Landsat: Yesterday, Today, and Tomorrow

Darrel L. Williams, Samuel Goward, and Terry Arvidson

Abstract
Landsat, first placed in orbit in 1972, established the U.S. as the world leader in land remote sensing. The Landsat system has contributed significantly to the understanding of the Earth’s environment, spawned revolutionary uses of space-based data by the commercial value-added industry, and encouraged a new generation of commercial satellites that provide regional, high-resolution spatial images. This PE&RS Special Issue provides an update to the 1997 25th Landsat anniversary issue, particularly focused on the contribution of Landsat-7 to the 34+ year history of the Landsat mission. In this overview paper, we place the Landsat-7 system in context and show how mission operations have changed over time, increasingly exploiting the global monitoring capabilities of the Landsat observatory. Although considerable progress was made during the Landsat-7 era, there is much yet to learn about the historical record of Landsat global coverage: a truly valuable national treasure. The time to do so is now, as the memories of the early days of this historic program are fading as we speak.

Introduction
Approximately 40 years ago, William T. Pecora had a dream. In a decade when most of the space industry and science community centered its attention on getting man to the moon and looking outward toward the universe beyond, Pecora felt that perhaps we ought to look in the mirror with some of our technological advances and at ourselves to learn more about the dynamics of our own planet as influenced by natural events and human activities. What evolved from that dream is what we know today as the Landsat series of Earth observation satellites.

The modern era of terrestrial satellite remote sensing was inaugurated in July 1972 with the launch of the first Landsat (then called Earth Resources Technology Satellite, or ERTS). Landsat-1 pioneered the use of space platforms for systematic collection of land images (Short et al., 1976). These repetitive measurements have produced a virtual revolution in terrestrial research, revealing the importance of medium-to-high spatial resolution, multispectral measurements for monitoring biospheric processes and demonstrating the value of tracking the seasonal and interannual evolution of land-cover conditions anywhere on the globe (Kauth and Thomas, 1976; McDonald and Hall, 1980; Tucker, 1979) (Plate 1). Most recently, on 15 April 1999, Landsat-7 was launched to continue the fulfillment of this dream, to carry on the mission of continuous monitoring and discovery of our terrestrial home at the human scale (Goward et al., 2001).

Our experience over the first several years of the Landsat-7 mission has shown that after adjusting for cloud cover interference, instrument duty cycle limitations, and other image acquisition constraints, a single Landsat satellite is barely capable of global and seasonal coverage (Arvidson et al., 2001). Clearly, improved coverage could be obtained if there were multiple satellites in orbit so as to reduce the number of days between subsequent overpasses. Nevertheless, the database of Earth observation imagery resulting from Landsat-7 and its predecessors is unmatched in quality, detail, coverage, and value. The fact that nearly 40 other Earth-observation missions have been launched or planned internationally in the intervening years speaks to the overall success and importance of the Landsat program (Stoney, 2006) (Plate 2).

Global Change: The Role of Landsat
Over the last quarter century, U.S. and international scientists have increasingly focused on improving our understanding of the Earth’s environmental systems (Bretherton, 1988). Measurements of atmospheric chemistry and models of the global climate system suggest that changes have occurred in the Earth system over the last century. These changes are continuing today, and may alter environmental conditions over the next century (Hansen, 2004). Initial efforts to estimate how the Earth might change over the next century confirmed that the current understanding of Earth systems is incomplete (National Research Council, 1993). For example, the annual atmospheric CO₂ budget cannot be balanced, with about 30 percent of the budget not completely understood. Linkages between land conditions and atmospheric dynamics are poorly defined and rarely specified in planetary climate models. The role and dynamics of human activities within the Earth system are only beginning to be investigated but appear to be a major source of Earth systems change (Houghton, 1999; Sarmiento and Wofsy, 1999). An integrated understanding of how the various elements of the Earth system (i.e., climate, hydrology, biospheric processes, and human activities) interact to produce environmental conditions is clearly needed.

