Policy and Findings

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Over the past three decades, several countries have undertaken an assortment of publicly funded programs to gather data about the atmosphere, land, oceans, and ice cover from Earth-orbiting spacecraft. The United States, in particular, has made a strong commitment to the development and operation of new satellite remote sensing systems for global change research.[1] By the end of this century, these systems will generate prodigious quantities of data, which will arrive on Earth in a range of formats. **If the United States is not prepared to manage efficiently the increase in quantities of remotely sensed data, it will not be able to reap the full benefits of its investment in its satellite systems.** In order to use remotely sensed data efficiently, scientists and other users will require adequate data storage and computer systems capable of managing, organizing, sorting, distributing, and manipulating these data at unprecedented speeds.

Governments expect that such data will help them predict weather, understand climate, and manage regional and global resources more effectively. Because satellite data can be acquired over broad geopolitical regions under consistent observational conditions, they are particularly valuable for supporting research into the causes, magnitude, duration, and effects of regional and global environmental change. Over the next 20 years, the U.S.

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[1] Research on the causes of changes in climate, ecosystems, and other aspects of the natural world as a result of anthropogenic or natural causes.

government alone expects to spend some $30 billion on building and operating remote sensing satellite systems.[2]

Each year, private industry invests hundreds of millions of dollars in hardware and software that are, among other things, used to turn satellite data into information for such markets as weather forecasting, mineral exploration, forestry management, urban planning, and fisheries. Although the market for information generated from satellite data is currently relatively small, it is likely to continue to grow rapidly, especially as information service companies find new ways to bring the benefits of remote sensing to the ultimate user.

The scale of public and private investments in remote sensing technologies raises the following question about the use of satellite data. How can remotely sensed data be efficiently and effectively collected, archived, and processed? Congress has particular interest in policy issues such as:

- What are the appropriate roles of government and the private sector in these tasks?
- Will scientific researchers and other users be able to access and use data, equitably, quickly, and easily?
- What investments in new information technologies will be needed to manage the distribution and use of these data?

This report, one in a series of reports and background papers on space-based remote sensing (box 1-1), explores these and other questions about the application of data gathered by satellites to scientific and practical problems on Earth. The assessment of Earth Observations Sytems of which this report is part 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 presents OTA's findings and policy options related to the application of remotely sensed data. The value of these data depends directly on the ease with which scientists and other users can turn such data[3] into useful information. Hence, the ability to generate information from satellite data in the future will depend directly on the development of user-friendly systems to collect, transfer, archive, and analyze a wide variety of data in many different formats

BOX 1-1: OTA Publications on Space Based Remote Sensing

Background Papers

- *Remotely Sensed Data From Space: Distribution, Pricing, and Applications* (Washington, DC Office of Technology Assessment, July 1992).
- *Data Format Standards for Civilian Remote Sensing Satellites* (Washington, DC 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).

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, August 1994).
- *Civilan Satellite Remote Sensing: A Strategic Approach OTA-ISS-607* (Washington, DC U.S. Government Printing Office, September 1994)

SOURCE Office of Technology Assessment, 1994

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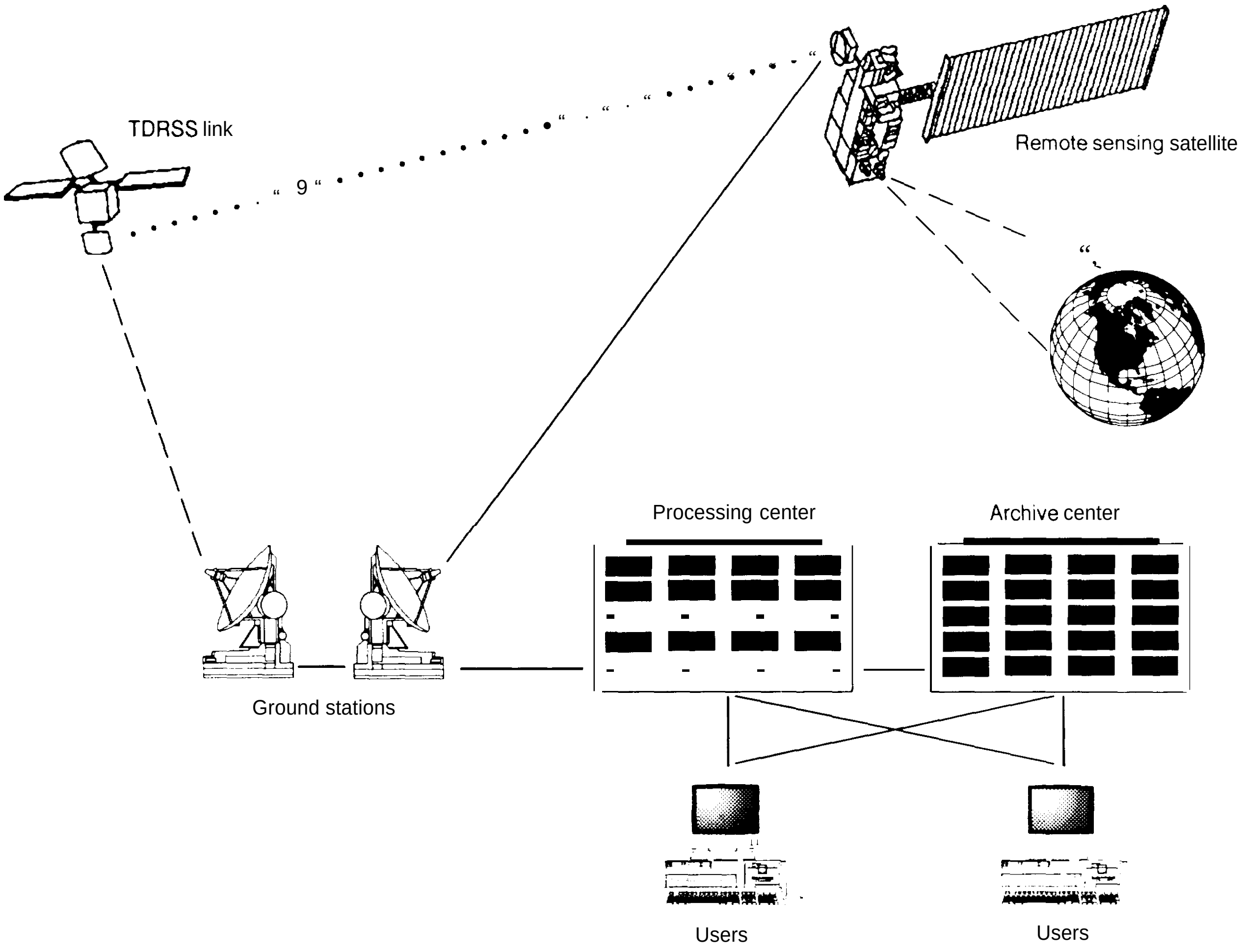
[2] In 1992 dollars. U.S. Congress, OffIce of Technology Assessment, OTA-ISC-430, *The Future of remote* from *Sensing From Space: Civilian Satillite Systems and Applications* (Washington, DC: U.S. Government Printing Office, 1993), pp. 2, 19. The figure of $30 billion was reached by summing planned expenditures between 1993 and 2000 and adding to them extrapolated estimates of what it would cost to continue the major U.S. remote sensing systems until *2015*.

[3] The term "data" as used in this report refers to data that have received only minimal processing to make them amenable to manipulation and analysis within a computer.

FIGURE 1-1: Data Collection, Archiving, and Distribution



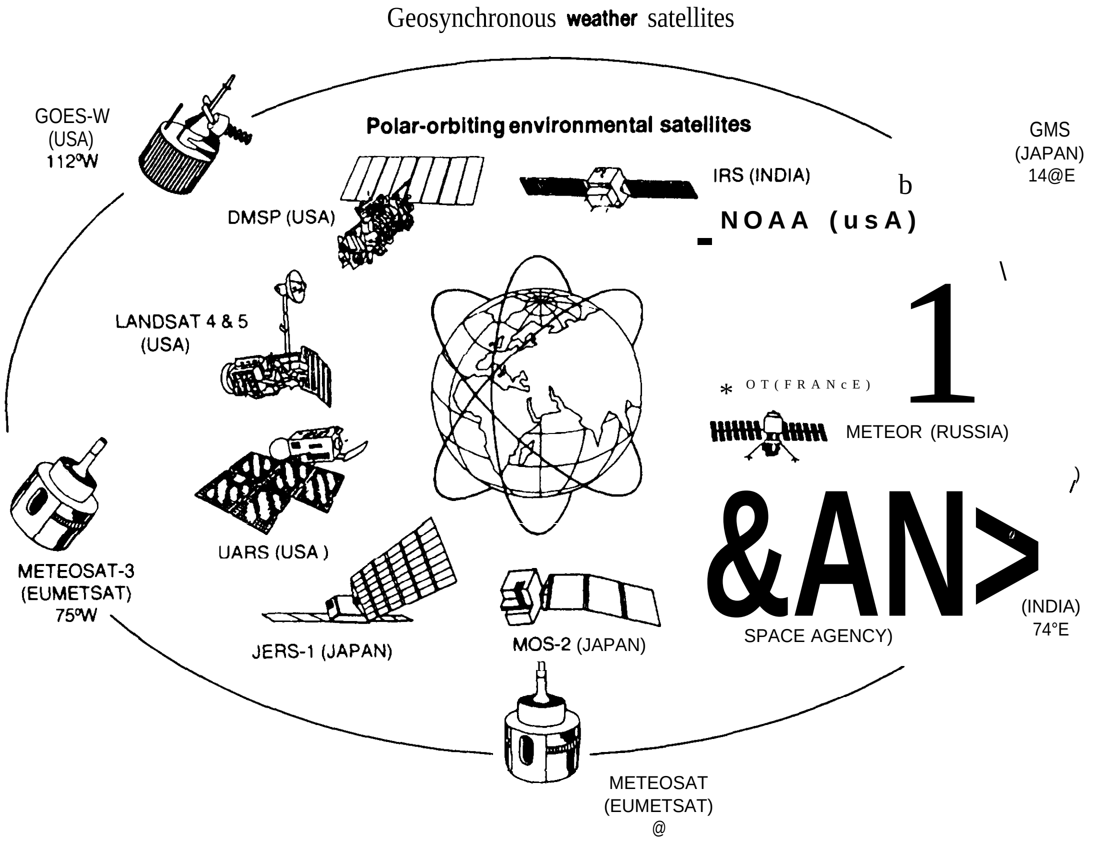
SOURCE Office of Technology Assessment, 1994

(figure 1 -1). **Chapter 2: Managing Data and Information** summarizes the use of remotely sensed data in the context of the highly diverse information industry. The chapter further examines how the federal government manages its extensive archives of remotely sensed data and makes them available to potential users. It also enumerates the technologies required to sustain these efforts.

