meeting/workshop summaries

Landsat Science Team Meeting Summary

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Meeting Overview

The Landsat Science Team—sponsored by the U.S. Geological Survey (USGS) and National Aeronautics and Space Administration (NASA)—met at the Rochester Institute of Technology (RIT) in Rochester, NY from June 22-24, 2009. **John Schott** [RIT Center for Imaging Science—*Landsat Science Team Member*] hosted the meeting. All presentations from the meeting are available at *landsat.usgs.gov/science_june2009MeetingAgenda.php*.

The meeting marked the halfway point in the Landsat Science Team's term. The two Landsat Science Team Chairs, **Tom Loveland** [USGS] and **Jim Irons** [NASA Goddard Space Flight Center] acknowledged the Team's exceptional input on a number of Landsat and Landsat Data Continuity Mission (LDCM) topics. Since the Team was assembled, they have witnessed the opening of the entire Landsat archive to free Internet access, the formulation of a Thermal Infrared Sensor (TIRS) for LDCM, and congressional interest in a Landsat 9 mission. Over the past six months, the Team has provided strong technical input and advice on TIRS, the Landsat Multispectral Scanner (MSS) backlog, Landsat data gap, and Landsat product topics.

Curtis Woodcock [Boston University—*Landsat Science Team Leader*] commented on how free web-enabled Landsat data has had a real impact on science and education. He stressed the need to learn more about how to mine the archive, and in particular, how to make it easier for the larger user community to use the archive. Woodcock also stressed the opportunity researchers now have to document the changes on the global land surface and report what these changes mean.

The RIT meeting primarily focused on three topics: (1) working group deliberations; (2) Landsat and LDCM status; and (3) science reports by the Landsat Science Team Principal Investigators.

Working Group Reports

At the conclusion of the January 2009 meeting, the Landsat Science Team organized four working groups to address: (1) future Landsat missions; (2) Landsat data gap readiness; (3) Landsat product issues; and (4) consolidation of the global Landsat archive. The first day of the RIT meeting focused on reports from the first three of these working groups.

Future Missions Working Group Report

The purpose of this working group is to develop and recommend to the USGS and NASA operational mission standards, requirements, and characteristics for future Landsat missions. The future missions group held several telephone meetings over the previous four months to discuss operational Landsat needs and issues.

The future missions group drew three conclusions. First, they concluded that the long-standing Landsat mission statement and fundamental mission capabilities are still appropriate. Monitoring land use and land cover change at the scale of human activity has been fundamental to the Landsat mission to date, but monitoring land-related carbon will become one of the key drivers for future Landsats. Schott reminded the group that while many Earth observation missions contribute to global science, only Landsat is at a resolution appropriate for managing global resources. The Landsat Science Team offered to work with NASA's Education and Public Outreach Program to document societal benefits for fact sheets that will highlight the value of Landsat.

Second, the group endorsed **Sam Goward's** [University of Maryland, College Park (UMCP)] conclusion that Landsat utilization can be greatly increased through the development of advanced land monitoring data sets (e.g., land cover change, vegetation canopy properties, etc.). A suite of operational GIS-ready geophysical products will expand the Landsat user base and increase the value of the Landsat Program.

Finally, the future missions group discussed a congressional appropriations committee request for a Landsat 9 strategy. The team strongly endorsed the efforts of NASA and the USGS to provide a strategy that can lead to the authorization and earliest possible launch of Landsat 9.

The conclusion from the future missions working group, consistent with the recommendations of the Future of Land Imaging working groups, is that future Landsat missions should be led by the Department of the Interior (DOI), and that NASA must build the satellites and be responsible for technology development missions. On behalf of the Landsat Science Team, Woodcock sent a letter to the new Secretary of the Interior, Kenneth Salazar, urging DOI to assume leadership of the Landsat Program and pursue funding from Congress at the earliest opportunity to build and launch another Landsat satellite—in partnership with NASA. Wood-

cock also stressed the need to minimize time between launches by reusing LDCM capabilities. Finally, he stressed the need to work with Congress and the Office of Science and Technology Policy to formally implement a National Land Imaging Program.

