PB86-152923

Remote Sensing of the Earth from Space
A Program in Crisis

National Research Council, Washington, DC

Prepared for

National Aeronautics and Space Administration
Washington, DC

Dec 85

U.S. Department of Commerce
National Technical Information Service
NTIS

50272-101

REPORT DOCUMENTATION PAGE	1. REPORT NO.	2.	3. Recipient's Accession No. PB86 152923 /AS

4. Title and Subtitle Remote Sensing of the Earth From Space: A Program in Crisis	5. Report Date December 1985
	6.
7. Author(s)	8. Performing Organization Rept. No.
9. Performing Organization Name and Address National Research Council Commission on Engineering and Technical Systems 2101 Constitution Avenue, NW Washington, D.C. 20418	10. Project/Task/Work Unit No.
	11. Contract(C) or Grant(G) No. (C) NASW-3706/C (with NASA) (G) NA83DA-C00013/C (NOAA)
12. Sponsoring Organization Name and Address National Aeronautics and Space Administration Washington, D.C. 20546 COMMERCE/NOAA/NESDIS Ashville, NC 28801	13. Type of Report & Period Covered Final report
	14.

15. Supplementary Notes

16. Abstract (Limit: 200 words)

This study had the objectives of describing the present situation in earth remote sensing, of determining why certain problems exist, and of trying to find out what can be done to solve these problems. The conclusion of the study is that operational remote sensing of the earth is in disarray. The difficulties are not technical, but rather involve policy and institutional issues. The findings of the report describe the difficulties in the U.S. remote sensing program and the recommendations describe directions in which the program must move for substantial improvement.

17. Document Analysis a. Descriptors

civil space program
shuttle
earth observations
land remote sensing
ocean remote sensing
practical applications
operational remote sensing
Public Law 98-365
civil earth remote sensing

b. Identifiers/Open-Ended Terms

COPARSS
EOSAT
GOES
GSFC
JPL
LACIE
LFC
MSS
NASA
NESDIS
NOAA
NROSS
SAB
SPOT
TM
TOXPEX

c. COSATI Field/Group

18. Availability Statement	19. Security Class (This Report)	21. No. of Pages
Distribution is unlimited.	Unclassified	111
	20. Security Class (This Page) Unclassified	22. Price

(See ANSI-Z39.18) See Instructions on Reverse OPTIONAL FORM 272 (4-77) (Formerly NTIS-35) Department of Commerce

Cover: Large-Format Camera photograph of northeastern coast of Australia and the Great Barrier Reef, taken October 11, 1984, on color infrared film from the NASA Space Shuttle at an altitude of 237 km. Photo courtesy of National Aeronautics and Space Administration.

Remote Sensing of the Earth From Space: A Program in Crisis

Space Applications Board
Commission on Engineering and Technical Systems
National Research Council

National Academy Press
Washington, D.C.
1985

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This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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This study by the Space Applications Board was conducted under Contract No. NASW-3706/C with the National Aeronautics and Space Administration in conjunction with Contract NA83DA-C00013/C with the Department of Commerce for the National Oceanic and Atmospheric Administration.

This report is available from the Space Applications Board, National Research Council, 2101 Constitution Avenue, N.W., Washington, D.C. 20418.

Printed in the United States of America.

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Preface

Remote sensing from space involves observing the earth, its land masses, oceans, and atmosphere with instruments carried in earth-orbiting satellites. This activity started in the National Aeronautics and Space Administration about 25 years ago with the first weather satellites. In 2½ decades it has progressed until it now provides, for example, data to large oil companies to aid them in locating deposits and to tuna fishermen to improve their catch as well as the material for cloud-cover pictures of the United States that are seen nightly by millions of American television viewers. These are only a few of the many uses of today's remote sensing from space.

One would think that such a useful activity would be thriving, but it is not. One portion, the weather satellites, continues to do its job with some difficulty under government sponsorship. Ocean satellites, absent from the scene for half a decade, may reappear in a few years. However, the 13-year-old program of land remote sensing is in serious trouble. Why has this happened? Why is one of the most useful activities of the space program struggling to survive? The answers are neither clear nor simple. But there is a need to find answers to these questions, and this report attempts to do so.

In the summer of 1983 the National Research Council's Space Applications Board established a Committee on Practical Applications of Remote Sensing From Space and requested it to study the problem. A copy of the Board's charge to that committee is given in Appendix A. In brief, the committee was asked to describe the present situation in earth remote sensing,* to determine why certain problems exist, and to find out what can be done to solve these problems. The committee visited National Oceanic and Atmospheric Administration (NOAA) and NASA centers where work on remote sensing is proceeding, heard briefings by government and industrial representatives, and had numerous discussions with experts in the field. In 1984 the committee met at Snowmass, Colorado, to compile its findings and draft a preliminary statement of its conclusions and recommendations.

Several drafts of the committee's conclusions along with supporting material were submitted to the Space Applications Board for review. The committee's draft addressed the objectives and benefits of remote sensing, but its description of the existing situation and its strategy for the future dealt primarily with

* In this report the term "earth remote sensing" refers to the civil program unless otherwise stated.

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improving the technical capabilities of the system. The Board, in successive reviews of committee drafts, emphasized that the principal "problems revolve around policy and institutional issues—the difficulties are not technical" (see Finding III, page 3).

For this reason, the Board found the committee's final draft unsuitable for providing advice to the sponsoring agencies, NASA and NOAA, about how to strengthen the earth remote sensing program. Therefore, the Board decided to prepare its own report using, wherever appropriate, material submitted by the committee. The final result is a report of the Space Applications Board with findings that deal primarily with policy and institutional problems and with recommendations that respond to the issues raised in the findings.

This report attempts to give the reader some insight into what is wrong with remote sensing in the United States and what can be done to reverse the decline in this activity and set it on a course that will make it more productive. The report sets forth 19 findings and 21 recommendations. Finding IX calls for a federal plan to reconcile institutional and programmatic diversity with efficient use of hardware. Some elements of the plan and the associated institutional functions are suggested in the recommendations following findings IX and X.

The Board believes the existing problems in the civil operational earth remote sensing program are in part due to NOAA's location in the Department of Commerce. These problems would be ameliorated by an appropriate change in NOAA's affiliation (see Finding VI). With regard to land remote sensing, the Board recommends that the government should accept the best industrial proposal that it can obtain for operation of the civil land remote sensing system (see Finding XIV). The remaining findings and recommendations deal with other significant aspects of earth remote sensing that need attention or require action. Remote sensing from space is at a crossroad; one road leads to further deterioration, the other to maintenance of U.S. leadership.

During the course of this study, we received generous assistance from organizations and representatives of government and industry. I take this opportunity to express my gratitude to everyone who helped us and to those who may inadvertently have been omitted from the acknowledgments. I want to express my appreciation to the members of the Committee on Practical Applications of Remote Sensing From Space for their long and arduous study of the difficult problems involved in remote sensing. Thanks are due also to the members of the Space Applications Board who contributed to the writing of this report. Finally, I wish to thank the Board's staff for its work in preparing this report for publication.

George A. Harter
Chairman
Space Applications Board

Acknowledgments

The organizations and persons listed below provided assistance to the Board and the Committee either by meeting with them, by supplying data for study and analysis, or by permitting us to visit an installation. We are grateful to all of those listed and to those who may have been inadvertently omitted.

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Barrett Rock
Eni Njoku
Joseph Waters

Radford Byerly, Committee on Science and Techonology, U.S. House of Representatives
David C. Honhart, Office of the Director of Naval Oceanography
William E. Kibler, U.S. Department of Agriculture
D. Wayne Mooneyhan, National Space Technology Laboratory
Don Paarlberg, formerly USDA and Purdue University
Charles Sheffield, Earth Satellite Corporation
Pitt Thome, Destek Group, Inc.

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Introduction and Overview

The civil space program of the United States is a study in contrasts. The shuttle program is now operational; funding for the space station has been included in the President's FY 1986 budget. In the field of science, the NASA program in physics and astronomy (for example) is strong and has received increases in funding. Several NASA research programs involving earth observations, the Upper Atmosphere Research Satellite (UARS), the Earth Radiation Budget Experiment (ERBE), and the development of an instrument to measure wind speed at the ocean surface are moving ahead vigorously.

There is, however, one major sector of the space program that is in disarray: the operational remote sensing of the earth. The successful weather satellite system in NOAA has been severely affected by programmatic reductions, by stretch-outs in satellite procurement, and by reduced cooperation between NOAA and NASA. The land remote sensing effort is endangered as the attempt to turn the program over to the private sector threatens to founder because of limitations placed on federal support. No civil operational program in ocean remote sensing is in place or planned, although the Navy (with the cooperation of NASA and to a lesser degree NOAA) plans to mount a significant effort, the Navy Remote Ocean Sensing Satellite (NROSS).

Information from operational earth remote sensing systems is needed for a host of practical purposes, such as weather forecasting, ocean transportation and utilization, land management, and mineral exploration. This information also is required to improve understanding of various earth sciences—meteorology, oceanography, geology, and geophysics. Not only practical applications of substantial economic importance but also the advance of earth-oriented science are inhibited by the inadequacies of this sector of the space program.

Why should such a practical program be floundering? Why is it that earth-oriented activities are being outdistanced by other, less applicable sectors of the space program? It is true that the surge into space is largely an investment in the future, but one might assume that we as a nation would make every effort to reap the benefits of our investment as soon as it became possible to do so. This is not being done. Indeed, the situation is even less logical than has already been stated: In at least one critical area of earth remote sensing, the United States is marking time as other countries move toward world leadership and prepare to reap the benefits of our investment—using technology developed in this country!

In evaluating the civil earth remote sensing program, the members of the Space Applications Board have sought to understand the reasons for the present state of affairs. We do not condone or accept as appropriate the disarray in operational earth remote sensing. Changes need to be made; priorities must be reevaluated. But effective action can be taken only if we understand the policy and institutional barriers that have prevented a more rational development of U.S. earth remote sensing programs. The present report seeks to contribute to this understanding. The report also points out the direction in which earth remote sensing must move if substantial progress is to be achieved in a reasonable period of time, and it outlines the essential characteristics of a high-value, cost-effective earth remote sensing system that could be in place by the mid-1990s.

The important findings and recommendations accepted by the Board are listed below. Each is discussed in later parts of this report. Eleven of the findings (and twelve recommendations) apply generally to the earth remote sensing* program. The first seven of these lead logically to Findings IX and X (and their associated recommendations), which outline the broad characteristics of a successful earth remote sensing system that could be in place in a decade and the recommended role to be played by participating institutions (public and commercial).

FINDING I. The earth remote sensing program has demonstrated that the timely acquisition of data from satellites can result in significant social, economic, and scientific benefits. The potential for the future is even greater.

FINDING II. The United States has achieved world leadership in earth remote sensing within the civil sector. It is in the country's interest to maintain and enhance this position, but in view of the costs involved, it must be done with minimum expenditure of public funds.

Recommendation: Earth remote sensing should be an established and significant part of the nation's civil space enterprise.

Recommendation: Special attention should be devoted to improving the cost-effectiveness of the federal effort in civil remote sensing (for example, by flying both operational and research instruments on the same satellite platforms).

FINDING III. The civil earth remote sensing program is in difficulty. In several parts of the program the United States is in danger of losing its world leadership. Problems revolve around policy and institutional issues. *The difficulties are not technical.*

FINDING IV. The Land Remote Sensing Commercialization Act of 1984 has moved the United States in the direction of two separate operational systems for

* In this report the term "earth remote sensing" is used to describe the total U.S. program of remote sensing from space, including observations of the land, the oceans, and the atmosphere.

the remote sensing of the earth: one for the land, to be transferred to the private sector; the second for the atmosphere, to be operated by the federal government. While the legislation is silent with regard to a policy for ocean remote sensing, the physical problems and measurement requirements facing oceanography are much more closely related to the meteorological than to the terrestrial sciences.

Recommendation: Operational atmospheric and oceanic remote sensing for civil purposes should be accomplished in the future by a single federally funded and managed satellite system.

Recommendation: Operational land remote sensing for civil purposes should be accomplished in the future by a system owned and managed by the private sector (if at all feasible). At least in the early years, funding will have to come, in large part, from government.

FINDING V. Within the federal establishment, civil earth remote sensing has been partitioned into operations (in NOAA) and research (in NASA). As a result of agency decision-making and funding pressures, this partition has become too rigid and divisive, to the detriment of the total program.

FINDING VI. The civil operational earth remote sensing program is handicapped by the existence of NOAA within the Department of Commerce. A change in the affiliation of NOAA has been discussed for many years: President Carter recommended that NOAA be transferred to a Department of Natural Resources; President Reagan (in his first term) recommended that NOAA be made an independent agency, as part of a reorganization of the Department of Commerce; a Presidential Commission has recently recommended that NOAA be made part of a new Department of Science.

Recommendation: The administration and Congress should agree on NOAA's future organizational affiliation as soon as possible. If a decision is made to keep NOAA within the Department of Commerce, steps should be taken to provide NOAA (and through NOAA the operational earth remote sensing program) with greater budgetary and management flexibility.

FINDING VII. From a purely technical point of view, the partition of the civil earth remote sensing program into private- and public-sector components and into operations and research is an unnecessary complication that has thus far only added to the cost and difficulty of creating and maintaining a successful operational program. In an earth-viewing system that uses space platforms and other hardware with a maximum degree of cost-effectiveness, each satellite could carry land, atmosphere, and ocean sensors, and each could carry operational and experimental sensors. Observational and orbital requirements, not institutional or programmatic labels, would determine on what satellite a given sensor was flown.

FINDING VIII. The volume of data flow in civil earth remote sensing is growing rapidly and will eventually exceed 10^{13} bits per day. Data processing, evaluation, analysis, dissemination, and archiving are becoming more difficult and costly. A subtantial effort is needed to plan and operate the required data-handling systems.

FINDING IX. The United States cannot afford the cost of launching a separate space vehicle for each programmatic need—for land, atmosphere, and ocean remote sensing as well as for operations and R&D. Some mechanism must be found to reconcile institutional and programmatic diversity with the realities of efficient use of hardware (space platforms and downlinks). A federal plan is urgently needed.

Recommendation: NOAA (in cooperation with NASA) should develop a long-range plan for the federal role in operational earth remote sensing. To the maximum degree possible, this plan should facilitate common use of spacecraft and data-handling systems by institutions (public and private) that mount earth remote sensing programs. To help control costs, the number of special-purpose satellites must be held to a minimum.

Recommendation: The system plan should center around the needs of operational programs (which have minimum flexibility in orbital, launch, and data-handling requirements). Whenever possible, space should be made available for research sensors on vehicles that are used primarily for operational purposes. The potentialities of the earth orbiting platforms (to be launched as part of the space station program) should be fully exploited. The polar orbiting space platform is especially important for earth remote sensing.

Recommendation: The present effort to encourage increased multinational cooperation in the earth remote sensing program is promising and should be continued and expanded. This will promote international goodwill and will further help to limit national expenditures.

Recommendation: Participating institutions (national and international, public and commercial) should share in the cost of the planned earth remote sensing system.

FINDING X. With careful planning and resolute action, a highly valuable and cost-effective civil earth remote sensing program can be in place by the mid-1990s. Among participating institutions in the United States (NASA, NOAA, and the commercial sector), each has a vital role to play.

Recommendation: NASA should launch and operate the space platforms and design and manage the downlinks to be developed as part of the space station program. Operational earth remote sensors (NOAA and commercial) should be given high priority on the polar orbiting platform. NASA should also develop station tending and repair capabilities for space platforms and retrieval capabilities for other earth-orbiting satellites (including those in geostationary orbit). NASA should develop new sensors for operations, in consultation with NOAA and other users, and should carry out basic space-oriented R&D on the physics and chemistry of atmosphere, ocean, and land systems.

Recommendation: NOAA should build and (under contract with NASA) launch operational satellites or lease space on commercial spacecraft. It should own and manage the atmosphere-ocean operational observing system and provide federal oversight (and, as appropriate, initial federal subsidy) for the commercially operated land remote sensing system. NOAA should carry out research on applications of space-derived information, should be responsible for archiving all earth remote sensing data, and should disseminate atmosphere and ocean data to the user community.

Recommendation: The commercial sector should own and manage the operational land remote sensing system, purchasing space when appropriate on NASA and NOAA satellites. It should build new operational sensors and should fly its own satellites as it deems necessary (leasing space when appropriate to NOAA or NASA). The commercial sector should also be responsible for marketing space-derived land remote sensing data to the various user communities, including government departments such as Agriculture and Interior.

FINDING XI. The priority of earth remote sensing should be reevaluated by the Executive Branch and by Congress. An effective earth remote sensing program is possible only if adequate funding and a stable budget are assigned to the program. This will require the attention of policy-setting individuals within government.

The following five findings (and four recommendations) apply specifically to the Land Remote Sensing Program.

FINDING XII. The economic and societal benefits of an operational land remote sensing program could be substantial. Although a commercially viable market for the data does not exist today, there could eventually be such a market. However, considerable training and experience are required to use the data effectively, and industrial managers would have to become familiar with the value of the data. This is an educational process that could only occur slowly over a period of many years.

FINDING XIII. The total multiyear funding that the federal government is willing to provide for the commercial operation of U.S. land remote sensing has been set by the administration at $250 million. At this level of federal support, it appears unlikely that operation by industry can ensure continuity of new data availability or improvement in the quality of the data.

Recommendation: The government should accept the best industrial proposal that it can obtain at the present time, if such a proposal provides for operation of the system over the next decade and will produce at least two follow-on satellites that provide data of quality equal to existing Thematic Mapper data.

FINDING XIV. Time is of the essence. There is no replacement for Landsat 5, now in orbit; a launch date (November 1985) has been set for the French Landsat, named SPOT (Systeme Probatoire d'Observation de la Terre). Unwarranted delay in resolving the future of the U.S. land remote sensing program will result in a gap in the availability of new data and a loss in market position for the United States.

Recommendation: If the proposal for industrial operation is accepted, the development of successor spacecraft should be expedited. If the proposal for commercial operation is rejected or is withdrawn, then NOAA should begin immediately to plan for continuation of operations beyond the present Landsat 5.

FINDING XV. The growth of a viable commercial market for Landsat data is essential to the future success of U.S. land remote sensing. In the Board's opinion, this objective is more likely to be achieved through the transfer of operations (including marketing) to the private sector. As previously noted, such transfer should take place as soon as possible, provided that satisfactory agreement is reached between NOAA and a private operator on the terms of such a transfer.

FINDING XVI. The full value of land remote sensing will be realized only if there is continued R&D to create new sensors and to learn how to use the data they will provide. A private-sector operator cannot be relied on to fund and conduct the necessary research. Additional R&D needs to be sponsored by the federal government.

Recommendation: Regardless of whether the Landsat operational system is transferred to the private sector or remains a government responsibility, NASA should reorient its priorities to place greater emphasis on research to develop new sensors and systems in support of land remote sensing activities.

Recommendation: Whether or not Landsat operations are transferred to the private sector, NOAA should sponsor and fund a research and development program that includes (a) the systematic evaluation of Landsat data by potential users, (b) the identification of new sensor requirements, (c) the development of user models, and (d) the improvement of data formats.

The following three findings (and five recommendations) apply specifically to the atmosphere and ocean remote sensing program.

FINDING XVII. Four federal agencies are involved in atmospheric and oceanic remote sensing: NOAA and NASA in the civil sector and the Air Force and the Navy in the Department of Defense. Agency parochialism has introduced unnecessary inefficiencies into the total effort.

Recommendation: NASA, in consultation with NOAA, should fund a basic program to develop and demonstrate new research and operational sensors for atmosphere and ocean measurement, and NASA and NOAA should cooperate to ensure the transfer of new technology to operations. As part of a federal plan for earth remote sensing, NOAA should provide space for NASA R&D sensors on its operational spacecraft; NASA should provide space for NOAA operational sensors on the Space Platforms planned as part of the space station program.

Recommendation: NOAA and DOD, while maintaining separate civil and military operational satellite systems, should consult and cooperate more closely in the design and management of their space- and ground-based systems. Such steps could provide assurance that, if one system fails, the other could be used as a temporary back-up to fulfill minimum mission requirements.

FINDING XVIII. Federal agencies, especially NOAA, do not sufficiently interact with the academic community in carrying out their atmospheric and oceanic remote sensing programs.

Recommendation: Programs to support academic research facilities, student training, and scientist visits and exchanges should be increased. The timely flow to research institutions of data from both operational and R&D satellites should be assured.

Recommendation: Research scientists at the universities and in government should be consulted with regard to the design of (and plans to improve) operational satellite systems. These systems provide information necessary to advance basic science.

FINDING XIX. The commercial sector has made only limited direct use of atmosphere and ocean remote sensing observations. The value of this information to the nation could be considerably enhanced through the efforts of the private sector.

Recommendation: Further development of a value-added industry that uses (or enhances) and markets remotely sensed data should be encouraged. A necessary requirement is a federal commitment to the continuity and timely dissemination of satellite observations.

These findings and recommendations are discussed individually in the following parts of this report.

2

The Earth Remote Sensing Program

THE SCOPE OF THE PROGRAM

The civil earth remote sensing program has many components. Historically, the program has been divided into three separate sectors: observations of the atmosphere, the oceans, and the solid portions of the earth. In each of these sectors there are (or will be) both R&D and operational programs.

The earth remote sensing program is as old as the space program. An early spacecraft launched by the United States (Vanguard II, 1959) carried a simple sensor to measure cloud cover, although the data obtained were impaired because of unplanned tumbling of the satellite. Shortly thereafter a much more sophisticated atmospheric observing system began to take form with the initiation of an intensive program of NASA and NOAA cooperation. The launch of TIROS (1960) marked the beginning of a long series of successful meteorological satellites.

Today, NOAA's civil weather satellite program normally includes four operational spacecraft: two in near polar orbit and two in geostationary orbit. These satellites use visible and infrared sensors to provide images of cloud systems. They also carry radiometers to determine the temperature of land, ocean, and cloud surfaces, together with the vertical distribution throughout the depth of the atmosphere of temperature, moisture, and (indirectly and to a limited degree) winds. The observations are used extensively in weather prediction by both the public and private sectors. In addition to the operational program, NASA launches research satellites as required. Most recently, the Earth Radiation Budget Experiment (ERBE) satellite was launched in 1984 by the space shuttle; the Upper Atmosphere Research Satellite (UARS) is due to fly in 1989.

Remote sensing of the solid earth began as a research program in NASA. Experimental geophysical satellites explored the earth's magnetic and gravitational fields and were used to improve geodetic measurements at the earth's surface. In land remote sensing, the first of a series of NASA satellites, Landsat I, was launched in 1972. The program proved to be successful; commercial and research requirements for land remote sensing information soon created a demand for an operational system that could provide data with a degree of reliability and timeliness beyond the capabilities of an R&D effort.

In 1979 a presidential decision assigned responsibility for operational land remote sensing to NOAA. More recently, the Land Remote Sensing Commercialization Act of 1984, Public Law 98-365 (see Appendix D), mandated a federal effort to transfer operational remote sensing to the private sector. The Department of Commerce (NOAA) was to retain regulatory responsibility as well as the option to provide an appropriate subsidy to a private-sector operator during a period of transition from public to commercial operation.

Today, Landsat 5 is in orbit, managed and operated by NOAA, although no back-up satellite is available (or funded) to launch as a replacement in the event of failure of this one operating satellite. The effort to commercialize operational land remote sensing is moving forward slowly, and federal research in land remote sensing has diminished to a low level. In the field of geophysics (as opposed to land remote sensing) NASA continues to launch experimental earth-viewing satellites. For example, MAGSAT B, planned for launch in 1989, will further improve knowledge of the earth's magnetic field.

Ocean remote sensing has also developed slowly. Following several "proof of concept" missions, an oceanographic research satellite (SEASAT) was flown by NASA in 1978. SEASAT carried three different types of radar devices and clearly demonstrated the value of active microwave sensing for oceanic purposes. Unfortunately, SEASAT failed after 3 months of operation, and efforts to mount a follow-up civil operational program, to take advantage of the demonstrated capabilities, were unsuccessful.

Today, in the civil sector, an operational ocean remote sensing program is still far away, although some information provided by weather satellites (such as the temperature and color of the ocean surface) is of substantial value to oceanographers. The initiative in operational ocean remote sensing has shifted to the Department of Defense, in which the Navy is taking the lead role in a major effort (NROSS) with cooperation from NASA and (to a lesser degree) from NOAA. Present plans for research in ocean remote sensing include TOPEX, a NASA experimental satellite designed to measure the mean elevation of the ocean surface to a degree of accuracy sufficient to make it possible to determine indirectly the direction and speed of ocean currents. Funds for construction of TOPEX have not yet been appropriated and are not included in NASA's FY 1986 budget.

More detailed reviews of the atmosphere-ocean and the land remote sensing programs are presented in later parts of this report.

THE VALUE OF THE PROGRAM

The brief description given here serves to illustrate the substantial breadth of the earth remote sensing satellite program. The effort includes measurements from space for both research and operational purposes. It affects a wide variety of disciplines, including not only basic sciences (such as atmospheric physics, oceanography, geology, and geophysics) but also applied fields (such as weather forecasting, ocean transportation, land use management, and mineral exploration). Information from space is useful to a wide variety of communities: government at all levels, industry, agriculture, and the general public.

Many examples of the value of earth remote sensing information can be cited. In the atmospheric sciences, weather satellites have been an essential element in the substantial improvement of weather forecasts. Today, predictions prepared 48 hours in advance are as accurate as 24-hour forecasts were 20 years ago. Improved predictions can reduce the damage caused by extreme weather, which amounts in an average year to approximately $20 billion. Improved predictions can also enhance the effectiveness and efficiency of industry and agriculture, can reduce injury and loss of life due to severe storms, and can improve the quality of living for the general public.

In oceanography, earth remote sensing information has proved to be valuable for a variety of marine operations, including shipping, offshore oil and gas platform operations, ocean mining, and marine recreation. Operational efficiency and safety can be improved, and damage caused by severe winds and waves can be reduced. A more detailed review of the meteorological and oceanographic benefits of remote sensing is given in Appendix C.

Land remote sensing information, despite the experimental nature of the observing program, has been applied successfully in many fields: mineral exploration, agriculture, forestry, environmental monitoring, rural and urban land-use analysis, rangeland management, and a score of others. Examples of the benefits of land remote sensing are given in Appendix B.

Progress in the atmospheric sciences, oceanography, geology, and geophysics depends to an ever-increasing degree on satellite information. The first step in any science is the accurate observation of the phenomena one seeks to understand, and in all of the earth sciences the large geographic scale and often remote location of significant phenomena pose special difficulties for effective measurement. The orbiting satellite provides an optimum platform from which global- or even regional-scale observations can be taken—whether one is examining the movement of a hurricane over the open sea, the development of eddies in the Gulf Stream, or the structure of a rift valley.

In the long run, existing and potential contributions of satellite-derived information to progress in basic science may provide one of the most significant arguments for an improved national earth remote sensing effort. Around the globe, social organizations are under severe stress. Problems of overpopulation, food and fiber production, transportation, and energy and natural resource development are ubiquitous. An improved understanding of the physical environment in which society must exist is essential to the solution of many of mankind's problems.[1]

A sound program in earth remote sensing should be a national imperative. Fortunately, an excellent foundation exists for the development of such a program. Despite its disorganization and despite the slowness of progress in several key

[1] Reader, John. GEMS, The Global Environment Monitoring System. U.N. Environment Program, 1982.

areas, earth remote sensing in the United States has recorded substantial achievements in the past 2 decades. Much more can be accomplished.

In developing and improving the effectiveness of the earth remote sensing program, substantial attention must be devoted to controlling costs. The deployment of satellite observing systems is expensive. Ways must be found to achieve important goals without incurring unnecessary expenditures through inefficiencies or redundancies in programs. The Board believes that the cost-effectiveness of the national civil earth remote sensing effort can be substantially improved. Specific recommendations concerning how this can be done are presented later in this report.

FINDING I. The earth remote sensing program has demonstrated that the timely acquisition of data from satellites can result in significant social, economic, and scientific benefits. The potential for the future is even greater.

FINDING II. The United States has achieved world leadership in earth remote sensing within the civil sector. It is in the country's interest to maintain and enhance this position, but in view of the costs involved, it must be done with a minimum expenditure of public funds.

Recommendation: Earth remote sensing should be an established and significant part of the nation's civil space enterprise.

Recommendation: Special attention should be devoted to the cost-effectiveness of the federal effort in civil remote sensing (for example, by flying both operational and research instruments on the same satellite platforms).

PRESENT STATUS AND PLANS

As a result of the achievements of the past 2 decades, earth remote sensing in the United States is in a position to move ahead vigorously. Yet an objective evaluation indicates that this is not occurring. Although the space program as a whole is moving toward new and exciting goals, earth remote sensing has lost momentum, and in many key areas it is actually losing ground.

The weather satellite program (reviewed in more detail in Part 4) has been one of the major successes of the U.S. effort in space. But in the past few years many problems have emerged to plague the operational weather satellite program and cause it to slip backward.

