The Landsat Legacy: Remote Sensing Policy and the Development of Commercial Remote Sensing

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Abstract

This paper summarizes the policy history of Landsat and examines its place in the development of land remote sensing for science, practical applications related to land use, and the marketplace. In particular, it identifies key steps in creating the foundations for a commercial market in remotely sensed land data and information products. This paper further analyzes the interplay between government policy and technology development for remote sensing. It concludes that one of the primary forces behind the developing market for Earth observation data is the creation of information technologies, including powerful personal computers, geographic information system (GIS) software, CD-ROM, and the Internet. These and other technologies are creating the infrastructure necessary to incorporate remotely sensed data into the broader information marketplace.

Introduction

The 25th anniversary of Landsat 1 provides an important opportunity to review the policies that have guided the development and operation of Landsat and led to other land remote sensing systems. First conceived as an experimental tool for studying and managing Earth's resources, in the 1980s the Landsat system became the focus of an ambitious, but flawed, experiment to transfer government-developed technology to private ownership and operation.

In the 1990s, the Landsat program was returned to the government to serve as a component of U.S. Government efforts to understand the global environment and to support national security needs. Scientists, supported by NASA and other sources, have used Landsat data to support their studies of land processes since 1972. Now, however, the Landsat system is being integrated into NASA's Mission to Planet Earth (NASA, 1996), and will be used to collect as much medium-resolution data about Earth's surface as possible.

Although the commercialization experiment failed, nearly taking the Landsat program with it, the long experience with Landsat data demonstrated the utility of land remote sensing and ultimately led to a new, more sustainable thrust toward a marketplace of remote sensing data and information. Commercial development of land remote sensing continues independently of the Landsat program in the efforts of several companies to serve the information needs of a wide diversity of existing and potential future data customers. Although much of the recent policy focus has been directed at high-resolution systems, the data marketplace, if it continues to expand, will in time likely include low- and moderate-resolution data in a variety of spectral bands selected to serve specific information needs. These efforts are much more likely to be successful because they are based on the pull of the marketplace, rather than the push of federal government policy. A key component of the evolution from programs centered on supporting government needs to private sector initiatives is the growing understanding that land remote sensing could have a significant role in the rapidly expanding information marketplace.

Early Landsat Policy

The Landsat system, taken for granted today, had a rocky beginning. In the early 1960s, experience with the TIROS series of meteorological satellites and the classified Corona reconnaissance program (McDonald, 1995), as well as many years of practical use of aerial photography, indicated both the value and the feasibility of routine satellite observations of the Earth's surface. If sufficient spatial resolution could be achieved, and the right spectral bands chosen, data acquired under similar lighting conditions would make powerful tools for understanding Earth's biophysical systems and managing and exploiting its resources.

Government-supported programs, especially of the magnitude necessary for building a new satellite system, require major policy backing from Congress and the Administration. Despite the allure of such data for a wide variety of useful applications, such backing was slow to come for several reasons (U.S. Congress, 1982:95-6):

- *Concern Over the Reaction of Other Nations.* The national security community was concerned about competition with its classified efforts, and of the possible international reaction if data of sufficiently high resolution were collected by a civilian system. The open skies policy, which was a major tenet of early U.S. satellite policy, became a part of international law with the 1967 Outer Space Treaty. According to the treaty, "Outer space ... shall be free for exploration and use by all States" (United Nations, 1967), which is generally interpreted to mean that nations are free to place in orbit any satellite that does not violate other provisions of the treaty or principles of international law. Despite this treaty, uncertainties about the reaction of other countries to the overflight of a civilian Earth observation satellite caused some officials to question the wisdom of operating such a system.
- *Lack of a Lead Agency with Operational Responsibility for Land Remote Sensing.* In the 1960s, no agency had a clear lead responsibility for mounting a land remote sensing program. Such data could be used effectively by several U.S. agencies, yet no single agency had a need for data great

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enough to be willing to support the investment required by a satellite program.

- *Concern Over Demonstration of Economic Benefits.* Proponents were unable to demonstrate a clear economic benefit compared to other methods of gathering and employing land surface data. In the mid-1960s, when a civilian land remote sensing program was first being debated, attitudes toward new space ventures had already begun to shift from the expansionist vision of Apollo to a concern for cost-effectiveness. In 1967, the President's Science Advisory Committee (PSAC), for example, argued that new programs must demonstrate "... a reasonably clear case of potential utility ..., which includes potential economic benefit, before significant development costs are assumed" (White House, 1967). To many proponents, the condition to demonstrate economic benefits in a new field for which a market did not exist appeared overly strenuous.
- *Competition from Alternative Systems.* Some observers promoted high-altitude aircraft survey instead, as more cost effective and flexible. Further, they believed that relying on aircraft platforms rather than satellites would ease foreign concerns on satellite overflight (Katz, 1976).
- *Lack of an Organized Community of Remote Sensing Data Users.* A land satellite system had only weak support from the several federal agencies and state and local governments that might benefit. In contrast with the earlier case of satellite telecommunications in which a strong commercial market for long-distance communications already existed, there was virtually no market for remotely sensed data. In telecommunications, satellite communications could demonstrate distinct cost advantages over long distance land lines or undersea cable for transmitting voice and data; investors in satellite systems found a ready market for services.

In one form or another, these issues, first raised at the early stages of the Landsat program, have been part of the continuing debate over the Landsat system ever since. Only recently has consensus over the future of multispectral remote sensing emerged.

