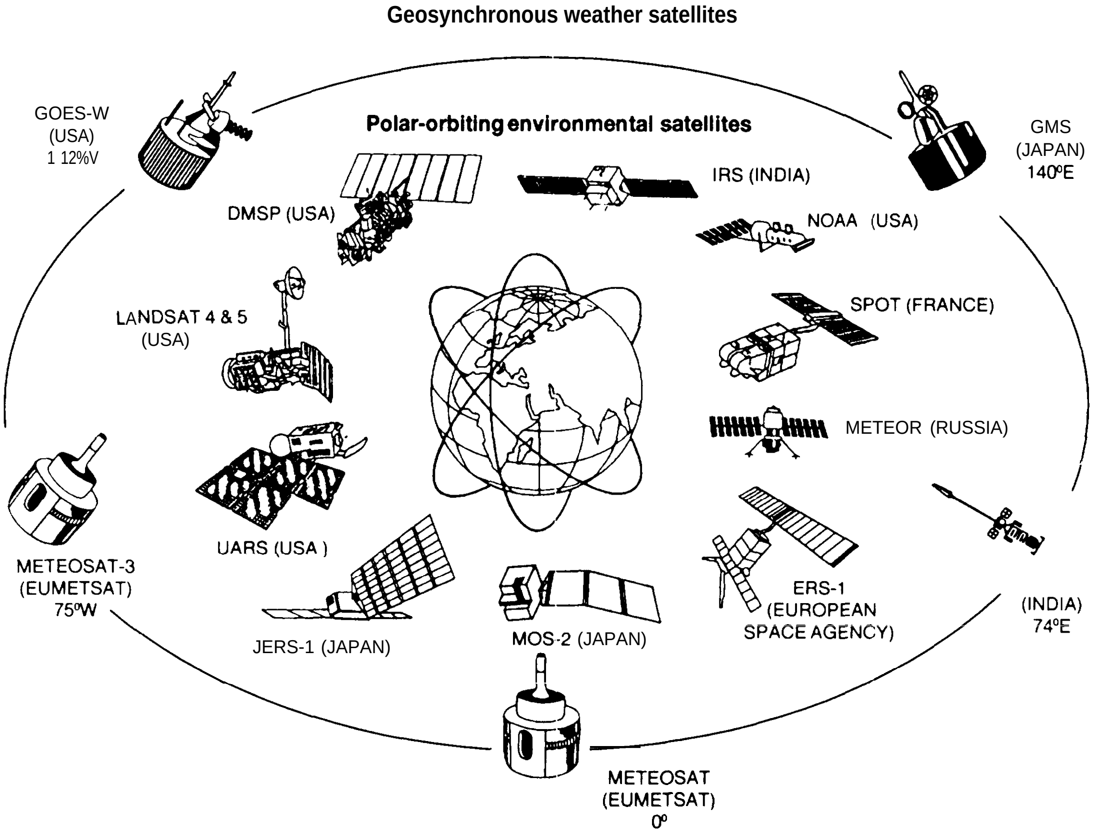
SOURCE Off Ice of Technology Assessment, 1994

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.

plications 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.

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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, I 994, pp. 3, 2 I

[24] Indeed, DOD is I ikely 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

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 the International Astronautical Federation*, 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.

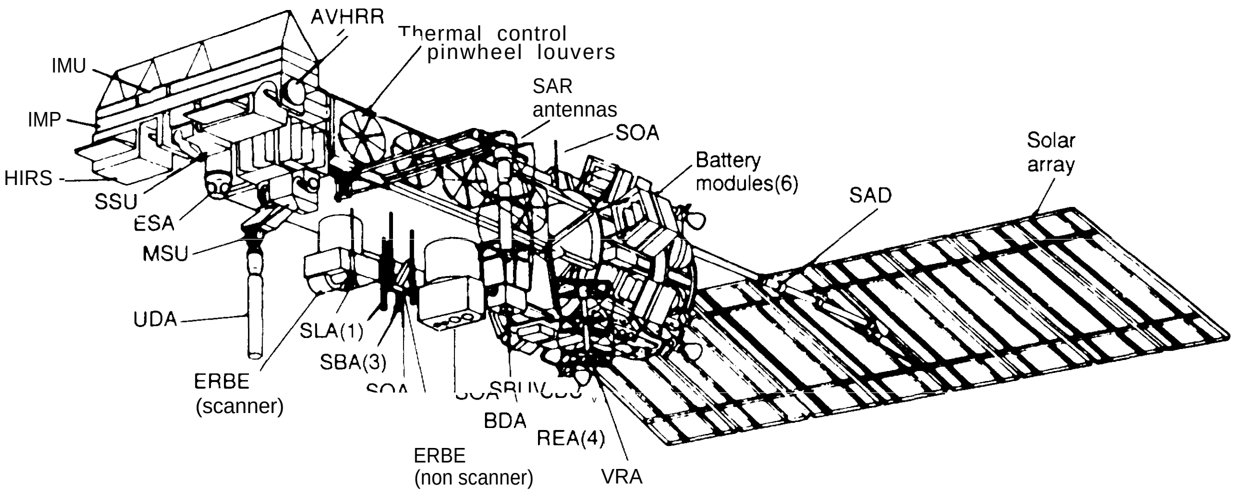
36 In 1993, two congressional committees requested a review of the NOAA and DOD polar-orbiting satellite programs to explore possible cost savings. See G.E. Brown, Chairman of the House Committee on Science, Space, and Technology, letter to D.J. Baker, Administrator of NOAA, Feb. 22, 1993; J.J. Exon, 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 office 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

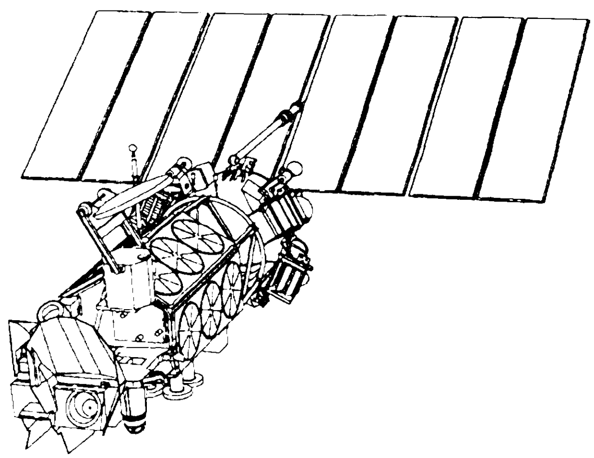


SOURCE: National Oceanic and Atmospheric Administration, 1993.

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

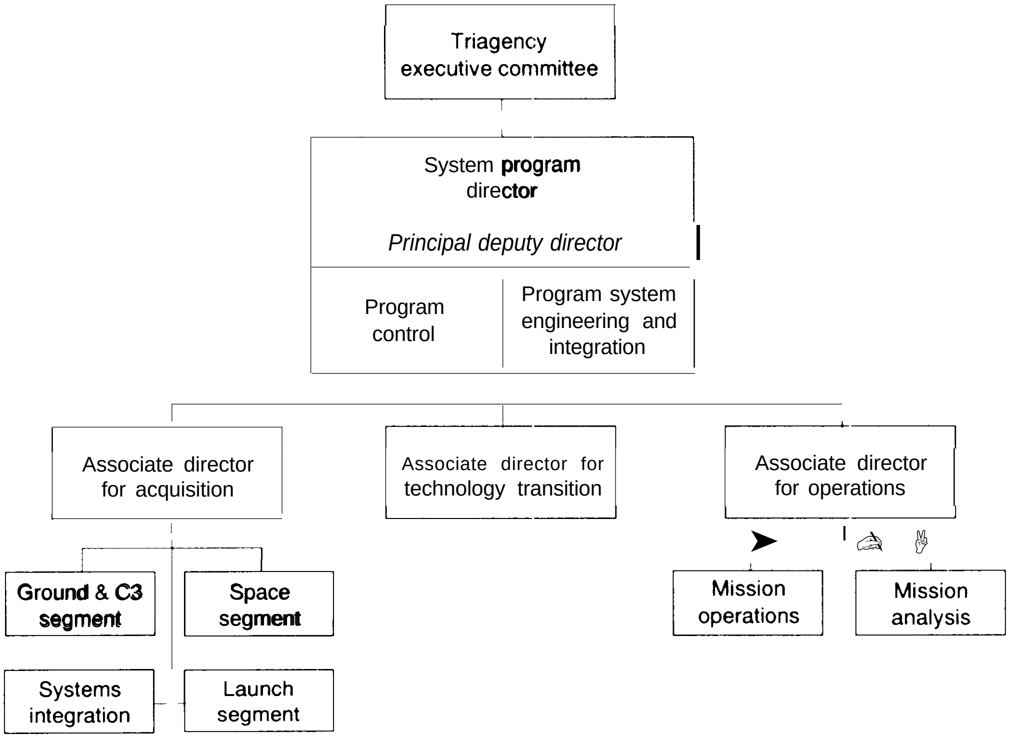
FIGURE 1–3b: DOD's Defense Meteorological Satellite Program Satellite



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 forecasting.
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.

National Remote Sensing Needs and Capabilities 2

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

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

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

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

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

Remote sensing satellites and their sensors differ in many characteristics:

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

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

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

SOURCE: Office of Technology Assessment, 1994.

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

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

NATIONAL USES OF REMOTE SENSING

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

Monitoring Weather and Climate

Weather Forecasting

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

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

Global Change Research

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

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

Long-Term Monitoring of Climate and Other Earth Systems

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

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

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

[3] Changes caused by people

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

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

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

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

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

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

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

Land Remote Sensing

Mapping and Planning

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

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

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

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

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

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

Terrestrial Monitoring and Natural Resource Management

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

Crop monitoring

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

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

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

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

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

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

Managing federal lands

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

Environmental regulation

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

Geology and Mining

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

Private Sector

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

Ocean Remote Sensing

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

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

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

Other Needs

Public Safety

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

International Development Assistance

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

Research and Education

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

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

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

[13] Ibid., ch. 5.

[14] Ibid., app. B.

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

U.S. REMOTE SENSING CAPABILITIES

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

National Oceanic and Atmospheric Administration

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

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

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

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

Department of Defense

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

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

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

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

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

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

BOX 2-3: The Geostationary Operational Environmental Satellite System

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

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

SOURCE: National Oceanic and Atmospheric Administration, 1994.

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

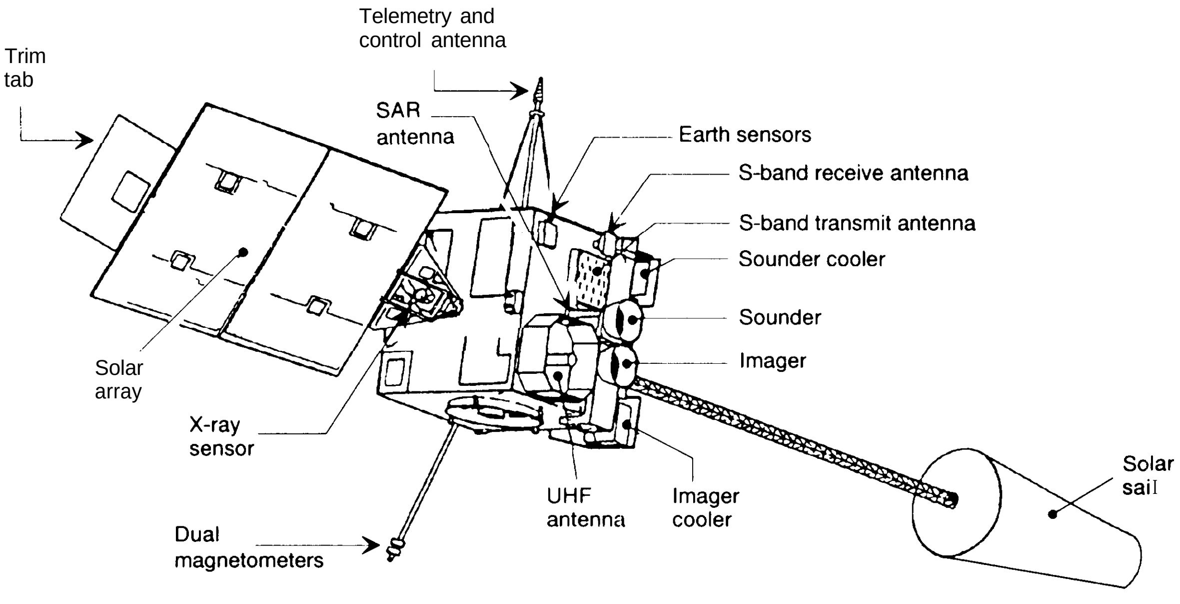
National Aeronautics and Space Administration

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

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

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

FIGURE 2-1: Engineering Drawing of GOES-Next



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

SOURCE: National Oceanic and Atmospheric Administration, 1994.

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

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

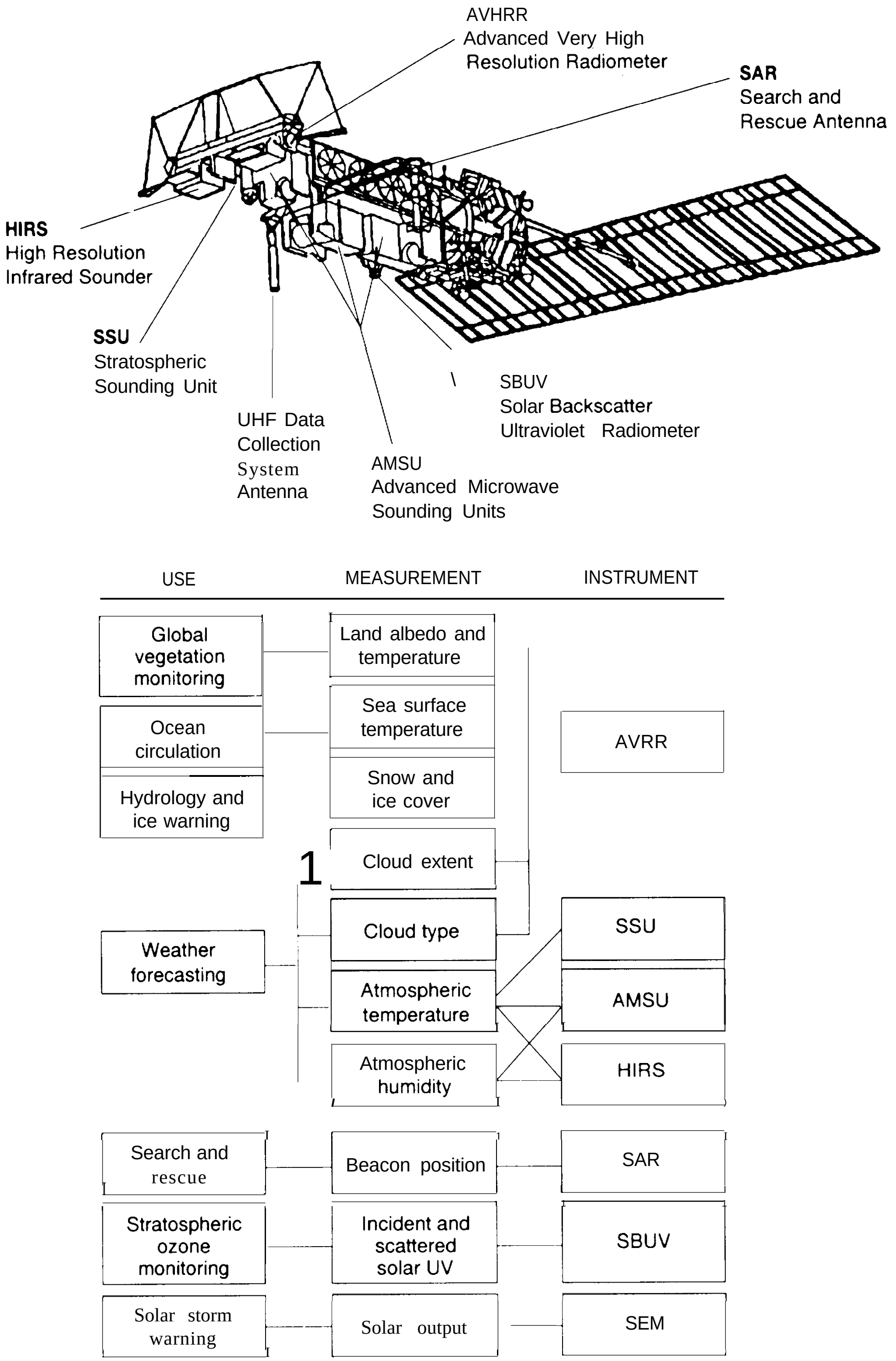
NASA also has a traditional role as the developer of new technologies for civil remote sensing, from the first TIROS weather satellite in 1960 and the first Landsat satellite in 1972 to the new systems being developed as part of MTPE. NOAA's environmental satellite systems reflect the legacy of NASA's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

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

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

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

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



SOURCE Martin Marietta Astrospace 1993

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

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

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

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

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

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

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

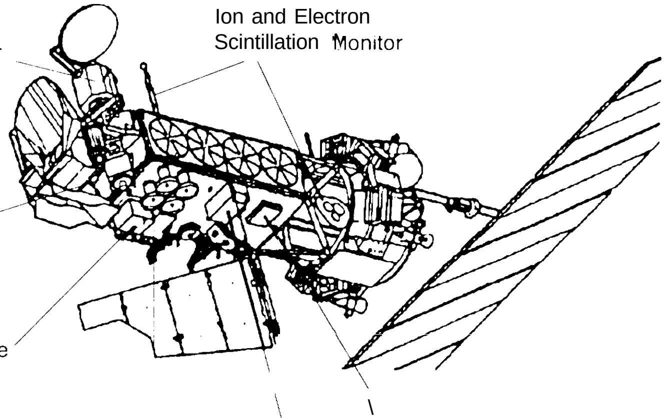
Instruments that fly on some POES satellites include:[1]

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

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

SOURCE: National Oceanic and Atmospheric Administration, 1994.

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



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

SOURCE Martin Marietta Astrospace 1993

BOX 2-5: The Defense Meteorological Satellite Program

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

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

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

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

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

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

Landsat

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

The Advanced Research Projects Agency and the Defense Laboratories

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

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

Private Sector

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

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

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

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

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

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

27 The Naval Research Laboratory built the Clementine satellite.

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

MATCHING CAPABILITIES TO NEEDS

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

■ The Requirements Process

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

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

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

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

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

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

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

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

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

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

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

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

Coordination Mechanisms

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

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

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

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

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

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

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

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

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

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

Market-Oriented Options

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

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

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

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

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

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

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

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[35] In FY 1989, several user agencies did contribute funds to pay for continued operation of Landsats 4 and 5. For a more detailed account of the history of Landsat, see U.S. Congress, Congressional Research Service, *The Future of Land Remote Sensing Satellite System (Landsat)*, *91-685* SPR (Washington, DC: The Library of Congress, Sept. 16, 1991).

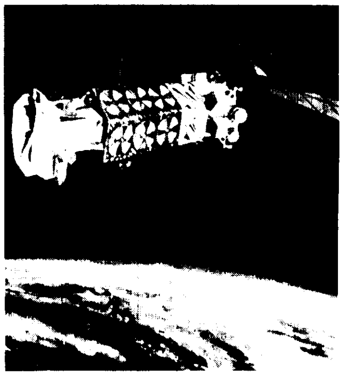
[36] This policy is outlined in OMB Circular A-130 and reaffirmed in the Global Change Data Exchange principles.

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

Planning for Future Remote Sensing Systems 3

This chapter provides an overview of institutional and organizational issues surrounding the development of operational environmental satellite remote sensing programs. In particular, the chapter examines issues related to the development of a multiagency weather and environmental monitoring satellite system and its place in a national strategic plan for environmental satellite remote sensing programs.

Three themes emerge from the discussion in this chapter. **First, the United States does not have an institutional mechanism for identifying national environmental remote sensing interests, ordering them by priority, and fashioning a coordinated approach to managing them.** In May 1994, the Clinton Administration announced its proposal to coordinate several existing environmental satellite remote sensing programs by consolidating ("converging") the National Oceanic and Atmospheric Administration's (NOAA's) and the Department of Defense's (DOD's) polar-orbiting operational meteorological programs and capitalizing on the National Aeronautics and Space Administration's (NASA's) experimental remote sensing programs.[2] However, with its focus on just three federal agencies and only weather and



[1] *Operational* programs are distinguished from *experimental* programs by having long-term stability in funding and management, a conservative philosophy toward the introduction of new technology, stable data-reduction algorithms, and, most importantly, an established community of data users who are dependent on a steady flow of data products

[2] The operational programs are NOAA's Polar-orbiting Operational Environmental Satellite Program (POES) and DOD's Defense Meteorological Satellite Program (DMSP). The NASA program most relevant to the convergence effort is the Earth Observing System (EOS).

climate monitoring, this proposal is not intended to serve as a comprehensive approach to satellite-based environmental remote sensing.

Second, the proposed consolidation of NOAA's and DOD's polar-orbiting meteorological programs raises both "cultural" and technical issues. The technical issues center on developing an affordable and reliable spacecraft and sensor suite that will meet the different requirements of the two agencies. This challenge is exacerbated—perhaps even dominated—by problems inherent in combining programs that originate in agencies that serve different user communities. NOAA's and DOD's meteorological programs have different priorities, different perspectives, and different protocols for acquisition and operations. These differences developed in over two decades of independent operation and have manifested themselves in numerous ways—most visibly in the different instruments that currently make up satellite sensor suites.

Third, the principal challenge to NOAA, DOD, **and NASA in implementing a joint-agency satellite system to monitor Earth's weather and climate will be to develop organizational mechanisms that ensure stable, multiyear funding and stable management.** Historically, executive branch agencies and their congressional authorization and appropriation committees have provided long-term stability in the management and funding of operational programs. Joint-agency operational programs would require similar continuity in management and funding. However, the involvement of multiple budget examiners within the Office of Management and Budget (OMB) and the involvement of multiple authorization and appropriation committees within Congress (all operating on an annual budget cycle) create new risks of program disruption.

The Clinton Administration's proposal to consolidate the nation's current and planned weather and climate satellite remote sensing programs had its origins in a desire to reduce costs. However, the Office of Technology Assessment (OTA) found that converging programs could have several benefits even if there were no cost savings. These include the institutionalization of efficient mechanisms to develop research instruments and manage their transition to operational use, the institutionalization of long-term (decadal-time-scale) environmental monitoring programs, and a strengthening of international partnerships that would facilitate new cooperative remote sensing programs.

A NATIONAL STRATEGIC PLAN FOR ENVIRONMENTAL SATELLITE REMOTE SENSING SYSTEMS

In an era of fiscal austerity, designing programs to perform space activities more efficiently and with greater return on investment has emerged as a key element of national space policy. Greater program integration, both domestically and internationally, has the potential to reduce costs and redundancy. However, it can also add such risks as program delays, increased costs, and the possibility that program goals will be compromised. In the past, the development of new or improved sensors and spacecraft has proceeded according to the specific needs of the funding agency. The nation is now engaged in a reexamination of this model as it considers the risks and benefits of multiagency programs and the emerging possibilities of engaging the private sector in providing satellite services.

In an earlier report,[3] OTA observed that the need to maximize the return on investments in remote sensing was spurring calls for the creation of a single, flexible, national strategic plan for remote sensing. The elements of such a plan, OTA suggested, should include mechanisms to:

- guarantee the routine collection of high-quality measurements of weather, climate, and Earth's surface over decades;
- develop a balanced, integrated, long-term program to gather data on global change that in-

3 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).

eludes scientifically critical observations from ground-, aircraft-, and space-based platforms[4]
- develop appropriate mechanisms for archiving, integrating, and distributing data from many different sources for research and other purposes; and
- ensure cost savings by incorporating new technologies in system design developed in either the private or the public sector.

A coherent plan for future environmental remote sensing systems can help guide the near-term decisions that are necessary to ensure that the data needs of users in the early part of the 21st century will be satisfied. A particular challenge in the development of a national strategic plan would be to address the needs of an expanding and diverse "user community." Several attendees of an OTA workshop[5] stressed the importance of the early involvement of frequent users of remotely sensed data for research, operations, and applications to inform the process that would set national policy and establish a strategy for developing national remote sensing capabilities (see chapter 2).

Users of environmental remotely sensed data are not just agencies of the federal government; they also include academic researchers, businesses, and state and local governments. Increasingly, the user community for remotely sensed data also includes foreign governments. The diversity of users reflects the varied applications of environmental remotely sensed data, which range from investigations of the physical and chemical processes responsible for ozone depletion and other "global change" phenomena to resource management and urban planning.

Meeting the data needs of the next century is likely to require new remote sensing spacecraft and sensors in addition to upgraded versions of current systems. The first priority of future environmental satellite remote sensing missions will be to continue the present collection of operational meteorological data for weather prediction and monitoring. However, to support state-of-the-art numerical weather prediction models, as well as other applications, these systems will need expanded capabilities, including sensors with higher spatial, spectral, and radiometric resolution.[6] In addition, the environmental remote sensing systems of the 21st century are likely to have to meet new observational needs for data over the oceans and land surface. These include:

- ***Monitoring of the oceans—for example, ocean productivity, ice cover and motion, sea-surface winds and waves, ocean currents and circulation, and ocean-surface temperature.*** NOAA's and DOD's monitoring systems currently gather data related to several of these variables; however, the data are not sufficient to support such high-priority scientific concerns as understanding the phenomena responsible for the onset of ENSO (El Niño and the Southern Oscillation) events.[7] Improved ocean monitoring data would also have commercial value, especially to the fishing and shipping industries. More generally, an expanded set of observations over the oceans is necessary to

[4] 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).

[5] *A National Strategy for Civilian Space-Based Remote Sensing*, OTA workshop, Office of Technology Assessment. Washington, DC, Feb. 10, 1994.

[6] Designers of remote sensing systems are forced to make compromises and tradeoffs among several parameters that characterize system performance. These parameters include spatial resolution, spectral resolution (the capability of a sensor to categorize electromagnetic signals by their wavelength), radiometric resolution (the accuracy with which intensities of signals can be recorded), and the number of spectral bands (a spectral band is a narrow wavelength interval). (See box 2- 1.)

[7] For example, by monitoring sea-surface levels in the Pacific Ocean, a satellite altimeter can detect the equatorial waves that tend to precede the onset of El Niño. See D.J. Baker, *Planet Earth: The View from Space* (Cambridge, MA: Harvard University Press, 1990), pp. 70-71.

improve understanding of the role of oceans in the global carbon, biogeochemical, and hydrologic cycles, and in regulating and modulating Earth's climate.

- ***Monitoring of the land surface with new operational sensors such as a synthetic aperture radar (SAR)[8] and with follow-ons and additions to the Landsat series.*** Future visible and infrared imaging systems are likely to feature higher spatial resolution, improved radiometric sensitivity, stereo imaging, and a larger number of spectral bands than does the current Landsat. Such systems would support operational needs to manage nonrenewable and renewable resources. The systems would also support applications such as mapping and land-use planning.
- ***Monitoring of key indices of global change, especially changes in climate, through programs designed to measure ozone concentration and distribution, Earth's "radiation budget," and the atmosphere's aerosol content and characteristics.*** Meeting these needs will require the development of affordable spacecraft and finely calibrated instrumentation that can be flown in a continuous series for periods measured in *decades.* Future systems will also have to support detailed "process studies" to improve scientific understanding of the complex physical and chemical ocean-land-atmosphere processes responsible for global change. This will require a mix of both satellite and in situ measurement systems.[9]

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 resilient" system for Earth observations. For example, NASA has designed the Earth Observing System (EOS) program with the assumption that it will be complemented by Landsat. However, the failure of Landsat 6 and recent budgetary problems have demonstrated that Landsat has not acquired the characteristics of an operational program, which include relatively stable budgets, spacecraft and launcher backups, and a "launch-on-failure" capability to ensure continuity of operation. Similarly, programs such as the Navy Geosat follow-on are vulnerable to budget cuts in a time of rapidly changing security requirements.

A national strategic plan might also assist in the development of new sensors and advanced technologies. In some cases, government and private-sector partnerships are needed to develop specific systems.[10] In others, such as the development of an affordable multifrequency SAR, these partnerships may have to be extended internationally. More generally, there is an urgent need to coordinate efforts among researchers in government laboratories, academia, and the private sector to reduce the size, weight, and resultant cost of satellite remote sensing systems. To lower costs, future systems should accommodate demonstrations of advanced technologies. However, the tension between continuing past observations and in-

8 A SAR would Provide a unique all-weather, day-and-night capability to make high-spatial-resolution global measurements of Earth's surface. As discussed below, it would complement visible and infrared sensors.

9 U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System,* op. cit., pp. 3, 13.

10 For example, unpiloted air vehicles. Government and private-sector partnerships might also assist in the development Of new technologies for Earth observation, which are described in appendix B of U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications,* op. cit. NASA is pursuing technology demonstration as part of its Landsat 8 program and through its Office of Advanced Concepts and Technology. On June 8, 1994, NASA announced contract awards for two new Smallsat Earth observation satellites that will demonstrate advanced sensor technologies. NASA expects them to cost less than $60 million each and be developed, launched, and delivered on orbit in 24 months or less on a Pegasus launch vehicle.

fusing new technology continues to be among the most challenging aspects of planning future remote sensing programs.

A national strategic plan would recognize explicitly that Earth observations cross agency boundaries. For example, NOAA's operational environmental satellites currently focus primarily on measurements of atmospheric variables. However, the study of Earth as a system will require complete coverage of both Earth's surface and the atmosphere, with instruments tailored in measurement frequency and duration to the particular local, regional, or global phenomena under study. For example. meeting the objectives of the U.S. Global Change Research Program (USGCRP)[11] will require integrating satellite data and in situ data with validated models to derive global data products that may be compared over periods ranging from seasons to centuries.

A comprehensive plan for environmental satellite remote sensing would help ensure that program and instrument choices were driven by truly national needs instead of the sometimes parochial interests of individual federal agencies. Currently, the United States does not have an adequate system for allocating funds to programs that serve data users who are outside the normal program bounds of the operating agency, nor does it have a reliable system for allocating funds to programs that cut across agency boundaries. Under the existing system for appropriating federal program funds, **the agency responsible for a program** must defend that program to **the office** of Management and Budget and to congressional committees. Programs compete for funding and attention both within and outside agency boundaries. As a result, programs that cut across agency boundaries or are perceived as peripheral to the agency's central mission are vulnerable regardless of how important they may be to the federal government as a whole (see discussion of Landsat below).

A national strategic plan should also strive to achieve an appropriate balance between "hardware" and "software" development. Sensors collect data, but models and algorithms are necessary to translate these data into useful information. Several participants at an OTA workshop[12] noted the tendency to meet new requirements for environmental remote sensing systems by "pushing the technology" and neglecting (by comparison) less costly software solutions. Meeting new **requirements for environmental remote sensing systems in the most cost-effective manner will require an examination of the "end-to-end" process that turns data into information.**

NOAA has historically been the lead agency in managing civil operational satellite programs. However, NOAA has lacked the budget authority and the in-house capability to develop and flight-test instruments for new operational programs. The majority of NOAA's funding is currently directed at meeting its principal mission, which is to provide reliable short-term weather forecasting and weather warning. Without new budget authority, NOAA might have difficulty funding expenditures for new climate and ocean monitoring instruments and spacecraft, or even for such improvements as upgrading the calibration and number of spectral channels of the Advanced Very High Resolution Radiometer (AVHRR) sensor to make it better suited for land remote sensing

[11] For a description of the USGCRP, see U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, op. cit., and references therein.

[12] *A National Strategy for Civilian Space-Based Remote Sensing*, op. cit

BOX 3-1: Monitoring Global Vegetation with AVHRR Sensors

The Clinton Administration's proposal to converge NOAA and DOD meteorological satellites has not altered NOAA's plans to design next-generation meteorological satellites with features that improve their utility for land remote sensing. In particular, NOAA plans to improve the calibration and sensitivity of the visible and infrared radiometers of the Polar-orbiting Operational Environmental Satellite System (POES). The improvements would greatly enhance the utility of future Advanced Very High Resolution Radiometer (AVHRR) instruments for monitoring changes in vegetation—a use that was not anticipated during the original design of AVHRR but that is now used operationally in recognizing and forecasting crop production, crop failures, and famines.

AVHRR's visible and infrared detection bands make observations in spectral bands that are similar to those on the Landsat instrument, which is used for vegetation monitoring. However, NOAA satellites provide daily observations of a particular region while Landsat revisits only once every 16 days. This can lead to unacceptably long gaps in coverage, especially in regions that are frequently cloudy. Furthermore, the lower spatial resolution of AVHRR (1.1 km nadir; 4 km at edge of scan) compared with the Multispectral Scanner (MSS) or Thematic Mapper (80- and 30-m ground spatial resolution, respectively) is currently more appropriate for generating global data sets. Using the high-spatial-resolution Landsat data would overburden current data-processing and -handling capabilities.

Even with NOAA's planned improvements, detecting and eliminating the effects of clouds—a problem more difficult over land than ocean—would remain a problem in interpretating the signals from land vegetation. Also complicating the interpretation are the effects of atmospheric absorption and scattering and the dependence of a satellite-sensed reflectance on the sun-ground target geometry.

SOURCE: Office of Technology Assessment, 1994.

(box 3-1) or for being better able to determine cloud type.[13]

Higher stability and better calibration of satellite sensors will also be required by global change researchers attempting to distinguish real changes from instrument-induced effects. In addition, experience has shown that satellite data can be applied to a host of applications for which they were not originally intended; instrument calibration is frequently the factor that limits the extent of these applications. For example, better calibration might allow climate trends to be discerned from an analysis of sea-surface temperatures, which are derived from weather satellite data.[14] A national strategic plan for environmental remote sensing may be useful in reaching a consensus on how best to fund and develop improvements such as better calibration of satellite sensors.

13 Cloud type is determined from analysis of multispectral-image data from instruments on operational meteorological satellites. Currently, the number of spectral channels available and the calibration is insufficient for unambiguous determination of some clouds (for example, polar clouds). Several proposed EOS instruments may help in cloud classification. See *Committee on Earth Observation Satellites (CEOS) 1993 Dossier—Volume C: The Relevance of Satellite Missions to Global Environmental Programs* (September 1993), p. C-34.

14 R.H. Thomas, *Polar Research from Satellites* (Washington, DC: Joint Oceanographic Institute, February 1991).

MONITORING WEATHER AND CLIMATE

B NOAA's Polar-orbiting Operational Environmental Satellite Program[15]

In 1960, the United States launched the world's first weather satellite, TIROS-1.[16] TIROS provided systematic cloud-cover photography and observations of Earth with broad-band visible and infrared imagery. Images obtained in visible wavelengths gave researchers global views of the structure of weather systems and weather movement. Infrared sensors allowed these views to be extended into hours of darkness. Combining both types of imagery allowed a determination of cloud type and the relative altitudes of the uppermost cloud layers. Although considered experimental, the success of TIROS- 1 led to operational uses of the data, which the U.S. Weather Bureau pursued simultaneously with NASA's research and development satellite-improvement program.

As noted in chapter 2, NOAA operates its current satellite programs primarily to support the data needs of the National Weather Service for weather warning (the geostationary satellites) and global forecasting (the polar satellite program). To support its Polar-orbiting Operational Environmental Satellite Program (POES), NOAA operates two Advanced TIROS-N (ATN)[17] spacecraft in complementary, circular, sun-synchronous polar orbits, with morning and afternoon equator crossings that designate the spacecraft as AM and PM (box 3-2). Since its inception, NOAA has operated its meteorological satellites to serve the public good. This has resulted in continuity of weather observations and public availability of weather warnings (figure 3-1).

The POES system primarily provides daily global observations of weather patterns and environmental conditions in the form of quantitative data that can be used for numerical weather analysis and prediction. As a result, NOAA's principal requirements for POES are high-quality imaging, primarily at optical wavelengths, and high-resolution temperature and humidity "soundings."[18] U.S. weather models are initialized with satellite temperature and humidity measurements immediately to the west of the United States in the eastern Pacific Ocean at times corresponding to the release of weather monitoring balloons (00 Greenwich mean time (GMT) and 12 GMT). Therefore, NOAA has a particular need for afternoon (PM) temperature and humidity measurements over the eastern Pacific. For similar reasons, European weather organizations need morning data acquired over the Atlantic Ocean.

The key instruments and services available from the two operational POES satellites have

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[15] For an overview of NOAA and DOD programs, see D.J. Baker, *Planet Earth: The View from Space,* op. cit. A detailed description of sensors and spacecraft design appears in National Oceanic and Atmospheric Administration, *ENVIROSAT-2000 Report: Comparison of Defense Meteorological Satellite Program (DMSP) and the NOAA Polar-orbiting Opera tional Environmental Satellite (POES) Program* (Washington, DC: U.S. Department of Commerce, October 1985).

[16] *TIROS* is the acronym for Television and Infrared Observing Satellite. In this chapter, the term *TIROS satellite* is used interchangeably *with* the term (NOAA) *POES satellite.* T] ROS was the culmination of a project begun under the Department of the Army, which was then transferred to a newly created NASA and completed by NASA's Goddard Space Flight Center.

[17] TIROS-N, launched in 1978, was the prototype for the modem NOAA polar-orbiting environmental satellite. The ATN, which dates to 1984, is an enhanced version of TIROS-N. Its increased capacity allowed the addition of the Solar Backscatter Ultraviolet (SBUV) instrument, the Earth Radiation Budget Experiment (ERBE) instruments, and the search and rescue system, SARSAT.

[18] Data on the temperature and humidity structure of the atmosphere are necessary to understand the stability of the weather patterns and to forecast short- and long-term changes. Satellite instruments used to remotel y probe the temperature and moisture structure of the atmosphere are generally refereed to as sounding instruments. To determine the temperature of the surface of Earth, infrared or microwave observations are made at wavelengths at which the atmosphere is transparent. To determine the temperature structure of the atmosphere, observations are made at wavelengths where there is absorption and emission by a uniformly mixed gas. Atmospheric moisture distributions may be monitored by sensors that detect emissions from water vapor. See National Oceanic Atmospheric Administration and National Aeronautics and Space Administration, *Space-Based Remote Sensing of the Ear/h: A Report to the Congress* (Washington, DC: U.S. Government Printing Office, September 1987).