Data Gap Working Group

Tom Holm [USGS—*Data and Information Project Manager*] summarized discussions with the working group dealing with alternative sources of moderate resolution imagery should Landsats 5 and 7 fail prior to the planned December 2012 LDCM launch. Previous evaluations identified the India ResourceSat and China–Brazil Earth Resources Satellite (CBERS) missions as the preferred solution to provide the spectral and twice-annual global coverage requirements. The working group, however, recommended looking at other missions, even those that may not meet the original data gap minimum specifications. The group concludes that the most basic requirement should be the acquisition of at least one clear pixel per year for the entire global land surface. After that, options should be prioritized according to how to best meet the original data gap specifications (e.g., shortwave infrared (SWIR) bands, twice annual global coverage, etc.) for as many areas of the Earth as possible.

Using input from the working group, the USGS will evaluate opportunities with other potential providers including the French Satellite Pour l'Observation de la Terre (SPOT) and the German *RapidEye* satellite constellation. The USGS will also develop a readiness plan that includes an architectural concept for using Earth Resources Observation and Science (EROS) reception, archive, and data discovery/delivery capabilities and proprietary data processing capabilities for product generations.

Products Working Group

This group was established to address a number of Landsat processing issues including data grids, cloud and shadow masking, and generation of surface reflectance datasets. The gridding issues are associated with the necessity for geospatial consistency of multi-date Landsat images. Schott concluded that the processing used by the USGS to generate Level One-T Data Products (L1Ts) are producing data sets gridded to the same post, but that issues arise because of differences in pixel origins used by different software vendors. The group concluded that there is a need to provide clear product specifications to software developers.

John Dwyer [USGS—*Landsat Project Scientist*] reviewed several topics associated with LDCM product specifications, including recent decisions to use scene center solar zenith to calculate top-of-atmosphere (TOA) reflectance, quality assurance band properties, and off-nadir acquisition naming conventions. Dwyer also mentioned that there are no plans at this time to add cloud shadow mask information to the quality assurance band, but that there is an option to add it if a shadow masking capability can be developed. Finally, Dwyer reaffirmed the necessity to co-register TIRS and Operational Land Imager (OLI) data.

The working group also addressed Goward's comments regarding the need for higher-level Landsat products. In order to produce the data sets discussed earlier, the Team concluded that there was an immediate need to go beyond the current L1T specification and establish surface reflectance products for all Landsat data. The Team suggested that the basic foundation for higher-level products includes cross-instrument calibration, accurate geo-location and orthorectification, cloud and shadow masking, TOA reflectance calculation, and surface reflectance–surface temperature (or surface brightness temperature) processing. Once this foundation is established, higher-level geophysical products suited for detecting long-term trends should be produced. Calibration across the full Landsat record and implementation of orthorectification capabilities has been completed, and the Team has defined the TOA processing strategy. The Landsat Science Team concluded that it is now time to address the remaining issues (e.g., cloud and shadow masking, surface reflectance processing) and to begin identification of future higher-level products that enable monitoring the state and dynamics of the Earth's terrestrial land surface.

Landsat Status

The Landsat session included an update on Landsat 5 and 7 status, global Landsat archive consolidation, planning for Global Land Survey (GLS) 2010, and a USGS discussion on potentially watermarking Landsat data.

Kristi Kline [USGS—*Landsat Project Manager*] reported that Landsats 5 and 7 continue to add to the global archive. Landsat 5 reached an incredible milestone this year by celebrating the 25th anniversary of its launch—March 1. Even though it is 22 years past its design life, Landsat 5 continues to acquire Thematic Mapper (TM) imagery over the U.S. and other selected areas around the world. Because there are no data recorders on Landsat 5, data are only being acquired through direct broadcast to an international ground station and to the USGS EROS data center. Global Landsat 5 coverage was expanded this year due to the establishment of temporary Global Land Survey (GLS) 2010 campaign stations covering portions of East Africa, northern Russia, and Central America. Landsat 7 continues to aggressively collect global coverage according to the Long-term Acquisition Plan. Assuming no technical failures, both satellites have sufficient fuel to operate until 2014 (Landsat 5) and 2015 (Landsat 7).

