Toward New Partnerships In Remote Sensing: Government, the Private Sector, and Earth Science Research

Steering Committee on Space Applications and Commercialization, National Research Council

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Toward New Partnerships In Remote Sensing

Government, the Private Sector, and Earth Science Research

Steering Committee on Space Applications and Commercialization

Space Studies Board

Division on Engineering and Physical Sciences

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3. Moderate Resolution Imaging Spectroradiometer (MODIS) image showing levels of chlorophyll fluorescence in phytoplankton in the Arabian Sea. SOURCE: Scientific Visualization Studio, NASA Goddard Space Flight Center.

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Preface

The technical, scientific, policy, and institutional environment for conducting Earth science research has been changing rapidly over the past few decades. Changes in the technical environment are due both to the advent of new types and sources of remote sensing data, which have higher spatial and spectral resolution, and to the development of vastly expanded capabilities in data access, visualization, spatial data integration, and data management. The scientific environment is changing because of the strong emphasis on global change research, both nationally and internationally, and the evolving data requirements for that research. And the policy and institutional environment for the production of Earth observation data is changing with the diversification of both remote sensing data and the institutions that produce the data. In this report, the Space Studies Board's Steering Committee on Space Applications and Commercialization explores the implications of this changing environment, examining the opportunities and challenges it presents.

As part of its data-gathering activities, the steering committee convened a workshop, "Remote Sensing and Basic Research: The Changing Environment," in March 2001 at the National Academies' facilities in Washington, D.C. The objectives were to identify and explain the opportunities and barriers to scientific research and the science policy issues that stem from the increased emphasis on commercialization of remote sensing data for scientific research; identify the range and types of users and those who are affected by the changing environment of remote sensing; and facilitate information exchange and discussion of existing and potential remote sensing applications among the science community, commercial firms, and members of federal and local government agencies. The second in a series of three workshops organized by the steering committee, the March 2001 workshop provided a forum for discussion of the changing environment and evolving collaboration among researchers, government, and data providers. It brought together representatives of academia, the government, and the commercial remote sensing sector for one and a half days of presentations, panel discussions, and topical breakout sessions.[1]

The steering committee's first workshop, held in May 2000, focused on the development of applications of remote sensing data and the nature of technology transfer in that development. The third and final workshop will focus on issues related to the adoption and use of remote sensing data by state and local governments. *Transforming Remote Sensing Data into Information and Applications*[2] was published as the first of three reports that draw, in large part, on the respective workshops.

The purpose of the current report, the second in the series, is to summarize the critical issues and perspectives most relevant to understanding the relationships evolving among and between the scientific community and data providers in the public and private sectors in the United States. The report aims to enhance understanding of these relationships so that they can be improved where needed, advanced where appropriate, and strengthened so as to improve the resources available for basic research. It focuses primarily on public and private sector interactions and relationships for the production and delivery of *satellite* remote sensing data for scientific research. Such relationships can include public-private partnerships, redistributor-end user relationships, and those involving "anchor tenancy" (advance purchases of data from companies developing remote sensing systems). The steering committee uses the generic term "public-private partnerships" to describe all of these relationships.

Although it recognizes that the long and successful commercial experience in aerial remote sensing provides valuable data for research and applications, the steering committee regards it as a type of enterprise that is, by virtue of its small capitalization requirements and scale of operation, essentially different from the

[1]The workshop was attended by a broad spectrum of scientists from academia and private industry; officials from federal agencies; representatives from not-for-profit organizations; and commercial photogrammetry, commercial remote sensing, and value-added companies (see Appendix C). Sponsorship for the workshop was provided by National Aeronautics and Space Administration (NASA) headquarters, NASA Stennis Space Center, the National Oceanic and Atmospheric Administration's National Ocean Service and National Environmental Satellite and Data Information Service, the Environmental Protection Agency, the U.S. Department of Transportation, the U.S. Army Corps of Engineers, and the U.S. Geological Survey.

[2]Space Studies Board and Ocean Studies Board, National Research Council, *Transforming Remote Sensing Data into Information and Applications,* Washington, D.C., National Academy Press, 2001.

emerging commercial satellite remote sensing industry. Moreover, the changes in the remote sensing environment that motivated this report and have stimulated the development of new types of public-private partnerships are occurring largely in the world of satellite remote sensing. Nevertheless, aerial remote sensing firms that are involved in public-private partnerships to provide data for scientific research, such as those firms participating in the National Aeronautics and Space Administration's (NASA's) Science Data Buy, were included in the workshop presentations and discussions and are reflected in this report.

The steering committee focused on public-private partnerships both because of the current national policy emphasis on such partnerships and because two multiyear public-private partnerships now exist to provide remote sensing data for scientific research and thus can serve as case studies of how such partnerships work. An alternative approach, such as examining the scientific impacts of the use of commercial satellite remote sensing data for science, was not feasible because of the short time frame in which purely commercial remote sensing data have been available. At the same time, the steering committee found that its examination of public-private partnerships to provide remote sensing data for scientific research raised many of the issues that might be anticipated in looking at the role of purely commercial firms in providing scientific data. In particular, the steering committee's examination of public-private partnerships highlighted basic differences in the ways that commercial and scientific enterprises function and potential problems resulting from those differences.

Workshop and steering committee discussions focused on the provision of civil remote sensing data, because it is in the civil sphere that legislative and administrative policy has attempted to foster new types of partnerships to provide data for scientific research. NASA is the government agency most deeply involved in public-private partnerships for producing Earth observation data for research, but the term "government" rather than "NASA" is used in this report to describe these activities, because other government agencies may become involved in such partnerships in the future. The international implications of public-private relationships in remote sensing, which were not the focus of this report, should also be examined as the remote sensing environment evolves.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of the report:

Francis Bretherton, University of Wisconsin, Madison,
Curtiss Davis, Naval Research Laboratory,
Samuel Goward, University of Maryland, College Park,
David Linden, DSL Consulting, and
Earnest D. Paylor II, Pacific Disaster Center.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by William J. Merrell, Jr., H. John Heinz III Center for Science, Economics, and the Environment. Appointed by the National Research Council, he was responsible for making certain that an independent

examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Executive Summary

Earth science research has been significantly enhanced over the past several decades through the use of satellite remote sensing data. Advances in the spatial and spectral resolution of civil satellite data and the accumulation of these data over multiple time periods have made it possible for scientists to examine new types of research problems and environmental changes at both global and local scales. Although remote sensing data were initially obtained by scientists through satellites developed and launched by federal science agencies, the institutional landscape for the production of remote sensing data has become more diverse, with both government and the private sector actively involved in providing data for science. In addition, public-private partnerships have been established in which the government and the private sector work together to provide data for research; and, since the advent of operational sources of commercially produced data, remote sensing data for scientific research are also produced in the private sector itself. This diversification has been encouraged and fostered by the U.S. government through both congressional and executive branch action. Together, these forces have contributed to a changing environment for remote sensing and Earth science research.

The Steering Committee on Space Applications convened a workshop in March 2001 to explore the implications of the changing environment and the new relationships among researchers, government, and private sector remote sensing data providers. Its purpose was to examine such issues as scientific requirements for data obtained from the private sector, the distribution of scientific data obtained from private sector sources, continuity and permanent archiving of scientific data, data cost and access, and intellectual property considerations in the use of data obtained from the private sector (see Chapter 4). The steering committee oriented the workshop, entitled "Remote Sensing and Basic Research: The Changing Environment," to issues related to public and private sector relationships and interactions involving commercially provided remote sensing data for scientific research. Attended by scientists, officials of federal science agencies, and representatives of the private sector, the workshop focused on the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) program and the National Aeronautics and Space Administration's (NASA's) Science Data Buy (SDB),[1] public-private sector interactions that have been ongoing for several years in the United States.

This report draws heavily on information from a workshop planning meeting with agency sponsors, on information presented by workshop speakers and by participants in breakout group discussions, and on the expertise and viewpoints of the members of the Steering Committee on Space Applications and Commercialization. It addresses domestic and civil issues related to public-private sector partnerships for remote sensing data. The recommendations are the consensus of the steering committee and are not necessarily those of the workshop participants.

The primary focus of this report is on public-private sector relationships and interactions for the production and delivery of *satellite* remote sensing data for scientific research. Such relationships could include public-private partnerships; redistributor-end user relationships; and "anchor tenant" relationships, in which the public sector guarantees that it will be a customer of commercial remote sensing enterprises. The steering committee uses the generic term "public-private partnerships" to describe all of these relationships.

Government and the private sector have come together on several previous occasions to produce remote sensing data. The relationship between Radarsat 1 and Radarsat International in Canada is that of a joint public-private venture, as is the relationship between System pour l'Observation de la Terre (SPOT) satellite and Spot Image company in France; and in the United States, the federal government privatized the Landsat remote sensing program through a commercial operator, Earth Observation Satellite Company (EOSAT), during the mid-1980s and early 1990s. These arrangements were devised to make it possible to market the data commercially, and the more recent SeaWiFS and SDB programs provide remote sensing data to scientists.

The steering committee found significant differences in the operating practices and goals of the three groups—government, the private sector, and the scientific community—involved in public-private partnerships. Because the government is publicly accountable for all its actions, it must operate in a complex

[1]The NASA Science Data Buy is also known as the NASA Science Data Purchase. In this report the steering committee refers to the program as the Science Data Buy.

regulatory environment. Government agencies are also subject to the policy and fiscal priorities of both the White House and the U.S. Congress. (Although both of the public-private partnerships examined at the workshop were conducted by NASA, this report speaks of the government sector as a whole, since other government agencies may become involved in public-private partnerships for data in the future.) Private sector firms engaged in the development of satellites must recover their investment costs and make a profit, and, as a consequence, they must perceive a new public-private partnership to be financially viable before they will take part in it.

Government acquisition of scientific data for research through an agreement with the private sector involves more than a simple commercial transaction. The partnership of entities with such dissimilar modes of operating inevitably raises complex issues related to how the new organization should function. Differences between the government and the private sector complicate negotiations on intellectual property and licensing agreements related to the use of privately owned remote sensing data, on data management and data continuity, on the development of measures of performance for public-private partnerships, and on realistic cost accounting in these partnerships (see the section below, "General Conclusions and Priority Issues"). These complications are heightened when the partnership is created to serve the needs of a third group—in this case, scientists, who have their own requirements. According to scientists at the workshop, having access to the high-resolution and other commercially produced remote sensing data available through public-private partnerships is extremely valuable and makes new types of research possible. However, scientists also value the free and open exchange of scientific data; the capacity to validate scientific results through reanalysis of the data; the calibration, validation, and verification of satellite data to ensure accuracy; long-term stewardship of data for future research; and continuity of the data over multiple points in time. The intersection of scientific and commercial interests in public-private partnerships can pose challenges to meeting these requirements.

It is not yet clear whether public-private partnerships will become the model for future institutions or are merely a temporary arrangement for obtaining data for research. It is clear, however, that existing public-private partnerships are valuable mechanisms for acquiring data that may not otherwise have been available to scientific researchers, that such partnerships have many advantages, and that they can be improved. Despite differences among the partners, clear benefits can be gained through their collaboration. The two public-private partnerships discussed at the workshop were instructive in terms of identifying both ways to meet the needs of commercial, government, and scientific participants in future partnerships and ways of improving how such partnerships function.

FINDINGS AND RECOMMENDATIONS

Licensing

Finding. Full and open access[2] to data and the opportunity both to replicate research findings and to conduct further research using the same data are critical to scientific research. Because private sector firms view their data as intellectual property, there may be additional costs or intellectual property problems in reusing the data for scientific research. The steering committee found that the Science Data Buy was, in fact, a "science data license." Rather than purchasing the data, the government obtained licenses or data property rights from those commercial companies that specified terms for use of the data. This raises intellectual property issues related to the subsequent redistribution and archiving of the data according to standard scientific practices.

Recommendation 1. The government partner in a public-private partnership should negotiate in its contract for open scientific distribution and reuse of data obtained under the partnership.

Evaluation of Public-Private Partnerships for Science Data

Finding. Two public-private partnership programs for science data—Sea-viewing Wide Field-of-view Sensor and Science Data Buy—have been in operation for several years, and the initial phases of one of them, the SDB, have been completed. Formal program evaluation will help the government assess existing operations and understand how best to structure future programs.

Recommendation 2. A formal, independent review of the Science Data Buy and of the SeaWiFS program should be conducted to evaluate the scientific benefits and the efficacy and economic benefits of each partnership to the parties involved.

Broadening Participation of Scientists in the Science Data Buy

Finding. All scientists at U.S. academic institutions should be able to compete for data from NASA's Science Data Buy. Participation in the SDB is limited to current NASA grantees, but other academic scientists could usefully participate in the program.

[2]Several policy statements guarantee full and open access to government and scientific data. See National Research Council, *Resolving Conflicts Arising from the Privatization of Environmental Data*, Washington, D.C., National Academy Press, 2001, p. 18.

Recommendation 3. NASA should permit any academic scientist to compete for data under the Science Data Buy or successor programs.

Data Continuity

Finding. Continuity of remote sensing observations over long periods of time is essential for Earth system science and global change research, and it requires that scientists have access to repeated observations obtained over periods of many years. Data obtained through public-private partnerships could continue to be useful as historical or "heritage" data. As scientists expand their use of data from both public and private sources, problems may arise in combining remote sensing data from multiple sensors with different capabilities and characteristics. Research on sensor intercomparisons is necessary to ensure that data from multiple sources can be exploited for future, time-series research. This approach is preferable to that of maintaining older technologies to assure continuity.

Recommendation 4. Existing remote sensing data series—for example, the Landsat series—within current or anticipated public-private partnerships should be maintained to provide comparable data for scientific research over time. Support should also be made available for research in either the scientific community or the private sector or both on how to generate seamless transitions from one data source to another as new sensors replace past or current sensors.

Archiving

Finding. Scientific data obtained through public-private partnerships must be available for future use through data centers and permanent archives. Since the government obtains a license for scientists to use data under existing public-private partnerships rather than purchasing the data, there are intellectual property issues related to depositing these data in open scientific archives. Archives and data centers should include data and relevant metadata that are amenable to reprocessing after algorithms have been improved.

Recommendation 5. Data produced by the private sector in a public-private partnership should be archived for subsequent redistribution to scientists and for creating long time series of data. The government partner should negotiate for permission to do this.

Calibration, Validation, and Verification

Finding. Scientists require instrument characterization and data calibration to physical units with quantified uncertainty. Access to calibrated data is an essential precondition for many scientific uses of remote sensing data, to ensure the quality of the data and to ensure that data sets differing in spatial, temporal, or spectral coverage, or acquired by different instruments, are comparable. In public-private partnerships, the government has often assumed responsibility for calibration, validation, and verification. The steering committee commends the government's role in providing excellent calibration, validation, and verification of commercially obtained remote sensing data for scientific use.

Recommendation 6. Public-private partnerships to acquire data for scientific research should ensure that the partnership agreement specifies who has responsibility for calibrating and validating the data, what the scope of the calibration and validation processes is, and what resources (financial, technical, and personnel) will be made available for these purposes.

Standardization of Data Management

Finding. Consistent approaches to documentation and preparation of data for long-term archiving are key to effective data stewardship in public-private partnerships.

Recommendation 7. In the process of negotiating a public-private sector data partnership, the parties should agree to use commonly accepted standards for metadata, data formats, and data portability.

Communication

Finding. Communication among government data providers, commercial data providers, and scientists is vital to effective partnerships. The interests and needs of the scientific community can be best incorporated into a public-private sector relationship during the early planning stages of the partnership. More opportunities for formal and informal communication are needed at all stages, especially between scientists and private sector representatives.

Recommendation 8. The government should facilitate direct communication between members of the scientific community and the private sector, including communication during the early stages of planning for public-private remote sensing programs.

Performance Measures

Finding. Public-private partnerships benefit from ongoing assessment, not just from retrospective evaluation. Performance measures should be tailored to the goals of the parties—that is, return on investment for industry, good science output for researchers, and cost-effective performance by government agencies.

Recommendation 9. Representatives of government agencies and commercial firms involved in public-private partnerships, together with scientists who use the data in these programs, should define performance measures at the time the public-private partnership is established. These performance measures should be taken into account in formal program evaluations.

Realistic Cost Accounting

Finding. Obtaining scientific data through a public-private partnership can involve significant nontransaction costs, such as support for data dissemination and for validation and verification on the government side and the expense of contract changes and delays on the private sector side. These buried costs may serve as a disincentive to future public-private partnerships.

Recommendation 10. Public-private partnerships for producing scientific data should practice realistic cost accounting, making all the costs of the partnership transparent and open to negotiation.

GENERAL CONCLUSIONS AND PRIORITY ISSUES

The steering committee found that several issues must be addressed in creating future public-private partnerships that produce remote sensing data for scientific research. Many of these issues are referred to in the findings and recommendations outlined above (licensing, data continuity, performance measures, and realistic cost accounting), while others such as the impact of government processes on public-private partnerships (e.g., contracting arrangements), intellectual property rights, and data management are discussed in the body of the report (see Chapter 4).

The steering committee prioritized these issues according to their significance for public-private partnerships and the degree of complexity and difficulty expected to be involved in resolving them (see Table ES.1).

The most significant and complex issues to be addressed for public-private partnerships are those related to intellectual property and licensing and to government processes. Little convergence exists between the public and private sectors on these topics, and yet future actions will have significant impact on the use of commercial remote sensing data for scientific research. Data management (e.g., data archiving and processing) and data continuity are rated by the steering committee as highly significant but of lesser complexity, because they can be addressed readily if financial resources are available. Measures of performance (metrics) for public-private partnerships were deemed highly complex, owing to the difficulty in determining performance measures, but of lesser significance

TABLE ES.1 Complexity and Significance of Cross-Cutting Issues

	Higher Complexity	Lower Complexity
Higher Significance	Intellectual property and licensing Impact of government processes	Data management Data continuity
Lower Significance	Performance metrics	Realistic cost accounting

than other issues involved in establishing successful public-private partnerships for providing remote sensing data for scientific research. The steering committee considered realistic cost accounting critical for creating future, successful partnerships, but of lower significance and complexity than other issues it analyzes in the report.

