Landsat Science Team Meeting Summary

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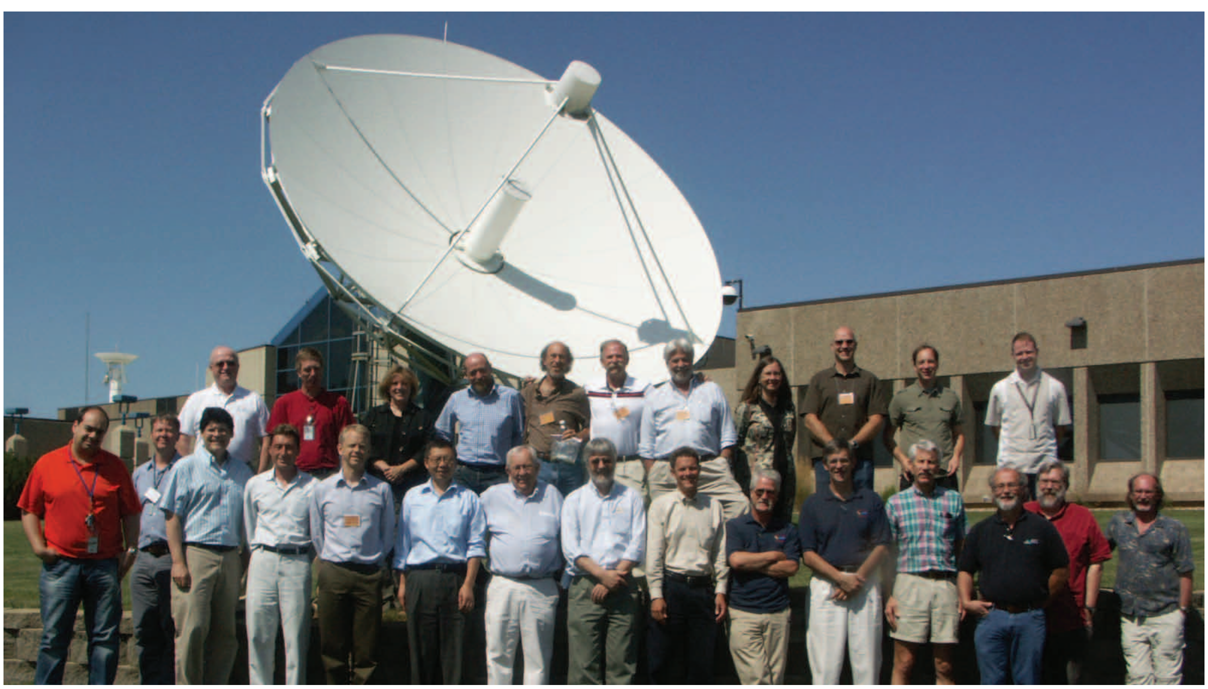
The Landsat Science Team (LST), sponsored by the U.S. Geological Survey (USGS) and NASA met at the USGS Earth Resources Observation and Science (EROS) Center on August 16-18, 2011. The LST, consisting of 18 scientists and engineers representing academia, private industry, federal agencies, and international organizations, was selected in 2006 to serve a five-year term. Since 2006 the LST has held two meetings per year (winter and summer) that focused on all aspects of the Landsat program, including the upcoming Landsat Data Continuity Mission (LDCM), Landsat 5 and 7 status, the Landsat archive, future Landsat requirements, and synergy with other space-based remote-sensing missions. The EROS meeting marked the tenth and final meeting of the group. All meeting presentations and summaries are available through the USGS EROS LST website at *landsat.usgs.gov/science_LST_Team_Meetings.php*.

Headquarters Updates

Matt Larsen [USGS—*Associate Director for Climate and Land Use*] and **Dave Jarrett** [NASA Headquarters (HQ)—*Landsat Executive*] provided a summary of high-level Landsat activities. Larsen stressed USGS's commitment to Landsat. He commented that the USGS 2011 Landsat appropriation did not include funds needed to meet the LDCM ground system development schedule, but that USGS and the Department of the Interior met LDCM financial needs through other sources. Ground system funding appears to be solid in 2012. Larsen also talked about USGS support for the president's plans to establish a National Land Imaging Program, and to authorize development of Landsat 9.