In support of its Earth Observing System (EOS), the National Aeronautics and Space Administration (NASA) is constructing a large system to collect, store, and distribute data to its scientists. **Chapter 3: NASA's Earth Observing System Data and Information System** outlines the technical and institutional features of this system and examines issues related to the timely delivery of data to scientists and other customers. It also explores the relationship of the Earth Observing System Data and Information System (EOSDIS) to the broader Global Change Data and Information System (GCDIS).

Chapter 4: Public and Private Roles in a Developing Market examines the role of the private sector in supporting the information needs of federal, state, and local governments, and in developing commercial uses for remotely sensed data. It also analyzes the issue of how to strike an appropriate balance between public and private re-

FIGURE 1-2: Existing Earth Monitoring Satellites



SOURCE Office of Technology Assessment, 1994

mote sensing activities. Some data—most notably those gathered by Landsat, Spot, and other Earth resources satellites—have substantial commercial value for a wide diversity of applications. Their use for public and private good therefore raises potential conflicts over pricing of these data and access to them.

Initiated by the United States and the Soviet Union in the 1960s, remote sensing of Earth's environment is now an international activity. China, the European Space Agency (ESA), the European Organisation for Meteorological Satellites (Eumetsat), France, India, Japan, and Russia operate Earth-observing satellites. Canada will join these entities in 1995, when it launches Radarsat, a satellite designed to monitor global ice and ocean conditions. **Chapter 5: International Data Issues** focuses on U.S. and international policies on the management and global use of remotely sensed data.

THE FUTURE OF SATELLITE DATA AND INFORMATION

Satellite remote sensing began in the 1960s and has become increasingly important for predicting the weather, understanding climate, and a host of other uses. Remotely sensed data from satellites (figure 1-2; table 1-1)[4] and aircraft have now be

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[4] Appendix A presents a summary description of satellite systems. OTA's report on *The Future of Remote Sensing From Space: Civilian Satellite Systems and Applications* examines a number of issues about the development and operation of U.S. and foreign satellite systems.

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

System	Operator	Mission	Status
Geostationary Operational Environmental Satellite (GOES)	NOAA	Weather monitoring, severe storm warning, and environmental data relay	2 operational, GOES-1 launched in April 1994
Polar-orbltlng Operational Environmental Satellitee (POES)	NOAA	Weather/climate, land, ocean observations; emergency rescue	2 partially operational, 2 fully operational, launch as needed
Defense Meteorological Satelllte Program (DMSP)	DOD	Weather/climate observations	1 partially operational, 2 fully operational, launch as needed
Landsat	NASA/NOAA EOSAT[b]	Mapping, charting, geodesy, global change, environmental monitoring	Landsat 4 and 5 operational
Upper Atmosphere Research Satellite (UARS)	NASA	Upper atmosphere chemistry, winds energy inputs	In operation, launched In 1991
Laser Geodynamlcs Satellite (LAGEOS)	NASA/ltaly	Earth's gravity field, continental drift	One in orbit, another launched In 1992
TOPEX/Pose(don	NAS#CNES (France)	Ocean topography	In operation; launched in 1992

[a] The United States also collects and archives Earth data for some non-U.S. satellites

[b] EOSAT, a private corporation, operates Landsat 4 and 5. Landsat 6 failed to achieve orbit when launched In September, 1993 NASA and NOAA Will operate a future Landsat 7

SOURCE Off Ice of Technology Assessment, 1994

mandates. Federal, state, and local agencies and many private sector entities routinely employ remotely sensed data in a variety of ongoing research and applications programs. Assisted by the growing availability of powerful geographic information systems, users continue to develop applications for data from the Landsat and SPOT systems (box 1-2). NASA's research satellites have contributed important environmental data that scientists are using to study and understand global change processes.

Research on regional and global environmental change places increasing demands on the acquisition and use of satellite data. Although data from NASA's EOS satellites (figure 1-3) will be of much higher quality than most currently existing satellite data,[5] and will be designed to answer specific questions of critical importance to understanding global change, EOS satellites will not be operating until 1998, at the earliest. In the meantime, global change scientists will have to depend on data gathered from surface facilities, aircraft,

BOX 1-2: Selected Applications of Land Remote Sensing Data

- Agriculture
- Forestry and rangeland management
- Land resource management
- Fish and wildlife inventory and assessment
- Environmental management
- Water resources assessment and management
- Mapping
- Archaeological assessment
- Land use and plannlng
- Oil, gas, and mineral exploration

SOURCE Office of Technology Assessment, 1994

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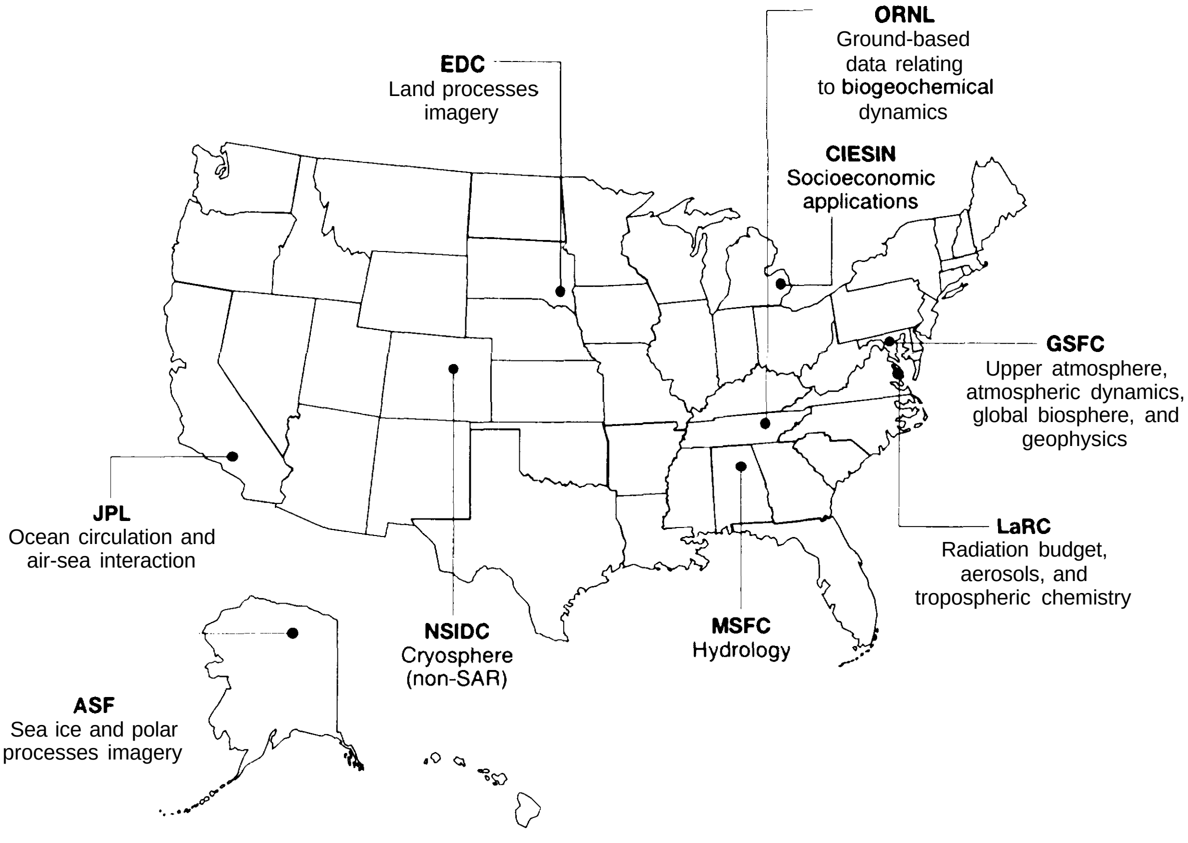
[5] Viz. from NOAA's operational satellites and from DOD'S DMSP. Although users are finding a wide variety of applications for data from these systems, they were primarily designed to serve the operational needs of weather forecasters and therefore lack the radiometric calibration and registration accuracy of instruments now in the design phase.

FIGURE 1-3: The EOSDIS Network



ASF = Alaska Synthetic Aperture Radar Facility, CIESIN = Consortium for International Earth Science Information Network, EDC = Earth Resources Observation Systems Data Center, GSFC = Goddard Space Flight Center, JPL = Jet Propulsion Laboratory, LaRC = Langley Research Center, MSFC = Marshall Space Flight Center, NSIDC = National Snow and Ice Data Center, ORNL = Oak Ridge National Laboratory

SOURCE National Aeronautics and Space Administration, 1993

operational satellites,[6] and pre-EOS research satellites. **Existing satellite data from the Landsat system, the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting and geostationary systems, and from the Defense Meteorological Satellite Program (DMSP) constitute a valuable record of regional and global environmental observations. The United States should protect and maintain these data in order to make them widely available for global change research.**

As noted in OTA's first report of this assessment, "To be effective in monitoring global change or in supporting resource management, the delivery of high-quality, well-calibrated, remotely sensed data must be sustained over long periods."7 In other words, the United States must maintain continuity of data delivery. In addition,

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[6] The term "operational" applied to satellite systems refers primarily to the way in which they are managed. Such systems have a large established base of users who depend on the regular, routine delivery of data in standard formats. Data users depend on such systems to operate indefinitely, and for the system operator to replace aging satellites and other system components when needed to maintain system operations.