First, the remarkable cooperation between NASA and NOAA, which had in large measure been responsible for the success of the program, came to an abrupt end when NASA, in 1981, ceased to support R&D for the operational system covered by the interagency agreement under which the cooperation had flourished. The motivation was budgetary: The cooperative effort was costly to NASA, and funds were urgently needed for research programs given higher priority within NASA. Additional budgetary pressures fell on NOAA, which was having its own fiscal problems. The costs of building and launching satellites increased. The superb engineering capability in NASA, which had led the way in developing new meteorological sensors, was no longer available to NOAA management without cost. The operational weather satellite program lost much of its ability to deploy innovative instruments to observe the atmosphere from space. At the same time, the NASA program in meteorology turned away from operational goals and became oriented more toward basic science—as in the Upper Atmosphere Research Satellite (UARS) program.

Other difficulties were encountered. Beginning in 1981, the President's budget has called annually for a reduced launch schedule for weather satellites that would (on the average) result in a single spacecraft in polar orbit. The cutback has not yet occurred; each year Congress has added the "second polar orbiter" back into the NOAA budget.

Finally, the construction program for NOAA operational weather satellites has lagged, in part due to budget pressure and in part due to difficulties with spacecraft contractors. Lack of availability of replacement satellites has already reduced the number of operational spacecraft in orbit and has raised concerns about the ability of NOAA to maintain continuity of observations. In the case of geostationary (GOES) weather satellites, the failure in 1984 of the eastern satellite reduced the number of spacecraft in operation to one—now stationed over the central United States. Should the remaining satellite fail, this country would be without an operational weather satellite in geostationary orbit for the first time since the GOES program began in 1974. Launch of a replacement for the already-failed satellite, to return the system to its normal complement of two GOES satellites in space, is not scheduled until late 1985, and there is a possibility of further delay if tight production schedules cannot be maintained.

In this gloomy picture there has been one positive note. The President's FY 1986 budget has called for a strengthened geostationary satellite program for weather monitoring and prediction. This next generation of GOES operational spacecraft is scheduled to be launched for the first time in late 1989.

In oceanography, the outlook in civil operational remote sensing is at best uncertain, despite the substantial success of Seasat in 1978. As noted previously, the Navy is moving toward operational remote sensing with the Navy Remote Ocean Sensing Satellite (NROSS), a developmental spacecraft planned for 1989 launch. But it is unclear at present whether the Navy will mount a fully operational ocean sensing system and, if so, to what degree the information derived from the observations could satisfy the requirements of civil agency and nongovernment scientists. The possibility seems remote that operational ocean sensors designed explicitly to meet the needs of the civil sector can be deployed in the forseeable future.

Yet there is some cause for optimism. The NASA research program in oceanography promises to contribute substantially to the ability to measure oceanographic phenomena from space. Research oceanographers are hopeful that TOPEX will be approved as a new start in FY 1987. Also, in support of NROSS, NASA development of the scatterometer (an innovative remote sensing technique for measuring from space the wind velocity at the ocean surface) promises to provide a major new capability for ocean-observing systems of the future. Meanwhile, oceanographers continue to use with increasing effectiveness the measurements of ocean temperature and color made by weather satellites.

It is the land remote sensing program that provides the largest question mark. As noted previously, the last of the NASA-designed R&D satellites (Landsat 5) is in orbit and is operated by NOAA for the sale and distribution of data. No back-up is available or planned. The federal effort to encourage the private sector to develop an operational land remote sensing system—mandated by the Land Remote Sensing Commercialization Act of 1984—is moving ahead with glacial speed. The involved process of federal negotiation with private-sector companies and consortia is nearing an end, with only one consortium remaining in the running. But it is still unclear what will emerge from the negotiation. The Administration has placed a limit of $250 million on the federal subsidy to be made available to the private-sector contractor during the transition of the land remote sensing system to full commercial operation, and this level of funding is considered marginal by industry.

While this report is being written, negotiations between the Secretary of Commerce and the one remaining private-sector consortium are continuing. One issue is whether, with the federal subsidy limited to $250 million, an operational system can be agreed on that satisfies the minimum requirements of the government. Another question is whether a stripped-down system can be commercially viable. Meanwhile, the likelihood becomes steadily more remote that a commercially built land remote sensing satellite can be placed in orbit before failure of Landsat 5. The requirement of continuity of observation may well become a moot issue. A more complete discussion of these and related questions is included in Part 3 of this report.

Difficulties also occur in land remote sensing research. Since the designation of NOAA as the federal agency responsible for operational land remote sensing, and since the transfer to NOAA of responsibility for the Landsat series of satellites, NASA has phased down its research in land remote sensing. Other than NASA, no organization in the United States, public or private, is working to develop new remote sensors (such as multispectral linear arrays). This void is certain to slow progress in this country toward the creation and maintenance of an effective land remote sensing system.

While the United States has been inactive, other countries have not. France is scheduled to launch its land remote sensing satellite (SPOT) in November 1985. SPOT will employ advanced remote sensing techniques developed in the United States, will take commercial orders for remote images, and will compete directly with any system developed by the private sector in this country. Japan has also indicated an interest in commercial land remote sensing.

From this discussion it is clear that the earth remote sensing program in the United States is in trouble. It is legitimate to question why this should be the case. Why, when the space program is booming and space technology is flourishing, should the United States find itself sliding backward in earth viewing programs? Even a cursory examination of this question leads to the conclusion that the problems we face are political and institutional; they are not technical. The space program is well funded, and in each field of earth remote sensing new and exciting technical ideas abound. The difficulty clearly lies in the selection of priorities—a selection that, in turn, is controlled by a series of policy assumptions and institutional issues. These will be explicitly addressed in following sections.

FINDING III. The civil earth remote sensing program is in difficulty. In several parts of the program the United States is in danger of losing its world leadership. Problems revolve around policy and institutional issues. *The difficulties are not technical.*

THE INSTITUTIONAL PARTITION OF THE EARTH REMOTE SENSING PROGRAM

It must be apparent from the previous discussions that one of the problems of earth remote sensing stems from one of its strengths: the broad array of institutions and scientific communities interested in the program. As a result of this breadth of interest and participation, earth remote sensing is a diffuse program. It is essential to examine some of the ways in which the program is divided—between the public and private sector and between various government agencies within the federal establishment.

Private Sector/Government

The Land Remote Sensing Commercialization Act, Sec. 103(c), states, "It shall be the policy of the United States both to commercialize those remote-sensing space systems that properly lend themselves to private sector operation . . . while continuing . . . to retain in the Government those remote-sensing functions that are essentially of a public service nature." The act commits the United States to examining carefully the possibility of commercializing land remote sensing while retaining within government the existing operational weather satellite system.

The effort to turn over the land remote sensing operational program to the private sector has turned out to be difficult and time-consuming. Nevertheless, the Board endorses this effort. It believes that in the long run the program will flourish better within the private sector, once the difficulties of transition from public to commercial management have been successfully negotiated.

The Act explicitly forbids the transfer of weather satellites from public to private ownership. The Board supports this decision also. Weather satellite observations can properly be considered to be of a public-service nature. They provide basic information used in preparing forecasts of severe weather (drought, flood-producing precipitation, damaging winds, fog, or freezing rain) that are of crucial interest to broad segments of society and often create situations dangerous to public health and safety.

As a result of the Land Remote Sensing Commercialization Act, it is clear that the United States is heading toward two earth remote sensing operational systems: one in the private sector, devoted to land remote sensing, and one in the public sector, devoted to weather remote sensing. But this is an incomplete resolution of the total problem. The act remains silent with regard to what shall happen to ocean remote sensing—a growing discipline that will be of increasing importance in future years.

Ocean remote sensing is far more closely linked to weather and climate than to land remote sensing. A close relationship exists between meteorology and oceanography, both in terms of the science involved and in terms of the kinds of global observations required. The ocean covers almost 75 percent of the earth's surface, and latent and sensible heat exchange at the air-sea interface is an important factor in atmospheric circulation. Conversely, the frictional force of the winds drives most of the important global ocean currents. On short time scales—up to a few days or even a fortnight—the two systems can be regarded as somewhat separate, with only limited interactions due to exchange processes at the air-sea interface. At longer time scales, however, any effort to understand and accurately predict the behavior of either the atmosphere or the oceans requires analysis of the two media as a single, coupled system. For example, in the dynamics of climate, the atmosphere and ocean systems are fully intertwined.

In terms of required observations, meteorology and oceanography are also similar. Both fields need global observations of solar radiation and cloudiness, as well as wind, temperature, and atmospheric moisture conditions near the air-sea interface. Both fields employ complex predictive models using high-speed digital computers. Both fields are working on interactive models of the coupled ocean-atmosphere behavior.

As a consequence of this strong overlapping, ocean remote sensing devices (when they become suitable for operational deployment) should be flown as part of the federally operated civil weather satellite system. These will supplement the ocean temperature sensors already operational on polar orbiting weather spacecraft. Over a period of years, the weather satellite system would thus become a fully integrated atmosphere-ocean satellite array. The long-term evolution of such a system should be an accepted policy of the U.S. earth satellite program.

FINDING IV. The Land Remote Sensing Commercialization Act of 1984 has moved the United States in the direction of two separate operational systems for the remote sensing of the earth: one for the land, to be transferred to the private sector; the second for the atmosphere, to be operated by the federal government. While the legislation is silent with regard to a policy for ocean remote sensing, the physical problems and measurement requirements facing oceanography are much more closely related to the meteorological than to the terrestrial sciences.

Recommendation: Operational atmospheric and oceanic remote sensing for civil purposes should be accomplished in the future by a single federally funded and managed satellite system.

Recommendation: Operational land remote sensing for civil purposes should be accomplished in the future by a system owned and managed by the private sector (if at all feasible). At least in the early years, funding will have to come, in large part, from government.

Intragovernment

Within the federal government there has also been a division within the earth remote sensing program. NOAA has concentrated its attention on operational earth remote sensing and has devoted very little of its resources to supporting research. NASA, on the other hand, has tended recently to move toward fundamental research and has devoted very little of its attention toward applied research, which would help the operational program. This has meant, for example, that neither agency is devoting adequate attention to the development of the new sensors (such as microwave devices) needed to extend the capability of the evolving operational system.

This was not always true. As has been previously noted, a major reason for the success of the weather satellite program was the superb cooperation that existed for over 2 decades between NASA and NOAA. NASA funded the development of new sensors, identifying priorities in consultation with NOAA. NASA also funded the development of the first of each new series of spacecraft, launched it, and turned it over to NOAA for operation. The two agencies were essentially partners in fashioning the operational weather satellite system, with NOAA (at least initially) playing the role of junior partner. As the capability of the NOAA satellite service increased, it was probably inevitable that NASA management would begin to think of the operational program as "their" program, not "ours." And when budget pressures increased, perhaps it was inevitable that NASA management would view the funds spent in support of the operational program as a burden when compared to more "NASA-like" research.

All of this is understandable in human and organizational terms. But the Board must point out that what suffered is the national operational program. NOAA has not been able to obtain from the Department of Commerce and the Office of Management and Budget the fiscal or engineering resources necessary to carry forward the tasks formerly contributed by NASA.

The same kind of division has occurred in land remote sensing. As has already been noted, NASA began phasing down the development of next-generation land remote sensing techniques when NOAA was given responsibility for the operational program in 1979. NOAA has neither the funds nor the engineering capability to carry forward such work. As a result, neither agency is carrying out this much-needed effort.

There are some exceptions to the pattern. NASA's Earth Radiation Budget Experiment (ERBE) sensors are carried on NOAA polar orbiters, and a sensor of substantial operational interest (the scatterometer) is being developed by NASA in support of the Navy (for NROSS). But these are the exceptions, not the rule. Some way must be found to enable the various federal agencies, especially NASA and NOAA, to work together effectively for the betterment of the national program.

FINDING V. Within the federal establishment, civil earth remote sensing has been partitioned into operations (in NOAA) and research (in NASA). As a result of agency decision-making and funding pressures, this partition has become too rigid and divisive, to the detriment of the total program.

Finally, some comments need to be made concerning the division of the federal earth remote sensing program between civil and defense agencies. Obviously, both communities have substantial and legitimate interests in earth remote sensing.

There are many possibilities for necessary as well as unneeded redundancies and for appropriate separateness as well as useful collaboration. Nevertheless, the topic will not be discussed in depth in the present report. It is difficult for an external Board to fully appreciate the requirements and priorities of the DOD earth remote sensing program. In the past, various administrations have studied the interactions of the civil and defense programs and have concluded that these efforts should develop in parallel. A good example is the parallel effort represented by the NOAA polar-orbiting weather satellites and the spacecraft of the DOD Defense Meteorological Satellite Program (DMSP).

In this study, the Board has concentrated its attention on the civil program, with only a few comments in a limited number of areas where the civil and defense programs interact strongly.

NOAA'S POSITION WITHIN THE FEDERAL STRUCTURE

Within the past 7 years, at least three different proposals have been advanced to move NOAA out of the Department of Commerce. President Carter recommended that NOAA be transferred to a Department of Natural Resources; President Reagan (in his first term) recommended that NOAA be made an independent agency as part of a reorganization of the Department of Commerce; most recently, a Presidential Commission recommended that NOAA be made part of a new Department of Science.

The Board prefers to remain silent concerning the merit of these three proposals. Clearly, a decision about where NOAA should be moved—or whether any move at all is desirable—must be based on an evaluation of issues and programs far broader than earth remote sensing. Nevertheless, several appropriate points can be made.

The operational earth remote sensing program has not fared well in the Department of Commerce. In the Board's opinion, the operational effort receives an unreasonably small part of the resources being devoted to the total space program.

The Board believes that the existing problems in the civil operational earth remote sensing program are in part due to NOAA's location in the Department of Commerce. These problems would be ameliorated by an appropriate change in NOAA's affiliation. If such a reorganization does not occur, it is highly desirable that NOAA (and through NOAA the operational earth remote sensing program) be given greater budgetary and management flexibility within the Department of Commerce.

FINDING VI. The civil operational earth remote sensing program is handicapped by the existence of NOAA within the Department of Commerce. A change in the affiliation of NOAA has been discussed for many years: President Carter recommended that NOAA be transferred to a Department of Natural Resources; President Reagan (in his first term) recommended that NOAA be made an independent agency, as part of a reorganization of the Department of Commerce; a Presidential Commission has recently recommended that NOAA be made part of a new Department of Science.

Recommendation: The administration and Congress should agree on NOAA's future organizational affiliation as soon as possible. If a decision is made to keep NOAA within the Department of Commerce, steps should be taken to provide NOAA (and through NOAA the operational earth remote sensing program) with greater budgetary and management flexibility.

TECHNICAL CONSIDERATIONS

In the previous sections we have reviewed how the civil earth remote sensing program has been partitioned between the federal and private sectors and (within government) between research- and operation-oriented agencies. These divisions have tended to fragment the total program and thus make it more difficult to maintain progress toward a well-balanced and effective total effort. For institutional reasons we tend to think separately of a "weather satellite program," an "ocean sensing program," and a "land remote sensing program," rather than of a single "earth remote sensing program." We also tend to think of a "research sensor" or an "operational sensor" rather than an "earth remote sensor."

Yet from a technical point of view there should be a single program. Whether one is remotely sensing the atmosphere, the oceans, or the land surfaces, all of the satellites are in earth orbit and all take measurements of the earth below. If the orbital requirements are compatible for a weather and a land remote sensor, there is (in principle) every reason to consider placing them on the same spacecraft. The same consideration applies to research and operational sensors.

The expense of building spacecraft and placing them in orbit is a major part of the total cost of any satellite program. An earth-viewing system that uses space platforms with a maximum degree of cost-effectiveness should be designed to provide satellites in an appropriate number of different orbits (near polar, lower inclination, and geostationary). The number and size of the spacecraft in each orbit should relate to the number and character of the required sensors. Observational and orbital requirements, not institutional or programmatic labels, should determine on what satellite a given sensor is flown.

Other technical problems are becoming critical. The volume of data flowing from earth-orbiting satellites is growing rapidly and will eventually exceed 10^{13} bits per day, even though on-orbit data reduction may slow the increase in data flow from future space platforms. Ground systems to handle this vast flow of data are becoming increasingly expensive and difficult to design and construct. Especially when the data flow is used to monitor and predict the development of physical phenomena with short life spans (as in meteorology and oceanography), additional complications are posed by the need to fashion on-line digital systems to process, evaluate, analyze, and disseminate the resulting information.[2] When immediate decisions (e.g., very short-range weather or ocean forecasts or warnings) result from the observed data, machine-assisted procedures must be developed to identify and call to the attention of the decision-maker the small amount of critical information embedded in the vast data stream.

[2] Data Management and Computation, Vol. I, National Academy Press, 1982.

Efficient data flow is essential to the satisfactory performance and utility of an earth remote sensing system. Nevertheless, ground systems have not received sufficient funding or attention. All too often when budget pressures arise, available funds are channeled into the effort to place the observing sensors in orbit, and not enough resources are preserved for the ground system.

FINDING VII. From a purely technical point of view, the partition of the civil earth remote sensing program into private- and public-sector components and into operations and research is an unnecessary complication that has thus far only added to the cost and difficulty of creating and maintaining a successful operational program. In an earth-viewing system that uses space platforms and other hardware with a maximum degree of cost-effectiveness, each satellite could carry land, atmosphere, and ocean sensors, and each could carry operational and experimental sensors. Observational and orbital requirements, not institutional or programmatic labels, would determine on what satellite a given sensor was flown.

FINDING VIII. The volume of data flow in civil earth remote sensing is growing rapidly and will eventually exceed 10^{13} bits per day. Data processing, evaluation, analysis, dissemination, and archiving are becoming more difficult and costly. A substantial effort is needed to plan and operate the required data-handling systems.

DIRECTIONS FOR THE FUTURE

Some of the reasons why the earth remote sensing program is in difficulty are clear. The program is fragmented, institutionally and programmatically. The public and private sector; research scientists and operational specialists; and meteorologists, oceanographers, geophysicists, geologists, and land-use managers all have legitimate needs for remotely sensed information. It has not been possible (nor would it be wise or efficient) to mount a separate program for each element of the multidimensional matrix thus formed.

Ideally, this country needs a federal plan for earth remote sensing—one that can be accepted both by the Executive Branch and by Congress. Such a plan would set forth the various orbits required for earth remote sensing satellites: near polar, lower inclination, and geostationary. It would assess the need for sensors in each of these orbits, without regard to the funding institution or scientific discipline involved. To the maximum degree possible, an ideal plan would call for common use of spacecraft and data-handling systems whenever this is economically advantageous. Special-purpose satellites that carry sensors developed for a specific experiment or requirement would be held to a minimum. Space for sensors flown by the private sector could be provided (for an appropriate fee) on spacecraft launched by federal agencies, or (when efficient) federal agencies could contract for space on commercially launched vehicles.

An ideal federal plan would be built around the requirements of the operational remote sensing program. Compared to research, the operational program has little flexibility in launch schedules and places more severe demands on data-processing systems.

Preparing and carrying out such an ideal national plan would require vigorous and concerted action at several levels of government. Within the Executive Branch, the Office of Science and Technology Policy would have to take the lead in interagency and interdepartmental planning. The Office of Management and Budget (which is not comfortable with interagency programs that cut across its internal budget review structure) would have to develop and adhere to a "crosscut" review procedure. Federal agencies would have to agree to give up some of their flexibility for individual action. Within Congress, methods would have to be found to coordinate the decision-making process between oversight, authorization, and appropriation committees. A master federal plan may be an ideal worth striving for, but it will have to evolve over time. Realistically, one must conclude that an all-inclusive plan cannot be developed quickly.

There are two reasons why conditions are ripe for a more limited step, but one that could be very important. First, Congress has requested from NOAA a plan for operational earth remote sensing, to be delivered by September 1985. In preparing this plan, NOAA has an opportunity to take a major step toward a hardware-integrated earth remote sensing system. The plan should bring together meteorology and oceanography in a single federal operational system and should consider possible integrated use of spacecraft and communication downlinks between the federal system and an evolving commercial land remote sensing system. It should evaluate the various orbits and the number of satellites needed, should point out the problems and requirements for improved operational data handling, and should (to the extent possible) provide space for NASA research sensors and experiments on operational spacecraft. Obviously, the plan should be carefully coordinated with NASA.

A second reason why this is an especially appropriate time to develop a federal plan for operational earth remote sensing is that NASA planning for the space station is moving ahead. In addition to the manned space station, the program calls for two unmanned space platforms, one at an inclination of 28½ degrees and one in near polar orbit. These two platforms—especially the polar orbiting platform—can be of substantial value to the earth remote sensing program, both in operations and in research. The cost-effectiveness of the total earth remote sensing system would be greatly increased if sensors were brought together on the orbiting platforms and if the need for procuring replacement hardware were reduced by an effective program of retrieval or in-orbit repair.

A federal plan for operational earth remote sensing, thoughtfully and carefully developed, could gain broad support within the Executive Branch and Congress. Such a plan would go far toward eliminating many of the problems now being experienced.

Another efficiency that could be instituted relates to multinational activities. The operational programs in meteorology and oceanography are of major interest to other developed countries. The United States has worked closely with Britain, France, Japan, and other nations in promoting earth remote sensing. The Search and Rescue system was developed jointly with France and Canada and is now being deployed under international agreement on polar orbiters launched by both the United States and the USSR. The United States has assisted in the development and launch of geostationary weather satellites by Japan, the European Space Agency, and India.

Other countries have expressed concern about the Administration's stated desire to cut back the launch schedule for weather satellites in near polar orbit. On the average, this reduction would result in a single spacecraft being in orbit at any given time, but on occasion there would be two operational satellites in orbit and at times there might be none. The latter situation would have especially serious consequences for weather forecasting, not only in the United States but around the world.

There is a real possibility that multinational participation can be expanded, especially with regard to polar-orbiting weather satellites. This could improve international cooperation and reduce the cost of the program to this country.

FINDING IX. The United States cannot afford the cost of launching a separate space vehicle for each programmatic need—for land, atmosphere, and ocean remote sensing as well as for operations and R&D. Some mechanism must be found to reconcile institutional and programmatic diversity with the realities of efficient use of hardware (space platforms and downlinks). A federal plan is urgently needed.

Recommendation: NOAA (in cooperation with NASA) should develop a long-range plan for the federal role in operational earth remote sensing. To the maximum degree possible, this plan should facilitate common use of spacecraft and data-handling systems by institutions (public and private) that mount earth remote sensing programs. To help control costs, the number of special-purpose satellites must be held to a minimum.

Recommendation: The system plan should center around the needs of operational programs (which have minimum flexibility in orbital, launch, and data-handling requirements). Whenever possible, space should be made available for research sensors on vehicles that are used primarily for operational purposes. The potentialities of the earth orbiting platforms (to be launched as part of the space station program) should be fully exploited. The polar orbiting space platform is especially important for earth remote sensing.

Recommendation: The present effort to encourage multinational cooperation in the earth remote sensing program is promising and should be continued and expanded. This will promote international goodwill and will further help to limit national expenditures.

Recommendation: Participating institutions (national and international, public and commercial) should share in the cost of the planned earth remote sensing system.

A FUTURE EARTH REMOTE SENSING SYSTEM: INSTITUTIONAL ROLES

With a satisfactory long-range plan in hand, it will be possible for this country to move ahead rapidly to establish a high-value, cost-effective earth remote sensing system, which could be in place by the mid-1990s. In doing so, the United States must avoid difficulties among the various domestic organizations involved: battles for turf as well as a parochial definition of institutional roles that leaves important parts of the effort undone.

The Board recommends the set of institutional responsibilities outlined below. Obviously, the list is not rigid; some adjustments are possible. However, the Board believes that the recommended distribution of responsibilities is appropriate and in accord with the demonstrated competence of the various participating agencies or sectors.

Earth remote sensing in the United States will not succeed unless NASA plays a prominent role. NASA's superb engineering and developmental capabilities in space cannot be matched elsewhere in government, and it would be senseless to try to reproduce this competence in NOAA. On the other hand, the Board respects NASA's position that it should concentrate on research and development and should not become too enmeshed in operational space activities.

The answer to this apparent dilemma is that NASA should provide engineering and R&D support for an operational earth remote sensing program, but the operational program itself should reside elsewhere—in NOAA for meteorology and oceanography and in the commercial sector for land remote sensing.

In the earth remote sensing of the 1990s, NASA scientific and engineering research should include programs to develop new earth measurement techniques from space—not only for meteorology and oceanography (in support of NOAA) but also for land remote sensing (in support of the commercial sector). It should also include (a) scientific research to improve understanding of the earth, in part through carefully selected space missions, and (b) engineering research to improve earth orbiting satellites and platforms and to develop better communication and data-handling systems (to meet the rapid expansion that will occur in the volume of information to be transmitted to earth).

NASA will, of course, build, launch, and manage the space station and its associated space platforms. The polar Space Platform is particularly important for earth remote sensing. NASA should lease space on these platforms to NOAA and to the commercial operator of a land remote sensing system. In fact, on the polar Space Platform NASA should give first priority to operational sensors. NASA should also develop and manage an integrated communication and data-handling system for the space platforms.

An especially important engineering task, which can greatly improve the cost-effectiveness of earth remote sensing, is the development of station-tending, in-orbit repair, and sensor retrieval systems for the space platforms. Retrieval systems for satellites in inclined or geostationary orbits are also needed. The development of such a capability—to be made available to NOAA and to the commercial sector under contract—will require a high degree of cooperation between NASA and NOAA.

In the earth remote sensing system of the 1990s, NOAA should own and manage the operational observing system for the atmosphere and the oceans. It should also provide federal oversight for a commercially operated land remote sensing system.

NOAA should work closely with NASA (and with a commercial operator) to maximize cost-effectiveness of the atmosphere-ocean remote sensing through the development of integrated hardware systems (spacecraft and downlinks) whenever feasible. NOAA should lease space (as appropriate) on NASA space platforms or on commercial satellites; similarly, when NOAA satellites are launched (e.g., in geostationary orbit), space could be leased to NASA (for research sensors) or to the commercial sector (for land remote sensing instruments). NOAA should also contract with NASA for satellite retrieval.

NOAA should carry out research in direct support of its operational responsibilities and should consult with NASA about requirements for new operational sensors. It should undertake research on the application of space-derived information to a variety of practical fields, not only weather and ocean-related (e.g., weather forecasting or marine operations) but also land-related (such as resource exploration or land management). The latter effort could be undertaken in cooperation with other federal agencies such as the Departments of Agriculture or Interior and will be needed (at least during an extended transition period) to help stimulate other agency and private-sector use of land remote sensing observations. This activity is discussed in greater detail in Part 3.

NOAA should continue to have archival responsibilities for earth remote sensing data and information. With regard to the atmosphere and the oceans, NOAA must place a high priority on making space observations available to both the commercial and the research communities on a real-time basis.

As noted in Part 3, the Board endorses the effort to turn over the land remote sensing operational program to the private sector. The previous paragraphs have assumed that this effort will be successful; in the present discussion, we will continue to make this assumption.

The commercial operator of the land remote sensing system will have to play a special role in marketing space-derived information—a function in which the private sector is more effective than government. Users of land remote sensing information will include, of course, not only industry and agriculture but also federal, state, and local governments.

A commercial operator will have strong incentives to develop cost-effective systems of earth observations. It will be to the operator's advantage to have the flexibility to lease space on orbiting platforms or satellites from NASA or NOAA or (alternatively) to sell space to these government agencies on commercial satellites. For this and other reasons, the commercial operator will find it beneficial to cooperate closely with both NASA and NOAA in the development of the privately owned operational land remote sensing system.

FINDING X. With careful planning and resolute action, a highly valuable and cost-effective civil earth remote sensing program can be in place by the mid-1990s. Among participating institutions in the United States (NASA, NOAA, and the commercial sector), each has a vital role to play.

Recommendation: NASA should launch and operate the Space Platforms and design and manage the downlinks to be developed as part of the space station program. Operational earth remote sensors (NOAA and commercial) should be given high priority on the polar orbiting platform. NASA should also develop station tending and repair capabilities for space platforms and retrieval capabilities for other earth-orbiting satellites (including those in geostationary orbit). NASA should develop new sensors for operations, in consultation with NOAA and other users, and should carry out basic space-oriented R&D on the physics and chemistry of atmosphere, ocean, and land systems.

Recommendation: NOAA should build and (under contract with NASA) launch operational satellites or lease space on commercial spacecraft. It should own and manage the atmosphere-ocean operational observing system and provide federal oversight (and, as appropriate, initial federal subsidy) for the commercially operated land remote sensing system. NOAA should carry out research on applications of space-derived information, should be responsible for archiving all earth remote sensing data, and should disseminate atmosphere and ocean data to the user community.

Recommendation: The commercial sector should own and manage the operational land remote sensing system, purchasing space when appropriate on NASA and NOAA satellites. It should build new operational sensors and should fly its own satellites as it deems necessary (leasing space when appropriate to NOAA or NASA). The commercial sector should also be responsible for marketing space-derived land remote sensing data to the various user communities, including government departments such as Agriculture and Interior.

SOME POLICY AND PRIORITY ISSUES

The earth remote sensing program, which made major strides during the 2 decades from 1960 to 1980, has faltered and slipped back in recent years. As noted previously, the difficulties are not technical. From a scientific and technical view, the program is positioned to surge forward. User communities in both science and applications are clamoring for more and better remotely sensed information; new and promising methods of measurement await development.

