*Remotely Sensed Data: Technology, Management and Markets*

September 1994

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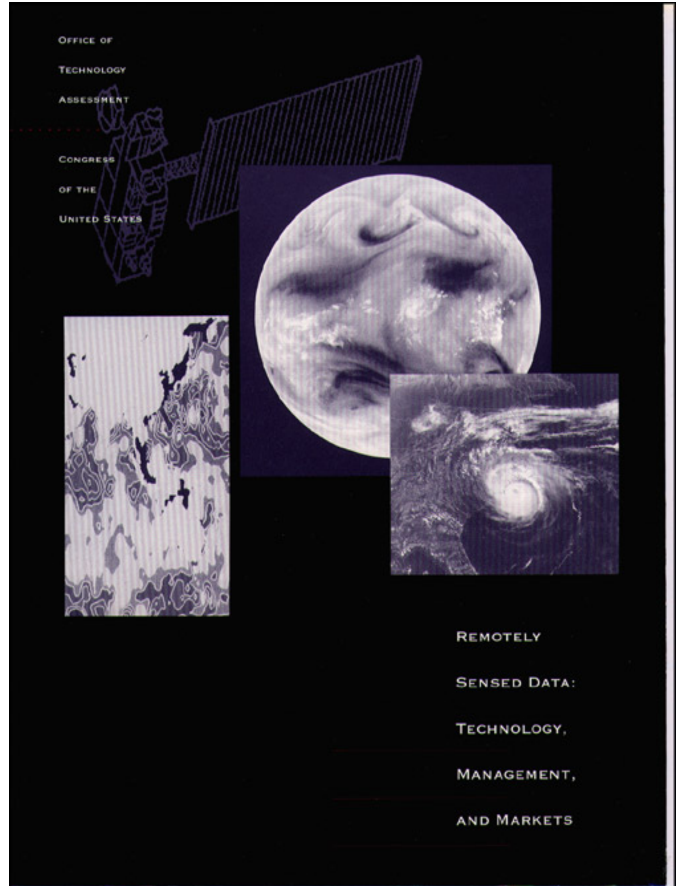

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# Foreword

The increasing volume of data about the Earth collected using spacecraft poses a challenge to U.S. data archiving and distribution facilities. The value of these data will depend on how effectively the data can be employed for scientific and other uses. As this report notes, turning remotely sensed data into useful information will 1 require adequate data storage and computers systems capable of managing, organizing, sorting, distributing, and manipulating the data at exceptional speeds. Efficient data management will be assisted by the large and fast growing information industry, which includes computer hardware and software and electronic data networks.

This report examines U.S. plans for managing the prodigious quantities of data expected from current, planned, and future remote sensing satellites. In particular, it explores the Earth Observing System Data and Information System, which NASA is developing to manage and process the data from its Earth Observing System of satellites. It also analyzes the factors affecting the growth of the market for privately generated remotely sensed data. The recent entry of private firms into the development and operation of remote sensing systems affords U.S. firms the opportunity to develop a new space industry, supplying high-quality data to worldwide markets. This circumstance raises questions about the appropriate role of the U.S. government in assisting this fledgling industry in competition with foreign governments and companies.

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 NASA, NOAA, and the Department of Interior. As with all OTA reports, the content of this report is the sole responsibility of the Office of Technology Assessment and does not necessarily represent the views of our advisors or reviewers.

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# Contents



# Exectuite Summary

By the early twenty-first century, satellite remote sensing systems will generate prodigous quantities of data about Earth's atmosphere, land, oceans, and ice cover. The value of these data will depend on how effectively they can be used. Turning remotely sensed data into useful information will require adequate data storage and computer systems capable of managing, organizing, sorting, distributing, and manipulating the data at exceptional speeds.

The large and fast growing information industry, which includes computer hardware and software and electronic data networks, is rapidly changing the way in which people handle data. Innovations in storage, imaging, and networking technologies could greatly improve the government's ability to analyze, archive, and manage remotely sensed data. However, in order to achieve higher performance from federal data management systems, the government will have to adapt quickly to changing technologies and allocate greater funding to data management.

Innovations in information technologies will also assist the rapid growth of a market for information produced from satellite data. However, significant market growth will depend on the availability of cheaper, improved data and less expensive, user--friendly software to process the data.

## THE MANAGEMENT AND ANALYSIS OF DATA AND INFORMATION

The federal government maintains several major archives that store and protect U.S. satellite and other Earth data. In order to serve future data customers most efficiently, these archives will require periodic upgrades to improve data storage and retrieval, data search algorithms, and online communications capability.

| Data collected by satellite are increasingly important for: |
| --- |
| • predicting weather<br>• understanding climate<br>• assessing environmental change<br>• managing regional and global resources<br>• resource exploration<br>• land-use planning |

The information industry is well-positioned to assist in improving the management of federal data archives. Yet **in the past, federal data analysis and management has often been underfunded. Congress may wish to scrutinize remote sensing budgets to assure that plans for data analysis, distribution, and archiving are adequate and that overruns of instrument and spacecraft budgets are not made up by underfunding data management.**

The rapid growth of online services and databases will markedly improve the ability of customers to locate and order data over the Internet and other online systems. **The widespread availability of high capacity networks is likely to increase significantly the number of users of remotely sensed data.** Despite major advances in database technologies, potential data users often have difficulty locating U.S. and foreign sources for data. 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 instruct federal agencies to develop a centrally coordinated "metadata set" that would provide a complete listing of the sources and types of remotely sensed data held in different U.S. facilities.** Such a metadata set should include a data tracking mechanism to provide government and private customers with access to data sources; it might also include listings of foreign and commercial archives.

Existing satellite data from the U.S. operational satellite systems—the Landsat system, the National Oceanic and Atmospheric Administration's polar-orbiting and geostationary systems, and the Defense Meteorological Satellite Program (DMSP)—constitute a unique record of regional and global change. **The United States should protect and maintain these data and make them widely available for global change research.** To create a more comprehensive global land data archive, Congress may wish to consider funding the purchase and archiving of a basic collection of Landsat scenes collected at foreign Landsat stations.

## NASA'S EARTH OBSERVING SYSTEM DATA AND INFORMATION SYSTEM (EOSDIS)

The National Aeronautics and Space Administration has recognized the critical importance of data management in designing its Earth Observing System (EOS). **EOSDIS will be the largest and most challenging civilian data management system attempted to date.** To derive the greatest value from EOS data, NASA plans to process and manage extremely large quantities of raw data and make them available to researchers quickly. Data processing on this scale has never before been done on a routine basis with such large data sets.

**NASA has structured EOSDIS to encourage interdisciplinary global change research.** As scientific priorities change, NASA will face the challenge of remaining responsive to data-user needs while also developing new methods of data management and analysis. **Maintaining EOSDIS as an operational system routinely accessible by data users and keeping up with advancements in technology will require adequate and stable funding.**

**The** success of EOSDIS will be measured in large part by how extensively EOS data are used beyond the relatively small community of NASA principal investigators. Many users will find EOS data advantageous for scientific research and for managing U.S. public and private resources. NASA is now developing methods to allow extensive, flexible access to EOSDIS, including through private firms. If EOSDIS is successful, NASA could be faced with sustaining the data needs of more users than it is funded to support.

EOSDIS must be flexible enough to provide easy access to the governmentwide Global Change Data and Information System (GCDIS), which is being developed by the U.S. Global Change Research Program. EOSDIS would also likely serve as the core of an operational environmental monitoring data system that many believe should follow the 15-year EOS program. Congress **may wish to instruct the agencies involved in the U.S. Global Change Research Program to examine the long term (decadal timescale) needs for climate and other environmental data from satellites and other sources and recommend a data system to produce, archive, manage, and distribute these data.**

## PUBLIC AND PRIVATE ROLES IN A DEVELOPING MARKET

The private sector is likely to play a crucial role in shaping the future of satellite remote sensing. Firms have already taken the lead in linking data sources to data users by turning raw data into productive information. These value-added companies, and firms that develop new, more efficient data management and processing software, will remain critical elements in expanding the remote sensing industry.

In addition, several private firms plan to market raw data from privately financed remote sensing systems. Their ability to operate a successful data supply business will depend on: strong market growth from new data applications; significant reductions in the costs of building and operating satellite systems; and the ability to transmit data to customers quickly and efficiently. **Government could assist in reducing industry's financial risks by: maintaining consistent, stable remote sensing policies and by not competing with private firms in providing value-added services. Government could assist market development by purchasing data rather than satellite systems from private enterprise.**

## INTERNATIONAL COOPERATION

Once dominated by the United States and the Soviet Union, Earth remote sensing is now a broad-based international activity. This development has transformed the ground rules for intergovernmental cooperation and offers new opportunities to reduce the costs and improve the effectiveness of overlapping national remote sensing programs. **Over the last three decades the United States 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.**

Global data from many sources are needed to forecast the weather and to understand global environmental change. The United States established the tradition of free and open exchange of data for these purposes. However, a growing interest in commercial applications and the desire, especially in smaller countries, to recover the costs of developing and operating remote sensing systems, have led to increasingly restrictive data access policies. **The United States should continue to press for open access to data that serve global environmental needs.**

The lack of adequate international coordination of data management systems has undermined the effectiveness of remote sensing programs. Users who need data from several satellites and ground systems are now forced to navigate a complex international array of data systems, each with its own policies and protocols. International coordination could greatly enhance the usability of remotely sensed data by encouraging the development of compatible data management systems, having adequate capacity to meet the needs of data users. **To improve U.S. access to global data, the United States should make the coordination of data management systems, including the creation of international metadata, a high priority in future negotiations.**

# Policy and Findings 1

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.

[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 l-l), 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

***Ba kground Papers***

- *Remotely Sensed Data From Space: Distribution, Pricing, andApp/ications* (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:***

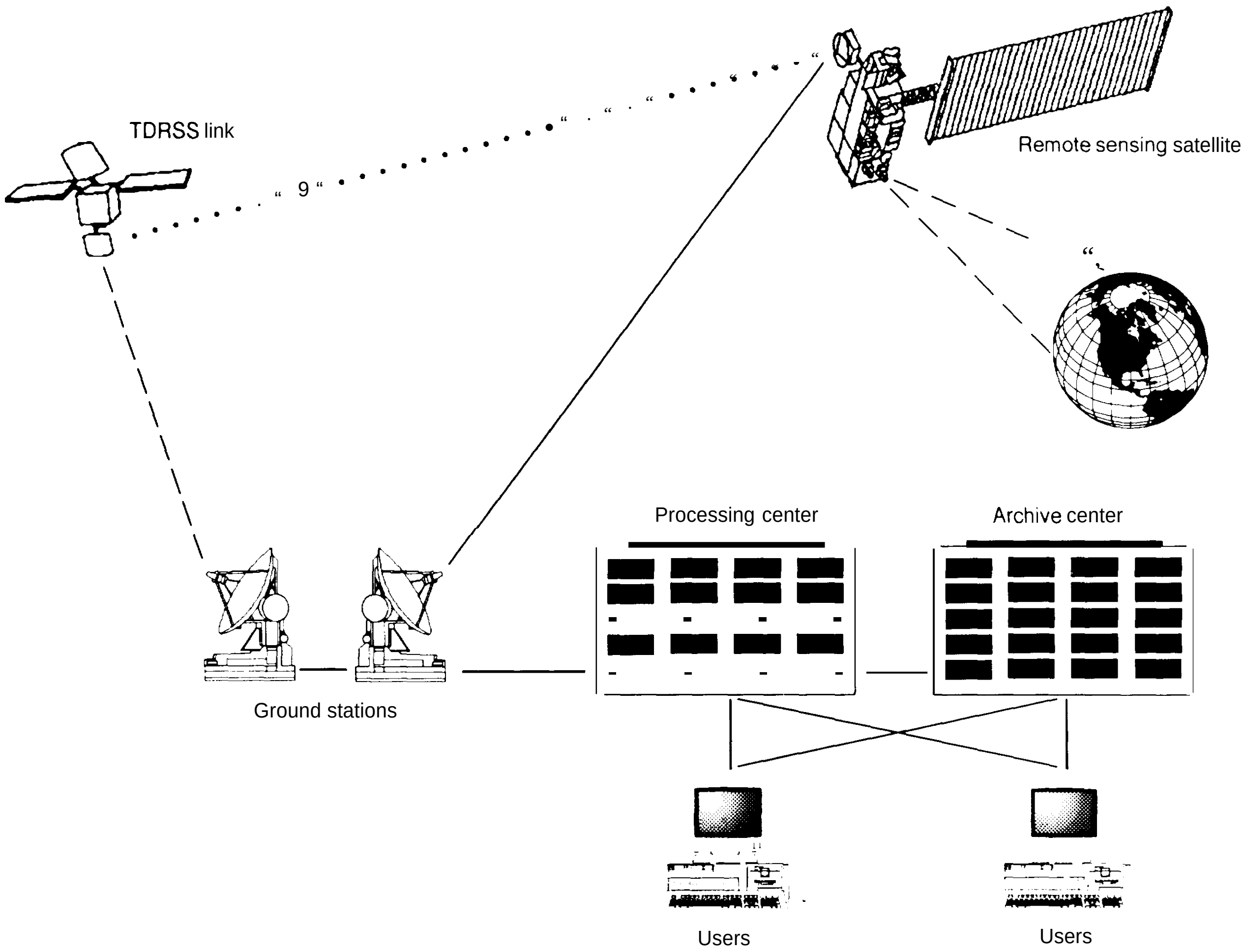
- *The Future of Remote Sensing From Space: Civilian Satellite Systems and Applications, OTA-ISC-558* (Washington, DC U.S Government Printing Office, July 1993).
- *Remote/y Sensed Data Technology Management, and Markets OTA- ISS-604* (Washington, DC U.S. Government Printing Office, August 1994).
- *Civilan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

SOURCE Office of Technology Assessment, 1994

‘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 t<sub></sub>erm "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



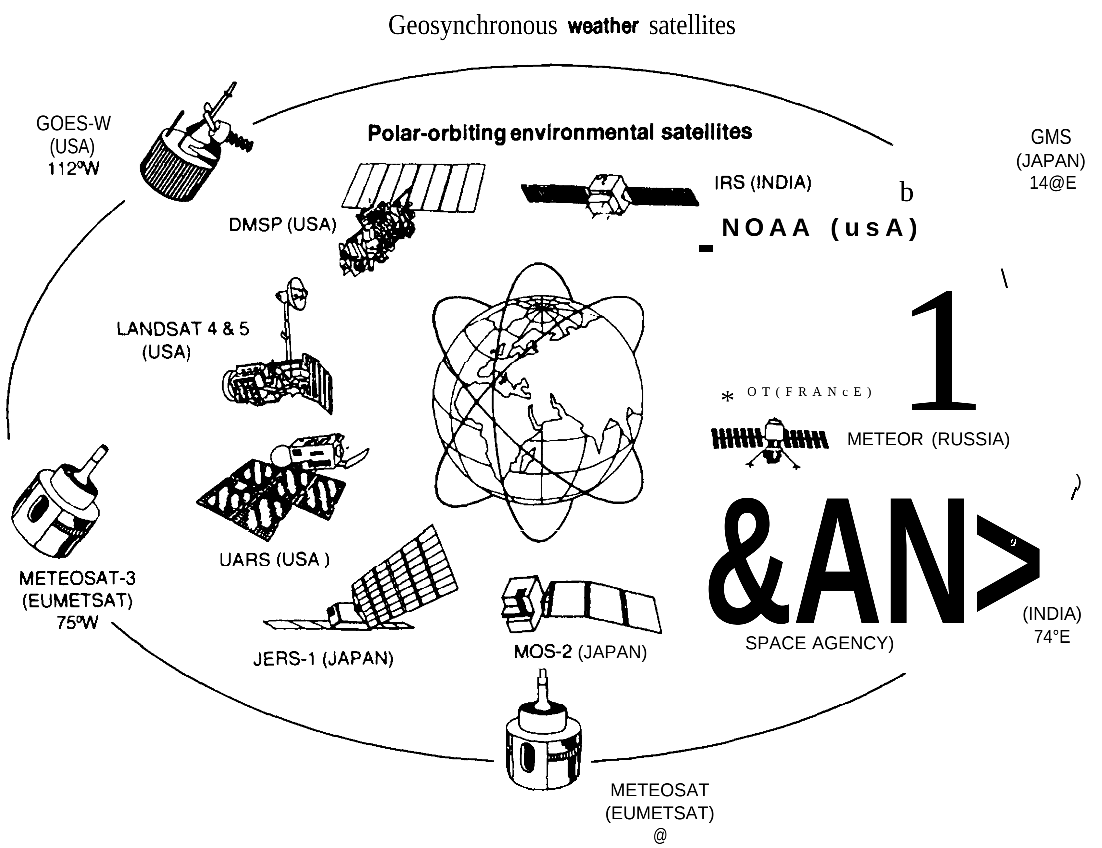

SOURCE Off Ice of Technology Assessment, 1994

(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 Off Ice 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

[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/Italy | 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 WiIl 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,

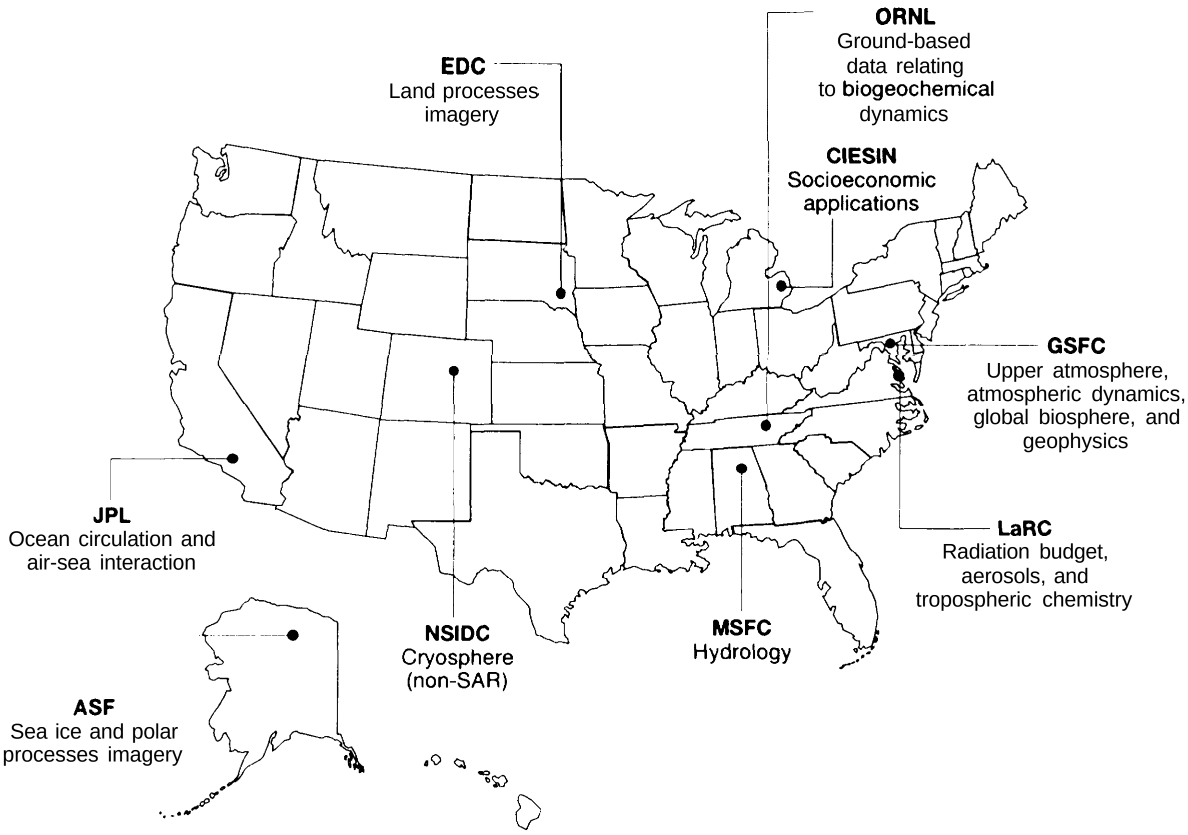
**BOX 1-2: Selected Applications of Land Remote Sensing Data**

- 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

[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 Synthettc Aperture Radar Fachty, CIESIN = Consortium for International Earth Science Information Network, EDC = Earth Resources Observation Systems Data Center, GSFC = Goddard Space Fllght 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 globa1 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,

6The 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.

'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 particular y 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

**g h m d If Cong w h o mp o h ffi a of mo n d a da a fo manag ng U S ou and fo g oba hang a h ma**

[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 extremel y 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**

[14] See U.S. congress, Office of Technology Assessment, *Data Format Standards for Civilian Remote Sensing Satel/i(es* (Wash ington, 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, Offfice 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 sevcral 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 cl imate from land and ocean observations presents a considerable challenge to NCDC.

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 as 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

[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.

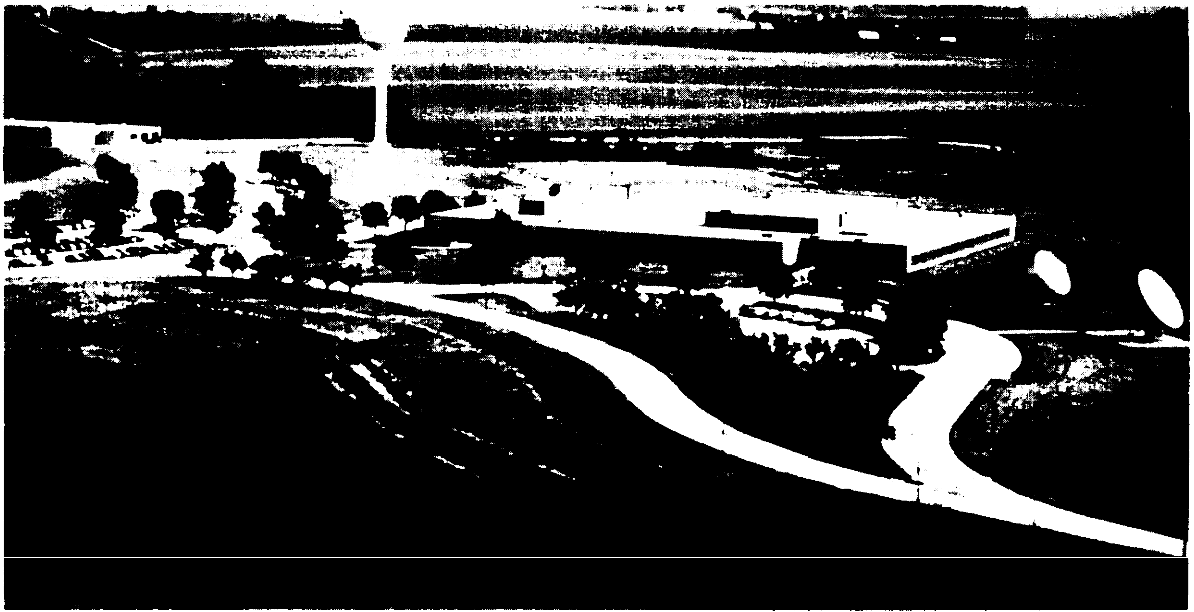
[23] Resolution is the measure of a viewer to distinguish between objects. For data of 4-kilometer resolution, the sensor averages the light intensity gathered by the sensor over a 4 kilometer square. See U.S. Congress, *The Future of Remote Sensing From Space*, op. cit., p. 60, for a discussion of resolution.

[24] See app. A.

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

[26] The *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. 34-36. 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-

[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 Off Ice 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. Especial-1 y given the wide availabil ity 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**

[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 m 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 [apes 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 [he National Media Lab{) ratory, 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

[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 EOS-DIS 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/Imager (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-

[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 EOS - DIS. 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

[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 full y 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 dewloping new data management and processing soft-

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[45] As noted above b, 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

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 satell ites 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 man y 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

[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

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

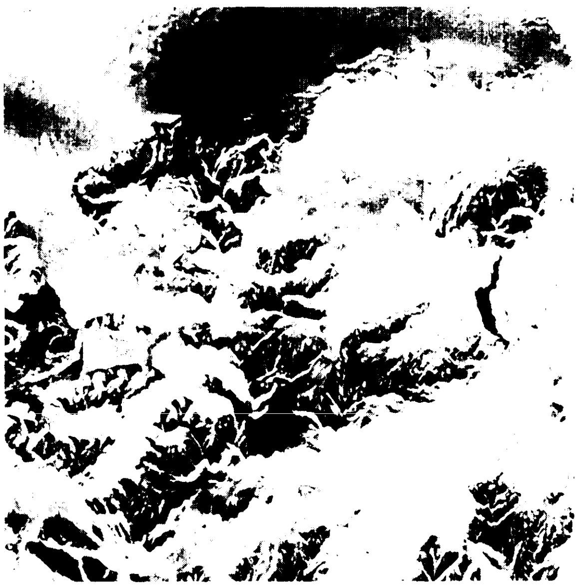
[65] This policy is similar to the commercialization policy adopted by the United States in 1984 for Landsat, but changed in 1992 with the adoption of the Land Remote Sensing Policy Act of 1992 (Public Law 102-555).

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 conditionsandland and sea ice cover similartoERS-1, U.S. scientists are dependent on ERS-l 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

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: 1s 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 andNASA 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.

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

# Managing Remotely Sensed Data and Information 2

By the end of this century, U.S. and foreign civilian remote sensing satellite systems will begin to generate huge volumes of data about the Earth on a daily basis. In order for weather and climate forecasters, researchers, resource managers, and other users to make the most efficient use of these data, the U.S. government will have to invest in new technologies for collecting, storing, distributing, and analyzing remotely sensed data. Private industry and government have already invested billions of dollars in a robust data and information infrastructure that can support government efforts to cope with the new data sources. **The information industry will greatly facilitate the rapid growth of a commercial and governmental market for information produced from satellite data.**

In the 1970s, when the operational environmental satellite systems and the Landsat system were first developed, data users had to rely on large, expensive mainframe computers to analyze the data. They further had to depend on the creation and delivery of data tapes and/or "hard copy" images from the central processing facilities. If users wished to browse through data files to select the best quality data, they would either have to depend on the judgement of personnel at the facility, or travel to the facility themselves and examine the data directly. Storage and archive facilities were highly limited and usually relied for data storage on thousands of paper copies, photographic images, or magnetic tapes. Working with the data meant physically retrieving archived data from storage by hand and copying them for each different user.

Since the 1970s, the rapid development of computer processing, storage, and data communications technologies has revolutionized the way data and information, including remotely sensed data, are treated. Today, for example, it is possible to examine sample data delivered online from the archive to the user's computer work station or PC, select the required data, and have the data subsequently delivered over the same data transmission lines. In many cases, billing for the data can be accomplished online as well.[1] These capabilities have come about as a result of the dramatic improvements that have occurred over the last decade in information technologies, changes that have led to the development and vigorous growth of a broad-based information industry.

This chapter provides an overview of the U.S. information industry and the technologies that support it. It explores the role these technologies play in the management and application of remotely sensed data. The chapter also summarizes Federal programs currently in place for archiving and distributing remotely sensed data and examines options for improving archive services.

## THE INFORMATION INDUSTRY

Virtually all segments of modern industrial society use some form of data and information technology to improve efficiency and capability. Research, manufacturing, service industries, financial markets, and governance have all been affected by the growth of the electronic information industry. Modem computers and allied technologies make it possible to acquire, organize, store, update, and distribute large amounts of data and information for a wide variety of tasks. In large part, the information industry, which consists of manufacturers and sellers of computer hardware and software[2] and data storage and transmission equipment, as well as information services, will determine the nation's ability to manage and process remotely sensed data. Although information technologies are increasingly capable, the requirements for making large quantities of remotely sensed data available to diverse users will stress the capabilities of existing storage, processing, and transmission systems. Improving the ability to deliver remotely sensed data quickly and accurately will also require improved institutional arrangements.

## Processing Data and Information

With the development of high-speed, integrated computer chips and other innovations, the ability to manipulate and analyze large amounts of data conveniently has improved dramatically over the last decade and a half. Personal computers and workstations with fast processing speeds, large amounts of storage, and random access memory adequate for rapid image processing have become standard.

Computer technologies are now much more broadly distributed now than they were just 10 years ago. Rather than working in a mainframe environment, most computer users now use personal computers and/or workstations, which may be linked electronically to mainframe databases, but are capable of running their own software applications independently.

Over the last three decades, computer hardware performance per unit cost has increased by a factor of a million,[3] and has led to rapid growth of digital processing capabilities. During the 1980s and early 1990s, the cost of computing capability dropped substantially—it costs less today *in* 1994 *dollars* to purchase a personal computer based on a 486 processing chip operating at processing speeds of 50 Megahertz (MHz) than it did in 1985 to purchase a system based on a 286 chip operating at **8** MHz.[4] Similar improvements have been

[1] Data fees vary according to the service provided, but for data supplied by government agencies, prices charged, if any, generally reflect the marginal cost of fulfilling a user's need.

[2] Computer hardware and peripherals accounted for sales of at least $65 billion in 1993. See U.S. Department Of Commerce, international Trade Administration, *U.S. Industrial Outlook 1993* (Washington, DC: U.S. Government Printing Office, 1993), p.26 -1.

[3] Malcolm Brown, "The March of the Mighty Chip," *Management Today*, quoting Andrew Sayer of Sussex University, UK, 1991, pp. 26-36.

[4] In this comparison, the 486 chip not only operates about *6* times faster, it is also much more capable.

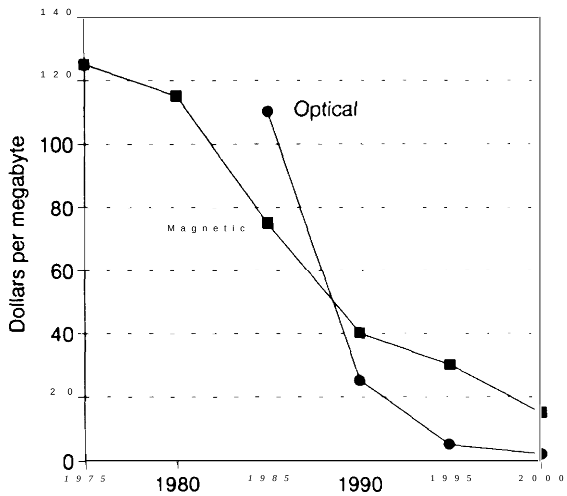
realized in workstation processors, data storage technology, and display technology.

These changes in the information industry have revolutionized the ability to process remotely sensed data. As recently as five years ago, digitally manipulating a remotely sensed image required expensive software and a high capacity workstation. Since then, advances in personal computer capability and software, and reductions in costs have led to much broader access to technology capable of processing remotely sensed data. Many image processing software packages now exist, ranging from "freeware" products to comprehensive professional systems that cost several thousand dollars.[5] Current systems also incorporate far greater amounts of data storage than did their predecessors. Data storage technologies, which include both magnetic and optical media, have improved dramatically while costs have plummeted (figure 2-1 ). In addition to making the data sets more usable, improvements in storage technologies have had a major impact on the ability of satellite operators to collect and store large amounts of data.

## Accessing and Using Data

In order to be beneficial to a variety of users, data must be transportable. Data can be hand carried on portable media like magnetic tapes and disks or optical disks; they can also be transmitted over standard telephone lines, fiber optic cables, or relayed by satellite. Increasingly, individuals and institutions transmit and receive data and information over computer networks similar to telephone lines, but capable of transmitting data at higher rates.[6]

FIGURE 2-1: Cost (in then-year dollars) Per Megabyte of Storage Has Dropped Considerably




SOURCE National Media Laboratory, 1993

The distribution of significant processing power in personal computers and workstations has solidified the interest in online access to data and information. Most large companies (box 2-1), universities, research organizations, and state, local, and Federal government agencies now rely on computer local area networks (LANs)[7] to help workers organize and use a wide variety of data and information. The available software allows users to transmit and receive messages, operate software programs, and access data and information stored in central locations. U.S. industry has spent over $30 billion on local area networks to link workstations.[8] Additionally, users can also be linked together through wide-area networks

[5] Many of the commercial packages developed exclusively for remote sensing/geographic information systems applications are priced competitively at $500-$2,5(X).

[6] Because cable television cables can transmit data at higher rates than existing telephone lines, they provide One possible avenue for linking computers. Recently, Continental Cablevision, Inc., and Performance Systems International, Inc., introduced a service to link home computers with the Internet, making it possible to transmit voice and full feature graphics quickly. See Jared Sandberg, "Cable That Ties PCs to Internet to be Unveiled," *Wall Street Journal*, Feb. 8, 1994, p. B10.

[7] Local area networks (LANs), Consist of a series of computer workstations linked together through a network server that provides each workstation with operating software and the ability to share electronic mail, data, and information.

[8] Information Industry Association, Digital Information Group, Link Resources 1993.

## BOX 2-1: Information Management in the Retail Industry

U.S. industry depends on the ability to manage, interpret, and transmit data quickly and efficiently. For example, retailers like K-Mart and Wal-Mart use real-time electronic data interchange to control inventory, meet customer requests, and handle payroll and scheduling. Efficient transfer of large data sets can cut costs to the retailer, and allow transfer of point-of-sale data to others on the computer network, 1

For example, Wal-Mart's operating costs are low relative to its competitors, in part because the company dedicates only about 10 percent of its stores' square footage to inventory, compared to an industry average of 25 percent. Because sales data are tabulated immediately, the company is able to inform suppliers in a timely manner, and use the information to negotiate better prices from suppliers. Wal-Mart uses satellite links to provide this electronic data interchange, as do K-Mart, Home Depot, and others.

[1] See Lucie Juneau, "Luring Consumers With Conspicuous Efficiency," *ComputerWorld*, September 14, 1992

SOURCE Off Ice of Technology Assessment, 1994

(WANS) that operate over a wider geographic area. A WAN might be made up of one or more LANs and a number of individual computers. In order for distributed information systems to be effective, they must allow easy access to multiple users, segment information in searchable fields, and generally increase the efficiency of those who use the system.

This amalgamation of technologies and businesses has led to important synergies among technologies: technology developments in one sector necessitate and encourage technology development in other sectors. For example, the recent dramatic growth in the availability of multimedia CD-ROM[9] readers, driven by market demand for entertainment and educational CD-ROMS , has led to increased use of the CD-ROM for storing and distributing large amounts of digital data. The development of smaller, more powerful computer processors has led to an explosive growth in cellular telecommunications (currently an industry worth over $7 billion annually).[10] This development, in turn, has made the concept of handheld computers more viable, since cellular links will eventually make wireless computer networking practical in the near future.[11]

The growth of the online information industry (table 2-1) reflects increasing demand for databases, analysis, and information products. Although online access to data and information is

## TABLE 2-1: Projected Growth of Online Information Industry (in billions of U.S. dollars)

| Market segment | 1990 | 1995 |
|---|---|---|
| Financial | 2,3 | 3.4 |
| Travel | 1.7 | 2.7 |
| Marketing | 1.5 | 2.9 |
| Credit | 1.5 | 2.0 |
| Legal/regulatory/scienti fic* | 1.0 | 1 9 |
| Real estate | 0.3 | 0 4 |
| Insurance | 0.3 | 0 5 |
| News | 0.3 | 0.4 |
| Other | 0.6 | 1,3 |
| Total | 9 5 | 15,5 |

* Including patient imformation

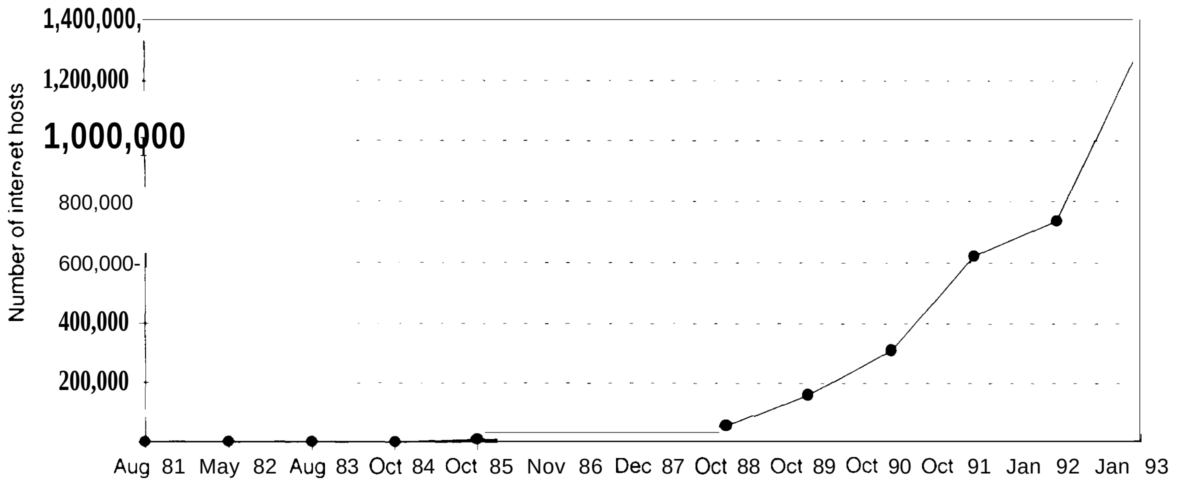
SOURCE. Information Industry Association, Digital information Group, LinkResources, 1993

[9] CD-ROM stands for compact disk with read-only memory, A CD-ROM is technically identical to the compact disk of the music industry.

[10] U.S. Department of Commerce, International Trade Administration, *U.S. Industrial Outlook 1993* (Washington, DC: U.S. Government Printing Office, 1993).

[11] Nine major Careers have teamed with IBM to develop a cellular data standard, and another, Cellular Data Inc., received an experimental license from the FCC to begin testing its technology in 1992.

FIGURE 2-2: Number of Host Computers Tied to Internet




SOURCE SRI International as cited in inforworld, April 12, 1993, p 38

only part of the information industry as a whole, the growth of online systems provides insight to future possibilities for remotely sensed data. The consumer of remotely sensed data can expect, eventually, to be able to tap into a wide variety of online databases.

Although U.S. industry and government have extensive experience using and transferring large tabular data sets among users, fews ystems require the amount of image storage and manipulation that data from some remote sensing systems, such as Landsat and SPOT, require. Processing and storing these geospatial data, which contain several levels of data about each geographic point, provide challenges that sales data do not. In addition, most applications of sales data are well known, making the selection of database formats relatively straightforward. By contrast, applications of satellite geospatial data are continually evolving as data users gain experience with the data. Thus, data and information systems for geospatial data must be flexible and easy to use.

The online distribution of remotely sensed data has been enhanced by the availability of the Internet, a wide-area information system funded in part by the National Science Foundation. Because of its ability to connect individuals with other Internet users and with widely scattered databases, Internet has grown rapidly over the past few years (figure 2-2).[13] The rapid growth of Internet has come about, in part, because many users have access to Internet through commercial data networks, provided by a host of commercial suppliers.

Growth of independent commercial systems such as Prodigy, America On-line, or CompuServe has occurred at rates similar to the growth of Inter-

[12] Internet began in the 1970s as a Department of Defense experimental project to connect computer systems dispersed around the country. The success of this system led the National Science Foundation to fund the development of similar technology to allow scientists and government employees to communicate electronically.

[13] See U.S. Congress, Office of Technology Assessment, *Advanced Network Technology*, OTA-BP-TCT-101 (Washington, DC: U.S. Government Printing office, 1993) for a summary of issues concerning the improvement of Internet and other computer netork technologies.

net. Commercial and public information networks now link millions of people.[14] Customers of such systems can exchange files, electronic mail, and obtain news and other current information. These commercial systems also provide links to the Internet. New remote sensing information systems will make use of Internet or Internet-like systems to serve consumers who want to browse data system holdings, but do not require rapid transfer of large data files.

Because of increased traffic, Internet needs to be upgraded continuously. Despite its value, the fate of the National Research and Education Network (NREN), which would provide a significant increase in communication capacity, is uncertain.[15] Because providers of remotely sensed data and information tentative y plan to use such a distribution system,[16] the Internet will have a Significant impact on remotely sensed data systems. Should a successor(s) to Internet be developed, it will place government in the position of providing services to customers who may want to use Internet for commercial traffic.[17]

Access to online information also provides quicker access to information than most other forms of distribution, and for some applications, timeliness is a key to effective data use. As data transmission techniques and capacity improve, more rapid delivery of data is likely to result in greater numbers of network users. The distribution of large data sets, such as remotely sensed Earth data, will require increasingly powerful communications networks (box 2-2).

Because upgrades to new transmission technologies are expensive, many data communication systems still operate at low data rates. Most dedicated data networks have a data transfer rate that ranges from 64,000 bits per second (bps) to 1.544 million bps. To see what these rates mean compared to a common storage medium consider a standard CD-ROM, which can store 5.4 gigabits of data, or approximately 680 megabytes. Current communication networks have data rates that range from slower integrated signal digital network (ISDN) standard lines[18] that would require nearly an entire day to transmit the equivalent of a CD-ROM to high speed, high capacity T-3 lines that can transmit this amount of data (table 2-2) in about a minute.

## COLLECTION AND PROCESSING OF REMOTELY SENSED DATA

Remotely sensed data are acquired by a sensor, then are either transmitted to Earth or stored on board for transmission at a later time.[19] If stored, data are eventually transmitted to a data relay satellite or directly to a ground station when the satellite's orbit takes it within line of sight of the station.[20] The amount of data generated by a sensor depends on several variables: resolution, swath width, and the number of spectral bands included in the sensor. As the resolution of a sensor im-

[14] For example, as of August, 1993, CompuServe, a provider of online services, had 1.4 million paying customers. The company adds approximately 10,000 online subscribers (on average) per month. America Online's subscriber base rose from 300,000 in July 1993 to 600,000 in January 1994. See Michael Dresser, "Getting on Line," *The Sun*. Mar. 6, 1994, pp. 1 D, 4D.

[15] NREN would result in a significant upgrade of the government-operated part of the Internet. See Off Ice of Science and Technology Policy, *The National Research and Education Network Program*, A Report to Congress in response to a requirement of the High Performance Computing Act of 1991 (P.L. 102-194), December 1992.

[16] NASA briefings. See also Committee on Earth and Environmental Sciences, *The U.S. Global Change Data and Information Management Plan* (Washington, DC: National Science Foundation, 1992) pp. 81-83.

[17] U.S. Congress, Office of Technology Assessment, *Advanced Network Technology*, op. cit., p. 19.

[18] The ISDN standard is currently met by phone lines in many parts of the country.

[19] Data would be stored if no appropriate ground station or relay satellite are within range of the remote sensing satellite.

[20] Currently, the Tracking Data and Relay Satellite System (TDRSS), a set of three satellites, receive data from proper'] y equipped satellites for retransmission to ground stations.

## BOX 2-2: Network Data Transmission

Data can be transmitted in either digital or analog mode, each of which has technical advantages. Current communications networks generally rely on a mixture of old and new communications media that support both analog and digital transmission. An analog signal is a continuously varying electromagnetic wave that can be propagated over a variety of media. A digital signal is a sequence of electrical, radio, or optical pulses that represent (binary) 1s and 0s (each 1 or O is referred to as a "bit" of data), Either analog or digital signals can be sent over wire or optical fiber transmission lines, A signal attenuates (e. g., becomes weaker) the further it travels from its source. Hence, some type of amplification is used to boost the energy in the signal. Unfortunately, amplification also increases the amount of noise mixed in with the signal, To prevent data errors digital transmission can use regeneration the use of repeaters to recover the bits (the pattern of 1s and 0s), and retransmit the signal This procedure preserves the integrity of the data,[1] The error rate can be made as small as desired (but cannot be made zero) by placing repeaters sufficiently close together

Transmission media (the physical path between the transmitter and receiver) range from insulated copper wires, known as twisted pairs, to optical fibers made from silica or high-grade plastics Twisted pairs carry most analog and digital transmissions. For analog signals, twisted pair transmission lines require amplifiers every 5 to 6 km, digital signals require repeaters every 2 to 3 km. Twisted pairs can accommodate data rates as high as 4 megabits (mega=million) per second (Mbps). Coaxial cable also uses two conductors, but is constructed differently than twisted pair to enable transmission over a wider range of frequencies Cable is used to transmit telephone and television signals and for local area computer networks. A data rate of 500 Mbps makes cable a versatile medium and, because it is better shielded than twisted pair, cable is less susceptible to external interference. Fiber optic cable, which transmits an encoded beam of light by reflecting it at shallow angles through the fiber at data rates of up to two gigabits (giga=billion) per second (Gbps) was one of the most significant technological breakthroughs in data transmission of the 1980s. Low attenuation and the need for fewer repeaters, in addition to light weight and small size, make fiber highly attractive.[2] However, the cost of fiber remains prohibitive for many applications, For instance, lease fees for a fully switched optical network would cost between $5,000 and $10,000 per month, depending on capacity, length of line, and the indvidual carrier's fee structure.[3]

[1] William Stallings, *Data and Computer Communications* (New York, NY: MacMillan Publishing, 1991) pp. 40-59

[2] Stallings, op cit, pp 59-72

[3] AT&T to Slash T1 Line prices, " *Communications Week,* Aug 10, 1992

SOURCE Office of Technology Assessment, 1994

proves, the resulting data rate increases as the square of the resolution, all other factors being equal. For instance, a sensor with a ground resolution of 10 meters has 4 times the data rate as a sensor with 20 meters resolution viewing the same area. As higher resolution sensors become a reality, the data handling problems become more severe. Higher rates of data collection also require ground stations capable of receiving more bits of data per second.[21]

[21] Or, for systems that transmit data through another satellite such as one of NASA's Tracking and Data Relay Satellites (TDRS), the relay satellite needs to have the capability of high-capacity transmission.

TABLE 2-2: Time Required to Transmit Information Equivalent to CD Storage

| Transmission medium | Data rate (bits per second) | Approximate time Required |
|---|---|---|
| 1,200 bps modem | 1,200 | 1 month |
| 9,600 bps modem | 9,600 | 1 week |
| ISDN | 64,000 | 1 day |
| T1 Fiber | 1.544 million | 1 hour |
| T3 Fiber | 45 million | 1 minute |
| **OC-48** Fiber | 2.488 billion | 1 second |

SOURCE U S Congress, Office of Technology Assessment, *Making Government* Work. New Directions for Electronic Service Delivery, OTA-TCT-578 (Washington, DC U S Government Printing Office, September 1993), p 40

Once received at the ground station, data undergo an initial stage of processing. Ground stations apply some calibration and geometric corrections to the sensed measurements. The data may also be geocoded—registered so that each data pixel corresponds to a known point on Earth.** In addition, data may be enhanced for visual presentation, analyzed for information content, and archived according to date, area of coverage, etc. These steps are important in transforming raw data into useful information.

As noted earlier, remotely sensed data can be delivered to the customer in a variety of ways—magnetic tape, photographic prints and transparencies, optical disk, CD-ROMs, and by online electronic transmission. Remotely sensed data present special problems for information systems because of their relatively high demands for storage, processing, and transmission capacity. Most land remote sensing scenes, which are typically 100 megabytes or more, have been transfered on magnetic tape or photographic media.[23] For customers who request delivery of a data product immediately, electronic delivery over commercial telephone lines or dedicated communications lines is possible. In order to transfer the large data sets represented by remotely sensed data, data providers must maximize the data flow rate by using high capacity data lines (box 2-2) and by employing compression techniques to condense the data files.

For example, a typical (multispectral) SPOT scene of 60x60 km is a digital file that requires about 100 megabytes of storage.[24] Hence, transferring an uncompressed SPOT scene of 100 megabytes at a rate of 64,000 bps would require nearly four hours. A single, 7-band Landsat Thematic Mapper image[25] of 185 km by 170 km contains about 400 megabytes of data, therefore taking about four times longer to transfer over an ISDN line than the SPOT scene. The amount of time required for transfer is also influenced by the method of connection. For example, users can download data faster from a database via Internet than over a modem[26] and phone line. This is because telephone line bandwidth is lower than network lines.[27]

Telecommunications companies are rapidly increasing the capacity of their networks. However, the average users' limited access to high capability T-3 lines often requires offline data distribution methods, particularly for a series of large data files. Most data from U.S. remote sensing satellites are available online only for preview; actual scenes are mailed to customers on tape or disc.

22 SPOT, Image Corp. for example, now markets data from the SPOT satellites that are corrected for terrain distortions and geocoded. These SPOT view image data are available in several different sizes, including the standard 7.5 minute quadrangles of the U.S. Geological Survey (USGS).

23 SPOT Image Corp. has begun to sell data in a wide variety of formats and along geographic lines customized for customer needs. For example, it can put up to 16 standard scenes on a CD-ROM or sell data by the square mile or by the linear mile (with a minimum of 2,500 square miles or minimum length of 100 miles). EOSAT, too, has broadened its range of data delivery media and products.

24 A byte is 8 bits of information, the number required to form an ASCII character. Hence, each character in this file requires 1 byte Of storage. A megabyte is one million bytes.

25 Six of the seven spectral bands have a spatial resolution of 30 meters. Band 6, the thermal band, has a resolution of 120 meters.

26 Modulate-demodulate (essentially a digital-to-analog converter).

27 &cause of this, many large data and information systems are not accessible via modem.

While the delay in transmitting data in this fashion may seem insignificant in most applications, more timely delivery is needed for uses such as disaster monitoring, agricultural production, or ship routing. In its Earth Observing System Data and Information Systems (EOSDIS)[28], NASA expects to provide the ability for scientists at widely dispersed sites to use networks to conduct research together on large remotely sensed data sets. Many telecommunications experts expect the costs associated with data transmission over high-speed lines (Tl and T3) to fall as capacity increases. Yet despite falling data transmission costs, minimizing the size of files transmitted will ensure further cost savings as data transmission needs increase.

In order to speed transmission and reduce the storage requirements, computer experts have devised a variety of data compression schemes to condense the amount of data into files of manageable size (box 2-3).

The development of compression techniques is critical to the development of large data systems and archives. Compression techniques can be "lossy" or "lossless," that is, the data can absorb some acceptable error level through compression

## BOX 2-3: Data Compression

Data compression is the process of condensing, or compressing, the amount of data that must be transmitted from point to point. For example, a single, black and white typed page (like this one) requires about 3.74 million bits (468,000 bytes) of storage when scanned at 200 pixels [1] per inch, and 132,000 bits (1 6,500 bytes) when compressed, Compression ratios (the ratio of uncompressed to compressed data files) range from 71 to 30:1, most remote sensing applications need compression schemes that have near zero loss and achieve 101 to 20:1 compression,[2]

One of the challenges for future remote sensing satellites will be the application of reliable data compression schemes to minimize the transmission time required for large amounts of data. Compression schemes for remote sensing work in two general ways. First, an image or other data set has a great deal of repetition For example, a printed page has many blank spaces that can be condensed for transmission by inserting a single symbol that indicates the length of the blank spaces. A half-tone photograph has fewer blank spaces, but many contiguous areas of equal density that can be indicated in a similar manner A measurement of ocean temperature represented by a color image Will similarly contain large areas of the same color A compression scheme will represent that area with a short instruction to the image processing software to recreate the area with the correct color. When the image is decompressed, the processor fills in the color appropriately,

A second compression technique involves reducing the changes required between scenes, Using the same example, if the temperature profile is updated, or a new area in the same region is measured, only the changes to the original image will be transmitted. New generations of remote sensors will rely on Improved compression techniques. At present, 10:1 compression is achievable for most Imaging applications.

1 Picture elements

2 Don M Avedon, *Introduction to Electronic Imaging,* (Silver Spring, MD Association for Information and Image Management, 1992)

SOURCE Office of Technology Assessment, 1994

28 See ch. 3.

or can emerge from a low rate compression scheme with no errors. For high-precision measurements, lossless compression is required.

Archiving data ordinarily requires lossless data compression because of the need for an accurate and complete record of the data. The use of lossy compression methods is acceptable when the user can tolerate some loss of precision. For example, users who wish to browse through low-resolution versions of data in order to check the appropriateness and quality of particular data sets do not require high precision.[29]

## DATA ARCHIVES

In order for data and information to be useful to a wide range of users over many years, they must be stored under archival conditions and made easily accessible. The federal government archives an astounding variety of data and information generated by the various departments and independent agencies. Because the government continues to make considerable investment in the acquisition of remotely sensed data, and since many of these data are crucial to environmental studies, especially studies of environmental change, protecting that investment by ensuring that the data are accurate, standardized, and of high quality has become increasingly important.

The U.S. government maintains several data archives, located around the country, which store, protect, and distribute climatic, hydrologic, geophysical, and other environmental data (table 1-2). Many of these archives currently have significant holdings that are used by government, academia, and industry. The two largest archives provide a glimpse of the challenges facing the archiving and distribution of satellite and related data:

### U.S. Geological Survey EROS Data Center

Established in 1972, the Earth Resources Observation Systems (EROS) Data Center is the primary archive for land remote sensing data collected by the U.S. government. As the National Satellite Land Remote Sensing Archive,[30] it archives digital data totaling nearly 80 terabytes[31] (figure **2-3) 53** terabytes of which are data from the Landsat system collected between 1972 and 1978.[32] The EROS Data Center also maintains an archive of data collected by National Oceanic and Atmospheric Administration's (NOAA) advanced very high resolution radiometer (AVHRR) carried by the polar orbiting satellites,[33] aerial photographs collected by the U. S. Geological Survey (USGS) National Aerial Photography Program, and USGS airborne radar data. It also contains a variety of Earth science, cartographic, and geographic data.

In 1993, the EROS Data Center distributed nearly $5.7 million worth of USGS and Landsat[34] data products and services. EROS Data Center provides data on a repay basis to government

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29 Online data services commonly offer images for customers to browse through, from which Up to 90 percent of the information has been removed in order to handle them quickly and easily. Nahum Gershon and Jeff Dozier, "The Difficulty With Data," *Byte*, April 1993, pp. 143-147.

30 Provided for in *the Land Remote Sensing Policy Act of* 1992, Public Law 102-555, Section 50*:

"The Secretary of the Interior, in consultation with the Landsat Program Management, shall provide for long-term storage, maintenance, and upgrading of a basic, global, land remote sensing data set (hereinafter referred to as the 'basic data set') and shall follow reasonable archival practices to assure proper storage and preservation of the basic data set and timely access for parties requesting data."

The *Land Remote Sensing Commercialization Act* of 1984, Public Law *98-365, sec. 602* contained a nearly identical provision relating to a data archive.

