Landsat Science Team Meeting Summary

Thomas R. Loveland, U.S. Geological Survey Earth Resources Observation and Science Center, Loveland@usgs.gov
James R. Irons, NASA Goddard Space Flight Center, James.R.Irons@nasa.gov
Curtis E. Woodcock, Department of Geography and Environment, Boston University, curtis@bu.edu

Meeting Overview

The Landsat Science Team—sponsored by the U.S. Geological Survey (USGS) and NASA—met January 8–10, 2008, at the USGS Earth Resources Observation and Science (EROS) Center near Sioux Falls, SD. The meeting objectives were to:

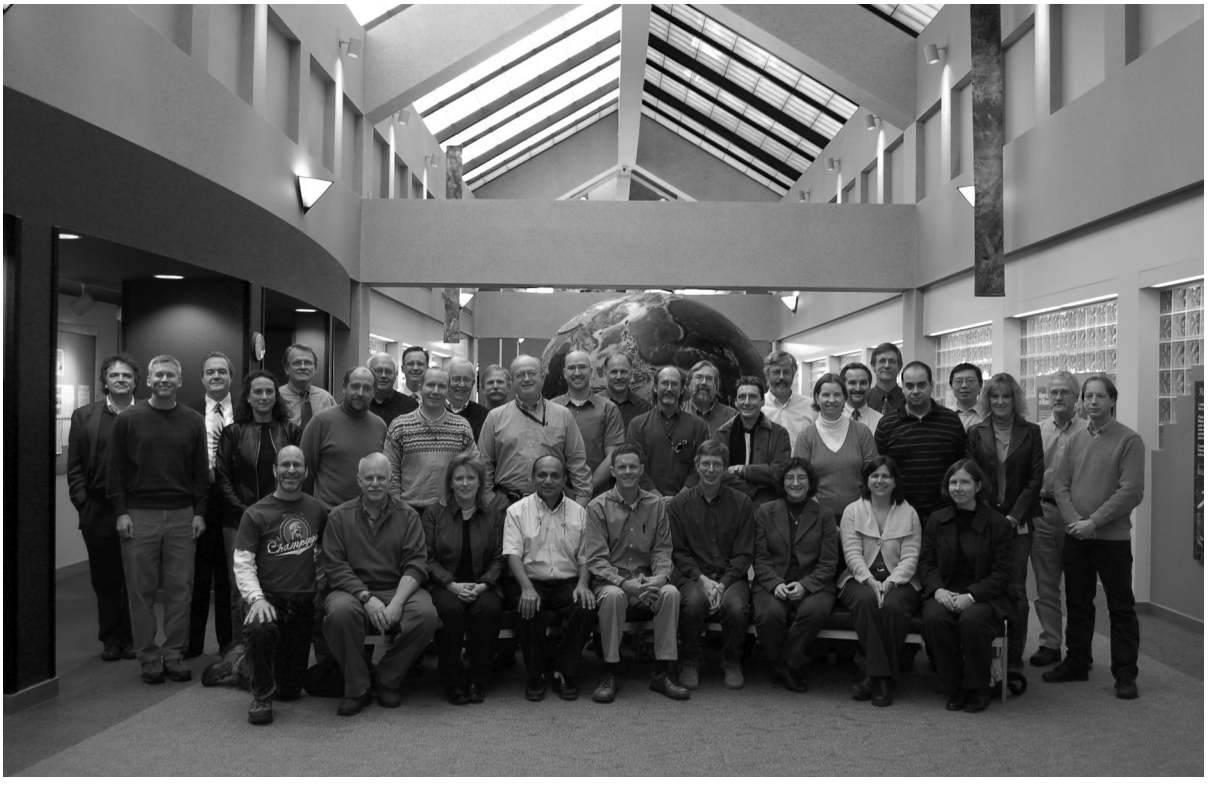
- review recent USGS and NASA Landsat Data Continuity Mission (LDCM) implementation steps and Landsat activities;
- review Landsat archive practices and opportunities with special emphasis on establishing a global consolidated Landsat archive and ensuring consistent data formats, access, and policies for all Landsat data holdings (Landsat 1–8); and
- provide recommendations on LDCM, Landsat, and other issues and opportunities.