Jarrett discussed the upcoming LDCM launch. He said that NASA is moving at "full speed" toward a December 2012 launch. He commented that the recent Operational Land Imager pre-shipment review was quite favorable, and that development for the Thermal Infrared Sensor (TIRS) was progressing well, despite its tight schedule. Jarrett concluded that NASA's Earth Science Division remains committed to Landsat, and is pleased with the advocacy and guidance provided by the LST.

Bruce Quirk [USGS—*Land Remote Sensing Program Coordinator*] provided additional information on planning for future Landsat missions. The USGS and NASA are meeting regularly to define agreements and plans needed for long-term Landsat collaboration. The current focus is on developing Landsat 9 Level 1 requirements. The LST suggested trade studies to address the daily acquisition rate, extending the TIRS design



Landsat Science Team Meeting participants.

life from three to five years, and improving the spatial resolution of visible red and near-infrared observations. A goal for Landsat 10 and beyond should be to increase the frequency of observations.

Current Landsat Mission Status

Kristi Kline [USGS—*Landsat Project Manager*] provided an update to the LST on Landsat 5 and 7, and on overall archive and data processing topics. The 27-year-old Landsat 5 mission continues to collect data, but the mission is threatened by the rising traveling wave tube amplifier (TWTA) current. If the current continues to rise the TWTA will likely fail, and Landsat 5 will no longer be able to transmit data to ground stations. The Landsat 5 Flight Operations Team is working on approaches to stabilize the TWTA current, but if the team is not successful the mission will end. **Gene Fosnight** [USGS—*Landsat Data Acquisition Manager*] added to the discussion by describing how the Long-Term Acquisition Plan used for Landsat 7 and planned for LDCM was being implemented for Landsat 5 in order to optimize both acquisitions and provide TWTA management options.

Landsat 7 is now 12 years post-launch. While the 2003 scan-line corrector failure causes the loss of approximately 22% of the data in each Enhanced Thematic Mapper Plus scene, all other systems are functioning well, and high-quality science data are being acquired. Because of the health of Landsat 7, the number of daily acquisitions has been increased to 350 scenes per day.

Regarding Landsat archive activities, Kline reported that demand for Landsat data continues to rise, and that 2011 download rates could exceed 3 million scenes. All new acquisitions are now automatically processed into Level 1 Terrain-corrected product (L1T)[1] or 1G[2] products[3]. To improve on-demand processing throughput efficiency, all archived Landsat data are being migrated to online disk storage.

Kline described the recent initiation of Landsat 5 forward stream network delivery directly from Argentina, Brazil, Canada, and China (Kashi) International Cooperator (IC) ground stations, with similar delivery of Landsat 5 data from South African and Australian ICs expected to begin soon. This development is adding significant amounts of new Landsat 5 acquisitions to the USGS EROS archive. Finally, Kline reported that the Landsat Global Archive Consolidation initiative is progressing, and that over 600,000 historical Landsat scenes held by IC ground stations were recently added to the USGS EROS archive. Acquisition of data from additional stations is planned.

Jeff Masek [NASA's Goddard Space Flight Center (GSFC)—*Landsat Project Scientist*] concluded the current Landsat session with an update on the Global Land Survey (GLS). The GLS provides consistently processed global, cloud-free, orthorectified Landsat datasets centered on 1975, 1990, 2000, 2005, and 2010. Over 200,000 Landsat 5 and 7 scenes acquired between 2009 and 2011 are the basis for the 2010 collection.

Landsat Data Continuity Mission Status

Phil Sabelhaus [NASA HQ—*LDCM Project Manager*] reported that the LDCM spacecraft is in the final stage of development, and that instrument integration is expected to start this fall. At this point, the development of all mission systems and instruments is on schedule. The next major hurdle is the Key Decision Point–D (KDP-D) review, which is set for October 2011.

Sabelhaus reported that the Operational Land Imager (OLI) instrument calibration is complete, and performance is excellent. Functional testing of all environmental, electromagnetic interference (EMI)/electromagnetic compatibility (EMC), vibration, and thermal vacuum systems was successfully completed. The shipment of OLI from Ball Aerospace in Boulder, CO, to Orbital Systems in Gilbert, AZ, was planned for July 20, 2011, but had to be delayed due to a heater circuit anomaly. Plans are still in place to integrate the OLI with the spacecraft this fall. Significant progress has been made on the TIRS, which is being built at GSFC. Environmental testing is planned for this fall, prior to the instrument being shipped to Orbital Systems.

