meeting/workshop summaries

Landsat Science Team Summary

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Meeting Overview

The Landsat Science Team, sponsored by the U.S. Geological Survey (USGS) and NASA, met at the Computer History Museum in Mountain View, CA, January 19–21, 2010[1]. Landsat Science Team members Jennifer Dungan and Rama Nemani [NASA Ames Research Center] hosted the meeting. All presentations from the meeting are available at: *landsat.usgs.gov/science_january 2010MeetingAgenda.php*.

Tom Loveland and **Jim Irons** [USGS and NASA Goddard Space Flight Center (GSFC), respectively—*Landsat Science Team co-chairs*] opened the seventh meeting of the Landsat Science Team with an identification of the issues requiring the team's attention:

- increased focus on the evaluation and utilization of Landsat Data Continuity Mission (LDCM) datasets;
- greater collaboration between LDCM and the European Space Agency's Sentinel-2 mission;
- better understanding of both requirements and technical/scientific readiness for advanced Landsat science products; and
- continued advancement of operational land imaging with the authorization of Landsat 9 and beyond an urgent priority.

Curtis Woodcock [Boston University—*Landsat Science Team Leader*] also emphasized the importance of these topics and credited the team for their efforts to advance these topics over the past three years. While progress is being made on many fronts, he stressed that authorization of Landsat 9 is still the most urgent issue and that the Landsat Science Team must continue to make it the focal point. Woodcock also noted European Space Agency participation in this as well as the June 2009 meeting, and encouraged an open dialog on topics that will lead to greater coordination between LDCM and Sentinel-2.

Bryant Cramer [USGS—*Associate Director for Geography*] provided an update on a range of USGS Landsat activities. He noted the attention that Landsat is receiving in the Department of the Interior. The USGS is scheduling a congressional briefing during the spring to address the importance of Landsat for a wide range

[1] This meeting took place in January but publication of the report in *The Earth Observer* was delayed, therefore it should be noted that a number of the events mentioned in this summary as *upcoming* have now taken place.

Landsat Science Team meeting participants

of science and applications topics, and to emphasize the importance of an operational Landsat capability. Cramer acknowledged the importance of a long-term NASA role in science and technology development but said that the USGS should also play a key role in operational terrestrial Earth observation. He said that NASA, USGS, and NOAA must work together to coordinate the linkages between each agency that ensure a strong U.S. Earth observation capability.

Cramer also commented that Web-enabled Landsat data are a "smash-hit." With the nearly 2.5 million Landsat scenes in the U.S. archive available at no cost, the ability for remote sensing to revolutionize resource management and advance global change science has never been greater. He concluded by asking the Landsat Science Team for help in prioritizing the measurements and processing needed to make Landsat an essential component of terrestrial science and applications.

David Jarrett [NASA Headquarters—*Landsat Program Executive*] introduced himself as the newest member of the Landsat leadership group. Jarret noted that the December 2009 LDCM Mission Confirmation Review was successful and NASA is now proceeding toward a December 2012 launch.

Bruce Quirk [USGS—*Land Remote Sensing Program Coordinator*] provided an update to the team on other USGS remote sensing developments. The USGS recently signed a contract with SPOT Image Corporation to acquire Satellite Pour l'Observation de la Terre (SPOT) 4 and 5 satellite data over the U.S. and parts of Canada and Mexico for the next twelve months. The Earth Resources Observation and Science (EROS) Center is already receiving electronic deliveries of SPOT scenes, and a direct reception capability will be implemented at EROS in the spring. SPOT data can be accessed over the Internet at no charge for U.S. federal civil agency and U.S. state and local government users. Quirk also described USGS interests in obtaining the GeoEye OrbView-3 archive. GeoEye has offered the USGS the opportunity to purchase over 500,000 images collected between 2003–2007. The collection includes 1-m panchromatic and 4-m multispectral images; 50% of these images have less than 10% cloud cover. The Landsat Science Team advised the USGS that this collection would have significant scientific value as a calibration and validation reference source for land change studies.