The earth remote sensing program is in crisis, especially with regard to the operational program. But it is a crisis caused by the absence of a firm national policy that this country should reap the advantages of its lead in space. The situation seems to be one of not-so-benign neglect: In the absence of a strong and positive policy in favor of exploiting the values of earth remote sensing, comparatively low-level decisions have eaten away at the national program in response to budget pressures and short-term agency priorities.

If earth remote sensing is to flourish, the priority of the program (especially its operational phase) must be more carefully examined by the Executive Branch and by Congress, and a positive policy decision must be made that earth remote sensing should receive a more substantial portion of the resources devoted to space. This will require the attention of policy-setting individuals within the Executive Branch.

What are the reasons for such a change in policy and priorities? One reason is that many fields of crucial scientific importance (the atmospheric sciences, oceanography, geology, and geophysics) are becoming increasingly dependent on earth observations from space, and in the long run the ability to deal successfully with problems of our environment are dependent on the strength of the earth sciences. This reason is often overlooked or discounted. There has been a tendency to overemphasize the immediate utility of operational earth remote sensing information and to ignore its contribution to fundamental understanding of the world around us. For example, the observation of hurricanes from geostationary weather satellites is usually recognized to be important in issuing hurricane warnings; it is less often realized that such observations also contribute to understanding the physics of hurricanes and will in the long run help improve the predicting of their formation and motion.

A second reason is, of course, the utility of the observational data. The ability of remote sensing systems to monitor phenomena on earth and to assist in the preparation of needed forecasts has been recognized, although the Board believes the amazing potentialities of earth remote sensing have usually been underestimated. But with regard to this issue, policy makers have tended to become entangled in questions about what kinds of measurements should be made by government and what kinds should be taken by the private sector.

One would hope that this issue was laid to rest when the Land Remote Sensing Commercialization Act of 1984 became law. This report is consistent with the policies set forth in that act: Operational land remote sensing should proceed, if possible under the aegis of the commercial sector, and weather remote sensing should continue as a federally funded and managed activity.

Until such time as Public Law 98-365 is changed, we must proceed in accordance with its directives. The crucial need is to recognize the substantial value of earth remote sensing and to move ahead to develop the research and operational programs required if the nation is to take full advantage of its space capabilities.

FINDING XI. The priority of earth remote sensing should be reevaluated by the Executive Branch and by Congress. An effective earth remote sensing program is possible only if adequate funding and a stable budget are assigned to the program. This will require the attention of policy-setting individuals within government.

3

The U.S. Land Remote Sensing Program

The NASA program of land remote sensing from space arose with the Gemini program, which obtained pictures of the earth with geological and agricultural significance. It was given an impetus by Project Apollo, the U.S. effort to land men on the moon. A crucial element of this effort involved the selection of landing sites on the moon, and for this purpose NASA undertook a precursor project called "Lunar Orbiter" in which five satellites orbited the moon (in 1966–67) and sent back thousands of pictures of the lunar surface. The instruments used in the Lunar Orbiter were first tested over terrestrial sites that simulated the lunar landscape, and the photographs thus obtained were compared with actual measurements on the ground (ground truth).

It soon became apparent that the photographs could be useful in studying geology and in mineral exploration on earth. The interest spread to other disciplines that could benefit from remote observation of the earth—i.e., agriculture, forestry, hydrology, cartography, coast and geodetic surveys, and urban planning. This interest led to the establishment of an earth resources survey program, sponsored by NASA and assisted by experimenters in universities and elsewhere.[1]

EARLY LANDSAT SATELLITES

The first satellite devoted primarily to observing the land areas of the earth was named Earth Resources Technology Satellite-1 (ERTS-1). It was launched July 23, 1972, into a near polar circular orbit of about 900 km altitude, an orbit that gave complete coverage of the earth with a repeat cycle of 18 days. The satellite carried two observing instruments, one called the Return Beam Vidicon (RBV) and the other, the Multispectral Scanner (MSS). Both instruments were focused to observe a strip 185 km wide as the satellite moved over the earth.

[1] Colwell, R. N., ed. Manual of Remote Sensing. American Society of Photogrammetry, 1983.

The RBV was a set of three television cameras aligned to observe the same scene. The cameras carried different filters that determined the three spectral bands of the instrument—i.e., blue-green, yellow-red, and near-infrared. Thus, for each scene, the RBV produced three 185 × 185-km pictures (one in each band) with a ground resolution of 80 m.

The central feature of the MSS was a mirror that oscillated in a plane perpendicular to the path of the satellite, thus continuously sweeping across the 185-km-wide ground track. The mirror focused the image of a small segment of the earth on a set of photoelectric sensors with different spectral responses. For the first MSS, there were four bands, two in the visible region and two in the infrared.

Although the RBV failed after a few weeks, the MSS continued to operate for 5½ years (far beyond its expected lifetime), and it became the primary source of Landsat data. ERTS-1, later named Landsat-1, was the first of five Landsat satellites, of which the principal characteristics are given in Table 1.

Landsat 2, similar to Landsat 1, was launched January 22, 1975, and did not cease operation until February 1982. Changes were made in Landsat 3, which was launched March 5, 1978, and operated until March 1983. A fifth band in the thermal infrared was added to the MSS, but this band did not operate properly. The RBV was redesigned to use two identical cameras that were aligned to simultaneously view adjacent 84-km-square ground segments, thus increasing resolution by a factor of two above the previous MSS and RBV instruments.

For all Landsats, data were transmitted directly to a ground receiving station when the satellite was within range of one. When the satellite was not within range of a ground station, the instruments were turned on and the data recorded on magnetic tape, within the satellite, in accordance with commands that had been sent to the satellite by radio.

On the ground, the data were corrected for radiometric and geometric errors and then converted by an analog electro-optical system to photographic scenes 185 km square. This was a slow, time-consuming process, and it delayed the availability of data to ultimate users. NASA distributed Landsat data to its

TABLE 1 Characteristics of Landsat Data

Landsat	Year	Sensor	Approximate Resolution	Bands	Bits/Pixel
1	1972	MSS	80 m	4	6
		RBV	80 m	3	
2	1975	MSS	80 m	4	6
		RBV	80 m	3	
3	1978	MSS	80 m	5*	6
		RBV	40 m	1	
4	1982	TM	30 m	7	8
		MSS	80 m	4	
5	1984	TM	30 m	7	8
		MSS	80 m	4	

MSS—Multispectral Scanner; RBV—Return Beam Vidicon; TM—Thematic Mapper; Pixel—Picture Element.
* IR Band 5 did not work.

associated experimenters; a broader distribution was provided by the Department of the Interior's Geological Survey. USGS established an EROS (Earth Resources Observation Satellite) data center in Sioux Falls, South Dakota, that made data available to all customers for the cost of reproduction.

During the first decade of operation (1972–1982), and prior to Landsat 4, the data had three principal limitations:

1. The spatial resolution was inadequate for some uses such as cartography, urban planning, and some agricultural studies. However, for other uses such as hydrology, coastal studies, and mineral exploration, the resolution was not of prime concern.
2. The choice of spectral bands was not optimum for some of the users because the choice had been a compromise between the needs of many users.
3. For most users, the time delay in availability of the data was a serious handicap. For example, in crop forecasting, especially during the growing season, prompt availability of data (within a few days) is critical. On the other hand, for geological studies, as in exploration for oil, timeliness is important only as a competitive element and has little relation to the utility of the data for analytical purposes.

For more than a decade the operation of Landsat, albeit in an experimental mode, created a new enterprise with at least a score of uses and hundreds of users in industry, in universities, and in federal, state, and local governments. NASA established educational facilities at several of its centers, principally at Goddard in Washington, Johnson in Houston, and MTF in Bay St. Louis, Mississippi, where potential users could come and be trained in the interpretation of Landsat data, using actual scenes, computers, and display equipment.

NASA attempted to interest federal agencies in the use of Landsat data as a way of improving the conduct of their normal functions. The U.S. Department of Agriculture (USDA) is responsible for crop forecasting both within the United States and worldwide. Starting in 1974, NASA, NOAA, and USDA undertook to use Landsat and other satellite data to predict the world wheat crop, especially the production of the Soviet Union, in a program called LACIE (Large Area Crop Inventory Experiment). Several years later, USDA, NASA, and NOAA combined in a long-term program called AGRISTARS (Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing) to extend the use of satellite data to other crops and to use it regularly in the United States. For example, the wheat, corn, and soybean production of seven states (Illinois, Iowa, Missouri, Kansas, Arkansas, Oklahoma, and Colorado) is forecast in this way.

LANDSATS 4 AND 5

Landsat 4 was launched July 16, 1982, and initiated a significant improvement in the quality of Landsat data. The RBV was abandoned and a new instrument, the Thematic Mapper (TM), commenced operation on an experimental basis. The Thematic Mapper was a considerably improved MSS. It had seven spectral bands (rather than the previous four). As in the MSS, the TM employed an oscillating mirror which (for TM) scans in both directions, making possible an improved resolution (30 m instead of 80 m for the MSS) for six of the seven spectral bands (all except the thermal IR band, for which the resolution was 120 m). Landsat 4 carried a four-channel MSS to provide continuity of MSS data and as a backup to the TM.

Although the superior quality of the TM data was recognized by many users, the data were not readily available because development of the ground processing system had not kept pace with the satellite-borne instrument. Landsat 4 was plagued with difficulties. Within months after launch, the X-band communications failed and limited the amount of TM data available. Then cables to two of the four solar panels separated, thus reducing power and limiting operation to one instrument at a time, either TM or MSS. The difficulties with Landsat 4 led to an early decision to expedite launching of a replacement, Landsat 5.

Landsat 5 (containing the same instruments as Landsat 4—MSS and TM) was launched March 1, 1984, and soon became the primary operational source of data. This is now the only earth resource satellite in operation, and no funds have been allocated by the government for follow-on satellites (Landsats 6 and 7).

Between 1979 and 1982 the responsibility for operation of Landsat was gradually transferred to NOAA, in the Department of Commerce. At first NOAA was given responsibility only for the MSS operation, since the TM was considered experimental until 1984, when NOAA also assumed responsibility for the TM. Responsibility for Landsat data handling at the EROS data center in South Dakota was also transferred, and NOAA was ordered to recover full operating costs through the sale of data, a result that was never achieved. NOAA increased the costs of MSS data by a factor of three, but sales fell off by the same factor, so that the revenue remained about the same. However, NOAA did actively prosecute the licensing of foreign stations and brought the total to ten: Argentina, Australia, Brazil, Canada, European Space Agency (2 stations), India, Japan, South Africa, and Thailand.

THE ROAD TO COMMERCIALIZATION

Also in 1979 NOAA was directed to study whether the private sector could operate a land remote sensing system in the future. President Carter cited commercialization of Landsat as a goal of his administration and committed the United States to providing continuity of data flow from the Landsat system at least through the 1980s.[2]

The Reagan administration decided early in its tenure to accelerate the process of transferring Landsat to the private sector. In the revised Fiscal Year 1982 budget request (submitted to Congress in March 1981), plans to build Landsat 6 and 7 were dropped in the expectation that the private sector would be able to launch land remote-sensing satellites by the late 1980s. In July 1981 the Cabinet Council on Commerce and Trade (CCCT), chaired by the Secretary of Commerce,

[2] U.S. Code Congressional and Administrative News, September 1984.

was assigned the responsibility for assessing (a) the best mechanism for transferring Landsat to the private sector as soon as possible and (b) whether the government's four operational civil weather satellites should be transferred at the same time. The CCCT met periodically through late 1982, and in March 1983 President Reagan announced his decision to transfer the civil land remote-sensing system, the civil weather satellite system, and future ocean-observing systems to the private sector as soon as possible.[3]

In the fall of 1983 both the House and the Senate passed concurrent resolutions expressing the sense of the Congress that weather satellites should not be transferred to the private sector. The Administration's proposal to transfer weather satellites was finally dropped in November 1983, after the passage of P.L. 98-166, the Fiscal Year 1984 Appropriations Act for the Department of Commerce, which contained language prohibiting the use of funds for the transfer.[3]

The question of commercialization of land remote sensing remained, and the need for a policy resolution was highlighted by the gradual and premature failure of Landsat 4 during 1983 and the early launch of Landsat 5 in 1984. These events dictated that a follow-on of some kind would be needed sooner than expected.

Meanwhile, in May 1983 the Department of Commerce had created a Source Evaluation Board (SEB) for civil space remote sensing to solicit and evaluate proposals from parties interested in acquiring and operating Landsat and weather satellites. The SEB issued a draft request for proposals (RFP) for industry comment that pertained to both Landsat and weather satellites. When Congress in the fall of 1983 forbade the sale of weather satellites, the RFP was revised to apply only to the transfer of the land remote sensing system and was issued on January 3, 1984. Seven bids were received in response to the RFP, two of which were selected by the Secretary of Commerce for further negotiation. One of these two has been withdrawn, leaving one company, the Earth Observation Satellite Company (EOSAT, a joint venture of RCA, Hughes Aircraft Company, and several other companies), as the sole remaining bidder.

PUBLIC LAW 98-365

The Congress recognized that the Secretary of Commerce could not transfer the Landsat system to the private sector without legislative authority and therefore in late 1983 began drafting the Land Remote-Sensing Commercialization Act of 1984. The House Bill, HR 5155, was finally passed by the House of Representatives on June 28, 1984, and by the Senate on June 29. The President signed the bill on July 17, 1984. The act provides for a phased commercialization of land remote sensing and appropriate federal regulation, research and development, and archiving of data.

Title I of the act contains findings, purposes, and policies. Title II represents the first phase of the commercialization process; the Secretary of Commerce is directed to contract for private marketing of Landsat data. The Secretary may also contract for private operation of the system. Title III of the bill provides for

[3] U.S. Congress, House of Representatives. Report 98-647, April 3, 1984.

the second phase of the commercialization, a 6-year transition to full commercial operation. The Secretary is directed to contract for private development, operation, and ownership of a follow-on system to Landsat. Title IV provides for licensing, by the Secretary of Commerce, of commercial land remote sensing systems, including the follow-on system established under Title III. Title V directs NASA and the Departments of Commerce, Interior, and Agriculture to continue remote sensing R&D programs. Other appropriate agencies are encouraged to conduct R&D in remote sensing. In Title VI, the Secretary of Commerce is directed to maintain an archive of land remote sensing data, and the Federal Communications Commission is authorized to allocate radio frequencies to operators of remote sensing systems.

The text of Public Law 98-365 is given in Appendix D.

BENEFITS OF THE PROGRAM

The estimate of benefits deriving from the U.S. land remote sensing program remains one of the program's most controversial issues. In this respect, the situation has changed little over the past 13 years.

At the very beginning of the Earth Resources Survey Program, from its inception in 1965 to the launch of ERTS-1 (later renamed Landsat 1) in 1972, large but unverifiable estimates of benefits from space remote sensing were used to "sell" the program within NASA and within the administration. Unfortunately, some of the early flamboyant and unrealizeable projections of benefits later came back to haunt the program. Furthermore, no allowance was made in early thinking for the difficulty in measuring some very real benefits. Despite this, some critics still point back to those early benefit estimates, and their failure to materialize is used to denigrate the program.

Following the launch of the first Landsat spacecraft, better defined cost-benefit studies were conducted by NASA and by the Department of the Interior. However, these studies drew markedly divergent conclusions, and no consensus emerged. Today's estimates of program benefits range from many billions of dollars to a few million. To understand that inconsistency, it is necessary to examine some of the facts about the U.S. land remote sensing program as it exists today.

1. Direct revenues to the U.S. government from license fees and product sales of Landsat data are small compared with the program's equipment and operating costs. The cost/revenue ratio is somewhere between 6 and 30 to 1.
2. The land remote sensing program, regardless of benefit estimates, was never designed as an enterprise that would make money in the usual commercial sense. It was set up as an experimental program intended to demonstrate that certain technical systems were feasible. Considered in those terms, the U.S. land remote sensing program has been a success. A whole new technology was pioneered—to sense the earth's surface with some detail from outside the atmosphere, return the signals electronically, reconstruct them to image format, extract information via computer processing, and disseminate the data widely, and to do so routinely and regularly with

synoptic coverage of almost the whole planet. Considered as science, the Landsat program is difficult to criticize; considered as business, it has, not surprisingly, fallen far short.

3. The United States was the pioneer in remote sensing of natural resources from space and held the leadership position for 13 years without challenge. The position will change in 1985, when the French satellite, SPOT, will offer observing instruments that are in some ways more advanced than any flown in the U.S. civilian program.
4. Despite its experimental nature, the Landsat program has had widespread application. Successful, cost-saving uses of the data have been made in many fields: geology, agriculture, forestry, environmental monitoring, land use, rangeland management, urban analysis, and a score of others. A handful of successful applications, drawn from several disciplines, are described in more detail in Appendix B. Two points should be made here about these examples. First, they are examples and in no sense an exhaustive list of uses; second, the repetitive use of the techniques described in Appendix B in an operational mode is hindered by lack of guaranteed continuity of data. Practical users will not allow themselves to become dependent on an intermittent or possibly disappearing data source.

The critics of the land remote sensing program from space will generally admit all the points made above. However, they have a powerful argument against continued government involvement or subsidy of the program, as follows: If the data derived from the Landsat program are valuable, then they are valuable to some group of users; therefore, that group of users should bear the cost of the program, rather than the general taxpayer. On the other hand, if the data are not commercially valuable, then why should the program be continued?

Two elements have been ignored in this argument. First, "value" has been equated with commercial value. Societal benefits and scientific values are not considered, nor are such general questions as the country's technological leadership position, international prestige, or future needs for a comprehensive time-sequenced geographic data base. Second, it is assumed that the value of the Landsat data can be estimated explicitly, using some technique such as cost-benefit analysis. In practice, Landsat data are seldom used in isolation. Even in the examples quoted in this report, Landsat data normally formed part of a suite of data that, taken together, make possible the application. When use of Landsat data takes place in such a situation, assignment of a specific dollar value to that role becomes difficult or impossible. And yet, in the opinion of most users of Landsat data, it is precisely in this role that it will be most often used and finally be most valuable. To some degree, remotely sensed data are analogous to census data. The U.S. Census cannot be justified by looking at the revenues generated from the sale of census tapes to the general public. It is justified because census data have thousands of uses, permeating all branches of industry, academia, and government and making definite but unquantifiable contributions to all. In the same way, the use of data about the surface of the world has minor or major uses in thousands of applications. It is the natural-science analog of the demographic information on this country provided by the decennial census.

Seen from that point of view, the argument that the United States can just as well buy its space-derived land data from the French or Japanese is badly flawed. Guaranteed continuity of (and access to) data will be beyond U.S. control and the formats and types of data will be dictated by the needs of the foreign programs, which do not necessarily serve U.S. needs.

In summary, quantifying the benefits of the U.S. land remote sensing program remains difficult. The value of the program cannot be equated to the revenues derived from direct sales or the fees paid by foreign ground receiving station operators. The program's value derives from data use in a broad range of industries, from its scientific contributions, from the part it plays in the worldwide position of the United States as a technological leader, and from the availability of data to address a wide range of future problems—from assessment of natural disasters to the long-term changes in soils, rainfall, erosion, pollution, and land use. A failure to include consideration of these considerable elements of public good in assessing the benefits of the U.S. land remote sensing program from space will inevitably produce a short-sighted evaluation.

FINDING XII. The economic and societal benefits of an operational land remote sensing program could be substantial. Although a commercially viable market for the data does not exist today, there could eventually be such a market. However, considerable training and experience are required to use the data effectively, and industrial managers would have to become familiar with the value of the data. This is an educational process that could only occur slowly over a period of many years.

AFTER LANDSAT 5: WHAT THEN?

Sometime in the next few years, Landsat 5 will cease operation. Will a replacement satellite be in orbit or be ready for launching soon thereafter? Probably not. Landsat 5 has already been in orbit for over a year; its remaining lifetime can only be estimated. The spacecraft builder estimates a total lifetime of about 3 years; NASA considers a Landsat successful if it lasts 18 months, but other Landsats have lasted as long as 5 years. It will take at least 3 years (from a go-ahead to manufacture) to produce a replacement for Landsat 5, either by the government or by a private operator. Hence, a gap of a year or more in the availability of new Landsat data appears to be likely.

When users of Landsat data are asked to list their requirements, most of them will give top priority to "continuity of data," which means a continuing supply of photographs and computer-compatible tapes of scenes that were taken a few days before delivery of the data. Most users would prefer that such photographs and tapes contain data in a format similar or identical to the data they have been using in the past, and for most users this now means Multispectral Scanner data.

But there are alternatives, should new MSS data become unavailable. The French SPOT is scheduled to begin providing data in late 1985. Although its data will be different from MSS, SPOT has some highly desirable qualities, such as higher resolution (20 m for a multispectral color mode and 10 m for a panchromatic black-and-white mode) and the possibility of off-nadir viewing of the landscape. Moreover, a limited amount of data can still be obtained (as before Landsat) by aircraft-borne instruments. So there are ways of filling the gap, but many users would consider them a lesser alternative to a continuing supply of MSS or TM data.

Users are divided about their desires with respect to the quality of follow-on data. Many will want data similar to what they have been receiving—i.e., MSS or TM data. Some, however, desire improvement: higher resolution, more and different spectral bands, and stereoscopic views of the scene.

Almost all users desire easier availability and more rapid delivery of the data. Delivery depends heavily on the ground processing system, and, in the view of many users, development there has not kept pace with the development of spaceborne instruments. Some users need the data within a few days after being transmitted from the satellite, and this has been possible only to users who received the data directly from the satellite.

Easier availability is desired not only for newly acquired data but for data taken in the past. Many observers will want to compare a scene taken recently with a scene taken a month, a year, or a decade before. This need is facilitated by what is called an archive, but archiving alone is not sufficient. What most users want is a data base. An archive implies a collection of data but does not necessarily mean there is a way to access the data on a regular basis. A data base, on the other hand, implies that there is a regular and systematic capability to access the data.

In view of the forgoing requirements, which represent a consensus of users' viewpoints, the Board is convinced that the long-term future of land remote sensing in the United States is best served by a tranfser of operational responsibility to the private sector. Government subsidy during the early years of private operation is necessary and appropriate. As we point out in ensuing paragraphs, there is not today a sufficient market for Landsat data to support the acquisition and distribution of such data. Development of such a market will take time—perhaps a decade—but the eventual success of a private Landsat enterprise depends on it. To be successful, private operation must eventually become self-supporting.

Time is of the essence. Landsat 5 is the only remaining operating satellite, and no successor is currently being built or will be built until the question of transfer to the private sector is settled. Even if this is done during the current year, a gap in availability of new Landsat data is bound to occur unless Landsat 5 has an unexpectedly longer than normal lifetime—i.e., 4 to 5 years. In the meantime, foreign competition is imminent from France, Japan, and eventually other European nations. A prompt decision on transfer to private operation, and in our view a favorable one, is in the public interest.

FINDING XIII. The total multiyear funding that the federal government is willing to provide for the commercial operation of U.S. land remote sensing has been set by the administration at $250 million. At this level of federal support, it appears unlikely that operation by industry can ensure continuity of new data availability or improvement in the quality of the data.

Recommendation: The government should accept the best industrial proposal that it can obtain at the present time, if such a proposal provides for operation of the system over the next decade and will produce at least two follow-on satellites that provide data of quality equal to existing Thematic Mapper data.

FINDING XIV. Time is of the essence. There is no replacement for Landsat 5, now in orbit; a launch date (November 1985) has been set for the French Landsat, named SPOT (Systeme Probatoire d'Observation de la Terre). Unwarranted delay in resolving the future of the U.S. land remote sensing program will result in a gap in the availability of new data and a loss in market position for the United States.

Recommendation: If the proposal for industrial operation is accepted, the development of successor spacecraft should be expedited. If the proposal for commercial operation is rejected or is withdrawn, then NOAA should begin immediately to plan for continuation of operations beyond the present Landsat 5.

Market Development

If Landsat operations are to be transferred to the private sector, and we believe they should be, then the development of a viable commercial market for data is essential to success and to continued operation by private enterprise. One could ask why, in 13 years of operation, the Landsat program has failed to produce such a viable market. Three reasons are of prime importance:

1. There is not a widespread understanding of the value of remotely sensed data. Some oil companies, some farmers, some fishermen, and some state and local governments use Landsat data, but they are a small minority of the potential users. Why has not their use expanded? Why has not the competitive advantage these users are alleged to have gained spurred others to enter the market? In 1983, 75 percent of the revenue from the sale of U.S. Landsat data came from federal, state, and local governments. U.S. industry accounted for only 9 percent of the Landsat data sales revenue in 1983.[4] Much of the market that now exists was created through the efforts of NASA, in cooperation with other federal agencies, but this effort has been curtailed in recent years—a severe loss to remote sensing.

2. The unprocessed Landsat data have limited value. What has much more value is the information derived from Landsat data after a lengthy and often very expensive process. It has taken the U.S. oil industry 6 to 8 years to develop the analytical and interpretive techniques and the applications models that make Landsat data useful to it today. But it is the unprocessed data* that are being offered for sale, now by the federal government and eventually by the private sector. It is revenue from the sale of unprocessed data that must support an acquisition and distribution system. This problem is central to an understanding

[4] Report by the Comptroller General of the United States. GAO/RCED 84-93, February 24, 1984.

* Such data are usually processed to incorporate geometric and radiometric corrections but can be considered unprocessed with respect to their ultimate use.

of why Landsat has failed to create a viable market. It is also the most underappreciated fact of life about land remote sensing.

3. Societal values (in addition to commercial values) result from the use of Landsat data. Societal values are those that accrue to the public and often cannot be measured in terms of dollars. Commercial values are those that accrue to individuals or corporations through the marketing of a product or service, and their value can be measured in dollars. In many governmental functions, societal values predominate—that is why their support by tax dollars is justified. The U.S. Census is an example; weather satellites are another (as Congress has recently decided). But Landsat falls somewhere in between, with values to society as well as marketable, commercial values. Hence Landsat requires participation by both governmental and private sectors and cooperation between these sectors.

FINDING XV. The growth of a viable commercial market for Landsat data is essential to the future success of U.S. land remote sensing. In the Board's opinion, this objective is more likely to be achieved through the transfer of operations (including marketing) to the private sector. As previously noted, such transfer should take place as soon as possible, provided that satisfactory agreement is reached between NOAA and a private operator on the terms of such a transfer.

DIRECTIONS FOR THE FUTURE

NASA Developments

Public Law 98-365, Title V, directs the Administrator of NASA to continue and to enhance remote sensing research and development by conducting experimental space remote sensing programs and by developing remote sensing technologies and techniques. Although NASA continues to do some of this R&D, it is not conducted on a scale comparable to earlier efforts, when NASA was responsible for operating an experimental system and providing data to users. A reorientation of priorities to place greater emphasis on R&D for new sensors and systems that support land remote sensing will be required if NASA is to meet the objectives of Public Law 98-365.

Although this report calls on NASA to increase its research and development in remote sensing, there are at present several NASA developments that hold promise for enhancing the value of land remote sensing data. Two instruments were flown in an experimental mode in the space shuttle in October 1984; they are the Large-Format Camera (LFC) and the Shuttle Imaging Radar-B (SIR-B). The LFC is a high-resolution photogrammetric camera with a 23 × 46-cm format. This was the first flight of the LFC, and a number of excellent pictures were obtained, one of which is reproduced on the cover of this report.

SIR-B is an upgraded version of the L-band Synthetic Aperture Radar (SIR-A) flown on the second space shuttle in 1981. The Synthetic Aperture Radar was first used in Seasat in 1978, and it yielded excellent pictures, not only of the oceans but also of land masses. In the visual and infrared spectra, where most observations have been made in the past, cloud cover has always been a serious limitation, but clouds are almost transparent to L-band radiation, and hence the

Synthetic Aperture Radar can operate continuously regardless of cloud cover and in the dark as well as in daylight.

Although the capabilities of the Thematic Mapper represent a significant improvement in the spectral and spatial resolution of Landsat data, there is a need for even higher resolution. The most promising approach for future systems is the pushbroom mode. In this mode an array of solid-state sensors is located at the focal plane of the instrument and the motion of the satellite sweeps the array of sensors across an image of the ground scene in a pushbroom-like motion. An early type of pushbroom instrument is the Multilinear Array (MLA), which was being developed in NASA but has recently been curtailed. The instrument to be used by the French in the SPOT satellite uses a multilinear array sensor system.

Future sensor systems could provide significant improvement in spatial, spectral, and temporal resolutions. In present instruments the spectral response is fixed in the instrument's design, but future developments could provide the ability to select and vary spectral responses in flight, thus enhancing the instrument's research capabilities. It would then be possible to determine the optimum spectral signature for monitoring a particular resource or for distinguishing between various minerals or various organic substances. NASA's Jet Propulsion Laboratory has undertaken a long-term development program to produce such an instrument, an imaging spectrometer.