The LDCM data window is December 1-30, 2012, with a launch readiness date of December 1, 2012. A contract is in place with United Launch Alliance for launch services; the spacecraft will be launched on an Atlas V *401* selected by the NASA's Kennedy Space Center. Sabelhaus stressed the need to maintain the December 1, 2012 date at all costs, as the Atlas V manifest is very crowded and the only slot currently open after that at Vandenberg Air Force Base is in October 2013. **Therefore, if a December 2012 launch cannot take place, there is a strong possibility of at least a 10-month delay.** Meeting the December 2012 window is, therefore, of key importance to a timely mission.

[1] Standard Terrain Correction (Level 1T) provides systematic radiometric and geometric accuracy by incorporating ground control points while employing a Digital Elevation Model (DEM) for topographic accuracy.

[2] Systematic Correction (Level 1G) provides systematic radiometric and geometric accuracy, which is derived from data collected by the sensor and spacecraft.

[3] Previously, only images with less than 30% cloud cover were automatically processed.

Jim Nelson [USGS—*LDCM Ground System Manager*] gave an update on the status of the LDCM ground system. He said that all aspects of the ground system development are on track, and that ground system readiness testing is ongoing. Technical performance results involving spacecraft contact time, data ingest and processing, distribution capacity, and latency are all outperforming margins. The emphasis is now turning to mission data testing, where end-to-end image assessments will be performed using a combination of tests with flight hardware and simulators.

Future Landsat-Related Capabilities

LST members, **Darrel Williams** [Global Science & Technology, Inc.] and **Sam Goward** [University of Maryland, College Park (UMCP)] summarized their *Earth Venture-2* concept for the Terrestrial Ecosystem Dynamics (TerEDyn) Mission. TerEDyn is a Landsat-class mission that is designed to improve the understanding of the current state and dynamics of land photosynthetic capacity. The mission is designed to study vegetation dynamics at 30-m spatial resolution using visible, near-infrared, and shortwave infrared imagery acquired globally every eight days. TerEDyn introduces evolving smallsat technology that will permit the collection of these datasets at a substantially lower cost than current missions.

One of the initiatives of the LST has been the development of priorities and technical strategies to generate additional Landsat science datasets. **Curtis Woodcock** provided a summary of the LST's work over the past two years. The LST has identified radiometric calibration, orthorectification, and cloud detection as foundational elements for all Landsat science products. Surface reflectance and temperature are also high-priority derived products.

Eric Vermote [UMCP] summarized progress toward a surface reflectance product. Vermote concluded that the surface reflectance algorithms used in the Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) are mature and can be used to translate Landsat 1 through LDCM data into surface reflectance products. He said that the implementation of LDCM surface reflectance should be done gradually, since the instrument is a new one.

John Schott [Rochester Institute of Technology (RIT)] outlined progress toward a surface temperature product strategy that can be applied across the entire archive. Several approaches are being tested, and the influence of different emissivity inputs is being evaluated. Initial results show mean land-surface temperature differences over diverse regions (e.g., the Sierra Nevadas) of 0.24 ± 0.51 K, with maximum differences of ~2 K. Shrublands and barren areas tend to have the largest errors (>1 K).

Landsat Science Team Member Presentations

The majority of the meeting focused on the Landsat engineering, science, and applications accomplishments of the LST members.

Robert Binschadler [GSFC] reflected upon the accomplishments and future of monitoring Earth's ice from Landsat. From early uses of ERTS-1 (a.k.a., Landsat 1) to improve coastal mapping of Antarctica, to the recent completion of the Landsat Image Mosaic of Antarctica (LIMA), Landsat-scale imagery has been of great value for land-ice monitoring and research. Increased radiometric resolution, a larger field of view, and more frequent coverage are improvements that would help make future Landsat instruments more useful for ice monitoring.

