Landsat Science Team Meeting Summary

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Meeting Overview

The U.S. Geological Survey (USGS)- and NASA-sponsored Landsat Science Team held its winter meeting from January 6-8, 2009. The U.S. Department of Agriculture (USDA) Forest Service in Fort Collins, CO hosted the meeting.

Tom Loveland [USGS—*Landsat Science Team Co-Chair*] and **Jim Irons** [NASA Goddard Space Flight Center (GSFC)—*Landsat Science Team Co-Chair*] reviewed the objectives of the fifth meeting. The objectives included:

1. Reviewing recent USGS and NASA Landsat Data Continuity Mission (LDCM) implementation progress and of the status of Landsats 5 and 7.
2. Reviewing the research and application activities within the Fort Collins area remote sensing community.
3. Identying requirements for, and technical issues associated with, future operational Landsat products.
4. Identifying the science and applications drivers for future missions.

Desired outcomes from the meeting included establishing priorities for future Landsat products, identifying advances needed in processing, and developing an improved understanding of the requirements and paths for future Landsat missions.

Curtis Woodcock [Boston University—*Landsat Science Team Leader*] challenged the team to evaluate new opportunities for Landsat applications, such as the global forest monitoring requirements associated with the United Nations Framework Convention on Climate Change (UNFCCC) initiative, Reducing Emissions from Deforestation in Developing Countries (REDD). Woodcock commented that the recent USGS action to make all Landsat data available at no cost will create many new opportunities, but to meet the needs of emerging applications there must also be improvements in product quality that will make it easier for people to use Landsat data more effectively. He also stressed the urgency to focus attention on the authorization and planning for Landsat 9 and beyond.

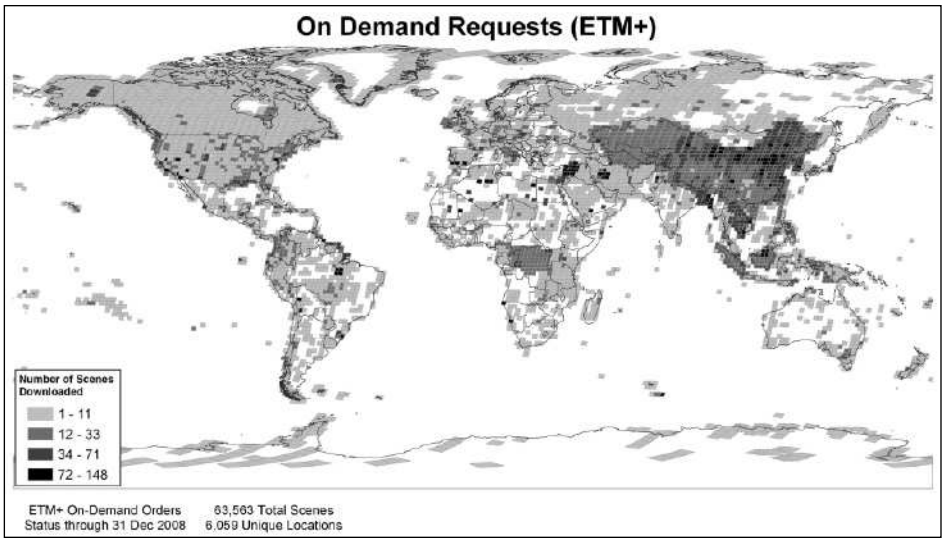
Bryant Cramer [USGS—*Associate Director for Geography*] challenged the group to contribute to the establishment of a national land imaging program. He also reiterated Woodcock's comments on the importance of Landsat for climate science applications, including carbon crediting and treaty verification.

The opening session closed with meeting attendees applauding Landsat Science Team member **Sam Goward** [University of Maryland, College Park] for his selection as the 2008 Pecora Award winner.

All presentations used during the Fort Collins meeting are available online at: *landsat.usgs.gov/science_january 2009MeetingAgenda.php*.