In the mid 1960s, NASA began to plan for a land remote sensing system. In 1967, the Department of the Interior (DOI) attempted to become the lead agency for a land remote sensing system by announcing the Earth Resources Observation Satellite (EROS) program, which would focus primarily on mapping and geology. Officials within DOI had become convinced of the need for an operational satellite. However, DOI had not obtained the concurrence of the White House and its agencies, including the Bureau of the Budget, the Office of Science and Technology, and the National Security Council (Mack, 1990:ch.5). DOI's attempt failed, leaving NASA, which has a clear role in space research and development (R&D) mandated by the National Aeronautics and Space Act of 1958 (24 USC 2451, 102c-1), in charge of R&D for land remote sensing. NASA continued to refine the program, called the Earth Resources Technology Satellite (ERTS) program. In order to understand the needs of users and develop appropriate satellite instruments, it also experimented with multispectral sensors mounted on aircraft, funding a number of scientific studies of the utility of remotely sensed data (Mack, 1990:50-52).

ERTS-1 was launched on 23 July 1972. It carried a return beam vidicon (RBV) camera for mapping and a Multispectral Scanner (MSS). The latter instrument, which collected data of 80-m resolution in four spectral bands along a swath 185 km wide, was found to be useful for geological exploration and resource monitoring, and became the basis for the current Thematic Mapper (TM) instrument aboard Landsats 4 and 5. In the early 1970s, having lost the battle to operate a satellite system, DOI argued successfully that it should have the primary role in archiving and distributing Landsat data. In 1972, the U.S. Geological Survey broke ground for a new Earth Resources Observations Systems (EROS) Data Center (EDC) in Sioux Falls, South Dakota.

Landsats 2 and 3 were launched in 1975 and 1978, respectively. Both carried the MSS and an updated version of the RBV. All three satellites also carried tape recorders, enabling NASA to download data directly to U.S. receiving stations when the satellite passed within range. During the 1970s, NASA's Landsat program included not only scientific investigations into the detailed relationship between reflectance and the character and condition of Earth's surface, but also applications of the data for resource management. These programs were managed by Ames Research Center, Goddard Space Flight Center, and Stennis Space Center. Between 1972 and 1982, in its Universities Program, NASA granted between $8 million and $10 million to the universities to support research, demonstration, and training in the uses of remote sensing technology. State, local, and private organizations, including the universities, matched NASA's funding with direct support and in-kind grants (U.S. Congress, 1984: 59; 121-125). NASA also embarked on several ambitious applications programs with the Departments of Agriculture (USDA), Commerce (NOAA), Interior, and State, and with state agencies. These programs were established to experiment with using satellite data and improving the understanding of their potential value in agriculture, forestry, land management, development, and resource exploration, among other uses. Two of the most ambitious were the Large Area Crop Inventory Experiment (LACIE), with USDA and NOAA, designed to determine how to estimate grain production in the Soviet Union and Canada, and the Agriculture and Resource Inventory Surveys through Aerospace Remote Sensing (AgRISTARS), with USDA. These programs developed much of the know-how, including software algorithms, that supported later uses of Landsat data in other disciplines. Proponents of the Landsat system argued that Landsat data would assist federal and state agencies to comply with the increasing number of laws requiring environmental monitoring (U.S. Congress, 1984:tab. 15). Landsat data were made available directly from NASA (generally for free), or through EDC for $200 per scene, the cost of reproduction and distribution set by EDC.

These applications programs also assisted in developing the nascent market for Landsat data, and in establishing a new industry devoted to converting raw digital data into useful information. This "value-added" industry became a principal source of innovation for developing methods to "tease" useful information from Landsat data.

One of the key policy thrusts of the Landsat program was to make the data widely available to all potential users, regardless of political affiliation. During the Cold War, Landsat data played an important role in demonstrating the open interchange of ideas and information to the world community. Hence, during the 1970s, despite the existence of onboard tape recorders, the United States also helped to establish Landsat receiving stations in ten other countries. This enabled NASA to collect Landsat data beyond the borders of the United States if the tape recorders failed, as they all eventually did. It also enabled the agency to spread the experience with remotely sensed data as widely as possible, enhancing local markets for data. As a result of these efforts, the Landsat program began to build a small cadre of data users, experienced in analyzing and applying remotely sensed multispectral data.

Data from Landsats 1 through 3 and aircraft experiments demonstrated that data of higher spatial resolution with a greater number of spectral bands than the MSS allowed, would be even more useful for most projects. Hence, in the mid 1970s, NASA began developing the TM, which would fly on Landsats 4 and 5. The TM collects data having 30-metre resolution in six visible and near infrared spectral bands along the same 185-km swath as the MSS. It also carries an additional thermal band of 120-m resolution. During that period, the Carter Administration decided that the system was ready for operational status and decided to transfer operational control to the National Oceanic and Atmospheric Administration (NOAA) (White House, 1979). As Administration officials viewed it, NOAA, which had a successful history of managing the geostationary and polar-orbiting environmental satellites, was much better suited to managing operational systems, leaving NASA free to pursue research and development of more advanced Earth observation instruments. They believed that under NOAA's management the user base for data would eventually mature to the point that private firms could fund, develop, and operate their own remote sensing systems for government and private markets. Additional experience with 30-m-resolution data from Landsats 4 and 5 would help pave the way.

The Office of Management and Budget (OMB) directed that system operating costs would be recovered by data sales, which meant that data prices would have to increase. In October 1981, prices for MSS data increased more than 300 percent to $650 per scene, resulting in a significant drop in the number of scenes purchased (U.S. Congress, 1984:60).