BOX 3-2: Sun-Synchronous Orbits

A space-based senor's view of Earth depends on the characteristics of its orbit and the sensor's field of view. A sun-synchronous orbit is a special polar orbit that allows a satellite's sensor to maintain a fixed relation to the sun, a feature especially useful for meteorological satellites. Each day, a satellite in a sun-synchronous orbit passes over a certain area at the same local time. One way to characterize sun-synchronous orbits is by the time the satellites cross the equator. Equator crossings ("nodes") occur at the same local time each day, with the descending crossings occurring 12 hours (local time) from the ascending crossings. "AM" and "PM" polar orbiters denote satellites with morning and afternoon equator crossings, respectively.

A morning platform allows viewing of the land surface with adequate illumination before the daily cloud buildup and provides an illumination angle that highlights geological features. Afternoon crossings are more appropriate for studies such as the role of clouds in Earth's weather and climate. NOAA's nominal 1330 crossing time for its weather satellites allows relevant measurements to be made while the operational need to deliver a daily weather forecast for the continental United States each evening is satisfied.

NOAA and DOD meteorological satellites are placed in sun-synchronous orbits to support such measurements as sea-surface temperature and cloud distribution and characteristics. Other satellites in sun-synchronous orbits include Landsat and the planned SeaStar ocean-color monitoring satellite (via the SeaWiFS instrument). However, some measurements, such as measurements of tides, waves, and ocean currents, do not require synchrony with the sun. The TOPEX/Poseidon satellite, for example, flies in midlatitude orbits. Sun-synchronous orbits are also not necessary for measurements of Earth's radiation budget.

The morning (AM) NOAA satellite orbits at an altitude of 810 km at an inclination of 98.86° and has a period of 101 minutes. Its local equatorial crossing time is approximately 0730. The early afternoon PM (nominally 1330) satellite orbits at an altitude of 850 km at an inclination of 98.70° and has a period of 102 minutes. Each satellite views the same portion of Earth twice each day. Thus, the two satellites give NOAA approximately 6-hour gaps between data collections. In the United States, the afternoon mission is primary, and the morning mission provides supplementary and backup coverage. In Europe, the morning mission provides the primary coverage.

SOURCES: Office of Technology Assessment, 1994; D.J. Baker, *Planet Earth: The View from Space* (Cambridge, MA: Harvard University Press, 1990), pp. 17-22.

changed only slightly since the launch of TIROS-N in October 1978. The principal instruments on recent POES satellites are an optical surface and cloud imager (i.e., AVHRR) and infrared and microwave temperature and humidity sounders (HIRS—High-Resolution Infrared Sounder, SSU—Stratospheric Sounding Unit, and MSU-Microwave Sounding Unit (box 2-4)).[19]

NOAA's current POES satellites are built with a design life of 2 years, which has usually been ex-

19 HIRS measures scene radiance in 20 spectral bands, permitting the calculation of the vertical temperature profile from Earth's surface [o about 40 km altitude. SSU is used to measure the temperature distribution in the upper stratosphere between 25 and 50 km. MSU gives NOAA an all-weather (i.e., cloudy or clear condition) capability for temperature and moisture measurements. NOAA is developing a completely new Advanced Microwave Sounding Unit (AMSU) for POES to improve the quality of temperature and humidity sounding. Ibid., pp. 60-68.

ceeded.[20] To ensure continuous availability of weather data, NOAA attempts to procure these satellites at intervals that would allow launch within 120 days of "call-up." The NOAA-J spacecraft and the enhanced NOAA-K, -L, and -M are in production or test. The launch vehicle for future POES satellites (and for DOD's Defense Meteorological Satellite Program (DMSP)) is the Titan 11,[21] The cost of the K, L, M series is approximately $100 million per satellite.

Before the Clinton Administration's convergence proposal was announced, agreement in principle had been reached between Europe, represented by the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat), and the United States, represented by NOAA, to transfer responsibility for the morning (AM) segment of NOAA's polar-orbiting constellation in approximately the year 2000.[22] The United States entered this arrangement to reduce costs and to gain the benefits of shared data, mutual backup, and some simplification in operations. The Administration's convergence proposal has not altered the U.S. desire to enter into an arrangement with Europe to provide the morning meteorological satellite; however, it has prompted the parties involved to start renegotiating the terms of the agreement. At the time this report was written, several issues relating to implementation of the agreement had not been resolved. In particular, issues regarding U.S. control of real-time data from U.S. instruments on board the European METOP[23] satellite had not been fully settled (see below).

FIGURE 3-1: POES Image of Hurricane Hugo, 1989

The proposed convergence of NOAA and DOD weather satellites has also not altered either agency's plans to implement major upgrades (block changes) in next-generation systems. For example, NOAA had planned to use the extra capacity of satellites O, P, and Q to fly an upgraded complement of its current instruments while testing new instruments that would be candidates for future operational use. At one time, the O, P, Q series had been scheduled for launch starting in

20 For example, NOAA's primary PM and AM mission spacecraft, NOAA-1 1 and NOAA- 12, are still operational after launch in September 1988 and May 1991, respectively. However, the next satellite in this series, NOAA- 13, which was launched into a PM orbit on August 9.1993, failed on August 21, 1993, because of a power system failure.

21 Titan II replaces the Atlas-E.

22 The first launch of an operational European spacecraft, METOP- 1, is scheduled for December 2000. Plans call for METOP to carry a U.S. operational instrument package in addition to European-supplied instruments. Europe has also agreed to supply a high-latitude ground station. This arrangement will eliminate blind orbits—that is, orbits where data transmission is not possible because the satellite is not in the line of sight of a ground station.

23 A term derived from metrological Operational Mission.

2000. However, when the series was delayed until 2005, NOAA developed plans to launch "gap-fillers," designated as NOAA-N and -N', to ensure continuity between K, L, M and the block upgrade. It now appears that satellites N and N' will serve as gap-fillers between J-M and a converged system (table 3-1).

TABLE 3-1: NOAA's POES Program Launch Schedule and Status

NOAA satellite	Projected launch date/status
J (PM)	September 1994/under contract
K (AM)	September 1995/under contract
L (PM)	September 1997/under contract
M (AM)	September 1998/under contract
N (PM)	September 2000/under contract anticipated
N' (PM)	September 2003/under contract anticipated
O (PM)	September 2005/old baseline[a]
P (PM)	September 2008/old baseline
Q (PM)	September 201 l/old baseline

[a] Schedule before the Clinton Administration's convergence proposal was completed, If the convergence plan is executed, NOAA will terminate the planned launch of satellites O, P, and Q and instead incorporate features of this block change into the proposed NOAA-DOD-NASA national polar-orbiting environmental satellites

Source National Oceanic and Atmospheric Administration, 1994

DOD's Operational Meteorological Program

Like NOAA, DOD has an operational requirement for meteorological data. As executive agent for a joint-service program to provide global weather data, the U.S. Air Force operates a series of meteorological satellites under its DMSP. The first satellite in the DMSP series was launched in 1976. The current system includes satellites and sensors; ground command and control (distinct from NOAA's); Air Force, Army, Marine Corps, and Navy fixed and mobile tactical ground terminals; and Navy shipboard terminals .24 Operational users of DMSP products obtain data via a centralized system (AFGWC, for Air Force Global Weather Central); direct links to DMSP are also possible.

DMSP satellites support the needs of classified surveillance programs and the tactical needs of the fighting forces for information about the weather. Data from DMSP are used by the military to:

- detect and forecast the absence or presence of clouds,
- determine wind speed over the open ocean,
- provide precipitation data to determine cross-country mobility of armor forces,
- optimize performance of electro-optical sensors,
- provide data for artillery and missile targeting,
- provide input data for weather forecasts over data-denied or enemy territory, and
- provide space environmental data to support space systems operations.[25]

The DMSP space segment normally consists of two satellites in 833-km, circular, sun-synchronous polar orbits that are similar to the POES satellites, but with different equator crossing times.[26] Unlike NOAA, DOD has designed its satellites to be flexible in orbit crossing times to support changing mission requirements.[27] DMSP carries payloads that are specific to DOD requirements for data encryption, survivability, launch responsiveness, flexibility in orbit selection,

24 Most DMSP terminals can also receive NOAA satellite data directly.

25 G.R. Schneiter, Director, Strategic and Space Systems, Office of the Under Secretary of Defense (Acquisition), U.S. Department of Defense, testimony before the Subcommittee on Space of the Committee on Science, Space, and Technology, House of Representatives, U.S. Congress, Nov. 9, 1993.

26 The most recent DMSP launches had local equator crossing times of 0530 and 0730.

27 NOAA's principal requirement for gathering data for its numerical weather forecasts does not require flexible orbit crossing times (in fact, NOAA weather models are designed to be initialized at the same time of day).

low-light imagery, and constant-resolution cloud imagery for automated data processing (box 2-5).[28]

The primary sensor carried on every DMSP satellite is a visible and infrared imager known as the Operational Linescan System (OLS), which was first flown in 1976 on Block 5D spacecraft. OLS imagery is used to depict cloud types and cloud distribution and to locate cloud-free areas. OLS data are also used to identify the location, extent, and development of significant weather systems; the location of jet streams, troughs, and ridges; and areas of potential turbulence and icing. DMSP satellites also carry an advanced passive millimeter-wavelength microwave imager, the Special Sensor Microwave/Imager (SSM/I), that provides information concerning sea states and ocean winds, polar ice development, precipitation, and soil moisture estimates, data that are of great interest to a wide variety of users (box 3-3). SSM/I is

BOX 3-3: Several Applications of Passive and Active Microwave Sensors

A "passive" microwave radiometer looking down at Earth from space measures the natural emissions from the viewed surface and from the intervening atmosphere. A satellite-borne microwave radiometer can distinguish sea ice from water, even though both may be at the same temperature, because the emissivity[1] of water differs markedly from that of sea ice. In fact, ice can be distinguished depending on whether it is new (a few centimeters thick), first-year (up to 2 m thick and generally snow covered), or old (characterized by having cracks and deformations because it has undergone freeze-thaw cycles; also, it is less saline than new ice). These distinctions are of more than academic interestold ice is harder and thicker than new ice and poses a greater hazard to shipping. Similarly, soil moisture measurements are possible because of the varying emission from dry or wet soil (however, these measurements are more difficult than those that distinguish ice from water).

An "active" microwave instrument, such as the radar altimeter on the Navy's GEOSAT, provides its own source of illumination. By measuring the radar returns, an altimeter can be used to deduce wave height, which is an indirect measure of surface windspeed. When the wavelength of microwaves is in the millimeter region, scattering from objects like raindrops becomes pronounced; thus, microwave sensors can be used to detect rainfall and water vapor in the atmosphere. A synthetic aperture radar (SAR) allows much higher spatial resolution than does ordinary radar. Operating at microwave frequencies, SAR returns, like all radar, are sensitive to the electrical and geometric properties of Earth's surface, its cover, and its near subsurface. The combination of high spatial resolution and surface-sensitive radar returns has applications in uses from mapping to global change research.[2]

[1] All matter at any temperature above absolute zero will emit electromagnetic radiation with an intensity proportional to its temperature. A perfect emitter, known as a *black body*, has an emissivity of unity, which means that it emits radiation at the maximum possible rate. This rate varies only with the temperature of the emitter and is independent of all other characteristics. However, real objects differ from this ideal, and the emissivity, or "brightness," of an object also varies according to its surface characteristics.

[2] For a discussion of SAR technology and applications, see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, OTA-ISC-558 (Washington, DC: Government Printing Office, July 1993), app. B.

SOURCE: Office of Technology Assessment, 1994.

[28] See Department of Defense comments in U.S. General Accounting Office, *Weather Satellites: Economies Available by Converging Government Meteorological Satellites*, GAO NSIAD-87-107 (Washington, DC: U.S. Government Printing Office, 1987), p. 51.

also used for hurricane and typhoon characterization.[29] DMSP carries two passive microwave sounding instruments—SSM/T-l and SSM/T-2—that provide **data that** allow derivation of vertical temperature and tropospheric water vapor profiles of the atmosphere, respectively.

Historically, to support tactical operations and other missions, one of the two operational DMSP spacecraft has had an equator crossing at dawn and the other has been operated at varying crossing times later in the morning (for example, 0830). These satellites meet DOD's particular needs for imagery at a time when clouds are less likely to obscure the ground. DOD also uses data from the DMSP satellites and from NOAA's PM satellites as inputs to numerical forecast models. Together, DMSP and POES weather satellites meet DOD's requirements for 4-hour refresh rates for cloud-imagery data and DOD-NOAA requirements for 6-hour refresh rates for sounding data.

Four DMSP satellites are in storage and five are under construction: S 11, **S** 13, S14, and S15-S20. S11, S13, and S14 are Block 5D-2 design; S 15-S20 are Block 5D-3.[30] The recurring cost of each 5D-3 satellite is approximately $134 million.[31] DOD expects the DMSP spacecraft to achieve *4 years* of operation on-orbit for the spacecraft in storage and 5 years for the spacecraft being constructed .32 Assuming that the historic reliability of DMSP spacecraft continues, the last DMSP under construction could be launched in 2006 or later.

Comparing NOAA's and DOD's Polar-Orbiting Operational Meteorological Programs

Differences between NOAA's and DOD's meteorological programs in part reflect the comparatively greater importance DOD attaches to cloud imagery (to support tactical operations) than to sounding measurements of atmospheric temperature and moisture. Although NOAA shares DOD's requirement for cloud imagery, it has a particular need for high-accuracy temperature and moisture profiles of the atmosphere. These data initialize NOAA's twice-daily global numerical weather forecasts.

The differences between NOAA's and DOD's requirements are reflected in the instrument suite on board DMSP and POES satellites. For **exam--** ple, POES satellites use high-resolution infrared soundings complemented by microwave soundings for their weather models, whereas DMSP satellites use only the lower-resolution microwave soundings.[33] NOAA plans to introduce an ad-

29 SSM/I is particularly useful i n monitoring the pacific Ocean, where it has replaced more costly aerial reconnaissance as a way to track typhoons. Although sometimes characterized as a "Navy" sensor, SSM/I is used by many federal agencies and serves a diverse user community. Workshop participants at a joint DOD-NOAA conference on DMSP retrieval products were, in fact, primarily civilian and international users. See R.G. Isaacs, E. Kalnay, G. Ohring, and R. McClatchney, "Summary of the NMC/NESDIS/DOD Conference on DMSP Retrieval Products," *Bulletin of the American Meteorology Society* 74(1):87-91, *1993.*

30 S-12 *is* already *i n* orbit. S-15 *is designated as a* 5D-3 *design* because it uses the 5D-3 spacecraft bus. However, its instrument package is identical to that found on 5D-2 satellites.

31 1992 dollars. 5D-2 satellites cost approximately $120 million in 1992 dollars. These figures refer only to recurring costs of the spacecraft and sensors. They do not include one-time initial startup costs such as RDT&E (for research, development, test, and evaluation), nor do they include costs associated with the ground segment, such as the costs of ground terminals and of the satellite command, control, and communications network.

32 The POES satellites have an on-orbit design life of 2 years, but they generally last longer.

33 Microwave sounders complement infrared sounders because they can penetrate clouds. For example, recent POES satellites have combined data from infrared sounders HIRS/2 and SSU, with MSU, a four-channel radiometer (sounder) that makes passive microwave measurements in the 5.5-mm oxygen band. DOD, having less need forhigh-resolution soundings and being most interested in an "all-weather" capability, has pioneered the development of microwave sounders (for example, the SSM/I). T'he infrared and microwave instruments on POES satellites are capable of resolving temperature differences in the vertical structure of the atmosphere of approximately 1.5 to 2 degrees kelvin {K), even in the presence of clouds. DMSP instruments can resolve approximately 3 K. Note that the all-weather capability of DMSP does not refer to seeing through precipitation. The millimeter wave instruments carried by DMSP will operate through clouds, but not rain. In fact, this property can be used to estimate rainfall.

vanced microwave sounder, AMSU, which will have a higher resolution than DOD microwave instruments. DMSP and POES satellites are also built differently for at least three other reasons:

1. The DMSP system must meet DOD's specification that it provide global visible and infrared cloud data through all levels of conflict. Therefore, components in DMSP must meet requirements for hardening and survivability that are not present in POES.
2. DMSP satellites are built to military specifications ("mil-spec'').[34]
3. DMSP satellites contain specialized electronics, such as those needed to implement encryption schemes that support DOD's requirement to control real-time access to data.

This last difference affects NOAA's and DOD's attitudes toward international data exchanges. In contrast to DOD's approach, the Department of Commerce's **weather forecasting (through NOAA) relies on international partnerships to fulfill its data needs and those of other U.S. agencies, including DOD.** Indeed, these partnerships, which have their historical basis in U.S. decisions to treat meteorological data as a public good, have been part of U.S. foreign policy since the Kennedy Administration.

As noted above, the primary sensor carried on every DMSP satellite is the Operational Linescan System (OLS). OLS provides day and night cloud imagery from two sensors, which operate in the visible and longwave-infrared regions .[35] OLS has several features that distinguish it from the AVHRR on NOAA's POES satellites. First, OLS has a photomultiplier that allows DOD to generate visible imagery from scenes illuminated at low light levels (as 1ittle as the light from a one-quarter moon).[36] Second, OLS is the only operational imager capable of nearly constant spatial resolution across its data swath width (box 3-4).[37] Constant resolution and other unique features of OLS result in expedited delivery of images directly to the field and reduced time for weather forecasts.[38] Third, the sensor cooler on OLS is designed to operate at a range of sun angles, allowing operation at different equator crossing times and, therefore, at different sun angles with respect to the spacecraft as needed. Thus, OLS is somewhat more flexible than AVHRR with respect to the orbits it can support.

The current series of DMSP and the POES TIROS-N satellites are built with a similar spacecraft "bus"[39] and several subsystems (an exception is the command and data-handling subsystem).

[34] DMSP is also built to last longer than POES, but this added cost may be balanced by the need for fewer satellites during the course of the program. For a detailed comparison of POES and DMSP, see National Oceanic and Atmospheric Administration, *ENVIROSAT-2000 Report: Comparison of Defense Meteorological Satellite Program (DMSP) and the NOAA Polar-orbiting Operational Environmental Satellite (POES) Program*, op. cit.

[35] OLS is used to provide cloud imagery, cloud-top temperature, sea-surface temperature, and auroral imagery. OLS's visible-near-infrared sensor operate\ in the 0.4-1. I -pm band; the infrared sensor operates in the 10-13-µm band. Three spectral bands are chosen to enhance the ability to distinguish among clouds, ground, and water. The extension of the visible band to near-infrared wavelengths is chosen to enhance the ability to distinguish tropical vegetation from water.

[36] OLS's low-light capability is no longer considered advanced technology. In fact, it is a feature of the recently launched NOAA GOES-8. However, design studies will be-needed to determine whether this feature can easily be incorporated into an instrument that replaces AVHRR and 01.S on a converged NOAA and DOD satellite.

[37] OLS is operated to produce a nearly constant ().6-k$_m$ spatial resolution across its approximate) 3,000-km data swath. Direct readout data at fine (0.6-km) and "smoothed' " (2.8-km) resolution can be received at tactical terminals; data can also be recorded on board the spacecraft at both fine and smoothed resolution for transmission to central receiving stations. Low -light-level nighttime v isible data are at 2.8-km resolution.

[38] For example constant resolution simplifies the ground processing that would otherwise be needed, especially if a user received imagery data at the edge of the field of view of the OLS (see discussion and figure in box 3-4).

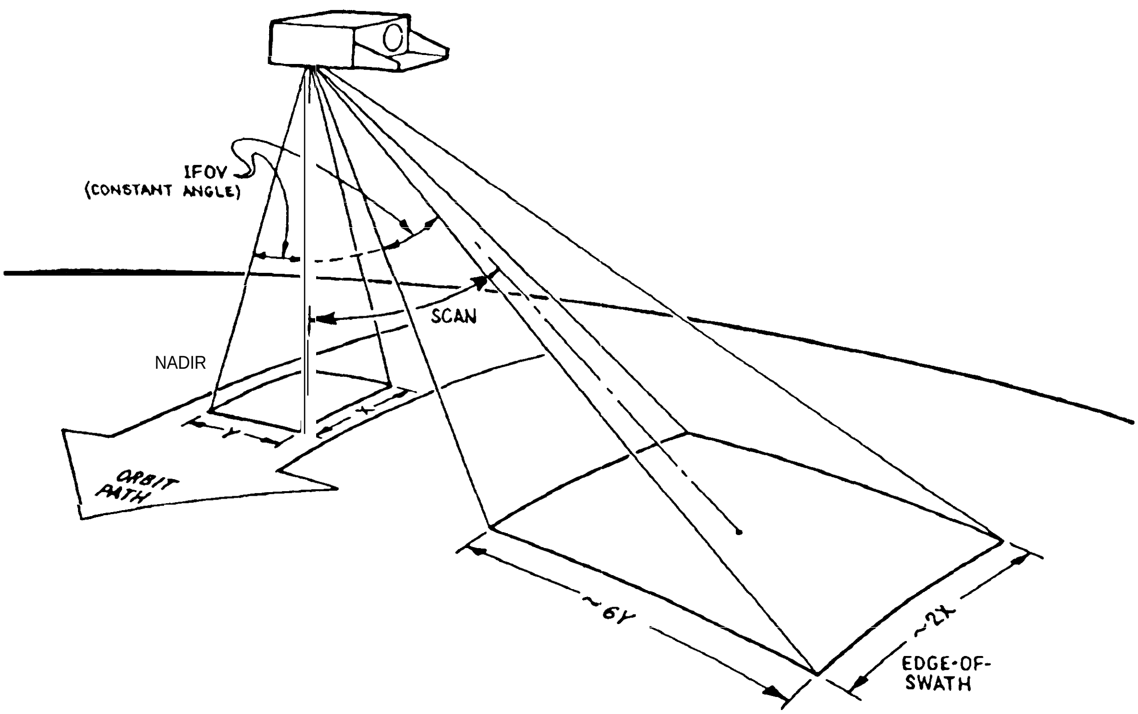
[39] The spacecraft bus carries the payload and includes systems and subsystems that provide several "housekeeping" functions, including propulsion; electrical power generation, conditioning, and distribution; communications (tracking, telemetry, and command): attitude determination and control: thermal control; and command and data handling. See E. Reeves, "Spacecraft Design and Sizing." *Space Mission Analysis and Design*, W.J. Larson and JR. Wertz (eds.) (Torrance, CA: Microcosm, Inc., 1992).

BOX 3-4: Constant Ground Resolution: A Unique Feature of DOD's Operational Linescan System

A cross-track scanner, such as NOAA's Advanced Very High Resolution Radiometer (AVHRR), has a ground "footprint" that grows coarser with increasing scan angle. Scan angle is measured from nadir; AVHRR and the Operational Linescan System (OLS) scan from 0° (nadir) to 55.4° and 56.2°, respectively. The AVHRR instantaneous field of view (IFOV), measured in angular units such as degrees, is maintained constant as the scan angle increases off-nadir. However, as shown in the figure below, the ground footprint increases with increasing scan angle.

In the cross-track direction (perpendicular to orbit path), this increase is larger by approximately a factor of 3 than the increase in the in-track direction (parallel to orbit path). The overall footprint area on the ground increases by more than 10-fold at a 57° scan angle, the approximate maximum scan for OLS and AVHRR. This is acceptable for civil and science applications, but, until now, has been unacceptable to the DOD user community. DOD's OLS imager has a nearly constant ground resolution because it uses a special scanning pattern that, in effect, reduces the angular IFOV with increasing scan angle.

A converged operational meteorology program will have to reconcile DOD's requirement for nearly constant ground resolution with NOAA's requirement for high-sensitivity calibrated imagery. Moreover, a converged program that is implemented in 2005 or later would be expected to satisfy the requirements planned for NOAA's follow-on Polar-orbiting Operational Environment Satellite System (NOAA-O, -P, and -Q) and DOD's follow-on Defense Meteorological Satellite Program (Block 6 upgrade). It may be possible to develop a single instrument that would, in effect, replace the planned AVHRR and OLS follow-ons. Alternatively, a converged satellite might be able to accommodate two separate instruments—an option likely to be less technically challenging. The practicality of either option cannot be established until the Integrated Program Office completes design-tradeoff studies. For example, narrowing the IFOV at the edge of the scan to meet DOD's constant ground resolution requirement decreases the available signal, which in turn might necessitate larger aperture, more costly optics to meet NOAA requirements.



SOURCES: Office of Technology Assessment, 1994; C.V. Scheuler, Hughes Santa Barbara Research Center, presentation at an OTA workshop, *A National Strategy for Civilian Space-Based Remote Sensing*, Washington, DC, Feb. 10, 1994.

Before the Clinton Administration's convergence proposal was announced, the Air Force had been planning a block change for DOD's meteorological satellites. Like NOAA, DOD planned to initiate this upgrade after the satellites in storage and under construction had been exhausted. Although recent DMSP and POES satellites have increased their use of common systems and subsystems, the follow-ons that DOD and NOAA had planned would have resulted in systems with less in common than the current series. For example, Block 6 DMSP and NOAA-O, -P, -Q satellites would likely have been built with different buses and would have had a greater number of different components and subsystems. These differences are noteworthy because they suggest that before the Administration's convergence proposal was made, the two agencies had been on a course that would have resulted in distinctive meteorological satellites and perhaps fewer opportunities for program savings through economies of scale.

NASA's Weather- and Climate-Related Programs

The Administration has involved NASA in proposals to converge operational meteorology programs for three reasons. First, NASA is funding and developing the Earth Observing System of satellites, which carry instruments that may later be modified for use on operational weather satellites. Second, NASA currently develops the POES satellites for NOAA. Third, NASA has historically been the agency that funds, develops, and demonstrates prototype advanced remote sensing technologies for civil applications. Once proven, these technologies are candidates for NOAA's operational missions.

The principal spacecraft in the EOS program are comparatively large, multi-instrument platforms designated AM, PM, and CHEM. Plans call for the 5-year lifetime AM, PM, and CHEM spacecraft to be flown successively three times. Under the current schedule, the first flight of AM would occur in 1998 (figure 3-2), the first flight of PM would occur in 2000, and the first flight of CHEM spacecraft would be in approximately 2002.[40] Instruments on AM are intended primarily for Earth surface observation (characterization of the terrestrial and oceanic surfaces; clouds, radiation, and aerosols; and radiative balance); instruments on PM are intended primarily for study of global climate (clouds, precipitation, and radiative balance; terrestrial snow and sea ice; sea-surface temperature; terrestrial and oceanic productivity; and atmospheric temperature); and instruments on CHEM are intended primarily for study of atmospheric dynamics and chemistry (ocean-surface stress and atmospheric chemical species and their transformations).[41]

EOS program officials have stated that they expect some research instruments to evolve into the next generation of instruments for routine and long-term data collection. In particular, the EOS PM series, scheduled for launch beginning in 2000,[42] will fly instruments that have potential application for operational weather and climate data collection.[43] (However, as discussed below, NOAA officials express concern about the high cost of flying EOS instruments as part of a system for long-term, routine data collection.) Consideration of converging EOS PM satellites with

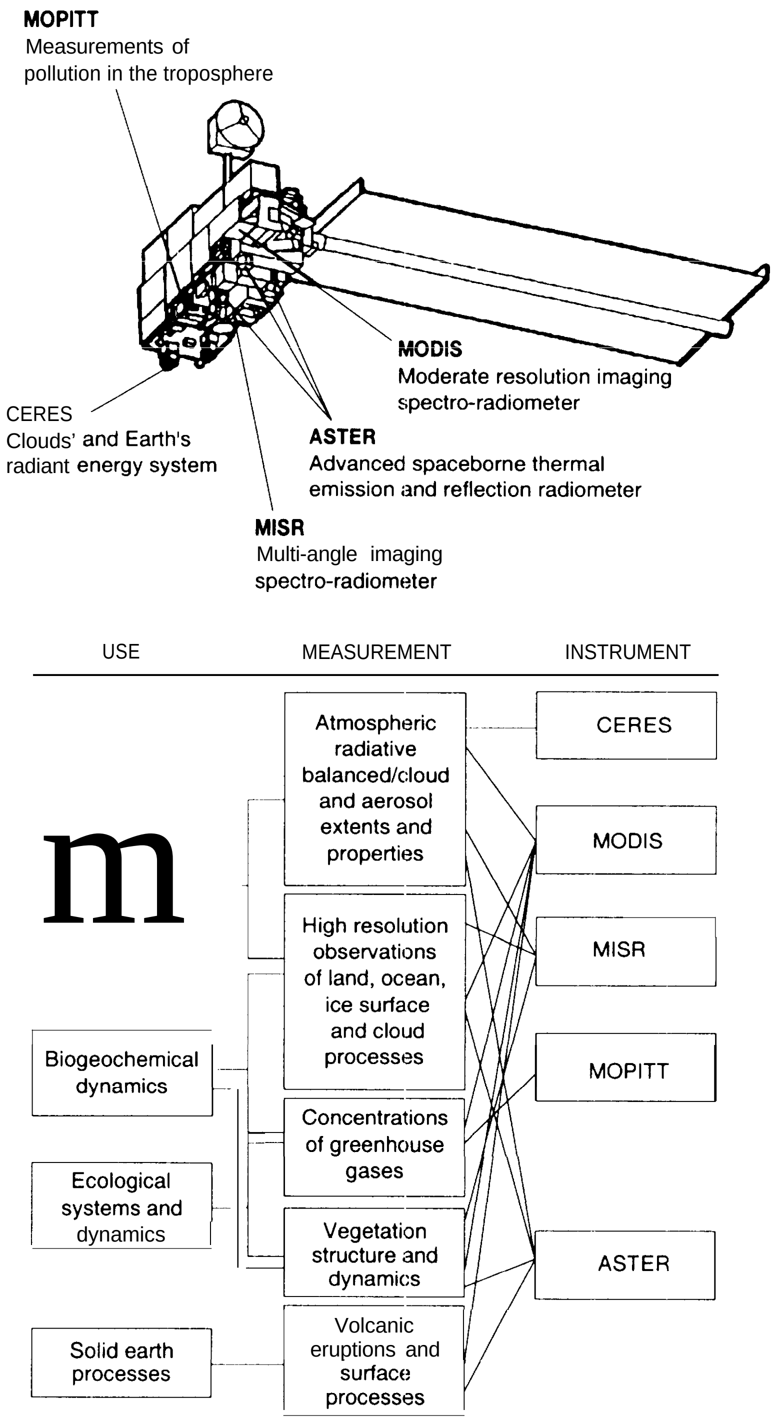
[40] Rescoping the EOS Program has particularly affected the CHEM mission. See G. Asrar and D.J. Dokken (eds.), *EOS Reference Handbook* (Washington, DC: NASA Earth Science Support Office, 1993).

[41] For a description of EOS spacecraft and instruments, see G. Asrar and D.J. Dokken (eds.), *EOS Reference Handbook*, ibid.

[42] However, tight EOS budgets may force NASA to delay PM-1 by at least 9 months.

[43] PM climate monitoring instruments include an atmospheric infrared sounder to measure Earth's outgoing radiation (AIRS); an advanced microwave radiometer to provide atmospheric temperature measurements from the surface to some 40 km (AMSU); and a microwave radiometer to provide atmospheric water vapor profiles (MHS). AMSU, which is actually three modules, will replace the Microwave Sounding Unit (MSU) and the Stratospheric Sounding Unit (SSU) on POES satellites, starting with NOAA-K. MHS is a European instrument that will be flown on the European morning polar weather satellite, METOP.

FIGURE 3-2: EOS AM-1, Instruments and Measurements



SOURCE Martin Marietta Astrospace, 1993

NOAA and DOD operational satellites might occur starting with PM-2 or PM-3, which are scheduled for launch in approximately 2005 and 2010, respectively. This plan would allow PM- 1 to serve as a demonstrate ion platform for subsequent operational instruments. The year 2005 also lies within the approximate period when DOD and NOAA had been considering block changes in their current programs. In principle, PM-1 could be designed to meet both the needs of the research community and the needs of NOAA and DOD for operational weather data: however, NASA, NOAA, and DOD have concluded that employing unproven research instruments in operational uses is too risky.

NASA is also sponsoring competitive "Phase B" studies aimed at developing a common spacecraft for EOS PM-1, CHEM- 1, and AM-2,3. These studies are examining the possibility of launching EOS payloads on either an intermediate-class expendable launch vehicle (IELV), such as the Atlas IIAS planned for AM-1, or a smaller medium-class expendable launch vehicle (MELV), such as the Delta II. Although these studies are independent of convergence studies, they are driven by a similar necessity to accommodate constrained budgets. As discussed below, an EOS PM series adapted for launch on an MELV might allow for a common spacecraft bus to be developed for EOS PM and a converged NOAA-DOD meteorological satellite.

Efforts To Converge NOAA's and DOD's Polar Weather Satellite Programs[44]

The United States has conducted Earth environmental remote sensing satellite programs for over 30 years: for most of this period, the programs have been under the auspices of NOAA, DOD, and NASA. These agencies have generally succeeded in providing a workable mix of capabilities to meet their own needs: DOD has managed the operational and research and development (R&D) programs dedicated to national security purposes; NASA has undertaken the sometimes risky development of the enabling technologies for new remote sensing programs; and NOAA has used the technical services of both NASA and DOD to develop and operate the civil operational environmental satellite system. On occasion, NOAA and DOD have provided backup capabilities in support of each other's programs.

Management and operation of the nation's civil operational weather satellite system has historically been vested in NOAA.[45] In general, the technologies that NOAA needs to conduct its satellite operations are the products of the R&D work already completed by NASA and DOD. NOAA also depends on the resources of NASA and DOD to procure and launch its spacecraft. For example, NASA administers the contracts for NOAA's satellites, and Air Force crews launch NOAA's polar-orbiting satellites from Vandenberg Air Force Base.

NOAA reimburses NASA and DOD for the personnel and other costs they incur when helping NOAA meet its space mission. Overall and specific agreements between NOAA and NASA and between NASA and DOD (launch agreements are between NASA and DOD) govern the responsibilities and costs of the support provided to NOAA. NOAA is responsible for determining the requirements of users of its satellite services, specifying the performance of the systems needed to satisfy requirements, and obtaining the necessary funds to build and operate both the space and ground segment of its systems. These arrangements are an

44 This section draws on material prepared for OTA by R. Koffler.

45 The world's first operational weather satellite, ESSA-1 (for Environmental Sciences Services Administration- 1; ESSA was the predecessor to NOAA), was launched on February 3, 1966. The system was brought to full operational capability with the launch of ESSA-2 on February 28, 1966. The operational *weather* satellite program has been in continuous existence since these launches; however, as its capabilities were upgraded, it was referred to as the operational *environmental* satellite program. NOAA'S policy to allow unrestricted collection of weather information by any ground station in the line of sight of its satellites dates to policies enunciated by President John F. Kennedy.

outgrowth of agreements first reached by the three agencies in the 1960s.

The distinction between NOAA operational satellites and NASA research satellites dates to 1963, when NOAA rejected NASA's NIMBUS satellite as the basis for an operational program because of delays in its development and because it was judged too complex and expensive. Throughout the 1960s, DOD was developing weather satellites specific to its needs. By 1972, the DMSP weather satellite system, which for the first time included atmospheric sounders in addition to cloud imagers, was supporting centralized and field ground stations. At the same time, NOAA was launching the first of a series of second-generation operational satellites (denoted as the Improved TIROS Operational Satellite (ITOS)).[46] Development of a third-generation series of operational satellites was also under way—an atmospheric-sounder instrument array, in part provided by the United Kingdom, was under development; an upgraded visible-infrared imager was being designed; and plans called for the use of a data-collection system that would be provided by France.

In 1973, a national space policy study led by the Office of Management and Budget and the National Security Council examined the fiscal and policy implications of conducting separate DOD and NOAA operational weather satellite programs. Before the study, some officials had anticipated that a merged system could meet both agencies' requirements (because each had a similar requirement to acquire imagery of clouds) while providing an overall savings to the government. As noted above, however, NOAA and DOD weather systems acquire different kinds of data at different times of day to support different users.

The 1973 study based assessments of the technical feasibility and costs of a converged system on NOAA, NASA, and DOD analyses. The study concluded that no option could maintain current performance levels while providing significant cost reductions. In addition, policy concerns argued for the two programs to remain separate.[47] The 1973 review did, however, result in the Nixon Administration directing NOAA to use the DMSP Block SD spacecraft bus, then under development by the Air Force, as the basis for the next-generation series of polar-orbiting satellites. In addition, NOAA and DOD were instructed to coordinate the management of the separate programs more closely.

On eight occasions since 1972, the Departments of Commerce and Defense have studied convergence and implemented recommendations designed to increase coordination and avoid unnecessary duplication in their respective polar-orbiting environmental programs. The 1973 study and subsequent studies have resulted in programs that have similar spacecraft with numerous common subsystems and components. In addition, both programs now use a common launch vehicle and share responsibility for creating products derived from the data. The two programs also work together closely on R&D efforts and provide complement environmental information. However, until now, foreign policy and national security concerns have precluded full convergence.[48]

The latest proposal to consolidate NOAA's and DOD's meteorological programs is more likely to

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46 In 1972, ITOS/NOAA-2 became the first operational polar-orbiting satellite to convert from the use of a television camera to a scanning radiometer, permitting day and night imaging and quantitative sea-surface and cloud-top temperature measurements.

47 DMSP data were not shared with other nations. However, the United States had pledged to maintain an open civil weather satellite system. Additionally, the NOAA system was a visible demonstration of the U.S. "open skies" policy, and it satisfied long-standing U.S. obligations to exchange Earth data with the meteorological agencies and scientific organizations of other nations.