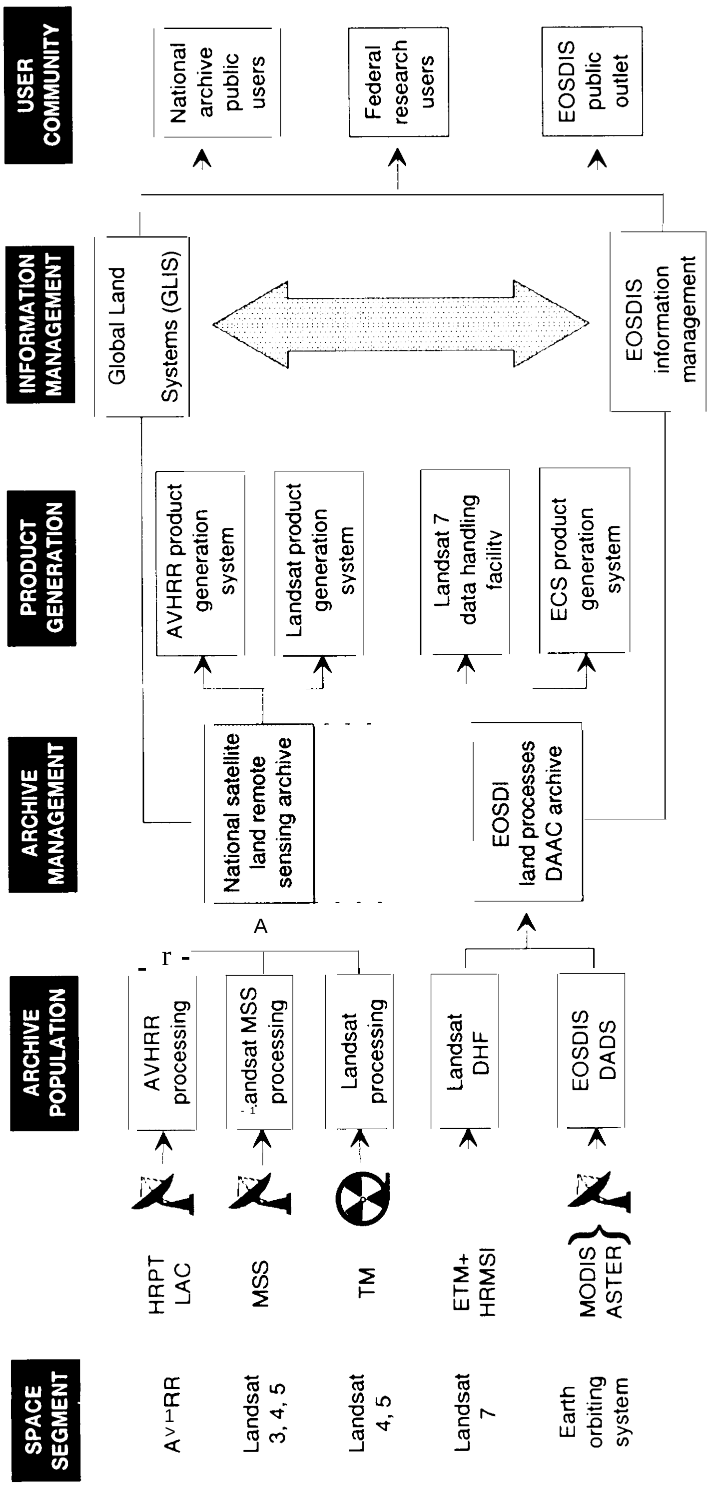
31 A terrabyte equals 1,000 gigabytes; a gigabyte equals 1,000 megabytes.

32 U.S. Department of the Interior, U.S. Geological Survey, EROS Data Center, National Satellite Land Remote Sensing Data Archive, Conference Aug. 26, 1993, Sioux Falls SD.

33 EROS Data Center's AVHRR holdings equal about 3 terrabytes.

34 Approximately $1 million of the Landsat data were produced at EOSAT, but billed by the EROS data center.

FIGURE 2-3: Satellite Land Remote Sensing Data Managment




SOURCE: EROS Data Center, 1994.

agencies and on a direct payment basis to foreign users and the public. It sells all data at the cost of reproduction, following the guidelines of the Office of Management and Budget's Circular A- 130, which sets out the terms by which government data and information are made available to the public.

In order to inform data customers about its holdings of satellite data, EROS Data Center has developed a "metadata" system that provides data about its digital data holdings, called the global land information system (GLIS). GLIS, which can be accessed through Internet, allows customers to determine what Landsat and other digital data the EROS Data Center holds. In addition, GLIS allows potential customers to examine data on-line [35] to check for extent of cloud cover and other features before placing an order. GLIS does not allow for direct digital downloading of data, primarily because officials of the EROS Data Center did not consider the investment in a billing system to be cost effective.[36] In addition, as described earlier, existing transmission rates are too low for efficient data transfer. Multispectral Sensor digital data on tape cost $200 per Landsat scene. Thematic Mapper data, when they first become available later this year, are likely to cost between $300 and $500 per scene on tape.

The EROS Data Center maintains a staff with expertise in the Earth sciences, such as geology, hydrology, cartography, geography, agronomy, soils science, and forestry. These scientists work on scientific problems of local, regional, and global change and assist EROS Data Center customers in making the best use of their data. The center's staff also includes experts in systems development, telecommunications, and computer sciences, which are needed to improve the center's ability to archive and deliver data more efficiently.

The EROS Data Center will serve as a distributed active archive center (DAAC) for NASA's EOSDIS,[37] adding archival responsibilities for land processes data from new NASA satellites to its current functions. It will archive data from several Earth Observation System sensors, including the advanced spaceborne thermal emission and reflection radiometer (ASTER) and multiangle imaging spectroradiometer (MISR). The process of archiving data from both sensors will require EROS Data Center to install new hardware and software to handle the additional archiving and distribution load.

## NOAA's National Climatic Data Center

The Federal Records Act of 1950 originally established the National Weather Records Center in New Orleans. In 1951, it was moved to Asheville, North Carolina and renamed the National Climatic Data Center (NCDC). NCDC is currently the world's largest active archive of weather and climate data, containing about 30 terrabytes of weather and climate data (figure 2-4).[38] It serves as the archive for data from the National Weather Service, military services, Federal Aviation Administration, and the Coast Guard. NCDC also accepts weather data from foreign sources (figure 2-5). The center archives 99 percent of all NOAA data, including satellite weather images back to 1960. The center archives data collected by satellites, radar, aircraft, ships, radiosonde, and National Weather Service stations. It archives about 55 gigabytes of new data each day. NCDC operates the World Data Center-A for Meteorology, and both gathers and shares data internationally.

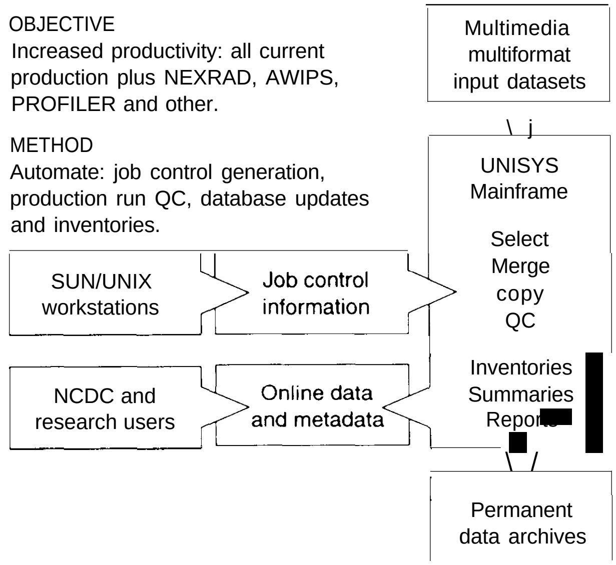
[35] These "sampled" scenes, Which are generated by extracting about 1 O percent of the original data, are not of sufficient quality to use. but provide customers with an excellent visual tool to determine whether the data can be used for their project.

[36] Data Center staff expressed concerns about maintaining credit card numbers and other confidential information in a data system that would allow virtually unlimited front-end access.

[37] See ch. 3 for an extensive discussion of EOSDIS.

[38] Source: NOAA, NESDIS, briefing, 1993.

FIGURE 2-4: National Climatic Data Center Comprehensive Archive Management System



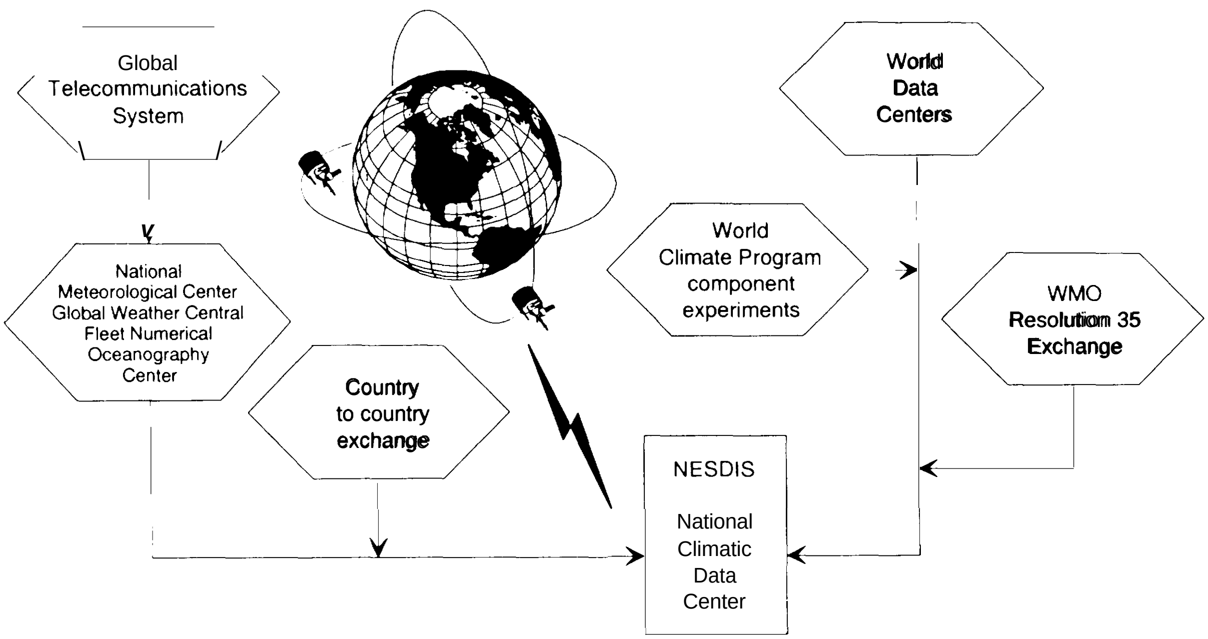

SOURCE National Cilmatic Data Center, 1994

Data from NOAA's Polar-orbiting Operational Environmental Satellite (POES) system are collected and stored at NCDC'S facility in Suitland, Maryland. Backup copies of data tapes are stored in Asheville.

NCDC maintains 455 different data sets and responds to about 90,000 data requests each year, supporting many forms of data dissemination: paper, photographs, magnetic tape, floppy disks, CD-ROM, electronic mail, online dial-up, telephone, and facsimile. Data costs vary according to the amount of effort NCDC personnel expend in providing the information. For example, NCDC charges an additional fee for certifying the authenticity y of climate data, often needed to support legal proceedings. In order to deliver data to data users as quickly as possible, NCDC has developed the OASIS online services (table 2-3).

In addition to publishing their own research on climate, center staff also provide historical perspectives on climate vital to studies of climate change and the environment. For example, in September 1993, the

FIGURE 2-5: National Climatic Data Center: Data Received From International Sources




SOURCE National Climatic Data Center, 1994

TABLE 2-3: National Climatic Data Center (NCDC) Online Access and Service Information System (OASIS)

| Data | Period of record | Process time before online availability |
|---|---|---|
| Wind Profiler | | |
| Winds -60 | 31 days | 1 1/2 -2 hours |
| Surface -60 | 31 days | 1 1/2 -2 hours |
| Moments -60 | 7 days | 1 1/2 -2 hours |
| Moments -60 | 7 days | 1 1/2 -2 hours |
| National Weather Service, surface hourly | 2 year | 2-3 weeks |
| National Weather Service, rawinsonde | 2 year | 3-4 months |
| National Weather Service, | | |
| Hourly | 2 year | 8-9 months |
| 15 minutes | 2 year | 8-9 months |
| N American rawinsonde | from Jan 1, 1992 | 24 hours |
| Cooperative Summary of the day (TD 3200) state files | 1992 | as required |
| General Circulation Model carbon dioxide | 100 year | as required |
| Field Experiment | | |
| CaPE | 06- 07/ 1991 | as required |
| STORM -FEST | 02- 03/1 992 | as required |
| GCIP | 02- 04/ 1992 | as required |
| NEXRAD Level II | | |
| Inventories | **03 / 91-** | 2-4 months |

NCDC has online data and metadata available by file transfer protocal (FTP) computer access Data are placed online as soon as possible after receipt or processing, Those data are available without charge via FTP for immediate downloading (up to 50 MB) or users can order data for offline delivery (standard NCDC charges). In addition to data, important metadata are Included with the online data Station histories, data dictionaries, field experiment information, and data inventories are Included,

SOURCE National Climatic Data Center, 1994

center published a technical report on the special weather stresses experienced in the United States during the summer of 1993 and their effects on the U.S. population.[39] The center also supports a wide variety of industrial, agricultural, and engineering applications for historical climate data (table 2-4).

## TECHNOLOGY FOR ARCHIVING DATA

Data archiving requires use of high-density storage media. Current media used by some of the larger data bases include magnetic tapes (1/2-inch tape, 8mm tape, 4mm tape), and optical disks (CD-ROM, CD-WORM,[40] and larger optical disks). Manufacturers now routinely develop and market new magnetic and optical media, forcing difficult choices among the government agencies and other data providers about how to improve their archives and distribution system. The development of storage standards can be a significant problem. If data are stored on media supported by only a few suppliers, they could become expensive and difficult to replace as they wear out. In the worst case, they could become unreadable as the

[39] Neal Lott, "The Summer of 1993: Flooding in the Midwest and Drought in the Southeast," NCDC Research Customer Service Group, Technical Report 93-04.

[40] CD-WORM stands for compact disk, write-once, read-many times memory.

TABLE 2-4: Applications of Historical Climate Data

| Customer type | Data used | PurPose |
|---|---|---|
| A Manufacturing | | |
| 1 Automobile | "Local Climatological Data"<br>Surface Weather Observations | Testing new batteries<br>Determining cause of air conditioning failure |
| 2 Weather dependent products: umbrellas, shoes, firelogs, sunglasses, etc | "Local Climatological Data" | Determining impact of weather on sales |
| 3 Software manufacturer | Surface Weather Observations | Database development |
| 4. EPA/consultants | Mixing Height Studies | Air pollution control |
| B Energy | | |
| 1 Electric power companies | Heating & Cooling Degree Data | Determining level of electrical demand through computer models |
| 2 Gas utility | "Monthly Station Normals of Temp, Precip, Heating and Cooling Degree Days" | Determine rate adjustments and expected demand |
| 3 Energy consultant | Wind Energy Resource Information System | Determining possibility of using wind mills |
| 4 Battelle Pacific Lab | DATSAV 2 data<br>(Hourly Surface Obs) | Study for wind energy usage in Third World Countries |
| 5 Oil companies | Navy Marine Summaries<br>International Station CD-ROM | Planning offshore oil drilling platforms |
| C Agriculture | | |
| 1 NWS Agricultural Weather Service | COOP Data | Advisory and research |
| 2 Horticultural firm | International Station CD-ROM | Design of greenhouses and determining areas for crops |
| 3 Herbicide manufacturer | Surface Weather Observations | Determining effects of temperature |
| 4 Horticultural firm | "Frost/Freeze" Publication | Planning for crops |
| 5 Entomologist | COOP Weather Reports | Determining life cycle of insects |
| 6 Commodities exchanges | "Local Climatological Data" | Crop storage planning<br>Effect of climate variations on crop yields |

| TABLE 2-4: Applications of Historical Climate Data (Cont'd.) | | |
|---|---|---|
| **Customer type** | **Data used** | **Purpose** |
| D Consultants and Engineers | | |
| 1 Meteorological consultant | All types of observations<br>Map Analyses<br>Climatic Averages | Expert testimony<br>Climatic Studies |
| 2 Marine consultant | Marine Wind/wave summaries | Port design |
| 3. Engineering firm | FAA Wind Rose | Airport design |
| 4 Engineering firm | Weather Bureau Technical Paper No, 40<br>NOAA Tech, Memo Hydro-35 | Building, highway, dam design/ flood control |
| 5 American Society of Civil Engineers | DATSAV 2 | Development of ice Ioadlng Guidelines |
| 6 Architects | COOP/Climatlc Summaries | Planning construction projects |
| 7 University research | North Atlantic Hurricane Tracking Data | Storm risk analyses |
| 8 Unversity research | Summary of the Day Weather Data | Land Use impact study |
| 9 Engineeting firm | Soil Freeze Depth Maps | Construction design and planning |
| E. Entertainment | | |
| 1 Festivals, concerts, sports events, conventions | COOP Weather Reports<br>Climatic Averages | Establish normals and patterns for planning purposes |
| 2 Golf course development | Climatic Averages | Planning useage |
| 3 Resort development Conference | Climatic Averages | Development |
| 4 Insurance industry | Climatic Averages<br>Hourly Precip Data | Planning insurance for entertainment events/verification |
| 5 Authors | ‘(Local Climatological Data”<br>Climatic Averages | Books: verification of data |
| F. Communications | | |
| 1 Institute of Telecommunications | International Station CD-ROM | Communication system planning |
| 2. Television advertising | Climatic Averages | Establish ideal filming times |
| 3 Ad agencies | Climatic Averages | Determine markets |
| 4 IV/Radio programs Magazines | “Local Climatological Data”<br>Surface Weather Observations | Fact verification |

TABLE 2-4: Applications of Historical Climate Data (Cont'd.)

| Customer type | Data used | Purpose |
|---|---|---|
| 5 Cable television firm | COOP Data | Microwave attenuation study for tower planning |
| G Services | | |
| 1 Physicians/medical research centers | Surface Weather Observations<br>Climatic Averages | DiSeaSe/Climate-weather correlations |
| 2 Highway departments | Climatic Averages | Planning snow removal |
| 3 Insurance companies | Climatlc Averages<br>Surface Weather Observations | Planning and verification |
| 4 Insurance companies | Surface Weather Observations<br>COOP Observations | Settle weather related disaster claims |
| 5 Attorneys | Surface Weather Observations<br>COOP Observations | Settle legal disputes |
| H Housing/real estate | | |
| 1 Contractors | Surface Weather Observations<br>"Local Climatologlcal Data"<br>COOP Observations | Determine construction deadline penalties or extensions |
| 2 Real estate developers | Climatic Averages | Site selection for resort and retirement developments |
| I Transportation | | |
| 1 Trucking companies | Climatic Averages | Expedite transport of perishable goods |
| 2 Airline companies | Climatic Averages<br>Map Analyses | Determine favorable air routes |
| 3 Marine shipplng companies | Climatic Averages<br>Storm Tracks<br>Marine CD-ROM | Determine optmal shipplng routes |
| 4 Railroad companies | Climatic Averages | Determine favorable seasons and routes for transport of goods and commodities |

As the repository of weather data from the United States and the world, the National Climatic Data Center is charged by law with providing accurate, historical data about US weather and climate. Historcal data about the climate serve a variety of useful applications in agriculture, construction, engineering, law, and transportation This table lists a sampling of uses of climate data in the U S Economy

SOURCE National Climatic Data Center, 1994.

## BOX 2-4: Rapidly Changing Technology and Data Storage

Because data must be stored on media available at the time of collection, electronic databases not only benefit from but require periodic storage upgrades. Upgrading data storage provides a number of benefits, including better performance, reduced storage costs, and greater storage density.

Data managers must transfer electronically stored data to new media for two reasons: First, magnetic media deteriorate over time, resulting in some data loss. Second, media often become obsolete as new technologies are developed and the readers for older media lose market share. The rapid shift from long-play records to compact disk technology for commercial music provides an instructive example of such changes in the consumer marketplace.

In the smaller marketplace for scientific data, major improvements in technology can cause special problems in maintaining data. For example, the EROS Data Center has encountered difficulties transferring data acquired from Landsat 1 to new media. Some of these data are of particular significance because they represent the oldest multispectral satellite data available about Earth's surface, and are therefore of considerable importance to research on local and regional land changes. NASA originally recorded the data using proprietary recording equipment that has since failed as a result of age. The development and production team for the original Landsat 1 tape system has dispersed over the years, making it impossible to replicate the system without extraordinary investment.

The EROS Data Center has encountered a different problem with data from Landsat 3. The tapes had been stored at the NASA Goddard Space Flight Center Landsat facility, which was operating in the late 1970s before Landsat operations were transferred to NOAA. Many of these high density tapes now suffer from "sticky tape syndrome, " a condition they developed when subjected to excessive humidity while in storage at Goddard Space Flight Center. The magnetic tape coating absorbed moisture making them unusable without special treatment. The EROS Data Center and the National Media Laboratory have discovered that by heating the tapes in an oven, they can literally cook the moisture out of the tapes, which restores their readability for several weeks. ' After undergoing such processing, they can then be read by the center's tape readers and transferred to more stable modern media, allowing the EROS Data Center to make the data available to customers.

[1] "Solving Sticky Tape Syndrome at EROS Data Center," *NML Bits* (Newsletter of the National Media Lab), VOl 3, September 1993

SOURCE: EROS Data Center, Office of Technology Assessment, 1994

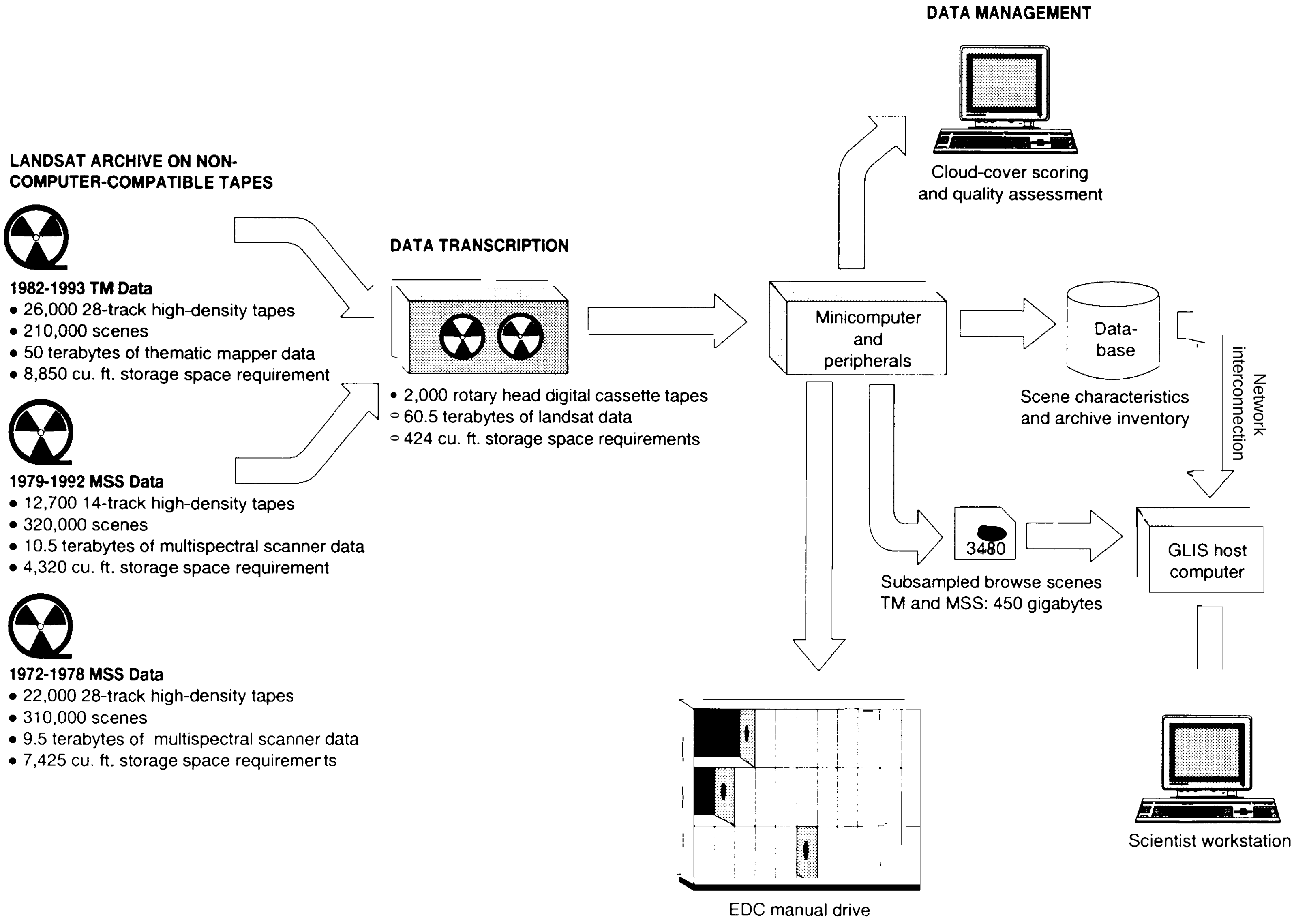
technology becomes obsolete (box **2-4;** figure **2-6).** Fortunately, the existing large market for information technologies gives archive managers some comfort that a storage medium in wide use will not become obsolete quickly.

## NAVIGATING THE ARCHIVES

Many archival data are increasingly stored as digital images in specialized **databases.**[41] Yet, data sets are useless if the appropriate information cannot be accessed and applied to solve problems. The development of powerful database software has resulted in systems that can sort through a wide variety of data quickly and provide users with information in several formats. The number and size of data and information systems continues to increase. In addition to the growing collection of data sets archived by the federal govern-

[41] Gershon and Dozier, op. cit.

FIGURE 2-6: Thematic Mapper/Multispectral Scanner Conversion System Functional Capabilities




SOURCE: EROS Data Center, 1994.

ment (table 1-2), many states are attempting to develop comprehensive information systems to store and access data specific to their needs. Many of these data are geospatial data.[42] Data and information systems dedicated to managing specific resources (land, timber, oil, minerals, agriculture) are also being developed by companies with a financial stake in such resources.

As archival holdings grow, it will be essential to have the ability to search databases quickly and obtain useful information. Each data center maintains its own database. However, data users, both within the federal government and outside, often have difficulty in determining precisely where data they may need reside, or if the data exist at all. Some data exist in hard copy form such as maps, photographs, lists, and charts. Others are stored in electronic form. Several advisory groups have suggested that the use of available data would be made much more effcient the creation of a metadatabase that listed all data that falls within certain categories in one readily accessible place. Metadata provide summary information about data holdings and guides to accessing them—what data are available, where they are held, and how to access them. Metadata therefore function like a library's electronic card catalog. Having such information is not only helpful in navigating the many available archives, but may make it possible for agencies to avoid creating data sets that are already available elsewhere.

The Federal Geographic Data Committee (FGDC),[43] which is composed of representatives from Federal agencies that generate and use geospatial data, was established to "lead the development of the national spatial data infrastructure (NSDI) and to coordinated its implementation."~ For geospatial data generally, the President has directed:

- FGDC to establish a National Geospatial Data Clearinghouse that would gather geospatial metadata from the agencies,
- each agency to:
  - a) document all new geospatial data with the FGDC metadata standard and make that documentation electronically accessible,
  - b) adopt a schedule for documenting (where feasible) existing data,
  - c) adopt a plan to establish procedures for public access to geospatial data, and
  - d) adopt internal procedures to use the clearinghouse prior to expenditure of federal funds for data collection.

The Executive Order further states that FGDC is to develop standards for implementing the NSDI, and to submit a plan to the Office of Management and Budget (OMB) for:

> completing the initial implementation of a national digital geospatial data framework... and for establishing a process for ongoing data maintenance.

It further instructs FGDC to develop strategies for:

> maximizing cooperative participatory efforts with State, local, and tribal governments, the private sector, and other nonfederal organizations to share costs and improve efficiencies of acquiring geospatial data.[45]

Geospatial remotely sensed data are also subject to these directives. However, as noted above,

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42 In other words, they have attributes such as soil type, resources, or other characteristics that can be placed geographically.

43 The FGDC is authorized by the Office of Management and Budget, Circular A-16 to coordinate federal agency involvement in the National Spatial Data Infrastructure.

44 Office of the Vice President, Department Of the Interior, "Recommendation DO1O3," *Accompanying Report of the National Performance Review*, September 1993. The Federal Government generates and uses many kinds of geospatial data. As conceived by the FGDC, NSDI is composed of the large collection of digital, geospatial data that constitutes a major part of the overall Federal information infrastructure. By establishing minimum standards for data acquisition and distribution, the FGDC hopes to "enable analysts and decisionmakers to integrate diverse geographic information" quickly and easily.

45 Executive Order 12906 of Apr. 11, 1994, "Coordinating Geographic Data Acquisition and Access: The National Spatial Data Infrastructure."

satellites collect nonspatial data about Earth systems. For the purposes of global change research, environmental monitoring, and other applications, users will need ready access to information about the location and availability y of these data as well.

**To avoid duplication in data acquisition and archiving, Congress may wish to consider instructing Federal agencies to coordinate on developing an online database that would hold metadata about all civilian remotely sensed data. Such a database would be able to field queries from government and private customers interested in remotely sensed data.** This metadata set, which would be small enough to be located in one site, or distributed among several sites in a network, would not be the source for the data themselves but provide a guide to the holdings thoughout the federal government. It could also store information about data held in local and state government offices, and in private archives. Development of a central metadata set will require the cooperation of the many government agencies, including the Department of Agriculture, Department of Defense (DoD), Department of Interior, Environmental Protection Agency, NOAA, and NASA, as well as agencies that hold other kinds of geospatial data, such as census and land use data. A centrally-organized metadata set would ensure maximum exploitation of data sets that have already been acquired by the government and other users.[46] It would constitute an important component of the larger geospatial metadata set recommended by the FDGC.

## GEOGRAPHIC INFORMATION SYSTEMS

Over the past decades, users of spatial data have harnessed the spectacular gains in the power and speed of computer hardware to develop systems capable of meeting their spec ial needs for processing and manipulating spatial data. These systems have become increasingly flexible, allowing users to analyze and manipulate digital images, add new information, and create layers of data that focus on different forms of information. Recent systems also allow users easily to convert various kinds of data to color-coded images that enable researchers to isolate patterns in the data.[47] This recent development is in part a result of new software programs that take advantage of increased processing speeds available in newer workstations.[48]

Data systems capable of assembling, storing, manipulating, and displaying geographically referenced data[49] are known as geographic information systems (GIS). Driven by simple commands, GIS can be used to display and analyze spatial data {box 2-5) in many different ways. GIS users can select from among many categories of information to display on a single digital image, depending on their needs. For example, in figure 2-7. the GIS layers display land use, transportation routes, potential hazardous waste sites, and hydrography. These scenes can be displayed with categories of information (grid lines, roads, zip codes) withheld, and added at a later time, or they can all be displayed at once. The variables are stored in relational data files, and the flexible program relates each variable to the proper image.

[46] See National Research Council, *Toward a National Spatial Data Infrastructure* (Washington, DC: National Academy Press, 1993), the report of the National Academy of Science's Federal Mapping Committee, for a detailed discussion of this point.

[47] For example the High Resolution Infrared Radiation Sounder aboard NOAA's POES satellites takes temperature and humidity soundings in a "column" through the atmosphere. By color-coding the data and plotting observations taken at different geographic locations, scientists can visual I/c changes in temperature and humidity at a given level of the atmosphere as the satellite sweeps across Earth 's surface.

W)\ computer's microprocessor design determines the number of calculations that can be made simultaneously. The clock speed is a measure of how fast the microprocessor operates. The microprocessor must synchron I/e sy stem operations, read in structions from the main memory cache, manipulate data stored there. A microprocessor in a system operating at I MHz would operate 1 mill ion times per second. Many new systems contain 486-based processors that operate at a clock speed of either 33 MHz, 50 MHz. or 66 MHz.

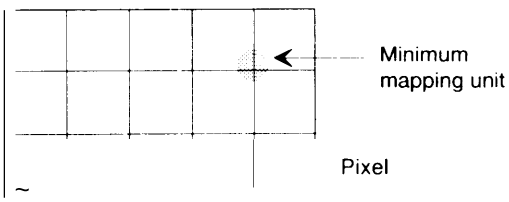
[49] Geographically referenced data are identified according to their location in some space—hence the term spatial data.

## BOX 2-5: What are Spatial Data Se

Spatial data sets provide information about conditions at various locations in 2 or 3 dimensions There two broad categories of spatial data raster data and vector data

Raster data sets are obtained by imaging (photographically or by electronic sensor) an area of interest In obtaining a raster data set, the imaging device develops a value of intensity for the physical quantity of Interest (e g land cover features, elevation in meters, land use class) for every cell, or picture element (pixel). The individual pixel represents what is essentially an average Intensity within that area Pixels are defined by their columns and rows; pixels may be square or rectangular

The minimum mapping unit or resolution unit , is the smallest element that can be distinguished by the Imaging system. The pixel size should be smaller than the minimum resolution element, so as not to miss Important features. For example, in the schematic below, if the gray shaded area represents the minimum mapping unit, and is thus detectable by the Imager, it would not show up in the pixel, since it would not cover the majority of any one cell. ' If the pixels were smaller, the feature would show up in the image.




Vector data sets are collectiions of Information based on elemental points whose locations (made up of a point and a direction from an origin) are known to arbitrary precision such as “point A is 25 kilometers north northeast from the map’s origin “ The placement of a point on a vector-generated map is not limited by the size of a pixel Vector representation allows the map maker to represent map elements much more simply than raster representation. For example, in a vector data structure a circle can be represented in the computer by a point, a radius, and the thickness of the line By contrast, to represent the same circle in raster format would require storing all the pixels that make up a circle in the right sequence to represent the circle as an image Conventional maps developed in a computer have been based largely on vector data sets because vector representation is much more economical of computer memory Because cconventional maps are collections of standard symbols arrayed in a pattern that represents an abstract image Vector data sets such as maps focus primariy on major features (e g., roads, rivers mountain ranges, cities) and present information in a relative way.

Both raster and vector data are Important to consumers of remotely sensed data Increasingly, both data types are being combined to produce products that hold valuable information regarding details of land features, land cover, elevation, *and* relational aspects such as distance between objects For example, the U S. Geological Survey develops combination products known as digital ortho-photo quads, or quadrangle maps that use dlgitzed photographs to correct standard vector maps (produced by USGS for decades) Vendors that produce software for GIS have found a significant market in software that can convert between raster and vector data sets

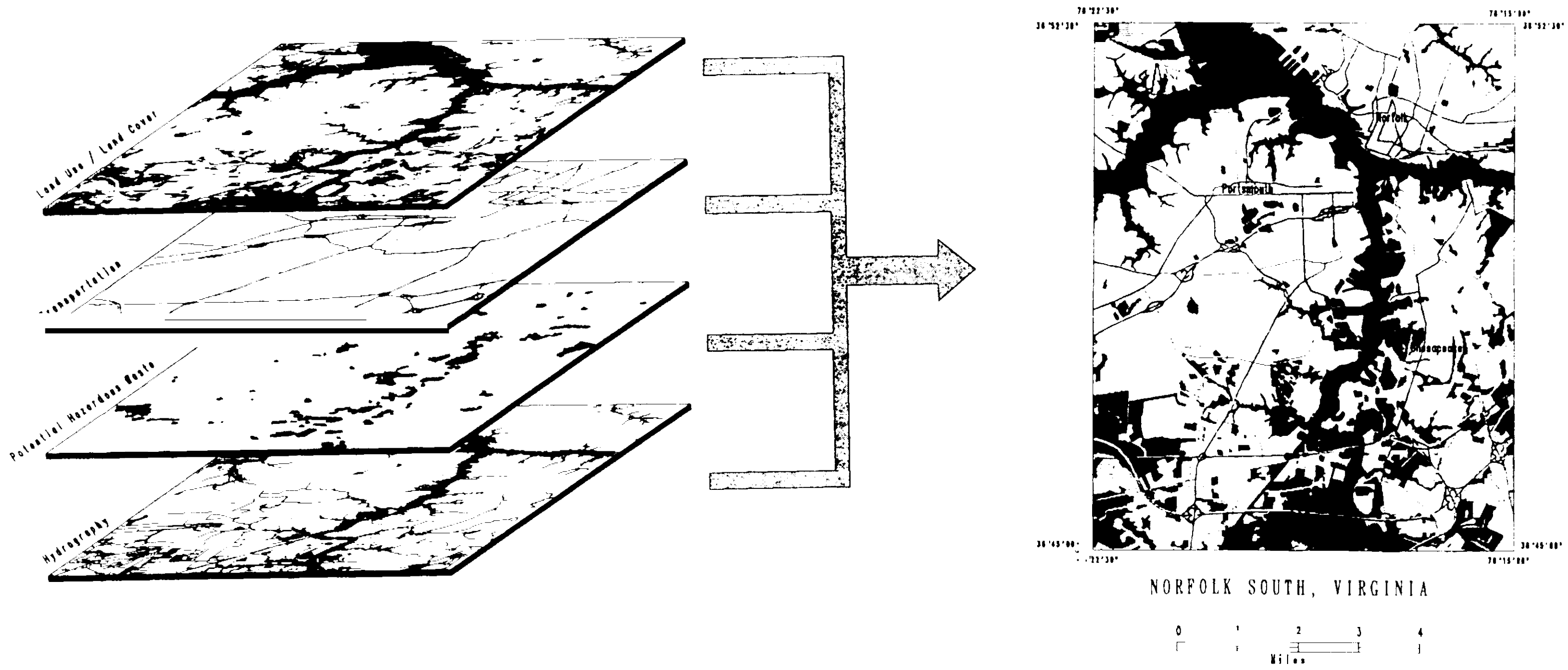
Increasingly, electronic maps are used to replace or augment paper. Paper maps, while an extremely effective way to display information, cannot match the density of similar information stored on floppy disks or CD-ROM A compact disk can store many digital maps and even images of places of particular interest.[2] Further, digital maps can be designed to contain Information of interest to specific classes of users Digital map readers can also be combined with Global Positioning System receivers, providing real-time position Information to the user

[1] If, however, the feature is extremely bright compared to its surroundings, it could be detected as present, though not resolved For example, the Landsat thematic mapper image of the Chernobyl reactor just after it suffered a failure and was burning registered a “hot spot” in the thermal band, which has a surface resolution of only 120 meters The burning reactor therefore could not be Imaged, but the fact that it was burning was never the less observed

2 For example De Lorne Mapping markets a CD-ROM, Street Atlas, USA, which enables users to locate most U S streets and create and print maps of varying scales The data are stored in vector format for quick call-up and presentation

SOURCE: Off Ice of Technology Assessment, 1994

FIGURE 2-7: Environmental and Urban Analysis Using the Use of Geographic Information System Technology




The National Mapping Division of the U.S. Geological Survey, the Water Resources Division of Virginia, and the Environmental Protection Agency have cooperated to produce a database for a nine-quad area in the Elizabeth River Watershed of the Chesapeake Bay. Data from these and other scientific studies, cartographic and thematic sources, and administrative or regulatory files will be formatted for entry into the GIS. This area is to serve as a pilot project location where GIS activities associated with the Chesapeake Bay Program can be studied and demonstrated. Each of the four layers of information on the left can be printed and studied independently, or can be combined in various ways to produce a composite product.

SOURCE: U.S. Geological Survey, 1993.

The development of GIS has been a major force in the enhanced use of remotely sensed data during the late 1980s and early 1990s. A rapidly growing collection of users now has the ability to use GIS to analyze remotely sensed data and to incorporate other data with them. For example, a remotely sensed image could be used as a foundation for adding ownership boundries, sensitive environmental areas such as wetlands, zoning, historic sites, population densities, and transportation routes. All or part of the additional information could be displayed or printed as needed. GIS users are becoming more familiar with satellite data, and are using them with greater frequency. For example, civil engineers increasingly rely on satellite images of large geographic areas to analyze and explain construction projects, such as the construction of new highways.[50] Planners of routes for pipelines or high-capacity electrical transmission lines find remotely sensed data, coupled with GIS software, extremely useful in locating suitable routes quickly and accurately.sl Field positions derived from the military's global positioning system (GPS) make the accurate determination of geographical locations much simpler than ever before (box 2-6). Appendix B presents other examples of the combined use of these powerful technologies:

> The past few decades have witnessed tremendous development and change in spatial data handling....What some have characterized as the "digital revolution' '...has had a profound effect on almost all activities utilizing geographic information. These effects have been felt in the research and academic sector...in the private sector, which is populated with a large number of digital spatial software system vendors and a larger number of users of such systems; and in the federal, state and local levels of government, which are some of the largest producers and users of digital spatial data.[52]

The rapid increase in computing capabilities and geographic information systems has resulted in many different methods of storing and using data. Because data formats are seldom standardized,[53] data analyzed by one GIS software package may not be readable by another.[54] Lack of standardized data sets can cause serious logistical problems for data users intending to integrate data from multiple sources. This problem is particularly acute in the federal government, where purchases of remotely sensed data are difficult to coordinate across agencies, and operating systems are purchased independently. The development of GIS standards could improve the usefulness of the technology and enhance the market for remotely sensed data.

Data standardization efforts are underway. For example, as noted earlier, federal agenc ies formed the Federal Geographic Data Committee (FGDC) to serve as a forum for the discussion of spatial data issues within the federal govemment.[55] Among other things, the committee has taken the lead in insuring that various software applications

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50Harold Hough, "Satellite Imagery Charts Course for Civil Engineers in Jacksonville, Florida," *Earth Observation Magazine*, June 1993, pp. 25-28.

51To accomodate such users, SPOT Image Corp. now sells data of arbitrary shape by the square mile. It will for example, sell data that stretches along linear features such as pipline rights of way. See "The New Benefits of Space Age *Technology, ''A-E-C Automation Newsletter,* November 1993, pp. 2-7.

52Harold Moellering, '* Opportunities for Use of the Spatial Data Transfer Standard at the State and Local Level," *Cartography* and Geo*graphic Information Systems*, Journal of American Congress on Surveying and Mapping, vol. 19, December 1992.

53See Victor Callaghan, "The image File Format Mess: What's Your TIFF?" *Advanced Imaging,* March 1994, pp. 44-47,85, for a discussion of the different file formats and the difficulties of working with so many.

54See also U.S. Congress, Office of Technology Assessment, *Data Format Standards for Civilian Remote Sensing Satellites*, (Washington, DC: OTA, International Security and Space Program, May 1993) for a discussion of data format issues. This background paper highlights incompatible data formats and storage media, concluding there is no central organization positioned to develop and implement data standards.

55Originally chaired by a representative of the USGS, in fiscal year 1994, Bruce Babbit, Secretary of the Interior took over chairmanship of this committee. His chairmanship demonstrates how important the Department of Interior considers the issue of data standards.

### BOX 2-6: Remote Sensing and the Global Positioning System

The ability to determine position quickly, simply, and with high accuracy from the Global Positioning System (GPS) constellation of satellites has markedly enhanced the use of remotely sensed data in geographic information systems. Developed by the Air Force for Department of Defense uses, GPS has found extensive use among a wide variety of civilian users.

GPS consists of three major segments: 1) a constellation of 24 satellites orbiting at approximately 11,000 nautical miles above Earth, 2) a mission control segment; and 3) a user segment, consisting of individual fixed and portable GPS ground receivers. GPS satellites have a 12-hour repeat cycle and an approximate 60-degree equatorial spacing. Between six and 11 satellites are always visible 5 degrees or more above the horizon. Ground receivers determine positions by measuring the signal travel time from four or more satellites, Civilian users can achieve position accuracies within 100 meters of the true geographical position. Better positioning (a few meters) is possible by using a correction signal from a ground-based differential position receiver/transmitter. The differential position recewer/transmitter, located at a known position, receives GPS signals from the satellites and calculates a correction, which it then broadcasts to GPS receivers within its range. Users with properly equipped GPS receivers can then automatically correct their calculated positions.

GPS can be used to geocode SPOT or Landsat imagery, and also to find sites within a study area. The merger of satellite imagery and GPS has proved invaluable in creating and updating GIS databases quickly and accurately. Doing so has saved time and money compared to using traditional methods such as field surveying and aerial photography.

SOURCE Off Ice of Technology Assessment, David A Turner and Marcia S Smith, *GPS Satellite Navigation* and *Positioning and the DoD's Navstar Global Positioning System,* 94-171 SPR (Washington, DC Congressional Research Service, Feb 15, 1994)

for GIS within the federal government are compatible. By coordinating with the user community and software developers, this committee has enabled the federal government to adopt a transfer standard.[56] As a consequence of this committee's work, as of February 15, 1994, all federal agencies must purchase and use computer hardware and software that allow the transfer of information among dissimilar systems. Vendors of spatial data processing software must comply with what has become known as Federal Information Processing Standard (FIPS), and can turn to the FGDC for advice. The vendors are now developing hardware and software to comply with the FIPS. USGS has designed a spatial data transfer processor to support transfer of data between various formats.[57]

GIS software has also suffered the drawback of requiring specialized training to use it effectively. Although GIS software is becoming more *'user friendly," most users still require intensive training.

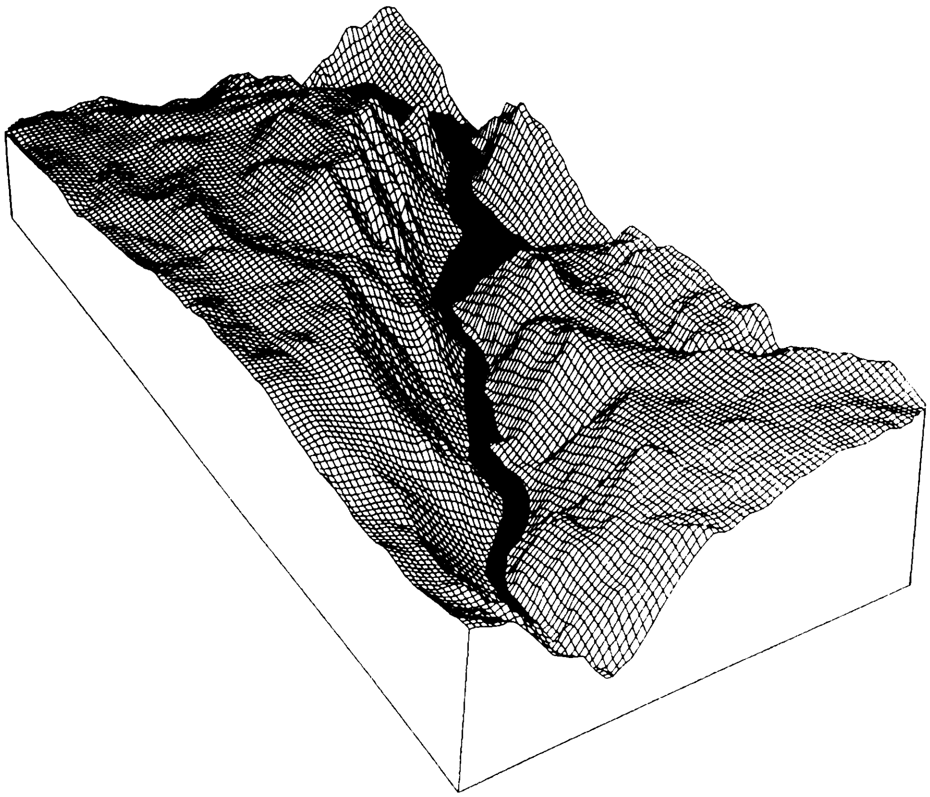
## NEW WAYS OF VISUALIZING DATA

People are often more adept at extracting information from properly prepared images than from text, and sometimes capable of culling information from a series of images or video. Increasingly, therefore, researchers use spatial data in video or simulated video. In addition, remotely sensed data sets can be used to simulate (in three-dimensions) landscapes and geologic formations. These too, can be used in video representations of spatial

[56]The Secretary of Commerce approved the Spatial Data Transfer Standard, known as a Federal Information Processing Standard 173 in July 1992.

[57]More information regarding Federal Information Processing Standard 173 and its implementation is available from the Federal Geographic Data Committee, within the USGS.

FIGURE 2-8: Terrain Analysis Using Geographic Geographic Information System Technology



The U S Geological Survey prepared this dlgltal elevation model of the Hetch Hetchy Canyon in Yosemlfe National Park, California using aerial photographs

SOURCE U S Geological Survey, 1993

data. Data collected by remote sensors, when joined with digital terrain models, have been used to simulate airborne approaches to airports, geologic formations, and to produce topographic models of cities and countries around the world (figure 2-8). Converting spatial data to three-dimensional scenes or video presentations is useful because:

- three-dimensional and video representation allow researchers to visualize more information than with two-dimensional still images;
- three-dimensional and video representation provide a sense that the viewer is within the landscape and moving through it;
- three-dimensional and video data sets increase the potential application of remotely sensed data—more stimulating presentations of spatial data make the prospect of commercial use of data more likely.

Using information in three-dimensional format requires increased processing capacity and large amounts of data storage. Many current users of three-dimensional imagery rely on advanced computer work stations (computers that can perform hundreds of million instructions per second, or MIPS). Methods of employing spatial data that were once regarded as frivolous have gained broad acceptance because of the value of visualizing data. For example, the interest in "virtual reality," or "computer simulation of reality," has become more widespread than it was several years ago, in part because image intensive applications have demonstrated the value of high resolution data display.[58]

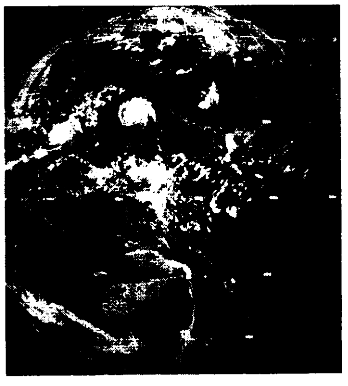
[58] See "The Third Branch of Science Debuts," Science, vol. 256, Apr. 3, 1992, pp. 44-47.

# NASA's Earth Observing System Data and Information System 3

The National Aeronautics and Space Administration (NASA) plans to make its Earth Observing System Data and Information System (EOSDIS) the world's most capable and advanced data and information system. Although some aspects of EOSDIS are unique, the program is an example of some of the capabilities and challenges common to advanced remote sensing data and information systems of the future. EOSDIS can also be expected to have influence beyond global change research, serving as a catalyst for advanced computing and data system technologies.[1]

## EOSDIS OVERVIEW

As a result of concerns that humanity is having a major, detrimental influence on the global environment, in 1990 the U.S. government initiated the U.S. Global Change Research Program (USGCRP).[2] NASA has played a major role in the USGCRP by orienting its Mission to Planet Earth (MTPE) toward the scientific objectives of the USGCRP. The centerpiece of NASA's MTPE,



[1] As one example, new tools for manipulating scientific imagery could benefit other fields relying on databases of three-dimensional structures, such as crystallography, medical imagery, and computer-aided design.

[2] "The USGCRP was established as a Presidential initiative in the FY 1990 Budget to help develop sound national and international policies related to global environmental issues, particularly global climate change." The USGCRP seeks to "address significant uncertainties in knowledge concerning the natural and human-induced changes now occurring in the Earth's life-sustaining environmental envelope . . The USGCRP is designed to produce a predictive understanding of the Earth system..." Office of Science and Technology Policy, Committee on Earth and Environmental Sciences, *Our Changing Plane/: The FY 1993 U.S. Global Change Research Program* (Washington DC: National Science Foundation 1992), pp. 3-4.

as well as the USGCRP, is the Earth Observing System (EOS). EOS consists of a space-based observing system (figure 3-1 ), a scientific research program, and its data and information system, EOSDIS.[3]

EOSDIS plays a crucial role in global change research. EOSDIS helps transform heterogeneous remotely sensed and other data into useful information for integrated, interdisciplinary, predictive studies of the Earth's environment. NASA planners expect EOSDIS to provide increasingly effective access to data, as well as extensive data processing and analysis, the tools needed by researchers to transform data into useful information for policy makers.

EOSDIS (figure 3-2) presents NASA with very difficult management and technology challenges. By the first years of the next century, NASA expects EOSDIS to manage over 80 trillion bytes of data per year from EOS satellites alone. Other spacecraft could contribute an additional 80 trillion bytes per year. Processed data from EOSDIS would be well over 300 trillion bytes per year, equaling more than 250 million 1.2 megabyte high-density floppy disks.[4] NASA faces the daunting challenge of making this enormous quantity of data easily usable for a wide variety of users, including 10,000 physical scientists and possibly as many as 200,000 other users, many with little detailed technical knowledge of remote sensing.[5] Furthermore, these data USHS and 'heir needs will change, as will the data system technologies used in the program.[6]

In addition, EOSDIS will administer the scheduling of observations, the calibration of EOS instruments, and the control of EOS spacecraft. To be successful, EOSDIS must effectively incorporate data from a wide range of sources: the EOS satellites, all other NASA Earth remote sensing missions, data from non-NASA space systems, and essential data from atmosphere-, ocean-, and land-based sensors.

NASA has strongly supported the EOSDIS portion of the Mission to Planet Earth since initial planning in the early 1980s. NASA officials believe interdisciplinary global change research demands much more from data systems than the traditional discipline-specific missions of the past. Data management from scientific spacecraft has sometimes suffered inadequate planning and budget neglect. Data systems in NASA programs generally have lower external visibility than accompanying space hardware, and problems in spacecraft and instrument development sometimes have depleted the nonspace portions of program funding. Figure 3-3 shows that most NASA Earth science funding in the 1980s was allocated to spacecraft development. In the 1990s, mission operations and data systems are a much larger proportion of NASA's Earth science budget.

NASA plans to devote more EOS funding to the nonspace segments of the program than to the

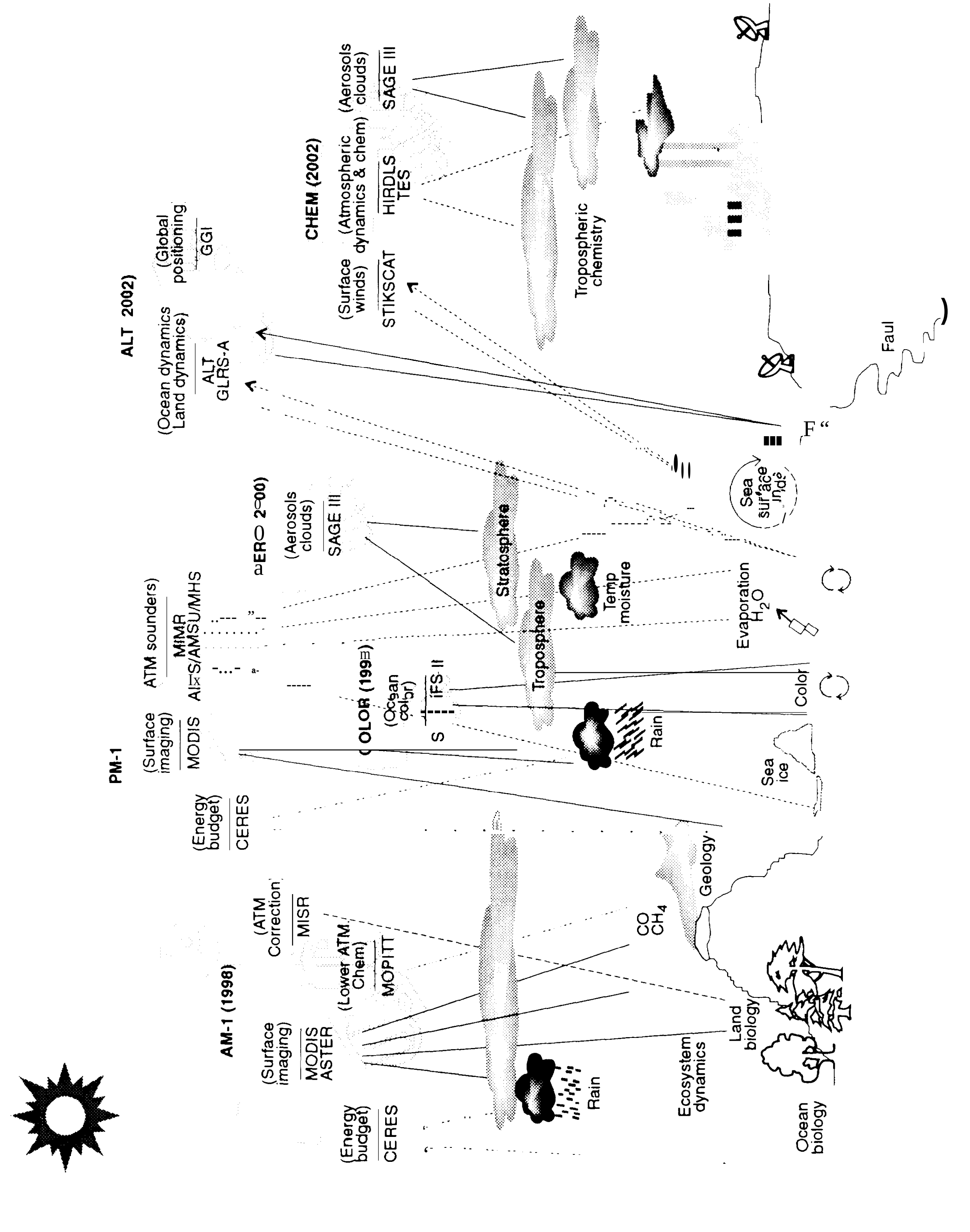
[3] See U.S. Congress, OffIce of Technology Assessment, *The Future ofRemote Sensin~fiom Space: Ci\'i/ian Satellite Systems and Applications.* OTA-ISC-558 (Washington, DC, U.S. Government Printing Office, July 1993) ch. 5.