Landsat Status and Activities Report

Kristi Kline [USGS—*Landsat Project Manager*] updated the team on the status of Landsats 5 and 7. Land-



Landsat ETM+ scenes obtained since the opening of the Landsat archive to no-charge access (October 1, 2008 –December 31, 2008).

sat 7 is now 9.5 years past launch. Enhanced Thematic Mapper Plus (ETM+) data are affected by the 2003 scan line corrector failure, and technical issues associated with spacecraft attitude control, solid state recorders, and other components require close monitoring. However, these issues have not had a negative impact on the Landsat 7 Long Term Acquisition Plan and the mission is continuing to aggressively collect global coverage. Landsat 5 is now nearly **25 years** past its March 1984 launch and operational acquisitions are continuing—a remarkable achievement! Landsat 5 has no solid state recorders and can only relay data to ground stations, limiting the volume of international coverage flowing into the USGS Landsat archive. A battery anomaly that occurred in late-2007 affected available power, resulting in seasonal reductions in acquisitions (i.e., high latitude coverage was eliminated during the Southern and Northern Hemisphere summer solstice) due to sun angle constraints. With both Landsats 5 and 7 past their design life, there is an increasing chance of mission-ending failures. However, both satellites have sufficient on-board fuel to continue operating for several years. Barring catastrophic system failure, the USGS has a goal to operate both satellites through 2012.

Kline reported that as of December 8, 2008, all 2.3 million scenes in the USGS Landsat archive are now available over the Internet at no cost. Landsat 7 data were released for no cost access on October 1, 2008. Since October 1, over 200,000 scenes have been downloaded—see distribution map on previous page. As an indication of the demand, during the month of October, over 60,000 scenes were downloaded. (The largest number of scenes distributed in any single year prior to the opening of the archive was in 2001, when approximately 21,000 scenes went out.) The interest in free Landsat data has led to a new global phenomenon with investigators from 137 countries downloading scenes through early January 2009. The highest demand has been from the U.S. and China.

Kline also reported that duplicates of nearly all scenes in the USGS Landsat archive have been shipped to a National Archives and Records Administration (NARA) managed limestone cave near Kansas City, MO. She also reported on discussions with Landsat International Cooperators (i.e., Landsat ground stations) regarding USGS planning for a consolidated global Landsat archive. In discussion, the Landsat Science Team members stressed that global Landsat archive consolidation is a high priority that would result in major benefits for science and applications. The team offered to work closely with the USGS to develop a prioritization strategy that identifies those areas and temporal periods where consolidation of data holdings is most urgent.

Kline and **John Dwyer** [USGS—*Landsat Project Scientist*] gave an update on the Global Land Survey (GLS) initiative. The GLS involves providing periodic epochs of global Landsat coverage that have been consistently processed for use in monitoring land-cover change. Kline reported that production of the GLS 2005 data set is nearly complete with only isolated continental land areas and small islands remaining. A status map of the GLS 2005 processing is available at *landsat.usgs.gov/science_GLS2005.php*.

Dwyer gave an update on the status of GLS 2010 planning. GLS 2010 is again a collaborative development between NASA and the USGS. Landsat 5 Thematic Mapper (TM) and Landsat 7 ETM+ data will be used in GLS 2010 and the USGS is working to augment Landsat coverage by establishing campaign stations in areas where their coverage is limited (e.g., northern Russia, east Africa, Mexico). In addition, efforts are underway to involve the Committee on Earth Observation Satellites Land Surface Imaging Constellation Working Group on Regional Data Set Compilation in order to make GLS 2010 an international multi-source initiative that includes Landsat-class data from India, China, Brazil, France, and other international providers.

Natalie Sexton [USGS—*Survey Scientist*] gave an update on a survey of Landsat data users designed to document societal uses and benefits of moderate resolution imagery. The goal of the survey is to better understand the uses of moderate resolution imagery, including those previously not captured or detailed. To meet this goal, the survey team first used a *snowball survey approach*—where one person is surveyed and then is invited to identify others who should be surveyed—to identify and classify users. This has resulted in the establishment of a sample group of nearly 3,800 data users that will soon be contacted to understand how and why moderate resolution imagery are being used and to qualitatively and quantitatively measure societal benefits associated with the use of the imagery. Plans are to distribute the survey to those identified in the first phase once approval is received from the Office of Management and Budget.

