Requirements for a Landsat Data Continuity Mission

by James R. Irons and Jeffrey G. Masek

Landsat Data Continuity Mission requirements rest on science, societal benefits, heritage, public law, Executive Office direction, and an eye to the future.

A Landsat Data Continuity Mission (LDCM) will advance the legacy of the Landsat program with the intent of serving science and society. The performance of the Landsat 7 satellite system, the predecessor to the LDMC, has set a standard with respect to rigorous calibration, an enlightened data policy, and global data collection. LDCM requirements advance this standard in accordance with public law, current technology, and Executive Office direction. The LDCM will provide a core capability that serves as a foundation for a global land observing system.

Introduction

The United States (and the rest of the world) require a Landsat Data Continuity Mission (LDCM) to succeed the Landsat-7 satellite system. Driven by population growth and developing technologies, the land surface of the Earth is changing at rates unprecedented in human history with profound societal consequences. The requirements for LDCM reflect basic needs to characterize land cover type, rates of change, and ecological health for Earth's land and coastal areas. In part these are articulated in the Strategic Plan for the U.S. Climate Change Science Program (CCSP), which calls for continued collection of global moderate- and high-resolution satellite data, and quantification of rates of global land-cover change to support research into climate change (U.S. Climate Change Science Program, 2003). In addition to scientific research, the Landsat program serves a large community within Government and private industry, including natural resource monitoring, agribusiness, forestry, and military planning. Each of these communities brings its own set of priorities to the mission.

Background

The current Landsat program is unique in its capacity to provide medium resolution intra-annual and inter-annual observations of the global land surface from space. No other satellite system is operated to collect even annual global coverage at this scale. No other nation maintains a multi-decadal record of land observations in an archive providing non-discriminatory data access to the general public. This capacity is now diminished by the Landsat-7 Enhanced Thematic Mapper Plus (ETM+) scan line corrector failure and by ageing subsystems aboard the Landsat-5 satellite. The LDCM is needed to renew the capacity for global land observations.

Landsat 7 Legacy

The Landsat-7 satellite system has set high standards for its successor mission. Responsibility for the Landsat program transferred from a commercial entity back to the United States Government with the development and launch of Landsat 7. In that transition the government embraced several new practices to more fully serve the public. These new practices include:

- Rigorous on-orbit calibration and performance monitoring of the ETM+ (Markham *et al.*, 2004). The inclusion of an Image Assessment System within the Landsat-7 ground system enables this practice and makes calibration and characterization a routine part of mission operations for the first time. The ETM+ is the best calibrated sensor of the Landsat series, resulting in the most accurate image products with respect to radiometry and geolocation. ETM+ data serve as a reference to which observations from other satellite sensors are compared.
- A strategy for capturing seasonal coverage of the global land mass into a U.S. archive. This strategy, implemented by a Long-Term Acquisition Plan (Arvidson *et al.*, 2006), realizes the satellite system potential as a global survey mission and may ultimately have the greatest impact.
- A data policy that lowers the data cost and removes the licensing restrictions imposed on Thematic Mapper (TM) data during the commercial operations of Landsat 4 and Landsat 5. The policy now applies to all Landsat data held in the United States Geological Survey (USGS) archive. The lower prices and unencumbered sharing of Landsat data increase the public's return on investment for the Landsat program (Green, 2006).

Landsat 7 leaves a legacy of rigorous calibration, enlightened data policy, and global survey operations for the LDCM to emulate.

LDCM Development

In addition to the Landsat-7 legacy, LDCM requirements derive from public law, from technology demonstrations, and from direction provided by the Executive Office of the President. The Land Remote Sensing Policy Act of 1992 (U.S. Congress, 1992) initially guided the development of specifications. The Advanced Land Imager (ALI) launched aboard the Earth Observing-1 (EO-1) spacecraft in 2000 demonstrated the capabilities of new technologies possibly applicable to the LDCM. Recent memoranda from the Executive Office of the President (White House) Office of Science and Technology Policy (OSTP) provide further direction. This paper discusses these drivers of current LDCM requirements.

