Landsat Science Team Meeting Summary

Thomas R. Loveland, U.S. Geological Survey Earth Resources Observation and Science Center, loveland@usgs.gov
Michelle A. Bouchard, SGT, Inc., Earth Resources Observation and Science Center, mbouchard@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 U.S. Geological Survey (USGS)–NASA-sponsored Landsat Science Team met for the fourth time on July 15–17, 2008, at the USGS National Center in Reston, VA.

The objectives of this meeting were to:

- assess the operational status and activities associated with Landsats 5 and 7;
- discuss Landsat Data Continuity Mission (LDCM) implementation progress; and
- review the science and applications activities of the Landsat Science Team principal investigators.

A particularly important element of the meeting included presentations and discussions on uncertainties in both LDCM and the proposed National Land Imaging Program (NLIP). All presentations used during the meeting are available at: *landsat.usgs.gov/science_july2008MeetingAgenda.php.*

Bruce Quirk [USGS—*Land Remote Sensing Program Coordinator*] opened the meeting and thanked the Landsat Science Team for supporting efforts to make the Landsat archive available for no-cost Internet access.

Barbara Ryan [USGS—*Associate Director for Geography*] also expressed her appreciation for the team's contributions on a number of Landsat issues, and especially for the May 28, 2008, editorial in *Science* on *web-enabled* free Landsat data. She also emphasized the challenges ahead to make Landsat an operational program.

Curtis Woodcock [Boston University—*Landsat Science Team Leader*] with Landsat Science Team co-chairs **Tom Loveland** [USGS] and **Jim Irons** [NASA Goddard Space Flight Center (GSFC)] reviewed the accomplishments from the first three meetings that addressed requirements for thermal infrared imaging, the necessity for no-cost access to the Landsat archive, as well as the consolidation of Landsat holdings in international archives into a single archive, and valuation of key LDCM requirements. Woodcock also emphasized the need to look beyond LDCM in order to ensure an operational Landsat future.

Landsat 5 and 7 Status and Activities

Kristi Kline [USGS—*Landsat Project Manager*] gave an overview of the status and health of Landsats 5 and 7. Landsat 5, launched in 1984, continues operational acquisitions. A battery anomaly that occurred in October 2007 caused a suspension of operational imaging until March 2008. However, the team implemented a new power configuration and operations strategy, and Landsat 5 was able to resume imaging over areas of the globe serviced by ground stations. Landsat 7 continues to collect global data despite the Scan Line Corrector anomaly. Recent solid state recorder problems have reduced storage capacity by approximately 20%, but the problems have not had any additional impacts on the Landsat 7 Long Term Acquisition Plan (LTAP). The team is working on recovery procedures and will attempt to restore additional storage capacity. With both Landsats 5 and 7 past their design life, there is an increasing chance of mission-ending failures. However, both satellites have sufficient onboard fuel to continue operating for several years. Barring catastrophic system failure, the USGS has a goal to operate both satellites through 2012.

Kline also gave a report on the status of USGS efforts to *web-enable* the complete Landsat archive. In April 2008, the USGS announced plans to make all Landsat data—both new acquisitions and data in the archive—available electronically over the Internet to users at no charge. The original intent was to make all data available by February 2009 but an accelerated schedule now targets a late December 2008 release of all data from Landsats 1-7. All new global Landsat 7 acquisitions were released in July 2008, and all archived Landsat 7 data will be available in September 2008. The remaining Thematic Mapper (TM) Multispectral Scanner (MSS) data will be released in December. Once the Landsat archive can be fully accessed electronically all Landsat data purchasing options from the USGS will be discontinued.

Kline and **Loveland** led a discussion on criteria that could be used to assess when it is necessary to end the Landsat 5 and 7 missions. The actual mission end will be the result of substantial decline in data quality or quantity, failed mechanical or electronic subsystems, or fuel depletion. The Landsat Science Team considered the issues associated with declines in data quality and quantity and concluded that decision-making is *situational*, and thus it is difficult to establish specific criteria. Instead, they suggested that a monitoring strategy be followed that includes internal assessments of data quality as well as periodic reviews by outside experts. The team offered to review data on anomalous conditions. Factors that need to be monitored include correctable versus uncorrectable geometric and radiometric

variations, reductions in acquisition coverage and scene quantity, utility of degraded data for key applications, and access to alternate data sources.

