On Research Uses of LANDSAT: Letter Report

Committee on Earth Studies, National Research Council
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The Committee on Earth Studies sent the following letter to Dr. Shelby Tilford, Director of NASA's Earth Science and Applications Division, and Mr. Russell Koffler, NOAA Deputy Assistant Administrator of the National Environmental and Space Data and Information Service, on September 12, 1991.

At the May 1991 meeting of the Space Studies Board's (SSB) Committee on Earth Studies (CES), there was an extensive discussion of the current status and future uncertainty regarding the Landsat program. At that meeting, several invited participants from the government, notably from the Office of Management and Budget, and from the House Committee on Science, Space, and Technology, expressed an interest in receiving the views of the CES on the research applications of the Landsat program and its role in the broader satellite Earth observations context. This letter provides a focused analysis based in large part on the previous advice given on this program by the CES, SSB, and other National Research Council (NRC) advisory groups.

The Terms of Reference for this report are to:

1. review the research uses of the Landsat program, referring both to past examples and future needs;

2. examine the research role of the Landsat program in the broader land remote sensing context;

3. identify the difficulties associated with the effective use of Landsat data for research; and

4. provide recommendations for addressing those difficulties.

The committee has been informed that the House Committee on Science, Space, and Technology is planning to introduce legislation regarding the Landsat program in mid-September, and a decision regarding the future of Landsat is expected to be made by the National Space Council and the Office of Management and Budget before the end of September. Given the short schedule for the committee's review, this letter is limited to issues directly related to the basic and applied civil research uses of Landsat and draws heavily on past NRC advice. The rest of this letter is organized according to the Terms of Reference set forth above, and the committee's summary conclusions and recommendations appear in the final section.

RESEARCH USES OF LANDSAT

For almost twenty years the Landsat program has documented both natural and anthropogenic changes on the world's land surface. An uninterrupted stream of observations has provided revealing images—almost three million to date—of the natural environment and the effects of our actions upon it. The many important uses of Landsat have been well documented, most recently at a congressional hearing, on "Military, Civilian, and Commercial Applications of the Landsat Program," held jointly by the House Committee on Science, Space, and Technology and the Permanent Select Committee on Intelligence on June 26, 1991 (referred to below as the "joint hearing"). In this section the Committee briefly reviews the research applications of the Landsat system, primarily as they have been discussed in earlier NRC reports.

Basic Research

As discussed in past SSB reports, Landsat data have been used to support high-priority basic research objectives in geology, hydrology, glaciology, global biology, ecology, and biogeochemical cycles. Additional research areas in which the Landsat program has been instrumental, but that were not covered in the SSB reports, include agronomy, forestry, geography, and soil science.

Landsat data are important to achieving the primary science objectives for continental geology from space, which were established by the CES in its report, *A Strategy for Earth Science from Space in the 1980's-Part I: Solid Earth and Oceans* (Space Science Board, National Academy Press, Washington, D.C., 1982). These objectives, which remain valid today, are (1) to determine the global distribution and composition of continental rock units; (2) to determine the morphology and structural fabric of the Earth's land surface; and (3) to measure temporal changes in geological conditions at the Earth's surface.

Landsat observations have been and continue to be used to address some of the research objectives for the related areas of hydrology and glaciology, as proposed by the committee in *A Strategy for Earth Science from Space in the 1980's and 1990's-Part II: Atmosphere and Interactions with the Solid Earth, Oceans, and Biota* (Space Science Board, National Academy Press, Washington, D.C., 1985). These objectives have included, in particular, the measurement of various land-surface characteristics that control hydrologic responses and are affected by hydrologic change, as well as the horizontal extent of the world's snow and ice cover.

Perhaps most importantly, Landsat data have been used extensively for the study of global biology, ecology, and biogeochemical cycles. In particular, the committee's 1985 report and another report, *Remote Sensing of the Biosphere* (Committee on Planetary Biology, Space

Science Board, National Academy Press, Washington, D.C., 1986), identified several objectives for research on land-surface vegetation and the study of wetlands for which Landsat observations have been especially well suited. These objectives include the measurement of total area covered and the geographic distribution of major biomes and coastal wetlands, and measurement of the rate of change of distribution of major biomes and of annual vegetation production.