With all Landsat data now available via the Internet at no cost, many data users are able to undertake studies over large areas and long time periods that were previously unaffordable. Less than a year after the USGS made all Landsat data free, over 800,000 scenes have been downloaded and the estimate for the first 12 months of web-enabled access is 1.1 million scenes. In the best year of data sales (2001) prior to this, 19,100 scenes were distributed.

While the opening of the Landsat archive has been successful, efforts to improve access are still ongoing. Perhaps the biggest challenge that still exists involves access to Landsat 1-5 Multispectral Scanner (MSS) data. USGS MSS processing capabilities are being modernized, but until the modernization is complete, orthorectification throughput is limited. As a result, the backlog for processing Landsat MSS to the L1T specification became unacceptably long and users needed to wait for a month or more for on-demand processing orders to be completed. To remedy the backlog, the USGS has increased daily throughput by temporarily reducing geolocation specifications. At the same time, an improved automated orthorectification process is being developed, and when completed (planned for Fall 2009), the geometric quality of MSS data will be significantly improved.

Kline briefly touched on the status of planning for a Landsat global archive consolidation initiative. An estimated 1.3 petabytes of Landsat data exist in past and current international ground station archives. While some of the data may already be duplicated in the USGS archive, there is a significant amount of data going back to 1972 that represents an invaluable resource for studies of global environmental change. The USGS has completed preparing an initial cost estimate and implementation plan that would result in bringing as much of the international holdings as possible into the USGS Landsat archive. The Landsat Science Team members strongly endorsed pursuit of funding for this initiative and offered to assist in the identification of priorities for acquiring data.

Jeff Masek [NASA GSFC—*LDCM Deputy Project Scientist*] and **Garik Gutman** [NASA Headquarters—*Land Cover and Land Use Change Program Manager*] provided an update on the overall GLS activity. Regarding GLS 2005, 8,860 scenes of the nearly 9,000 Landsat scenes have been added to the collection. EROS is awaiting delivery of additional scenes by Brazil and Thailand—international cooperators. Scenes from the advanced Land Imager on Earth Observing-1 covering islands will be added by late-July 2009. For GLS 2010, Landsat 5 Thematic Mapper (TM) data are being collected from eight campaign stations. In addition, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data are being collected over the rest of the global land mass. Efforts are continuing to establish cooperation through the Committee on Earth Observation Satellites (CEOS) Land Surface Imaging Constellation initiative to add data from additional sources. So far, the response has been minimal.

Gutman provided an overview of NASA-sponsored land cover research based on GLS data. NASA is currently funding seven research projects ranging from humid tropical forest mapping and monitoring to Synthetic Aperture Radar (SAR) optical data fusion. He challenged the Team to work toward a goal of establishing international collaboration between operators of all Landsat-scale missions to work together to provide daily 30-m global coverage by the year 2020.

Bruce Quirk [USGS—*Land Remote Sensing Program Coordinator*] briefed the Team on the possibility for adding a USGS watermark to Landsat L1T data. *Watermarking* has been suggested as an approach to increase the visibility of the role of the USGS in providing Landsat data. The Landsat Science Team supported the concept of increasing USGS visibility but concluded that the scientific value and integrity of the data would be reduced through watermarking. The team elected to provide input to the USGS Director regarding their opposition to Landsat watermarking. (**Update**: Based on the Team's input, the USGS is no longer pursuing watermarking L1T data.)