The final Landsat-related topic involved the status of planning for a Landsat *data gap*. There is a strong probability that Landsat 5 and 7 will cease operation prior to the launch of LDCM. **Tom Holm** [USGS—*Data Management Advisor*] reviewed the analysis of international moderate resolution candidates that could fill a *data gap* and the steps ahead to implement a *data gap* activity. Previously, an interagency Landsat *data gap* study team established radiometric, spectral, spatial, and geographic criteria that replacement data sources should ideally meet (*see calval.cr.usgs.gov/documents/LDGST_Technical_Report_Final.pdf*). The group concluded that no single source would meet all of the criteria but that the leading candidates are the instruments on the Indian Remote Sensing ResourceSat-1 and the Chinese–Brazilian Earth Resources Satellites. It is clear that additional sources (e.g., the French Système

Pour l'Observation de la Terre (SPOT) satellites and the German *RapidEye* system) are also candidates and that some other data sources are still being evaluated. The USGS will develop a detailed implementation plan by mid-2009 that addresses technical and policy/programmatic issues. Holm requested input from the Landsat Science Team on data requirements for operational and scientific purposes.

LDCM Status

Bill Ochs [NASA GSFC—*LDCM Project Manager*] and **David Hair** [USGS—*LDCM Project Manager (Acting)*] updated the team on the LDCM development status. **Ochs** led off with the news that in September 2008, the NASA Program Management Council gave approval for LDCM to proceed into *Phase B* of the project life cycle. *Phase B* is the system preliminary design phase of the mission. This decision follows the May 2008 System Requirements Review/Mission Definition Review/Preliminary Non-Advocate Review. The review findings included the determination that the original LDCM launch readiness date of July 2011 was excessively aggressive and added risk to the mission because of the conclusion that there was less than a 20% chance that the 2011 launch date could be achieved. Because NASA mission schedules must reflect a 70% chance of achieving the launch readiness date, five independent schedule assessments were made. Based on those assessments, the LDCM launch readiness date approved by the NASA Program Management Council was December 2012. The conclusion was that the revised date provided an appropriate level of confidence and that it resulted in sufficient schedule reserve on the mission critical path.

Ochs next reviewed the status of the Operational Land Imager (OLI). Ball Aerospace & Technologies Corp. (BATC) successfully conducted the OLI critical design review in October 2008. There are a few issues that have been discovered recently. Analysis of the OLI optical model showed reflections from the focal plane assembly window onto adjacent bands on the focal plane module. BATC has adjusted the baseline design to tilt the focal plane assembly window 16.7º based on results of the refined ghosting analysis. The second concern is that the OLI engineering design unit focal plane module has surface leakage. If not corrected, it could lead to degraded detector response. The NASA LDCM and Ball engineers are developing *decision milestone* dates regarding options for solving the problem. This issue could have a potential impact on the OLI delivery date.

Ochs also reported that the spacecraft system requirements review was held in September 2008. As a result of this review, NASA and the spacecraft vendor (General Dynamics) are concentrating on instrument interfaces [both OLI and the Thermal Infrared Sensor (TIRS)—see discussion on TIRS below] and resolution of open requirements. Ochs mentioned that The Hammer Company received the mission operations element award to provide capabilities for controlling and managing the spacecraft.

Finally, **Ochs** provided a detailed update on the status of TIRS. While thermal imaging capabilities are currently not authorized, there is still significant congressional and scientific interest in adding thermal imaging capabilities to LDCM. In July 2008, NASA initiated a *Phase A* Study to proactively investigate the implementation of a TIRS for LDCM and provide risk mitigation to the December 2012 launch readiness date. This included assessing all requirements, creating a concept design, and assessing the programmatic implementation, including the schedule and required early procurements needed. The concept developed is based on the use of Quantum Well Infrared Photodetector (QWIP) technology. At this point, TIRS is still not authorized but it has been fully integrated into the LDCM planning process.

David Hair summarized USGS LDCM accomplishments. The USGS is in the final stages of completion of the ground system preliminary design and elements of the ground system critical design have been initiated. The full ground system preliminary requirements review is scheduled for May 2009. Hair also reported on a USGS investigation of the need for access to *Level 0R* (L0R) format data for historical Landsat data. The investigation included an evaluation of the potential frequency and volume of requests for L0R data and whether there were expectations on the need to provide processing software. Results of the study were inconclusive and there was relatively little interest in low-level Landsat products, especially if there would be a cost associated with access to L0R products.