1

Introduction: The Changing Environment

This is an opportune time for a discussion of the scientific use of new remote sensing data resources and the emergence of new types of partnerships among data producers and scientists seeking to obtain access to these data. A large number of civil U.S. and international remote sensing satellites are in orbit, including systems owned and operated by the governments of the United States, Europe,[1] Japan, France, India, and China/Brazil;[2] systems jointly owned or operated by government and commercial entities, such as Canada's Radarsat and France's System pour l'Observation de la Terre (SPOT); and two commercially owned and operated systems, Space Imaging, Inc.'s IKONOS and DigitalGlobe Inc.'s QuickBird (see Appendix A). In addition, over the next 5 years more than a dozen new spacecraft are planned for launch and operation by both U.S. and non-U.S. operators, including some systems that will be wholly commercial.[3] These systems represent an expanding range of capability in spectral, spatial, and temporal resolution and a growing role for the private sector in system ownership and operation. The current and anticipated diversity in

[1]The European Space Agency (ESA) comprises 14 member states; Canada also participates in certain ESA programs. ESA operates Earth remote sensing satellites that collect data for use in Earth science research and applications.

[2]China and Brazil launched the China-Brazil Earth Resources Satellite (CBERS) in October 1999. CBERS-2 and CBERS-3 are in development.

[3]William E. Stoney, "Summary of Land Imaging Satellites (with Better Than 30 Meters Resolution) Planned to Be Operational by 2006," McLean, Va., Mitretek Systems, June 6, 2001. Available online at <http://www.asprs.org/asprs/news>. Accessed on September 25, 2001.

operational remote sensing systems opens up new types and sources of data for scientific research.

The legal foundation in the United States for a commercial presence in satellite remote sensing was laid out in presidential directives and in the Land Remote Sensing Commercialization Act of 1984. (See Table 1.1, "U.S. Satellite Remote Sensing Commercialization and Policy Time Line.") This legislation, which was consonant with presidential directives from two previous administrations, established a process for commercializing land remote sensing satellites. The policy outlined, among other things, the terms and conditions for competing and for awarding a contract with a private entity to market unenhanced Landsat data for a period of 6 years.[4] More recent legislation, including the Land Remote Sensing Policy Act of 1992 and the Commercial Space Act of 1998, was intended to improve the legal and competitive environment for remote sensing in the private sector. The 1992 act specifically stated that one objective for Landsat 7's data policy was to stimulate the development of a private market for enhanced data and value-added services, and it reiterated the terms for licensing private sector remote sensing satellite systems introduced in the 1984 legislation.[5] The Commercial Space Act of 1998 encouraged the administrator of the National Aeronautics and Space Administration (NASA) to purchase, as appropriate, space-based remote sensing data from commercial providers for Earth science research.[6] These legislative milestones, initiated by the U.S. Congress and supported by several administrations, have also been encouraged by others in the space community,[7] and the health and commercial viability of the private sector remote sensing industry will obviously be a factor in the future of public-private partnerships.

Congressional legislation and executive policy, as detailed in Table 1.1, have long encouraged the development of public and private sector relationships and interactions as a means of producing remote sensing data for scientific research. The most recent example is NASA's Science Data Buy (SDB),[8] an experimental program that began with both administration and congressional support in 1997. Earlier examples include the sale of Landsat data by the Earth Observation Satellite Company (EOSAT) in the 1980s and 1990s; the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) program, an ongoing collaboration between NASA and OrbImage, Inc., that began in the 1990s; the Canadian government and private sector partnership with Radarsat; and the French government and private sector

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[4]Public Law 98-365, Land Remote Sensing Commercialization Act of 1984.

[5]Public Law 102-555, Land Remote Sensing Policy Act of 1992, Section 2.

[6]Public Law 105-303, Commercial Space Act of 1998, Section 105.

[7]Richard E. Rowberg, "Commercial Remote Sensing by Satellite: Status and Issues," Washington, D.C., Congressional Research Service, December 20, 2001, p. 1.

[8]The NASA Science Data Buy is also known as the NASA Science Data Purchase. In this report the steering committee refers to the program as the Science Data Buy.

TABLE 1.1 U.S. Satellite Remote Sensing Commercialization and Policy Time Line

Year	Document	Significance
March 1978	Presidential Directive released to encourage domestic commercial exploitation of space capabilities (PD-37).	Carter administration lays the groundwork for eventual commercialization of U.S. civil space assets.
Oct. 1978	Presidential Directive on an operational land remote sensing system (PD-42).	Carter administration subscribes to data continuity in the land remote sensing satellite program.
1979	Presidential Directive to assign NOAA operating responsibility for all civil remote sensing satellites (PD-54).	Carter administration shifts Landsat operations from NASA to NOAA. NOAA was to ensure data continuity through the 1980s and the operation of two additional satellites.
1981	Withdrawal of data continuity commitment (President's FY 1982 Budget).	Reagan administration withdraws Carter commitment to data continuity. Additional satellites beyond Landsat 5 would require private sector investment and operation.
1981	Cabinet Council on Commerce and Trade begins discussions on transfer of land and weather satellites to the private sector.	Reagan administration forms body to study the effects of privatization on government agencies and to explore how the government should interact with private remote sensing companies.
March 1983	NOAA transfers the nation's civil operational remote sensing satellites to the private sector.	Reagan administration accelerates move to commercialize civil remote sensing satellites.
Nov. 1983	Commerce, Justice, State, and Judiciary Appropriations bill for FY 1984 forbids the sale of U.S. weather satellites (Public Law 98-166).	Congress and the Reagan administration keep weather satellites within the public domain.
1984	Land Remote-Sensing Commercialization Act (Public Law 98-365).	Congress establishes the process for commercialization of land remote sensing satellites.
1985	EOSAT wins contract to operate Landsats 4 and 5.	Earth Observation Satellite Company (EOSAT) begins operation of Landsats 4 and 5 and sales of the data on the commercial market.
1986	Principles Relating to Remote Sensing of the Earth from Outer Space.	United Nations resolution adopts legal principles for remote sensing.

continued

TABLE 1.1 (continued)

Year	Document	Significance
1992	Land Remote Sensing Policy Act (Public Law 102-555).	Congress transfers responsibility for the Landsat program back to the government (NASA and U.S. Department of Defense [DOD]) and also provides for the continuation of the program with Landsat 7. DOD later withdraws from the program.
1994	U.S. Policy on Foreign Access to Remote Sensing Space Capabilities (PDD-23).	Presidential Decision Directive addresses licensing and operation of private remote sensing systems.
1994	Convergence of U.S. Polar-Orbiting Operational Environmental Satellite Systems (NSTC-2).	Clinton administration decision converges into a single national system the planned polar-orbiting operational environmental satellite programs of DOD and NOAA, with NASA participation.
1994	Landsat Remote Sensing Strategy (NSTC-3).	Presidential Decision Directive establishes scope of responsibilities for NASA, NOAA, and the U.S. Department of the Interior in continuing the Landsat program.
1996	U.S. National Space Policy.	The national space policy is updated to be consistent with the administration's civilian, national security, and commercial space programs and policies.
1996	Kyl-Bingaman Amendment to the National Defense Authorization Act for FY 1997.	Amendment prohibits the collection of detailed satellite imagery relating to Israel.
1996	Omnibus Civilian Science Authorization Act of 1996 (HR-3322).	Congress authorizes $50 million for commercial data purchases for Earth science research for FY 1997.
1998	Commercial Space Act (Public Law 105-303).	Congress establishes a framework to keep the U.S. space industry competitive and promote the commercial development of space.
2000	Memorandum of Understanding (MOU) Concerning the Licensing of Private Remote Sensing Satellite Systems.	MOU establishes interagency procedures between the U.S. Departments of Commerce, State, Defense, and Interior and the intelligence community for handling remote sensing licensing actions.
2000	U.S. Department of Commerce Licensing of Private Land Remote-Sensing Space Systems—Interim Final Rule.	U.S. Department of Commerce issues interim final rule, which sets the requirements for licensing, monitoring, and compliance for private remote sensing systems under the Land Remote Sensing Policy Act of 1992, the Commercial Space Act of 1998, and Presidential Decision Directive 23.

investment in SPOT and Spot Image. In the United States, attempts to develop a publicly and privately funded small synthetic aperture radar (SAR) satellite program[9] were unsuccessful, and a government (military)-funded hyperspectral sensor, "Warfighter," housed on a commercial remote sensing spacecraft ended in a launch failure. The steering committee focused on the two active public-private partnerships that were established to provide scientific data to the research community—the SDB and SeaWiFS.

ACTORS AND STAKEHOLDERS

At present, a wide array of actors is involved in the production of satellite remote sensing data in the public, private, and scientific sectors. In the federal government, a functional division of labor for civilian remote sensing exists across science and operational agencies. NASA is the science agency responsible for technological innovation in space, including innovations in remote sensing technologies, and for providing remote sensing data for scientific research. NASA also was given responsibility for maintaining data centers for near-term access and dissemination of these research data, although it does not have responsibility for permanently archiving or preserving the data. The National Oceanic and Atmospheric Administration (NOAA) has responsibility for maintaining operational weather satellites, for archiving environmental and climate data,[10] and for licensing commercial remote sensing satellite companies, as assigned in the Land Remote Sensing Policy Act of 1992. NOAA works closely with the U.S. Departments of Defense, Interior, and State, and the Central Intelligence Agency in this capacity. The U.S. Geological Survey maintains the National Satellite Land Remote Sensing Data Archive at the Earth Resources Observation Systems (EROS) Data Center in Sioux Falls, South Dakota, for data from Landsats 1 through 5 and 7 and the Advanced Very High Resolution Radiometer (AVHRR), and it plans to hold additional land remote sensing data as well. Other federal agencies, such as the Environmental Protection Agency, the U.S. Departments of Transportation, State, and Agriculture, and the U.S. Army Corps of Engineers, are increasingly found in the ranks of both research and applied data users. The National Imagery and Mapping Agency (NIMA) is a clearinghouse

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[9]For more background on the LightSAR, see Jet Propulsion Laboratory, "LightSAR Business Development and System Design Definition Study," RFPP No. L04-1-37900-924, Attachment 2: LightSAR Point Design, Pasadena, Calif., National Aeronautics and Space Administration, 1997; and Space Studies Board, National Research Council, *Development and Application of Small Spaceborne Synthetic Aperture Radars*, Washington, D.C., National Academy Press, 1998.

[10]NOAA and NASA have a memorandum of understanding whereby NOAA is to archive Earth Observing System data, but on a "best-effort" basis. See Space Studies Board, National Research Council, *Ensuring the Climate Record from the NPP and NPOESS Meteorological Satellites*, Washington, D.C., National Academy Press, 2000, p. 2.

for remote sensing imagery and mapping data collected by the U.S. Department of Defense and the intelligence community.

The private sector in this field is divided into a large number of aerial remote sensing firms and a small number of satellite remote sensing firms. There are, at present, more than 200 aerial remote sensing firms in the United States.[11] There are also 12 U.S. private sector firms with licenses to launch some 40 satellites for Earth observation.[12] The private sector also includes value-added firms that provide services for clients.

The research community consists of scientists and engineers who are generally affiliated with universities and dedicated research centers, but can also be found in the government, the private sector, and nongovernmental organizations. The workshop held in March 2001 by the Steering Committee on Space Applications and Commercialization reflected this mix by including university scientists, government scientists, and those conducting research in the private sector.

Several variations of public-private sector interactions and relationships exist. In fact, the examples of partnerships discussed in this report—SeaWiFS and the SDB—represent two different approaches. SeaWiFS is partnership, while the SDB is akin to a redistributor-end user interaction. (The steering committee uses the term "public-private partnerships" to describe these relationships.)

STUDY APPROACH AND ORGANIZATION

Despite the policy emphasis in Washington, D.C., on the importance of public-private partnerships in satellite remote sensing and the belief that in some cases these partnerships or private sector data providers could replace government programs to provide remote sensing data for science, not all workshop participants agreed that this approach, a priori, was better than other possible approaches. The steering committee learned that some workshop participants saw great opportunities in new partnerships, while others said that public-private partnerships for science data have not met expectations to date. Most participants were more measured, seeing clear benefits in partnerships but recognizing that not all of the problems associated with the production and use of commercial data sources for research have been resolved. This report reflects these differences and emphasizes ways to enhance and strengthen new partnerships to the benefit of all partners. It became clear in the course of the steering committee's work, and is discussed at greater length throughout the report, that public-private part-

[11] American Society for Photogrammetry and Remote Sensing–NASA Industry Forecast, available at <http://aspsrs.org/news.html>; and James Plasker, executive director, American Society for Photogrammetry and Remote Sensing, personal communication, February 22, 2002.

[12] The National Oceanic and Atmospheric Administration's Office of International and Interagency Affairs handles licensing of commercial remote sensing satellite systems. Information on NOAA licenses can be found online at <http://www.licensing.noaa.gov>. Accessed October 11, 2001.

nerships intended to produce data for scientific research have great promise, but that they must involve scientists throughout discussions that lead to arranging public-private partnerships.

Through the workshop and its discussions, the steering committee examined public-private partnerships in satellite remote sensing in terms of their capacity to provide useful data for scientific research. In Chapter 2, four models for providing satellite remote sensing data for scientific research are examined. Chapter 3 discusses the NASA Science Data Buy and SeaWiFS as experiments in public-private partnerships. Both programs were developed in response to the changing environment for satellite remote sensing, and both have been operating long enough to provide guidance for developing future public-private partnerships. In addition, these cases are the only examples to date of public-private partnerships that were created to provide remote sensing data for scientific research. Chapter 4 examines the differences in requirements and operations for scientific users of remotely sensed data and for commercial companies that produce the data. Issues such as data management, intellectual property, government processes, metrics, and others that surfaced at the workshop illustrate the contrast in priorities and requirements of the commercial sector and the scientific community. Chapter 5 reports on the steering committee's findings and recommendations. Appendix A presents a table of selected remote sensing systems, Appendix B provides brief biographies of steering committee members and workshop speakers and panelists, Appendix C includes the workshop agenda and a list of participants, and Appendix D provides a list of acronyms for the report.

2

Models for Providing Remote Sensing Data for Scientific Research

In the early 1990s, the federal government was the principal provider of remote sensing data to the scientific community,[1] but it had already begun to encourage a private sector role in supplying the data. The Land Remote Sensing Policy Act of 1992 directed Landsat Program Management (NASA and DOD) to assess four approaches for developing the Landsat follow-on program: (1) a government effort, (2) a commercial-private sector effort, (3) a government-private sector cooperative effort, and (4) an international consortium.[2]

In the decade since the 1992 act, the federal government and private sector have explored the first three of the four approaches; an international consortium has not yet been attempted. Although these four models were suggested specifically as options for the Landsat follow-on, they also provide a useful framework for considering the institutional arrangements for providing new remote sensing data for scientific research. Three of these approaches—government, commercial, and public-private—were discussed at the steering committee's March 2001 workshop.[3] This chapter outlines the four models.

[1]The Earth Observation Satellite Company (later bought by Space Imaging, Inc.) operated Landsat and marketed the data from 1985 to 2001.

[2]Public Law 102-555, Land Remote Sensing Policy Act of 1992.

[3]The international model has not been tested in the United States and was not discussed at the workshop.

MODEL 1: THE GOVERNMENT AS DATA PROVIDER FOR SCIENCE

The first model—with the government as data provider—is the traditional approach. It assumes that federal science agencies and operational agencies will continue to launch and operate satellites that provide data for scientific research. Examples are NASA's Terra satellite and NOAA's Advanced Very High Resolution Radiometer (AVHRR). Examples still in development are NASA's Aura mission and the NOAA-DOD-NASA National Polar-orbiting Operational Environmental Satellite System (NPOESS).[4] The operating assumption behind this approach is that the data are primarily intended for public purposes, such as research and government operations, rather than for for-profit uses in the commercial marketplace. In cases where the government is the data provider of choice for science, NASA and NOAA (and their partners) will continue to dominate in the production of the data.

Landsat 7 is an example of the government-provider approach. Although developed by NASA, it is currently operated by the U.S. Geological Survey (USGS). USGS also archives and disseminates Landsat 7 data, which are available to all users at the cost of reproduction.

MODEL 2: THE PRIVATE SECTOR AS DATA PROVIDER FOR SCIENCE

The model involving the private sector as data provider is a more experimental approach, made possible by recent legislation.[5] In this model, the private sector finances, builds, launches, and operates a satellite, making data available on a commercial basis for multiple purposes, including research. The government may be a user of the data, but it does not specify data requirements. At present, the best and possibly only examples of completely private sector Earth observation satellites are IKONOS and QuickBird, although there are 12 fully private sector systems now planned for launch during the next 5 years.[6]

Transactions between scientists and private sector satellite providers may occur on an individual basis (e.g., scientists may use funds from research grants

[4]The National Performance Review and Presidential Decision Directive of 1994 directed the DOD (Air Force) and U.S. Department of Commerce (NOAA) to create a converged weather satellite program that would meet U.S. civil and national security requirements and fulfill international obligations. NPOESS is the converged system.

[5]The Land Remote Sensing Policy Act of 1992 (Public Law 102-555) allows for the Secretary of Commerce to issue licenses to private sector parties to operate private remote sensing systems. Presidential Decision Directive 23 lays out the terms for licensing and operation of private remote sensing systems.

[6]William E. Stoney, "Summary of Land Imaging Satellites Planned to be Operational by 2006," Mitretek Systems, March 2, 2001, p. 3. Available online at <http://www.asprs.org/asprs/news>. Accessed September 25, 2001.

to procure satellite data from aerial remote sensing firms or commercial satellite remote sensing firms); however, many scientists may not have the funding to purchase research data from the private sector. NASA grantees can submit a competitive proposal and, if selected, receive commercial remote sensing data at no cost through the Science Data Buy (SDB) program, which is managed out of NASA's Stennis Space Center (see Chapter 3). If funding for the SDB program does not continue, these researchers may no longer be able to obtain commercial data, as they may lack the resources in their grants to purchase the data directly at market prices. However, as the number of private remote sensing satellite data collectors increases, market forces and competitive pricing could make commercial data more affordable to scientists. As the use of commercial remote sensing data for scientific research evolves, several issues must be considered—including data management, data processing, long-term archiving, and intellectual property and data access—if privately collected data are to meet the requirements of and the broader needs for scientific research. (These issues are discussed in Chapter 4.)