The Land Remote Sensing Policy Act of 1992

The Land Remote Sensing Policy Act of 1992 (U.S. Congress, 1992) initiated formulation of the LDCM. The Act directs Landsat Program Management to study options for a Landsat 7 successor mission that "adequately serve the civilian, national security, commercial, and foreign policy interests of the United States" and that "maintain data continuity with the Landsat system." The Act defines data continuity as data "sufficiently consistent (in terms of acquisition geometry, coverage characteristics, and spectral characteristics) with previous Landsat data to allow comparisons for global and regional change detection and characterization." Landsat Program Management currently consists of an inter-agency partnership between the National Aeronautics and Space Administration (NASA) and the Department of Interior (DOI) / USGS per an amendment to a Presidential Decision Directive (The White House, 2000). LDCM requirements derive essentially from Landsat Program Management interpretations of the phrases "adequately serve" and "sufficiently consistent" in the 1992 Act.

Figure 1. Rapid growth of Shenzhen, China between 1988 (top) and 1996 (bottom) shown in Landsat 5 TM images (courtesy of NASA GSFC Science Visualization Studio).

The Advanced Land Imager

The 1992 Act also directed Landsat Program Management to "incorporate system enhancements, including any such enhancements developed under the technology demonstration program under section 303, which may potentially yield a system that is less expensive to build and operate, and more responsive to data users." The Advanced Land Imager (ALI) aboard EO-1 constitutes the principal instantiation of the demonstration program. Launched on November 21, 2000, EO-1 is designed to demonstrate new technologies for land imaging (Ungar et al., 2003). It includes three sensors: the ALI, a Landsat-like multispectral imager; Hyperion, a hyperspectral imager; and a hyperspectral Atmospheric Corrector. As of mid-2006 over 46,000 ALI and Hyperion images had been collected and archived at the USGS Center for Earth Resources Observation and Science (EROS).

The ALI offers an important demonstration of technologies that could be applied to the LDCM. Unlike the Landsat TM or ETM+ whiskbroom scanners, ALI is a push-broom imager. ALI visible and near infrared detectors are constructed from silicon, while short wave infrared (SWIR) detectors are constructed from mercury-cadmium-telluride (HgCdTe) photodiodes, thus allowing higher ambient operating temperatures (approximately 220 K) compared to the TM/ETM+ SWIR bands that use indium- antimony (InSb) photodiodes cooled to 91 K. Individual detectors are organized into a series of overlapping sensor chip assemblies (SCAs) that extend across the focal plane in the cross-track direction. Each SCA contains 320 separate multispectral detectors. Since ALI is a demonstration mission, only one-fifth of the focal plane was populated with four SCAs, giving an image swath width of 37 km.

ALI collects image data for nine multispectral bands (with 30 m ground sample distance) and one panchromatic band (with 10 m ground sample distance). The ALI push-broom architecture offers greater dwell time and significant radiometric improvement over TM or ETM+. At 5 percent of maximum radiance, the ALI signal-to-noise ratios (SNRs) range from 100-300, while the ETM+ only manages SNRs of 15-50 (Lencioni et al., 2005). The simpler, push-broom architecture, combined with the use of passive cooling, allows ALI to give improved radiometric performance at substantially lower volume, mass, and power consumption than ETM+. Several studies have now been published comparing the performance of ETM+ and ALI for remote sensing applications. Without exception, these studies find that ALI offers improved ability to classify images, detect land cover change, and map environmental features and conditions. For example:

- Pu *et al.* (2005) compared the ability of Hyperion, ALI, and ETM+ to retrieve crown closure and leaf area index at Blodgett Forest Research Station in Northern California, finding that ALI consistently outperformed ETM+ at mapping crown closure and leaf area index variability.
- Lobell and Asner (2003) assessed the relative performance of ALI and ETM+ for crop classification. Corn and wheat were separated with 85 percent accuracy using ETM+, but 95 percent accuracy using ALI. Significantly, the at-sensor radiance values were within 3 percent between the sensors for common bands.
- Elmore and Mustard (2003) assessed estimates of percent green vegetation cover in the U.S. Great Basin using spectral

continued on page 1104

continued from page 1103

mixture analysis, and found comparable estimates from both ALI and ETM+. However, the ALI exhibited lower spatial variance in areas of low green cover.

- Goodenough *et al.* (2003) attempted to separate several types of conifer and hardwood forest types in British Columbia, Canada. Hyperion gave an overall accuracy of 90 percent, ALI 85 percent, and ETM+ 75 percent.
- Neuenschwander *et al.* (2005) demonstrated higher classification accuracy for mapping flood features in the Okavango Delta, Botswana when using ALI compared to ETM+.
- Kuster *et al.* (2005) attempted to map colored dissolved organic matter (CDOM) in Nordic boreal lakes. ETM+ was not suitable for mapping CDOM at high concentrations. On the other hand, they found a strong correlation between the 565 nm/660 nm ALI band ratio and CDOM absorption.