48 D.J. Baker, Under Secretary for Oceans and Atmosphere, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, testimony before the Subcommittee on Space of the Committee on Science, Space, and Technology, House of Representatives, U.S. Congress, Nov. 9, 1993.

succeed than past attempts because of the confluence of several factors, including:

- ***Extremely tight agency budgets in an era of fiscal austerity.*** Officials from NOAA, NASA, and DOD agree that this is the most important factor spurring convergence.
- ***Calls from members of Congress and the President to streamline government and effect cost savings.*** Satellite environmental remote sensing programs were among the programs targeted for cost savings in the President's National Performance Review.[49]
- ***Plans to make substantial upgrades ("block changes") in both the DMSP and POES programs during approximately the same period after the turn of the century.***
- ***A changed international security environment.*** The importance of this factor is uncertain. DOD requirements for meteorological data have not changed in the post-Cold War era. Nevertheless, some analysts believe the changed security environment has encouraged DOD to moderate its historical objection to shared military-civil systems.

Two other factors influencing the current convergence effort are: 1) the involvement of NASA, especially through the potential use of its EOS PM instruments, and 2) the involvement of foreign governments. especially through the planned use of Europe's METOP satellite.

Issues and Options for Convergence[50]

Satellite environmental remote sensing systems consist of both a ground and a space segment; therefore, consolidation of separate programs (convergence) could involve a range of options. For example, convergence could occur at the level of data processing and dissemination if common data requirements, standards, and distribution systems were established. Convergence might also occur at the instrument level if common requirements and designs for the acquisition of instruments were mandated. At a still higher level, convergence could involve the merging of operational programs under the direction of a single agency or a single new organizational entity. Finally, a fully converged system would do all of the above and use common spacecraft and instruments to satisfy what are now separate operational and research needs.

There are two principal scenarios for consolidating meteorological programs. The first would, in effect, involve combining plans for DOD DMSP Block 6 with NOAA-O, -P, and -Q meteorological satellites. The principal technical challenge in this convergence scenario would be meeting DOD's requirement for constant-resolution imaging and NOAA's requirement for calibrated imaging and atmospheric sounding. For example, DOD and NOAA have both studied concepts that would improve their respective imagers; convergence would require a new study to determine whether a single imager could be developed to meet both agencies' needs at an acceptable cost, or whether to fly two separate imagers would be more practical.

The second scenario would involve developing a common satellite and spacecraft bus and modified EOS sensors that would satisfy NOAA's and

[49] 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, Sept. 7, 1993). See also National Performance Review, Office of the Vice President, *National Aeronautics and Space Administration: Accompanying Report of the National Performance Review* (Washington, DC: Office of the Vice President, September 1993).

[50] This section draws on interviews and briefings from NOAA, NASA, DOD, and industry officials. It also draws on briefing papers provided by attendees of an OTA Workshop, *A National Strategy for Civilian Space-Bared Remote Sensing,* held Feb. 10, 1994. For a review of technical and policy issues specifically related to the Clinton Administration's convergence plan, see D. Blersch, *DMSP/POES: A Post Cold War Assessment (A Re-Examination of Traditional Concerns in a Changing Environment)* (Washington, DC: ANSER Corp., June 1993); and H. Kottler, J.R. Lifsitz, J.J. Egan, and N.D. Hulkower, *Perspectives on Convergence,* Project Report NOAA- 10 (Lexington, MA: Massachusetts Institute of Technology Lincoln Laboratory, Feb. 8, 1994). See also U.S. Department of Commerce, Office of the Inspector General, *National Strategy for Remote Sensing Is* Needed, AIS-0003-0-0006 (Washington, DC: U.S. Department of Commerce, February 1991).

DOD's operational requirements and NASA's science research missions. Attention has focused on NASA's planned PM series of satellites because these satellites will carry instruments that have previously been identified as candidates for future NOAA weather and climate monitoring needs. NASA is studying the practicality of reconfiguring EOS payloads into smaller MELV Delta II-class expendable launch vehicles. This "three-way" convergence scenario would offer greater savings to the government than NOAA-DOD convergence because it would use a common bus and might use EOS instruments to satisfy both operational and research objectives. Several economies of scale would also result if a converged Delta II-class spacecraft and bus were suitable for all three agencies.

The Clinton Administration's convergence proposal combines the two scenarios outlined above. It seeks to consolidate NOAA's and DOD's meteorological programs while capitalizing on NASA's EOS technologies. Any convergence plan—whether the Administration's or one of its many permutations-has several generic elements that raise a common set of issues. The following section provides an overview of these issues, giving particular attention to questions about program synchronization, program implementation, and the effect of combining U.S. civil and military programs with European civil programs. The future of Landsat, options for converging future land remote sensing programs with the EOS AM series, and potential ocean monitoring systems are not part of the Administration's proposal. They are discussed in this report because, as noted earlier, land and ocean monitoring systems would be an essential part of any comprehensive long-term plan for U.S. satellite-based environmental remote sensing.

National Security Considerations and the Role of International Partners

Historically, meteorological programs at NOAA and DOD have differed in their reliance on cooperative international ventures and in their policies toward sharing data. NOAA has a long record of international cooperation in its environmental remote sensing programs. Indeed, international cooperation has proved essential to NOAA in its geostationary operational environmental satellite system (GOES). By an agreement signed in July 1993, ESA and Eumetsat are making METEOSAT-3 available to replace the failed NOAA geostationary satellite, GOES-6.[51] Similarly, by international agreement, meteorological data from NOAA's POES satellites are provided to the U.S. National Weather Service and to foreign weather services. As noted ealier, convergence has not altered the U.S. intent to use European METOP satellites to satisfy a requirement for an AM polar orbiter. Plans call for METOP to carry U.S.-supplied sounders and imagers as well as European payloads.[52]

In addition to the foreign policy benefits usually associated with successful international ventures, foreign cooperation in meteorological and climate monitoring programs may benefit the United States by reducing expenditures for operational programs (e.g., METOP replaces NOAA AM satellites) and by increasing opportunities to flight-test advanced technologies (on METOP-1

51 Currently, five geostationary Satellites orbit Earth; two are operated by Europe, and the United States, Japan, and India each operate one. If GOES-6 had not failed, the United States would be operating two satellites to monitor regions of Earth of interest to NOAA weather forecasters.

52 Europe Originally planned to launch a polar-orbiting Earth observation satellite, denoted as POEM. METOP, whose primary mission is operational meteorology, and ENVISAT, which is primarily an atmospheric chemistry mission, resulted when the POEM platform was divided into two smaller platforms. Before the Administration's convergence proposal was announced, the United States had planned to fly the following instruments on METOP- 1: AVHRR/3 (Advanced Very High Resolution Radiometer); AMSU-A (Advanced Microwave Sounding Unit-A, a U.S. instrument that will be flown on NOAA POES satellites beginning with NOAA-K in 1996 andon EOS PM- 1 in 2000); and HIRS/3 (High-Resolution Infrared Sounder). VIRSR (Visible and Infrared Scanning Radiometer), an upgraded version of AVHRR/3, had been scheduled for inclusion on METOP-2. It could be replaced by anew sensor to match the needs of both NOAA and its partner in convergence, DOD. However, partly to achieve economies of scale, ESA may wish to make METOP-2, in effect, a clone of METOP-1.

and its successors). European, Japanese, and Canadian cooperation is also essential if the long-term objectives of NASA's Mission to Planet Earth and the U.S. Global Change Research Program are to be fulfilled (chapter 4).[53]

Plans to use European satellites for NOAA's AM mission—in effect, an international "convergence''—were in place well before the Administration initiated its convergence studies. It is not known yet whether a convergence plan that combines NOAA's and DOD's meteorological programs with European programs will require changes in the U.S.-supplied portion of METOP's payload. In particular, the question of whether successors in the METOP series would carry an instrument combining the functions now performed by NOAA's AVHRR and DOD's OLS remains unresolved. This issue is independent of the more general question of whether Eumetsat will agree to U.S. conditions regarding control of data from U.S. instruments on board METOP.[54]

Maintaining international cooperative relationships in environmental remote sensing is an important consideration in **any convergence proposal.** Therefore, any convergence proposal must address the following questions:

- What contingency plans are needed if delays arise from the U.S. development of a combined payload-spacecraft for NOAA, DOD, and, perhaps, EOS PM?
- Does the plan reconcile European desires for self-sufficiency in sensors and spacecraft with U.S. needs for data consistent among spacecraft? Although the United States and Eumetsat plan to fly three U.S. sensors on METOP-1 and METOP-2, Europe plans to develop its own sensors for future METOP spacecraft. To maintain consistent data, U.S. officials will have to coordinate closely with Eumetsat and ESA officials concerning the technical characteristics of new sensors. Issues related to technology transfer may also arise, especially if the United States concludes that meeting NOAA's and DOD's requirements in a converged program will require that METOP carry a new advanced visible and infrared imager.
- Does the plan address European concerns about data access while satisfying DOD needs for data protection during times when U.S. national security interests would be threatened by open access? Who decides when such times exist? What happens if an agreement cannot be reached?
- What contingency plans are needed should delays occur in the launch of METOP- 1, and what contingency plans are needed to maintain service should a launch or on-orbit failure occur? In particular, when should METOP-2 be available to ensure continuity with METOP- 1, and what are the European plans beyond METOP-2?

The Administration's convergence proposal answers many of these questions. However, one issue in particular remains unresolved: DOD's approval of European involvement in the converged program is subject to Europe's acceptance of several conditions relating to data access and control.

Program Synchronization

The last satellite in the current NOAA POES series is scheduled for launch near the end of 2005. Similarly, the last of the current series of DOD DMSP satellites under development or contract (S11-S20) may be launched around this time or later. This schedule focuses attention on the possibility of redesigning NOAA-N and -N as merged

[53] See G. Asrar and D.J. Dokken (eds.), *EOS Reference Handbook, op. cit.*

[54] Most likely, it is already too late to develop new instruments for inclusion on METOP-1, which is under development, with a scheduled launch in 2000. Whether Eumetsat would agree to a new instrument in METOP-2 was unknown at the time this report was completed (July 1994). METOP-2 is also under development; its scheduled launch is 2005, However, if DOD and NOAA merge their weather programs, the United States may ask that METOP-2 be available sooner to ensure continuity of service with METOP- 1. This would reduce the time available to make changes in METOP. In addition, for reasons noted above, European space officials may be reluctant to change METOP-2.

NOAA and DOD meteorological satellites.[55] It also raises such issues as whether it would be cost-effective to redesign DMSP satellites for joint missions,[56] whether a new spacecraft should be developed, and whether instruments on NASA's PM satellites could be adapted to satisfy NOAA's and DOD's operational requirements. PM-2 is scheduled for launch in approximately 2005; therefore, it and PM-3 would be the most likely candidates for inclusion in a combined research-operational satellite program. An added complication in these issues is the possibility that NOAA's and DOD's satellites will exceed their expected lifetimes.

To meet NOAA's and DOD's requirements, the Administration's convergence plan calls for three polar-orbiting satellites, with local equator crossing times of 0530, 0930, and 1330, to replace the current constellation of four satellites. Europe's METOP satellite is scheduled to assume the morning NOAA mission beginning in 2000 (assuming the successful resolution of ongoing negotiations). National security and other considerations unique to DOD missions (see above) effectively foreclose the possibility y of a combined DMSP-METOP AM mission. Therefore, it is most likely that convergence would result in a system architecture consisting of both U.S. and European AM satellites, with the U.S. satellite designed to satisfy DOD's imagery needs and the European AM satellite (carrying U.S. instruments) designed to satisfy NOAA's and DOD's sounding needs. Depending on the results of ongoing studies, the PM satellite could either be a NOAA-DOD meteorological satellite or a combined NOAA-DOD-NASA satellite that would satisfy current and anticipated needs for operational meteorological and climatological data.

Land remote sensing is *not* part of the current convergence effort, but it could be part of a future effort to coordinate polar Earth observation programs. NASA hopes to launch Landsat 7 by the end of 1998. Assuming a 5-year satellite lifetime, a Landsat 8 might follow in approximately 2004. Given the advanced state of preparations for EOS AM-1, scheduled for launch in 1998, AM-2, scheduled for launch in approximately 2003, would be the first opportunity to converge land remote sensing programs. The many issues associated with developing follow-ons in the Landsat series are discussed below.

Impact of NASA's Redesign of EOS

Originally, NASA planned to launch the largest EOS satellites—AM-l,2,3; PM-1,2,3; and CHEM-1,2,3-on intermediate-class expendable launch vehicles such as the Atlas IIAS. As noted above, NASA is now determining whether these missions (except AM- 1, which is too far into development) can be launched on a smaller MELV such as a Delta II. However, the more restrictive volume and weight constraints of the Delta II might force NASA to reduce the size, weight, and capability of instruments such as MODIS and AIRS.[57] Such "descoping" might also prove necessary even if NASA retains IELVS because the

[55] NOAA-N and -N' were "gap-fillers" that were intended to maintain continuity between NOAA's last scheduled PM spacecraft in the current ATN series and the block change. They are now supposed to serve as gap-fillers before the first launch of a converged satellite. Currently, NOAA and DOD do not plan to attempt to redesign N or N' as a converged satellite.

[56] For example, according to a DMSP official, the SD-3 bus was not designed to carry the heavier NOAA instruments.

[57] AIRS an instrument designed for determining global atmospheric temperature and humidity profiles, would effectively be a much more capable version of NOAA's HIRS (box 2-4). Its improved capabilities include an increase by a factor of 2 in ground resolution (13 km looking nadir). These and other improvements would support NOAA's desire to extend its weather predictions to 7 to 8 days. MODIS is considered a "keystone" instrument for the EOS program. It is a multispectral instrument for measuring, on a global basis every 1 to 2 days, biological and physical processes on the surface of Earth, in the oceans, and in the lower atmosphere. MODIS may be thought of as a highly advanced, or next-generation, AVHRR. It is being designed with 36 visible and infrared bands (from 0.41 to 14.4 pm) compared with AVHRR'S five bands and will incorporate extensive on-board "end-to-end" calibration features. These calibration features, which are not present on AVHRR, are designed to give MODIS unprecedented spatial and radiometric accuracy across its spectral bands. As a result, MODIS should be able to distinguish instrument effects from subtle changes in the various processes researchers hope to study. Modifications to the MODIS focal plane and scanning mode might also allow it to serve as a replacement for DOD's OLS.

AIRS and MODIS original y planned for flight by NASA had capabilities that exceeded NOAA's "core" requirements and would have strained NOAA's budget. Operational programs typically require the launch of a series of spacecraft that acquire data over periods measured in decades.[58] In their original configuration, AIRS and MODIS would likely have been unaffordable. In addition, they would have strained NOAA's data-processing capabilities. These "descoping" options affect convergence proposals because AIRS and MODIS have long been identified as candidates for future operational instruments.

Several options would satisfy NASA's desire to accommodate its EOS payloads on a smaller, less expensive launch vehicle and the Administration's goal to consolidate polar-orbiting satellite programs. For example, PM-1 could be developed and launched on an IELV as currently planned in 2000, but that experience could be used to determine the practicality of modifying EOS research instruments to make them smaller, less expensive, but highly reliable operational instruments suitable for converged spacecraft launched on an MELV. The end result of such an exercise would be to develop versions of PM-2,3 that satisfy the needs of both research and operational users of environmental data. A critical, as yet unresolved, question is whether such a payload suite is practical.

Instrument Convergence

A converged meteorological satellite will have to satisfy DOD's needs for advanced imagery sensors and NOAA's requirements for highly calibrated operational and affordable sounders (table 3-2).[59] Accommodating some of the EOS tech-

TABLE 3-2: Key Sensors and Priorities for NOAA's and DOD's Polar Meteorological Programs

Agency and mission	Sensor[a]	Attributes
NOAA		
Multispectral Imagery (cloud, vegetation)	AVHRR	Calibrated, multispectral imagery
Temperature and humidity (initialize numerical weather prediction models)	TOVS	High spatial resolution, cross-track scanning (PM equator crossing)
DOD		
Visible and infrared cloud imagery (cloud-detection forecast, tactical imagery dissemination)	OLS	Constant field of view, low-light (early AM equator crossing)
Microwave imagery (ocean winds, precipitation)	SSM/I	Conical scan
Temperature and humidity (electro-optical propagation, initialize numerical weather prediction models	SSM/T- 1 SSMT-2	Low spatial resolution, cross-track scanning

[a]AVHRR = Advanced Very High Resolution Radiometer, TOVS = TIROS Operational Vertical Sounder, OLS = Operational Linescan System SSM/ I = Special Sensor Microwave/Imager Special Sensor Microwave/T-1 = SSM/Temperature Sounder Special Sensor Microwave T-2 = SSM Water Vapor Sounder

SOURCE: Office of Technology Assessment 1994

[58] version of AIRS now planned for flight on EOS satellites will be supplied by LORAL Infrared and Imaging Systems. AIRS was "descoped" in 1992 to reduce its cost; the current design will better match NOAA's requirements than the original EOS design (the changes involved a reduction in the spectral coverage, but not the sensitivity}. of the instrument). NASA's EOS MODIS instrument will be supplied by Hughes Santa Barbara Research Center. MODIS has not been redesigned; NASA scientists envision flying MODIS to determine how best to design a version suitable for operational missions.

[59] A combined environmental satellite would likely also carry instruments for search and rescue and space environment monitoring, but these instruments are small and do not appear to present significant technical challenges.

nology demonstration and science research programs in an operational satellite program would add to this challenge. Issues related to the development of an appropriate suite of instruments for converged environmental satellites cannot be fully **resolved until the technical requirements for a joint program are finalized.** If convergence efforts were to be integrated into a broader effort to coordinate operational, scientific, and commercial remote sensing efforts (that is, if convergence was subsumed into a larger national strategic plan), then the NOAA and DOD search for a common set of requirements would also require consultation with the broader scientific community and with other users of remotely sensed data (see chapter 2). However, several reviewers of a draft of this report expressed concern that broadening the focus of convergence would complicate the already difficult process of determining joint-agency operational requirements.

The principal technical challenge in designing a suite of instruments to meet the current NOAA and DOD requirements is the imager for supplying data now provided by AVHRR and OLS (box 3-4). Another issue is how to meet DOD's and NOAA's needs for high-resolution wide-area microwave imaging and high-resolution sounding, respectively. DOD now uses the SSM/I to meet its microwave-imaging needs. An upgraded version of SSM/I, whose features include a wider ground coverage, is also under development by DOD.[60] However, the scanning method used by these instruments differs from the type of scanning NOAA sounders use. Because NOAA requirements dictate the use of their particular scanning method, instrument designers would face a problem designing a common DOD-NOAA microwave imager-sounder.[61] Separating NOAA and DOD instruments on a converged satellite maybe possible, but not without weight and volume penalties. This scan-method mismatch has its roots in the instrument heritage and acquisition strategy peculiar to NOAA and DOD. It maybe viewed as a manifestation of the cultural differences that have developed between the two agencies.

Another issue relates to the possible U.S. use of MIMR (Multi-frequency Imaging Microwave Radiometer), a more capable version of SSM/I being developed in Europe for use in both METOP and, under a Memorandum of Understanding between NASA and ESA, for use on EOS PM-1. MIMR uses advanced millimeter-wave technology. Millimeter-wave environmental sensing is a DOD technology that is highly developed in DMSP spacecraft. Some experts in this technology expressed concern about ceding its continuing development to a foreign partner.

Implementing a combined NOAA-DOD operational program with NASA's EOS PM science research program would add both opportunities and complications to instrument and spacecraft bus design. A tri-agency converged satellite program would present challenges that include the need to:

- satisfy operational requirements for data continuity with comparatively unproved instruments;
- accommodate the different production standards and the different data and communication protocols that heretofore have distinguished operational and research instruments;
- develop 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 a medium-class expendable launch vehicle; and

60 SSM/IS will replace SSM/I, SSM/T-1, and SSM/T-2 on DMSP 5D-3 spacecraft. It will have improved equatorial coverage, which is particularly important to the Navy because storms originate in the equatorial regions.

61 NOAA weather forecast models require near-simultaneous infrared and microwave sounding measurements through a particular column of air. Because the NOAA infrared sounder on recent POES satellites, HI RS, uses a "cross-track" scan, the NOAA microwave sounder, MSU (and the AMSU to be flown on NOAA's K-N series), is also a cross-track scanner. However, DOD's microwave imager, SSM/I, and its planned upgrade, SSM/IS, execute a conical scan to generate images.

- accommodate technology demonstration and prototyping on operational spacecraft.

Program Funding and Management

The overriding consideration in the current round of convergence proposals is reducing program costs. If implemented successfully, convergence 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 to enable them to develop the technology that will be needed for future operational spacecraft. Historically, NASA funded, developed, and demonstrated space technology and flight-worthy instruments and spacecraft that were then used for operational missions. Currently, NOAA has the lead role in managing operational programs, but it lacks the funds and in-house expertise to develop the instruments and spacecraft it will need to carry out new missions, such as ocean monitoring and long-term monitoring of Earth's climate.

Convergence also poses risks, especially the disruption in operational programs that, by definition, are designed to provide stable data products on a routine basis. **The principal challenges in implementing converged operational satellite remote sensing programs are not technical (that is, developing an instrument suite and spacecraft suitable for joint programs). Instead, the challenges are likely to be centered in program management and program funding.**

Developing joint program management structures that will mesh with existing congressional and executive branch budgeting procedures may prove particularly challenging. Currently, NOAA's, NASA's, and DOD's environmental remote sensing programs originate within separate parts of the Office of Management and Budget and are submitted yearly for authorization to several different congressional authorization committees in the Senate and the House of Representatives.[62] Budgets are then authorized by three different appropriations subcommittees in the House of Representatives and three different appropriations subcommittees in the Senate. OMB, NOAA, NASA, and DOD can develop mechanisms for integrating budget submissions; however, the congressional authorization and appropriations process would still involve multiple subcommittees.

The current authorization and appropriations process is not designed to formulate a national weather and environmental satellite system. **There is no congressional organizational structure parallel to that of the executive branch, where the Office of Science and Technology Policy and the Office of Management and Budget seek to coordinate policy across the different departments and agencies.**[63] Currently, congressional committees long familiar with NOAA, NASA, and DOD oversee each agency's particular needs and problems. Thus, joint management of satellite programs will add new elements of uncertainty in the authorization and appropriations process. Disputes between different committees that result in a shortfall in one agency's budget would affect all participating agencies.

Under the current congressional authorization and appropriations process, a joint program would, in effect, be considered in pieces, with each agency contribution analyzed in the context of the agency's overall budget, rather than in the

[62] In the House of Representatives, oversight for R&D activities related to Landsat and NOAA operational satellite programs (POES and GOES) lies in the House Committee on Science, Space, and Technology (HSST). NASA R&D activities are also overseen in the House by HSST. However, HSST does not have jurisdiction over basic research conducted by DOD, which is overseen by the House Armed Services Committee. A similar situation exists on the Senate side, with the Committee on Commerce, Science, and Transportation (SCST) playing a role analogous to HSST's and the Senate Armed Services Committee playing a role analogous to the House Armed Services Committee's. See Carnegie Commission on Science, Technology, and Government, *Science, Technology, and Congress: Organization and Procedural Reforms* (New York: Carnegie Commission on Science, Technology, and Government, February 1994).

[63] Ibid.

context of its contribution to the joint program. Historically, federal agencies have been reluctant to fund systems 1) that do not fit completely into the framework of their missions, **2)** that carry a price tag disproportionately high for the good they do for the agency, or 3) that commit large sums over many years to another agency's control. **The government has few examples of successful multiagency programs-recent problems with joint NASA-DOD management of the Landsat system suggest that proposals to consolidate operational programs should, at the very least, be scrutinized with great care.**

Before the announcement of the Clinton Administration's convergence proposal, NOAA, NASA, and DOD officials had stated that a single agency should lead a joint-agency environmental satellite program. NOAA's assignment as the lead agency was made, in part, to ensure the continuation of successful international partnerships in operational meteorology programs. The Administration's plan assigns NASA the lead role in technology transition efforts and DOD the lead role in system acquisition. This division of responsibilities represents a significant change from current practices only with respect to acquisition-currently, NASA manages satellite acquisition for NOAA.

The Administration's plan is organized with mutual interdependence and shared interests as key objectives. Such arrangements are designed to minimize the chances for a repeat of the breakdown in joint program management that occurred between NASA and DOD in the development of Landsat 7 (see box 3-5). Nevertheless, they still leave open the possibility that in a constrained fiscal environment, agencies or appropriations committees will fully fund only those programs perceived to be of highest priority ("burden shifting").

In a previous report, OTA described how the Committee on Earth and Environmental Sciences (CEES) coordinated the U.S. Global Change Re-

BOX 3-5: Developing Multiagency Programs

The Integrated Program Office proposed in the Clinton Administration's convergence plan (figure 1-4) would be funded by NASA, NOAA, and DOD. Each agency would take the lead on one function 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. On the other hand, it is more bureaucratic than other management options, and it suffers the weakness of depending on three different sources of funding to support the system.

The traditional process for annual budget submission was not designed to develop integrated multiagency programs. For example, within the Office of Management and Budget, programs and budget submissions for NOAA, NASA, and DOD are reviewed by different branches. This structure makes an integrated review of agency requirements difficult because agency initiatives for upgrading or developing new systems are submitted to different budget examiners. Furthermore, budget submissions for agency initiatives may appear in different years.

The Administration's management plan is designed to avoid the problems that have plagued joint agency management of Landsat. Its weaknesses are unavoidable given the existing differences between executive branch and congressional mechanisms for developing and funding programs that cross agency budgets. These problems are exacerbated for operational programs, which place a premium on continuity of operations.

SOURCE: Office of Technology Assessment, 1994.

search Program (USGCRP).[64] The CEES mechanism for reducing redundancy and coordinating disparate efforts among some dozen federal agencies engaged in global change research is generally considered to have "worked," at least on the executive branch side. However, agencies participating in the USGCRP may have supported the CEES process, despite some loss of control over the global change portion of their budget, because CEES delivered increased funding through its multiagency "cross-cut" budget. In contrast, convergence is an effort to reduce overall government expenditures. Whether this will affect the success of the tri-agency management plan remains to be seen. Administration officials note the success of aground-based interagency remote sensing effort, NEXRAD (Next-Generation Weather Radar), as a model for how convergence might work. In NEXRAD, the Departments of Commerce, Transportation, and Defense cooperate on the purchase and operation of powerful radar systems. However, a joint-agency environmental satellite program would differ from NEXRAD in at least one important way: the nation is less dependent on NEXRAD radars than it is on its weather satellites. Furthermore, the failure of a single radar or a delay in the introduction of radar upgrades would affect the ground radar system to a far less degree than would a similar problem with the weather satellites.

Establishing Common Requirements

To implement a convergence plan, NOAA and DOD will have to establish a common set of requirements for converged operational environmental satellites. However, requirements for satellite data depend not only on the sensors, but also on how sensor data are analyzed (the "retrieval" algorithms used to translate measurements into useful information) and how data are assimilated into the models by users.[65] Thus, establishing a common set of requirements for NOAA's and DOD's meteorological systems will require an examination of the hardware and software involved—from data acquisition to data analysis—in both the space and ground segments of the POES and DMSP systems.

The differences between NOAA and DOD practices noted earlier-different priorities, different user communities, different perspectives, and different protocols with respect to acquisition and operations—will complicate the effort to arrive at a mutually satisfactory set of requirements. For example, NOAA had planned for its next-generation POES satellites (O, P, and Q) to provide improved global atmospheric temperature and humidity profiles to support state-of-the-art numerical weather prediction models.[66] However, DOD requirements for infrared sounding had been set only to meet those of the current 5D-3 satellites.[67] The resolution of this and similar differences will directly affect sensor selection and cost. As discussed below, another complication in setting requirements is determining the role of NASA in a tri-agency satellite program.

Cost Savings

The Administration expects convergence to achieve economies by developing and procuring common space hardware from a single contractor,

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64 U.S. Congress, Office of Technology Assessment, *Global* Change *Research and NASA Earth Observing System,* op. cit. On November 23, 1993, President Clinton announced the establishment of the National Science and Technology Council. With this announcement, coordination of the USGCRP transferred from CEES to the newly formed Committee on Environmental and Natural Resources Research (CENR).

65 The federal government operates three operational numerical weather prediction centers: NOAA'S National Meteorological Center (NMC), the Navy's Fleet Numerical Oceanographic and Meteorological Center (FNMOC), and the Air Force Global Weather Center (AFGWC). The way that satellite data is used by these centers is somewhat different; however, there is a Memorandum of Understanding coordinating a Shared Processing Network among the centers.

66 For example, the requirements of the Atmospheric Infrared Sounder, which have been set to meet NOAA's requirements, call for vertical resolution of 1 km, temperature accuracy of I K, and ground resolution of 13 km—all approximately a factor of 2 better than what is now available. This will support NOAA's desire to extend its weather prediction models to 7 to 8 days.

67 DOD's DMSP Block 6 upgrade emphasized cost savings and enhanced microwave-imaging capabilities over enhanced sounding capabilities.

reducing the number of spacecraft (the current total of four DOD and NOAA operational meteorological satellites in orbit simultaneously would be reduced to two), and reducing the cost of launch services. The Administration also expects savings to accrue from reductions in the cost of program and procurement staff, consolidation of ground control centers, and economies of scale related to data-receiving and -processing hardware and software. Common instruments and data formats would allow increased production volumes for data-capture terminals and related equipment that would service a broader community. However, in the next several years, convergence would offer only limited opportunities for savings—for example, from the termination of parallel design efforts for block changes and new spacecraft bus designs in both the POES and DMSP satellites. A tri-agency convergence plan would also consolidate some of NASA's planning for its PM satellites.

Implementing convergence would also require funding several new activities. Requirements studies, instrument-tradeoff studies, the development of new instruments, a new spacecraft bus (or the adaptation of an existing bus), and the possible adaptation of MELVs[68] to launch converged spacecraft would be "upfront" costs that would be incurred before the longer-term savings from convergence could accrue. Moreover, because the architecture and instrument complement of converged spacecraft programs are not finalized,[69] estimates of the savings expected from reduced numbers of launches and spacecraft are more uncertain than are estimates of the additional costs of implementing convergence. **Therefore, Congress may wish to examine estimates for the net savings of convergence with particular attention to the question of how these estimates would change if unexpected problems or delays occurred in the design or adaptation of sensors, spacecraft buses, and launch vehicles.**

Transition from Research to Operational Satellites

A principal requirement for operational satellite systems is the unbroken supply of data. Therefore, operational systems require backup capability in space and on the ground and a guaranteed supply of functioning hardware. In turn, these requirements translate into maintaining a proven production capability when new versions of operational satellites are introduced. They also require a parallel effort to improve system capability continuously without jeopardizing ongoing operations. Finally, new technology must be introduced without placing an undue financial burden on the operational system. Historically, the transition from research instrumentation to operational instrumentation has been successful when 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 (box 3-6).

During the 1960s and 1970s, the development of NOAA's operational weather satellites was assisted by both a vigorous R&D program within the agency and by strong ties to several NASA programs, especially OSIP (Operational Satellite Improvement Program) and NIMBUS. The NIMBUS program began in the early 1960s. Initially, NASA conceived of NIMBUS as an Earth observation program that would provide global data about atmospheric structure. In addition, NASA intended NIMBUS to replace its TIROS satellite and to develop into an operational series of weather satellites for NOAA. However, NOAA chose to

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68 For example, launching a converged EOS-PM/POES/DMSP satellite on a Delta II MELV might require redesigning and testing an enlarged fairing.

69 Even when program details are announced, there will still be uncertainty surrounding the introduction of technology to be demonstrated by EOS-PM. Technical studies to resolve issues such as how to meet DOD'S and NOAA's imaging and sounding requirements can be completed in less than 1 year; however, the on-orbit record of EOS PM instruments will not be available until 200 I or later.

BOX 3-6: NOAA Practices in Developing Operational Satellites

NOAA is chartered to provide environmental observations as a routine service to U.S. and foreign users. NOAA recognizes three practices as critical in planning for mission success:

- **Accommodating long lead times.** A "new" NOAA satellite, based on low-risk, proven technology, is generally representative of technology conceived of and developed a decade earlier by NASA or DOD. Because a NOAA satellite series can continue in operation for a decade or more, the last satellite may be based on technology that is 20 years old. NOAA's conservative philosophy toward the introduction of new technology was apparent as early as 1963 when NOAA rejected NASA's NIMBUS satellite as the basis for an operational satellite because its development was judged too complex and expensive.
- **Providing for data continuity.** NOAA's environmental data are provided as a public good. The agency makes the data available free of charge to national environmental service agencies in the United States and other countries and to a diverse group of scientific and other users here and abroad. Ground stations throughout the world receive NOAA data for purposes ranging from regional weather warnings to global numerical weather analysis, and from graduate- to hobby-level education. Many users rely on unbroken data flows and consistency in data characteristics. Therefore, when it introduces new satellite systems, NOAA's plans typically include system backups and overlapping operation (to assist in calibrating between satellites). As a rule, NOAA does not make abrupt changes in system characteristics.
- **Managing system cost.** NOAA's success is judged by its ability to deliver environmental data reliably at low cost. Historically, NOAA has operated under relatively flat budgets. Unlike NASA's or DOD's, NOAA's budgets have comparatively little allowance for budget increments to develop new technology or to meet special national security requirements.

SOURCE: Office of Technology Assessment, 1994.

develop TIROS as its operational system, in part to minimize technical risk. Both programs then went forward, with NASA developing NIMBUS as a research test bed for observational payloads. Eventually, NASA launched a total of seven NIMBUS satellites with payloads that have matured into advanced research and operational instruments for current and planned spacecraft including POES, DMSP, UARS (Upper Atmosphere Research Satellite), and EOS.[70]

Throughout the 1970s and early 1980s, NASA also assisted with the development of NOAA operational satellites through its funding for OSIP. For example, NASA built and paid for the launch of the first two geostationary operational satellites (called SMS, for synchronous meteorological satellite) that NOAA operated. TIROS-N, the prototype for the modern NOAA POES satellite, also started out at NASA and was transferred to NOAA. OSIP ended in 1981 as NASA, faced with a tightly constrained budget (in part, the result of Shuttle cost overruns), withdrew from its interagency agreement with NOAA. NASA's support for NOAA operational programs continued but was carried out with NOAA reimbursing NASA. The end of the NASA-NOAA partnership may

[70] For example, NIMBUS 7, launched in October 1978 and partially operational 15 years later, carried the Scanning Multi frequency Microwave Radiometer (SMMR) that became the SSM/I on DMSP. It also earned the Solar Backscatter Ultraviolet and Total Ozone Mapping Spectrometer (S BUV/TOMS) and the Coastal Zone Color Scanner (CZCS). SBUV is now carried on TIROS, and CZCS is the predecessor for the planned SeaWiFS ocean-color-monitoring instrument. Other NIMBUS 7 instruments were predecessors to instruments now flying on UARS or planned for EOS. See H.F. Eden, B.P. Elero, and J.N. Perkins, "Nimbus Satellites: Setting the Stage for Mission to Planet Earth," *Eos, Transactions, American Geophysical Union 74(26):281* -285, 1993.

have contributed to the subsequent difficulties NOAA experienced in the development of "GOES-Next" (GOES I through M).[71] It also marked a lessening of support within NASA for the development of operational meteorological instruments. Instead, as illustrated by the precursor and planned instruments for the EOS series, NASA became more focused on experimental research instruments designed to support basic scientific investigations.

Convergence **provides an opportunity to restore what had been a successful partnership between NASA and NOAA in the development of civil operational environmental satellites.** However, even with convergence, tensions will likely arise in the new relationship. NOAA and NASA will 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, NASA considers MODIS, a key EOS instrument, a potential successor to NOAA's AVHRR. However, MODIS is unlikely to fit within NOAA's budget.

NASA'S NIMBUS program **was successful in facilitating the transition between research and operational instruments because the instruments that flew on Nimbus did not require extensive modification after they were turned over to NOAA.** In contrast, EOS instruments such as MODIS would likely have to be restructured to be affordable to NOAA or other operational users. This raises the obvious question of whether it is more cost-effective to develop a new instrument designed for NOAA than it is to demonstrate a research instrument and then "descope" its capabilities.[72] Unlike NIMBUS, **NASA's EOS program was not conceived as a test bed for advanced technology.** EOS is primarily a system designed with the research and the policymaking communities in mind. With or without convergence, NASA, NOAA, and DOD will face challenges in adapting EOS programs to serve both research and operational needs.

As noted in the introduction to this chapter, future operational missions are likely to include monitoring the land surface and monitoring the oceans. The last two sections of this chapter discuss several issues related to the development of these programs, with particular attention to the Landsat program—a quasi-operational system that illustrates both the promise and the challenges of implementing new operational programs.