Anita Davis [NASA GSFC—*Education and Public Outreach*] was the last speaker in the Landsat Status session, and led a discussion on Landsat-specific outreach activities. NASA supports a number of educational activities through the development of brochures, training kits, and other materials addressing Landsat and other aspects of environmental remote sensing. Davis summarized efforts to support tribal educators through faculty development and student internships at Salish Kootenai College and a Bureau of Indian Education high school teacher's workshop. NASA is also contributing to public outreach through the *Earth and Sky* initiative and as part of that effort they are actively fostering collaboration between the science and interpretation/education communities of the National Park Service and U.S. Fish and Wildlife Service in ways that enrich the visitation experiences of park and refuge visitors. Finally, Davis 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 existing GIS programs.

LDCM Status

Bill Ochs [NASA GSFC—*LDCM Project Manager*] initiated an in-depth update of the status of LDCM development. He provided an overview of all major mission components. Ochs briefly discussed the July LDCM Preliminary Design Review (PDR) in which

the LDCM team must demonstrate that the overall preliminary design meets all requirements with acceptable risk and within cost and schedule constraints. This review establishes the basis for proceeding with detailed design[1]. The Mission Confirmation Hearing, in which NASA commits to Congress the cost and schedule for LDCM launch, begins with the July PDR and includes a non-advocate review in which an independent assessment of the readiness of the project to proceed to implementation is made. These events lead to the NASA Key Decision Point-C meeting in which the NASA Program Management Council will determine whether LDCM is confirmed to build to launch—this decision is expected in November 2009.

Ed Knight [Ball Aerospace and Technology Corporation—*Systems Engineer*] reviewed Ball's progress in building the LDCM Operational Land Imager (OLI). OLI represents the next generation Landsat imager and replaces the ETM+. OLI is a pushbroom Visible–Near Infrared (VNIR)/SWIR sensor with a four-mirror telescope, a focal plane array (FPA) consisting of 14 passively cooled sensor chip assemblies, and on-board calibration with both diffusers and lamps. Knight reported that the telescope mirrors and main optical bench assemblies are completed and the telescope build is underway. The engineering development unit focal plane array (FPA) is completed and the FPA flight parts are proceeding on schedule. Early measurements showed degradation in some of the silicon detectors but NASA, Ball Aerospace, and Raytheon engineers conducted an investigation and found the root cause and now, new flight detectors are being manufactured. Knight summarized his presentation with the conclusion that the major hardware is being delivered, artifacts are being identified and corrected, and performance predictions are all positive.

Dennis Reuter [NASA GSFC—*TIRS Instrument Scientist*] provided a thorough review of TIRS development. TIRS is a stand-alone two channel (10.8 and 12 um) pushbroom thermal imager that provides thermal data continuity for LDCM. It will operate in concert with, but independently of, the OLI. TIRS uses Quantum Well Infrared Photometer (QWIP) detectors and FPA that are being built in-house at GSFC. TIRS will provide 12-bit data with <120 m Ground Sample Distance (100 m nominally) resolution for a 185-km ground swath (15° field of view). It is a *Class C* instrument with a three-year design life. TIRS will produce radiometrically calibrated, geo-located thermal image data. The scene data will be merged with OLI into a single data product by the USGS. TIRS instrument delivery is scheduled for December 2011, a year prior to the December 2012 LDCM launch readiness date.

Jim Irons added to the TIRS discussion by retracing the history that is leading to the development of TIRS. The Fiscal Year 2009 omnibus budget legislation authorized the development of a thermal instrument based on the most affordable and efficient approach. A key consideration was to develop an instrument that could be ready for an LDCM launch in December 2012. Recently, NASA considered moving the instrument from LDCM to a replacement mission for the failed Orbital Carbon Observatory. However, based on a thorough evaluation of the impacts of that option, NASA is staying on course to include TIRS on LDCM.

Bill Anselm [NASA GSFC—*LDCM Observatory Manager*] summarized spacecraft development progress. NASA contracted with General Dynamics Advanced Information Systems to develop the spacecraft/observatory and simulators, and provide mission operations support. Anselm described the spacecraft as a kit in which the LDCM-specific components are being knitted to the spacecraft's major modules—the primary structure (main body), propulsion, and instrument deck. He concluded that the spacecraft relies on sound heritage designs, is sound, buildable, testable, and meets the mission's needs.