Most of these studies indicate that the improved signal-to-noise characteristics of ALI led directly to improved applications performance. In addition, Lobell and Asner noted that the information content of ALI band MS4´ (845 – 890 nm) was more suitable to crop classification than the wider ETM+ near-infrared band (775 – 900 nm), possibly due to the sensitivity of the ALI band to canopy water content.

Experience with EO-1 ALI has also offered some cautionary lessons for the LDCM mission. ALI has been afflicted with a variety of imaging artifacts, including excess stray light caused by inadequate optical baffling, and image ghosting caused by internal reflection from spectral filters. Several imaging requirements for LDCM were generated in direct response to these issues. In addition, the original ALI processing system at NASA Goddard Space Flight Center (GSFC) did not correct ALI imagery for band-to-band parallax errors, leading to mis-registration between bands (Storey and Choate, 2003). Thus, several analyses by the EO-1 Science Team (including those papers listed above) had to contend with a degree of "blurriness" when using multispectral indices and ratios (e.g., Fig. 7 in Elmore and Mustard, 2003). In 2005 USGS EROS implemented a full geometric processing suite for ALI imagery including corrections for terrain displacement. It would be expected that ALI performance for science applications should be further enhanced with the improved band-to-band registration now available. Both these lessons and the ALI radiometric performance have informed the development of current LDCM requirements.

Memoranda from the Office of Science and Technology Policy

Direction from the Executive Office of the President has also impacted requirements as NASA and DOI/USGS struggled to implement the LDCM.

1992 Act

The 1992 Act directed Landsat Program Management to study four options for the management of the successor system: private sector funding and management; an international consortium; United States Government funding and management; and a cooperative effort between the United States Government and the private sector.

To encourage private sector management, NASA released a Request for Proposals (RFP) at the beginning of 2003 that offered to share the cost and risk of developing a privately-owned system capable of delivering data meeting LDCM specifications to the U.S. Government. NASA declined to accept any of the proposals submitted in response to the RFP and terminated the solicitation in September 2003. NASA selection officials concluded that the proposals failed to adequately address the explicit goal of sharing development risk between the government and the private sector. Regardless, the requirements for a successor system were initially expressed through the LDCM data specifications.

OSTP August 2004 Memo

The Executive Office of the President quickly convened an interagency working group to identify other options for LDCM management following the termination of the data procurement RFP. The findings of the working group are captured in a memorandum released August 13, 2004 and signed by John H. Marburger, III, the Director of the Office of Science and Technology Policy (OSTP) (Marburger, 2004). The memorandum declares that "Landsat is a national asset," and directs federal agencies to "Transition Landsat measurements to an operational environment through incorporation of Landsat-type sensors on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) platform." Pursuant to this direction NASA and DOI/USGS began to work with the NPOESS Integrated Program Office (IPO) to translate LDCM requirements from data specifications into performance specifications for sensors flown aboard NPOESS satellites. The sensors were referred to as Operational Land Imagers (OLIs) and NASA posted a draft OLI specification on a web site in 2005 in anticipation of the release of an OLI RFP. The process of defining OLI specifications, however, revealed daunting technical challenges to meeting LDCM requirements with sensors aboard NPOESS satellites.

OSTP December 2005 Memo

Discovery of these technical complexities led Dr. Marburger to sign a second OSTP memorandum on December 23, 2005 (Marburger, 2005) with a subject line reading "Landsat Data Continuity Strategy Adjustment." This memorandum supercedes the direction to fly Landsat-like sensors aboard NPOESS satellites. Instead, the second memorandum directs NASA to acquire a single "free-flyer" spacecraft for the LDCM and assigns DOI/USGS responsibility for operating the spacecraft after launch. NASA and DOI/USGS are again revising LDCM requirements as performance specifications for a free-flyer satellite system reflecting the latest adjustment in the LDCM implementation strategy.

Current LDCM Requirements

LDCM requirements have remained fundamentally consistent as the implementation strategy transitioned from a data procurement to the launch of a free flyer satellite. Current requirements are captured in a collection of draft performance specifications under review by NASA and DOI/USGS. Basically, the draft performance specifications require the LDCM to provide synoptic, multispectral, medium-resolution observations of the global land surface on a seasonal basis. The specifications will result in data consistent with ETM+ data and the requirements specify several evolutionary advancements in performance.