With the Reagan administration, the policy focus shifted to more rapid commercialization of the system, and officials called for "transferring the responsibility [for Landsat] to the private sector as soon as possible" (Wright, 1981). NASA launched Landsat 4 in July 1982, ushering in the use of data from the TM instrument. In 1983, NOAA took over full responsibility for Landsat operations. To cover its costs and prepare customers for commercial prices, NOAA raised the price of data a second time. Not surprisingly, data sales slumped again. Administration officials, who believed that all operational government programs should be transferred to private hands where possible, attempted to move not only the Landsat system to private operation and control, but also NOAA's meteorological satellites (Baldridge, 1983).

Data users in the United States and abroad reacted strongly against the transfer of the weather satellites, which implied that weather data would be sold, rather than exchanged freely. Several foreign governments warned that they would begin to charge for the data they had exchanged freely with the United States. U.S. opponents of this proposal argued that metsat data were public goods and that the means of production should be retained with the public sector. As a result of strong resistance abroad and within Congress, the Administration failed to win approval for transferring the meteorological satellites. Both the House and Senate expressed formal opposition to the sale (U.S. Congress, 1983a; U.S. Congress, 1983b).

Receiving no strong opposition within Congress to private sector transfer of the Landsat system, the Reagan Administration pressed ahead. However, neither the small market for Landsat data sales nor three studies commissioned by the Department of Commerce to consider the matter, provided support for commercializing the Landsat system (U.S. Congress, 1983c). Nevertheless, the likelihood that the Reagan Administration would cancel operation of the system altogether with the demise of Landsat 5, or even sooner, caused Landsat system supporters within Congress and elsewhere to assist in crafting the best possible policy toward commercial transfer. In 1983 and 1984, Congress held a series of hearings on the issue, concluding that Landsat was ready for a phased transfer to private-sector development and operation (U.S. Congress, 1983c). Among other things, supporters worried that continued uncertainty over the future of the Landsat system would hinder the development of operational uses of remotely sensed land data. In the early 1980s, outside of the NOAA Advanced High Resolution Radiometer (AVHRR) aboard the TIROS series of polar-orbiting satellites, the only alternative source of remotely sensed data was from an aircraft, which lacked the repeatability of a polar-orbiting satellite and its worldwide coverage. AVHRR data, however, have extremely low resolution (1 km or worse), though they are available daily. Potential users were reluctant to invest in the hardware and software to process Landsat data, if operation of the system would be discontinued in the near future.

Continuity of a source of similar data became an important factor in the debate over the Landsat system. In order to use the ability of remotely sensed data to detect changes in surface conditions, customers want data that retain similar technical characteristics over time. Commercialization proponents argued that involving the private sector in system operation would assure continuity and in time would bring down the high costs of data. Scientists and educators nevertheless worried that continuing the trend toward high data prices in the near term would make it difficult or even impossible for them to continue pursuing those research and educational activities for which remotely sensed data were crucial (U.S. Congress, 1984:60-61).

On 3 January 1984, the Department of Commerce issued a Request for Proposal (RFP) for a private firm to assume operational control of the system, market the data, and prepare to assume full responsibility for the Landsat system in a few years. Congress crafted a bill that laid out the legal terms for such transfer; it was passed and signed into law on 17 July 1984. EOSAT, Inc., a new company formed by RCA and Hughes Aircraft, won the competitive bidding process in August 1984 and soon took over operation of the system.

According to the plan, NOAA would work with EOSAT to develop Landsat 6 and 7, which EOSAT would operate. EOSAT would put some of its capital at risk by providing partial funding for both satellites, each of which would be designed to last 5 years. In 1985, officials expected that Landsat 6 would be ready for launch in 1990 or 1991, followed five years later by Landsat 7. During the late 1980s, Congress, the Administration, and EOSAT made several abortive attempts to find a funding plan acceptable to all parties.

Because the Landsat system had been built by the government, EOSAT was required by the 1984 Act to "make unenhanced data available to all potential users on a nondiscriminatory basis" (15 USC 4242, 402 b (2)). In order to permit a level playing field for other value added services, the law also required the licensee to "notify the Secretary of any 'value added' activities ... and provide the Secretary with a plan for compliance with the provisions of this Act concerning nondiscriminatory access" (15 USC 4242, 402 b (9)). The two provisions inhibited EOSAT's ability to establish commercial sales policies that might favor one client over another and protected the value added community from the possibility that EOSAT could compete with it for sales of enhanced data products. These policies also inhibited EOSAT's control over sales terms and conditions (Gabrynowicz, 1993: 321). Sales growth of unenhanced Landsat data was steady but slow.

Although the 1984 Act supported the concept of providing sufficient subsidy to ensure commercial success of the program, Landsat's operation was nearly terminated several times for lack of a few million dollars of operating funds (U.S. Congress, 1992:20-23). In addition, EOSAT complicated the negotiations by proposing to fly the TM on a spacecraft designed to be launched by the Space Shuttle and capable of being serviced in orbit by Shuttle crews. Although NOAA agreed to the proposal in March 1986, the Reagan Administration's decision to limit Shuttle payloads to those requiring the unique characteristics of Shuttle (White House, 1986) caused NOAA to instruct EOSAT to prepare for launch on an expendable launch vehicle. Other disagreements between the Administration and Congress delayed a decision to fund the

Landsat system until the spring of 1987 (U.S. Congress, 1991: 6-7).