Foreign Developments

Considerable attention has been attracted by the French Systeme Probatoire d'Observation de la Terre, almost always referred to by its acronym, SPOT. This will be an earth-observation satellite in a near polar orbit at an altitude of 800 km. It is scheduled to be launched by the European three-stage rocket, ARIANE, in November 1985. The French have undertaken a vigorous campaign to market SPOT data throughout the world and especially in the United States. The satellite will contain two identical instruments, each operating in either of two modes: (a) a three-band multispectral color mode, in the visible and near-infrared, with a ground resolution of 20 m, and (b) a black-and-white panchromatic mode with a ground resolution of 10 m. As previously noted, SPOT employs a multilinear sensor array and uses the pushbroom mode of operation.

The National Space Agency of Japan (NASDA) has obtained Landsat data since the start of the program in 1972. Japan now operates an earth station that receives data directly from Landsat 5 and disseminates it to government agencies, universities, and private industry in Japan. NASDA has undertaken the development of a series of earth-observing satellites; the first of these, the Marine Observation Satellite 1 (MOS 1), is scheduled to be launched in the near future. The spacecraft will have an orbital altitude of 900 km and will carry three instruments, a multispectral electronic radiometer to measure sea surface color, a visible and thermal-infrared radiometer to measure sea surface temperature, and a microwave scanning radiometer to measure atmospheric water content.

The European Space Agency has developed a large research facility called Spacelab to be installed in and flown by the space shuttle Orbiter. Spacelab consists of a pressurized compartment that houses personnel and equipment and a space-exposed platform to accommodate sensing instruments. Of the numerous experiments to be performed within the Spacelab, two are of particular interest to remote sensing. The first of these is a metric camera developed by Zeiss in West Germany and similar in operation to the American large-format camera. In a further development, the metric camera will have motion compensation, and the focal length will be increased from 30 cm to 60 cm. The second instrument is the microwave remote sensing experiment (MRSE), which is intended to measure backscatter from the ocean surface and also surface temperature.

Canada is developing a RADARSAT, scheduled for launch in 1990, that will carry a C-band or L-band synthetic aperture radar. This satellite is designed to provide information that distinguishes frozen from open ocean and that aids in forestry, geology, hydrology, and agriculture. Other nations considering development of remote sensing satellites are the Netherlands, India, and the Peoples Republic of China.

Applications R&D

Applications R&D is needed, and we recommend that NOAA sponsor a program that includes (a) the systematic evaluation of Landsat data by potential users, (b) the identification of new sensor requirements, (c) the development of user models, and (d) the improvement of data formats.

For example, a typical research program for model development might consist of three phases. During Phase 1, one might address the question, "What spectral bands would permit distinguishing between different types of carbonates and different types of clays?" Data to arrive at this decision could be drawn from university studies. Phase 2 might address the question, "Can the signatures identified in Phase 1 be identified in a natural setting by sensors on board aircraft or spacecraft?" Because of the diversity of nature, this requires actual testing of sensor systems. Phase 3 could then address the question, "In what ways can data that differentiate between different clays and carbonates be used effectively in geological exploration?" This last phase is important and yet is almost completely ignored by government programs because of the assumption that industry will do it.

There are two major reasons why the government should sponsor applications R&D of this nature: First, such studies require a systematic evaluation of large amounts of data; second, when private organizations conduct these studies, they usually keep their successful results secret.

FINDING XVI. The full value of land remote sensing will be realized only if there is continued R&D to create new sensors and to learn how to use the data they will provide. A private-sector operator cannot be relied on to fund and conduct the necessary research. Additional R&D needs to be sponsored by the federal government.

Recommendation: Regardless of whether the Landsat operational system is transferred to the private sector or remains a government responsibility, NASA should reorient its priorities to place greater emphasis on research to develop new sensors and sys[illegible] support of land remote sensing activities.

Recommendation: Whether or not Landsat operations are transferred to the private sector, NOAA should sponsor and fund a research and development program that includes (a) the systematic evaluation of Landsat data by potential users, (b) the identification of new sensor requirements, (c) the development of user models, and (d) the improvement of data formats.

4

Atmosphere and Ocean Remote Sensing

The first experimental weather satellite was launched by the United States a quarter of a century ago. Since that time, research sensors in space have played an ever-increasing role in efforts to understand the behavior of the earth's atmospheric and oceanic environment, and operational sensors on weather satellites have become essential components of our observing system for both operational and research use.

Substantial advances have occurred in the technology for making qualitative and quantitative observations of environmental parameters from space. Today, operational weather satellites use visible and infrared sensors to provide images of cloud systems, day and night, from both low-altitude (polar orbiting) and geostationary levels. Operational sensors also determine the temperature of land, ocean, and cloud surfaces, together with the vertical distribution of temperature and moisture throughout the depth of the atmosphere. Atmospheric winds are deduced from the motion of clouds, using sequential images from geostationary satellites.

The quality, frequency, spatial coverage, and resolution of the observations make this information extremely valuable for developed areas such as the United States. The data are of equally great importance for the oceans, polar regions, and less-developed land areas, where satellites often provide the only accurate information about the physical environment.

Under normal conditions the United States has four operational weather satellites in near polar, sun-synchronous* orbit. Two are operated by NOAA and two by the Department of Defense. In addition, NOAA normally has two operational satellites in geostationary orbit, one over the western Atlantic, the other over the eastern Pacific. The system of four civil satellites provides data that have helped bring about a substantial improvement in weather prediction on

* In a sun-synchronous orbit, for each daylight crossing of the equator the angle between the sun's rays and the ground (or solar lighting) is the same.

time scales of 1 hour to several days. The two DOD satellites provide essential information for defense purposes. There is a full and timely exchange of data between the civil and military sectors.

Unlike weather observations, ocean remote sensing measurements are largely in the R&D state, although some of the information provided by operational weather satellites (such as the temperature of the ocean surface) is of substantial value to oceanographers. Research has already demonstrated that a valuable operational ocean remote sensing system is possible and could become a reality during the coming decade. SEASAT, an ocean research satellite flown by NASA in 1978, showed the power of active microwave sensing for oceanic purposes. SEASAT carried three different types of radar devices to measure wind speed and direction near the ocean surface, as well as waves and ocean currents. These observations, together with earlier "proof of concept" missions, demonstrated that ocean measurements from satellites can be made with accuracies and resolutions consistent with the research and operational needs of oceanographers.

Neither atmosphere nor ocean remote sensing programs can afford to remain static. New and exciting remote sensing capabilities are technically feasible; some of these are now being developed or are in the planning stage. Plans for R&D in ocean sensing include TOPEX, a NASA experimental program designed to measure (from a satellite in inclined orbit) the mean elevation of the ocean surface with a degree of accuracy sufficient to make it possible to determine (from geostrophic relationships) the direction and speed of ocean currents. TOPEX would also test improved sensors to measure wind speed and direction and wave characteristics at the ocean surface.

In the atmospheric sciences, recent advances include the VISSR (Visible Infrared Spin Scan Radiometer) Atmospheric Sounder (VAS). This was originally an experimental sensor system designed to measure the vertical distribution of atmospheric temperature and moisture from geostationary orbit. The first VAS instrument was placed on an operational weather satellite launched in 1981. The VAS experimental system was successful, and the observational program is now being converted to operational status.

Ongoing atmospheric R&D includes NASA earth radiation sensors now deployed to measure the incoming (solar) and outgoing (earth) radiation, as part of the Earth Radiation Budget Experiment (ERBE), and the development of experimental sensors designed to improve understanding of the upper atmosphere. NASA plans to launch the Upper Atmosphere Research Satellite (UARS) in 1989.

Research on new sensors, and the use of these sensors to improve our understanding of the behavior of the atmosphere and the oceans, is an important part of the atmosphere-ocean remote sensing program. But a number of questions remain. The catalog of possibilities for new sensor development is large. Some very promising techniques, such as the use of microwave sensors that enable us to "see" through clouds, do not seem to be receiving the attention they merit.

Several fundamental questions can be raised about the national program. Is the level of effort devoted to new sensor development adequate? Is the choice of priorities appropriate? What should be the balance between the development of the next generation of operational sensors and the development of specialized sensors that are useful for research but have no forseeable impact on the operational program?

The following sections address these and other policy questions. There will be no attempt in this part to recite the history of atmosphere-ocean remote sensing or to review in detail ongoing research or operational programs. Rather, the discussion will emphasize specific topics or issues important to the future of the programs where the Board's comments may be useful to decision-makers.

THE VALUE OF ATMOSPHERE AND OCEAN OBSERVATIONS FROM SPACE

The level of funding that the government is willing to allocate to earth remote sensing is strongly related to the immediate or potential value of such observations. The Board's first finding (discussed in Part 2) addresses this issue by stating in part: "The earth remote sensing program has demonstrated that the timely acquisition of data from satellites can result in significant social, economic, and scientific benefits." This finding is valid for atmosphere and ocean observations as well as for broader earth remote sensing programs.

Understanding the physics and chemistry of the atmosphere and the oceans, and being able to accurately observe and predict their behavior, is a matter of major economic importance in today's complex world. Historically, man's major concern was to protect himself against a frequently hostile environment. Prediction of local, life-threatening conditions—intense precipitation, tornadoes, hurricanes, severe wave conditions, storm surges—was a major concern. Today, with improvement in understanding of the dynamics of the atmosphere-ocean system, we are equally concerned with larger scale phenomena such as regional droughts or anomalies like El Nino that can affect fisheries and cause global variations in climate for periods as long as a year.

The development of modern technology has, to a limited degree, reduced man's vulnerability to a hostile environment. But as technology has evolved, a new phenomenon has been observed: the vulnerability of an overstressed system of social activity to even modest environmental hazards. For example, the modern commercial aircraft, considered as an individual entity, is comparatively immune to usual weather changes, yet an overburdened air transportation system can be seriously disrupted by comparatively minor snow or fog conditions that close one or more major airports. The same kind of exposure exists for the effects of fog, rain, snow, or ice storms on municipal transportation; of drought, flood, or freezing weather on overstressed food or energy distribution systems; or of storm surges on highly developed coastal communities.

Today we are also concerned about man's effect on his environment. How will climate change as a result of the increase of carbon dioxide in the atmosphere resulting from the combustion of fossil fuels? How much will the acidity of precipitation be reduced by a contemplated program that limits sulfur emissions from industrial plants? Which regions will benefit most from the effort? How extensive and how debilitating to the biosphere are the effects of global (or local) pollution of the oceans? Major policy decisions involving the expenditure of substantial financial and human resources rest on the answers to these and similar questions.

Our society is concerned about the behavior of the atmosphere-ocean environment on all time and space scales, ranging from the local thunderstorm that lasts a few minutes and plays havoc at a local marina to a global rise in sea level associated with long-term climatic change, and from the flash flood that disrupts the life of a mountain community to the major drought that severely reduces food production over an entire continent. To provide information to help guide society in its daily work or in its long-term planning, accurate global observations must be made of the atmosphere and the oceans, and this cannot be done without an effective weather and ocean satellite monitoring system. As a result of its ability to provide more information, with higher accuracy, at lower costs, a sophisticated satellite system will inevitably be the centerpiece of the observing system of the future.

The stakes are high. It has been estimated that in an average year the economy of the United States loses about $20 billion in damages due to inclement weather alone.[1] This figure does not include the tremendous untapped benefits associated with improved industrial, agricultural, and public policy decision-making that would result from better understanding and improved predictions of the environment, nor does it include the intangible benefits to the public of better environmental information or the reduction in death and injury from more timely and accurate forecasts.

By way of comparison, the cost of the existing operational civil weather satellite program is about $250 million per year, but costs of satellite and sensor construction, launching, and operation have been growing rapidly. The maintenance and improvement of the atmosphere-ocean satellite system (including the provision of adequate oceanic data) must be accompanied by a careful review of the total earth viewing program, to increase efficiency and eliminate unnecessary costs. Expenditures can be moderated in a variety of ways; several of these are discussed in following sections.

Another factor must be considered. The technology to develop and improve earth-viewing satellites has, until now, been primarily created in the United States. This is equally true of land remote sensing and of atmosphere-ocean remote sensing systems. As noted elsewhere in this report, the land remote sensing program in this country has stalled, at least temporarily. Sensor technology developed by U.S. research but never used on U.S. spacecraft will probably be deployed first on satellites launched by other countries. The Board believes that if this experience is repeated in atmosphere and ocean remote sensing, the economic and political leadership of the United States will have suffered an unfortunate and unnecessary setback.

The immediate and potential value of atmosphere and ocean sensing is clear. The Board believes that an expanded program of operations and research is in the national interest and should be mounted as an established part of the space program.

[1] The National STORM Program. University Corporation for Atmospheric Research, 1983, p. 26.

INTRAGOVERNMENT INSTITUTIONAL ISSUES

What are the prospects for more rapid improvement of our atmosphere and ocean remote sensing capability? As noted previously (see Finding III, in Part 2 of this report), the difficulties are not technical. Problem areas center on institutional and policy issues. The most vexing of the institutional questions are intragovernmental.

The Roles of NASA and NOAA

For more than 2 decades the cooperation between NASA and NOAA in earth remote sensing was exemplary. This cooperation was based on an interagency agreement developed during the early days of the weather satellite program. As noted in Part 2, NASA and NOAA worked together under the agreement to establish the requirements for new sensor development. NOAA, as the agency responsible for the operational program, took the lead in setting observational requirements. NASA, as the agency with the premier engineering capability, moderated the priorities by analyzing the technical feasibility of needed instrumentation. When a technical objective was established, NASA provided funds in its budget to develop the new sensor and procure a prototype. Subsequent sensors, beyond the prototype, were funded by NOAA.

A similar cooperation existed with regard to spacecraft. When the need for a new series of satellites was established, NASA funded the development of the first satellite, launched it, and turned it over to NOAA for operation. NOAA funded subsequent spacecraft in the series. The two agencies were partners in fashioning the operational satellite program.

In 1981 NASA ceased to support R&D for the operational weather satellite system. There may have been many reasons for this change. The support of the operational program required NASA resources that could have been used in other activities. Probably, as the NOAA satellite effort grew and its managers became more experienced, the feeling developed within NASA that NOAA should budget for the entire cost of the operational program. After all, NASA could continue to provide engineering support as necessary, if NOAA would transfer the necessary funds to support the effort.

It is possible that the new relationship between the two agencies would have worked, except for two developments. First, NOAA found itself unable to win resources from the Department of Commerce and the Office of Management and Budget to fully fund the required engineering support program. And second, NASA, once it decided to abandon the direct operational support role, tended to concentrate on fundamentally oriented space research that had only a delayed relevance to immediate operational needs.

Today there is an unfortunate gap in the national program. Neither agency is actively and effectively developing the next generation of operational sensors or satellites—NOAA because it is short of both money and engineering talent, and NASA because it has chosen a different set of priorities.

The problem seems to be financial: to identify within the federal budget the funds necessary to provide engineering support for the operational program. In reality, the problem may be a more fundamental one that has plagued managers in many different organizations: how to develop and maintain an appropriate level of cooperation between operations and research in an organization with both responsibilities (in this case the federal government).

NOAA is an operational organization, stimulated by practical requirements. NASA prides itself on its R&D capability and is stimulated by a scientific or engineering challenge. In earth remote sensing, the two organizations, whatever their level of funding, will tend to drift apart unless there is some overlap in their talents and responsibilities.

The Board believes that an appropriate level of cooperation should and can be structured, to the mutual benefit of both agencies. The sharp distinction between operational and research satellites has become blurred in recent years. To cite two examples, experimental VAS sensors developed by NASA were first flown on a NOAA operational satellite in 1981, and, as a part of the Earth Radiation Budget Experiment (ERBE), NASA experimental sensors were launched by NOAA on an operational satellite in 1985. The Board has recommended that this kind of multiple use of spacecraft and downlinks be increased (see Finding X and its related Recommendations in Part 2). If this happens, the operational and research programs will become more interdependent (as they should be), and a structured, positive cooperation will become easier to achieve.

Many different forms of the relationship could be developed. The Board favors one that will keep the major costs for the operational programs within NOAA but will directly involve NASA in the operational program in a manner consistent with its R&D orientation.

Both of these objectives could be achieved if a new interagency agreement could be drawn up that would require NOAA to fund all operational systems except the development of new operational sensor prototypes—an area in which NASA has shown creativity in the past. NASA, in consultation with NOAA, would fund the program to develop new sensors for atmosphere and ocean measurement. NASA would provide other engineering support only if there were an appropriate and mutually agreed-upon interagency transfer of resources.

If such a program of cooperation could be established, together with multiagency use of both NOAA operational satellites and NASA earth-orbiting space platforms (as recommended by the Board), there would probably be sufficient interaction between the operational and research programs to reestablish and maintain an appropriate level of cooperation in earth remote sensing between these two key civil agencies.

The Roles of NOAA and DOD

A second intragovernment problem concerns the relation between the civil (NOAA) polar orbiting satellite system and the Defense Meteorological Satellite Program (DOD). The question has repeatedly been raised whether these two systems are redundant and whether cost savings could be achieved without compromising the legitimate requirements of either the civil or the defense communities.

The Board does not propose to examine this issue. It was extensively investigated on two different occasions (more than a decade apart) by two different administrations. In each instance, the conclusion reached was that there was a legitimate need for both systems. The Board is willing to accept this conclusion.

The assumption that parallel civil and military polar orbiting systems will continue to exist does not eliminate the need to compare these two systems and to see if constructive changes can be made. At present the systems do not provide adequate back-up for each other. For example, the atmospheric sounding sensors on the DMSP satellites are unsuitable as an emergency back-up for the civil system, should unexpected launch or instrument failures occur. Similar deficiencies may exist in the civil system with respect to meeting military needs.

The Board believes that the NOAA and DOD polar orbiting programs should be carefully reevaluated to determine whether (with proper attention to the system design) the two systems could become more satisfactory as emergency back-ups for each other. The additional cost should be small; the additional assurance of observational continuity should be beneficial to both communities.

Defense plans for the Navy Remote Ocean Sensing Satellite (NROSS) will raise new questions about possible redundancy between civil and military programs, especially if DOD moves to establish NROSS as a full-fledged operational program. Oceanographic remote sensing is at too early a stage to resolve these questions now. It is perhaps sufficient to note that (as is the case in meteorology) the civil and the military communities each have legitimate needs for remotely sensed ocean observations, that these needs are not fully congruent, and that each community would benefit by the existence of an emergency back-up. As the civil and military oceanographic observing systems evolve, care must be taken to assure complementarity and emergency back-up while avoiding unnecessary redundancies.

FINDING XVII. Four federal agencies are involved in atmospheric and oceanic remote sensing: NOAA and NASA in the civil sector and the Air Force and the Navy in the Department of Defense. Agency parochialism has introduced unnecessary inefficiencies into the total effort.

Recommendation: NASA, in consultation with NOAA, should fund a basic program to develop and demonstrate new research and operational sensors for atmosphere and ocean measurement, and NASA and NOAA should cooperate to ensure the transfer of new technology to operations. As part of a federal plan for earth remote sensing, NOAA should provide space for NASA R&D sensors on its operational spacecraft; NASA should provide space for NOAA operational sensors on the Space Platforms planned as part of the space station program.

Recommendation: NOAA and DOD, while maintaining separate civil and military operational satellite systems, should consult and cooperate more closely in the design and management of their space- and ground-based systems. Such steps could provide assurance that, if one system fails, the other could be used as a temporary back-up to fulfill minimum mission requirements.

GOVERNMENT AND THE PRIVATE SECTOR

Other institutional issues affect the atmosphere-ocean remote sensing program. These involve government and various parts of the private sector.

The research community, especially within the universities, has a major stake in the atmosphere-ocean remote sensing program. It is essential that there be a high degree of interaction between the academic community, NOAA, and NASA.

The usefulness of remotely sensed atmosphere and ocean information increases primarily as a result of research undertaken at universities. NASA and NOAA must sponsor research to interpret the collected data (in the case of an experimental system) or to improve the ability to interpret and use the observations (in the case of an operational system). Earth remote sensing is still in its infancy. Progress requires adequate facilities, support for imaginative research, and a healthy program of graduate-level instruction to train the leaders of tomorrow. The timely flow to research institutions of observations from both R&D and operational satellites must be assured to stimulate and facilitate creative research.

It has already been noted that progress in the atmospheric and ocean sciences depends to an ever-increasing degree on satellite information. Operational satellite observing systems are important not only for weather forecasting; they are equally needed to better understand the physics of the atmosphere. Therefore, it is essential that the observational needs and priorities of research scientists be taken into account when changes in the operational observing systems are being planned, as well as when priorities for space research and development are being decided.

NOAA, as an operational agency responsible for weather and ocean services, has been deficient in building a strong relationship with the research community. NASA has been substantially better in this regard, but there is room for improvement.

FINDING XVIII. Federal agencies, especially NOAA, do not sufficiently interact with the academic community in carrying out their atmospheric and oceanic remote sensing programs.

Recommendation: Programs to support academic research facilities, student training, and scientist visits and exchanges should be increased. The timely flow to research institutions of data from both operational and R&D satellites should be assured.

Recommendation: Research scientists at the universities and in government should be consulted with regard to the design of (and plans to improve) operational satellite systems. These systems provide information necessary to advance basic science.

The commercial sector is another part of the national economy with a direct interest in the information obtained from atmosphere-ocean remote sensing. A growing community of private and consulting weather and ocean service companies uses remotely sensed observations in preparing specialized information for clients. The level of use of such satellite-derived information is growing in volume and sophistication. As an example, one commercial company now receives data directly from NOAA geostationary weather satellites, processes the data stream, and markets pictures and film-loops of weather systems to television stations all over the United States.

As industry, agriculture, and local government learn how to use weather and ocean information more effectively, the demand will steadily rise for weather forecasts and displays based (at least in part) on remotely sensed information from polar orbiting and geostationary satellites. This process can be accelerated by the effective marketing of such information by weather and ocean service companies. NOAA has been helpful in encouraging commercial use of satellite data streams. This should continue to be the policy of the federal government.

FINDING XIX. The commercial sector has made only limited direct use of atmosphere and ocean remote sensing observations. The value of this information to the nation could be considerably enhanced through the efforts of the private sector.

Recommendation: Further development of a value-added industry that uses (or enhances) and markets remotely sensed data should be encouraged. A necessary requirement is a federal commitment to the continuity and timely dissemination of satellite observations.

SOME POLICY CONSIDERATIONS

Organizational problems have been cited as contributing to the present lack of vigor in the civil atmosphere-ocean remote sensing program. But the difficulties extend deeper than this. Some of the problems relate to policy issues that are complex and vexing.

One such policy issue is the definition of the boundaries of federal responsibility. How deeply should the United States government be involved in the "business" of taking atmosphere and ocean observations and of preparing and disseminating weather and ocean information and forecasts? Almost everyone would agree that the federal government has some responsibilities in this arena, as a result of the impact of the physical environment on public safety and health. But how far do government responsibilities extend, and to what degree can some functions be taken over by the private sector?

This is far too complex an issue to be adequately discussed in the present report. But it is evident to the Board that differing views on this policy question cause some of the problems faced by atmosphere-ocean remote sensing. The contrast with other parts of the space program is notable. If programs such as space astronomy and planetary exploration are to exist, government must fund them. Clearly, no other institution is interested enough and has sufficient resources to take on the task. But what about programs that improve the ability to describe the behavior of the atmosphere and the oceans? Information derived from these programs is extremely valuable, not only to government but also to industry and agriculture. To what extent should the private sector help pay for these efforts?

This question was partially addressed by the Land Remote Sensing Commercialization Act of 1984, now Public Law 98-365 (see Appendix D), which prohibits federal sale of operational weather satellites. The Board accepts this decision and has recommended that the federally managed atmospheric remote sensing program be extended to include ocean remote sensing.

The United States needs a strong operational atmosphere-ocean remote sensing system and should move vigorously to implement such a program within the constraints imposed by PL 98-365. This country cannot afford to allow differences in social philosophy and public policy to delay constructive action indefinitely.

When the space station and its associated Space Platforms are in orbit during the coming decade, operational (as well as research) atmosphere and ocean remote sensors should be using these new platforms.

Acronyms

AGRISTARS	Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing
CCCT	Cabinet Council on Commerce and Trade
COPARSS	Committee on Practical Applications of Remote Sensing From Space
CZCS	Coastal Zone Color Scanner
DMSP	Defense Meteorological Satellite Program
DOC	Department of Commerce
DOD	Department of Defense
DOI	Department of the Interior
EOSAT	Earth Observation Satellite Company
EPA	Environmental Protection Agency
ERBE	Earth Radiation Budget Experiment
EROS	Earth Resources Observation Satellite
ERTS	Earth Resources Technology Satellite
FCC	Federal Communications Commission
GIS	Geographic Information Systems
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
HRIS	High Resolution Infrared Sounder
JPL	Jet Propulsion Laboratory
LACIE	Large Area Crop Inventory Experiment
LFC	Large-Format Camera
Landsat	Land Remote Sensing Satellite
MAGSAT	Earth's Magnetic Field Satellite
MLA	Multilinear Array
MOS-1	Marine Observation Satellite 1
MRSE	Microwave Remote Sensing Experiment
MSS	Multispectral Scanner
MSU	Microwave Sounding Unit
NASA	National Aeronautics and Space Administration
NASDA	National Space Agency of Japan
NESDIS	National Environmental Satellite, Data, and Information Service
NOAA	National Oceanic and Atmospheric Administration

NROSS	Navy Remote Ocean Sensing Satellite
NSF	National Science Foundation
OMB	Office of Management and Budget
RBV	Return Beam Vidicon
RFP	Request for Proposals
SAB	Space Applications Board
SAR	Synthetic Aperture Radar
SEB	Source Evaluation Board
SIR-A, B	Shuttle Imaging Radar-A, B
SPOT	Systeme Probatoire d'Observation de la Terre
SRS	Statistical Reporting Service
TIROS	Television Infrared Observation Satellite
TM	Thematic Mapper
TMS	Thematic Mapper Simulator
TOPEX	The Ocean Topography Experiment
UARS	Upper Atmosphere Research Satellite
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VAS	VISSR Atmospheric Sounder
VHRR	Very High Resolution Radiometer
VISSR	Visible and Infrared Spin-Scan Radiometer

APPENDIX A

Charge to the Committee on Practical Applications of Remote Sensing From Space

It shall be the Committee's objective to recommend to the Space Applications Board strategies for NASA and NOAA activities related to remote sensing of the earth (land, oceans, and atmosphere) from space, designed to assure that the needs of practical users of remotely sensed data are adequately reflected from the beginning in planning of research and/or development programs for remote sensing from space.

To implement the objectives stated above, the Space Applications Board has requested the Committee to prepare a report that

1. Recommends what the objectives should be of the civilian program in remote sensing of the land, the oceans, and the atmosphere.
2. Gives examples of the benefits that have been and may be derived from remote sensing.
3. Describes the existing situation in civil remote sensing in the United States.
4. Presents strategy for improving the future outlook for U.S. remote sensing of the land, the oceans, and the atmosphere.
5. Draws conclusions and makes recommendations derived from items 1,2,3, and 4 above.

APPENDIX B

Examples of Benefits of Land Remote Sensing

In this Appendix we present seven examples in which land remote sensing images or data have been used beneficially, i.e., to enhance the return on an investment, to reduce the cost of a survey, or to achieve a result not otherwise attainable. The examples are drawn from the fields of agriculture, mineral exploration, engineering planning, cartography, geodesy, and geologic mapping. These are only a few of the many fields of endeavor that could and do benefit from the use of Landsat data. These examples are presented to give the reader some insight as to how remotely sensed data are used in several widely different applications.

POTATO GROWERS USE LANDSAT[1]

The Columbia Basin, located in central Washington and north central Oregon, contains from 500,000 to 700,000 irrigated acres and is the location of a significant portion of the nation's potato industry. In recent years the region has cultivated from 120,000 to 140,000 acres of farmland with potatoes for the fresh and processing markets.

Potatoes are a high-risk, high-reward crop that demands close attention to the many details of growing and marketing. Potato growers know the value of accurate information regarding their own fields for production management and for timely information regarding the regional, state, and national crop for marketing decisions.

There are many sources of information and predictions regarding acreage, production, and quality. A common reference point is the series of USDA reports, but in addition there are statistics developed by market analysts and grower organizations. Potato processors also conduct detailed field surveys early in the

[1] Lamb, Frank G., President, Eastern Oregon Farming Company, Irrigon, Oregon, private communication, February 10, 1985.

season. By midsummer there are several sets of acreage predictions available, and they invariably indicate differences large enough to be significant in the market. At the same time weather, irrigation, and fertility problems as well as disease and insects begin adversely affecting some of the fields. There are many reports and rumors of these occurrences and much speculation about their extent and the implications on overall crop performance and market prices. These events occur at a time when growers and processors are fully occupied and are unable to repeat the extensive ground surveys that would be necessary to document the severity and extent of the problems.

Potato markets change significantly with relatively minor changes in production. The volatility is often increased as a result of inadequate or inaccurate information regarding crop acreage and condition. Price swings can go in either direction, and both processors and growers would benefit if the severity of price variations could be reduced by the availability of more timely and accurate information regarding the size and condition of the crop.

One potato farmer has responded to this situation by establishing a microcomputer-based image processing facility in the basement of his home. He is utilizing data from repetitive passes of Landsat to monitor the development and condition of the Columbia Basin potato crop and has contracted with a potato processor and a group of potato growers to provide them with regional information for the 1985 growing season.