[7] U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing From Space,* op. cit., p. 25.

putting remotely sensed data to use for myriad applications and for scientific research will require continuity in the management of data and information, using consistent, transportable data formats and methods to assure timely access to data originally acquired at many epochs. Satellite sensors gather several types of data. For example, most surface data, such as Landsat and Spot data, are collected electronically and stored as digital images.[8] Viewing these geospatial *data*[9] allows the user to see the underlying characteristics and patterns of the sensed surface (figure 1-4). Many atmospheric data, by contrast, are not images of a surface[10] but are sensed over a moderately wide field of view along a column of the atmosphere. Satellites can also collect data about the global magnetic and gravitational fields.[11]

Large data sets present a challenge to data and information managers.[12] Geospatial data represent a particularly difficult task for storage and access because standard database software does not handle spatial data particularly well.[13] Using spatial data more effectively and integrating them with other forms of data will require the development of new methods of manipulating and analyzing spatial data.

As noted, by the year 2000, U.S. and foreign satellite remote sensing systems will begin to generate massive amounts of data on a daily basis. These data will require adequate storage capacity. They will also require systems capable of managing, organizing, sorting, distributing, and manipu-

FIGURE 1-4: Landsat Image of Cape Cod, Southeast Massachusetts, 1974

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[8] The Russian Resurs-F satellites use a phonographic" imaging system, returning the film to Earth in capsules. Most aircraft imagery is collected photographically, although the use of electronic imaging devices on aircraft is growing.

[9] Data that are organized according to their location in some space. See ch. 2.

[10] In order t. visualize certain processes, and to watch (hem change over space and time, scientists may create images from nonspatial data sets. These *derived* data sets constitute powerful analytic tools but do not represent surfaces.

[11] See U.S. *congress,* Office of Technology" Assessment, *The Future of Remote Sensing from Space*, op. cit., p.6., for a synposis of satellite remote sensing characteristics.

[12] Each Landsat thematic mapper scene of six visible and infrared spectral bands (30 meters resolution) and one thermal band (120 meters resolute covers an area of 170 kilometers by 185 kilometers on a side and equals about 400 megabytes. Each SPOT scene of three spectral bands (20 meters resolution) and one panchromatic band (10 meters resolution) and 60 kilometers on a side equals 100 megabytes.

[13] See Nahum Gershon and Jeff Dozier, "The Difficulty With Data,"' *BYTE*, April 1993, pp. 143-147, for a discussion of the difficulties of using standard database software to handle spatial data.

wish to increase the U.S. investment in the development of data and information management systems. Such investment could also stimulate private sector development of high volume data and information management systems.

Data acquired by satellite also feed into a large and rapidly growing information industry that contributes markedly to the U.S. and global economy. Hence **the development of the market for remotely sensed data will be strongly influenced both by government policy and the capacity of the private sector to create new, more efficient methods of working with large assemblages of data.** Consumers of remotely sensed data increasingly expect the same type of service from government data providers that they expect from commercial suppliers in the information industry. Data consumers will demand online access to increasing numbers of remotely sensed data products, rapid turnaround, and responsive service. Additionally, consumers will concern themselves less with the technical particulars of the satellite platforms that provide data, focusing instead on the content of the data, and their value, timeliness, and ease of access.

Remotely sensed data exist on several different media, and in several formats.[14] Futher, the SYSterns used to archive and process the data use different software formats and operating systems. Data users often merge similar data from different satellites, or merge different data types, in order to create new information products.[15] For example, users have commonly merged 10-meter resolution panchromatic (black and white) data from the SPOT system with 30-meter resolution multispectral data from the Landsat system in order to achieve more detailed spatial and spectral coverage than is possible using the data from either satellite system alone.

More recently, as users gain experience with synthetic aperture radar (SAR) data from the European Space Agency's ERS- 1 satellite, they have begun to merge these data with SPOT and Landsat data.[16] However, because the data are of different scale and stored in different formats, successfully merging them can be extremely labor and computer intensive and may require heroic software development. **Although complete standardization of data formats is not feasible because of the various sensor characteristics, where possible the formats of remotely sensed Earth data should be selected to facilitate data transmission and processing with a minimum of reformatting.** At a minimum, data experts suggest, all data should contain a standard header that would communicate to the user how to read the data electronically. Because the federal government is the largest single supplier *and* purchaser of remotely sensed data, it could take a strong role in establishing standards for all spatial data. The Federal Geographic Data Committee (FGDC), operating under the aegis of the Office of Management and Budget (OMB), was established to coordinate U.S. geospatial data standards and formats. **Congress could assist the development of data standards by supporting the role of the Federal**

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[14] See U.S. congress, Office of Technology Assessment, *Data Format Standards for Civilian Remote Sensing SateI/i(es* (Washington, DC: Office of Technology Assessment, April 1993), for a discussion of the wide variety of data formats and media in use for remotely sensed data.

[15] SPOT Image Corp., for example, has developed a wide variety of data products to meet the diversity of market demand, including its SPOTView geographically corrected images available in 7.5 minute or 15 minute quadrangles.

[16] The ITD Remote Sensing Center at Stennis Space Center, Mississippi, has merged ERS-1 and SPOT data to examine the extent of the 1993 flooding along the Mississippi River near St Louis, MO. The two systems produce data in quite different formats at 12.5 meters and 10 meters resolution, respectively. The merged image reveals the boundaries of flooded agricultural fields and the extent of flood damage to urban and suburban areas. "Merged Satellite Images Map Midwest Flood Plain," *Aviation Week and Space Technology*, Aug. 16, 1993, p. 27.

[17] U.S. Congress, *Of* ffice of Technology" Assessment, *Data Format Standards for Civilian Remote Seining satellites* (Washington, DC: Office of Technology Assessment, April 1993), p. 11.

Geographic Data Committee in setting standards for Federal Government data producers.[18]

The development of commonly available high-capacity storage media such as CD-ROM will make possible the delivery of remotely sensed data to non-specialists who could use them for education, entertainment, and to analyze regional and local environmental, demographic, and municipal developmental conditions.[19] **Non-specialized users who would like to use remotely sensed data and integrate them with other spatial data will also need more user friendly software and cheaper, more powerful hardware.** If current trends continue, the general information industry will have the capacity to develop the necessary hardware and software.

Remotely sensed data are collected by systems operated by NOAA, NASA, and DOD. Many other government agencies, including the Department of Interior and the Department of Agriculture, make extensive use of satellite data. These agencies have attempted, with partial success, to coordinate geospatial data management and the development of data standards through the Federal Geographic Data Committee. **The congressional committee structure, in which responsibility for agency matters is spread across several committees, complicates oversight of a cohesive, comprehensive strategy for managing remotely sensed data.** More intensive coordination among committees with oversight and jurisdiction over remote sensing activities will be essential in supporting attempts to establish and use common data standards.

THE MANAGEMENT AND ANALYSIS OF DATA AND INFORMATION

The growing dependence on satellite data raises several significant questions: Is the United States archiving the appropriate data? Can potential users retrieve existing data when needed? Does the United States have sufficient institutional facilities and data management systems to serve users quickly and efficiently? What new investments might be needed to support the ability of Federal agencies to protect and manage the data for which they are responsible?

NASA, NOAA, and the Department of the Interior currently archive remotely sensed data in several facilities under a variety of physical conditions and data management regimes (table 1 -2). In the future, most of these archives will participate in NASA's EOSDIS, either directly as distributed active archive centers or indirectly as associated active archives.

Even without the development of EOSDIS, the proliferation of remote sensing systems requires the federal government to devote increasing resources to archiving data and managing their distribution. Properly archiving remotely sensed data will require periodic upgrades to systems for data storage and retrieval, improvements to the search algorithms, and expansion of communications capacity at archive centers. Handling data distribution from future remote sensing systems also will require innovative data management systems. Supporting the requests of increasing numbers of scientists and other data users may require substantial additional future investment. Because the efficient management of remotely sensed data is so important to effective use of the data, **Congress may wish to monitor the plans of NASA, NOAA, and the Department of the Interior for updating their data management facilities to assure that they are meeting the needs of increasing numbers of data users.**

Potential data users often have difficulty locating U.S. and foreign sources for their data, some of which are now stored in universities or local

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[18] See, National Research Council, *Toward a Coordinated Spatial Data Infrastructure for the Nation* (Washington, DC: National Academy Press, 1993) for a discussion of spatial data infrastructure issues and recommendations.

[19] The Prices of CD-ROM readers have fallen dramatically over the past year, increasing their availability to the public. Many data centers already distribute selected data sets on CD-ROM.

TABLE 1-2: U.S. Government Remotely Sensed Data Archives

Archive center	Location	Archive holdings
U S. Geological Survey, EROS Data Center	Sioux Falls, SD	Land imagery acquired by the US government
NOAA National Climate Data Center	Asheville, NC	Weather and climate data from NOAA satellites
National Center for Atmospheric Research	Boulder, CO	Atmospheric data; atmosphere and climate modeling data
NASA. Goddard Space Flight Center	Greenbelt, MD	Upper atmosphere, atmospheric dynamics, global biosphere, and geophysics
NASA. Jet Propulsion Laboratory	Pasadena, CA	Sea surface, ocean circulation, and air-sea interaction data
NASA Langley Research Center	Hampton, VA	Radiation budget, aerosols and tropospheric chemistry
NASA Alaska SAR Facility	Fairbanks, AK	U S ground station and archieve for ERS-1, JERS-1, and eventually ERS-2 and Radarsat
NOAA-GOES archive	Madison, WI	Soundings and images from U S GOES satellites
NASA - WetNet: Marshall Space Flight Center	Huntsville, AL	Hydrologic data
National Snow and Ice Data Center, University of Colorado	Boulder, CO	Snow and ice data

SOURCE National Aeronautics and Space Administratlon, 1993

government holdings. **In order to take full advantage of the existing investment in remotely sensed data, and to avoid duplication in future data acquisition, Congress may wish to consider instructing Federal agencies to develop a centrally coordinated "metadata set," a complete listing of the sources and types of remotely sensed data held in different facilities, and a data tracking mechanism to provide government and other customers with access to the sources of appropriate data.** A metadata set would ensure maximum exploitation of data that the government has already acquired, and allow creation of an online catalog to facilitate use of new data.[20]

| NOAA Operational Satellite Data

NOAA routinely archives data from its polar orbiting satellites at the National Climatic Data Center (NCDC), whose central office is located in Asheville, NC (figure 1 -5).[21] NCDC is a division of the NOAA Environmental Satellite Data and Information Service (NESDIS). NCDC also archives all U.S. and many foreign historical climatic records, which NCDC receives on paper, magnetic tape, and through online delivery. Proper storage of these important historic records of weather and climate from land and ocean observations presents a considerable challenge to NCDC.