Ultimately, EOSAT, the Administration, and Congress resolved the confused commercialization effort by agreeing to develop only Landsat 6 under the subsidy terms of the 1984 Act. President Bush "directed the National Space Council and the Office of Management and Budget to review options with the intention of continuing Landsat-type data collections after Landsat 6" (White House, 1989). NOAA and EOSAT planned to launch Landsat 6 in 1992. The federal government provided most of the funding for building and launching Landsat 6. Assuming that Landsat 6 successfully reached orbit and operated as designed, this plan still left the United States with the prospect of entering the late 1990s with no capability to collect Landsat data.

Much of the dispute over the future of the Landsat system involved differing views of its nature. In collecting moderate-resolution data, the Landsat system serves both public and private interests. On the one hand, it provides government agencies with data for carrying out mandated responsibilities in their pursuit of scientific research, managing federal lands, and maintaining public safety (U.S. Congress, 1984:45-47). Yet, data from the system also have direct economic value in the search for oil, gas, and minerals, or for managing private lands. In part, the argument over the future of Landsat concerned which use was more important. If the use of the public good was more important, then the system should remain in government hands. If it predominantly served private interests, or could in the near future, then it was appropriate to take immediate steps to transfer the system to private hands.

Complicating the question was the fact that, in the 1980s, proponents of Landsat technology faced the same problem they had experienced in the 1960s. Despite the fact that the federal government as a whole was, and remains, the largest customer for Landsat data, no single agency was willing to commit sufficient operating funds to continue system operations. System operating costs were estimated to equal \$25 to \$40 million, of which only about \$10 million could be recovered through data sales. Unlike the situation with the weather satellites, for which NOAA had a clear mandate to provide satellite data for weather services, the Department of Commerce had no internal requirement to collect remotely sensed land data. NOAA was selected because of its experience in operating satellite systems. However, because NOAA itself had no operational demand for such data, it had no internal constituency for building follow-on systems. Furthermore, the authorization and appropriations committees of Congress overseeing NOAA's operations provided relatively little support for long term operation of Landsat. This lack of commitment to a continuously operated remote sensing system undercut what little confidence data customers had in the landsat system. Especially those customers needing repetitive data were unwilling to develop necessary infrastructure, train personnel, and make other investments that depended on the delivery of Landsat data.

Non-U.S. Entrants

As the United States continued to debate the future of the Landsat system, other countries, which recognized the economic and social values of acquiring land data, were building their own systems. The French space agency, CNES, had begun planning for the SPOT remote sensing satellite system in 1978. From the first, French planners envisioned the SPOT system as a government-developed, commercially operated system, and set up SPOT Image, S.A., to operate it and to develop a marketing strategy. They initially planned on developing three SPOT satellites, in order to underscore their commitment to an operational system. They also set up receiving stations in other countries, and with NASA's encouragement designed SPOT's downlink frequencies to be compatible with Landsat's characteristics. This commercial stance led SPOT planners to design their system around operational, rather than scientific, needs, considerations that resulted in data of higher resolution but fewer spectral bands.

SPOT-1, which carries a sidelooking, pushbroom electro-optical sensor capable of gathering digital panchromatic data of 10 m resolution, was successfully launched in February 1986. The higher resolution of SPOT data and the satellite's ability to reimage areas of interest in only a few days, rather than waiting a full 26 days to pass over again, gave SPOT data a significant advantage over Landsat data for applications that require such capabilities. The ability to gather data off nadir also enables SPOT Image to create quasi-stereo images of the surface. Although the SPOT instrument has a much smaller swath width of only 60 km, and less spectral coverage than the TM, Landsat supporters worried that SPOT's data sales would undercut sales of Landsat data. On the contrary, SPOT Image helped develop the overall data market by aggressive salesmanship and by demonstrating useful data applications, leading to greater data sales for EOSAT as well as for SPOT Image (Figure 1), thereby setting the stage for future innovation.

During the Cold War, the Soviet Union also built a formidable remote sensing capability, developing a full range of satellite systems, from polar-orbiting weather satellites to photographic film return and digital land systems. Russia inherited these systems, and the Russian firm Soyuzkarta began to market data from the Resurs series of film-return cameras in the early 1990s.

Beginning in 1988, the Indian space agency launched the first of a series of Earth resources satellites that generate digital data compatible with data from Landsat and SPOT. IRS-1A and -1B collect multispectral data of 36- and 72-m resolution. IRS-1C, launched in December 1995, collects multispectral data of 24-m resolution. In December 1993, EOSAT signed an agreement with the Indian National Remote Sensing Agency for exclusive global marketing rights to data from the IRS satellites.

The European Space Agency (ESA) launched its ERS-1 satellite, which carries a synthetic aperture radar (SAR) instrument, in 1991. An identical ERS-2 is also now in orbit. These satellites were designed primarily to collect scientific data about the ocean and ice surface, but also have application to the land. SAR data are particularly useful in geographic areas that experience significant cloud cover. Though data sales have reportedly been extremely slow, customers for data from the ERS satellites can purchase them through Eurimage, the European organization founded to market these and other remotely sensed data.

Japan, which has developed a strong interest in satellite remote sensing, launched its first Marine Observation Satellite (MOS-1) in 1987 to gather data about the ocean's surface. In 1992, it orbited the Japanese Earth Resources Satellite (JERS-1), which carried both a visual and infrared instrument and a SAR. Japan markets data from its remote sensing satellites through the Remote Sensing Technology Center (RESTEC). Data for scientific purposes are available directly from the Japan Space Development Agency, NASDA.