The meeting agenda and presentations are available at: *ldcm.usgs.gov/january2008MeetingAgenda.php*

Introductory Comments

Tom Loveland [USGS—*Landsat Science Team*] initiated the meeting with a review of the issues that the Landsat Science Team addressed and provided inputs to NASA and the USGS since the June 2007 meeting. The topics and outcomes included:

- *Landsat data policy*: The Team provided input on content and wording that USGS and NASA incorporated into the recently approved data policy.
- *Landsat-LDCM archive continuity and consolidation*: USGS is implementing a plan to make all Landsat data available at no cost via the Internet.
- *Standard product pixel dimensions*: USGS has accepted the Team's recommendation to change standard product pixel dimensions to 15- and 30-m rather than the current 14.25- and 28.5-m sizes.
- *Cloud cover cut-off specifications*: USGS agreed to raise the cloud threshold for no-cost Landsat 7 standard products from 10% to 20% and will make scenes with higher amounts of cloud cover available using on-demand processing.
- *LDCM standard product requirements*: The Team assessed the science and applications value of a lower level LDCM standard product (e.g., Level 0) and recommended adding one to the LDCM product suite. USGS and NASA concluded that there is benefit to the additional product, and an analysis of cost and schedule impacts is being carried out.



Curtis Woodcock [Boston University—*Landsat Science Team Leader*] set the tone for the meeting by emphasizing the importance of viewing Landsat and LDCM in the same context. He urged the Team to contribute to LDCM requirements studies and to help ensure that all Landsat products will be available with consistent formats, access strategies, and data policies.

Landsat 5 and 7 Status

Kristi Kline [USGS—*Landsat Project Manager*] provided an update on the status of Landsats 5 and 7. Landsat 5 imaging was suspended in October 2007 due to a loss of a cell from one of two batteries. The Landsat flight operations staff is working on a solution and a new operations strategy. Resumption of Landsat 5 acquisitions is scheduled for February 2008.[1] Other than the 2003 Scan Line Corrector (e.g., SLC-off) anomaly, Landsat 7 is fully functional and continues to collect extensive global coverage. Kline reported that the pilot activity that provided no-cost Landsat 7 Enhanced Thematic Mapper Plus (ETM+) SLC-off data (May 2003 through the present) for the U.S. has been continued and expanded. The pilot originally consisted of data with less than 10% cloud cover but was expanded in October 2007 to scenes with 20% or less cloud cover. The pilot is the first step toward making all Landsat data in the USGS archive available via the Internet at no cost (see Landsat Archive Discussion).

Jeff Masek [NASA Goddard Space Flight Center (GSFC)—*LDCM Deputy Project Scientist*] gave an update on the NASA–USGS Global Land Survey (GLS) 2005 initiative. The GLS-2005 activity is a continuation of the Landsat *GeoCover* orthorectified global dataset (1975, 1990, and 2000 epochs) and adds 2005-era global Landsat to the GLS archive. The original *GeoCover* data for the three periods are being reprocessed to improve geometric accuracy through improved Shuttle Radar Topography Mission digital elevation models and additional ground control. The reprocessed data are based on 15-, 30-, and 60-m pixels rather than the 14.25-, 28.5, and 57-m pixel dimensions used previously. The 2005-era data will use the improved geometric baseline. The reprocessed North America data have been delivered (November 2007) and the initial validation indicates ~18-m root mean square error (RMSE) on a per-scene basis. All GLS products will be made available online at no cost to users. The data will be made available immediately after production and the first datasets should be released in late January 2008.

[1] Landsat 5 is now back on-line and the Thematic Mapper instrument is approaching normal operating temperatures.

LDCM Status

Bill Ochs [NASA GSFC—*LDCM Project Manager*] and **Mike Headley** [USGS—*LDCM Project Manager*] provided reports on the status of LDCM planning and implementation. The NASA and USGS team is working toward a launch readiness date of July 2011.

Ochs reported that the Operational Land Imager (OLI) development was awarded to Ball Aerospace and Technology Corporation (BATC) of Boulder, CO, in July 2007. Since the award, numerous subsystem peer reviews have been conducted and OLI systems requirements and integrated baseline reviews were successfully completed. The spacecraft procurement is in the final stages and a contract award is expected in early spring 2008. The contract for the launch vehicle, an *Atlas V*, was awarded to Lockheed Martin Commercial Launch Services of Littleton, CO, in October 2007. The request for proposals (RFP) for the final part of the space segment, the Mission Operations Element, will be released soon and an award decision is expected in early Summer 2008.

