Landsat Science Team Meeting: Winter 2015

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Introduction

The U.S. Geological Survey (USGS)-NASA Landsat Science Team (LST) met at NASA's Goddard Space Flight Center (GSFC) from February 3-5, 2015. LST co-chairs **Tom Loveland** [USGS Earth Resources Observation and Science (EROS) Center—*Senior Scientist*] and **Jim Irons** [GSFC—*Landsat 8 Project Scientist*], opened the three-day meeting with a review of meeting objectives. Primary meeting topics included agency plans for a sustainable land imaging program; Landsat 7 and 8 operations, with special attention paid to the Landsat 8 Thermal Infrared Sensor (TIRS); and concepts and plans for making the Landsat archive and Landsat products more science-relevant. The presentations from the meeting presentations are available at *landsat.usgs.gov/science_LST_feb2015.php*.

Sustainable Land Imaging Status

Brad Doorn [NASA Headquarters—*Water Resources Program Manager of the Applied Science Program*] and **Sarah Ryker** [USGS—*Deputy Associate Director of the Climate and Land Use Mission Area*] presented the proposal for the formation of a Sustainable Land Imaging (SLI) Program, which is part of the President's proposed fiscal year 2016 budget. The program goal is to provide investments in technology innovations and observational capabilities that ensure continuation of land imaging for the next 20 years. The major components of the plan include:

- A Class-D Thermal Infrared Free Flyer (estimated 2019 launch) to fly in constellation with a reflective band imager (e.g., Landsat 8 or Sentinel-2[1]) and provide low-cost mitigation against an early loss of the Class-C TIRS instrument on Landsat 8, while demonstrating the feasibility of constellation flying.
- Landsat 9, referred to as the "Landsat 8 repeat build," which is a full-Class-B system (including thermal imager), with a 2023 launch target. This is viewed as a low-programmatic-risk implementation of a proven system.
- Investments in sustained technology and systems innovation, which are to include several hardware, operations and data-management; and data-processing investigations that will be conducted to identify appropriate technologies for next-generation missions.
- Landsat 10 Class-B, full-spectrum mission, with a tentative 2030 launch. The mission definition will be shaped by the technology investments conducted between 2015 and 2018.

Doorn and Ryker stressed that the plans are subject to congressional approval and that the specific configuration could be modified based on budget realities and scientific and technical investigations.

The LST members had a lively discussion about the SLI proposal, and in particular, the projected 2023 Landsat 9 launch date. With Landsat 7's end-of-mission date currently estimated to be early 2018, there could be at least a three-year period with only one Landsat acquiring imagery. Since there have been two functioning Landsats providing 8-day global coverage for the majority of Landsat's nearly 43 years, the loss of 8-day coverage would have significant impacts on Landsat data users. For example, there would be a reduction of cloud-free observations needed for all land applications. This would have a major impact on the many applications that need cloud-free observations at specific periods (e.g., growth, senescence, harvest periods), and studies in regions with persistent seasonal cloud cover, short growing seasons, and rapid phenology. In addition, there are a growing number of operational applications requiring more-frequent observations, including agricultural assessments, snow mapping, water resources investigations, and wildfire and other emergency response applications. The LST acknowledged that Sentinel-2 could provide important data-gap mitigation, but there are unresolved technical and programmatic issues that add risks.

The LST members concluded that the SLI program is a needed step towards securing Landsat operational status, and that after nearly 43 years of continuous imaging, Landsat may finally achieve the funding commitment needed to ensure definitive measurements of the condition of Earth for future generations. They suggested that the next phase of the approval and definition process pay close attention to ensuring Landsat continuity, including the longstanding *ad hoc* requirement of eight-day repeat coverage needed for time sensitive applications and for mitigation of frequent cloud cover. In order to avoid a data gap, creative strategies that reduce the time until Landsat 9 launch deserve attention.

[1] Sentinel-2 will be a land-monitoring constellation that will consist of two satellites: Sentinel-2A is scheduled to launch June 11 from the European Space Agency's spaceport near Kourou, French Guiana; Sentinel-2B is scheduled to launch in mid-2016 from Plesetsk Cosmodrome in Russia. These missions were described in "An Overview of Europe's Expanding Earth-Observation Capabilities," which appeared in the July–August 2013 issue of *The Earth Observer* [**Volume 25**, **Issue 4**, pp. 4-15].

Attendees at the Winter 2015 Landsat Science Team meeting at GSFC

The LST committed to writing a white paper expressing support for moving towards establishing a long-term plan for SLI.