Landsat was one of the major forces leading to the development of the global-scale Earth Systems Science concept, the International Geosphere-Biosphere Program (IGBP), and the U.S. Global Change Research Program (USGCRP) (National Research Council, 1983). In the mid-1980s, after a decade of Landsat research, it became evident that satellite remote sensing could provide the type of globally consistent, spatially disaggregated, and temporally repetitive measurements of land conditions needed to describe terrestrial systems (National Research Council, 1993). Early research using Landsat data demonstrated the significance of the spectral vegetation index measurements as
a record of vegetation conditions (Jackson, 1983; National Research Council, 1986; Tucker, 1979). This index of green foliage density is a fundamental attribute of the landscape, describing the absorption of sunlight, photosynthetic capacity, and evaporation rates. These physical and biological processes are primary descriptors of how land conditions modulate the Earth system (Sellers et al., 1995). Once it was understood that space-based Earth imaging could provide such information about land patterns and dynamics, the possibility of developing fully integrated land-ocean-atmosphere monitoring and modeling capabilities was realized. Landsat image data provide one of the most important elements of Earth observation needed to develop the concept of Earth Systems Science (Goward and Williams, 1997).

The Politics of Landsat

Given its important role in Earth observation, one would think that the Landsat program has been managed with great care over its more than three decades of existence, but unfortunately the Landsat mission has experienced a variety of stresses over its lifetime (Lauer et al., 1997; Mack, 1990). Developed originally as an experimental demonstration of capabilities by the National Aeronautics and Space Administration (NASA), Landsat never found a comfortable operational home (Marshall, 1989a; Marshall, 1989b; National Research Council, 1985 and 1995). The Land Remote Sensing Commercialization Act of 1984 (Public Law 98–365, 1984) charged the National Oceanic and Atmospheric Administration (NOAA) with the task of transferring the Landsat program to the private sector. The Earth Observation Satellite Company (EOSAT) was awarded a contract to take over operations of Landsats 4 and 5 for ten years and to develop and build two new satellites, including the ground system. Over the next decade, numerous problems were encountered including substantially increased data costs, limited global acquisitions, severe data exchange constraints, and a failure to successfully place Landsat-6 in Earth orbit. In 1992, on the heels of the Department of Defense’s (DOD) successful Desert Storm activities in Iraq and Kuwait, the U.S. Congress passed U.S. Public Law 102-555 to return the Landsat mission to Federal government management (Public Law 102-555, 1992). In the years following, several different Federal agencies (DOD, NASA, NOAA, and the U.S. Geological...
Survey) became involved in the Landsat-7 program, which was ultimately built and launched by NASA and then turned over to the USGS for oversight of day-to-day operations and maintenance of the Landsat archive to support both the U.S. Earth science research goals and the broader applications community.

Landsat Observation Record
The fact that we have had a continuous record of Landsat coverage since July 1972 without any gaps in that coverage is more a matter of good luck and excellent engineering rather than careful management oversight (Plate 3). For example, Landsat-5, launched in March 1984 with a three-year design life, remains operational today (July 2006), nearly two decades beyond its design life: truly amazing and very fortunate. The high quality of the early Landsat images was a primary cause of its tumultuous history. Because the images looked so good, many felt that Landsat had to have significant commercial value and should be turned over to the private sector, as was being done with communications satellites in that era. In the next section, a more complete, yet still brief, discussion of the Landsat program history is provided.

Historical Overview of Landsat
Yesterday
Early experiments in Earth imaging from space persuaded Earth scientists that detailed imaging of the Earth’s land areas was possible (Lowman, 1998). These experiments involved Explorer-6 in 1959, the Television Infrared Operational Satellite (TIROS) series of satellites beginning in 1960, and Earth photographs by astronauts during the Gemini and Apollo missions. By the late 1960s, both the Department of the Interior (DOI) and NASA were involved in planning an Earth observation mission (Sheffner, 1994). This work came to fruition in 1972 with the launch of Landsat-1.

Multispectral Scanner Era
The first Landsat mission included a three spectral-band (green, red, near infrared) return beam vidicon (RBV) camera, which was to provide a high-quality, calibrated television-like image (Freden and Gorden, 1983; Mika, 1997). Landsat-1 also carried a new experimental instrument called the multispectral scanner (MSS), which was a four spectral-band instrument (green, red, and two near-infrared bands). As originally planned, the RBV sensor was meant to be the primary Landsat-1 imager, producing replicates of the high-altitude, aircraft-acquired, color-infrared photography then widely used in Earth resources management. The MSS imager was considered experimental because it tested the concept of calibrated line scanner multispectral imaging (which was indicative of the state-of-the-art aircraft multispectral scanners of that era). The possibility of conducting numerical analysis on either the RBV or MSS data was envisioned. However, the RBV was viewed primarily as a source of pictures, whereas the MSS lent itself more easily to spectral imaging and analysis. An early failure of the RBV sensor on Landsat-1 caused a significant shift toward numerical imaging analysis during the early years of the Landsat mission.