4 In contrast, in 1990 the amount Of data archived from all NASA missions to date was about 8 trillion bytes, about 2.7% Of what is expected each year from EOSDIS.

5 The most recent estimates from Hughes predict 7, zoo to 16,000 EOSDIS users by 1998, excluding social scientists, libraries, and students. Adding these categories brings the estimated number of users to 76,000 to 200,000 (including a possible 174,000 students). In contrast, today's major supercomputer centers normally serve between 1,000 and 3,000 users. NASA and Hughes currently expect up to 1,000,000 EOSDIS user requests annually. NASA, *EOSDIS: EOS Data and Information System* (Washington DC 1992), p. 25, and Pitt Theme, "Demographics," EOSDIS Progress Review, Dec. 13- I 4, 1993, Landover, MD.

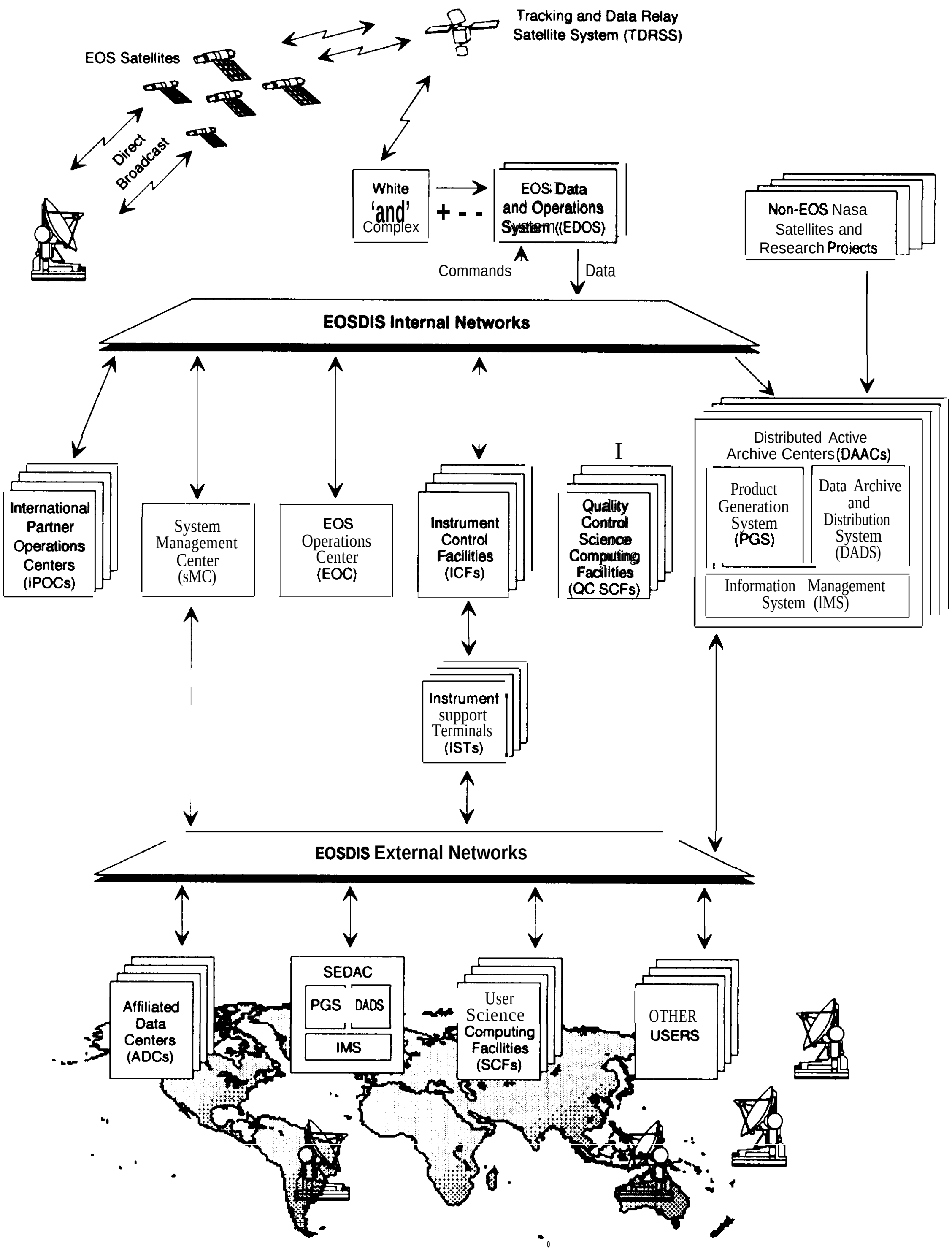
6 Recent experience with Europe's ERS-1 satellite underlines the importance Of data systems in the success of research missions involving remote sensing. Although ERS is a single satellite with much smaller data flows than those planned for EOS, ESA has had difficulty processing some of the detailed data researchers need. "ERS- 1 Gives Europeans New Views of Oceans," *Science, vol. 260*, June 18, 1993, pp. 1742- 1743; see also ch. 5.

FIGURE 3-1: NASA's Planned Earth Observing System Sensors and Satellites



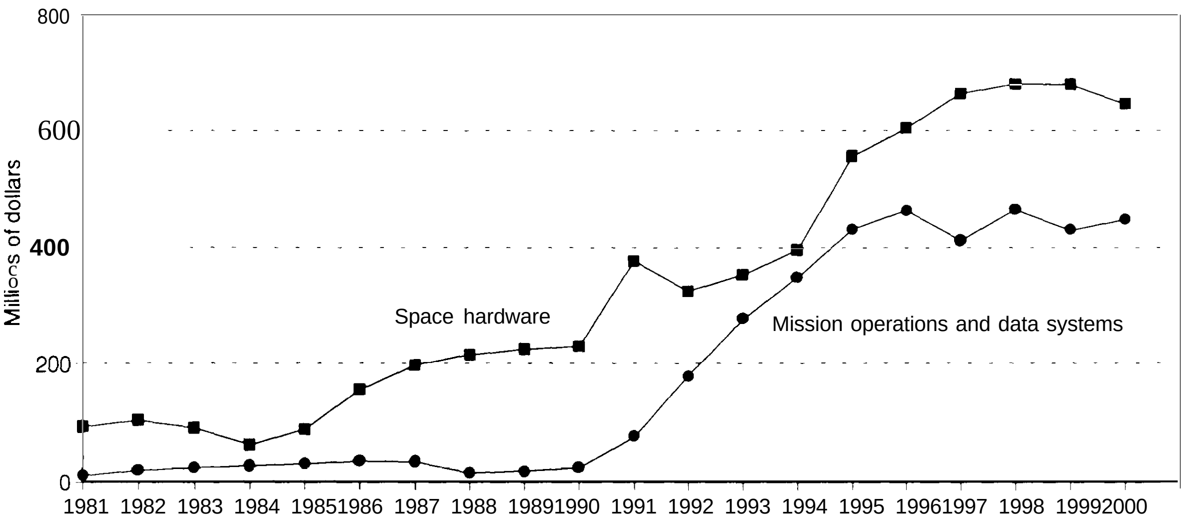

SOURCE: National Aeronautics and Space Administration, 994.

FIGURE 3-2: EOSDIS Architecture




SOURCE National Aeronautics and Space Administration, 1994

FIGURE 3-3: Budgets for Earth Science Space Hardware and Operations and Data Systems




SOURCE National Aeronatics and Space Administration, 1994

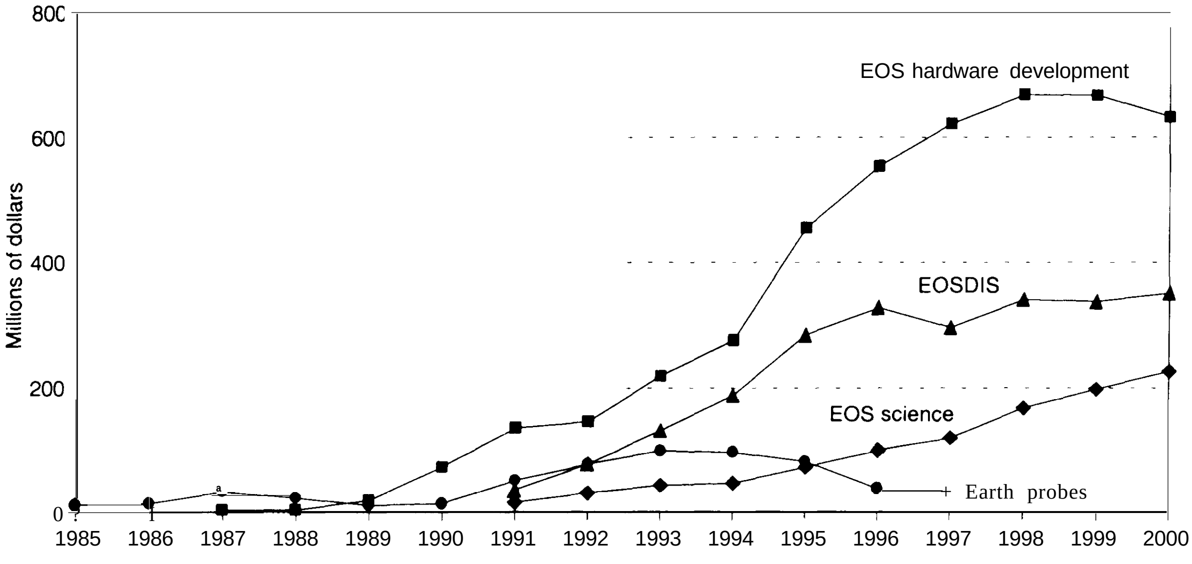
space segments, a major departure from previous space missions (figure 3-4). In the 1990s, about 30 percent of EOS funding will support EOSDIS, totaling about $2.37 billion.[7] NASA expects this massive government investment in EOSDIS to maximize its return on investments in space-based remote sensing hardware.

The previous chapter noted problems data users currently face navigating data archives. If EOSDIS is successful, researchers will spend much less time acquiring data, and will have easy and quick access to vastly increased amounts of data, allowing more time to transform these data into information.

Some other problems in the use of Earth observation data stem from the isolation of research disciplines. Research communities and individual researchers have highly individual views of how data should be organized and used. Disciplinary researchers also approach their research differently, using widely disparate nomenclature and methodologies, sometimes making communication across disciplines difficult. Some researchers claim Earth remote sensing data sometimes suffers from inadequate peer review of production algorithms, scientific quality control, and assessment. If EOSDIS is successful, it will help bridge the gaps among these diverse environmental re-

[7] At a projected 10,000 scientific users, EOSDIS funding in the 1990s would be an expenditure of $240,000 per research user. NASA Modeling, Data, and Information Systems Program Office, February 1993, and NASA *Budget Estimates, FY 1993* and FY 1994.

FIGURE 3-4: NASA EOS Expenditures—Hardware, Data Management, and Science




SOURCE Office of Technology Assessment, 1994

search communities, increasing interaction among disciplines and stimulating new research questions.[8]

Thus, the success of EOSDIS will be critical to the overall success of the Mission to Planet Earth and the USGCRP (box 3-l).

## \ Incremental and Evolutionary Design

NASA states it has adopted an "incremental and evolutionary" approach to the development of EOSDIS. Because science and data requirements for studies of the Earth system will change as knowledge and experience grow, while computer technology develops extremely rapidly, EOSDIS must be capable of evolving.

NASA's approach to EOSDIS is a marked deviation from the typical data system development in which scientists and engineers perform a detailed "requirements analysis" for the system, followed by a comprehensive system design and development. Instead, by using an "open" architecture, NASA plans to reduce system costs and increase performance by delaying acquisitions of system components to take advantage of technology growth. This approach should also allow system users to play a role in each new increment of EOSDIS, a "learn-as-you-go" approach. NASA hopes to avoid costly system modifications that would follow delivery of a "monolithic" data system.[9] However, traditional government policies for budgeting, procurement, and contracting are all challenged by the trends of rapid increase in performance and decrease in cost of information technologies and rapidly changing user expecta-

[8] For further information on the possible impacts of information technology on scientific research, see National Research Council, *National Collaboratories: Applying Information Technology for Scientific Research* (National Academy Press, Washington, DC, 1993).

[9] Futher explanation of this development on on the possible impacts of information oach can be found in Taylor, Ramapriyan, & Dozier, "The Development Of the EOS Data and Information System," paper presented at 29th Aerospace Sciences Meeting, Reno Nevada, January 1991, p. 2.

**BOX 3-1: Success Criteria for EOSDIS**

Criteria to measure long-term success in EOSDIS are not quantifiable, However, NASA management Will consider EOSDIS a "success" to the extent it meets the following descriptive criteria

1 Maximization of number of users and '(intensity" of use of Earth science data.

2 Continuous Improvement in data access and services,

3 User satisfaction expressed in endorsements, political support, integration of EOSDIS into research plans, and willingness to use and contribute to the system.

4 Research results Increasingly robust to invalidtion by previous results or overlooked data

5 Users able to acquire the observations they request.

6 Voluntary provision of researchers' datasets for archiving and use by others,

7 Decrease In lag time from data Ingest to published research results.

8 Decrease in proportion of researcher time spent handling data vs. analyzing them

9 Increased use of EOSDIS data in wide ranging applications.

SOURCE NASA Modeling and Data Information Systems Program Management breif to OTA, Feb. 11, 1993

tions. The **EOSDIS evolutionary design will require steady, continuous funding, extremely close cooperation between NASA and the system contractors, and rapid procurement.**

## Distributed Architecture

NASA states it has implemented a "distributed architecture" for EOSDIS, rather than central processing for all Earth observing data. Because expertise in various Earth science disciplines is geographically distributed across the country, NASA has chosen eight of the existing discipline-specific data centers as "Distributed Active Archive Centers" (DAACS); they will serve as geographically distributed "nodes" of the EOSDIS system (figure **3-5**).[10]

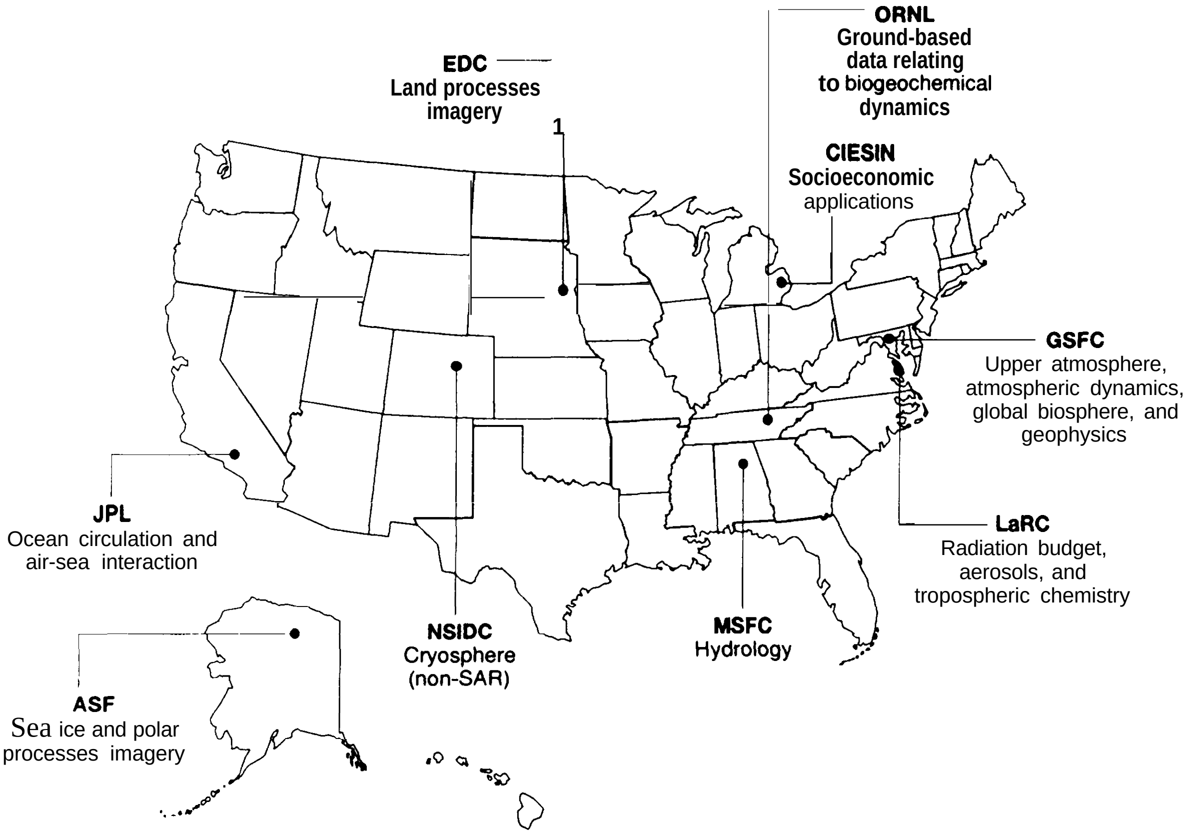
Until recently, these DAACS functioned as relatively independent data centers requiring users to contact each one individually in order to view data stored there. Each center set its own policies and methods for distributing data. By contrast, when EOSDIS is fully operational, users at any DAAC site will have complete access to all data sets anywhere in EOSDIS, regardless of physical location. Box 3-2 discusses DAAC system architecture.

A truly distributed system approach reduces the problems associated with failures at a *central* or *controlling* site. NASA expects the specialization and competition inherent in a distributed architecture to result in much better overall service to the EOSDIS user community, and avoid problems inherent in centralized, "bureaucratic control" of the system.[11]

[10] EOSDIS is working C] osely with the NOAA data centers, both to broaden access to NOAA data through EOSDIS, and to acquire operational, real-time or near-real-time data required for some EOSDIS data products. The special agreements between NASA and NOAA designate the NOAA data centers as '"Affiliated Data Centers" in EOSDIS. Affiliated Data Centers are not as closely linked to EOSDIS development as the DAACs and do not receive funding from NASA. However, officials of both NASA and NOAA expect to be able to access data easily from each other's systems.

[11] An early description of the rationale behind distributed architecture can be found in Dozier and Ramapriyan, "Planning for the EOS Data and Information System (EOSDIS )," 1990.

FIGURE 3-5: Geographically Distributed Architecture




ASF = Alaska Synthetic Aperture Radar Facility, CIESIN = Consortuim 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 Aeronauhcs and Space Administration, 1993

Technical requirements call for a distributed system as well, as NASA expects the computational power required to produce high-level EOSDIS data products to be immense. No single system could provide this performance. Instead, EOSDIS requires multiple systems, each with different characteristics. Also, the sheer number of expected users projected for EOSDIS would present a formidable service task if all users were using one site or had to interact with EOSDIS through a single site or system.

## I EOSDIS Status

EOSDIS implementation includes three comprehensive contracts with information systems firms:

- The **EOSDIS Core System (ECS)** provides command and control of EOS spacecraft, science data processing, data archive and distribution, and communications, networking, and systems management. NASA selected Hughes Applied Information Systems as prime con-

**BOX 3-2: EOSDIS DAAC Systems**

Three systems Will operate at each DAAC

1) *Product Generation System (PGS);* the Product Generation System at each DAAC WIll convert raw data signals into standard sets of Earth science data, using data processing software developed by the scien - tific user community

2) *Data Archiva/and Distribution System (DADS);* the Data Archival and DIstribution System at each DAAC wiIl serve as the archive and dlstribution mechanism for EOS and interdiscplinary data products, as well as essential ancillary data such as radiometric and geometric calibrtions, metadata, command history, algorithms documentation, and correlative data from EOS and non-EOS Sensors

3) *information Management System (/MS)* The Information Management System IS the user Interface for EOSDIS The IMS at each DAAC will give users access to all data throughout EOSDIS, as well as help in locating and ordering data, through convenient, easy user Interfaces for both novices and experts The IMS will use simple search critera such as instrument name, product name, time of collection, and spatial location, as well as cross-instrument and cross-disciplinary searches

SOURCE National Aeronautics and Space Administration , 1993

tractor on September 29, 1992; contract negotiations were completed March 30, 1993. The combined cost and fee has been set at $766 million for the contract period 1993 through 2003.[12]

- The **EOS Data and Operations System (EDOS)** will capture data from EOS spacecraft, provide systematic corrections processing, distribute preprocessed data to the DAACS, and archive these data. NASA has selected TRW for this contract; cost and fee are under negotiation.
- The **Independent Validation & Verification (IV&V)** contract will provide for the testing and verification of the performance and capabilities of all elements of the EOS ground system and their integration with the EOS flight system. This contract will also provide for "acceptance testing" of all EOSDIS contractor deliveries. NASA has selected Intermetrics Corp. for this contract, at a cost and fee of $64 million.
- NASA and the EOSDIS contractors will build EOSDIS in a series of versions. The first is Version O, which is providing interoperability among the 8 DAACs and connections with other Earth science data systems. NASA expects Version O to be fully operational as an integrated "virtual" system in July 1994 (box 3-3).

The strategy and schedule for delivering subsequent EOSDIS "versions" is undergoing major revision, because NASA and Hughes are reevaluating overal1 planning for EOSDIS .As a result of advice from the EOS Investigators Working Group in October 1993, and the National Academy of Sciences report of January 1994,[13] NASA and Hughes have

[12] NASA stated Hughes's proposed cost and fee for the program was $685 million in September 1992, while Hughes' and TRW's original bids were much lower and rejected as unrealistic estimates. Subcontractors to Hughes are : Electronic Data Systems (new technology evaluation), Loral AeroSys (flight operations Applied Research Corp. (algorithm tookits) the Center for Space and Advanced Technology (research ), and NYMA (independent verification liaison).

[13] National Research Council, Space Studies Board, *Panel to Review EOSDIS Plans, Final Report* (Washington, DC: National Academy Press, 1994).

## BOX 3-3: EOSDIS Version 0

Version O is a working prototype of EOSDIS with some operational elements. However, Version O will not have all the functions, reliability, and performance of subsequent versions. Planning and preliminary design of Version O began in the summer of 1990, and development of Version O as an integrated system began in January 1991,

NASA has focused the bulk of Version O prototyping on achieving system interoperability among the DAACS, NASA's philosophy for Version O is to allow individual DAAC systems to develop at their own rate, and focus on providing interconnections among those systems, Version O is improving user access to the DAACS by providing an overall view of the data available from the various DAAC systems, establishing common systemwide services, e.g., user assistance and support, problem resolution, and request and tracking statistics, and providing a single point from which any user can search and order data from *any* archive. [1]

- NASA Climate Data System
- NASA Ocean Data System
- Cryospheric Data Management System
- Alaska Synthetic Aperture Radar Facility
- Global Land Information System
- NASA Pilot Land Data System
- NASA Crystal Dynamics Data Information System
- Trace Gas Dynamics Data Information System

NASA and the EOSDIS contractors plan to transfer knowledge and experience from Version O into subsequent Versions of EOSDIS However, Version O IS not a true working prototype of EOSDIS in many respects. Version O is a relatwely small effort, compared to subsequent versions of EOSDIS, Thus, Version O projects cannot address some of the technically critical areas of EOSDIS, nor IS the effort substantial enough to allow users to assess some important EOSDIS functions. Nonetheless, the Version O effort has already successfully achieved user involvement, Interoperablllty among heterogeneous and distributed data systems, and a cooperative development environment that enables NASA to use DAAC expertise and data system experience,

[1] Such interoperability is likely to be an expensive task, since computer and network systems are increasingly complex, usually requiring specialists to enable applications to operate properly

SOURCE Office of Technology Assessment, 1994, and Judy Feldman, "Building on Version O', EOSDIS Progress Review, Dec 13-14, 1993, Landover, MD.

Implemented a major shift in orientation, focusing on responsiveness to user needs and a more open, distributed, and evolutionary architecture. Many of the details and results of this reorientation are not yet clear, but the reaction from the Earth science community is generally positive. [14]

[14] The former plan was for Version 1 to provide a fully functioning science data processing segment of EOSDIS (processing, archiving, and distribution). This Version would be much more capable than Version O, appearing completely integrated to users. NASA and Hughes planned its initial release for 1995, with a fully operational system in 1997.

Version 2 would have provided for full EOSDIS data system capacity and flight operations for the EOS-AM spacecraft launch in 1998. It would have been followed by Version 3, which would have supported data collection and operation of other EOS flights, in 2001.

Instead, Hughes plans 8 releases of the ECS, through 4 overlapping release cycles, beginning with the first full releases in September 1996. Hughes expects this "dual track" approach to improve incorporation of operational feedback as well as feedback from incremental development activities. "Release Schedules", John Gainsborough, EOSDIS Progress Review, Dec. 13-14, 1993, Landover, MD.

## Impact of EOS Restructuring

The overall EOS program has undergone major restructuring since its initial congressional approval in 1990, resulting in significant reductions in scope and capabilities. In the summer of 1991, the EOS External Engineering Review Committee, organized at the request of the Office of Management and Budget and the National Space Council, restructured the EOS program. The result was a smaller more focused program of about $11 billion through fiscal year 2000 (down from the previous $17 billion estimate). The External Engineering Review Committee focused on distributing EOS instruments, and the reduced EOS instrument requirements, onto a larger number of smaller spacecraft to provide increased budgetary and technical resilience. The Restructuring Committee did not examine EOSDIS, but the delay in deploying some EOS instruments allowed EOSDIS to be smaller than originally planned, with a reduced budget.[15] NASA Stated it made this adjustment in EOSDIS without altering the basic architecture or the evolutionary design of EOSDIS.[16]

In the fall of 1992, the restructured EOS program was further reduced by an internal NASA review to fit within an $8 billion budget envelope through fiscal year 2000. Again, NASA reduced the overall EOSDIS budget roughly commensurate to the overall program reduction. NASA reduced the planned suite of data products available at launch of EOS-AM 1 from 600 to approximately 160 data products.[17] Other changes included deferring the migration of existing data sets into Version O in cases where the data are already available through an existing operational system, deletion of the HIRIS science computing facility, and a major reduction in program reserves.[18]

As a result of these changes, EOSDIS is smaller than originally envisioned and program resources are substantially reduced. However, resilience in meeting future challenges has also been reduced, although many goals regarding data delivery remain unchanged. EOSDIS remains complex and demanding, raising a number of technical and programmatic challenges, discussed below.

## EOSDIS TECHNOLOGY CHALLENGES

EOSDIS will be only as capable as the information systems technology on which it relies. Overall data rates and volumes will be unprecedented. EOS instruments will require very precise calibration, and data will require extensive validation to be useful. The DAACS will need to reprocess previously acquired data periodically, to accommodate updated processing algorithms. EOSDIS will have many simultaneous users, many of whom will require access to interactive databases. Data analysis and visualization[19] will be highly sophisticated and complex. **Although EOSDIS faces these and other technical challenges, there appear to be no technical obstacles to an operational EOSDIS that NASA could not overcome with sufficient funding and infrastructure.** In

15 The EOSDIS estimated budget dropped from $3.900 billion to $2.141 billion, a change of 45% compared to an overall EOS program budget change of 31%. U.S. Congress, General Accounting Office, *NASA: Changes to the Scope, Schedule, and Estimated Cost of the Earth Observing System,* NSIAD-92-223 (Gaithersburg, MD: U.S. General Accounting Office, July 1992), p. 18.

16 N h a t i e *Earth Observing System,* Mar. 9, 1992, p. a l 13.

17 NASA Earth Science and Applications Division, "Earth Observing System (EOS) Status," briefing to OTA, Washington DC, Nov. 6, 1992.

18 National Aeronautics and Space Administration, "Adapting the Earth Observing System to the Projected $8 Billion Budget: Recommendations from the EOS Investigators," Washington DC, October 1992, p. 39. The House Science, Space, and Technology Committee Report to accompany the NASA FY 1994 and FY 1995 Authorization Bill, Report 103-123, notes EOSDIS reserves were cut by $550 million, or 60 percent, in the rescoping (p. 46).

19 Using computer-generated pictures to represent data instead of a list of numbers, and viewing time sequences to track temporal change.

other words, data processing and communication capacity and speeds have evolved to the point that a system approximating an EOSDIS in some respects, but with less capability, could conceivably be built with existing hardware. Developing a highly capable EOSDIS, however, will present a challenge to NASA.

Simply "keeping up with" rapidly advancing technology will bean important challenge. Rapid new technology insertion will be essential for the system to retain its value to researchers. If users have independent access to data processing systems significantly more advanced than EOSDIS, many researchers would eventually use EOSDIS simply to download data into their own computing systems. This would defeat one of the primary goals of EOSDIS—interoperability among a variety of researchers and disciplines. On the other hand, reliance on emerging technologies that are not field proven would threaten system operability if they were to fail in full-scale implementation.

## ~ Data Storage and Access Technology

The data storage systems for EOSDIS will be extremely demanding. The archives will last for at least the lifetime of the EOS satellites,[20] and will be interactive with users, in contrast to the more traditional (and simpler) view of archives as a repository in which to store data for occasional use.[21] In short, as a result of the high **demands for** data storage that will be placed on EOSDIS, performance and cost of storage media may need to be much improved over current technology.[22]

Data mass storage costs are falling rapidly, but they remain a major expense for a system like EOSDIS. Most industry experts expect no breakthroughs in the cost of data storage in the next several years, although the development of optical storage systems should continue to bring storage costs down. Perhaps what is more important is that storage and access performance is not improving as rapidly as storage capacity. Searching the vast Earth science datasets for specific features will require major improvements in the ability to access specific data sets.

The advanced mass storage systems attempted in recent years have experienced serious problems.[23] Since the EOSDIS program philosophy is to procure hardware as late as possible to take advantage of falling cost and improved performance, EOSDIS may rely on advanced mass storage systems that have not yet proven commercially reliable. Maintaining a flexible system development strategy to accommodate rapid technological change successfully will be important.

NASA has not decided how much and which kinds of EOSDIS data will be directly available online to users but expects to use a hierarchy of data storage, in which small, often-used data sets are rapidly accessible, and very large datasets that are rarely used are stored offline. EOSDIS offline archives will be vast, and standards and media considerations (tape, cartridge, optical storage technologies) for offline archives should not be overlooked. The offline media will need to be easily serviced, and have reliable backups. Technology advancements and funds to archive and service

20 NASA EOSDIS planning currently extends only through the 15-year EOS mission lifetime.

21 Several Earth science data systems are already *improving* on this model. For example, the EROS Data Center, operated by the U.S. Geological Survey and included in EOSDIS as a DAAC, operates a large active archive for Landsat and AVHRR data, featuring online search. Some smaller data sets at NASA centers, such as the Coastal Zone Color Scanner System and the NASA Climate Data System, also allow these capabilities.

22 The EOSDIS project management team at Goddard Space Flight Center has estimated that a roughly thousand-fold increase in NASA Earth science data volume will occur during the 1990s. National Aeronautics and Space Administration, "Presentation to the EOSDIS Team on Ground Infrastructure Interfaces, Formats, and Directions," paper presented at IPD/EOSDIS seminar, Mar. 12, 1992.

23 U.S. Congress, General Accounting Office, *Space Data: NASA's Future Data Volumes Create Formidable Challenges,* IMTEC-91-24 (Gaithersburg, MD: General Accounting Office, April 1991).

## BOX 3-4: EOSDIS Networks

The EOSDIS network system consists of four networks:

1, Ecom (dedicated network providing real-time, high reliability and secure communications between ground and spacecraft)

2 ECS Internal Network (dedicated EOSDIS network providing communication among EOS Principal Investigators, DAACS, and the External Network)

3. External Network (NASA Science Internet) (shared network providing communications among EOSDIS and users who are not Principal Investigators, including CIESIN and the Affiliated Data Centers)

4, Version O Network (dedicated network for prototyping)

Although more demanding than previous Earth remote sensing satellite communication systems, NASA does not expect serious difficulty implementing the Ecom network. NASA expects more challenges Implementing the EOSDIS Internal Network, but the "External Network, " which will essentially connect EOSDIS with the outside world beyond NASA, will offer the most difficult technical obstacles

The External Network, using the services of NASA's Science Internet (coordinated by Ames Research Center), supports several protocols and is interoperable with the NSF Internet, This network con-.sIsts of T1 transmission lines (1.5 million bits per second (Mbps)) connecting 27 regional networks and over 100 lower capacity circuits to research sites (although the tail circuits have much lower bandwidths) The NASA Science Internet reaches approximately 2500 end users. In 1994, NASA plans to upgrade the NASA Science Internet to T3 technology (45 Mbps). Eventually, NASA expects half of the NASA Science Internet (NSI) users to be EOSDIS users,

NASA planned to employ the UNIX operating system, HDF format, and the communications-related standards of the Consultive Committee on Standard Data Services where appropriate. However, a more "open" system is now planned,

SOURCE National Aeronautics and Space Adminiarration, 1994

the tremendous amounts of EOSDIS data, often overlooked in the past, maybe critical to EOSDIS long-term success. Recent surveys show substantial increases in estimates of EOSDIS processing and storage/distribution requirements.[24]

## Data Communication

Networks perform the crucial tasks of linking researchers to EOSDIS and integrating the EOSDIS user community through cooperative research (box 3-4). The mode of delivery of data to EOSDIS researchers and the uses of the system will be determined by network capacity. Fortunately, network performance continues to increase as system costs decrease.

EOSDIS users are likely to request increasingly greater online access to increasing volumes of data. NASA has designed EOSDIS to deliver large data sets through EOSDIS networks, in contrast to routine data delivery through physical media (tapes, CD-ROMs, optical disks, etc.).[25] Current input/output and networking technologies cannot support this increased on-line data demand, nor the expected data rates required for

24"CostiPerfonmmce," Joe Guzek, EOSDIS Progress Review, Dec. 13-14, 1993, Landover, MD.

25 National Aeronautics and Space Administration, "Adapting the Earth Observing System to the Projected $8 Billion Budget: Recommendations from the EOS Investigators,'' Washington DC, October 1992, p. 9. On the other hand, if a researcher acquires a large datasct through a network, he or she still must store it on a physical medium.

browsing and visualization of EOSDIS data. Very high data rate workstation network interfaces also will be required for doing research using EOSDIS.[26]

External EOSDIS users will vary greatly in their sophistication; most will connect to EOSDIS through the future equivalent of today's personal computer and modem. NASA does not plan to provide a level of service to the larger global change community and other users equal to that available to NASA Investigators. However, NASA plans to provide the maximum of services to users who do not possess highly sophisticated workstations. This will place a considerable burden on EOSDIS design. **Because providing the maximum benefit from the public investment in EOSDIS may require broad access, Congress may wish to examine the potential of providing EOSDIS services to a broad community of users.** On the other hand, it is not feasible for EOSDIS to provide full service capabilities to casual users.

The National Research and Education Network (NREN) is currently of great value to the EOSDIS program in distributing data widely. However, NREN must be an operational system to be of use for EOSDIS; development of NREN is in the early stages, and the question of its status as an operational system has not been decided. It is also undecided whether NREN will be free for researchers, or if the system will require tariffs similar to the national telephone system (the EOSDIS program has not budgeted the funds to pay for NREN service for Earth science researchers). Finally, access to NREN would need to be widely distributed, serving the broader academic community outside the networks operated by the National Science Foundation, the Department of Energy, and NASA. It is unclear whether NREN will achieve such extensive distribution. For these reasons, EOSDIS planners are avoiding dependence on NREN.

## DATA MANAGEMENT TECHNOLOGY (ORGANIZATION AND ACCESS)

Advanced techniques for indexing data for storage and access must be developed by NASA, the EOSDIS contractors, and the computer industry. Current relational data management technology, developed for use in commercial applications, is improving significantly in performance, and is accommodating some new types of data. However, relational databases have difficulty accommodating searches of spatial data sets and many other data processing and display requirements of EOSDIS. Relational data management software is most appropriate for manipulating small records of highly similar text or numeric data. Earth science data records are enormous, temporal, highly varied, and contain many more dimensions (time, latitude, longitude, spectral value, etc.) than most data records. Current commercial relational database systems and data processing software cannot efficiently work with these diverse types of data (e.g., point, vector, raster, text).[27] Version O (box 3-3) focuses on satellite data, but EOSDIS must incorporate non-satellite datasets[28] and their special requirements, complicating data management.

The interdisciplinary nature of global change research requires the capability to view the same data in different ways. It also requires common, and broader, access of data among different disciplines. In order to give data maximum utility, the EOSDIS program may have to support basic re-

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26 Note that access to EOSDIS capabilities will be quite limited without advanced equipment. For example, at present, using a typical 9,600 baud modem, a single typical browse image of approximately 1.4 Mbytes would require approximately an hour to transmit.

27 See ch. 2 for a discussion of different data types.

28 Data acquired for ground-based facilities and from aircraft provide essential calibration for satellite data, and provide much essential data impassible to acquire from orbit. See U.S. Congress, Office of Technology Assessment, OTA-l SC-538, *The Future of Remote Sensing from Space: Civilian Satellite Systems and Applications* (Washington, DC: U.S. Government Printing Office, July 1993), ch.5 and app. B.

search into data management software tailored to scientific needs.

## Data Processing, Analysis, and Assimilation Technology Issues

Much data acquired by satellite instruments go unused as a result of the time needed to process them on conventional computers, particularly to compute images. The tasks of visualization and assimilation of EOSDIS data into climate models are critical steps in the transformation of data into information.

The algorithms used by scientists to transform digital remote sensing data into information will undergo revision as knowledge grows. **Because changes in processing algorithms could leave small errors larger than any change in the global environment, rapid reprocessing of years of older data must be possible to maintain a continuous record of comparable data for research use.** Given the high spectral and spatial resolution of EOS instruments, and massive data volumes, this will be a formidable, continuous task.[29] Updated algorithms, which can have more than a million lines of code, must be transferred from the scientists to the DAAC Product Generation System for execution. Transporting and integrating these complex algorithms to generate "bug-free" products is a serious technical challenge.

Effective visualization technology will be an important challenge for the program, requiring significant *advances* in data processing technologies (e. g.. researchers can be expected to eventually use virtual reality to enter into a dynamic model ).[30]

EOSDIS will generate higher level data sets by assimilating applicable observations into global climate and other models, which then will generate new data sets based on these models. These data sets will need to be of much higher quality than those currently produced for numerical weather prediction, and will be much more complex, since they will require assimilation of many more types of data (including non-EOS spacecraft; measurements from the ground, ocean, and air; and non-U. S. data sources). The computational requirements to produce these datasets will eventually go far beyond current practice in Earth science. Mass storage, network bandwidth, and processing power of computers will need to be greatly expanded for use of EOS data in future global climate models.[31]

EOSDIS will produce assimilated data sets on computers distributed geographically, which in some cases will use different system architectures. Computer languages and other technologies to allow these high-level analyses on massively parallel computer architectures are not yet well-developed. Standards are only just emerging in distributed systems management.

Computer processing power and network performance are increasing rapidly, while costs are decreasing. However, based on experience with other spacecraft projects, scientists typically underestimate the computer resources required to process their algorithms. This is considered the top risk in the entire EOSDIS Product Generation System, according to a recent risk assessment.[32] Although EOSDIS processing requirements appear great now, they could very well become several times greater when the system is actually implemented. Box 3-5 provides a summary of technical challenges in EOSDIS.

## EOSDIS PROGRAM CHALLENGES

Overcoming technical obstacles will be important to the success of EOSDIS, but managerial, insti-

[29] Ibid., p. 38.

[30] In this manner, the scientist can virtually "become" a particle flowing through the model.

[31] Major reanalysis programs are now beginning at several data centers, including Goddard.

[32] Computer Sciences Corp., *Earth Observing System Data and Information System (EOSDIS) Product Generation System (PGS) Risk Analysis and Mitigation Strategies* (February 1993), p. 47.

**BOX 3-5: Summary of Technical Challenges in EOSDIS**

*Data Storage*

Demands on storage media performance and reliability Will be tremendous m EOSDIS, and data storage system throughput is not keeping pace with improvements processing or communications. Commercial data storage performance may not be successfully adaptable to EOSDIS needs Data storage currently appears to be a "weak link" m EOSDIS.

*Data Communications*

Demand for online access to larger amounts of data IS increasing, as is the numbers of users, user sosphistication, interagency and inteernational cooperation, data system distribution, and scientific cooperate work through networks. EOSDIS will not succeed If bandwidth and access are limited

*Data Management*

Effectively searching for data in EOSDIS could be difficult as a result of the quantity and variety of data in the systems Efficiently classifying vast amounts and varieties of data will be challenging, requiring new models of data management that are not yet well developed.

*Data Processing, Analysis, and Assimilation*

Processing demands will be much greater in EOSDIS than any previous system Software for use on parallel and distributed systems IS difficult to write, and visualization technology is not well developed

SOURCE Off Ice of Technology Assessment, 1994

tutional, and cultural challenges may be even greater.

## The Role of EOSDIS in GCDIS

The Global Change Data and Information System (GCDIS) is meant to allow routine access to all U.S. global change data (box 3-6). Some have called for a stronger NASA role in GCDIS. The National Research Council's Panel to Review EOSDIS Plans, in its April 1992 *Interim Reporf* and its September 1992 letter report, expresses concerns that EOSDIS may become a program ● 'oriented solely to EOS," rather than an integral part of the GCDIS.[33] The NRC Panel believes NASA has the responsibility for "establishing firm and specific plans and budgets for the development and operation of the GCDIS, in conjunction with other agencies''[34]. Thus, the panel desires a national directive to give NASA the lead agency role in the GCDIS, thereby transforming EOSDIS into a prototype for the GCDIS. The House Committee on Science, Space, and Technology largely agrees:

> The National Aeronautics and Space Administration, in coordination with other agencies that belong to the Committee on Earth and Environmental Sciences, shall establish the requirements and architecture for, design, and develop a Global Change Data and Information System that shall serve as the system to process, archive, and distribute data generated by the Global Change Research Program.[35]

[33] "National Research Council Panel to Review EOSDIS Plans: Interim Report," April 1992! p. 11.

[34] [bid., p, 2.

[35] U S .Congress, House Committee on Science, Space, and Technology, *National Aeronautics and Space Administration Authorization Act, Fiscal Years /994 and /995,* H.R. 2200, June 1993, Sec. 109.

**BOX 3-6: Global Change Data and Information System**

The GCDIS, as conceived by the Interagency Working Group on Data Management for Global Change (IWGDMGC), would provide a single data system for the various federal agencies involved in global change research GCDIS would use a combination of indivdual agency data system assets and a shared Infrastructure to become the primary mechanism for the exchange of data and information among USGCRP participants. GCDIS would include processes for Identifying and generating key inter-agency global change data sets, coordination of data submission procedures for GCDIS centers, standard methods for decribing and documenting data, a common set of archive responsibilities, and uniform order validation, tracking, and billing among agencies Proponents expect GCDIS WIII make data search and access among the various agency data sets much simpler and more effective

Interagency cooperation in GCDIS is currently a collection of extensive, but voluntary, indivdual agency efforts coordinated under the CEES IWGDMGC, GCDIS commonality and Interoperabilty would be made by the agencies in concert. The GCDIS does not have a separately funded budget, but resource requirements for focused program activities are included in USGCRP planning. For GCDIS to be successful, the effort will need to avoid becoming merely a "collector" of individual agency data and Information system plans Ensuring interoperabillty among the data systems of the USGCRP agencies, agreeing on standards for data among agencies so that researchers can easily exchange data, and maintaing high levels of data service among the several agencies will be the most difficult and important issues for GCDIS to resolve

SOURCE Office of Technology Assessment, 1994

NASA has agreed to seek funding to develop the techniques to allow interoperability among agency systems, thus "enabling and not precluding" extension of EOSDIS. All agencies, however, would require substantial additional funding for GCDIS to be implemented as envisioned.

The objectives of the EOSDIS program are already challenging, and NASA's responsibilities for GCDIS are an additional complexity in the program. **However, because NASA is already performing many of the necessary tasks for GCDIS in its EOSDIS program, giving the agency responsibility for GCDIS would be a more efficient use of public funds than assigning GCDIS to another agency. Attempting to add GCDIS requirements to EOSDIS after the latter is built would prove far more costly than planning for them as it is developed.**

## Alternative Definitions for DAACS?

NOAA data will be critical for global change research. NOAA is already responsible for collecting and distributing operational and research data for monitoring and predicting the behavior of the atmosphere and oceans. NOAA data centers contain the majority of U.S. Earth remote sensing and in situ environmental data, and NOAA makes these data continuously available for its operational data systems. The National Research Council panel convened to review EOSDIS plans recommended including NOAA data centers as full DAACS (they are currently "Affiliated Data Centers'').[36] However, NOAA officials believe the cost of setting up DAAC, as currently defined, is more than NOAA can afford. Making NOAA data centers, as well as other essential sources of Earth science data, interoperable with EOSDIS should

[36] National Research Council, Space Studies Board, *Panel to Review EOSDIS Plans: Final Report*, op.cit.

be a priority, whether or not they are considered DAACs.[37] The development of alternative definitions of DAACS that prevent disruption of quality service, yet give good data access at minimum added cost, seems essential.

## | Socioeconomic Data in EOSDIS

For EOSDIS to be effective in meeting the long-term goals of the USGCRP NASA must transform Earth remote sensing data into information useful for nonspecialists (e.g., policy-makers, social scientists, resource managers, etc.). The system should also make potential users aware of, and able to use, available data and information. While EOSDIS and other Earth science data systems have been designed primarily to facilitate physical science-based global change research, the Consortium for International Earth Science Information Network (CIESIN) was founded in 1989 to assist a broader community of users of global change information, with a focus on integrating Earth remote sensing and other global change data with social science data.

CIESIN defines itself as an "international, non-profit consortium of academic, governmental, public, and private organizations that share a mutual goal of understanding global change."[38] Because CIESIN is not housed within any goverment agency, the organization can be more flexible than an agency and can maintain greater institutional neutrality.[39] This flexibility enables CIESIN to work closely with the several government agencies concerned with global environmental change, as well as academia, private companies, and other nongovernmental organizations, encountering fewer bureaucratic impediments.

In its first few years, CIESIN activities focused on assessing the needs and capabilities of users and providers of global change information. While assessment activities continue, CIESIN has begun to design systems to meet those needs. CIESIN is providing "tools and expertise" for data management, statistical analysis and modeling, visualization and imaging, and communications and collaboration.[w]

Although CIESIN intends to produce some new socioeconomic data, and integrate a variety of data from other sources, CIESIN'S strongest role could be as an access point to data and information from diverse sources worldwide. The organization would serve as a global "information cooperative," enabling interdisciplinary links between the natural and human sciences in global environmental change research.

CIESIN'S Socioeconomic Data and Applications Center (SEDAC) is one of the nine data centers in EOSDIS. As the data center responsible for providing access and distribution of interdisciplinary science data sets relating to the human dimensions of global change, SEDAC will make

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37 Becoming a DAAC may not mean improved data services. For example, officials of the important CDIAC archive (trace gas and climate data), one of the three main climate change archives at Oak Ridge, do not want it to become a DAAC, and DOE does not want it to be part of the Oak Ridge DAAC. The threat is a fundamental change in operations and possible compromise of current good service. ARM atmospheric radiation data also will not be included in the Oak Ridge DAAC.

38 The founding organizations of CIESIN were the Environmental Research Institute of Michigan, Michigan State University, Saginaw Valley State University, and the University of Michigan. New York's Polytechnic University, Utah State University, and the University of Maryland at College Park were later included in Cl ESIN. CIESIN also works closely with the University of California at Santa Barbara.

39 Although CIESIN receives a majority of its funding from NASA (6I.7 percent in fiscal year 1993), CIESIN also receives substantial project funding from DOD (1 7.2 percent), EPA (1 6.3 percent), USDA (3.1 percent), and OSTP ( 1.7 percent) (fiscal year 1993 figures). Robert Coullahan, Director Washington Operations, CIESIN, personal communication, 1993.

40 CIESIN is also involved in many other projects outside the EOSDIS SEDAC, including software applications, data cataloging, data policy studies, the Global Change Research Information Office (GCRIO) supporting international data exchange, partnerships with federal agencies including the EPA, DOD, and USDA, and international data networks. CIESIN also serves as a training and education center for a diverse audience of current and potential users, teaching users about its application technologies and information products through summer institutes and scientific fellowships.

## BOX 3-7: Data Categories in the Socioeconomic Data and Applications Center

The Socioeconomic Data and Applications Center will provide eight general categories of data to its users. The National Research Council has repeatedly identified the first four categories as the highest priorities of the U S research program in the human dimensions of global environmental change; they also are the expicit categories of emphasis for data collection and model development in the USGCRP, The fifth category serves the economics element defined in the FY93 USGCRP, The final three categories serve dlsclpllne-specific studies in the social and health sciences that relate to the human causes and human effects of global environmental change.

1. *Land Use and Land* Cover—land cover describes the land surface in generalized categories, whale land use describes the driving forces behind land cover
2 /ndustrla/Metabolism—the mass flows for key industrial materials, waste emissions, energy, and technical forces that drive the evolution of industrial processes,
3 *Agricultural* Metabolisml—the effects of agriculture and changing agricultural practices.
4. *Population* Dynamucs—demographic data on population and attributes.
5. Economic Activity
6 *Human Attitudes, Preferences,* and behavior-the personal motivations, and thelr sources, among individuals.
7. Social and Political *Structures and* Institions—the organization of human groups and the Influences of such organization on global environmental change
8 *Human and Environmental Health—effects* of global environmental change on the health of humans and the broader environment

SOURCE Consortium for International Earth Science Information Network, 1993

physical science data available for use by social scientists, and vice versa. It is the task of CIESIN and SEDAC to make EOSDIS data easily available to the estimated 100,000 to 200,000 users who are not physical scientists.

SEDAC will also serve as the designated Data and Information System for the Human Dimensions of Global Environmental Change Program of the International Social Sciences Council. In this role, SEDAC will provide international access for social scientists, and other international users, to all of NASA's Mission to Planet Earth data, as well as CIESIN'S socioeconomic data.

Data that serve the more particular research interests of social scientists are already collected and archived by existing data centers, and SEDAC will serve as an information network linking these data centers. Unlike other data centers in EOS DIS, SEDAC will not be a massive data archive, since most archiving of pertinent social science data is already done elsewhere. SEDAC will, however, archive some unique CIESIN-produced data sets. Box 3-7 describes the categories of data to be collected at SEDAC.

## CIESIN ISSUES

CIESIN has been vigorously debated by policymakers. CIESIN detractors criticize the program for high costs of facilities, too many programs with insufficient focus, excessive spending for lobbying efforts in Washington DC, inappropriate allocations of funding, and a lack of peer review for funding.[41] CIESIN supporters refute these

[41] As a congressionally initiated program, CIESIN funding was not included in NASA budgets until the FY 1994 request. Instead, funding for CIESIN was inserted each year through congressional "earmarking" in the appropriations process.

claims or believe they have already been resolved, and maintain CIESIN is necessary to redress the lack of priority given to human dynamics research in global change in the USGCRP and EOSDIS.[42]

Congress must decide whether CIESIN funding is justified in comparison to alternative uses of the funding, whether CIESIN is indeed necessary to the success of the USGCRP, and if CIESIN is using resources appropriately. NASA plans to depend heavily on CIESIN for developing the use of global change data beyond the scientific community. **A USGCRP without CIESIN is possible; yet, many of the functions now provided by CIESIN would still need to be supplied by other organizations.**[43] On the other hand, some critics maintain that many of CIESIN'S activities duplicate services provided by other agencies, and will not provide them as effectively as agencies that have already provided such services for decades.

## Use of Outside Expertise in EOSDIS

Most observers agree EOSDIS would benefit from increased involvement by data centers outside NASA and technologies developed outside the EOSDIS program.[44] The adaptation of superior technologies or methods used successfully in other systems could greatly enhance overall system capability. For example, recent demonstrations of Version O have elicited criticisms that the system is too narrowly focused. Some data experts argue EOSDIS is being developed as a system for "satellite researchers," while the needs of in situ researchers are not met. Increased consultation with experts at other agencies presumably would result in a more versatile system design.

For example, NOAA holds a majority of all current data related to global change, and pursues some applications likely to be required by EOSDIS. The National Center for Atmospheric Research, with amass storage system of over 36 terabytes (noted by the NRC for its effectiveness), makes extensive use of supercomputers and large data sets to model environmental phenomena such as global warming and depletion of the ozone layer. The University of Wisconsin, with an archive of about 130 terabytes, is the largest archive in the atmospheric sciences. The University Corporation for Atmospheric Research, sponsored by NSF, has developed the nationwide, distributed, real-time Unidata system to facilitate accessing, organizing, storing, analyzing, and displaying Earth science data on-line for educational uses. DOD and the intelligence community have invested heavily in software to transform remotely sensed data into information for national security purposes. In response to criticisms, officials at NASA and Hughes have promised to increase their efforts to examine non-NASA data systems.[45]

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42 A recent audit from NASA's Office Of the Inspector General (IG) criticizes CIESIN funding and management. The IG recommends reducing NASA funding to space-based data support only. CIESIN supporters contend NASA is obstructing the will of Congress. *Space* News, June 20-26, 1994, p. 1.

43 See U.S. Congress, Office of Technology Assessment, OTA-BP-ISC- 122, *Global Change Research and NASA's Earth Observing System* (Washington, D. C.: U.S. Government Printing Office, November 1993) for a discussion of the need for policy-related data and assessment of the effects of global change.

44 National Research Council, The US *Global Change Research Program: An Analysis of the FY1991 Plans* Washington, DC: National Academy Press, 1990), p. 76. Also, the 1991 EOS Engineering Review Committee, which was mainly preoccupied with restructuring the EOS space hardware implementation strategy, expressed concerns that "EOSDIS makes no provision for bringing non-NASA Global Change Research projects or other investigative teams involved in global change research into the system." Earlier in the program GAO reports also criticized EOSDIS planning for insufficient use of existing database expertise at other federal agencies. "In designing and building its Version O prototypes, NASA has not taken full advantage of experience available at Earth science data and research centers other than the designated DAACs...Previous expert panels, including an internal NASA committee as well as the National Research Council, have noted the value of this experience base and urged NASA to make use of it." U.S. Congress, General Accounting Office, *Earth Observing System: NASA's EOSDIS Development Approach Is* Risky, IMTEC-92-24 (Gaithersburg, MD: General Accounting Office, February 1992), p. 21.

45 "EOSDIS Progress Review: Introduction," D. Butler, J. Dalton, EOSDIS Progress Review, Dec. 13-141993, Landover, MD.

The NRC Panel to Review EOSDIS Plans advocated a much stronger computer science research program for EOSDIS. The U.S. computer science community, Goddard's own in-house computer science experts, and experts at NASA's Ames research center have apparently had very limited input into EOSDIS implementation and operations decisions.[46] ability of EOSDIS to exploit rapid advances of technology may depend on the consistent involvement of computer scientists both within and outside of NASA. NASA has recently devoted some of the EOSDIS budget to computer science and data handling technology development (approximately $20 million over the next few years), and is now soliciting proposals for advanced computer technology work.[47]

## Version O and Pathfinder

NASA, NOAA, and USGS have initiated development of "Pathfinder" data sets in EOSDIS Version O to increase the amount of data available to Earth science researchers in the near term. Pathfinder datasets are large data sets collected over a number of years by NOAA environmental operational satellites, DOD DMSP satellites, and Landsat.[48] They are potentially useful to researchers because they span enough years to allow detection of ecological and climate trends. However, Pathfinder datasets require careful reprocessing, since they have been collected from multiple instruments of varying calibration standards mounted on many satellites. Pathfinder datasets include:

- Advanced Very High Resolution Radiometer (AVHRR) data sets held by NOAA,
- TIROS Operational Vertical Sounder (TOVS) data,
- GOES data (figure 3-6) held under NOAA contract by the University of Wisconsin,
- Special Sensor Microwave/Imagery (SSM/1) data acquired by NOAA from the Department of Defense,
- Scanning Multichannel Microwave Radiometer (SMMR) data recorded from the Nimbus-7 satellite, and
- Landsat data in the USGS archive at the EROS Data Center.[49]

NASA and Hughes have recently expanded the influence to be derived from Pathfinder data sets and Version O experience. NASA and Hughes appear to be moving toward using Version O as a testbed for further EOSDIS development, instead of replacing Version O with a different system for the EOSDIS EOS Core System ECS (box 3-4). NASA and Hughes plan to reuse the incremental development process, small development teams, "tirekickers,"[50] and other experience gained in Version O development and integration in subsequent versions of EOSDIS.