Phil Dabney [GSFC—*Landsat Data Continuity Mission (LDCM) Instrument Scientist*] and **Jeff Masek** [GSFC—*Landsat Project Scientist*] wrapped up with a discussion of new imaging technologies that may play a role in future land-imaging missions. They reviewed a range of technical capabilities including smaller, lower-cost satellite technologies and a number of instrument design considerations (e.g., imaging spectroscopy, wider imaging swath); they also discussed notions of multi-satellite constellations. Their broad conclusions were that primary drivers are to reduce Landsat instrument size while maintaining image quality. While new technologies will help, there are fundamental restrictions on how far size reductions can go without compromising shortwave infrared (SWIR) and thermal infrared measurements. It was also suggested that new imaging technologies may be able to maintain current capabilities while also offering broader spectral coverage with finer resolution, with spectroscopy offering new and unique opportunities to the science community.

Landsat Archive Status

Gene Fosnight [USGS—*Landsat Data Acquisition Manager*] summarized changes in the Long Term Acquisition Plan (LTAP) that governs Landsat 7 and 8. Landsat 7 data acquisitions are focused on continental landmasses in order to increase imaging rates and reduce instrument wear. Over 500 Landsat 7 images per day are currently being acquired and Landsat 8 acquisitions have been increased to 725 images per day.

Brian Sauer [USGS EROS—*Landsat Sustaining Engineering Project Manager*] reported that the Landsat archive continues to expand rapidly due to both the increased daily acquisitions from Landsats 7 and 8, and because of the repatriation of historical scenes from international ground stations. The Landsat archive now contains more than 5.5-million scenes. Since the repatriation activity started, 3-million new images have been added to the USGS EROS archive. The largest outstanding source of historical coverage is held by the European Space Agency (ESA), and the transfer of their holdings is underway. India and Thailand recently announced plans to transfer data from their archives. An estimated 3-million images will be transferred from these stations.

Sauer also reported that downloads continue to rise significantly. Nearly 6.8-million scenes were downloaded by users in Fiscal Year 2014. That was an increase of nearly 2.5-million downloads from the previous fiscal year.

Landsat 7 and 8 Status

Guy Thayer [The Aerospace Corporation/USGS—*Flight Systems Manager*] gave a brief summary of the status of Landsat 7 and 8. Landsat 7 has been on orbit for 15 years—well past its 5-year design life. A number of spacecraft components are being monitored (e.g., attitude control system, remote telemetry command box, power control unit) but overall, Landsat 7 is acquiring more imagery than at any point in its history.

There was considerable discussion on the end-of-mission for Landsat 7. Fuel depletion is expected by late 2018, but the imaging life can be extended with reduced orbit maintenance. Preliminary analysis shows that if Landsat 7 is authorized to continue imaging outside of its nominal 10:00 AM equator crossing time window, the mission could be extended until early 2020. At that point, however, the local solar time would be 9:15 AM. The LST encouraged continued imaging until 2020. As Landsat 5 orbit decayed to an approximate 9:15 AM orbit in the late-1990s, there is precedent for imaging outside the nominal crossing time.

Thayer reported that, except for Landsat 8 TIRS issues, all other systems are functioning normally. The acquisition rate has been raised from the design requirement of 400 images per day to 725. Operational Land Imager (OLI) performance is stable and radiometric and geometric performance continue to exceed requirements.

As indicated earlier, the Landsat 8 TIRS has two issues. The first is a stray-light anomaly that creates nonuniform radiometric response across the focal plane. The effect is most acute in band 11, varies within and between scenes, and is most noticeable in homogeneous areas that should have a uniform

instrument response. **Dennis Reuter** [GSFC—*TIRS Instrument Scientist*] explained that stray light was adding a spatially varying signal (ghosting) to the focal plane. Analysis indicates that the stray-light artifacts are related to out-of-field light reflecting from a lens mounting ring in the TIRS telescope.

Ron Morfitt [USGS EROS—*Calibration/Validation Manager*] summarized NASA, USGS, and Rochester Institute of Technology (RIT) efforts to define potential correction strategies for the issues named in the previous paragraph. One approach uses external coincident thermal sensor data from NOAA's Geostationary Operational Environmental Satellites (GOES) or the European Organisation for the Exploitation of Meteorological Satellite's (EUMETSAT's) Meteosat series. This approach provides the most accurate compensation, but cannot be used in areas where GOES or Meteosat data are unavailable. There would also be extended latency in product generation. A second approach, using in-scene data, would not have latency issues, but the correction is not as robust. The group concluded that because neither approach is mature enough for implementation, potential solutions will be revisited at the next LST meeting. Meanwhile, use of band 11 is not recommended.

The second TIRS issue is a problem with the side-A scene-select mirror (SSM) encoder electronics, a component that controls the alignment of the TIRS scene-select mirror, which moves the TIRS field-of-view from Earth-facing to an internal blackbody and to deep space for calibration. In October 2014 a steady unexpected increase in the mechanism control electronics (MCE) current magnitude was observed and by mid-December, the threshold current limits were exceeded and imaging was suspended. Imaging was resumed with the SSM in mode-0 and thermal collections continued while an anomaly resolution board (ARB) investigated the root cause of the SSM problem and assessed the hazards to the TIRS instrument. In mode-0, radiometry is only minimally affected (~0.2 K, worst case), but geometry is degraded. The Landsat product generation system is not currently capable of processing mode-0 products, so the collected data have been archived, but not processed for distribution.