The early focus of the Landsat program was a mix of technology development and resource mapping, and the first decade was marked by steady progress within various application domains. Early researchers had to confront the coarse spatial and spectral resolution of the MSS sensor and the tremendous data volume (tremendous in that era, but trivial today) that largely confined early analysis to visual interpretation of photographic products (Mack, 1990). Nevertheless, Landsat MSS data proved useful for agricultural monitoring, petroleum exploration, mining, and environmental surveys (Draeger et al., 1997). By the time Landsat-1 was retired in 1978, it had delivered more than 300,000 images of Earth. More importantly, the quality and value of the information far exceeded all expectations. During pre-launch ceremonies at Vandenberg Air Force Base in 1975, just prior
to the launch of Landsat-2, Dr. James Fletcher, the administrator of NASA at that time, stated that if he had to name one space-age development to save the world, it would be Landsat and its successor satellites.

**Thematic Mapper Era (Privatization)**

With the July 1982 launch of Landsat-4, the new Thematic Mapper (TM) sensor was introduced (Salomonson, 1984). The TM was a significant improvement over the MSS, providing better spatial resolution, as well as three additional spectral bands (Table 1). The Landsat-3 version of the MSS also was flown on Landsat-4 to ensure overlap with the new sensor and to provide additional backup. The same MSS and TM instrument payload was on Landsat-5, launched in 1984.

Technological innovation was not the only form of experimentation with Landsat. The 1980s also saw a fundamental shift in the country’s policy toward Earth remote sensing. Intense discussion focused on the roles of the government and the private sector. One view was that all civilian Earth remote sensing (meteorological, oceanic, and terrestrial) should be performed by the private sector (Pace et al., 1999). An opposing view was that remote sensing was the proper function of government because it was for the common good. This conflict focused on the land observations. The meteorological and oceanic communities already had satellite missions and/or an entire Federal agency specifically focused on addressing those topical areas of research, whereas routine monitoring of the land surface had no similar program. In accordance with the Landsat Remote Sensing Commercialization Act of 1984, the NOAA transferred the Landsat program to the private sector, awarding the contract to EOSAT.

As in any transition, there was much to learn. The change to private management resulted in a steep increase in the price of the image data, and this drove away many academic researchers who turned instead to Advanced Very High Resolution Radiometer (AVHRR) data or synthetic aperture radar (SAR) data (Draeger et al., 1997). Those who continued to use Landsat data generally were confined to the purchase of only a few scenes or the sharing of data among Federal agencies, largely defeating the promise of multi-temporal monitoring defined by earlier programs (Townshend, 1994). In addition, the acquisition policy for images (which was never clearly defined for Landsat) became even more piecemeal, with large gaps in the U.S. archival coverage for southern Asia, Africa, and Latin America, where little demand existed for commercial sales of Landsat data.

**Blossoming of Earth Systems Science**

A fundamental shift in science priorities also occurred in the 1980s, with the evolution of the concept of global change research (Bretherton, 1988). Earth science began to focus on the interconnections between the atmosphere, terrestrial biosphere, and hydrosphere in an attempt to quantify the response of the Earth system to natural and anthropogenic forces. A delicate dialog between global climate models and long-term observations that both feed and validate these models was required to understand these complex relationships (National Research Council, 1986; Sellers and Schimel, 1993). The three-decade record of Landsat observations has proven to be particularly useful for studying long-term changes of the terrestrial biosphere. For example, tropical forests represent a large store of terrestrial carbon, and deforestation represents a significant perturbation of the global carbon cycle (Houghton et al., 1990). Long-term observations using Landsat MSS and TM image data have proven essential to quantifying the rates of tropical deforestation, yielding results significantly different than those obtained using coarser AVHRR data (Tucker et al., 1984; Cross et al., 1991; Skole and Tucker, 1993).