The LDCM status discussion continued on the final day of the meeting when the Landsat Science Team traveled to Boulder, CO for a detailed briefing on OLI status by the BATC team. During that session, **Charlie Vanhouten, Ed Knight,** and other BATC engineers and scientists provided a comprehensive overview and tour of OLI development. They gave the Team an in-depth tour of the development labs and showed flight hardware including the optical bench, telescope mirrors, and other components. They also introduced the Team to their testing facilities and other capabilities used in the OLI development process.

Remote Sensing Science and Applications

As the host of the Fort Collins meeting, Landsat Science Team member **Eileen Helmer** [U.S. Forest Service] organized a technical session to showcase selected Fort Collins remote sensing activities.

Helmer's U.S. Forest Service team is involved in tropical vegetation assessments in the Caribbean. **Bonnie Ruefenach** [USFS Remote Sensing Applications Center] provided a detailed introduction to a set of image analysis tools that she has developed for vegetation characterization. **Tom Ruzycki** [Colorado State University] gave an overview of the methods used to create cloud-free Landsat time series mosaics for use in modeling of Puerto Rico and the Virgin Islands forest characteristics. In addition, he described a geospatial framework that uses remote sensing and other inputs along with regression tree analysis to predict tropical species occurrences. **Helmer** provided an overview of their research on the interactions between the spatial patterns of tropical forest disturbance and biomass in Puerto Rico. The research documents the changes in tropical forest types and an analysis of the shifting of the Puerto Rican economy from agriculture to industry and services. It also estimates the total biomass of forest cleared for land development from 1991–2000 based only on forest type and also based on both forest type and age class.

Jeff Morisette [USGS—*Research Biologist*] summarized the USGS Fort Collins Science Center remote sensing of invasive species program. Satellite data provide predictor layers for habitat modeling that is used to estimate where species will thrive. There has been considerable effort at the Center to use satellite data to enhance habitat modeling. Initial work was with Landsat 5, using tasseled cap transformations. Recent work has been with national-level mapping using the Moderate Resolution Imaging Spectroradiometer (MODIS). Potential future work includes using disturbance mapping to anticipate invasion (e.g., predicting the likelihood of invasion as a function of burn severity.)

John Gross [National Park Service Inventory and Monitoring Program—Fort Collins] described efforts to establish inventory and monitoring as a standard practice throughout the National Park Service. This program emphasizes inventorying natural resources, monitoring park ecosystems, and integrating natural resource information into planning, management, and decision making. In addition to providing an overview of the program, Gross reviewed the role of remote sensing in contributing to the spatial and temporal scales of analysis that form the basis for the inventory and monitoring framework. A key requirement for the program is long-term data continuity from which change products can be derived. MODIS, Landsat, and *IKONOS* imagery are current inputs to the integrative land-cover change element. A particular interest for the future is the establishment of tools for detecting change in long Landsat time series. In addition, the Inventory and Monitoring Program is working toward a tighter link to climate change issues.

Products Discussion

The morning of the second day was dedicated to discussing future products. **Brian Markham** [NASA GSFC] reviewed the LDCM *Level-1* product. The *Level-1* product will be 16-bit integers, radiometrically and geometrically corrected, and scaleable to reflectance or radiance with linear scaling factors that will be provided with the product. The reflectance product will be for a scene-center zenith sun and will include the Earth-Sun distance correction. The Team agreed to the use of a scene-center angle as long as information for all four corners will be provided in the metadata.

Dennis Helder [South Dakota State University] discussed ongoing calibration work for Landsat TM and Multispectral Scanner (MSS) sensors. *Pseudo-invariant* calibration sites (sites with non-changing surface properties such as non-vegetated desert sites) have been used for radiometric trending and to help cross-calibrate TM and MSS sensors. Cross-calibration of TM4 to TM5 is complete and Helder is currently expecting to incorporate the new calibration for Landsat 4 TM by May 2009. Radiometric calibration of the MSS 1-5 showed good stability over time and cross-calibration validation showed good consistency between sensors. Cross-calibration for MSS/TM is more difficult due to differences in the spectral bands and his team is looking at developing a spectral-based cross-calibration technique.