LAND REMOTE SENSING AND LANDSAT

Land remote sensing from satellites began in the late 1960s with the development of the Earth Resources Technology Satellite (ERTS). NASA launched ERTS-1, later renamed Landsat 1, in 1972. Throughout the 1970s, NASA and other U.S. agencies demonstrated the usefulness of satellite-based multispectral remote sensing for civil purposes, using expensive mainframe computers and complex software to analyze data from Landsat multispectral scanner (MS S). NASA also encouraged the development of Landsat receiving stations around the world (figure 3-3), both to col-

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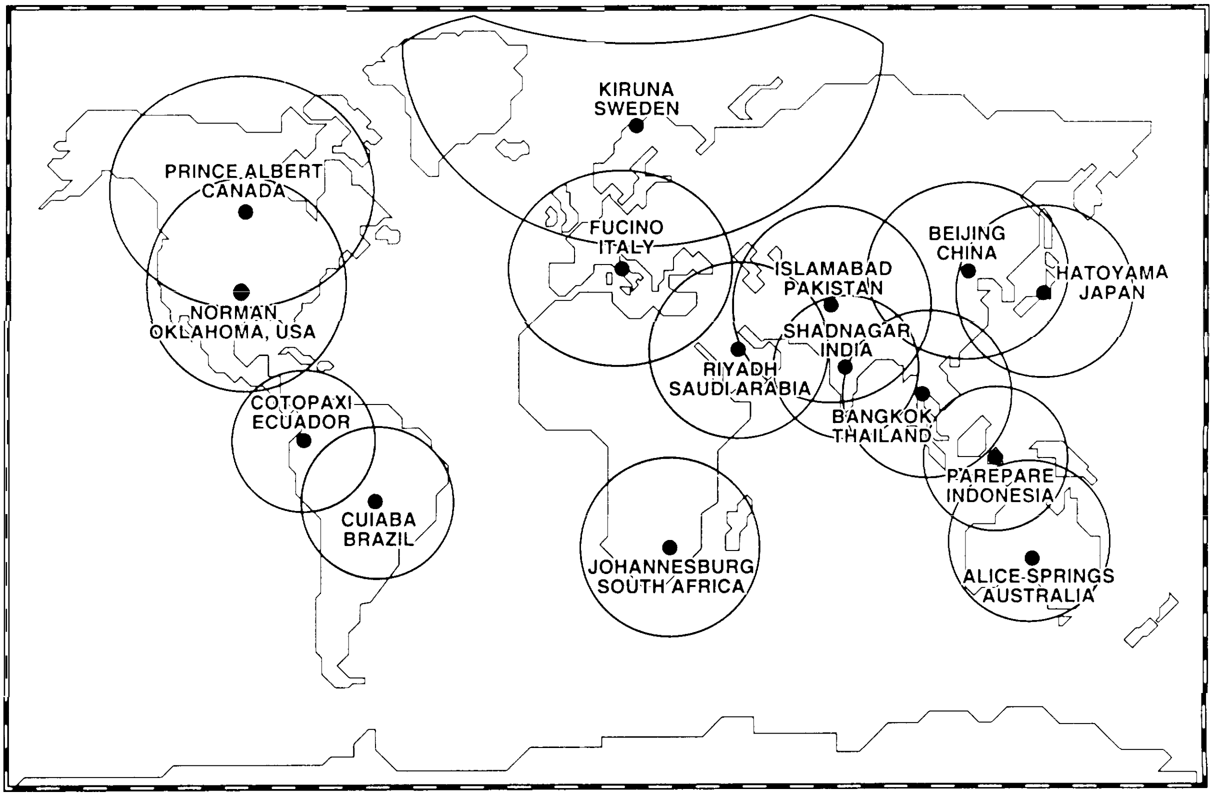
71 Problems with the GOES program began with the addition of a sounding capability to the visible and infrared spin scan radiometer (WSSR), which became the VISSR Atmospheric Sounder (VAS). See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space,* op. cit., pp. 38-39.

72 Reviewers of an early draft of this chapter raised two other issues. One stated, "If one accepts the earlier arguments about adding oceanic, terrestrial, and cloud imaging requirements to the operational satellites, there are two options to fulfill these requirements. First, building three independent instruments to meet specific requirements of each discipline (i.e., AVHRR, CSCZ/SeaWiFS and Landsat). Second, build a single instrument to meet all these requirements (i.e., MODIS). A cost, technology, and requirements analysis should reveal which option is optimum." A second reviewer noted, "Until MODIS, or some instrument with similar capabilities, is flown, it will not be possible to define the instrument that NOAA really needs. Only by using MODIS, with its high spectral resolution, high signal-to-noise ratio (SNR), and excellent calibration to acquire an extensive data set, can we establish what spectral bands, what SNRS, and what calibration accuracies are required for what applications. . . . Atmospheric remote sensing instruments can be designed almost from first principles . . . but the utility of land remote sensing instruments for many applications really cannot be assessed without acquiring the large-scale data sets that only satellites can provide."

FIGURE 3-3: Landsat Receiving Stations



SOURCE: EOSAT, 1994

lect data for U.S. needs and to encourage widespread use of the data.[73] For example, NASA and the U.S. Agency for International Development collaborated on Landsat demonstration projects and training in developing countries.[74] These efforts made the advantages of satellite data for mapping, resource exploration, and managing natural resources well known around the world.

Landsats 1, 2. and 3 carried the MSS. In the 1970s, NASA also developed the Thematic Mapper (TM), a sensor with more spectral bands and higher ground resolution (table 3-3).[75] Landsats 4 and 5, which were launched in 1982 and 1984, respectively, carried both the MSS and TM sensors. Until the first French Système pour l'Observation de la Terre (SPOT-1) satellite was launched in 1987, Landsat satellites provided the only widely available civil land remote sensing data in the world. The SPOT satellites introduced an element of market and technological competition by pro-

73 NASA's Landsat policy was a Cold War strategy to demonstrate the superiority of U.S. technology and to promote the open sharing of remotely sensed data.

74 For a discussion of several Landsat projects in developing countries, see U.S. Congress, Office Of Technology Assessment, *Remote Sensing and the Private Sector: Issues for Discussion*, OTA-TM-ISC-20 (Washington, DC: U.S. Government Printing Office, March 1984), app. A.

75 Users of MSS data had argued that more spectral bands and higher ground resolution would lead to wider use of remotely sensed data.

TABLE 3-3: Landsat Sensors

Sensor	Satellite	Spectral bands, resolution
Multispectral Scanner (MSS)	Landsat 1-5	2 visible, 80 m 1 shortwave Infrared, 80 m 1 Infrared, 80 m
Thematic Mapper (TM)	Landsat 4, 5	3 visible, 30 m 1 shortwave Infrared, 30 m 2 Infrared, 30 m 1 thermal, 120 m
Enhanced Thematic Mapper (ETM)	Landsat 6 (failed to reach orbit)	3 visible, 30 m 1 shortwave Infrared, 30 m 2 Infrared, 30 m 1 thermal, 120 m 1 panchromatic, 15 m
Enhanced Thematic Mapper Plus (ETM+)	Landsat 7	3 visible, 30 m 1 shortwave Infrared, 30 m 2 Infrared, 30 m 1 thermal 60 m 1 panchromatic, 15 m
High Resolution Multispectral Stereo Imager (HRMSI) (proposed but since dropped from the satellite)	Landsat 7	2 visible, 10 m (stereo) 1 near Infrared, 10 m (stereo) 1 Infrared, 10 m (stereo) 1 panchromatic, 5 m (stereo)

SOURCE Off Ice of Technology Assessment, 1994

vialing data users with data of higher resolution and quasi-stereo capability.[76]

In the 1980s, the development of powerful desktop computers and geographic information systems (GIS) sharply reduced the costs of processing data and increased the demand by potential users in government, universities, and private industry. In the late 1980s, India entered into land remote sensing with its launch of the Indian Remote Sensing Satellite (IRS)[77] and the Soviet Union began to market data from its photographic remote sensing systems.[78]

During the 1990s, continuing improvements in information technology and the proliferation of on-line data-distribution systems have increased dramatically the accessibility of remotely sensed data and other geospatial data.[79] As a result of the maturation of the market for remotely sensed data and the development of lower-cost sensors and spacecraft technology, several U.S. private firms are now poised to construct and operate their own remote sensing systems. These firms expect to market remotely sensed data on a global basis. **De-**

76 The SPOT satellites are capable of collecting data of 10-m resolution (panchromatic) and 20-m resolution in four visible and near-infrared multispectral bands.

77 However until 1994, India had not made data from its system readily available beyond its borders. In fall 1993, Eosat signed an agreement with the National Remote Sensing Agency of India to market IRS data worldwide.

78 Through the Russian firm Soyuzkarta.

79 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. 2.

spite these technical advances and the steady growth of the market for data, the United States still lacks a coherent, long-term plan for providing land remote sensing data on an operational basis. This section explores the elements of a long-term plan for U.S. land remote sensing.

Future of the Landsat System

After more than two decades of experimentation with the operation of the Landsat system, during which the government attempted but failed to commercialize land remote sensing[80] (appendix E), the Clinton Administration has now decided to return the development and procurement of Landsat to NASA and has assigned NOAA the responsibility of operating the Landsat system. The U.S. Geological Survey's Earth Resources Observation System (EROS) Data Center will distribute and archive data.[81] NASA plans to launch Landsat 7 (figure 3-4) in late 1998.82

Since 1972, Landsat satellites have imaged most of Earth's surface in different seasons at resolutions of 80 or 30 meters (m).[83] Because a spacecraft in the Landsat series has been in orbit continuously, the Landsat system now serves an established user community that has become dependent on the routine, continuous delivery of data. However, **the Landsat system is only quasi-operational and has been developed without the redundancy and backup satellites that characterize NOAA's and DOD's operational meteorological programs. As currently structured, the Landsat program is vulnerable to a launch system or spacecraft failure and to instability in management and funding.** Despite the Administration's resolve to continue the Landsat program, the earlier difficulties in maintaining the delivery of data from the Landsat system (appendix E) provide ample warning that the path to a fully operational land remote sensing system is full of obstacles.

- ***Technical vulnerabilities.*** As illustrated by the loss of Landsat 6, the existing Landsat system is vulnerable to total loss of a spacecraft in the critical phase of launch and spacecraft deployment. If historical patterns hold, even the most successful of expendable launch vehicles will occasional y suffer catastrophic failure and loss of payload.[84] Furthermore, the failure of NOAA-1 3 after a successful launch[85] demonstrates the additional risk of spacecraft hardware failure. The failed part was designed in the 1970s and had flown repeatedly without incident on earlier spacecraft. Despite attempts to design and build launch vehicles and spacecraft with a high degree of reliability, operations in space are inherently risky.

  In contrast to the Landsat system, in which designers planned to fly only a single satellite at any time[86] and did not plan for a backup satellite, the NOAA POES satellites have sufficient backup that NOAA can replace a failed satellite within a few months of the failure. The decision not to provide a backup Landsat satellite was driven by the relatively high costs of

80 see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., PP. 48-52.

81 Presidential Decision Directive NSTC-3, May 5, 1994.

82 Landsat 7 had been scheduled for launch in late 1997. The slip in schedule is the result both Of the recent policy turmoil and 'he 'ceed fit Landsat into NASA's budget for Mission to Planet Earth.

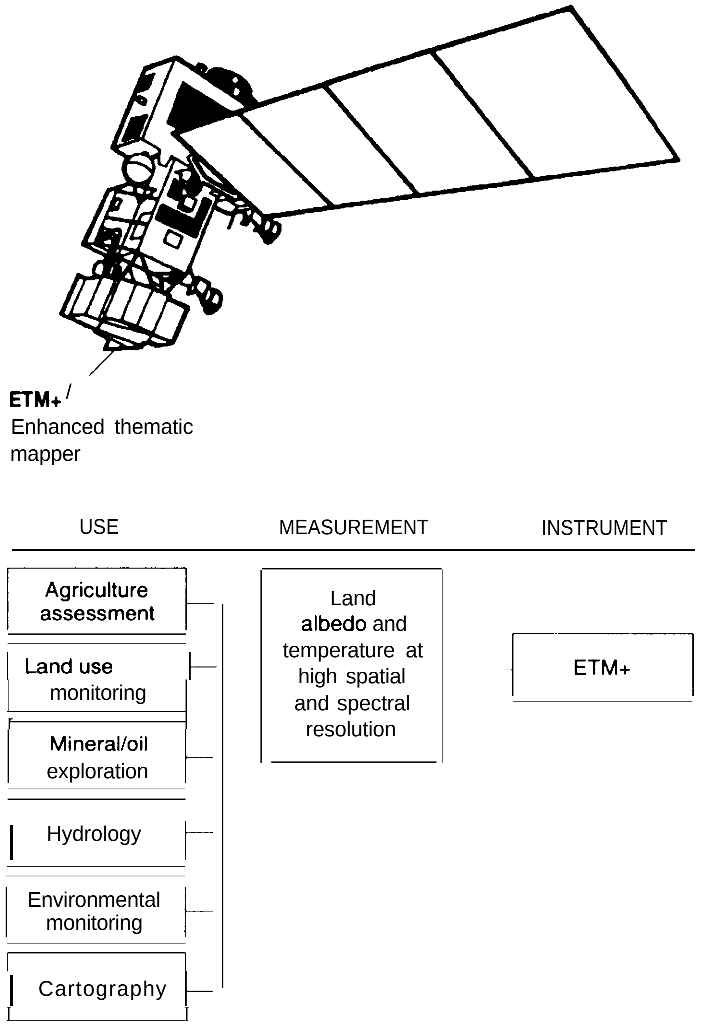
83 The Advanced Very High Resolution Radiometer sensors that have been orbited on NOAA's POES satellites have also provided multispectral imaging (two visible channels; three infrared channels) but at much lower resolution (1km and 4 km).

84 At a rate of approximately, 2 percent of total launches. See U.S. Congress, Office of Technology Assessment, *Access to Space: The Future of* L'. S, *Space Transportation Systems*, OTA-ISC-415 (Washington, DC: U.S. Government Printing Office, May 1990), p. 22.

85 NOAA-1 3 was launched on August 9, 1993. It suffered a failure on August 21, 1993.

86 Landsat 5 was launched only 2 years after Landsat 4 reached orbit because Landsat 4 had experienced a subsystem failure and NOAA was unsure how long it would continue to function.

FIGURE 3-4: Landsat 7



SOURCE: Martin Marietta Astrospace, 1993

the Landsat spacecraft compared with the documented need for the data. Lack of agreement within the U.S. government over the need for the Landsat system also influenced this decision. The mid- 1980s effort to commercialize Landsat also played a role in the decision to forego a Landsat backup.

Comparing the experiences of foreign governments in developing systems similar to Landsat is also instructive. Noting U.S. difficulties with Landsat, Centre National d'Études Spatiales (CNES), the French space agency, designed a cheaper, simpler system and Committed initially to building three satellites.

SPOT was a technical success, providing better resolution than Landsat's and the ability to gather quasi-stereo data.[87] In part because the system was designed from the start as a commercial venture, CNES officials also placed a premium on designing SPOT as an operational entity, capable of delivering data on a routine basis. Three SPOT satellites are now in orbit. SPOT-2 and SPOT-3 are operational. SPOT-1, which has been in orbit since 1989, can be reactivated to provide data during times of heavy use of the system, such as the spring growing season.

- ***Institutional vulnerabilities.*** The TM sensor aboard Landsats 4 and 5 was designed to gather data that would be appropriate for many uses. When combined with other remotely sensed data, such as the 10-m panchromatic data from SPOT, higher-resolution aircraft data, or other geospatial data,[88] TM multispectral data constitute a powerful analytic tool. Indeed, the data already serve most federal agencies in applications such as land-use planning; monitoring of changes in forests, range, croplands, and hydrologic patterns; and mineral resource exploration (chapter 2), However, the very diffuseness of the customer base for Landsat data has made the process of developing an operational system extremely difficult.

  DOD has historically been a large Landsat data user, but DOD officials do not want to be responsible for funding the entire system. Although NASA developed the Landsat system, it has not routinely generated and distributed operational data products to an established community of data users. Rather, as demonstrated by its long history of successfully operating the GOES and POES satellite systems (developed by NASA), NOAA has the requisite operational experience. However, NOAA has no established constituency of users either within or beyond the agency to defend its Landsat budget in competition with other agency priorities.

  The proposed arrangement for Landsat 7 was arrived at through consultations among NOAA, NASA, DOD, and the Department of the Interior, overseen by the Office of Science and Technology Policy. Although a Presidential Directive such as the one that President Clinton signed regarding the development and operation of Landsat 7[89] can be a powerful method for creating new interagency cooperative institutions, such institutions remain vulnerable to a change of Administration. As the experience with providing long-term funding for the USGCRP demonstrates, interagency cooperative programs are also vulnerable to changes in program balance as budgets are altered in congressional committees.[90] Therefore, ensuring the future of the Landsat program will require close and continuing cooperation among NASA, the Department of Commerce, and the Department of the Interior and among the three appropriations subcommitties.[91] procuring and launching Landsat 7

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87 The SPOT satellite is capable of pointing off nadir, which enables SPOT Image, the operating entity, to generate stereo images on different passes. However, the SPOT system has the limitation (compared with Landsat) of having only four spectral bands. It also covers an area of only 60-by-60 km per scene, compared with Landsat's 185-by-170-km coverage.

88 These might include data about soils, terrain elevation, zoning, highway networks, and other geospatial elements.

89 Presidential Decision Directive NSTC-3, May 5, 1994.

90 U.S. Congress, Office of Technology Assessment, The *U.S. Global Change* Research program *and NASA's Earth Observing System*, op. cit., p. 9.

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

will cost NASA an estimated $423 million, spread over 5 years.[92] NOAA estimates that constructing the ground system and operating the satellite through 2000 will cost about $75 million.

- ***The need to improve Landsat program resiliency.*** Because the United States has never committed to a fully operational land remote sensing system, its land remote sensing effort faces the significant risk of losing continuity of data supply. 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 United States 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, it might be possible to maintain the continuity of Landsat-type data delivery.

  Options for sharing costs include a partnership with a U.S. private firm, or firms (discussed below), and/or a partnership with another government. The high costs of a truly operational land remote sensing system have, from time to time, led observers to suggest the option of sharing system costs with another country.[93] However, national prestige and the prospect of being able to make such a service commercially viable[94] have generally prevented the United States and other countries from cooperating.

- ***The need to insert new technology into the Landsat program.*** The Land Remote-Sensing Policy Act of 1992 (P.L. 102-555) calls for a program to develop new technology for the Landsat series. According to the earlier Landsat Program Management Plan, Landsat 8 was anticipated in approximately 2003. Although still in the early stages, planners are considering advanced capabilities, such as greater numbers of spectral bands, stereo data, and much better calibration than the existing Landsat has. It is not too early to begin planning for the characteristics needed for a follow-on Landsat satellite.

  One option for demonstrating new technology will be available on Landsat 7. Landsat 7 was not redesigned after the DOD decision to withdraw from the program and the subsequent cancellation of the HRMSI (High-Resolution Multispectral Stereo Imager) sensor. As a result, the spacecraft will have the room and the electrical power needed to incorporate an additional sensor. NASA is offering to fly an experimental sensor paid for by other federal agencies or by private firms. This represents an opportunity for testing new technology at relatively low cost. The Department of Energy (DOE) laboratories have been exploring the development of different sensors that might be candidates. In addition, NASA is exploring the potential of using small satellites for Earth observation through its Small Satellite Technology Initiative. Recently, NASA awarded two contracts to teams led by TRW and CTA, both of whom will demonstrate advanced technology and rapid development in low-cost, Smallsat-based satellite remote sensing. A variety of technical developments, including increasing capabilities for on-board processing and the potential to fly small satellites in formation, may,

[92] R. Roberts, NASA Landsat Office, personal communication, August 1994.

[93] N. Helms and B. Edelson, "An International Organization for Remote Sensing," presented at the *42nd Annual Meeting of the International Astronautical Federation*, Montreal 1991 (IAF-9 I -1 I 2).

[94] However, systems that produce calibrated multi spectral data of moderate resolution-of greatest interest to global change scientists and other users who require coverage of large areas—may never be commercially viable. Should this be the case, the United States might find several partners to develop a system that would explicitly be designed to serve the public good. These include France, which is operating the SPOT system; Germany, which has developed several sensors but has no satellite system; Japan, which operates JERS - I; and Russia, which has a long history of using photographic remote sensing systems but whose multispectral digital systems have yet to prove themselves.

in the longer term, allow small satellites to perform some of the missions now accomplished with comparatively largr and expensive Earth observation satellites.[95]

Other future land sensors that the United States may wish to develop and operate include an operational synthetic aperture radar. The proposed EOS SAR, based on technology demonstrated in airborne and Space Shuttle experiments, was canceled in large part because of its high cost. The EOS SAR would have been capable of making multiangle, multifrequency, multi polarization measurements.[96] These capabilities allow more information to be extracted from an analysis of radar backscatter and have more general application than do currently operational Japanese and European single-frequency, single-polarization satellite-based SARS. The Canadian Radarsat, planned for launch in 1995, will also carry a single-frequency, single-polarization SAR. In contrast to the broad-based capabilities of an EOS SAR, which would be particularly suited to global change research. these SARS are designed for specific applications, such as mapping sea ice and snow cover.

Role of the Private Sector

By launching Landsat. NASA created the potential for a new market in remotely sensed data. However, as the policy history of the Landsat program demonstrates, commercial markets cannot be developed solely by government policy. Among other elements, growth in commercial data markets requires technological innovation and the ability to tailor production to user needs. Government policy can either impel or impede the development of markets that will support new technologies.[97]

Private firms have had an important part to play throughout the development of land remote sensing technologies. The information industry has developed powerful computers and software, capable of handling large remotely sensed data files quickly and efficiently. Through firms that convert raw data to information (so-called value-added firms), the information industry has also expanded the utility of remotely sensed data acquired from spacecraft. Aerospace firms have also served as contractors for government civil and classified remote sensing systems. Hence, they have contributed to the technology base that now enables private firms to develop their own remote sensing systems. Government laboratories pursuing related technologies have also assisted in the creation of this technology base.

Three privately financed land remote sensing systems are now under development (box S-7). These systems focus on providing data of comparatively high resolution with only one '-panchromatic" visible band, or a few multi spectral bands over relatively narrow fields of view. As a result. they cannot substitute for the Landsat system, which collects calibrated multi spectral data over a large field of view. The privately financed systems are not intended or designed to supply the repeat. multi spectral, global coverage that is the mainstay of Landsat. However, if these systems operate as planned, they will provide data for many applications, including those now served primarily by aircraft imaging firms. These systems especially target international markets that require digital data for mapping, urban planning, military planning, and other uses.[98]

For one or more of these systems to be successful. they will have to overcome hurdles of market acceptance. competition with systems from firms

[95] For example, see U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., app. B, "Developing Follow-ons in the Landsat Series."

[96] Ibid.

[97] For a discussion of the factors influencing market development, see U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., ch. 4.

[98] P. Seitz, "Imagery Firms Court Partners," *Space News*, May 16-22, 1994, pp. 3, 21.

that supply similar data acquired from aircraft, and competition among themselves. If they can deliver data in a timely manner and at low prices, one or more are likely to be highly successful. Ultimately, the U.S. government may wish to move to a new partnership with the private sector in providing land remote sensing and other data that have commercial value. Four broad options are possible:

- ***Contract with a private firm to operate a government-supplied system.*** Under this arrangement, the government would procure the satellite system and submit a request for proposal (RFP) for a private firm to operate the system and distribute data. Data would be made available at the cost of reproduction, according to the direction of OMB Circular A-130. This arrangement is very similar to current plans for Landsat 7 in which NOAA will operate the satellite and the EROS Data Center will archive and distribute the data.[99] Proponents of private-sector operation contend that such an arrangement would make the operation and distribution of Landsat data more efficient. However, when NOAA operated Landsat 4 and 5, much of the actual operation and the distribution of Landsat data was carried out by private firms under contract to NOAA and the EROS Data Center. Hence, some of the potential efficiency of private-sector involvement had already been realized.
- ***Return to an EOSAT-like arrangement in which government supplies a subsidy and specifies the sensor and spacecraft.*** This arrangement would capture most details of the existing EOSAT contract in which EOSAT operates Landsats 4 and 5 under contract with the Department of Commerce and markets data worldwide. Income from data sales and from the licensing of foreign Landsat ground stations pays for satellite operations and provides EOSAT'S profit. EOSAT is free to charge market rates for the data as long as it makes data available on a nondiscriminatory basis to all customers, according to U.S. remote sensing policy.[100]
- ***Create data-purchase arrangements.*** Under this arrangement, the government would specify data characteristics and would contract with industry to provide a stream of data for a specified period for an agreed-upon price. NASA has chosen this path in a contract with Orbital Sciences Corporation to provide data about the ocean surfaces. OTA has explored this option in two earlier reports.[101]

  DOD had expected to use the data from the HRMSI sensor aboard the earlier version of Landsat 7 to support its needs for mapping and other applications. If WorldView is successful in providing data from its 3-m/l 5-m system, these data may fit DOD's needs and be available 2 years before the HRMSI sensor would have flown under the previous interagency arrangement. In like manner, DOD may wish to purchase data with even higher resolution from either the Lockheed or the Eyeglass system, should either or both prove successful (box 3-7).
- ***Create government-private partnerships.*** In this arrangement, the government and one or more private firms would enter into a partnership to build, operate, and distribute data from a land remote sensing satellite. This partnership would have the advantage of enlisting private-sector innovation and ability to target applications markets while supplying the government's data needs. It would also have the advantage of reducing the financial risk of the private firm. The experience of the French

99 Presidential Decision Directive NSTC-3, May 5, 1994.

100 See U.S. Congress, Office of Technology Assessment, *Remotely Sensed* Data *from Space: Distribution, Pricing, and* Applications (Washington, DC: Office of Technology Assessment, International Security and Space Program, July 1992).

101 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., p. 5; U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets,* op. cit., ch. 4.

BOX 3-7: Existing and Potential Remote Sensing Satellite Firms

Orbital Sciences Corporation

The SeaStar satellite will carry the SeaWiFS sensor for measuring ocean color and other attributes of the ocean surface. SeaStar is scheduled for launch in January 1995 aboard a Pegasus launcher. Orbital Sciences Corporation (OSC) plans to market SeaWiFS data to fisheries, ocean shipping firms, and other ocean-related enterprises. However, OSC's primary customer is NASA, which will use the data for global change research.

WorldView Imaging Corporation

WorldView is developing a two-satellite, multispectral land remote sensing satellite system capable of 3-m resolution in stereo (3-m panchromatic, 15-m in three color bands). It received an operating license from the Department of Commerce in January 1993 and has begun to develop a satellite and data-distribution system. WorldView expects to launch its first satellite in late 1995 and the second in 1996.

Space Imaging, Inc.

Space Imaging, Inc., a subsidiary of Lockheed, Inc., is designing a multispectral stereo land remote sensing satellite system capable of achieving resolutions of 1 m (panchromatic). The Department of Commerce has granted Lockheed an operating license, and it expects to launch its first satellite by late 1997.

Eyeglass International, Inc.

Orbital Sciences Corporation, Itek, and GDE Systems, Inc. have entered into a joint venture to build and operate the Eyeglass Earth Imaging System, a stereo land remote sensing satellite system capable of gathering 1-m resolution panchromatic data. Eyeglass International received its operating license in May 1994. The consortium plans to begin operations in early 1997.

SOURCE: Office of Technology Assessment, 1994

space agency, CNES, and SPOT Image (figure 3-5) provides one possible model of such an arrangement. However, U.S. firms that are already building a remote sensing system would likely charge that such an arrangement would be unfair competition (unless the system's characteristics guaranteed them a niche in the data market). For example, NASA's contract with TRW to build a small satellite capable of gathering data of 30-m resolution in many spectral bands would serve the needs of the government and probably enhance the private market for such data. However, as noted in chapter 1, NASA's similar arrangement with CTA could actually impede commercial development unless the distribution of data from the satellite was severely restricted.

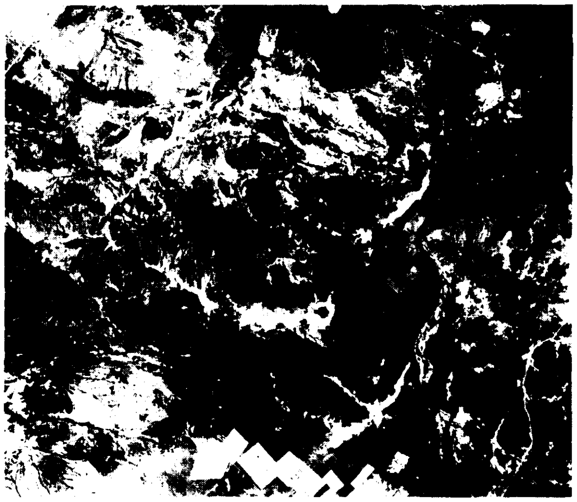
OCEAN REMOTE SENSING

The impetus for ocean monitoring comes from users of remotely sensed data in both the civil and military communities. As D. James Baker wrote: [102]

> The large-scale movement of water in the oceans, also called "general circulation," influences many other processes that affect human life. It affects climate by transporting heat from the equatorial regions to the poles. The ocean also absorbs carbon dioxide from the atmosphere, thus delaying potential warming, but how fast this occurs and how the ocean and atmos-

102 D.J. Baker, *Planet Earth: The View from Space*, op. cit., p. 66

FIGURE 3-5: Image of Soviet Nuclear Testing Facility, Semipalatinsk, Russia



Visible are cable scars and access roads connecting with drill holes Ten-meter panchromatic image taken by the French SPOT satellite.

SOURCE: SPOT Image Corp., Reston, VA.

phere interact in this process depend on surface currents, upwelling, and the deep circulation of the ocean. Fisheries rely on the nutrients that are carried by ocean movement. Large ships, such as oil tankers, either use or avoid ocean currents to make efficient passage. The management of pollution of all kinds, ranging from radioactive waste to garbage disposal, depends on a knowledge of ocean currents. And the ocean is both a hiding place and a hunting ground for submarines.

Scientific, commercial, and government users of remotely sensed data have long argued for an operational ocean monitoring system. An ocean monitoring system would facilitate the routine measurement of variables related to ocean productivity,[103] currents, circulation, winds, wave heights, and temperature. In turn, these measurements would allow scientists to study and characterize a range of phenomena (figure 3-6), including those described above by Baker. The development of an operational system that would assist in the prediction of the onset of El Niño and the Southern Oscillation (ENSO) events (box 3-8) is of particular interest.

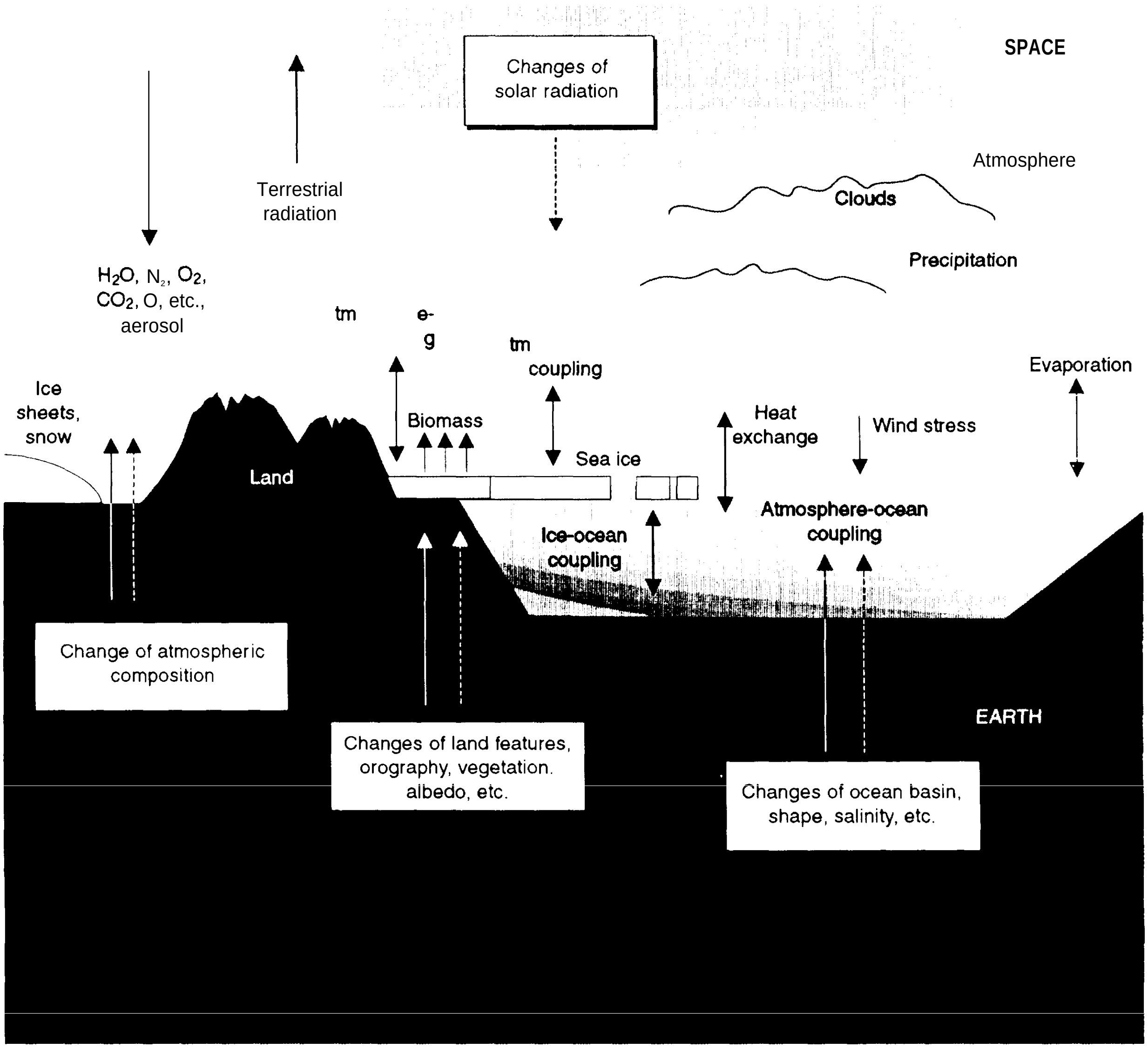
The distinction that is sometimes made between satellite-based "atmosphere," "ocean," and "land" remote sensing instruments is somewhat arbitrary.[104] U.S. ocean monitoring is currently carried out on a routine basis by sensors on POES and DMSP. In addition, ocean data are being provided by satellite-borne altimeters on board the TOPEX/Poseidon satellite, SARS that are part of the instrument suite on the European ERS-1 and the Japanese JERS-1, and Shuttle-based observat ions using the multi frequency, polarimetric SAR, SIR-C.[105] NOAA is especially interested in sea-surface temperature imagery, which is acquired by analyzing AVHRR data. Because its ships travel through and on the surface of the ocean, the Navy has a particular interest in DMSP (especially SSM/I) and altimetry data, which allow mapping of the ocean's topography and assist in detecting

103 In a process similar to photosynthesis on land, phytoplankton in the ocean convert nutrients into plant material through an interaction between sunlight and chlorophyll. Measurements of ocean color provide estimates of chlorophyll in surface waters and, therefore, of ocean productivity. Ocean-color measurements are also used to help detect ocean-surface features. Satellite ocean-color data have not been available since the failure of the Coastal Zone Color Scanner (CZCS) in 1986. NASA has contracted with Orbital Science Corporation (OSC) for the purchase of data resulting from OSC'S launch of SeaWiFS (Sea-viewing, Wide-Field-of-view Sensor), a follow-on to CZCS.

104 Although in some cases, orbit requirements differentiate one type from another. For example, an EOS rev iew committee recently concluded that "the science objectives of EOS land-ice altimetry and ocean altimetry dictate that these sensors be on separate spacecraft. Polar orbits with non-repeating or long-period repetition ground tracks are required for complete ice sheet surface topography, while lower inclination orbits with reasonable values for mid-latitude and equatorial ground track crossover angles are required to achieve optimal recovery of ocean surface topography." B. Moore III and J. Dozier, "A Joint Report: The Payload Advisory Panel and the Data and information System Advisory Panel of the Investigators Working Group of the Earth Observing System," Dec. 17, 1993. This report is available through NASA's Office of Mission to Planet Earth.

105 U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., app. B.

FIGURE 3-6: Schematic Diagram of Coupling Between Oceans, Atmosphere, and Land



Broken arrows indicate those influences external to the Earth or altered by human activities

NOTE Adapted from Joint Oceanographic Commission, Global Atmospheric Research Programme A Physical Basis for Climate and Climate Modeling *GARP Publ Ser 16* [1975)

BOX 3-8: The Links Among Earth's Systems: El Niño and the Southern Oscillation

Coastal Peru is arid enough so that sun-baked mud is often used to build houses. In the neighboring ocean, intense upwelling pumps nutrients to the surface to create one of the world's richest fisheries. In late 1982 the nutrient pump shut down, eliminating the local fishery. And the rains began: some normally arid zones received as much as 3 m [118 inches] of rain within a 6 month period. Mud houses dissolved, and much of the transportation infrastructure washed away. Almost 1,000 years ago, a similar climatic disaster destroyed a prosperous agricultural civilization rivaling the Incas.

Peru was not alone: the impact of the strange climatic events of 1982-83 was global. In Indonesia, vast areas of rainforest were destroyed in fires spawned by a devastating drought. Australia experienced the worst drought in its recorded history: firestorms incinerated whole towns, livestock herds had to be destroyed, and production of cotton, wheat, and rice was sharply reduced. In Brazil, an exceptionally poor rainy season distressed the impoverished Nordeste region, while southern Brazil and northern Argentina were hit with destructive flooding. Throughout southern Asia, poor monsoon rains in 1982 reduced crop yields and slowed economic growth. China saw drought over the northern part of the country and unusual winter floods in the south, leading to major losses in the winter wheat crop . . . Severe winter storms rearranged the beaches of California; spring floods covered the streets of Salt Lake City . . .—*M.A. Cane, 1991*

The events described above are an example of an irregularly recurring pattern known as ENSO. The abbreviation combines its oceanographic manifestation in the eastern tropical Pacific, El Niño, with its global atmospheric component, the Southern Oscillation. ENSO is an irregular cycle with extremes of variable amplitude recurring every 2 to 7 years. The 1982-83 events are a instance of its warm phase. Events of 1988, including catastrophic flooding of Bangladesh, demonstrate the impact of the cold phase. Historically, El Niño was the name given to the marked warming of coastal waters off Ecuador and Peru. It is now understood that during the ENSO warm phase, the warming covers the equatorial Pacific from South America to the dateline, fully one-quarter of the circumference of Earth.

SOURCE: M.A. Cane, Lamont-Doherty Geological Observatory, Columbia University, NY, unpublished remarks at the 1991 American Geophysical Union annual meeting.

large-scale ocean fronts and eddies, surface ocean currents, surface wind speed, wave height, and the edge of sea ice.[106] Radar altimetry data have also been used to estimate ice-surface elevations in polar regions.

U.S. efforts to develop satellites suitable for ocean monitoring have lagged behind those for land-surface monitoring. Seasat,[107] a notable success during its 3 months of operation, was followed by a NOAA, DOD, and NASA proposal for a similar National Oceanic Satellite System (NOSS). NOSS instruments included a SAR, a scatterometer, an altimeter, a microwave imager, and a microwave sounder. This effort was canceled in 1982, as was a subsequent proposal for a less costly Navy Remote Ocean Sensing Satellite (NROSS).[108]

As noted above, the only U.S. systems that routinely monitor the oceans are the weather satellites. Of particular interest for this report is the de-

[106] D.J. Baker, *Planet Earth: The View from Space,* op. cit., pp. 70-71.

[107] Seasat, which was designed in part to demonstrate the feasibility of using radar techniques for global monitoring of oceanographic phenomena, carried an altimeter, a scatterometer, a seaming multichannel microwave radiometer, a SAR, and a visible and infrared radiometer. An electrical failure caused the satellite to fail prematurely. See D.J. Baker, *Planet Earth: The View from Space,* op. cit., pp. 66-71.