Figure B-1 is an example of the analysis performed on one small portion of the region. Similar analyses can be performed over the entire Columbia Basin and summarized statistically to provide crop information. This procedure is more efficient than the alternative of extensive ground surveys.

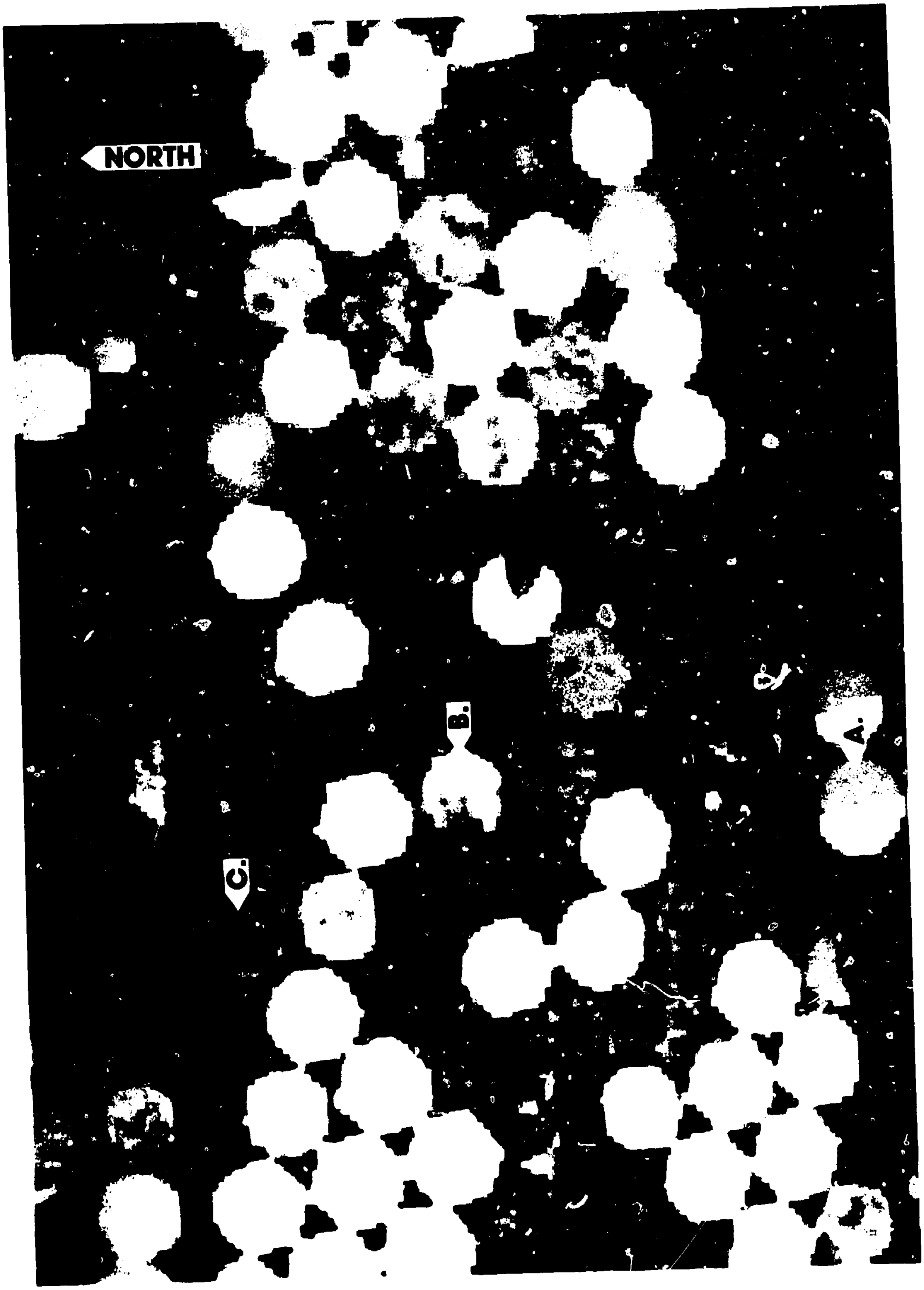
The area shown is approximately 8 × 13 km. The circular fields are approximately 800 meters in diameter and contain approximately 52 hectares (128 acres). Digital values for the near-infrared (MSS band 7) reflectance were divided by those for the red (MSS band 5) reflectance to allow display of data from two bands for each acquisition and to enhance variations in vegetation vigor. June 3, 1984, data are coded blue, June 27 are green, and July 5 are red.

Wheat and barley appear blue because they were healthy in early June but had little green foliage as maturity approached in late June and early July. Potatoes generally appear yellow (red + green); there was little vegetation in early June, but by late June and early July they were growing strongly. Variation in the color of the potato fields indicates differences in stage of growth or stress from a wide variety of causes. Corn appears dull orange or red because it was the slowest crop to develop. Alfalfa displays a wide variety of colors because of the many different stages of growth on each date as a result of the patterns of harvest and regrowth.

These particular features are to be noted in Figure B-1:

A. A field of potatoes with the east side showing stress in early July because the foliage is being dried out to mature the tubers for harvest.

FIGURE B-1 Multitemporal image of the center pivot irrigated farmland located in north central Oregon. ▶


NORTH
A.
B.
C.

B. Early-season potatoes with the west side of the fields being dried out for harvest.

C. A corn field, the center of which had not developed at the same rate as the balance of the field. The pattern of nonuniformity indicates that the problem is likely due to a series of plugged sprinklers at the center of the sprinkler system.

SATELLITE DATA ENHANCE CROP PRODUCTION ESTIMATES[2]

The U.S. Department of Agriculture (USDA) is responsible for preparing a series of forecasts of crop production. The traditional approach is to develop acreage estimates based on extensive samples taken by ground survey. These acreage estimates are then combined with estimates of yield to determine anticipated production. Periodic updates of weather conditions, insect and disease infestations, and other factors affecting production provide the basis for revisions in the prediction as the crop season progresses.

Early attempts at replacing this traditional approach with one based on using data from Landsat met with failure. The new technology was unproved and represented a radical departure from established practice. In recent years, however, experience has shown that crop production estimates are enhanced by combining the traditional approach with information obtained from satellite observations.

For the 1983 crop year, acreage estimates of major crops from seven states were calculated by combining Landsat-4 MSS data with ground data. The seven states were Arkansas, Colorado, Illinois, Iowa, Kansas, Missouri, and Oklahoma. Crops included were winter wheat, corn, soybeans, rice, and cotton. The ground data consisted of information on crop field acreages obtained from the USDA/SRS (Statistical Reporting Service) June Enumerative Survey (JES). The estimates that used both Landsat and JES data averaged about twice as efficient as those based on the JES data alone. SRS has reduced the project cost per state associated with using Landsat data from $305,000 in 1978 to $120,000 in 1983.

Acreage estimates are combined with predictions of yield made by crop growth models to obtain estimates of production by area. The traditional method is to obtain information required for input into the crop models from observations made by a series of weather stations. This information is limited because it is based on point observations. Satellite systems provide an improvement in accuracy because of their ability to average observations over large areas. Meteorological quantities that are needed for crop models and that can be produced from satellite data include estimates of precipitation, daily temperature extremes, canopy temperatures, insolation, snow cover, and vegetation indices.

The combination of data from traditional ground observations with those from Landsat and weather satellites is providing the USDA with the ability to efficiently provide more accurate crop production estimates.

[2] AGRISTARS Annual Report, Fiscal Year 1983, JSC-18920, National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, June 1984.

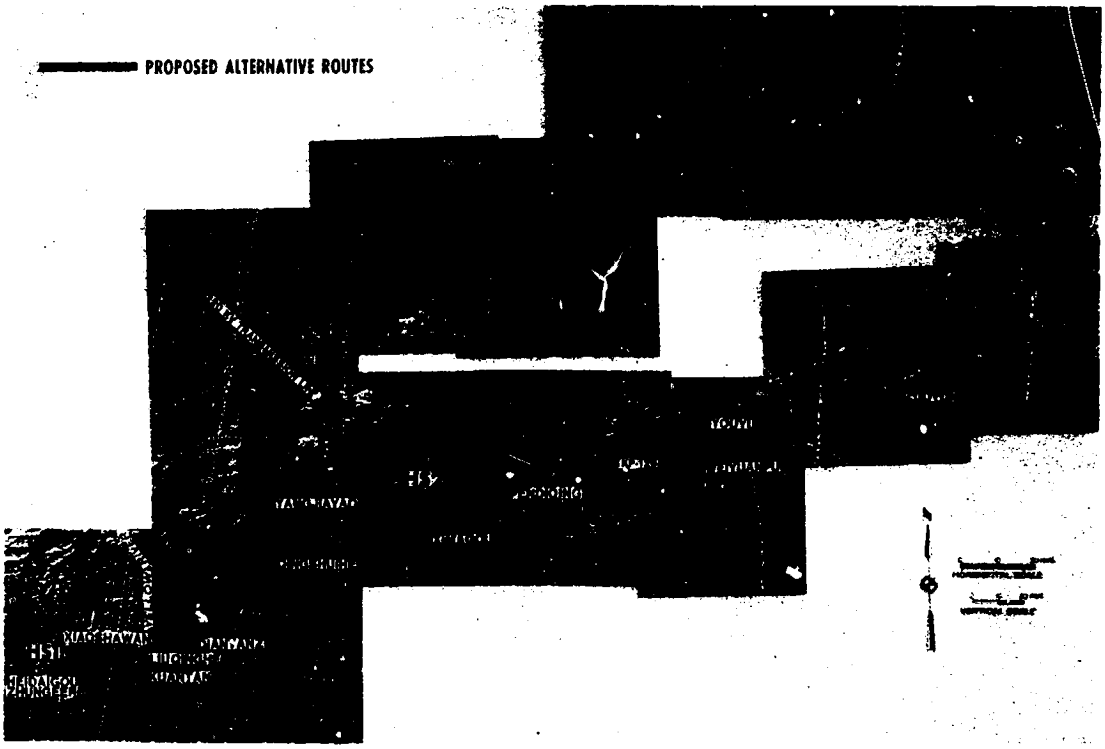


FIGURE B-2 Zhungeer coal slurry pipeline. Alternative routes are indicated by the heavy black line.

COAL SLURRY PIPELINE IN CHINA[3]

Space-derived, remotely sensed imagery offers a valuable new tool in siting pipelines, transmission lines, roads, and other structures that traverse inadequately mapped territories. For example, an engineering study for a new 800-km pipeline in the Peoples Republic of China was made recently using Landsat imagery. The information obtained from this study provided preliminary planning for route selection by an American company preparing to bid on the construction of the pipeline in China.

The information, obtained from digitally enhanced Landsat imagery, included general topography, land use, general geology, geologic hazards, methods of excavation, dewatering estimates, and subsidence potential. A preliminary evaluation of all of these factors was prepared on the basis of digital image processing of Landsat data. Traditional methods for obtaining preliminary engineering data require topographic map coverage of the route, aerial photographs, and geologic maps, but these data were not available. Field studies to obtain them would have required 6 months of delay and increased the total engineering study cost by a factor of two.

Figure B-2 is a composite of five MSS images of northern China; alternative routes for the pipeline are indicated by the heavy black lines.

[3] McClure, Cole R., Bechtel Corporation, private communication, July 24, 1984.

LANDSAT AIDS OIL DISCOVERY IN MICHIGAN[4]

Exploration for oil and gas in the Michigan Basin is difficult. Up to 200 m of relatively young glacial till mask the geological structures that lie underneath. Even the collection of seismic data, designed to yield information about subsurface structures, is difficult in glacial till, which absorbs much of the energy that is reflected back to the surface by rock strata beneath. Structural mapping with Landsat MSS imagery overcame the problems presented by glacial till in a cost-effective manner.

In 1975 a geological exploration company performed a Landsat study of an area in Bay County, Michigan. This study began with the mapping of a long linear feature from two different types of computer-enhanced images. The linear feature was suspected of being a fault that followed a northeast-southwest trend from the southeastern corner of Saginaw Bay. Examination of other linear features and drainage patterns interpreted from the Landsat images, and a study of the few well logs available near the previously unexplored area, led to a hypothesis that the suspected fault marked the edge of large down-dropped blocks (graben) that probably was the controlling factor in the origin of Saginaw Bay. This block was suspected of dipping toward the northeast, i.e., toward the bay.

The company tried to sell the Saginaw Bay study to petroleum companies but was unsuccessful because the companies then involved with petroleum exploration in Michigan were unfamiliar with and skeptical of satellite data. In 1977 a few individuals agreed to obtain oil and gas leases on both sides of the hypothesized graben. One year later they reached an agreement with an independent oil company to perform seismic evaluation and drilling.

Twenty-five line miles of seismic data were collected in the vicinity of the suspected fault at a cost to the oil company of approximately $125,000. (By comparison, the Landsat study had cost $25,000). Figure B-3 is a structural contour map interpreted from seismic data on the top of the Devonian-aged Dundee Formation. It shows seismic confirmation of the fault mapped from Landsat data indicated as a dashed line. Figure B-4 shows three-dimensional contour maps of the seismic return times from the tops of the Dundee Formation and a Cambrian-aged stratum. These figures give evidence that the Cambrian rock strata dip toward the northeast, which supports the interpretation of a graben structure dipping toward the northeast. Drilling at the point designated "2" in Figure B-4 led to discovery of a new oil field, expected to result in 90 to 100 producing wells. Without the Landsat study, it is likely that more than 150 line-miles of seismic data at a cost of about $750,000 would have been required to come to the same interpretation using seismic data alone.

[4] Vincent, R. K., and D. H. Coupland. Petroleum exploration with LANDSAT in Bay County, Michigan: An interim case study. Pp. 379-387 in Proceedings of the 14th International Symposium on Remote Sensing of Environment, April 23-30, 1980.

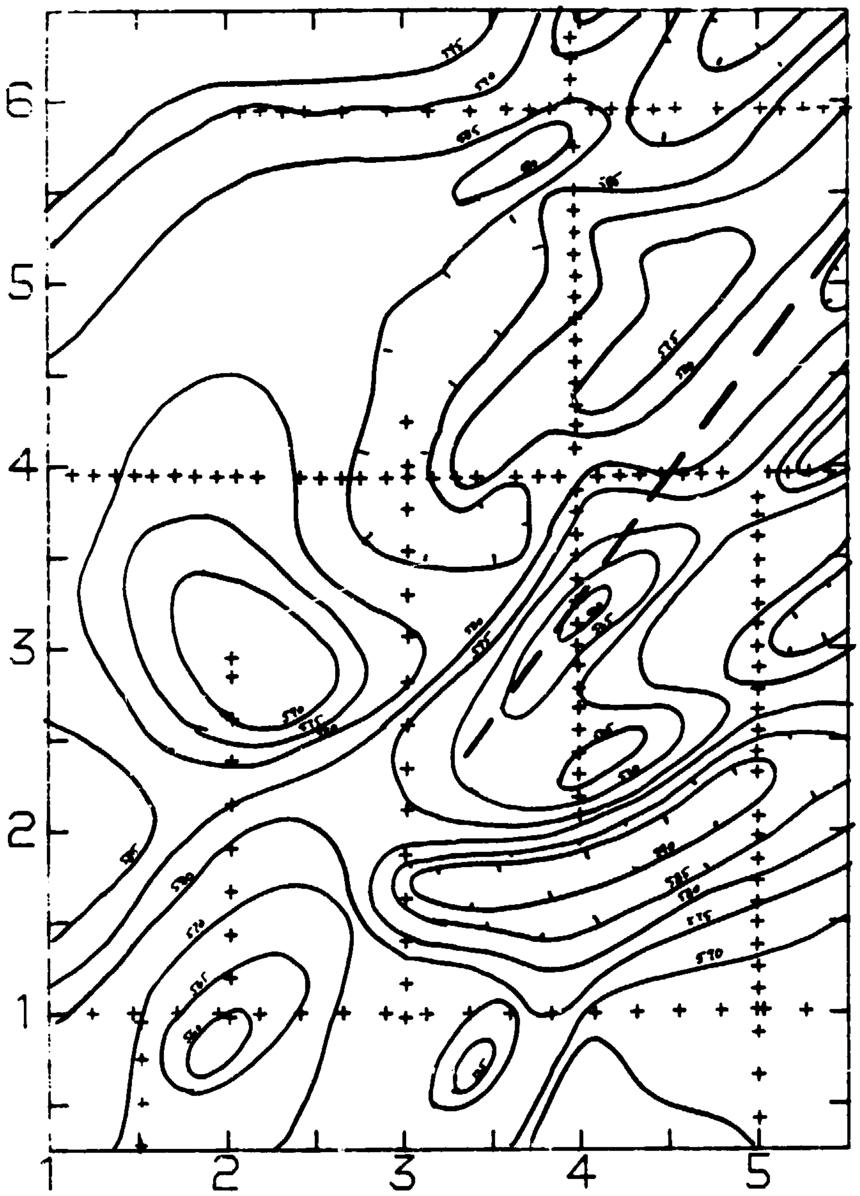
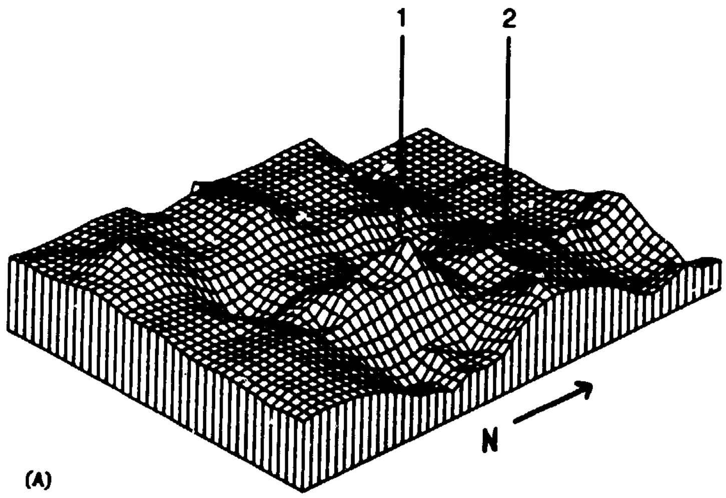
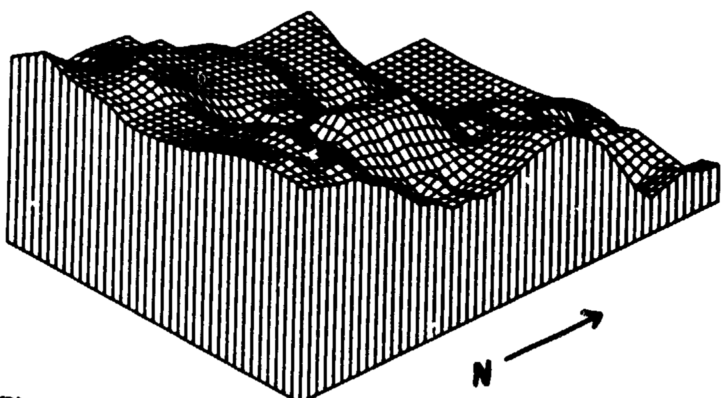


FIGURE B-3 Structural contour map interpreted from seismic data on the top of the Devonian-aged Dundee Formation.



(A)



(B)

Figure B-4 Three-dimensional contour maps of the seismic return times from the tops of the Dundee Formation and a Cambrian-aged stratum.

LAND COVER MAPS FOR SEISMIC SURVEY LINES IN SUDAN[5]

An international oil company was examining a large exploration concession in the Sudan. The limited coverage and poor quality of existing topographic maps of the area prompted the company to construct drainage maps using digitally enhanced Landsat imagery at the beginning of the project in 1975. In addition, comprehensive geological, soil, and vegetation maps had been constructed, chiefly from aerial photographs. These maps were used for planning seismic data collection activities, and they proved adequate for several years.

However, as the program extended into the heart of the Sudd Swamp, it became apparent that more terrain detail was required. A manual interpretation of digitally enhanced, false-color Landsat images resulted in a map showing varying wetness conditions of the area. In addition to the 1:250,000-scale color-composite images, 1:100,000-scale enlargements were used in the base office as well as in the field for planning and navigation.

Swamp buggies—specially designed vehicles for use in marsh or swamp areas—were used to transport recording equipment and personnel in the seismic survey. As the survey operations progressed deeper into the swamp, tall and massive stands of papyrus and bullrush began to slow the operation drastically. These reed stands, ranging from 6 to 12 ft high, became entangled in the drive mechanisms and filled the gear boxes of the swamp buggies. Frequent breakdowns resulted, and much time was lost in cleaning out and repairing the drive trains.

More reliable advance knowledge of vegetative types and patterns was needed to avoid the largest stands of the troublesome reeds. New computer-compatible tapes of Landsat images were acquired. Computer classification techniques were used to develop categories of ground cover, such as water hyacinth, bullrush, wet bullrush, dry grass, wet grass, and natural levee. Maps were then produced showing the various categories in different colors.

The vegetation classification proved to be of great value. In the field it was used as a navigational aid in both airborne and tracked-vehicle scouting missions. In the field office it was used to great advantage for designing seismic lines to avoid the worst problem areas. After these maps were introduced, swamp buggy downtime was reduced to near zero, and progress on the survey improved dramatically. The maps were used ultimately to aid in planning well sites and access routes. A major oil discovery on this concession was reported in 1983.

The use of digital Landsat imagery to support oil exploration in difficult areas is becoming more common, especially in less developed countries. Present exploration activities use techniques similar to those described here, but modified for particular areas and problems.

GEOLOGIC MAPPING OF INDONESIA WITH RADAR IMAGERY[6]

Geologic maps of Irian Jaya, Indonesia, were compiled in the early 1960s by field reconnaissance with the aid of available aerial photos. However, because

[5] Vandenakker, J., and J. Ryan. Landsat application for geophysical field operations. Pp. 71-74 in Proceedings of the International Symposium on Remote Sensing of Environment, Second Thematic Conference: Remote Sensing for Exploration Geology, Fort Worth, Texas, December 6-10, 1982, Vol. 1.

[6] Sabins, F. F. Geologic interpretation of space shuttle radar images of Indonesia. American Association of Petroleum Geologists Bulletin, Vol. 67, No. 11, 1983, pp. 2076-2099.

of the persistent cloud cover in the region, air photos were incomplete, and many parts of the area could not be mapped. Better geologic maps were required for petroleum and minerals exploration. Although the all-weather capability of airborne radar imaging systems had been used in other parts of the region to extract geologic data, the cost of airborne radar data acquisition is very high, and a more cost-effective method was sought.

The NASA space shuttle mission in November 1981 acquired images of parts of Irian Jaya, Indonesia, with a synthetic aperture radar system called SIR-A. The imagery has a resolution of 38 m (125 ft) and a swath width of 50 km (31 miles). Both lithologic and structural information were interpreted from 1:250,000-scale SIR-A images.

Despite dense vegetation cover, six major terrain types could be identified. These correspond to carbonate rocks, clastic rocks, volcanic rocks, metamorphic rocks, melange complexes, and alluvial deposits. Geologic structure is recognizable at two different scales. These include major tectonic elements such as fold belts, basins, and uplifts at a regional scale and individual faults and folds on a more local scale.

The application showed that radar images acquired by the space shuttle can readily be used for geologic interpretation of persistently cloud-covered regions, even in the presence of dense vegetation. The acquisition of radar imagery by satellite or shuttle eliminates the operational and economic difficulties often encountered in airborne radar surveys.

LANDSAT AIDS CARTOGRAPHY, MAPPING, AND GEODESY

The United Nations reported recently that only about 42 percent of the earth's land area (other than Antarctica) has been developed.[7] In many less-developed countries, neither topographic nor planimetric mapping is adequate. According to the United Nations,[8] these mapping needs at medium to large scale are not being met by conventional mapping techniques. In particular, lack of funds and rugged terrain limit the conversion of aircraft images to usable maps.

Satellites have yet to collect data of sufficient resolution to allow precise mapping in undeveloped regions. Adequate topographic contours of unmapped regions cannot be provided without stereoscopic viewing with high positional fidelity[9,10,11] and such systems have not as yet been flown except for the large-format camera. The LFC has produced significant coverage suitable for stereo-

[7] International Society for Photogrammetry and Remote Sensing, Working Group IV/3, Committee for "Acquisition and Processing of Space Data for Mapping Purposes," June 1984, p. 2.

[8] World Cartography, Vol. 17, p. 3, 1983.

[9] Colvocoresses, Alden P. An automated mapping satellite system (Mapsat). Photogrammetric Engineering and Remote Sensing, Vol. 48, No. 10, October 1982, pp. 1585-1591.

[10] Welch, Roy. Map accuracy requirements: The cartographic potential of satellite image data. Proceedings of the NASA Workshop on Registration and Rectification, Jet Propulsion Laboratory Publication 82-83, 1982, pp. 215-223.

[11] Welch, Roy, and W. Marko. Cartographic potential of a spacecraft line-array camera system: Stereosat. Photogrammetric Engineering and Remote Sensing, Vol. 47, No. 8, 1981, pp. 1173-1185.

scopic use. Depth contours, or bathymetry, of shallow seas have been determined in several areas by mapping satellites.

Although the accurate measurement of the dimensions of the earth for mapping reference systems has undergone major advances using earlier satellite systems, satellite geodesy is still needed to establish ground-control points in inadequately surveyed regions of the world. In the past, thematic mapping, concentrating on land use, has been very expensive when prepared from conventional sources, but it is necessary on a renewable basis for land development and information on the distribution of food and housing. With Landsat imagery, the cost of each new land use map has been greatly reduced.[12] The need continues for more geologic mapping to establish lineaments and mineral districts, and remote sensing from space has accelerated this work.

During the period that Landsat has been operating, scores of image maps (as opposed to image scenes), formatted to match the scale and coverage of published topographic maps, have been prepared and published, for cities ranging in topography and population from Wenatchee, Washington, to Washington, D.C., and for nations ranging from Nepal to the United States.

An example of how a satellite image can serve as a cartographic product is shown in Figures B-5 and B-6. A 1:100,000-scale map served as a reference, and the Landsat-4 TM subimage was processed to have the same scale and cartographic projection. The processed image is a current representation of the San Francisco area, and can be used to update and correct the map.[13]

The improved resolution of the thematic mapper (of Landsats 4 and 5) over the earlier Landsat multispectral scanners has made a marked change in product quality. With SPOT's still higher resolution beginning in 1985, mapping from space will more nearly approach aerial-photographic quality, but the United States may be on the sidelines of this technological advancement.

Landsat imagery has been used to chart reefs, shallow seas, and changes in marine shipping channels for oil tankers.[14] Pollution from oil slicks, thermal changes, and other types of pollutants have been tracked and mapped. Both temporal and permanent updating of coastal and navigational charts result.

[12] Short, Nicholas M., Paul D. Lowman, Jr., Stanley C. Freden, and William A. Finch, Jr. Mission to Earth: Landsat Views the World. Washington, D.C.: National Aeronautics and Space Administration, 1976, pp. 7-11.

[13] Bernstein, R., J. B. Lotspiech, H. J. Myers, and H. G. Kolsky. Analysis and processing of Landsat-4 sensor data using advanced image processing techniques and technologies. IEEE Trans. Geosci. Remote Sensing, Vol. GE-22, No. 3. May 1984, pp. 192-221.

[14] Mack, Pamela E. The Politics of Technological Change: A History of Landsat. Doctoral dissertation, University of Pennsylvania, 1983.

Overleaf:

FIGURE B-5 San Francisco area thematic mapper scene ID E-40168-18143, December 31, 1982 (corrected and enlarged image).

FIGURE B-6 San Francisco area thematic mapper scene ID E-40168-18143, December 31, 1982 (enlarged image with map overlay).