NASA and the USGS are involved in a number of reviews of LDCM systems. The USGS completed the ground system requirements review and is now conducting the ground system element requirements reviews. The system requirements reviews are examining the functional and performance requirements defined for the LDCM systems. Ochs said that the Mission Definition Review (MDR) is scheduled for April 2008. The MDR is a formal examination of the proposed requirements, the mission architecture, and the flow down to all functional elements of the mission to ensure that the overall concept is complete, feasible, and consistent with available resources.

Ochs also discussed the status of two additional instruments that are being considered for the LDCM spacecraft. The Thermal Infrared Sensor (TIRS) would provide two thermal channels with 120-m resolution and would provide much needed continuity with past Landsat thermal measurements. NASA has completed studies that resulted in the development of a feasible concept, but no funds are available to continue the planning or to build TIRS. The LDCM spacecraft specifications require the capability for carrying the TIRS instrument. **A decision to add TIRS to the LDCM payload at this time would likely delay the LDCM launch by at least a year.**

The second instrument is the Total Solar Irradiance Sensor (TSIS), which consists of the Total Irradiance Monitor (TIM) and the Spectral Irradiance Monitor (SIM). TSIS was originally planned for the National Polar-orbiting Operational Environmental Satellite System (NPOESS) platform but was removed. The Office of Science and Technology Policy recommended

placing TSIS on any available and suitable vehicle in time to overlap with the Glory mission; LDCM is the prime candidate. The purpose of TSIS is to improve the understanding of the sun–Earth climate connection.

Jeanine Murphy-Morris [NASA Goddard Space Flight Center—*OLI Instrument Manager*] provided an overview of OLI characteristics, status, and schedule. Baseline instrument design characteristics include:

- Pushbroom instrument with 9 channels ranging from 443 nm to 2200 nm;
- four-mirror telescope;
- focal plane array consisting of 14 sensor chip assemblies;
- solar calibrator to be used once per week;
- intra-orbit calibration lamps;
- dark shutter for offset calibration; and
- twelve-bit resolution.

The telescope optical design has been completed; contracts are in place for the optical bench; and the primary, secondary, and quaternary mirrors are being polished, while the tertiary mirror light weighting is nearing completion. The preliminary design review for key focal plane array components (detector and readout integrated circuits) are complete as is the peer review of filters. Plans for algorithm and integration and test functions are also underway.

Headley reported that the ground systems requirements review was successfully completed in September 2007 and the element requirements reviews are now underway. The ground system preliminary design review is targeted for September 2008. Headley also provided an update on key ground systems procurements.

Ground antenna and network services procurements are planned for mid-2008, and the flight operations team procurement Request for Proposal (RFP) will be released in spring 2008 with a contract award planned for late summer 2008.

Finally, Headley summarized discussions with representatives of the International Cooperator (IC) network regarding their interest in LDCM. IC respondents included Argentina, Australia, Brazil, Canada, China, European Space Agency, German Aerospace Center, Hiroshima Institute of Technology in Japan, Remote Sensing Technology Center of Japan, South Africa, and Thailand. All expressed interest in continuing as ICs in the LDCM era and prefer to receive LDCM data via a direct downlink. While some expressed interest in also receiving Level 1T data via the Internet, many ICs desire having control over processing specifications. The ICs expressed their support for thermal imaging capabilities. IC representatives will be invited to future Landsat Science Team meetings.

Ed Grigsby [NASA Headquarters—*Landsat Program Executive*] and **Jim Irons** [NASA GSFC—*LDCM Project Scientist*] led a discussion on recent reviews within NASA on LDCM and OLI schedule issues and risks. The LDCM schedule is driven by the need to minimize a data gap with Landsat 7. Since a data gap could occur at any time, the LDCM instrument schedule is very aggressive. The resulting risks associated with the aggressive schedule are recognized and NASA has been conducting a requirements analysis to determine options for potential risk reduction and mitigation. Specific elements that could affect the launch readiness date include the addition of TSIS and TIRS, and OLI specifications dealing with the coastal aerosol and cirrus bands, pixel-to-pixel uniformity, radiometric stability, and signal-to-noise ratios. The Landsat Science Team was asked to provide input to NASA management on these issues.

The Team found value in all of the targeted capabilities and reiterated the benefits of adding a thermal infrared sensor. The Team recognized the value of the new coastal band for coastal and inland lake water quality monitoring as well as the potential for improving the atmospheric correction of the other OLI bands. Similarly, the new short-wave infrared band for cirrus cloud detection will improve the ability to account for ice–cloud attenuation of the signal received in the other OLI bands. The Team also concluded that across track pixel-to-pixel uniformity and radiometric stability are essential to detecting and characterizing land cover change, while the specified signal-to-noise ratios will substantially advance capabilities to recognize and characterize land cover.