[108] NROSS was canceled in 1986, reinstated in 1987, and terminated in 1988. NROSS would have been less costly than NOSS, primarily because of the elimination of the SAR.

velopment of new *operational* satellite-borne instruments for ocean monitoring. These include an altimeter, to continue the TOPEX/Poseidon mission; a scatterometer, to measure sea-surface wind vectors; a lidar (laser radar), to measure tropospheric winds; a SAR, for a variety of high-spatial-resolution measurements (meters to tens of meters) in ice-covered waters; and an ocean-color sensor, to monitor ocean productivity. Box 3-9 gives an overview of applications of radar altimeters and scatterometers for ocean monitoring. Applications of SAR and lidar are discussed in a previous OTA report. [109]

NOAA currently lacks the budget authority to undertake major expansion of its operational satellite program. Early in NASA's planning for

BOX 3-9: TOPEX/Poseidon and the NASA Scatterometer

TOPEX/Poseidon is a joint U.S.-French NASA-Centre National d'Études Spatiales (CNES) research satellite devoted primarily to highly accurate measurements (to an accuracy of about 2 cm) of the height of the oceans. Instruments on TOPEX/Poseidon include a radar altimeter and a microwave radiometer, which corrects for the effects of water vapor in the atmosphere. Accurate measurements of the ocean's topography may lead to better understanding of ocean circulation and a variety of other ocean-related quantities. In addition, an altimeter passing over polar regions acquires information about the topography of polar ice sheets and the formation and flows of glaciers (however, the orbit of TOPEX/Poseidon does not allow sampling above 66° latitude).

Radar altimeters have flown previously on NASA's GEOS-3 (1975-1978) and Seasat (July-October, 1978) and the Navy's Geosat (1985-1989). The Navy is currently developing a Geosat Follow-On (GFO) satellite for launch in 1996, and NASA is planning an altimetry mission, EOS-Alt, to be launched in approximately 2002. A 1998 launch of a TOPEX/Poseidon Follow-On (TPFO), which might replace or subsume EOS-Alt, is less certain because of budget problems. NASA's Payload Advisory Panel has recommended that the EOS project explore options that will ensure that "the important measurements provided by the current TOPEX/Poseidon mission be continued to bridge the gap between the end of TOPEX/Poseidon and the launch of EOS Ocean Alt [or, if funded and developed, a TPFO]." The Navy's GFO is a candidate for this "gap-filler," but it would require modifications in instrument complement and, possibly, orbit selection.

A scatterometer is a radar instrument that can be used to determine wind speed and direction over the ocean by analyzing the radar returns from wind-generated waves. Radar returns are affected by both the size of wind-generated waves and their orientation with respect to the radar signal (look angle). An analysis of the radar returns from multiple antennas yields multidirectional data that can be used to determine both wind speed and direction. NASA plans to fly a scatterometer (NSCAT) as part of its EOS program (on the Japanese Advanced Earth Observing Satellite (ADEOS) mission in 1996). ADEOS has a planned 3-year lifetime; a follow-on is expected to be launched in 1999. NASA is also developing a follow-on to NSCAT (NSCAT II). An important application of scatterometer, altimeter, and in situ measurements would be monitoring the ocean conditions associated with the onset and severity of El Niño.

SOURCES: Office of Technology Assessment, 1994; B. Moore III and J. Dozier, "A Joint Report: The Payload Advisory Panel and The Data and Information System Advisory Panel of The Investigators Working Group of the Earth Observing System," Dec. 17, 1993.

[109] U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., app. B.

EOS, when it was still a broad-based earth science program, the program appeared to be a vehicle for developing instruments that would become an operational ocean monitoring program. However, cutbacks to the EOS program and its subsequent "rescoping" to emphasize climate change [110] have resulted in the cancellation, deferral, or dependence on foreign partners of several instruments with oceanographic application. Rescoping actions include the cancellation of EOS SAR (less capable European and Japanese SARS are available and Canada plans to launch a SAR in 1995); transfer of the U.S. scatterometer to a Japanese satellite; and deferral of development of next-generation microwave-imaging radiometers (the United States will use European and Japanese instruments). In addition to scientific losses, several reviewers of this and previous OTA reports on Earth Observing Systems were concerned that allowing the U.S. lead to slip in these technologies would harm the nation technology base for environmental remote sensing.

Observing this situation, the Ocean Studies Board of the National Research Council wrote:111

> A major obstacle for marine science lies in the difficulty of development and managing spaceborne instruments over the next decades. Historically, NASA developed meteorological spacecraft that evolved into operational systems managed by NOAA. However, for marine observations, apart from the long-standing efforts in the visible and infrared sea-surface temperature observations and microwave sea ice measurements (both of interest to short-term forecasting), there is no effective mechanism for the systematic development or transfer of technology from research to operations. Some mechanism must be found to routinely collect such observations that are important to the NOAA mission. NOAA will need additional funding to carry out these observations, and a partnership arrangement will be necessary to identify the essential variables to be observed.

In summary, with respect to ocean monitoring systems, OTA finds that the development of a national strategic plan for Earth environmental remote sensing offers an opportunity to:

- provide coherence, direction, and continuity to disparate programs that have previously suffered from fits and starts;
- assist in the selection and enhance the utilization of EOS sensors;
- assist in the development of advanced technologies; and
- restore a beneficial relationship between NASA and NOAA to manage the transition between research and operational instruments more effectively (the same benefit noted above for other environmental remote sensing instruments).

110 U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA'S Earth Observing System*, op. cit.

111 Ocean Research Council of the National Research Council, *Oceanography in the Next Decade: Building New Partnerships* (Washington, DC: National Academy Press, 1992).

International Cooperation and Competition 4

A U.S. national strategy for satellite remote sensing must take into account the increasing importance of international remote sensing activities. The growing number of countries that are active in remote sensing and the increasing number and depth of international interactions among remote sensing programs have created expanding opportunities for the United States to benefit from international cooperation in remote sensing. The changing international scene also poses new challenges to U.S. competitiveness in commercial remote sensing and force a reconsideration of national security interests in remote sensing technologies.

Several factors have led to the increasing international interactions in remote sensing, which include both cooperation among governmental programs and competition in commercial activities. First, the market for satellite data is naturally a global one, in terms of both supply and demand. The supply is global because satellites are capable of viewing the entire globe as they orbit Earth.[1] The demand is global because users around the world are making increasing use of satellite data and because many of the

[1] Not all satellites have global scope, but all are capable of viewing very large regions of Earth. Satellites in polar orbit can observe the entire globe as Earth rotates under their orbits; those in lower-inclination orbits miss regions that are too far north or south; those in geosynchronous orbit view continuously the same region—roughly a third—of Earth's surface. Article 11 of the Outer Space Treaty (United Nations, *Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies*, Jan. 27, 1967) recognizes the right of satellites to pass over international boundaries with impunity, and *The United Nations Principles Relating to Remote Sensing of the Earth from Space* reaffirm the legitimate role of remote sensing satellites. See U. S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, OTA-ISS-604 (Washington, DC: U.S. Government Printing Office, August 1994), box 5-3.

applications of satellite data, such as weather forecasting and global change research, depend on the availability of global data sets.

The national pursuit of technological self-sufficiency has helped produce a second factor behind the internationalization of remote sensing: the increasing international diffusion of technical capabilities. Although commercial firms are playing an increasingly large role in satellite remote sensing, national governments continue to predominate. Canada, Europe, India, Japan, and Russia all have substantial and overlapping capabilities in remote sensing. This creates new opportunities for international cooperation in remote sensing, but it poses challenges to U.S. leadership. U.S. policies and practices no longer determine international standards by default. Instead, the United States faces the more difficult task of providing leadership through consensus building and accommodating the interests of other countries.

The third critical factor affecting international remote sensing activities is the worldwide interest in reducing costs. This leads to two competing impulses:

- the growing interest in international cooperation in order to increase the cost-effectiveness of remote sensing programs, particularly to eliminate unnecessary duplication among various national programs; and
- the tendency toward commercialization, provided by government agencies to recover some of the costs of developing and operating remote sensing systems.

These two impulses are in conflict because international cooperation relies on the relatively open exchange of data, while commercialization depends on the ability to limit data access only to paying customers. Because of this conflict, efforts to promote international cooperation in an era of multiple suppliers have focused first on the coordination of data policies.[2] **The development of successful data-exchange policies will be critical to future international cooperation in remote sensing.**

These three factors have led to programs of international cooperation and plans for continuing the expansion of international cooperation in remote sensing. The ultimate scope and direction of this cooperation will depend on several factors:

- the ability to preserve effective data-exchange mechanisms;
- the ability to share equitably both the costs of developing and operating remote sensing systems and control over those systems, without creating cumbersome financial and administrative arrangements;
- the confidence of all international partners in their ability to rely on one another (thus, the United States needs to judge the reliability of its partners and to strive to be a reliable partner itself); and
- the uncertain political and economic stability of Russia.

International cooperation will evolve slowly through successive generations of satellite systems as experience determines whether the United States can work effectively with other countries on remote sensing programs.

This chapter begins with a brief discussion of international interests and activities in satellite remote sensing. The following sections discuss the risks and benefits of expanded international cooperation in remote sensing, with particular attention to the implications for commercial markets and for national security interests. The concluding sections apply these considerations to an analysis of a range of options for future organizational structures to support enhanced international cooperation in remote sensing.

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

INTERNATIONAL REMOTE SENSING NEEDS

For the most part, international uses of remote sensing are similar to those in the United States (see chapter 2). Some of these applications have data requirements that are truly international in character. In other cases, the data requirements are essentially local, although the needs of some foreign users, particularly in developing countries, are qualitatively different from those of U.S. data users.

Weather forecasting is the most established international application of satellite remote sensing.[3] The related endeavors of scientific studies and operational monitoring of oceans and climate, as proposed under the planned Global Climate Observing System (GCOS) and Global Ocean Observing System (GOOS),[4] also require data that are international in scope, as would a proposed Environmental Disaster Observation System (EDOS).[5] These global applications require operational mechanisms for the international exchange of raw and processed data, including the in situ data[6] that remain critical to the quantitative interpretation of satellite data.

Many applications of remote sensing—particularly land remote sensing—require only local or regional data. Yet these uses of remote sensing, applied in widely dispersed locations, often require nearly identical types of data. With their global coverage, satellites offer an economy of scope in meeting data needs in different parts of the world. Despite this, the desire for technological development and autonomy has led many countries to develop independent capabilities in land remote sensing. These countries have taken a range of approaches to the public and private-sector roles.

Other international differences arise from contrasting data needs in different parts of the world, particularly in the developing world. Poorer, developing countries often lack fundamental information about land cover, land use, and natural resources and have limited administrative and financial resources for collecting that information on their own.[7] Providing this basic information through remote sensing could improve substantially the ability of developing countries to manage their natural resources and develop their economies in ways that respect the natural environment,[8] although it could also be used to strengthen the control of authoritarian regimes. Accomplishing development and resource management goals involves much more than simply providing satellite data; it often requires foreign assistance in developing national capabilities to

3 For more information on the data-exchange requirements and mechanisms used in weather forecasting, see U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets,* op. cit., ch. 5.

4 Plans for GCOS and GOOS, which are currently under development, will probably rely on a mixture of new satellite and in situ instruments and instruments planned for other purposes. For information on GCOS, see Joint Scientific and Technical Committee for GCOS, *GCOS: Responding to the Need for Cl/inure Observations,* WMO No. 777 (Geneva: World Meteorological Organization, 1992); for information on GCOS, see D.J. Baker, "Toward a Global Ocean Observing System," *Oceans* 34(1):76-83, spring 1991; and National Oceanic and Atmospheric Administration, *First Steps Toward a U.S. COOS: Report of a Workshop on U.S. Contributions to a Global Ocean Observing System*, October 1992 (available from Joint Oceanographic Institutions Inc., Washington, DC).

5 For a history of this idea, see J. Johnson-Freese, "Development of a Global EDOS: Political Support and Constraints," *Space Policy IO(1)*1:45-55, 1994. EDOS would not necessarily require a new, dedicated system of satellites, but could rely on timely access to data from satellites designed primarily for other purposes.

6 In contrast to remotely sensed data, in situ data are measured at the location of the phenomenon that is being observed.

7 India is the main exception to this rule, with a substantial commitment to developing its own remote sensing capabilities. China and Brazil also have significant remote sensing programs.

8 Committee on Earth Observations Satellites, "The Relevance of Satellite Missions to the Study of the Global Environment," paper presented at the United Nations Conference on En\ ironment and Development, Rio de Janeiro, June 1992.

BOX 4-1: International Remote Sensing Activities

The past decade has seen a large number of countries join the United States and the former Soviet Union in civilian space-based remote sensing activities. Europe (particularly France), Japan, India, and China have deployed satellite systems, several others plan to do so, and many more countries and organizations use the data obtained from these satellites. These countries have undertaken remote sensing programs for a variety of reasons, including national security and national autonomy in space technology, but also in large part to benefit from the practical applications of environmental data from satellites.

The countries now involved in satellite remote sensing share many common interests. This has led to competition both for prestige and for a share of international markets and increasing intergovernmental cooperation of various types (see appendix B for more details):

- **Data exchanges.** Agreements for the cooperative reception and exchange of data from satellites, along with complementary in situ data, were the earliest form of cooperation in remote sensing. From the earliest days of its civilian remote sensing programs, the United States developed partnerships with other countries for the scientific and operational use of remotely sensed satellite data.
- **Joint projects.** Joint satellite projects are one common form of cooperation. Typically, these involve one country providing instruments to fly on another country's satellite. NOAA and NASA have both flown instruments from other countries and have provided instruments to fly on foreign platforms. As examples, Canada, France, and Britain have contributed instruments to NOAA's Polar-orbiting Operational Environmental Satellite System (POES) platforms, and NASA placed the Total Ozone Mapping Spectrometer (TOMS) on a Soviet Meteor satellite in 1991.[1] More such joint projects are under way.
- **International coordinating bodies.** Several formal and informal intergovernmental bodies also exist to promote broader international coordination of remote sensing programs and policies. The Committee on Earth Observation Satellites (CEOS) has broad membership (table B-4) and works to develop agreements by consensus on data policies and standards. CEOS adopted a revised Resolution on Satellite

(continued)

[1] At the time, this involved difficult export-control negotiations because the TOMS instrument carries electronic circuits hardened to withstand radiation.

make effective use of data from satellites and of in situ data.[9]

THE BENEFITS AND RISKS OF INTERNATIONAL COOPERATION

These common interests in remote sensing, combined with the equally common desire for technological independence, have led an increasing number of countries to undertake civilian space-based remote sensing programs (appendix B). The programs have often begun as independent efforts, but many countries have pursued international cooperation as a way to increase the cost-effectiveness of their national programs. This cooperation has taken a variety of forms (box 4-1).

Each cooperative arrangement has dealt with the problem of facilitating data exchanges and harmonizing data-access policies among the participating agencies (box 4-2). These efforts to coordinate satellite remote sensing programs and their associated data policies form the foundation for a steady expansion of international cooperation.

International cooperation in remote sensing presents the United States with an array of benefits and risks. Many of these benefits and risks apply

[9] See the section on international development in U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., ch. 5.

BOX 4-1: International Remote Sensing Activities (Cont'd.)

Data Exchange Principles in Support of Global Change Research in 1992[2] and has begun to develop similar principles for operational environmental uses of satellite data for the public benefit. The Earth Observation International Coordination Working Group (EO-ICWG) represents a different type of cooperation, a working partnership among a smaller set of agencies (table 4-2) to provide more detailed coordination of selected satellite programs into an International Earth Observing System (IEOS, box 4-5).

- **Regional organizations.** The closest international cooperation occurs among the countries of Europe, which have established two regional organizations that deal extensively with remote sensing. The European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) (box 4-6) exist primarily to aggregate the technical and financial resources of European countries to support space research and development and meteorological satellites, respectively; they play roles similar to those of NASA and NOAA in the United States.
- **United Nations organizations.** Several international organizations affiliated with the United Nations also have substantial roles in remote sensing, most notably, the World Meteorological Organization (WMO) and its World Weather Watch (WWW) program (box 4-3). WWW is a cooperative program for carrying out the international exchange of basic meteorological data for operational weather forecasting. This includes shared responsibility for data collection, processing, and transmission.
- **Research programs.** The modern tradition of large-scale international cooperation in earth and environmental sciences dates back to the International Geophysical Year in 1957. It has expanded in recent years because of growing international concerns over changes in the global environment. International programs[3] have helped establish an international global change research agenda that guides national research efforts, including the U.S. Global Change Research Program.

[2] See the minutes of the Sixth CEOS Plenary Meeting, London, December 1992, available from the CEOS Secretariat through the European Space Agency, NASA, and Japan's National Space Development Agency.

[3] The World Climate Research Programme (WCRP), the International Geosphere-Biosphere Programme (IGBP), and the Human Dimensions of Global Environmental Change Programme (HDP) are international research programs aimed at understanding the physical, chemical, biological, and social processes that contribute to global change. The Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the Global Terrestrial Observing System (GTOS), all in various stages of planning, aim to provide continuous comprehensive measurements of key indicators of global change. 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. 5.

SOURCE: Office of Technology Assessment, 1994

equally (o interagency coordination within the U.S. government. but some issues are unique or more pronounced in an international context. An expansion of international cooperation should aim to enhance the benefits of cooperation without adding unnecessary risks.

Benefits of Cooperation

- ***Reducing cost.*** Many of the agencies involved in remote sensing share common goals and have developed overlapping satellite programs. Facing budget constraints, these agencies are looking for ways to coordinate their programs to eliminate unnecessary duplication and, thereby, to reduce their overall cost.
- ***Reducing technological and program risk.*** Some degree of redundancy is necessary, particularly for meteorological and other operational satellite programs. The exchange of backup satellites between the National Oceanic and Atmospheric Administration (NOAA) and its European counterparts is a case in point: NOAA provided a backup geostationary satellite, the Geostationary Operational Environmental Satellite (GOES), when Europe had problems with its Meteosat program, and Eu-

BOX 4-2: The Importance of Data Access and Exchange

International data access and exchange is critical to any future cooperative arrangements in remote sensing. The principal purpose of cooperation is to satisfy the data and information requirements of all parties as effectively and economically as possible. Any cooperative effort, therefore, requires a workable mechanism for providing the participants with the data they need. The same considerations apply to commercial remote sensing ventures.[1]

Data exchange involves a combination of formal agreements on data-access policy and the development of data-management systems to carry out those agreements. Data-access policy involves questions of who should have access to data and under what conditions. These conditions include considerations of price, timeliness, and restrictions on redistribution to third parties. Data management includes the acquisition, transmission, processing, storage, and dissemination of data and information, as well as the information systems necessary to carry out these functions. Both data policy and data management pose potential problems for international cooperation.

NOAA, NASA, and the Department of State have traditionally pushed for the full and open exchange of environmental satellite data in international agreements, particularly cooperative agreements on global change research. However, other national agencies have adopted a variety of more restrictive policies on data access.[2] For example, Eumetsat is planning to encrypt Meteosat data and charge nonmember countries in Europe for access to the raw data. NOAA and other national agencies will probably continue to have free access but may not make the data freely available to third parties as they have in the past. As another example, Canada plans to recover the costs of operating Radarsat by commercial sales, including sales to government agencies.[3]

These more restrictive policies reflect differences in policy and circumstance between U.S. and foreign agencies. For years, the United States has debated the proper role of the public and private sectors in remote sensing, particularly land remote sensing. The Land Remote Sensing Policy Act of 1992 (P.L. 102-555) codifies the current working consensus on these roles.[4] Many countries, especially in Europe, see remotely sensed data as valuable commodities, obtained at substantial cost and not to be given away freely. Many national agencies in Europe face considerable pressure to recover some of their costs through the sale of data. Their limited data needs might not justify the cost of a satellite system unless they can spread the costs over a broader range of users by charging them for data access.

Many countries also argue that those who use remotely sensed data should pay a larger share of the costs of collecting the data. This applies whether the user is a private company or a government agency. These payments would give the users a greater interest in and greater influence over the operation of the remote sensing system.

Some countries also advocate making government agencies pay a greater share of data costs as a more honest form of accounting. To maintain current activities or undertake new ones, user agencies

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[1] See R. Mansell and S. Paltridge, "The Earth Observation Market: Industrial Dynamics and Their Impact on Data Policy," *Space Policy* 9(4):286-298, November 1993; and R. Harris and R. Krawec, "Earth Observation Data Pricing Policy," *Space Policy* 9(4):299-318, November 1993.

[2] R. Harris and R. Krawec, "Some Current International and National Earth Observation Data Policies," *Space Policy* 9(4): 273-285, November 1993.

[3] In exchange for providing launch services, the U.S. government will receive free access to Radarsat data for some purposes.

[4] See chapter 3 and appendix D on Landsat policy history.

BOX 4-2: The Importance of Data Access and Exchange (Cont'd.)

would then need additional budget authority, presumably budget authority that currently belongs to the agency that supplies the data. This transfer of budget authority can be difficult.[5]

Furthermore, many countries allow a much greater commercial role for the government than does the United States. For example, the British Meteorological Office charges oil companies operating in the North Sea commercial rates for specialized weather forecasts, and the French space agency Centre National d'Études Spatiales (CNES) owns a 34-percent share of SPOT Image. Open data access would interfere with these state commercial ventures. Not only are government data not generally considered to belong to the public, but national governments often hold copyrights on the data they collect.

Disagreements over pricing policy also reflect different views of how best to stimulate the market—both governmental and commercial—for remotely sensed data. Does charging commercial prices encourage the market to be more responsive or discourage the development of new applications? Do payment mechanisms and restrictive license agreements create unnecessary impediments to the efficient and effective use of satellite data? Should governments continue to build their own data-collection systems or rely more on commercial data suppliers?

Beyond the coordination of policies on data access and pricing, international data exchange requires systems for collecting, processing, archiving, and disseminating remotely sensed data. The development and implementation of these data-management systems pose substantial challenges for international coordination.

First, the data-management systems need to have adequate capacity to meet the needs of users both inside and outside a given agency. Especially in their initial implementation, data systems often do not satisfy these requirements, as evidenced by early problems in distributing data from both Europe's ERS-1 and Japan's JERS-1 satellites. Most foreign agencies recognize the need for adequate data-management systems, but none has yet made a commitment of resources comparable to NASA's planned investment in the EOS Data and Information System (EOSDIS).[6]

Second, data-management systems need to be sufficiently compatible that users of one system can easily identify and obtain data held by another. This involves the development of agreed-upon standards for data and metadata[7] formats, computer-system interfaces, and data-processing algorithms. Discussions in CEOS have led to efforts to improve the compatibility of systems in the United States, Europe, and Japan, but much work remains to be done to ensure full interoperability of data systems. Coordination of algorithms for preprocessing data to extract physical information is particularly important for global studies that require comparable data from different regions of Earth.

[5] In the late 1980s, the Office of Management and Budget attempted to convince agencies that use Landsat data to help pay for a next-generation Landsat satellite, but the agencies refused to go along. See D. Radzanowski, *The Future of the Land Remote Sensing Satellite System (Landsat)*, 91-685 SPR (Washington, DC: Congressional Research Service, September 1991), p. 12. A similar difficulty arises with the U.S. Global Change Research Program (USGCRP), which NASA dominates in budgetary terms in large part because its overall budget is so much larger than those of other USGCRP agencies. See 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), p. 24.

[6] 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. 3; National Research Council, *Panel to Review EOSDIS Plans, Final Report* (Washington, DC: National Academy Press, 1994).

[7] *Metadata* are descriptive catalog data that include such information as the time, geographic location, and quality of data and images and about how to obtain the actual data. See chapter 2 of *Remotely Sensed Data*, ibid.

SOURCES: 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. 5.

rope returned the favor when NOAA faced problems with its GOES program, lending Meteosat 3 to NOAA in place of GOES-East (see appendix B). Because the United States and Europe could rely on each other for backups, they avoided more serious disruptions in their operational programs while maintaining the deliberate pace of their satellite-development programs.

- ***Increasing effectiveness.*** The elimination of unnecessary duplication can also free up resources and allow individual agencies to match those resources more effectively with their missions. This reallocation of resources can eliminate gaps that would occur if agency programs were not coordinated. International discussions can be valuable even if they merely help to identify such gaps, but they can be particularly useful if they lead to a division of labor that reduces those gaps. Cooperation on data collection and exchange, especially for data collected in situ, can also provide important benefits.
- ***Sharing burdens.*** International cooperation can lead to a more equitable sharing of costs for existing remote sensing programs. One organization, the International Polar Operational Meteorological Satellite organization (IPOMS), was founded largely for this purpose. IPOMS was disbanded in 1993, having accomplished its mission with Europe's commitment to polar meteorological satellite programs, particularly the Meteorological Operational Satellite (METOP).[10] The growing interest and activity by other countries in remote sensing has also helped to equalize this burden. In 1993, U.S. programs accounted for roughly 40 percent of worldwide spending for civilian remote sensing (table 4-1).
- ***Aggregating resources.*** International cooperation can also provide the means to pay for new programs and projects that individual agencies cannot afford on their own. This has been the case in Europe, where the formation of the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) has allowed European countries to pursue much more ambitious and coherent programs than any of them could have accomplished alone. The need to aggregate resources is particularly great for remote sensing programs, such as the Earth Observing System (EOS), that are organized into large, multi-instrument platforms. In addition to aggregating financial resources, cooperation can also allow countries to combine complementary technical capabilities.

TABLE 4-1: International Civilian Remote Sensing Budgets, 1993

Agency or country[a]	Budget ($ million)
NASA	938
NOAA	320
DOD (Landsat and DMSP)	150
Total United States	1,408
ESA	354
Eumetsat	143
France	415
Germany	88
Italy	66
United Kingdom	127
Total Europe	1,193
Japan[b]	396
Canada	95
Russia[c]	228
China	128
India	90
Others[d]	39
Total	3,577

[a] NASA = National Aeronautics and Space Administration, NOAA = National Oceanic and Atmospheric Administration DOD =Department of Defense, DMSP = Defense Meteorological Satellite Program ESA = European Space Agency

b Including $150 million estimated for the Japan Meteoroloical Agency

[c] From Anser - $100 million estimated for Meteor

[d] From Anser

SOURCES National Oceanic and Atmospheric Administration/Natiion-a Environmental Satellite Data and Information Service, 1994, Anser Corporation, 1994, Off Ice of Technology Assessment, 1994

10 The Coordination Group for Meteorological Satellites (CGMS) assumed the remaining coordination functions of IPOMS

- ***Promoting foreign policy objectives.*** Cooperation in space also serves important foreign policy objectives, as exemplified by the international space station program.[11] Important cooperative remote sensing activities grew out of the space station program[12] and from the agreements on space cooperation signed in 1993 by Vice President Albert Gore and Russian Prime Minister Viktor Chemomyrdin.[13] Cooperation on data exchange helped the United States promote the ideal of openness during the Cold War.

Risks of Cooperation

- ***Decreased flexibility.*** The planning, development, and operation of a major remote sensing project require a substantial long-term commitment of resources and do not allow a great deal of flexibility. International coordination could further reduce that flexibility y by making the decisionmaking process more complicated, leading to inefficient choices that limit the potential reductions in cost and risk.
- ***Increased management complexity.*** International cooperation can introduce an extra layer of complexity to the management of a remote sensing program. Not only does the decision-making process become more complicated, but the political and budgetary processes of cooperating agencies in different countries may be difficult to reconcile.
- ***Decreased autonomy.*** The commitment of a substantial portion of an agency's budget to international activities reduces its ability to modify its programs in response to changing needs or budgets. An agency may be forced to compromise on meeting its own requirements in order to meet the requirements of an international program, or it may have to defer desired programs of its own.
- ***Potential unreliability of foreign partners.*** Complementing the loss of autonomy is the concern over the reliability of foreign partners and their commitments. An attempt by one partner to reduce or withdraw its commitment to a joint program could jeopardize the entire program, including portions that had been proceeding steadily as separate national programs. This could pose particular difficulties when cooperation rests on political arrangements of uncertain stability, as is now the case with Russia. The reliability of U.S. commitments is also a concern to potential foreign partners. given recent uncertainties over U.S. commitments to the space station and other major international science and technology programs.[14]
- ***Decreased scope for private markets.*** As discussed in chapter 3. one way to meet the government's remote sensing data needs is to purchase data from the private sector. This has particular advantages when the aggregate demand for a certain type of data is large but no single agency can afford the satellite system. International agreements to fund remote sensing systems jointly could eliminate an important opportunity for the private sector. On the other hand, agreements to discuss common requirements and meet those requirements through coordinated data purchases could stimulate private-sector activities.
- ***Increased technology transfer.*** Although many countries now possess the technical ability to build remote sensing systems oft heir own, the United States maintains a substantial lead

[11] U.S. Congress, Office Of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., box 5-1.

[12] In particular, the Earth Observation International Coordination Working Group (EO-ICWG) grew out of the international polar platforms of the international space station program.

[13] White House, *Plan for Russian-American Cooperative Programs in Earth Science and Environmental Monitoring from Space* (Washington, DC: White House, Oct. 27, 1993).

[14] The cancellation of the Superconducting Supercollider may be instructive in at least two ways. First, the willingness of Congress to cancel a large ongoing project casts some doubt on the U.S. abi I ity to make the needed commitment to large cooperative programs. Second, uncertainty over the U.S. commitment to this project deterred other countries, particularly Japan, from taking part.

in several critical technologies. Cooperative programs require some sharing of technological information, and simply working together inevitably promotes the exchange of technological knowledge. This transfer could, in turn, undermine U.S. national security interests as well as the technological advantages of U.S. companies in the international market.

International cooperation offers many of the same benefits and risks as cooperation among U.S. agencies, with one important difference: International agreements have no central authority **like the U.S. federal government to set the agenda and adjudicate disputes.** Central authority in the U.S. government is relatively weak, and interagency discussions often resemble international negotiations, but national political decisions can intervene to resolve disputes. For example, the planned convergence of polar meteorological satellites was dictated by a Presidential Decision Directive NSTC-2 (appendix C), and NOAA and the Department of Defense (DOD) must answer to presidential and congressional authority in carrying out that decision.

Two areas that deserve special attention as potential constraints on international cooperation in remote sensing are the potential effects on emerging commercial markets and on national security. The next two sections deal with these issues in more detail.

INTERNATIONAL COMPETITION IN REMOTE SENSING

Countries compete in remote sensing for many reasons, including military power, technological prowess, and political symbolism. This section focuses on the more concrete issue of international competition in the commercial aspects of satellite remote sensing.

The United States dominated the development of scientific, operational, and commercial applications of remote sensing as part of the Landsat program in the 1970s and early 1980s. The Land Remote Sensing Commercialization Act of 1984 (P.L. 98-365) and the emergence of the French Systéme pour l'Observation de la Terre (SPOT) system in 1987 helped launch an international market in remote sensing. More recently, enterprises in Europe, Russia, and Japan have attempted to break into the commercial market, and several U.S. firms have announced plans to sell high-resolution land imagery (box 3-7).

Current markets for remotely sensed data are becoming more specialized, with the development of a variety of niche markets, each with its own requirements.[15] The growth in commercial data markets has been stimulated by the most rapidly growing sector: the value-added firms that convert raw data into usable information. European value-added firms are playing a growing role,[16] although U.S. firms continue to dominate the market for Geographic Information Systems (GIS).[17]

National governments continue to dominate both the supply and the demand for remotely sensed data. Because of this, national remote sensing policies play a major role in international data markets. To compete in international markets, U.S. firms must confront markets that are shaped in part by foreign governments. European coun-

15 For example, agricultural users require moderate-resolution multispectral images with short revisit times. The mapping and planning market often requires high-resolution stereoscopic images, but timeliness is less important. For an outline of the differing requirements for some commercial markets, see U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markers,* op. cit., ch. 4.

16 The countries of Eastern Europe have demonstrated their interest and capabilities in software development, particularly in analyzing data for operational purposes. See R. Armani, Managing Director of Vitro-SAAS Kft., testimony before the Senate Select Committee on Intelligence, November 1993.

17 GIS are flexible, computer-based mapping software systems that allow users to manipulate and combine information of different types that comes from a variety of sources, including satellite images. For a more detailed discussion of GIS, see U.S Congress. Office of Technology Assessment, *Remotely Sensed Data: Technology>, Management, and Markets,* op. cit., ch. 4.

tries in particular have strikingly different policies from the United States on pricing and access to data from government-funded systems, as well as on the role of governments in commercial markets. [18]

Furthermore, government standards for data format and quality can have major effects—beneficial or detrimental----a data markets. They are beneficial when they reduce market risks by encouraging users to coalesce around a predictable set of data requirements, and they can be detrimental if they discourage the emergence of new markets that require different types of data. [19]

Recent events pose several dangers for U.S. firms in the international market. First, the failure of Land sat 6 has created great uncertain y over the continuing supply of Landsat-type data and has encouraged many users to seek other sources of supply, including SPOT data. Any interruption in the data supply could undermine established value-added firms and make it difficult for U.S. data suppliers to break back into a reshaped market.

Chapter 3 identified several options for mitigating these risks, including strengthening government support for continuation of the Landsat system, developing public-private partnerships for a possible Landsat successor or gap-filler, and using long-term data-purchase contracts. Alternatively, the United States could attempt to prevent any data gap by exploring the use of data from foreign satellite systems.[20]

The lack of a U.S. source for operational synthetic aperture radar (SAR) satellite data[21] also poses a danger for U.S. firms, particularly in the value-added market. Although heavy data-telecommunication and data-processing demands currently make SAR data too expensive for most commercial purposes. SAR systems could open up a range of new commercial applications.[22] Europe, Canada, and Japan all have experience operating SAR systems, and Europe has promoted the development of new SAR applications through public-private partnerships. Each of these countries has designated a specific firm[23] to market the data for commercial purposes, and these firms could have a particular advantage in the value--added market.

As described in chapter 3, the United States has several options in order to avoid being left out of the SAR data and value-added market, including deploying its own SAR and funding the purchase of SAR data for the development of commercial applications. In addition, the United States could push for international agreements on equal access to SAR data from foreign sources. Ideally, such agreements would prevent foreign countries from charging higher rates to U.S. commercial users or giving preferential access to designated companies.

Finally, U.S. firms could face obstacles in international markets because of the data policies and commercial subsidies that other governments provide to their national firms. These issues arise frequently in international trade negotiations. and a range of trade policy tools is available to address them.

[18] Ibid.. ch. 5.

[19] U.S. Congress, Office of Technology Assessment, International Security and Space Program, *Data Format Standards for Civilian Remote Sensing Satellites*, background paper (Washington, DC: Office of Technology Assessment, April 1993).

[20] The Indian Remote Sensing Satellite (IRS) system may be one of the closest to Landsat in its technical characteristics, but the Russian Resurs-O or the Japanese Advanced Earth Observing Satellite (A DEOS) sy stem could provide a usable substitute.

[21] The only U.S. space-based SAR system is the Shuttle Imaging Radar-C (SIR-C), which has flown on the Space Shuttle. SIR-C is a much more sophisticated radar than any of [he foreign systems, but fire\ only in frequently.

[22] The ability of SAR systems to "see" through clouds provides a particular advantage over optical systems in providing prompt and reliable imagery when timeliness is critical.

[23] Eurimage in Europe, Radarsat International rn Canada, and the Remote Sensing Technology Center (RESTEC) in Japan.

NATIONAL SECURITY ISSUES

National security concerns also pose constraints on the extent of international cooperation in remote sensing and on U.S. participation in global markets for satellite data and technologies. Remote sensing serves a variety of military and other national security purposes, including many that are similar to civilian applications, such as mapping and weather forecasting, and many that have no obvious civilian counterpart, such as arms control verification, reconnaissance, targeting, and damage assessment. Because the technologies and many of the applications are similar, a national strategy for civilian remote sensing must also consider national security concerns.

U.S. military strategy has long relied on technological superiority, including the superior information that comes from advanced remote sensing systems. The ability to obtain superior information and to deny it to an adversary can be decisive on the battlefield. For this reason, military approaches to remote sensing emphasize control over both technology and data. As discussed below, however, U.S. military requirements may change with the evolving international security environment and the increasing diffusion of technological capabilities.

International Issues in Convergence

The likely European role in a converged weather satellite system designed to meet both military and civilian requirements raises two related issues: control over the data stream, and U.S. reliance on foreign sources of data. DOD has an explicit requirement that it be able to deny the meteorological data stream to an enemy in a crisis or in wartime (chapter 3). Encryption of the broadcast data stream would accomplish this, while preserving the availability to broadcast cloud imagery to properly equipped troops in the field. On-board data storage would allow uninterrupted records for climate and land-use monitoring to be maintained.

The United States would like to be able to control the data stream from the European METOP platform as well, and has insisted on control over data from U.S.-supplied instruments. For METOP- 1, these include the most critical proven meteorological imaging and sounding instruments: the Advanced Very High Resolution Radiometer (AVHRR), the High-Resolution Infrared Sounder (HIRS), and the Advanced Microwave Sounding Unit (AMSU). Initially, Eumetsat has balked at this proposal, noting that data from these instruments is currently freely available by satellite broadcast.[24]

The Clinton Administration's convergence proposal calls for U.S. imagers and sounders to continue to fly on future generations of METOP satellites, but Europe will probably develop some of its own instruments. France and Italy are collaborating to develop the Interferometric Atmospheric Sounding Instrument (IASI), which could become a candidate to replace HIRS.[25] Similarly, ESA is developing a Multifrequency Imaging Microwave Radiometer (MIMR), which could replace the Special Sensor Microwave/Imager (SSM/I), although budget and satellite size constraints have led Europe to review both of these instruments.[26]

Operational users would prefer that compatible data come from the same instruments on METOP as are on the U.S. converged weather satellites. If Europe wanted to fly its own operational instruments, this compatibility could come into question. Alternatively, European instruments could fly on all three satellites, but this would raise con-

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24 A. Lawler, "Data Control Complicates Weather Merger," Space *News*, June 20-26, 1994, p. 3.