Basic LDCM Performance Requirements

Spectral/Spatial Coverage

Table 1 provides the draft specifications for LDCM spectral bands and associated ground sample distances. Following the TM and ETM+ heritage, the ground sample distances are specified at no greater than 30 m except for the no-greater-than 15 m requirement for the panchromatic band.

The specifications include nine spectral bands. Seven of the bands correspond to the reflective bands sensed by the TM and ETM+ sensors, with band edges refined to avoid atmospheric absorption features. The greatest refinements occur in the LDCM near-infrared (NIR) and panchromatic bands. The LDCM NIR band specification avoids a water vapor absorption feature centered at approximately 825 nm in the middle of the TM and ETM+ NIR bands (approximately 775 to 900 nm). The LDCM panchromatic band specification will increase the contrast between vegetation and soil relative to ETM+ panchromatic band (515 to 896 nm) images. Two new LDCM spectral bands are specified, a new blue band (#1) principally for coastal zone observations and a new SWIR band (#9) for cirrus cloud detection. Thermal band specifications are discussed in the next section.

Radiometric Requirements

The draft LDCM signal-to-noise-ratio (SNR) specifications (Table 2) also represent a performance advancement relative to the ETM+. The measured performance of the ALI (Lencioni et al., 2005) demonstrated the capability to achieve the specified SNRs with margin and the studies cited above demonstrated benefits that can be expected from the advanced performance. The LDCM requirements also specify 12-bit quantization of image data to accommodate the specified SNRs. The draft LDCM specifications contain much more detail with respect to radiometric and geometric performance. The specifications, for example, require absolute radiometric calibration to an uncertainty less than 5 percent with respect to at-aperture spectral radiance.

Geometric Performance

The absolute geodetic accuracy is specified to an uncertainty less than 65 m (90 percent circular error) relative to a standard geodetic reference system. Band-to-band registration is specified to an uncertainty less than 4.5 m in both the line and sample directions at the 90 percent confidence level. NASA has posted the full set of draft LDCM specifications at http://ldcm.nasa.gov/procurement.html, along with

continued on page 1106

Table 1. Draft LDCM Spectral Band and Ground Sample Distance (GSD) Specifications

#	Band	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)	Center Wavelength	Maximum GSD
1	Coastal	433	453	443	30 m
2	Blue	450	515	482	30 m
3	Green	525	600	562	30 m
4	Red	630	680	655	30 m
5	NIR	845	885	865	30 m
6	SWIR 1	1560	1660	1610	30 m
7	SWIR 2	2100	2300	2200	30 m
8	Panchromatic	500	680	590	15 m
9	Cirrus	1360	1390	1375	30 m

Table 2. Draft LDCM Dynamic Range and SNR Specifications

#	Band	Saturation Radiances (W/m2 sr μm)	Radiance Level for SNR (W/m2 sr μm)		SNR Requirements	
			Typical, $L_{Typical}$	High, L_{high}	At $L_{Typical}$	At L_{high}
1	Coastal	555	40	190	130	290
2	Blue	581	40	190	130	360
3	Green	544	30	194	100	390
4	Red	462	22	150	90	340
5	NIR	281	14	150	90	460
6	SWIR 1	71.3	4.0	32	100	540
7	SWIR 2	24.3	1.7	11	100	510
8	Panchromatic	515	23	156	80	230
9	Cirrus	6.0	N/A	88.5	9	N/A

continued from page 1105

other draft procurement documents in preparation for the release of an RFP for a free-flyer satellite system. The final specifications and documents will be posted to this site when the RFP is released. The performance specifications can be found in a document entitled "Space Segment Requirements Document."

Thermal Data Requirements

Requirements for thermal data were initially left out of LDCM specifications for the data procurement RFP and for the OLI sensors aboard the NPOESS satellites. This omission represented a departure from data continuity. The TM and ETM+ sensors all collected data for a single thermal band (1040 – 1250 nm) with the TM's affording a thermal image spatial resolution of 120 m and the ETM+ providing a 60 m thermal image resolution. The potential private sector partners engaged during the data procurement effort did not, however, see a viable commercial market for thermal data and had little interest in incorporating the capability into a privately-owned satellite system. NASA at that time decided that the cost and technical risk of imposing thermal data requirements on a private partner outweighed the benefits. Then, when the implementation strategy changed, the technical complexities of integrating Landsat-like sensors onto NPOESS platforms discouraged the restoration of thermal requirements. These complexities ultimately led to the current implementation strategy that may provide more flexibility with respect to thermal imaging.