The Team agreed that current spectral band and radiometric performance requirements should be relaxed or waived only if the full achievement of the requirements does not jeopardize the overall mission and the ability to observe the 2012 growing season. Small departures from specification may be acceptable in some cases, but dramatic degradations in performance might compromise the entire mission. The Team also values the inclusion of the thermal sensor if the development and integration can be completed in time for LDCM to reach operational status by March 2012. The addition of TIRS could add up to a year of additional development time. **A delay of a year is not acceptable, and the Landsat Science Team suggested that NASA find and implement other approaches for restoring the thermal imaging capabilities provided by Landsats 5 and 7.**

Landsat Archive Discussion

A special focus during the meeting was a review of Landsat archive practices and opportunities with special emphasis on establishing a global consolidated Landsat

archive and ensuring consistent data formats, access, and policies for all Landsat data holdings. **Ray Byrnes** [USGS—*Liaison for Satellite Missions*] led off the topic with a summary of the recently implemented USGS–NASA Landsat Data Distribution Policy. The policy concludes, *"in accordance with OMB Circular A-130 and the USGS Data Policy, the USGS provides selected satellite data products for retrieval via the Internet at no charge to users."* This sets the stage for significantly expanded access and use of the Landsat archive for science and applications.

Kristi Kline explained that the USGS is beginning to phase in no-cost access to all archived Landsat data (July 1972 to present). The USGS-operated Landsat archive currently includes close to 2.2 million scenes, or over 1,100 terabytes of data. Access to the archive will be staged incrementally as system conversions, calibration strategies, and other implementation issues are resolved. The images will be in a rolling data pool or processed using an on-demand strategy based on a single L1T product definition (calibrated, terrain corrected, orthorectified to a Universal Transverse Mercator projection, and 15-, 30-, and 60-m pixels resampled using cubic convolution). LDCM data will also be processed to the same L1T specifications. Once the transition is completed, all Landsat data held in the USGS National Satellite Land Remote Sensing Data Archive will be available in electronic format over the Internet to anyone at no cost.

The next Landsat archive issue discussed dealt with assembling a consolidated global Landsat archive. While the USGS archive of global coverage is extensive, there is a significant amount of coverage held by Landsat ICs. **Steve Labahn** [USGS— *International Ground Station Network Manager*] gave an overview of the current IC network and discussed its role, capabilities, and expectations in the global Landsat ground network. Twelve ICs are receiving Landsat 5 TM data and nine are collecting Landsat 7 ETM+ data.

Steven Covington [The Aerospace Corporation—*Landsat 5 & 7 Flight Systems Manager*] presented an evaluation of the process, cost, and relative merit for consolidating a copy of the global archive of historical Landsat imagery at EROS. International ground stations have collected Landsat scenes since the launch of Landsat 1 in July 1972. Over the past 35 years, over 50 ground stations have been configured to receive Landsat data. There are nine historical collection sites operated by seven organizations that likely have some significant, unique historical Landsat data not duplicated in the USGS Landsat archive. There is also growing concern about the state of the historical international archives, especially at inactive stations where there are no active contacts. It is clear that a consolidated archive would have many benefits for global studies.

Covington explained that the global consolidated archive has several objectives.

- Determine the willingness of the ICs to participate in this effort.
- Determine the location, extent, and condition of the historical Landsat archives around the world.
- Generate a list of the instrument (return beam vidicon, MSS, TM, ETM+), data format, and media type at each location.
- Assess the equipment, software, logistics, and level of effort necessary to acquire, ingest, process, and archive the data.
- Develop an estimated cost and schedule for establishing a global consolidated archive.

This investigation is in the fact-finding stage. An update will be provided at future Landsat Science Team meetings.

The next topics involving the Landsat archive focused on radiometry and calibration. **Brian Markham** [NASA GSFC—*Landsat Calibration Scientist*] reported on the status of Landsats 5 and 7 radiometric performance. Markham concluded that Landsat 7 ETM+ performance is stable, except for changes induced by the switch to bumper mode operations. The switch made in April 2007 disrupted the ETM+ sensor alignment calibration. Prior to the switch, 97% of the scenes had better than 50-m Root Mean Square Error, but with bumper mode operations, only 65% of the scenes had better than 50-m RMSE. Markham also concluded that Landsat 5 TM performance was stable through October 2007 when imaging was suspended. With the January 2008 resumption of imaging, there will be a need for frequent bumper mode calibration. He also reported that Landsat 5 TM reflective and thermal band calibrations were updated in April 2007 and that the thermal band calibration accuracy since 1999 is now comparable to the ETM+ thermal band.