Finally, in the late 1980s Canada began to develop its Radarsat, designed specifically for tracking ice and sea surface conditions. The Canadian government partnered with NASA and with Radarsat International, a private Canadian firm, in building and launching the satellite. Data from this system, which was launched in 1996, are being sold commercially through Radarsat International. Space Imaging EOSAT is the U.S. sales representative for Radarsat data. As a Radarsat partner, NASA receives data from the system for U.S. government-supported scientific studies.

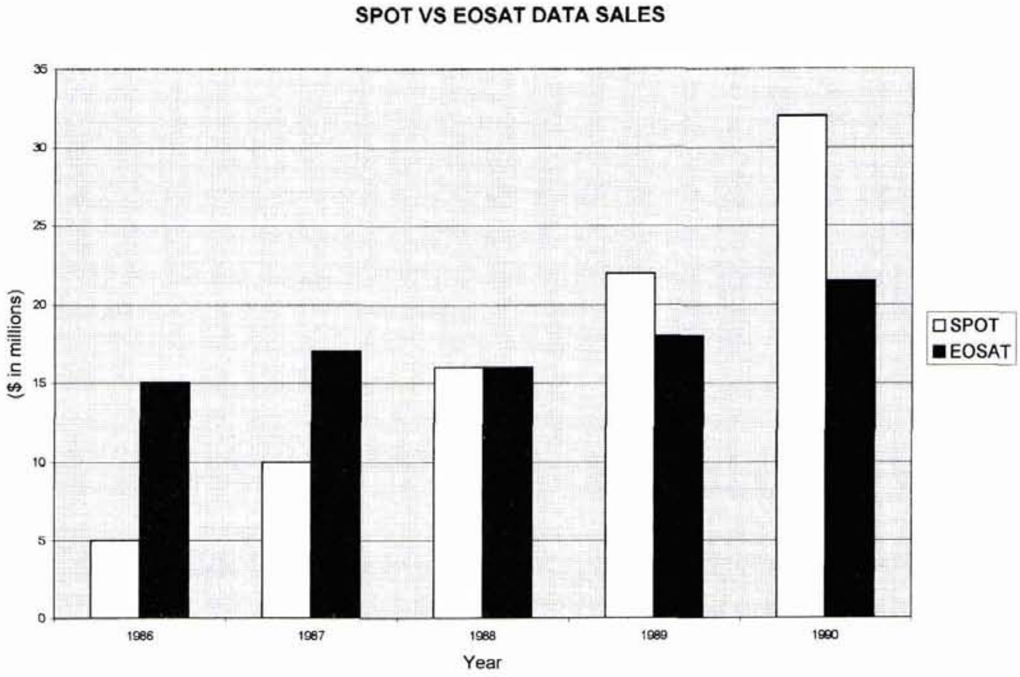

Figure 1. SPOT Image versus EOSAT data sales (source: EOSAT and Space Business Indicators, Office of Space Commerce, Department of Commerce, June 1991).

These efforts, and many others throughout the world, signaled to U.S. policymakers that other countries saw remote sensing as important components of their stance toward technology development. Many worried that the United States had lost an important lead in remote sensing technology.

The Land Remote Sensing Policy Act of 1992

By the early 1990s, considerable pressure had built to return the Landsat system to government operation, aided by four circumstances. First, data from Landsat and SPOT proved extremely important in planning U.S. maneuvers in the 1992 Gulf Conflict. Among other things, these data provided the basis for creating up-to-date maps of the Persian Gulf (Gordon, 1991). The maps had the distinct advantage that, in working with the Gulf coalition, the United States could share them openly with allies. Second, proponents of maintaining the U.S. stake in remote sensing worried that failing to develop Landsat 7 would leave SPOT Image in control of the international market for multispectral satellite data. Third, global change researchers began to realize how important Landsat data are for following environmental change. By 1992, the Landsat archives had accumulated 20 years of multispectral data that could be mined for land cover change information. ESA's successful operation of the ERS-1 radar satellite and construction of ERS-2, as well as France's development of the Helios military reconnaissance satellite, demonstrated that Europe intended to continue investing in remote sensing technology. Fourth, the attempt to commercialize the Landsat system had faltered badly and policy makers began to feel that no private company was likely to be able to provide equivalent data on the scale needed by federal agencies. According to 1990 testimony of John Knauss, NOAA Undersecretary for Oceans and Atmosphere, "Our experience with the Landsat program ... [has] led us to the conclusion that commercialization of Landsat, as had originally been envisioned, is not possible" (Knauss, 1990).

As a result of these and other pressures to continue collecting Landsat data, the Administration, with the strong support of Congress, moved in 1992 to transfer operational control of the Landsat system from NOAA and EOSAT to DoD and NASA (White House, 1992). Under the Landsat management plan negotiated between DoD and NASA, DoD would have funded development of the spacecraft and its instruments and NASA was to fund construction of the ground-data processing and operations systems, operate the satellite, and provide for distribution of Landsat data. The Land Remote Sensing Policy Act of 1992 (P. L. 102-555; 106 Stat. 4163-4180), signed into law in October, codified the management plan and authorized approximately equal funding from each agency for the operational life of Landsat 7.

The act reaffirmed Congressional interest in the "continuous collection and utilization of land remote sensing data from space" in the belief that such data are of "major benefit in studying and understanding human impacts on the global environment, in managing the Earth's natural resources, in carrying out national security functions, and in planning and conducting many other activities of scientific, economic, and social importance" (15 U.S.C. 5601, Sec. 2.). Thus, continuity of data collection became of paramount importance, especially because by 1992, Landsat 4 was capable of transmitting very little data to ground stations and Landsat 5, though still healthy, could have failed at any time.