25 The Atmospheric Infrared Sounder (AIRS) instrument currently under development by NASA for EOS PM-1 is another candidate to replace HIRS, as is the Interferometric Temperature Sounder (ITS) proposed by the Hughes Santa Barbara Research Corporation. Chapter 3 discusses the development of future meteorological instruments.

26 Europe currently has no plans to develop an imager to replace AVHRR.

cerns over U.S. self-sufficiency in basic meteorological systems.

The use of European imaging and sounding instruments on METOP would reduce U.S. leverage over access to and management of the METOP data. Even with a formal agreement on the conditions for restricting access to METOP data, DOD would lose direct control and would have less confidence in its ability to cut off the data flow during times of crisis. In part for this reason, the convergence proposal calls for the United States to operate two of the three operational satellites. Restricting the data flow from these two satellites-either by outright denial or, more likely, by delayed access—would reduce the value of the data from METOP alone. Controlling two of three satellites also limits DOD's reliance on foreign sources of data. The convergence plan calls for the United States to maintain the ability to launch a spare satellite on short notice, which further reduces U.S. reliance on European data sources.

Control over the data flow from a converged satellite system would not necessarily limit all access to comparable data sources. DOD has resisted attempts to make its meteorological imagery available operationally, especially the sea-surface wind data derived from SSM/I, although Europe has developed similar capabilities.[27] Russia also operates polar satellites in the Meteor series, which broadcast some data in the low-quality Automatic Picture Transmission (APT) format. and China has deployed experimental polar weather satellites as well. If these sources continue and improve, the United States could lose all ability to restrict access to high-quality meteorological data. However. maintaining open access (except in a crisis) to data from the converged satellite system could forestall this development by limiting the motivation of other countries to develop advanced meteorological instruments of their own.

Control of Data and Reliance on Foreign Sources

Military concerns over control of access to and management of U.S. data and reliance on foreign sources of data apply to issues beyond convergence. Data from government-run civilian land remote sensing systems have primarily civilian applications, although some types of data have significant military utility.[28] The U.S.-led coalition used data from Landsat and France's SPOT during the Persian Gulf War, and the United States and France restricted the flow of those data to other countries. DOD's Defense Mapping Agency now relies heavily on SPOT data, but may switch to U.S. commercial suppliers once their systems become operational.

The United States will remain a leader in providing satellite weather data and will have strong influence over the shape of cooperative agreements in that endeavor, but the situation could be quite different in other areas. For example, it may be difficult to establish a working partnership on ocean remote sensing that involves two of the leading players—Japan and the U.S. Navy—because of the Japanese policy to support remote sensing only for peaceful purposes. A lack of operational experience with civilian SAR systems could hamper DOD ability to make effective use of data from foreign SAR systems.

Although U.S. security policies have traditionally relied on superior intelligence and information, some people have argued that open access to satellite intelligence would provide greater security benefits than keeping access restricted. French and Canadian proposals in the 1980s, which were

[27] The Active Microwave Instrument (AMI) on board ERS-1 can function as a scatterometer, measuring sea-surface wind speeds.

[28] 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), ch. 6 and app. C.

never realized, called for an international satellite monitoring agency to help verify arms control agreements and promote openness in military deployments in order to defuse military tensions and deter surprise attacks.[29]

Licensing Commercial Data Sales

The differences in technical capability between military and civilian remote sensing systems are narrowing, particularly in the light of proposed high-resolution civilian systems. The Land Remote Sensing Policy Act of 1992 (P.L. 102-555) reiterated the authority of the Department of Commerce to license commercial sales of remotely sensed data. This act presumes that a license should be granted, with possible restrictions on data access. As noted in chapter 3, several firms have since applied for and received licenses to sell data with resolutions as high as 1 to 3 meters (m).

In March 1994, the Clinton Administration announced its policy on licensing the sale of remotely sensed data (appendix F). This policy requires the satellite operator to keep records so that the U.S. government can know who has purchased what data, and it authorizes the government to restrict the flow of data to protect national security interests during a crisis or war.

The principal considerations in permitting such data-sale licenses are: 1) the military sensitivity of the data in question and 2) the availability of comparable data through other channels.[30] Data with 1 -m resolution could certainly be used to identify targets for military attack, although restrictions on data access during a crisis or war could limit their use against mobile military targets. Data of similar resolution will soon be available internationally, from SPOT 4, with 5-m resolution,[31] from Russian satellites, with 2-m resolution or less,[32] and from the French HELIOS satellite.

Diffusion of Technological Capabilities

U.S. export-control policies have been designed to prevent the spread of technologies with critical military applications, including remote sensing. The United States leads the world in many specific sensor technologies, in the development of lightweight sensors and satellite systems, and in the hardware and software of signal process ing.[33] These advantages are important for the commercial competitiveness of U.S. industry as well as for national security. However, the spread of these technological capabilities as other countries pursue remote sensing programs has reduced these U.S. advantages substantially.

The United States no longer leads in all aspects of remote sensing technology, and increasing foreign investments in remote sensing technology are likely to narrow the gaps. For example, the United Kingdom is the world leader in active cooling of infrared sensors. For the type of technology involved in international remote sensing partnerships, technology transfer has become a more equal two-way process in which commercial control of proprietary technologies is more important than military control of sensitive technologies.

International partnerships often involve contractual restrictions that forbid those who receive technical information to support joint projects from using that information for other purposes. Another way to limit the transfer of sensitive technologies is to restrict cooperative programs to less sensitive activities. The imagers and sounders NOAA is providing for METOP-1 fall into this

29 This technical capability alone is not enough to prevent such attacks. U.S. intelligence satellites detected the Iraqi buildup on Kuwait's border in July 1990 but did not conclude that Iraq was planning to attack Kuwait until a few hours before the attack.

30 These are the normal considerations for all export controls.

31 SPOT *4* is scheduled for launch in 1996. See appendix B.

32 Russia has indicated that it might also sell images with resolution of less than 1 m.

33 See chapter 3 for a discussion of the role of technology development in the future Of remote sensing.

category. Finally, the use of "black box" arrangements can minimize the likelihood of inadvertent technology transfers. This entails providing as little detail as possible about the internal functioning of specific instruments while providing such essential information as their weight, power requirements, data quantity and format, and physical tolerances. Such arrangements are generally consistent with the standard engineering practice of modular design, making the components of an overall system as independent as possible.

With any cooperative project, some technology transfer is inevitable, even necessary. Having scientists and engineers work together is probably the most efficient way to transfer technological knowledge, particularly for system-level technologies such as bus design and spacecraft integration and for signal transmission and processing. The various instruments on a satellite generally share common data-communication channels, and the exchange of raw and processed data is essential to any cooperative arrangement.

National security concerns about technology transfer will continue to pose constraints on international cooperation in remote sensing. Given the increasing diffusion of technological capabilities, however, the desire to protect competitive advantages in international commercial markets may take on greater relative importance, and the ability to maintain these advantages through technology controls is likely to erode in any case.

Licensing Satellite Sales

Some countries have expressed an interest in purchasing high-resolution remote sensing satellite systems from U.S. companies, and some U.S. companies have responded with proposals to sell "turnkey" systems for other countries to operate.[34] This type of transfer raises issues that go beyond concerns over the sale of data. Specifically, it would offer the recipient country the opportunity to gain experience in satellite operations and in data processing and management, while limiting the ability of the U.S. government to restrict the flow of data. U.S. policy continues to restrict the sale of these sensitive technologies (see appendix F).

Export Controls and Cooperative Projects

Cooperative remote sensing projects often involve foreign agencies providing instruments to fly on U.S. satellites or U.S. agencies providing instruments to fly on foreign satellites. The transfer of instruments for joint projects differs from more sensitive exports in several important ways. First, instruments can be transferred under a "black box" arrangement that minimizes the opportunities for technology transfer. Second, the sensors involved in joint projects generally have little or no specific military application. Finally, the United States usually undertakes joint projects with allies who often have comparable technical capabilities, so technology transfer is less of a concern (the placement of the Total Ozone Mapping Spectrometer (TOMS) instrument on a (then) Soviet satellite was a significant exception).

Currently, most satellite instruments are treated as munitions under export-control regulations.[35] For most joint projects, these controls are not applied at the time of transfer but at the time when the Memorandum of Understanding (MOU) governing a project is being negotiated. Such an MOU gives NASA the authority to license the necessary transfer of instruments.[36] Complete export control reviews are still required for certain countries, including Russia (although this may change in response to growing U.S.-Russian space cooperation). Another option being considered is to treat remote sensing instruments—at least those that do

[34] J. H. Frey, President of Itek Optical Systems, testimony before the Senate Select Committee on Intelligence, Nov. 17, 1993.

[35] They are listed on the U.S. Munitions List, which is administered by the Department of State.

[36] L. Shaffer, Acting Assistant Associate Administrator for External Coordination, Office of Mission to Planet Earth, NASA, personal communication, July 22, 1994.

not contain sensitive technologies—as dual-use technology items[37] rather than as munitions.

OPTIONS FOR INTERNATIONAL COOPERATION

The preceding sections considered the risks and benefits of international cooperation in remote sensing. This section applies those considerations to a range of options for increasing cooperation in the future.

Current plans for international projects and the agendas of international organizations call for a steady expansion of international cooperation in remote sensing over the next decade and raise the prospect of further long-term growth in international cooperation. This section analyzes three principal alternative approaches to the long-term future of international cooperation in remote sensing. Each of these approaches uses existing international organizations as models or building blocks,

- ***Develop an international information cooperative for environmental data,*** modeled on the World Weather Watch (WWW). The free and open exchange of data has been traditional both in operational meteorology and in the earth and environmental sciences but has come under increasing pressure from promoters of restrictive data-access policies.
- ***Develop formal specialization and division of labor,*** based on the Earth Observation International Coordination Working Group (EO-ICWG). The logical extension of current coordination efforts, this approach would develop formal commitments outlining specific roles for each agency.
- ***Create an international remote sensing agency,*** modeled on ESA or Eumetsat. The long-term need for efficient and reliable international arrangements could lead to a formal international organization for satellite remote sensing.

These options are not mutually exclusive, nor do they provide an exhaustive list of possible future arrangements. They do provide a framework for thinking about the long-term future of international cooperation in remote sensing. The variations on each of these approaches also illustrate possible paths for evolution toward greater cooperation.

International Information Cooperative

Modeled on WWW, an international information cooperative could develop broad institutional mechanisms for data exchange and for sharing responsibilities for data and information management. WWW (box 4-3) has three main functional elements: 1) a Global Observing System, consisting of the observational equipment whose data stream WWW member countries make available for broader use; 2) a Global Data Processing System of forecast centers operated by WWW members; and 3) a Global Telecommunications System for transmitting raw and processed data and forecast information among WWW members. The World Meteorological Council meets regularly to coordinate plans for these systems and for other purposes.

The most important feature of WWW may be its underlying assumption that the mutual benefit of open data exchange is greater than the costs of providing access to data. WWW members provide basic meteorological data and forecast information for the general use of all other members in real time and at no charge. In addition, all programs of the WWW are carried out through the voluntary cooperation of WWW members.

Information cooperatives have significant advantages over more-restrictive data-access mechanisms. Cooperatives are well-suited to modern information technologies that make it easy to provide access to data and information but difficult to control that access. They also allow for an informal sharing of the burden of data collection that does not require a strict accounting of costs and

[37] Controls on dual-use technology items are administered by the Department of Commerce under the Commerce Control List.

BOX 4-3: The World Weather Watch

The World Weather Watch (WWW) was established in 1963 as the operational weather information system of the World Meteorological Organization (WMO), affiliated with the United Nations. WMO itself grew out of the data exchanges of the International Meteorological Organisation, founded in the late 19th century. The purpose of WWW is to provide national and regional weather services with timely access to meteorological data and forecasts. WWW has since become the principal activity of WMO and remains the only worldwide program for international cooperation on operational meteorological data and information.

WWW has three main functional elements: the Global Observing System (GOS), the Global Data-Processing System (GDPS), and the Global Telecommunications System (GTS). GOS consists of a wide variety of components, including weather satellites and their associated ground stations, aircraft, and surface-based observing stations on land and at sea. This collection of meteorological instruments provides fairly complete weather data across the temperate latitudes but has significant gaps over the oceans and in the tropics. The quality of surface-based observations also varies substantially from region to region.

GDPS includes an array of global, regional, and specialized forecast centers. The three World Meteorological Centres—in Washington, DC, Moscow, and Melbourne—provide worldwide weather forecasts on a global scale. An additional 29 Regional and Specialized Meteorological Centres provide more detailed forecasts for specialized purposes; three of these centers are devoted to forecasting tropical cyclones as part of the Tropical Cyclone Programme. These centers use meteorological data and models to develop weather forecasts, which they provide to participating National Meteorological Centres. The forecasts vary from regional to global in scope and cover a range of time scales from a few days to over a week, with increasing emphasis on near-term warning of severe storms and on long-term forecasting.

GTS is a communications network for transmitting meteorological data collected by the Global Observation System and forecast information produced by the Global Data Processing System. The Main Telecommunication Network links the three World Meteorological Centres and 15 Regional Telecommunication Hubs on six continents, which then provide links to regional and national telecommunication networks. The maximum GTS data rate is currently 64 kilobytes per second (kbps), which is inadequate for the routine transfer of satellite imagery, but regional data are available through direct satellite broadcast.[1] GTS is used mostly for transmitting ground-station data, atmospheric soundings, and weather forecast data products. Current limitations on connectivity and data rates restrict the availability of surface weather data and access to useful forecast information in certain regions, particularly the tropics.

The World Meteorological Congress meets every 4 years to develop and revise its long-term plans. To a lesser extent, WWW also provides a vehicle for assisting developing countries in establishing modern weather forecast services. However, the implementation of WWW plans occurs through the Voluntary Cooperation Programme and depends on the willingness of WMO members and international development organizations to provide technical and financial assistance.

[1] There are some exceptions to this rule. India does not make cloud-cover data available directly from Insat, but it does provide derived cloud-motion wind-vector data to WWW. Eumetsat is developing plans to encrypt Meteosat data, but it will continue to make basic data available on GTS.

SOURCES: World Meteorological Organization, 1994; Office of Technology Assessment, 1994.

benefits to each party. Furthermore, information cooperatives facilitate the development of information services in the private sector, such as Accu-Weather, by reducing the cost of raw data. Finally, the open data exchange that would occur under an international information cooperative is compatible with U.S. government data policies and practices.[38]

Information cooperatives also carry substantial disadvantages, however. Some agencies feel that they are bearing a disproportionate share of the costs of data collection and perceive relatively low benefits from the data they receive in exchange. Others will be tempted to act as free riders, using freely available data without contributing proportionately to the cost of collecting those data. **The greatest potential disadvantage of an information cooperative is that it impedes the emergence of a commercial market for data and of the financial mechanism of data sales that could give data users leverage over the data-collection system.**

Eumetsat has made the strongest objection to the free exchange of data: if Eumetsat makes its data freely available, nonmember countries will have little incentive to join Eumetsat and pay its operating costs. This is why Eumetsat plans to encrypt Meteosat data.[39] In addition, some developing countries have reduced their provision of in situ data from weather stations. The countries argue that the benefit goes mainly to developed countries, so developed countries should pay a greater share of the cost. These circumstances have raised fears for the future of the WWW system.

The possible erosion of the WWW system might not have a great effect on the availability of satellite data to NOAA. As the leading supplier of such data, NOAA would almost certainly retain access to other sources through bilateral exchange agreements. However, the erosion of the WWW system could undermine the exchange of in situ data as well as efforts to improve the collection of high-quality in situ data that are essential for understanding climate change and other aspects of global change. Furthermore, bilateral data exchanges usually entail restrictions on access by third parties, which could undermine the ability of private information services to obtain the data they need.

The International Council of Scientific Unions (ICSU) established an information cooperative that is similar to WWW, the World Data Centres (WDCS) (box 4-4), to support international collaboration in earth and environmental sciences and to archive data gathered during the International Geophysical Year in 1957. These centers, which hold both satellite and nonsatellite data, now constitute a valuable resource for global change research. WDCS are generally national data centers, but not all national data centers are WDCS. The WDC system provides open access to data on the basis of reciprocal data exchange among centers. Because of their desire to recover costs through data sales, however, some countries have reduced their contributions of data to the WDC system.[40]

The model of an information cooperative could also be applied to other areas, such as oceanic and terrestrial monitoring. Programs of the International Oceanography Commission (IOC) could provide the basis for operational exchanges of oceanic data, and programs of the Food and Agriculture Organization (FAO) and the United Nations Environment Programme (UNEP) could provide the basis for exchanging data about the

38 US policy elucidated in Office of Management and Budget Circular A-130, treats information owned by the federal government as being in the public domain and allows agencies to charge those requesting information only the marginal cost of fulfilling user requests.

39 L. Shaffer and M.L. Blazek ("International and Interagency Coordination of NASA's Earth Observing System Data and Information System," ERIM Symposium on Remote Sensing and Global Environmental Change, Graz, Austria, Apr. 4-8, 1993) argue that European countries already have substantial reasons to join Eumetsat, including national prestige and the opportunity to have a say in Eumetsat decisions. This may explain why 17 countries already belong to Eumetsat, although Austria's decision to join is generally attributed to Eumetsat's encryption policy.

40 For example, Canada has stopped providing geomagnetic data to the WDC for geomagnetism in Boulder, Colorado.

BOX 4-4: The ICSU World Data Centres

The International Council of Scientific Unions (ICSU), whose members are national scientific academies and international scientific unions, established the World Data Centre (WDC) system as a way to preserve data collected as part of the International Geophysical Year in 1957 and, more generally, to enhance the sharing of earth science data. WDCs serve as international archives for the preservation and exchange of a variety of earth science data.

As of January 1994, there were 44 WDCs in 11 countries, grouped into five geographic areas.[1] Most WDCs are located in National Data Centres (NDCs) established by host countries for their own purposes. The United States hosts 13 WDCs, operated by NOAA, NASA, the U.S. Geological Survey (USGS), the Department of Energy (DOE), and the Department of Defense (DOD).[2] NASA has proposed designating Distributed Active Archive Centers (DAACs) of the Earth Observing System Data and Information System (EOSDIS)[3] as World Data Centers, with the exception of the Alaska Synthetic Aperture Radar Facility, which holds data only from foreign sources.

The WDCs operate under a set of agreed-upon international principles. These principles call for a WDC to make data available to scientists in any country. A WDC should charge no more than the cost of filling the user's request, and WDCs generally share data among themselves on a reciprocal basis at no charge. A country or institution hosting a WDC agrees to provide the resources needed to operate the center on a long-term basis. Most WDCs are now located in national data centers and serve as liaisons to the international scientific community. In return, taking part in the WDC system makes it easier for these national centers to gain access to international data. Very few NDCs existed when the WDC system was established, and the WDC system played an important role in encouraging their formation. In addition, scientists argue that the open exchange of data provides benefits that far outweigh the costs of maintaining a WDC.

WDCs generally have limited resources and depend on their host institutions for these resources and for the services they provide to data users. This limits their ability to undertake initiatives of their own. They also depend for their data holdings on voluntary submissions, which are becoming less frequent as a result of pressures to reduce costs by selling data commercially. The future of the WDC system may depend on the reemergence of more open exchange of scientific data through such international bodies as the Committee on Earth Observation Satellites and the International Earth Observing System.

[1] These regional groups are designated A, B, C1, C2, and D. WDC-A comprises 13 centers in the United States; WDC-B, four in Russia; WDC-C1, nine in Europe; WDC-C2, eight in Japan and one in India; and WDC-D, established in 1988, comprises nine centers in China.

[2] See S. Ruttenberg, "The ICSU World Data Centers," *EOS Transactions* 73(46):494-495, Nov. 17, 1992.

[3] For further information on EOSDIS, see 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 1944), ch. 3.

SOURCE Off Ice of Technology Assessment 1994

terrestrial environment. However, interest in the operational use of these types of data has been relatively weak and fragmented, so these exchange mechanisms remain largely unexploited for operational purposes.

Alternatively, the Committee on Earth Observations Satellites (CEOS) could provide the basis for a more comprehensive information cooperative involving satellite data of all types. A broad-based information cooperative may be difficult to achieve at a time when many agencies are emphasizing cost recovery and potential commercial applications of satellite data. **Congress may wish to monitor international negotiations that address the challenge of maintaining open access and exchange of data for operational me-**

teorology programs and for global change research.

International Specialization and Division of Labor

Rather than pursue comprehensive remote sensing programs that go far beyond their means, most agencies have little choice but to specialize in one way or another. In some cases, such as NOAA and Eumetsat, this specialization reflects the scope of an agency's missions, but frequently, it reflects deliberate decisions about where to focus limited resources, particularly in relatively new programs. These decisions are based on a variety of factors, including national and regional needs, technological strengths and opportunities, and the potential for commercialization.

For example, ESA'S nonmeteorological remote sensing programs place special emphasis on atmospheric chemistry and the development of SAR technology and applications. Japan has emphasized observations of ocean color and dynamics and of coastal zones. Canada has focused on the application of SAR to monitor snow and ice cover on land and at sea. Even EOS, which the National Aeronautics and Space Administration (NASA) originally planned as a comprehensive system, has been "rescoped" in response to budget constraints in order to focus on observations related to climate change.[41] Although most agencies have activities outside these core areas, the tendency toward specialization is real and significant.

This specialization arose in part through the coordination activities of CEOS and the Earth Observation International Coordination Working Group (EO-ICWG) and, more importantly, in part from the independent choices of independent agencies. Even this informal division of labor allows the participants to receive the benefits of a comprehensive remote sensing system without any one group bearing all the costs. For example, NASA has been able to reduce its costs for EOS based on the commitment of other agencies to perform some of its functions. Specifically, NASA has eliminated or deferred instruments, such as a SAR and HIRIS, based in part on the fact that Europe, Japan, and Canada are flying similar instruments, though these instruments are less capable and less expensive than those NASA would have flown.[42] NASA could also benefit from the coordination of atmospheric chemistry missions between NASA's EOS Chem and ESA'S Envisat.[43] Even with some division of labor, however, the United States may prefer not to rely too heavily on foreign sources of data, especially in technologically promising areas such as SAR and hyperspectral land sensing.[44]

Relying on the current division of labor without formal commitments from foreign agencies carries significant risks. These risks are twofold. First, an agency could eliminate or substantially modify its plans so that it no longer meets U.S. needs. Second, even if the program continues, the data it produces might not be readily available to users in the United States. Although formal agreements can also collapse, they at least provide assurance of an agency intention and make it more difficult politically for that agency to change direction.

Under a formal division of labor, agencies would agree to take on specialized functions not only for their individual benefit but for the collective benefit of all cooperating agencies. This

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41 U.S. Congress, Office of Technology Assessment, *The Future of emote Sensing from Space*, op. cit., app. B.

42 The Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) will fulfill some of the functions of [he canceled HIRIS (High-Resolution Imaging Spectrometer), and the SAR instruments on Europe's ERS-1, ERS-2, and Envisat and Canada's Radarsat will fulfill some of the functions of the canceled EOS SAR.

43 Recommendation of the EOS Payload Advisory Panel Report, Office of Mission to Planet Earth, National Aeronautics and Space Administration, Dec. 17, 1993, p. 11.

44 See the earlier section on international competition.

BOX 4-5: The Earth Observation International Coordination Working Group

The Earth Observation International Coordination Working Group (EO-ICWG) was established to coordinate the remote sensing activities associated with the international space station program. Now independent of the space station program, EO-ICWG aims to coordinate a selected set (table 4-2) of programs of the United States, Europe, Canada, and Japan into an International Earth Observing System (IEOS). The current focus of EO-ICWG is to develop an IEOS Implementation Plan to make the IEOS missions as effective as possible, which includes coordinating payloads, making ground systems interoperable, and harmonizing operations.

EO-ICWG has focused much of its effort on developing a set of IEOS Data Exchange Principles. The current draft of the IEOS Data Exchange Principles states that "all IEOS data will be available for peaceful purposes to all users on a nondiscriminatory basis and in a timely manner" and that data will be available for noncommercial uses at no more than the cost of reproduction. So far, however, Europe is committed to including only one of its planned polar platforms—Envisat-1—in IEOS to be subject to these rules, although other platforms may be incorporated later. ESA has stated its intention to include future systems in IEOS, but Eumetsat has made no commitment regarding METOP.

Unlike CEOS, EO-ICWG deals directly with operational matters. The IEOS Implementation Plan is expected to address a wide range of data issues, including access, formats and standards, archives, networks, catalogs, and user services. Current plans do not yet amount to an IEOS Data and Information System comparable to NASA's EOSDIS, although they represent a major step in that direction.

SOURCES: National Aeronautics and Space Administration, 1994; Office of Technology Assessment, 1994.

would permit each agency to limit the scope of its programs with some confidence that it would not at the same time narrow the range of data it might receive or the applications it might pursue.

A formal division of labor would require a structured mechanism for negotiating and reaching agreement on the roles of individual agencies. EO-ICWG provides an example of how this might work (box 4-5). In its ongoing efforts to coordinate selected agency programs (table 4-2) into an International Earth Observing System (IEOS), EO-ICWG provides a framework that facilitates the implementation of instrument exchanges and joint projects. The mandate of EO-ICWG is quite broad and includes coordinating plans for future remote sensing programs. This broad mandate would allow the formation of a joint planning group responsible for coordinating agency plans.

The option of a formalized division of labor raises two principal issues. First, can one agency rely on others to meet its data requirements? For example, can NOAA rely on ESA, Eumetsat, and

TABLE 4-2: International Earth Observing System Members and Platforms

Country or region	Agencies[a]	Satellites
United States	NASA, NOAA	EOS-AM, EOS-PM, EOS-Chem, EOS-Alt, EOS-Aero, POES
Europe	ESA, Eumetsat	Envisat-1
Japan	NASDA, JEA, JMA, MITI	ADEOS, ADEOS-2
Canada	CSA	Contributor to Envisat-1
Japan, United States	NASA, NASDA	TRMM

[a]NASA - National Aeronautics and Space Administration: NOAA - National Oceanic and Atmospheric Administration, ESA - European Space Agency NASDA National Space Development Agency, CSA = Canadian Space Agency

SOURCE National Aeronautics and Space Adminitration, 1994

Japan's National Space Development Agency (NASDA) for atmospheric and oceanic data? The long history of convergence efforts for NOAA and the Defense Meteorological Satellite Program (DMSP) polar systems shows the difficulties of building confidence even among agencies of the U.S. government.[45] To build that level Of Confidence, a formal division of labor requires a formal process through which the agencies that develop and operate remote sensing systems can address the requirements of those who use the data.

The risks of relying on foreign agencies for remotely sensed data are greatest when the data requirements are the most demanding, particularly in terms of operational timeliness and reliability. Therefore, the challenge of international coordination grows with the transition from research and demonstration to operational monitoring, whether for global change research, weather forecasting, or environmental management.

To meet particularly critical needs, an agency may provide in-kind contributions of instruments or share responsibility for data management. For example, NOAA is contributing imagers and sounders to the European METOP platform. NASA is providing a scatterometer to measure sea-surface winds for the Japanese Advanced Earth Observing Satellite (ADEOS) platform and taking responsibility for processing the data from this instrument. Cash contributions are also possible, but nations usually prefer to make in-kind contributions in order to develop and maintain their own technological capabilities.

The willingness of agencies to continue bearing the costs of maintaining and operating a system they have developed can also be an issue, especially if these costs stand in the way of pursuing new programs. Eumetsat has moved toward a more restrictive data policy in large part to spread its costs more broadly. Under a formal division of labor, it would be clearer what each country received in return for its contributions and there would be a mechanism for addressing the division of costs, but it would be difficult to avoid the tendency for each agency to value its own contributions more highly than what it receives in return. Furthermore, some agencies have relatively narrow charters and would not benefit from the data they receive from others. For example, Eumetsat might not be willing to make data from METOP freely available to Japan in return for ocean data from ADEOS, which would have relatively little value to Eumetsat's meteorological mission.

Finally, a division of labor might spread the burden too narrowly among the participating agencies, and the pressure would remain to spread the burden more broadly by restricting data access and charging others for the use of data.

International Remote Sensing Agency

Over the years, several authors have proposed establishing an international satellite remote sensing agency or consortium.[46] These proposals generally envision an organization that is broad-based both in the international scope of its membership and in the functional scope of its observations and their application. It would collect contributions from national governments and, in turn, make data and information available to those governments. This section considers the assumptions that underlie these proposals and summarizes some alternative approaches.

Many proposals cite the International Telecommunications Satellite Corporation (Intelsat) as a model for an international satellite monitoring consortium. Intel sat provides a mechanism for national telecommunications services to combine resources to pay for satellites that provide international telecommunications links. National ser-

[45] See chapter 3 for a discussion of convergence.

[46] J.H. McElroy, '. INTELSAT, INMARSAT, and CEOS: Is ENVIROSAT Next?" In *Space Monitoring of Global Change,* G. MacDonald 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,*

vices receive access to these links in proportion to their investment in Intelsat. The International Maritime Satellite Organization (Inmarsat) plays a similar role for mobile and maritime communications.

The Intel sat model may not be directly applicable to remote sensing because of the nature of the service Intelsat provides. It is much more difficult for remote sensing than for telecommunications services to distribute the benefits of a satellite system in proportion to contributions. Weather forecasting and global change research provide information as a public good. Furthermore, investors in Intelsat recoup their costs by charging users for the telecommunications service they provide.

Other organizations created for international cooperation in the noncommercial applications of space technology, such as the European organizations ESA and Eumetsat (box 4-6), may provide more appropriate models than Intelsat for an international remote sensing organization. Further experience with interagency cooperation through the Integrated Program Office, planned as part of the convergence of the Polar-orbiting Operational Environmental Satellite (POES) and DMSP systems, may also provide important lessons for structuring such an organization.

In general, an international remote sensing organization requires a closer, more formal cooperative structure that could increase both the benefits and the risks of cooperation. Compared with an information cooperative or a formal division of labor, an international organization offers a greater ability to share costs broadly and equitably[47] and a more formal method for meeting international requirements. It could also lead to the most cumbersome administrative arrangements. An international agency also requires the greatest degree of trust among its participants.

The effectiveness of an international monitoring agency will depend on how it deals with several issues:

- ***How much does each member contribute?*** For example, members of Eumetsat contribute a percentage of their gross domestic product (GDP). Members of ESA contribute to so-called mandatory programs (mostly operations and overhead) on a percentage-of-GDP basis and to other programs on a voluntary basis.
- ***What are the procedures for making decisions?*** ESA and Eumetsat generally require consensus among member agencies. which often impedes decisionmaking. In contrast, Intelsat makes decisions like a corporation, on the basis of a majority of share ownership. The decisionmaking process is particularly important in establishing system requirements and matching those requirements to available resources.
- ***What are the policies on data access, for member and nonmember governments as well as for private organizations?*** To create incentives for membership, ESA and Eumetsat give preferential access—providing data at reduced cost, in a more timely manner, or in a more complete form-to member governments.
- ***What should the agency buy-satellite systems or data-and from whom?*** Under its "juste retour" policy, ESA spends contract money in a member country in proportion to that country's voluntary contribution to ESA. This policy has been criticized as cumbersome and inefficient, but it aims to provide technological and economic benefits in proportion to national contributions. Intelsat and Eumetsat have no such policies. For now, the absence of rules on procurement sources would benefit U.S. aerospace firms, which hold the technological lead in many areas. But in the long run, this approach might not guarantee a continuing role for U.S. companies in providing the systems they currently produce.
- How ***comprehensive should the agency's mission be?*** Eumetsat focuses on weather and c1i-

47 In principle, such an organization could lead to an unfair distribution of costs. However, it is unlikely to impose a greater relative burden than current arrangements do on the United States.

BOX 4-6: Eumetsat

The European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) grew out of satellite programs of the European Space Agency (ESA) and its predecessor, the European Space Research Organisation (ESRO). ESA launched the first two experimental geosynchronous satellites in the Meteosat series in 1977 and 1981. The national weather services of Europe established Eumetsat in 1986 to continue this program, and Eumetsat is now responsible for the Meteosat Operational Programme (MOP). Eumetsat has since grown to 17 members and has taken on an increasingly important role in data transmission, data processing, and nonsatellite observations.[1] Eumetsat is also developing the polar platform METOP for launch in the year 2000 and is negotiating with ESA and the National Oceanic and Atmospheric Administration (NOAA) over the provision of instruments for this satellite and over participation in a converged polar satellite system with the United States.

Eumetsat headquarters are in Darmstadt, Germany, which also hosts ESA's European Space Operations Centre (ESOC). Many of the ground-segment functions of Eumetsat are currently performed at ESOC, including satellite operations and control, data downlinks, data processing, and data archiving, but Eumetsat is building its own operations center in Darmstadt and plans to take over satellite and data operations in 1995. Raw Meteosat data are preprocessed for radiometric calibration, geographic referencing, and quality control before being distributed by satellite relay through Meteosat. These data are available in full digital form to Primary Data User Stations (PDUS) and in reduced analog form to Secondary Data User Systems (SDUS). As of 1990, there were 119 PDUS in 25 countries and 1,127 SDUS in more than 75 countries, mostly in Europe and Africa.

Eumetsat also collects data from other sources, including satellite data from the U.S. GOES-East[2] and polar NOAA satellites and in situ data from Eumetsat's Data Collection System. This system consists of an array of automated data-collection platforms on land, at sea, and on board commercial aircraft, which relay data to ground stations through Meteosat transponders.

Eumetsat maintains a complete digital archive of Meteosat images at ESOC, dating back to the first Meteosat data collected in 1979. Currently, responsibility for these archives is transferred to ESA after 5 months, but Eumetsat intends to take over permanent responsibility for these archives when it assumes responsibility for Meteosat operations.

[1] See the Eumetsat brochure *EUMETSAT: The European Organisation for Meteorological Satellites* (Darmstadt, Germany: Eumetsat, 1992). As of December 1993, the members of Eumetsat were Austria, Belgium, Britain, Denmark, Finland, France, Germany, Greece, Ireland, Italy, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and Turkey.

[2] When a launch failure and delays in the GOES-Next program left the United States with a single operational geosynchronous meteorological satellite, Eumetsat reactivated Meteosat 3 in 1991 and made it available to the United States in place of GOES-East.

SOURCES: Eumetsat, 1994; Office of Technology Assessment, 1994.

mate observations, for example, but most proposals envision a comprehensive agency that encompasses all aspects of operational remote sensing. A comprehensive international agency offers several advantages. Because of (he synergies between different types of measurements and because measurements often serve multiple purposes, it makes sense to consider the requirements of multiple applications simultaneously.[48] Defining a program too nar-

~ See chapter 2. NASA originally planned to make EOS a comprehensive system but has since narrowed the intended scope of EOS to focus on climate. EOS is meant to be a research program rather than an operational one, although some of its elements may lead to long-term operations.

rowly may make it more difficult to pursue applications that have been left out, and it may ultimately be simpler to administer a single international program under a single set of procedures than to allow special-purpose organizations to proliferate.

But a comprehensive international agency also carries significant drawbacks that limit its feasibility for the near term. By maximizing the scope of the proposed agency, one also maximizes the disadvantages that come with cooperation: administrative complexity and loss of autonomy. Furthermore, some of the participating national agencies have more restricted missions and would not be willing to take part in an international organization with a broader scope.

Options for a More Specialized International Remote Sensing Agency

A narrowly focused international remote sensing agency could concentrate its cooperative efforts on those areas where cooperation may offer greater benefits, with less risk of disrupting existing national programs. Over time, such an agency could broaden its mandate if member governments saw an advantage in doing so.

The main drawback of embarking on a more focused mission is that it could fail to take advantage of the synergies between various remote sensing missions and capabilities. For example, an ocean monitoring agency might not give adequate weight to monitoring ocean processes that affect the climate system. However, in the context of currently emerging mechanisms to address these issues in other ways, this drawback may not be critical. The following are several possible international agencies with more limited scope:

- ***An international weather satellite agency.*** Like NOAA's satellite programs, this kind of agency could include both polar and geostationary satellites. The polar satellite component might grow out of a future converged U.S.-European system based on POES, DMSP, and METOP. Because these satellites cover the entire planet, however, the agency that supports them might seek a broad global membership incorporating systems from Russia, Japan, and, possibly, China, although this might make it difficult or impossible to exercise control over data for national security purposes. The funding formula and benefits of participation could be designed to encourage the broadest possible membership and to discourage free riders. and the administrative procedures would have to be relatively simple. For example, the international agency might simply contract with the United States, Europe, or Russia to provide polar satellite services. much like the way Inmarsat, early in its operation, built on preexisting capabilities, leasing communications channels from satellite operators.

  Geostationary satellites have a more limited scope and, therefore, present slightly different issues. Rather than contributing to a worldwide agency, members might contribute to regional agencies centered on the current U. S., European, and Japanese programs. The central Asian region presents a problem because India has not allowed access to its data, and Russia and China have encountered problems in deploying satellites of their own.[49] An interregional coordinating body could establish minimum agreed standards for these satellites and simplify data exchange across regions.

- ***An international climate monitoring agency.*** Climate monitoring depends on much of the same information as weather forecasting but requires more precise meteorological measurements as well as a broader range of in format ion. For example, satellite measurements must be validated by comparison with well-calibrated in situ measurements from around the world. Climate depends on a range of ocean and land processes, so climate monitoring requires ob-

[49] The Russian Geostationary Operational Meteorological Satellite (GOMS) has reportedly been ready for launch since 1992 and may be awaiting foreign funding. The Chinese FY-2 satellite, scheduled for launch in April 1994, was destroyed during ground testing.

servation of these processes as well. Climate also depends on information about atmospheric chemistry—the concentration of aerosols and greenhouse gases—which is not essential for most other applications of remote sensing.[50]

A climate monitoring agency, which might evolve from the proposed Global Climate Observing System, could function in several ways. It could operate satellites to collect only those data unique to climate studies, such as atmospheric chemistry measurements, while maintaining archives of high-quality meteorological data and related land and ocean data obtained from other sources. This would require the cooperation of other agencies or programs, which would collect those data. Alternatively, climate monitoring could be carried out by a weather forecasting agency; Eumetsat is considering expanding its mandate to include climate monitoring. Given the broad national commitments to climate research and the scope of international cooperation in global change research, however, such an agency may not be needed.