John Dwyer [USGS—*LDCM Project Scientist*] concluded the LDCM session with an update on the status of the LDCM ground system development. Due to budget challenges, the USGS has adjusted the overall ground system approach and architecture to take advantage of existing Landsat processing capabilities to the extent possible. As a result, the budget shortfall has been mitigated to the extent possible and additional funding has been requested to fully resolve the problem. Dwyer also reported that the ground system preliminary design now includes accommodations for processing TIRS data and integrating it with OLI into integrated data sets. The Preliminary Design Review of the ground system is set for September 2009, and the Critical Design Review is tentatively scheduled for March 2010.

Update on European Space Agency (ESA) Sentinel 2 Mission

The meeting included a special session on Earth observation cooperation with the European Space Agency. **John Cullen** [USGS—*Senior Advisor for Geography*] explained that the U.S. has been engaged in a space policy dialog with the European Union (EU) since 2006. As part of this, the USGS and ESA, along with NASA, are discussing LDCM and Sentinel 2 mission cooperation for the purpose of advancing the use of Earth observations for sustainable development and increasing scientific exploration and knowledge.

[1] The Preliminary Design Review took place July 14-17 and went very well.

Tim Stryker [USGS—*Land Remote Sensing International Cooperation Coordinator*] elaborated on the LDCM–Sentinel 2 relationship by outlining areas of cooperation including Landsat and Sentinel 2 acquisitions coordination, science and applications development, operational decision support tools, and contributions to international treaties.

Philippe Martimort [ESA—*Sentinel-2 Mission and Payload Manager*] provided a detailed introduction to the key features of the Sentinel 2 mission. Sentinel 2 is part of the EU Global Monitoring for Environmental Security (GMES) Program, and includes a series of dedicated satellites—i.e., "the Sentinels." GMES is to provide data and integrated services that contribute to the European goals for environmental monitoring and security. There are five Sentinel series; the Sentinel 2 series is similar to Landsat and provides high-resolution optical imaging. There are two Sentinel 2 satellites planned and they are to provide both general and thematic services that include:

- **General services:** Global carbon, crop monitoring, spatial planning (vegetation, urban), forest monitoring, water services, soil erosion, large-scale natural or man-made disasters, and surveillance of infrastructures.
- **Thematic services:** Sustainable management of developing countries, nature protection services, support to humanitarian aid, and food security.

Sentinel 2 will carry a pushbroom multispectral instrument that provides 13 channels of 12-bit data VNIR and SWIR imagery. The spectral bands will have 10-20-60-m ground resolution. The imaging swath is 290 km with a 10:30 a.m. viewing and the imaging range will be 84°N–56°S. When both Sentinel 2 satellites are in orbit, this will provide 5-day repeat coverage at the equator. Sentinel 2 will also have a pointing mode that can be used in emergencies to provide 1–2 day repeat imaging. The planned lifetime of each satellite is 7.25 years with 12 years of consumables.

Sentinel 2 will use four core ground stations. There will be a direct download capability but the primary approach is to downlink to the network of four stations. Three product levels are planned. Level 1 products include radiometric and geometric corrections, level 2 will have cloud screening, atmospheric corrections, and geophysical variables, and level 3 products will represent spatial and temporal synthesis. The first Sentinel 2 satellite is scheduled for launch in late 2012.

Principal Investigator Science Presentations

The final day of the meeting was devoted to research presentations by the members of the Landsat Science Team. The following is a brief summary of each presentation (full presentations are available at: *landsat.usgs.gov/science_june2009MeetingAgenda.php*.