Landsat 5 and 7 Status

Tom Kalvelage [USGS EROS—*Data Management Branch Chief*] updated the team on Landsats 5 and 7 operations. Both satellites continue to acquire global imagery. Landsat 7 service has now exceeded ten years. Although the ETM+ Scan Line Corrector failed in 2003, the mission continues to aggressively collect global coverage. A recent orbit conflict with the Taiwanese Formosat 3D resulted in a Landsat 7 avoidance maneuver, which removed the risk of collision. The burn maneuver has no impact on the end-of-mission prediction (post-December 2012) for Landsat 7.

Landsat 5 is approaching its 26th year in orbit acquiring Thematic Mapper data. The flight operations team has confronted and is tracking several problems. In August 2009, saturated gyro rates caused the satellite to tumble into a critical state. However, operators recovered from the problem and Landsat 5 acquisitions returned to normal less than two days after the event. In December, the redundant Traveling Wave Tube Amplifier (TWTA) failed and was not recoverable. The redundant TWTA had been used since the primary TWTA failed in 1986. In early January, the flight operations team successfully reestablished functionality to the dormant primary TWTA. The collection of science data resumed on January 10, 2010.

Kalvelage also reported that there is significant user demand for free Landsat data. Approximately 25,000 scenes were processed each month in 2009, and over 100,000 scenes per month were downloaded. The Landsat Project is experiencing periods in which processing requests are creating backlogs, but efforts are underway to continue to improve EROS Landsat processing capabilities. An important step is the conversion of Landsat Multispectral Scanner (MSS) process from the legacy National Land Archive Production System (NLAPS) to the Landsat Product Generation System (LPGS) so that Landsat MSS, Thematic Mapper (TM), and Enhanced Thematic Mapper (ETM+) products are consistently processed. The conversion to LPGS will be completed in September 2010. Other physical improvements underway include moving the Level Zero-R Archive (L0Ra) currently stored on tape to online disk, updating storage area network throughput, and expanding storage space for file transfer protocol (FTP)-accessible processed Landsat scenes. In addition, planning is underway to improve *metadata* so that the processing levels and calibration updates are identifiable. Finally, Kalvelage announced that on-demand access to Landsat Level Zero-R Processed (L0Rp) data was instituted in January 2010. Users needing access to L0Rp data should contact EROS Customer Services.

Gene Fosnight [USGS—*Landsat Data Acquisition Manager*] briefed the team on processing changes associated with Landsat MSS in particular, and on full-resolution browse and thermal products in general. MSS processing is being migrated from NLAPS to LPGS to create Level 1 products and *metadata* that are consistent with TM and ETM+. MSS LPGS processing will use cross-calibrated gains, biases, and time dependent variables to map the MSS archive data to radiance using

the Normalized Radiance method developed at South Dakota State University (SDSU). A hierarchical image registration approach is being refined to achieve more robust and effective geometric processing, and a product verification module is being developed to evaluate and document the positional accuracy of Landsat Level One-T (L1T) data against GLS 2000 reference. Three MSS LPGS processing releases are planned through August 2010, after which a consistent, cross-calibrated archive of Landsat data will be available. The Landsat Project is also working toward a goal of having consistent radiometric calibration of all Landsat data from 1972 to the present. The final step in achieving this goal is to complete the calibration of the MSS record.

Dennis Helder [South Dakota State University] has led the MSS calibration research. Helder is calculating cross-calibration gains and biases using the whole lifetime response of the MSS sensors. He reported that the absolute gains of the five MSS sensors (Landsats 1–5 carried MSS instruments) exhibit a maximum difference of 17%, which has been reduced to less than 1% in Band 1, 2% in Band 2, 3% in Band 3, and 5% in Band 4. Spectral differences within MSS sensors can contribute errors approaching 2%. Helder also concludes that spectral differences between MSS and TM sensors can lead to 10% errors with vegetated targets. Helder's radiometric calibration results will be part of the LPGS MSS processing capabilities that will be released in September.