John Schott spoke about Landsat's new potential to monitor fresh and coastal waters. The OLI exhibits the potential to be an improved tool for monitoring water quality due to enhanced spectral coverage, lower noise, and improved quantization compared with the Enhanced Thematic Mapper Plus (ETM+) instrument. Two over-water atmospheric correction algorithms have been developed for the OLI instrument, and successfully applied to both synthetic data and Airborne Visible InfraRed Imaging Spectrometer (AVIRIS) data. Significant improvements in OLI over ETM+ for estimating levels of dissolved organic matter, chlorophyll, and suspended materials bode well for a new era of water-quality monitoring from LDCM.

Prasad Thenkabail [USGS] surveyed research gains and gaps after 40 years of hyperspectral remote sensing of vegetation. When compared with broadband data, hyperspectral data can significantly improve vegetation discrimination, increase classification accuracy, enable targeting of specific biophysical properties, and explain greater variability in vegetation models. About 33 narrow bands from 400–2500 nm provide optimal information for vegetation studies. Hyperspectral indices formed from these bands have potential for advanced study of vegetation biochemical and physiological properties.

Dennis Helder [South Dakota State University (SDSU)] described calibration activities for the Landsat archive and LDCM. Calibration for Landsat 4 TM and the Landsat 1–5 MSS sensors has been completed, bringing consistency to the entire archival record. OLI and TIRS will be substantially better than any previous Landsat sensor with respect to radiometric performance. End users were encouraged to examine where Landsat calibration meets needs or falls short in their applications.

Eric Vermote returned to summarize activities on a surface reflectance product for Landsat. The atmospheric correction is consistent with the Moderate-Resolution Imaging Spectroradiometer (MODIS), Advanced Very High Resolution Radiometer (AVHRR), and National Polar-orbiting Operational Environmental Satellite System (NPOESS) Preparatory Project [NPP]'s Visible/ Infrared Imager/Radiometer Suite (VIIRS) approaches, ensuring consistent reflectance data across resolutions, based on rigorous radiative transfer models. Several Landsat and MODIS validation studies demonstrated that the surface reflectance algorithm is generic, mature, and intercomparable across multiple sensors.

David Roy [SDSU] gave a Web-enabled Landsat Data (WELD) project update, and offered lessons learned from bulk Landsat data processing. The number of users registering to use WELD *version 1.5* products continues to grow. *Version 2.0* is planned for spring 2012. The new algorithm utilizes advances in atmospheric correction and reflective wavelength radiometric normalization to improve the seamlessness of Landsat 7 surface reflectance composites. The *version 2.0* product will also contain a percent tree, bare ground, vegetation, and water classification. Lessons learned included early and frequent community engagement and the need for continuous quality assessment.

Feng Gao [U.S. Department of Agriculture, Agricultural Research Service (USDA ARS)] spoke about developing consistent time series Landsat data products. Activities since 2006 are summarized as follows:

1. The Automated Registration and Orthorectification Package (AROP) has been used for orthorectification and registration of Landsat (MSS, TM and ETM+), Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER), Advanced Wide Field Sensor (AWiFS), China–Brazil Earth Resources Satellite (CBERS) and Hai Yang (HY-1) data[4].

2. The Spatial and Temporal Adaptive Reflectance Fusion Model (STARFM) approach has been extended and applied to build and simulate dense Landsat time series for various applications.

3. A normalization approach has been used to combine multiple-sensor data for change detection and phenology detection.

4. A consistent impervious extension mapping approach has been tested and applied to Landsat MSS, TM, ETM+, and CBERS data.

5. An empirical reference-based approach has been tested to generate compatible Landsat data products from MODIS data products.

Sam Goward examined the role of clouds in moderate-resolution land observations using results from a study in the Western U.S. Using MODIS data, obtaining a clear image using an eight-day rolling window was not always possible, even for generally clear sites. Compositing, however, was always successful using an eight-day rolling window. The number of clear views captured by Landsat TM or ETM+ was highly variable, even for clearer sites. Goward concluded that land observations must be collected daily to circumvent most difficulties with cloud-obscured views.

Lazaros Oreopoulous [GSFC] presented an overview of cloud masking and other research for Landsat and LDCM. The Landsat Long Term Acquisition Plan (LTAP) could be simplified to always acquire data over land, regardless of cloud climatologies and forecasts. Thermal capabilities are important, and should be included in future missions. Cloud masking will never be perfect (i.e., 85–90% accuracy is achievable), but a standard product should be provided. Shadow detection is much harder (especially with automation attempts), and its importance should be emphasized.