Landsat observations have become invaluable in helping scientists understand changes in the land surface, cope with the challenges of nature, and exploit the resources of the Earth. Landsat is no longer an experiment; it is a fundamental part of the country’s infrastructure. The Landsat program has become a central pillar of the national remote sensing capability. Landsat established the U.S. as the world leader in terrestrial remote sensing, contributed significantly to the understanding of the Earth’s environment to Advancing Satellite’s Open Data (National Academy of Sciences, 1991; National Research Council, 1990; National Academy of Sciences, 1984).

**Today**

Following the successful launch of Landsat-7 in April 1999, coupled with the continuing good fortune of having Landsat-5 remain operational far beyond its three-year design life, we have had the luxury these past seven years of having two operational satellites in orbit (Goward et al., 2001). The orbit cycles of these two satellites have been phased so as to yield eight-day repeat coverage anywhere on the globe, but with the caveat that Landsat-5 data can only be captured within line of sight of those locations where operational ground stations are being maintained.

**Enhancing the Observatory**

The Landsat-7 mission has been more than just a mission of “continuity” because with each successive Landsat mission the expectation has been to improve upon the foundation built by its ancestors whenever possible (Goward et al., 2001). Given our improved and evolving understanding of what was most desirable and needed, coupled with significant advances in data handling and computer processing capabilities throughout the 1990s, we have added for several enhancements during the development of Landsat-7. These enhancements ranged from improved sensor capabilities (Table 1), to a dramatic increase in the average number of scenes.

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**Table 1. Evolution of the Landsat Sensor Suite**

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Enhancements Over Previous Sensors</th>
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<tbody>
<tr>
<td>Multispectral Scanner (MSS)</td>
<td>• Four spectral bands (green, red, two near-in)</td>
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<tr>
<td></td>
<td>• 80 m resolution</td>
</tr>
<tr>
<td></td>
<td>• Multispectral scanner versus camera</td>
</tr>
<tr>
<td>Thematic Mapper (TM)</td>
<td>• 3 additional bands in shortwave IR (2) and thermal IR</td>
</tr>
<tr>
<td></td>
<td>• 30 m resolution</td>
</tr>
<tr>
<td></td>
<td>• 15 m panchromatic band added for edge sharpening</td>
</tr>
<tr>
<td>Enhanced Thematic Mapper (ETM)*</td>
<td>• Selectable high/low gain for each spectral band</td>
</tr>
<tr>
<td>Enhanced Thematic Mapper Plus (ETM+)</td>
<td>• 60 m thermal IR versus 120 m</td>
</tr>
<tr>
<td></td>
<td>• Onboard partial aperture and full aperture calibrators</td>
</tr>
</tbody>
</table>

*This sensor was never operated on-orbit; it was on Landsat-6, which never achieved orbit.*
As one might expect, the failure of the Landsat-7 ETM+ scan-line corrector caused a great deal of concern within the Landsat user community about maintaining the continuity of global data collection with a Landsat-class sensor. The question quickly arose, when might the next Landsat mission be ready for launch? This is truly an obvious question, but unfortunately it is one with a very convoluted and complex answer. When the U.S. Congress passed U.S. Public Law 102-555 in 1992 to return the Landsat mission to Federal government management, one of its provisions called for the timely development of a follow-on system to maintain continuity beyond Landsat-7. However, the law further stipulated that four different options for such a follow-on system must be fully investigated, namely:

1. Private/commercial solution,
2. Joint government/commercial venture,
3. International consortium solution, or
4. Federal government solution, such as that implemented for Landsat-7.

The wording of the law made it clear that the last option, a wholly Federal government solution, was not preferred.

Landsat Data Continuity Mission

NASA and the USGS began planning for a follow-on mission well before Landsat-7 was even launched. However, the tumultuous political history of the Landsat program has prevailed. In 2001, NASA and USGS initiated the Landsat Data Continuity Mission (LDCM) to meet the goal of the law. Following initial attempts to explore a procurement of commercial imagery, and then integration of a Landsat-class sensor aboard the NOAA Polar-orbiting Operational Environmental Satellite System (NOOPESS) platform, current plans call for a government-managed “free flyer.” Draft requirements for the LDCM specify nine reflective spectral bands, including a shortwave infrared band for cirrus cloud detection and a new blue band principally for coastal zone observations (NASA, 2006). The draft specification also requires a 30 m spatial resolution for each spectral band, with the exception of a 15 m spatial resolution for the panchromatic band, and improved radiometric performance compared to Landsat-7.