Dennis Helder [South Dakota State University—*Landsat Science Team Member*] briefed the Team on using Landsat 7 ETM+ to calibrate OLI data. Helder also presented a strategy for consistent calibration of the entire Landsat archive. The Government Calibration/Validation Plan defines scope, roles, and responsibilities. Essentially, NASA leads through commissioning and the USGS leads during operations. The plan specifies performing characterizations on every scene acquired. Because of the increase in the number of detectors, automation will be used to provide immediate alerts of the need to update calibration and warnings of instrument and product performance degradation. An overflight between Landsat 7 and LDCM provides the best opportunity for calibration continuity through cross-calibration. Cross-calibration with bridge sensors provides a limited capability to ensure consistent calibration. This, augmented with the use of pseudo-

invariant sites for trending and vicarious calibration, may provide a second approach to bridging the gap. Helder recommended that a cross-calibration plan using Landsat 7 ETM+ and Landsat 5 TM with bridge sensors and with pseudoinvariant sites be developed and implemented.

Finally, Helder laid out a strategy for achieving the goal of having consistently calibrated data across the entire Landsat archive. The basic tenets of the strategy are as follows.

- Landsat 5 TM has already been consistently calibrated with Landsat 7 ETM+.
- Landsat 4 TM can be cross-calibrated to Landsat 5 TM due to the availability of coincident collections over multiple targets.
- Landsats 4 and 5 Multispectral Scanner (MSS) can be cross-calibrated with TM, but there will be complications due to differences in spectral response functions.
- Landsat 3 MSS calibration is a critical step for achieving consistent calibration for the first decade of Landsat observations. There are very few overlapping scenes available for using the *pseudoinvariant site approach* to link Landsat 3 to Landsat 4 MSS. The usefulness of onboard calibration information (e.g., calibration wedge) for instrument trending is unknown.
- Landsats 1 and 2 MSS calibration can take advantage of the substantial numbers of scenes over *pseudoinvariant* sites. The usefulness of onboard calibration information is also unknown.

The final Landsat archive related discussion involved the National Land Imaging Program (NLIP). **Bruce Quirk** [USGS—*Land Remote Sensing Program Coordinator*] gave a summary of NLIP history, status and plans, and opportunities for Landsat Science Team input. The NLIP concept is the outgrowth of the Future of Land Imaging Interagency Working Group that concluded that the United States: (1) must commit to continuing the collection of moderate-resolution land imagery; (2) should establish and maintain a core operational capability to collect moderate-resolution land imagery through the procurement and launch of a series of U.S.-owned satellites; and (3) should establish the NLIP, hosted and managed by the Department of the Interior (DOI), to meet U.S. civil land imaging needs. As defined, NLIP will *"serve the Nation by acquiring and providing operational land imaging capabilities and applications to support U.S. economic, environmental, foreign policy, and security interests."* To achieve this goal, the DOI will:

- Oversee a Federal Land Imaging Council and Land Imaging Advisory Committee;
- manage U.S. land imaging requirements;
- acquire U.S. land imaging systems and data;
- develop new applications for federal, state, and local governments;
- investigate and develop new remote sensing technology;
- ensure data delivery to universities and scientists, nongovernmental organizations, and international organizations; and
- coordinate acquisition and data distribution plans with U.S. industry, foreign governments, and foreign commercial firms.

Above all else, NLIP will *"ensure availability, access, and ease of use of land imaging data for the Nation."*

Quirk concluded by asking the Landsat Science Team members to continue their efforts to advocate for Landsat capabilities and to provide specific input to NLIP by participating in the Land Imaging Advisory Committee, reviewing strategic plans, providing guidance on the Landsat 9 requirements definition process, contributing to the definition of the science component of NLIP, and developing new applications for federal, state, and local governments.

Principal Investigator and Other Reports

Several Landsat Science Team members and other researchers gave updates on their activities related to Landsat and LDCM. **Patricia Vornberger** [SAIC] presented the recently released Landsat Image Mosaic of Antarctica (LIMA) *lima.nasa.gov* that was produced by NASA, USGS, the National Science Foundation, and the British Antarctic Survey as a contribution to the International Polar Year. LIMA represents the first Landsat mosaic of Antarctica and was constructed from 1,100 Landsat scenes as well as MODIS imagery where Landsat coverage was unavailable.