MODEL 3: PUBLIC-PRIVATE SECTOR RELATIONSHIPS FOR PROVIDING SCIENCE DATA

The public-private sector approach can take several forms. An early example was the privatization of the government's Landsat program in the mid-1980s. Landsats 1, 2, 3, and 4 had been developed in the 1970s and 1980s and were initially operated by the federal government as an experimental system. According to a report of the Space Studies Board, Office of Management and Budget (OMB) approval of Landsat assumed that markets would grow to provide funding for all future systems.[7] However, government policy makers saw the slow initial growth of the market as a programmatic failure. The OMB had supported an operational weather satellite system, but was reluctant to support Landsat as an operational program. The budget situation for Landsat had been uncertain from the very beginning. In the late 1960s, just as Landsat reached the development stages, space budgets were beginning to incur serious cutbacks. There was a need to "sell" NASA, the Congress, and the administration on the future growth of a private market, which was expected to underwrite the cost of the government's data needs. A long debate ensued over the question of whether to maintain Landsat as a public program or transfer it to the private sector.[8] The debate culminated in 1984 with the administration's decision under the Land Remote-

[7]Space Studies Board, National Research Council, *Earth Observations from Space: History, Promise, and Reality*, Washington, D.C., National Academy Press, 1995, p. 110.

[8]For further background on the debate over whether or not to privatize Landsat, see a report by the Office of Technology Assessment, U.S. Congress, *Remote Sensing and the Private Sector: Issues for Discussion, A Technical Memorandum,* Washington, D.C., U.S. Government Printing Office, March 1984.

Sensing Commercialization Act of 1984 (Public Law 98-365) to transfer Landsat to the private sector[9] to operate and sell the data on the commercial market.

A series of steps led to the selection of the Earth Observation Satellite Company (EOSAT) as the private operator for Landsat, and in October 1985, the company took charge of the Landsat system (see Table 1.1 in Chapter 1). Thus, the government role changed midstream in the program from being developer, operator and distributor of Landsat data to being data purchaser, although the EROS Data Center continued to distribute data for the commercial operator until 1989. As a result of new ground processing technology, the data volume of Landsat digital tapes increased sevenfold. In turn, the government increased the price of a Landsat satellite scene seven times, to $4,400, in preparation for the transfer of the Landsat program to the private sector.[10] Both NASA and EOSAT raised prices for photographic images of Landsat scenes cumulatively by 1,000 to 2,000 percent over the period from 1980 to 1990. Consequently, sales of the data to users, including the academic community, dropped significantly.[11]

During the 1990s, the U.S. government in effect tested different types of public-private sector partnerships or hybrid approaches to obtaining data expressly for scientific research. The Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and NASA's Science Data Buy (SDB) are examples of this approach. In both cases the government agreed to purchase data for scientific research in advance of its use. There was also a proposal from the Jet Propulsion Laboratory in 1996 to partner with industry in developing a small synthetic aperature radar program (called LightSAR) for both scientific and commercial applications.[12] However, potential industrial partners did not believe that a viable market existed for data from a "system that focused primarily on meeting the NASA science requirements," and they declined to participate.[13] In addition, a proposed remote sensing venture between the Office of Naval Research and the private sector for a hyperspectral imager, the Naval EarthMap Observer (NEMO) satellite, faces challenges resulting from the commercial partner's difficulties in attracting

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[9]John M. Logsdon, Roger D. Launius, David H. Onkst, and Stephen J. Garber, *Exploring the Unknown: Selected Documents in the History of the U.S. Civil Space Program*, Volume III: *Using Space*. Washington, D.C., National Aeronautics and Space Administration, 1998, p. 329.

[10]John Boyd, EROS Data Center, U.S. Geological Survey, personal communication, October 18, 2001.

[11]Donald Lauer, John Estes, John Jensen, and David Greenlee, "Institutional Issues Affecting the Integration and Use of Remotely Sensed Data and Geographic Information Systems," *Photogrammetric Engineering and Remote Sensing* 57(6): 647-654, June 1991.

[12]For more background on NASA's interest in developing a small SAR satellite, see Space Studies Board, National Research Council, *Development and Application of Small Spaceborne Synthetic Aperture Radars*, Washington, D.C., National Academy Press, 1998.

[13]Jet Propulsion Laboratory, "Synthetic Aperture Radar Mission Study Report, Prepared for the National Aeronautics and Space Administration Headquarters," JPL D-18559, Pasadena, Calif., Jet Propulsion Laboratory, February 2000, p. 16.

necessary private sector investment. Private industry is reluctant to fund the system because it questions whether a commercial market exists for hyperspectral data.[14]

For SeaWiFS, the relationship between the government and the private sector was closer to the traditional approach of government supplier: NASA scientists specified the data requirements and were heavily involved in developing specifications for the instrument. Though the private vendor owned and operated the satellite and could sell the data commercially, the guaranteed purchase of data by the government enabled the company to obtain the private sector capital it needed to develop the system.

Unlike SeaWiFS, which was developed to meet science data needs, the SDB program acquires data from private sector firms—including both operational satellite and aerial remote sensing firms whose primary market is commercial and applied users, rather than researchers. For this program, NASA guarantees that it will purchase data at a specific cost for purposes of scientific research. The agency serves as middleman between scientists and private sector data suppliers. In addition, NASA provides verification and validation of all data distributed through the program.

Another variation on the public-private sector approach is exemplified by the case of the French remote sensing satellite, SPOT. Under this arrangement, initially conceived and developed as a public-private partnership, the French space agency supports the research and development of the satellites, and a quasi-private company, Spot Image, sells the data commercially. Spot Image includes among its investors government space agencies of France, Sweden, and Belgium, as well as private companies. Similar to the French system is Canada's Radarsat 1, which was funded by Canada and developed by the Canadian Space Agency with contributions from the United States.[15] A private company, Radarsat International (RSI), markets, processes, and distributes Radarsat 1 data.[16,17]

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[14]Comments of Curtiss Davis, Naval Research Laboratory, who was a panelist at the steering committee's workshop, "Remote Sensing and Basic Research: The Changing Environment," on March 27-28, 2001.

[15]John C. Baker, Kevin M. O'Connell, and Ray A. Williamson, *Commercial Observation Satellites: At the Leading Edge of Global Transparency*, Arlington, Va., RAND and American Society of Photogrammetry and Remote Sensing, 2001, pp. 264-265.

[16]John C. Baker, Kevin M. O'Connell, and Ray A. Williamson, *Commercial Observation Satellites: At the Leading Edge of Global Transparency*, Arlington, Va., RAND and American Society of Photogrammetry and Remote Sensing, 2001, pp. 187-199.

[17]Several second-generation public-private partnerships are now being proposed. The Landsat follow-on satellite, as planned, will maintain continuity in the collection of medium-resolution (e.g., 30-m), multispectral imagery. The U.S. government is currently considering a public-private sector approach similar to that used in the SDB to disseminate the data from a Landsat follow-on system. A second program, the Warfighter-1, is a joint venture with the U.S. Air Force and OrbImage to develop the hyperspectral imaging sensor that was housed on the Orbview-4 satellite (the launch on September 21, 2001, failed and the satellite re-entered the atmosphere). A third program is the Naval EarthMap Observer (NEMO), a joint venture between the Naval Research Laboratory and Earth

MODEL 4: INTERNATIONAL CONSORTIUM FOR PRODUCING SCIENCE DATA

The use of an international consortium for producing remote sensing data for scientific research was not discussed at the March 2001 workshop. This approach has been explored in other reports,[18] and some organizations are currently using or working toward this model. As an example, the European Meteorological Satellite Organization (EUMETSAT) is an intergovernmental, member-funded organization of European states that launches, operates, and delivers meteorological data to end users and monitors the climate.[19] In addition, several international remote sensing organizations use the consortium approach to coordinate remote sensing systems and data distribution, though they do not own the satellites jointly. An example is the World Meteorological Organization's World Weather Watch, which coordinates the meteorological satellites of several countries and delivers unprocessed global weather data. (This model, which falls outside the committee's charge, is not explored in this report.)

A number of reports from the National Research Council have focused on the role of government programs in providing remote sensing data for scientific research (Model 1). These include *Global Environmental Change: Research Pathways for the Next Decade*[20] and several report of the Space Studies Board.[21] The focus of the steering committee's discussions and of the workshop was public-private sector partnerships (Model 3). The discussion in Chapter 3, "Toward Successful Public-Private Cooperation," concentrates on the two most fully developed examples of such partnerships, SeaWiFS and SDB, and explores how they work, what their strengths and weaknesses are, and how effective they are in meeting scientific data needs. Although the two programs have been operating for only a few years, it is not too soon to highlight what is working well, to identify what needs improvement, and to call attention to issues that are not being adequately addressed.

Search Sciences, Inc., that would include a hyperspectral Coastal Ocean Imaging Spectrometer. The latter two programs, which were only briefly mentioned during the workshop, are intended for both military applications and civil research purposes.

[18]See, for example, Office of Technology Assessment, U.S. Congress, *Civilian Satellite Remote Sensing: A Strategic Approach*, Washington, D.C., U.S. Government Printing Office, September 1994, pp. 101-128.

[19]For additional information, see the European Meteorological Satellite Organization Web site at <www.eumetsat.de/en/area1/topic1.html>. Accessed September 25, 2001.

[20]National Research Council, *Global Environmental Change: Research Pathways for the Next Decade*, Washington, D.C., National Academy Press, 1999.

[21]See reports of the Space Studies Board, Committee on Earth Science of the National Research Council: *Issues in the Integration of Research and Operational Satellite Systems for Climate Research: Science and Design* (2000); *Issues in the Integration of Research and Operational Satellite Systems for Climate Research: Implementation* (2000); *The Role of Small Satellites in NASA and NOAA Earth Observation Programs* (2000); and *Development and Application of Small Spaceborne Synthetic Aperture Radars* (1998), all published by the National Academy Press, Washington, D.C.

3

Toward Successful Public-Private Partnerships

There is strong support, according to discussions at the March 2001 workshop, for developing more effective public-private partnerships for the production of remote sensing data for scientific research. Such partnerships entail both strengths and weaknesses. A closer examination of the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and NASA's Science Data Buy (SDB) can provide a set of "lessons learned" for the development of future public-private partnerships to produce scientific data.[1] Although SeaWiFS collects coastal and ocean data and SDB collects land data, the steering committee's examination of these cases is focused on the institutional arrangements involved in collecting the data rather than on the particular type of remote sensing data.

Strong economic reasons may exist for entering into a public-private partnership, but the benefits of a successful relationship are not merely financial. On the government side, a public-private partnership can be a means of providing scientists with access to research data that are otherwise unavailable. In the private sector, a partnership through which scientists use private sector data can contribute to the development of new commercial applications of the data. The steering committee learned at the workshop, however, that it is unrealistic for either the government or the scientific community to pursue a public-private data partnership with the expectation that scientists will also be able to obtain new research

[1]This discussion is not intended as a comprehensive evaluation of either program. The steering committee learned at the workshop that NASA's Stennis Space Center is planning to conduct an evaluation of the Science Data Buy (SDB) program.

funding from the private sector. As discussed at the workshop, it is similarly unrealistic for those in the private sector to expect that a public-private partnership could be a vehicle for obtaining federal subsidies to support an enterprise that is not commercially feasible. The steering committee learned that financial motivations for a public-private partnership cannot be ignored, and that if the partnership does not make financial sense, it will not come about. However, if economic motivations are the only reason for the partnership, the inevitable difficulties encountered in joining public and private sector approaches could create significant disincentives to successful programs. Other issues, such as the long lead time required for government contracts or the small size of the scientific market for data at this time, could also discourage participants from entering into working public-private sector relationships.

SCIENCE DATA BUY

The NASA Science Data Buy is an experimental project to evaluate the utility of commercial remote sensing products for Earth science research.[2] The program was seen by the OMB and Congress as a means of providing scientists with additional sources of data. The SDB is managed by the Commercial Remote Sensing Program (now the Earth Science Applications Directorate) at NASA's Stennis Space Center, under the direction of the Applications Division within the Office of Earth Science at NASA Headquarters.

The SDB was initiated in 1997 by NASA in response to Senate language in the NASA Authorization Act, FY 1997, that directed the NASA administrator, "where feasible and cost effective, to make acquisitions of space-based and airborne Earth remote sensing data services, distribution, and applications provided by the United States private sector . . . if such acquisitions fully satisfy the scientific requirements of NASA."[3] The Commercial Space Act of 1998 reiterated this sentiment: "The Administrator shall, to the extent possible and while satisfying the scientific or educational requirements of the National Aeronautics and Space Administration . . . acquire, where cost-effective, space-based and airborne Earth remote sensing data, services, and applications from a commercial provider."[4] The injunction to obtain data and services from commercial providers was not confined to Earth science data, although neither NASA nor private sector firms have yet provided planetary, space environment, or astronomical data on a commercial basis.

[2]For additional information, see Scientific Data Purchase Program Overview at <http:www.esad.ssc.nasa.gov/datapurchase>. Accessed July 17, 2002.

[3]S. 1839, Sec. 206, 104th Congress, National Aeronautics and Space Administration Act, FY 1997 (reported in Senate).

[4]Public Law 105-303, Commercial Space Act of 1998.

In FY 1997, NASA allocated $50 million for the SDB program to provide commercial remote sensing data to the Earth science community. Authorization to spend the $50 million on SDB continued through FY 2000. In FY 2000, NASA received $20 million in appropriations, under the heading "commercial data buy."[5] According to NASA, the SDB program fosters advances in global Earth systems research, strengthening the U.S. economy through the development of remote sensing technologies and new ways of doing business.

In May 1997, NASA's Stennis Space Center issued a Request for Offers (RFO), soliciting proposals for Phase I of the SDB program. The announcement requested proposals for data sets that would provide important new scientific measurements or more cost-effective ways of supporting NASA's Office of Earth Science research. These data sets would be available for Earth science and applications research. Information on data price, validation, rights, and applicability to NASA's Earth science and applications themes (Land-Cover and Land-Use Change Research; Seasonal to Interannual Climate Variability and Prediction; Natural Hazards Research and Applications; and Long-Term Climate: Natural Variability and Change Research) was requested from prospective data providers. NASA received 18 proposals from companies under the Phase I program; 10 companies were selected to provide prototype data sets and products. The objective of Phase I was to evaluate the prototype data sets and to select those to be purchased in Phase II.

The final selection of data sets was conducted by an independent science assessment team that included academic and government scientists organized around NASA's Earth science themes, looking at data quality, science relevance, data usability, data rights, and provisions for collaborations. NASA management considered the recommendations from the assessment group and, in 1998, selected five companies for the Phase II data purchases, as shown in Table 3.1. Phase II was completed in September 2001.

Scientists who currently have a NASA Earth science research grant can compete for SDB data by electronically submitting tasking requests for data at specific locations and on certain dates. A Science Tasking and Measurement Committee composed of scientists from NASA Headquarters and Stennis Space Center evaluates and prioritizes the data requests to ensure that the data support Earth science and applications research and that they provide valuable and cost-effective products.[6]

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[5]Authorization for the SDB was continued under the NASA Authorization Act of 2000 (Public Law 106-391). The act also included $20 million in authorization for commercial remote sensing data in FY 2002. The $20 million appropriation was for purchases of commercial remote sensing data; new contracts separate from the SDB were arranged.

[6]Tasking requests must include responses to the following questions: What scientific or application problem are you addressing? What is your research objective? How will you use this data to support your research? What specific data products do you request? Who sponsors your research? In

TABLE 3.1 Contractors Selected for Phase II of the Science Data Buy

Company	Data Type	Product
Astrovision	Satellite imagery from geostationary orbit	Not yet developed
Earthsat, Inc.	Landsat multispectral and thematic mapper imagery	Medium-high resolution global databases
Earthwatch, Inc. (now DigitalGlobe, Inc.)	Airborne interferometric synthetic aperture radar (2.5-meter resolution)	Radar and elevation data processed into quadrangle mosaics
Positive Systems, Inc.	Multispectral aerial imagery (1-meter resolution)	Image mosaics and collateral ground truth data
Space Imaging, Inc.	Panchromatic and multispectral imagery (1- and 4-meter resolution)	Multispectral image mosaics and digital elevation models

The role of Stennis Space Center includes management of the contracts with providers, tasks related to collecting research data, selection of and coordination with the researchers who receive the data, and verification and validation efforts to ensure that the data meet the quality and other specifications required for scientific research. Verification and validation services supplied by Stennis Space Center have not generally been provided by commercial companies.

SDB: What Is Working Well

Workshop participants reported that the SDB is working well in many ways. Scientists said that the application process is well designed and that requests are easy to submit. NASA officials said that they have more applicants than they can serve under the current program. Private sector representatives were enthusiastic about the opportunity to work with scientists. Most importantly, however, scientists at the workshop who had participated in the SDB expressed satisfaction with the quality of the data and with their spatial, spectral, and radiometric resolution. They said that the data are making significant contributions to their research and teaching. The high-resolution data from the private sector are used by some

turn, the NASA Science Tasking and Measurement Committee considers several factors in approving or rejecting tasking requests: relevance of the science/applications investigation to NASA's Earth Science Enterprise objectives; importance of the requested data/products to the investigation; coverage and schedule implications of the request; available resources.

scientists to calibrate less-expensive, lower-resolution data from sensors produced and managed by the government. In this way, the SDB not only provides new data for research, but it also enhances the usefulness of lower-resolution data produced in the public sector.

All participants saw the need for the increased communication between scientists and data producers in the commercial sector. Representatives of some private sector firms that participate in the SDB said that the opportunity for direct communication with their scientist "customers" is an important strength of the program. Others acknowledged that communication with scientists is important but too infrequent. Some participants thought that when scientists and private sector data providers are able to interact directly, it is more effective than when such communication is mediated by government officials.

SDB: What Needs Improvement

Workshop attendees identified several areas that they believe need improvement. Some of these areas relate to differences in the way public sector and private sector remote sensing programs operate, and others relate to the way the SDB program operates. In the first category, scientists stated concerns about the impact of the private sector practice of obtaining data by task orders. In some cases, the concern was that science data requests through the SDB are postponed or given lower priority in the tasking queue when they conflict with the needs of commercial customers. Some participants also expressed concern about timely receipt of their data, which is related to tasking. If every order for science can only be filled by tasking and if obtaining the data is subject to delays caused by weather or cloud cover, the time between the SDB award to a scientist and having the data in hand can be lengthy. Some scientists reported delays of a year or more. Concern was expressed not only about delays in receiving data, but about what this signifies regarding future private sector support for scientific data. If, they reasoned, private sector data producers have not given sufficient priority to scientists' data requests during the experimental phase of the SDB, the data buy might limit scientific applications of commercial data in the future. In the longer term, delays in obtaining science data could undercut the utility of public sector data purchases for scientific research.