As of July 2006, the request for proposals for the LDCM is expected to be released later this year, with projected launch no earlier than 2011. Given the age and condition of Landsat-5 and Landsat-7, a gap in Landsat coverage is highly likely, if not certain, before the LDCM becomes operational. To avoid a repetition of this situation, the White House Office of Science and Technology Policy (OSTP) has recently convened a working group to address Landsat continuity and the future of land imaging. For additional information the reader is referred to the “Highlight” paper in this special issue by Irons and Masek that provides some additional details about the planned LDCM procurement. As for the cause of some of the political issues that have plagued the Landsat program over the past three decades, the reader is encouraged to read the “Landsat Business Model” paper by K. Green in this special issue.

Special Issue Synopsis

As mentioned previously, the Landsat-7 mission included several enhancements to the Earth-observing instruments (i.e., the ETM+) and various other elements of mission operations (i.e., ACCA) that would directly impact the quantity and quality of data acquired by the system. Our goal since launch has been to quantify and validate whether these intended enhancements were successful. This validation would provide us not only lessons learned but also would be of value for future mission planning for Landsat-type mission, including the Landsat Data Continuity Mission.

Given the insights we had gained in developing the Landsat-7 mission operations model, we recognized the value of also taking a retrospective look at the composition and character of the historical global Landsat observation record held in the U.S. National Satellite Land Remote Sensing Data Archive (NSLRSDA) at USGS/ERS.

U.S. NSLRSDA Landsat Holdings

Within the community of data users, there is an oft-held misperception that the Landsat missions have always acquired all possible data at all times, and therefore, the archive of global coverage should be complete for all 34+ years of the Landsat era dating back to 1972. This is not the case, as is described and illustrated in Goward et al. (2006): “Historical Record of Landsat Global Coverage: Mission Operations, NSLRSDA, and International Cooperator Stations.” This paper provides a comprehensive review of the U.S. Landsat archive holdings, which has revealed that data gaps of varying magnitude do exist in our archive of Landsat acquisitions. Analyses are underway to identify the reasons for these gaps and, where possible, identify holdings at
International Cooperator ground stations may assist in filling the gaps in the U.S. archive at USGS/EROS.

**Landsat-7 LTAP**

Perhaps the most significant element in the development of the Landsat-7 mission operations approach is the long-term acquisition plan (LTAP), by which the scenes to be acquired on any given day are automatically selected. This is how the exceptional coverage of Landsat-7 was achieved. The validation of this LTAP system is described in Arvidson et al. (2006): “Landsat-7 Long-Term Acquisition Plan: Development and Validation.” The LTAP was designed to assure the acquisition of a seasonally-refreshed, essentially cloud-free global archive of Landsat-7 data, by incorporating seasonal-ity and cloud avoidance into the decision making used to schedule image acquisitions, the Landsat-7 data in the U.S. Archive is more complete and of higher quality than has ever been previously achieved in the Landsat program. Furthermore, when the Landsat-7 ETM+ scan-line corrector mirror failed, we were able to adjust the LTAP operations concept, thereby demonstrating the flexibility of the LTAP concept to address unanticipated needs.

**Automated Cloud-Cover Assessment**

A critical element in the LTAP success has been the automated identification of cloud cover in acquired scenes. Irish et al. (2006) discuss the approach used for Landsat-7 in the “Characterization of the Landsat-7 ETM+ Automated Cloud-Cover Assessment (ACCA) Algorithm.” The ACCA scores are a primary means to confirm successful acquisition of global “cloud-free” imagery for the U.S. archive. Based on our experience with Landsat-7, we believe that future Earth remote sensing systems should place increased importance on the ability to perform image cloud screening so that multi-date compositing can be more easily performed as is currently done with Landsat-7 data, by incorporating seasonal-ity and cloud avoidance into the decision making used to schedule image acquisitions, the Landsat-7 data in the U.S. Archive.