Jeff Masek [NASA GSFC—*Deputy LDCM Project Scientist*] and **John Dwyer** [USGS—*LDCM Project Scientist*] provided an update on the Global Land Survey (GLS) 2005 initiative. GLS 2005 adds global, cloud-free, orthorectified Landsat data from 2005 to the GLS series that already includes 1975, 1990, and 2000 Landsat images. GLS 2005 is primarily based on Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 5 TM imagery, with Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Earth Observing-1 Advanced Land Imager (ALI) data used as needed. The Landsat 7 portion of GLS 2005 will be completed and available by the end of July 2008, and the Landsat 5 data will be completed by the end of September 2008; the entire database will be completed by the end of December 2008.

With GLS 2005 nearing completion, planning has begun on adding 2010 coverage to the GLS collection. Masek and Dwyer reported that NASA and the USGS are developing GLS 2010 as an international initiative with Landsat TM and ETM+ serving as the baseline with data from international space agencies included in the overall dataset. The Committee on Earth Observation Satellites (CEOS) Land Surface Imaging (LSI) Constellation Study Team (see details below) is being consulted about playing a role in formulating international participation. The planning team hopes to begin implementing GLS 2010 by early 2009 with global image acquisitions ongoing between 2009 and 2011.

Bryan Bailey [USGS—*Principal Scientist*] updated the team on the CEOS LSI Constellation study. The LSI study team is working toward international cooperation in mid-resolution (e.g., Landsat) scheduling, acquisitions, processing, and sharing so that there is more complete global coverage available for addressing societal issues. The GLS 2010 initiative, for example, has a goal of using data collected by the various members of the constellation. Bailey explained that the team is forming a Working Group on Regional Dataset Compilation that will select one or two regions (subcontinental or larger in size) for which mid-resolution data will be acquired and compiled by mid-resolution satellite systems operated by CEOS agencies. The next steps for acquiring new data that contribute to GLS 2010 will be specified based upon the results of the regional dataset compilation effort.

Steve Covington [The Aerospace Corporation—*Landsat 5 and 7 Flight Systems Manager*] provided a brief update on a USGS feasibility study for establishing a consolidated global Landsat archive. Over the past 35 years, over 50 ground stations have been configured to receive Landsat data, and 19 are currently active. Many of the Landsat scenes found in the international ground station archives are unique and not duplicated in the USGS archive at the Earth Resources Observation and Science (EROS) Center near Sioux Falls, SD. Almost 4.5 million scenes are estimated to be held in international archives compared to 2 million in the USGS EROS archive. There is growing concern about the state of historical archives, especially at inactive stations where there are no operational contacts. A consolidated archive would better support/facilitate global change analysis and assessment. Initial discussions with current International Cooperators have been positive and a more detailed determination of the level of effort and cost is underway.

The final Landsat status report was on a USGS Landsat benefit analysis study that will estimate the size and characteristics of mid-resolution imagery such as Landsat and evaluate the benefits of the use of the data.

Holly Stinchfield and **Natalie Sexton** [USGS—*Natural Resources Social Scientists*] described the first phase of the study that will enable a better understanding of the uses of moderate resolution imagery (e.g., Landsat), including those previously not captured or detailed. The survey team has identified over 22,000 e-mail addresses of potential data users and will use a snowball technique to further expand the survey size to reach an even broader user base. The effort is focused on identifying the broader societal benefits versus just cost benefits of moderate resolution imagery. **Rich Bernknopf** [USGS—*Economist*] provided additional information on the planned cost/benefit analysis and described a planned case study that will evaluate the economic benefit of resolving spatial and temporal uncertainty associated with crop production and greenhouse gas emission forecasting using moderate resolution imagery.

Anita Davis [NASA GSFC—*Education and Outreach*] and **Ron Beck** [USGS—*Land Remote Sensing Outreach*] concluded the Landsat session and gave an update to the team on their efforts to expand public awareness of the usefulness of Landsat data and to make remote sensing more prominent in educational programs.

LDCM Status

Bill Ochs [NASA GSFC—*Landsat Data Continuity Mission Project Manager*] and **John Dwyer** [USGS—*LDCM Project Scientist*] updated the team on LDCM development status. Ochs reported that the preliminary design review for the Operational Land Imager (OLI) was successful and that Ball Aerospace is doing an extraordinary job. The critical design review is scheduled for early fall. General Dynamics was awarded the spacecraft contract in April 2008 and the systems requirements review will be held in early fall.