EOSAT expected to continue supplying Landsat data through Landsat 6. Landsat 6, which was under construction, would carry an Enhanced Thematic Mapper (ETM) that, in addition to having better radiometric calibration, also included an additional "sharpening" panchromatic band of 15 m resolution, allowing the instrument to deliver data with sharpness nearly equivalent to SPOT data. This additional capability had been studied in the mid 1970s but dropped as a result of national security restrictions (L. Walter, personal communication, 1997).

Initial NASA and DoD plans called for Landsat 7 to carry an ETM Plus, an improved version of the ETM that was aboard Landsat 6. Later, the two agencies began to consider including a new multispectral sensor, the High Resolution Multispectral Stereo Imager (HRMSI), which would collect 5-m-resolution data of particular interest to DoD. Cost estimates for developing, launching, and operating Landsat 7 for 5 years equaled $880 million (1992 dollars). NASA considered the instrument optional; in the course of discussions, DoD decided that it should be an operational requirement. However, including the HRMSI sensor on the spacecraft would have cost an additional $400 million for procurement of the instrument and the ground operations equipment. The high data rates expected for the HRMSI nearly doubled the overall required system data rate and would have added significant costs to NASA's yearly ground operations budget.

In September 1993, Landsat 6 was launched but failed to reach orbit. This failure added to concerns that high system costs for Landsat 7 would delay satellite development and might cause appropriators to cancel the project. In September 1993, NASA officials concluded that the costs of operating Landsat 7 with HRMSI were too large to sustain, given other strains on NASA's budget, and did not include sufficient funds to initiate procurement of the necessary ground station processing equipment. In December 1993, DoD decided not to fund the resulting Landsat 7 budget shortfall. As a result of disagreement over the Landsat 7 requirements and budget, DoD decided to drop out of the agreement (Deutch, 1993) and the two agencies pursued separate paths. NASA would fund development of Landsat, carrying only the planned 30-m-resolution ETM Plus. DoD transferred $90 million to NASA to assist in developing the satellite and sensor.

In early 1994, the question of whether NASA or some other agency would operate Landsat 7 had not been resolved. NASA plans to use Landsat data to support its research into land use and land change as part of the U.S. Global Change Research Program. However, Landsat data also support many government operational programs and the data needs of state and local governments, the U.S. private sector, and foreign entities. Hence, Landsat data have national and international value extending far beyond NASA's research needs.

In May 1994, the Clinton Administration resolved the outstanding issue of procurement and operational control of the Landsat system by assigning it to NASA, NOAA, and DOI. Under this plan, NASA will procure the satellite, NOAA will manage and operate the spacecraft and ground system, and DOI will archive and distribute the data at the marginal cost of reproduction (White House, 1994b). This institutional arrangement, because it divides responsibilities for the system, is vulnerable to the Congressional appropriations process and to changes of leadership within the agencies and the White House.

True Commercialization Begins

For commercial remote sensing prospects, the most important provision in the '92 Act was Title II, which set out the terms for licensing private operators of remote sensing satellite systems. Title IV of the 1984 Act had included identical wording, requiring that potential private operators of remote sensing satellites acquire an operating license from the federal government in accordance with international obligations, but, until 1992, no company had taken advantage of it. The licensing obligation proceeds from the 1967 Treaty on Outer Space, which states that "States Parties to the Treaty shall bear international responsibility for national activities in outer space" (United Nations, 1967). Both acts assigned the Secretary of Commerce the lead in considering applications for licenses and required that the Secretary act on such applications within 120 days, "in consultation with other appropriate United States Government agencies ..." (15 USC 5621, Sec. 201 (c)).

In October 1992, shortly after the '92 Act was signed, WorldView, Inc., a small startup company, applied for a license to operate a commercial remote sensing system capable of achieving 3-m panchromatic resolution in stereo. WorldView also planned to collect multispectral data of 15-m resolution in green, red, and near infrared spectral bands. WorldView's sensor was designed to collect stereo pairs along track and could also look sideways off track, enabling rapid revisit of areas of particular interest to customers. The company was able to contemplate operating a commercial system because it had developed a smallsat design based in part on technology created in Lawrence Livermore Laboratory's technology development program for ballistic missile defense. The basic design kept instrument and spacecraft costs down and allowed launch on a small, relatively inexpensive launch vehicle. Perhaps more important, the company developed a data marketing plan based on commercial objectives, rather than on meeting government requirements. WorldView had judged that the ultimate market for these data was the information industry. From the first it planned to use the Internet, CD-ROM, and other information technologies to reach customers quickly and efficiently.

Because granting such a license affects the interests of several agencies beyond the Department of Commerce, including the Department of Defense, the Central Intelligence Agency, and the Department of State, Commerce officials had to coordinate the Administration response. The end of the Cold War heralded by the political collapse of the Soviet Union ushered in a new era for national security planners, moving intelligence officials to ease the earlier restrictions on the resolution limits of civilian data and open up aspects of the previously highly classified reconnaissance establishment. Although the national security community raised concerns about the use of timely, relatively high resolution commercial data by U.S. adversaries or by neighboring belligerent nations, officials were also aware that the French were planning to improve the sharpness of its SPOT system in the near future. In addition, in 1992 the Russian firm Soyuzkarta began to market high resolution multispectral photographic data from the formerly secret Russian KVR-1000 sensor. These data suffer from the drawback that they derive from film return systems and therefore cannot be delivered with timeliness. Because they were designed primarily for reconnaissance tasks, they also lack the radiometric calibration of most data collected by civilian digital systems and hence have limited scientific utility. Nevertheless, 2-m-resolution images of the Pentagon sparked considerable interest in Washington, D.C. and raised worries that other nations would sell high resolution data whether or not the United States decided to do so. In January 1993, in one of the last acts of the Bush administration, the Department of Commerce delivered a license to WorldView to operate a 3-metre satellite system.