Awareness of the benefits of thermal data from the Landsat satellites is now increasing. In particular, the emergence of energy balance models for operational water management has raised awareness. Landsat thermal data used in conjunction with energy balance models is proving to be an efficient, cost-effective, and synoptic approach to water management in the western U.S. (Allen *et al.*, 2005) and world wide (Bastiaanssen, W.G.M. *et al.* 2005).

This growing appreciation for thermal image benefits has led NASA to consider including an option for a thermal imaging capability as part of the LDCM free-flyer satellite RFP. Table 3 provides the draft thermal band specifications for this option. Two bands are specified to facilitate atmospheric correction for the retrieval of absolute surface temperature. The 120 m ground sample distances were specified after consideration of potential cost impacts and the maturity of thermal detector technology. Not all irrigated fields will be individually resolved at this resolution, but circular-pivot irrigation is commonly used in the West, leaving resolvable circular fields with diameters between 400 and 800 m. The full set of thermal performance specifications can be found in the LDCM "Space Segment Requirements Document." An option in the LDCM RFP offers a possibility of continuing the collection of thermal images, but an option falls short of a firm requirement. Concern remains with respect to the cost impact, technical risk, and schedule risk of a thermal imaging option.

Requirements beyond the LDCM

The Landsat program launched the first civilian satellite designed for land observations in 1972 and the monopoly on land observations from space persisted until the mid 1980s. With the only land-observing systems in orbit, the Landsat program developed a broad and varied constituency of data users. The Landsat community remains diverse today even with the advent of multiple international, commercial, and Earth Observing System satellites providing land data. This fact was recognized by the public law requirement to develop a Landsat-7 successor that adequately serves the full scope of Landsat data users. The program requirement to provide multiple-use land observations continues for the LDCM.

Potential Future Evolution of Land Imaging

The diversity of users in the Landsat community continues to present a challenge to developing future Landsat mission specifications. Various factions within the community have a range of observation needs that go well beyond current LDCM specifications; for example,

- Ecologists seek hyperspectral observations to better differentiate vegetation species and to better map continuous fields of biophysical parameters.
- National security officials require finer spatial resolutions, in the 5-10 m range, over wide areas for war fighters and homeland security applications.
- Agriculturists monitoring crop development and water consumption require more frequent observations, such as weekly, cloud-free coverage.
- Other earth scientists and resource managers call for multiple angle, synthetic aperture radar, or profiling laser altimetry measurements to map vegetation canopy structure, topography, or ice thickness.

All of these requirements are legitimate and the current LDCM concept will not address this broad range of requirements. These needs point to future land observatories that could evolve into a comprehensive global land observing system.

The LDCM Role

Today, to best serve the broad scope of users, the mandate for data continuity has served as the guiding force behind the development of current LDCM requirements. These requirements include the collection and archiving of well-calibrated, synoptic, multispectral images of the global land mass that are a significant advance beyond Landsat 7. In addition, these observations will be distributed on a non-discriminatory basis. These elements of the LDCM mission are paramount and have directed the development of LDCM specifications. Realization of these requirements will allow the LDCM to serve as a cornerstone for a future infrastructure of geospatial land information built upon the Landsat mission heritage.

One additional step will be needed to fully realize the role of the

Table 3. Draft LDCM Thermal Band and Ground Sample Distances (GSD) Specifications

#	Band	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)	Center Wavelength (nm)	Maximum GSD
10	Thermal 1	10300	11300	10800	120 m
11	Thermal 2	11500	12500	12000	120 m

LDCM. While the current price of an ETM+ scene from the USGS EROS archive ($600) is significantly less than prices charged during the commercial operations of Landsat 4 and Landsat 5, the price still impedes the full exploitation of the Landsat data archive for the public good. The capacity now exists to process and analyze hundreds of Landsat scenes for long-term or broad area investigations and applications. Few, however, can afford to procure hundreds of scenes from the archive. A further reduction in Landsat data prices will be necessary for the LDCM to achieve its potential for serving society.