The work of NASA, NOAA, and the Department of Interior in developing the Pathfinder data sets is lauded by the scientific community. Congress may wish to encourage NASA to accelerate the Pathfinder activity to enhance the near-term benefits of EOSDIS. This action would also pro-

46 "Likewise, the nation's computer science community currently has very limited involvement in the Project, despite the fact that EOSDIS, to be successful, must implement the latest advances in scientific data management technology and, in some cases, stimulate the development of new technologies." *National Research Council Panel to Review EOSDIS Plans Interim Report,* April 1992, p. 16. The EOSDIS Advisory Panel also noted in October, 1993, "Experts in computing technology, with credentials comparable to those of the most prominent EOS investigators, have not had the opportunity to contribute to the architecture and design of EOSDIS."

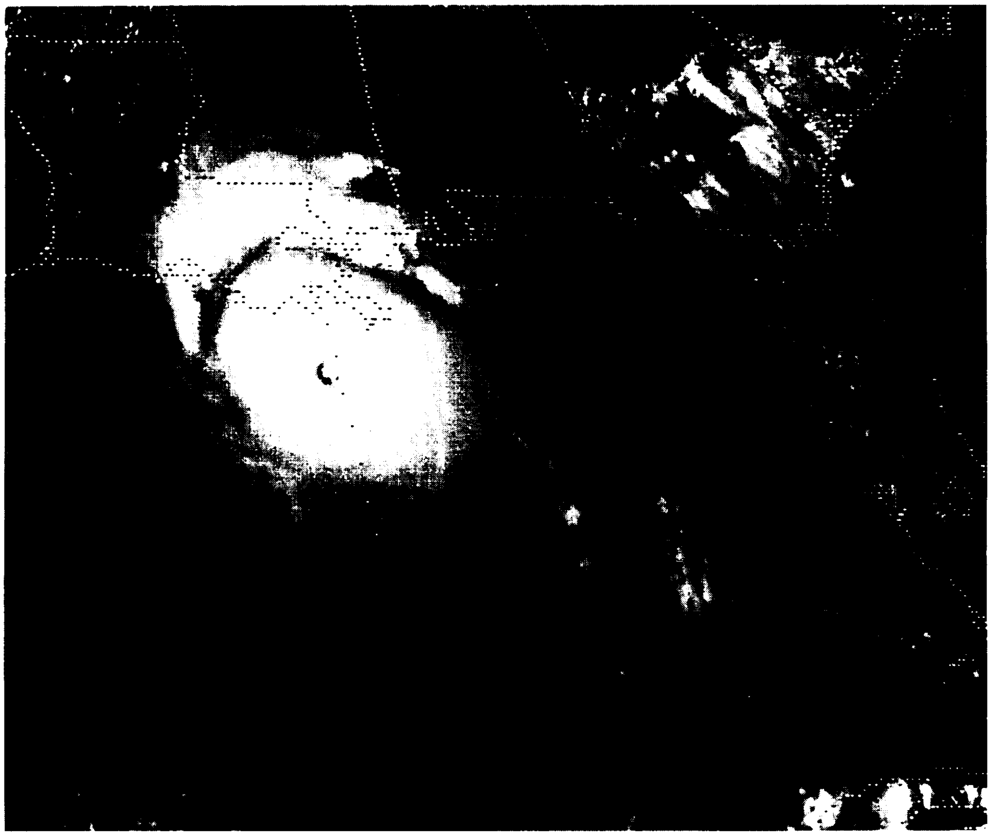
47 Researchers in academic computer science departments generally work with fairly small-scale interactive systems, and thus have little experience with large data flows—with some exceptions. Most experience with handling large data sets still resides in NASA projects, some science teams within NASA, and other agencies.

48 See U.S. Congress, Office Of Technology Assessment, *The Future of Remote Sensing from Space, OTA-* ISC-558 (Washington DC: U.S. Government Printing Office, July 1993) for a discussion of these programs.

49 Roughly 80 to 90 percent Of Version O data are from NOAA satellites. Pathfinder could be considered art exchange of technology for data between NOAA and NASA.

50 Interdepartmental engineering experts charged with testing overall system capability.

FIGURE 3-6: GOES–7 Image of Hurricane Hugo, Sept. 20, 1989



GOES images like this are effective in tracking severe storms in real time HIstorical data of the storms' changing form and track are useful in Improving scientists' understanding of the formation and evolution of severe weather patterns

SOURCE National Oceanic and Atmospheric Administration, 1994

vide more experience in providing Earth science data to the broad research community before NASA and Hughes implement later versions of EOSDIS.

## Requirements-Driven Approach vs. R&D Experimental Approach

NASA is confident that an operational approach to the EOS Core System, integrating available commercial hardware and software to EOSDIS needs coupled with limited software development, will be sufficient to bring about dramatic improvements in the ability to use Earth science data. NASA and Hughes have designed the system to meet minimum standards of performance in all areas, an approach that decreases risk and is appropriate for the design and execution of an operational data system. However, this approach to EOSDIS will not push the state of the art in technology.

GAO and the NRC have criticized EOSDIS plans for insufficient attention to advanced technology development,[51] expressing concern that the contractor's near-term requirement to develop an operational system could detract from a thorough prototyping program to support the *long-term* needs of global change researchers.[52] Efficiently working with large, complex, and heterogeneous global change data sets may require special advanced technology. Much of this technology will not be available commercially, if scientific research is not considered a sufficient market.[53]

NASA does not usually sponsor the development of new technologies required for a flight program through the flight program budget itself, but rather uses other programs specifically established to sponsor flight and ground systems R&D. NASA previously intended to sponsor EOSDIS-related computer science research and technology through its computer/data systems R&D programs.[54] In response to external pressures, however, NASA has taken the unusual step of setting aside direct EOSDIS project funds to sponsor computer science research and advanced data systems technology development for EOSDIS. NASA is soliciting proposals, through a Headquarters Research Announcement, for technology development or adaptation for EOSDIS, and funding will be used for research and development at DAACS, Earth science organizations, and university computer science departments. Unfortunately, these steps may reduce the overall budget available for implementation and operations.

Congress has in the past had the opportunist y to direct NASA to strengthen the advanced technol-

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51 As early as 1990 the NRC noted that: "According to NASA's development strategy, the EOSDIS Core System contractor will be responsible for initiating and conducting prototyping efforts after the contract is awarded and full-scale development begins. Prototyping is intended to be an ongoing aspect of the contractor's work. However, we believe that devolving responsibility for prototyping to the Core System contractor may make it difficult for NASA to ensure that the full range of critical technological risk areas are addressed in a timely fashion." The following technology areas were recommended for prototyping by the NRC:

1) data display & user interface,
2) browsing capability,
3) data formats & media,
4) accessibility of data and information,
5) cataloging,
6) search and query capabilities,
7) model and data interaction,
8) data structures,
9) data reduction algorithms, and
10) networking.

National Research Council, *The US Global Change Research Program: An Analysis of the FY1991 Plans* (Washington, DC: National Academy Press, 1990), p. 79.

52 The EOSDIS Advisory Panel noted in October 1993: "The system is being driven by detailed requirements, with little sense of the overarching issues about information systems." The Panel also noted that Hughes' managers had "too little knowledge of the characteristics and computing styles of Earth scientists." GAO previously stated: "It is vital that NASA not allow the near-term operational requirements to prevent it from building a system that can ultimately provide a "next generation" of capabilities beyond what current Earth science data systems provide." U.S. Congress, General Accounting Office, *Earth Observing System: NASA's EOSDIS Development Approach 1s Risk>, 1* MTEC-92-24 (Gaithersburg, MD: General Accounting Office, February 1992), p. 33.

53 However several organizations outside NASA are pursuing technology development that would enhance EOSDIS capabilities. Sequoia 2000, a Digital Equipment Corp. project involving computer and Earth scientists at five campuses in the University of California, is pursuing a number of technology development efforts, including working with very large data sets using advanced query styles, searching for large objects, and techniques for working with diverse types of data. The Mitre Corp. is also exploring advanced query capabilities and object-oriented data management systems. Visualization techniques are being pursued at a number of research organizations, Including the IBM Watson Research Center, JPL, the Mitre Corp., and the Xerox Palo Alto Research Center.

54 Robert Price, Director, Mission to Planet Earth office, NASA/Goddard Space Flight Center, personal communication, January 1994.

ogy research component of the EOSDIS program. **Congress may yet wish to expand the higher risk technology development aspects of EOSDIS within NASA. This approach would have the potential to yield higher functionality of the system. Such a research effort would also have the potential to produce more generic technologies that might prove useful beyond meeting the operational requirements of EOSDIS.** Finally, an expanded technology development effort would enhance the oversight capability of NASA EOSDIS project staff.

On the other hand, successful and timely implementation of EOSDIS could be jeopardized if NASA and Hughes rely on custom-designed hardware and software, or new technologies without widespread commercial support or commitment. Most scientists currently desire basic online functionality with a small set of critical services presented in a way that matches how they work. Advanced graphics interfaces or similar '*extras" may be less important than simply having a system that is consistent throughout, works correctly every time, has a well-stocked archive of scientific data sets, performs quickly, and has a simple and inexpensive procedure to acquire data rapidly.

## | Long-Term Archives

NASA has limited experience with operational Earth remote sensing data systems. Although the EOSDIS budget has fared no worse than other parts of the Mission to Planet Earth in recent program reductions, continuous operation and upgrading of an operational data system may prove a challenge for an agency historically oriented toward high-profile engineering hardware development and an emphasis on human spaceflight.

Since it is not known which data will prove useful in the future, and in order for scientists to understand the genesis of environmental changes they discover in the future, it is important to preserve all data.[55] Responsibility for long-term archiving of EOS data, however, has not been decided, and planning has barely begun for data maintenance after the 15-year life of EOS. NASA has promised to have all EOS data preserved for possible future use, and the pertinent Federal agencies are conducting negotiations concerning the means and mechanisms of long-term preservation of these data. The policy on archives will be an essential element in the long-term value of EOSDIS.

## EOSDIS SCIENTIFIC INVOLVEMENT

NASA has sometimes conducted early mission planning and system development phases of space data systems without actively involving researchers and data consumers in the planning process. Insufficient scientific participation frequently has resulted in improperly implemented data systems and rejection of data systems by the scientific community. EOSDIS poses a special challenge, because its large scope could result in the domination of "system" concerns while science and service needs are overlooked.

Officials in the EOSDIS DAACS have already indicated that early and continuous involvement of the science community is the most important aspect of DAAC development. They also recognize that failure to involve scientists early in the planning can lead to a DAAC receiving little use by the scientific community.[56] To assist scientific input into EOSDIS development, NASA has

55 For example, when the AVHRR instrument was constructed, NOAA scientists were generally unaware of how important AVHRR data would be in following changes in vegetation. Now, NOAA distributes data on changes in vegetation throughout the year as a standard data product.

56 National Aeronautics and Space Administration, NASA Goddard Space Flight Center, Earth Science Data and information Systems Project, "EOSDIS Version O (V0): Lessons Learned," April 1993, p. 6. This document is tilled with references to the prime importance of a close working involvement between system development and the scientific community at the DAACs.

## BOX 3-8: Science Advice in EOSDIS

The EOSDIS Advisory Panel of the NASA EOS Investigators" Working Group is the primary mechanism for obtaining user input in EOSDIS, with its 24 members drawn from the primarily academic community of 551 EOS Investigators Panel members have been on the procurement team for the ECS contract, and Panel members also communicate to Industry independently The EOSDIS Advisory Panel examines the "integrated picture' of EOSDIS, reviewing and assisting in planning, proposals, and system testing This group was Important in promoting the redirection of EOSDIS development toward a more open, evolutionary, and distributed system after the September 1993 Systems Requirements Review.

DAAC User Working Groups also provide essential guidance to EOSDIS. These groups provide "grass roots" input on science community requirements, data set needs and priorities, required functions and services, assistance in setting DAAC priorities, review and comments on DMC and EOSDIS system efforts, and assistance in the annual update of the EOSDIS science data plan Only half of the membership of these groups are EOS Investigators

The DMC User Services Working Group includes User Support Off Ice staff at the DMCS and NOM data centers, as well as members from the EOSDIS project at Goddard Space Flight Center This group is responsible for improving access to exiting data, developing common user services at all DMCS, and encouraging and gaining feedback from Version O use

Program scientists at NASA Headquarters take part in the MDIS Management Operations Working Group, which provides an overall review of EOSDIS program structure and performance, Insight into the larger outside Information systems world, and ties to the Earth Science and Applications Advvisory Subcommittee

Day-to-day scientific operational input and data product support IS provided by the DAAC project scientists on the staff of each DMC. At Goddard, the EOSDIS project has a project scientist on staff, as well as a scientist n the role of Science Data and External Interface Manager

EOSDIS at the system level and the DMCS attempt to be receptive to science advice through Individual comments and experiences from all users

SOURCE National Aeronautics and Space AdministrationmvstratoP 1993

constructed an extensive system for providing science advice (box 3-8).[57]

In spite of this system of science advice and assertions about the importance of close involvement with the science community, observers have complained that the role of Earth scientists is limited to advisory committees, while the DAAC scientists have no direct input into basic design. development, and operations decisions. Also, some assert EOSDIS planning is conducted under almost exclusive advice from NASA-affiliated scientists, to the exclusion of other users .5X

57 "One of the first activities of EOSDIS was to &fine methods for increasing participation by the research community in the definition, testing, and re-design of the system...The success of EOSDIS hinges on the users' being empowered to shape it to their needs—needs which will evolve with progress in Earth science research and with experience gained in manipulating the data systems." National Aeronautics and Space Administration, *EOSDIS: EOS Data and Information System* (Washington, DC, 1992), pp. 7, 23.

58 "The predominant users of EOSDIS are expected to be the thousands of Earth scientists who are not affiliated with the EOS program. However, NASA's planning for the system thus far has relied largely on input from the relatively small number of researchers funded directly by NASA. NASA's guidelines and mechanisms for obtaining further user input in the future do not provide assurance that c/// segments of the user community will he adequately represented" LT. S. Congress, General Accounting Office, *Earth Observing System: Broader Involvement of the EOSDIS User Community Is ,$'ceded,* IMTEC-92-40 (Gaithersburg, MD: General Accounting office, May 1992), p. 1.

Having individual investigators actually perform data processing, validation, and intercomparisons in EOSDIS development would provide important feedback on EOSDIS operations. Emphasizing this approach would be more expensive, but has proven to be crucial in past data systems such as the WETNET at MSFC.[59] At the same time, EOSDIS could be more effective if EOSDIS officials look beyond the advice of current users and successfully anticipate the likely modes of computer interaction of future users of EOSDIS. Hughes has sent teams of scientists and engineers to many science user facilities to gain better insight into the needs of scientific users of EOSDIS.

## Data Pricing: User Fees?

Whether data centers will actually collect money from the research community for the use of EOSDIS remains an open question. Current pricing policy for EOSDIS. and all U.S. global change data, ensures that data will cost no *more* than the "marginal cost of reproduction." At present, several EOSDIS DAACS distribute their data free to the scientific community.[60]

User fees have the advantage of providing the recovery of a portion of the data system operations costs, without seriously impeding data use if prices are sufficiently low. User fees also provide accountability, serving as a constraint against users ordering vast amounts of data simply because they are free. They also encourage user involvement in the data system.

However, the costs of a billing system can sometimes outweigh the benefits. In some cases, especially for online data distribution, establishing a system to monitor payments, checks, purchase orders, etc., may cost ***more*** than giving data away (especially for smaller data sets), and may reduce overall use of the data. Many researchers (e.g., unfunded researchers doing exploratory research, graduate students, educators, some foreign researchers) cannot raise sufficient funds to purchase large quantities of data, even at incremental costs.

Would EOSDIS be "flooded" with requests if data were free? EOSDIS could depend on commercial data distribution networks to limit data demand, similar to current use of the telephone network. Users would be required to pay for the time they spend on the network accessing and transferring data, but no billing system would be required at the DAACS. Network access would still need to be relatively inexpensive, however, for EOSDIS data to have broad distribution.[61] Another alternative would be to institute the use of research vouchers, allocating a limited number of data credits per researcher. Time and storage limitations alone might serve to discourage an individual undisciplined acquisition of large data sets.

This issue needs to be resolved relatively soon to facilitate the appropriate design of EOSDIS. It is essential that whatever is decided, the data policy be consistent within the government, and supported by appropriate funding.

## Equipment Requirements for EOSDIS Users

Use of EOSDIS will be determined in large part by the equipment required to access the network. NASA will provide Science Computing Facilities (SCFS) for use by the 551 EOS primary investigators, ranging from personal workstations to super-

s9 National Aeronautics and Space Administration, NASA Goddard Space Flight Center, Earth Science Data and Information Systems Project, "EOSDIS Version O (V0): Lessons Learned," April 1993.

60 As noted in chapter 2, the EROS Data Center, with by far the largest remote sensing data archive of the DAACs, has a user fee system in operation. The Alaska SAR Facility also charges for data. Goddard Space Flight Center expects to have a charging mechanism in place by 1994. The other DAACs do not currently charge for data, and do not plan to unless so directed by NASA Headquarters.

61 It is highly likely that future commercial data networks costs will be charged in terms of bandwidth, not bits, making EOSDIS data transfer economical compared to other uses.

computers, for algorithm development. Besides direct NASA support, many other sources of research funding, both within and external to NASA, provide funding for computing equipment and communications to support the needs of the broader Earth science community. For this larger community, NASA expects the minimum SCF required for full access to EOSDIS services would be commensurate with what is currently affordable with a "typical research grant" (about $10,000 fiscal year 1993 dollars).[62] EOSDIS plans to make available software toolkits for use on these computers.[63] Furthermore, NASA and Hughes have promised to design EOSDIS to provide user access and as many services as possible.

However, under the present product generation system, scientists not directly involved with the program cannot easily contribute to the development and distribution of new algorithms. Version O is criticized by some observers for requiring highly specific equipment and software to be usable. A need for special equipment, software, or formats could be a major liability, considering the many researchers expected to use the interagency GCDIS.

Breadth of EOSDIS services, based on special equipment requirements, could be one of the first casualties of any future program difficulties or budget shortfalls. **If Congress desires to maintain the advantages of broad use of EOSDIS, it will need to monitor this aspect of the program to ensure that highly specialized and advanced computer hardware and software does not become a requirement for use of EOSDIS.**

## Cost Savings in EOSDIS?

Congress has provided EOSDIS with funding at the level of agency requests thus far, with additional funding added for CIESIN. However, the continued availability of such resources is likely to be a central issue in the program in the future, given the strained budget context in NASA, the deficit problem in the U.S. government, and the planned increase of over 50 percent in EOSDIS funding for fiscal year 1995—from $188 million to about $285 million. Also, cost overruns have been the rule, rather than the exception, in large data systems. Figure 3-7 illustrates changes in total EOSDIS funding between 1991 and 2000.

Some observers claim the sizing of EOSDIS is unrealistic, since it was not rescoped to reflect the new reality of the smaller EOS program with smaller data flows. The EOS satellites are now about the size of the current UARS, and the launches are staggered. A new, reduced set of requirements for EOSDIS, some argue, could cut the costs of the program significantly.[64]

The EOS Investigator Working Group sounded a general caution concerning EOSDIS staffing costs:

> "From experience with other data systems, we caution that costs are only moderately sensitive directly to storage volumes and processing operations; they are more sensitive to the work

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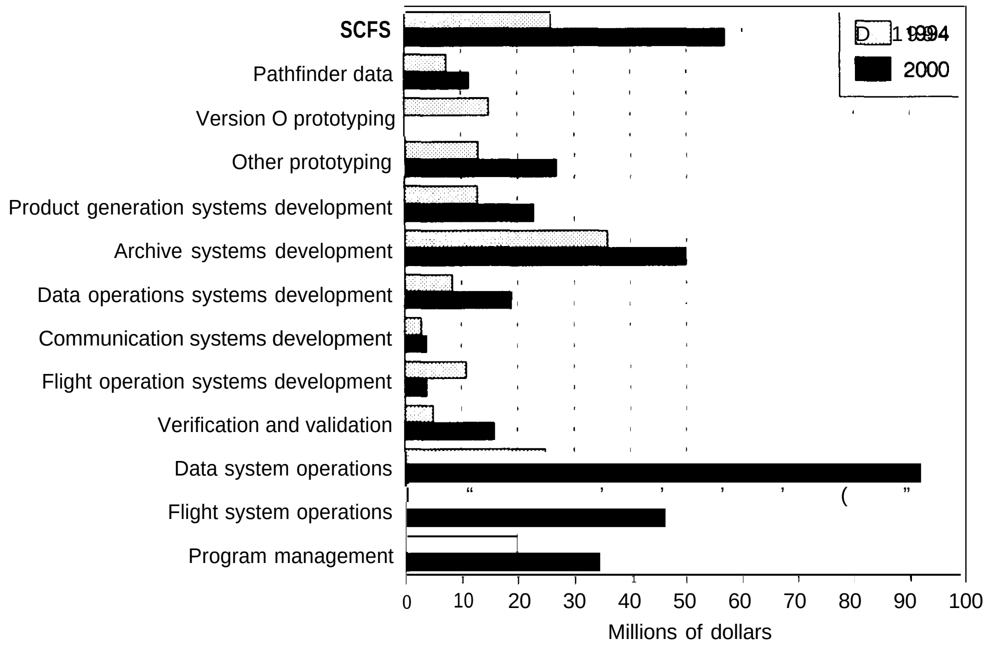
62 National Aeronautics and Space Administration, Modeling, Data, and Information Systems briefing to OTA, February 1993.

63 It is unclear what difficulties may be encountered from government restrictions on distribution of software. Hardware distribution difficulties were a major problem in the MSFC WETNET program. NASA ESDIS, "EOSDIS Version O: Lessons Learned," April 1993, p. 79.

64 An example is a recent ocean Wind scatterometer project at JPL, which was planned to cost $20 million. A new design review reduced the expected costs to $11 million, apparently with little negative impact.

Some observers argue that enough new information has been learned about the production of data products to warrant re-evaluation of the EOSDIS product generation system by DAACs and PIs to determine whether changes could bring more quality data products while saving resources. The present strategy is to plan each product in great detail. Top levels of NASA prepare and update detailed plans (to avoid delay of data products to "fine tune" the algorithms, or a focus on only a small subset of the data). As an alternative, however, more control could be passed back to the investigators and project groups. An agreed set of goals and delivery schedules for primary products would be required, but secondary products could be more creatively developed by investigators. This might give NASA many more good products, although there would be more failures as well. This approach would promise delivering more and better data products, lowering costs, and increasing productivity and satisfaction of the scientists. NASA and Hughes moved toward this conception at the EOSDIS Progress Review, December 1993.

FIGURE 3-7: Estimated EOSDIS Program Funding




SOURCE National Aeronautics and Space Adminstration Office of Technology Assessment, 1993

force needed for system engineering, algorithm integration, etc."[65]

The EOSDIS Advisory Panel noted in October 1 993:

"By far the greatest expense in EOSDIS is the sum of the salaries for maintenance and operations, and the currently proposed staffing levels seem high."

EOSDIS plans require excellent data delivery at all times of the day; some costs could be saved if this capability were reduced.[66] If researchers can wait up to a week for most data products, the dif-

65 National *Aeronautics* and Space *Administration, Adapting the Earth Observing System to the* ***Projected $8 Billion*** *Budget:* ***Recommendations from*** *(he EOS investigators,* October 1992, p. 39. The **EOSDIS** Advisory Panel noted in Oct., 1993, that"...**the** putative costs seem too sensitive to the floating-point operations needed to create the **EOS** standard products, when the constraints are more likely to be the population of users who can be served and the rate at which the system can deliver products to users,.."

66 If 8-hour shifts **are substituted** for 24-hour shifts, DAAC operations costs are estimated to be reduced by 8.2% to 17.9% (depending on "non prime time" operations levels, and assuming processing and electronic access/distribution of data during *'non prime time"). This is an estimated savings of $15.7 to $34.4 million through October 2002. **"Cost/Performance,"** Joe **Guzek, EOSDIS** Progress Review, Dec. 13-14, 1993, Landover, MD.

ference in costs could also be expected to be substantial.

However, underestimation of required data system personnel would also be a serious problem. User services (establishing communications for users, training researchers and computer experts in the use of the system, solving communication and network problems for users, providing information on data product generation and delivery, special requests for data, etc.) usually have required *more* effort than initial estimates. In EOS, with a projected 100,000 to 200,000 users, the number of people dedicated to user services can be expected to be large.[67]

While many climate problems require global data for many years, there may be ways to acquire samples from the data stream rather than store the entire data set in order to reduce the volume sharply. These opportunities could make it easier to pursue the scientific search while reducing costs.

EOSDIS has ambitious plans for providing data online. A few EOSDIS data streams will be needed by NOAA for real-time weather forecasting, and NASA plans to deliver these data to NOAA rapidly. Some observers claim the rest of the EOSDIS data products do not need to be available in real-time, as currently planned. Short delays in data transmission offline might result in significant cost savings.

Observers have noted that to achieve good service at reduced cost, some competition is usually necessary. While this is difficult to achieve without some duplication, furthering efforts to provide choices to researchers might result in overall higher efficiency, better service, and lower cost. Placing the entire responsibility for meeting diverse user needs through a single, pre-planned data and information system could be very difficult. EOSDIS could become a very "brittle" system if EOSDIS were "monolithic," and the only means of communication between researchers and NASA officials. Examples of resilience - enhancing alternatives would include the use of the CIESIN network, direct broadcast of data, commercial high-volume/high-speed lines, and NREN.

As technology and economics change, the system must adapt to enable functions to migrate to where they can most economically be performed (e.g., the shift from centralized mainframe computers in the 1970s to today's distributed workstations). NASA and Hughes plan to isolate functions where technology change is most likely to occur, so these functions can easily be changed or replaced as technology matures.[68]

Some observers point out that many of the functions in EOSDIS might well be provided by the private sector. This view posits that it is inappropriate and inefficient for government to plan and build operational science networks in an era of rapidly expanding technical capability. For example, special funding for networks of very high bandwidth would be redundant if sufficient bandwidth becomes widely available and inexpensive commercially. As noted in chapter 2, computer processing speed, and storage capacity and access, largely funded by the commercial sector, have been increasing markedly in recent years.

As an alternative or supplement to EOSDIS, NASA could rely on direct-broadcast of data from satellites to ground stations at scientists' research institutions. Proponents of this approach claim costs increase dramatically when government performs computing tasks, noting many researchers already receive data directly over communications links. Reliance on this strategy would, however, hamper the fundamental goal of fostering scientific interdisciplinary research. Such a plan also might increase costs, not decrease them, since each user would require the ability to process raw data signals to final products, a costly process for many types of data. Using a few well-controlled facilities (DAACS) is advocated as a less expensive and more effective system.

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67 "Members of most user communities will continue to want to talk to knowledgeable user service personnel via telephone-specially as the number of data products and their complexity increases...training is not a trivial matter, especially for a large number of data products with frequent changes." Pitt Theme, "Demographics", EOSDIS Progress Review, Dec. 13- I 4, 1993, Landover, MD.

68 "EOSDIS Progress Review: Introduction," D. Butler, J. Dalton, EOSDIS Progress Review, Dec. 13-141993, Landover, MD.

There are other alternatives. As noted in chapter 2, many government data distribution programs, including remote sensing data systems, have derived and distributed products with fairly modest costs. While these programs do not achieve the broader goals of EOSDIS, they do provide less expensive models of data distribution.

## | Commercial Relevance

**NASA has planned and developed EOS as an operational scientific data system, relying on USGCRP goals and scientific and technical considerations for program planning and execution. NASA has not designed EOS to stimulate the Earth remote sensing market, nor as a "test-bed" for advanced Earth remote sensing technologies, nor to contribute to the national goal of "global competitiveness." The two original EOS instruments with the most potential commercial relevance, HIRIS and SAR, were deleted from the program in the 1992 restructuring. EOS data are generally low-resolution, and land observations have not been emphasized in the program, limiting the commercial value of EOS data.**

**Nonetheless, a strong potential may exist for commercial value of some EOS data. While** current EOSDIS plans to make all data available almost immediately could destroy the commercial value of similar data from other sources, such as from the Sea Star Satellite (ch. 4), easy access to EOS data by the commercial sector could result in valuable enhancements ("value-added" products) that could satisfy various needs the government cannot meet.[69] NASA and Hughes are conducting studies of the potential commercial relevance of EOSDIS data.

## DATA FORMATS/STANDARDS

The issue of data formats for remote sensing has been debated for several years, especially in NASA. Until recently, NASA and Hughes had supported only high density format (HDF) for EOSDIS data storage and retrieval. However, this implied anew way to ingest data that very few scientists have used. Many scientists might desire to continue to obtain small datasets in a simple binary or character format, such as ASCII.

Data formats should be easy to use. Formats also should not substantially increase data volume or slow down the processing of large datasets. Finally, formats must be capable of allowing data processing on primary workstations and PCs. The appropriateness of HDF by these criteria is debated in the science and computing communities. Designating a present format system as the standard for future EOS data would doubtless cause problems with using the data. Instead, NASA and Hughes plan to provide translators within EOSDIS so users can easily access data in different formats.

## | Is EOSDIS "Distributed" and "Evolutionary"?

At the first EOSDIS ECS system requirements review in September 1993, Earth scientists expressed concern that EOSDIS architecture appeared too centralized and inflexible to evolutionary change. The EOSDIS Advisory Panel of the EOS Investigators' Working Group, in October 1993 concluded the system was not a distributed system:

> Instead it is a system of geographically dispersed elements with tightly centralized management [a central architecture forced to reside at several geographic locations] . . . Essential elements of a distributed system-competition among elements, and different approaches, distributed responsibility, power, and resources—are missing .70

The Panel also stated EOSDIS was not an evolutionary system:

69 For example, Orbital Science Corp. is currently attempting to develop a commercial market for value-added enhancements to data that will be collected by its SeaWiFS ocean color sensor. See U.S. Congress, Office of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., footnote 2, ch. 7.

70 EOSDIS Advisory Panel, EOS Investigators' Working Group Payload Panel meeting, Oct. 4-6, 1993.

> Instead its developers focus tightly on the near future, use tools and standards that are already obsolete, view "technology insertion" as synonymous with evolution, and have little vision of the computing environment of this century and the early part of the next.[71]

The Panel noted the EOSDIS design had changed little since 1990, despite important technological achievements in the architecture of distributed information systems since then.

In response, Hughes is conducting studies of alternative ECS architectures, with study teams selected from top universities in computer and Earth science.[72] NASA is also funding the development of prototypes and discipline-specific functions, and encouraging increased involvement in ECS development and funding for added functions and services to meet the needs of specific science disciplines.[73] The EOSDIS ECS system is now being designed to accept alternative implementations at all levels, including new developments not created by NASA or Hughes, as well as test marketing new ideas, products, and methods.[74]

EOSDIS needs to maintain the flexibility to deal with different methods of data management among the DAACS, since different science communities will have different data management needs. The report of the NRC Panel to Review EOSDIS Plans Interim of September 1992 stated DAAC managers did not have well-defined authority or accountability in building EOSDIS, that DAACS were not sufficiently involved in EOSDIS implementation, and their primary role appeared to be simply to operate hardware and software at their sites after delivery.[75] According to the NRC Panel, 'The centralized management of the design and implementation of EOSDIS functions at each DAAC is not conducive to active user involvement and responsiveness to changing technology."[76]

Decentralization also has its risks, however. To build an integrated, interoperable system requires sufficient central authority to ensure interoperable system architecture and interfaces. As a project serving multiple agencies, EOSDIS requires smooth and efficient interpersonal communications, as well as computer communications, in a highly complex environment. Parochial interests need to be controlled to some degree. Completely autonomous DAACS, each with its distinctive system architecture, data formats, and so on, was one of the primary reasons for the development of EOSDIS. While insufficient input from DAAC management would endanger system responsiveness to scientists, excessive DAAC autonomy might endanger integration and interoperability of EOSDIS.

Instead of increasing the authority of DAACs as a means of dealing with centralization, NASA might arrange a system having a manager for each cluster of major products for related disciplines. This manager would make agreements on how to develop products that would be stored in the DAAC. Data distribution could be separated from product generation, with the DAACS and advisors having most control over distribution while science experts have control over product generation. This is similar to older NASA project management philosophy in which a single manager has control over the priorities and the level of ef-

7 Ibid.

72 D. Butler, J. Dalton, "EOSDIS progress Review: Intrxduction," EOSDIS Pn)gress Review, Dec. 13-141993, Larrdo\cr, MD.

73 Ibid.

74 Gal] McConaughY, ESDIS Project, "The Evolving Context of EOSDIS (Focus: Science Support)" EOSDIS Progress Review, Dec. 13-14, 1993, Landover, MD.

75 NASA has been criticized for allowing the DAAC managers little influence over the operation and maintenance of ECS as a whole, no financial control over the long-term strategy of the DA AC, and no responsibility to reallocate resources to maximize the provision of services.

76 A reliance on standard data products alone could be too rigid. For example, users would have difficulty in automatically combining data from different sensors, altering products to meet new scientific needs, or revising algorithms to meet various purposes. The DAACs currently have little control over the forms in which they receive their data, the management and evolution of the ECS, or budgets.

fort of each task, with less influence from NASA headquarters and more authority from those in the "field," along with freedom to cut across organizational boundaries to accomplish tasks.

The level of autonomy at each DAAC could have a significant impact on the success of EOS-DOS. Congress may wish to consult with NASA management, DAAC management, and informed members of the global change research community, to monitor the appropriate level of centralization in EOSDIS management.

## I The New Future of EOSDIS: "UserDIS" and the "Earth Science Web"

The UserDIS is a vision of the future information infrastructure in which there will be a multiplicity of data sources and information integrators available to scientists and other users of Earth science and global change data. EOSDIS would be one of the key providers of data services in this "Earth Science Web" of easily accessible pooled computing and data resources.[77]

A Hughes study of this issue found: '*There are many things which ECS could provide without leaving its mission envelope for GCDIS/UserDIS."7[8] In response to ideas from the EOSDIS Advisory Group and the NRC Panel to Review EOSDIS plans, NASA and Hughes have recently promised to design EOSDIS ECS as part of a larger environment from which users can freely find, invoke, and selectively combine services.[79] While focusing on Earth science data and its users, other uses would not be excluded by the new EOS - DIS design architecture. The distinction between user and provider would be elmininated, effective y using the computer resources and expertise in the distributed user community beyond EOSDIS. Responsibility, power, and resources would be dispersed throughout the Earth Science Web, with any provider having the ability to add a new idea to the Web. No restrictions would be placed on the number of providers, their locations, and the services and data they offer.[80] Beyond the DAACS, the UserDIS would accommodate autonomous provider sites dealing with researchers and research groups as individuals rather than relying on sponsoring "institutions''.[81]

If EOSDIS is to evolve toward UserDIS, as advocated by the NRC Panel to Review EOSDIS Plans, specific EOSDIS goals should be limited, relying instead on the entrepreneurial spirit of DAACS and other organizations. The Panel expects the cost of communication and switching to drop dramatically in the 1990s, meaning a variety of approaches to computing not previously envisioned would be made available by entrepreneurial companies and other organizations. The role of EOSDIS would be to remain open, not excluding the use of new developments or other users and uses of the system.

77 Gail McConaughy, "The Evolving Context of EOSDIS (Focus: Science Support)," op cit.

78 Mark Elkington, "GCDIS/UserDIS—Background and Issues," EOSDIS Progress Review, Dec. 13-14, 1993, Landover, MD.

79 Gail McConaughy, "The Evolving Context of EOSDIS (Focus: Science, Support)," op Cit.

80 Mark Elkington, "GCDIS/UserDIS—Background and Issues," op Cit.

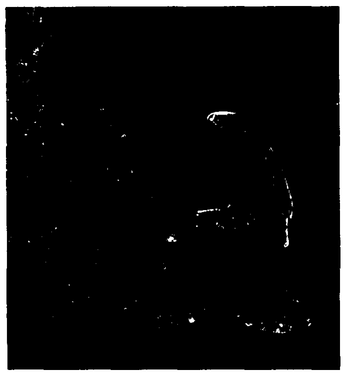
81 Ibid.

# Government and Private Sector Roles in a Developing Market for Geospatial Data

4

As noted in chapter 2, all of the civilian remote sensing satellite systems the United States now operates were developed with public funds to provide data in support of the public good for weather predictions, climate and global change studies, and to manage U.S. renewable and nonrenewable resources. Some of these data, especially multispectral data that provide information about Earth's surface, have proved to have commercial value as well. [1]Such data are provided by the Landsat system and the AVHRR instrument on the National Oceanic and Atmospheric Administration (NOAA)'S POES system.[3] In the future, data from synthetic aperture radar systems will likely develop significant commercial value as well.[4]

Today, space technology, coupled with advanced computer software and hardware techniques, provides expanding opportunities for viewing and analyzing the Earth, its environment, and its resources. As entrepreneurs continue to work with remotely sensed data, they are likely to discover new profit-making uses



[1] See app. B and U.S. Congress, Office of Technology Assessment, *Remote Sensing and the Private Sector: Issues for Discussion* (Washington, DC: U.S. Government Printing Office, 1984), appendices A-1, for a discussion of some of these uses.

[2] Advanced Very High Resolution Radiometer

[3] Polar-orbiting Operational Environmental Satellite

[4] For example, researchers using data collected by the synthetic aperature radar aboard the European Space Agency's ERS-I satellite have shown their utility in monitoring agricultural activities and in urban planning. See Commission of the European Communities, Institute for Remote Sensing Applications, *Annual Report, 1992,* for discussions of applications in agriculture, mapping, and monitoring that would have commercial value,

for data from remote sensing satellite systems.[5] Although most applications of remotely sensed data are now oriented toward supporting government programs, private firms have expressed increasing interest in 1) expanding value-added[6] activities using remotely sensed data, and 2) building and operating satellite systems.

This chapter discusses how remotely sensed data of Earth's surface, increasingly termed geospatial data, serve public and private interests and examines industry efforts to operate and market data from privately developed remote sensing systems. The chapter also summarizes the characteristics of the current and potential future market for remotely sensed land data. Finally, it discusses the competitive position of the United State vis-a-vis other spacefaring nations in data delivery and applications.

## REMOTE SENSING AS A PUBLIC GOOD

Photography and other remote sensing technologies that use aircraft and balloons as platforms have been an important source of data about the Earth for over a century. In 1960, with the launch of its experimental weather satellite, TIROS, NASA was able to show the utility of gathering data from space. Remote sensing satellites are particularly well suited to providing information about weather and the environment.[7] They offer synoptic, worldwide coverage, can operate over hostile territory, and can cover the entire Earth in a period ranging from a day to several weeks.[8]

Experiments with data from TIROS and other research satellites led to the development of the POES and GOES[9] systems, operated by NOAA, and the DMSP[10] satellite system operated by the Department of Defense. These systems provide important data about weather and climate, as well as low-resolution data about the land and oceans. The contributions of remotely sensed data to the public good became especially apparent after the launch of the first operational weather satellites in the 1960s and 1970s: the GOES system (first launched in 1975) tracks both slow moving weather fronts and rapidly developing violent storms. GOES images have contributed to improved early warning of violent storms, resulting in an estimated 50-percent decrease in storm-related deaths[11] (table 4-1), GOES-8, the most advanced GOES satellite,[12] is expected to provide increased ability to track damaging storms (figure 4-l).

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[5] For example, NASA IS designing the sensors for its Earth Observing System (EOS) to serve the interests of global change scientists. However, if previous experience with data from the Landsat multispectral scanner and the AVHRR sensor aboard NOAA's polar-orbiting satellites provide a guide, we may expect that entrepreneurs will find profit-making uses for data from EOS as well.

6 Value-added firms provide information" services to both private and government customers by processing and "adding value to" remotely sensed data.

7 A public good is a good or service for which it is impossible or undesirable for reasons of efficiency to charge customers a Price or user fee for services rendered. Public goods are therefore frequently provided by government and paid for out of tax revenues. See U.S. Congress, Office of Technology Assessment, *Remote Sensing and the Private Sector, Issues for Discussion,* op. cit., pp. 45-47.

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

[9] Geostationary Operational Environmental Satellite

10 Defense Meteorological Satellite Program

11 For a history of weather satellites, see *Weather sate//i/es: Systems, Data, and Environmental Applications,* edited by P. Krishna Rao, Susan J. Holmes, Ralph K Anderson, Jay S. Winston, and Paul E. Lehr, Boston, American Meteorological Society, 1990. Also see William James Burroughs, *Watching the World's Weather* (Cambridge, MA: Cambridge University Press, 1991).

12 This is the first satellite in the GOES-Next series, which was successfully launched on Apr. 12, 1994 aboard an Atlas launcher. NOAA expects to make it operational by October.

**TABLE 4-1: Billion-Dollar U.S. Weather Disasters, 1980-1993**

| | |
|---|---|
| 1 | **California Wildfires,** fall 1993 Southern California, estimated at least $10 billlon damage/costs, 4 deaths |
| 2 | **Severe Flood,** summer 1993, Central U.S , estimated $120 billion damage/costs, estimated 48 deaths |
| 3 | **Drought./Heat Wave,** summer 1993, Southeastern U S , estimated $1,0 billion damage/costs, death toll unknown |
| 4 | **Storm/Blizzard,** March 1993 Eastern US , over $20 billion damage/costs, estimated 270 deaths |
| 5 | **Hurricane Iniki,** September 1992 Hawaiian island of Kauai, about $1,8 billion damage/costs, 6 deaths |
| 6 | **Hurricane Andrew,** August 1992 Florida and Louisiana, about $25.0 billion damage/costs, 58 deaths |
| 7 | **Hurricane Bob,** August 1991 Mainly coastal North Carolina, Long Island, and New England, $1 5 billion damage/costs, 18 deaths |
| 8 | **Hurricane Hugo,** September 1989 North and South Carolina, $71 billion damage/costs, 57 deaths |
| 9 | **Drought/Heat Wave,** summer 1988. Central and Eastern U S , estimated $400 billion damage/costs, estimated 5,000 to 10,000 deaths |
| 10 | **Hurricane Juan,** October-November 1985 Louisiana and Southeastern U S , $15 billion damage/costs, 63 deaths |
| 11 | **Hurricane Elena,** August-September 1985 Florida and Louisiana, $1 3 billion damage/costs, 4 deaths |
| 12 | **Hurricane Alicia,** August 1983 Texas, $20 billion damage/costs, 21 deaths |
| 13 | **Drought/Heat Wave,** June-September 1980 Central and Eastern U S , estimated $200 billion damage/costs, estimated 1300 deaths |

The U S has sustained some very expensive weather-related disasters over the past 14 years. These disasters have placed a great strain on federal, state and local governments as well as the insurance industry In fact, the past SIX years (1 988-1 993) have produced nine weather related disasters exceeding $1.0 billion with estimated costs exceeding $91 4 billion All figures reflect direct and indrect damages or deaths

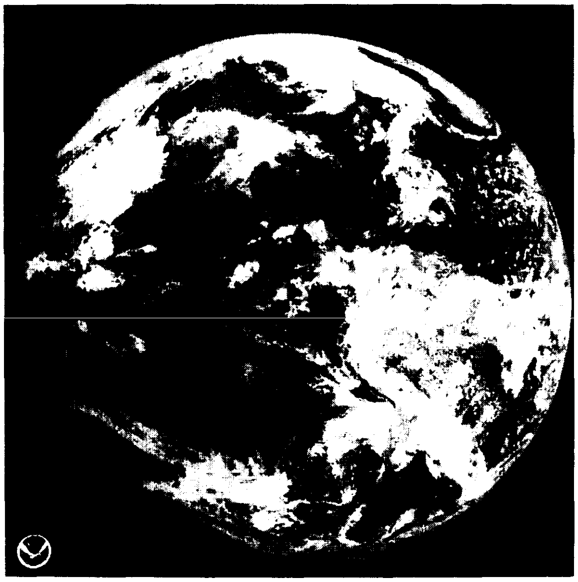
SOURCE NOAA National Climactic Data Center, Research Customer Service Group, 1994

Realizing that moderate-resolution, multispectral data about the land would benefit the scientific analysis of land processes, as well as provide data for a wide variety of applications, NASA designed and launched (in 1972) the world's first land remote sensing satellite—Landsat 1. Follow-on Landsat satellites'[3] have expanded the capabilities of land remote sensing from space and have led to a small, but growing user community.

Remotely sensed data are used by state and local governments for civil engineering, urban planning, resource management, and a host of other applications (apps. B and C). Satellite data are also critical to many legislatively mandated functions of federal government agencies. The Departments of Agriculture and Interior routinely employ remotely sensed data to monitor and inventory crops and habitat. The Forest Service uses these data to monitor the forests and to make resource decisions (app. C). One program, the National Wetlands Inventory, conducted by the Department of Interior's Fish and Wildlife Service,

[13] Landsats 4 and 5, launched in 1982 and 1984, respectively, are still operating, though at much reduced capacity. The replacement Landsat 6 was launched in September 1993, but failed to reach orbit.

FIGURE 4-1: First Image Captured by GOES-8, May 9, 1994



SOURCE National Oceanic and Atmospheric Adminstration, 1994

has particular impact on land use and wildlife management. The inventory[14] requires extensive use of both aircraft and satell ite data to track available habitat for wildlife and extent of wetlands. Remotely sensed data may also allow resource managers to be more efficient in managing renewable and non-renewable resources, providing information on pollution and pollution abatement, and ensuring the safe disposal of hazardous materials. Appendix B offers an example of the use of Landsat and other data by the Bureau of Land Management in categorizing and monitoring land characteristics of the El Malpais National Conservation Area in New Mexico.

Remote sensing technologies have also contributed to military and intelligence successes. The military services and the intelligence community use satellites to monitor international military activities, monitor compliance with arms control treaties, and prepare for deploying troops. U.S. and allied troops made extensive use of Landsat and SPOT imagery in the Persian Gulf Conflict to make maps, determine potential transportation routes, assess enemy fortifications, and analyze damage to the landscape from oil well fires. Afterward, Landsat and SPOT images were used to evaluate the environmental consequences of the war.[15] In addition to using dedicated surveillance satellites, the military services also rely on Landsat imagery for cartography, terrain analysis, and change detection.[16]

## COMMERCIAL PROVISION AND USE OF REMOTELY SENSED DATA

Successful government projects involving remote sensing from space sparked commercial interest almost from the very beginning of the programs. Until recently, virtually all private efforts have been centered in the value-added industry, composed of a growing number of relatively small firms who provide information services for local, state, and federal agencies and private customers. Value-added firms use geographic information systems (GIS)[17] and other analytical tools to combine data from the Landsat and SPOT satellites, and from NOAA's POES satellites, with other data to provide a wide variety of useful information for customers. During the past 15 years, oil and mineral extraction companies, urban planners, retail chains, resource managers, futures traders, and cartographers (table 4-2) have recog-

14 Mandated by the *Wild Bird Conservation Act*, 1992 (PL 102-440); the *Coastal Wetlands Planning protection and Restoration Act, 1990 (Sec.* 305); *Emergency Wetlands Resource Act, 1986 (See* 401A, PL 99-1288); and the *Clean Water Act, 1977,* as Codified in U.S. Code 33, Section 1288.

15 National Geographic Society, Committee for Research and Exploration, "Environmental Consequences of the Gulf War: 1990-1991," *Research and Exploration, vol. 7* (special issue), 1991.

16 U.S. Congress, Office Of Technology Assessment, *The Future of Remote Sensing from Space: Civilian Satellites and Applications,* app. C.

17 *See* ch. 2.

TABLE 4-2: Potential Remote Sensing Markets

| Industry | Government |
|---|---|
| Agricultural/agribusiness | State and local government |
| Engineering and construction | Department of Agriculture |
| Extraction | NOAWDept of Commerce |
| Fisheries | Department of Defense |
| Forestry | Department of Energy |
| Insurance | Department of Interior |
| Investment | Department of Transportation |
| Legal | Environmental ProtectIon Agency |
| Mapping (Including land-use, urban planning) | NASA |
| Marketing | Agency for International Development |
| News Media | |
| Real Estate | **Other** |
| Simulation trainlng | Foreign governments |
| Transportation (land and ocean) | Archaeology research |
| Utilities | Biology/botany |
| Waste management | Global change research |
| | Disease tracking and health management |

SOURCE KPMG Peat Marwck, NASA, and the Ohio State Unwersity Center for 'Mappingat *Market Review*, 1992

nized the commercial potential of remote] y sensed data. Appendix B provides several specific examples demonstrating how firms and government agencies turn remotely sensed land data into useful information.

Starting in the late 1970s, the government attempted to commercialize the Landsat series of satellites, an experiment that proved only partially successful. [18] During the Carter Administration, officials had reached the conclusion that remote sensing technology was sufficiently mature to move Landsat from an R&D project to an operational system. Eventually, they believed, sufficient market for data would develop to allow a transition to commercial development and operation. Because NASA's charter stresses the research and development character of the agency and does not specifically give the agency the mandate to operate on-going systems, the operational elements of Landsat were transferred to NOAA in the Department of Commerce, which has extensive experience in operational satellite systems. However, NASA retained the R&D program for remote sensing hardware. Effectively, this separated the research from the operational users who constituted the data market and lessened the ties between these two areas.

In 1992, after it became clear that the attempt to commercialize Landsat was not fully successful, Congress, the National Space Council, NASA, NOAA, and Department of Defense (DOD) reached the conclusion that maintaining continu-

18 See U.S. Congress, Office Of Technology Assessment, *The Future of Remote Sensing from Space*, op. cit., p. 49 for a summary of those attempts. David P. Radzanowski, *The Future of the Land Remote Sensing System (Landsat)*, Congressional Research Service, 91-685 SPR, 1991, for a more detailed account.

ity of the Landsat program was important to the national interest. 19 They also wished to provide in some form for the continued commercial ization of land remote sensing from space. Congress passed the Land Remote Sensing Policy Act of 1992 (box 4-1 ), which established a joint DOD-NASA effort to build and operate Landsat 7.

The argument for continuing to acquire Landsat-type data for use by government agencies was strengthened by the realization that these data

## BOX 4-1: A Synopsis of the Land Remote Sensing Policy Act of 1992

On October 28 1992, Congress passed the Land Remote Sensing Policy Act of 1992 (Policy Act),[1] repealing the Land-Remote Sensing Commercialization Act of 1984 (i-andsat Act)[2] The new law's focus is long-term remote sensing policy and its numerous facets. Specific matters addressed by the Policy Act include program management; Landsat 7 procurement; Landsat 4 through 7 data policy; transfer of Landsat 6 program responsibilities; regulatory authority and admimstration of public and private remote sensing systems; federal research and development, advanced technology demonstratin; Landsat 7 successor systems, data availability and archiving; and the continued prohibition of weather satellite commercialization As a whole the new legislation has three primary features a focus on the value of remote sensing in conducting global change research and other public sector applications, a recashng of the remote sensing activities, and provisions for the future evolution of remote sensing policy

The new law recognizes that Landsat data has research value to educational institutions, nonprofit public interest entitieshtles, and federal governmental researchers and that the previously high cost of Landsat data impeded its use for scietific purposes. Availability of unenhanced Landsat data to U.S government supported researchers and agencies IS the minimum standard set by the act with full availability of Landsat 7 data to all users at the cost of fulfilling user requests its long-term objective Global change research and the United States Global Change Research Program are both specifically cited as activities to be supported by the acquisition of unenhanced Landsat data. Research needs contained in the Global Change Research Act of 1990 are adopted as Policy Act mandates

The Policy Act also recognizes the commercial value of land remote sensing but acknowledges that full commercialization of the Landsat program cannot be achieved within the foreseeable future and is, therefore, an inappropriate near-term national goal It identifies successful commercialization of the Landsat program as a long-term goal with a viable role for the private sector in the promotion and development of the value-added market Preference is also expressed for the private sector in operating U S ground stations and other means for direct access to unenhanced data from government satellites, and utilizing governmental satellites on a space available basis. Long-term private sector preference is expressed for funding and managing a Landsat 7 follow-on system. Commercial remote sensing licenses have already been granted to three private sector corporations under the Act

[1] Public Law 102-555 (106 STAT 4163)

[2] Public Law 98-365 (98 STAT 451)

*(continued)*

19 As the House Committee on Science, Space, and Technology Report to accompany H.R. 3614 points out (pp. 32-3), the term "continuity" can be used in at least three different ways: 1 ) continuity of the Landsat program, 2) continuity of the data stream from the Landsat satellites, and 3) continuity of data format, scale, and spectral response. The latter is especially important to Earth scientists attempting to study global change. The Committee report then noted, "The Committee has decided that one of the bill's principal goals should be to enhance the use of Landsat data for public service applications." p. 43.

could be a major contributor to understanding and monitoring the effects of global change.[20] For this application, continuity of the data stream is extremely important.

The rapid growth of the GIS industry provides a third important incentive to continue the Landsat program, because these systems have aided the value-added industry (firms that process and add

**BOX 4-1: A Synopsis of the Land Remote Sensing Policy Act of 1992 (cont'd.)**

A major change from the Landsat Act is that the new law modifies the nondiscriminatory access data policy as applled to private system operators. They are now required to make unenhanced data available only to the governments of sensed states, thus freeing them 10 make data available to all other customers according to market forces, Originally a foreign policy Intended to assuage nonspacefarlng nations' fears of economic and military espionage, nondiscriminatory access required that data from the government funded and operated Landsat system be made available to all users at the cost of reproduction and distribution Under the Landsat Act the policy was Interpreted to mean that private operators had to charge the same price to all users which, at thousands of dollars per frame, put the data beyond the reach of many researchers and developing nations.

The converse effect of requiring private operators to make data available only to sensed states is that the Policy Act recommits the United States to the foreign policy aspects of nondiscriminatory access and acknowledges the Interests of foreign nations in preserving nondiscriminatory distributiondlstnbutlon The Act still places government systems under the nondiscriminatory access policy,

The Secretary of Defense and the NASA Administrators are jointly responsible for the Landsat Management Program and maintaing unclassified data continuity The management program is to be equally funded by NASA and DOD and had to report to Congress in October 1993, and biennially thereafter, regarding public comments about system use, volume of use, and, recommendations for policyy and programmatic changes. Management responsibilities include contract oversight, bringing Landsat 7 online, operating the Landsat system, meeting the requirements of the Global Change Research Act of 1990, and coordinating an advanced remote sensing technology demonstration program DOD was responsible for satellite and sensor design and development NASA was responsible for ground operations and data distribution The President is authorized to declassify intelligence satellite technology for the Landsat advanced technology demonstration program, The Landsat Management Program WilI seek Impartial advice through the Landsat Advisory Process, which will draw perspectives from state and local government agencies, academia, and business, as well as from a broad diversity of people of age, gender, and race

3 Now that the Department of Defense has decided not to participate in procuring and operating Landsat 7 the Clinton Administration and Congress have worked out new arrangements for managing Landsat NASA, NOAA, and the U S Geological Survey will jointly develop operate and distribute data from Landsat 7

SOURCE Joanne Gabrynowicz, 1994.