- ***An international ocean satellite agency.*** This differs from the weather satellite case in that no operational systems now exist, except as adjuncts to meteorological systems. An international agency could facilitate the establishment of an operational program by aggregating resources from the various interested agencies. Because proposed requirements led to high costs, the United States has been unable to make a commitment to an ocean observing satellite system, but U.S. participation in an international system should be more affordable.[51] Like an international weather satellite agency, however, an international ocean satellite agency would make it more difficult to control data for national security purposes.

  An ocean monitoring agency poses some unique problems. One is how to determine national contributions. An island nation such as Japan is naturally more interested in oceanic information than is a landlocked country such as Austria, although both could be concerned about the influence of oceans on climate. This suggests that a division of labor based on varying degrees of' interest may be more appropriate than an international agency. However, the formation of an international agency could sidestep the potential problems of direct cooperation between Japan and the U.S. Navy, given Japan's policy to support only nonmilitary applications of remote sensing.
- ***An international land remote sensing agency.*** Internationally as well as nationally, the problem of aggregating demand is particularly acute for terrestrial monitoring, which involves a variety of national and local government agencies having overlapping but often quite different requirements (see chapter 3). Harmonizing these requirements into a mutually agreed to and affordable basic set presents a considerable challenge. Terrestrial monitoring also faces the greatest overlap between public and private-sector interests,[52] as well as civilian and military interests. An international agency could also stifle the development of commercial ventures in land remote sensing.
- ***An international data-purchase consortium.*** Instead of organizing resources to develop and operate satellite systems, any international remote sensing agency could accomplish its mission—whether narrow or comprehensive—through the purchase of data from commercial

50 other satellite instruments can also provide important climate information. These include the Earth Radiation Budget Experiment (ERBE), which measures the balance between incoming solar and outgoing thermal radiation from Earth, and the Active Cavity Radiometer Irradiance Monitor (ACRIM), which measures the total energy flux from the sun.

51 For a discussion of U.S. options for ocean monitoring, see chapter 1.

52 The public sector tends t. be more interested in Landsat-type imagery (high spectral resolution, moderate spatial resolution) while the private sector may be more interested in high-spatial-resolution imagery prov ided by SPOT and other proposed commercial ventures, but there is no clear line of demarcation between the two.

suppliers. NASA is testing this relatively novel arrangement with its purchase of data from the Sea-Viewing Wide Field Sensor (SeaWiFS) (chapter 3). A data-purchase consortium would then operate a data-management, -processing, and -distribution system to serve its members, but its greatest challenge could be to aggregate and coordinate its members' data requirements and to match the needs of its members with the available resources. The principal advantage of this type of agency is that it would stimulate international private-sector activity by demonstrating a guaranteed demand for the data in question, rather than competing with and potentially crowding out private-sector activities. A data-purchase consortium would raise the question of data access by third parties, that is, nonmember governments and private companies or individuals.

Any of these proposed organizations could function independently, with varying degrees of cooperation with other programs. They could also provide manageable steps on the road toward a more comprehensive international remote sensing agency.

International Convergence Processes

All of these cooperative arrangements-an information cooperative, a formal division of labor, or an international agency—face several common challenges. In each case, decisionmakers must consider the tradeoff between the perceived advantages of cooperation—increased effectiveness and reduced costs—and the drawbacks—reduced autonomy and the risks of relying on others.

These approaches to international cooperation also provide alternative methods of dealing with the tradeoff between maintaining a manageable organizational structure and ensuring a fair allocation of the burden of paying for it. An information cooperative requires the least formal structure but allows for the greatest inequity in sharing costs. A formal international division of labor could reduce but not eliminate these perceived inequities and could restore the attractiveness of open information sharing. An international agency would formalize the distribution of costs but would require careful design to avoid becoming excessively bureaucratic.

Over the years, international cooperation in remote sensing has steadily expanded. Initially, the open sharing of meteorological and other environmental data from U.S. satellites strengthened the WWW information cooperative. The entry of other countries with more restrictive data policies threatens to undermine this tradition, but it could also lead to a more equal partnership based on an international division of labor. Such a partnership offers substantial improvements in cost-effectiveness, providing the participants can accept a relatively open exchange of data.

An international agency seems unlikely under current international conditions, but the growth of mutual trust that could emerge from intermediate stages of cooperation might make it seem feasible or even inevitable in the future. Because remote sensing systems and programs take decades to develop and mature and because some setbacks and disagreements are inevitable, cooperative relationships will probably evolve through gradual, measured steps.

Intergovernmental cooperation stands in contrast to the alternative of relying on the private sector for data and allowing individual agencies to fend for themselves in the private-data market. In principle, these markets should provide an efficient system of sharing costs without a cumbersome organizational structure. As discussed previously, however, private markets for remote sensing take time to develop and mature and have not yet demonstrated that they are economically viable. Furthermore, reliance on private markets can discourage investments in remote sensing as a public good.

Cooperation with Russia

The United States and Europe have sought to expand technological cooperation with Russia, for both practical and political reasons. This cooperation is a symbol of Russia's reintegration into the international community[53] and provides financial support to maintain the Russian economy and Russia's skills in science and technology. But Russia's future, including the stability of its political relationships and its ability to maintain an ambitious space program, remains uncertain. This situation increases the risk of relying on Russia for important remote sensing needs and imposes limits on the scope of current cooperative efforts.

In 1993, Vice President Gore and Russian Prime Minister Chernomyrdin signed several agreements on U.S.-Russian cooperation in space activities. Although these agreements emphasized Russian participation in an international space station, they also included agreements to expand cooperation in earth science and remote sensing.[54] Russia has a long history and important capabilities in civilian remote sensing.

Building on past cooperative efforts, these agreements include several possible projects:

- Strengthening Russia's data-management capabilities.
- Encouraging Russian participation in international projects of global change research.
- **Arranging future flights of U.S. TOMS and Stratospheric Aerosol and Gas Experiment (SAGE) instruments on future Russian spacecraft.**[55]

Congress may wish to explore ways for Russia to contribute to improving the robustness of existing operational satellite programs. For example, Russia's Meteor satellites could provide valuable backup capability for a converged U.S. and European satellite system. Similarly, Russia's RESURS-O satellites could help fill in possible gaps in the U.S. Landsat system.

These projects could provide the basis for Russia's gradual integration into international cooperative programs in remote sensing. But this integration must overcome major obstacles and withstand the test of time. Expanding cooperation with Russia on remote sensing depends on steadily growing mutual confidence in Russia's political relationships and its ability to maintain its programs through difficult economic limes.

53 U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., box 5-1.

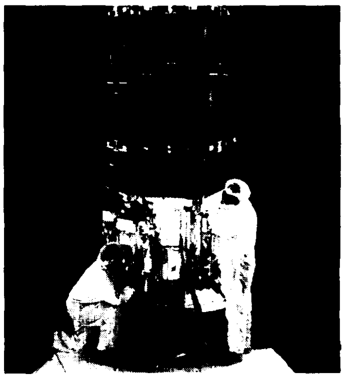
54 White *House Plan for Russian-American Cooperative Programs in Earth Science and Environmental Monitoring from Space*, *op. cit.*

55 The United States and Russia have agreed in principle that a TOMS instrument will fly on a future Meteor satellite, and negotiations fOr the placement of a SAGE instrument are under way.

Appendix A: NASA's Mission to Planet Earth

A

NASA established its Mission to Planet Earth (MTPE) in the late 1980s as part of its program in earth sciences. MTPE includes the Earth Observing System (EOS), which would consist of a series of satellites capable of making comprehensive Earth observations from space; a series of Earth Probe satellites for shorter, focused studies: and a complex data-archiving and -distribution system called the Earth Observing System Data and Information system (EOSDIS). In the near term, MTPE research scientists will rely on data gathered by other earth sciences satellites, such as the Upper Atmosphere Research Satellite (UARS), the U.S.-French TOPEX/Poseidon,[1] Landsat, and NOAA's environmental satellites. Data from the EOS sensors may provide information that will reduce many of the scientific uncertainties cited by the Intergovernmental Panel on Climate Change (IPCC)--climate and hydrologic systems, biogeochemical-dynamics, and ecological systems and dynamics.[2] NASA designed EOS to provide calibrated data sets, acquired over at least 15 years,[3] of environmental processes occurring in the oceans, the atmosphere, and over land.



[1] This U.S.-French cooperative satellite was successfully launched into orbit August 10, 1992, aboard an Ariane 4 rocket.

[2] The U.S. Global Change Research Program, *Our Changing Planet: The FY 1991 Research Plan*, a report by the Committee on Earth and Environmental Sciences, October 1990.

[3] NASA has proposed t. build and launch two sets of three satellites. The first set (called the AM satellite because it will follow a polar orbit and cross the equator every morning) would be launched in 1998, 2003, and 2008. The second set (called the PM satellite) would be launched in 2(X)0. 2005, and 2010.

EOS is the centerpiece of NASA's contribution to the Global Change Research Program. Managed by NASA's newly created Mission to Planet Earth Office,[4] EOS is to be a multiphase program that would last about two decades. The original EOS plan called for NASA to build a total of six large polar-orbiting satellites, which would fly two at a time in 5-year intervals over a 15-year period. In 1991, funding constraints and concerns over technical and budgetary risk[5] narrowed EOS'S scope.

The core of the restructured EOS consists of three copies each of two satellites (smaller than those originally proposed and capable of being launched by an Atlas II-AS booster), which would observe and measure events and chemical concentrations associated with environmental and climate change. NASA plans to place these satellites, known as the EOS-AM satellite (which would cross the equator in the morning while on its ascending, or northward, path) and the EOS-PM satellite (an afternoon equatorial crossing), in polar orbits. The three AM satellites would carry an array of sensors designed to study clouds, aerosols, Earth's energy balance, and surface processes. The PM satellites would take measurements of clouds, precipitation, energy balance, snow, and sea ice.

NASA plans to launch several "Phase I" satellites in the early and mid- 1990s that would provide observations of specific phenomena. Most of these satellites pre-date the EOS program and are funded separately. UARS, which has already provided measurements of high levels of ozone-destroying chlorine oxide above North America, is an example of an EOS Phase I instrument. NASA's EOS plans also include three smaller satellites (Chemistry, Altimeter, and Aero) that would observe specific aspects of atmospheric chemistry, ocean topography, and tropospheric winds. In addition, NASA plans to include data from its Earth Probes and from additional copies of sensors that monitor ozone and ocean productivity in EOSDIS.

NASA will develop EOSDIS[6] so that the system can store and distribute data to many users simultaneously. This is a key feature of the EOS program. According to NASA, data from the EOS satellites would be available to a wide network of users at minimal cost to researchers through EOS-1>1S. NASA plans to make EOSDIS a user-friendly, high-capacity, flexible data system that will provide multiple users with timely data and that will facilitate the data-archiving process critical to global change research. EOSDIS will require substantial amounts of memory and processing. as well as extremely fast communications capabilities.

4 Created in March 1993 when the Office of Space Science and Applications was split into the Office of Mission to Planet Earth, the Office of Planetary Science and Astrophysics, and the Office of Life Sciences.

5 National Research Council, "Report of the Earth observing System (EOS) Engineering Review Committee," September 1991.

6 Hughes Information Technology won the contract to develop the EOSDIS Core System in 1992.

Appendix B: Survey of National and International Programs

B

The level of international activity in remote sensing has grown steadily since the first TIROS weather satellite in 1960. The extent of cooperation among these agency programs has grown in tandem with the **increasing number** of national and regional agencies[1] that have undertaken remote sensing programs. Nations pursue remote sensing programs for both their direct utility and the technological development they stimulate. Remote sensing. therefore, also involves an element of international competition for technological advantage in national security, national prestige, and commercial markets for remote sensing systems and data.

NATIONAL AND REGIONAL PROGRAMS AND PLANS

This section focuses on the remote sensing programs of non-U.S. agencies (tables B-1 and B-2)[2]; see chapter 3 for descriptions of the main U.S. programs. Figure B-1 summarizes the existing and proposed U.S. and non-U.S. remote sensing systems.

Europe. The French space agency, CNES (Centre National d'Études Spatiales), has the largest national remote sensing program in Europe. CNES was the first European agency to develop and deploy a remote sensing system, the commercially operated

[1] Here OTA is using the term *agency* to refer both to national agencies such as NASA and NOAA and to regional organizations such as the European Space Agency and Eumetsat.

[2] For more details, see U.S. Congress. Office of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications*, OTA-ISC-588 (Washington, DC: U.S. Government Printing Office, July 1993).

TABLE B-1: Operational U.S. and Foreign Remote Sensing Platforms

Platform	Country	Year	Function[a]
Landsat 4	United States	1982	Land remote sensing
Landsat 5	United States	1984	Land remote sensing
NOAA-1 1	United States	1988	Meteorology (polar)
NOAA-1 2	United States	1991	Meteorology (polar)
GOES-7	United States	1987	Meteorology (GEO)
GOES-8	United States	1994	Meteorology (GEO)
UARS	United States	1991	Atmospheric chemistry
SPOT 1	France	1986	Land remote sensing
SPOT 2	France	1990	Land remote sensing
SPOT 3	France	1993	Land remote sensing
Meteosat 3	Europe	1988	Meteorology (GEO)
Meteosat 4	Europe	1989	Meteorology (GEO)
Meteosat 5	Europe	1991	Meteorology (GEO)
Meteosat 6	Europe	1993	Meteorology (GEO)
ERS-1	Europe	1991	SAR and ocean dynamics
TOPEX/Poseidon	United States/France	1992	Ocean dynamics
GMS-4	Japan	1989	Meteorology (GEO)
MOS-1b	Japan	1990	Land and ocean color
JERS-1	Japan	1992	SAR and land remote sensing
IRS la	India	1988	Land remote sensing
IRS 1 b	India	1991	Land remote sensing
INSAT IIa	India	1992	Meteorology (GEO) and telecommunications
INSAT IIb	India	1993	Meteorology (GEO) and telecommunications
Meteor 2	Russia	1975 (series)	Meteorology (polar)
Meteor 3	Russia	1984 (series)	Meteorology (polar)
Okean-0	Russia	1986 (series)	Ocean
Resurs-0	Russia	1985 (series)	Land

[a] GEO = geostationary Earth orbit, SAR = synthetic aperture radar

SOURCE: *Committee on* Earth Observation Satellites (CEOS) 1993 Dossier--Volume A, 1993

SPOT (Systeme Pour l'Observation de la Terre) satellite system.[3] France is also developing the Helios reconnaissance satellite, which may have civil as well as military applications. Germany, Italy, and the United Kingdom also have substantial remote sensing programs.

A large portion of Europe's remote sensing activities take place through the European Space Agency (ESA) and the European Organisation for the Exploitation of Meteorological Satellites (Eumetsat; box 4-6). ESA currently operates ERS- 1 and is preparing ERS-2 for launch in early 1995. These are part of an ambitious long-term plan that includes Envisat-1, now under development for launch in 1998, and as yet unspecified future systems. Eumetsat operates the geosynchronous Meteosat weather satellite system and is developing the polar platform METOP-1 for launch in 2000

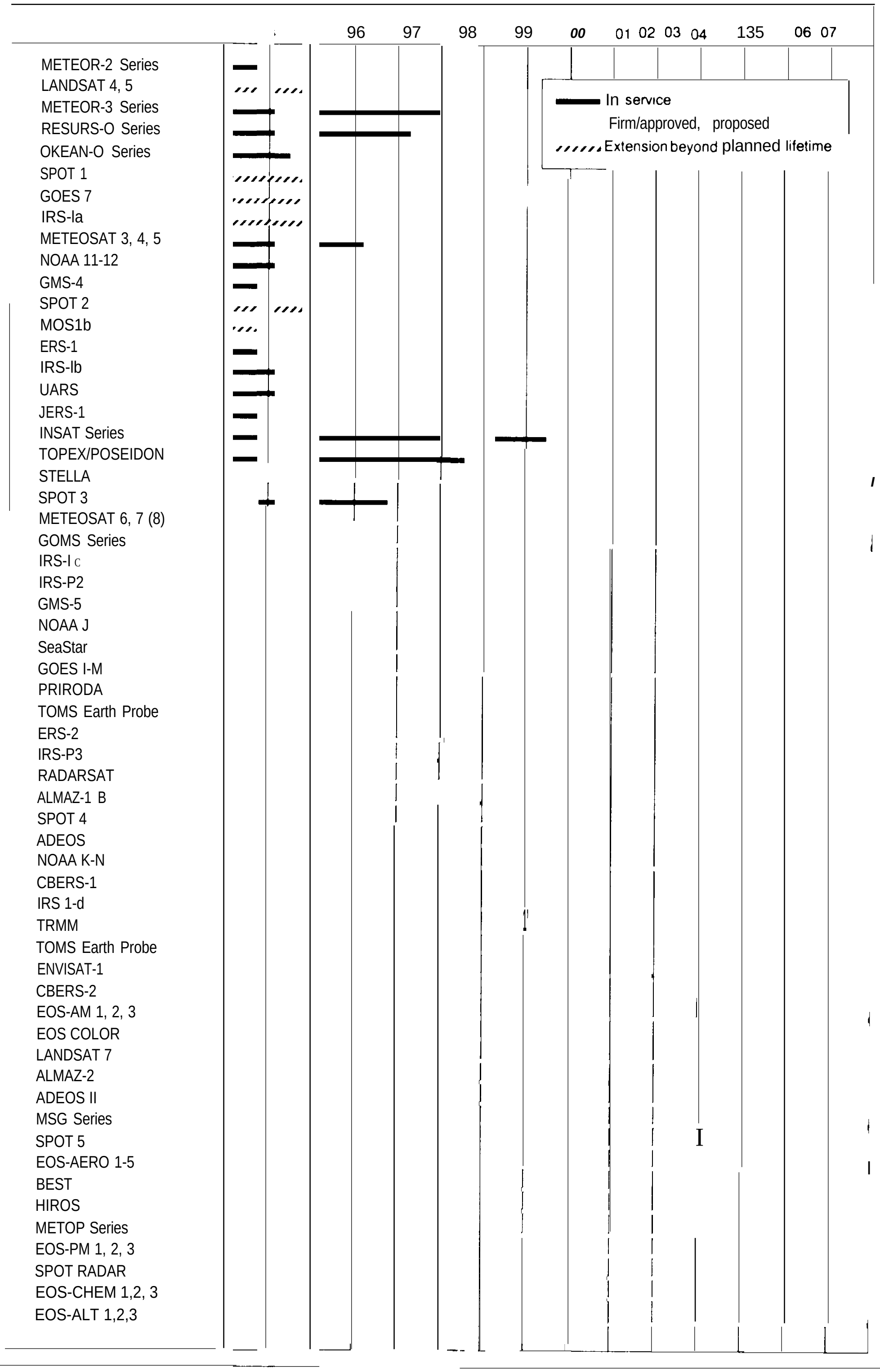
3 Although SPOT is operated Commercially through SPOT Image, it continues to receive subsidies from CNES, which pays the costs of developing, procuring, and launching new satellites and owns a 40 percent share of SPOT Image.

TABLE B-2: Planned U.S. and Foreign Remote Sensing Platforms

Platform	Country	Year	Function[a]
NOAA-J	United States	1-994 '--	Meteorology (polar)
NOAA-K	United States	1996	Meteorology (polar)
NOAA-L	United States	1997	Meteorology (polar)
NOAA-M	United States	1999	Meteorology (polar)
NOAA-N	United States	2000	Meteorology (polar)
GOES-J	United States	1995	Meteorology (GEO)
GOES-K	United States	1999	Meteorology (GEO)
GOES-L	United States	2000	Meteorology (GEO)
TOMS Earth Probe	United States	1995	Atmospheric chemistry
EOS AM-1	United States	1998	Climate, atmospheric chemistry, ocean color, land remote sensing
EOS PM-1	United States	2000	Climate and meteorology
EOS Aero-1	United States	2000	Atmospheric chemistry and aerosols
EOS CHEM	United States	2002	Atmospheric chemistry, solar ultraviolet, trace gases, ozone
EOS Color	United States	1998	Ocean color
Landsat 7	United States	1998	Land remote sensing
SeaStar	United States	1995	Ocean color
WorldView	United States/ Commercial	1994	High-resolution land remote sensing
TRMM	United States/ Japan	1997	Climate and tropical precipitation
Meteosat 7	Europe	1995	Meteorology (GEO)
Meteosat 8	Europe	2000	Meteorology (GEO)
METOP	Europe	2000	Meteorology (polar)
SPOT 4	France	1996	Land remote sensing
ERS-2	Europe	1994-95	SAR, ocean dynamics, atmospheric chemistry
Envisat- 1	Europe	1998	SAR, atmospheric chemistry, ocean dynamics and color
Radarsat	Canada	1995	SAR
GMS-5	Japan	1994	Meteorology (GEO)
ADEOS	Japan	1996	Oceans, climate, and atmospheric chemistry
GOMS	Russia	1994	Meteorology (GEO)
Almaz-1B	Russia	1996	SAR
Almaz-2	Russia	1999	SAR
IRS-1 *c*	India	1994	Land remote sensing
IRA-1 d	India	1996	Land remote sensing
MECB SSR-1	Brazil	1996	Land remote sensing (vegetation)
MECB SSR-2	Brazil	1997	Land remote sensing (vegetation)

[a] GEO= geostationary Earth orbit SAR = synthetic aperture radar

SOURCE *Committee on Earth Observayion Satellites (CEOS)* 1993 Dossier—Vohxne *A, 1993*



SOURCE Committee on Earth Observations Satellites, 1993

TABLE B-3: METOP-1 Instruments and Sources

Instrument	Agency or government[a]
AATSR-Advanced A-long-Track Scanning Radiometer	U. K., Australia
AMSU-A—Advanced Microwave Sounding Unit	N O M
ASCAT—Advanced Scatterometer	ESA
AVHRR/3—Advanced Very High Resolution Radiometer	N O M
GOMI—Global Ozone Monitoring Instrument	ESA
HIRS/3—High Resolution Infrared Sounder	N O M
IAS1—infrared Atmospheric Sounding Interferometer	CNES/ASI
MHS—Microwave Humidity Sounder	Eumetsat
MIMR—Multifrequency Imaging Microwave Radiometer	ESA
ScaRaB—Scanner for Earth's Radiation Budget	CNES/DARA
SEM—Space Environment Monitor	N O M

[a] NOAA = National Oceanic and Atmospheric Administration, ESA = European Space Agency, CNES/ASI = Centre National d'Études Spatiales/Agenza Spaziale Italiana, CNES/DARA = CNES/Deutsche Agentur fur Raumfahrtsangelegenhelit.

SOURCE *Committee on Earth Observation Satetellites (CEOS) 1993 Dossier—Vo/ume A, 1993*

(table B-3). The European Union is also involved in remote sensing applications and data management.

Japan. Japan launched its remote sensing programs with the Geosynchronous Meteorological Satellite (GMS) series, which began in 1977. Since then, Japan has concentrated on ocean remote sensing, with the infrared and ocean-color sensors on the Marine Observation Satellites (MOS-1) and the imaging radar on the Japan Earth Resources Satellite (JERS-1).[4] Japan's remote sensing plans include the Advanced Earth Observation Satellite (ADEOS), with an international suite of instruments for observing the oceans, atmospheric chemistry, and land surface, and the joint Tropical Rainfall Measurement Mission (TRMM) with NASA.

Canada. Canada has contributed search-and-rescue instruments to NOAA polar satellites and plans to deploy Radarsat, its first remote sensing satellite, in 1995. Radarsat will provide synthetic aperture radar (SAR) data for operational purposes—mainly for monitoring sea ice cover—and for research. The Canadian Space Agency hopes to recover some of its operational costs through commercial data sales to foreign governments, although the United States will receive free access to Radarsat data in exchange for providing launch services.

Russia. Russia continues several series of satellites inherited from the Soviet Union for observing weather, oceans, and land. This includes the Meteor-2 and Meteor-3 series of polar weather satellites, the Okean-O series of low-resolution ocean observing satellites, and the Resurs-F and Resurs-O series of moderate-resolution land remote sensing satellites. These series have been quite stable, although the satellites often have short lives or use old technologies. Russia has also deployed the Almaz-1 radar satellite and is preparing a follow-on Almaz-1b. Since 1992, Russia has listed its first Geosynchronous Operational Meteorological Satellite (GOMS) as ready for launch, but funds for this launch have not been forthcoming.

Russian enterprises have attempted to sell data from the Resurs-F and Resurs-O series and from Almaz-1 but have had difficulty meeting commercial demand for timeliness and reliability. Russia has also begun offering 2-m resolution land imag-

4 JERS-1 encountered problems with its antenna and power systems and produces low-quality data.

ery from intelligence satellites and is reportedly considering offering still higher-resolution imagery.[5]

India. India has the most active remote sensing program among developing countries. Telecommunications satellites in the Insat series carry a Very High Resolution Radiometer (VHRR) for cloud cover and infrared images. The Indian Remote Sensing (IRS) satellite series, similar to Landsat but with lower resolution and fewer bands, is part of India's commitment to technological self-sufficiency. Except for wind data derived from Insat, these data have not been available outside India, but the Indian Space Research Organization (ISRO) recently signed an agreement with the U.S. firm EOSAT to market IRS imagery outside India.[6]

China. China has deployed the FY-1 (Feng Yun—''Wind and Cloud") series of experimental polar weather satellites and has developed a geosynchronous weather satellite (FY-2) as well, but neither has been very successful.[7] In 1988, China and Brazil signed an agreement to develop two China-Brazil Earth Resources Satellites (CBERS-1 and 2) for observing land and vegetation, but no firm plans have yet emerged.

Brazil. In addition to working with China on CBERS-1 and 2, Brazil has deployed a data-relay satellite for collecting environmental data from remote ground stations and is developing a follow-on satellite with a camera for vegetation monitoring.

South Africa. South Africa is developing the lightweight Greensat for commercial sale, with both civilian and military applications.

Ground Segment. Many countries are active in the applications of remote sensing through the operation of ground stations for collecting and processing satellite data from Landsat, SPOT, ERS-1, and JERS-1. Hundreds of ground stations around the world receive data of various kinds from polar and geostationary meteorological satellites.

JOINT SATELLITE PROJECTS

Joint satellite projects are a growing form of international cooperation in remote sensing. Typically, these projects involve one agency providing instruments for a satellite being developed by another agency. Joint satellite projects have paved the way for many countries to enter the field of remote sensing through relatively modest initial steps, which, over the years, has led to more equal international partnerships. Other forms of partnership include providing launch services and cooperating on data management. The partnerships also require coordination in such areas as export controls, the operation of satellite ground stations, and the exchange of data.

NOAA Polar Series. Canada, France, and Britain have contributed instruments to NOAA polar satellites for search and rescue, data relay, and stratospheric temperature soundings.

TOMS. The Total Ozone Mapping Spectrometer was developed by NASA and has flown on a variety of platforms, including the Russian Meteor 3 series. It will also fly on the planned Japanese ADEOS satellite and a future Meteor 3. The negotiations for placing the first TOMS on Meteor were complicated by export restrictions on radiation-resistant electronics included in TOMS.

TOPEX/Poseidon. This joint mission between NASA and CNES provides accurate measurements of ocean topography and, indirectly, ocean current. NASA and CNES provided instruments and NASA built, assembled, and operates the spacecraft, which was launched by a French Ariane rocket.

TRMM. Japan's National Space Development Agency (NASDA) is providing a Precipitation Radar for NASA's Tropical Rainfall Measurement Mission.

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5 B. Iannotta, "Russia Expected To Raise Ante in Satellite Image Market," *Space News*, Apr. 18-24, 1994, p. 18.

6 EOSAT press release, Feb. 28, 1994.

7 China's polar satellites all failed within a few months of launch, and its first geosynchronous satellite was destroyed during ground testing.

ADEOS. In addition to NASA's TOMS instrument. the Japanese ADEOS will carry a NASA scatterometer and the POLDER instrument provided by CNES to measure greenhouse gases and acrosols.

ASTER. The Japanese Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER). a moderate-resolution land imager, will fly on EOS AM-1.

METOP. Eumetsat plans for METOP grew out of international discussions on sharing the cost burden of polar weather satellites. Because of the need to coordinate with NOAA and because of Eumetsat's relative inexperience in satellite development, METOP will be the most heavily international remote sensing satellite in history, with instruments provided by eight separate national and European agencies (table B-3). Plans for cooperation depend on future agreements between NOAA and Eumetsat about data-access policy and encryption.[8]

INTERGOVERNMENTAL ORGANIZATIONS

Several organizations have arisen to promote cooperation between government agencies in remote sensing. Some of these organizations address remote sensing comprehensively, while others deal with specific applications of remote sensing. Though they operate with varying degrees of formality, they all offer mechanisms for voluntary cooperation among the national and regional member agencies.[9]

CEOS. The Committee on Earth Observation Satellites (box B-1: figure B-2) grew out of a 1984 summit of the Group of Seven Industrialized Nations. It was created to improve coordination among those countries' remote sensing programs. Its membership has since expanded to include all the major remote sensing agencies in the world (table B-4). CEOS is a voluntary association, with no legal authority over its members, and works to achieve consensus on a range of issues that focus on data policy. The committee also provides a forum for its members to discuss these and other issues with its affiliates, which are international organizations of users of remotely sensed data. In recent meetings, CEOS has focused on data policies designed to promote global change research and operational uses for remote sensing.

EO-ICWG. The Earth Observation International Coordination Working Group (box 4-5) grew out of remote sensing programs originally associated with the international space station program but has since become independent of that program. It aims to coordinate the details of selected major Earth observation platforms of its member agencies (table 4-2) into an International Earth Observation System (IEOS). EO-ICWG has reached formal agreement on data policics for these IEOS platforms, which would form the basis for binding agreements applying to specific joint projects. These policies do not apply to platforms such as METOP that are not part of IEOS, although such platforms could be included at a later date.

WMO/WWW. The World Weather Watch of the World Meteorological Organization is a cooperative program for worldwide sharing of meteorological data and information. It operates through the voluntary cooperation of its members to collect, transmit, and process meteorological data from satellites and a variety of in situ sources and to disseminate meteorological forecast products. The WWW depends on a longstanding tradition of open and timely sharing of meteorological data (box 4-3).

CGMS. The Coordination Group for Meteorological Satellites was founded in 1972 to harmonize the operations of geosynchronous meteorological satellites in connection with the WMO'S

[8] See chapter 4.

[9] See U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, OTA-ISS-604 (Washington, DC: U.S. Government Printing Office, August 1994), ch. 5, for more detailed descriptions of many of these organizations.

BOX B-1: The Committee on Earth Observations Satellites

The Committee on Earth Observations Satellites (CEOS), established in 1984 as an outgrowth of a summit of the Group of Seven,[1] provides a forum for voluntary cooperation among its 19 members, five observers, and nine affiliates. The members and observers are national and regional agencies involved in remote sensing, and the affiliates are international organizations of data users. CEOS has come to play a critical role in developing an international consensus on policy related to remote sensing.

Most CEOS activities take place through established working groups and their subgroups, with major decisions ratified in regular and ad hoc Plenary Meetings. The working groups have particular responsibility for data issues. The Working Group on Calibration and Validation deals with the calibration of sensors to ensure a consistent relationship between sensor readings and the physical quantities being measured. The Working Group on Data deals with ground networks, data catalogs, data formats, and general data policy issues. At its seventh Plenary Meeting in November 1993, CEOS agreed to establish a Working Group on Networks to facilitate the coordination and integration of data networks. CEOS has held several ad hoc plenary-level meetings on data policy.

CEOS has devoted much of its attention to data policy in support of global change research. The Sixth CEOS Plenary Meeting on December 1992 adopted a revised Resolution on Satellite Data Exchange Principles in Support of Global Change Research.[2] Although these principles call for data to be made available to global change researchers at the cost of filling the request, they reflect a clear tension between this goal and the desire to recover costs through the sale of data. An ad hoc CEOS data policy meeting in April 1994 developed tentative data principles in support of the operational use of satellite data for the public benefit.

CEOS also provides a forum for CEOS affiliates—international organizations of users of remotely sensed data—to discuss their needs with the agencies that collect those data. These affiliates include organizations devoted to global change research and to operational environmental monitoring. Discussions between CEOS members and affiliates have influenced the implementation of CEOS data policies for global change research and led to the preparation of an *Affiliates Dossier* describing the data needs of the affiliates, the counterpart to the *CEOS Dossier*, which describes the remote sensing systems of CEOS members.

[1] The Group of Seven consists of the United States, Canada, Japan, France, Germany, Italy, and the United Kingdom.

[2] See the minutes of the Sixth CEOS Plenary Meeting, available from the CEOS Secretariat through ESA, NASA, and NASDA.

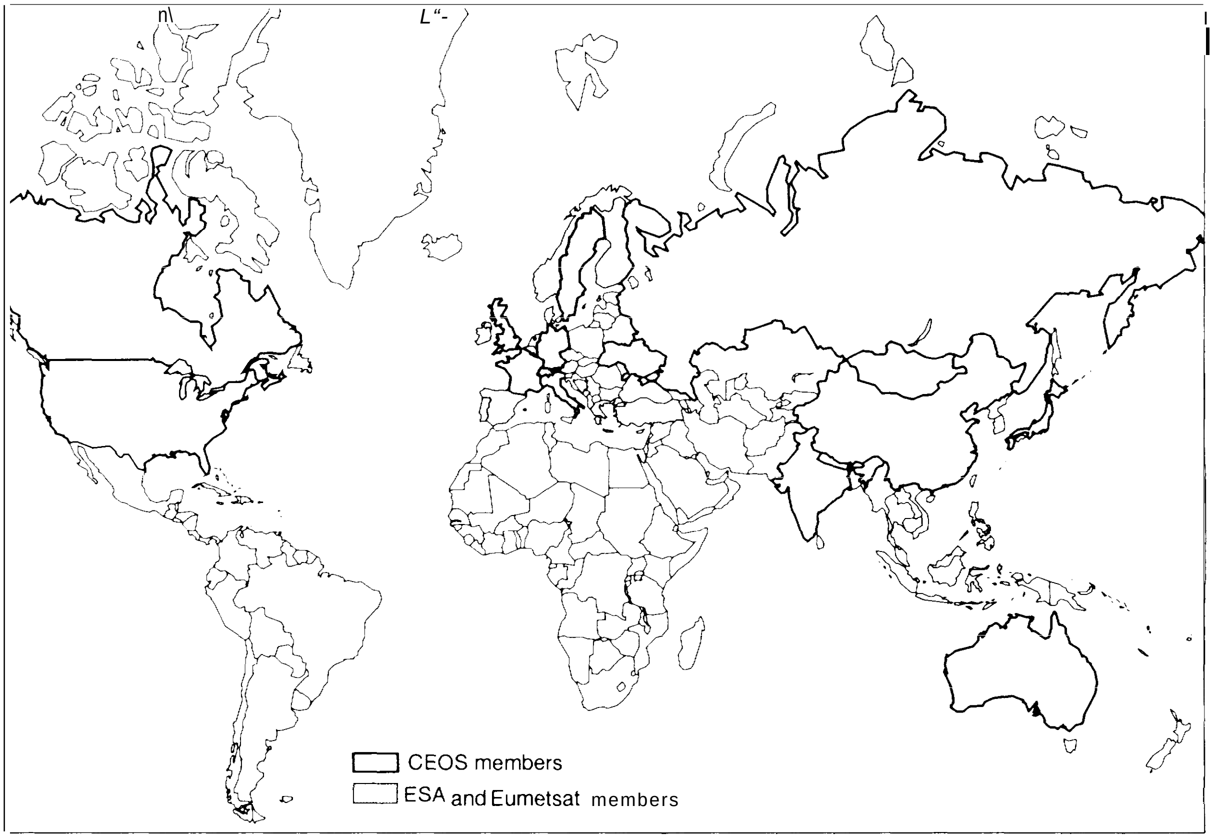
SOURCES: National Oceanic and Atmospheric Administration, 1994 Office of Technology Assessment, 1994.

Global Atmospheric Research Program (GARP). The mandate of CGMS has since expanded to inelude polar satellites as well.[10] CGMS provides a forum in which international issues in the convergence of weather satellites can be addressed.

IOC. The Intergovernmental Oceanographic Commission is a U. N.-affiliated organization that promotes international cooperation in oceanographic research. Several data centers around the world serve as archives for oceanographic data,

[10] The original name of CGMS was the Coordination of Geosynchronous Meteorological Satellites group. For more details, see 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).

FIGURE B-2: Committee on Earth Observations Satellites Membership



SOURCE Committee on Earth Observations Satellites, 1994

including remotely sensed data, and take part in the Intergovernmental Oceanographic Data Exchange (IODE) program.

UNEP. The United Nations Environment Programme supports two related programs that use remotely sensed data. The Global Environmental Monitoring System (GEMS) collects information to support international environmental protection and management programs. The Global Resource Information Database (GRID) serves as an archive with 10 centers on five continents that provide environmental data to natural resource managers around the world. Although they frequently use satellite data, GEMS and GRID do not have the resources to support operational satellite data-gathering activities.

FAO. The U.N. Food and Agriculture Organization also supports programs that use remotely sensed data in agriculture, forestry, and environmental monitoring. The Global Information Early Warning Network uses satellite imagery and national crop reports to provide early warning of possible famine conditions. The Forest Resource Assessment program aims to provide an updated inventory of tropical forests every 10 years.