A survey of citations in seven databases performed by our committee in August 1991 showed that since 1972, the Landsat program and its data have been discussed in over 13,000 research articles in a broad range of disciplines. The databases surveyed were those of the National Technical Information Service and the Public Affairs International Service, as well as Georef, Geobase, Environmental Bibliography, Meteorological/Geoastrophysical Abstracts, and Water Resources Abstracts.

With regard to basic scientific research needs in the future, the Landsat program has provided an irreplaceable two-decade data set on land-surface processes, which is of critical importance to the U.S. Global Change Research Program (USGCRP) and the International Geosphere-Biosphere Program (IGBP). As noted in the committee's most recent report, *Assessment of Satellite Earth Observation Programs—1991* (Space Studies Board, National Academy Press, Washington, D.C., 1991), the effective "integration of the Landsat data into the research framework of the [NASA] Mission to Planet Earth and USGCRP is especially important." The Landsat program provides a baseline database that can be used to detect signal changes and climate change impacts to the land surface on regional scales. The importance of Landsat data to global change research was underscored by the testimony of Dr. Robert Corell, assistant director for geosciences at the National Science Foundation and chairman of the interagency Committee on Earth and Environmental Sciences' (CEES) Working Group on Global Change, at the joint hearing.

Applied Research

The program has also had a major impact in applied research. In a report of the NRC's Space Applications Board (SAB), *Remote Sensing of the Earth from Space: A Program in Crisis* (Space Applications Board, National Academy Press, Washington, D.C., 1985), the SAB found that "the Earth remote sensing [Landsat] program has demonstrated that the timely acquisition of data from satellites can result in significant social, economic, and scientific benefits," and that the "potential for the future is even greater." The report documented a number of representative examples of the applications of Landsat data and recommended that "Earth remote sensing should be an established and significant part of the nation's civil space enterprise."

Landsat data have become increasingly important in applied research and in the rapidly growing use of Geographic Information Systems (GISs). The far-reaching potential for use of Landsat data in environmental protection, resource management, and numerous socioeconomic applications was amply documented at the joint hearing in the testimony given by Dr. Dallas Peck, director of the U.S. Geological Survey; David Thibault, executive vice president of the Earth Satellite Corporation; Steven Sperry, manager of marketing at ERDAS, Inc.; and Lawrence Ayers, vice president for International Marketing at Intergraph Corp.

In summary, the committee concludes that Landsat observations have provided invaluable environmental information important for both basic research and applications, that the needs and uses for these data have grown steadily, and that they may be expected to continue to increase in the future. Moreover, as discussed in the next section, the Landsat system's capabilities have not been duplicated by other remote sensing systems, nor will they be replaced by any planned system—U.S. or foreign—before the end of the decade.

LANDSAT IN THE BROADER LAND REMOTE SENSING CONTEXT

Although the existing and potential applications of Landsat data provide a compelling incentive for the future continuation of the program, it is important to understand the role of the Landsat system in the overall land remote sensing context. Just as there have been significant advances in and expansion of the basic and applied research uses of Landsat, there have been concomitant advances in land remote sensing technologies and programs, not only in the United States, but internationally. The current and planned land remote sensing systems are reviewed here and compared with the Landsat-6 system, which will fly a Thematic Mapper with 30-m resolution and an Enhanced Thematic Mapper with 15-m resolution.

Table 1 provides a summary of all current and planned land remote sensing capabilities comparable to those of Landsat-6 that are expected to be launched prior to the launch of the NASA Earth Observing System (EOS) in the latter part of this decade. Not included in this comparative overview are lower-resolution sensors such as the Advanced Very High Resolution Radiometer onboard the NOAA polar-orbiting operational environmental spacecraft, or airborne and Shuttle-operated land remote sensing systems. These types of sensors are considered complementary rather than comparable, because of either lower resolution, or limited geographic or temporal coverage. Also not included in this list are several Soviet systems, some of which have high spectral and spatial resolution, but whose data are not available at this time on a consistent basis or in a digitized format.