[20] J. Roughgarden et al., "What Does Remote Sensing Do for Ecology'?" *Ecology, vol.* 72, No. 6, 1991, pp. 1918-192 l; U.S. Executive office of [he president, Office of Science and Technology Policy, Committee on Earth Sciences, *Our Changing Planet: A U.S. Strategy for Global Change Research: A Report by the Committee on Earth Sciences to Accompany the U.S. President's Fiscal Year 1990 Budget* (Washington, DC Office of Science and Technology Policy, 1989).

interpretive information to Landsat data). The ease of incorporating remotely sensed data with other geospatial informational has led to a broadly diversified market for these data and has markedly increased their market potential.

Under the joint management agreement between DOD and NASA, DOD was to procure the satellite and NASA would operate it. As conceived by DOD and NASA, Landsat 7 would have carried two primary sensors—an Enhanced Thematic Mapper (ETM) and the High Resolution Multispectral Stereo Imager (HRMSI).[22] NASA decided in late 1993 that it could not afford to pay for the installation and operation of the ground station capable of receiving and processing data from the HRMSI sensor. In response, DOD decided to drop out of the agreement and turn the development and operation of Landsat 7 over to NASA.[23]

Given the importance of Landsat data to global change research, NASA officials have reluctantly decided to build a Landsat 7 including only the ETM. The spacecraft will have the capacity to carry an additional sensor. NASA is making space available for a "flight of opportunity" for a small sensor developed and funded by a government or private entity outside NASA.

The Landsat system may eventually build a large enough market to sustain full commercial operations. However, the recent entry of privately financed systems will likely push commercialization of land remote sensing in another direction.

Major technological improvements, which enable industry to build smaller, less costly satellite systems, has led to proposals from several firms or consortia to build and operate commercial remote sensing satellites focused on serving the market for images of the land and coasts. Data from these satellite systems, if deployed, would not be comparable to data from the Landsat and SPOT systems but would complement them. The following paragraphs summarize the systems and the kinds of data they expect to market:

- ***Orbital Sciences Corp. (OSC)*** plans to launch the company's SeaStar satellite, which will carry the Sea Viewing Wide Field-of-View Sensor (SeaWiFS). SeaWiFS will collect low-resolution ( 1 to 4 km) multispectral digital data (eight color bands in the visible and near infrared) about the surface of the ocean.[24] OSC expects to market these so-called ocean color data to companies engaged in marine transportation, fishing, offshore oil exploration and productions, and environmental management. The SeaWiFS sensor is based on the Coastal Zone Color Scanner originally developed and flown by NASA. In an experimental arrangement, NASA agreed to purchase five years of SeaWiFS data from OSC in return for an up-front payment of $43.5 million. With NASA as an anchor tenant, the arrangement allowed OSC to approach the financial market for the balance of funding OSC needed to build and operate the satellite. This arrangement will provide a useful test of the principle of purchasing data rather than satellite systems from the private sector.[25]
- ***WorldView Imaging Corp.*** is developing a multispectral land remote sensing satellite system capable of *3* meter resolution in stereo (3 meter panchromatic; 15 meter in three color

[21] Such as maps delineating ownership boundaries and data on soils, hydrology, and ecology.

[22] The ETM would collect data of 30 m resolution in 6 visible and infrared bands and of 60 m resolution in a thermal infrared band. It would also carry a panchromatic "sharpening" band of 15 m resolution. The HRMSI would collect stereo data of 10 m resolution in four visible and infrared bands and 5 m resolution in a panchromatic band,

[23] Letter of John Deutch, Under Secretary of Defense, to Congressman George E. Brown, Chairman of the House Committee on Science, Space, and Technology, Dec. 9, 1993.

[24] Matthew R. Willard, "SeaStar to Offer Ocean Monitoring Data," *Earth Observation Magazine,* January 1994, pp. 30-32.

[25] See Office of Technology Assessment, *The Future of Remote Sensing From Space*, op. cit., p. 87, for a discussion of the OSC/NASA agreement and the role of data purchases in promoting the remote sensing industry.

bands). It received an operating license from the Department of Commerce in January 1993 and has begun to construct two satellites and an online data distribution system. World View expects to launch its first satellite in late 1995.

= ***Space Imaging Inc.*** (Lockheed) is designing a multispectral stereo land remote sensing satellite system capable of 1 meter resolution (1 meter panchromatic; 4 meter in four color bands). Lockheed received an operating license on April 22, 1994,[26] and expects to launch its system by late 1997.

-Eyeglass *International. Orbital Sciences Corp., Itek, Inc. and GDE Systems, Inc.* have formed a consortium to develop the Eyeglass Earth Imaging System, which would collect 1 meter stereo panchromatic data and received an operating license on May 9, 1994. The Eyeglass consortium plans to begin operations in early 1997.

These developments provide convincing signs that the remote sensing industry is changing. Eventually, a stronger commercial presence is likely to make additional types of data available to consumers at a range of prices. However, for the next decade the provision of remotely sensed data is likely to continue to be dominated by governments, which will function both as providers and as consumers of data.

## ELEMENTS OF RISK AND THE ROLE OF GOVERNMENT

The advent of commercial remote sensing raises important questions for Congress regarding the appropriate roles of government and the private sector in this market. For instance, is it in the public interest to provide funding or tax breaks for commercial remote sensing startups? Will government users purchase data from commercial providers? Will government investigate new ways of obtaining data sets in partnership with commercial firms? Answers to these and other related questions will have a significant impact on companies about to enter the commercial remote sensing industry. **The United States is at a critical point in the development of the market for remotely sensed data and for private operation of remote sensing systems. By its actions, the federal government could help or hinder the development of the data market.**

All space exploration and most satellite development have been made possible by massive government investment. Satellites and space payloads are generally complex, expensive to build,[27] and require years of development. Satellite communications remains the only well-developed commercial space effort. Transportation to orbit remains very expensive and relatively risky. In other words, the technological and market risks of space-based business endeavors are considerable. Therefore, private financial sources have been unwilling to fund most ventures. Within the U.S. political system, which maintains as much distance as possible between government agencies and private enterprise, government programs designed to encourage new private commercial ventures must be structured to reward a certain level of risk taking on the part of private industry, while staying out of its way as much as possible.

Firms must consider several types of risks when beginning new technologies to market. The following briefly summarizes these risks and outlines the possible role of government in reducing them:

1. *Technoligical risk.* Will the invention or innovation work as intended?
2. *Market risk.* Is there a market and can the company capture sufficient market share to be successful? Will the U.S. government or other governments compete?
3. *Financial risk.* Will investors be rewarded with the prospect of sufficient return to encourage

[26] Lockheed applied for an operating license from the Department of Commerce on June 10, 1993.

[27] See U.S. Congress, Office of Technology Assessment, *Affordable Spacecraft: Design and Launch Alternatives*, OTA- BP-I SC-60 (Washington, DC U.S. Government Printing office, January 1990).

them to finance a project in comparison to other investment opportunities?

4. *Policy risk.* Will federal government policy encourage investors to place their money at risk? Will government policy remain stable?

## Technological Risk

Government research and development (R&D) in a vast array of technologies related to remote sensing has already helped in overcoming technological risks in the development of commercial instruments and satellites. For example, technology developed at the national laboratories has led to the availability of lightweight, low cost sensors and cameras.[28]

The government can also assist firms to overcome technological barriers by pursuing an aggressive R&D program oriented toward the problems facing commercial firms in providing remote sensing information products. NASA, for example, has pursued several programs since 1972 to encourage the development of new applications for data from Landsat and other systems.

## Market Risk

Through policy and legislation, government provides for the protection of intellectual property rights. Government can contribute to new market development in various ways, ranging from in-house government research to cooperative research ventures. In addition, government agencies can monitor their own operations to ensure that projects with commercial appeal do not compete with private alternatives.

NASA has provided training and other help to state and local governments in applying remotely sensed data to problems such as transportation routing, urban planning, environmental inventory, and coastal ecosystem studies. It has also supported universities in the development of educational materials and courses to train students in the use of remotely sensed data. In the early years of Landsat, NASA distributed data to researchers, universities, and other interested parties at no cost. In the 1980s, it established two programs designed to target commercial uses of the data, the Earth Observations Commercial Applications Program (EOCAP), and a program to support commercial demonstrations of space technologies, including remote sensing.

NASA's EOCAP, which is administered by NASA's Stennis Space Center in Mississippi, awarded approximately $10 million between 1988 and 1991 for 31 projects.[29] The funding was matched by private sector financing. In late 1993, NASA made an additional $3,000,000 in matching grants.[30] The program is oriented toward Commercial remote sensing and covers a wide variety of applications and markets. EOCAP'S contributions to commercial interests are designed to encourage transfer of knowledge and know-how from R&D efforts to business.[31] Revenues realized from the first round of projects is far below that anticipated.[32] Yet the program has resulted in many process innovations that may eventually be commercially significant.[33]

[28] Walter S. Scott, testimony before a joint hearing of the Committee on Science, Space, and Technology and the Permanent Select Committee on Intelligence, U.S. House of Representatives, Feb. 9, 1994.

[29] See Molly K. Maculey, "NASA'S Earth Observations Commercialization Program: A Model Government Approach," May 1993, for additional details.

[30] William Boyer, "NASA Center Ready To Award More Remote-Sensing Grants," *Space News*, Aug. 23-29, 1993, p. 18.

[31] See app. B, "Managing Pipeline Rights-of- Way," for one example of an EOCAP partnership project.

[32] Ibid., p. I I.

[33] Tom Koger, "NASA's EOCAP Program: The Partnership Advantage from Vision to Real ity," *Earth Observation Magazine*, July/August 1993, pp. 36-40.

A 1984 amendment to the National Aeronautics and Space Act of 1958 directed NASA to assist the private sector in commercializing space activities.[34] Since 1985 NASA has funded the Centers for the Commercial Development of Space (CCDS) Program, a three-way partnership with universities and industry in which NASA provides start-up funds, and industry and the universities contribute funding and expertise. In time, NASA expects the centers to operate without government aid. NASA's objective is to locate centers at universities and to induce companies outside the aerospace industry to cooperate in developing future commercial uses of space through R&D. Remote sensing is one of several commercial opportunities that qualify for CCDS funds.[35]

The Center for Mapping of Ohio State University focuses on integrating GPS, GIS, and remote sensing technologies for a variety of mapping projects. The Space Remote Sensing Center in Mississippi has developed methods of using remotely sensed data for agricultural and other purposes.

The government can also reduce market risk by agreeing to purchase data rather than satellite systems from private firms,[36] much as the U.S. Geological Survey or the U.S. Department of Agriculture purchase aerial photographs from engineering and survey firms.[37] Agencies can also work directly with private firms in developing products that have broad market potential as well as being of use to the government.[38]

## Financial Risk

Under present conditions, the single most important risk faced by private firms is financial. Can they convince the venture capital markets that they have reduced risks to an acceptable level? The government could assist in overcoming these financial risks by working with firms to provide creative financing arrangements, especially for data that the government needs anyway.

Various creative commercially driven incentive programs in space activities have been or are being implemented. If Congress wishes to stimulate greater creativity in government's assistance to civilian remote sensing, it could consider encouraging innovative management techniques, coupled with adequate incentives for government managers to explore new business arrangements with industry. Congress might also consider options to modify existing restrictions on multiyear funding for long-term R&D programs, and up-front payment for goods/services to be delivered at a later date.

Several examples of cooperative mechanisms exist. For instance, NASA joint endeavors are a mechanism for industry and government to work on a project together without exchanging funds

34 However, as noted in the 1992 report, U.S. Congress, Congressional Budget Office, *Encouraging Private Investment in Space Activities* (Washington, DC: Congressional Budget Office, February 1991), few of these ventures have sufficient market to prove commercially successful.

35 In December 1993, NASA decided to close down six of the 17 CCDS it had funded, on grounds that they had failed to draw matching funds from industry or to establish clearly defined commercial goals, None of the closed CCDSs were pursuing the development of remote sensing technologies. Liz Tucci, "Six CCDs To Close: Industry Divided," *Space News*, Jan. 3-10, 1994, pp. 1,20.

36 See below for details about NASA cooperation with Orbital Sciences Corp. in its SeaStar commercial satellite program.

37 The USGS manages a highly successful program in partnership *with* the states to provide complete aerial coverage of the United States. The National Aerial Photographic Program now reimages the entire United States once every five years.

38 While not yet an accepted process in government, large companies regularly team with small companies, providing them with expertise collected by large organization (lawyers, accountants, facilities, etc.), receiving in return access to new technology and a partner that is more flexible and can respond rapidly to new developments.

## BOX 4-2: The SeaStar Program as an Example of Innovative Government Role

The SeaStar system is a commercial/government partnership between NASA and Orbital Sciences Corp (OSC). The following discusses the mechanics of the SeaStar program and its characteristics. Some of these might be applied to other proposals for commercial remote sensing systems.

Orbital Sciences Corp. and the U.S. government entered into a unique agreement in which NASA contributed $43.5 million over the 18 months of satellite construction in return for a stream of data over a five-year period beginning after the satellite is launched and transmitting data. Then, the "price" of the data sales to the government was calculated to equal the sum of monthly data "purchases" over the five year period that would reimburse the government for the upfront commitment, The government was willing to finance a major part of the construction costs, forgo the interest on the investment, and recover its investment by acquiring data at no additional cost over five years, Regardless of whether this was a good financial investment for the government (a difficult and unreliable metric since the value of the SeaStar data is not established and the comparative costs of obtaining the data through other mechanisms or programs is not known), this type of government/industry arrangement can stimulate the private sector into attempting commercial ventures that it otherwise would not be able to afford,

Other factors that influenced the creation of this public-private partnership include:

- Relatively inexpensive satellite with focused commercial use and market (fishing industry primarily),
- Data that the government is willing to purchase for its own needs and for research needs,
- Sensor that is an improvement on the earlier Ocean Color Sensor, which NASA had already tested extensively.
- Data from the Ocean Color Sensor had been used extensively by ocean scientists.
- Encryption techniques that permit data to be withheld, if necessary, for security reasons.
- Identified commercial market,
- Minimal government oversight in satellite construction and launch.
- Government liens on satellite until completion of contractual requirements.

SOURCE: Office of Technology Assessment, 1994

(therefore taking the agreements out of the acquisition regulations). Many research joint endeavors have worked smoothly and well.[39] However, when companies proposed hardware sharing through joint endeavors, many questions were raised about the use of this mechanism and the legality of it compared to normal procurements.[40] The anchor tenant concept provides a way around the U.S. government ban on multiyear contracts and guaranteed future purchases (box 4-2).[41]

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39 The first, and best documented, joint endeavor was for electrophoresis research in space. NASA agreed to provide flight opportunities and McDonnell-Douglas/Johnson & Johnson provided the research equipment, supplies, and personnel. The research efforts were successful, but the project ended and companies developed alternative terrestrial methods of producing similar drugs. Other joint endeavors between NASA and private companies (e.g., DuPont, John Deere, 3M) have been primarily for research on materials processing in space.

40 The Industrial Space Facility (Space Industries, Inc.) is an example where NASA negotiated a memorandum of agreement to proceed, but the project was not approved. The reasons for the failure of this agreement were complicated, but one of the primary concerns was the overlap in uses of the Industrial Space Facility and NASA's proposed Space Station.

41 Spacehab, which is a private company formed to construct a module for the Space Shuttle that would include space to be sold to Private customers for performing research, could not get a future guarantee of purchases from the government, only a nonbinding commitment. To obtain private financing, Spacehab had to purchase an expensive private insurance policy that covered the loan if the government reneged on the purchases. Spacehab has flow one Shuttle mission. However, relatively few commercial customers have bought space and most experiments on Spacehab have been government sponsored. Its future as a commercially profitable venture has not yet been proven.

Other examples include long-term lease arrangements (often used in real estate transactions involving government use of facilities, but also applied to other situations), lease-purchase agreements, government-owned, company operated laboratories (government cooperatives such as Oak Ridge, Jet Propulsion Laboratory, etc.), and newer joint research consortia such as Sematech.

## Policy Risk

New ventures that require a government license must meet the licensing requirements. However, in areas where government policy has not been formulated, or where it is in flux, private firms face substantial risk that they will be caught up in the process of developing new policy. Such was the case with Lockheed Corp. and the Eyeglass consortium. Lockheed applied for a license to launch and operate a private remote sensing system on June 10, 1993. Because Lockheed was seeking permission to operate a system capable of sensing objects as small as 1 meter, and sell the data worldwide, officials in the Clinton Administration became concerned that the sale of data from such a system would jeopardize national security. They delayed issuing a license until all the agencies concerned could agree on the license terms. Because no policy was in place for developing operational guidelines, the process took until April 22, 1994, far longer than the 120 days specified in the *Land Remote Sensing Policy Act of 1992.*[42] First the policy had to be developed[43] and then each individual license had to be considered on its merits. While such policy deliberations are extremely important in ensuring the maintenance of U.S. national security, extensive policy debate among several government agencies, or changes of policy, can inhibit the development of new industries.

In summary, **Congress could assist most effectively in the development of the remote sensing industry by providing upfront funding in return for future data deliveries and modest R&D support for the development of new technologies. The** federal government has invested heavily in research satellites, data receiving equipment, data processing facilities, and other technologies. Instruments and expertise are readily available for satellite construction and launch, and private companies are contributing to the development of the data and information market by adding value to the unenhanced data and selling data to consumers. Finally, researchers have demonstrated the utility of remotely sensed data.

# GROWTH OF DATA MARKETS

Over the lifetime of the Landsat program, the market for remotely sensed data has increased,[44] with new market segments added as customers have found new applications for the data.[45] If the brief history of this industry is any indication, future systems that offer improved resolution, stereo capability, or other features will result in still greater expansion of the market. When Landsat was the only operating civilian land remote sensing satellite, it generated considerable interest, but market growth was slow. When SPOT Image. S. A., entered the market in 1987 (box 4-3), many in the U.S. space community feared that SPOT data, because of their higher resolution, would draw customers from EOSAT. Yet sales of SPOT data has helped to stimulate overall market growth.

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42 15 USC 5621.

43 "U.S. Policy on Foreign Access to Remote Sensing Space Capabilities," White House Fact Sheet, Mar. 10, 1994.

44 However, revenue from data sales alone is not sufficient to support development of sensors, satellite platforms, and the launch and operation of the Landsat system.

45 David L. Evans and Zhilian Zhu, "AVHRR for Forest Mapping: National Applications and Global Implications", David G. Wagner. et.al., "Determination of Irrigated Crop Consumptive Water Use by Remote Sensing and GIS Monitoring", and Young -Kyun Lee and Mark McCord, "Vessel Routing Impacts of Temporal Altimeter Coverage in the Gulf Stream Region" in *Proceedings of 1993 Convention of the American Congress of Surveyors and American Society of Photogrammetry and Remote Sensing*, Feb. 15-18, 1993.

## BOX 4-3: Non-U.S. Surface Remote Sensing

The utility of remotely sensed data in serving public needs, plus the prestige that the operation of sophistcated remote sensing systems confers on a space organization, have led other countries and organizations to develop remote sensing systems.

France In 1987, the French space agency, Centre National ‘Etudes Spatial (CNES) launched the first SPOT satellite to gather remotely sensed land data in the visible and near infrared wavelengths France planned from the start to sell data from the SPOT system on a commercial basis and started a French Incorporated firm, SPOT Image, S A , to market the data around the world SPOT Image has created subsidiary corporations in several other countries to sell data in regional markets and to assist in developing new data products The SPOT satellites provide strong competition to sales of data from the Landsat system

Japan In 1992, the Japanese government launched its Japanese Earth Resources Satelite (JERS-1) to gather Earth resources data from both a visual and infrared instrument and a synthetic aperature radar Japan is marketing data from JERS-1 through the Remote Sensing Technology Center (RESTEC), a foundation established in 1975 under the guidance of the Science and Technology Agency and NASDA, the Japanese Space Agency

India The Indian government operates the Indian Remote Sensing (IRS) satellite, which collects multispectral data of 36 and 72 meters resolution Recently, the U S firm EOSAT signed an agreement with the National Remote Sensing Agency of India for exclusive global marketing rights to data from the IRS satellites

Russia Russia operates the Resurs remote sensing satellite, which collects multispectral photographic data of relatively high resolution (2-10 m) Soyuzkarta, a Russian company, IS marketing data of 2 m resolution Earlier, Russia operated the Almaz synthetic aperature radar satellite and attempted to market data from it, with only partial success

Canada Canada is developing Radarsat, a synthetic aperature radar satellite devoted to collecting data for a variety of tasks, Including ice mapping, ship navigation, and resource exploration and management. Canada expects to launch Radarsat in 1995

The proliferation of non-U S systems poses a long-term competitive challenge to the United States, particularly as users gain more experience using the data On the other hand, users’ experience can be expected to contribute to overall global growth of the data market

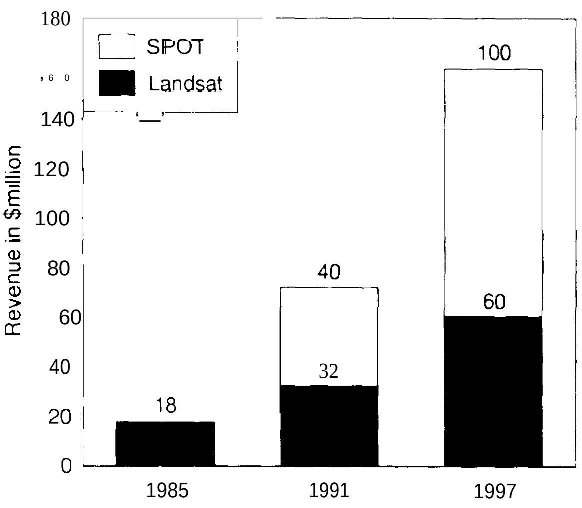
SOURCE : Office of Technology Assessment, 1994

Except for 1993, the market for remotely sensed data from both Landsat and SPOT has increased over the lifetime of the satellites (figure 4-2).

Market studies of land remote sensing range from studies of demand for geospatial data to evaluations of the growth of data processing, especially for GIS. Many past market surveys were overly optimistic. For example, some studies conducted in the mid 1980s forecast a demand for remotely sensed data approaching $1 billion per year by 1994, and between $6 and $10 billion by the end of the decade.[46] Current studies often lump the

[46] The Department of Commerce predicted in 1988 that data, value-added services, and associated products would be worth $6 billion by 1998. Former EOSAT executive vice-president Peter Norris predicted unprocessed data sales of $1 billion by 1994. See "The Selling of Remote Sensing," *Satellite Communications,* December 1988, p. 14; "Growth Stability Predicted for Commercial Space Ventures," *Aviation Week and Space Technology*, Mar. 14, 1988.

**FIGURE 4-2: Remotely Sensed Data Sales Trends**




Revenue generated by SPOT and Landsat Increased after the introduction of SPOT 10 meter data The trend will likely continue into the future especially If systems with higher resolution are developed

SOURCE National Aeronautics and Space Administratlon, Advanced Research Projects Agency 1993

amount spent on data together with the amount of data processing equipment purchased. Although sales of remote] y sensed data may spur some commerce in data processing hardware and software, most sales of general purpose computers and other equipment will serve other purposes as well and cannot be counted for remote sensing industry totals.

Table 4-3 summarizes the market for land remote sensing data, services, and associated hardware and software. Table 4-4, which provides a breakdown of raw data sales, estimates a market for raw (unprocessed) data in 1992 of about $150 million. The value-added industry ($300 million) provides finished data products to users internationall y. The revenues of the value-added industry will likely increase, as additional data customers discover the value of remotely sensed data.

**TABLE 4-3: Revenue Generated by Remote Sensing Activity, 1992 ($ millions)**

| Activity | Annual Revenue |
|---|---|
| Data acquisition (Includes satellite and aircraft) | $150 |
| Data distribution/conversion (Includes GIS) | $100 |
| Information products/services (value-added processing) | $300 |
| Hardware/software | $300 |
| Total | $850 |

SOURCE National Aeronautic and Space Administration EOSAT, Matra.Peat-Marwick

Data from aircraft and from satellites are characterized by geographic coverage and by price: satellite images tend to cover larger areas at a low'er price per area than images acquired by aircraft.[47] Satellite systems have high capital costs, but produce data of low marginal cost. Aircraft systems are the reverse. Satellites do not require a dedicated flight each time new data tire needed. and are more likely to provide digital multispec - tral data than aircraft systems. On the other hand, aircraft remote sensing systems can provide higher resolution than existing civilian satellite systems over well-defined geographic areas. In addition, aircraft can fly below high-level clouds that would make satellite data unusable. Increasingly. aircraft and satellite data are combined and merged with other data to create valuable information products.

The revenues of individual data providers continue to increase. EOSAT'S total revenues have grown consistently since 1979 (figure 4-3).[48] EOSAT'S international sales revenue has increased by 12 to 16 percent annually between 1989 and 1991; over the same period, U.S. sales increased by 10 to 24 percent per year. Spot Image's revenue has increased at similar rates. Data sales from the European Space Agency's first Environmental Research Satellite (ERS - 1 ) are increasing as well, By

[47] The costs of producing satellite data are generally higher than aerial photography. The development and launch costs of even a small remote sensing satel I ite are substantial. A commercial venture must recoup up front Investment from data sales over a period of 2-5 years.

[48] EOSAT's Landsat data sales experienced a modest downturn in 1993 as a result, in part, of the loss of Landsat 6. SPOT Image also experienced a downturn in its 1993 revenue.

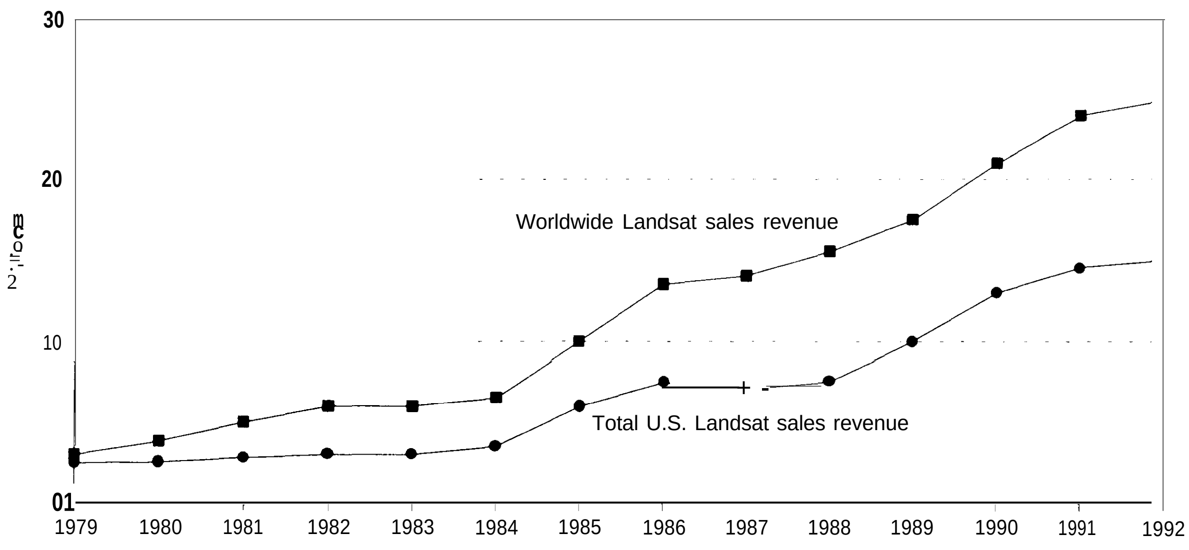
## TABLE 4-4: Market for Surface Remote Sensing Data (1992)

| Provider | Product | Annual Revenue |
|---|---|---|
| SPOT Image | Multispectral | $40,000,000 |
| EOSAT | Multispectral | $25,000,000 |
| ESA | ERS-1 Radar | $1,000,000 |
| USGS | Orthophotoquads; 1 meter aerial photos; Landsat, AVHRR data | $7,300,000 |
| USDA | USGS orthophotoquads, 1 meter aerial photos | $3,500,000 |
| U S Commercial aerial photography firms | Aerial photography | $40,000,000’ |
| Non-U S commercial aerial photography | | $25,000,000’ |
| Indian, Chinese, Russian satellite data | Multispectral digital and film | $1 0,000,000’ |
| Estimated total | | $151,000,000 |

* Estimate

SOURCE Offlce of Technology Assessment, 1993

## FIGURE 4-3: Landsat Data Sales, U.S. and Worldwide, 1979-1992




SOURCE EOSAT, *Worldwide Landsat Data Sales*, 1991 See also Arturo Silvestrini testimony before the House Committee on Science, Space, and Technology spring 1992 the end of May, 1993, the total 1993 sales of Europe's ERS- 1 satellite ($480.000) had already surpassed the total sales amount for 1992.[49]

As noted in chapter 2, the primary repository for Earth resources data is the U.S. Geological Survey's Earth Resources Observation Systems (EROS) Data Center, located in Sioux Falls, SD. EROS Data Center annually sells about $6 to 8 million worth of remotely sensed products, derived from both aircraft and satellite based sensors. Tables 4-5, 4-6 and 4-7 detail the 1992 sales activity of the EROS Data Center

The U.S. Department of Agriculture (USDA) also sells remotely sensed data, most of it acquired by aircraft. In 1992, the USDA sold $3.5 million worth of data, or nearly 1.3 million photographic units. Seventy-five percent of the sales were government purchases.

Appendix B provides examples of several applications of remote sensing. As the resolution and other aspects[50] of commercially available remotely sensed data improve, and as customer access to data expands, it is likely that these applications will create a greater market for data, and other new applications will be added. The data market will also likely increase as software developers improve the user-friendliness of their software for processing and analyzing data.

Current market demand for remotely sensed data is concentrated in five segments (figure 4-4). As the remote sensing industry matures, it will likely experience increased diversification in the application of data, and the development of niche markets. For example, the data needs of a timber company are quite different from the needs of a vineyard, both of which are included in the agriculture/forestry segment. In particular, the vineyard will have far more stringent time requirements for delivery of data than the timber company; the two products have varying value per acre, and grapes require annual harvesting and more careful monitoring during certain seasons.

**TABLE 4-5: Fiscal Year 1992 Numbers of Products and Services Provided by USGS**

| | USGS | EOSAT* |
|---|---|---|
| Photographic products | 2,916,346 | 73,658 |
| Dlgltal products/processing | 1,497,596 | 1,738,810 |
| Reference aids | 9,020 | 8,641 |
| Miscellaneous | 79,685 | 1,026,233 |
| **Total** | **4,502,647** | **2,847,042** |

* Products produced at EOSAT but sold through EROS Data Center

SOURCE U.S Geological Survey, EROS Data Center FY 1992 *Annual Report,* p 16

**TABLE 4-6: Photographic Data Sold by the EROS Data Center**

| Aerial photography products | Market |
|---|---|
| National aerial photography program | $1,777,533 |
| Side looklng airborne radar | 17,123 |
| Other | 13,566 |
| **Satellite** | |
| AVHRR | 50,309 |
| Other | 449,781 |
| Digital film recorder products | 174,705 |
| USGS Landsat MSS data | 122>700 |
| Other photographic | 310,630 |
| **Total** | **S2,916,347** |

SOURCE EROS Data Center 1992

**TABLE 4-7: Digital Data Sold by EROS Data Center**

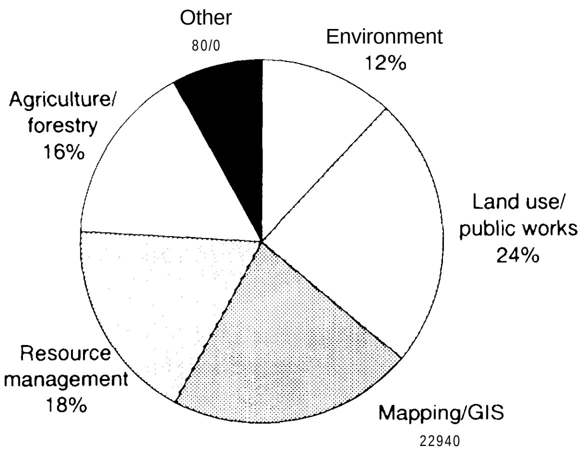
| Digital data products | Market |
|---|---|
| Data processing | $815,014 |
| Side Looking Airborne Radar | 4,384 |
| AVHRR | 404936 |
| National Digital Cartographic Data Base | 62,092 |
| USGS Landsat MSS Data | 164,200 |
| National Uranium Data | 1,840 |
| Other digital products | 55,669 |
| Total | $1,508,135 |

SOURCE EROS Data Center Annual Report of Dala Services, Fiscal Year 1992

[49] *Space News*, May 24-30,1993, p. 12.

[50] For example, the availability of stereo data.

FIGURE 4-4: Estimated Remote Sensing Market Demand (as a percent of 1992 revenues)




NOTE Demand for remotely sensed data in these markets is likely to grow GIS/Mapptng is perhaps the fastest growth area for remotely sensed data but in some ways is an artificial distinction since the data used in GIS often support applications classed in one of the other categories above

SOURCE National Aeronautics and Space Administration Advanced Research Projects Agency 1993

Remotely sensed data provide tools for improving productivity in many industries. Data providers consider a combination of factors (including price, required resolution, swath width, and the availability of data in a timely fashion) characterizing groups of consumers that cross-cut traditional "applications."[5] For example, cartographers generally have different resolution, scene size requirements and price thresholds than do agricultural users. Yet in many instances, customers in both markets would purchase similar data. Data providers are also challenged to find ways to sell data multiple times, lower the cost of data to users, and meet other requirements of customers. Table 4-8 offers a general depiction of some factors that influence the consumers of remotely sensed data products,

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;

TABLE 4-8: General Market Requirements for Remotely Sensed Data

| Bands | Resolution | Minimum scene size* | Revisit | Price tolerance | Application |
|---|---|---|---|---|---|
| Visble near-IR, radar | 5-15 m | 40km x 40km | Weekly-monthly | $150-1,500 | Land-use planning |
| Visble, near-IR, radar | 1-5 m | 40km x 40km | Monthly | $500-1,500 | Mapping |
| Visible, near-IR, (hyperspectral) | 4-3cl m | 40km x 40km | Weekly | $1,000-4,000 | Resource management |
| Visible, IR | 2-10 m | 40km x 40km | Weekly | $1,000-4,000 | Environmental assessment |
| IR, radar | 20-1000 m | 80km x 80km | 2 days | $500-1,000 | Marine |
| Visble, IR | 4-30 m | 40km x 40km | 2 days | $500-2,000 | Agricultural/ forestry |

* Varies by specific application

SOURCE National Aeronauticshcs and Space Administration Advanced Research Projects Agency, Off Ice of Technology Assessment

[5] Some potential markets have specific timeliness demands--the data will only be useful (and, therefore, will only be purchased) if they can be reliably delivered within certain time constraints. If these constraints cannot be met, the market will not materialize. Likewise, historical data will have appeal to other markets. Reliable access to well-archived data sets will be required for many research applications.

2. the distribution of data with higher spectral, spatial, and temporal resolution than now collected;
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; 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.

An $850 million remote sensing market itself is not enough to support a commercial venture with high costs. The costs to develop, launch, and operate a remote sensing satell ite have ranged between $100 and $800 million, depending on the satellite's capability and weight. Since the sales of raw satellite data will capture only a small part of that $850 million market, commercial viability of the market will depend on reducing system costs significantly, and/or tapping a new market niche. Regardless, the financial risks involved in this market are substantial.

## INTERNATIONAL COMPETITION IN DATA SERVICES

As noted earlier, the United States faces increasing competition from sales of data generated by foreign satellite systems (box 4-3). During the 1970s and the 1980s, the United States had a monopoly on satellite systems, and gained considerable experience in working with the data for scientific and operational purposes. U.S. agencies and companies developed powerful software to process and analyze large quantities of data efficient] y. Over the last decade, however, data users around the world have acquired similar experience. Recently, software developers, especially in Europe, have begun to develop powerful GIS and other software for processing remotely sensed data and turning them into useful information .52

FIGURE 4-5: Synthetic Aperature Image of Zermatt, Rhone Valley, Taken by ERS-1

SOURCE European Space Agency, 1993

The Europeans and the Japanese are gaining valuable experience in working with multispectral and SAR data. **The lack of a U.S. operational synthetic aperture radar system (box 4-4) may, in time, present a considerable competitive challenge to the United States, both in terms of experience with building and operating a SAR satellite system and in terms of using the data for operational purposes. Although** U.S. scientists have access to ERS-1 data for research purposes, relatively few U.S. resources have been devoted to experimenting with the data for operational purposes. Data from the SAR instrument on ERS-1 (figure 4-5) have potential for use in a wide variety of applications. European scientists have devoted considerable time and effort into learning

[52] The countries of Eastern Europe have demonstrated their interest and capabilities in software development, particularly in analyzing data for operational purposes. See Robin Armani, testimony before the Senate Select Committee on Intelligence, Nov. 17, 1993.

## BOX 4-4: U.S. Synthetic Aperature Radar Experiments

Instead of developing a free-flying synthetic aperature radar instrument to continue the experiments begun with NASA's Seasat in the late 1970s, NASA decided to build SAR instruments capable of being operated from the Space Shuttle. It has flown Shuttle Imaging Radar-A (SIR-A) and SIR-B on several Shuttle flights, gathering data that would allow NASA scientists to experiment with SAR data.

NASA'S-C (SIR-C), has recently flown on the Shuttle. Although the flight was highly successful, it returned several days worth of data along the orbital path of the Space Shuttle. Although these data will contribute to greater scientific understanding of spaceborne radar systems and their capabilities, the system will not return data that can be used for operational purposes. If SIR-C proves successful in operations from the Shuttle, NASA could convert the instrument to a free-flying, polar-orbitingl spacecraft for $150 to $250 million,[2] giving U.S. scientists and remote sensing specialists important experience in using SAR data for both scientific and operational uses.

1 The use of the polar orbit would make it possible for the satellite to gather data about the land, ocean, and ice Over the entire Earth. The shuttle is limited to covering only mid latitudes

[2] Jet Propulsion Laboratory internal study, 1993.

SOURCE Office of Technology Assessment, 1994

how to make the data useful for ocean shipping, agriculture, and other applications.

The U.S. private sector has been a world leader in the development of GIS and other data processing software. It is likely to continue to lead the world for some time. However, the development and operation by other nations of multispectral and SAR satellite systems will give the private sectors of those countries considerable incentive to improve their own software and market it world wide. The operation of satellite systems and the market for data systems is closely linked. **If Congress wants to maintain U.S. competitiveness in remote sensing data handling and processing, it may wish to ensure that the United States continues to operate one or more multispectral satellite systems that would provide moderate resolution data about the land and oceans on an operational basis.** Congress has several options to assist U.S. competitiveness. It could continue to fund the development and operation of Landsat 7, funded by the federal government. Alternatively, it could assist the development of privately operated land remote sensing satellites by directing agencies to purchase data rather than systems from industry. Because the data from Landsat 7, and the data from proposed privately operated satellites would complement each other, rather than compete, Congress may want to pursue both courses of action.

# International Issues in Data Management and Cooperation

5

As noted in earlier chapters, remote sensing of Earth was in the 1960s and early 1970s nearly the sole province of the United States and the Soviet Union. During the late 1970s and early 1980s, Europe, India, Japan, China and other countries began ambitious remote sensing programs. Since the breakup of the Soviet Union, Russia has begun to open its remote sensing programs to cooperative efforts with other countries and with non-Russian private industry.

Until recently, U.S. technology and policy dominated the international scene in remote sensing, and U.S. practices established de facto international standards for remote sensing data policy and management. Now the expanding array of national and regional agencies involved in remote sensing has changed the ground rules for cooperation.[1] **International cooperation has long been the norm in civilian remote sensing, but the changing international environment demands a changing approach to cooperation. The** United States remains the leading player in remote sensing but is increasingly the first among equals. Because the United States is no longer in a position to dictate the terms of international space activities, it can exercise its leadership most effectively through negotiation, persuasion, cooperation, and possibly compromise.[2]

[1] This chapter uses the term agency to refer to any of the national government agencies involved in remote sensing, such as NASA and NOAA, as well as regional organizations such as the European Space Agency (ESA).

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

This chapter examines international issues in remote sensing data policy and management. It focuses on cooperative activities in the public sector, primarily in environmental research and weather forecasting, as well as related commercial issues.[3]

## REASONS FOR COOPERATION

Nations seek to cooperate in space activities for scientific, economic, and political reasons (box 5-l). Economic motivations stem from the increasingly tight budgets for space activities worldwide. International cooperation offers the promise of reducing costs by reducing unnecessary redundancies between the remote sensing programs of different agencies, either by allowing greater specialization and division of labor between agencies or by permitting the development of joint satellite systems that meet the combined needs of several agencies. International coordination can also improve the effectiveness of remote sensing programs by bringing together the complementary strengths of different agencies and enabling them to identify and eliminate the gaps among their programs. These incentives for cooperation are reflected in increasing efforts to resolve disagreements over the international exchange of data and to coordinate programs of data management, both of which aim to increase the ability of various agencies to use each other data.

**Remote sensing from space is an increasingly international activity.** Increasing numbers of countries support remote sensing satellites, which are capable of providing data from around the world, and collecting those data often requires cooperation with receiving stations in many different countries. Furthermore, many applications of remotely sensed data are by their nature regional or global in scope. Modem weather forecasting requires global data to support increasingly capable computer forecasting models, and understanding changes in the global environment requires accurate information on the state of the atmosphere, oceans, and terrestrial ecosystems. **There is a long history of productive international exchanges of Earth data, including remotely sensed data, for these and other purposes.**

## CHALLENGES OF COOPERATION

As more countries have become active in remote sensing they have taken a variety of approaches to data policy and management, which pose increasing challenges for established mechanisms of data exchanges. Some agencies have adopted policies that restrict who may have access to data or have decided to charge others for the use of their data. The international community has developed mechanisms that hold substantial promise of dealing with these conflicts, but their ultimate resolution remains uncertain.

As described in chapter 3, the prodigious quantities of Earth data produced by current and planned remote sensing systems poses a substantial challenge for data management. Recognizing this challenge, NASA has begun a concerted effort to develop the Earth Observing System Data and Information System (EOSDIS).[4] Other countries have taken different approaches to data management, and none have yet made a comparable commitment of resources.

International data management will require the development of systems for data transmission, processing, and storage that support international data exchanges. The requirements may vary widely depending on the applications. Operational activities such as weather forecasting require reliable networks for the prompt transmission of critical data worldwide, as provided by the World Weather Watch. Scientific research and monitoring require the maintenance of accessible high-quality archives that operate effectively together across national boundaries. Efficient international data management will require international coor-

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[3] See ch. 4 for a discussion of international competition in the private sector.

[4] See ch. 3.

## BOX 5-1: Political Motivations for Cooperation in Space

The political symbolism of cooperation can promote two closely related sets of goals First, cooperation in space can provide a highly visble symbol that reinforces broader political ties between the countries involved Second, cooperation on space projects can build support for those projects failure to live up to an International commitment could undermine the political relationships Involved [1]

At the 1972 Moscow summit, President Nixon and Soviet Premier Alexel Kosygln signed an agreement on peaceful cooperation in space [2] that culminated in the Apollo-Soyuz Test project of 1974-1975[3] Although both the United States and the Soviet Union maintained active military space programs, the 1975 rendezvous provided a highly visible symbol of the detente that characterized the U S -Soviet relationship at that time The ApoHo-Soyuz mlsslon didnot lead to further, highly visible cooperative missions, however, as the U S -Soviet relationship grew more strained

In 1984 President Reagan announced the U S commitment to building a permanently Inhabited space station and began to seek International partners to share the costs of this project, which came to be known as Space Station Freedom In 1988, the international partners in the space station—Canada, Japan, and the members of the European Space Agency—signed an Intergovernmental agreement [4] laying out their contributions to the International space station project, Despite several redesigns to reduce its cost, the space station became a symbol of U.S leadership of a unified western alliance during the Cold War, and the International commitment also became one of the leading arguments in Congress for continued funding of the space station

In 1993, President Clinton called for another redesign to reduce the cost of the space station This redesign left open the possibility of Russ Ian participation, which was eventually agreed to in November 1993 In addition to providing some needed components of the space station at relatively low cost, this agreement serves to dramatize the end of the Cold War and provides a symbol of Russias reintegration into the International community. Cooperation for political purposes carries the risk that the political considerations within either country could undermine cooperate agreements Indeed, the possibilty of political and economic instabiltyty in Russia makes this reintegration as much a hope as a fact, and poses risks to the space station if Russia is not able to meet its commitments

[1] See app C of U S Congress Off Ice of Technology Assessment, *Civilian Space Station and the U S Future in Space* OTA-STI-241 (Washington DC U S Government Printing Office November 1984)

[2] The 1972 Intergovernmental Agreement on Cooperation in Exploration and Use Of Outer Space for peaceful puporses

[3] U S Congress Off Ice of Technology Assessment *U S -Soviet Cooperation in Space* OTA-TM-STI-27 (Washington DC U S Government Printing Off ce July 1985) pp 27-31

[4] The Agreement Among the Government of the United States of America Governments of Member States of the European Space Agency the Government of Japan and the Government of Canada on Cooperation in the Detailed Design Deve opment Operation and Utilization of the Permanently Manned Civil Space Station '

SOURCE Off Ice of Technology Assessment 1994.

dination that addresses worldwide data management needs in a systematic way.

International cooperation in remote sensing can also carrys ignificant drawbacks. First of al 1, it can complicate management and decision-making processes. leading to delays, inefficiencies, and a loss of flexibility that reduce the advantages of cooperation. Second, international cooperation can reduce U.S. autonomy in x-emote sensing, making the United States vulnerable to changes in policies or programs by foreign governments and limiting the ability of the United States to modify its programs in response to its own changing needs and circumstances. Finally, the open exchange of data internationally can undermine the ability of U.S. companies to compete in commercial data sales.

## NATIONAL AND REGIONAL ACTIVITIES

As the number of agencies involved in remote sensing has grown (figure 5-1; app. A),[5] so has the variety of approaches to data distribution and management policies. These policies vary not just from country to country but from agency to agency and even from program to program within a single agency. In distributing remotely sensed data, NASA and NOAA follow the guidelines set out in Office of Management and Budget Circular A-130, making data available to users at or below the cost of reproduction. Non-U.S. agencies often view their data as valuable property, restricting access through licenses and charging substantially higher fees for access. Some agencies engage in value-added services for private customers while others, including U.S. agencies, leave this mostly to the private sector. In designing their data management systems, some agencies concentrate on managing data for their own internal purposes, while others invest in systems that provide access for a broader group of users.[6]

These variations in data policy and management have important implications for international data exchange. Agencies with restrictive access policies are often reluctant to exchange data with agencies that allow more open access, and sometimes provide data subject to restrictions on third-party access that add to the recepient's data management costs. Furthermore, the exchange of large amounts of data requires data access and transmission systems that are both compatible and have sufficient capacity to operate together effectively.

### United States

The United States has the longest history in civilian remote sensing and its applications. With its early weather satellites and the first Landsats, the United States decided to make the data available to domestic and foreign users as cheaply as possible.[7] The marginal cost of open access was low, and it reinforced the ideal of free and open exchange of information as an element of U.S. foreign policy during the Cold War. During the late 1970s and 1980s the United States adopted a much more commercial approach to data access,[8] and this had a major impact on the emerging policies of other countries that were becoming active in remote sensing.

U.S. efforts at remote sensing now include NASA's Earth Observing System (EOS), which is the largest single component of the broader U.S. Global Change Research Program (USGCRP). The emergence of these programs prompted a review of data policy and management, with two important consequences. First, the Committee on Earth and Environmental Sciences (CEES) elaborated the Global Change Research Data Principles,[9] which reaffirmed policies of open data access and exchange[10] and the commitment to

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[5] See app. D of 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) for a description of these activities.

[6] Ray Harris and Roman Krawec, "Some Current International and National Earth Observation Data Policies," *Space Policy,* vol. *9,* No. *4,* November 1993, pp. 273-285.

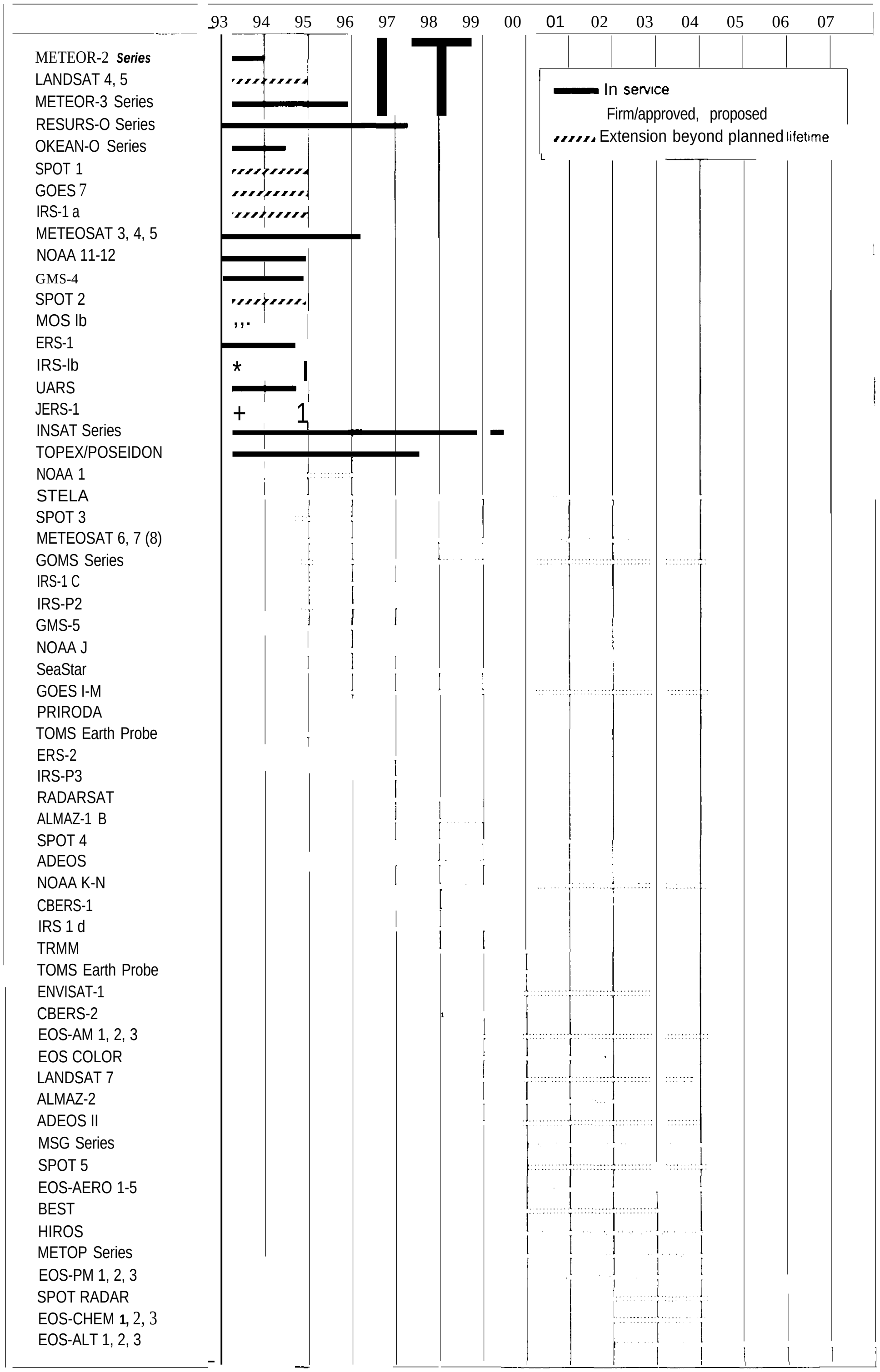
[7] Generally at no cost or at the cost of reproduction.

[8] See ch. 4 and David Radzanowski, The *Future of the Lund Remote Sensing Satellite System(Lundsal)91 -685* SPR (Washington, DC: Congressional Research Service, September 1991).

[9] Committee on Earth and Environmental Sciences, *The U.S. Global Change Data and Information Management Program Plan* (Washington, DC: National Science Foundation, September 1992). These principles were made public by OSTP Director D. Al Ian Bromley and became known as the Bromley Principles.

[10] This position was strongly influenced by data exchange principles of the ICSU World Data Centers. See Box 5-10.

FIGURE 5-1: Time Lines for Existing and Planned Earth Observation Satellites




SOURCE Commitee on Earth Observations Satelites 1993 adequate data management systems (box 5-2). Second, NASA made a major commitment to developing the EOS Data and Information System (EOSDIS) in order to manage effectively the huge quantities of data expected from EOS.[11]

## Europe

Western Europe has emerged as an increasingly important player in satellite remote sensing. The European Space Agency (ESA), the European Organisation for the Exploitation of Meteorological

### BOX 5-2: U.S. Global Change Research Data Principles

In July 1991, the Office of Science and Technology Policy (OSTP) released the Policy *Statement on Data Management for Global Change Research,* which was elaborated on in a report by the Committee on Earth and Environmental Sciences.[1] This report forms the basis for U.S. policy on data access, exchange, and management The statement reads

"The overall purpose of these policy statements is to facilitate full and open access to quality data for global change research They were prepared in consonance with the goal of the U S Global Change Research Program and represent the U S Government's position on the access to global change research data

- The U S Global Change Research Program requires an early and continuing commitment to the establishment, maintenance, validation, description, accessibility, and distribution of high-quality long-term data sets
- Full and open sharing of the full suite of global data sets for all global change researchers is a fundamental objective
- Preservation of all data needed for long-term global change research is required For each and every global change data parameter, there should be at least one explicitly designated archive Procedures and criteria for setting priorities for data acquisition, retention, and purging should be developed by participating agencies, both nationally and internationally. A clearinghouse process should be established to prevent the purging and loss of Important data sets
- Data archives must include easily accessible Information about the data holdings, including quality assessments, supporting ancillary information, and guidance and aids for locating and obtaining the data
- National and International standards should be used to the greatest extent possible for media and for processing and distributing global data sets
- Data should be provided at the lowest possible cost to global change researchers in the Interest of full and open access to data This cost should, as a first principle, be no more than the marginal cost of filling a specific user request Agencies should act to streamline administrative arrangements for exchanging data among researchers
- For those programs in which selected principal investigators have initial periods of exclusive data use, data should be made openly available as soon as they become widely useful In each case the funding agency should explicitly define the duration of any exclusive use period "

[1] CEES, *The U S Global Change Data and Information Management Program Plan,* National Science Foundation, September 1992

SOURCE National Science Foundation, Committee on Earth and Environmental Sciences, 1992

[11] See ch. 3 for a discussion of EOSDIS.

Satellites (Eumetsat), ’2 and the French space agency CNES (Centre National d’Etudes Spatiales) all have major remote sensing satellite programs with corresponding data receiving and distribution systems. Germany, Italy, and the United Kingdom maintain strong data analysis and applications programs. The European Space Research Institute (ESRIN) near Rome has principal responsibility for ESA’S Earthnet program, which manages ESA’S data archives, catalogs, and networks. The European Community (EC) has also taken an active interest in remote sensing, particularly in data management and in research on the application of remotely sensed data, ’s and has joined ESA in developing the Centre for Earth Observation, but the management of data in Europe generally has been left to individual research institutes.

European data policies arose as the United States was attempting to commercialize the Landsat system. Europe’s first land remote sensing satellite program, the French Satellite Pour Observation de la Terre (SPOT) 14 system, is operated as a commercial enterprise by the private company SPOT Image. Though more successful in data sales than EOSAT, SPOT Image still requires a substantial subsidy from the French government.[15] ESA has also arranged for the commercial sale of data from its research and operational satellites, beginning with ERS-[16] After initial problems caused by an incomplete data management system and by severe limitations on the quantity of data made available to researchers, ERS- 1 data are now available to users in the United States. Eumetsat is moving toward more restrictive policies for access to data from its Meteosat meteorological satellite system.