Landsat Global Archive Consolidation

One of the top priorities of the Landsat Science Team is Landsat global archive consolidation. An estimated 1.3 petabytes of Landsat data are held in up to 20 international archives, and a significant percentage of these data are unique and not part of the U.S. Landsat archive at EROS. In addition, a considerable amount of data is in danger of being lost due to storage conditions and obsolete media.

Tom Kalvelage summarized recent USGS planning for an initiative to recover as much of this international data as possible. The initiative is challenging because a wide range of data formats, storage media, and storage practices exist. Essentially, each of the 20 international Landsat stations must be treated as a unique project. To scope the activity, the USGS has contacted all international stations and has requested archive metadata. Data from China, Pakistan, Ecuador, and Canada have been received and analyzed. The Pakistan station has requested help in reading old tapes and will send sample tapes to the USGS in early 2010. Communications with the Ecuador station are underway to initiate efforts to move their data to the USGS. Kalvelage pointed to the Pakistan and Ecuador activities as important first steps toward the goal of consolidating as much international data into the USGS as possible.

Global Land Survey (GLS) Update

Jeff Masek [NASA—*Deputy LDCM Project Scientist*] and **Garik Gutman** [NASA HQ— *Land Cover and Land Use Change Program Manager*] provided an update on the overall Global Land Survey (GLS) activity. GLS 2005 was completed in September 2009 when Brazil and Indonesia delivered the last scenes to the USGS and NASA. This dataset consists of 5,764 Landsat 7 ETM+ scenes and 2,425 Landsat 5 TM scenes. In addition, the datasets include 555 Earth Observing-1 (EO-1) Advanced Land Imager (ALI) scenes covering islands and reefs. Masek said that the acquisition of images for the GLS 2010 dataset is now underway. As with the 2005 collection, Landsat 5 TM, Landsat 7 ETM+, and EO-1 ALI images will be acquired. The acquisition window is 2009–2010 and will include Landsat International Cooperator station participation, as well as up to eight campaign stations. All data will be processed to the L1T standard by the USGS and NASA will *gap-fill* the Landsat 7 scenes. The complete GLS 2010 dataset will be available by late 2011.

LDCM Status

Bill Ochs [GSFC—*LDCM Project Manager*] reviewed the progress of the primary LDCM systems. Ball Aerospace and Technologies Corporation (BATC) is progressing with development and construction of the Operational Land Imager (OLI). Alignment and thermal vacuum and vibration testing has been completed. Testing of the focal plane array engineering development unit and the flight solar calibration subsystem is also complete, as is stray light testing. Functional tests of the flight focal plane electronics are now underway and the flight software has passed qualification tests. The flight focal plane assembly and frame are ready for module delivery. The thermal control system thermal balance test is also ongoing.

Ochs also updated the team on the status of some detector performance issues he had discussed at a previous meeting, and he also identified some more recent issues that have come up. Because of these issues, OLI delivery could slip two months, reducing the overall OLI reserve to less than four months. NASA and BATC are working together to identify *mitigations* that could recover more reserve time and lower schedule risk.

Ochs further reported that all major procurements are in place for the second LDCM instrument—the Thermal Infrared Sensor (TIRS). TIRS is progressing satisfactorily, but the LDCM team continues to examine the schedule to identify parallel development paths and compress the overall delivery schedule.

General Dynamics Advanced Information Systems is designing the LDCM spacecraft, which passed its

Critical Design Review in October 2009. Upcoming development issues include accommodating TIRS (this instrument was a late addition to LDCM), spacecraft to ground risks, spacecraft structure qualification, and jitter assessment.

There was a Critical Design Review for the mission operations element in November 2009. Ochs reported that the mission operations center ribbon cutting was also held in November, and *Build-2* of the mission operations element (developed by the Hammers Company) was delivered to the mission operations center at GSFC ahead of schedule. At this point, the flight operations team is on site and supporting early spacecraft integration and testing and procedure development, ground readiness test planning, and development of operations documentation.