Other companies soon followed WorldView's lead. In June 1993, Lockheed, Inc. filed with the Department of Commerce for a license to operate a system capable of achieving 1-m resolution. Shortly after, Orbital Sciences Corp., in partnership (now dissolved) with GDE Systems and Itek, also filed a similar license request. The higher resolution caused the Clinton administration to reconsider the entire process and to develop an overall policy for commercial remote sensing. Although the sale of such data abroad posed no threat of transfer of critical technology, in the view of some, 1-m data were inching too close to the reconnaissance capabilities of high flying aircraft and classified satellites (Gupta, 1994). Others, while recognizing the risk of these data, have argued that they can moderate potential conflict by making data available to all sides in a dispute (Gordon, 1996).

In my view, the emphasis on high resolution to the exclusion of other attributes of modern digital remote sensing technology has distorted the debate over commercial use of the data. Although the photo interpreter would prefer to have access to the highest possible resolution possible, as Jasani (1993) and other researchers have shown, much information of military utility can be gleaned even from moderate-resolution data, especially when their multispectral aspects are used to best effect. Multispectral analysis may be used, for instance, to detect areas that emit excessive amounts of heat or to distinguish camouflaged areas. Among other things, moderate-resolution data can be used for creating maps, to detect the effects of large-scale military maneuvers, and for detecting changes in or near known military installations (Richelson, 1990). For example, bomb damage from Gulf Coalition strikes against bridges and other targets in Baghdad show clearly on images gathered by the SPOT satellites (U.S. Congress, 1993:82).

Nevertheless, 1-m data, delivered in a timely manner, are of significant security utility for surveillance, for military planning, and for creating the up-to-date maps needed to fight battles effectively. When combined with the geolocational capabilities of the Global Positioning System, these data also make it possible for belligerent nations to target specific locations for cruise missile and other precision attacks. Hence, intelligence officials argued, if the data were sold globally, there would have to be some sort of control over distribution. Yet, only if the firm selling the data were a U.S.-licensed firm would the federal government have any control at all. Ultimately, after several months of discussion and hand wringing, officials decided that the benefits of making these data available for a wide variety of civilian uses under the control of U.S. suppliers, were greater than the risks posed by possible misuse of the data.

In March 1994, eight months after receiving the first license application, the White House released a policy statement concerning licenses for commercial remote sensing systems. The policy requires the satellite operator to maintain satellite tasking records and to make them available so that the federal government can determine who purchased what data, if necessary. It also authorizes the government to cut off or restrict the flow of data during times of crisis in order to protect national security interests (The White House, 1994). Several licenses based on this policy have been granted.

The policy also spoke to another aspect of commercial remote sensing — sale of satellite systems to foreign entities. Earlier, Itek, Inc., sought to have the restrictions against selling remote sensing satellite systems to other countries lifted (Frey, 1993). Although Itek also offered to adhere to strict controls over how and where the data were to be gathered, the Administration judged that putting a high-resolution system under the primary control of a foreign government violated U.S. restrictions on transfer of sensitive technology and refused to grant an export license. The Clinton administration policy concluded that "the United States will consider applications to export remote sensing space capabilities on a restricted basis ... . Such sensitive technology shall be made available to foreign entities only on the basis of a government-to-government agreement" (The White House, 1994).

Building the Infrastructure for a Data Market

Building the market for remotely sensed data has required time, patience, and considerable, mostly uncoordinated, effort from many different quarters. One of the impediments to developing a data market was the absence of a supportive information infrastructure. During the 1970s and early 80s, data users had to rely on expensive mainframe computers to process and analyze Landsat digital data. Hence, considerable analysis was carried out using traditional visual techniques on hard copy images. Further, it was extremely difficult to browse through the archives to find the best Landsat images. The facilities for storage and archiving were limited and often relied on paper copies, photographic copies, or magnetic tapes. Although the EDC had been established in 1972 as the central archive for land remote sensing data, until the late 1980s it did not control all the U.S.-held data that had been gathered in the Landsat program. Many tapes were stored at the Goddard Space Flight Center (GSFC) under poor conditions (U.S. Congress, 1994:ch. 2). Users found it difficult to determine what data were available or their quality.

That condition began to change in the early 1980s with the development of software tailored to process Landsat scenes that would run on workstations, rather than mainframe computers. By the late 1980s, inexpensive personal computers became powerful enough to process Landsat data efficiently. In addition, the software industry was producing more capable, more user-friendly software.

One of the biggest drivers toward usability of remotely sensed data was the advent of geographic information system (GIS) software that allows users of spatial data to create layers of information in two-dimensional format, and to manipulate them with relative ease. For the most part, this development occurred independently of remote sensing analysis, but the latter has greatly benefited from it (U.S. Congress, 1994:53-59).