## Russia

Russia is the main heir to the long Soviet tradition in civil remote sensing, but aside from imagery from its meteorological satellites, Russia did not begin making satellite data available outside the Soviet Union until the late 1980s. Several firms now market Russian remotely sensed data, Multispectral images are available in photographic form with resolutions as fine as 2 meters.[17] Attempts to sell photographic images and data from its Almaz synthetic aperture radar (SAR) commercially have met with only limited success because of difficulties in providing timely access to data, and inexperience with commercial markets. A shortage of funds is also inhibiting Russian efforts and has delayed the launch of the Geostationary Operational Meteorological Satellite (GOMS).[18] The United States and Russia signed an agreement on cooperation in civilian space activities in 199219 and have begun to develop plans for cooperation in Earth observations, including joint projects on data exchange and interoperabil-

12 The evolving relationship between ESA and Eumetsat is similar to that between NASA and NOAA. ESA develops and launches the satellites, and Eumetsat processes and distributes the data.

13 The Joint Research Centre at Ispra near Milan, Italy, is the main center for this research.

14 SPOT was originally named Satellite Probatoire d'Observation de la Terre, indicating its experimental nature, bill the name was later changed to reflect its current, operational status.

15 CNES pays most Capital costs, including satellite development, and holds a 34 percent interest in Spot Image, S.A.

16 The private company Eurimage was established to market remote sensing images by publicly owned ground stations within Europe, including data from Landsat, AVHRR, ERS - 1, and future systems. ERS - 1 data have not experienced strong sales to date. The Canadian Radarsat International has the North American marketing rights for ERS- 1, and SPOT Image has marketing rights in other parts of the world.

17 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, U.S. Government Printing Office, July 1994), app. D, pp. 179-180.

18 GOMS has been listed as ready for launch since 1992.

19 *Agreement Between the Russian Federation and the United States of America on Cooperation in Peaceful Space Research and Exploramm*, June 17, 1992.

ity of data systems.[20] The future of Russian involvement in cooperative remote sensing activities remains uncertain.

## Japan

Four Japanese agencies play important roles in remote sensing: the National Space Development Agency (NASDA); its parent organization, the Science and Technology Agency (STA); the Ministry of International Trade and Industry (MITI); and the Japan Meteorological Agency (JMA). Both NASDA and MITI have undertaken joint programs with NASA.[21] Japan makes data available on a nondiscriminatory basis for nonmilitary applications, distinguishing only between research and nonresearch applications. NASDA distributes data to scientific users at or below the cost of reproduction through the Earth Observations Center (EOC) and receives royalties for data sold commercially through the Remote Sensing Technology Center (RESTEC). However, it has had serious problems in distributing data from its MOS and JERS-1 satellites and plans major improvements in data management for future satellite missions. Japan has also made proposals for greater international coordination of remote sensing data networks.

## Canada

The Canadian Space Agency (CSA) plans to enter the remote sensing business with Radarsat, which promises to carry the first SAR to be used on an operational basis. Canada hopes to recover most of the operating costs of Radarsat through commercial data sales by Radarsat International, although most of the intended customers are foreign governments seeking data on sea ice cover. The Canadian government will receive free access to data, as will the U.S. government in exchange for NASA's launch of Radarsat.

## India

India has developed an active remote sensing program, aimed mainly at domestic applications, but has refused to make satellite data regarding India available to other countries and, until recently, has not attempted to distribute satellite data for other countries. In October 1993, India's National Remote Sensing Agency (NRSA) and EOSAT announced an agreement under which EOSAT would market data from India's IRS satellites.[22]

## Other

China has developed experimental weather satellites and has joined with Brazil to develop the China-Brazil Earth Resources Satellite (CBERS). South Africa is developing a land remote sensing satellite called Greensat, capable of gathering multispectral data of 16.25 meters resolution and panchromatic data of 2.5 meters resolution. A number of other countries have programs in remote sensing and operate ground stations that receive and process data from other countries' satellites.

These agency programs have substantial overlap and duplication, often because countries have pursued independent national space programs for reasons of national prestige and technological autonomy.

# INTERNATIONAL TREATIES AND LEGAL PRINCIPLES

National, international, and commercial Earth observations from space take place in the context of an evolving system of international principles and legal regimes. The main forum for international agreements under the United Nations umbrella is

[20] *Plan for Russian-American Cooperative Programs in Earth Science and Environmental Monitoring from Space,* Oct. 27, 1993.

[21] *These* include the ASTER instrument, which MITI will supply for EOS AM-1, the joint NASA/NASDA Tropical Rainfall Monitoring Mission (TRMM) satellite, and NASA/NASDA instrument exchanges on ADEOS and EOS-Chem.

[22] Ben Iannotta, "Landsat 6 Loss Opens Door to Other Imagery Suppliers," *Space News,* Nov. 1-7, 1994, p. 18.

the U.N. Committee on the Peaceful Uses of Outer Space (COPOUS), which negotiated four international agreements on space activities. The 1967 Outer Space Treaty establishes abroad framework for outer space law, encouraging scientific cooperation and prohibiting claims of sovereignty in outer space. Along with the 1972 Liability Convention and the 1975 Registration Convention, the Outer Space Treaty establishes the principle of national jurisdiction over satellites, including commercial remote sensing satellites, and includes the requirement that private companies obtain licenses for their satellites from their national government and that those satellites be listed in the U.N. Registry by that national government.

The 1987 U.N. principles on remote sensing express international ideals for the use of remote sensing, although observers disagree about how these principles should be interpreted. These principles embody the view that outer space is a resource for all humanity and should be used for the general benefit of all nations (box 5-3). The 1992 Landsat Act incorporated some of these principles into U.S. law (box 5-4).

## INTERNATIONAL COOPERATION

The earliest efforts to promote international cooperation in remote sensing dealt with meteorological satellites. The World Weather Watch (WWW) is a cooperative program for collecting, process-

### BOX 5-3: U.N. Principles on Remote Sensing

The United Nations Principles Relating to Remote Sensing of the Earth from Space (Principles) are contained in a 1987 resolution adopted by the General Assembly. As a resolution, the Principlesnnclples are not currently legally blinding but do provide the basis for a multilateral treaty. Much of the language and intent of the principles stems from the four major space treaties promulgated by the U N Committee on the Peaceful Uses of Outer Space (COPOUS) from 1967 through 1975 Of particular importance is the Treaty on Principles Governing the Actiities of States in the Exploration and use of Outer Space, including the Moon and Other Celestial Bodies (Outer Space Treaty) This treaty, which has been in force for 26 years and to which the United States is a party, provides that outer space and celestial bodies are governed by international law and are not subject to national appropriation

The Princilples cite provisions of the Outer Space Treaty and the Convention on the RegistrationReglstratlon of Objects launched into Outer Space (Registration Convention) as applying to remote sensing actvities The Outer Space Treaty provisions cited mandate that outer space and celestial bodies are the "province of all mankind" and require that the exploration and use of space be for the benefit of all nations regardless of their degree of economic or scientific development

The provions cited also encourage international cooperation, require individual nations to oversee the space activitles of nongovernmental entities, and allow claims for damages to be presented in the courts of either the claimant or the launching state The Registration Convention provision cited in the Principles requires a state to provide information about space objects launched by it to the Secretary-General of the United Nations The information includes the name of the Iaunching state(s), a registra tion number, orbital parameters, date and location of launch, and the general function of each object.

The Principles augment the legal role of the United Nations in remote sensing by making it and its relevant agencies responsible for providing technical assistance and coordination The Secretary-General's role includes being informed of national remote sensing activities and making relevant Information available to other states upon request

(contiued)

## BOX 5-3: U.N. Principles on Remote Sensing (Cont'd.)

The Principles address access and distribution of data and information generated by national civilian remote sensing systems, Primary data are defined as the raw data delivered in the form of electromagnetic signals, photographic film, magnetic tape, or any other means. Processed data are the products resulting from processing primary data, and analyzed information means information resulting from interpreting processed data. Remote sensing activities addressed by the Principles include operations, data collection, storage, processing, interpretation, and dissemination.

As a whole, the Principles set a standard of international cooperation among states operating remote sensing systems (sensing states) and states whose territory is being observed (sensed states) while attempting to achieve a balance between the rights and interests of both groups. The needs of the developing nations are to be given special regard. Sensing states are encouraged to provide cooperative opportunities in a wide array of activities ranging from data collection to establishing and operating storage stations and processing facilities. If requested, a sensing state must consult with a sensed state to make participation opportunities available. Regional agreements are preferred wherever feasible.

Protection of the Earth's environment and of humanity from natural disasters are specific purposes promoted by the Principles, States participating in remote sensing activities that possess information useful for averting harmful phenomena are required to disclose the information to concerned states. If the potential harm threatens people, the obligation to disclose requires promptness and extends to processed data and analyzed information.

The relationship between sensed and sensing states—and the rights and responsibilities that issue from that relationship-are particularly addressed by Articles IV and X11 of the Principles, In political terms, the challenge of the relationship between sensed and sensing states is to reconcile the interests of economically and technologically advantaged and disadvantaged states, In legal terms, the challenge of the relationship is to provide governing standards for a whole activity with integral components occurring in legal regimes framed by different organizing principles. Sovereignty-the primary organizing principle on Earth—is prohibited in space. Articles IV and X11 stress both the nonexclusive right to use and explore space as well as respect for sovereignty of states over their own wealth and natural resources.

Article IV sets a legal standard for behavior among sensed and sensing states and Article Xll is a dissemination statute. Together, they provide a fluid legal regime for national remote sensing systems and activities that obliges sensing states to avoid harm to sensed states and to provide them with access to primary data and processed data concerning their own territory on a nondiscriminatory basis. Analyzed information available to sensing states is also to be available to the sensed states on the same basis and terms. In turn, sensed states are to meet reasonable cost terms and do not have access to analyzed information legally unavailable to the sensed states, for example, proprietary information.

The legal literature contains an ongoing debate as to whether the Principles add substantive value to the body of remote sensing law. One view points to the reiteration of Outer Space Treaty and Registration Convention provisions to demonstrate that the Principles are ambiguous and repetitious. From another view, it is pointed out that the Principles do contain new general principles, such as using remote sensing data for the protection of humankind and the Earth environment, thus expanding the law. From either perspective, the fact remains that the United Nations Principles Relating to Remote Sensing of the Earth from Space was the first major resolution to emerge from COPOUS in over a decade and represents persuasive authority that provides a foundation for the continued evolution of international remote sensing law.

SOURCE Joanne Gabrynowlcz, 1994

## BOX 5-4: The Land Remote Sensing Policy Act of 1992 and the United Nations Principles

The Land Remote Sensing Policy Act of 1992 (Policy Act) has implications for international remote sensing activties because it sets regulations that can clarify the 1987 U.N. Principles Relating to Remote Sensing of the Earth from Space (Principles), As a major remote sensing nation, the domestic legislation of the United States has persuasive authority for the development of international remote sensing law, similar to the way that practices of strong maritime nations influenced the development of International Maritime law The Policy Act addresses some issues left ambiguous by the Principles Among them are protecting the Earth's environment through remote sensing, the role of the private sector in carrying out the Principles, and providing remote sensing assistance to developing nations

### Protecting the Earth's environment through remote sensing

A driving force behind the repeal of the Land Remote Sensing Commercialization Act of 1984 (Landsat Act) was its lack of attention to the environmental value of remote sensing Replacing the Landsat Act with a law that focuses on the environmental value of remote sensing conforms with the Principles' positive duty that sensing states avoid harm to the Earth's natural environment.

### Private sector obligations and the U.N. Principles

Prior to the Policy Act, U.S. officials took the position that Principle Xll, the dissemination statute, applied only to data from states, leaving open the obligation of a private entity under national jursdiction to make data available Now, timely access by an sensed state to at least one Principle Xll data category produced by the private sector—primary data—is required by the Policy Act Whereas the Landsat Act did not impose a time constraint on the operator as did the Principles, the Policy Act's licensing conditions do correspond to the Princple's time constraints by requiring that access occur as soon as data are available

The Policy Act also may require private operators, on a case-by-case basis, to make unenhanced data available on terms similar to that applied to the Landsat system or other government systems the value placed by the Policy Act on promoting widespread access to U.S. and foreign remote sensing data This, in turn, would allow the application of equitable principles to situations like protecting the Earth' environment, protecting humanity from natural disasters, and meeting the needs of the developing nations—all of which are contained in the Principles.

### The Policy Act and developing nations

Landsat management responsibilities Include ensuring system operation is responsive to the broad Interests of foreign users Landsat 7 data policy requires timely and dependable delivery of unenhanced data to foreign users. Federal agencies, particularly NASA, DOD, and the Departments of Agriculture and Interior have mandates to continue remote sensing research and development, which can extend to cooperation with foreign governments and International organizations. This authority can be exercised to develop the nature and extent of the obligations contained in the Principles, which include promoting International cooperation, creating opportunities for inteternational participation establishing and operating facilities for data collection, storage, and processing. promoting regional agreements, and providing technical assistance to states and the U N

Particular consideration of the needs of the developing nations, as required by Principle Xll, is specifically authorized for U S government agencies, which the Policy Act encourages to provide remote sensing data, technology, and training to developing nations Agencies are also authorized to utilize excess government civilian remote sensing capabilities to carry out their missions which gives them access to technology that could provivide necessary infrastructure for Internationnal aid programs

SOURCE Joanne Gabrynowlcz 1994

ing, and disseminating meteorological data from satellites and other sources. WWW is the principal activity of the World Meteorological Organization (WMO), which also hosts satellite activities that involve both satellite operators and data users and aim to maximize the utilization of meteorological data from satellites. The Coordination Group for Meteorological Satellites (CGMS)[23] was established to coordinate technical standards among satellite operators.

A broader forum for international cooperation in remote sensing emerged in 1984, with the formation of the Committee on Earth Observation Satellites (CEOS). CEOS (figure 5-2) provides an informal and voluntary forum for discussing international issues remote sensing (box 5-5). The Earth Observation International Coordination Working Group (EO-ICWG) grew out of the international space station program and aims to coordinate selected remote sensing programs of the United States, Europe, Canada, and Japan into an International Earth Observing System (IEOS) (box 5-6).

Each of these organizations has important strengths. The WMO involves both users and suppliers of data who share a common interest in improving the effectiveness of operational meteorology. CEOS benefits from its informal, voluntary nature: participants share a commitment to cooperation and CEOS allows a substantial degree of flexibility. In dealing directly with operational matters, EO-ICWG provides a natural forum for coordinating ground data systems among the main remote sensing agencies.

These organizations have made substantial progress in promoting international exchanges of remotely sensed data through the harmonization of data policies and data systems. They have provided a forum that U.S. agencies have used to press for more open data access policies, but important obstacles remain. Some countries have been reluctant to accept the U.S. position. **Whether these international organizations can reach a working consensus on data exchange policies will have a major bearing on the ability of international cooperation to improve the effectiveness and reduce the cost of remote sensing programs.**

## OPERATIONAL ENVIRONMENTAL APPLICATIONS

Weather forecasting is by far the largest operational application of remote sensing, both in terms of the scale of public investment and the level of international cooperation. Earth observing satellites also have begun to play a significant role in ocean monitoring, but apart from ocean meteorology most of these applications are experimental in nature. A number of operational uses exist or have been proposed for terrestrial data, including crop forecasting, forestry, and land use monitoring (appendix B).

As discussed below, operational applications have much in common with scientific monitoring of the environment,[24] but there are also substantial differences, as illustrated by the difference between weather forecasting and climate monitoring. What distinguishes operational applications of remote sensing is the use of the data to support timely decision-making, either in response to environmental changes or for the management of natural resources.

The exchange of data for operational purposes requires international data systems for timely data collection, transmission, processing, and dissemination. These systems necessarily involve sharing the burden of data collection and communication, and they also benefit from a division of labor in data processing; current limits on data communications and processing capabilities dictate that much of the raw data must be processed into a

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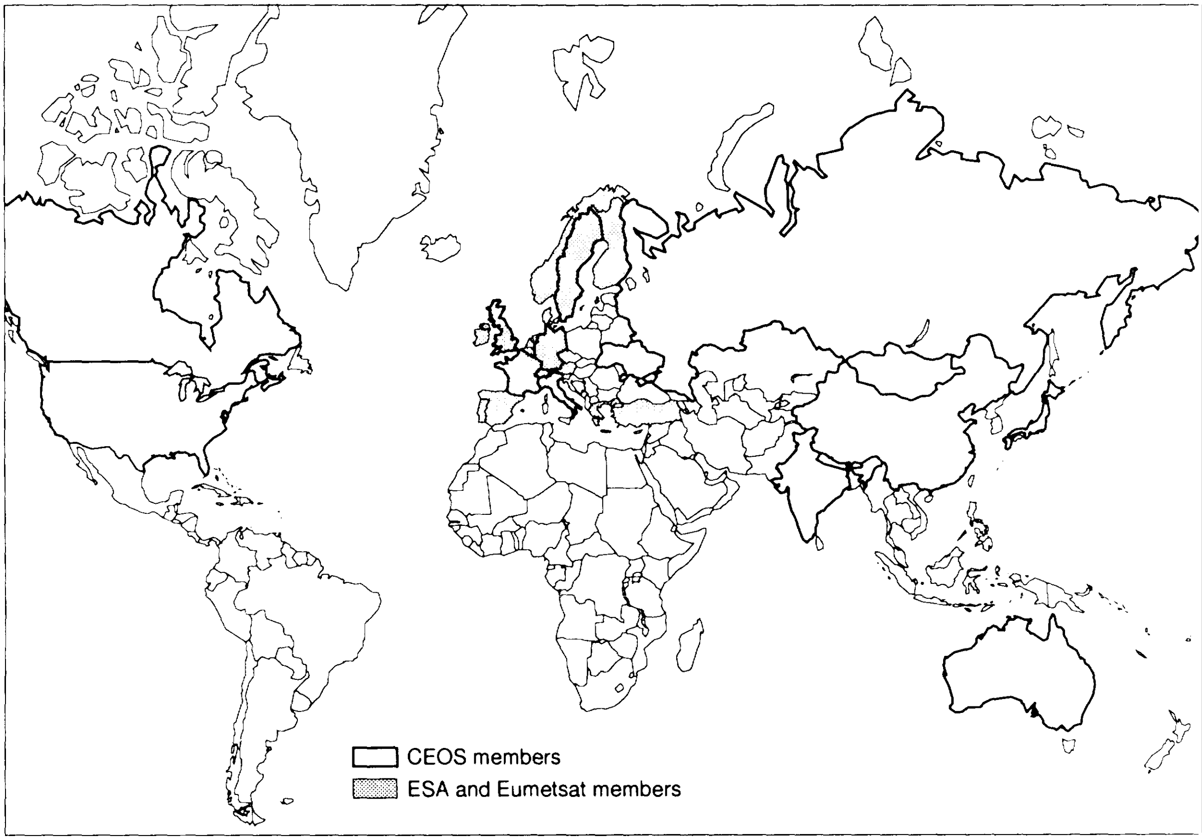
[23] CGMS was founded in 1972 as the Coordination of Geosynchronous Meteorological Satellites group.

[24] See box 5-9 and 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), pp. 34-36.

FIGURE 5-2: Committee on Earth Observations Satellites membership




SOURCE Committee on Earth Observations Satellites 1994

more usable form before it can be shared on an international network.

The establishment of operational data networks involves some technical issues of compatibility and capability, but these issues are less important than the establishment of an institutional commitment to data exchange. Of the three primary operational domains, meteorology, ocean monitoring, and terrestrial monitoring, meteorology has by far the most extensive activities and the most established mechanisms for international data exchange. Although many of the issues apply generally, this section focuses on weather forecasting, which has both the strongest need and the best established mechanisms for international data exchange. The final report in this assessment discusses operational activities in ocean and terrestrial monitoring.

## WEATHER FORECASTING

Modem computer models for weather forecasting require high-quality data from a variety of sources. Instruments based on land, at sea, and in the atmosphere provide the most detailed information, but often have limited scope. Satellite data and images are essential in providing broad coverage to fill in the gaps between in situ measurements.[25] Furthermore, weather is a global

[25] For a description of current weather satellite programs, see ch. 3 of *The Future of Remote Sensing* from *Space.*

## BOX 5-5: The Committee on Earth Observation Satellites

The Committee on Earth Observation Satellites was established in 1984 as an outgrowth of a summit of the Group of Seven,[1] and 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 (table 5-1 ). 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. All CEOS working groups have responsibility for data issues. The Working Group on Calibration and Validation deals with the calibration of sensors to insure 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 coordination of specific cooperative projects. At its seventh Plenary Meeting in November 1993, CEOS agreed to establish an ad hoc 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 distinguishes among four types of data use:

- scientific research on global environmental change;
- operational uses for the public benefit, including environmental monitoring,
- other research; and
- other uses, including commercial use,

Of these, CEOS has focused mainly on global change research. The Sixth CEOS Plenary Meeting in 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.

*(continued)*

[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

SOURCE Off Ice of Technology Assessment, 1994, BOX 5-5: The Committee on Earth Observation Satellites (Cont'd.)

TABLE 5-1: Participants in CEOS

**Members**

National Aeronautics and Space Administration (NASA)
National Oceanographic and Atmospheric Administration (NOAA)
Canadian Space Agency (CSA)
European Space Agency (ESA)
European Organisation for the Exploitation of Meteorological Satellites (Eumetsat)
Centre National d'Etudes Spatiales (CNES)/France
British National Space Centre (BNSC)
Deutsche Agentur fur Raumfahrtangelegenhelt (DARA)/Germany
Agenzia Spaziale Italiano (ASl)/ltaly
Swedish National Space Board (SNSB)
Science and Technology Agency (STA)/Japan
Russian Space Agency (RSA)
Russian Committee for Hydro- meteorology and Environment Monitoring (Roskomgidromet)
National Space Agency of Ukraine
Chinese Academy of Space Technology (CAST)
National Remote Sensing Centre of China (NRSCC)
Indian Space Research Organisation (ISRO)
Commonwealth Scientific and Industrial Research Organisation (CSIRO)/ Australia
Instituto Nacional de Pesequias Espaciais (lNPE)/Brazil

**Observers**

Norwegian Space Centre (NSC)
Belgian Office of Science and Technology (BOST)
Commision of the European Community (CEC)
Canada Centre for Remote Sensing (CCRS)
Crown Research Institute (CRl)/New Zealand

**Affiliates**

International Council of Scientific Unions (ICSU)
International Geosphere-Biosphere Programme (IGBP)
World Climate Research Programme (WCRP)
Global Climate Observing System (GCOS)
Global Ocean Observing System (GOOS)
United Nations Environment Programme (UNEP)
Intergovernmental Oceanographic Commission (IOC)
World Meteorological Organisation (WMO)
Food and Agriculture Organisahon (FAO)

SOURCE Committee on Earth Observations Satellites, 1994

## BOX 5-6: The Earth Observation International Coordination Working Group

The Earth Observation International Coordination Working Group 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 5-2) 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, Including coordination of payloads, interoperability of ground systems, and harmonization of operations.

TABLE *5-2:* Members of EO-ICWG and IEOS

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

SOURCE National Aeronautics and Space Administration, 1994.

EO-ICWG is developing a set of IEOS Data Exchange Principles. Like CEOS, these principles distinguish between four types of data use, although the categories are slightly different

- scientific research, including global change research,
- noncommercial operational uses for the public benefit, including environmental monitoring and meteorology,
- applied research and development of new applications of remote sensing; and
- other uses, including commercial uses.

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 non-discriminatory basis and in a timely manner,” and that data will be available for non-commercial uses at no more than the cost of reproduction, So far, however, Europe has committed to include only one of its planned polar platforms—Envisat-l —in IEOS to be subject to these rules, although other platforms may be incorporated later.

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.

SOURCE Off Ice of Technology Assessment, 1994 phenomenon —the weather in one location is influenced by conditions around the globe, Long-range forecasting, in particular, requires systematic monitoring of weather in distant locations with both space-based and in situ measurements. Therefore, effective weather forecasting requires international cooperation in data collection and benefits greatly from a formalized division of labor in data processing and dissemination. **International data exchanges are essential to maintain and improve the quality of weather forecasts.**

A number of international organizations have arisen to meet the need for international cooperation in weather forecasting and meteorological data exchange. Foremost among these is the World Meteorological Organization and its operational program, the World Weather Watch. The WMO has limited resources of its own, and relies on the voluntary cooperation through the national weather services of member countries to carry out its agreed programs.

The WMO provides a forum for both satellite operators and users of satellite data to coordinate operational weather satellite programs. These activities have the principal objectives of improv ing the standardization of satellite instruments and measurements, ensuring continuity of satellite measurements, and promoting the more effective use of these data by WMO members. WMO formalized these actions in 1993 by forming the Working Group on Satellites within the WMO Commission on Basic Systems.

For the most part, the operational World Weather Watch program (box 5-7) has been effective at making meteorological data available for weather forecasting around the world, but the program also manifests some weaknesses, especially in collecting in situ data. High-quality surface data are scarce for the oceans, deserts, and tropical regions. With current computer models for weather forecasting, the ability to make long-range forecasts is limited by the quality and coverage of available data, not computing power. WWW long-term plans have consistently called for an expansion of these surface-based observations, but these plans frequently go unrealized because they rely on voluntary commitments from countries. Some developing countries have reduced their provision of weather station data, which they see as providing the greatest benefit to developed countries, and developed countries generally do not provide the financial support necessary to operate these stations.[26] To **improve the quality of data for long-range weather forecasting as well as climate monitoring, Congress may wish to boost the priority of technical assistance on weather monitoring and forecasting in bilateral and multilateral foreign aid programs.** Even with improved satellite instruments, in situ observations will still be necessary both to complement and to calibrate and validate satellite data.[27]

Several other international coordinating groups deal specifically with meteorological satellites, The Coordination of Geosynchronous Meteorological Satellites (CGMS) group was founded in 1972 as a forum for technical discussions to promote common operating procedures and standards among the operators of meteorological satellites, in part for the joint WMO/ICSU Global Atmospheric Research Programme, complementing the activities of the WMO.

The International Polar Orbiting Meteorological Satellite group (IPOMS) was established in 1984 primarily to promote a more equitable sharing of the burden of maintaining polar orbiting meteorological satellites. NOAA's polar satellites have long been the principal source of Automated Picture Transmission (APT) imagery for users around the world,[28] and the sole source of higher quality High Resolution Picture Transmission (HRPT) data. Both types of data are broadcast and

[26] The section below on Remote Sensing and International Development discusses several related issues.

[27] For example, of atmospheric chemistry, temperature, pressure, and wind speed.

[28] The Russian Meteor satellites also broadcast images in APT format.

## BOX 5-7: The World Weather Watch

The World Weather Watch (WWW) was established in 1963 as the operational weather information system of the World Meteorological Organisation (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 W is to provide national and regional weather services with timely access to meteorological data and forecasts. W has since become the principal activity of WMO, and remains the only worldwide program for international cooperation on operational meteorological data and information.

W has three main functional elements: the Global Observing System (GOS), the Global Data-Processing System (GDPS), and the Global Telecommunications System (GTS). The Global Observing System consists of 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.

The Global Data Processing System includes an array of global, regional, and specialized forecast centers. Three World Meteorological Centres—in Washington, 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 short-term warning of severe storms and long-term projections.

The Global Telecommunication System 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 kbps, which is inadequate for the routine transfer of satellite imagery, but satellite data within any region are available directly from the satellites.1 GTS is used mostly for transmitting ground station data, atmospheric soundings, and weather forecast data products. The NOAA polar orbiters provide more limited global coverage by collecting sounding data[2] and storing them for later transmission to the ground. On the so-called "blind" orbits, these satellites do not pass over the United States, and the data are transmitted to the ground station in Lannion, France, which relays them to the United States. Current limitations on connectivity and data rates restrict the availability of surface weather data and access to useful forecast reformation in certain regions, particularly the tropics.

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

[2] These infrared and microwave soundings are converted into temperature and moisture profiles in the air column along the satellite ground track

*(continued)*

**BOX 5-7: The World Weather Watch (Cont'd.)**

W also encompasses a number of planning, support, and other specialized functions, The Committee on Data Management works to improve the integration and utilization of the elements of the W system GOS, GDPS, and GTS The Instruments and Methods of Observation Programme attempts to improve the quality and standardization primarily of surface-based meteorological observations System Support Activities provide technical support, advice, and training especially to developing countries

W's Tropical Cyclone Programme provides information about hurricanes, typhoons, and other tropical storms in order to minimize loss of life from these severe storms. Because they are large and slow-moving, tropical storms are particularly amenable to a coordinated international response. The Tropical Cyclone Programme integrates the forecasting of tropical storms with flood prediction as well as disaster prevention and preparedness measures

Weather is a global phenomenon, and W provides an essential service in planning and coordinating the collection, processing, and transmission of meteorological data and Information The World Meteorological Congress meets every four years to develop and revise its long-term plans, To a lesser extent, W also provides a vehicle for assisting developing countries in establishing modern weather forecast services, However, the Implementation of W 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.

SOURCE Off Ice of Technology Assessment, 1994

freely available to anyone with the appropriate receiving equipment. IPOMS was disbanded in 1993, its principal mission accomplished with the commitment by Eumetsat to deploy its own polar platform, Metop, which would take over the mission currently filled by NOAA's POES-AM platform.[29]

CEOS and EO-ICWG also deal with operational meteorological satellites in a broader context that includes their capacity to provide meteorological data for nonmeteorological purposes such as global change research, as well as the ability of other satellites to provide data that are useful for meteorology.

The European organization Eumetsat represents a significant step beyond voluntary cooperation and coordination to a regional intergovernmental consortium with shared budgetary responsibility based on a fixed percentage of gross domestic product. Eumetsat was established through a formal intergovernmental convention in 1986 to provide an institutional mechanism for aggregating national resources within Europe to support a weather satellite program, and specifically to support the operation of the geostationary Meteosat satellites and their data systems (box 5-8). Eumetsat and the European Space Agency have a relationship similar to that between NASA and NOAA in the United States—ESA develops, procures, and launches satellites and Eumetsat has overall operational responsibility—although Eumetsat has a narrower charter than NOAA. The national weather services of Eumetsat member countries share the responsibility for collecting data from surface stations and other instruments, and for weather forecasting.

[29] Metop is a cooperative effort involving NOAA, ESA, and the national space agencies of France, Italy, and Canada as well as Eumetsat.

## BOX 5-8: Eumetsat

The European Organisation for the Exploitation of Meteorological Satellites (Eumetsat) grew out of satellite programs of ESA and its predecessor, the European Space Research Organisation (ESRO). ESA launched the first two experimental satellites in the Meteosat series in 1977 and 1981. The national weather services of Europe established Eumetsat in 1986 in order to continue this program, and Eumetsat now serves as the responsible agency for the Meteosat Operational Programme (MOP). Eumetsat has since grown to 17 members and 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 NOAA over the provision of instruments for this satellite.

Eumetsat headquarters are located 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 onboard 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 five months, but Eumetsat intends to take over permanent responsibility for these archives when it assumes responsibility for Meteosat operations.

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[1] See the Eumetsat brochure *EUMETSAT: The European Organisation for Meteorological Satellites* (Darmstadt, Germany: Eumetsat, 1992) As of May 1994, the members of Eumetsat are Austria, Belgium, Britain, Denmark, Finland, France, Germany, Greece, Ireland, Italy, the Netherlands, Norway, Portuga 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

SOURCE Off Ice of Technology Assessment, 1994.

# OPERATIONAL DATA EXCHANGE ISSUES

Operational monitoring poses two principal issues regarding access to data and information: who should receive the data on an operational basis—soon enough to support operational use—and what price should they pay. These questions apply both to commercial users and to the use of data by other government agencies. The United States has followed the tradition of placing operational data into the public domain, allowing unrestricted access for all users.[30] This policy is based on the theory that the government must provide these data for its own use, and serving additional users does not add significantly to overall system costs. The United States receives essential foreign data in return. To the extent that data exchanges can reduce costs for each participating agency, such exchanges provide one mechanism for sharing costs internationally.

Others agencies, particularly in Europe, argue that an equitable sharing of costs requires that the agencies using the data bear some of those costs. For example, Britain's Meteorological Office charges the Civil Aviation Authority and the Department of the Environment for the use of weather and climate data, and Canada plans to recoup some of the costs of operating Radarsat through commercial data sales to foreign agencies. Such policies on data pricing can provide a formal mechanism for sharing the burden of remote sensing systems. This approach might lead to a fairer distribution of costs in the long run, but it could also make data exchanges more difficult and undermine established exchange mechanisms that rely on less formal notions of reciprocity.

European agencies argue that requiring data users to pay a substantial share of system costs results in a more rational allocation of costs. They also argue that it gives data users—most of whom are value-added service providers—greater influence over the evolution of remote sensing programs and moves closer to the goal of user-operated remote sensing programs. This argument raises the question of how mature these remote sensing applications are and what price to charge to give users leverage without stifling development of new applications.

A second concern in data exchange policy stems from differences over the proper boundaries between public and private sector activities: which services provide a broad enough public benefit that they should be undertaken in the public sector, and which provide such narrow benefits that the costs should fall more narrowly on those who use them. The U.S. government makes raw data and general forecast information freely available but leaves it to others to provide more specialized services. Many weather services in Europe are under pressure to generate revenues and recover operating costs through value-added services. For example, the British Meteorological Office charges oil companies for forecasts essential to the operation of drilling platforms in the North Sea.[31]

Eumetsat has announced its plans to use encryption to restrict the availability of Meteosat data beginning in 1994. This move serves at least two purposes: encouraging nonmember countries in Europe to join Eumetsat and contribute to paying its system costs[32] and protecting European national weather services from potential commercial competitors. These restrictions should increase the ability of Europe national weather services to recover some of their operating costs.[33] Initially, Eumetsat will make all data available to NOAA and weather services outside western Europe that now receive them, but will impose some restrictions on access by third parties. For example, NOAA would not redistribute Meteosat data to

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[30] This policy does not apply to data from the Defense Meteorological Satellite Program (DMSP), which are broadcast in encrypted form. Low-resolution data and up to 30 percent of high-resolution data are stored and transmitted to DMSP ground stations, from which they are available to NOAA and the Department of Defense. A limited set of DMSP data—the temperature and moisture soundings-are made available operationally through the WWW, but with delays and potential restrictions that may make them unsuitable for operational use. All DMSP data are unclassified and are being archived at the National Geophysical Data Center in Boulder, Colorado.

[31] With these and other activities, the British Meteorological Office was able to recover 36 percent of its operating costs in 1992 through interagency transfers and commercial sales. Commercial sales alone accounted for 11 percent of operating costs.

[32] Austria joined Eumetsat in December 1993 for this reason.

[33] There has been some debate in Europe between those who worry that governments will use their control over meteorological data to gain an unfair advantage over private companies and those who worry that free access to data will give private companies—which do not have to bear the costs of data collection systems-an unfair advantage over government agencies.

companies that provide aviation weather forecasts in Europe.[34] Eumetsat plans to continue to make basic meteorological data and products available through direct broadcast and the World Weather Watch,[35] and will continue its bilateral relationship with NOAA for the full exchange of more detailed operational data.

The United States is likely to retain free access to data from foreign weather satellites, in part because it will remain a leading provider of satellite weather data, and in part because meteorological data exchange is essential to all countries. Other countries would probably continue to provide data on the basis of reciprocal exchanges, although possible restrictions on data access by third parties could complicate U.S. data management. NOAA is also negotiating with Eumetsat over the possible provision of instruments for Europe's Metop polar satellite, insisting that data from U.S. instruments be broadcast unencrypted for all users. These negotiations provide added leverage for influencing Eumetsat data policies.

Other countries have chosen to restrict data for a variety of reasons. Most notably, India does not make available any images of its territory, including cloud imagery from Insat, although it does provide the WWW with wind vector data derived from these images.

In the future, governments may choose to purchase data for operational purposes from commercial satellite operators. The relationship between NASA and Orbital Sciences in developing the SeaWiFS system provides an example of how this might occur (box 4-2). However, commercial data access policies can conflict with the need for international data exchanges, and government agencies will have to exercise care if they are to ensure that commercial data purchases do not undermine international cooperation in the operational use of those data. A related issue arose in the early 1980s when the Reagan Administration attempted to privatize U.S. weather satellites. Congress decided that the provision of weather data should remain a government activity, and included provisions in the *Land Remote Sensing Commercialization Act of 1984*[36] and again in the *Land Remote Sensing Policy Act of 1992*, forbidding the transfer of these functions to the private sector.

The proposed convergence of U.S. civilian and military weather satellite programs raises several issues relevant to the international exchange of weather satellite data. The National Performance Review led by Vice President Gore proposed consolidating the DMSP and NOAA weather satellite systems,[37] and President Clinton recently directed NOAA, DoD, and NASA to implement the convergence of NOAA, DMSP, and relevant NASA satellite programs.[38] These proposals raise the issues of access to data currently supplied by DMSP satellites and the reliance of the Department of Defense on foreign meteorological data sources. These issues and convergence in general are treated in the final report in this assessment.

## INTERNATIONAL COOPERATION ON GLOBAL CHANGE RESEARCH

Space agencies around the world have made major commitments to remote sensing systems to improve understanding of changes in the global en-

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[34] Any company providing commercial services in Europe would have to pay for the use of this key or purchase decrypted data from national weather services in Europe.

[35] The WMO charter calls for the exchange of "basic meteorological data and products."

[36] Public Law 98.365 (98 STAT. 45]), 15USC 429] : "Neither the president nor any other official Of the Government shall make any effort to lease, sell, or transfer to the private sector, commercialize, or in any way dismantle any portion of the weather satellite systems operated by the Department Of Commerce or any successor agency."

[37] Recommendation" DOC12 in Office of the Vice president, *From Red Tape to Results.. Creating a Government that Works Better and Costs Less, Report of the National Performance Review*, September 1993.

[38] The White House Presidential Decision Directive/NSTC-2, convergence of US. Polar-Orbiting Operational Environmental Satellites, May 5, 1994.

vironment. Individually, these agencies are taking part in national and international programs of environmental research. Collectively, through CEOS and EO-ICWG, they are coordinating their remote sensing programs and implementing data policies to support that research.[39]

## I Scientific Programs

Established in 1990, the U.S. Global Change Research Program (USGCRP)[40] plays a leading role in environmental research worldwide, with other countries also making important contributions. Because they can provide consistent measurements with global scope, remote sensing satellites are critical to obtaining the data needed for these research programs. NASA's Mission to Planet Earth made up over *70* percent of the $1.446 billion appropriated for the USGCRP for fiscal year 1994.

These national research efforts are largely organized around the agendas of three major international research programs (box 5-9): the World Climate Research Programme (WCRP), which studies physical aspects of climate change; the International Geosphere-Biosphere Programme (IGBP), which studies biogeochemical aspects of global change and their relationship with climate change; and the Human Dimensions of Global Environmental Change Programme (HDP), which studies socioeconomic processes and their interaction with the global environment.

Although national governments take part in these programs, the programs are planned and organized by international organizations—intergovernmental agencies affiliated with the United Nations and international organizations of scientists. The International Council of Scientific Unions (ICSU) is an organization of national scientific academies around the world, with the National Academy of Sciences (NAS) as the U.S. member. Similarly, the Social Science Research Council (SSRC) is the U.S. member of the International Social Science Council (ISSC), which is an organization of social science academies. NAS, SSRC, and their international counterparts have varying degrees of independence from and influence over their respective national governments. The Intergovernmental Oceanographic Commission, United Nations Environment Programme, United Nations Educational, Scientific, and Cultural Organization, and World Meteorological Organization also help in planning these international research efforts. **Existing international programs of global change research depend almost entirely on informal mechanisms to persuade national governments to support research agendas developed by the international scientific community.** These mechanisms include personal contacts with national government agencies and participation in informal intergovernmental coordinating bodies like CEOS and the International Group of Funding Agencies for Global Change Research (IGFA).

Data from various countries' satellites and from in situ measurements contribute to both process-oriented research and long-term environmental monitoring. Process-oriented research aims to improve the understanding of the key environmental processes and develop improved models of global change. Scientific monitoring of the environment aims to develop systematic records of critical environmental variables in order to document the state and rate of change to compare observations of the environment and with global

39 Committee on Earth Observation satellites, "The relevance of satellite missions to the study of the global environment," presented at the United Nations Conference on Environment and Development, Rio de Janeiro, June 1992. Chapter 3 discusses the more general aspects of data management for global change research.

resee Committee on Earth and Environmental Sciences, *Our Changing Planet: The FY 1993 U.S. Global Change Research Program*, (Washington, DC: National Science Foundation, 1993) and U.S. Congress, Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, OTA-B P- ISC- 122 (Washington, DC: Government Printing Office, November 1993).

## BOX 5-9: International Global Change Research Programs

A number of international research programs (table 5-3) have been established to improve our understanding of various aspects of change in the global environment. Despite their diverse agendas, these programs share one remarkable feature: instead of national governments and their research programs, they involve an independent organization of natural and social scientists and international bodies in the United Nations system. As such, these programs do not have the financial authority to sponsor research projects, but rely on their authority within the scientific community to convince national governments to take part.

The oldest of these programs is the World Climate Research Programme (WCRP), established by the International Council of Scientific Unions (ICSU) in 1979. WCRP has since grown into a joint program with the United Nations Environment Programme (UNEP) and the World Meteorological Organisation (WMO), which hosts the WCRP Secretariat, With its focus on understanding the physical aspects of climate change, WCRP began with three main research projects. Tropical Ocean and Global Atmos-

*(continued)*

### TABLE 5-3: International Global Change Research Programs

| Acronym | Name | Description |
|---|---|---|
| UNEP | United Nations Environment Programme | |
| WMO | World Meteorological Organisation | The U.N. meteorological organization, |
| Ioc | Intergovernmental Oceanographic Commission | The U.N. oceanographic organization, affiliated with UNESCO. |
| Icsu | International Council of Scientific Unions | An international association of scientific academies, The National Academy of Sciences is the U.S. representative, |
| Issc | International Social Science Council | An international association of social science organizations. The Social Science Research Council is the U.S. representative. |
| IGBP | International Geosphere-Biosphere Programme | The international global change research program of ICSU. |
| WCRP | World Climate Research Programme | A joint climate research program of IGBP and WMO. |
| HDP | Human Dimensions of Environmental Change Program me | The global change research program of ISSC. |
| START | System for Research and Training | A project of IGBP, WCRP, and HDP to promote global change research in the developing world. |
| GCOS | Global Climate Observing System | A joint program of WMO, ICSU, IOC, UNEP, |
| GOOS | Global Ocean Observing System | A joint program of IOC, ICSU, UNEP. |
| GTOS | Global Terrestrial Observing System | A proposed program of ISSU, IGBP, UNEP, |
| GEMS | Global Environmental Monitoring System | A program of UNEP, |
| GRID | Global Resource Information Database | A program of UNEP. |
| IGFA | International Group of Funding Agencies for Global Change Research | A forum for coordinating national and international research programs, |

SOURCE National Aeronautics and Space Administration, 1994

## BOX 5-9: International Global Change Research Programs (Cont'd.)

phere (TOGA), aimed at understanding the El Nino/Southern Oscillation phenomenon,[1] the Global Energy and Water Cycle Experiment (GEWEX), and the World Ocean Circulation Experiment (WOCE) The U S Global Change Research Program (USGCRP) explicitly supports U.S. participation in these international projects [2] WCRP has since added three new projects, Climate Variability and Predictability (CLIVAR), Stratospheric Processes and their Role in Climate (SPARC), and the Arctic Climate Systems Study (ACSYS), and is planning a fellow-on to TOGA

Recognizing that global change, including climate change, also depends on complex blologlcal, geological, and chemical processes, ICSU established the International Geosphere-Biosphere Programme (IGBP) in 1986 IGBP has five core projects now underway: International Global Atmospheric Chemistry (IGAC), Global Change and Terrestrial Ecosystems (GCTE), Biospheric Aspects of the Hydrological Cycle (BAHC), the Joint Global Ocean Flux Study (JGOFS), and Past Global Changes (PAGES) Two additional projects are currently under development Land-Ocean Interactions in the Coastal Zone (LOICZ), and the Global Ocean Euphotic Zone Study (GOEZS), In addition to these empirical research projects, IGBP supports three major cross-cutting activities the task force on Global Analysis, Interpretation, and Modeling (GAIM), the System for Analysis, Research, and Training (START) to promote global change research in developing countries, and the IGBP Data and Information System (IGBP-DIS) [3]

IGBP-DIS has three main foci The first of these is the development of critical data sets. An example is the global 1 -km resolution AVHRR data set proposed by IGBP-DIS to meet the need for systematic records of land cover and land use This comprehensive proposal included a survey of existing archives of high-resoluhon AVHRR data, proposals for filling the gaps with additional ground stations (fig 5-1) and data exchange agreements, and for several additional data sets derived from the AVHRR data,[4] and was adopted as one of the Pathfinder data sets for EOSDIS.[5]

The second focus of IGBP-DIS is to ensure the establishment of effective systems to manage the data needed for IGBP's core research projects This Involves defining the data management needs of IGBP projects, developing data and operating standards that facilitate interoperability, and convincing government agencies or research Institutes to act as hosts and commit themselves to maintaining the needed data systems and standards

The third focus of IGBP-DIS is to act as an International liaison with other organizations This includes coordination with other organizations revolved in global change research, as well as with organizations that collect the necessary data As part of this acstivity, IGBP-DIS represents IGBP as an affiliate to CEOS

*(continued)*

[1] The El Niño Southern Oscillation is a periodic change in atmospheric circulation and ocean temperatures in the tropical southern Pacific Ocean and is correlated with widespread changes in rainfall in other regions

[2] National Science and Technology Council Committee on Environmental and Natural Resources Research, *Our Changing Planet* the fiscal year 1995 U S *Global Change Research Program 1994*

[3] *See* IGBP report No 12, *The International Geosphere-Biosphere Programme A Study of Global Change The Initial Core Projeels* (Stockholm IGBP 1990) and *Reducing Uncertainties* (Stockholm IGBP, 1992)

[4] See IGBP report No 20

[5] See ch 3

## BOX 5-9: International Global Change Research Programs (Cont'd.)

The International Social Science Council (ISSC) established the Human Dimensions of Global Environmental Change Programme (HDP) in 1990 to improve understanding of the human environment and the mutual influences between human activities and the natural environment. HDP involves a number of research projects, including a joint project with IGBP on land use and land cover One major emphasis of HDP is improving the quality and management of data, which often involves combining socio-economic and environmental data, much of it obtained through remote sensing, using Geographic information Systems (GIS). The HDP Data and Information System (HDP-DIS) is currently involved in a joint project with the Consortium for International Earth Science Information Network (CIESIN) and its Socio-economic Data and Applications Center (SEDAC) to develop an international data network for social science workers.

WCRP, IGBP, and HDP are aimed at understanding the basic processes that underlie global environmental change, like cloud formation, ocean circulation, and evapo-transpiration in plants, In addition to research on these basic processes, it is also important to monitor the state of processes and related environmental variables, both to develop a baseline understanding of the state of the global environment but also to detect and measure the scope of changes in that environment and to support the development of more accurate and comprehensive theoretical models of Earth systems This need is the main motivation behind the formation of a number of Global Observing Systems (table 5-3): the Global Ocean Observing System (GOOS),[6] the Global Climate Observing System (GCOS),[7] and the proposed Global Terrestrial Observing System (GTOS) [8] As with WCRP, IGBP, and HDP, these Global Observing Systems rely on the voluntary cooperation of national governments. In one likely scenario they would build on the operational monitoring programs of those governments For example, GCOS could collect data from operational weather satellites and surface-based meteorological stations, with the relatively modest additional investment required for Improving the quality of the data for scientific applications and the maintenance of systematic archives, GTOS would probably have to be a significant exception to this, in that few operational programs exist for monitoring terrestrial processes, In part, the GTOS proposal aims to stimulate the establishment of such programs,

There is one intergovernmental organization that deals with the funding of global change research, On the initiative of the FCCSET Committee on Earth and Environmental Sciences (CEES), the international Group of Funding Agencies for global change research (IGFA) was established in 1990 as an informal forum to exchange information on national research programs. IGFA has no formal intergovernmental mandate and no authority to determine overall budgets, but it offers the opportunity for coordinating environmental research programs internationally and provides an intergovernmental base of support for national and international programs.

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6 National Oceanic and Atmospheric Administration, *First Steps Toward a U S GOOS. Report of a Workshop on U.S. Contributions to a Global Ocean Observing System,* October 1992 (available from Joint Oceanographic Institutions, Inc , Washington, DC)

7 GCOS Joint Planning Office, c/o WMO, Case Postale 2300, ch- 1211, Geneva, Switzerland

8 *Towards a Global Terrestrial Observing System (G TOS) Detecting and Monitoring Change in Terrestrial Ecosystems,* O William Heal *et al,* eds (Paris UNESCO, June 1993)

9 Generally, science quality data must be systematic and well -calibrated, attributes that are not as important for operational use Temperature measurements with an accuracy of one degree may be adequate for operational purposes, but not for detecting climate changes of a few tenths of a degree

SOURCE Off Ice of Technology Assessment, 1994 change models. **An effective international research program on global environmental change requires a balance between process-oriented research and long-term monitoring.**[41]

Concerned over the need for a greater commitment to long-term monitoring, the scientific community is developing plans for the Global Climate Observing System (GCOS), the Global Ocean Observing System (GOOS), and the proposed Global Terrestrial Observing System (GTOS) (box 5-9). Scientific monitoring has much in common with operational applications of remote sensing; both require reliable and consistent data streams. While operational applications place heavy demands on the timely distribution of data, scientific monitoring emphasizes high-quality and consistent y calibrated data. As currently conceived, GOOS and GTOS would combine operational and scientific monitoring functions.

Climate monitoring presents more complicated choices. Marginal improvements in instrument performance and data management for weather satellites would meet many of the requirements of climate monitoring.[42] But other variables, such as atmospheric chemistry, aerosols, and radiation balance, are less important for weather forecasting. These could be measured with additional instruments on weather satellites, or by developing separate, dedicated satellite systems. Furthermore, both operational and scientific monitoring programs require high-quality in situ data from around the world, with effective mechanisms for international data exchange.

A central purpose of these research programs is to inform and influence national policies and international agreements on environmental management. The effective use of this knowledge requires an institutional mechanism to assess the state of understanding of environmental problems and inform policy makers .43 The Intergovernmental Panel on Climate Change (IPCC) provides a model for this process at the international level. IPCC completed its first full assessment of the state of the global climate in 1990, with an update in 1992 and a full reassessment planned for 1995, and has played a critical part in motivating and informing the Intergovernmental Negotiating Committee in developing the Framework Convention on Climate Change, which entered into force in March 1994. **The IPCC provides a model for the scientific assessment of international environmental problems that could be applied to other issues currently under international discussion, such as biodiversity, forest conservation, and desertification.**

As discussed in chapter 3, environmental research and monitoring places heavy demands on data management systems. These include the large quantity of raw and processed data, the high quality control standards in data processing, and the need to maintain long-term records of environmental change. Making the best use of improved scientific models or data processing algorithms could require the reprocessing of large quantities of archived data.

Many countries have substantial archives of Earth data, some of them from satell ites. These archives are of uneven quality.[44] Some of these archives belong to the ICSU system of World Data Centres (WDCS), established in 1957 to preserve and exchange data from the joint research pro-

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[41] See IGBP Report 20 *Improved Global Data for Land Applications: A Proposal for a New High Resolution Global Data Set, Report of the Land Cover Working Group of IGBP-DIS* (Stockholm: IGBP, 1992) for a discussion of these two types of data use. See also, 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) for a discussion of the need for greater attention to monitoring within the USGCRP.

[42] As an example of this synergy, Eumetsat is moving toward incorporating scientific climate monitoring as part of its miss ion.

[43] See Office of Technology Assessment, *Global Change Research and NASA's Earth Observing System*, pp. 6-7 and 43-45.

[44] The data may be stored on poorly maintained media, may be recorded using obsolete formats and technologies, and may be calibrated in undocumented ways, if at all. See ch. 2.

grams of the International Geophysical Year. The WDC system now consists of 44 centers in 11 countries (box 5-10), repositories of a wide variety of Earth science data that are made available without restrictions at the lowest possible cost to users. The WDC commitment to the free exchange of scientific data, which persisted through many international crises, set an important precedent that is reflected in U.S. policies (box 5-2) and in those of the international remote sensing organizations such as CEOS and EO-ICWG.

The international scientific community has become concerned over restrictions on access to Earth data. In response to these concerns, ICSU established an Ad Hoc Working Group on Data Policy Issues. Its greatest concern is that commercial and other restrictive policies for data access could effectively put much essential data beyond the reach of working scientists. For example, because of national cost recovery programs, several countries have reduced their voluntary data submissions to the WDC system.[45] In order to obtain data, scientists often have to agree not to redistribute it, which forces them to choose between their contractual obligations and the normal scientific process of data sharing. Second, scientists need meteorological and other data sets of higher quality than now available from many sources. Finally, scientists believe that countries need to make greater investments in data management systems. As noted in chapter 2, the technology is available and growing cheaper, but the demands of data management are also growing rapidly.

## INTERNATIONAL COORDINATION OF DATA POLICIES

The international organizations for cooperation in remote sensing have made the coordination of data policy for global change research a top priority. Both CEOS and EO-ICWG have agreed that Earth science data should be made cheaply and readily available for global change research (box 5-5 and box 5-6), and are taking actions to implement these agreements.

CEOS plays a unique role in providing a forum for data users to discuss their requirements directly with the operators of Earth observing satellite systems. This includes international scientific organizations, who are active as CEOS affiliates. As part of a pilot project coordinated through CEOS to make multispectral land imagery available for IGBP projects, NASA, CNES, and NASDA have agreed to make data from Landsat, SPOT, and MOS available at reduced cost to IGBP researchers. Many scientists who use remotely sensed Earth data are hopeful that CEOS will be effective as a forum for discussing the needs of scientists and improving their access to remotely sensed Earth data.

Data access depends as much on effective data management systems as it does on formal policies. The U.S. government has recognized the need for such systems and is attempting to meet that need through the EOSDIS and GCDIS programs.[46] Other countries have also recognized this need, but are in earlier stages of developing plans for data management systems.

Superficially, Europe's Earthnet data management system resembles NASA's EOSDIS, with Processing and Archive Facilities (PAFs) corresponding to the U.S. Distributed Active Archive Centers (DAACs), and the European Space Research Institute (ESRIN) in the role of the EOSDIS Core System. In fact there are significant differences. In Europe, research programs are generally managed through research institutes rather than through grants to individual investigators, and European data management plans reflect this. The PAFs are located in research centers and serve primarily to meet the needs of those centers.

[45] M. Chinnery and S. Ruttenberg, personal communications. Canada has stopped providing geomagnetic data, for example.

[46] Ch. 3 describes existing U.S. data archives and discusses plans for EOSDIS and GCDIS.

## BOX 5-10: The ICSU World Data Centres

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

As of May 1994, there are 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, USGS, DOE, and DOD (table 5-4)[2]

### TABLE 5-4: ICSU World Data Centres in the United States

| U.S. National Data Center | World Data Centre(s) |
|---|---|
| National Geophysical Data Center (Boulder, Colorado) | Glaciology |
| | Marine Geology and Geophysics |
| | Solar-Terrestrial Physics |
| | Solid Earth Geophysics |
| | Paleoclimatology |
| National Climate Data Center (Asheville, North Carolina) | Meteorology |
| National Oceanographic Data Center (Washington, DC) | Oceanography |
| National Earth Information Center (Golden, Colorado) | Seismology |
| U.S. Naval Observatory (Washington, DC) | Rotation of the Earth |
| Oak Ridge National Laboratory (Oak Ridge, Tennessee) | Trace Gases |
| EROS Data Center (Sioux Falls, South Dakota) | Remotely Sensed Land Data |

SOURCE National Oceanic and Atmospheric Administration, 1994.