Pat Scaramuzza [Stinger Ghaffarian Technologies (SGT) Inc.] showed results from the Cloud Cover Assessment algorithms developed for LDCM. Scaramuzza's task was to create an Automated Cloud Cover Assessment (ACCA) that does as well or better than the current Landsat ACCA, but without the use of a thermal band and with minimum processing time. The *See5* algorithm correctly identified 89% of the cloud/non-cloud pixels and outperformed the current ACCA. The final system may include several algorithms with intermediate masks that will be merged to create a final cloud cover mask.

David Roy [South Dakota State University] presented his Web-enabled Landsat Data (WELD) project. The goal is to generate 30-m mosaic temporally composited products over the continental U.S. Similar to MODIS. Roy's team will create monthly, seasonal, and annual products such as surface reflectance, brightness temperature, and Normalized Difference Vegetation Index (NDVI). In some areas they are having difficulty getting enough data to create monthly and seasonal mosaics due to the USGS data policy restricting the automated processing of Landsat to scenes that have 40 percent or less cloud cover.

Warren Cohen [USDA Forest Service] presented work on tools that use Landsat's long-term archive for large-

scale monitoring. *LandTrendr* analyzes Landsat time series using automated algorithms to track trends in disturbance and recovery, and can also create composites removing SLC-off gaps and clouds. *Timesync* uses Landsat's rich archive to validate time-series maps by allowing a visual interpretation of what has been automatically detected.

Future Missions Discussion

The Landsat Science Team devoted an afternoon to a discussion of the future of the Landsat Program. The Future of Land Imaging Plan recommended by the White House Office of Science and Technology Policy called for the establishment of a National Land Imaging Program (NLIP) with an operational Landsat program as a central part of NLIP. Thus far, there has been little congressional support for NLIP and as a result, planning for Landsat 9 and beyond is not underway.

Tony Willardson [Western States Water Council (WSWC)—*Deputy Director*] led off the discussion. The WSWC has been a strong advocate for Landsat data, and in particular, thermal infrared imagery. Willardson reviewed the information needs for western state's water resources management with emphasis on the importance of Landsat. Issues being addressed by western state's water managers include:

- general lack of data on water needs and past, present, and future uses;
- climate change and variability;
- endangered species and other in-stream water uses;
- outflows to bays and estuaries;
- increasing energy needs; and
- unquantified Native American water rights.

These issues are further complicated by population growth in the West, which has created even greater demands for water and is threatening water-dependent agricultural practices. Landsat data are being used throughout the West to provide data and information needed to manage these issues. For example, five court cases that WSWC is currently involved in are using Landsat thermal data in the deliberations. Because of the importance, the WSWC is working with western congressional delegations to advocate for Landsat thermal data continuity.

The Landsat Science Team spent the remainder of the session identifying the issues and steps that need to be taken to establish an operational Landsat program. There was strong agreement that the future of Landsat must be viewed as a two stage process with the first stage being the authorization and development of Landsat 9, and the specification and development of the long-term operational configuration starting with Landsat 10 and beyond. The need for continuity that extends the Landsat record without periods of observation gaps is the most urgent driver for Landsat 9. Given the extended lead time required for authorization, planning, and development of each Landsat mission, there is real urgency to embark on a course for Landsat 9 that has a shortest possible development time. The team generally agreed that the current LDCM specifications, plus a thermal imaging capability, were appropriate for planning Landsat 9. The technology improvements incorporated into LDCM (e.g., pushbroom scanner) and improved capabilities (e.g., 12-bit quantization, additional spectral channels, and expanded acquisition capabilities), were sufficiently demonstrated in the Earth Observer-1 mission to suggest that the current LDCM specifications and design be used for Landsat 9. While the specific cost and schedule savings associated with reuse are not known, the Team expected that this approach was the most logical short-term strategy.

While the Landsat Science Team considered Landsat 9 progress to be the most urgent issue, they also remain committed to an operational Landsat program as envisioned in NLIP. NLIP is clearly the long-term solution to mid-resolution imaging and authorization of the program remains an important need.

Discussions focused on three issues associated with an operational Landsat program as summarized below.