TABLE 1 Major Characteristics of Selected Land Remote Sensing Systems

	Landsat-6 U.S.A.	SPOT France	MOS-1,2 India	IRS-1,2 India	JERS-1,2 Japan (1992)	ADEOS Japan (1995)
Visible/Near-Infrared Bands	5	3	4	4	3	5
Shortwave Infrared Bands	2	1 (SPOT-4, 1995)	(none)	(none)	4	(none)
Thermal Infrared Bands	1 (120 m)	(none)	(none)	(none)	(none)	(none)
Spatial Resolution of Images	15 m 30 m	10 m 20 m	50 m	36 m 73 m	18 x 24 m	8-16 m
Swath Width	185 km	60-80 km	100 km	148 km	75 km	80 km
Equatorial Crossing Time (+/- 15 mins)	10:30 a.m.	10:30 a.m.	10:30 a.m.	10:30 a.m.	10:30 a.m.	10:30 a.m.
Repeat Cycle	16 days	26 days (1-5 days with pointing)	17 days	22 days	44 days	41 days
Orbital Inclination	98.2°	98.7°	99.1°	polar	98°	98.6°

SPOT - Satellite Pour l'Observation de la Terre
MOS - Marine Observation Satellite
IRS - Indian Remote Sensing Satellite
JERS - Japanese Earth Resources Satellite
ADEOS - Advanced Earth Observing Satellite
Years in parentheses indicate planned launch dates.

As Table 1 indicates, there are at least five other land remote sensing systems, with sensors observing in the visible to infrared portions of the spectrum, that will be operating in the time frame of Landsat-6 and its immediate successor. Each of these systems shares several characteristics with Landsat-6, but none is identical. The other systems differ most significantly in their complete lack of thermal infrared coverage, their narrow swath widths, and, for the JERS and ADEOS systems, long repeat cycles. Thermal infrared observations provide data on surface geology, soil moisture, flooding, water temperature, and coastal currents. Landsat also has better shortwave infrared coverage than all but the planned JERS system. These bands are important for observing, among other things, vegetation characteristics such as biomass, plant stress, and deforestation. The broader swath width (and reduced spatial resolution) of Landsat makes it less costly to acquire and process data for large geographical areas. Finally, only the SPOT series can provide more frequent and timely coverage than Landsat because of SPOT's pointable sensor capability.

Although the technical comparison of Landsat to the other pre-EOS land remote sensing systems demonstrates its unique features, the most important features are not technical. The Landsat program has archived data for 13 years longer than has the second-oldest system, SPOT, and it therefore offers the longest uninterrupted satellite data set for global change research. The other systems' data sets, while partially analogous, are not directly intercomparable with Landsat data. Even more importantly, all the other high-resolution, land-remote-sensing systems are operated by other nations, which means that the U.S. government and research community have only an indirect influence on the technical, programmatic, and policy decisions regarding the characteristics, cost, and availability of the data.

In the latter part of the decade, there are a number of land remote sensing instruments planned as part of NASA's EOS program, in cooperation with the European Space Agency, Canada, and Japan. Although the configuration and instrument payload of the NASA EOS spacecraft have not yet been finalized, it is possible to make some preliminary comparisons with Landsat. The EOS parameters for climate research, and therefore only four of the planned sensors—the Moderate-Resolution Infrared Spectrometer (MODIS), the Multi-Angle Imaging Spectro-Radiometer (MISR), the High-Resolution Imaging Spectrometer (HIRIS), and the Advanced Spaceborne Thermal Emission and Reflection (ASTER) Radiometer—will collect land-surface data in the visible and infrared portions of the spectrum. The highest spatial resolution capabilities of the MODIS and the MISR will be approximately 250 m, and so they are not directly comparable to Landsat.

The two EOS instruments that would have features similar to Landsat-6 are the HIRIS and the ASTER. Although the HIRIS is expected to have 192 spectral bands in the 0.4- to 2.45-micron wavelength region, the instrument would have a swath width of only 24 km and would be used for local area process studies, rather than for regional or global coverage. The narrow swath width would allow the HIRIS to view the entire Earth surface only every 138 days. Moreover, the HIRIS will not fly on the initial EOS spacecraft, and its development under that program is uncertain.