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[20] The National Research Council has recommended the development of such a metadata set for geospatial data generally. See National Research Council, National Mapping Committee, *Toward a Coordinated Spatial Data Infrastructure for the Nation* (Washington, DC: National Academy Press, 1993), recommendations 1 and 2, pp. 120-123.

[21] The archive of satellite data is maintained at NESDIS headquarters, Silver Hill, MD.

FIGURE 1-5: The National Climatic Data Center Building, Asheville, North Carolina

SOURCE National Climatic Data Center, 1994

Satellite and other data are available to customers in a variety of forms, including paper; photographs; magnetic tape; floppy disks; CD-ROM; electronic mail; online dial-up; telephone; and facsimile. NCDC provides data for the cost of fulfilling the user's request. NCDC has a new archiving and data distribution facility that should improve its efficiency in responding to the many yearly requests it receives for data. In particular, NCDC is experimenting with making current data available online through Internet using NCDC'S On-Line Access and Service Information System (OASIS) .22 OASIS distributes weather and climate data as soon after processing as possible through file transfer protocol (FTP) computer access. Up to 50 MB can be downloaded from the system at a time free of charge via FI'P. Alternatively, users can order data offline at standard NCDC charges. OASIS also distributes metadata about the data that include weather station histories, data dictionaries, field experiment information, and data inventories.

NOAA collects data of 1 and 4 km resolution[23] over the United States from the Advanced Very High Resolution Radiometer (AVHRR) sensor on its polar-orbiting satellites[24]. Among other things, NOAA uses these data to generate vegetation index maps of 4 km resolution. These maps have proved extremely useful in following broad trends in the seasonal vegetation round (app. B).

1 Land Data

The Earth Resources Observation Systems (EROS) Data Center (figure 1 -6) is the official archive for all Landsat data. The Earth Observation Satellite Corp. (EOSAT) manages the operation of Landsats 4 and 5, collecting and marketing data from the Thematic Mapper (TM) instrument. EOSAT ceased collecting data from the lower resolution (80 - meter) Multispectral Scanner (MSS) instrument in December 1992 because the market for such low-resolution data had become very small. Following U.S. law, EOSAT sells TM data to all customers[25] on a nondiscriminatory basis.[26] As the result of an agreement between EOSAT and the Department of Commerce, the EROS Data Center distributes all multispectral sensor (MSS) data to all customers for $200 per scene (on

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[22] See ., National Climatic Data Center Products and Services," brochure available from NCDC, Asheville, NC, for information about NCDC products and services, and an Internet address.

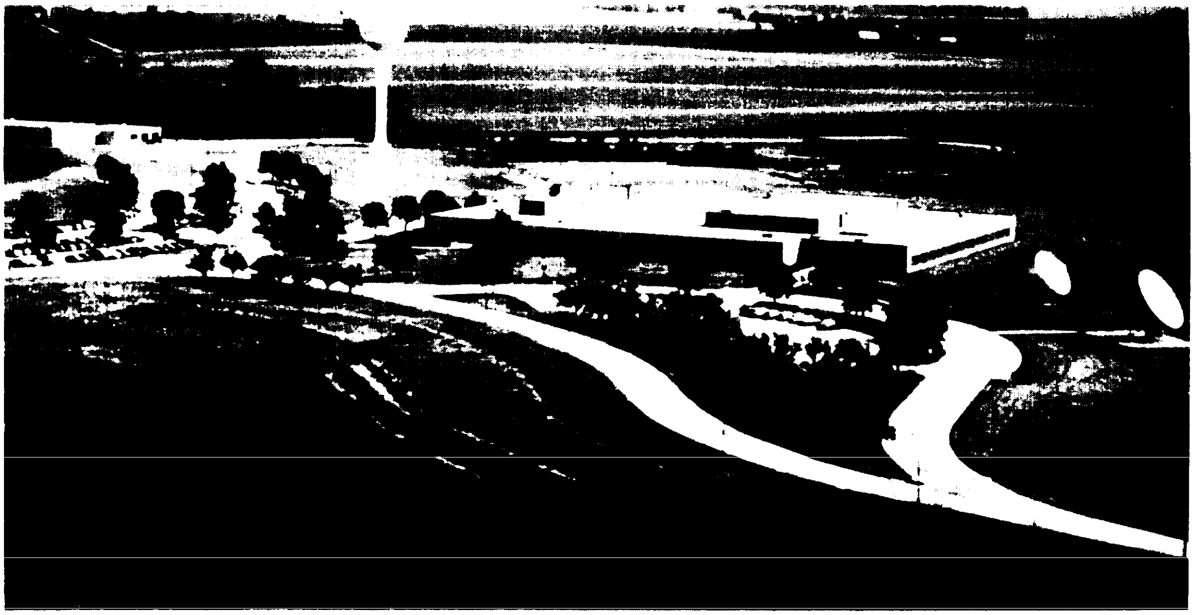
[23] Resolution is the measure of a viewer to distinguish between objects. For data of 4-kilometer resolution, the sensor averages the light intensity gathered by the sensor over a 4 kilometer square. See U.S. Congress, *The Future of Remote Sensing From Space*, op.cit.,p.60,for a discussion of resolution.

[24] See app. A.

[25] Consumers include federal, state, and local government agencies and private consumers.

267-he *Land Remote-Sensing Commercialization Act of 1984* codified the concept of nondiscriminatory access to data from remote sensing systems developed and owned by the federal government (98 STAT. 453; 15 USC 4204). See U.S. Congress, Office of Technology Assessment. *Remote Sensing and the Private Sector: Issues for Discussion* (Washington, DC: U.S. Government Printing Office, 1984), pp. 34-.?6. The policy was continued with the passage of *The Land Remote Sensing Policy Act of 1992* (Public Law *102-555).*

FIGURE 1-6: EROS Data Center, Sioux Falls, South Dakota



SOURCE EROS Data Center, 1994

magnetic tape). Starting in 1994, it will begin to sell thematic mapper (TM) data that are more than 10 years old for between $300 and $500 dollars a scene.[27] EOSAT retains the right to sell TM data from Landsats 4 and 5 that are less than ten years old.[28] For certain uses, such as geological survey, archaeology, or mineral exploration, the older data are often sufficient. However, time-critical uses, such as agriculture, natural disaster damage assessment (box 1-3), or rights of way planning, require recent data delivered quickly.

For observing and analyzing the extent and types of changes to the landscape over the long term, the archives of Landsat and SPOT data are extremely valuable. Landsat data have been collected for more than 20 years; SPOT data since 1987. However, the EROS Data Center holds only a limited number of scenes from other countries. Foreign Landsat ground stations have archived many MSS and TM scenes over the years. **In order to assist with global change research, Congress may wish to consider funding the EROS Data Center to assemble and archive a basic collection of historic Landsat scenes collected at foreign Landsat stations.**

At a minimum, as noted above, data customers should have access to a comprehensive database of historic and contemporary international holdings. The EROS Data Center has begun to develop such a database in connection with the development of its online database, the Global Land Information System (GLIS). GLIS enables potential customers to browse USGS remote sensing, cartographic, hydrologic, and geologic data and in-

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[27] The price of TM data has not yet been set, but will depend on the cost of producing and distributing the data.

[28] EOSAT retains exclusive rights to sell data from Landsats 4 and 5 as long as they remain operational. See Ben Ionatta "EOSAT Retains Landsat Rights," *SpaceNews*, May 2-8, 1994, p. 10. EOSAT charges $4,400. for a single standard TM scene. Other prices may apply for volume purchases or for federal government purchases.

BOX 1-3: Disaster Preparation and Assessment

As the recent experiences of Hurricane Andrew, with the Midwest floods, and the Los Angeles earthquake have demonstrated, remotely sensed data can be extremely useful for assessing the damage after a natural disater. Of more Importance, such data can also be used to prepare for natural disasters by analyzing areas most at risk, Identifying escape routes, and making specialized maps to guide assistance efforts

The broad availability of digital data and geographic Information systems for analysis makes these complicated tasks much easier than ever before Thorough citizen preparation in land and coastal regions at risk could save millions of dollars In State and Federal disaster relief and possibly save lives as well However, such preparation Will require a coordinated effort by local, state, and federal agencies

SOURCE Office of Technology Assessment, 1994

formation. In addition, users will need relatively effortless access to information on other, nonspatial data sets.

Because SPOT data are also of interest for scientific research, the United States may also wish to purchase a representative set of SPOT scenes for these purposes. Global change scientists and other users could be polled for suggestions of which areas are of greatest significance.

Some data from both Landsat 1 and Landsat 3 have become extremely difficult for the EROS Data Center to make available to potential cus-Costomers.[29] The Data Center holds some 310,000 scenes of wide band video tape from Landsat 1, which, at present, cannot be read because they were recorded on a proprietary system that no longer functions. In addition, some 30 percent of these tapes have degraded and will need special processing in order to recover the data they contain. The EROS Data Center has a program underway to recover historic Landsat data and put them on more permanent media. **In order to complete the task of recovering these early data, the EROS Data Center will need between $1 and $3 million of additional funding over the next three years.** Some Landsat 3 data tapes also have degraded and will require special processing.[30] Recovering the data on these tapes could be a relatively inexpensive way to gather data regarding longterm ecological change.

These situations underscore the importance of proper archiving of data from both government and private sources. The experience with Landsat 1 data also illustrates the importance of avoiding specialized data systems designed to optimize storage and delivery of one type of data. Especially given the wide availability of standard information technology today, it should be possible for agencies to avoid developing such systems.