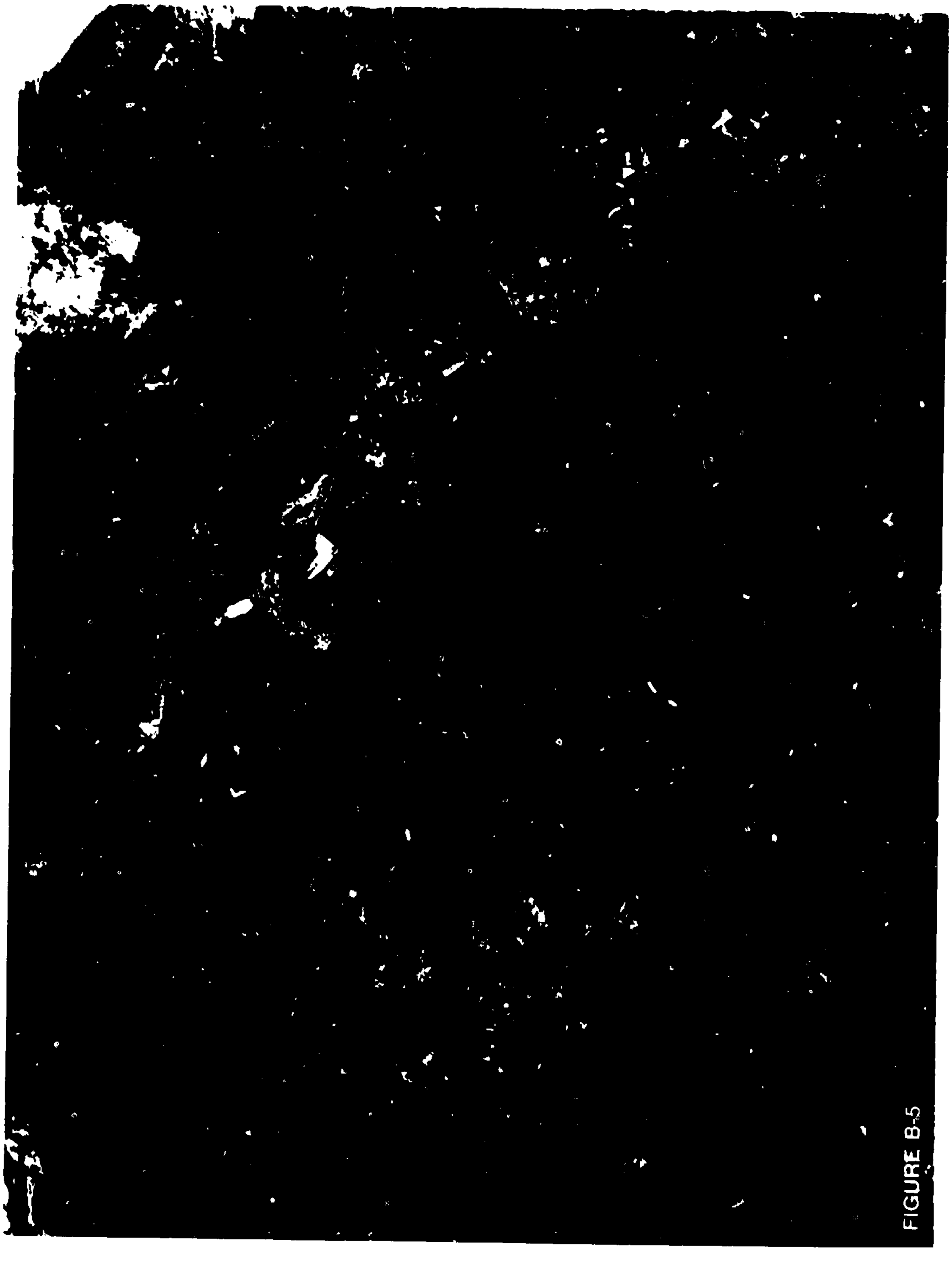


FIGURE B-5

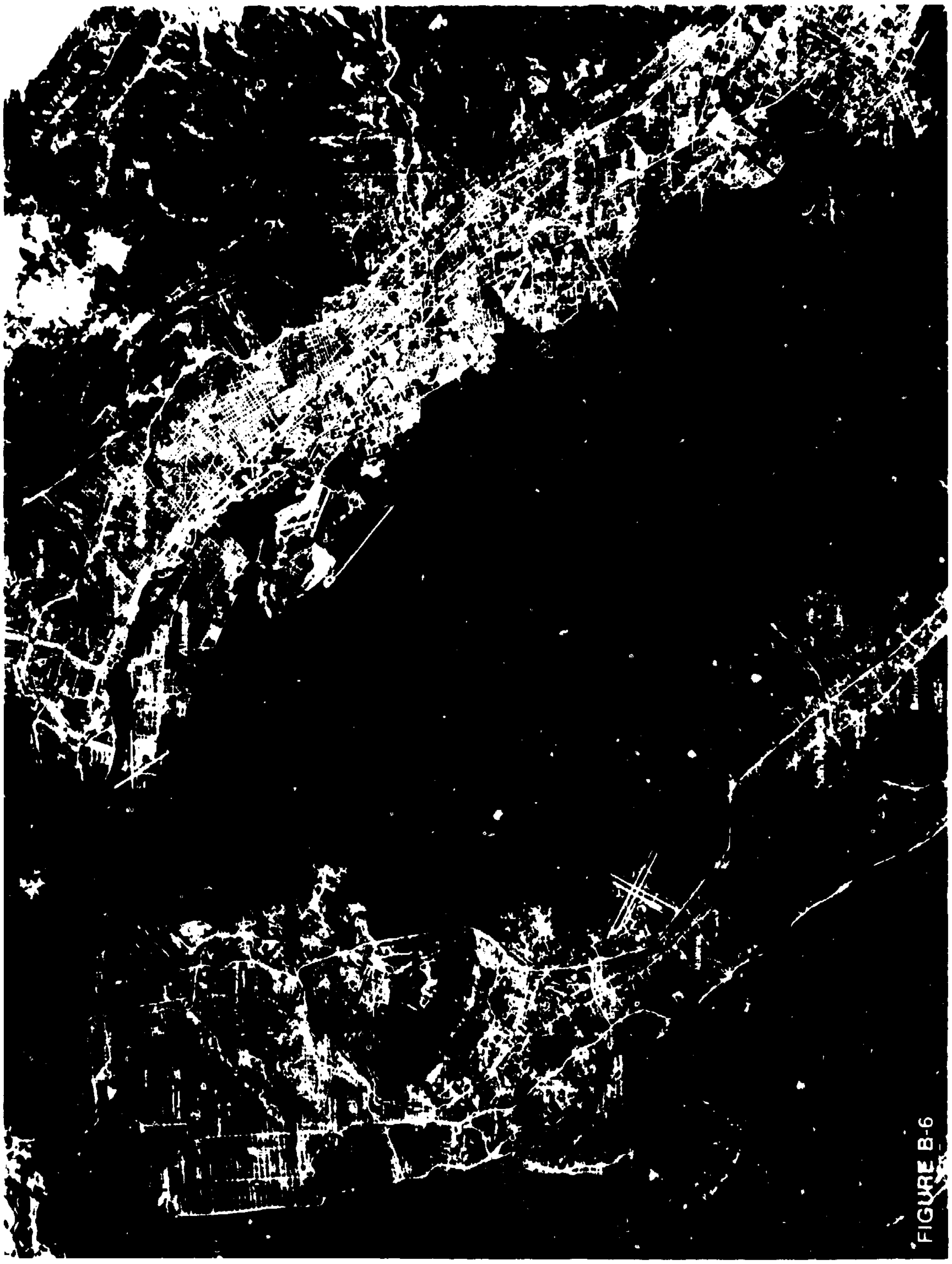


FIGURE B-6

APPENDIX C

Examples of Benefits of Remote Sensing of the Oceans and Atmosphere

In this Appendix we present examples showing how remotely sensed information about the earth's oceans and atmosphere can assist several practical and scientific endeavors. The fields of interest in these examples are weather monitoring, marine transport, commercial fishing, estuarine pollution, ocean dumping, and climate studies. These are only a few of many practical and scientific activities that can and do benefit from remotely sensed data about the atmosphere and oceans. The data used in these examples and in other applications are often a mix obtained from land, ocean, and weather satellites and also may be combined with ground truth observations made at the surface.

THE USE OF SATELLITE IMAGERY FOR MONITORING HURRICANES, FLASH FLOODS, AND TORNADOES

Meteorological satellite imagery is now routinely used to detect and monitor hurricanes as well as intense convective storms over land that can produce tornadoes and flash floods. Techniques developed by research meteorologists are the basis on which empirical analyses of these storms are routinely made.

One technique, developed by meteorologist Vernon Dvorak, uses satellite imagery to estimate the strength and development of tropical cyclones. A second technique, used to determine precipitation rates in flash flood events, was developed by Roderick Scofield and Vincent Oliver of NESDIS. Forecasting of tornadic storms was greatly improved in the early 1970s when scientists discovered that intense thunderstorms, which often spawned tornadoes, had a specific signature in satellite imagery.

Hurricanes: The Dvorak Technique[1,2]

Meteorologists use infrared or visible satellite images of tropical cyclones (depressions, tropical storms, or hurricanes) to determine their intensity by relating certain cloud features to "model" storms of known intensity in various stages of development. The cloud features that are measured for comparison include the diameter of the central dense overcast of the storm, the diameter, shape, and imbedded distance of the eye if one exists, the concentric coverage and intensity of spiral feeder bands, and the relative change in time of all these features. By analyzing a hurricane using the Dvorak technique, the meteorologist gets an estimate of the central pressure and maximum sustained winds of the storm, as well as a feel for the storm's change in intensity.

The intensity of each storm is rated using the Dvorak "T-number" scale—the higher the T-number, the more intense the storm. Figure C-1 shows a composite of five stages in the development of a hurricane, each annotated with the current T-number.

Flash Floods: The Scofield-Oliver Technique[3,4,5]

Most flash floods in the United States are caused and sustained by heavy rains that fall from very active deep convective storms of small geographic area (mesoscale) in the warm season. Flash flooding is also common, however, under very active but slow-moving synoptic, or large-scale, frontal systems. The Scofield-Oliver technique was originally used for estimating rainfall rates in the active mesoscale systems. This technique has been expanded in recent years to include enhanced methods for estimating precipitation from tropical weather systems and winter storms.

The technique empirically relates rate of growth of the coldest tops of vigorous convective clouds, as measured on specially enhanced satellite imagery, to rainfall rates. Using half-hourly GOES infrared imagery, meteorologists determine how rapidly clouds residing in an atmospheric environment favorable for sustained heavy rains (high moisture inflow, weak winds aloft, convergent low-level outflow areas, etc.) are developing. The meteorologist examines other cloud signatures of intense precipitation (e.g., diffluent cirrus aloft) and estimates rainfall rates to tenths of an inch per hour for areas as small as about 20 km^2. These estimates

[1] Dvorak, Vernon F. Hurricane intensity analysis using McIDAS. Pp. 164-165 in Proceedings From the 16th Conference on Hurricanes and Tropical Meteorology, May 14-17, 1985, Houston, Texas.

[2] Dvorak, Vernon F. Tropical cyclone intensity analysis and forecasting from satellite imagery. Monthly Weather Review, Vol. 103, No. 5, May 1975, pp. 420-430.

[3] Scofield, R. A., and V. J. Oliver. A Scheme for Estimating Convective Rainfall From Satellite Imagery. Washington, D.C.: U.S. Department of Commerce, NOAA Technical Memorandum NESDIS 86, 1977, pp. 47.

[4] Scofield, R. A., and L. E. Spayd, Jr. A Technique That Uses Satellite, Radar and Conventional Data for Analyzing Precipitation From Extratropical Cyclones. Washington, D.C.: U.S. Department of Commerce, NOAA Technical Memorandum NESDIS 8, 1984, p. 51.

[5] Spayd, L. E., Jr., and R. A. Scofield. A Tropical Cyclone Precipitation Estimation Technique Using Geostationary Satellite Data. Washington, D.C.: U.S. Department of Commerce, NOAA Technical Memorandum NESDIS 5, 1984, p. 36.

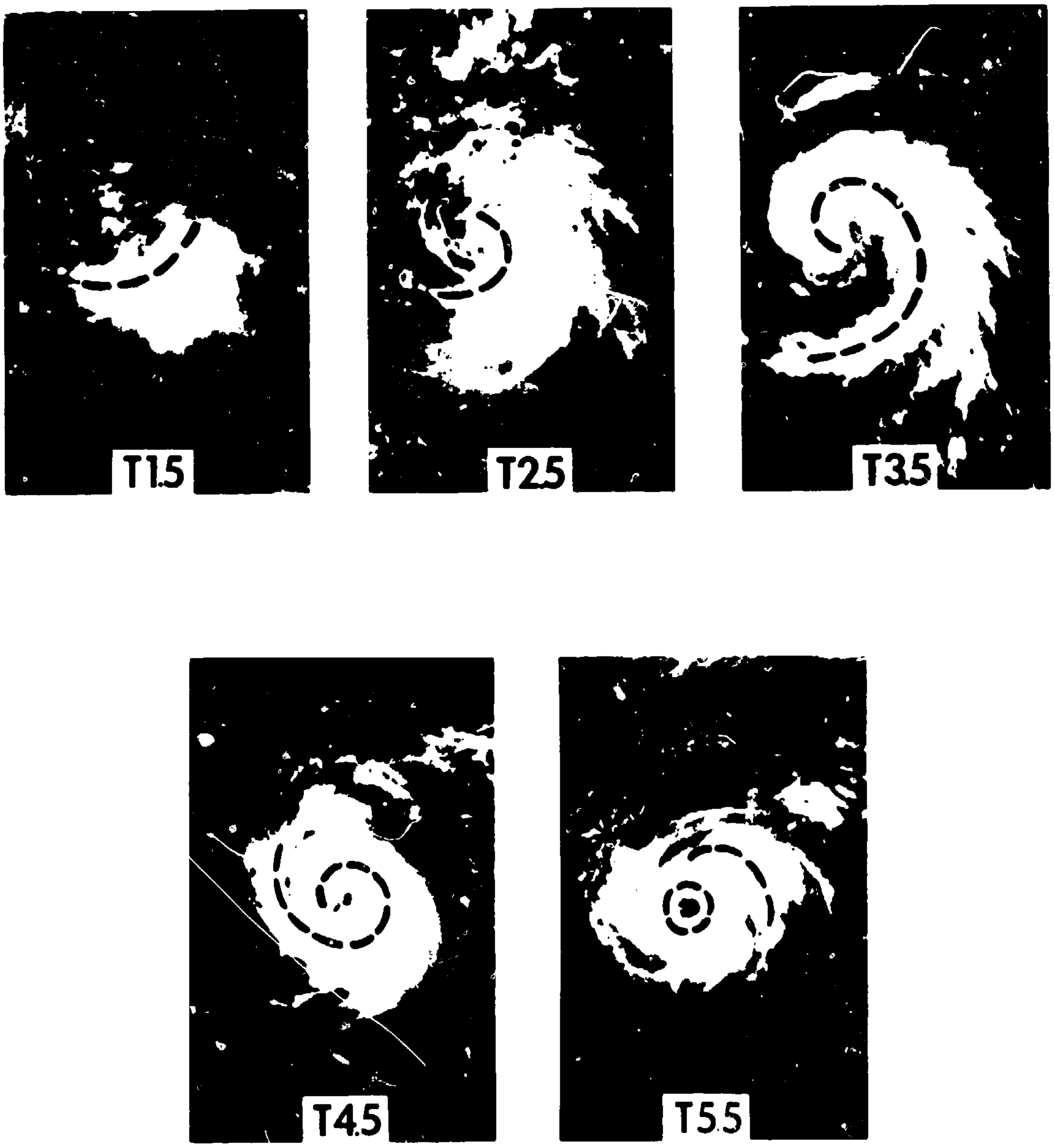


FIGURE C-1 Five stages in the development of a hurricane.

can be accumulated over a specific grid (e.g., a state map with county boundaries), and storm totals can be generated. Flash flood thresholds (how much rain a given area can absorb in a 3-hour period before flooding) are distributed by the National Weather Service daily for each forecast zone within each state. When the satellite-estimated precipitation approaches the threshold level, these estimates become a vital part of watch or warning decisions in local forecast offices.

Figure C-2 shows a very active mesoscale convective complex over south-central Pennsylvania that deluged Johnstown, causing a catastrophic flood on July 20, 1977. The special stepped enhancement, based on derived cloud temperature in the infrared imagery, delineates the coldest, most active tops of the complex.

Severe Thunderstorms and Tornadoes

Although tornadoes cannot actually be forecast or analyzed from satellite imagery, the development of severe thunderstorms that spawn tornadoes can be.

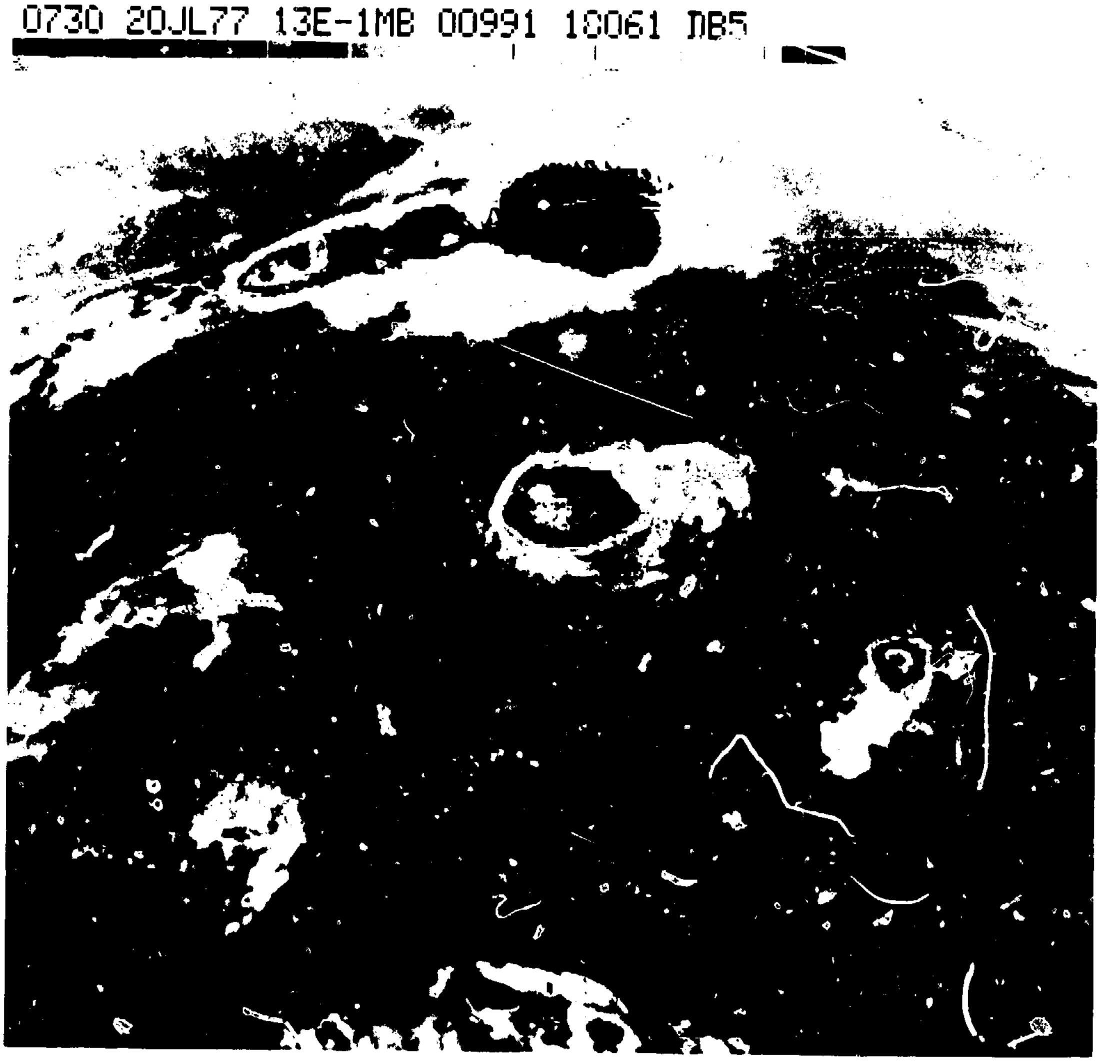


FIGURE C-2 Mesoscale convective complex over south-central Pennsylvania that caused catastrophic flooding in Johnstown on July 20, 1977.

Certain cloud signatures in the satellite imagery provide clues to the imminent genesis and ensuing propagation of severe thunderstorms and squall lines. Meteorologists have learned to recognize a V-shaped wedge of deep cumulus clouds as a general shape of severe-weather-producing clouds. Theodore Fujita[6,7] showed that extreme upward motions in tornadic thunderstorms induced rapid vertical cloud growth, causing overshooting turrets above the tropopause. While not always a certainty, severe weather—including large hail, damaging winds, and tornadoes—is often associated with such overshooting tops in a V-shaped wedge on satellite imagery. Other cloud signatures, such as intersecting low-level outflow boundaries from active neighboring thunderstorms, are often foci for severe weather and are observable only by satellite.

The fact that clouds can be analyzed at rapid intervals (5 to 15 minutes) in data void areas between surface reporting stations makes GOES imagery an irreplaceable tool in severe weather forecasting. This is especially true considering the relatively short life cycle of tornadic storms.

Figure C-3 shows a classic line of rapidly developing severe thunderstorms over Ohio and northwest Pennsylvania that devastated many communities on May 31, 1985.

SEA-ICE MONITORING: SEA TRANSPORT OF PIPELINE MACHINERY IN THE ARCTIC OCEAN[8]

Construction of the Trans-Alaska oil pipeline and development of the North Slope oil field required ocean transport of heavy, bulky machinery from Seattle to Prudhoe Bay, Alaska. This machinery was much too bulky and heavy for land transport, especially in the fragile Arctic environment. Many large sea-going barges were loaded with critically scheduled equipment at Seattle and other ports and towed into the southern ice-free part of the Bering Sea each year, usually in June, to await the brief 2- to 6-week period of open water around Point Barrow. This period of open water is caused by a summer shift in prevailing winds that causes the Arctic Ocean ice pack to retreat northward, leaving a narrow opening of navigable water around the northwest tip of Alaska at Point Barrow. This weather pattern is well established and can generally be predicted for mid-July or later. The usual practice was to have the barge trains arrive in the Bering Sea staging area in early July and await the opening. Daily aircraft flights augmented weather observations at Point Barrow and other locations along the route.

Late-spring and early-summer storms disrupted the normal pattern in 1975, an especially critical year in the construction schedule. The expected July opening

[6] Fujita, Theodore T. Manual of Downburst Identification for Project NIMROD. SMRP Research Paper No. 156, May 1978, p. 103.

[7] Fujita, Theodore T. The Downburst, the Microburst and Macroburst. Project Reports and NIMROD, SMRP Research Paper No. 210, 1985, p. 125.

[8] Wiley, M. A., co-principal investigator for the remote sensing project. From unpublished files and correspondence.

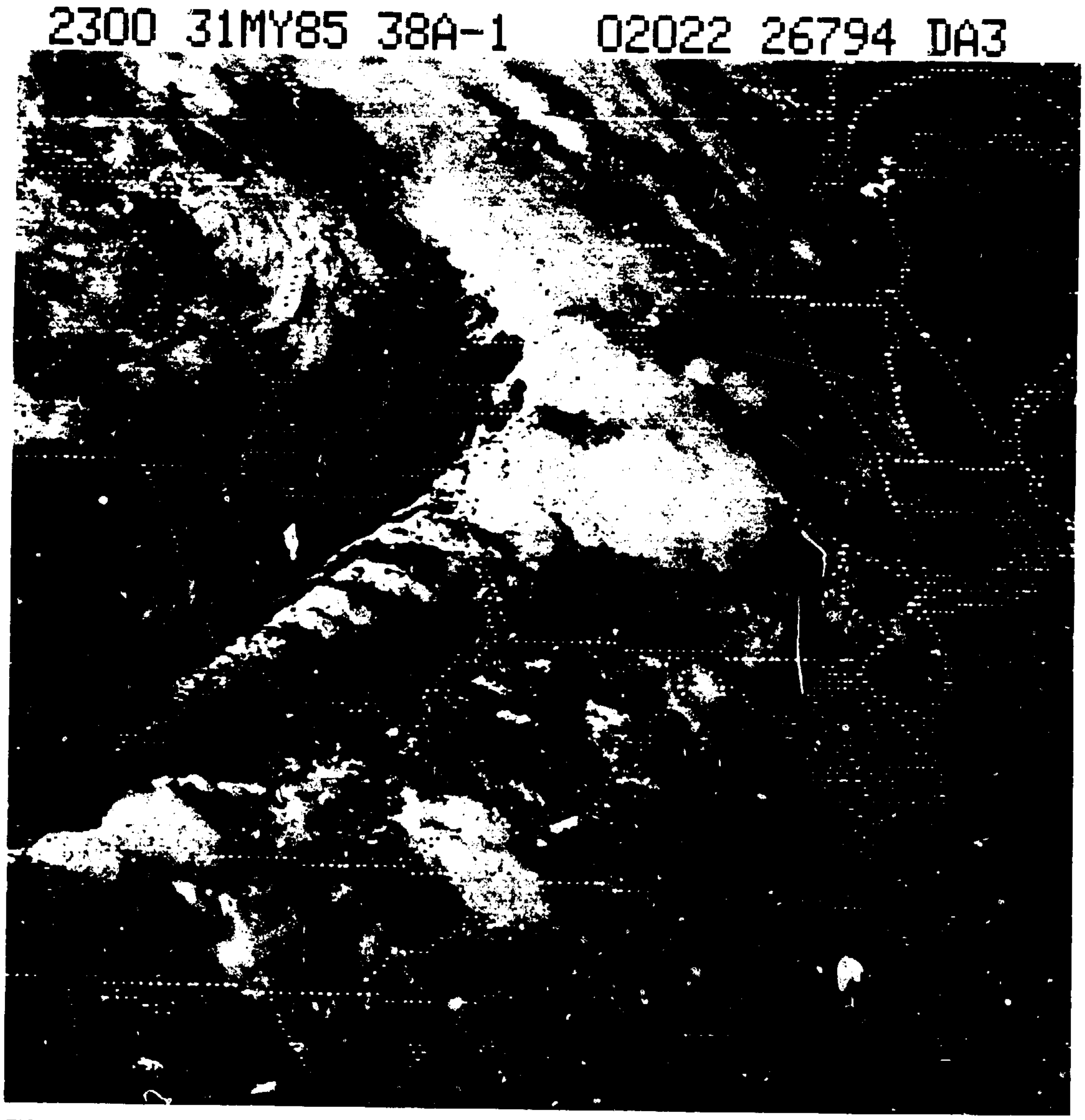


FIGURE C-3 A classic line of rapidly developing severe thunderstorms over Ohio and northwest Pennsylvania on May 31, 1985. Many communities were devastated by the storms.

of the route did not happen, and by early August the situation was becoming critical. A decision had to be made to either continue to wait and risk closing of the southern escape route by early ice or to immediately return the barge trains to Seattle. Abandoning delivery would result in a year's delay in pipeline completion and in delivery of oil to the United States. Also delayed would be billions of dollars of revenue to the oil companies and the resulting inflow of taxes to federal and state governments.

Analysis of daily weather satellite imagery showed encouraging, if subtle, changes in weather patterns that might lead to a mid- or late-August opening. It was decided to wait another week before ordering the barges back to Seattle. The encouraging trends continued, and the decision date was set back another week. In that final week, the first signs of opening occurred. The ice retreated long enough to get the barges through and save the critical construction schedule. Most of the empty barges made the return around Point Barrow and back to Seattle, although a few were locked in ice for the winter at Prudho Bay.

The region is under cloud cover much of the time. Meteorological analysis of cloud movement obtained from satellite imagery provided much of the data in the 1975 situation. Satellite radar systems, to be launched in the 1980s, will provide direct observation of sea ice regardless of cloud cover. They could yield data for the equipment-shipping decisions that will be made in the future.

COMMERCIAL FISHING: TUNA CATCH AND OCEAN COLOR

Tuna fishermen in the Pacific are using satellite ocean color images to optimize their search for albacore tuna and to gain substantial savings in fuel and time. Rising fuel and operating costs have created economic hardships for the West Coast tuna industry. Because tuna are highly migratory and swim through vast stretches of the open oceans, they are extremely difficult to locate. However, fishermen have known for years that tuna tend to be found where the clear, warm blue waters meet the cooler, turbid green waters. In the past, finding these boundaries or fronts has been a costly, time-consuming endeavor. It is extremely difficult to detect fronts from ships, but satellites equipped with ocean color and infrared sensors can give fishermen and scientists the appropriate vantage point.

The Coastal Zone Color Scanner (CZCS) measures the intensity of light that has been reflected from the upper meters of the ocean within four narrow color bands. This ocean color is predominantly a function of photosynthetic pigments in microscopic marine plants (phytoplankton) that tend to absorb blue and reflect green light. The greater the phytoplankton abundance, the greener the water. These variations in color can be measured quite accurately from space. The resulting digital images can be computer-processed to yield quantitative plankton pigment concentrations or, as in this case, can be computer-enhanced to accentuate ocean color patterns.

The image in Figure C-4 shows gradations in ocean color off central California with locations of albacore tuna catches superimposed. The ocean color data were obtained on September 21, 1981, with the CZCS on board NASA's Nimbus-7 satellite. The CZCS data were enhanced to reveal oceanic features and show a transition from coastal waters (red, orange) to offshore regions (blue). The superimposed circles show the size and location of albacore tuna catches during the period from September 19 to 24, 1981. A comparison of ocean color variations with fish catch data indicates that most of the albacore were caught along the seaward side of the boundary between offshore and coastal waters.