The lack of historical or "heritage" data from the commercial remote sensing sources under the SDB was another issue raised at the workshop. While this problem may limit the usefulness of the data, particularly in global change research, it could diminish over time as the availability of commercial data for scientific research increases. However, an inherent limitation is that commercial data are not routinely collected, as they are usually tasked to meet customer requirements. This characteristic may limit the routine production of data acquired at multiple time periods that can be archived and made available in future years.

Workshop participants also expressed concern about the lack of consistency in intellectual property provisions among the various data providers in the SDB. Each of the five companies that participates in the program negotiated separate intellectual property provisions with NASA. This is not surprising, given that standard practices for the treatment of intellectual property in the remote sensing industry are still evolving. However, since intellectual property issues are a pervasive concern in the scientific community, this area was seen as one that needs improvement. Participants suggested that, in the future, a single, standard agreement for all participants in the data buy program would be more useful to scientists and would promote the development of common policies.

Differences in data purchase policies of firms in the program also posed a problem for some workshop participants. One vendor used Landsat data to provide orthorectified global land data sets using data collected during the mid-1970s and in 1990. Other vendors, who provided data through aerial and space-borne platforms, needed a minimum-sized ground area to obtain the requested data. This meant that scientists who wanted data over a small study site might have to accept data for an area 10 to 100 times the size of their request. Consequently, they would have to search through a large data set for the requested data and store data that were not required for the study. Scientists reported that paying for data that are irrelevant to their scientific needs is an inefficient use of government resources; they would rather obtain repeat coverage of their study sites than coverage over areas that are not of scientific interest to them.

Workshop participants from federal agencies expressed some concern that participation in the SDB was limited to NASA grantees instead of being open to the broader Earth science research community in both academia and government. Scientific data that NASA collects from its own satellites (e.g., Terra) are, in contrast, open to anyone. These participants noted that scientific and policy research in government agencies is increasingly based on remote sensing data, that the cost of data is a problem for some agencies, and that they could also benefit from participation in the SDB.

SEA-VIEWING WIDE FIELD-OF-VIEW SENSOR

Originally envisioned as a data buy arrangement, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) is the first example of a public-private partnership to procure scientific data.[7] In 1991, NASA signed a fixed-price contract with Orbital Sciences Corporation (OrbImage, a subsidiary of Orbital Sciences, purchased the spacecraft from Orbital after launch) for $43.5 million that guaranteed the purchase of five years of ocean color data. These data would provide

[7]For additional information on SeaWiFS, see <http://seawifs.gsfc.nasa.gov>. Accessed September 25, 2001.

detail on global ocean bio-optical properties that are important to Earth science research.[8] The agreement grew out of concern in the ocean biogeochemistry community over the availability of follow-on data to those collected by the Coastal Zone Color Scanner on Nimbus-7 that operated from 1978 to 1986. Ocean color data are important for understanding the process by which oceans store carbon, a cycle believed to influence the global climate; the data provide evidence of phytoplankton concentrations and thus also indicate where fish feed; and, the data are commercially valuable. Consequently, a public-private partnership seemed a good vehicle for obtaining the data.

In the agreement between NASA and Orbital Sciences, the private sector partner incurred the costs of instrument and satellite development, placement in orbit, and data acquisition. NASA scientists developed the specifications and design for the sensor, and the agency was responsible for disseminating data to the scientific community. Through an open competition, NASA appointed a science team associated with SeaWiFS and also staffed a project office in the agency that played pivotal roles in data processing, instrument calibration, and product validation.

Since 1991, the relationship of the partners has evolved in ways that make SeaWiFS an instructive example of a public-private partnership, or "hybrid" approach. NASA's upfront investment in SeaWiFS provided an "anchor tenant" for Orbital Sciences. Although the original plan called for launch of the satellite in 1993, it was not successfully launched until 1997. The launch was late because of delays in construction of the satellite and problems with the Pegasus XL launch vehicle. The delay cost NASA approximately $2 million to $3 million per year over a four-year period to keep the SeaWiFS project office running. During this time, NASA focused on data preparation and documentation.[9] As a result of this preparatory work, NASA was capable of providing high-quality scientific data in a matter of hours after initial data collection from the sensor.

SeaWiFS: What Is Working Well

From the point of view of a data user, the SeaWiFS partnership of scientists, government, and the private sector has been a success in many ways, providing a constant data stream with global coverage of ocean chlorophyll since late 1997. From the scientists' perspective, SeaWiFS provides high-quality data unmatched by those from any other ocean color sensor. It is less clear that the government and private sector view SeaWiFS as a success, given delays of launch following

[8]See "Background on the SeaWiFS Project" at <http://seawifs.gsfc.nasa.gov>. Accessed February 28, 2002.

[9]Charles McClain, remarks at the National Research Council's Space Studies Board Workshop on Remote Sensing and Basic Research: The Changing Environment, March 28, 2001.

development of the contract in spring 1991 and unrealized revenues from the projected commercial market that have made SeaWiFS unprofitable from a business perspective.

Reports to the workshop from NASA and OrbImage highlighted successful aspects of the partnership, focusing on the essential contribution of each partner in specific areas of calibration, validation, processing, archiving, and dissemination of data. Criticisms voiced by participants at the workshop focused on inadequate estimates and lack of full accounting of the true costs of the partnership, which actually included significant investment beyond the contract price. A fair assessment of SeaWiFS must take into account that it was not a simple data buy, because without contributions from the scientific and government partners, no usable products could have been generated. From a scientific perspective, it provides global data on ocean chlorophyll that are important for research.

In establishing the partnership, stipulations on data distribution attached to SeaWiFS dictated a delay of 14 days to allow the private sector partner to market real-time data to prospective users of ocean chlorophyll products—particularly the commercial fishing industry. Because the market did not mature as forecast, the impact of these stipulations on the commercial venture was unclear. For most scientific purposes, the delay posed little or no impediment, as a great deal of the research relying on satellite ocean color data addresses plankton dynamics and requires analysis over periods of weeks to years, rather than immediate access to data. Exceptions to the embargo policy are made for users that have real-time needs on a request basis (for example, oceanographic projects requiring imagery may request data in real time), and a number of such requests have been honored by the project office and private sector provider.

Scientists would like to extend the SeaWiFS mission beyond its intended 5-year duration, and serious attention is now being given to a contract extension to enable continued operation. Government and industry partners reported that they would like improvements in the terms of a new contract—for example, that a longer timeframe be specified so that the private sector might realize sufficient revenues to cover costs and make a profit. It is clear that this approach to acquiring Earth science data from space by partnering with the private sector has pluses and minuses. It is also clear that, with the extensive participation on the part of the government in data processing and distribution, the output of SeaWiFS has been a resounding scientific success.

SeaWiFS: What Needs Improvement

Both partners in this public-private partnership also find room for improvement. From the perspective of the private sector partner, the 5-year data purchase contract was too short, given the extension of the satellite beyond its 5-year design. In addition, during the development of SeaWiFS, a number of contract changes were imposed by the government. Private sector representatives at the workshop argued that their costs were increased by contract changes, changes in the regulations that affect the contract in future missions, or delays in the contracting process. Other issues that arose included a need to price the product to reflect the investment, based on market analyses that reflect the true costs of providing data both to government-sponsored users and to commercial users. That is, market analyses should estimate both government and nongovernment revenues. It would also be useful to have the government guarantee in writing that it will meet its part of the contract over the life of the program.

From the government partner perspective, additional investments—which included carrying the science team over an extended period—were required because of delayed data delivery. There is a residual, yet unanswered question of whether a realistic cost accounting of the system would have shown that the partnership concept reduced the total public-private investment required for the mission below what would have been required by a government-only system.

SUMMARY

The SDB and SeaWiFS represent two examples of the federal government's efforts to create public-private partnerships that lead to new types of remote sensing data for scientific research. In SeaWiFS, the government is involved throughout the process of producing the data by virtue of its role as a principal customer, or "anchor tenant" of the program. In the SDB, remote sensing data are produced by the private sector, and the government agrees to purchase specific amounts of data to be used for scientific research. Although the two partnerships represent different approaches, some issues related to public-private partnerships are common to both examples and arise in other types of public-private partnerships. These cross-cutting issues are discussed in Chapter 4.

4

Two Ways of Doing Business

INTRODUCTION

Because the private sector and the scientific community (including those in universities, government, and other research organizations) have different requirements and operate in different ways, forging an effective collaborative relationship will take careful work. The situation is even more difficult because neither community can exercise substantial economic force. The scientific community depends, for much of its research funding, on a decentralized process based on annual appropriations for science agency budgets, distributed through competitive scientific review processes. The commercial remote sensing industry is also decentralized and remains economically fragile. For the industry to survive, it must make a financial profit in a commercial market. It is unlikely to succeed by serving the needs of small, niche markets such as the scientific research community. Despite these obvious differences, those in both the scientific community and the commercial remote sensing industry believe that significant advantages are to be gained by working together.

A robust remote sensing industry can provide valuable new data, such as the high-resolution data used in many commercial applications, to the scientific community. High-resolution data, essential for certain types of research, are currently unavailable except through the private sector. Production of these data could probably not be justified by a government science agency because of their high cost and because the number of scientific users is still low. Because of their value to other customers, however, these data can be produced by the private sector for a commercial market, and they are also useful to scientists. In short, the data needs of the applied commercial-user community are serving to expand the data resources available to scientists.

The use of commercial remote sensing data by scientists can, in turn, benefit the commercial remote sensing industry. The private sector often looks to scientists and engineers for innovations in the construction, use, and application of new sensors and new algorithms; for research that eventually leads to the development of new applications; and for training technical experts who will work in applied settings and be responsible for using commercial imagery.[1]

Although both the commercial remote sensing industry and the scientific research community are important for policy and economic reasons in the United States, and government science agencies are important to each, significant differences and some incompatibilities still exist in the ways these groups operate. Such differences complicate the process of building partnerships. Workshop participants from both the scientific community and the private sector emphasized that the need to generate a return on investment drives the private sector. Individual firms must identify a viable commercial market consisting of actual or potential customers who have well-defined requirements and the resources necessary to purchase data.[2] According to a workshop participant from the private sector, defense and national security applications present commercial image providers with a mature market possessing well-known requirements. Civil infrastructure applications represent a potential second market, but this market is fragmented and its requirements are still evolving. Two other potential markets are the management of natural resources and of the environment; scientific research is a component of each of these. These primary and secondary markets (defense, national security, civil infrastructure, natural resources, and the environment) are all, to a large extent, government markets. Commercial markets also exist—for applications such as agricultural monitoring and crop forecasting—but these are not well developed.

SCIENTIFIC AND COMMERCIAL DATA REQUIREMENTS

Workshop participants identified critical differences between the data requirements of the science community and the commercial practices of data providers. Table 4.1 identifies these differences in data archiving and management, data continuity, resolution, instrument specifications and calibration, satellite tasking, cost, and data access. These issues are discussed later in the chapter.

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[1]For a discussion of the process of developing applications using remote sensing data, see Steering Committee on Space Applications and Commercialization, Space Studies Board, *Transforming Remote Sensing Data into Information and Applications*, Washington, D.C., National Academy Press, 2001.

[2]For further discussion of commercial and research issues in the use of environmental data, see National Research Council, *Resolving Conflicts Arising from the Privatization of Environmental Data*, Washington, D.C., National Academy Press, 2001.

TABLE 4.1 Two Ways of Doing Business: Science Versus Commercial Requirements

Type of Requirement	Scientific Research	Commercial/Applications
Data archiving and management	Long-term requirements	Short-term requirements
Data continuity	Consistent coverage over time and space	Coverage by request—no temporal or spatial pattern
Instrument specifications and calibration	Full disclosure essential	Proprietary, "black box" approach
Satellite tasking	Routine acquisition	Tasking by purchase order
Data costs	Contracts and grants (have not included sufficient funds for data purchases)	Cost recovery and return on investment
Data access	Public domain; open data sharing	Data are proprietary; licensed to users

Remote Sensing Industry Requirements

Most commercial data providers acquire data by tasking on demand, that is, data are obtained when a specific request is received from a customer for the data. Additional data may be collected in areas of anticipated use, such as urban planning, if estimates of future sales justify the investment both in operations and processing and in archiving. This approach is in contrast with that of the government, typified in Landsat and the Earth Observing System (EOS), which is to obtain observations systematically with a goal of full coverage, regardless of current demand, and to archive the data on a routine basis for future use. These data become part of a historical or "heritage" archive that can be used by scientists for research on global change (which by definition requires data at multiple time periods) and regional trends. According to scientists at the workshop, data continuity in space and time is a basic requirement for global change research, and public-private partnerships have not addressed this issue.

Another area in which the requirements of the private sector and the scientific community differ is related to instrument design and development of algorithms. The remote sensing industry understandably takes a proprietary approach to instrument design and algorithms. They are part of the unique intellectual and technological property of a firm and cannot be distributed publicly without undercutting the firm's competitiveness. This approach leads to what scientists call the black box, in which technical details of instrument design and performance are not shared with customers. As one of the participants at the workshop noted, black boxes prevent scientists from obtaining technical information that is necessary to their research—specifically in such areas as calibration and validation that require openness to assure data quality.

Science Requirements

The science community operates in a way that often appears diametrically opposed to the modus operandi of the commercial remote sensing industry. Scientists generally have very specific data requirements, demanding greater assurance of data quality than most commercial users. Specifically, scientists require the following information about remote sensing data:

- The sensor mechanisms that collect the data;
- The sensor reference and light sources used to provide calibration of the collected data;
- The changes of the sensor instrument and calibration sources over time; and
- The software algorithms used to make adjustments to the raw collected data.

In addition, scientists using remote sensing data span a host of disciplines (e.g., environmental sciences, coastal sciences, oceanography, forestry, global change research, and atmospheric sciences) and have widely different research interests. Their data requirements are not standardized and can vary greatly from project to project in terms of geographic coverage and the required spatial and temporal resolution. Scientists often require wide-area coverage and access to archival data to address trends. Scientists attending the workshop reported that data of low spatial resolution may be sufficient for global science that requires long-term observations over large areas. Their evolving data needs are more often met by systematic data acquisition or monitoring programs that obtain remote sensing data on a sustained and regular basis than by commercial tasking practices that require specification of data before tasking and delivery of the data.

At the same time, the availability of higher-resolution data may be creating new research opportunities. Government science agencies have supplied scientists working on global change research, for example, with large-area data sets that have been obtained at lower and medium resolution (e.g., 15 to 30 meters) and at wider swath widths than the high-resolution commercial data available today. Yet, workshop participants noted that the demand for higher-resolution data for science could grow if scientists are able to integrate the new data into long-term observational frameworks.

Most scientists at the workshop also mentioned the need for open access and sharing of data as a problem when using commercially produced remote sensing data. Because science operates on the basis of collaboration, public review, and evaluation of research, scientists make their data openly available for working with collaborators, testing hypotheses, and replicating scientific results. The intellectual property practices of the private sector often run counter to scientists' ways of operating.

Data Management

Significant differences exist between the scientific community and the private sector in data management, including archiving and data processing. In general, scientists require well-calibrated, consistent data records at multiple points in time for intertemporal comparisons. Management of these data involves the following: minimizing deterioration or loss of data; providing access to "heritage" data for current and future research; and making all data available through an active data center for immediate use, and through a long-term data archive for future use. Scientists also require verification and validation of remote sensing data according to open protocols.

Private sector data providers respond to a different set of requirements, which are a result of their need to operate a commercially successful enterprise. Many commercial clients do not require validation and verification, or if they do, they do not need to know the protocols that are used. Once the data are delivered, the commercial firm archives the data for potential resale to another client at a later time. Ownership of the data may be transferred to the user in some cases but not in others. The treatment of intellectual property is not standardized across the private sector, and NASA reported to the steering committee that the agency negotiated separate intellectual property agreements with each of the companies involved in the Science Data Buy.

In response to scientific requirements for data management, NASA, NOAA, and the USGS have established data centers and archives for government-produced data. Guidelines for data archiving are available in other National Research Council (NRC) reports, such as *Adequacy of Climate Observing Systems,*[3] and are monitored by various NRC committees.[4]

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[3]National Research Council, *Adequacy of Climate Observing Systems*, Panel on Climate Observing System Status, Climate Research Committee, Washington, D.C., National Academy Press, 1999.

[4]A number of National Research Council (NRC) reports have examined long-term archiving of scientific and technical data. See, for example, NRC, Committee on Issues in the Transborder Flow of Scientific Data, *Bits of Power: Issues in Global Access to Scientific Data* (1997); NRC, Steering Committee for the Study on the Long-Term Retention of Selected Scientific and Technical Records of the Federal Government, *Preserving Scientific Data on Our Physical Universe: A New Strategy for Archiving the Nation's Scientific Information Resources* (1995); NRC, Committee for Geophysical and Environmental Data, *Review of NASA's Distributed Active Archive Centers* (1999); NRC, Committee on Global Change Research, *Global Environmental Change: Research Pathways for the Next Decade* (1999), all published by National Academy Press, Washington, D.C.

As yet, no provision has been made for data management for subsequent scientific use of data obtained through the public-private partnerships discussed at the workshop, other than the stipulations outlined in the U.S. Department of Commerce licensing regulations (see the subsection "Long-Term Archiving," below). Workshop participants suggested that steps be taken to improve the management of private sector data for subsequent scientific research. Workshop participants suggested that data management protocols should be part of the overall design of all operational data production systems, including public-private partnerships. Data management encompasses quality assurance, validation and verification, data processing, and data archiving. When done according to standards of best practice, according to workshop participants, data management can be costly, amounting to as much as 5 to 10 percent of observing system costs.[5] This amount does not include the costs of validation and verification, which are currently provided by the government in public-private partnerships.

If science data management were mandated at the time public-private partnerships were negotiated, it would add to the immediate cost of the data, but over the long term would result in making more data available for scientific research at lower unit costs. From a scientific perspective, data management issues to be taken into account in these negotiations would include the cost of data management and archiving, ownership of the data, and future access restrictions. Intellectual property provisions in public-private partnerships might also be standardized (see the subsection "Intellectual Property and Access to Data," below). Both parties in the partnership might seek ways to provide scientists with ongoing access to data obtained in the partnership for multitemporal comparisons.