The increasing number of online databases, such as the EROS Data Center GLIS, will improve the ability of data customers to locate and order needed data over the Internet. **The availability of the Internet to a wide variety of users will have a significant effect in increasing the**

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[29] Landsat 1 was launched in 1972 as the Earth Resources Technology Satellite. It transmitted data until 1977. Landsat 2 was launched in 1975 and transmitted data until 1977. Landsat 3 was launched in 1978 and returned MultiSpectral Scanner (MSS) data until 1982, when NASA launched Landsat 4.

[30] During the early 1980s when the Landsat program was in doubt, many Landsat tapes were allowed to remain in storage at the Goddard Space Flight Center under poor environmental conditions. There, they took on moisture, which caused the binder in the tape to degrade. The tapes are now stored in a humidity-controlled environment at the EROS Data Center. By carrying out careful research on the tapes with the help of the National Media Laboratory, the center has discovered that it can recover data on some of these tapes by baking them. See National Media Laboratory *Bulletin*, *1993.*

number of potential customers for remotely sensed data and other forms of environmental data. Eventually, customers may be able to acquire data online as well, rather than waiting for data sets to be delivered on magnetic tape or other media. However, because most satellite data sets are so large, such improved methods of data delivery will have to wait until higher capacity transmission lines are installed. At present, online database systems display spatial data scenes that have been drastically reduced in detail and size by sampling so they can be transmitted to the customer for viewing over normal telephone lines. The costs of installing high-speed, high-capacity transmission lines will be substantial. Although users of remotely sensed data are likely to benefit from having access to improved transmission lines, driven by large-scale commercial applications, the remote sensing market alone is too small to propell such installation.[31]

NASA'S EARTH OBSERVING SYSTEM DATA AND INFORMATION SYSTEM

NASA has begun full scale development of the Earth Observing System Data and Information System (EOSDIS) in order to support the data storage and distribution needs of its Earth Observing System (EOS), the centerpiece of NASA's Mission to Planet Earth. NASA is designing EOS to provide continuous, high-quality data over a minimum of 15 years[32] to assist in the scientific study of Earth's atmosphere and surface.[33] When EOS is fully operational, sensors aboard EOS satellites will generate immense quantities of data. NASA scientists estimate that each day, EOS instruments will generate an average of 220 gigabytes[34] of digital data, the equivalent of the storage capacity of 2,200 one-hundred megabyte hard disks found on modern personal computers. Data from other U.S. and foreign satellite systems could double this inflow. When EOS and EOSDIS are fully operational, scientists may use the unprocessed data to generate as much as 400 megabytes of additional processed data per day, most of which would be stored and distributed through the EOSDIS network. The complexity and amount of EOS data will therefore require a highly sophisticated data system in order to make these data useful to EOS program scientists and other potential users. EOSDIS will be the largest and most complicated civilian data system ever attempted. Possible future satellites using many visible and infrared spectral bands or synthetic aperature radar, would add substantially to the EOSDIS data burden.

Architecturally, EOSDIS will represent a departure from previous data management systems, as it will be composed of eight interconnected Distributed Active Archive Centers (DAACs). Located at regional sites across the country (fig. 1-3), each archive will store, process, and distribute data related to specific disciplines. For example, the EROS Data Center in Sioux Falls, South Dakota, archives and distributes satellite and aircraft land data; the Jet Propulsion Laboratory in Pasadena, California, holds data on ocean circulation and the interaction between the atmosphere and the oceans; and NASA's Alaska SAR facility archives synthetic aperature radar (SAR) data of snow, ice, and sea surface (table 1-2). However, if EOSDIS works as planned, users stationed at terminals in any EOSDIS archive or other properly

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[31] The telephone companies and the cable television companies are competing for the opportunity to install high transmission capacity lines for commercial purposes.

[32] To achieve 15-year data sets, NASA plans to fly EOS "AM" and "PM" platforms 3 times at 5 year intervals. NASA scientists expect that 15 years will be long enough to observe the effects of climate change caused by the sunspot cycle (1 1 years), several El Nios, and eruptions of several major volcanoes. Large-scale changes such as deforestation should also be detectable over such a period.

[33] See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing From Space*, op. cit., ch. 4 and app. B, for descriPtions of the EOS program.

[34] A gigabyte is equal t. 1 billion bytes of data; a megabyte is equal to 1 million bytes.

equipped facility will be able to access data from anywhere in the system routinely.

Concern over the size and complexity of EOSDIS has caused some data processing experts to question whether the system will ever meet one of its primary objectives-ass i sting scientists from a wide variety of disciplines to work collaborative y on global change research online, using data sets that have been acquired by satellite only a few hours or few days earlier. **Data management will be especially challenging for EOSDIS. Not only does NASA plan to process extremely large quantities of raw data daily, it also expects to make them available to users within a day or so of initial reception.**

As part of its EOSDIS efforts, NASA has funded the development of so-called Pathfinder data sets composed of data gathered over the past decade or two from sensors aboard the Landsat satellites and from the NOAA operational environmental satellites (box 1 -4), These have already proved extremely valuable in pointing the way toward more effective global change research; they are proving especially helpful in managing natural resources.[35] The early experience of NASA, NOAA, and the EROS Data Center in developing these Pathfinder data sets illustrates some of the difficulties NASA will likely encounter in processing the massive amounts of data from the EOS satellites.[36] Not only have experimenters had to recalibrate data from various epochs to the same standard, they have had to locate sources of data to assemble complete data sets. For example, NASA funded the EROS Data Center to develop a global data set of 1 -km AVHRR data from the NOAA polar-orbiting satellite system (POES).[37] NOAA does not routinely archive 1 -km data collected globally and does not normally record 1 -km data on its POES tape recorders. Hence, the EROS Data Center, working with NOAA, the international Committee on Earth Observations Systems (CEOS), and other organizations had to establish a network of foreign suppliers of data collected on High Resolution Picture Transmission (HRPT) stations[38] around the world. The EROS Data Center now receives AVHRR data tapes from about 26 foreign and 3 domestic HRPT stations on a monthly basis.

BOX 1-4: Pathfinder Data Sets

- Advanced Very High Resolution Radiometer (AVHRR) data sets held by NOAA
- `TIROS Operational Vertical Sounder (TOVS) data held jointly by NOAA and NASA
- GOES data by the University of Wlsconsln under contract with NOAA
- Special Sensor Microwave/lmager (SSM/1) data acquired by NOAA from the
- Department of Defense
- Scanning Multichannel channel Microwave Radiometer (SMMR) data recorded from the Nimbus-7 satellite
- Landsat data in the USGS arch we at the EROS Data Center.

SOURCE Office of Technology Assessment, 1994

The very creation of EOSDIS represents a major departure from existing practices for NASA. Generally, scientific data acquired by satellite are first examined and used by the principal investiga-

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[35] For example data from AVHRR are proving how Earth's vegetation reacts to changes in climate. See Debra Polsky Werner. "Satellite Data Used in Carbon Dioxide Exchange Study"' , *Space News* Jan. 17-23, 1994, p. 17. They are also serving to monitor deforestation in Amazonia.

[36] U S Congress, General Accounting Office, GAO/IMTEC-92-79, *Earth Observing System: Information on NASA's Incorporation of Existing Data Into* I; *OSDIS* (Washington, DC General Accounting Office, September 1992).

[37] NOAA does, however, archive 4-kilometer data that it uses to create global vegetation maps.

[38] The High Resolution picture Transmission stations are standard systems for collecting data from NOAA's POES satellites. Some 140 countries and other entitites maintain such systems. Tbey are much more capable than the Automatic Picture Transmission stations that collect low resolution data from the polar orbiters.

tors, and later made available for other users. NASA has no central guidelines for archiving data for possible future use. Each facility has established its own methods and guidelines. Over the years satellite data have been stored on a diversity of media in many different storage facilities and environments.

However, with the advent of global change research, which requires consistency in the collection, archiving, and distribution of most satellite data, NASA recognized the need to establish a much more structured approach to the storage and management of data. Hence, it is attempting to design and develop a data system that can be employed to detect subtle changes in the Earth's environment by providing long term data sets. NASA expects to operate EOSDIS for at least 15 years after the launch of the second major satellite (PM-1) in the year 2000. The program will therefore take on the characteristics of what has been called an "operational program''—in other words, sustained, routine acquisition of data that must be consistently available to researchers and other users on a timely basis. NASA may not be well structured to operate a program like EOSDIS on a long term basis.[39] The development of an operational system for EOS data will challenge NASA's institutional culture, which prides itself on adopting the latest in technology for its systems, and pushing the limits of research. However, to maintain operability of EOSDIS, the technology employed in EOSDIS must be capable of operating continuously and with high reliability.

On the other hand, NASA also must make EOSDIS responsive to changes in scientific priorities and in the development of new technologies for data management and analysis. **A continual tension will exist between the need to maintain EOSDIS as an operational system that can be accessed routinely by a wide variety of data users and the desire to keep up with advancements in technology that would make the system ever more capable.** EOSDIS will require periodic oversight by the scientific community to ensure that it serves the needs of scientists studying local, regional, and global change and other long-term environmental effects. Current plans call for EOSDIS to receive upgrades of hardware and software over time. NASA will have to work diligently to make certain that these upgrades will not interfere with the routine operation of EOSDIS. **Maintaining EOSDIS as an operational system routinely accessible by data users and keeping up with advancements in technology will require adequate and stable funding.**

NASA has designed EOSDIS primarily to provide researchers, particularly those funded by NASA, with access to the data collected by EOS and other satellites supported by NASA's Mission to Planet Earth. However, **the utility of data held in EOSDIS extends far beyond the use of these data by NASA-supported scientists. Myriad other users will find them useful for scientific research and for managing U.S. public and private resources.** As a result, NASA is now developing methods to enable extensive access to EOSDIS. In broadening access to EOSDIS data and information, NASA could be faced with pressure to support the data needs of more users than it is funded to support, thereby jeopardizing NASA's plans to develop a research data and information system for the global change research community. Many of these data will be of interest to regional users. **NASA** plans to limit direct involvement in providing data to the general research and data applications community by making data available at the cost of reproduction. **Congress may wish to monitor NASA's plans for making EOS data available to the community beyond NASA in order to assure itself that these data are widely distributed.**

Making EOSDIS data available online requires the use of extremely high speed data lines. NASA intends to create its own high-speed data links

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[39] U.S. Congress, Office Of Technology Assessment, *Civilian Space Policy arid Applications* (Washington, DC: U.S. Government Printing Office, July 1982), pp. 242-43.

among DAACS. Unless the federal government plans to underwrite public high-capacity data networks, the high costs of high-capacity data communication could constrain public access to EOSDIS. Although broader network access entails significant benefits beyond EOSDIS, the development and operational costs of a broad communications network could be extremely high.