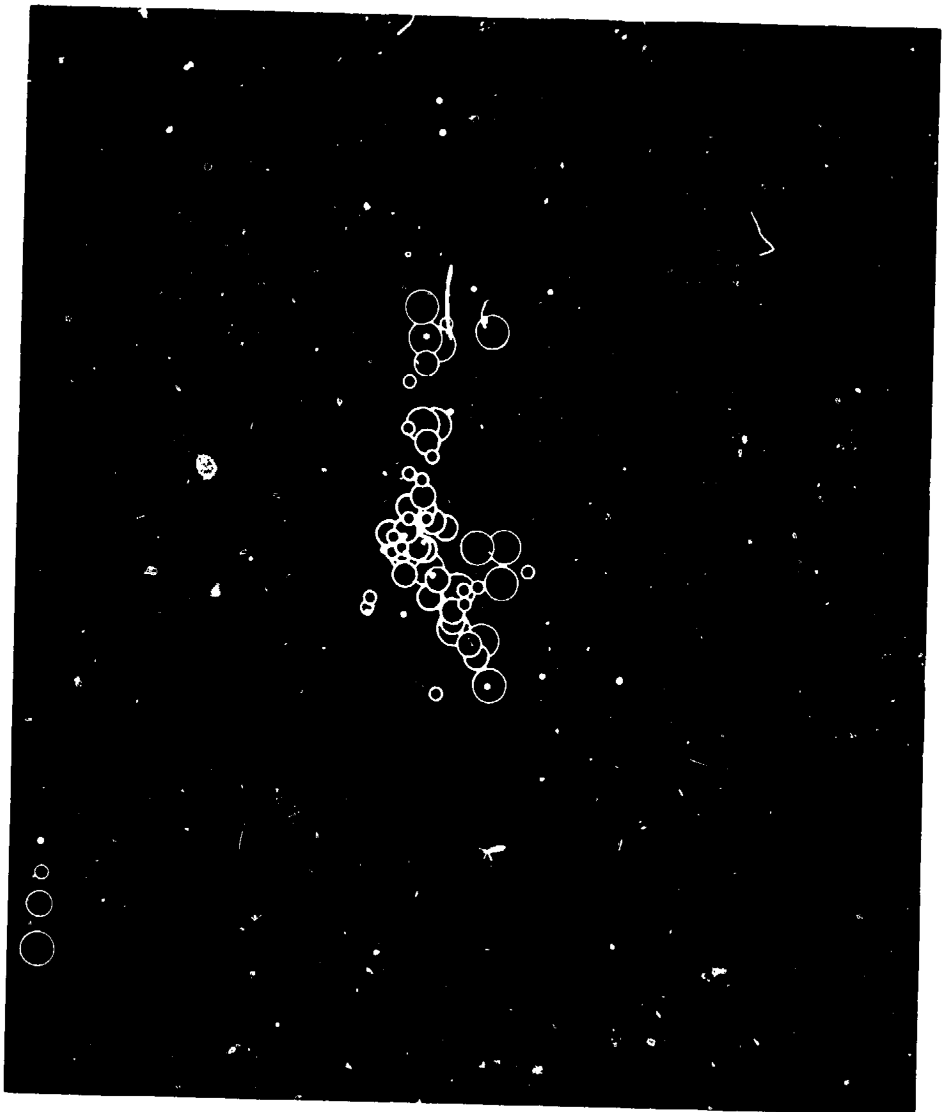


FIGURE C-4 Gradation in ocean color off central California coast as detailed by the Coastal Zone Color Scanner (CZCS).[9]

ESTUARINE POLLUTION: MAPPING SUSPENDED SEDIMENT AND PREDICTING OIL SLICK DISPERSION AND CAPTURE BY FRONTS

In 1974-76, under a grant from the National Science Foundation, University of Delaware scientists developed a dispersion model for Delaware Bay. The two-dimensional model gave accurate predictions of oil slick drift in response to

[9] Oceanography From Space. National Aeronautics and Space Administration, NASA/??L 400-222-J, 1984.

current and wind conditions, except when the oil was captured by estuarine fronts.[10] Thirty-six scenes from Landsat MSS, covering all portions of the tidal cycle, were used to determine the behavior of the fronts in Delaware Bay. This information was used to modify the two-dimensional oil slick drift and dispersion model to include a three-dimension subroutine on frontal capture of oil slicks. The predictive model helps oil clean-up crews anticipate the arrival of oil slicks at ecologically sensitive areas of the coast. The cost of the remote sensing portion of the study was about $70,000. Without satellite and aircraft data, the cost would have been at least $300,000, and it would have taken twice the 2-year period to perform.

Landsat MSS was also used to study suspended sediment properties. Figure C-5 shows a suspended sediment concentration map of Delaware Bay prepared by computer analysis of Landsat MSS imagery of July 7, 1983 (I.D. No. 1349-15134). The satellite data were correlated with ship and helicopter water samples ranging in concentration from 211 mg/liter upstream from the Bay to about 6 mg/liter at the mouth. Landsat MSS imagery has been used in similar fashion to study fronts and the dispersion of industrial waste dumped 40 miles off the coast of Delaware.[11]

OCEAN DUMPING: REMOTE SENSING OF OCEAN-DUMPED WASTE DRIFT AND DISPERSION

The University of Delaware has used Landsat MSS to study the drift and dispersion of acid waste and sludge dumped by industry and municipalities at a dumpsite 65 km off the coast of Delaware. The results were used as important evidence during EPA hearings on dump permit renewal.[12]

Satellites such as Landsat offer an effective means of assessing the drift and dispersion of industrial wastes dumped on the continental shelf. This is particularly true for the acid wastes disposed about 64 km off the Delaware coast, since these wastes are from a sparse but optically persistent ferric flow that can be observed by Landsat's MSS band 4 up to 2 days after dumping.

Most of the sixteen waste plumes shown by Landsat data were found to be drifting at average rates of 0.59 km/hour (0.32 knots) to 3.39 km/hour (1.83 knots) into the southwest quadrant. The plumes seemed to remain above the thermocline, which was observed to form from June through August at a depth ranging from 13 to 24 m. During the remainder of the year, the ocean at the test site was not stratified, permitting wastes to mix throughout the water column to the bottom.

[10] Klemas, V. Remote sensing of coastal fronts and their effects on oil dispersion. International Journal of Remote Sensing, Vol. 1, No. 1, 1980, pp. 11-28.

[11] Klemas, V., M. Otley, W. Philpot, C. Wethe, R. Rogers, and N. Shah. Correlation of coastal water turbidity and current circulation with ERTS-1 and Skylab Imagery. Pp. 1289-1317 in Proceedings of the Ninth International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, April 14-19, 1974.

[12] Klemas, V., and W. D. Philpot. Drift and dispersion studies of ocean-dumped waste using Landsat imagery and current drogues. Photogrammetric Engineering and Remote Sensing, Vol. 47, No. 4, 1981, pp. 533-542.

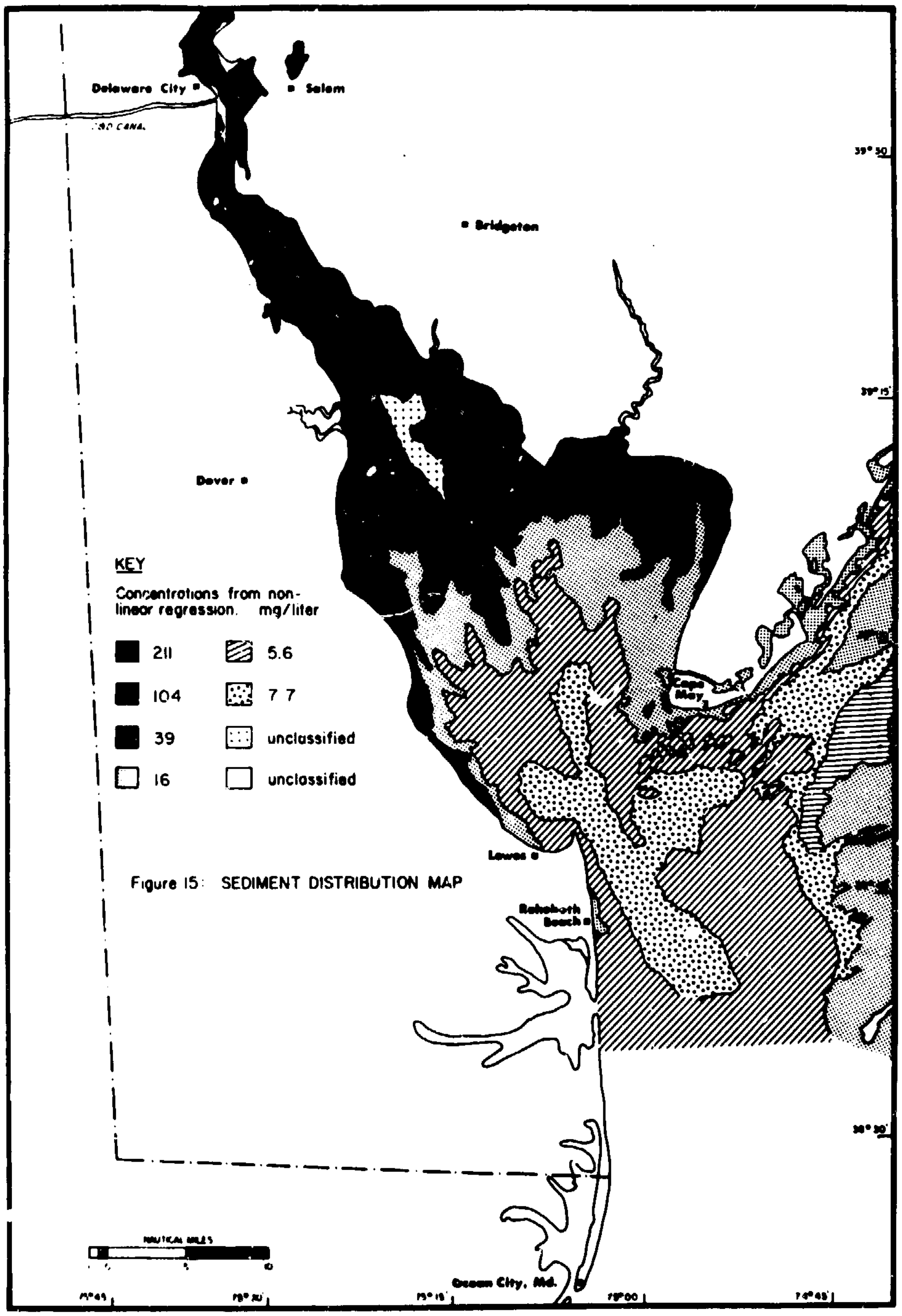


Figure C-5 Suspended sediment concentration map of Delaware Bay.[11,12]

The magnitudes of plume drift velocities were compatible with the drift velocities of current drogues released over a 12-month period at the surface, at mid-depth, and near the bottom. However, during the stratified warm months, more drogues tended to move in the north-northeast direction, while during the nonstratified winter months, a southwest direction was preferred.

Rapid movement toward shore occurs primarily during storms, particularly northeasters. During such storms, however, the plume is rapidly dispersed and diluted. The plume width was observed to increase at a rate of about 1.5 cm/second during calm sea conditions, yet attain spread rates in excess of 4 cm/second on days when winds reached speeds of 24 km/hour (13 knots) to 38 km/hour (21 knots). These results are in agreement with model estimates of plume dilution, which indicate that by the time a waste plume moves 37 km from the dump site, dilution is at least 1 million to one.

The cost of these investigations was about $150,000. Without Landsat data, aircraft would have to be used to track the plumes at higher cost and with severe limitations because of bad weather during part of the study period.

MARINE TRANSPORTATION: OPTIMUM-TRACK SHIP ROUTING

Optimum-track ship routing techniques are used widely to minimize transit time or fuel costs and to reduce the exposure of the ship and its cargo to severe weather. Case studies showed that the improved analysis and forecast products using Seasat data could further improve ship routing, producing substantial savings in operating costs and reducing losses from cargo damage and personnel injuries.[13] Analysis of selected rerouted vessels operating in the Atlantic, North Pacific, and Indian Oceans indicated a savings in operating costs alone of $1 million to $3 million per year.

In 1978 the *Queen Elizabeth 2* was crossing the Atlantic along a northerly route from England to the United States. The northern route was chosen because it was shorter. Halfway to its destination, the QE-2 ran into a severe storm, with waves in excess of 25 feet. It was a traumatic experience for the passengers and crew, resulting in injuries and material damage. A subsequent analysis of Seasat scatterometer data clearly showed the developing storm. If this information had been available earlier, the storm encounter could have been prevented by redirecting the QE-2 to a more southerly route.

As oil tankers and other ships are forced to take more northerly routes, ocean ice observations become important to marine transportation. The image in Figure C-6 (top) shows a cloud-free view of the Bering Sea, with Alaska on the right and Siberia on the left. It was obtained by the Very High Resolution Radiometer (VHRR) aboard the NOAA-4 satellite on March 21, 1976. Here, sea ice is characterized by a filigree of black, open-water "leads" separating individual ice floes. The light-toned gray areas are either thick ice or ice covered with fresh

[13] An Evaluation of the Utility of Seasat Data to Ocean Industries. National Aeronautics and Space Administration, NASA/JPL Final Report, Seasat Commercial Demonstration Program, February 2, 1981.

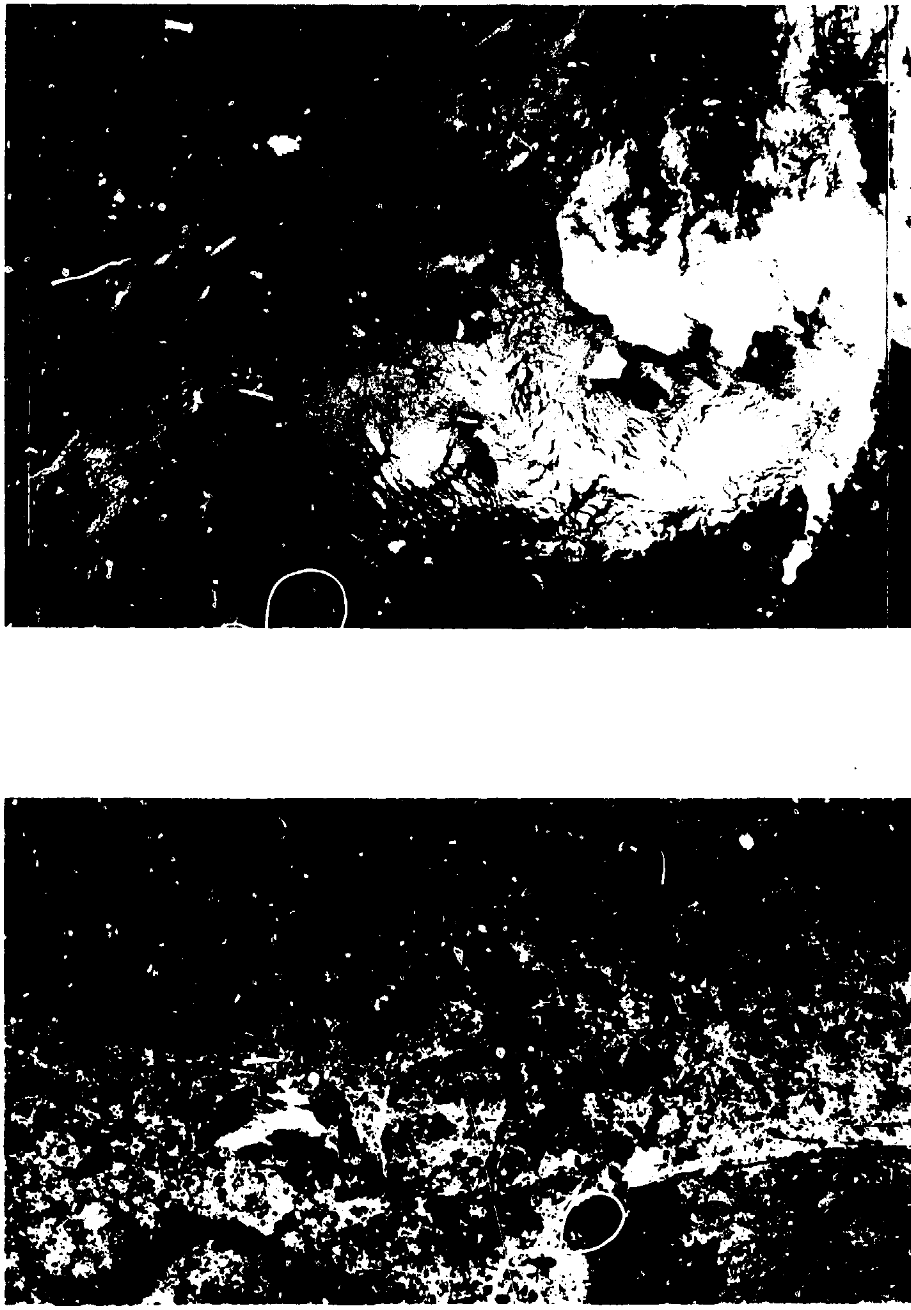


Figure C-6 (Top) Cloud-free view of the Bering Sea, with Alaska on the right and Siberia on the left. (Bottom) Seasat radar picture.[9]

snow; medium-gray tones lack snow cover and are probably thinner; ice-free areas are dark.

A Seasat radar picture is shown in Figure C-6 (bottom). The Synthetic Aperture Radar (SAR) transmits a radar beam from space and then measures the surface reflections. This image has a resolution of 25 m (80 ft) and was obtained by the SAR aboard NASA's Seasat on October 3, 1978. It shows a region near Banks Island in the Beaufort Sea north of Canada and covers a width of 100 km (62 miles). The image is filled with ice floes separated either by dark areas of open-water "leads" or very new ice. Many of the floes appear to be a patchwork of smaller units, separated by light-shaded streaks.[13]

GLOBAL SURFACE TEMPERATURES FOR CLIMATE STUDIES

As the sun migrates annually between hemispheres, the atmosphere, land, and ocean systems respond with annual temperature variations. While the atmosphere and land experience large temperature changes in the high and mid-latitudes, the ocean remains more constant because of the high heat capacity of water relative to that of air and land. Without the oceans, the earth's temperature would fluctuate radically. Thus the waters, covering 70 percent of our planet's surface, act as a massive thermostat that moderates our global climate. Conversely, small changes in ocean temperature patterns can result in dramatically altered global weather—for example, the phenomenon known as El Nino.

Monitoring global temperatures, especially from the oceans, has traditionally been impossible because of the lack of data from many areas. Now, satellite sensors are used to observe month-to-month and year-to-year changes in surface temperatures. Examples shown in Figure C-7 are images produced using data from the High Resolution Infrared Sounder (HRIS) and the Microwave Sounding Unit (MSU). Both of these instruments measure natural radiation emitted from the earth's surface and atmosphere and have been flying on NOAA weather satellites since 1979. Temperatures are on an absolute Kelvin scale (273°K = 32°F). Temperatures below freezing (273°K) are green and blue. Warmer temperatures are red and brown.[9]

In Figure C-7 (middle panel), January 1979, the Northern Hemisphere is experiencing extreme cold. Siberia and most of Canada record temperatures approaching −30°C (−22°F). In Eastern Europe and the northern United States, temperatures are below 0°C. In the Southern Hemisphere, the people at mid-latitudes (30° to 50°) are enjoying summer, with temperatures ranging from 20° to 30°C (68° to 86°F). In the open oceans, the isotherms (or contours of equal temperature) show deviations from their zonal patterns on the eastern and western sides of the various oceans. Generally, in the subtropics of both hemispheres (10° to 30° latitude), the western sides of the oceans are warmer than their eastern counterparts, primarily because of ocean currents. An exception to this rule is the Gulf Stream, a warm current in the western Atlantic. The current moves along the North American continent, then turns northeastward, transporting warm waters across the Atlantic that moderate the climate of Western Europe.

Figure C-7 (top panel) shows that by July most areas of the Northern Hemisphere

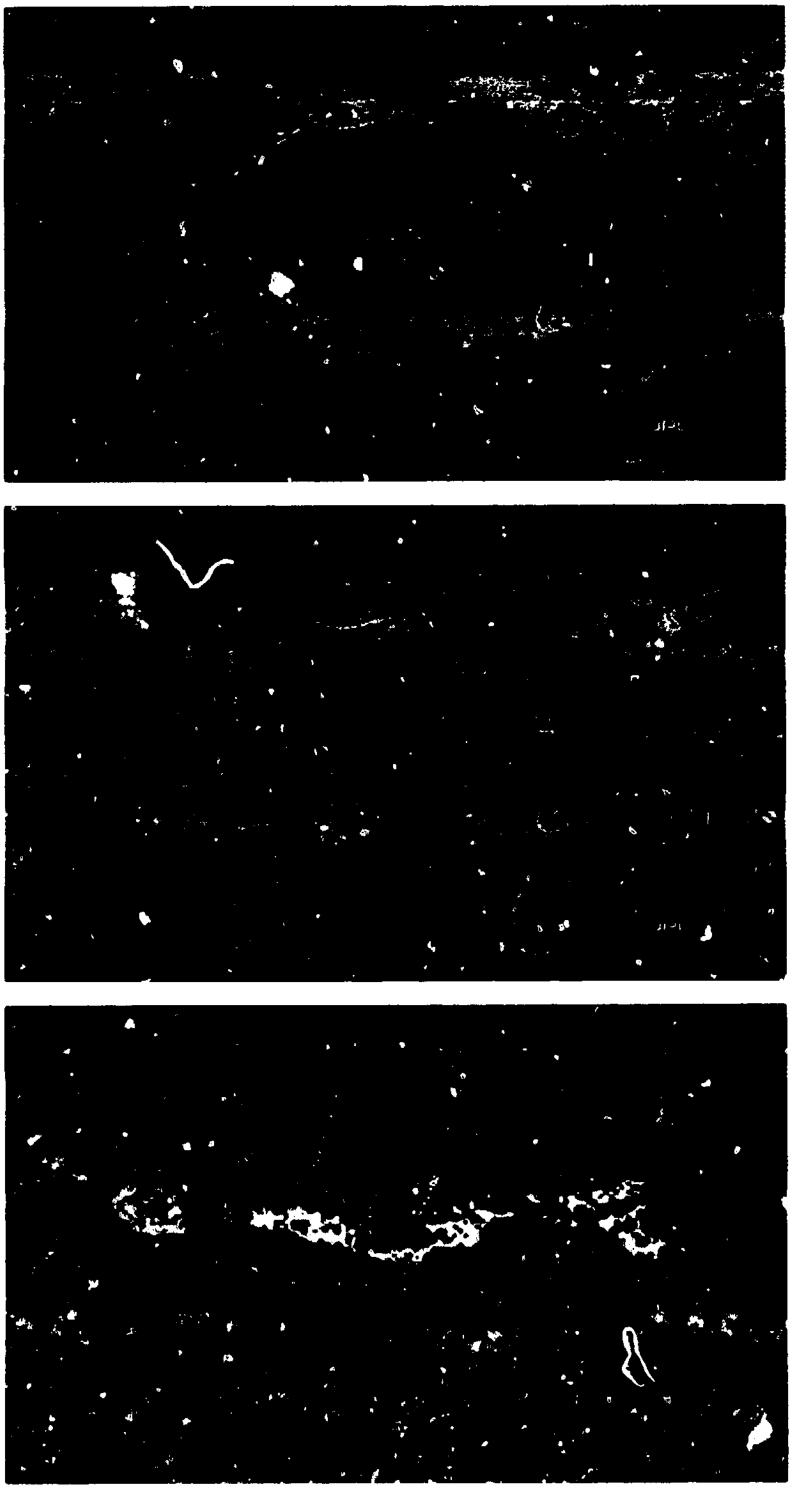


Figure C-7 Global surface temperatures in July 1979 (top panel), in January 1979 (middle panel), and temperature difference between January and July (bottom panel).

have warmed to 10° to 20°C (50° to 68°F). Equatorial Africa and India are the hottest, in dramatic contrast to the frozen Himalayan Mountains. In the Arctic, Greenland remains frozen, while Hudson Bay has thawed. In the Southern Hemisphere, Antarctica is much cooler than the Arctic, and ice has formed in the Weddell Sea. At this high latitude, zones of constant temperature are much more zonal than in the northern oceans. Here the ocean, driven by strong westerly winds, moves in a circular path around Antarctica from west to east.

In Figure C-7 (bottom panel), temperature differences between January and July show that the greatest warming and cooling has occurred over land (dark blue, brown). Marked seasonal changes of up to 30°C are seen in both hemispheres. In contrast, the changes in ocean temperature rarely exceed 8° to 10°C (14° to 18°F). The greatest deviations are in the mid-latitudes, while the near-equatorial regions are quite stable. In the Northern Hemisphere, mid-latitude changes in ocean temperature are influenced by the position of continents. The continents divert the ocean currents and affect wind patterns. In the Southern Hemisphere, which has half the land area of the north, changes are primarily due to seasonal variations in incoming solar radiation. Thus the oceans in the two hemispheres interact in fundamentally different ways with the atmosphere and land.[9]

APPENDIX D

Public Law 98-365

98th Congress
July 17, 1984

An Act

To establish a system to promote the use of land remote-sensing satellite data, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That this Act may be cited as the "Land Remote-Sensing Commercialization Act of 1984".

TITLE I—DECLARATION OF FINDINGS, PURPOSES, AND POLICIES

FINDINGS

Sec. 101. The Congress finds and declares that—

(1) the continuous civilian collection and utilization of land remote-sensing data from space are of major benefit in managing the Earth's natural resources and in planning and conducting many other activities of economic importance;

(2) the Federal Government's experimental Landsat system has established the United States as the world leader in land remote-sensing technology;

(3) the national interest of the United States lies in maintaining international leadership in civil remote sensing and in broadly promoting the beneficial use of remote-sensing data;

(4) land remote sensing by the Government or private parties of the United States affects international commitments and policies and national security concerns of the United States;

(5) the broadest and most beneficial use of land remote-sensing data will result from maintaining a policy of nondiscriminatory access to data;

(6) competitive, market-driven private sector involvement in land remote sensing is in the national interest of the United States;

(7) use of land remote-sensing data has been inhibited by slow market development and by the lack of assurance of data continuity;

(8) the private sector, and in particular the "value-added" industry, is best suited to develop land remote-sensing data markets;

(9) there is doubt that the private sector alone can currently develop a total land remote-sensing system because of the high risk and large capital expenditure involved;

(10) cooperation between the Federal Government and private industry can help assure both data continuity and United States leadership;

(11) the time is now appropriate to initiate such cooperation with phased transition to a fully commercial system;

(12) such cooperation should be structured to involve the minimum practicable amount of support and regulation by the Federal Government and the maximum practicable amount of competition by the private sector, while assuring continuous availability to the Federal Government of land remote-sensing data;

(13) certain Government oversight must be maintained to assure that private sector activities are in the national interest and that the international commitments and policies of the United States are honored; and

(14) there is no compelling reason to commercialize meteorological satellites at this time.

PURPOSES

Sec. 102. The purposes of this Act are to—

(1) guide the Federal Government in achieving proper involvement of the private sector by providing a framework for phased commercialization of land remote sensing and by assuring continuous data availability to the Federal Government;

(2) maintain the United States worldwide leadership in civil remote sensing, preserve its national security, and fulfill its international obligations;

(3) minimize the duration and amount of further Federal investment necessary to assure data continuity while achieving commercialization of civil land remote sensing;

(4) provide for a comprehensive civilian program of research, development, and demonstration to enhance both the United States capabilities for remote sensing from space and the application and utilization of such capabilities; and

(5) prohibit commercialization of meteorological satellites at this time.

POLICIES

Sec. 103. (a) It shall be the policy of the United States to preserve its right to acquire and disseminate unenhanced remote-sensing data.

(b) It shall be the policy of the United States that civilian unenhanced remote-sensing data be made available to all potential users on a nondiscriminatory basis and in a manner consistent with applicable antitrust laws.

(c) It shall be the policy of the United States both to commercialize those remote-sensing space systems that properly lend themselves to private sector operation and to avoid competition by the Government with such commercial operations, while continuing to preserve our national security, to honor our international obligations, and to retain in the Government those remote-sensing functions that are essentially of a public service nature.

DEFINITIONS

Sec. 104. For purposes of this Act:

(1) The term "Landsat system" means Landsats 1, 2, 3, 4, and 5, and any related ground equipment, systems, and facilities, and any successor civil land remote-sensing space systems operated by the United States Government prior to the commencement of the six-year period described in title III.

(2) The term "Secretary" means the Secretary of Commerce.

(3)(A) The term "nondiscriminatory basis" means without preference, bias, or any other special arrangement (except on the basis of national security concerns pursuant to section 607) regarding delivery, format, financing, or technical considerations which would favor one buyer or class of buyers over another.

(B) The sale of data is made on a nondiscriminatory basis only if (i) any offer to sell or deliver data is published in advance in such manner as will ensure that the offer is equally available to all prospective buyers; (ii) the system operator has not established or changed any price, policy, procedure, or other term or condition in a manner which gives one buyer or class of buyer de facto favored access to data; (iii) the system operator does not make unenhanced data available to any purchaser on an exclusive basis; and (iv) in a case where a system operator offers volume discounts, such discounts are no greater than the demonstrable reductions in the cost of volume sales. The sale of data on a nondiscriminatory basis does not preclude the system operator from offering discounts other than volume discounts to the extent that such discounts are consistent with the provisions of this paragraph.

(C) The sale of data on a nondiscriminatory basis does not require (i) that a system operator disclose names of buyers or their purchases; (ii) that a system operator maintain all, or any particular subset of, data in a working inventory; or (iii) that a system operator expend equal effort in developing all segments of a market.

(4) The term "unenhanced data" means unprocessed or minimally processed signals or film products collected from civil remote-sensing space systems. Such minimal processing may include rectification of distortions, registration with respect to features of the Earth, and calibration of spectral response. Such minimal processing does not include conclusions, manipulations, or calculations derived from such signals or film products or combination of the signals or film products with other data or information.