**Sensor Gain Changes**

Curiously, Landsat-7, through its heritage from ERSAT and Landsat-6, had the potential of selecting from two gain states for each spectral band. From the beginning of Landsat-7 operations, this “feature” created serious stress on the mission operations. Markham et al. (2006) document these struggles in “Landsat-7 Long-Term Acquisition Plan Radiometry – Evolution Over Time,” which addresses the history, rationale, and results for the various strategies that were employed to set the radiometric gains for the ETM+ instrument as part of the Landsat-7 long-term acquisition plan. The Landsat-7 LTAP team had to go through several iterations on various acquisition strategies to effectively use the two gain states.

Although the gain setting strategy has improved with time, the results are still not totally satisfactory as gain changes still impact some scenes and saturation still occurs, particularly over the thermally snow-covered regions. The future solution is for the sensor system to have the capability of measuring the full range of Earth targets sensed. This can be achieved at the precision required without the need for a gain change. This type of solution is currently being used on the Advanced Land Imager (ALI) sensor on the Earth Observer-1 satellite, where a 12-bit analog-to-digital converter is used and the saturation radiances cover up to full-diffuse solar at the appropriate sun angles. As a lesson learned, the Landsat Data Continuity Mission instrument has been specified to meet the necessary dynamic range and precision requirements without implementing gain changes.

**Landsat Business Model**

The root of the complex administrative history of the Landsat mission, and the major factor which served as a drag in the development of this information technology to meet societal needs, has been the confusion about what business model should be used to manage the Landsat mission. Kass Green provides a clear retrospective view in her invited paper “Landsat in Context: The Land Remote Sensing Business Model.” This paper extends beyond mission technical insights to provide a perspective on how the management history of the mission conflicted with the development of the mission technologies. We feel that her perspective helps to explain the tumultuous “Perils of Pauline” history of the Landsat program. The reader is encouraged to read this paper, and we provide the following excerpts:

“Earth remote sensing has long been considered essential to human endeavors. Beginning with military reconnaissance and evolving to weather, agriculture, environmental, and disaster monitoring, remote sensing broadens our view and provides context for our actions. While the provision of airborne remote sensing data is overwhelmingly a function of the commercial sector, space remote sensing remains predominately the purview of the public sector. Most attempts to commercialize space remote sensing have failed, because there has not been a consumer base large enough to finance the enormous fixed costs of designing, building, launching and operating space remote sensing systems. . . . A program for the provision of moderate resolution Landsat-like satellite data, moderate resolution imagery is a public good whose provision/acquisition must be the responsibility of the government sector. While commercial ventures will surely benefit from the public provision of moderate resolution satellite data (as the weather and GPS value-added industries have), they are merely spin-offs, and not a reason to fund the program. . . . "A program for the provision of moderate resolution Landsat-like data must be funded by the government because the public needs it: both the people of the United States and our global community." . . . “The American public and the global community need moderate resolution multi-spectral land remote imagery for environmental security, homeland security, and food security. It is a public need, and must be provided as a public good.”

**Remaining Challenges**

Our comprehensive look at the composition and character of the historical global Landsat observation record has made us realize how little we know about some of the details of how this historical record was accumulated and has been maintained in archives, both within the U.S. and internationally. With each passing day, we move further away from the technicians, experts, and visionaries who originally set up and have operated this system over more than three decades. With this first analysis of the U.S. NSLRSDA holdings complete, we are now highly aware of the need to move quickly to embrace all possible collections of these data, particularly those held within the International Cooperator holdings. Furthermore, we now also understand that we do not know enough about the U.S. and international archives to accurately characterize and describe the holdings, never mind address issues such as data calibration and comparability between observatories.

To develop the limited understanding of the history of past Landsat operations presented in “Historical Record of Landsat Global Coverage: Mission Operations, NSLRSDA, and International Cooperator Stations (2006)” by Goward et al., we used interviews, IC meeting minutes, Landsat program newsletters, personal notes and correspondence, and status
reports and personal knowledge. Unfortunately, there is a lot of information about policies, scheduling drivers, and other factors affecting coverage patterns that has not yet been found. In some cases, we can only make semi-informed guesses as to what might have been the reasons for the spatial-temporal coverage patterns we see (Goward et al., 2006).