The need for a data and information system for global change research extends well beyond NASA's EOSDIS. The Subcommittee on Global Change Research, Committee on Environment and Natural Resources Research of the National Science and Technology Council,[40] which coordinates research of the U.S. Global Change Research Program, has noted the desirability of establishing a Global Change Data and Information System (GCDIS) that would bring all global change data together in one system.[41] GCDIS, as conceived by the ad hoc Interagency Working Group on Data Management for Global Change (IWGDMGC), would provide mechanisms for assembling, storing, and sharing global data and information among participants in the USGCRP. EOSDIS is the largest single element of GCDIS. Although CEES has included funding for archiving and sharing global change data in projected USGCRP budgets, GCDIS is not funded as a separate activity. In addition, no single agency has responsibility for assembling and managing the data that would be included in GCDIS.

The House Committee on Science, Space, and Technology has proposed assigning NASA the lead role in GCDIS, on grounds that the effort could otherwise remain a "rhetorical program," without sufficient focus.[42] In terms of funding, NASA already has de facto leadership in global change research.[43] Its EOSDIS eventually will also contain the largest holdings of global change data. From a practical standpoint, therefore, making NASA the lead agency for GCDIS might be appropriate. EOSDIS could be expanded to include access to other, nonsatellite data. However, this would require NASA to increase spending on EOSDIS by modest amounts to make EOSDIS fully interoperable with other data sources. Additional funding for this would likely amount to a total of $10 to $20 million, spread over several years. In addition, such an action would also give NASA even more responsibility and authority in global change research, and increase the influence of satellite data in that research.[44] The objectives of EOSDIS are challenging enough, and giving NASA responsibility for GCDIS would add complexity to its program. If Congress decides to give NASA responsibility for GCDIS, the decision should be made soon in order to allow NASA to include GCDIS requirements in its plans for EOSDIS. Attempting to add GCDIS requirements to EOSDIS after NASA completes its specifications would be costly. **If Congress gives NASA the responsibility for managing GCDIS, it will also have to provide additional funds to do so. Alternatively, it could direct NASA to transfer funding from its other programs to accommodate the requirements of GCDIS.**

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[40] This committee superceded the committee on Earth and Environmental Sciences (CEES). See Committee on Environment and Natural Resources Research. *Our Changing Planet: the FY 1995 U.S. Global Change Research Program,* Supplement to the President 's Fiscal Year 1995 Budget, 1994.

[41] Committee on Earth and Environmental Sciences, *The U.S. Global Change Data and Information Management Program Plan* (washington, DC National Science Foundation, 1992).

[42] U.S. Congress, House Committee on Science, Space, and Technology, *National Aeronautics and Space Administration Authorization Act, Fiscal Years 1994 and 1995,* report 103-122, June 10, 1993, p. 86.

[43] U s Congress, Office of Technology Assessment, *The Future of Remote Sensing,* op. Cit., p. 13.

[44] 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).

As noted above, the NOAA archives hold significant global change data. Under present NASA plans, the NOAA archives would be affiliated archives, and not part of the DAAC structure.[45] NASA prefers not to fund NOAA data centers and NOAA prefers to maintain a high degree of autonomy for its data centers. If the NOAA data archives do not become part of EOSDIS, it will be extremely important for NASA and NOAA to work closely together to assure that EOSDIS data centers and the NOAA data centers are fully interoperable. Otherwise. the United States could lose a valuable asset in the study of global change. **Congress may want to hold periodic hearings focused on the structures and roles of the various data centers to assure that they will operate efficiently and effectively for the greatest benefit to the nation.**

If EOSDIS is successful, it could provide a model for operational data archives of the future. For example, EOSDIS could continue to operate after the existing EOS program has been completed, when or if EOS has been superseded by an international global satellite monitoring system.[46] However, EOSDIS will be expensive to maintain. For EOSDIS to continue to provide data will require continual efforts to reduce operating costs. EOSDIS will also require steady funding on a long-term basis.

Increasingly, researchers see the need to develop an operational climate monitoring system to operate over decades, well beyond the 15-year lifetime of the EOS program.[47] That system will also need a data archiving and management system in order to make the data from climate monitoring satellites available to researchers in a timely manner. **Congress may wish to instruct NASA and NOAA to examine the long-term needs for climate data from satellites and recommend a data system to archive, manage, and distribute such data. The agencies should also recommend which agency or agencies should operate such a system, if developed.** Although a decision about a system will not be needed before the end of the century, the development of EOSDIS and NOAA's data systems could provide some useful lessons for such a long-term climate monitoring system.

PUBLIC AND PRIVATE ROLES IN A DEVELOPING MARKET

If current trends continue, the private sector will play a crucial role in the future of satellite remote sensing. Until recently, private industry acted solely as supporting contractors in building and operating government remote sensing systems and as participants in the value-added industry, turning raw geospatial data into useful information. More recently, several private firms have decided to build and operate their own satellite systems, providing raw geospatial data as well.

Private industry has particularly demonstrated its strength by developing methods to enhance the utility of remotely sensed data. The commercial value-added industry has grown significantly over the past decade. Increased interest in, and availability of, remotely sensed data, combined with advances in data processing and storage technologies, have enabled value-added data resellers to process and analyze data for Federal, State, and Local governments and many industries.[48] Value-added companies and firms developing new data management and processing soft-

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[45] As noted above, by contrast the U.S.G.S. EROS Data Center will be a NASA DAAC, and will receive funding from NASA to participate in EOSDIS.

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

[47] U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, op. cit., pp. 3-4; pp. 34-36.

[48] For example, for the agriculture, timber, mining, and oil and gas industries. See app. B.

ware will remain important elements in the data industry, as they find more efficient, powerful methods for turning data into information.

Private industry is very active in providing photographic and digital data from aircraft (figure 1 -7). Recently, four private firms or consortia have developed plans to build and operate private satellite systems (box 1 -5). Others may also enter the marketplace. The ability of private firms to operate successful private satellite systems will depend on several factors, including potential market growth provided by the development of new, more capable data sources and new applications. It will also depend on government policy toward these firms, including how many of the sources of production the government decides to retain.

Potential for Market Growth

OTA estimates the existing market for raw data alone to be about $150 to $200 million per year, growing at a rate between 15 and 20 percent per year.[49] These estimates include the sales of satellite data from Landsat (through EOSAT and EROS Data Center[50]), SPOT (through SPOT Image Corp.), and aircraft data from private corporations and the EROS Data Center. The market for value-added services is much larger, and is estimated at $300 to $500 million yearly. It is growing at a similar rate. Remote sensing experts contend that as satellite systems become more capable and begin to produce data of higher resolution in stereo mode that can be used for detailed maps, the global market for remotely sensed data will grow much more quickly.

Prospective satellite operators expect to compete directly with the aerial imagery industry, which use photographic, rather than digital means to acquire imagery. However, data of 1 to 3 meters resolution are at the low end of the potential resolution scale for aerial imagery. The aerial imagery industry is likely to respond to competition from satellite-generated data by developing powerful digital sensors and by targeting markets for data of higher resolution than 1 meter. Satellite data will be of greatest interest over areas that for political or geographic reasons are difficult to reach by aircraft. They are likely to be in especially strong demand for military and intelligence uses.[51]

FIGURE 1-7: Photographic Image of Seattle Taken as Part of the National Aerial Photography Program, 1980

SOURCE EROS Data Center, 1994

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[49] The loss of Landsat 6 will likely inhibit expected market growth. Had Landsat 6 functioned successfully, the Enhanced Thematic Mapper (ETM) aboard Landsat 6 would have provided panchromatic data of 15 m resolution, 6 visual and infrared bands of 30 m data, and 1 thermal infrared band of 60 m resolution. The improved resolution of the ETM compared to Landsats 4 and 5 was expected to boost the market for land remote sensing data.

[50] The U. S.G.S. EROS Data Center distributes all Landsat multispectral scanner (MSS) data. It charges fees for data equal to the cost of reproduction and distribution.

[51] Brian McCue, "The Military Utility of Civilian Remote Sensing Satellites," *Space Times*, January - February, 1994, pp. 11 - 14; and Ray A. Williamson, "Assessing U.S. Civilian Remote Sensing Satellites and Data," *Space Times*, January - February, 1994, pp. 6-10.

BOX 1-5: Remote Sensing Satellite Firms

Orbital Sciences *Corp.*

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 Corp. (OSC) plans to market SeaWiFS data to the fisheries, ocean shipping firms, and to other ocean-related enterprises, However, OSC'S primary customer is NASA, which will use the data for global change research.

WorldView Imaging Corp.

World View is developing atwosatellite-multispectral land remote sensing satellite system capable of 3-meter resolution in stereo (3-meter panchromatic; 15-meter 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.

Lockheed Missiles and Space Co., has formed a company to design and build a multi spectral stereo land remote sensing satellite system capable of achieving resolutions of one meter (panchromatic), The Department of Commerce has granted Lockheed an operating license. Lockheed expects to launch its first satellitete by late 1997.

Eyeglass *international*

Orbital Sciences Corporation, Litton's Itek, and GDE Systems, Inc. have entered into a joint venture to build and operate a land remote sensing satellite system capable of gathering 1-m resolution panchromatic stereo data. The Department of Commerce has issued an operating license for the system, and Eyeglass plans to launch its first satellite in 1997,

SOURCE Off Ice of Technology Assessment, 1994.