(5) The term "system operator" means a contractor under title II or title III or a license holder under title IV.

TITLE II—OPERATION AND DATA MARKETING OF LANDSAT SYSTEM

OPERATION

Sec. 201. (a) The Secretary shall be responsible for—

(1) the Landsat system, including the orbit, operation, and disposition of Landsats 1, 2, 3, 4, and 5; and

(2) provision of data to foreign ground stations under the terms of agreements between the United States Government and nations that operate such ground stations which are in force on the date of commencement of the contract awarded pursuant to this title.

(b) The provisions of this section shall not affect the Secretary's authority to contract for the operation of part or all of the Landsat system, so long as the United States Government retains—

(1) ownership of such system;

(2) ownership of the unenhanced data; and

(3) authority to make decisions concerning operation of the system.

CONTRACT FOR MARKETING OF UNENHANCED DATA

Sec. 202. (a) In accordance with the requirements of this title, the Secretary, by means of a competitive process and to the extent provided in advance by appropriation Acts, shall contract with a United States private sector party (as defined by the Secretary) for the marketing of unenhanced data collected by the Landsat system. Any such contract—

(1) shall provide that the contractor set the prices of unenhanced data;

(2) may provide financial arrangements between the Secretary and the contractor including fees for operating the system, payments by the contractor as an initial fee or as a percentage of sales receipts, or other such considerations;

(3) shall provide that the contractor will offer to sell and deliver unenhanced data to all potential buyers on a nondiscriminatory basis;

(4) shall provide that the contractor pay to the United States Government the full purchase price of any unenhanced data that the contractor elects to utilize for purposes other than sale;

(5) shall be entered into by the Secretary only if the Secretary has determined that such contract is likely to result in net cost savings for the United States Government; and

(6) may be reawarded competitively after the practical demise of the space segment of the Landsat system as the contractor finds necessary for commercial operations.

(b) Any contract authorized by subsection (a) may specify that the contractor use, and, at his own expense, maintain, repair, or modify, such elements of the Landsat system as the contractor finds necessary for commercial operations.

(c) Any decision or proposed decision by the Secretary to enter into any such contract shall be transmitted to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology of the House of Representatives for their review. No such decision or proposed decision shall be implemented unless (A) a period of thirty calendar days has passed after the receipt by each such committee of such transmittal, or (B) each such committee before the expiration of such period has agreed to transmit and has transmitted to the Secretary written notice to the effect that such committee has no objection to the decision or proposed decision. As part of the transmittal, the Secretary shall include information on the terms of the contract described in subsection (a).

(d) In defining "United States private sector party" for purposes of this Act, the Secretary may take into account the citizenship of key personnel, location of assets, foreign ownership, control, influence, and other such factors.

CONDITIONS OF COMPETITION FOR CONTRACT

Sec. 203. (a) The Secretary shall, as part of the advertisement for the competition for the contract authorized by section 202, identify and publish the international obligations, national security concerns (with appropriate protection of sensitive information), domestic legal considerations, and any other standards or conditions which a private contractor shall be required to meet.

(b) In selecting a contractor under this title, the Secretary shall consider—

(1) ability to market aggressively unenhanced data;

(2) the best overall financial return to the Government, including the potential cost savings to the Government that are likely to result from the contract;

(3) ability to meet the obligations, concerns, considerations, standards, and conditions identified under subsection (a);

(4) technical competence, including the ability to assure continuous and timely delivery of data from the Landsat system;

(5) ability to effect a smooth transition with the contractor selected under title III; and

(6) such other factors as the Secretary deems appropriate and relevant.

(c) If, as a result of the competitive process required by section 202(a), the Secretary receives no proposal which is acceptable under the provisions of this title, the Secretary shall so certify and fully report such finding to the Congress. As soon as practicable but not later than thirty days after so certifying and reporting, the Secretary shall reopen the competitive process. The period for the subsequent competitive process shall not exceed one hundred and twenty days. If, after such subsequent competitive process, the Secretary receives no proposal which is acceptable under the provisions of this title, the Secretary shall so certify and fully report such finding to the Congress. In the event that no acceptable proposal is received, the Secretary shall continue to market data from the Landsat system.

(d) A contract awarded under section 202 may, in the discretion of the Secretary, be combined with the contract required by title III, pursuant to section 304(b).

SALE OF DATA

Sec. 204. (a) After the date of the commencement of the contract described in section 202(a), the contractor shall be entitled to revenues from sales of copies of data from the Landsat system, subject to the conditions specified in sections 601 and 602.

(b) The contractor may continue to market data previously generated by the Landsat system after the demise of the space segment of that system.

FOREIGN GROUND STATIONS

Sec. 205. (a) The contract under this title shall provide that the contractor shall act as the agent of the Secretary by continuing to supply unenhanced data to foreign ground stations for the life, and according to the terms, of those agreements between the United States Government and such foreign ground stations that are in force on the date of the commencement of the contract.

(b) Upon the expiration of such agreements, or in the case of foreign ground stations that have no agreement with the United States on the date of commencement of the contract, the contract shall provide—

(1) that unenhanced data from the Landsat system shall be made available to foreign ground stations only by the contractor; and

(2) that such data shall be made available on a nondiscriminatory basis.

TITLE III—PROVISION OF DATA CONTINUITY AFTER THE LANDSAT SYSTEM

PURPOSES AND DEFINITION

Sec. 301. (a) It is the purpose of this title—

(1) to provide, in an orderly manner and with minimal risk, for a transition from Government operation to private, commercial operation of civil land remote-sensing systems; and

(2) to provide data continuity for six years after the practical demise of the space segment of the Landsat system.

(b) For purposes of this title, the term "data continuity" means the continued availability of unenhanced data—

(1) including data which are from the point of view of a data user—

(A) functionally equivalent to the multispectral data generated by the Landsat 1 and 2 satellites; and

(B) compatible with such data and with equipment used to receive and process such data; and

(2) at an annual volume at least equal to the Federal usage during fiscal year 1983.

(c) Data continuity may be provided using whatever technologies are available.

DATA CONTINUITY AND AVAILABILITY

Sec. 302. The Secretary shall solicit proposals from United States private sector parties (as defined by the Secretary pursuant to section 202) for a contract for the development and operation of a remote-sensing space system capable of providing data continuity for a period of six years and for marketing unenhanced data in accordance with the provisions of sections 601 and 602. Such proposals, at a minimum, shall specify—

(1) the quantities and qualities of unenhanced data expected from the system;

(2) the projected date upon which operations could begin;

(3) the number of satellites to be constructed and their expected lifetimes;

(4) any need for Federal funding to develop the system;

(5) any percentage of sales receipts or other returns offered to the Federal Government;

(6) plans for expanding the market for land remote-sensing data; and

(7) the proposed procedures for meeting the national security concerns and international obligations of the United States in accordance with section 607.

AWARDING OF THE CONTRACT

Sec. 303. (a)(1) In accordance with the requirements of this title, the Secretary shall evaluate the proposals described in section 302 and, by means of a competitive process and to the extent provided in advance by appropriation Acts, shall contract with the United States private sector party for the capability of providing data continuity for a period of six years and for marketing unenhanced data.

(2) Before commencing space operations the contractor shall obtain a license under title IV.

(b) As part of the evaluation described in subsection (a), the Secretary shall analyze the expected outcome of each proposal in terms of—

(1) the net cost to the Federal Government of developing the recommended system;

(2) the technical competence and financial condition of the contractor;

(3) the availability of such data after the expected termination of the Landsat system;

(4) the quantities and qualities of data to be generated by the recommended system;

(5) the contractor's ability to supplement the requirement for data continuity by adding, at the contractor's expense, remote-sensing capabilities which maintain United States leadership in remote sensing;

(6) the potential to expand the market for data;

(7) expected returns to the Federal Government based on any percentage of data sales or other such financial consideration offered to the Federal Government in accordance with section 305;

(8) the commercial viability of the proposal;

(9) the proposed procedures for satisfying the national security concerns and international obligations of the United States;

(10) the contractor's ability to effect a smooth transition with any contractor selected under title II; and

(11) such other factors as the Secretary deems appropriate and relevant.

(c) Any decision or proposed decision by the Secretary to enter into any such contract shall be transmitted to the Committee on Commerce, Science, and Transportation of the Senate and the Committee on Science and Technology of the House of Representatives for their review. No such decision or proposed decision shall be implemented unless (1) a period of thirty calendar days has passed after the receipt by each such committee of such transmittal, or (2) each such committee before the expiration of such period has agreed to transmit and has transmitted to the Secretary written notice to the effect that such committee has no objection to the decision or proposed decision. As part of the transmittal, the Secretary shall include the information specified in subsection (a).

(d) If, as a result of the competitive process required by this section, the Secretary receives no proposal which is acceptable under the provisions of this title, the Secretary shall so certify and fully report such finding to the Congress. As soon as practicable but not later than thirty days after so certifying and reporting, the Secretary shall reopen the competitive process. The period for the subsequent competitive process shall not exceed one hundred and eighty days. If, after such subsequent competitive process, the Secretary receives no proposal which is acceptable under the provisions of this title, the Secretary shall so certify and fully report such finding to the Congress. Not earlier than ninety days after such certification and report, the Secretary may assure data continuity by procurement and operation by the Federal Government of the necessary systems, to the extent provided in advance by appropriation Acts.

TERMS OF CONTRACT

Sec. 304. (a) Any contract entered into pursuant to this title—

(1) shall be entered into as soon as practicable, allowing for the competitive procurement process required by this title;

(2) shall, in accordance with criteria determined and published by the Secretary, reasonably assure data continuity for a period of six years, beginning as s practicable in order to minimize any interruption of data availability;

(3) shall provide that the contractor will offer to sell and deliver unenhanced data to all potential buyers on a nondiscriminatory basis;

(4) shall not provide a guarantee of data purchases from the contractor by the Federal Government;

(5) may provide that the contractor utilize, on a space-available basis, a civilian United States Government satellite or vehicle as a platform for a civil land remote-sensing space system, if—

(A) the contractor agrees to reimburse the Government immediately for all related costs incurred with respect to such utilization, including a reasonable and proportionate share of fixed, platform, data transmission, and launch costs; and

(B) such utilization would not interfere with or otherwise compromise intended civilian Government missions, as determined by the agency responsible for the civilian platform; and

(6) may provide financial support by the United States Government, for a portion of the capital costs required to provide data continuity for a period of six years, in the form of loans, loan guarantees, or payments pursuant to section 305 of the Federal Property and Administrative Services Act of 1949 (41 U.S.C. 255.)

(b)(1) Without regard to whether any contract entered into under this title is combined with a contract under title II, the Secretary shall promptly determine whether the contract entered into under this title reasonably effectuates the purposes and policies of title II. Such determination shall be submitted to the President and the Congress, together with a full statement of the basis for such determination.

(2) If the Secretary determines that such contract does not reasonably effectuate the requirements of title II, the Secretary shall promptly carry out the provisions of such title to the extent provided in advance in appropriations Acts.

MARKETING

Sec. 305.(a) In order to promote aggressive marketing of land remote-sensing data, any contract entered into pursuant to this title may provide that the percentage of sales paid by the contractor to the Federal Government shall decrease according to stipulated increases in sales levels.

(b) After the six-year period described in section 304(a)(2), the contractor may continue to sell data. If licensed under title IV, the contractor may continue to operate a civil remote-sensing space system.

REPORT

Sec. 306. Two years after the date of the commencement of the six-year period described in section 304(a)(2), the Secretary shall report to the President and to the Congress on the progress of the transition to fully private financing, ownership, and operation of remote-sensing space systems, together with any recommendations for actions, including actions necessary to ensure United States leadership in civilian land remote sensing from space.

TERMINATION OF AUTHORITY

Sec. 307. The authority granted to the Secretary by this title shall terminate ten years after the date of enactment of this Act.

TITLE IV—LICENSING OF PRIVATE REMOTE-SENSING SPACE SYSTEMS

GENERAL AUTHORITY

Sec. 401. (a)(1) In consultation with other appropriate Federal agencies, the Secretary is authorized to license private sector parties to operate private remote-sensing space systems for such period as the Secretary may specify and in accordance with the provisions of this title.

(2) In the case of a private space system that is used for remote sensing and other purposes, the authority of the Secretary under this title shall be limited only to the remote-sensing operations of such space system.

(b) No license shall be granted by the Secretary unless the Secretary determines in writing that the applicant will comply with the requirements of this Act, any regulations issued pursuant to this Act, and any applicable international obligations and national security concerns of the United States.

(c) The Secretary shall review any application and make a determination thereon within one hundred and twenty days of the receipt of such application. If final action has not occurred within such time, the Secretary shall inform the applicant of any pending issues and of actions required to resolve them.

(d) The Secretary shall not deny such license in order to protect any existing licensee from competition.

CONDITIONS FOR OPERATION

Sec. 402. (a) No person who is subject to the jurisdiction or control of the United States may, directly or through any subsidiary or affiliate, operate any private remote-sensing space system without a license pursuant to section 401.

(b) Any license issued pursuant to this title shall specify, at a minimum, that the licensee shall comply with all of the requirements of this Act and shall—

(1) operate the system in such manner as to preserve and promote the national security of the United States and to observe and implement the international obligations of the United States in accordance with section 607;

(2) make unenhanced data available to all potential users on a nondiscriminatory basis;

(3) upon termination of operations under the license, make disposition of any satellites in space in a manner satisfactory to the President;

(4) promptly make available all unenhanced data which the Secretary may request pursuant to section 602;

(5) furnish the Secretary with complete orbit and data collection characteristics of the system, obtain advance approval of any intended deviation from such characteristics, and inform the Secretary immediately of any unintended deviation;

(6) notify the Secretary of any agreement the licensee intends to enter with a foreign nation, entity, or consortium involving foreign nations or entities;

(7) permit the inspection by the Secretary of the licensee's equipment, facilities, and financial records;

(8) surrender the license and terminate operations upon notification by the Secretary pursuant to section 403(a)(1); and

(9)(A) notify the Secretary of any "value added" activities (as defined by the Secretary by regulation) that will be conducted by the licensee or by a subsidiary or affiliate; and

(B) if such activities are to be conducted, provide the Secretary with a plan for compliance with the provisions of this Act concerning nondiscriminatory access.

ADMINISTRATIVE AUTHORITY OF THE SECRETARY

Sec. 403.(a) In order to carry out the responsibilities specified in this title, the Secretary may—

(1) grant, terminate, modify, condition, transfer, or suspend licenses under this title, and upon notification of the licensee may terminate licensed operations on an immediate basis, if the Secretary determines that the licensee has substantially failed to comply with any provision of this Act, with any regulation issued under

this Act, with any terms, conditions, or restrictions of such license, or with any international obligations or national security concerns of the United States;

(2) inspect the equipment, facilities, or financial records of any licensee under this title;

(3) provide penalties for noncompliance with the requirements of licenses or regulations issued under this title, including civil penalties not to exceed $10,000 (each day of operation in violation of such licenses or regulations constituting a separate violation);

(4) compromise, modify, or remit any such civil penalty;

(5) issue subpenas for any materials, documents, or records, or for the attendance and testimony of witnesses for the purpose of conducting a hearing under this section;

(6) seize any object, record, or report where there is probable cause to believe that such object, record, or report was used, is being used, or is likely to be used in violation of this Act or the requirement of a license or regulation issued thereunder; and

(7) make investigations and inquiries and administer to or take from any person an oath, affirmation, or affidavit concerning any matter relating to the enforcement of this Act.

(b) Any applicant or licensee who makes a timely request for review of an adverse action pursuant to subsection (a)(1), (a)(3), or (a)(6) shall be entitled to adjudication by the Secretary on the record after an opportunity for an agency hearing with respect to such adverse action. Any final action by the Secretary under this subsection shall be subject to judicial review under chapter 7 of title 5, United States Code.

REGULATORY AUTHORITY OF THE SECRETARY

Sec. 404. The Secretary may issue regulations to carry out the provisions of this title. Such regulations shall be promulgated only after public notice and comment in accordance with the provisions of section 553 of title 5, United States Code.

AGENCY ACTIVITIES

Sec. 405. (a) A private sector party may apply for a license to operate a private remote-sensing space system which utilizes, on a space-available basis, a civilian United States Government satellite or vehicle as a platform for such system. The Secretary, pursuant to the authorities of this title, may license such system if it meets all conditions of this title and—

(1) the system operator agrees to reimburse the Government immediately for all related costs incurred with respect to such utilization, including a reasonable and proportionate share of fixed, platform, data transmission, and launch costs; and

(2) such utilization would not interfere with or otherwise compromise intended civilian Government missions, as determined by the agency responsible for such civilian platform.

(b) The Secretary may offer assistance to private sector parties in finding appropriate opportunities for such utilization.

(c) To the extent provided in advance by appropriation Acts, any Federal agency may enter into agreements for such utilization if such agreements are consistent with such agency's mission and statutory authority, and if such remote-sensing space system is licensed by the Secretary before commencing operation.

(d) The provisions of this section do not apply to activities carried out under title V.

(e) Nothing in this title shall affect the authority of the Federal Communications Commission pursuant to the Communications Act of 1934, as amended (47 U.S.C. 151 et seq.).

TERMINATION

Sec. 406. If, five years after the expiration of the six-year period described in section 304(a)(2), no private sector party has been licensed and continued in operation under the provisions of this title, the authority of this title shall terminate.

TITLE V—RESEARCH AND DEVELOPMENT

CONTINUED FEDERAL RESEARCH AND DEVELOPMENT

Sec. 501. (a)(1) The Administrator of the National Aeronautics and Space Administration is directed to continue and to enhance such Administration's program of remote-sensing research and development.

(2) The Administrator is authorized and encouraged to—

(A) conduct experimental space remote-sensing programs (including applications demonstration programs and basic research at universities);

(B) develop remote-sensing technologies and techniques, including those needed for monitoring the Earth and its environment; and

(C) conduct such research and development in cooperation with other Federal agencies and with public and private research entities (including private industry, universities, State and local governments, and international organizations) and to enter into arrangements (including joint ventures) which will foster such cooperation.

(b)(1) The Secretary is directed to conduct a continuing program of—

(A) research in applications of remote-sensing;

(B) monitoring of the Earth and its environment; and

(C) development of technology for such monitoring.

(2) Such program may include support of basic research at universities and demonstrations of applications.

(3) The Secretary is authorized and encouraged to conduct such research, monitoring, and development in cooperation with other Federal agencies and with public and private research entities (including private industry, universities, State and local governments, foreign governments, and international organiza-

tions) and to enter into arrangements (including joint ventures) which will foster such cooperation.

(c)(1) In order to enhance the United States ability to manage and utilize its renewable and nonrenewable resources, the Secretary of Agriculture and the Secretary of the Interior are authorized and encouraged to conduct programs of research and development in the applications of remote sensing using funds appropriated for such purposes.

(2) Such programs may include basic research at universities, demonstrations of applications, and cooperative activities involving other Government agencies, private sector parties, and foreign and international organizations.

(d) Other Federal agencies are authorized and encouraged to conduct research and development on the use of remote sensing in fulfillment of their authorized missions, using funds appropriated for such purposes.

(e) The Secretary and the Administrator of the National Aeronautics and Space Administration shall, within one year after the date of enactment of this Act and biennially thereafter, jointly develop and transmit to the Congress a report which includes (1) a unified national plan for remote-sensing research and development applied to the Earth and its atmosphere; (2) a compilation of progress in the relevant ongoing research and development activities of the Federal agencies; and (3) an assessment of the state of our knowledge of the Earth and its atmosphere, the needs for additional research (including research related to operational Federal remote-sensing space programs), and opportunities available for further progress.

USE OF EXPERIMENTAL DATA

Sec. 502. Data gathered in Federal experimental remote-sensing space programs may be used in related research and development programs funded by the Federal Government (including applications programs) and cooperative research programs, but not for commercial uses or in competition with private sector activities, except pursuant to section 503.

SALE OF EXPERIMENTAL DATA

Sec. 503. Data gathered in Federal experimental remote-sensing space programs may be sold en bloc through a competitive process (consistent with national security interests and international obligations of the United States and in accordance with section 607) to any United States entity which will market the data on a nondiscriminatory basis.

TITLE VI—GENERAL PROVISIONS

NONDISCRIMINATORY DATA AVAILABILITY

Sec. 601.(a) Any unenhanced data generated by any system operator under the provisions of this Act shall be made available to all users on a nondiscriminatory basis in accordance with the requirements of this Act.

(b) Any system operator shall make publicly available the prices, policies, procedures, and other terms and conditions (but, in accordance with section 104(3)(C), not necessarily the names of buyers or their purchases) upon which the operator will sell such data.

ARCHIVING OF DATA

Sec. 602. (a) It is in the public interest for the United States Government—

(1) to maintain an archive of land remote-sensing data for historical, scientific, and technical purposes, including long-term global environmental monitoring;

(2) to control the content and scope of the archive; and

(3) to assure the quality, integrity, and continuity of the archive.

(b) The Secretary shall provide for long-term storage, maintenance, and upgrading of a basic, global, land remote-sensing data set (hereinafter referred to as the "basic data set") and shall follow reasonable archival practices to assure proper storage and preservation of the basic data set and timely access for parties requesting data. The basic data set which the Secretary assembles in the Government archive shall remain distinct from any inventory of data which a system operator may maintain for sales and for other purposes.

(c) In determining the initial content of, or in upgrading, the basic data set, the Secretary shall—

(1) use as a baseline the data archived on the date of the enactment of this Act;

(2) take into account future technical and scientific developments and needs;

(3) consult with and seek the advice of users and producers of remote-sensing data and data products;

(4) consider the need for data which may be duplicative in terms of geographical coverage but which differ in terms of season, spectral bands, resolution, or other relevant factors;

(5) include, as the Secretary considers appropriate, unenhanced data generated either by the Landsat system, pursuant to title III, or by licensees under title IV;

(6) include, as the Secretary considers appropriate, data collected by foreign ground stations or by foreign remote-sensing space systems; and

(7) ensure that the content of the archive is developed in accordance with section 607.

(d) Subject to the availability of appropriations, the Secretary shall request data needed for the basic data set and pay to the providing system operator reasonable costs for reproduction and transmission. A system operator shall promptly make requested data available in a form suitable for processing for archiving.

(e) Any system operator shall have the exclusive right to sell all data that the operator provides to the United States remote-sensing data archive for a period to be determined by the Secretary but not to exceed ten years from the date the data are sensed. In the case of data generated from the Landsat system prior to the implementation of the contract described in section 202(a), any contractor selected pursuant to section 202 shall have the exclusive right to market such data on behalf of the United States Government for the duration of such contract.

A system operator may relinquish the exclusive right and consent to distribution from the archive before the period of exclusive right has expired by terminating the offer to sell particular data.

(f) After the expiration of such exclusive right to sell, or after relinquishment of such right, the data provided to the United States remote-sensing data archive shall be in the public domain and shall be made available to requesting parties by the Secretary at prices reflecting reasonable costs of reproduction and transmittal.

(g) In carrying out the functions of this section, the Secretary shall, to the extent practicable and as provided in advance by appropriation Acts, use existing Government facilities.

NONREPRODUCTION

Sec. 603. Unenhanced data distributed by any system operator under the provisions of this Act may be sold on the condition that such data will not be reproduced or disseminated by the purchaser.

REIMBURSEMENT FOR ASSISTANCE

Sec. 604. The Administrator of the National Aeronautics and Space Administration, the Secretary of Defense and the heads of other Federal agencies may provide assistance to system operators under the provisions of this Act. Substantial assistance shall be reimbursed by the operator, except as otherwise provided by law.

ACQUISITION OF EQUIPMENT

Sec. 605. The Secretary may, by means of a competitive process, allow a licensee under title IV or any other private party to buy, lease, or otherwise acquire the use of equipment from the Landsat system, when such equipment is no longer needed for the operation of such system or for the sale of data from such system. Officials of other Federal civilian agencies are authorized and encouraged to cooperate with the Secretary in carrying out the provisions of this section.

RADIO FREQUENCY ALLOCATION

Sec. 606(a) Within thirty days after the date of enactment of this Act, the President (or the President's delegee, if any, with authority over the assignment of frequencies to radio stations or classes of radio stations operated by the United States) shall make available for nongovernmental use spectrum presently allocated to Government use, for use by United States Landsat and commercial remote-sensing space systems. The spectrum to be so made available shall conform to any applicable international radio or wire treaty or convention, or regulations annexed thereto. Within ninety days thereafter, the Federal Communications Commission shall utilize appropriate procedures to authorize the use of such spectrum for nongovernmental use. Nothing in this section shall preclude the ability of the Commission to allocate additional spectrum to commercial land remote-sensing space satellite system use.

(b) To the extent required by the Communications Act of 1934, as amended (47 U.S.C. 151 et seq.), an application shall be filed with the Federal Communications Commission for any radio facilities involved with the commercial remote-sensing space system.

(c) It is the intent of Congress that the Federal Communications Commission complete the radio licensing process under the Communications Act of 1934, as amended (47 U.S.C. 151 et seq.), upon the application of any private sector party or consortium operator of any commercial land remote-sensing space system subject to this Act, within one hundred and twenty days of the receipt of an application for such licensing. If final action has not occurred within one hundred and twenty days of the receipt of such an application, the Federal Communications Commission shall inform the applicant of any pending issues and of actions required to resolve them.

(d) Authority shall not be required from the Federal Communications Commission for the development and construction of any United States land remote-sensing space system (or component thereof), other than radio transmitting facilities or components, while any licensing determination is being made.

(e) Frequency allocations made pursuant to this section by the Federal Communications Commission shall be consistent with international obligations and with the public interest.

CONSULTATION

Sec. 607. (a) The Secretary shall consult with the Secretary of Defense on all matters under this Act affecting national security. The Secretary of Defense shall be responsible for determining those conditions, consistent with this Act, necessary to meet national security concerns of the United States and for notifying the Secretary promptly of such conditions.

(b)(1) The Secretary shall consult with the Secretary of State on all matters under this Act affecting international obligations. The Secretary of State shall be responsible for determining those conditions, consistent with this Act, necessary to meet international obligations and policies of the United States and for notifying the Secretary promptly of such conditions.

(2) Appropriate Federal agencies are authorized and encouraged to provide remote-sensing data, technology, and training to developing nations as a component of programs of international aid.

(3) The Secretary of State shall promptly report to the Secretary any instances outside the United States of discriminatory distribution of data.

(c) If, as a result of technical modifications imposed on a system operator on the basis of national security concerns, the Secretary, in consultation with the Secretary of Defense or with other Federal agencies, determines that additional costs will be incurred by the system operator, or that past development costs (including the cost of capital) will not be recovered by the system operator, the Secretary may require the agency or agencies requesting such technical modifications to reimburse the system operator for such additional or development costs, but not for anticipated profits. Reimbursements may cover costs associated with required changes in system performance, but not costs ordinarily associated with doing business abroad.

AMENDMENT TO NATIONAL AERONAUTICS AND SPACE ADMINISTRATION AUTHORIZATION, 1983

Sec. 608. Subsection (a) of section 201 of the National Aeronautics and Space Administration Authorization Act, 1983 (Public Law 97-324; 96 Stat. 1601) is amended to read as follows:

"(a) The Secretary of Commerce is authorized to plan and provide for the management and operation of civil remote-sensing space systems, which may include the Landsat 4 and 5 satellites and associated ground system equipment transferred from the National Aeronautics and Space Administration; to provide for user fees; and to plan for the transfer of the operation of civil remote-sensing space systems to the private sector when in the national interest."

AUTHORIZATION OF APPROPRIATIONS

Sec. 609 (a) There are authorized to be appropriated to the Secretary $75,000,000 for fiscal year 1985 for the purpose of carrying out the provisions of this Act. Such sums shall remain available until expended, but shall not become available until the time periods specified in sections 202(c) and 303(c) have expired.

(b) The authorization provided for under subsection (a) shall be in addition to moneys authorized pursuant to title II of the National Aeronautics and Space Administration Authorization Act, 1983.

TITLE VII—PROHIBITION OF COMMERCIALIZATION OF WEATHER SATELLITES

Sec. 701. Neither the President nor any other official of the Government shall make any effort to lease, sell, or transfer to the private sector, commercialize, or in any way dismantle any portion of the weather satellite systems operated by the Department of Commerce or any successor agency.

FUTURE CONSIDERATIONS

Sec. 702. Regardless of any change in circumstances subsequent to the enactment of this Act, even if such change makes it appear to be in the national interest to commercialize weather satellites, neither the President nor any official shall take any action prohibited by section 701 unless this title has first been repealed.

Approved July 17, 1984.

LEGISLATIVE HISTORY—H.R. 5155:

HOUSE REPORT No. 98-647 (Comm. on Science and Technology).
SENATE REPORT No. 98-458 (Comm. on Commerce, Science, and Transportation).
CONGRESSIONAL RECORD, Vol. 130 (1984):
April 9, considered and passed House.
June 8, considered and passed Senate, amended.
June 28, House concurred in Senate amendment with an amendment.
June 29, Senate concurred in House amendment.
WEEKLY COMPILATION OF PRESIDENTIAL DOCUMENTS, Vol. 20, No. 29 (1984):
July 17, Presidential statement.