Data Processing

Scientists who use commercial remote sensing data for research purposes are always concerned about data quality and processing. The first real requirement is accurate knowledge of the observation location on Earth's surface. These data can be translated to specific map projections, as needed. The locational precision desired is typically some factor less than the pixel size of the observatory. For example, with Landsat 30-meter observations, it would be desirable to know pixel center location to at least 15 meters. Today this is generally not achieved, even with postacquisition processing of the observations, such as those provided by Earthsat with its orthorectified Landsat data product. The accuracy requirement becomes more difficult with the increased spatial resolution of current

[5]This information is based on the experience of major observing systems that have successfully provided data and stewardship of these data to the scientific- and nonscientific-user communities. The 5 to 10 percent is based on the experience with the U.S. doppler radar data and weather satellites. Those systems in which NOAA data users have had good data access and customer satisfaction have spent up to 10 percent of observing system costs on data access, archiving, and data quality.

commercial systems with 1- to 4-meter resolution. Accurate geometric correction allows scientists to compare images obtained on multiple dates, to detect change, and to identify the processes at work.

The second requirement that scientists are concerned about is the radiometric processing of the data. When remotely sensed data are radiometrically processed to meaningful physical units such as "percent reflectance," the spectral measurements obtained on different dates can be accurately compared in order to detect change.

Many scientists who attended the workshop praised the quality of the data processing provided by NASA under both the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and the Science Data Buy (SDB). Many said they believe that the most important government contribution to the use of commercial remote sensing data by scientists has been the validation and verification of the remotely sensed data. In the SeaWiFS program, the quality of the data for science users was assured by having government-supported research scientists intimately involved with OrbImage personnel in the design of the data collection and processing components. This resulted in data that are calibrated to meet science requirements. The SDB instituted an entirely different validation and verification effort to assess the quality of the commercial data—by establishing a validation and verification center at NASA's Stennis Space Center to undertake these tasks. Stennis Space Center set up an elaborate sensor test-bed facility in which data buy vendors can test their remote sensing instruments according to engineering specifications. In addition, the validation and verification team assures the quality of every SDB data set prior to passing the data to the scientist for research purposes.[6] If the data do not meet specifications, they are not sent to the scientist. SeaWiFS and SDB validation and verification efforts have also resulted in the creation of detailed metadata that are valuable for current research and future scientific uses of the data.

Long-Term Archiving

Because data archiving has both scientific and public benefits, it may be a more appropriate responsibility for the public sector than for the private sector at this time. If the private sector discovers a market for time-series data, private sector interest in long-term archiving could change. Remote sensing data archives contribute to the nation's information infrastructure and provide benefits to global change research, environmental monitoring and projections, environmental and food security, public health, disaster management, and sustainable management of natural resources. Workshop participants stressed that all raw data and related

[6]For additional background on validation of data for science at Stennis Space Center, see <http://www.esad.ssc.nasa.gov/vv/vvssc.asp?show=science>. Accessed October 22, 2001.

metadata should be archived, because the future scientific value of environmental and climate data records is difficult to predict. Participants at the workshop said that plans for archiving should also require that metadata be archived with the remote sensing data, including sufficient information to support future scientific applications, and that back-up data files should be held in a separate location to avoid single-point failure. The growing volume of remote sensing data is likely to place steadily increasing demands on archiving facilities, although improvements in data storage and compression may lead to more cost-effective archiving procedures in the future.

Data archiving presents a different challenge in the context of public-private partnerships. Given the cost of archiving and its long-term public rather than short-term commercial benefits, it is unlikely that the private sector will assume this responsibility. At present, firms that obtain commercial licenses through NOAA are required to provide, at a reasonable cost, land observation data to the National Satellite Land Remote Sensing Data Archive maintained by the USGS in Sioux Falls, South Dakota, before they purge the data.[7]

Data produced or obtained for scientific use under a public-private partnership are in a somewhat different category. These data have not only present scientific value, but future scientific value as historical or "heritage" data for use in multitemporal comparisons. At present, however, the data in the SDB are licensed or restricted, not purchased. It is not clear what the government's rights are regarding the archiving of these data, except for the stipulations made in the U.S. Department of Commerce licenses issued to commercial remote sensing satellite operators.[8] Moreover, since separate licenses or data distribution rights were negotiated with each firm participating in the SDB, there may be no single answer.

Workshop participants emphasized that, at a minimum, common standards are needed for documentation and preparation of data, obtained through either the public or the private sector, that are to be placed in permanent archives. The development of standards is most effectively completed early in the design of data systems, and it is most effective when it involves government, the private sector, and the scientific community. These standards could cover metadata, formats, and portability of data, and adherence to them might be required as part of the award process for public-private partnerships or the licensing process.

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[7]This stipulation is stated in the *Federal Register*, Vol. 65, No. 147, Part IV, Department of Commerce, National Oceanic and Atmospheric Administration, 15 CFR Part 960, "Licensing of Private Land Remote-Sensing Space Systems: Interim Final Rule," Section VI, July 31, 2000, p. 46826.

[8]*Federal Register*, Vol. 65, No. 147, Part IV, Department of Commerce, National Oceanic and Atmospheric Administration, 15 CFR Part 960, "Licensing of Private Land Remote-Sensing Space Systems: Interim Final Rule," Section VI, July 31, 2000, p. 46826.

Intellectual Property and Access to Data

Data access was the primary focus of one breakout group at the workshop. Participants recognized that the scientific community and the private sector have different perspectives on data rights that provide access to commercial remote sensing data. The commercial remote sensing industry, which is premised on obtaining financial profit through data sales, regards remote sensing data as its intellectual property and protects its right to resell the data. In contrast, the scientific community tends to view large-scale databases as a public or collective commodity that should be openly available for use in research.[9] Yet if this approach were extended to the private sector, the practice of making data universally available could compromise the property rights of the data producer and could seriously affect, if not destroy, the commercial base of the industry. Many of the issues related to the interests of the scientific community, the public sector, and the private sector were explored in the NRC report *A Question of Balance: Private Rights and the Public Interest in Scientific and Technical Databases*.[10]

There is no easy solution to this problem, and both the scientific and commercial remote sensing communities have debated the issue of data access in the context of a potential Landsat data continuity mission.[11] Workshop participants suggested that because the value of data changes over time, private sector data producers might reduce the cost of older commercial data to the research community as a way both to protect their intellectual property and to meet the needs of scientists. Imposing a 14-day delay in providing scientific access to data to ensure the value of the data for commercial customers has been the practice in the SeaWiFS project. This waiting period usually does not cause a problem for scientific data users and could be applied in connection with future science data buy programs.

A related concern expressed by scientists is that of obtaining access to instrument calibration details contained in the "black box." This information is used to develop algorithms for processing the data and for distinguishing data that correspond to the performance of the instrument from data that have scientific meaning. One possible solution might be "third party" certification that data meet scientific quality standards and calibration as specified by researchers. Scientists may not need to "see" inside the box if they are convinced that the data meet specific quality standards. The federal government could provide this certifica-

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[9] Several national policy statements guarantee the full and open access of government and scientific data. See National Research Council, *Resolving Conflicts Arising from the Privatization of Environmental Data*, Washington, D.C., National Academy Press, 2001.

[10] National Research Council, *A Question of Balance: Private Rights and the Public Interest in Scientific and Technical Databases*, Washington, D.C., National Academy Press, 1999.

[11] Related discussions can be found online at <http://ldcm.usgs.gov> and <http://www.imagingnotes.com>.

tion, much in the way that the National Institute of Standards and Technology provides calibration information for manufacturing, or that the Environmental Protection Agency safeguards proprietary data obtained from the chemical industry (data used to report publicly the industry's compliance with environmental regulations). Alternatively, a nongovernmental third party could provide certification, much like the assurances supplied by the Underwriter's Laboratory for consumer electrical devices.

Licensing Commercial Earth Observation Satellites

The process of licensing commercial firms to launch Earth observation satellites also affects data rights. NOAA, the U.S. government agency responsible for licensing commercial remote sensing systems, can encourage private sector firms to employ favorable terms for use of the data in research.[12] NOAA may also require that an applicant have a nondiscriminatory access policy and provide broadly defined data rights for systems developed with significant government funding. The licensing process is probably not an appropriate vehicle for imposing operational data management and intellectual property requirements on commercial firms, however, because it does not encompass issues related to markets and applications of the data. In addition, the commercial sector would prefer a faster licensing process; however, there was no suggestion at the workshop that the current process was excessively long, given the requirements of licensing. If development of a remote sensing system involves foreign participants, either from the science community or the private sector, export control licenses are required under the International Traffic in Arms Regulations (ITAR). ITAR requirements can add more time to the licensing process.

Impact of Government Processes

Several workshop participants mentioned problems posed by the lengthy time involved in completing government processes associated with establishing public-private partnerships. Given the complexity of the issues under negotiation, the length of the contracting process has created a financial hardship for private sector firms involved in the SDB and SeaWiFS. Specifically, long procurement processes with changing schedules created cost burdens and uncertainties that decreased the real value of data contracts. Two factors are important here. First, if a company must maintain staff to work on a contract and there are delays in start-up, substantial unanticipated costs can be incurred that cannot be recovered. Second, for projects in which private sector investments and capital

[12] *Federal Register*, Vol. 65, No. 147, Part IV, Department of Commerce, National Oceanic and Atmospheric Administration, 15 CFR Part 960, "Licensing of Private Land Remote-Sensing Space Systems; Interim Final Rule," July 31, 2000, p. 46827.

are required, the cost of money to cover these long lead items in the face of schedule uncertainty can create a financial hardship. Thus, lengthy contracting procedures may create a private sector disincentive to producing scientific data with government funding.

Another area of great importance is the length and stability of the public-private contract. Space remote sensing systems require substantial front-end investments prior to launch. To finance these systems at reasonable rates, a public-private partnership of less than 5 to 10 years is not likely to be attractive to a commercial firm. Such a long-term commitment may also require that a government agency seek all of the funding for its purchase of scientific data in a single fiscal year or that the government create a means to make financial commitments for long-term contracts with the private sector.

Performance Metrics and Evaluation

There is value in both ongoing and periodic evaluations of public-private partnerships to facilitate scientific access to commercial data. Ongoing evaluation involves the establishment of performance metrics and their use in program management. Periodic evaluation also involves the appointment of an external group to review the program. Emphasis on performance metrics in the government has existed since the passage of the Government Performance and Results Act of 1993.[13] This act requires that agencies develop performance standards and periodically report to Congress on their progress in reaching these standards. The experience of government agencies in the years after passage of the act has been that developing accurate and appropriate standards is very difficult, particularly for metrics that measure the quality or utility of scientific research.[14] Nonetheless, despite the difficulty, the discipline of identifying performance metrics for public-private partnerships in remote sensing data for science can be valuable both in making the operational goals of the partnership explicit and in the management of the program.

Some performance measures would be applicable only to the public sector, the private sector, or the scientific community, although others would transcend these boundaries. For example, is the partnership cost-effective for government,

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[13]Additional background on the Government Performance and Results Act of 1993 can be found in *Demonstrating Results: An Introduction to the Government Performance and Results Act*, Higher Education Programs, Office of Secondary Education, U.S. Department of Education online at <http://www.ed.gov/pubs/DemoResults/title.html>. Accessed October 23, 2001.

[14]For further background on the Government Performance and Results Act and scientific research, see National Academy of Sciences (NAS), National Academy of Engineering (NAE), and Institute of Medicine (IOM), *Implementing the Government Performance and Results Act for Research: A Status Report*, Washington, D.C., National Academy Press, 2001; NAS, NAE, and IOM, *Evaluating Federal Research Programs: Research and the Government Performance and Results Act,* Washington, D.C., National Academy Press, 1999.

industry, and science? What is its track record in data quality and the efficiency of data processing, delivery, and contracting procedures? Are significant scientific results generated from the data? Specifying and measuring attainment of specific goals require collaboration among all parties early in the process of establishing a public-private remote sensing data partnership, and could involve independent review by external groups.

Realistic Cost Accounting

The true costs of public-private partnerships can go significantly beyond the purchase price of the data. Both the government and the private sector may have to assume expenses in a partnership that they do not face in other transactions. These added expenses are generally not calculated as part of the cost of establishing a public-private partnership.

In the SDB, NASA selects the scientists who will receive data under the program through a competitive process open to its current grantees. This requires the agency to cover the cost of staff time to set up the program and to conduct the competition for data. Prior to redistributing the data to scientists, NASA also conducts validation and verification checks on data received from the vendors, because commercial image providers do not routinely provide such information. In SeaWiFS, calibration, validation, and verification are supported by NASA's Goddard Space Flight Center.

From the private sector side, the costs of procuring a government contract and responding to contract changes can raise the cost of the transaction to the private sector partner, the government, or both, above the agreed purchase price of the data. In public-private partnerships that involve the launch of satellites, additional expenses are also encountered in engineering, prelaunch, and quality assurance.

Other reports of the Space Studies Board have urged NASA to use full-cost accounting on an agencywide basis,[15] and progress to this end is slow. Realistic cost accounting for public-private partnerships is a separate issue. Because it involves both the public and private sectors, accounting information required for evaluating the true costs of a public-private partnerships may be different from general financial data that are used in agency accounting practices.

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[15]Space Studies Board, National Research Council, *Assessment of Technology Development in NASA's Office of Space Science*, Washington, D.C., National Academy Press, 1998, pp. 25-25, 33; and "Continuing Assessment of Technology Development in NASA's Office of Space Science," letter from Daniel J. Fink, Chair, Task Group on Technology Development in NASA's Office of Space Science, and Claude Canizares, Chair, Space Studies Board, to Dr. Edward J. Weiler, Associate Administrator, Office of Space Science, NASA, on NASA's response to the 1998 Report of the SSB Task Group on Technology Development in NASA's Office of Space Science, March 15, 2000.

TABLE 4.2 Complexity and Significance of Cross-Cutting Issues

	Higher Complexity	Lower Complexity
Higher Significance	Intellectual property and licensing Impact of government processes	Data management Data continuity
Lower Significance	Performance metrics	Realistic cost accounting

SUMMARY

A number of the cross-cutting issues discussed above—data archiving and management, data continuity, resolution, intellectual property, licensing, performance metrics, government processes, and realistic cost accounting—are related to the different approach or orientation of scientists and the private sector. These issues must be reconciled if public-private sector partnerships are to play a significant role in producing data for scientific research. The steering committee prioritized these issues, as shown in Table 4.2, according to their significance for public-private partnerships and the difficulty in resolving them.

Two of the most important issues for scientists are data management, including archiving and data processing, and data continuity. The steering committee judged them to be low in complexity because they can be resolved easily, provided sufficient financial resources are available. Intellectual property issues and the impact of government processes on the effectiveness of public-private sector partnerships were judged to be high in significance and high in complexity, largely because there is no convergence on these issues between parties with legitimate but different needs. An example of a high-significance/high-complexity issue is the redistribution of private sector remote sensing data. Scientists believe that the open distribution of research data is critical to the advance of science. Private sector firms producing remote sensing data, on the other hand, must charge scientists for access to their data, both to recover their initial investments and to make a profit for their investors. If the use of commercially generated remote sensing satellite data by the government and the scientific community increases, the need to resolve intellectual property issues will intensify.

Two other issues were of lower significance but were still considered highly complex. These are the development of metrics for evaluation purposes and the issue of licensing data. Finally, realistic cost accounting, although of lower significance and complexity than other topics, is critical in evaluating the costs and benefits of alternative means of acquiring and distributing scientific data.

5

Findings and Recommendations

Cooperation between the public and private sectors to provide remote sensing data for scientific research is expanding the data resources available to scientists. From the perspective of scientists, this cooperation has provided new, valuable sources of research data. From the perspectives of the government and the private sector, partnerships in remote sensing across the public and private sectors demonstrate that government science agencies, the U.S. scientific community, and commercial firms can work together usefully in producing scientific data. Because of continuing policy interest in the U.S. Congress in using commercial sources to obtain remote sensing data for scientific research, new approaches to developing public-private relationships are likely to arise in the future. The two major public-private sector partnerships that have operated for several years are instructive in assessing what has worked well, what requires further attention, and what in such partnerships can be improved.

The steering committee found widespread support in the scientific community for maintaining and even expanding public-private partnerships to provide remote sensing data for scientific research. According to information provided to the steering committee, scientists welcome the involvement of the commercial remote sensing industry in research data, but they also see an essential, continuing role for the government in these activities. From the scientists' perspective, the benefits of partnerships extend beyond the opportunity to use commercially produced data. The success of these partnerships is directly related to the ongoing role of government agencies in data preparation and management. Moreover, the steering committee found that these partnerships must involve scientists throughout the process.

DIFFERENCES AMONG THE THREE SECTORS

The steering committee also found that the different, characteristic modes of operating in the public, the private, and the scientific sectors can potentially create problems in public-private partnerships that must be resolved if these partnerships are to be an effective means of providing research data to scientists. With respect to the private sector, it must both recover investment costs and make a profit. The commercial remote sensing satellite industry is still becoming established and can only continue to participate in public-private sector partnerships for science data if these partnerships are financially rewarding. This requirement has implications for the commercial approach to intellectual property, the nature and extent of services provided to data users, and private sector firms' response to the competing needs of scientists and nonscientific customers. In this respect, the validation and verification services provided by industry are limited because of the lack of demand for these services among commercial applications users, and are generally inadequate for scientific users of the data.

The government has extensive experience in providing remote sensing data for scientific research, but it is constrained in what it can do. Government agencies that are involved in obtaining or disseminating remote sensing data for research must respond to the policy priorities of both the White House and the Congress and are dependent upon annual budget allocations that may constrain or reshape their programs. In addition, government agencies operate in an environment of complex regulations and public accountability that requires them to engage in what are often lengthy contract negotiations with private sector firms in order to establish a public-private partnership to provide data for scientific research.

Members of the research community are target users of the remote sensing data obtained through the partnerships. Many researchers have not been required to purchase data in the past and consequently have limited research budgets for this purpose. They may lack the financial resources to purchase significant amounts of commercial remote sensing data on the open market. Yet scientists also have well-defined requirements for remote sensing data that are based on the ways the data are used in research. Scientists require a thorough understanding of the algorithms used in calibration, validation, and verification of data—information that may be considered proprietary by a commercial firm. Once data are obtained for research, scientists assume that the data will be available to other scientists for testing research results or conducting related research.