The combined LDCM System Requirements Review/ Mission Definition Review/Preliminary Non-Advocate Review was held in May 2008. The review focused on ensuring that the functional and performance requirements and preliminary project plan satisfy the mission, and determined whether the proposed requirements, the mission architecture, and overall concept are complete, feasible, and consistent with available resources. The review highlighted several mission *strengths*.

- Project objectives are clearly aligned with Agency strategic goals and objectives.
- People managing and implementing the LDCM project are of exceptionally high quality with significant relevant experience, and the strong communications and trust between all participating agencies and contractors significantly improve the probability of success.
- The OLI instrument, spacecraft, and ground systems benefit from strong heritage from previous Landsat and other relevant NASA and non-NASA missions.
- LDCM is based on a comprehensive and stable set of requirements.
- The LDCM project and contractor have implemented a strong risk mitigation plan for the OLI instrument.

The review also identified the following three *issues*.

- The launch readiness date requirement of July 2011 results in an extremely aggressive, high-risk schedule, which lacks any schedule reserve at the mission level. As a result, the review team concluded that the probability of the LDCM project successfully implementing this schedule is extremely low.
- There is a requirement for the LDCM spacecraft to accommodate the addition of a thermal imaging instrument. The review panel concludes that adding a thermal instrument at this point would have significant cost and schedule impacts.
- Based on the schedule assessment, which identified the current baseline schedule as very high risk, independent mission cost assessments conclude that the current LDCM budget may not be adequate.

Ochs commented that at the previous meeting, two additional instruments were being considered as additional mission payloads: the Total Solar Irradiance Sensor (TSIS) and the Thermal Infrared Sensor (TIRS). In May 2008, NOAA announced that TSIS will be flown on the National Polar-orbiting Operational Environmental Satellite System (NPOESS) and is no longer an option for LDCM. However, based on continued Congressional interest, the project is ensuring that TIRS will not be precluded from being accommodated on LDCM.

Ed Grigsby [NASA Headquarters—*Landsat Program Executive*] elaborated on LDCM cost and schedule issues and the efforts to restore TIRS to the mission. He warned the Landsat Science Team that **there is a strong likelihood that the official LDCM launch date will be delayed 6–18 months** because of the independent cost and schedule assessments, along with NASA policy requiring launch readiness dates that meet a 70% likelihood probability. Five different independent reviews are nearing completion, and all agree that July 2011 is unobtainable, but the various models are yielding divergent results regarding how much additional time is needed. He said that a revised launch date would be announced in early Fall 2008. Grigsby added that the 6–18-month slip is just for the current baseline mission. If the decision is made to include a TIRS, there could be additional delays. He acknowledged that there has been growing Congressional interest in adding TIRS, but at this point, it is neither authorized nor funded.

Dwyer summarized the status of USGS LDCM ground systems development. Ground systems development and engineering support services contracts were awarded in March 2008, with Science Applications International Corporation (SAIC) undertaking the development effort and Stinger Ghaffarian Technologies (SGT), Inc. responsible for integration, testing, and calibration/validation tasks. The selection of a flight operations team contractor is in progress, and the engineering and design of a mission operations center is underway. The preliminary design of most of the ground systems elements is progressing, and the overall ground systems preliminary design review is targeted for December 2008. Of particular interest to the Landsat Science Team was the status of the LDCM Long Term Acquisition Plan (LTAP-8) and cloud detection plans. LTAP-8 was raised as an issue during the collection and acquisition element system requirements review. Since then, an LTAP-8 working group composed of USGS, NASA, and Landsat Science Team members has worked out roles and responsibilities and has developed an algorithm description document to define inputs, software components, decision rules and prioritization algorithm, and outputs.

Pat Scaramuzza [SGT, Inc./USGS/EROS—*Senior Scientist*] reviewed the status of research leading to an automated cloud detection strategy. LDCM plans call for a cloud mask that includes both the presence/absence of clouds and a confidence level for each measure. The research is focusing on an artificial thermal (AT) approach that uses visible and shortwave infrared inputs. The AT strategy is necessary because the thermal channel inputs used in the current Landsat automated cloud detection algorithm are not currently planned for LDCM. Several approaches to cloud detection have been tested using the AT concept and the results have been consistent with the current thermal-based cloud detection algorithm. Additional testing will take place before the operational algorithm is finalized and implemented. In addition,

development of a land/water mask will be explored, and Landsat Science Team members suggested investigation of shadow masking techniques and the role of the LDCM cirrus band in cloud detection.