Ochs concluded by reporting that the LDCM mission recently reached a major milestone in its development as it was confirmed by NASA. The process for confirmation began with the July 2009 mission Preliminary Design Review and concluded with the Key Decision Point–C meeting with NASA's Program Management Council in December 2009. As part of this confirmation, a non-advocate review of LDCM readiness took place. This later review included the generation of a joint confidence level estimate, which consists of an evaluation of the LDCM schedule and budget in order to verify that NASA can meet its obligations to mission stakeholders. Based on the analysis, the conclusion was reached that a December 2012 launch is *"aggressive but achievable"* and LDCM was given the authority to proceed with a December 2012 launch readiness date. However, an external commitment date of June 2013 was communicated to Congress along with the explanation that the LDCM team was striving for a December 2012 launch. Ochs summarized by stating that the team continues to be committed to the December 2012 launch date and that great progress has been made so far, but he acknowledged that there are still many challenges ahead. The mission Critical Design Review is scheduled for Spring 2010.

Dave Hair [USGS EROS—*Acting LDCM Ground System Manager*] provided an update on the status of the ground system development. The USGS has adopted a ground system approach and architecture that takes advantage of existing capabilities to the greatest extent possible. Hair reported that both the overall ground system and data processing and archive system Preliminary Design Reviews were successfully completed in September 2009. In addition, the first delivery of the Collection Activity Planning Element (CAPE 1.0) occurred in January 2010. This release includes the majority of the functionality associated with scheduling science data acquisitions via implementation of the Long Term Acquisition Plan (LTAP). The Critical Design Reviews for both the overall ground system and data processing and archive system are planned for Spring 2010. Ground readiness testing begins in Summer 2010 and concludes with final data processing and archive system readiness testing in Summer 2012.

USGS and NASA Outreach Activities

Anita Davis [NASA GSFC—*Education and Public Outreach*] reviewed a number of educational activities addressing Landsat and other aspects of environmental remote sensing. Davis reviewed the *Earth to Sky* initiative in which NASA is working with the National Park Service and U.S. Fish and Wildlife Service in ways that enrich the visitation experiences of park and refuge visitors. Davis also described the Integrated Geospatial Education and Technology Training (iGETT) project, which is focused on training two-year college faculty in the integration of remote sensing into GIS programs.

Ron Beck [USGS—*Land Remote Sensing Program*] summarized USGS efforts to increase the visibility of Landsat within education, professional, and congressional venues through the development of information articles, exhibit materials, brochures, and fact sheets.

Sentinel-2

Bianca Hoersch [European Space Agency—*Sentinel-2 Third Party Mission Manager*] presented an update on Sentinel-2 development. Sentinel-2 is part of the European Global Monitoring for Environment and Security (GMES) initiative that provides operational services needed for emergency management, air quality monitoring, land monitoring, and ocean and sea ice monitoring. Sentinel-2, a Landsat-class multispectral imaging mission focused on land applications, has the following key attributes:

- thirteen spectral bands (VIS, NIR, and SWIR);
- spatial resolutions of 10, 20 and 60 m with a 290-km swath;
- a five-day repeat cycle (cloud free) with two satellites;
- a sun synchronous orbit at 786-km mean altitude; and
- a seven-year design lifetime, consumables for 12 years.

Sentinel-2 is scheduled to launch in May 2013, with operational imaging available by Summer 2013. The mission concept calls for the systematic imaging of the global land surface. A range of products are planned including:

- **Level 0** and **Level 1A**: system products corresponding to raw compressed and uncompressed data;
- **Level 1B**: radiometrically corrected data;

- **Level 1C:** orthorectified top-of-atmosphere reflectance; and
- **Level 2A:** orthorectified bottom-of-atmosphere reflectance that includes enhanced cloud screening and atmospheric corrections.

Hoersch also reviewed the Sentinel data policy, which calls for full and open access to Sentinel data to all users. The European Space Agency member states approved the proposed data policy in September 2009 but the European Commission still must give its approval.