Although these differences in the ways that public, private, and scientific sectors function might initially appear to constitute a barrier to effective cooperation, the steering committee finds that this barrier is not insurmountable. New public-private partnerships should draw on the strengths of each sector and on the experience gained in existing partnerships and should focus on the long-term needs of the scientific community.

THE ROLE OF GOVERNMENT

The steering committee concluded that government science agencies must play a strong and continuing role in public-private partnerships to provide remote sensing data for scientific research. The government plays a critical role in the development of new sensors and instruments for the collection of data. Government agencies also play a unique role in producing low- to medium-resolution, broad-swath data that may have little commercial applicability but do have significant scientific value, particularly in monitoring changes in the Earth system.

The government also has provided calibration, validation, and verification for data obtained through public-private partnerships. These services are essential to the scientific use of remote sensing data and must be provided by one of the partners. (As discussed in Chapter 4, in the subsection "Intellectual Property and Access to Data," third parties could also provide this service.) To calibrate the data, scientists need to know the sensors used to collect the data, sensor reference and light sources, and changes in the sensor and calibration sources, in addition to the software algorithms used to make adjustments to the data. The validation and verification role is equally important. In NASA's Science Data Buy (SDB), the government ensures that the data sets provided to scientists are traceable to standards, assuring comparability and saving researchers valuable time and resources that they would otherwise have to expend.

Finally, Congress and federal agencies and the administration play invaluable roles as brokers for the interests of science—for example, NASA by acquiring commercially derived data through public-private partnerships and the executive branch by providing the legislative means to encourage the use of new private sources of data for scientific research. In the SDB, NASA negotiated data acquisition schedules, the price for delivered products, intellectual property restrictions, and delivery schedules with the five firms selected to participate in the program. Because the government already maintains data centers and long-term archives for scientific data collected through government satellite programs, a logical extension of this role is for the government to provide similar services for data collected under public-private partnerships. This function would be valuable for research, particularly research involving long time periods, and it is unlikely to be done by the private sector under current funding programs.[1]

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[1]Because NASA was the only government agency involved in the public-private partnerships examined at the workshop, most of the comments about government involvement in public-private partnerships are related to NASA. In the future, however, other government agencies are likely to be involved in public-private partnerships as well, so the generic term "government" is used throughout this report.

Licensing

Finding. Full and open access[2] to data used in research and the ability both to replicate research findings and to conduct further research using the same data are critical to the scientific process. However, commercial entities view their data as intellectual property, and consequently there may be intellectual property issues or additional costs involved in reusing data obtained through public-private partnerships. Because of the importance of this property to firms, each participant in the Science Data Buy negotiated a separate intellectual property agreement with the government. In this situation, the data requirements of the scientific community and the profit objectives of the private sector appear to be in conflict. U.S. Department of Commerce licensing procedures provide that all remote sensing data under a government license be offered to a government data repository before they can be destroyed. However, no timeframe during which this must occur is specified.

Recommendation 1. The government partner in a public-private partnership should negotiate in its contract for open scientific distribution and reuse of data obtained under the partnership.

Evaluation of Public-Private Partnerships for Science Data

Finding. Public-private partnership programs for science data have been in operation for several years. The initial phases of the Science Data Buy have been completed. Formal program evaluation will help the government both evaluate existing operations and understand how best to structure future programs.

Recommendation 2. A formal, independent review of the Science Data Buy and of the SeaWiFS program should be conducted to evaluate the scientific benefits and the efficacy and economic benefits of each partnership to the parties involved.

Broadening Participation of Scientists in the Science Data Buy

Finding. Participation in the SDB is limited to current NASA grantees, but other academic scientists could usefully participate in the program. If the SDB is intended to benefit scientists, there should be no restrictions on scientists' eligibility to compete for access to data because of their current sources of research funding; all scientists at U.S. academic institutions should be able to compete for data from the SDB.

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[2]Several policy statements guarantee the full and open access of government and scientific data. See National Research Council, *Resolving Conflicts Arising from the Privatization of Environmental Data*, Washington, D.C., National Academy Press, 2001, p. 18.

Recommendation 3. NASA should permit any academic scientist to compete for data under the Science Data Buy or successor programs.

THE SCIENCE PERSPECTIVE

From the perspective of scientists, public-private partnerships are valuable because of their potential to provide access to data that might otherwise not be available to them. This includes new types of data, such as have been made available through the SDB and the SeaWiFS programs.

Data Continuity

Finding. Continuity of remote sensing observations over long periods of time is essential for Earth system science and global change research, and it requires that scientists have access to repeated observations obtained over periods of many years. Problems may arise with the use of remote sensing data from sensors that have different capabilities and characteristics. The problem of data continuity existed when scientific data came solely from the government, but it is exacerbated when scientific data are obtained from a mixture of government and public-private sources. Data obtained through public-private partnerships could continue to be useful as historical or "heritage" data and should be archived for future use. Data management is a major responsibility of the public sector partner; it should be done in collaboration with the scientific community.

Programs designed to ensure intercomparability of data and information derived from different sensors, exemplified by the Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) project at NASA's Goddard Space Flight Center,[3] are essential to providing continuity of data series. Such efforts will make it possible to have seamless transitions among sensors that will allow advances in technology to be realized while maintaining a data stream on key properties over a period of years.

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[3]"The Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) program at NASA's Goddard Space Flight Program arose following a NASA management review of the agency's strategy for monitoring bio-optical properties of the global ocean. SIMBIOS addresses the need to achieve comparable measurements from successive ocean color remote sensing missions and generate time-series information spanning a period of years to decades. The program consists of a science team and a project office that combine research expertise of academia and technical capabilities of government. A central role of SIMBIOS is to consolidate data holdings on bio-optical properties in support of ocean color remote sensing, and to facilitate and support research that enables inter-comparisons. These efforts hinge on the creation of global bio-optical time series products." Additional information on SIMBIOS can be found at <http://simbios.gsfc.nasa.gov>.

Recommendation 4. Existing remote sensing data series—for example, the Landsat series—within current or anticipated public-private partnerships should be maintained to provide comparable data for scientific research over time. Support should also be made available for research in either the scientific community or the private sector or both on how to generate seamless transitions from one data source to another as new sensors replace past or current sensors.

Archiving

Finding. Scientific data obtained through public-private partnerships must be available for future use through data centers and permanent archives. The inclusion of data and relevant metadata that are amenable to reprocessing after algorithms have been improved will be an important function in permanent archives and data centers.

Recommendation 5. Data produced by the private sector in a public-private partnership should be archived for subsequent redistribution to scientists and for creating long time series of data. The government partner should negotiate for permission to do this.

Calibration, Validation, and Verification

Finding. Scientists require instrument characterization and data calibration to physical units with quantified uncertainty. Access to calibrated data is an essential precondition for many scientific uses of remote sensing data, to ensure the quality of the data and to ensure that data sets differing in spatial, temporal, or spectral coverage, or acquired by different instruments are comparable. Because most of the customers of private sector remote sensing firms do not require highly calibrated data, commercial firms have not routinely provided calibration, validation, and verification services at the level required by the science community. In public-private partnerships, the government has often assumed responsibility for calibration, validation, and verification. The steering committee commends the government's role in providing excellent calibration, validation, and verification of commercially obtained remote sensing data for scientific use.

Recommendation 6. Public-private partnerships to acquire data for scientific research should ensure that the partnership agreement specifies who has responsibility for calibrating and validating the data, what the scope of the calibration and validation processes is, and what resources (financial, technical, and personnel) will be made available for these purposes.

Standardization of Data Management

Finding. Consistent approaches to documentation and preparation of data for long-term archiving are key to effective data stewardship in public-private partnerships.

Recommendation 7. In the process of negotiating a public-private sector data partnership, the parties should agree to use commonly accepted standards for metadata, data formats, and data portability.

THE PRIVATE SECTOR ROLE IN PUBLIC-PRIVATE PARTNERSHIPS

The private sector has made laudable strides in forging new partnerships with the government. It has taken commercial and technical risks in these partnerships and has gained an appreciation of the requirements of scientific data users.

Communication

Finding. Communication among government data providers, commercial data providers, and scientists is vital to effective partnerships. More opportunities for formal and informal communication are needed. Communication between the private sector and the academic scientific community is particularly valuable. Planning for public-private partnerships to produce remote sensing data for research should include opportunities for direct communication among the partners and scientists who use the data.

Recommendation 8. The government should facilitate direct communication between members of the scientific community and the private sector, including communication during the early stages of planning for public-private remote sensing programs.

THE PUBLIC-PRIVATE PARTNERSHIP

The SDB and SeaWiFS were created to obtain commercially produced remotely sensed data for scientific research and to stimulate the U.S. remote sensing iindustry. Both programs have been operating long enough to provide guidance for the development of future public-private partnerships. Defined objectives and efficient and accurate feedback on the progress of these programs can contribute to meeting these goals. Public-private partnerships for obtaining new sources of data for scientific research are new entities that may share some characteristics of each partner but at the same time are independent of both founding partners.

Performance Measures

Finding. Public-private partnerships benefit from ongoing evaluation, not just from retrospective assessment. Performance measures help all parties (industry, government, and scientists) benchmark progress, identify problems, and communicate results to stakeholders (including taxpayers, university administrators, corporate stockholders, the U.S. Congress, federal agencies, and others). Such measures also guide partnership activities in defining and establishing incentives for future success. Performance measures should be tailored to the goals of the parties—that is, return on investment for industry, good science output for researchers, and cost-effective performance by government agencies. Although NASA is conducting an internal review of the SDB program, and other reports have analyzed public-private partnerships,[4] no performance measures exist for assessing the quality of these public-private programs.

Recommendation 9. Representatives of government agencies and commercial firms involved in public-private partnerships, together with scientists who use the data in these programs, should define performance measures at the time the public-private partnership is established. These performance measures should be taken into account in formal program evaluations.

Realistic Cost Accounting

Finding. The purchase of private sector data by the public sector for use in scientific research involves many more costs to both parties than the simple transaction cost. They include the costs of data dissemination and of verification and validation on the government side and the costs to both the government and the private sector if changes are made to a contract or if delays occur on the private sector side. These buried costs, if unacknowledged, can serve as a disincentive to the formation of further public-private relationships. If these costs are realistic and transparent, discussions about future partnerships could take into account alternative ways to provide the services at issue.

Recommendation 10. Public-private relationships for producing scientific data should practice realistic cost accounting, making all the costs of the partnership transparent and open to negotiation.

[4]Scott Pace, David Frelinger, Beth Lachman, Arthur Brooks, and Mark Gabriele, *The Earth Below: Purchasing Science Data and the Role of Public-Private Partnerships,* Santa Monica, Calif., RAND, 2000.

Appendixes

A

Remote Sensing Systems

Table A.1 on pages 56-61 presents selected historical, current, and planned remote sensing systems operated by governmental, commercial, and public-private (government and commercial) organizations that provide data of value for scientific research.

TABLE A.1 Selected Government, Commercial, and Public-Private Remote Sensing Systems

Remote Sensing System	Data Acquisition Model	Operator	Launch (end service date)	Capability: Spatial/Spectral Resolution	Revisit in Days	Status
U.S. Data Providers						
Landsat 3 RBV MSS	Government	NASA and NOAA	1978 (1983)	1 RBV band at 40 m 4 MSS bands at 80 m 1 MSS TIR band at 240 m	18	Retired
Landsat 4 TM MSS	Public-Private	EOSAT, Inc. Space Imaging, Inc. NASA	1982 (1987)	6 TM bands at 30 m 1 TM TIR band at 120 m 4 MSS bands at 80 m	16	Retired
Landsat 5 TM MSS	Public-Private	EOSAT, Inc. Space Imaging, Inc. NASA	1984	6 TM bands at 30 m 1 TM TIR band at 120 m 4 MSS bands at 80 m	16	Operational
Landsat 6 ETM	Commercial	EOSAT, Inc.	1993	1 ETM Pan band at 15 m 6 ETM bands at 30 m 1 ETM TIR band at 60 m	16	Failed
Landsat 7 ETM+	Government	USGS EROS Data Center	1999	1 ETM+ Pan band at 15 m 6 ETM+ bands at 30 m 1 ETM+ TIR band at 60 m	16	Operational
Landsat Follow-on	Public-Private	TBD	2003	TBD	TBD	Planned

AVHRR	Government	NOAA	1970s to present	2 MS bands at 1.1 km 3 MS TIR bands at 1.1 km	Daily	Operational
IKONOS 1 Pan MS	Commercial	Space Imaging, Inc.	1999	1 Pan band at 0.82–1 m 4 MS bands at 4 m	3 to 5	Failed
IKONOS 2	Commercial	Space Imaging, Inc.	1999	1 Pan band at 0.82–1 m 4 MS bands at 4 m	3 to 5	Operational
IKONOS 3	Commercial	Space Imaging, Inc.	2003	0.5 Pan band at <1 m 2 MS bands at 4 m	3 to 5	Planned
Earlybird	Commercial	EarthWatch, Inc. (now DigitalGlobe, Inc.)	1997	1 Pan band at 3 m 3 MS bands at 15 m	1 to 5	Failed
QuickBird 1	Commercial	EarthWatch, Inc. (now DigitalGlobe, Inc.)	2000	1 Pan band at 1 m 4 MS bands at 4 m	1 to 5	Failed
QuickBird 2	Commercial	EarthWatch, Inc (now DigitalGlobe, Inc.)	Oct. 2001	1 Pan band at 61 cm 4 MS bands at 4 m	1 to 5	Operational
OrbView 2 (SeaWiFS)	Public-Private	OrbImage, Inc.	1997	8 MS bands at 1.13 km	1	Operational
OrbView 3	Public-Private	OrbImage, Inc.	2002	1 Pan band at 1 m 4 MS bands at 4 m	<3	Planned

continued

TABLE A.1 Continued

Remote Sensing System	Data Acquisition Model	Operator	Launch (end service date)	Capability: Spatial/Spectral Resolution	Revisit in Days	Status
OrbView 4	Public-Private	OrbImage, Inc.	2001	1 Pan band at 1 m 4 MS bands at 4 m 8-m hyperspectral data (can sell reprocessed 20-m hyperspectral data to nongovernment [approved] entities)	<3	Failed
Terra Satellite	Government	NASA	2000		Variable	
ASTER				4 MS bands at 15 m 6 SWIR bands at 30 m 5 TIR bands at 60 m		Operational
MISR				4 MS bands at 9 look angles from 275 m to 1.1 km		Operational
MODIS				2 MS bands at 250 m 5 MS bands at 500 m 12 MS bands at 1 km 7 SWIR bands at 1 km 10 TIR bands at 1 km		Operational

European Data Providers						
SPOT 1-2	Public-Private	Spot Image, Inc.	1986 and 1990	1 Pan band at 10 m 3 MS bands at 20 m	1 to 4	Standby in 1990
SPOT 3	Public-Private	Spot Image, Inc.	1993 (1996)	1 Pan band at 10 m 3 MS bands at 20 m	1 to 4	Failed
SPOT 4	Public-Private	Spot Image, Inc.	1998	1 Pan band at 10 m 3 MS bands at 20 m 1 SWIR band at 20 m 4 vegetation bands at 1.15 km	1 to 4	Operational
SPOT 5	Public-Private	Spot Image, Inc.	2003	1 Pan band at 2.5 m 3 MS bands at 10 m 1 SWIR band at 10 m 4 vegetation bands at 1.15 km	1 to 4	Planned
ERS-1	Government	ESA	1991	30–50-m SAR	3 to 35	Operational
ERS-2	Government	ESA	1995	30–50-m SAR	3 to 35	Operational
ENVISAT	Government	ESA	2001	30-m SAR	3 to 35	Operational
SPIN-*N* KVR-1000	Government	Russian Sovinformsputnik	1992 [available publicly in 2000]	1 band at 2 m	45 days in orbit, each launch	Operational

continued

TABLE A.1 Continued

Remote Sensing System	Data Acquisition Model	Operator	Launch (end service date)	Capability: Spatial/Spectral Resolution	Revisit in Days	Status
Canadian Data Providers						
Radarsat 1*a*	Government	Canadian Space Agency	1995	8-m SAR at various resolutions	3 to 24	Operational
Radarsat 2	Public-Private	Canadian Space Agency and McDonald Detwiller, Inc.	2004	3-m SAR at various resolutions	3 to 24	Planned
Other Data Providers						
EROS A1	Commercial	ImageSat, Int.	2000	1 Pan band at 1.8 m	1 to 4 (depends on number of satellites in orbit)	Operational
EROS B1	Commercial	ImageSat, Int.	2003	1 Pan band at 0.82 m		Planned
EROS B2	Commercial	ImageSat, Int.	2003	1 Pan band at 0.82 m		Planned
EROS B3	Commercial	ImageSat, Int.	2004	1 Pan band at 0.82 m		Planned
EROS B4	Commercial	ImageSat, Int.	2004	1 Pan band at 0.82 m		Planned
EROS B5	Commercial	ImageSat, Int.	2004	1 Pan band at 0.82 m		Planned
EROS B6	Commercial	ImageSat, Int.	2004	1 Pan band at 0.82 m		Planned
IRS-1 A	Government	Indian Space Research Organization (ISRO)	1988	4 MS bands at 36.25 and 72.5 m	22	Operational
IRS-1 B	Government	ISRO	1991	4 MS bands at 36.25 m and 72.5 m	22	Operational
IRS-1 C	Government	ISRO	1995	1 Pan band at 5.8 m 3 MS bands at 23 m 1 SWIR band at 70 m 2 MS bands at 188 m	5 to 24	Operational

IRS-1 D	Government	ISRO	1997	1 Pan band at 5.8 m 3 MS bands at 23 m 1 SWIR band at 70 m 2 MS bands at 188 m	5 to 24	Operational

NOTE: All acronyms are defined in Appendix D; TBD, to be determined.

[a]Radarsat 1 is noted as a government system because it was funded by the Canadian government.

SOURCES: Commercial and government remote sensing data-provider Web sites; Yahya A. Dehquanzada and Ann M. Florini, *Secrets for Sale: How Commercial Satellite Imagery Will Change the World,* Washington, D.C., Carnegie Endowment for International Peace, 2000; John R. Jensen, *Remote Sensing of the Environment: An Earth Resource Perspective,* Upper Saddle River, N.J., Prentice-Hall, 2000; and William E. Stoney, "Summary of Land Imaging Satellites Planned to Be Operational by 2006," Mitretek Systems, July 2, 2001, available online at <http://www.asprs.org/news>.