Jennifer Dungan [NASA's Ames Research Center] talked about developing biophysical products for Landsat, particularly Leaf Area Index (LAI). The Landsat LAI approach was adapted from the physically based MODIS LAI method. A provisional dataset has been produced for California, with plans to expand to the conterminous U.S. A technical paper has been submitted for peer review, and validation and verification efforts continue.

Martha Anderson [USDA ARS] presented work on daily evapotranspiration (ET) data at Landsat scales using multi sensor data fusion. Thermal remote sensing data were found to have great utility for multi scale ET mapping, drought monitoring, and soil moisture mapping. A Landsat revisit time of eight days or less would improve seasonal ET estimation.

Rick Allen [University of Idaho] described the evolution, successes, and future challenges for operational ET data from Landsat-based energy balance data. Primary accomplishments were advances and refinements in components of the Mapping EvapoTranspiration with high Resolution and Internalized Calibration (METRIC) approach; improved handling of Landsat imagery; and support for TIRS on future Landsat missions. Challenges included dealing with cloudy periods, missing precipitation events between image acquisitions, and fusion of energy balance estimates with gridded weather data during observational gaps. Data fusion with

[4] AWiFS flies on Resourcesat-1, which was launched by the Indian Space Research Organization; HY-1 is a Chinese land imaging instrument.

MODIS and a higher frequency of Landsat observations could mitigate these challenges.

Eileen Helmer [USDA Forest Service (FS)] summarized a variety of mapping efforts in tropical forest habitats. Landsat time-series data were used in combination with other data sources for mapping forest regrowth in Amazonia, forest vertical structure and disturbance in Bahamian forests, tree species distributions and stand variables in Puerto Rico, and tree species associations in Trinidad and Tobago.

Jim Vogelmann [USGS EROS] reflected on recent results using Landsat time-series data to monitor ecological trends. Landsat data have been a foundational element for the Landscape Fire and Resource Management Planning Tools (LANDFIRE) and Monitoring Trends in Burn Severity (MTBS) projects. Several factors have increased the utility of Landsat data for studying larger areas and longer timeframes. These include the switch to a free and open data policy, well-characterized geometry and radiometry, better algorithms for automatic trend detection, and movement towards a standard atmospheric correction.

Randy Wynne [Virginia Polytechnic Institute and State University] spoke about the use of multispectral Landsat data for forest science applications. No-cost Landsat data offer enticing opportunities for basic and applied ecosystem science at detailed spatial scales. Wynne showed examples where Landsat data have been used for mapping, change detection, and phenology studies, including multi sensor data fusion to address challenges in Landsat temporal coverage. He concluded by asserting that managed ecosystems are the norm, and that Landsat has become essential to management for production of both commodities and ecosystem services.

Mike Wulder [Canadian Forest Service] examined Landsat opportunities and directions for large-area land cover and dynamics. Increasingly complex questions require more frequent and spatially exhaustive data. Landsat has promoted consistency and compatibility across national program outcomes. Opportunities abound for building around remote sensing for policy and reporting, especially in terms of continuity, cross-sensor integration, and modeling.

Alan Belward [European Commission Joint Research Centre] summarized contributions to the United Nations Food and Agriculture Organization's (FAO) Forest Resource Assessment 2010 remote sensing survey and beyond. While 39 satellites carrying optical imagers with better than 100-m resolution are currently flying, only one provides free and open access to a global archive: Landsat. The Landsat GLS and L1T have proven robust, reliable, and immensely valuable. The openness of the U.S. Landsat archive policy and data acquisition program have had profound effects on influencing European Union data policy discussions, enabling internationally mandated forest monitoring and governance programs, and helping build knowledge bases in developing countries.

Warren Cohen [USDA FS] talked about success stories within the FS as the agency continued to embrace Landsat. During the last five years, FS inventory and research units have rapidly gravitated toward Landsat retrievals as a fundamental dataset. The FS is now committed to complimenting traditional plot-based measurements with critical and consistent Landsat-derived forest-change information. Common ingredients for programmatic success include free Landsat data, a vision for monitoring, and strong partnerships between scientific research and large-scale production efforts.