The ASTER instrument, which is being designed and built by Japan as a contribution to the NASA EOS program, would provide data most comparable to Landsat data. The ASTER is expected to have three visible and near-infrared bands at 15-m resolution, six shortwave infrared bands at 30-m resolution, and five thermal infrared bands at 90-m resolution. The swath width would be only 60 km, however, with a pointable cross-track range of 106 km. A significant difference for all of the EOS instruments may be in the spacecraft crossing time, which is currently planned for 1:30 p.m. The afternoon crossing time favors atmospheric and oceanic research objectives rather than the study of land-surface processes, which are better

observed in the morning when there is statistically less cloud cover that might obscure the ground surface.

Thus, even if the follow-on to Landsat-6 were to contain no additional technical improvements, it would still provide a unique observational capability and continuity of this important data set well into a third decade. The committee must point out, however, that copying 1970's technology in the mid-1990s, even though serving a valuable data-collection function, will not take full advantage of current technological capabilities. Although the committee has not been able to review directly competitive technical options for improving the space segment of the Landsat system, it is aware of a number of proposed systems that may be able to provide more effective alternatives. The committee therefore recommends that the government, in considering alternative and innovative technologies for collecting a fully comparable data set into the next century, place the highest priority on maintaining uninterrupted continuity of the Landsat data set, even if that necessitates flying only a slightly improved version of Landsat-6.

IMPEDIMENTS TO EFFECTIVE UTILIZATION OF LANDSAT DATA

Despite the demonstrated success of Landsat technology and the well-documented importance of both the current and historical data to a host of applications, the committee has identified several factors that significantly inhibit more effective use of those data. These impediments may be divided into three categories: those associated with the perennial uncertainty about the long-term continuation of Landsat observations, those related to the cost of the data, and those concerning effective archiving of the data.

As noted in the committee's most recent report (*Assessment of Satellite Earth Observation Programs—1991*, Space Studies Board, 1991), uncertainty about the future continuation of the Landsat program began almost immediately upon its transfer from NOAA to the Earth Observation Satellite (EOSAT) Company in September 1985. Under the terms of the transfer, the government agreed to subsidize the operation of Landsat-4 and -5, as well as the procurement and launch of Landsat-6 and -7. For several years following the transfer, however, the budgets proposed by the Office of Management and Budget did not provide the funds to implement the transition plan. After much debate, the funding was restored each year by Congress. These funding uncertainties caused delays and cost overruns in the development of Landsat-6 and postponed the development of Landsat-7. Potential end users consequently were unwilling to invest resources necessary either to learn how to use the data, or to develop the infrastructure to process the data. This uncertainty, unfortunately, still exists.

In 1990, at the request of Dr. D. Allan Bromley, assistant to the President for science and technology, the NRC undertook a special study to review the U.S. Global Change Research Program as described in the President's FY 1991 budget, and to address several specific questions about NASA's EOS program in the context of global change research. That report, *The U.S. Global Change Research Program-An Assessment of the FY 1991 Plans* (Committee on Global Change, National Academy Press, Washington, D.C., 1990), observed that:

> Current policies that govern the use, distribution, and cost of the Landsat and SPOT data make it difficult for the research community to take advantage of this resource. When purchased from the commercial remote sensing industry, the data are generally too expensive for most research purposes.

In testimony before the Senate Subcommittee on Science, Technology, and Space in October 1990, Dr. Lennard Fisk, Associate Administrator for the NASA Office of Space Science and Applications, estimated that it would cost over $50 million to purchase enough Landsat Thematic Mapper data to compose one "snapshot" of Earth.

Even if access to Landsat data were not significantly inhibited by cost, there would still be a problem in using many of the oldest data. According to a General Accounting Office report, *Environmental Data—Major Effort Is Needed to Improve NOAA's Data Management and Archiving* (GAO, Washington, D.C., November 1990), approximately half of the 130,000 Landsat tapes stored at the USGS EROS Data Center are over 10 years old and are deteriorating. The center does not have the hardware to read, process, and maintain over 30,000 tapes of Landsat-1, -2, and -3 data, and some have already deteriorated beyond recovery.