Growth of the market for geospatial data will depend primarily on:

1. the ability of the marketplace to find additional applications for data from existing systems;
2. the distribution of data with higher spectral, spatial, and temporal resolution;
3. the development of user friendly software that will enable a wider set of users to apply raw data to new problems;
4'. the ability of data providers to reach the customer quickly and efficiently after aquiring data; and
5. reductions in the costs of providing raw data. The availability of data having better features (e.g., stereo) than currently offered by either EOSAT (the Landsat system) or by SPOT Image, could also stimulate the market, especially if these data can reach the customer in a timely and cost-efficient manner.

Government Production

Private industry has the capability of building and operating high resolution satellite systems. As required by the Land Remote Sensing Policy Act of 1992,[52] the federal government plans to develop and operate Landsat 7 to generate moderate-resolution (30-meter) data for public and private uses. Landsat data, which are extremely important for global change research and other uses, will continue to complement high-resolution aircraft data. In

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[52] In order to maintain data continuity from the Landsat system. See Public Law 102-555, 106 STAT. 4163, Sec. 2, Findings.

the future, Landsat data are likely to contribute to the growth of data sales of higher resolution (1 to 3m) data from privately operated systems.

Government Policy Toward Private Satellite Operators

Government policy toward private operators is likely to be the most important determinant in the success or failure of private firms. The Land Remote Sensing Policy Act of 1992 removed two major impediments to potential private data suppliers. First, it clarified and simplified the rules by which the Department of Commerce could grant an operating license, and restated that the Department of Commerce had 120 days to rule on a license request.[53] it also clarified data distribution and pricing policy by allowing firms to set their own terms and prices for remotely sensed data, provided they receive no direct development support from the Federal Government.

Commercial growth in remote sensing poses several challenges for government policy. The federal government could let the market grow naturally, provided such activity would not threaten U.S. security.[54] However, private *firms Still may* face competition from data gathered and sold by the Federal Government, which could inhibit the firms' ability to earn a profit.[55]

Government could also assist in reducing the risks faced by new entrants into the remote sensing industry by purchasing data from private enterprise rather than procuring competing satellite systems in competition with industry.[56] **If Congress wishes to encourage the market for data from private satellite systems, it could require the Federal agencies to purchase data rather than satellite systems from the private sector, where feasible.** If the proposed private sector systems prove successful in delivering high-quality data in a timely manner, federal agencies are likely to save money on their data needs.

In particular, data purchase arrangements, in which the government agrees in advance to purchase a specified quantity of data of specified quality and type, might enable agencies to reduce the costs associated with data acquisition. Such a data purchase agreement also helps the commercial provider to mitigate some of the financial risk associated with commercial ventures. On the other hand, the government must be prepared to accept market conditions that might produce data to specifications other than what the government would set; i.e., the government might not be able to set the precise terms of data acquisition, especially if external market forces dictate different specifications. Scientists might have particular difficulty purchasing appropriate data from private firms because they are likely to have less control over such matters as data calibration and spectral characteristics.

Because privately acquired data are likely to have considerable importance in research on global change and for long-term resource management, the federal government may wish to archive many of these data. The Land Remote Sensing Policy Act of 1992 provides for the federal gov-

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[53] However, Lockheed Corp. submitted its formal request for a license to operate a satellite capable Of collecting data Of 1 meter resolution and selling these data world wide. The Administration took until March 10 to agree on the set of policies that would guide license decisions. It took another month to develop the conditions for Lockheed's license.

[54] See Ray A. Williamson, "Assessing U.S. Civilian Remote Sensing Satellites and Data," op. cit., and Brian McCue, "The Military Utility of Civilian Remote Sensing Satellites," op. cit., for a discussion of both commercial and national security issues related to private operation of remote sensing satellites.

[55] For example the Central Intelligence Agency (CIA) plain to make some data collected by the so-called National Technical Means (classified remote sensing satellites) available for purchase. If these data were of recent origin, they could well compete with privately acquired data and inhibit the ability of firms to obtain needed financing. However, the CIA plans to make only data from older systems available for purchase. See lames Woolsey, testimony before a joint hearing of the Committee on Science, Space, and Technology, and the Permanent Committee on Intelligence, U.S. House of Representatives, Feb. 9, 1994.

[56] U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing From Space*, OP. cit., p. 87.

emment to archive data collected by privately-owned systems.[57] However, the choice of which data to archive and under what terms are not spelled out. **Congress may wish to instruct NASA, NOAA, and DOI to establish guidelines for the types and quantities of privately acquired data to archive, based on market demand and anticipated future applications for such data.** Such guidelines should also take into account the needs of private data consumers.

INTERNATIONAL COOPERATION

International remote sensing activities involve both governmental and commercial interests. Governments cooperate in remote sensing activities to broaden their capabilities, reduce costs, and expand their base of scientific and technical expertise. They compete for political and technical prestige by developing new indigenous capabilities and by establishing leadership in managing remote sensing systems. Commercial interests compete for market share of the rapidly growing value-added services market and the market for raw data. Although the growing number of countries involved in remote sensing (app. A) has contributed to expanded international competition by governments and the private sector, it has also produced a striking increase in the scope of international cooperative efforts.

Government-funded remote sensing programs have a long history of international cooperation, in which for many years the United States was the dominant player. U.S. practices formed de facto international standards for data policy and management. But as other countries have become active in remote sensing, they have taken a variety of approaches to data policy. In most cases their policies are still being formulated. **This new international environment dictates a new approach to cooperation. Over the past three decades, the United States was determined much of the scientific and operational agenda for international remote sensing activities and set the technical standards; it now faces the more difficult task of leadership through cooperation.**

Several factors encourage national and regional space agencies toward greater cooperation in remote sensing.[58] First, remote sensing from space is an inherently international activity. Earth satellites are capable of providing data from around the world. By international treaty, "outer space is not subject to national appropriation by claim of sovereignty."[59] Hence, although nations retain jurisdiction and control over objects they have launched into space,[60] satellites pass over national boundaries with impunity. Because of the limited onboard data storage capacity and the limited availability of satellite cross-links, collecting remotely sensed data often requires ground stations dispersed in many countries.[61] Operating these ground stations usually requires formal agreements on data access and exchange. Increasingly, the satellites themselves are owned and operated by more than one agency and require formal data exchange agreements.

Second, many applications of remotely sensed data, such as weather forecasting and global change research, are by their nature regional or global in scope. Modem weather forecasting requires global data, especially to improve long-range predictions, data that are provided by satellites and ground-, sea-, and air-based instruments.

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[57] *Land Remote Sensing Policy Act of 1992*, Public Law 102-555, Sect. 502 (15 USC 5652).

[58] John M. Logsdon, "Charting a Course for Cooperation in Space," *Issues in Science and Technology*, vol. 10, No. 1, fall 1993, pp. 65-72.

[59] 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 (The Outer Space Treaty)*, Jan. 27, 1967, Article II.

[60] *The Outer Space Treaty*, Article VIII.

[61] For example, even though ~&a@ 4 and 5 were designed to transmit data on X-band through NASA'S TDRS system, they also carry antennas to transmit to ground stations. Because the TDRSS transmitters have failed, Landsat data can only be transmitted to Earth by means of the ground stations located around the world.

Research on the status of and changes in the global environment also depends on access to data on a global basis. Obtaining this access in turn rests on cooperative agreements for sharing data from a variety of satellites and ground stations. Effective cooperation on these applications requires established international user communities and organizations to represent them, such as the World Meteorological Organization and the International Council of Scientific Unions, which are actively involved in international discussions of data policy. For many other applications of remotely sensed data, such as resource management and environmental monitoring, similar communities do not yet exist.

Finally, space budgets are shrinking in most countries and many agencies may be forced to curtail their ambitious plans for remote sensing. International cooperation offers the opportunity for each country to save money by eliminating unnecessary redundancies and improve program effectiveness by sharing data and eliminating unwanted gaps. Recognizing their overlapping interests, agencies from various countries and regions have pursued joint remote sensing projects. However, they have generally embarked on such projects on an ad hoc basis.

Typically, cooperative projects involve placing instruments developed by one agency on satellite platforms developed by another. For example, France and the United Kingdom have contributed instruments to NOAA's Polar-Orbiting Operational Environmental Satellites,[62] and the United States and Europe are contributing instruments to Japan's Advanced Earth Observation Satellite (ADEOS), designed for global change research. Such cooperative arrangements will continue into the next century, when Japanese and European instruments will fly on U.S. spacecraft and vice versa. These projects require formal agreements to coordinate data policies and management systems.

Alongside the growth in these ad hoc cooperative arrangements, a number of formalized organizations have arisen for cooperation in remote sensing and related activities. The most striking of these are the regional organizations in Europe. The European Space Agency (ESA), organized in 1975, provides a formal mechanism for European countries to develop and pool resources for joint space programs; ESA has given a high priority to Earth observations. The European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) was formed in 1985 to maintain and expand European cooperation on weather satellites and their uses.

A number of less formal organizations provide fora for discussions of policy and coordination of plans. The one with the broadest scope is the Committee on Earth Observations Satellites (CEOS), which includes almost every national and international agency involved in remote sensing as participants. These agencies are broadly committed to improving the level of international cooperation on remote sensing in order to harmonize and increase the overall effectiveness of their remote sensing programs, but the ultimate scope of this cooperation remains uncertain. Resolution of data policy issues will be critical to enhanced future cooperation.

Closer international cooperation carries significant potential drawbacks, however. Commitments to cooperative ventures can limit the resources available for national programs.[63] Close

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[62] U. S. Congress, Office of Technology Assessment, *The Future of Remote Sensing From Space,* op. cit., ch. 3.

[63] In Europe, for example, where some countries contribute I() ESA programs and fund their own space agencies, cooperative efforts may compete with national (roes for a share of the budget. Officials of the the French space agency, Centre National d'Études Spatiales (CNES), have expressed concern that ESA's needs might take over the CNES budget and have thereby capped CNES contributions to ESA: Peter B. de Selding, "French Space Agency Holds Budget Ground," *Space News*, Mar. 21-27, 1994, pp. 1, *20.*

cooperation may also result in programs that are more cumbersome and less flexible than if agencies pursued their own programs independently. Flexibility is particularly important for data and information systems, where the technologies for data transmission, storage, and processing are rapidly evolving. Efforts to coordinate programs can also result in disagreements that delay project progress and ultimately raise costs. To date, U.S. efforts at international cooperation in remote sensing have not reached the level where they would impede U.S. national programs.