Landsat Management

Progress toward ensuring future land observations will require overcoming the historical uncertainty of Landsat program management and planning. The changes in implementation strategy noted earlier have already postponed the launch of an LDCM to a point well past the Landsat-7 design life. Dr. Marburger acted to reduce future uncertainty by including the following in his memorandum of December 23, 2005, "The National Science and Technology Council, in coordination with NASA, DOI/USGS and other agencies and EOP offices as appropriate, will lead an effort to develop a long-term plan to achieve technical, financial, and managerial stability for operational land imaging." The EOP responded by forming a Future of Land Imaging – Interagency Working Group (FLI-IWG) to develop this plan. The working group held an open workshop on July 26, 2006 in Washington, D.C. to introduce its planning process and receive feedback from the public. The working group acknowledged the need for data continuity and added that the future would not be constrained to current capabilities. Planning for a comprehensive infrastructure that more fully serves the wide community requiring land observations presents the working group with a difficult assignment. The LDCM can best facilitate this future if it serves as a core capability that compliments future observatories forming a global land observing system.

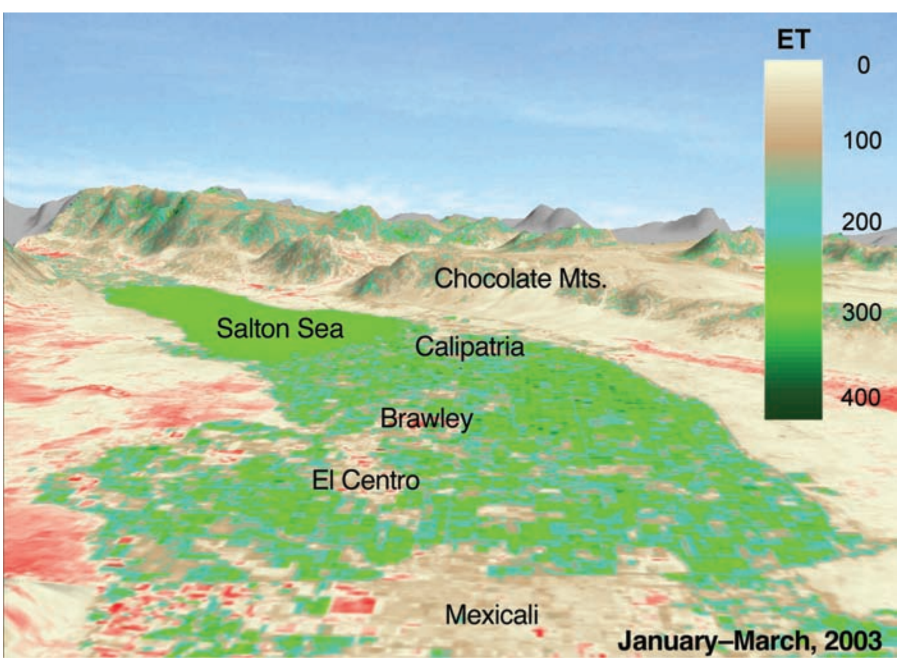

Figure 2. Evapotranspiraton (ET) in the Imperial Valley, California between January and March 2003 derived from Landsat 7 ETM+ data used in conjunction with an energy balance model (courtesy of Richard Allen, Kimberly Research and Extension Center, University of Idaho).

Conclusion

NASA and DOI/USGS are now embarked on the third (and hopefully!) final implementation strategy for the LDCM. The previous implementation delays will most likely result in a Landsat data gap. Some users are already hindered by the Landsat 7 ETM+ scan line corrector failure. The impending gap should not serve as justification for compromising LDCM requirements. As the Landsat 7 demonstrated, there are considerable advances that can be achieved in land imaging if we build upon previous successes. The Landsat-7 mission advanced the practice of land imaging and set a standard for the LDCM. Likewise the LDCM needs to serve as a foundation upon which to build the future of land imaging.

References

Allen. R.G, M. Tasumi, and A. Morse, 2005. Satellite-based evapotranspiration by METRIC and Landsat for western states water management, presented at the US Bureau of Reclamation Evapotranspiration Workshop, February 8-10, 2005, Ft. Collins, CO, 19 p., http://www.idwr.idaho.gov/gisdata/ET/allen_et_al_metric_summary_paper2.pdf.