TABLE B-4: Participants in CEOS

Members	Observers	Affiliates
National Aeronautics and Space Administration (NASA)	Norwegian Space Centre (NSC)	International Council of Scientific Unions (SCU)
National Oceanic and Atmospheric Admmistration (NOAA)	Belgian Office of Science and Technology (BOST)	International Geosphere-Biosphere Programme (IGBP)
Canadian Space Agency (CSA)	Commission of the European Community (C EC)	World Climate Research Programme (WCRP)
European Space Agency (ESA)	Canada Centre for Remote Sensing (CCRS)	Global Climate Observing System (GCOS)
European Organisation for the Exploitation of Meteorological Satellites (Eumetsat)	Crown Research Institute (CRl)/New Zealand	Global Ocean Observing System (GOOS)
Centre National D'Études Spatiales (CNES) (France)		United Nations Environment Programme (UNEP)
British National Space Centre (BNSC)		Intergovernmental Oceanographic: Commission (IOC)
Deutsche Agentur fur Raumfahrtangelegenheit (DARA) (Germany)		World Meteorological Organisation (WMO)
Agenzla Spaziale Italiano (ASI) (Italy)		Food and Agriculture Organization (FAO)
Swedish National Space Board (SNSB)		
Science and Technology Agency (STA) (Japan)		
Russian Space Agency (RSA)		
Russian Committee for Hydrometeorology and Environment Monitoring (Rosgidromet)		
National Space Agency of Ukraine		
Chinese Academy of Space Technology (CAST)		
National Remote Sensing Centre of China (NRSCC)		
Indian Space Research Organisation (SRO)		
Commonwealth Scienific and Industrial Research Organisation (CSIRO) (Australia)		
Instituto Nacional de Pesequias Espaciais (INPE) (Brazil)		

SOURCE Committee on Earth Observations Satellites

INTERNATIONAL RESEARCH PROGRAMS

In addition to the intergovernmental and U. N.-affiliated organizations that use remotely sensed data. international scientific organizations' have developed research programs involving the use of remotely sensed data. Although these programs often involve U. N.-affiliated organizations, they rely for their effectiveness on personal contacts and an international imprimatur to influence the research agendas of national research agencies.[12]

The World Climate Research Programme (WCRP), founded in 1972, focuses on geophysical aspects of climate change. WCRP projects such as the World Ocean Circulation Experiment (WOCE), the Global Energy and Water Cycle Experiment (GEWEX), and the Tropical Oceans Global Atmosphere (TOGA)[13] form the core of the U.S. Global Change Research Program. The International Geosphere-Biosphere Programme (IGBP) was founded in 1986 to address the gaps in WCRP (specifically, the biogeochemical interactions that are critical to understanding the effects of climate change, the feedbacks][4] that could amplify or moderate climate change, and other important areas of global change). IGBP projects and proposals are beginning to influence national research programs. The Human Dimensions of Global Environmental Change Programme (HDP), founded in 1991. studies the interactions between environmental change and human conditions and activities.

In addition to these process-oriented programs, scientists are pursuing several international programs to address the related need for long-term monitoring to assess the state of the global environment and its rate of change.[15] These programs would also address the needs of natural resource managers around the world for operational satellite data. The evolving concepts for the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the Global Terrestrial Observing System (GTOS) will involve a mixture of improvements in existing operational systems and the development of dedicated new systems.

11 These are the International Council of Scientific Unions (] CSU), which includes national science academies such as the U.S. National Academy of Sciences as members, and the International Social Science Council (ISSC), which include, national social science organizations such as the U.S. Social Science Research Council.

12 See U.S. Congress, Office of Technology Assessment, *Remotely Sensed Data: Technology, Management, and Markets*, op. cit., box 5-9 for more information on these research programs.

13 TOGA aims to monitor and model the El Niño phenomenon.

14 The potential magnitude of Warning fro_m the emission of greenhouse gases depends on a variety of feedback effects, some of which involve the reaction of natural ecosystems to changes in climate and atmospheric chemistry. See U.S. Congress, Office of Technolog y Assessment, OTA-BP-ISC- 122, *Global Change Research and NASA'S Earth Observing System* (Washington, DC: U.S. Government Printing Office. November 1993).

15 Process-oriented research aims t. understand the basic physical, biological, and chemical processes that underlie global environmental change. Research monitoring aims to provide high-quality measurements to detect subtle change\ in the critical indicators of global change. Operational monitoring aims to use the data for day-to-day environmental and resource management decisions.

C Appendix C: Convergence of U.S. POES Systems

THE WHITE HOUSE
WASHINGTON
May 5, 1994

PRESIDENTIAL DECISION DIRECTIVE/NSTC-2

TO:	The Vice President The Secretary of State The Secretary of Defense The Secretary of Commerce The Director, Office of Management and Budget The Administrator, National Aeronautics and Space Administration The Assistant to the President for National Security Affairs The Assistant to the President for Science and Technology The Assistant to the President for Economic Policy
SUBJECT:	Convergence of U.S.-Polar-orbiting Operational Environmental Satellite Systems

1. Introduction

The United States operates civil and military polar-orbiting environmental satellite systems which collect, process, and distribute remotely-sensed meteorological, oceanographic, and space environmental data. The Department of Commerce is responsible for the Polar-orbiting Operational Environmental Satellite (POES) program and the Department of Defense is responsible for the Defense Meteorological Satellite Program (DMSP). The National Aeronautics and Space Administration (NASA), through its Earth Observing System (EOS-PM) development efforts, provides new remote sensing and spacecraft technologies that could potentially improve the capabilities of the operational system. While the civil and military missions of POES and DMSP remain unchanged, establishing a single, converged, operational system can reduce duplication of efforts in meeting common requirements while satisfying the unique requirements of the civil and national security communities. A converged system can accommodate international cooperation, including the open distribution of environmental data.

II. Objectives and Principles

The United States will seek to reduce the cost of acquiring and operating polar-orbiting environmental satellite systems, while continuing to satisfy U.S. operational requirements for data from these systems. The Department of Commerce and the Department of Defense will integrate their programs into a single, converged, national polar-orbiting operational environmental satellite system. Additional savings may be achieved by incorporating appropriate aspects of NASA's Earth Observing System.

The converged program shall be conducted in accordance with the following principles:

Operational environmental data from polar-orbiting satellites are important to the achievement It of U.S. economic, national security, scientific, and foreign policy goals.

Assured access to operational environmental data will be provided to meet civil and nation ll security requirements and international obligations.

The United States will ensure its ability to selectively deny critical environmental data to an adversary during crisis or war yet ensure the use of such data by U.S. and Allied military forces. Such data will be made available to other users when it no longer has military utility.

The implementing actions will be accommodated within the overall resource and policy guidance of the President.

III. Implementing Actions

a. Interagency Coordination

1. Integrated Program Office (IPO)

The Departments of Commerce and Defense and NASA will create an Integrated Program Office (IPO) for the national polar-orbiting operational environmental satellite system no later than October 1, 1994. The IPO will be responsible for the management, planning. development, fabrication, and operations of the converged system. The IPO will be under the direction of a System Program Director (SPD) who will report to a triagency Executive Committee via the Department of Commerce's Under Secretary for Oceans and Atmosphere.

2. Executive Committee (EXCOM)

The Departments of Commerce and Defense and NASA will forma convergence EXCOM at the Under Secretary level. The members of the EXCOM will ensure that both civil and national security requirements are satisfied in the converged program, will coordinate program plans, budgets. and policies, and will ensure that agency funding commitments are equitable and sustained. The three member agencies of the EXOM will develop a process for identifying, validating, and documenting observational and system requirements for the national polar-orbiting operational environmental satellite system. Approved operational requirements will define the converged system baseline which the IPO will use to develop agency budgets for research and development, system acquisitions. and operations.

b. Agency Responsibilities

1. Department of Commerce

The Department of Commerce, through NOAA, will have lead agency responsibility to the EXCOM for the converged system. NOAA will have lead agency responsibility to support the IPO for satellite operations. NOAA will nominate the System Program Director who will be approved by the EXCOM. NOAA will also have the lead responsibility for interfacing with national and international civil user communities, consistent with national security and foreign policy requirements.

2. Department of Defense

The Department of Defense will have lead agency responsibility to support the IPO in major system acquisitions necessary to the national polar-orbiting operational environmental satellite system. DOD will nominate the Principal Deputy System Program Director who will be approved by the System Program Director.

3. National Aeronautics and Space Administration

NASA will have lead agency responsibility to support the IPO in facilitating the development and insertion of new cost effective technologies that enhance the ability of the converged system to meet its operational requirements.

c. International Cooperation

Plans for and implementation of a national polar-orbiting operational environmental satellite system will be based on U.S. civil and national security requirements. Consistent with this, the United States will seek to implement the converged system in a manner that encourages cooperation with foreign governments and international organizations. This cooperation will be conducted in support of these requirements in coordination with the Department of State and other interested agencies.

d. Budget Coordination

Budgetary planning estimates, developed by the IPO and approved by the EXCOM, will serve as the basis for agency annual budget requests to the President. The IPO planning process will be consistent with agencies' internal budget formulation.

IV. Implementing Documents

a. The "Implementation Plan for a Converged Polar-orbiting Environmental Satellite System" provides greater definition to the guidelines contained within this policy directive for creating and conducting the converged program.

b. By October 1, 1994, the Departments of Commerce and Defense and NASA will conclude a triagency memorandum of agreement which will formalize the details of the agencies' integrated working relationship, as defined by this directive, specifying each agency's responsibilities and commitments to the converged system.

V. Reporting Requirements

a. By November 1, 1994, the Department of Commerce, the Department of Defense, and NASA will submit an integrated report to the National Science and Technology Council on the implementation status of the national polar-orbiting operational environmental satellite system.

b. For the fiscal year 1996 budget process, the Departments of Commerce and Defense and NASA will submit agency budget requests based on the converged system, in accordance with the milestones established in the Implementation Plan.

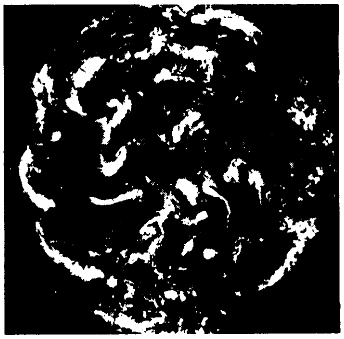
c. For fiscal year 1997 and beyond, the IPO will provide, prior to the submission of each fiscal year's budget, an annual report to the National Science and Technology Council on the status of the national polar-orbiting operational environmental satellite system.

Appendix D: A Brief Policy History of Landsat

D

After winning a policy dispute with the Department of the Interior (DOI) over which agency should operate a land remote sensing satellite,[1] NASA developed the Landsat system during the 1970s, made the data widely available at low cost, and funded a variety of demonstration projects.[2] After determining that the system was ready for operational status, Congress and the Carter Administration decided to transfer operational control to NOAA, which had a successful history of managing the weather satellites. Eventually, experts believed, remote sensing technology and the user base would mature to the point that private firms could fund, develop, and operate their own remote sensing systems for government and private markets. In their view, additional experience with the 30-m-resolution data from Landsats 4 and 5 would help pave the way.

In the early 1980s, the Reagan Administration attempted to hasten the commercialization process by transferring to a private firm operational control of the satellite and responsibility for collecting and marketing data. In 1983 and 1984, Congress held a series of hearings on the issue, concluded that Landsat was ready for a phased transfer to private-sector development and operation, and passed the Landsat Commercialization Act in 1984.[3] After holding a competition, NOAA selected the Earth Observation Satellite Company (EOSAT) in 1985. NOAA retained overall responsibility for system operation. Administration officials



[1] P. Mack, *Viewing the Earth: The Social Construction of the Landsat Satellite System* (Cambridge, MA: The MIT Press, 1990), ch. 5.

[2] Data were either free or delivered at the cost of reproduction.

[3] P.L. *98.365* (15 *U.S. C, 4201,* et seq.).

and Congess expected that EOSAT, assisted by the value-added industry, would be able to generate sufficient market for data to assume full responsibility for funding future Landsat satellites. According to the plan, government officials would work with EOSAT to develop Landsat 6 and 7, which EOSAT would operate. EOSAT would put some of its capital at risk by providing partial funding for both satellites, each of which would be designed to last 5 years. In 1985, officials expected that Landsat 6 would be ready for launch in 1990 or 1991, followed 5 years later by the launch of Landsat 7.

During the late 1980s, Congress, the Administration, and EOSAT made several abortive attempts to find a funding plan acceptable to all parties. Although the Landsat Commercialization Act supported the concept of providing sufficient subsidy to ensure commercial success of the program, the operation of Landsat was nearly terminated several times for lack of a few million dollars in operating funds. Ultimately, the three parties resolved the confused commercialization effort by agreeing to develop only Landsat 6, to be launched in 1992. The federal government provided most of the funding for Landsat 6. Assuming that Landsat 6 successfully reached orbit and operated as designed, this plan still left the United States with the prospect of entering the late 1990s with no capability to collect Landsat data. Three circumstances helped convince government officials of the importance of continuing to provide Landsat data. First, multispectral data from Landsat and France’s Systéme pour l’Observation de la Terre (SPOT) proved extremely important in the 1992 Gulf War. These data provided the basis for creating up-to-date maps of the Persian Gulf.[4] Second, global change researchers began to realize how important Landsat data are for following environmental changes. Third, failing to develop Landsat 7 would leave SPOT Image in control of the international market for remotely sensed data from spacecraft.

As a result of these and other pressures to continue collecting Landsat data, in 1992, the Administration, with the strong support of Congress, moved to transfer operational control of the Landsat system from NOAA and EOSAT to DOD and NASA. Under the Landsat management plan negotiated between DOD and NASA, DOD would have funded development of the spacecraft and its instruments and NASA was to fund construction of the ground-data processing and operations systems, operate the satellite, and provide for distribution of Landsat data. The Land Remote-Sensing Policy Act of 1992,[5] passed by Congress and signed into law in October 1992, codified the management plan[6] and provided for approximately equal funding for the operational life of Landsat 7. The act reaffirmed Congress’s interest in 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’s natural resources, in carrying out national security functions, and in planning and conducting many other activities of scientific, economic, and social importance.”[7]

Initial NASA and DOD plans called for Landsat 7 to carry an Enhanced Thematic Mapper Plus, an improved version of the Enhanced Thematic Mapper that was aboard the failed Landsat 6 (table 3-3). Later, the two agencies began to consider including a new multispectral sensor, the High Resolution Multispectral Stereo Imager (HRMSI). Cost estimates for developing, launching, and operating Landsat 7 for 5 years equaled $880 mil1ion (1992 dollars). Including the HRMSI sensor on the spacecraft would have cost an additional $400 million for procurement of the instrument and the

[4] Maps and other data products made from these civilian systems have the advantage that they can be shared among U.S. allies in a conflict.

[5] P. L. 102-555, 106 Stat. 4163-4180.

[6] 15 U.S.C. 5611.

[7] 15 U.S.C. 5601, Sec. 2. Findings.

ground operations equipment. Because of the high data rates expected for the HRMSI, operating the sensor would have added significant costs to NASA's yearly ground operations budget.

The September 1993 loss of Landsat 6 left the United States with a substantial risk that continuity of data from Landsat would be lost. Although the TM sensors on Landsat 4 and Landsat 5 continue to operate, both have suffered data-transmission-subsystem failures and the spacecraft are substantially beyond their projected operating lifetimes.[8] They could fail completely at any time.[9] Hence, to maintain the potential for continuity of data delivery, DOD and NASA had to act expeditiously to develop and launch Landsat 7. However, in September 1993, NASA decided that the costs of operating Landsat 7 with HRMSI were too large compared with the benefit NASA researchers would receive from HRMSI data. HRMSI was of greater interest to DOD and other U.S. national security agencies because it would have provided 5-m-resolution stereo data of sufficient quality to create high-quality maps. Hence, NASA decided that it could not support the ground operations of HRMSI and did not include sufficient funds in its FY 1995 budget request to begin developing the data system. In December 1993, DOD decided that it could not fund the resulting Landsat 7 budget shortfall. As a result of their disagreement over the Landsat 7 requirements and budget, NASA and DOD subsequently decided that each agency should go its own way. NASA would fund development of Landsat, carrying the planned 30-m-resolution ETM Plus.[10] DOD would decide later whether or not to develop a 5-m-resolution sensor on its own.[11]

Still undetermined in early 1994 was the question of whether NASA or some other agency would operate Landsat 7. NASA needs Landsat data to support its global change research program. However, Landsat data support many government operational programs and the data needs of state and local governments, the U.S. private sector, and foreign entities. Hence, Landsat data have both national and international value that extends far beyond NASA's requirements for global change data.

In May 1994, the Administration decided to resolve the outstanding issue of procurement and operational control of the Landsat system by assigning it to NASA, NOAA, and DOI. Under the new plan, NASA will procure the satellite, NOAA will manage and operate the spacecraft and ground system, and DOI will archive and distribute the data at the marginal cost of reproduction.[12]

[8] Both satellites were designed to operate for 3 years. Landsat 4 was launched in 1982; Landsat 5 was launched in 1984.

[9] However, it might still be possible to retrieve data from the MSS aboard both satellites because the MSS sensor is still capable of operating and it uses an S-Band transmitter that is also still operational.

[10] DOD transferred $90 million to NASA for the development of Landsat 7.

[11] Letter from Undersecretary of Defense John Deutsch to Congressman George Brown, December 1993.

[12] Presidential Decision Directive NSTC-3, May 5, 1994.

E Appendix E: Landsat Remote Sensing Strategy

THE WHITE HOUSE
WASHINGTON
May 5, 1994

PRESIDENTIAL DECISION DIRECTIVE/NSTC-3

TO: The Vice President
The Secretary of Defense
The Secretary of Interior
The Secretary of Commerce
The Director, Office of Management and Budget
The Administrator, National Aeronautics and Space Administration
The Assistant to the President for National Security Affairs
The Assistant to the President for Science and Technology
The Assistant to the President for Economic Policy

SUBJECT: Landsat Remote Sensing Strategy

1. Introduction

This directive provides for continuance of the Landsat 7 program, assures continuity of Landsat-type and quality of data, and reduces the risk of a data gap.

The Landsat program has provided over 20 years of calibrated data to a broad user community including the agricultural community, global change researchers, state and local governments, commercial users, and the military. The Landsat 6 satellite which failed to reach orbit in 1993 was intended to replace the existing Landsat satellites 4 and 5, which were launched in 1982 and 1984. These satellites which are operating well beyond their three year design lives, represent the only source of a global calibrated high spatial resolution measurements of the Earth's surface that can be compared to previous data records.

In the Fall of 1993 the joint Department of Defense and National Aeronautics and Space Administration Landsat 7 program was being reevaluated due to severe budgetary constraints. This fact, coupled with the advanced age of Land sat satellites 4 and 5, resulted in a re-assessment of the Landsat program by representatives of the National Science and Technology Council. The objectives of the National Science and Technology Council were to minimize the potential for a gap in the Landsat data record if Landsat satellites 4 and 5 should cease to operate, to reduce cost, and to reduce development risk. The rcsults of this re-assessment are identified below.

This document supersedes National Space Policy Directive #5, dated February 2, 1992, and directs implementation of the Landsat Program consistent with the intent of P. L. 102-555. the Land Remote Sensing Policy Act of 1992, and P. L. 103-221, the Emergency Supplemental Appropriations Act. The Administration will seek all legislative changes necessary to implement this PDD.

II. Policy Goals

A remote sensing capability, such as is currently being provided by Landsat satellites 4 and 5, benefits the civil, commercial, and national security interests of the United States and makes contributions to the private sector which are in the public interest. For these reasons, the United States Government will seek to maintain the continuity of Landsat-type data. The U.S. Government will:

(a) Provide unenhanced data which are sufficiently consistent in terms of acquisition geometry. coverage characteristics, and spectral characteristics with previous Landsat data to allow quantitative comparisons for change detection and characterization;

(b) Make govemment-owned Landsat data available to meet the needs of all users at no more that the cost of fulfilling user requests consistent with data policy goals of P.L. 102-555; and

(c) Promote and not preclude private sector commercial opportunities in Landsat-type remote sensing.

III. Landsat Strategy

a. The Landsat strategy is composed of the following elements:

(1) Ensuring that Landsat satellites 4 and 5 continue to provide data as long as they are technically capable of doing so.

(2) Acquiring a Landsat 7 satellite that maintains the continuity of Landsat-type data. minimizes development risk, minimizes cost, and achieves the most favorable launch schedule to mitigate the loss of Landsat 6.

(3) Maintaining an archive within the United States for existing and future Landsat-type data.

(4) Ensuring that unenhanced data from Landsat 7 are available to all users at no more than the cost of fulfilling user requests.

(5) Providing data for use in global change research in a manner consistent with the Global Change Research Policy Statements for Data Management.

(6) Considering alternatives for maintaining the continuity of data beyond Landsat *7.*

(7) Fostering the development of advanced remote sensing technologies, with the goal of reducing the cost and increasing the performance of future Landsat-type satellites to meet U.S. Government needs, and potentially, enabling substantially greater opportunities for commercialization.

b. These strategy elements will be implemented within the overall resource and policy guidance provided by the President.

IV. Implementing Guidelines

Affected agencies will identify funds necessary to implement the National Strategy for Landsat Remote Sensing within the overall resource and policy guidance provided by the President. {In order to effectuate the strategy enumerated herein, the Secretary of Commerce and the Secretary of the Interior are hereby designated as members of the Landsat Program Management in accordance with section 10l(b) of the Landsat Remote Sensing Policy Act of 1992, 15 U.S.C. 5602(6) and 5611 (b).} Specific agency responsibilities are provided below.

a. The Department of Commerce/NOAA will:

(1) In participation with other appropriate government agencies arrange for the continued operation of Landsat satellites 4 and 5 and the routine operation of future Landsat satellites after their placement in orbit.

(2) Seek better access to data collected at foreign ground stations for U.S. Government and private sector users of Landsat data.

(3) In cooperation with NASA, manage the development of and provide a share of the funding for the Landsat 7 ground system.

(4) Operate the Landsat 7 spacecraft and ground system in cooperation with the Department of the Interior.

(5) Seek to offset operations costs through use of access fees from foreign ground stations and/or the cost of fulfilling user requests.

(6) Aggregate future Federal requirements for civil operational land remote sensing data.

b. The National Aeronautics and Space Administration will:

(1) Ensure data continuity by the development and launch of a Landsat 7 satellite system which is at a minimum functionally equivalent to the Landsat 6 satellite in accordance with section 102, P. L. 102-555.

(2) In coordination with DOC and DOI, develop a Landsat 7 ground system compatible with the Landsat 7 spacecraft.

(3) In coordination with DOC, DOI, and DOD, revise the current Management plan to reflect the changes implemented through this directive, including programmatic, technical, schedule, and budget information.

(4) Implement the joint NASA/DOD transition plan to transfer the DOD Landsat 7 responsibilities to NASA.

(5) In coordination with other appropriate agencies of the U.S. Government develop a strategy for maintaining continuity of Landsat-type data beyond Landsat 7.

(6) Conduct a coordinated technology demonstration program with other appropriate agencies to improve the performance and reduce the cost for future unclassified earth remote sensing systems.

c. The Department of Defense will implement the joint NASA/DOD transition plan to transfer the DOD Landsat 7 responsibilities to NASA.

d. The Department of the Interior will continue to maintain a national archive of existing and future Landsat-type remote sensing data within the United States and make such data available to U.S. Government and other users.

e. Affected agencies will identify the funding, and funding transfers for FY 1994, required to implement this strategy that are within their approved fiscal year 1994 budgets and subsequent budget requests.

V. Reporting Requirements

U.S. Government agencies affected by the strategy guidelines are directed to report no later that 30 days following the issuance of this directive, to the National Science and Technology Council on their implementation. The agencies will address management and funding responsibilities, government and contractor operations, data management, archiving, and dissemination, necessary changes to P. L. 102-555 and commercial considerations associated with the Landsat program.

F | Appendix F: Clinton Administration Policy on Remote Sensing Licensing and Exports

On March 10, 1994, the White House released a statement of policy on two issues: the licensing of commercial remote sensing systems and the export of remote sensing technologies. This statement follows verbatim:

U.S. Policy on Licensing and Operation of Private Remote Sensing Systems

License requests by US firms to operate private remote sensing space systems will be reviewed on a case-by-case basis in accordance with the Land Remote Sensing Policy Act of 1992 (the Act). There is a presumption that remote sensing space systems whose performance capabilities and imagery quality characteristics are available or are planned for availability in the world marketplace (e.g., SPOT, Landsat, etc.) will be favorably considered, and that the following conditions will apply to any US entity that receives an operating license under the Act.

1. The licensee will be required to maintain a record of all satellite tasking for the previous year and to allow the USC access to this record.
2. The licensee will not change the operational characteristics of the satellite system from the application as submitted without formal notification and approval of the Department of Commerce, which would coordinate with other interested agencies.
3. The license being granted does not relieve the licensee of the obligation to obtain export license(s) pursuant to applicable statutes.
4. The license is valid only for a finite period, and is neither transferable nor subject to foreign ownership, above a specified threshold, without the explicit permission of the Secretary of Commerce.
5. All encryption devices must be approved by the US Government for the purpose of denying unauthorized access to others during periods when national security, international obligations and/or foreign policies may be compromised as provided for in the Act.
6. A licensee must use a data downlink format that allows the US Government access and use of the data during periods when national security, international obligations and/or foreign policies may be compromised as provided for in the Act.

7. During periods when national security or international obligations and/or foreign policies may be compromised, as defined by the Secretary of Defense or the Secretary of State, respectively, the Secretary of Commerce may, after consultation with the appropriate agency (ies), require the licensee to limit data collection and/or distribution by the system to the extent necessitated by the given situation. Decisions to impose such limits only will be made by the Secretary of Commerce in consultation with the Secretary of Defense or the Secretary of State, as appropriate. Disagreements between Cabinet Secretaries may be appealed to the President. The Secretaries of State, Defense and Commerce shall develop their own internal mechanisms to enable them to carry out their statutory responsibilities.
8. Pursuant to the Act, the US Government requires US companies that have been issued operating licenses under the Act to notify the US Government of its intent to enter into significant or substantial agreements with new foreign customers. Interested agencies shall be given advance notice of such agreements to allow them the opportunity to review the proposed agreement in light of the national security, international obligations and foreign policy concerns of the US Government. The definition of a significant or substantial agreement, as well as the time frames and other details of this process, will be defined in later Commerce regulations in consultation with appropriate agencies.

U.S. Policy on the Transfer of Advanced Remote Sensing Capabilities

Advanced Remote Sensing System Exports

The United States will consider requests to export advanced remote sensing systems whose performance capabilities and imagery quality characteristics are available or are planned for availability in the world marketplace on a case-by-case basis.

The details of these potential sales should take into account the following:

- the proposed foreign recipient's willingness and ability to accept commitments to the US Government concerning sharing, protection, and denial of products and data; and
- constraints on resolution, geographic coverage. timeliness, spectral coverage, data processing and exploitation techniques. tasking capabilities, and ground architectures.

Approval of requests for exports of systems would also require certain diplomatic steps be taken, such as informing other close friends in the region of the request, and the conditions we would likely attach to any sale; and informing the recipient of our decision and the conditions we would require as part of the sale.

Any system made available to a foreign government or other foreign entity may be subject to a formal government-to-government agreement.

Transfer of Sensitive Technology

The United States will consider applications to export remote sensing space capabilities on a restricted basis. Sensitive technology in this situation consists of items of technology on the US Munitions List necessary to develop or to support advanced remote sensing space capabilities and which are uniquely available in the United States. Such sensitivc technology shall be made available to foreign entities only on the basis of a government-to-government agreement. This agreement may be in the form of end-use and retransfer assurances which can be tailored to ensure the protection of US technology.

I Government-to-Government Intelligence and Defense Partnerships

Proposals for intelligence or defense partnerships with foreign countries regarding remote sensing that would raise questions about US Government competition with the private sector or would change the US Government use of funds generated pursuant to a US-foreign government partnership arrangement shall be submitted for interagency review.

SOURCE: White House Press Office, March 10, 1994.

Abbreviations G

AATSR	Advanced Along-Track Scanning Radiometer
ACR	Active Cavity Radiometer
ACRIM	Active Cavity Radiometer Irradiance Monitor
ADEOS	Advanced Earth Observing Satellite
AES	Atmospheric Environment Service
AID	Agency for International Development
AIRS	Atmospheric Infrared Sounder
ALEXIS	Array of Low Energy X-Ray Imaging Sensors
ALT	Altimeter
AMS	American Meteorological Society
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
AMTS	Advanced Moisture and Temperature Sounder
APT	Automatic Picture Transmission
ARA	Atmospheric Radiation Analysis
ARGOS	Argos Data Collection and Position Location System
ARM	Atmospheric Radiation Monitor
ARPA	Advanced Research Projects Agency
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced Scatterometer
ASF	Alaska SAR Facility
ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
ATLAS	Atmospheric Laboratory for Applications and Science
ATN	Advanced TIROS-N
ATMOS	Atmospheric Trace Molecules Observed by Spectroscopy
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible Infrared Imaging Spectrometer
AVNIR	Advanced Visible and Near-Infrared Radiometer
CCD	Charged Coupled Device
CCDS	Centers for Commercial Development of Space
CCRS	Canada Centre for Remote Sensing
CEES	Committee on Earth and Environmental Science
CENR	Committee on Environment and Natural Resource Research
CEOS	Committee on Earth Observations Satellites
CERES	Clouds and Earth's Radiant Energy System
CES	Committee on Earth Studies
CFC	Chlorofluorocarbon
CGC	Committee on Global Change

CGMS	Coordination of Geostationary Meteorological Satellites
CIESIN	Consortium for International Earth Science Information Network
CLAES	Cryogenic Limb Array Etalon Spectrometer
CNES	Centre National d'Études Spatiales
CNRS	Centre National de la Recherche Scientifique
COSPAR	Congress for Space Research
CPP	Cloud Photopolarimeter
CSA	Canadian Space Agency
CZCS	Coastal Zone Color Scanner
DAAC	Distributed Active Archive Center
DARA	Deutsche Agentur fur Raumfahrt-Angelegenheiten
DB	Direct Broadcast
DCS	Data Collection System
DDL	Direct Downlink
DMA	Defense Mapping Agency
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DOE	Department of Energy
DOI	Department of the Interior
DORIS	Doppler Orbitography and Radiopositioning Integrated by Satellite
DOS	Department of State
DPT	Direct Playback Transmission
DRSS	Data Relay Satellite System
EC	European Community
EDC	EROS Data Center
EDOS	EOS Data and Operations System
EDRTS	Experimental Data Relay and Tracking Satellite
ELGA	Emergency Locust Grasshopper Assistance
ENSO	El Niño/Southern Oscillation
EOC	EOS Operations Center
EO-IC-WG	Earth Observation International Coordination Working Group
EOS	Earth Observing System
EOS-AERO	EOSAerosal Mission
EOS-ALT	EOS Altimetry Mission
EOS-AM	EOS Morning Crossing (Ascending) Mission
EOSAT	Earth Observation Satellite company
EOS-CHEM	EOS Chemistry Mission
EOSDIS	EOS Data and Information System
EOSP	Earth Observing Scanning Polarimeter
EOS-PM	EOS Afternoon Crossing (Descending) Mission
EPA	Environmental Protection Agency
ERBE	Earth Radiation Budget Experiment
ERBS	Earth Radiation Budget Satellite
EROS	Earth Resources Observation System
ERS	European Remote-Sensing Satellite
ERTS-1	Earth Resources Technology Satellite- 1
ESA	European Space Agency
ESDIS	Earth Science Data and Information System
ESOC	European Space Operations Center
ESRIN	European Scientific Research Institute
ETS-VI	Engineering Test Satellite-VI
Eumestat	European Organisation for the Exploitation of Meteorological Satellites
FAA	Federal Aviation Administration
FAO	Food and Agriculture Organization
FCCSET	Federal Coordinating Council for Science, Engineering, and Technology
FEMA	Federal Emergency Management Agency
FEWS	Famine Early Warning System
FOV	Field-of-View
FST	Field Support Terminal
FY	Feng Yun
GCDIS	Global Change Data and Information System
GCOS	Global Climate Observing System
GDP	gross domestic product
GDPS	Global Data-Processing System
Geosat	Navy Geodetic Satellite
GEWEX	Global Energy and Water Cycle Experiment
GFO	Geosat Follow-On
GGI	GPS Geoscience Instrument
GIS	geographic information system(s)

GLAS	Geoscience Laser Altimeter System
GLI	Global Imager
GLRS	Geoscience Laser Ranging System
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GOMI	Global Ozone Monitoring Instrument
GOMOS	Global Ozone Monitoring by Occultation of Stars
GOMR	Global Ozone Monitoring Radiometer
GOMS	Geostationary Operational Meteorological Satellite
GOOS	Global Ocean Observing System
GOS	Global Observing System
GPS	Global Positioning System
GTS	Global Telecommunications System
HIRDLS	High-Resolution Dynamics Limb Sounder
HIRIS	High-Resolution Imaging Spectrometer
HIRS	High-Resolution Infrared Sounder
HIS	High-Resolution Interferometer Sounder
HRMSI	High-Resolution Multispectral Stereo Imager
HRPT	High-Resolution Picture Transmission
HSST	House Committee on Science, Space, and Technology
HRV	High-Resolution Visible
HYDICE	Hyperspectral Digital Imagery Collection Experiment
IAF	International Astronautical Federation
IASI	Interferometric Atmospheric Sounding Instrument
IEOS	International Earth Observing System
IELV	intermediate-class expendable launch vehicle
ICSU	International Council of Scientific Unions
IGBP	International Geosphere-Biosphere Program
ILAS	Improved Limb Atmospheric Spectrometer
INSAT	Indian Satellite
IMG	Interferometric Monitor for Greenhouse Gases
IOC	Intergovernmental Oceanographic Commission
IPCC	Intergovernmental Panel on Climate Change
IPO	Integrated Program Office
IPOMS	International Polar Operational Meteorological Satellite organization
IRS	Indian Remote Sensing Satellite
IRTS	Infrared Temperature Sounder
ISAMS	Improved Stratospheric and Mesospheric Sounder
ISY	International Space Year
ITS	Interferometric Temperature Sounder
JOES	Japanese Earth Observing System
JERS	Japan’s Earth Resources Satellite
JPL	Jet Propulsion Laboratory
JPOP	Japanese Polar Orbiting Platform
LAGEOS	Laser Geodynamics Satellite
Landsat	Land Remote-Sensing Satellite
Lidar	Light Detection and Ranging
LIMS	Limb Infrared Monitor of the Stratosphere
LIS	Lightning Imaging Sensor
LISS	Linear Imaging Self-scanning Sensors
LITE	Lidar In-Space Technology Experiment
LR	Laser Retroreflector
MELV	medium-class expendable launch vehicle
MERIS	Medium-Resolution Imaging Spectrometer
MESSR	Multispectrum Electronic Self-Scanning Radiometer
METOP	Meteorological Operational Satellite
MHS	Microwave Humidity Sounder
MIMR	Multifrequency Imaging Microwave Radiometer

MI PAS	Michelson Interferometer for Passive Atmospheric Sounding
MISR	Multi-Angle Imaging SpectroRadiometer
MITI	Ministry of International Trade and Industry
MLS	Microwave Limb Sounder
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOP	Meteosat Operational Programme
MOPITT	Measurements of Pollution in the Troposphere
MOS	Marine Observation Satellite
MSR	Microwave Scanning Radiometer
MSS	Multispectral Scanner
MSU	Microwave Sounding Unit
MTPE	Mission to Planet Earth
MTS	Microwave Temperature Sounder
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency (Japan)
NESDIS	National Environmental Satellite, Data and Information Service
NEXRAD	Next-Generation Weather Radar
NIST	National Institute for Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NOSS	National Oceanic Satellite System
NREN	National Research and Education Network
NROSS	Navy Remote Ocean Sensing Satellite
NRSA	National Remote Sensing Agency
NSCAT	NASA Scatterometer
NSPD	National Space Policy Directive
NSTC	National Science and Technology Council
OCTS	Ocean Color and Temperature Scanner
OLS	Operational Linescan System
OMB	Office of Management and Budget
OPS	Optical Sensors
OSB	Ocean Studies Board
OSC	Orbital Sciences Corporation
OSIP	Operational Satellite Improvement Program
POEM	Polar-Orbit Earth Observation Mission
POES	Polar-orbiting Operational Environmental Satellite
POLDER	Polarization and Directionality of Earth's Reflectance
RA	Radar Altimeter
Radarsat	Radar Satellite
RESTEC	Remote Sensing Technology Center
RF	Radio Frequency
RIS	Retroreflector in Space
SAFIRE	Spectroscopy of the Atmosphere using Far Infrared Emission
SAFISY	Space Agency Forum on ISY
SAGE	Stratospheric Aerosol and Gas Experiment
SAMS	Stratospheric and Mesospheric Sounder
SAR	synthetic aperture radar
SARSAT or S&R	Search and Rescue Satellite Aided Tracking System
SBUV	Solar Backscatter Ultraviolet Radiometer
SCARAB	Scanner for the Radiation Budget
SCST	Senate Committee on Commerce, Science, and Transportation
SeaWiFS	Sea-Viewing Wide Field Sensor
SEDAC	Socio Economic Data Archive Center
SEM	Space Environment Monitor
S-GCOS	Space-based Global Change Observation System
SIR	Shuttle Imaging Radar
SLR	Satellite Laser Ranging
SMMR	Scanning Multispectral Microwave Radiometer
SMSIGOES	GOES synchronous meteorological satellite
SNR	signal-to-noise ratio
SOLSTICE	Solar Stellar Irradiance Comparison Experiment
SPOT	Système pour I 'Observation de la Terre
SSM/I	Special Sensor Microwave/Imager
SSTI	Small Satellite Technology Initiative
SSU	Stratospheric Sounding Unit

STIKSCT	Stick Scatterometer
SWIR	Short Wave Infrared
TDRSS	Tracing and Data Relay Satellite System
TUSK	Tethered Upper Stage Knob
TIROS	Television Infrared Observing Satellites
TM	Thematic Mapper
TOGA	Tropical Ocean Global Atmosphere
TOMS	Total Ozone Mapping Spectrometer
TOPEX	Ocean Topography Experiment
TOVS	TIROS Operational Vertical Sounder
TRMM	Tropical Rainfall Measuring Mission
UARS	Upper Atmosphere Research Satellite
UAVS	Unpiloted aerospace vehicles
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific, and Cultural Organization
USDA	U.S. Department of Agriculture
USGCRP	U.S. Global Change Research Program
USGS	U.S. Geological Survey
VAS	VISSR Atmospheric Sounder
VHRR	Very High Resolution Radiometer
VISSR	Visible and Infrared Spin Scan Radiometer
VTIR	Visible and Thermal infrared Radiometer
WCRP	World Climate Research Program
WDC	World Data Center
WEU	Western European Union
WMO	The U.N. World Meteorological Organization
WOCE	World Ocean Circulation Experiment
WWW	World Weather Watch
X-SAR	X-band synthetic aperture radar

Index

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