B

Biographical Information for Steering Committee Members and Workshop Speakers and Panelists

STEERING COMMITTEE MEMBERS

Roberta Balstad Miller, *Chair*, has worked and published extensively in the areas of science and technology policy and human interactions in global environmental change. She received her Ph.D. from the University of Minnesota. Currently the director of the Center for International Earth Science Information Network at Columbia University, she was previously a staff associate with the Social Science Research Council (1975 to 1981), the founding executive director of the Consortium of Social Science Associations (1981 to 1984), and director of the Division of Social and Economic Science at the National Science Foundation (NSF) (1984 to 1993). She received NSF's Meritorious Service Award in 1993. Dr. Miller has served as chair of a number of scientific advisory groups, including the North Atlantic Treaty Organization (NATO) Advisory Panel on Advanced Science Institutes and Advanced Research Workshops; the Committee on Science, Engineering, and Public Policy of the American Association for the Advancement of Science; the Human Dominated Systems Directorate of the U.S. Man in the Biosphere Program; and others. From 1992 to 1994, she served as vice president of the International Social Science Council. Dr. Miller's National Research Council (NRC) service includes former membership on the Space Studies Board, the Board's Task Group on Research and Analysis Programs, and the Climate Research Committee. She currently serves on the NRC Committee on Global Change Research and the NRC Committee on the Geographic Foundation for Agenda 21.

Mark R. Abbott[1] was an acting assistant professor for the Section of Ecology and Systematics at Cornell University (1978 to 1979) and a postgraduate researcher for the Institute of Ecology at the University of California at Davis (1979 to 1980). From 1980 to 1982, Dr. Abbott was a NATO/NSF postdoctoral fellow of ocean ecology at the Institute of Ocean Studies in Sidney, British Columbia. He was a member of the technical staff of the Oceanography Group at the Jet Propulsion Laboratory from 1982 to 1988. At the same time, he was also an assistant adjunct professor of the Marine Life Research Group at the Scripps Institution of Oceanography. In 1988, Dr. Abbott joined the faculty of the College of Oceanic and Atmospheric Sciences at Oregon State University, where he is a professor of biological oceanography. He currently serves on the National Aeronautics and Space Administration (NASA) Earth Observing System (EOS) Investigators Working Group (1989 to the present) and is a member of the EOS Moderate Resolution Imaging Spectrometer Science Team (1989 to the present). He currently chairs the EOS Payload Panel (1995 to the present). In addition, he serves on NSF's Joint Global Ocean Flux Study Science Executive Committee (1996 to the present). Dr. Abbott was chair of the Space Studies Board's Committee on Earth Studies and a member of the Space Studies Board. He currently serves as a member of the NRC's Committee on NASA-NOAA Transition from Research to Operations.

Alexander F.H. Goetz[2] has been a professor of geological sciences and director of the Center for the Study of Earth from Space/Cooperative Institute for Research in Environmental Sciences at the University of Colorado, Boulder, since 1985. Dr. Goetz received degrees in physics, geology, and planetary science from the California Institute of Technology. Previously he spent 15 years at the NASA Jet Propulsion Laboratory (JPL), where he started and headed the geologic remote sensing group and initiated the development of imaging spectrometry, now known as hyperspectral imaging. Prior to joining JPL, he spent 3 years at Bellcomm, a subsidiary of AT&T Bell Labs, working on the Apollo program. Dr. Goetz has been a principal investigator in the Apollo, Skylab, Shuttle, and Landsat programs. He is currently a member of the Landsat 7 science team and plays a similar role in the EO-1 satellite team. Dr. Goetz has received numerous awards—among them the NASA/Department of the Interior William T. Pecora award. In addition, Dr. Goetz was a founder and the CEO of Analytical Spectral Devices, Inc., in Boulder, for 10 years, and is currently its chairman.

Lawrence W. Harding, Jr., is a research professor at the University of Maryland Center for Environmental Science, with appointments at Maryland Sea Grant

[1]Mark Abbott served on the steering committee until April 2001.
[2]Alexander Goetz joined the steering committee in August 2001.

and the Horn Point Laboratory. His research focuses on the use of aircraft and satellite remote sensing of ocean color to study phytoplankton responses to nutrient enrichment in estuarine and coastal waters. He also directs Sea Grant educational activities in remote sensing in collaboration with NASA scientists. His main interests include coordination of a regional, multiplatform remote sensing program in the Chesapeake Bay region to further the understanding of ecosystem health by applying new technologies to contemporary ecological issues.

John R. Jensen is a Carolina Distinguished Professor of Geography and director of the Remote Sensing and GIS Center at the University of South Carolina. His research focuses on remote sensing of vegetation biophysical resources, especially inland and coastal wetlands; remote sensing of urban, suburban, and land-use cover; development of improved digital image processing classification, change detection, and error evaluation algorithms; and development of educational materials for remote sensing instruction. Dr. Jensen has conducted contract and grant research for the U.S. Department of Energy's Savannah River Site, NASA commercial applications, and National Oceanic and Atmospheric Administration (NOAA) CoastWatch. He is the author of textbooks on remote sensing, *Introductory Digital Image Processing: A Remote Sensing Perspective* (1996) and *Remote Sensing of the Environment* (2000). He was president of the American Photogrammetry and Remote Sensing Society in 1996 and is now a fellow with the society.

Chris J. Johannsen is director of the Laboratory for Applications of Remote Sensing and a professor of agronomy at Purdue University. His research interests are in spatial, spectral, and temporal aspects of remote sensing relating to geographic information systems (GIS) as applied to precision agriculture, land resource development, and land degradation. He was director of the Environmental Sciences and Engineering Institute (previously, Natural Resources Research Institute) (1988 to 1995) and director of the Agricultural Data Network (1985 to 1987) at Purdue University. From 1981 to 1985, Dr. Johannsen was the director of the Geographic Resources Center, Extension Division, at the University of Missouri at Columbia. Dr. Johannsen has been named fellow to the American Society of Photogrammetry, the American Society of Agronomy, the Soil Science Society of America, and the Soil Conservation Society of America and is a member of the International Soil Society, Gamma Sigma Delta, and Sigma Xi. He has served on the Space Studies Board (1996 to 2001) and on the Board's Committee on Earth Studies (1995 to 1998), the Committee on NASA Information Systems (1986 to 1987), and the Panel on Earth Resources (1982 to 1983).

Molly Macauley is a senior fellow at Resources for the Future (RFF), where she directs the space economics research program. Her research interests include space economics and policy, recycling and solid waste management, and the use of economic incentives in environmental regulation. An economist at RFF since 1983 and a long-time analyst of the commercial use of space technology, Dr. Macauley offered her views to Congress in May 1997 on how government can foster commercial ventures into satellite remote sensing. Her research projects include exploring the use of economic incentives to manage space debris; the allocation of scarce energy, water, utilities, and telecommunications resources on the International Space Station; the value of the geostationary orbit; and the value of information, particularly information derived from space-based remote sensing. She was a member of the Space Studies Board's Task Group on Setting Priorities for Space Research, the NRC Committee on the Impact of Selling the Federal Helium Reserve, and the NRC's Aeronautics and Space Engineering Board's Committee for the Assessment of NASA's Space Solar Power Investment Strategy.

John S. MacDonald is a consultant and chairman of the Institute for Pacific Ocean Science and Technology. He is one of the founders of MacDonald, Dettwiler and Associates Ltd., where he was responsible for all aspects of business operations, overall strategic leadership, technical leadership, and market positioning worldwide. Dr. MacDonald's professional interests lie in the areas of advanced digital systems engineering, remote sensing, and image processing. He led the design team for the first Landsat ground-processing system produced by MDA, Ltd., and was involved in the early development of synthetic aperture radar processing at this company. His technical activities have been in the areas of information extraction from advanced sensor systems and the applications of remote sensing with particular emphasis on the physics of the backscatter process and the use of integrated data sets as a means of increasing the ability to extract useful information from remotely sensed data.

Jay S. Pearlman is an advanced system manager at TRW Systems. His background includes basic research, program management, and program development in sensors and systems. He has played an important role in the development and implementation of new concepts and capabilities for both the military and the civil sectors of the U.S. government. He is actively involved with the NASA EO-1 Science Validation Team in assessing the benefits of hyperspectral imagery. Dr. Pearlman is also involved in an assessment of the viability of multispectral and hyperspectral commercial applications.

PLENARY SPEAKERS

Ron Birk is vice president of global terrain for Intermap Technologies, Inc. He is responsible for business development, distributor management, and e-commerce for delivering digital elevation model and orthorectified image map products that provide high-resolution information on locations around the globe. Mr. Birk has received national and international recognition as a remote sensing expert and key developer of innovative decision support solutions using remote sensing systems and data, through 15 years of experience and accomplishments. His past experience includes technical management of the Commercial Remote Sensing Program at NASA's Stennis Space Center, where he completed more than 100 remote sensing application projects and the development of five airborne remote sensing systems, including the Calibrated Airborne Multispectral Scanner (CAMS) and the Airborne Terrestrial and Land Acquisition Sensor (ATLAS) multispectral scanner. He has experience with Interferometric Synthetic Aperture Radar (IFSAR,) Synthetic Aperture Radar (SAR), multispectral, hyperspectral, lidar, and panchromatic remote sensing systems and applications. Mr. Birk received a B.S. degree in physics from the University of Notre Dame in 1982.

Raymond A. Byrnes is liaison for satellite programs at U.S. Geological Survey (USGS) Headquarters. He works closely with other federal agencies and the private sector to facilitate the performance of USGS responsibilities within the Landsat program. In that capacity, he worked closely with NASA and NOAA management to transition end-to-end Landsat 7 satellite and ground system operations to the USGS in 2000 and with Space Imaging LLC management to transition Landsat 5 operations to the USGS in 2001. He is the lead USGS representative on the NASA/USGS team that is working toward a commercially based Landsat Data Continuity Mission (circa 2006) and served in a similar capacity to extend the successful one-year technology demonstration mission of NASA's Earth Observing 1 (EO-1) satellite. His association with the Landsat program began in 1979 when he left a tenured college English faculty position within the University of Minnesota system to join the staff of the USGS Earth Resources Observation Systems Data Center near Sioux Falls, South Dakota. There he established its first Technical Information Office, to produce print and video publications on remote sensing. Mr. Byrnes also held line management positions with the Earth Observation Satellite Company from 1985 to 1992, during the initial Landsat commercialization era.

Bruce Davis is chief scientist for the Commercial Remote Sensing Program at NASA's Stennis Space Center. In this capacity, he designed and coordinated the applications research investment by this program, as well as coordinating with program engineers in the area of technology validation. Dr. Davis has spent 14 years at Stennis working with industry partners and others through the Commercial Remote Sensing Program to develop innovative partnership programs that allow universities, government, and industry to engage in applications and technology projects. Prior to joining NASA, he worked as a land use planner for a county government. Dr. Davis holds an undergraduate degree in urban and regional planning, a master's degree in geography, and Ph.D. in geographic information processing.

Curtiss O. Davis is senior scientist for Optical Remote Sensing in the Remote Sensing Division of the Naval Research Laboratory in Washington, D.C. He received his Ph.D. in oceanography from the University of Washington in 1973. His current research is on using hyperspectral remote sensing to assess the optical properties and phytoplankton dynamics of coastal ocean ecosystems. He has worked on coastal upwelling systems off the coasts of North and South America, Africa, and the Arabian Peninsula, and conducted studies of Puget Sound, Chesapeake Bay, San Francisco Bay, and the Laurentian Great Lakes. He is a member of the NASA SeaWiFS Science Team and has participated in numerous calibration and validation experiments. He is also the project scientist for the Hyperspectral Remote Sensing Technology (HRST) Program. HRST is a focused program to develop the use of hyperspectral imaging for the characterization of the coastal ocean and to fly the Coastal Ocean Imaging Spectrometer (COIS) on the Naval EarthMap Observer (NEMO) satellite.

PANELISTS

Shana Dale has been the assistant vice chancellor for federal relations for the University of Texas (UT) System since March 2000. In this capacity, she interacts with federal government officials regarding particular projects and issues of the UT System and coordinates UT System initiatives with the broader, higher-education community at the federal level. Previously, Ms. Dale served as the staff director of the Subcommittee on Space and Aeronautics, from 1995 to 2000. Ms. Dale codrafted, negotiated, and managed the Commercial Space Act of 1998 (P.L. 105-303) through enactment. She also investigated and staffed the committee's hearing on potential missile technology transfers to China, as well as managing the committee's investigation into the safety of the Mir space station and numerous oversight issues associated with the International Space Station. She served on the board of directors for Women in Aerospace from 1997 to 2000. Previously she was a Republican assistant legislative director and counsel on the Space Subcommittee. She was appointed to the Committee on Science, Space and Technology in March 1991, as the Republican counsel on the Subcommittee on Science. Before moving to Washington, D.C., Ms. Dale was employed in private practice in San Diego, California. She received her B.S. degree with honors in management information systems from the University of Tulsa and her J.D. degree from California Western School of Law. She also completed the Senior Managers in Government program at the John F. Kennedy School of Government at Harvard University. She is a member of the Bars of California, the District of Columbia, and the U.S. Supreme Court.

James A. Flowers is vice president for commercial programs for Orbital Imaging Corporation (OrbImage). He served previously as vice president for North American Sales for OrbImage, and has been part of the company's strategic development team since 1997. Prior to joining OrbImage, Mr. Flowers was responsible for strategic marketing and technology commercialization for TRIFID Corporation, a provider of geodetic engineering and software development services and image-based map products. Previously, Mr. Flowers held senior positions in several companies offering emerging technologies to industrial markets.

Alexander F.H. Goetz (See biographical information for Dr. Goetz under the heading "Steering Committee Members," above.)

Kass Green is the president of Space Imaging Services, an organization offering value-added remote sensing, GIS, and training services to clients throughout the world. Space Imaging Services is one of the largest remote sensing/GIS services organizations in the world, providing mapping services, desktop and Web application development, geospatial analysis, and training. Ms. Green is also the cofounder and president of Pacific Meridian Resources, a GIS consulting firm recently purchased by Space Imaging. In January 2001, Pacific Meridian Resources was merged with Space Imaging's program management division to create Space Imaging Services. Ms. Green's background includes more than 25 years of experience in natural resource policy, economics, GIS analysis, and remote sensing. She is the author of numerous articles on GIS and remote sensing and has coauthored a book on the practical aspects of accuracy assessment. In addition to her responsibilities at Space Imaging, Ms. Green serves on advisory boards and committees for several academic, government, and private sector organizations, including NASA, USGS, and the University of California. Ms. Green is also the president of MAPPS (Management Association for Private Photogrammetric Surveyors), an organization of private mapping firms dedicated to advancing the mapping industry.

James Irons holds a B.S. degree in environmental resources management (1976) and an M.S. degree in agronomy (1979) from The Pennsylvania State University. He holds a Ph.D. in agronomy (1993) from the University of Maryland. Dr. Irons has been employed as an earth scientist in the Biospheric Sciences Branch at NASA Goddard Space Flight Center since 1978. He has conducted research there on Landsat data applications and on characterizing the bidirectional reflectance distribution functions of soil surfaces and plant canopies. He was the instrument scientist for the airborne Advanced Solid State Array Spectroradiometer (ASAS) from 1987 to 1999. He has served as the NASA deputy Landsat project scientist since 1992. Dr. Irons was recently designated the NASA study scientist for the Landsat Data Continuity Mission (LDCM). In these roles he works to ensure the scientific integrity of the Landsat missions.

Dale R. Johnson is vice president of Positive Systems, Inc. Mr. Johnson has a background in forestry from Oregon State University, with a degree in electronic/ electrical engineering. He has held various positions within Positive Systems, beginning with that of flight engineer; he then became operations manager, and his current position is in sales. He has managed the Scientific Data Buy program contract with NASA for the past three years.

Christopher O. Justice is a professor at the geography department, University of Maryland. He is a science team member and leader of the land discipline group for the NASA Moderate Imaging Spectroradiometer (MODIS) and heads up a small research group responsible for MODIS land data processing at NASA Goddard Space Flight Center. He is responsible for the MODIS fire product and is currently the forest fire monitoring and mapping implementation team leader for the Global Observation of Forest and Land Cover Dynamics (GOFC-GOLD) project, which is part of the Global Terrestrial Observing System. Dr. Justice was a coinvestigator on the AVHRR Pathfinder II Project that developed AVHRR land products and a coinvestigator on the Landsat Pathfinder Humid Tropical Forest Monitoring Project based at the University of Maryland. Dr. Justice is the project scientist for NASA's Land Cover and Land Use Change Program. He is also on the Science Advisory Panel for the NOAA Office of Global Programs. He is on the strategic objective team for the Agency for International Development's Central Africa Regional Project for the Environment and has projects on forest and land-cover monitoring and modeling in Central Africa. Dr. Justice played a key role in the International Geosphere-Biosphere Program Data and Information System and in the development of the NASA EOS Science Working Group on Data. Dr. Justice recently served on the NRC Committee on Earth Sciences.

Thomas R. Karl is the director of NOAA's National Climatic Data Center and also manages NOAA's Climate Change Data and Detection Program Element for NOAA's Office of Global Programs. He holds a master's degree in meteorology from the University of Wisconsin. Mr. Karl is a fellow of the American Meteorological Society and the American Geophysical Union. He recently completed his chairmanship of the National Academy of Sciences Climate Research Committee. Mr. Karl has received numerous awards for his scholarly work on climate, including the Helmut Landsberg Award, the Climate Institute's Outstanding Scientific Achievements Award; he is a two-time recipient of the U.S. Department of Commerce's Gold Medal, its Bronze Medal, and the NOAA Administrator's Award. He is currently editor of the *Journal of Climate* and an associate editor for *Climate Change*. Mr. Karl has been a lead author on each of the Intergovernmental Panel Assessments of Climate Change since 1990 and is cochair of the U.S. National Climate Assessment. Mr. Karl has written nearly 100 peer-reviewed journal articles, has been coauthor or coeditor of numerous texts, and has published more than 200 technical reports and atlases. He has been called upon by the U.S. Congress and the White House to testify and brief on matters related to climate variability and change, and currently is cochair of NOAA's Decadal-to-Centennial Strategic Planning Team.