(continued)

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

[2] See S Ruttenberg, 'The ICSU World Data Centers, *EOS Transactions,* VOl 73, No 46, Nov. 17, 1992, pp 494-495

They are not well equipped to meet the needs of outside users or the demands of other data applications.

The main focus of ESA'S Earthnet data management system is managing SAR data from ERS-1. This system overcame severe inadequacies at its beginning, and still suffers from a lack of standardization and interoperability among the PAFs. Because of different data processing techniques, data from different PAFs are dificult to compare. ESA is in the preliminary stages of developing management plans for data from its global change system, Envisat-1, and it remains unclear what level of support these planned data systems will receive and how effective y they w ill serve outside users.

Japan's principal data management center for scientific users is NASDA'S Earth Observations Center (EOC) in Tokyo. This center has principal responsibility for managing SAR data from JERS-1, but has experienced serious problems in meeting the data requests of scientific users. Recognizing the need for improved data systems, Japan is planning an Earth Observation Information System (EOIS), built around the EOC. This system would include three main components, a Data

## BOX 5-10: The ICSU World Data Centres (Cont'd.)

The WDCS operate under a set of agreed international principles. These principles call for a WDC to make data avaible to scientists in any country. A WDC should charge no more than the cost of filling the data 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 a liaison 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 catalyzing the formation of those national centers Most scientists believe that the open exchange of data provides benefits that far outweigh the costs of maintaining a WDC,

From the beginning, WDCS have attempted to adopt the most modern practical data and information technologies. WDC data are becomming increasingly available on electronic networks at high data rates and on emerging media standards such as CD-ROM. In the past, the WDC system has devoted a major effort to developing standardized data formats, but the development of more flexible software capable of using data in a variety of formats has greatly reduced the need The challenge of providing efficient methods for searching and browsing data may also be eased by increasing network capacity and the emergence of network search software [3] These capabilities are only available to those with sufficient computing and communications capabilities, which are not available in many parts of the world, especially in developing countries.

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 CEOS and IEOS

[3] See ch 2

SOURCE Off Ice of Technology Assessment 1994.

Acquisition and Processing System, a Data Analyzing System, and a Data Managing and Distribution System, but the plans are still under development and funding remains uncertain.

International efforts are under way to coordinate these data management plans. At its seventh Plenary meeting in November 1993, CEOS created a working group on international data networks. EO-ICWG has begun to address the issue of forming and coordinating IEOS data management systems. Discussions await the commitment of resources and the development of a planning process in other agencies participating in IEOS, with a view toward forming an IEOS Data and Information System, or IEOSDIS.

Some elements of an international data system are essential for effective data exchange mechanisms. First of all, the individual national data systems must have archives that provide adequate quality control and standardization of data[47] and

[47] See U.S. Congress, Office Of Technology Assessment, *Data Format Standards for Civilian Remote Sensing satellites*, OTA-BP-ISC-114 (Washington, DC: Office of Technology Assessment, May 1993).

readily usable systems for searching metadata sets. Second, the various data management systems must be sufficiently compatible to operate effectively together, allowing users of one system to access data held by another in a relatively transparent manner.[48] In practice, this could involve the routine exchange of metadata among designated archive centers. The CEOS International Directory Network has links between Europe, Japan, and the U.S. Global Change Master Directory[49] at its core (fig. 5-3). Finally, the international data system must have the capability to provide data to users, either through electronic transmission or through the exchange of physical storage media like magnetic tapes or CD-ROM.[50]

**The simplest approach to international data management is to build on national and regional data systems and plans by establishing basic requirements for compatibility and interoperability. This approach has the advantage of flexibility, allowing different agencies to meet their various** needs in the manner they deem appropriate. In an era when information technology is rapidly evolving, such flexibility is particularly important. The principal disadvantage of this approach is that it makes it easier for some agencies to give inadequate attention to data management and create "weak links" in the international network, with corresponding gaps in data availability.

**An alternative approach is for the international community to collaborate on the definition and implementation of data management requirements. EO-ICWG in particular** could consider this approach in developing plans for IEOSDIS. This would allow for a greater degree of harmonization and interoperability of systems, but it could prove cumbersome and inflexible.

**A complementary option would be to share the burdens of data management systems and pursue a division of labor and specialization in data management as in satellite systems. The European ground segment plans, for example, rely heavily on indigenous European resources to acquire data from Envisat- 1. This includes the use of onboard data storage on satellites and data relay satellites to transmit data directly to ground stations in Europe. An alternative would be to rely on ground stations located in other countries to acquire the data and use other communications links to transmit the data to Europe if that is desired. So far, the various national and regional agencies do not appear to have given great attention to managing data from other agencies' satellites or relying on other countries for data acquisition.**

## REMOTE SENSING AND INTERNATIONAL DEVELOPMENT

Social and economic conditions in many parts of the world are poor and often stagnant or even deteriorating. Over the years concern has grown that the mismanagement of natural resources and the environment is contributing to these poor conditions and vice versa. The United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, in the summer of 1992, solidified international support for the concept of sustainable development-economic development that improves human conditions in the short run while preserving environmental resources to make those gains sustainable in the long runs The United States and other industrialized countries have established national and international programs of financial and technical assistance to developing countries, and have

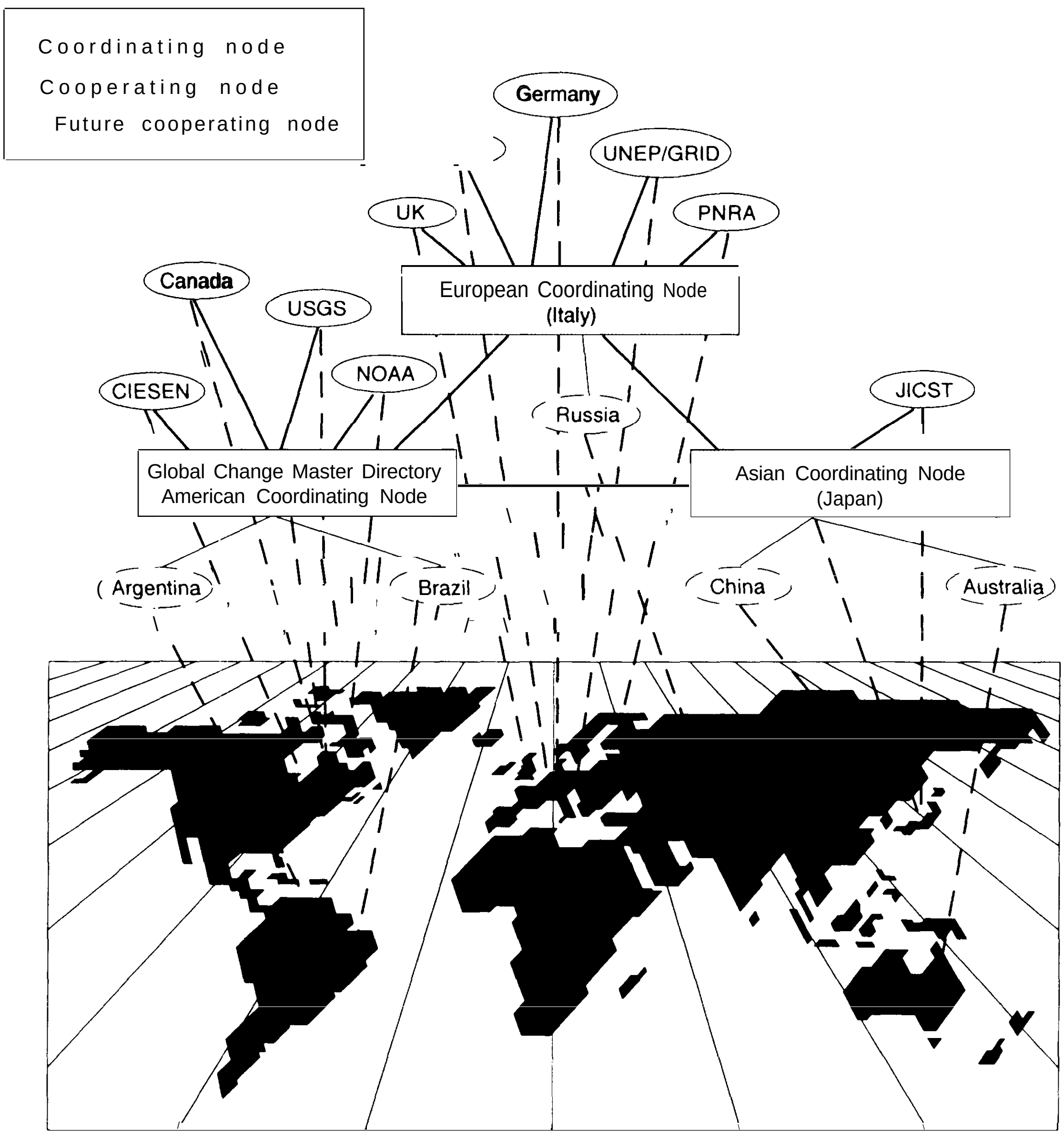
[48] NASA and ESA are testing the interoperability of NASA's Information Management System (IMS) and ESA's User Interface Terminal (UIT), and NASA and NASDA are undertaking similar tests.

[49] See ch. 3.

[50] See ch. 3 for a discussion of these requirements in the context of EOSDIS.

[51] K. Dahle, "Environment, development, and belief Systems," *Futures*, December 1993, pp. 1070-1074.

FIGURE 5-3: The CEOS International Directory Network




SOURCE Committee on Earth Observations Satellites, 1994

committed themselves to the principle of sustainable development, although the degree of support for its implementation remains to be seen.

The concept of sustainable development is based on the view that current patterns of development **in many cases pose unsustainable burdens** on the natural and human environments. The reasons for this include inefficent economic structures, rapid population growth, and a lack of knowledge and capacity to implement more sustainable practices. **Satellite remote sensing can contribute to more sustainable development by**

**providing some of the knowledge necessary for a more efficient management of natural resources.** For example, satellites can: observe the burning of forests and other biomass and the resulting deforestation,[52] can help monitor the condition and vegetative cover of vulnerable arid lands,[53] and can support the monitoring of land use, and of air and water quality.[54]

**Developing countries often lack the capability to make use of data from Earth observing satellites for these or other purposes.[55] This shortage has many related aspects, and presents a complicated challenge to those who seek to develop this type of capability. First, many countries lack the technical resources+ computers and communications equipment—for data collection, transmission, processing, and analysis. Second, they face shortages of trained personnel who** know how to use such systems or even have the necessary background to learn how to use them, Finally, they often lack the public and private institutions to make use of the information provided through remote sensing.

**Financial and technical assistance from developed countries can help overcome these obstacles, but the effective use of remotely sensed data requires a comprehensive approach and a long-term commitment from both donor and recipient. This comprehensive approach** would have to include startup funding to develop the required data and information systems, as well as sustained support for the supply of data and long-term training in the use of these systems and data.[56] Geographic Information Systems can make these tasks much easier, but they cannot eliminate the need for long-term follow up to support the initial investment. Another way to promote the development of related capacities is to support the development of indigenous scientific expertise in developing countries through programs like the START initiative (box 5-9). This would allow those countries to develop an independent understanding of their particular needs in environmental research, monitoring, and resource management, A variety of international principles, including the U.N. Principles on remote sensing (box 5-2) and the UNCED agreements, call for this type of technical assistance.

Decisions on foreign assistance are based on the level of public interest, both on humanitarian grounds and national self-interest. For example, the United States has long supported weather services in the Caribbean region as a way to improve the ability to track hurricanes and tropical storms. A broader vision of national interest might include a national commitment to global environmental monitoring, which might require support for programs of in situ monitoring in developing countries. A decision on whether or not to support the use of satellite data for international development would also depend on an assessment of the effectiveness of that type of assistance in comparison with other forms of assistance.[57]

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[52] See app. C, D. Skole and C. Tucker, "'Tropical Deforestation and Habitat Fragmentation in the Amazon; Satellite Data from 1978 to 1988," *Science*, vol. 260, June 25, 1993, pp. 1905-1910. Direct observation of biomass burning requires a highly sensitive instrument such as the Optical Linescan Sensor (OLS) on the Defense Meteorological Support Program (DMSP) satellites.

[53] C.J. Tucker et al., "Expansion and Contraction of the Sahara Desert From 1980 to 1990," *Science*, vol. 253, No. 5017, July 19, 1991, pp. 299-301.

[54] See *New Technologies: Remote Sensing and Geographic Information Systems*, Environment and Development Brief No. 3 (Paris: UNESCO, 1992).

[55] India is a notable exception to this rule, with an active remote sensing program that includes both satellites and programs to analyze and use the data they produce.

[56] U.S. Congress, Office of Technology Assessment, Working Group on Approaching Sustainable Development, meeting held Dec. 7, 1993, in Washington, DC.

[57] The Office of Technology Assessment is currently engaged in an assessment of science and technology, renewable resources, and international development, which will address this issue in a broader context.

# Appendix A: Operational and Planned Earth Observing Satellite Systems

A

| Satellite platform | Country | Agency | Year of launch | Description |
|---|---|---|---|---|
| Landsat 4 | u s | NOAA | 1982 | Land remote sensing |
| Landsat 5 | u s | NOAA[1] | 1984 | Land remote sensing |
| NOAA 11 | u s | NOAA | 1988 | Meteorology (polar) |
| NOAA 12 | u s | NOAA | 1991 | Meteorology (polar) |
| GOES-7 | u s | NOAA | 1987 | Meteorology (GEO) |
| GOES-8 | u s | NOAA | 1994 | Meteorology (GEO) |
| Upper Atmospheric Research Satellite (UARS) | u s | NASA | 1991 | Atmospheric chemistry |
| SPOT 1 | France | CNES | 1986 | Land remote sensing |
| SPOT 2 | France | CNES | 1990 | Land remote sensing |
| SPOT 3 | France | CNES | 1993 | Land remote sensing |
| Meteosat 3 | Europe | Eumetsat | 1988 | Meteorology (GEO) |
| Meteosat 4 | Europe | Eumetsat | 1989 | Meteorology (GEO) |
| Meteosat 5 | Europe | Eumetsat | 1991 | Meteorology (GEO) |
| Meteosat 6 | Europe | Eumetsat | 1993 | Meteorology (GEO) |
| ERS- 1 | Europe | ESA | 1991 | Ocean dynamics, Ice |
| Topex/Poseldon | U S /France | NASAJ CNES | 1992 | Ocean dynamics |
| GMS-4 | Japan | JMA | 1989 | Meteorology (geosynchronous) |
| MOS-1 b | Japan | NASDA | 1990 | Land and ocean color |
| JERS-1 | Japan | NASDA | 1992 | Ocean/Ice and land remote sensing |
| IRS 1 a | India | ISRO | 1988 | Land remote sensing |
| IRS 1 b | India | ISRO | 1991 | Land remote sensing |
| IN SAT Ila | India | ISRO | 1992 | Meteorology (GEO) and telecommunications |
| Meteor 2 | Russia | Hydromet | 1975 (series) | Meteorology (polar) |

*(continued)*

| Satellite platform | Country | Agency | Year of launch | Description |
|---|---|---|---|---|
| Meteor 3 | Russia | Hydromet | 1984 (series) | Meteorology (polar) |
| Okeun-O | Russia | Hydromet | 1986 (series) | Ocean |
| Resurs-O | Russia | Hydromet | 1985 (series) | Land |
| Planned | | | <2000 | |
| NOAA-J | U.S. | NOAA | 1994 | Meteorology (polar) |
| NOAA-K | U.S. | NOAA | 1996 | Meteorology (polar) |
| NOAA-L | U.S | NOAA | 1997 | Meteorology (polar) |
| NOAA-M | U.S. | NOAA | 1999 | Meteorology (polar) |
| NOAA-N | u s | NOAA | 2000 | Meteorology (polar) |
| GOES-J | u s. | NOAA | 1995 | Meteorology (GEO) |
| GOES-K | Us. | NOAA | 1999 | Meteorology (GEO) |
| GOES-L | us. | NOAA | 2000 | Meteorology (GEO) |
| TOMS Earth Probe | us. | NASA | 1995 | Atmospheric chemistry |
| EOS AM-1 | u s | NASA | 1998 | Climate, atmospheric chemistry, ocean color, land remote sensing |
| EOS PM-1 | u s | NASA | 2000 | Climate and meteorology |
| EOS Aero-1 | u s | NASA | 2000 | Atmospheric chemistry and aerosols |
| EOS Color | u s | NASA | 1998 | Ocean color |
| Landsat 7 | u s | NASA/ NOAA | 1998 | Land remote sensing |
| SeaStar | U. S./ Commercial | Orbital Sciences Corp. | 1995 | Ocean color |
| WorldView | U. S./ Commercial | WorldView Imaging Corp | 1995 | High-resoluhon land remote sensing |
| Space Imaging | U S / Commercial | Lockheed Corp | 1997 | High-resolution land remote sensing |
| Eyeglass | U. S./ Commercial | Orbital Sciences Corp. | 1997 | High-resolution land remote sensing |
| | | Itek Corp | | |
| | | GDE Systems Crop | | |
| TRMM | US/Japan | NASA/NASDA | 1997 | Climate and tropical precipitation |
| Meteosat 7 | Europe | Eumetsat | 1995 | Meteorology (GEO) |
| Meteosat 8 | Europe | Eumetsat | 2000 | Meteorology (GEO) |
| METOP | Europe | Eumetsat | 2000 | Polar meteorological satellite |
| SPOT 4 | France | CNES | 1996 | Land remote sensing |
| ERS-2 | Europe | ESA | 1 994/95 | Ocean dynamics, Ice, atmospheric chemistry |
| Envisat-1 | Europe | ESA | 1998 | Atmospheric chemistry, ocean dynamics and color |
| Radarsat | Canada | CS/VRadarsat, Int | 1995 | Ocean surface, ice |
| GMS-5 | Japan | NASDA | 1994 | Meteorology (GEO) |
| ADEOS | Japan | NASDA | 1996 | Climate, atmospheric chemistry, ocean dynamics, ocean color, land remote sensing |
| GOMS | Russia | Hydromet | 1994 | Meteorology (GEO) |
| Almaz-1 B | Russia | | 1996 | Ocean surface, ice |
| Almaz-2 | Russia | | 1999 | Ocean surface, ice |

*(continued)*

| Satellite platform | Country | Agency | Year of launch | Description |
|---|---|---|---|---|
| IRS- 1 C | India | iSRO | 1994 | Land remote sensing |
| IRA- 1 d | India | iSRO | 1996 | Land remote sensing |
| IRS-P2 | India | ISRO | 1994 | Land remote sensing and ocean color |
| W - 2 | China | NRSC | 1994 | Meteorology (GEO) |
| MECB SSR-1 | Brazil | INPE | 1996 | Land/vegetation |
| MECB SSR-2 | Brazil | INPE | 1997 | Land/vegetation |

# B Appendix B: Selected Remote Sensing Applications

Data produced by remote sensing have intrinsic value because they carry information that can be displayed pictorial y for the worlds of sc ience, resource management and commerce. When properly interpreted, “pictures” produced by remote sensing, whether from satellites, aerial photography, ground-based radar, or other sources, can show the location of a hidden bunker, a caravan route used a thousand years ago, ancient stream beds, or the relative health of agriculturally significant crops. Remote sensing can also be combined with other techniques to produce additional kinds of information for decisionmakers. Geographic information systems (GIS) and the global positioning system (GPS) are two technologies often used to add value to remotely sensed data.

Remotely sensed data are increasingly accessible to users. Potential data users can also purchase a wide array of geographic information systems of varying levels of sophistication that run on inexpensive desktop computer platforms to process and interpret those data. Similar advances in GPS technologies have assisted in making remotely sensed data much easier to use and more affordable.

As noted in chapter 2, GIS are computer-based analytical programs that can run on the full range of computer platforms, from main frames to laptops. Their output are maps that portray any data that can be spatially arrayed. The power of a GIS lies in its ability to combine different kinds of spatial information and display them on a single map in combined or overlapping layers.

Imagine, for example, that you are a Red Cross administrator concerned with planning relief efforts following a major hurricane. You start with a map of the southeastern United States. Remotely sensed data provides you with the path of the hurricane and updates this information regularly. But you need other data, which may not depend on remote sensing, and you especially need to know the relationship of this information to the storm path and to the level of destruction along its path. What areas are likely to suffer the greatest damage? Where are your existing service centers? What are their human and materiel resource levels and how do these relate to the anticipated destruction of the storm? What is the strength of other services in the area? These are the kinds of overlapping information that can be portrayed with a GIS. Remotely sensed data are just one source of information for such a system, and they are easily combined with other sources, such as the manning levels of Red Cross relief centers.

GPS provides latitude, longitude, and elevation information-for example, for ships lost at sea or hikers lost in a forest (box 2-6). Depending on the system, such information may be provided to the subject (the lost ship or hiker) or transmitted to someone searching for them. Thus, GPS is of value in its own right. GPS also helps provide verification on the ground, or "ground truth" for analyses with geographic information systems. GPS anchors remotely sensed data with map coordinates.

Examples of the value of remotely sensed data, GIS, and GPS for a variety of applications follow. These examples provide a sense of the diversity of applications of these new technologies. People using these methods provided the material that is the basis of what follows; the names of the organizations that employ them appear in the summaries. [1]

## MONITORING AGRICULTURE AND VEGETATION

Environmental satellites provide day-to-day monitoring of agricultural crops, changing weather patterns that affect agriculture, and the condition of noncrop vegetation, such as forests and rangelands. Information from satellite monitoring is valuable to national economies, private organizations, and individuals whose success or 1ivelihoods are determined by agricultural and other types of renewable resources.

Within-season and post-season agricultural information is especially important to subsistence economies, such as those in Africa, Asia, and Latin America. Information derived from satellites can be used to anticipate regional food grain shortages or surpluses and to help with real-time planning for labor and marketing. Since environmental satellite data are directly available to all nations, information derived from such data can help promote more efficient agricultural commodity markets.

Agricultural and vegetation monitoring can be carried out with low-resolution environmental satellite data obtained from Russian, Japanese, European, and especially U.S. satellites.[4] While somewhat lacking in spatial detail and geometric accuracy, they provide daily coverage, immediate availability, and comprehensiveness. Environmental satellite images cover north-south swaths 3,000 kilometers wide or whole continents at spatial resolutions of 1 to 8 kilometers. Dozens of new images are obtained for every location each day and night. These data are broadcast directly to

[1] Other authors might have been used. These descriptions should not be construed as an endorsement by the Office of Technology Assessment of the technology used or the expertise found in any particular firm.

[2] Tom Wagner, Environmental Research Institute of Michigan, Ann Arbor, Ml.

[3] Such satellites are often termed weather satellites because they were originally designed to gather and transmit weather data. Increasingly, the data collected by these satellites find use in a much broader array of environmental tasks.

[4] See U.S. Congress, Office of Technology Assessment, OTA-I SC-588, *The Future of Remote Sensing from Space: Civilian Satellite Systems* (Washington, DC: U.S. Government Printing Office, July 1993).

low-cost ground receiving stations established in most countries around the world. By international convention, in most cases no licenses, fees, or special permissions are required to receive and use these data.[5]

For agricultural purposes, data from the Advanced Very High Resolution Radiometer (AVHRR) aboard three U.S. polar orbiting NOAA (TIROS) satellites are of particular interest. The AVHRR data are routinely processed by private and public agencies (including the National Weather Service, the U.S. Department of Agriculture, and the U.S. Geological Survey) to produce multi-date, composite vegetation index (VI) images. These composite VI images are produced using multiple NOAA satellite passes obtained over periods of several days to several weeks and show large areas with little or no cloud cover.

Vegetation index images provide direct evidence of the greenness of terrain, a good indicator of vegetation health and density during the growing season. To knowledgeable interpreters, such quantitative measurements of greenness provide objective, up-to-date evidence of crop or rangeland conditions. From such data, image analysts can deduce planting and harvesting times, areas affected by drought, disease, or flood, and the stages of crop development.

The Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture routinely obtains AVHRR VI data from the National Weather Service. These data, in turn, are reformatted and processed to provide pictures of vegetation conditions in major agricultural regions outside the United States. To the FAS analysts these pictures, when combined with their knowledge of local crop calendars, growing conditions, and the weather, prov ide direct evidence of current crop status and early warning of possible problems that even local agricultural officials may not suspect.

For the past six years, with the help of such images, within-season small grain estimates in South Asia have been within 5 percent of final production figures. Analysts have accomplished this despite the general lack of crop progress reports from these countries during the growing season. Such information contributes to world crop forecasts and influences USDA policies and strategies.

In fiscal year 1994, FAS will spend $3 million to upgrade its satellite image monitoring system and develop strategies to integrate it with GIS and statistical data anal ysis methods. FAS sees emerging GIS technologies as key to integrating soil and rainfall data and historical production information.

The crop damage assessment conducted after the flood in Bangladesh in 1988 provides an example of the use of environmental satellite data for agriculture. In late August and early September of that year, the Ganges and Bhramaputra rivers flooded to record levels and inundated large areas of the country, including much of the emerging fall rice crop. Figure B-1 shows an AVHRR Vegetation Index image obtained with a United States Agency for International Development (USAID) supplied ground station in Bangladesh. This image was made about a month after the flood waters had receded. Damaged rice crop areas are light gray. They are primarily adjacent to the two major rivers, which appear dark. The areas affected and the level of damage can be estimated from images such as this one. Combining such information with local data enabled forecasts of the production for each administrative district and estimates of shortfalls. The total production estimate came within 5 percent of the official total estimate that was published six months after the harvest. (While some areas of Bangladesh were heavily damaged by the flooding, other areas had record harvests, and the total shortfall was not as great as originally feared.)

Historically, donor countries provide emergency food grain assistance based on rough estimates of anticipated needs. With communications and transportation disrupted and available govem-

[5] See, however, ch. 5,

FIGURE B-1: AVHRR Vegetation Index Image of Bangladesh

This image was made about a month after the 1988 flood Damaged rice crop areas are light gray

SOURCE Foreign Agricultural Service, 1988

ment resources directed at emergency relief operations, such estimates are often guesses based on hearsay and anecdotal evidence. If too little emergency food is received, people starve, while if too much is received, the local markets become saturated and prices for local farmers fall. Satellite data provide objective information that complements traditional means of forecasting crop production.

## MANAGING CROPS[6]

Since 1984, Cropix, Inc. has used satellite imagery to estimate potato production in the Columbia River Basin of Oregon and Washington.[7] Unfortunately, two to four weeks typically pass from the time of satellite overpass to the time image data were delivered. The delay means stress patterns were detected too late in crops to aid the farmer, which frustrated both farmers and researchers. This situation will soon improve. With funds from NASA's Earth Observation Commercializtition Applications Program (EOCAP), Cropix is investigating the utility and economic feasibility of providing a crop monitoring and management service based on rapid delivery of satellite data.

Potatoes are the region's main cash crop, and consequently are the primary crop being monitored. Image data from SPOT, Landsat, and Marine Observation Satellite (MOS). a Japanese Space Agency satellite, are delivered within 24 to 48 hours after satellite overpass, enabling detection of field problems in time for farm managers to take corrective action.

The project is in its second of three years. With four customers who operate large farms, a prototype operation is underway for a region of rough] y 250,000 acres of irrigated farmland, an area that is covered by a single SPOT scene. Plans for the 1994 crop season include expansion of the service to monitor more than 300 fields, which will create a customer base large enough to demonstrate economic viability on a commercial basis. Once proven with the prototype, expansion of the service area to the entire Columbia Basin, southern Idaho, and California would be pursued.

Project success depends on the ability to receive satellite data within 24 to 48 hours. Through

[6] George R. Waddington, Cropix, Inc., Hermiston, OR.

[7] Lamb, F. G., "Agricultural Uses of Low-altitude Aerial Photography", *Remote Sensing for Resource Management*, C.J. Johannsen and J.L. Sanders, Editors. Soil Conservation Society of America, Ankeny, 1A (1982). Waddington, G. R., Jr., C.F. Chen, and L.J. Mann, "Estimating Potato Acreage and Yield in the Columbia River Basin of Oregon and Washington Using Landsat: A Commercial Application," *Advances in Image Analysis*, Y. Mahdavieh and R.C. Gonzalez, Editors. SPIE, Bellingham, WA (1992). Waddington, G. R., Jr., and F.G. Lamb, "'Using Remote Sensing Images in Commercial Agriculture", *Advanced Imaging*, vol. 5, pp. 46-49 (Sept. 1990).

the combined efforts of Cropix, Oregon State University, SPOT Image Corp., EOSAT, and the Canada Centre for Remote Sensing, most image data turnaround times are just under 48 hours, using commercial courier services. However, limited courier services out of Prince Albert, Saskatchewan, the ground receiving station location, result in Friday and weekend satellite acquisitions being delivered in three to four days. To alleviate this problem and secure 24-hour turnaround, Cropix is investigating alternate data delivery methods, including the Internet, and ANIK, a Canadian-based satellite communications link. A full SPOT scene has been successfully transferred from SPOT Image Corp. 's Reston, Virginia, office to Oregon State University via Internet in 133 minutes.

Sub-images covering each customer's farm are extracted from the full scene image data. Commercial products include an "Early Warning Report," issued by 5:00 pm on the second day after each satellite image acquisition, and a "Temporal Analysis Report," issued monthly during the crop season. The Earl y Warning Report provides satellite views of each customer's field with subtle variations in the crop canopy enhanced and comments on possible causes for the apparent anomaly. This report is being upgraded in 1994 to include a statistical comparison of field performance versus the average for fields in the survey area, displayed below the imagery. The Temporal Analysis Report provides a visual record of a customer's field as it appeared on each image acquisition date during the crop season, and a detailed graphic showing field performance plotted against average performance for all surveyed fields. An example of this report is shown in figure B-2.

During the 1993 crop season, the four test customers received both Early Warning and Temporal Analysis reports on a regular basis. The experience of Glenn Chowning, president of Terra Poma Farms, provides an example of the power of this technology. Chowning pointed out an interesting occurrence within his field No. P2. As shown in the figure a dark patch appeared in the July 12 SPOT image at the right edge of the circle, and spread to engulf the entire right half of the circle by July 28. The dark patch was the result of late blight, a disease common to potatoes (the same disease that caused the Irish potato famine last century). The July 7 SPOT image shows a possible inoculation point, a small dark spot below and slightly to the right of the field center. Glenn said that harvest on the left half of the circle produced above average yields, whereas when the right half of the field was harvested, the potatoes showed signs of rot and yields were lower. Had the field been harvested a few days later, the rot would have progressed to the point that the balance of the potatoes would have been lost, at a cost of $200,000. Glenn did not base his decision on when to harvest on the imagery. However, in retrospect, he realized he could have prevented any loss if he had verified that late blight was infesting the field at the earliest signs of the dark patch in the imagery and sprayed at that time.

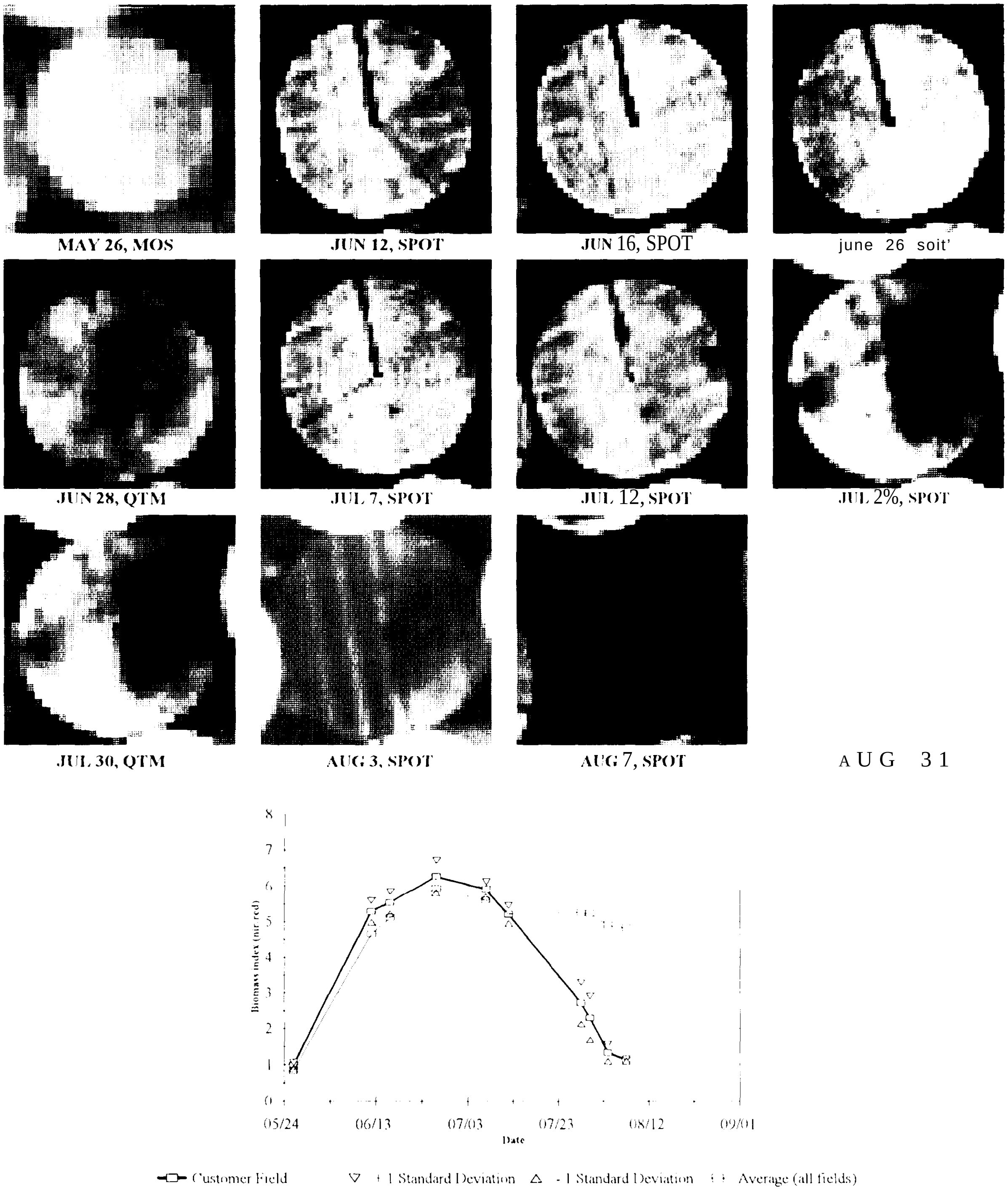
The cost of the service for the entire crop growing season is $7 per acre. The farming cost for potatoes is approximately $1,800 per acre with an additional cost of $400 per acre to store and deliver the crop to market. Average returns for a good crop can be anywhere from $3,000 to $4,000 per acre depending on market conditions, resulting in profit margins of $800 to $1,800 per acre. With such a large investment at stake, the service is an inexpensive insurance policy. Timely information regarding potential crop problems can help the customer take corrective action and adjust farming plans as needed.

## MANAGING PIPELINE RIGHTS-OF-WAY[8]

Pipeline companies are faced with ever-increasing regulatory and operating pressures. New regulations are proposed or enacted each year that require mapping, facility inventories, pipe inspec-

[8] Mark A. Jadkowski, James W. Sewall Co., Old Town, ME

FIGURE B-2: Temporal Analysis Report on Terra Poma Farms, September 20, 1993




SPOT: SPOT Image Corporation Data © CNES 199320m pixel (O 1 acre) TM: Landsat-5 Thematic Mapper Data suppled by EOSAT, 30m pixel (O 2acre) MOS:Japanese MOS Datavia Canadian Center for Remote Sensing 50m pixel (O 6acre) QTM:Quick Delivery Raw TM Data corrected by CROPIX, 30m pixel (O 2 acre)

SOURCE CropIx, Inc 1993

FIGURE B-3: Pipeline Rehabilitation

SOURCE James W Sewall Co , 1993

(ions, rehabilitation, and environmental reporting (figure B-3). These pressures are compounded by the need to stay competitive in today's rapidly changing marketplace.

Automation has long been an answer to the problem of having to do more work with less people, and Automated Mapping/Facilities Management Geographic Information Systems (AM/FM/GIS) solutions are being proposed and implemented at a number of pipeline companies. The U.S. pipeline industry, which operates over 453,000 miles of gas, crude, and refined products lines, is expected to be a significant growth segment of the AM/FM/GIS market.

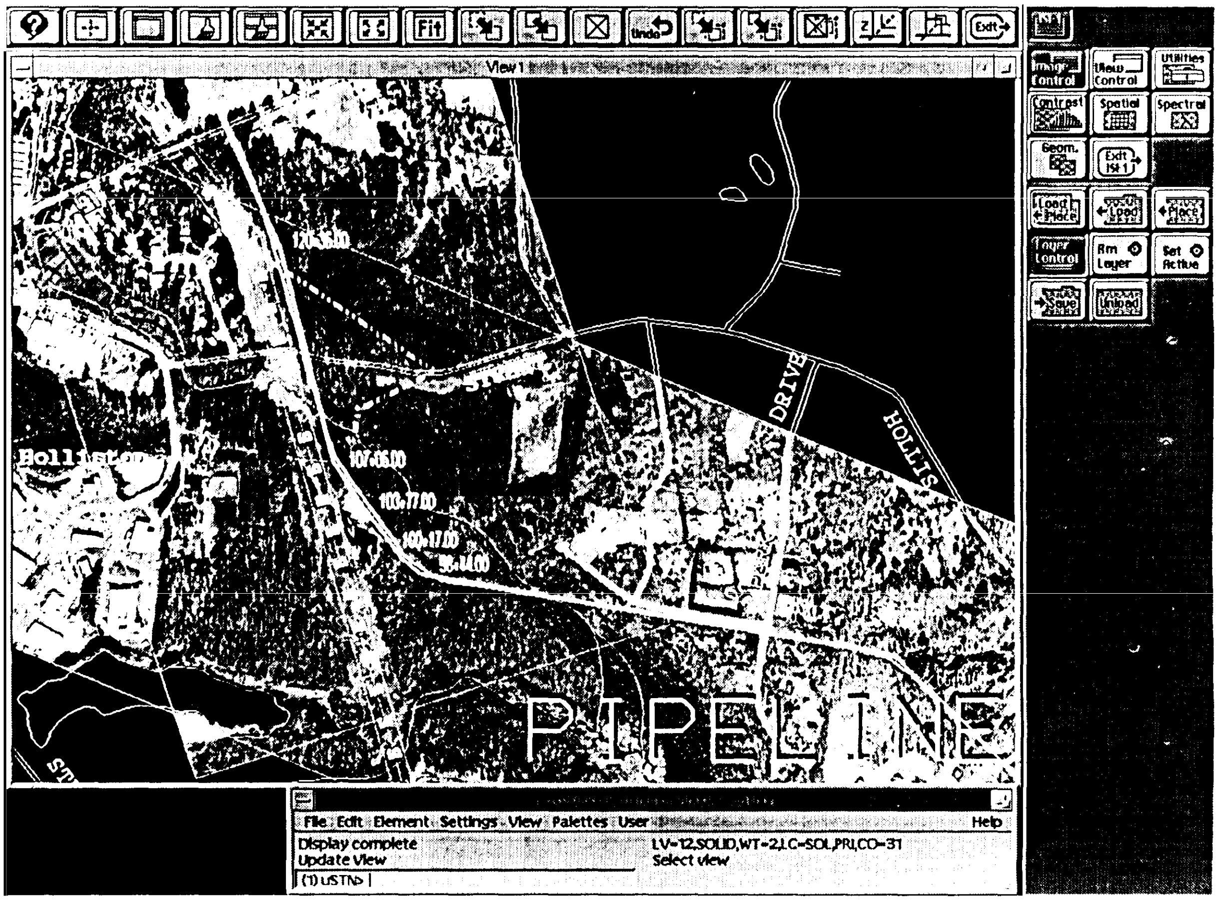
Pipeline companies index and track the location of their facilities using a system of survey stations that can at times baffle even the most seasoned professional. A small pipeline system can cross three or four state boundaries and map coordinate systems. A medium-sized company can have as many as 50 district offices that may require online AM/FM/GIS accessibility. A large company might operate over 30,000 miles of pipeline and manage 15,000 miles of rights-of-way and associated parcel easement records. These and other technical issues suggest the need for new and innovative mapping techniques, database design and management strategies, and approaches to providing system accessibility.

Until development of digital aerial photographic imagery, the ability to acquire and incorporate up-to-date land information cost-effectively into an AM/FM/GIS was out of reach for most pipeline companies. Alignment sheets, the most common pipeline facility maps, are almost always out of date. New photogrammetric mapping is cost-prohibitive in most cases. County maps and U.S. Geological Survey 7.5 minute quadrangle maps are not detailed enough. Resolution of satellite imagery is at present too coarse. The two commercial Earth observation satellite systems operating today, SPOT and EOSAT, offer 33-foot and 100-foot spatial resolutions, respectively, whereas optimal image resolutions for most pipeline applications range between one and three feet. Manual handling of hundreds or thousands of hardcopy aerial photographs is unmanageable.

Digital aerial photography provides an economic and versatile alternative. Photographic images can be scanned at resolutions of 1 to 3 feet, providing important land detail. The images provide the location of roads, hydrography, wetlands, cleared rights-of-way, structures, and other cultural features. Image processing is a mature technology that has been made affordable through competition in the desktop publishing industry. Disk storage capacity and laser printers capable of producing sharp images are relatively inexpensive. Today, major vendors of AM/FM/GIS systems provide the capability to integrate computerized aerial images with a facilities database (figure B-4). With these developments, it is possible to perform rapid online query and display of aerial photography for day-to-day operations of pipeline emergency management.

Many monitoring applications of digital aerial photography exist for pipeline rights-of-way, including general map updating, marketing, pipeline planning, and wetland delineation. Pipeline companies that handle crude and refined products are concerned with environmental damage from pipe rupture. They can use the imagery for locat-

FIGURE B-4: Pipeline Route Overlaid on Digitized Aerial Photograph




SOURCE James W Sewall Co 1993

ing sensitive areas and for planning access and placement of cleanup equipment in case of emergencies.

Gas pipeline companies are required to perform annual dwelling surveys, mandated by the U.S. Department of Transportation, which has jurisdiction over pipeline safety issues. In the surveys, dwelling densities within 660 feet of each pipeline are assessed. Four density classifications are used to set the operating stress level for the pipeline. The higher the dwelling or population density, the lower the allowable stress level in the pipeline. It is common for a company to decrease the movement of gas or replace pipeline at a cost of mil1ions of dollars because of the construction of a few dwellings. Digital aerial photography in an AM/FM/GIS can greatly add to the efficiency with which pipel ines are monitored and the accurac y of these regular safety-related surveys. However, the cost of flying, processing, and then scanning conventional aerial photography can still be cost-prohibitive for a large pipeline company. The technical solution to this economic problem is to cut costs drastically through the use of low-cost and easily operated digital camera systems for monitoring pipeline rights-of-way.

In 1992, Algonquin Gas Transmission Co. and James W. Sewall Co. initiated a project with the National Aeronautics and Space Administration to develop an aerial photography-based system that can be used commercially for pipeline management. A third partner in this development effort is NASA's John C. Stennis Space Center. Stennis Space Center's role in the project is to provide access to NASA technological resources, Sewall is the prime contractor, and Algonquin and its parent, Panhandle Eastern Corp., are responsible for defining all operational parameters. The project was funded by NASA's EOCAP, which commercializes remote sensing technology originally developed to support scientific and space exploration missions.

The technical objectives of this EOCAP project are threefold. First, the Project Team has developed a computerized system for storing and retrieving digital aerial photography of pipeline rights-of-way. The computerized system provides an accurate inventory of rights-of-way locations and pipeline surroundings for engineering, maintenance, and regulatory purposes. The system also provides very rapid access to much-needed information in case of emergencies. The second technical objective is to adapt a digital camera system for more routine aerial pipel ine rights-of-way monitoring. The Digital Aerial Rights-of-Way Monitoring System (DARMS) was designed and assembled for this purpose from commercially available components and specialized software. The third objective of the EOCAP project is to unite the digital aerial images described above with a working pipeline AM/FM/GIS system. This involves development of a series of specialized computer programs that facilitate pipeline-specific applications.

The project, now in its final stage, has succeeded in bringing to the pipeline industry a set of new and innovative remote-sensing tools for pipeline monitoring and management.

## THREE ENVIRONMENTAL APPLICATIONS

The use of remote sensing for environmental applications has grown continuously since digital satellite imagery became available. Its growth is driven by the increasing number of environmental concerns and new knowledge and technology developed by the scientific community. The field includes such diverse topics as identification and mapping of endangered vegetation communities, monitoring and modeling animal habitats, and monitoring the effects of natural disasters. Purposes of the work include pure scientific exploration, environmental preservation, resource management, and regulatory activities. The following describes three specific application projects, including their purposes, methods, and results.

### Protecting Endangered Animals

Wildlife biologists use satellite data to study animal populations that are at risk. In the Upper Peninsula of Michigan, habitat destruction and over-(rapping exterminated the fisher and marten populations. The U.S. Forest Service and the Department of Natural Resources of Michigan reintroduced both species, but little was known about the status of the new populations. Thomas maetal. used satellite imagery in conjunction with radio location data to evaluate the preferred winter habitat characteristics of fishers and martens. [10]

Animals trapped in the fall were fitted with radio callers and tracked from an airplane through the winter. Researchers recorded the geographic location of the animals on board the plane. They then referenced Landsat Thematic Mapper satellite data of the study area to precise geographic

[9] Janice L. Thomson, The Wilderness Society - Washington State Region, Seattle, WA.

[10] L. E. Thomasma, R. O. Peterson, and T. D. Drummer, 1991. "An Ecological Study of Fishers and Martens in the Upper Peninsula of Michigan." *Annual Report - Year 2 (1991-1992)* to the Michigan Department of Natural Resources (Houghton, Ml., Michigan Technological University), 24 pp.

coordinates. The satellite data were classified using digital image processing software to generate a forest cover map delineating the different forest types available to the fisher and marten. The animal location data were overlaid on the forest cover type map using computer algorithms. The resulting data showed that fisher and marten both prefer conifer forest for their winter habitat. However, monoculture pine plantations, a less desirable habitat to the animals, have begun to replace the natural coniferous groves in the region. The same authors are now using Landsat satellite imagery to assess varying conifer patch size and shape on habitat preference.[11] Studies such as these provide important information that can guide forest management policy to preserve animal habitats. Similar studies are ongoing with other species around the country.

### Locating Ancient Forests

Endangered ecosystems are being mapped using remotely sensed data. The ancient forest ecosystem of the Pacific Northwest is a dwindling resource that both the timber industry and a host of plant and animal species depend on. Morrison et al. demonstrated how Landsat Mutispectral Scanner data and aerial photographs can be used to locate groves of ancient forest across 12 national forests of the western Cascade Mountains of Washington, Oregon, and California.[12] Basic satellitc image classification techniques generated maps of both ancient forest and old-growth forest. Twelve national forest maps highlighted the stands of ancient forest and old growth. The results were input into a GIS to calculate the acreage of ancient forest in each national forest. The data set became a valuable source of information for subsequent studies, including a critique of President Clinton's Forest Plan for the Pacific North-West.[13] Because these data were in GIS format. they were ideally suited for analyzing the forest plan, which also was generated and distributed as GIS data. The ancient forest data allowed rapid analysis of 3.8 million acres of forest to determine how much of the ancient forest ecosystem would be preserved under the different options in the forest plan. The combination of vegetation maps generated from remotely sensed data, plus the geographic data processing capabilities of GIS, make possible rapid review of government land management policy and give nongovernrnent organizat ions a means to check and r-nonitor the government's use of public resources.

## Enforcing Fishing Limits

Monitoring and enforcing fisheries harvest limits are important to maintaining marine fish populations. Yet enforcement agencies are taxed beyond their resources trying to monitor violators of fishing harvest limits and harvest in off-limit waters. Between 1983 and 1989, the number of over-exploited fish stocks more than doubled.

Freeberg et al.[14] developed a method to monitor ship tracks in the North Pacific and Bering Sea using Advanced Very High Resolution Radiometry (AVHRR) satellite data. The researchers found that moisture condenses around particulate material from stack emissions of ships. The resulting cloud lines can be detected in processed satellite data. Multiple data sets over a short time period allow the determination of ship direction and speed. Currently, Freeberg and his coworkers ( 1992) are designing a system complete with satellite ground receiving station, computing hardware, and soft-

[11] L. E. Thomasma, personal communication, 1993.

[12] P. H. Morrison, D. Kloepfer, D. A. Leversee, C. M. Socha, and D. L. Ferber, 1991. "Ancient Forests in the Pacific Northwest: Analysis and Maps of Twelve National Forests, " The Wilderness Society, Washington DC, 14pp.

[13] The Wilderness Society, 1993. "A Critique of the Clinton Forest Plan," The Wilderness Society, Washington, DC, 47pp.

[14] M. H. Freeberg, E. A. Brown, and R. Wrigley, "Vessel Localization Using AVHRR and SAR Technology," Marine Technology Society Annual Meeting, Washington DC. Oct. 19, 1992, 18pp.

ware for data processing that w ill support the rapid turnaround time necessary for fisheries enforcement agencies.

## MAPPING BIODIVERSITY IN PAPUA NEW GUINEA[15]

The island of New Guinea is considered one of only three major tropical wilderness areas left on Earth (the other two are the Amazon Basin and a large rain forest in Africa's Congo Basin). Papua New Guinea (PNG), the eastern half of the island, has large expanses of relatively undisturbed coral reefs, mangroves, and tropical forests. Within the forests, PNG highly varied geography and the island's isolation have led to the evolution of many species found nowhere else in the world. Nearly a quarter of the nation's mammalian species are endemic, as are 77 species of birds, and half of the amphibians. Species unique to PNG include such unusual animals as the world's largest pigeon, butterfly, and grasshopper and 34 species of birds of paradise.

Over 80 percent of the country is covered by forest. Today these forests are seriously threatened by high population growth, which adds some 100,000 new inhabitants every year, and by rapid economic development. Foreign companies, attracted to PNG's large reserves of timber, oil, and minerals, are a particular threat to the forests and their many species of plants and animals. Landowners, who once relied exclusively on subsistence farming, are increasingly tempted to sell rights to their land for cash from these companies.

However, conservationists are also taking an interest in PNG, and the government has decided to intensify efforts to protect the nation's biodiversity, an important future economic resource. In choosing where to focus its resources, the government of PNG will consider a variety of factors including social, cultural and economic conditions throughout the country. Because both time and funds for conservation are limited, deciding precisely and quickly where to work is the first logical step in any sensible conservation plan.

In April 1992, at the invitation of the PNG government, Conservation International organized and led a workshop in Madang, PNG, in which biologists and government representatives reached consensus on areas that are most important for protecting PNG's vast biological wealth.[16] The approach used was first applied at a workshop held in Manaus, Brazil, in January 1990, where experts on Amazonian ecosystems came to a consensus on biological priorities for conservation within the vast Amazon Basin.[17] So far, results of that workshop have led to the establishment of six new forest reserves in the Brazilian state of Arnazonas, as well as new protected areas in Colombia. The methodology used in Manaus was refined during the workshop in PNG.

The methodology relies on biological information. Field biologists who are the world's leading experts on a region's species and ecosystems are assembled. Each of these scientists may be an expert on only a few species or geographic areas, but together their knowledge and experience provide the best possible understanding of the region as a whole, GIS technology plays a key role in the process, for it provides the means to synthesize the scientists' knowledge.

Before the workshop, Conservation International prepared a set of base maps for the entire country using a GIS. These base maps brought together on one piece of paper for the first time a variety of basic geographic data needed to set conservation priorities: political boundaries, coast-

15 Laura Tangley and Andy Mitchel, Conservation International, Washington, DC.

16 Alcorn Janis, ed. 1993 "Papua New Guinea Conservation Needs Assessment." The Biodiversity Support Program, Washington, DC. Conservation International, BSPand PNG Dec. 1993. "Biodiversity Priorities for Papua New Guinea."' Map, Conservation International, Washington, DC.

17 Conservation International, IBAMA and INPA. 1991. "Workshop '90, Biological Priorities for Conservation in Amazonia." Map, Conservation International, Washington, DC.

lines, rivers, lakes, roads, topography, vegetation type, population centers, protected areas, and Timber Rights Purchases.[18] The maps would have been even more useful if they had included such important data as land use and forest cover, but this information was not available for PNG at the country-wide level. In most cases such information must be derived from remotely sensed data, often from satellite imagery. The expense of acquiring and processing these data was beyond the means of the PNG workshop. Nonetheless, the base maps enabled by GIS technology were of great value.

To help them prepare for the workshop, the base maps were sent to key scientists in each of several disciplines: mammalogy, botany, ornithology, and others. These "'team leaders" used the maps to plot biological information they had collected from other scientists in their field. When the scientists arrived in PNG, they had a set of maps that not only captured the experience of dozens of experts, but also were compatible with one another. They could then immediately begin working to achieve group consensus on the areas most important for conserving PNG's biodiversity.

At the workshop in Madang, the researchers began a long, give-and-take process that led to a consensus within the group several days later. Working on large transparent Mylar sheets that could be overlaid on the base maps, group members focused on priority areas one by one, filling out a detailed data sheet for each of them and arguing over what the area's size, shape, and exact borders should be. During this stage the maps were critical to making tiny progress. By focusing on maps, the biologists bypassed disagreements over definitions and theory and focused on practical questions about the location of biologically important areas.

The borders the biologists drew on the Mylar overlays were digitized into the GIS and output as new maps, providing instant feedback to the scientists. This GIS analysis was critical to identifying the final set of biologically significant areas. During the deliberations, for example, the GIS was used to combine the initial borders the biologists had drawn with data sets of elevation and vegetation type. The result showed that only 8 percent of the country remaining lowland rain forest had been included within the borders of the biologically important areas; most of the low-lying lands that had been included were either mangrove forest or savanna. The botanists had grossly under-represented lowland rain forest, by far the most endangered ecosystem in PNG. They went back to the Mylar overlays and further discussions.