Ed Knight [Ball Aerospace and Technologies, Inc.] presented a detailed summary of OLI technical requirements and development status. OLI is a pushbroom sensor with visible, near-infrared, and shortwave infrared capabilities and is based on a four-mirror telescope, front aperture stop with a focal plane assembly consisting of 14 sensor chip assemblies—all passively cooled. He provided a summary of major instrument requirements and concluded that testing thus far indicates sufficient margin is available on all specifications. The instrument's hardware is being constructed with considerable progress made on the optical bench, mirrors, electronics, and filters. Knight's conclusions were that OLI is on schedule, the key requirements and design specifications are stable, hardware is being delivered on schedule, and the preliminary data from focal planes and filters are all positive.

Tim Newman [USGS—*Principal Systems Engineer*] discussed a related topic—planning for Landsat 9. National Land Imagery Program (NLIP) aims *"to serve the Nation by acquiring and providing operational land imaging capabilities and applications to support U.S. economic, environmental, foreign policy, and security interests."* Central to NLIP is transforming Landsat into an operational program. With Landsats 5 and 7 aging, and LDCM development underway, planning for Landsat 9 must begin immediately. A formal requirements gathering and analysis process is needed. However, because of the urgency in initiating Landsat 9 planning, Newman reported on a notional review of mission concepts that assume similar capabilities to those of recent Landsat missions. Concepts being evaluated include following the traditional Landsat development model (i.e., developing a single large observatory along the lines of LDCM, with increased capability), cloning the LDCM design (i.e., taking advantage of current engineering developments), and using either single or multiple small satellites.

Landsat Science Team Science and Applications Reports

The second day of the meeting was devoted to science and applications reports by the Principal Investigators or their representatives. (All presentations are available at: *landsat.usgs.gov/science_july2008MeetingAgenda.php*.)

- *Monitoring trends in forest condition in the western United States using Landsat time-series data,* **Jim Vogelmann** [Arctic Slope Regional Corporation Research and Technology Solutions/USGS]
- *Update on tropical forest monitoring with Landsat image mosaics*, **Eileen Helmer** [U.S. Forest Service]
- *The promise of an open Landsat archive: A new era for landscape monitoring and management?*, **Robert Kennedy** [Oregon State University]
- *Benefits of the new Landsat data access policy*, **Alan Belward** [European Commission Joint Research Centre]
- *Interannual, multitemporal applications of Landsat to forest ecosystem monitoring and management*, **Randy Wynne** [Virginia Tech]
- *Monitoring forest change with Landsat and early rumblings on cirrus clouds*, **Curtis Woodcock** [Boston University]
- *Synergistic use of EOS/MODIS and Landsat/TM for mapping global forest carbon fluxes*, **Rama Nemani** [NASA ARC]
- *Cloud contamination in Landsat imagery: Current and future possible solutions*, **Sam Goward** [University of Maryland, College Park]
- *Advancing ice sheet research with the next generation Landsat sensor*, **Robert Bindschadler** [NASA GFSC]
- *Water resource assessment with LDCM*, **John Schott** [Rochester Institute of Technology]
- *Mapping drought and evapotranspiration at high resolution using Landsat/GOES thermal imagery*, **Martha Anderson** [USDA Agricultural Research Service]
- *Peace in the water rights world through Landsat thermal data*, **Tony Morse** [Idaho Department of Water Resources]
- *Developing ideal spectral signatures of irrigated areas for use in spectral matching techniques and decision trees*, **Prasad Thenkabail** [International Water Management Institute]
- *Developing consistent moderate resolution data products from Landsat and Landsat-like data*, **Feng Gao** [Earth Resources Technology, Inc./NASA]
- *A surface reflectance standard product from LDCM and supporting activities*, **Chris Justice** [University of Maryland]
- *Cloud detection challenges in LDCM*, **Lazaros Oraiopoulos** [University of Maryland Baltimore County/NASA]
- L*ong-term radiometric calibration: Can we extend consistent calibration parameters from Landsats 7 & 5 back through Landsats 1-4 MSS?*, **David Aaron** [South Dakota State University]

The collection of presentations provided strong evidence of the maturity of Landsat science and applications and showcased several crucial aspects of the Landsat mission design.