David S. Linden has been directly involved with remote sensing since 1978, when he worked at the USGS's EROS Data Center as an application scientist. He has worked extensively in both the public and private sectors over the past 20 years. Some of his previous jobs include these: president of QC Data, Inc. (oil industry services); executive vice president of Genasys, Inc. (GIS software); and vice president and general manager of Johnson Control's GIS division (GIS and remote sensing). Dr. Linden has been involved in the commercialization of space-based remote sensing since 1990, when he became an EOSAT distributor while employed with Johnson Controls. He has been continuously involved with the commercialization of remote sensing for the past 10 years. He is currently president of DSL Consulting, Inc., a small consulting firm that focuses on the public and private use of both remotely sensed data and GIS. Dr. Linden is a member of the editorial board of *GEOWORLD*, as well as of many professional societies involved with remote sensing and resource management. He received a Ph.D. from Colorado State University in 1995, an M.S. from the University of New Hampshire in 1978, and an A.B. from Cornell University in 1972.

Rolf Mamen is director general of the David Florida Laboratory (DFL), a national facility for the integration and environmental test of spacecraft, and director general of the Canadian Space Agency's space operations branch. Dr. Mamen's career began with a short consultancy with RCA Limited relating to the HERMES communications satellite. He then joined the Canadian Department of Communications (DOC) as a research scientist at the Communications Research Centre (CRC). His professional activities within CRC dealt predominantly with satellite orbit and attitude determination/prediction and with inertial navigation. He gained experience in space program management at DOC headquarters and then at the R&D branch of the Department of National Defence. He returned to the CRC where, in January 1982, he assumed responsibility for the management of the DFL. Since that appointment, the DFL has successfully supported the Associazione Nazionale Idrokinesiterapisti (ANIK)-D, Brazilsat, Olympus, ANIK-E, Radarsat-1 and M-SAT satellites. It is currently providing test support to the Mobile Services System (MSS), Canada's contribution to the International Space Station, and is preparing for Radarsat-2. Upon creation of the Canadian Space Agency, the DFL was transferred to this new department. Dr. Mamen earned a B.Eng. (Hon.) in electrical engineering at McGill University in 1966 and a Ph.D. in electrical engineering from Imperial College, University of London, in 1970.

Charles McClain received a B.A. degree in 1970 from William Jewell College in Liberty, Missouri, with a major in physics and a minor in mathematics, and a Ph.D. in marine sciences from North Carolina State University in 1976. He worked for two years as a National Research Council postdoctoral associate at the Naval Research Laboratory, where he used airborne laser profilometry to validate GEOS-III altimeter estimates of surface wave heights. He has worked at NASA Goddard Space Flight Center (GSFC) since 1978. Since joining the research staff at NASA/GSFC, his research has focused on the utilization of satellite ocean color observations and numerical models to study the interactions between physical and biological processes in the oceans. He has been involved with the SeaWiFS (Sea-viewing Wide Field-of-view Sensor) mission in a number of roles, including calibration and validation manager, project scientist, and project manager. He is presently the head of the Office for Global Carbon Studies and is also the project manager of the SIMBIOS (Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies) project.

Edward D. Nicastri is president of EdN Consulting. Mr. Nicastri has more than 30 years' experience developing and operating commercial and government ground and space systems, developing and transitioning advanced technologies, and maintaining Air Defense and Federal Aviation Administration command and control systems. He currently provides consulting services to private industry and government agencies. Mr. Nicastri was previously a vice president for Orbital Imaging Corporation (OrbImage), where he was responsible for engineering development and operation of OrbImage's space and ground assets. He has held previous executive positions within Orbital Science Corporation (Orbital) and was responsible for completing the development and launch of Orbital's first series of Pegasus-class satellites. Prior to entering private industry, Mr. Nicastri served 24 years in the Air Force. In his last military assignment, he was the director for space systems at the Defense Advanced Research Projects Agency (DARPA). In a 5-year period, he and his team successfully developed and launched 10 satellites and 2 new launch vehicles. He also served on seven U.S. Department of Defense senior-level steering committees. Prior to his assignment at DARPA, Mr. Nicastri held key positions in the development and operation of several Air Force and National Reconnaissance Office space systems. Mr. Nicastri received his bachelor of science degree in electrical engineering from Clemson University and a master's degree in electrical engineering from the Air Force Institute of Technology. He has received numerous military and civilian awards, including a 1990 laurel from *Aviation Week and Space Technology* for his achievements at DARPA.

Robert A. Schiffer serves as deputy director of the Research Division in the NASA Office of Earth Science. He earned a master's degree in aeronautical engineering from the Polytechnic University in 1958 and a Ph.D. in atmospheric physics from the University of California at Los Angeles in 1971. He spent 12 years on the technical staff of Caltech's Jet Propulsion Laboratory before transferring to NASA Headquarters in 1972. He chairs the interagency Working Group on Observations and Monitoring and cochairs the Working Group on the Global Water Cycle for the U.S. Global Change Research program, serves as principal Earth Science Enterprise (ESE) representative on various interagency and international groups that coordinate global observing systems programs, and chairs the ESE panel responsible for evaluating and approving proposals submitted by the scientific community to the NASA commercial Science Data Purchase Program.

David L. Skole is currently the director of the Basic Science and Remote Sensing Initiative, a research program focused on environmental research using remote sensing systems. Dr. Skole's research interests focus on the role humans play in changing land cover throughout the world. He uses satellite data to measure the patterns of landscape change at regional and global scales, then employs field research to uncover the fundamental processes of change. Dr. Skole is also developing analyses and models of the carbon cycle and biodiversity. Currently he is involved in research projects focused on understanding the interannual variation in deforestation rates and the social and ecological controls on its variation over time. He is principal investigator (PI) of a NASA Earth Science Information Partners center. He is also PI for the NASA Landsat Pathfinder Project, and PI on a number of other funded research projects including the Large Scale Amazon Basin Experiment. He is a PI and member of the Landsat 7 science team, and is a PI with the Canadian Radarsat program and the Japanese Earth Resources Satellite program. Dr. Skole is the PI on the NASA-funded Center of Excellence in the Applications of Remote Sensing at Mississippi State University. He is also PI and coinvestigator on several studies of the human dimensions of land use and cover change. Dr. Skole is the chairman of the International Geosphere-Biosphere Programme (IGBP)/International Human Dimensions Programme on Global Environmental Change (IHDP) Core Project on Land Use and Cover Change, a steering committee member for the IGBP Data and Information Systems project, as well as a member of the standing committees of the IGBP and IHDP. He has served on several NASA committees and panels for EOS and its data system and other programs. He is currently the High Resolution Design Team Leader for the Committee on Earth Observation Satellites project on Global Observations of Forest Cover.

William E. Stoney is currently principal engineer for Mitretek Systems supporting NASA's Stennis Space Center's Commercial Data Buy and Land Imaging Satellite Data Base programs. He was director of NASA's Earth Observation Program from 1972 through 1978, during which time Landsats 1, 2, and 3 were launched, the Thematic Mapper sensor was defined and developed, and NOAA's

TIROS and GEOS satellites and sensors were developed and launched. Since leaving NASA, he worked for RCA and GE supporting NASA in the development of the EOS program and for MITRE and now Mitretek on the current and future Landsat systems.

David A. Thibault has served as executive vice president of Earth Satellite Corporation since 1987. He joined EarthSat in 1971. From the mid-1970s to 1985, Mr. Thibault directed EarthSat's Environmental Applications Group. He was a NASA principal investigator on several joint projects with state environmental agencies that examined the utility of Landsat data for inventory and monitoring. He also directed aerial remote sensing programs that included wetlands mapping and abandoned mined lands inventories for New Jersey, Pennsylvania, Maryland, and New York. He was a principal participant in early studies for the Council on Environmental Quality, and the Office of Management and Budget on the utility and cost-effectiveness of remotely sensed data for a variety of public and private purposes. From 1985 to 1987, Mr. Thibault was international vice president of EOSAT, and the chief of EarthSat's team assigned to the Landsat commercialization effort conducted by EOSAT under contract to NOAA. In this role, he worked closely with the international receiving stations and was a private sector representative of the United States government to remote sensing policy development workshops conducted by the United Nations, the International Bank for Reconstruction and Development, and the European Economic Community.

Michael R. Thomas was appointed acting director of the applications division of NASA's Office of Earth Science in March 2000. He is on loan to NASA Headquarters from the Stennis Space Center in Mississippi, where he is currently the director in waiting for the Geospace Applications Development Directorate. Before joining NASA, Dr. Thomas spent 15 years in research and development in the defense intelligence industry. His areas of technical expertise include remote sensing, information fusion, and artificial intelligence. Since joining the Earth Science Enterprise, he has focused on developing an applications program that can bridge the gap between scientific knowledge and its routine, operational use to improve public and private sector policy and decision making.

Kurtis J. Thome received his B.S. degree in meteorology from Texas A&M University, and M.S. and Ph.D. degrees in atmospheric sciences from the University of Arizona. He has been with the Optical Sciences Center at the University of Arizona since 1990 and is currently an associate professor. His research interests include radiometric calibration of optical sensors, atmospheric remote sensing, radiative transfer, and satellite atmospheric correction. His work includes research with such current sensors as Landsat-7 Enhanced Thematic Mapper Plus, Advanced Spaceborne Thermal Emission and Reflection Radiometer and

MODIS on the Terra platform, Advanced Land Imager and Hyperion on the EO-1 platform, IKONOS, Multispectral Thermal Imager, and several airborne hyperspectral systems.

Ferris Webster is professor of oceanography in the College of Marine Studies of the University of Delaware. He received a Ph.D. in geophysics at the Massachusetts Institute of Technology. Since 1994 he has served as chair of the Panel on World Data Centers of the International Council for Science (ICSU). He is active in working for open international access to data and information as chair of the ICSU/CODATA ad hoc Group on Data and Information. His research interests include the role of the ocean in climate change, ocean variability, time-series analysis, and oceanographic data management and processing. Most of his current work involves data management and computer-based information management systems for the World Ocean Circulation Experiment, for developing systems for global observations of the environment, and for research studies leading to climate prediction.

Gregory W. Withee is the assistant administrator for Satellite and Information Services of the National Oceanic and Atmospheric Administration. Mr. Withee leads the U.S. civil operational environmental satellite programs, which supply the nation's weather and environmental satellite data, and he also leads three national environmental data centers that archive and make accessible climate, ocean, and geophysical data and products. Mr. Withee has worked in other areas at NOAA, the private and university sectors, and in the United Nations system. He has written more than 100 publications and reports and has received numerous awards, including the Presidential Distinguished Rank Award for extraordinary performance in the Senior Executive Service. Mr. Withee received his undergraduate degree in physics from Pomona College and an M.S. in oceanography from the Scripps Institution of Oceanography.

C

Workshop Agenda and Participants

AGENDA

Tuesday, March 27, 2001

8:30 a.m. Workshop Introduction
Roberta Balstad Miller, Chair, Steering Committee on Space Applications and Commercialization

8:40 Keynote I: Fostering the Development of Commercial Remote Sensing for Science
Introduction: Roberta Balstad Miller
Shana Dale, Former Staff Director, House Committee on Science, Subcommittee on Space

9:15 Panel I: Remote Sensing and Basic Research: The Perspective of Data Producers
Introduction: Chris Johannsen, Purdue University, Steering Committee Member

Moderator: Chris Justice, University of Maryland
Panelists: Ron Birk, Intermap Technologies, Inc.
James Flowers, OrbImage Corp.
Kass Green, Space Imaging, Inc.
David Linden, DSL Consulting
Robert Schiffer, NASA Headquarters

10:45 Break

11:15 Keynote II: Future Directions for Remote Sensing Regulations and Licensing
Introduction: Mark Abbott, Oregon State University, Steering Committee Member
Gregory Withee, Assistant Administrator, NOAA/NESDIS

12:00 Lunch

1:15 p.m. Panel II: Remote Sensing and Basic Research: The Perspective of Basic Research
Introduction: Larry Harding, Horn Point Laboratory, Steering Committee Member

Moderator: David Thibault, Earth Satellite Corporation
Panelists: Alexander Goetz, University of Colorado
James Irons, NASA Goddard
David Skole, Michigan State University

2:45 Break

3:00 Breakout Sessions

- Data Rights

Co-Moderators: Ferris Webster, University of Delaware, and
Ray Byrnes, USGS

- Data Management

Co-Moderators: Tom Karl, NOAA/NCDC, and
Chris Justice, University of Maryland

- Research–Commercial Relationships

Co-Moderators: Rolf Mamen/Marcel St. Pierre, Canadian Space Agency, and
David Skole, Michigan Sate University

5:15 Adjourn

5:30 Reception

Wednesday, March 28, 2001

8:30 a.m.	Breakout Sessions Reconvene		
9:30	Moderator's Reports from Breakout Sessions *Chair, John Jensen, University of South Carolina, Steering Committee Member*		
10:30	Break		
10:45	Panel III: Lessons Learned from Government, Commercial, and Science Interactions		
		Introduction:	John MacDonald, Institute for Pacific Ocean Science and Technology, Steering Committee Member
		Moderator:	William Stoney, Mitretek Systems
		Science Data Buy Panelists:	Bruce Davis, NASA Stennis Kurtis Thome, University of Arizona Dale Johnson, Positive Systems, Inc.
		SeaWiFS Panelists:	Charles McClain, NASA Goddard Curtiss Davis, Naval Research Laboratory Ed Nicastri, EdN Consulting
12:15 p.m.	Closing Remarks *Roberta Balstad-Miller, Steering Committee Chair*		
12:30	Adjourn		

PARTICIPANTS

Mark Abbott, Oregon State University
Joseph Alexander, NRC, Space Studies Board
Timothy Alexander, NASA Contractor
G. Bryan Bailey, U.S. Geological Survey
Roberta Balstad-Miller, CIESIN
Robert Bassett, NOAA/NESDIS
Michael Beckman, NOAA/NESDIS
Ron Birk, Intermap Technologies
Ray Byrnes, U.S. Geological Survey
Charles Chesnutt, U.S. Army Corps of Engineers
Thomas Clines, U.S. Geological Survey

Shana Dale, University of Texas Systems
Bruce Davis, Stennis Space Center
Curtiss Davis, Naval Research Laboratory
Fernando Echavarria, State Department
Rose Fletcher, NASA Stennis
James Flowers, OrbImage Corp.
Alexander Geotz, University of Colorado, Boulder
Graham Gibbs, Canadian Space Agency
Richard Gomez, George Mason University
Kass Green, Space Imaging, Inc.
Lawrence Harding, Horn Point Laboratory
Fred Henderson, Hendco Services
James Irons, NASA/GSFC
Tony Janetos, World Resources Institute
John Jensen, University of South Carolina
Chris Johannsen, Purdue University
Dale Johnson, Positive Systems, Inc.
Chris Justice, University of Maryland
Tom Karl, NOAA/NCDC
Tom Koger, Resource21, LLC
David Linden, DSL Consulting, Inc.
Anne Linn, NRC, Board on Earth Sciences and Resources
John MacDonald, Institute for Pacific Ocean Science and Technology
Rolf Mamen, Canadian Space Agency
Kenneth Markowitz, EarthPace
Aya Matsune, Washington CORE
Charles McClain, NASA/GSFC
John McIver, Boeing Space & Communications Group
Edward Nicastri, EdN Consulting
Geotz Oertel, U.S. National Committee for CODATA
John Palatiello, Management Association for Private Photogrammetric Surveyors
Tom Palmerlee, National Research Council
Aaron Peters, Washington/CORE
James Plasker, American Society for Photogrammetry and Remote Sensing
Fritz Policelli, NASA Stennis
Bruce Quirk, U.S. Geological Survey/EROS Data Center
Roberta Rand, University of Miami
David Rosage, NASA/GSFC Earth Sciences
Tod Rubin, Chevron Information Technology Company
John Rumble, NIST
James Schepers, USDA-Agricultural Research Service
Robert Schiffer, NASA Office of Earth Science
David Skole, Michigan State University

Christopher Small, Columbia University
Brent Smith, NOAA/NESDIS
Marcel St. Pierre, Canadian Space Agency
William Stoney, Mitretek Corporation
William Teng, NASA/GSFC
David Thibault, Earth Satellite Corporation
K. Thirumalai, Department of Transportation
Mike Thomas, NASA Office of Earth Science
Kurtis Thome, University of Arizona
R.J. Thompson, U.S. Geological Survey
Paul Uhlir, NRC, Office of International Affairs
Ron Weaver, CIRES, University of Colorado
Ferris Webster, University of Delaware
Michael Wehde, Raytheon
David Williams, Environmental Protection Agency
Gregory Withee, NOAA/NESDIS
Charles Wooldridge, NOAA/NESDIS

D

Acronyms

ASTER	Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR	Advanced Very High Resolution Radiometer
CBERS	China-Brazil Earth Resources Satellite
DOD	Department of Defense
ENVISAT	Environmental Satellite
EOS	Earth Observing System
EOSAT	Earth Observation Satellite Company
EROS	Earth Resources Observation Systems
ERS	European Remote Sensing Satellite
ESA	European Space Agency
ETM	Enhanced Thematic Mapper
ETM+	Enhanced Thematic Mapper Plus
EUMETSAT	European Meteorological Satellite Organization
IRS	Indian Remote Sensing Satellite
ISRO	Indian Space Research Organization
ITAR	International Traffic in Arms Regulations
MISR	Multi-angle Imaging Spectroradiometer
MODIS	Moderate-resolution Imaging Spectroradiometer

MS	Multispectral
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NEMO	Naval EarthMap Observer
NIMA	National Imagery and Mapping Agency
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRC	National Research Council
NSTC	National Science and Technology Council
OMB	Office of Management and Budget
Pan	Panchromatic
PD	Presidential Directive
PDD	Presidential Decision Directive
R&D	research and development
RBV	Return Beam Vidicon
SAR	synthetic aperture radar
SDB	Science Data Buy
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SIMBIOS	Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies
SPIN-2	A trademark for Russian digital ortho-rectified geocoded 2-meter-resolution satellite imagery data
SPOT	System pour l'Observation de la Terre
SSB	Space Studies Board
SWIR	short-wavelength infrared
TM	Thematic Mapper
TIR	thermal infrared
USGS	U.S. Geological Survey