Feng Gao [Earth Resources Technology, Inc.—*Landsat Science Team Member*] presented his research on developing a more robust land monitoring system. His approach is based on combined observations from multiple, international sensors. Gao uses the General Empirical Relation Model (GERM) to convert sensor digital numbers to surface reflectance directly using MODIS products as reference datasets. However, even with perfect calibration and atmospheric correction, direct comparison of surface reflectance from different sensors is still limited by viewing and illumination geometries, spectral band response function, geolocation accuracy, and resampling approaches.

Richard Allen [University of Idaho—*Landsat Science Team Member*] reviewed his investigation of methods for sharpening 120-m land surface temperature from Landsat 5 to 30-m resolution using normalized difference vegetation index (NDVI) inputs. The approach

is based on using land surface temperature endpoints representing high NDVI (wet/cold) and low NDVI (hot/dry) conditions in an image. Allen concluded that sharpening creates no net bias to the original 120-m land surface.

Lazaros Oreopoulos [University of Maryland Baltimore County and NASA Joint Center for Earth Systems Technology—*Landsat Science Team Member*] gave an overview of the role of 1.38 µm observations for cloud detection. Using MODIS data, Oreopoulos showed that due to strong water vapor absorption, when no high clouds are present, radiation scattered by surface and low clouds is absorbed by water vapor, but when high clouds are present, the 1.38 µm signal is scattered and reaches the sensor. He concluded that quantitative use for cloud masking is difficult.

David Roy [South Dakota State University] summarized his NASA-funded project to create a consistent and seamless Landsat ETM+ data stream in near-real time for use in terrestrial monitoring applications. The strategy contributes to NASA's Land measurement theme by per-pixel quality assessment information and derived land cover characterizations at monthly and longer time periods.

John Schott [Rochester Institute of Technology—*Landsat Science Team Member*] reviewed resampling issues associated with the OLI. The USGS had previously determined that the standard product would use cubic convolution resampling. Schott revisited this decision and concluded that because of the change to pushbroom technology and the inherent challenges associated with accounting for terrain spectral sampling and timing, cubic convolution is more appropriate than nearest neighbor or bilinear resampling.

Schott's presentation stimulated a follow-up discussion on the merits of using a predefined tessellation where spectral data are populated to form a point on the ground rather than being sensor specific. This should provide greater geometric consistency for temporal investigations. The USGS agreed to evaluate the feasibility of a predefined grid.

Bryan Bailey [USGS—*Principal Scientist*] summarized the work of the Committee on Earth Observation Satellites (CEOS) Land Surface Imaging Constellation Study Team. The CEOS Constellation concept was initiated to enhance effective planning and development of future Earth observing systems by maximizing international collaboration without eroding the independence of individual space agencies. The Land Surface Imaging Constellation seeks to promote the effective and comprehensive collection, distribution, and application of space-acquired image data of the global land surface. This is expected to be met through cooperative enhancement of data access, coordinated data acquisition planning, and cooperation in ground segment planning.

Meeting Conclusions

Curtis Woodcock provided the meeting wrap-up by summarizing the discussions, conclusions, and actions. The key outcomes included the following.

- Meeting the current launch readiness date is the top priority and any discussion regarding OLI and other specifications must consider impacts on launch. **The Team also concluded that LDCM must be operational by March 2012 so that it is available for use during the Northern Hemisphere growing season.** A letter will be sent to NASA and the USGS expressing this view. The Team also concluded that consideration of additional payloads (e.g., TIRS, TSIS) that could delay launch should be discontinued. This will also be expressed to NASA.

- A letter expressing enthusiastic support for DOI and USGS efforts to open the access to the Landsat archive and the completion of the new data policy stating the change to no-cost Landsat standard products over the Internet will be sent. The actions will significantly increase the value of Landsat for a wider range of science and applications.

- The Team agreed to investigate key OLI performance parameters including the effects of changes in signal-to-noise ratios on land cover characterization accuracy and the applications benefits of the coastal aerosol and cirrus bands.

Other follow-up activities include assisting in identifying contacts that may be familiar with inactive ICs, providing recommendations for potential pseudoinvariant calibration sites, contributing evaluation criteria for determining the pros and cons of predefined tessellations, and identifying science opportunities in the NLIP era.

The next Landsat Science Team meeting will be held July 15–17, 2008, in the Washington, DC, area. The meeting will focus on OLI, NLIP, and principal investigator research. ■