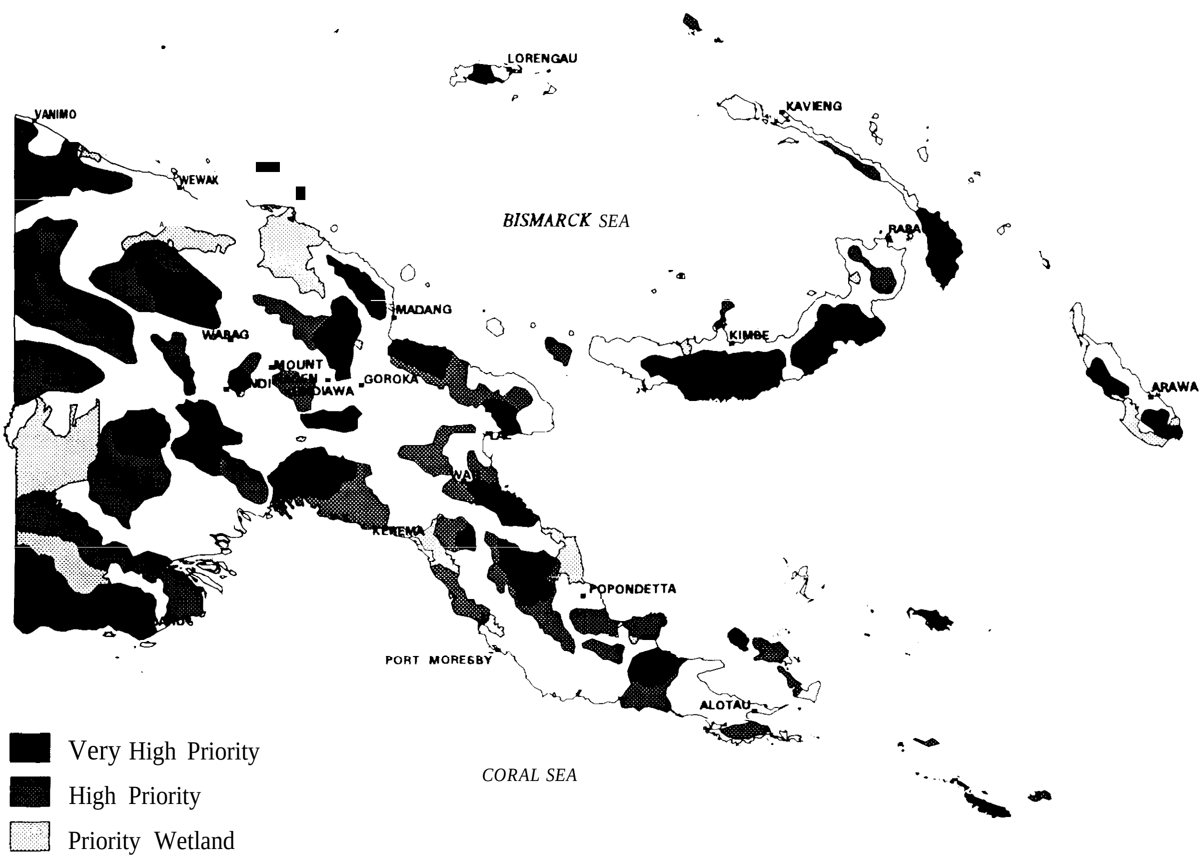
After several days of correcting such errors, arguing over the relative importance of certain areas, and agreeing on precise borders of priority areas, the biologists finally agreed on a map (figure B-5) identifying PNG most biologically significant areas. The final boundaries were then digitized into the GIS. A few months after the workshop ended, a final report and wall-size map of the biodiversity priority tireas were published tind distributed to scientists and government officials in PNG and throughout the world.[19]

The PNG Department of Conservation (DEC) is using the biodiversity map in a variety of land planning activities, including selecting new sites for protected areas, targeting environmental education programs, financing sustainable development projects, and negotiating with logging and mining companies over the select ion of sites for new resource extraction schemes. The map has also helped DEC convince international aid agen-

[18] Timber Rights Purchases are areas that have been identified for leasing to logging companies and thus face the greatest risk of deforestation.

[19] Tangley, Laura. 1992. "Computers and Conservation Priorities, Mapping Biodiversity". Lessons From The Field 1, Conservation International, Washington, DC.

FIGURE B-5: Papua New Guinea Map of Significant Biological Areas




SOURCE Conservation International, 1992

cies to fund conservation projects in PNG. Early in 1993, south New Ireland province, one of the areas identified as highest priority during the workshop, was chosen as the site of the first Global Environmental Facility (GEF) funded project for PNG.

In addition to building consensus among local and international scientists and government officials, a key element of the workshop approach is in building local capacity within the country to continue conservation efforts. In PNG, Conservation International left behind the entire GIS database generated by the workshop as well as the hardware and software needed to use it. In addition, Cl provided GIS training to both government and university technicians. Thus, PNG scientists can add new information to the database as it becomes available, including land cover data derived from satellite images. and can conduct more detailed analyses. The workshop left PNG better prepared scientifically to study and protect its own biodiversity in the future.

## HELP FOR VICTIMS OF HURRICANE ANDREW[20]

Hurricane Andrew struck southern Florida in late August 1992, wreaking enormous damage and leaving many without homes. As the rain and wind subsided, federal, state, and local agencies, corporations, and individuals gathered resources to support those who were in the storm's path. Two questions needed to be answered quickly.

- Where should relief centers be established and how can people be notified of their locations?
- How much destruction occurred and where?

Science Applications International Corp. (SAIC) donated its geographic information system (G IS) services and computers to help find the answers. The GIS technology was immediately useful for keeping track of a variety of relief efforts, and later, as data became available. for evaluating the extent of destruction.

A digital database of the area was created and continually updated as reports came in from individuals in various sectors of the hurricane area. The location and status of Red Cross Service Centers, U.S. Army kitchens, bum sites, FEMA Disaster Application Centers, HRS Centers, tent cities, portable toilets, hazardous waste sites, and other facilities were maintained as digital information. When users needed updated maps, the digital data were printed in the form of a large hardcopy color map. Relief workers could use the maps to direct people to the proper facility to handle their needs.

After a few days, aerial photographs were taken. The hardcopy aerial pictures were converted to digital form and combined with the previously created digital line map database to provide an up-to-date pictorial view of the area, which was then used to begin evaluating the extent of the damage. The value of high-technology digital map information in a crisis situation quickly became clear. The database became a depository for field reports. As the information received was validated and integrated, it was redistributed in a graphic format easily interpreted by the user.

An important question that was difficult to answer during the Hurricane Andrew crisis support effort was, "How did the area look before Andrew?"' In some cases, only scattered debris remained of what had been trailer parks or subdivisions a few hours earlier. A reliable up-to-date record of what occupied land parcels prior to the hurricane did not exist. but such information is, of course, essential in assessing damage, in determining what aid is needed, and in establishing who is eligible for aid.

SAIC is currently developing technology called orthorectification to help satisfy this need. The technology creates digital image maps, precisely positioned to a worldwide coordinate system, from aerial photography and satellite imagery. The maps are stored on small cassette tapes or CD-ROM disks that are easily input to a computer and viewed. Image maps being produced for a national program have single elements (pixels) that cm-respond to one square meter on the Earth. Although higher resolution images could be used, maps with one-meter resolution offer an attractive cost compromise. These digital image maps are rapidly becoming popular with users, since they offer data that are more precise, more current, and less costly than the conventional line map paper products. Such digital image maps would have been very valuable in support of the Hurricane Andrew relief effort, as well as in estimating damage from the Mississippi floods.

## I Other Mapping Activities

The U.S. Geological Service in Menlo Park, California, is currently creating a national image map database. The effort is supported by a multitude of agencies at the federal, state, and local levels, as well as private utilities, architectural and engineering firms, and individual property own-

[20] Jerry A. Maupin, Assistant Vice President, Science Applications International Corp., Melbourne, FL.

ers. Keying information to a precisely positioned image map is essential to being able to manage and digest the massive amounts of data generated today.

New remote sensing technology is making the collection of image map information even more practical and less costly. Airborne synthetic aperture radar (SAR) systems with onboard GPS now return digital SAR images that have been processed in real time onboard the aircraft. These images can be acquired under almost any weather conditions, and thus are ideal for supporting crises where poor weather conditions and atmospheric haze are likely. Satellite images from systems such as Landsat and SPOT offer data that cover broad areas and are easily processed. New commercial satellites will soon be launched that promise resolutions an order of magnitude finer than those offered by Landsat and SPOT.

It appears a major thrust over the next few years will be improving U.S. infrastructure. Much of the cost will be in planning and coordinating the projects and documenting the results. Remotely sensed photographic information can contribute to the success of these projects. Image maps will be useful in planning and controlling urban sprawl, transportation routes, utility routes, land use, watershed analysis, public land inventory, wetlands documentation, and many other applications. GIS/image maps can save millions of dollars compared with conventional land survey techniques. In addition, results will be consistent and well documented.

## ECOSYSTEM MANAGEMENT USING BIOPHYSICAL LAND UNITS (BLU)[21]

Management of natural resources and the ecosystems they comprise is becoming increasingly complex. In particular, the resources and systems contained in public lands are subject to escalating competition and conflict over their use. For example, the public has expressed heightened concerns for conservation and preservation of lands historical] y considered only for "disposal ." Because ecological change is continuous and inevitable it is crucial to understand and predict natural processes, as well as the interplay of cultural (human-induced) uses and impacts. Quantifying, monitoring, predicting, and subsequently protecting "natural" change, or directing "desired" change, must be scientifically evaluated to help resolve conflicts of ecosystem management and use.

The Albuquerque District of the Bureau of Land Management is responding to these needs by using geographic technologies, including GIS and satellite remote sensing. The Albuquerque District has developed a management tool using these technologies called Biophysical Land Units (BLU), which are spatial (geographic) representations of the location, extent, and dynamics of multiple ecological components. These components are the biological and physical (biophysical) attributes of an ecosystem or ecot ype. The attributes may include: soils grouped by texture or erodability, geological type, terrain features such as a limited elevation range or degrees of aspect or slope, vegetation/landcover types, surface water—in short, whatever characteristic is pertinent to the geographic location. For example, in New Mexico, some of the ecosystem attributes may consist of stands of conifers on steep slopes of volcanic cinders, or shrubs and forbs on low-slope, highly erodible soils, which are subject to violent storm runoff. In comparison, a coastal ecosystem may include attributes such as geological type, vegetation, water depth in an estuary, or tidal flow dynamics. In simple terms, BLUS are a graphic representation of ecological responses (condition) in a single map layer.

Historically, land managers have described the existing environment of regions or administrative units (wilderness areas, range allotments, etc.) by extrapolating from field surveys that cover only small percentages of the ecological components. By contrast, GIS technology allows a manager to develop BLUS from a matrix or cross-reference of

[21] Christa Carroll, Albuquerque District, Bureau of Land Managment, U.S. Department of the Interior.

ecological attributes, without regard to administrative or ownership boundaries-or personal hunches. The GIS sets no limitations on the number of ecological component layers that can comprise the BLU model matrix, and is intentionally exploited to represent hierarchical ecological structure. Further, if the programmed matrix combination of ecological components doesn't exist, it simply leaves a blank space in the model. Beyond minimizing human preferences, BLU model "drop out" is beneficial because it can define a previously unknown ecological response, or draw attention to an area that is a unique or potential "hot spot."

For example, when the BLU model was first developed for the El Malpais National Conservation Area in New Mexico, parts of the project area had been subject to extensive previous study. This known information was combined with intensive field verification of the BLU model, resulting in a high degree of confidence in the use of BLUS. Furthermore, through BLU modeling, parts of the project area that were previously little known were found to be different and more complex ecologically than expected. Once these "surprise" areas were identified, they were the focus of additional field verification.

Satellite remote sensing data, (specifically Landsat Thematic Mapper data) are being used in the BLU model for vegetation/landcover and surface geology/soils. It is well known that satellite data provide total spatial coverage of a large area in a "snapshot in time." But satellite data alone are not sufficient for resource analysis and modeling. Vegetation/landcover is only the *surficial* expression of ecological systems. The BLU model incorporates ecological components to understand the *dynamics* of systems. Using satellite images from different times, changes in the system can be detected and analyzed.

An initial iteration of "core" BLUS is usually a matrix combination of vegetation/landcover, soils, surface hydrology, and terrain characteristics. This initial iteration of BLUS is sufficiently flexible to provide "common ground" resource information to a wide spectrum of resource specialists. More detailed BLUS can be tailored for specific questions or conflict analyses by adding layers of biophysical or cultural information and/or site-specific data. Data collected from a particular site might include observed assemblages of flora and fauna, rain gauge or other climatic data, or a particular localized use or management practice.

So why go to all this trouble to model ecosystem dynamics? Ecosystem management requires understanding of energy exchanges and processes, which are constantly moving targets. GIS technologies can measure, track, and repeat ecosystem anal yses through time. The GIS never tires of repeating the processes at different points in time, or trying a different scenario. For instance, to track the rehabilitation of a riparian zone, changes in vegetation/landcover or availability of surface water can be measured and compared to changes in pasture rotation, weather variations, or the relationship of an additional stock and wildlife watering site. Further, a management alternative of improving an access road or establishing a trailhead can be analyzed for predicting the potential amount and direction of visitor use patterns and impacts.

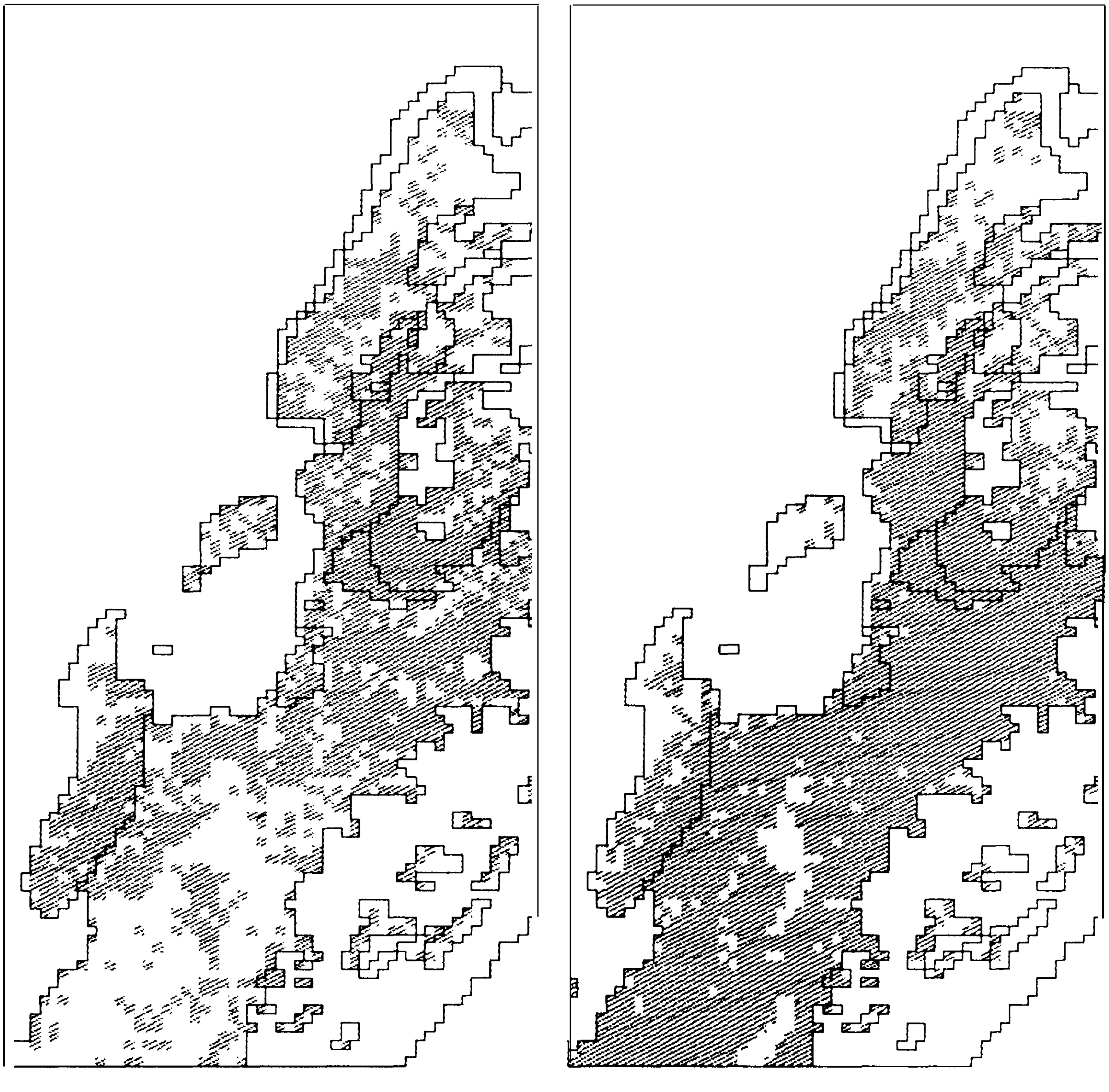
Additionally, BLUS are designed to be hierarchical in structure, representing three dimensional surfaces. They are thus flexible in scale, or resolution. When the element of *time* (satellite data snapshots-in-time, and/or other historic information) is added, they also become four-dimensional. This facet of the BLU concept provides a method to link past and present datasets with predictions of future landscape behavior. Improving methods of relating historic and current environmental data is crucial to identifying past patterns and developing analytic models for predicting change.

Spatial change detection and analysis of ecological responses in BLUS are key to ecosystem monitoring. BLUS can be used to track and evaluate the amount, direction, and rate of responses. The spatial distribution and location of BLUS has been shown to document trends from a patchy to more homogeneous landscape—a measure of *biodiversity.* Detailed site data within BLUS help to identify the reasons for change, and to show if they are related to dramatic impacts or slow trends.

The BLU approach is providing land/ecosystem managers with practical information for day-to-day decisions. There are many data sources now going unused, simply for lack of a frame of reference. GIS and satellite remote sensing can provide such a framework. The Albuquerque office of the BLM expects to expand the four-dimensional concept of BLUs to a global scale to accomplish "global change monitoring" spatially.

Figure B-6 illustrates how BLU monitoring can assist in understanding the relationship between "potential plant communities" and use of

FIGURE B-6: Geographic Information Systems Comparison of Potential Plant Communities in El Malpais National Conservation Area in 1984 and 1988



SOURCE Albuquerque Off Ice of the Bureau of Land Management, 1993 the landscape. A potential plant community is the biotic community that an undisturbed site is capable of supporting, based on the site's physical characteristics. The GIS plots in figure B-6 show outlines of potential plant communities derived in GIS from soils and terrain data. The hatched areas depict a comparable BLU. The left plot displays the BLU in a "snapshot in time" in June 1984. The right plot displays the same BLU in June 1988. There has been a change in the location and size of the BLU indicating a change in ecological response or condition. A larger portion of the site's potential for supporting plant life has been achieved in 1988, the result of less vehicular travel, good vegetation growth in a wet year, and subsequent reduced grazing pressure. With BLUS in GIS we can quickly compare the actual condition of acres of vegetation to their theoretical potential, and determine what may be the "desired" state under various conditions of use. Additionally, proposed land uses can be compared with each other for potential conflicts. The causes of change can then be analyzed in GIS by overlaying specific "natural" layers and "cultural" layers such as roads, oil and gas wells, or range allotments. This simple example shows the power of GIS and satellite remote sensing as a framework and "common ground" for resource analysis.

GIS provides extensive modeling capabilities. All that is required is the desire to think and model spatially—not just in two dimensions, but in three or four dimensions. Dealing with these basic concepts of "space" (geography) includes taking full advantage of Earth-observing space platforms.

# Appendix C: Applications of Remotely Sensed Data for Forestry[1]

Nearly one-third of the land area of the United States, some 737 million acres, is forested. The world's forests account for nearly two-thirds of global photosynthesis. Indeed, forests are complex, long-lived ecosystems that are critical to Earth's ecological well-being. Forests replenish the air, conserve the soil, and maintain its fertility, store water, and serve as a habitat for wildlife. Forest assets provide the necessary wood and fiber products that contribute to a nation's development. Moreover, the world's forests play a critical role in regulating the climate. Forests, therefore, are consequential to the economic, social, and environmental health of all nations.

The need to conserve the planet's forests, balanced against proper use of these resources for development, has increasingly raised concerns about their vitality. Threats to the forests do not rest within the boundaries of any one country; forest problems in one nation can impact the forest resources in another.[2] Today's industrial world has placed varying degrees of stress on both temperate and tropical forests. Be it the ravages of air pollution in the form of acid rain, the unconstrained cutting down of trees for timber, or the clearing of forests for agricultural pursuits—forests are

[1] Prepared by Leonard David, Space Data Resources & Information.

[2] H. Gyde Lund *How to Watch the Forests—IUFRO Guides for World Forest Monatoring*, USDA Forest Service, Washington, DC, 1992 ;see also *Photogrammetric Engineering & Remote Sensing*, Vol. LVIII, No. 8, August 1992. The entire issue is devoted to a national repro on photogrammetry, remote sensing, and geographic information systems in the United States.

considered by many to be under siege. Many believe the ecological consequences of forest loss will have global repercussions.

Satellite remote sensing provides one important technique for monitoring the status of trees and determining the role they play, not only on a local, regional and national level, but also on a global scale. Since the early 1970s civilian spacecraft have provided, in ever-increasing detail, knowledge about the world's vegetation cover—including forests.

The following two sections detail programs that focus on the monitoring of forest reserves. These programs are discussed in broad terms, but should provide the reader an appreciation of the utility of spaceborne remote sensing tools for overseeing the status of the world's forests.

## FOREST INVENTORY

### Forests on Maine's Remote Islands[3]

Thousands of islands dot the coastline of Maine, creating a challenging problem in inventorying and managing the state's coastal forests. Many of the over 3,000 islands are remote, reducing the number of onsitc inventories that can be conducted economically. As a result, past inventories could only approximate the size of Maine's coastal forests. For 100 percent coverage, aerial photography of the islands was considered too expensive and time-consuming. Additionally, many of the islands could not be reached year round by surveying aircraft.

State forestry managers purchased seven SPOT Imagc scenes to create up-to-date maps of the rich spruce forests and other forest lands along Maine entire coastline. The area covered by the images totaled 5,000,000 acres of marine and terrestrial habitaits.Making use of software developed by The Island Institute of Rockland, Maine, planners classified the 20-meter multispectral data gathered by SPOT into 11 land cover types. This information included old growth and younger spruce, hardwoods like maples and oak, other vegetative covers, wetlands, and waterways. The resolution gleaned from the SPOT satellite (one-tenth acre pixels) improved classification accuracy over previous surveys, particularly for smaller islands. Ground truth in accessible locations gave planners assurances they were able to distinguish tree species reliably using the satellite data, allowing them to estimate species acreages by tallying pixels in the computer.

### Vegetation Covering in Bighorn National Forest, Wyoming and Montana[4]

The U.S. Forest Service has used Landsat thematic mapper (TM) data for mapping vegetation covering some 1.2 million acres of the Bighorn National Forest. Using July 1988 TM data purchased from EOSAT, Forest Service personnel mapped specific vegetation types. They merged digitized data from their inventory with the classification and computed acreage summaries of each vegetation class per area. The Landsat data and services cost about $100,000. The Forest Service estimates that an equivalent survey using traditional manual survey methods would have cost at least $500,000.

### Vegetation Classification of Old Growth Forests in New Mexico[5]

The U.S. Forest Service's Nationwide Forestry Applications Program used Landsat TM data to produce a geographic information system (GIS) database containing vegetation characteristics of a portion of the Jemez Mountains in northern New

[3] SPOT FactSheets, 1989- 1991, "*Forest Inventory-SPOT Helps Maine Manage Its Forested Islands.*" SPOT Image Corp., Reston, VA.

[4] *Forest Service Remote Sensing Summary—1991,* compiled by Stan Bain. U.S. Department of Agriculture, Forest Engineering Staff. EM 7140-33, Washington, DC.

[5] Jessica Gonzales et. al., *Vegetation Classification and Old Growth Modeling in the Jemez Mountains*—Santa Fe National Forest New Mexico. Prepared for The Remote Sensing Steering Committee of the USDA Forest Service. Final Repro, May 1992.

Mexico. The study demonstrated that Landsat TM data can provide useful vegetation data for GIS, even when used in the widely varying vegetation conditions in New Mexico. The Forest Service produced relatively accurate crown cover and tree size classifications from Landsat TM data over large areas, although some vegetation characteristics were found to be easier to derive than others. For example, developing accurate estimates of tree size proved to be difficult because of the spatial resolution limitations of Landsat data and the variability of average tree size over the study area.

The study showed Landsat TM data have several desirable qualities as a data source for GIS. Each Landsat TM scene covers a large area (170 kilometers by 188 kilometers); therefore, information derived from Landsat data fills the gaps that may exist in other data bases. For instance, areas with little or no vegetation data, such as large tracts of private land or wilderness areas, may contain information that can significantly affect estimates of distribution and abundance of old growth trees.

Furthermore, the study reported that collection of Landsat TM data is repeatable and consistent through time, which provides for both current and future data needs. Not only can current old growth conditions be assessed, but changes in these conditions can also be detected using Landsat imagery acquired at a later date. Because the data are already in digital form, they provide accessible and flexible data sources for GIS.

## I Conifer Forest Regeneration in the Western Cascade Mountains of Oregon[6]

The Environmental Remote Sensing Applications Laboratory at Oregon State University in Corvallis, Oregon has completed an analysis of conifer forest regeneration using Landsat TM data. Standard forestry practices call for harvested timber areas to be reforested. Once replanted, the reforested areas need continual monitoring to determine their progress.

The laboratory study compared spectral data from well-regenerated Douglas-fir stands with those from poorly regenerated conifer stands. Using the satellite data, poorly-regenerated stands were found to be spectrally distinct from well regenerated Douglas-fir stands after they reached an age of approximately 15 years. The researchers concluded that although TM satellite data were incapable of assessing regeneration in Douglas-fir plantations younger than 15 years, the success in identifying poorly regenerated stands should be high after this initial period.

TM satell ite data were also found to be useful in identifying stages of succession as a forest regenerates and useful for analyzing the condition of wildlife habitat. Herb and shrub stages provide important habitat and forage areas for some wildlife species. Identifying poorly regenerated stands can thus help in estimating wildlife and plant biodiversity.

## Old Growth Forest Monitoring in the Pacific Northwest[7]

The U.S. Forest service has been working with Pacific Meridian Resources of Emery vine, California, to assess a region of forest resources in the Pacific Northwest that has been the site of disputes over environmental, economic, and recreational uses of the forest.

Fourteen layers of GIS data derived from satellite imagery and other sources covering more than 20 million acres of forestland in Washington and Oregon, have been entered into a GIS database. This permits forest managers quick and accurate access to information that should prove useful in resolving management and policy disputes in the area. The GIS layers include: slope of areas, eleva-

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[6] Maria Fiorella, and William Ripple. "Analysis of Conifer Forest Regeneration Using Landsat Thematic Mapper Data," *Photogrammetric Engineering & Remote Sensing*, September 1993, pp. 1383-1388.

[7] Russell G. Conga ton, Kass Green, and John Teply. *'Mapping Old Growth Forests on National Forest and Park Lands in the Pacific Northwest from Remotely Sensed Data," *Photogrammetric Engineering & Remote Sensing,* April 1993, pp. 529-535.

(ions, hydrology, current vegetation type, suitable spotted owl habitat, suitable lands for timber production, habitat conservation areas, forest boundaries, and historical distribution of vegetation and old growth.

The study relied primarily on 12 Landsat TM data that had been geocoded[8] and corrected for the effects of terrain. Study managers also purchased SPOT panchromatic imagery (l O-meter resolution) for use on the Olympic Peninsula. The study demonstrated that a powerful marriage of satellite imagery, GIS, and statistical software is now possible. Fully integrating these disparate capabilities allows researchers to analyze relationships between spectral variation on the image and land-cover variation on the ground.

Because today computers are far more powerful than in prior years, image classifications can be completed in mere hours rather than weeks. This merging of technologies into an integrated whole permits their use by numerous disciplines,—foresters, geographers, and ecologists, among others. Finally, the Oregon work illustrates that the spatial resolution of SPOT imagery and the spectral and spatial resolution of Landsat TM data are high] y desirable compared to earlier multispectral scanner ( MSS) data, and far more useful than the single layer of data that results from traditional aerial mapping.

The Forest Service has concluded it can use the resulting information to address many issues such as:

- fragmentation of old growth and its implications for wildlife habitats;
- developing initial estimates of the biological diversity of forest vegetation;
- and detailing how much old growth acreage is presently in National Parks and wilderness areas.

Perhaps the most important benefit of packaging satellite imagery, GIS, and appropriate software together lies in the ability to model the implications of varying management decisions regarding forests *before they are put into effect.*

## AVHRR Sensors in Forestry Studies[9]

Dedicated Earth remote sensing satellite systems are not the only spacecraft that can provide useful data for forest mapping procedures. A forest cover map for the United States has been created using Advanced Very High Resolution Radiometer (AVHRR) data collected from the sensor aboard the National Oceanic and Atmospheric Administration's NOAA- 11, an afternoon crossing satellite in the Polar-orbiting Operational Environmental Satellite program.

AVHRR data have the advantage that they are collected daily. The satellite passes over the continental United States in early afternoon, collecting five channels of data, ranging from the visible and reflected infrared to the emitted (thermal) infrared portions of the electromagnetic spectrum. They have the disadvantage that AVHRR imagery yields a maximum of only 1.1 kilometer geospatial resolution.

The AVHRR data used in this study were compiled by the Earth Resources Observation Satellite (EROS) Data Center in Sioux Falls, South Dakota, which developed the "normalized difference vegetation index" (NDVI). The NDVI is effective for vegetation classification because it is highly correlated to the amount of vegetation (chlorophyll and leaf reflectance) present and it is relativel y independent of solar and sensor scan angles.

The first phase of the mapping project produced data sets from different seasons: two spring, one summer, and two fall. Each composite covers the lower 48 states of the continental United

[8] I.e., registered to ground control points in such a way that each pixel on the image corresponds to a known geographic location.

[9] Zhiliang Shu, and DavId L. Evans. "Large Scale Forest Land Mapping with AVHRR Data—A Support Project for the 1993 RPA Update," presented at the Fourth Biennial USDA Forest Service Remote Sensing Application Conference, Orlando, Florida, April 6- I(J, 1992. Also, "Summary of Forest Type Mapping procedures For RPA Purposes at SO-FIA." Provided by Roy Beltz of U.S. Forest Service, Southern Forest Experimental Station, Starkville, MS.

States. A second phase of the mapping project began in 1993 to support the U.S. Forest Service's Resources Planning Act (RPA) update.

Use of AVHRR data---combined with Landsat TM data—is expected to augment continental and global resource surveys and climatological models. The AVHRR images have already been used to derive forest-density values and forest types, particularly in the Midsouth. The AVHRR maps are expected to provide unprecedented detail on forest cover distributions of the United States.

## Utility of GIS and GPS for Forest Management[10]

Geographic information system (GIS) technologies and Global Positioning System (GPS) satellites have enhanced the utility of satellite remote sensing for forestry management. For instance, GPS and SPOT digital imagery was used in a GIS database to classify 16 vegetation types within the 69,000 acre Everglades National Park, near Homestead, Florida. National Park Service managers wanted to understand how plant cover in the slash pine forests of the Everglades affects tire management practices.[11]

GPS was used to geocode the SPOT imagery, as well as navigate to sites within the study area for ground-truthing the vegetation classifications. The availability of GPS signals made ground-truthing 30 randomly chosen locations hundreds of meters apart much easier, as many of the sites were kilometers from the nearest road and hidden by thick underbrush.

Using a GPS data receiver, researchers verified the accuracy of both the standard U.S. Geological Survey quad map of selected areas and the SPOT Image geocoded image. They used GPS readings of 16 identifiable features within the Everglades, such as surveying benchmarks, roads, and plant community boundaries. At the selected sites, field analysts recorded pertinent plant community information for comparison with the computerized vegetation classification yielded by satellite imagery. The merger of satellite imagery and GPS proved invaluable in creating and updating GIS databases quickly and accurately. Doing so saved time and money compared to the use of traditional methods such as field surveying and aerial photography.

In the GIS arena, the U.S. Forest service has made use of SPOT 10-meter panchromatic imagery coupled to a GIS database to update forest vegetation maps. The Forest Service requires these updates to show harvest activities and areas affected by fires, as well as the location of conifer plantations. One area in need of updating was primarily confined to Six Rivers National Forest and the western portions of Klamath and Trinity National Forests.[12] SpOT imagery in the form of SPOT QuadMaps was selected to meet the 1:24,000 scale requirement and was chosen over aerial photography because the necessary imagery could be obtained in a timely manner and within budget for these large forested areas.

The images were incorporated into a database derived primarily from 1980 aerial photography. The newer data were used to create a "change layer" GIS database indicating areas harvested, those touched by fire, locations of new plantings compared to old growth forests, and roads accessing new clearcut locales.

This updated GIS database assisted the U.S. Forest Service in managing forest lands, planning timber sales, inventorying forests, and selecting suitable habitats for wildlife. Furthermore, this

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10 Paul V. Bolstad, "GPS Basics: Forestry Applications," 7-he *Compiler*, A Forest Resources Systems Institute Publication, vol. 11, No. 3, Fall 1993, pp. 4-8.

11 "SPOT and GPS—Space Technologies for Down-to-Earth Applications, " SPOT Image Cm-p., Reston, VA, 1991.

12 .. Map and GIS Updating for the U.S. Forest Service—-SPOT Shows a New View of Old Growth in California's Douglas Fir Region," SPOT Image Cm-p., Reston, VA, 1990

GIS database can now be updated more cost-effectively.

The Forest Service has provided yet another demonstration of remote sensing and GIS use in the Tongass National Forest in Alaska. Beginning in 1984, the Forest Service created GIS databases by digitizing field maps and aerial photographs taken in the early 1980s to help establish a forest management plan. Later. to update and enhance the accuracy of the maps, it used geocoded, ortho-corrected SPOT imagery in 15 minute x 20 minute quadrangles. Using the satellite and GIS data, the Forest Service found almost 30 percent of the land, covering over 2.5 million acres of forest, had been previously miscoded in terms of clearcut size, unmapped clearcuts, and forests mapped as clearcuts. The errors had little effect on the overall statistics, because they tended to cancel each other, but these data flaws were not known prior to use of the satellite data.

Combining satellite imagery and a GIS database delivered ready-to-use information for one-seventh the cost and in about one-tenth the time required for aerial photo prints. Previously. the U.S. Forest Service updated the Tongass National Forest site every 10 years, due to the expense involved and necessary time needed for the update. using satellite and GIS data sets, The forest Service now plans to update their databases of the area every three years, to better manage this forest asset.

## FOREST PROTECTION

### Gypsy Moth Damage in the Shenandoah

SPOT imagery of Shenandoah, Virginia was acquired by the U.S. Forest Service for four consecutive years, starting in 1987. The images were collected as part of the Forest Service's 13.5 million acre pest management project. The focus of the project was to monitor defoliation by gypsy moths and assess the effectiveness of eradication techniques in the national forests of Virginia and West Virginia. The project defined a procedure that delineates forest susceptible to gypsy moth attack. The approach taken in the project also involved the "masking out" of nonsusceptible forests and areas with clouds or cloud shadows for a given year. A vegetation index was calculated for the susceptible forests with a range of index values describing each defoliation class. Spatially processing and "clumping" the pixel data allowed restoration of the data, facilitating GIS coverage.

Use of satellite imagery for the project replaced field and aerial photographic surveys. These techniques were considered too inefficient, inaccurate, and time consuming to be effective in tracking the gypsy moth—a fast-acting pest. A single SPOT scene allowed investigators to identify and map defoliation up to 25 times more quickly than aerial photography, according to SPOT officials.

On the other hand, the U.S. Forest Service notes that the cost of geocoded terrain-corrected SPOT imagery at $2.60 per square mile is somewhat higher than the average project cost for NASA photography at $2.00 per square mile, although still less than the cost of conventional photography. Using SPOT is now considered a viable technique for gathering relatively detailed defoliation information for areas of up to 10,000 square miles. By comparing year-to-year SPOT images, the effects of a topographical y controlled appl ication of pesticide to control the gypsy moth population could be assessed.

### 1 Deforestation Monitoring

Portions of Brazil tropical forests are being eradicated due to population growth. The Amazon Basin, in particular, has been under stress due to the encroachment of people. To monitor the growth of deforestation patterns in the area, a combination of satellite data sets have proven useful.

As an example, the coarse resolution of AVHRR from NOAA polar-orbiting meteorological satellites can spot fires and smoke in the rain

[13] "Tongass National Forest—SPOT Fills the Information Void, " SPOT Image Corp., Reston, VA., 1991.

forest. AVHRR images cover a land area of approximately 260,000 square kilometers. In 1993, NASA and the seven Central American nations began a program to preserve and protect that region's rain forest by expanding use of AVHRR satellite data by Central American scientists.

For a more exacting view of deforestation patterns, Landsat and SPOT satellites are used. In the case of SPOT, the spacecraft's 20-meter resolution multispectral imagery can assess exact levels of deforestation. A typical SPOT image of a deforested area is 60 x 60 kilometers. SPOT data is of such clarity as to delineate vegetated and non-vegetated parcels of land--data useful in the existing AVHRR classification scheme. Use of SPOT can denote individual clearings that rarely approach the size of a single AVHRR 1 -kilometer pixel. Typical clearings range only from 10 to 20 percent of this size.

The use of Landsat imagery has proven effective in the Pan Amazonia Project. Institutions of several Amazon countries, including Bolivia, Colombia, Ecuador, Peru, Venezuela, and the Guianas have coordinated efforts to gather near wall-to-wall coverage of the countries participating.

U.S. Landsat imagery was used in the survey taken in two time periods: from 1984 to 1987 and from 1988 to 1991. The project was directed by the National Institute for Space Research (NIPE), of the Secretariat of Science and Technology of the Presidency of the Republic of Brazil.

The focus of the project was to determine the extent of gross deforestation in the sequence of Landsat surveys. This data was then used to estimate the annual rate of gross deforestation in Brazilian Amazonia between consecutive surveys.

A survey of the entire Legal Amazonia—which covers 5 million square kilometers-consisted of hundreds of black-and-white images and color composites taken by Landsat multispectral scanner and thematic mapper sensors. Both dense tropical forest and thick savannah were surveyed.

Data presented in 1992 showed that the peak of deforestation in the region in the second half of the 1980s was much less severe than higher estimates projected by some groups, such as the United Nations Forest Resource Assessment, which indicated more than 80,000 square kilometers per year were lost to deforestation. Using the Landsat satell ite survey, estimates of the mean rate of deforestation were lowered to 21,500 square kilometers.

The results of the Brazilian Amazonia work was corroborated by independent analysis completed at the University of New Hampshire in Durham. That assessment also made use of Landsat thematic mapper data and was presented in May 1992 to the World Forest Watch, a conference held in Sao Jose dos Campos, Brazil.

## Integrating Forest Monitoring Surveys

The Tropical Ecosystem Environment Observations by Satellites (TREES) project is considered by many to offer the best evaluation of satellite remote sensing of forestry assets. TREES is jointly carried out by the European Communities' Joint Research Centre in Ispra, Italy and the European Space Agency (ESA). A first phase of TREES was concluded in 1993.

The objectives of the TREES project are two-fold:

1. to provide quantitative space data sets and information on the spatial distribution and temporal evolution of the tropical ecosystems (e.g., rate of change in forest cover, forest cover, biomass burning) for an improved scientific assessment of their impact on global climate change issues, such as the greenhouse effect; and
2. to establish an integrated satellite observational program for a long-term, continuous and operational monitoring of forest cover and rate of deforestation in the tropical regions to provide for the implementation of various European Communities policies.

Under assessment in the TREES endeavor is the value of ESA's ERS- 1 Synthetic Aperture Radar to provide data useful in monitoring tropical forest vegetation. A test image was displayed for the first time at the May 1992 World Forest Watch, making use of ERS- 1's radar to show deforestation in the Amazonian rain forest. The test image clearly shows rectangular patches of destroyed forest extending over areas as large as 20 square kilometers.

TREES research has concentrated on the use of low resolution AVHRR data generated by the polar-orbiting NOAA satellites of the Tires series. This AVHRR data provides 1 -kilometer resolution, as well as 4-kilometer resolution for global area coverage, to assess changes in tropical forest canopy.

The first phase of the TREES project involved use of NOAA AVHRR data at 1-kilometer resolution to assemble "wall-to-wall" coverage of Southeast Asia. This tests the feasibility of analyzing the low resolution multi spectral data set for forested areas where both evergreen and seasonal formations are to be found. A similar assessment of West Africa was completed in 1990. The results of these studies are to be integrated into a Tropical Forest Information System.

AVHRR image analysis for the TREES effort is grouped into several categories that permit a spectral study of differences and contrasts between forest features; a spatial assessment of textural forest features, such as patterns; temporal discriminators, such as seasonality: and indicators of deforestation, such as fires and roads.

The analysis of 1 -kilometer resolution multispectral AVHRR data will be later compared with 4-kilometer resolution AVHRR data, as well as high resolution images produced by Landsat and SPOT spacecraft. This work will be undertaken by scientists at the European Communities Joint Research Centre in Ispra.

### *For Further Information*

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D

# Appendix D: Quantitative Products from Satellite Observational

Interpreting clouds from satellite pictures was the first application of remotely sensed data from environmental satellites in the early 1960s. Satellite image interpretation is still critical today for monitoring weather patterns, severe storms, snow and ice fields, flood coverage, biomass burning, volcanic ash dispersion, and numerous other applications. High and low resolution satellite imagery are received by users worldwide in real time through local ground receivers and by central processing facilities where the image data are further processed into quantitative products.

Three operational satellite systems provide continuous views of the Earth-the Geostationary Operational Environmental Satellite (GOES) and the polar-orbiting National Oceanic and Atmospheric Administration (NOAA) satellites, both operated by NOAA; and the Defense Meteorological Satellite Program (DMSP), operated by the Department of Defense (DOD). NOAA and DOD work closel y together in exchanging data from their respective programs. The two most common modes of receiving real time NOAA polar imagery are through the Automatic Picture Transmission (AFT) and High-Resolution Picture Transmission (HRPT) direct broadcast systems.

APT and HRPT require receiving antennae that acquire imagery at ground resolutions of 4 kilometers and 1.1 kilometers, respectively. Geostationary satellites provide similar direct broad

[1] Arthur L. Booth, National Oceanic and Atmospheric Administration/National Environmental Satellite, Data, and Information Systems.

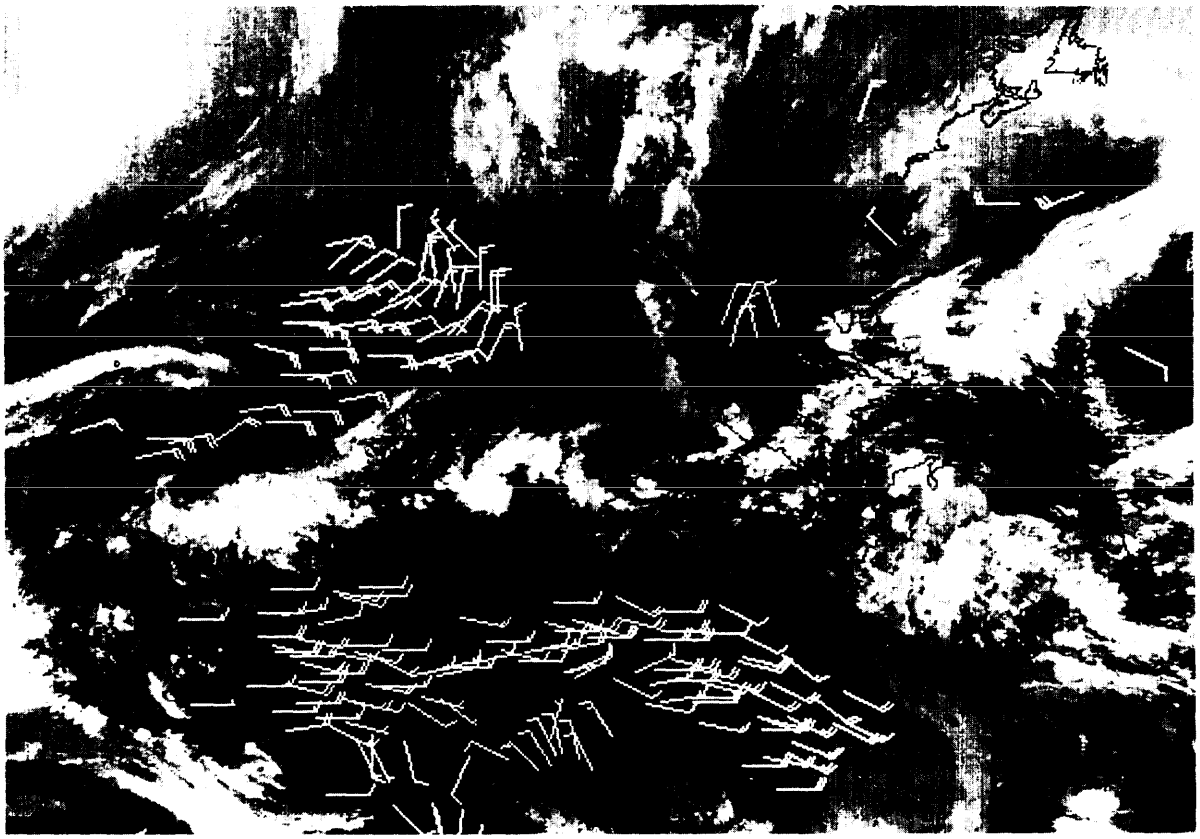


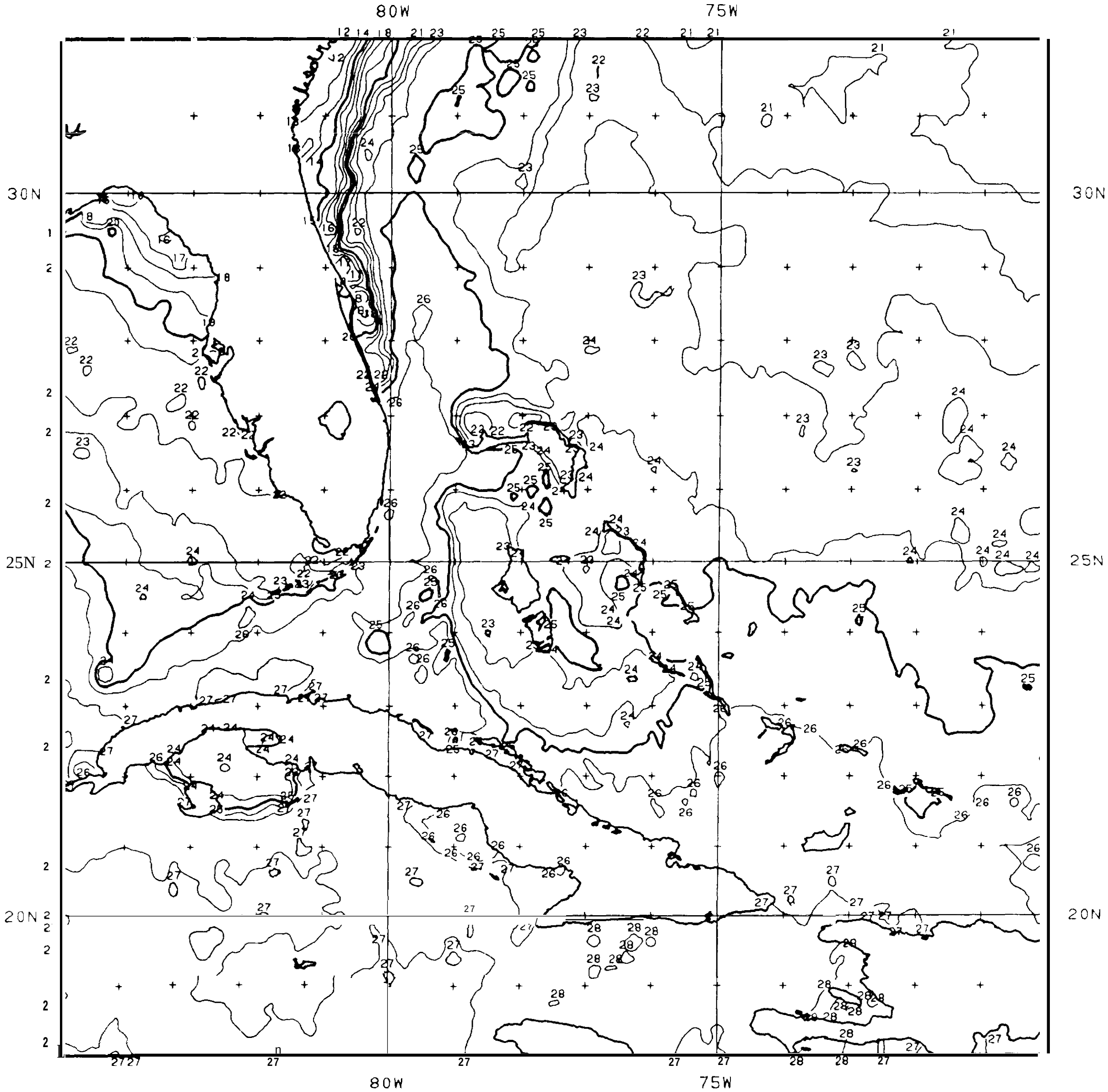
*Image of cloud cover and derived wind speeds from GOES-7, 19 May 1994*

cast services through Weather Facsimile (WEFAX) and regularly scheduled (normally every half-hour) direct transmissions.

In addition to collecting cloud and surface imagery, environmental satellites also provide global data used in generating quantitative products for numerical weathcr prediction models, assessments, and analyses of the oceans, atmosphere, coastal zone and land areas. NOAA currently produces about 80 quantitative satellite products on an operational basis. Many products are generated in special formats, grids, and projections to meet operational and research requirements for global, regional, and local applications. Moreover, many quantitative products have been produced on a routine operational basis from NOAA satellites since the late 1970s. resulting in one of the largest and longest continuing time series of satellite-derived global measurements in the world. These products provide important sources of global data in climate and global change studies.

Although the majority of products currently produced are derived from NOAA polar-orbiting operational data, important quantitative products are also developed from research satellites (e.g., NIMBUS and Upper Atmosphere Research Satellite (UARS) managed by the National Aeronautics and Space Administration (NASA).

Quantitative products have been made possible over time by improvements in sensor resolution, spectral coverage (e.g., infrared and microwave), and ground coverage in successive generations of satellite programs. Routine production of quantitative products from operational satellite observations started in the early 1970s with the Improved TIROS Operational System (ITOS) and improved considerable y with the launch of the current NOAA series in 1978.




NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, 1994

*Sea surface temperature (SST) contours around Florida, the Bahamas, and Cuba, derived from the AVHRR sensor aboard a* NOAA *POES* satellite on *Feb. 2, 1993. Increasing numbers indicate increasing temperatures (degrees centigrade).*

Satellite products are typically generated at central automated processing facilities where the full-resolution data are received from satellite readout stations and processed through a series of steps commonly designated as Levels 1, 2, and 3. Each level results in the creation of a digital data set, or product, with data volumes decreasing with each higher level of processing. Level 1 is a pre-processing step in which the raw satellite data are ingested and formatted into sensor-specific data sets with calibration, Earth-location, and quality control information appended to the data set. A global, 24-hour, Level 1 data set contains on the order of hundreds of millions of bytes of data. The next step, Level 2, uses statistical or physically based retrieval algorithms to transform the raw satellite data into geophysical products at satellite observation locations. For example, NOAA produces global sea surface temperatures on an 8-kilometer grid and global ozone measurements on a 200-kilometer grid. A typical global Level 2 product contains on the order of tens of millions of bytes of data. Level 3 products usually involve interpolation and analysis and are generally mapped to standard global or regional map projections and grids. For example, NOAA maps some products depicting aerosol concentrations into 10-degree latitude and longitude grids. A typical Level 3 product contains approximately several hundred thousand bytes of data and is in a format most accessible to the user community. NOAA performs its validation of satellite measurements in most Level 2 and 3 processing steps. Validation involves merging and intercomparing satellite measurements with conventional meteorological and geophysical data (e.g., surface-based radar, radiosonde ascents, ocean buoys, and rain gauges).

All quantitative products require special processing to correct for clouds, the atmosphere, seasonal changes, the sun-Earth-satellite geometry, and sensor calibrat ion degradation and anomalies. Two important automated processing functions (usually done in Level 2 processing) are “cloud clearing” and atmospheric attenuation. A “cloud clearing” step is necessary to identify an observation as either clear, partly cloudy, or cloudy. The information is critical for surface variables that require cloud-free, or clear-view, satellite observations, such as sea surface temperature and vegetation measurements, However, atmospheric variables such as temperature profiles and outgoing longwave radiation also require accurate cloud detection and estimates. NOAA averages some surface products, such as vegetation and sea ice measurements, over a 7- to 10-day period to insure removal of all cloud effects. Also, satellite-derived measurements must be corrected for the effects of the intervening atmosphere (attenuation) resulting from atmospheric gases (e.g., water vapor) and aerosols (e.g., dust and volcanic ash).

NOAA transmits satellite data and derived products in real time to operational users through dedicated networks. Many of the products are transmitted to customers over worldwide networks, such as the Global Telecommunications System (GTS). For researchers and the general user community, all satellite data and products are available through NOAA’s three National Data Centers—the National Climatic Data Center, the National Geophysical Data Center, and the National Oceanographic Data Center. NOAA is currently improving access to its satellite data holdings by providing users with online access and services to data browse and inventory information, and data set downloading on the Internet.

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# F Appendix F: Acronyms and Abbreviations

| | |
|---|---|
| ADEOS | Advanced Earth Observing Satellite |
| 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 |
| ARGOS | Argos Data Collection and Position Location System |
| ARM | Atmospheric Radiation Monitor |
| ARPA | Advanced Research Projects Agency |
| ASCAT | Advanced Scatterometer |
| ASF | Alaska SAR Facility |
| ASTER | Advanced Spaceborne Thermal Emission and Reflection Radiometer |
| ATLAS | Atmospheric Laboratory for Applications and Science |
| ATMOS | Atmospheric Trace Molecules Observed by Spectroscopy |
| ATN | Advanced TIROS-N |
| AVHRR | Advanced Very High Resolution Radiometer |
| AVIRIS | Airborne Visible Infrared Imaging Spectrometer |
| AVNIR | Advanced Visible and Near-Infrared Radiometer |
| CCDS | Center 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 |

| | |
|---|---|
| CNES | Centre National d'Études Spatiales |
| CNRS | Centre National de la Recherche Scientifique |
| COSPAR | Congress for Space Research |
| CSA | Canadian Space Agency |
| CZCS | Coastal Zone Color Scanner |
| DAAC | Distributed Active Archive Center |
| DARA | Deutsche Agentur fur Raumfahrt-Angelegenheiten |
| DCS | Data Collection System |
| 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 |
| 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 Nine/Southern Oscillation |
| EOC | EOS Operations Center |
| EO-IG-WG | Earth Observation International Coordination Working Group |
| EOS | Earth Observing System |
| EOS-AERO | EOS Aerosal 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 |
| 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 |

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|---|---|
| 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 |
| HIRIS | High-Resolution Imaging Spectrometer |
| HIRS | High-Resolution Infrared Sounder |
| HIS | High-Resolution Interferometer Sounder |
| HRMSI | High-Resolution Multispectral Imager |
| HRPT | High-Resolution Picture Transmission |
| HSST | House Committee on Science, Space, and Technology |
| HRV | High-Resolution Visible |
| IAF | International Astronautical Federation |
| IELV | intermediate-class expendable launch vehicle |
| IEOS | International Earth Observing System |
| ICSU | International Council of Scientific Unions |
| IGBP | International Geosphere-Biosphere Program |
| ILAS | Improved Limb Atmospheric Spectrometer |
| IMG | Interferometric Monitor for Greenhouse Gases |
| INSAT | Indian Satellite |
| 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 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 |
| 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 |
| MIPAS | Michelson Interferometer for Passive Atmospheric Sounding |
| MISR | Multi-Angle Imaging Spectroradiometer |

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|---|---|
| MITI | Ministry of International Trade and Industry |
| MLS | Microwave Limb Sounder |
| MODIS | Moderate-Resolution Imaging Spectroradiometer |
| MODIS-N | Moderate-Resolution Imaging Spectrometer-Nadir |
| 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 |
| 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 |
| 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 | Search and Rescue Satellite Aided Tracking |
| 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 |
| SMS/GEOS | GEOS synchronous meteorological satellite |
| SNR | signal-to-noise ratio |
| SOLSTICE | Solar Stellar h-radiance Comparison Experiment |
| SPOT | Systeme pour l'Observation de la Terre |

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|---|---|
| SSM/I | Special Sensor Microwave/Imager |
| SSTI | Small Satellite Technology Initiative |
| Ssu | Stratospheric Sounding Unit |
| STIKSCT | Stick Scatterometer |
| SWIR | Short Wave Infrared |
| TDRSS | Tracking and Data Relay Satellite System |
| 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 |
| TUSK | Tethered Upper Stage Knob |
| UARS | Upper Atmosphere Research Satellite |
| UAVS | Unpiloted aerospace vehicles |
| UNEP | United Nations Environment Program |
| UNESCO | United Nations Educational, Scientific, and Cultural Organization |
| USAID | U.S. Agency for International Development |
| 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 |

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