In the discussion following the Sentinel-2 presentation, there was a consensus among Landsat Science Team members that significant attention should be given to opportunities for synergy between programs, both as a means to reduce risk and to increase coverage and interoperability.

Landsat Science Products Requirements

Previous Landsat Science Team meetings have addressed the need for higher level Landsat science products. **Bruce Quirk** [USGS Land Remote Sensing Program Coordinator] introduced the session on science products with an update on USGS interest in moving beyond orthorectified multispectral products. **The USGS believes that terrestrial *essential climate variables* produced from Landsat data are needed to understand human impacts on the Earth and the status of natural ecosystems and looks to the Landsat Science Team for recommendations on data priorities and processing requirements.** Quirk's remarks were followed by presentations by members of the Landsat Science Team and guests on science product topics.

John Schott [Rochester Institute of Technology] described the Digital Imaging and Remote Sensing Image Generation (DIRSIG) modeling approach and applications in support of LDCM. DIRSIG is being used to model OLI/TIRS imaging capabilities. Modeling geometric effects are a top priority, with radiometric modeling planned for future releases. A fusion of Digital Globe, Hyperion, Landsat, ASTER emissivity, and Digital Elevation Model (DEM) data are used to establish virtual truth datasets. A first release is anticipated in early 2010 and will include the first DIRSIG-modeled OLI image, orbital geometry, and angular detection locator. The first DIRSIG-generated TIRS image is planned for soon after, with future development releases on a semi-annual basis. Each DIRSIG release will improve sensor and scene fidelity.

Lazaros Oreopoulos [NASA GSFC] presented a decadal reassessment of Landsat 7 LTAP cloud avoidance. Terra Moderate Resolution Imaging Spectroradiometer (MODIS) cloud data products were valuable for assessing past performance of the Landsat 7 LTAP for cloud avoidance, for formulating an improved Automated Cloud Cover Assessment simulator for the LTAP model, and for potentially improving the LTAP by replacing the International Satellite Cloud Climatology Project D2 nominal climatology database.

Eric Vermote [University of Maryland] updated the team on his work on surface reflectance products for Landsat. The Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) code has been tested, evaluated, and updated. Surface reflectance estimates produced from LEDAPS for Landsats 5 and 7 were highly correlated with MODIS surface reflectance products over Africa (overall correlation coefficient (R^2) = 0.98), indicating extensibility of the approach outside North America. The LEDAPS internal cloud mask is conservative for cloudy scenes and performs well for clear scenes with a few exceptions. Cloud shadow validation remains an issue.

Curtis Woodcock [Boston University] discussed a number of considerations for cloud and cloud shadow masking. Many approaches have been developed. These range from single-date, scene-level cloud estimation (e.g., Automated Cloud Cover Assesment) to multi-date, pixel-level cloud and cloud shadow mask generation. A comparison of results from a number of approaches against a refined truth dataset was proposed.

David Roy [South Dakota State University (SDSU)] provided the status of the Web-enabled Landsat data (WELD) project. WELD products include composited large-area mosaics that are updated at the pixel level using all available acquisitions. Systematic calibration, geolocation, cloud screening, gap-filling, and radiometric correction are used to generate the products, which are similar to MODIS products but have Landsat resolution. *Version 1.3* of the products are currently available online at *landsat.usgs.gov/WELD.php*. Additional data processing and distribution capabilities (developed at SDSU) are scheduled to be ported to USGS EROS during 2010.

Greg Asner [Carnegie Institution] described the Carnegie Landsat Analysis System—Lite (CLASlite). The goal of CLASlite software is routine deforestation and degradation mapping in the tropics. The software provides powerful functionality, including image preprocessing, calibration, and correction routines, but is packaged such that a low level of remote sensing expertise is required to generate the final maps. CLASlite dissemination and capacity building has been extended to over 240 users from more than 70 agencies in six countries. An online version of CLASlite is running on *Google Earth* Engine.