- Clear value is associated with access to the full Landsat archive containing consistent temporal coverage.
- While 16-day repeat capabilities are important, there is a need for increased temporal frequency.
- Major forestry and agriculture applications offer strong evidence of the necessity for shortwave

infrared observations, and there are significant examples demonstrating the importance of thermal infrared data for operational water and agriculture investigations.
- Experimental results show potential value of the planned LDCM aerosol blue band for water resources applications.
- Landsat offers a high level of geometric and radiometric consistency, including consistent calibration of all spectral bands. These traits aid all science and applications, especially studies of land change.
- Improved signal to noise performance and greater than 8-bit quantization will improve analytical results. (LDCM OLI data will be 12-bit.)
- The range of applications is expanding and will accelerate when full access to free data occurs over the next six months. The expanded use of Landsat to national, continental, and global land surveys is particularly noteworthy.
- There is increased acceptance that 30-m resolution is appropriate for both commercial and governmental resource management and land monitoring.
- There is a need to move to more robust product paradigms for map-quality data that are based on cloud- and shadow-free orthorectified surface reflectance data.
- Landsat data are increasingly integrated with other remote sensing geospatial datasets, and as no-cost data become available, the trend will accelerate.

At the end of the presentations, the Landsat Science Team concluded that the evidence of continuing expansion of the value and importance associated with Landsat's heritage in Earth observation, and the technical lessons learned by the Principal Investigators need to be presented to the broader science and applications community. The team's plan is to organize a special session at the Fall 2008 American Geophysical Union (AGU) meeting on *The Landsat Legacy in Understanding a Changing Earth*. In addition, the team will pursue the authorization of a special issue of a remote sensing journal on Landsat science and applications.

Landsat Science Team Discussion

The primary issues facing LDCM and Landsat are associated with maintaining long-term mission continuity without data gaps. While the reports on LDCM development progress were encouraging, and the progress on OLI was especially significant, NASA's consideration of a 6–18-month launch delay is troubling. Even though there is continuing Congressional support for TIRS, both the uncertainty of potential authorization and funding, and the chance of further delays in finalizing a decision regarding TIRS, is viewed as another threat to the earliest possible LDCM launch. The team concluded that thermal imaging is an important capability and that TIRS should be authorized as quickly as possible and an aggressive TIRS development schedule should be established so that there are no additional launch delays. However, as concluded during the January 2008 Landsat Science Team meeting, **schedule requirements should drive mission planning and decisions rather than the addition of more observation capabilities**.

There was also considerable discussion on the slow progress and apparent lack of Congressional support for the NLIP, which is considered to be critical to the establishment of an ongoing operational Landsat program. Because USGS views NLIP as the framework for moving ahead with Landsat 9 planning, this news is particularly troubling. Following a lengthy discussion, the Landsat Science Team concluded that Landsat 9 planning was already behind schedule and is now more urgent than NLIP authorization. The team recognizes the need to support NLIP since it will be the long-term framework for future Landsat-scale Earth observations. However, they believe that **priority must be given to Landsat 9**. The team also concluded that the Landsat science and applications user community must become more active in advocating for the earliest possible Landsat 9 launch.

Conclusions

The Landsat Science Team praised the plans and progress made to make the full Landsat archive accessible via the Internet at no cost. This bold and visionary move will have a profoundly positive impact on Landsat science and applications. In addition, the team stressed the importance of a global consolidated Landsat archive and urged forward progress. They also offered encouragement for the plans by NASA and the USGS to make GLS 2010 an international initiative, and endorsed the role of the CEOS LSI.

The importance of Landsat data continuity was reiterated, as it has been in previous meetings. Because of the importance of Landsat data continuity, **LDCM launch delays must be minimized and TIRS should not be pursued if it causes further launch delays**. In addition, the team concluded that because of the uncertainty in the LDCM schedule and capabilities, the uncertainty of NLIP, and the absence of concrete planning for Landsat 9, there is a strong need for broader community engagement on the needs of Landsat data users. The NLIP concept is critical since it is the framework for the future of moderate resolution imaging. However, the more urgent need is to move ahead on planning and developing Landsat 9. LDCM and Landsat 9 are key measures of success for achieving NLIP objectives.

The next meeting of the Landsat Science Team is tentatively scheduled for January 6–8, 2009, and will be hosted by the U.S. Forest Service in Fort Collins, CO. ■