As increasing numbers of national and regional agencies have undertaken remote sensing programs, each one has had to develop policies regarding data archiving, distribution, and management. Who should receive the data, how quickly, and at what cost? What raw and processed data should be kept in archives, and for how long? How should the archives be maintained? The emerging policies of some agencies are quite different from those in the United States. For example, in order to assure that users of Eumetsat's meteorological satellite systems help support them, Eumetsat has developed a policy in which it charges nonmember European states for the raw data.[64] Canada has contracted with the private Canadian firm, Radarsat International to collect and market data from its Radarsat synthetic aperature radar satellite system after Radarsat is launched in 1995.[65] Differences in policies internal to each agency can create problems for the exchange of data among agencies, particularly when it comes to access for users outside those agencies.

Failure to coordinate policies on data access and exchange could greatly complicate access to data; users who need data from a variety of sources could be forced to navigate a complex array of different data systems, each with its own policies and protocols. This outcome would seriously undermine the effectiveness of remote sensing programs, especially for cooperative global change research, where large amounts of complex data are often needed to develop and verify global environmental models.

Coordination of policies on data access and pricing has been high on the agenda of CEOS and other international bodies and in a variety of bilateral negotiations. To date, international discussions have dealt primarily with weather forecasting and global change research, both concerns that extend across international boundaries. These data requirements have led to the establishment of international exchanges of data from satellites and other sources. **The increasing diversity of approaches to data access among nations with remote sensing programs poses significant challenges, but the United States and most foreign agencies share a broad commitment to maintain effective data exchange mechanisms.**

Coordination of data and information systems is as important as the coordination of formal data policies in making satellite Earth data useful to potential users. Given the challenge of managing large quantities of satellite Earth data, agreed policy statements have limited effect without data and information systems to provide ready access to data. This raises two questions. First, will the data and information systems of various national and regional agencies be capable of operating efficiently together? This compatibility is essential for data to flow easily from one country to another.

Second, are foreign agencies devoting adequate resources to their data and information systems? So far, no other agency has matched NASA's level of commitment to data management and analysis systems equivalent to EOSDIS; most are only beginning to grapple with the issue. For example, the European Space Agency discovered that its data management system was inadequate

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[64] Eumetsat, however, provides data freely to the less developed countries of Africa. (See discussion of international Development, below.)

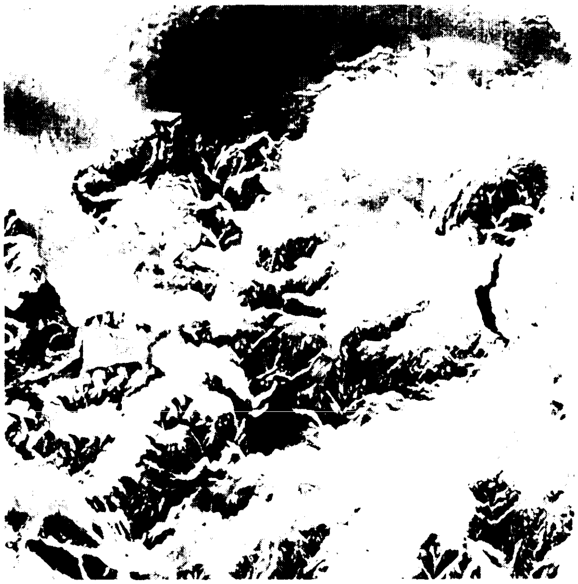
[65] This policy is similar to the commercialization policy adopted by the United States in 1984 for Landsat, but changed in 1992 with the adoption of the Land Remote Sensing Policy Act of 1992 (Public Law 102-555).

to process and distribute more than a fraction of the synthetic aperture radar data gathered by its ERS-1 satellite.[66] Because the United States has no instrument that provides data on ocean conditions and land and sea ice cover similar to ERS-1, U.S. scientists are dependent on ERS-1 data (figure 1-8) for their global change research.[67] **Inadequate data systems or inadequate coordination of international data systems could undermine the ability of scientists in the United States and elsewhere to use foreign sources of data, some of which will be extremely important in developing global environmental models.**

Preliminary international discussions are now underway to deal with these issues. **Congress may wish to monitor these international developments in order to assure that U.S. scientists and other users have as much access as possible to data from international sources.**

Several authors have proposed developing international remote sensing consortia as a way to pool international resources on remote sensing and its applications.[68] Eumetsat, the European organization devoted to satellite systems and data management for weather forecasting and climate monitoring, provides one possible model. A more modest approach might be to establish new organizations or strengthen existing ones for particular international applications of remotely sensed data, such as ocean monitoring. The final report of this assessment will explore the advantages and drawbacks of an international consortium for remote sensing and relate it to U.S. remote sensing policy.

FIGURE 1-8: ERS-1 Synthetic Aperature Radar Image of Antarctica



SOURCE European Space Agency, 1992

UNDERUTILIZATION OF REMOTELY SENSED DATA

The United States has made a major commitment to Earth observing satellite systems, but many potential applications of remotely sensed data, such as routine monitoring of wetlands, coast fisheries, or National Forests, remain untested or little used. Often, these applications are suggested by basic scientific research, but their development requires

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[66] "ERS-1 Gives European News views of Oceans," *Science, vol. 260,* June 18, 1993, pp.1742-1743.

[67] R. Keith Raney, "Probing Ice Sheets With Imaging Radar," *Science, vol.* 262, Dec. 3, 1993, pp. 1521-1522.

[68] John H. McElroy, "INTELSAT, INMARSAT, and CEOS: Is ENVIROSAT Next'?" In *Space Monitoring of Global Change,* Conference Proceedings, Institute on Global Conflict and Cooperation and the California Space Institute, Oct. 8-10, 1992. John McLucas and Paul M. Maughan, "The Case for Envirosat," *Space Policy, vol. 4, No.* 3, August 1988, pp. 229-239; Neal Helms and Bert Edelson, "An International Organization for Remote Sensing," Presented at the 42nd Annual Meeting of the International Astronautical Federation, Montreal 1991, IAF-91-112.

some additional investment. Investments in applications are generally modest compared to the cost of the satellites themselves, but NASA has often found it easier to suggest new satellites. **Congress may wish to provide greater funding to the Departments of Agriculture, Energy, and Interior, and to the Environmental Protection Agency and the National Weather Service to develop new applications of remotely sensed data to support their missions, and to standardize access and data requirements.**

ENVIRONMENTAL MONITORING

Human activities are causing dramatic changes in the natural environment, changes that have provoked widespread concern. This concern has led to increasing interest in the use of remote sensing for environmental monitoring. But environmental monitoring has been used in two distinctly different senses. In the scientific context, monitoring seeks to collect and maintain a lasting record of the state of the global environment for current and future scientific use.[69] For example, systematic archives of weather data can be used to study changes in the Earth's climate, and to inform environmental decision making, especially in the long term. The international scientific community is developing organizations to address these needs, but the U.S. Global Change Research Program has not yet committed substantial resources to those efforts.[70] **In funding global change research, Congress may wish to consider giving a higher priority to development of the capability for (decadal-scale) calibrated measurements of Earth's environment.**

Environmental monitoring is also used to describe operational activities to gather and analyze environmental land data that support the more immediate needs of decision makers, just as meteorological forecasts help people respond to changes in the weather. Earth data collected by a variety of land and ocean remote sensing satellites can provide timely support for the management of rangeland, forests,[71] coastal zones, arid lands, polar regions and other ecosystems and natural resources. These applications have become especially cost-effective with the development of geographic information systems (GIS). Operational monitoring activities such as weather forecasting can provide broad benefits to the general public as well as particular benefits to a few individuals. Except for weather forecasting, the level of investment and institutional commitment to operational environmental monitoring is generally low. Because of this, operational users of satellite Earth data are not strongly represented in international discussions.[72] Many potential applications of remote sensing for environmental monitoring are untested or only partially developed and tested. To develop these applications to the point where they can become operational requires investment in applied research and development. **Congress may wish to ask the mission-oriented agencies to expand their attention to applied research and the development of new applications of remotely sensed data for environmental monitoring, as well as for other purposes.**

INTERNATIONAL DEVELOPMENT

Social conditions in many parts of the developing world are desperate and not rapidly improving, in part, because of inadequate economic planning and the associated erosion of environmental quality. The United States and other developed coun-

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[69] See U.S. Congress, Office Of Technology Assessment, *Global Change Research and NASA Earth Observing System*, OTA-BP-ISC-122 (Washington, DC: U.S. Government Printing Office, November, 1993), pp. 34-36.

[70] *Ibid.*, pp. 3-4.

[71] For example, see app. C.

[72] In April 1994, NOAA hosted a meeting of CEOS to discuss data policies for operational environmental monitoring. CEOS arrived at a draft "Resolution on Principles of Satellite Data Provision in Support of Operational Environmental Use for the Public Benefit," which will be discussed at the CEOS plenary session in fall, 1994.

tries are committed to supporting economic development in these countries which is economically and environmentally sustainable. Remote sensing can contribute important information to improve the quality of planning for environmental protection and natural resource management. For many of these potential applications, satellite data are or will soon be available, but most developing countries lack the capability to use those data effectively.[73]

In the late 1970s and early 1980s, the U.S. Agency for International Development (AID) and NASA had an active training program in the use of remotely sensed data. **Congress may wish to consider reinstituting a training program and providing greater technical and financial assistance to improve the use of remotely sensed Earth and environmental data in developing countries.** This will require funding for equipment to receive, process, and archive satellite data and training and technical support in the use of the equipment and data. Among other things, such training would make developing countries more skilled in managing their own resources (see app. B). It might also help build a larger general market for remote-sensing data.

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[73] Indla has an active remote sensing program and is a major exception to this role.