1. **Definition of what an operational program involves**. **Bryant Cramer** suggested the Team consider the operational threshold for *data gaps* by considering the length of time that is permissible between the failure of one mission and the launch and operation of a follow-on. This could also be addressed through an expression of what probability of a *data gap* is acceptable to the user community. In other words, how much risk can users tolerate—and why?
2. **Definition of the Landsat 10 mission… and beyond**. The definitions must address the purpose of an operational Landsat program and express the fundamental mission requirements. Landsat Science Team members agreed that the long-standing mission definition to detect land changes at the scales relevant to human activities remains valid but that climate change and emerging operational environmental monitoring applications will necessitate evolutionary changes. There was general agreement that future missions must include additional science data products such as land-cover change, fraction of absorbed photosynthetic radiation, albedo, fire products, and others.
3. **The importance of periodic technology missions to test new capabilities or technologies for future Landsats.** An operational program must have a strong research and development component to test and evaluate new capabilities.

In general, the Team agreed that Landsat missions must continue to serve as the "gold standard" that is used to maintain calibration between constellations of international missions. However, there was also agreement that miniaturization of instruments to lower mission costs and enable faster development-to-launch schedules is needed. It is also important to work through the international community and coordinate acquisition schedules.

Summary

The primary topics addressed during the January 2009 meeting were Landsat products and future Landsat missions. While there was considerable discussion of options associated with each topic, many issues were not resolved and have to be carried over to the summer meeting. Six working groups were established to study the unresolved issues and each was tasked with identifying and evaluating options and presenting them for discussion and resolution when the Team meets in June 2009. The six working groups and a brief summary of the responsibilities of each follows.

Data Gap Working Group

The Data Gap Working Group will contribute a science and applications perspective to the development of a USGS operational plan for acquiring data during a Landsat *data gap* period. In particular, the group should contribute to the strategy and preparations associated with acquiring replacement moderate resolution remotely sensed data as soon after the failure of Landsat as possible. Specific topics that the working group must address include: (1) confirmation of the technical and programmatic specifications for data gap candidates; (2) evaluation and validation of candidates; and (3) assessment of the science and applications potentially associated with both individual and integrated multi-source data sets.

Future Missions Working Group

The Future Missions Working Group will develop and recommend to the USGS and NASA operational mission standards, requirements, and characteristics for future Landsat missions. This includes determining the meaning of an "operational" Landsat program, suggesting a long-term mission definition including the purpose of an operational Landsat program, providing recommendations on what the key technical elements of an operational program are, and identification of the key innovations needed in the Landsat program over the next 5-10 years.

Global Consolidated Landsat Archive Group

The Global Consolidated Landsat Archive Group will develop and recommend a prioritization strategy for acquiring data from International Ground Stations to the USGS. Some of the topics for the team to address are: (1) where are there data gaps in the USGS Landsat archive; (2) which data gaps are most important to fill and where is the data held; (3) which stations hold the highest volume of unique data; and (4) what are other mechanisms for acquiring data? Each of the station's holdings and the importance of the data should be documented for the USGS.

Cloud and Shadow Masking Group

The Cloud and Shadow Masking Group will identify and evaluate methods for improving cloud and shadow masking. The team will develop and assess algorithms to create a *Level 2* cloud and shadow mask. The team will also evaluate and determine the feasibility of implementing additional algorithms as part of the Cloud Cover Assessment for the LDCM Image Processing Element.

Gridded Data Sets

The Gridded Data Set Working Group should provide recommendations to the USGS Landsat and LDCM projects on the specifications for standard product generation to ensure the highest levels of product quality and usability. The Working Group should address issues related to the map projections, resampling methods, and pixel coordinate referencing schemes for Landsat and LDCM data products to ensure the consistency in image geometry and geolocation necessary to support large area and time-series research and applications. Particular consideration should be given to the geometric registration and georeferencing across the multiple Landsat and LDCM sensors and spectral bands.

Surface Reflectance and Temperature

The Surface Reflectance and Temperature Working Group should provide recommendations to the USGS Landsat and LDCM projects on the specifications for standard product generation with particular emphasis on the derivation of geophysical parameters from calibrated at-sensor radiance data. These recommendations will be considered in the design and implementation of algorithms used for ground processing and standard product generation. The Working Group should address issues associated with radiometric calibration, data processing algorithm and scaling parameters, product metadata, and data usability to support the needs of the research and applications community.

Next meeting

The next meeting of the Landsat Science Team is tentatively scheduled for June 22-24 in Rochester, NY. Landsat Science Team member **John Schott** from the Rochester Institute of Technology will host the meeting.