John Schott [RIT] presented an overview of the RIT Digital Imaging and Remote Sensing Laboratory (DIRS). DIRS research focuses on spectral measurements and phenomenology, sensor system development, physics-based algorithms and phenomenology, and modeling and simulation of land surfaces through a wide variety of sensors. Schott presented a method for calibrating Landsat 5 thermal data using a physics-based approach. By modeling water temperatures from the long standing National Data Buoy Center, they were able to determine the calibration curve over the life of the instrument.

Martha Anderson [USDA Agricultural Research Service] summarized work on sharpening thermal images with NDVI for use in mapping evapotranspiration (ET) over irrigated landscapes. Even with sharpening, resolutions of greater than 100 m are too coarse for mapping ET over U.S. irrigated lands.

Eric Vermote [University of Maryland, College Park] provided an update of his work on a surface reflectance standard product for LDCM. Error budget and performances were developed for each Landsat band. The product also produces a pixel-based cloud and shadow mask.

Jennifer Dungan [NASA Ames Research Center] discussed progress toward developing an operational capability to produce vegetation green leaf area index from Landsat surface reflectance data and ancillary parameters.

Feng Gao [Earth Resources Technology, Inc.] reported on his research using multi-temporal Landsat data to look at the rate of change of impervious surfaces. This technique will provide a consistent map to the user because it only allows uni-directional change. Gao also updated the team on the use of StarFM for burn severity mapping and forest monitoring.

Rick Allen [University of Idaho] found that systematic geo-registration error between OLI and TIRS could effect evapotranspiration retrievals. Allen also presented research that showed how thermal images and retrieved evapotranspiration increased vegetation classification accuracy in northeastern Portugal.

Randy Wynne [Virginia Tech] used a multi-temporal approach to delineate reclaimed mines and changes in vegetation development pattern. They are also working on web-based ecosystem service models to determine real-time carbon estimates and water quality.

Sam Goward [UMCP] made the case for acquiring all Landsat scenes due to the prevalence of persistent cloud

cover in some areas. The use of Long Term Acquisition Plan (LTAP)-8 may reduce the possibility of retrieving cloud-free pixels.

Aaron Gerace [RIT], with **John Schott**, modeled the retrieval process of constituents in optically complex waters. LDCM shows promise for retrieving chlorophyll, suspended materials, and color dissolved organic matter.

Eileen Helmer [USDA Forest Service] discussed the creation of cloud-free Landsat image mosaics for vegetation and land-cover mapping over tropical landscapes using regression tree normalization.

Jim Vogelmann [USGS EROS] updated his research on the use of a Landsat time series for landscape change assessments in the western U.S. He used ancillary data about forest health to strengthen his assessment.

Mike Wulder [Canadian Forest Service] presented approaches for disturbance and ecosystem characterization in forested landscape using Landsat and ancillary data.

Warren Cohen [USDA Forest Service] described research focused on automated time-series change maps to look at disturbance intensity and recovery rates. He used human interpretation and ancillary data sets to validate the series.

Curtis Woodcock [Boston University] discussed the need to work toward a global land surface history in the Landsat era.

Lazaros Oreopoulos [NASA GSFC] updated his research on LDCM cloud detection, including cirrus and marine clouds.

At the end of the presentations, the Team concluded that the availability of free Landsat data allows them to be more creative about how they approach studies. Time series data are important for consistent change detection, but improvements in cloud and shadow screening are needed if the uses of longer Landsat time series, and studies of larger geographic areas are to become operational. The team also concluded that now is the time to work toward operational provision of higher-level geophysical products.

Future Meetings

As a result of the technical discussions on Landsat products, the Team agreed to hold a "specialists" meeting from October 27-29, 2010 in Boston, MA to address data products and processing strategies. Topics that will be addressed include cloud- and shadow-masking approaches, top-of-atmosphere parameters, surface reflectance processing, and priorities for generating essential climate variables.

The next full meeting of the Landsat Science Team is scheduled for January 19-21, 2010 and will be held at the NASA Ames Research Center in California. ■

NASA Earth System Science at 20: A Symposium to Explore Accomplishments, Plans, and Challenges

continued from page 30

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