**Landsat Legacy Project**

There are still large holes in our information base. As a result of these studies, the NASA Goddard Landsat Project Science Office (LPSO) and the USGS NELRSDA team have undertaken a new effort to more fully capture the history of the Landsat program. Within the LPSO, we have named this activity the Landsat Legacy Project.

The Landsat Legacy Project (Rocchio et al., 2005) aims to capture the technical and policy baseline for the Landsat program. Another component of the Legacy Project is to digitally record oral histories from prominent figures in the Landsat program. Although many of these important sources of information are still affiliated with the Landsat program, sadly some very key contributors are no longer alive. As a reader of this article, if you feel that you have either documents or unique personal knowledge to contribute to this process, we ask that you contact us to arrange for document transfer or an interview.

**International Cooperators and the Landsat Global Archive**

We are at risk of losing a significant portion of the historical Landsat record, not in terms of policy decisions and documentation, but more importantly in terms of the millions of scenes resident in IC archives around the globe. There is no question that the IC archive holdings are an important element of the full historical record of Landsat data. Even if only half of the greater than 4 million scenes currently in IC holdings are complements to U.S. NSLSDA holdings, they would double the size of the U.S. archive, and for many years, may fill serious holes in the current U.S. holdings. We have begun to work with the ICs to make sure that this important historical record is preserved and made easily accessible to the global user community.

**Beyond Data Inventory**

There are many other aspects of the global Landsat data record that still need examination. Basic information about the instrument characteristics as well as the processing systems that generated the archival data is becoming difficult to find and must be captured before it is irrevocably lost. In part, we hope to capture this information through the Landsat Legacy project and employ Legacy documents to produce adequate documentation for the entire Landsat mission, 1972 to present. We are also pursuing this with the ICs, most recently by capturing the radiometric correction history of the IC processing systems. Full documentation of each mission, from Landsat-1 to Landsat-7, is needed, preferably in a form similar to the Landsat-7 Science Data Users Handbook: [http://landsathandbook.gsfc.nasa.gov/handbook/handbook_toc.html](http://landsathandbook.gsfc.nasa.gov/handbook/handbook_toc.html). Already, the NASA LPSO is incorporating radiometric and geometric information on the early Landsat sensors into the current Landsat-7 version of the handbook.

**Observation Interoperability**

There is increasing discussion about the need to seamlessly incorporate remote sensing observations from different sources (Landsat-7, Système Probatoire d’Observation de la Terre (SPOT), Indian Remote Sensing (IRS) satellite) into the global change analysis process. This is equally a problem in moving from Landsats 1 through 7. Much effort has been put into making the ETM+ one of the best calibrated instruments in Earth remote sensing (Goward et al., 2001). Work is well underway on calibrating the Landsat-5 TM with Landsat-7 ETM+ (Teillet et al., 2001) calibration information. There are plans for including Landsat-4 TM in this effort as well. However, there is currently little if any effort being given to characterizing the earlier MSS data sets, or to understanding the current state of their calibration. This should be addressed to assure the best quality data is available for long-term global change analyses.

Even if we attain consistent calibration parameters, all of that effort will be wasted if the community does not embrace consistent processing algorithms. Today, many differing archives of Landsat data exist, not only at USGS/EROS but also at other Federal agencies, universities, non-Governmental organizations (NGOs), and within private companies throughout the world. These holdings vary in their quality and attributes (including geometric registration methods, radiometric calibration sources, and resampling methods) thus increasing the difficulty in carrying out long-term land change detection studies. Before full value of the historical record of Landsat observations can be realized, a new undertaking, similar to what has previously been done with NOAA’s AVHRR series of instruments, is needed (James and Kullari, 1994).

**Conclusion**

The digital image data provided by the Landsat series of satellites over more than 34 years are one of the most valuable scientific assets available to the Earth science user community. Indeed, Landsat data have done as much to solidify the concept of Earth systems science over the past two decades as any other single source of terrestrial information. These data provide the most consistent, reliable documentation of global land-cover type and land-cover change over the past three decades.

The work presented in this PE&RS Special Issue on Landsat provides an update on efforts to maintain and increase the quality of the Landsat observation record through the Landsat-7 mission. Hopefully, the lessons learned in this decade will continue to influence land remote sensing scientists and engineers in the decades to come.

**References**