Robert Kennedy [Oregon State University] described new insights into terrestrial processes as facilitated by the open Landsat archive. Researchers can now follow the life history of pixels and objects, and match change over time to drivers, follow long-term trends, and better describe conditions now knowing what went before. Landsat data have given rise independently to similar use strategies—for example, the use of many images in time series to exploit maximum information content. Numerous opportunities exist to improve information extraction, attribution, and integration in the areas of disturbance, land cover, and trends.

Curtis Woodcock concluded the science presentations with a discourse on the prospects of continuous monitoring of the land surface using all available Landsat imagery. Topics of study over the years have included cloud and shadow screening, continuous monitoring of forest change using Landsat, and MODIS/Landsat fusion for near-real-time change detection. Woodcock concluded that the utility of new observations can be improved by leveraging the geographic and temporal context of previous observations; all available Landsat measurements may be used constructively; and after 40 years, new and improved uses of Landsat continue to emerge—primarily as a result of improved access to the data.

Next Steps

The five-year term for the LST ended in September 2011. The USGS is now working toward the competitive selection of a new LST that will serve for another five years. The new LST will be convened in early 2012.

Looking Back at the Landsat Science Team's Five-Year Mission

Tom Loveland [USGS—*LST Co-chair*] opened the meeting with a review of the contributions and impacts the LST has had on Landsat, USGS, and NASA. While the LST made many noteworthy contributions that advanced LDCM and the Landsat program, Loveland focused on five major impacts:

- *Web-Enabled Landsat Data:* The LST strongly supported the decision to distribute Landsat data for free. This was the single most profound Landsat-related event that occurred during the LST's tenure. The LST advocated this in the first year, and supported all aspects of USGS efforts to open the Landsat archive.

- *LDCM Thermal Infrared Sensor (TIRS):* The LST's proactive advocacy contributed to NASA's decision to restore LDCM thermal imaging capabilities. The LST consistently stressed that "…failing to continue the 28-year history of Landsat-scale thermal surveillance will have negative consequences in terms of safeguarding the future economy, environment, health, and natural resources of the U.S. and our ability to address water supply crises abroad."

- *Landsat Global Archive Consolidation:* The LST initially suggested making repatriation and consolidation of international Landsat holdings a priority, and called on the USGS to "…bring copies of foreign holdings into the U.S. archive. The sooner work begins on this front the better, as delays will result in more images being lost." The LST's continued encouragement and input on priorities resulted in a major expansion of Landsat archive holdings.

- *Supporting the National Land Imaging (NLI) Program and Future Landsats:* The LST collectively and individually advocated for NLI and an operational Landsat program throughout their term, and contributed to the development of mission concepts for Landsats 9 and 10.

- *Research and Development:* The LST's science, applications, and engineering accomplishments had significant impacts on Landsat, remote sensing, and environmental science. Through more than 400 peer-reviewed scientific publications, the team reported on a wide array of research topics, including approaches for using large volumes of Landsat data for long-term and broad-area studies. The LST established the foundation for generating higher-level Landsat science products.

In addition, the LST was frequently called on to evaluate specific issues facing the Landsat program. For example, they addressed issues such as Landsat pixel dimension standards; Landsat program priorities for release of Web-enabled Landsat data; recovery of old Multispectral Scanner System (MSS) data; LDCM requirements, including provision of Level 0R products; and launch delay impacts. **In almost every case, the relevance and clarity of the LST's input resulted in USGS and NASA accepting and following the LST's recommendations.**

Loveland concluded that the USGS-NASA LST has had a tremendous impact on the Landsat program over the past five years, playing an instrumental role as a catalyst for major advances in data quality and quantity, and in the science and applications of Landsat data. The members of the LST provided relevant and practical input that demonstrated their clear commitment to the needs of the diverse Landsat science and applications user communities, and a clear understanding of the operational challenges facing USGS, NASA, and Landsat.

On behalf of the LST, **Curtis Woodcock** [Boston University—*LST Leader*] thanked USGS and NASA for seeking and considering their input. He suggested that the LST's strength has been its focus on the entire Landsat program, rather than on individual agencies, projects, and missions.