Arvidson, T., S.N. Goward, D.L. Williams, and J. Gasch, 2006. Landsat-7 long-term acquisition plan: Development and validation, *Photogrammetric Engineering & Remote Sensing*, 72(10), 1137-1146.

Bastiaanssen, W.G.M, E.J.M. Noordman, H. Pelgrum, G. Davids and R.G. Allen, 2005. SEBAL for spatially distributed ET under actual management and growing conditions, *ASCE J of Irrigation and Drainage Engineering*, 131(1), 85-93.

Elmore, A.J., and J.F. Mustard, 2003. Precision and accuracy of EO-1 Advanced Land Imager (ALI) data for semiarid vegetation studies, *IEEE Trans. Geosci. Remote Sens.*, 41, 1311-1320.

Goodenough, D.G., A. Dyk, K.O., Niemann, J.S. Pearlman, H. Chen, T. Han, M. Murdoch, C. West, 2003. Processing Hyperion and ALI for forest classification, *IEEE Trans. Geosci. Remote Sens.*, 41, 1321-1331.

Green, K., 2006. Landsat in context: The land remote sensing business model, *Photogrammetric Engineering & Remote Sensing*, 72(10), 1147-1153.

Kutser, T., D. Pierson, L. Tranvik, A. Reinart, S. Sobek, K. Kallio, 2005. Using satellite remote sensing to estimate the colored dissolved organic matter absorption coefficient in lakes, *Ecosystems*, 8, 709-720.

Lencioni, D.E., D.R. Hearn, C.J. Digenis, J.A. Mendenhall, and W.E. Bicknell, 2005. The EO-1 Advanced Land Imager: An overview, *Lincoln Laboratory J.*, 15, 165-180.

Lobell, D.B. and G.P. Asner, 2003. Comparison of Earth Observing-1 ALI and

continued on page 1108

continued from page 1107

Landsat ETM+ for crop identification and yield prediction in Mexico, *IEEE Trans. Geosci. Remote Sens.*, 41, 1277-1282.

Marburger, J., 2004. *Landsat Data Continuity Policy*, Executive Office of the President, Office of Science and Technology Policy, August 13, 2004.

Marburger, J., 2005. *Landsat Data Continuity Strategy Adjustment*, Executive Office of the President, Office of Science and Technology Policy, December 23, 2005.

Markham, B.L., J.C. Storey, D.L. Williams, and J.R. Irons, 2004. Landsat sensor performance: history and current status, *IEEE Trans. Geosci. Remote Sens.*, 42, 2691-2694.

Neuenschwander, A.L., M.M. Crawford, S. Ringrose, 2005. Results from the EO-1 experiment - A comparative study of Earth Observing-1 Advanced Land Imager (ALI) and Landsat ETM+ data for land cover mapping in the Okavango Delta, Botswana, *Int. J. Remote Sens.*, 19, 4321-4337.

Pu R., Q. Yu, P. Gong, G.S. Biging, 2005. EO-1 Hyperion, ALI, and Landsat 7 ETM+ data comparison for estimating forest crown closure and leaf area index, *Int. J. Remote Sens.*, 26, 457-474.

Storey, J.C., and M. Choate, 2004. A geometric performance assessment of the EO-1 Advanced Land Imager, *IEEE Trans. Geosci. Remote Sens.*, 42, 602-607.

Thenkabail, P.S., E.A. Enclona, M.S. Ashton, C. Legg, M.J. De Dieu, 2004. Hyperion, IKONOS, ALI, and ETM plus sensors in the study of African rainforests, *Remote Sensing of the Environment*, 90, 23-43.

Ungar, S.G., J.S. Pearlman, J.A. Mendenhall, and D. Reuter, 2003. Overview of the Earth Observing One (EO-1) mission, *IEEE Trans. Geosci. Remote Sens.*, 41, 1149-1159.

U.S. Climate Change Science Program, 2003, Strategic Plan for the U.S. Climate Change Science Program, Washington, D.C., http://www.climatescience.gov/Library/stratplan2003/final/default.htm.

U.S. Congress, 1992. Public Law 102-555: *Land Remote Sensing Policy Act of 1992*, 102nd Congress, 28 October, U.S. Government Printing Office, Washington, DC.

The White House, 2000. Amendment to Presidential Decision Directive/NSTC-3, October 16, 2000.

Authors

James R. Irons and **Jeffrey G. Masek**

Biospheric Sciences Branch

NASA Goddard Space Flight Center

Greenbelt, Maryland 20771