SUMMARY CONCLUSIONS AND RECOMMENDATIONS

The Landsat system has provided an invaluable environment information resource to our nation and the world. Landsat data have been used in a broad spectrum of basic and applied research. Even more significantly, however, the existing Landsat database and the system's anticipated observations are expected to play an increasingly important role in data-intensive endeavors such as global change research and Geographic Information Systems applications. Finally, there is no existing or planned remote sensing system that currently duplicates or can continue such observations in the event that the Landsat program is discontinued.

Not withstanding its notable successes and growing potential, the full capabilities of this unique data-collection system have been consistently underutilized and insufficiently

supported, and the future continuity of the program remains in doubt. Although the committee has not analyzed the various options available for managing and operating the Landsat system in the future and makes no recommendations on those issues at this time, we wish to reiterate a number of recommendations made by this and other NRC committees that remain relevant to improving the effectiveness of the Landsat system for basic and applied research.

Program Continuity

As noted above, the committee places highest priority on maintaining uninterrupted continuity of the Landsat data set. Simply building and flying another spacecraft, however, is not enough to ensure continuity in the observations. First, a single spacecraft in orbit presents the possibility of a single-point failure and an interruption in observations. Most Earth observation spacecraft series that have been designated as "operational"—including the current Landsat series—maintain two spacecraft in orbit. This issue should be addressed in any decision to continue the program. Second, the sensors should be operated to obtain global land-surface data sets on a consistent basis. Third, all future sensors must be fully calibrated to enable long-term data intercomparability. Finally, the full value of land remote sensing will be realized only if there is continued research and development to create new sensors and if new generations of researchers are trained to use these data. This latter issue deserves greater attention and coordination among the agencies represented on the Committee on Earth and Environmental Sciences.

Access to Data

The effective utilization of Landsat data continues to be seriously compromised by their high cost. Although some progress has recently been made in this regard, notably the availability at the cost of reproduction of all Multispectral Scanner data that are at least two years old, the committee agrees with the 1990 NRC report (*The U.S. Global Change Research Program—An Assessment of FY 1991 Plans*) that:

> Landsat data are sufficiently important to global change research that means should be found to include them in the EOSDIS, whether by revising the Land Remote Sensing Commercialization Act, if necessary, or by paying (again) for the data.

Early inclusion of the Landsat data set in the EOSDIS would be especially useful for the prototype data analysis studies planned under the EOS program. The recommendation is consistent with the "Data Management for Global Change Research Policy Statements,"

officially released by the Office of Science and Technology Policy on July 2, 1991, which states:

> Data should be provided at the lowest possible cost to global change researchers in the interest of full and open access to data. This cost should, as a first principle, be no more than the marginal cost of filling a specific user request . . . .

The 1990 NRC report cited above also emphasized that:

> it is in the interest of international research to make all environmental data readily available to the global scientific community . . . . Similarly, U.S. scientists should have access to relevant data in foreign archives, and it is important that other nations be encouraged to establish similar data policy assessments.

This latter issue takes on increasing significance as the other nations with remote sensing capabilities are placing restrictions on data obtained in their environmental satellite programs. It is particularly important to note that many of the Landsat observations of areas outside North America—relevant to global change research—are received and archived by Landsat ground stations in other countries, and can only be obtained through them.

Maintenance of Historical Data

As the 1990 GAO report (*Environmental Data—Major Effort Is Needed to Improve NOAA's Data Management and Archiving*) pointed out, a significant fraction of the older Landsat data is rapidly deteriorating. Although the USGS has done an outstanding job overall in maintaining voluminous data sets and making them available to the research community, the restoration to the extent possible and proper maintenance of all the Landsat data, whether archived in the United States or abroad, should receive high-priority attention for future research use.

The committee believes that a renewed commitment by the government to the continuity of the Landsat program and to its effective applications will benefit the nation, and indeed the world. I would be pleased to discuss these issues with you further at your convenience.

Signed by
Byron D. Tapley
Chairman, Committee on Earth Studies