Until commercial satellite systems are delivering data on a routine basis, it will be impossible to assess the precise growth potential for remotely sensed data. Nevertheless, the creation of commercial image processing software and the development and widespread marketing of CD-ROM disks and readers for multimedia presentations have made remotely sensed data more accessible to a wider base of customers. CD-ROM disks are capable of storing massive amounts of digital data, making it possible to distribute Landsat images and other data with considerable ease. CD-ROM readers are relatively inexpensive and are now a standard feature on personal computers. Equipment capable of creating CD-ROMs is also becoming a common item in the marketplace. The ease of creating CD-ROM disks has encouraged companies to tailor remote sensing digital information products for convenient, cost-effective distribution. For example, SPOT Image, Inc., sells data in a wide variety of products, tailored to market needs, and distributes them on CD-ROM, cartridge tape, or other standard media as customers require.

Development of the Internet and database software have had a marked effect on market potential by supporting the search for and transfer of large data files quickly and efficiently by electronic means. Internet access to databases and specific data content also makes it attractive for the data seller to create sample browse images for each scene, so customers can determine for themselves whether or not the scene in question will serve the need in mind. The EROS Data Center has established such a service for its customers. SPOT Image and EOSAT have created similar services. The Internet also promotes electronic queries of databases and ordering. Such net-based solutions, whether through the Internet or through dedicated, private networks, have improved the ability of data suppliers to deliver data quickly and efficiently, vastly improving the timeliness of data delivery.

Another aspect of developing the market for remotely sensed data is the creation of a wide variety of data applications, data products, and the software necessary to analyze them more effectively. For example, Pacific Meridian Resources has recently developed change-detection software that supports "production-oriented methods and services for assessing and monitoring land-use and land-cover change" (Green *et al.*, 1994). As the advertisements in *Earth Observations Magazine, GIS World*, and other magazines attest, other firms are developing software for a wide variety of map making and remote sensing applications.

Pacific Meridian Resources and other firms have been assisted in their development efforts by a program at NASA Stennis Space Center that attempts to foster the development of new products for using remotely sensed data. Called the Earth Observations Commercial Applications Program (EOCAP), this NASA effort annually solicits proposals for small matching grants that will result in improvements in remote sensing "product performance, establishment of standards, reduction in costs, and expansion of market size (Brannon *et al.*, 1994)."

EOCAP (Maculey, 1993) is part of a larger effort by Stennis' Commercial Remote Sensing Program (CSRP) Office. CSRP also supports a Visiting Investigator Program that provides businesses with the opportunity to investigate how remotely sensed data and information tools might serve their spatial information needs. It provides access to Stennis facilities and remote sensing experts. Finally, Stennis also supports the spatial information industry by providing facilities for validating new sensor systems and prototype data sets.

Throughout the history of the Landsat system, the value-added industry has been the primary interface between the data producer and the ultimate user of information generated from remotely sensed data. Most have been relatively small firms, serving the needs of industry, state and local government, and, of course, federal agencies. They, too, have helped build the data market by providing innovative solutions to the information needs of data users.

As noted above, NASA, NOAA, and EDC currently plan to offer data from Landsat 7 for the cost of reproduction and delivery. This policy is governed by the Paperwork Reduction Act of 1995 (44 U.S.C., chapter 35) and the Office of Management and Budget Circular A-130, which states that information collected for government needs should be provided to the public at no more than the cost of dissemination, without restrictions on use or redistribution. This policy is based on the rationale that the public has already paid for data collection to meet a public need. U.S. policy for Landsat 7 is in sharp contrast with policies established by ESA, Canada, and India, which are selling remotely sensed data from government and hybrid government-private multispectral and SAR systems in order to recover part of the system costs (International Space University, 1997). Making Landsat data broadly available at relatively low cost should enhance the overall market for commercial remotely sensed data of much higher resolution. Because Landsat data cover a relatively wide 185-km swath in seven spectral bands, data customers will be able to use inexpensive Landsat data to establish a firm analytical basis for their higher resolution data needs. The open availability of other supportive satellite data (National Aeronautics and Space Administration, 1997) through NASA's Earth Observation System Data and Information System (EOSDIS) should further enhance the commercial market for remotely sensed data and data products of all kinds.

Conclusions

It is much too early to tell which new commercial satellite remote sensing ventures will succeed. Nevertheless, the Landsat program provides an instructive case for transferring technology, developed originally within the government for government needs, to the private sector. It also illustrates the myriad forces at work in developing a new market for goods and services. Government policy enabled the initial development of Landsat technology, promoted it internationally, and made possible the creation of advanced sensors for the new private systems. Ultimately, however, external factors not directly related to remote sensing have played a larger part in developing conditions that make possible a private market for remotely sensed data. The end of the Cold War, which has led to greater openness within the national security community, had a major role in removing technical barriers to commercial systems. The largest influence, however, has been in the development and heavy marketing of information technologies for business and entertainment — GIS, personal computers, and information storage and distribution technologies. The Internet, the result of a different set of government policies than those influencing the development of space technology, has also supported these developments.

Beginning in 1997, several firms expect to launch satellites to collect data for the commercial marketplace. Although the success of these commercial ventures remains to be determined, the inflow of private capital to support remote sensing ventures reflects an increasing vitality in this space sector. Especially in this twenty-fifth year of Landsat, it is important to remember that these companies, as well as many other government-developed systems throughout the world, have built on the Landsat experience in producing consistent, reproducible images of Earth's surface.

The failed attempt to commercialize Landsat technology illustrates one of the great lessons of technology transfer to the marketplace — the infrastructure has to be in place before new technologies can result in successful commercial ventures. Despite the policy failures of the Landsat program, it also shows that government technology efforts can be effective in developing the basic technologies, testing them extensively, and building the knowledge base. However, a new market cannot be legislated. Private industry must find its own way into the marketplace.

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