Rebecca Moore [Google.org] demonstrated the *Google Earth* Engine concept and prototype. *Google* is very

interested in providing greater access to Landsat data and providing capabilities for users to generate forest products that can be used to monitor deforestation. The prototype enables online observation and measurement of forest change by combining Landsat data, CLASlite, and cloud computing technology. The concept may be extended to other types of science questions, satellite data, and processing algorithms.

Robert Kennedy [Oregon State University] presented tools to tap the Landsat archive for monitoring and validation. Landscapes are dynamic, and the Landsat data record captures important change phenomena. *LandTrendr* is an algorithmic approach for segmenting Landsat time series into pixel-level change vectors. The segments provide information about state change, cyclical change, and condition change on the landscape. Validation is critical, and the *TimeSync* approach allows for robust validation of change information extracted from Landsat time series.

Eileen Helmer [USDA Forest Service] summarized work using Landsat (TM and ETM+) and EO-1 (ALI) time series imagery to map forest disturbance and structure. Seamless, cloud-cleared image mosaics were generated using a *regression tree* approach, and these data were invaluable for the mapping and change detection approaches used.

Matt Hansen [SDSU] described global forest monitoring approaches. Satellite-based capacity for monitoring forest change at national to global scales is maturing quickly, and generic methods to ensure consistency among regions are now feasible. Data used for monitoring must include systematic global acquisitions and easy no-cost access. Discussion of future sensing systems should begin with data policy, not engineering specifications.

Mike Wulder [Canadian Forest Service] presented multi-resolution data blending to enable wide area synthetic-Landsat coverage, predictable product development, and change detection. Seamless, high temporal resolution, pixel-based mosaic products are feasible. Sensor data with high temporal and spatial resolutions can be integrated. High-frequency change and other information products can be generated, but care should be exercised with respect to factors such as input dates and change attribution.

Chengquan Huang [University of Maryland] reported progress on an Earth Science Data Record (ESDR) for global forest cover change. The approach is characterized by a mass processing capability (covering four Global Land Survey epochs), radiometric adjustment and atmospheric correction using LEDAPS code, automated change mapping, and consistency and quality assurance. Challenges include coverage gaps and calibration difficulties with certain GLS epochs.

NASA Ames Activities

Rama Nemani [NASA Ames Research Center (Ames)] presented his research on the use of Landsat for developing biophysical datasets for use in monitoring, modeling, and forecasting. His project, *Ecocast*, is using the Terrestrial Observation and Prediction System (TOPS) to deliver environmental data and assessments from local to global scales. This activity takes advantage of the NASA Advanced Supercomputing Division processing capabilities. Nemani described his efforts to use the MODIS leaf area index (LAI) strategy to develop a global 30-meter LAI dataset from the GLS 2000 and 2005 Landsat data. He is using the Landsat Ecosystem Adaptive Processing System to process Landsat scenes to a surface reflectance standard prior to calculating LAI. After his presentation, Nemani and **Jennifer Dungan** [Ames] led a tour of the NASA Advanced Supercomputing facilities.

Open Discussion on Higher Level Products

Following the science product presentations, **Curtis Woodcock** led a discussion on the needs and priorities for higher level Landsat science products. He noted the overall interest and need and concluded that the immediate priority should be to improve cloud and shadow masking of Landsat data and to generate surface reflectance and temperature products. Also, since the limitations of Landsat coverage will challenge product generation in many parts of the world, the team noted the potential for developing basic multispectral fusion products. Such processing advances are a necessary foundation for developing higher level science products such as terrestrial *Essential Climate Variables*. The Landsat Science Team members agreed with Woodcock's assessment and stressed the importance of biophysical measures such as leaf area and land cover and land cover change. The group recognized that there are major definition and methodology issues that will need resolution and will require continued research. However, the team concluded that there is a need to develop surface reflectance and temperature products as quickly as possible.

Next Meeting

The next meeting of the Landsat Science Team will be in Boise, ID, June 15–17, 2010. The meeting will be hosted by the University of Idaho and Idaho Department of Water Resources. ■