The ARB investigation concluded that the likely cause of the current rise is restricted to side-A electronics, so plans were made to switch to the redundant side-B electronics. This change was made on March 6, 2015. Following a brief period for instrument calibration, TIRS acquisitions, processing, and distribution resumed. For the mode-0 imagery collected between late-December and early-March, ground system processing modifications will be in place by mid-May and all mode-0 TIRS imagery will be processed and released for public distribution. For a full summary of the schedule for TIRS reprocessing, see *landsat.usgs.gov/mission_headlines2015.php*.

Landsat Product Improvements

Brian Sauer reviewed USGS plans for Landsat product enhancements and took input from the LST on technical issues or user impacts that require further consideration. Sauer explained that a specific goal is to have consistent products across the full Landsat record.

In the area of *Quality Band Cloud Assessments*, Sauer described plans to convert to the *Fmask* algorithm for the cloud and shadow mask elements of Thematic Mapper (TM), Enhanced Thematic Mapper (ETM+), and OLI scenes. For Multispectral Scanner System (MSS) data, a simple decision tree algorithm is planned. In addition, a land-based cloud-cover-score attribute would be added to the quality band that provides cloud percentages just for the land area within scenes. The LST supported the changes, but emphasized the need to conduct comparisons between alternative methods and to provide provisional products prior to the implementation so that operational users can adjust their processing flows to the new quality-band data. They also suggested adding confidence ratings that would provide additional information on the quality of the cloud and shadow attributes.

Several topics related to *Auto-reprocessing and Other Improvements* dealt with improvements in scene geometry and radiometry, including reprocessing when definitive ephemeris become available, *bumper-mode calibration*[2], and Level-1 systematic processing with terrain correction. The LST supported the improvements. However, there was considerable discussion of near-real-time product *versus* more "controlled," higher-quality products. The LST members expressed concern about the current lack of sufficient information to enable users to know which version is being accessed. Policies for flushing the Landsat on-demand Level-1 product cache and clearer version information for filenames and metadata are urgently needed. Until version information becomes available, any significant changes to Level-1 processing parameters should result in clearing out the cache.

In reference to the *Top-of-Atmosphere* (TOA) *Reflectance Metadata and Coefficients File*, improvements in metadata add coefficients that enable scaling to TOA reflectance and the generating solar illumination and viewing angles for use in per-pixel TOA reflectance and downstream surface reflectance processing. The additions are

[2] The scan mirrors on the Landsat 5 and 7 satellites switched from their primary operating mode to a backup mode in early 2002 and 2007 respectively in order to overcome internal synchronization problems arising from long-term wear of the scan mirror mechanism. When the instruments operate in this so-called *bumper mode*, scan start and stop angles are impacted and scan timing telemetry, used to correct the image geometry, is eliminated. A mathematical model of the scan mirror's behavior must be applied that includes parameters that characterize the time-varying behavior of the scan mirror bumpers.

only to the content of metadata and ancillary files; the per-pixel corrections will initially have to be applied by the users. Once implemented in Level-1 processing by the ground system, this will make TM and ETM+ data consistent with OLI. The LST generally supported the improvements, but recommended releasing provisional products for community review.

An evaluation of *Level-1 Data Format* is underway to assess alternatives to GeoTIFF file formats that permit use of data delivery services such as Open-source Project for a Network Data Access Protocol (OPeNDAP) and Open Geospatial Consortium (OGC) Web Coverage Service (WCS). Evaluation of several data format alternatives to GeoTIFF, such as HDF5 and JPEG2000, concluded that JPEG2000 provides the highest lossless compression rates and small additional computation times; it is also the format planned for Sentinel-2. This change, if implemented, will not take place until 2016. The LST supported the format change but suggested that sample data be provided as early as possible so that users can test the format in current and planned applications.

Jim Storey [USGS/Stinger Ghaffarian Technologies Inc.—*Landsat 8 Geospatial Imaging Scientist*] presented plans to improve geolocation accuracy results by *Ground Control Point (GCP) Library Updates*. The improved Landsat 8 geolocation accuracy has led to identification of areas where the current GCP library is deficient. Regions with poor accuracy are being retriangulated, using Landsat 8 data for control while holding the surrounding area fixed, to ensure scene-to-scene consistency. This is being implemented in three phases, with first phase corrections addressing those regions with the most significant geolocation errors. Once the inaccurate GCPs are corrected, additional Landsat 8 GCPs will be added to the global library. Since the current GCPs are from the 2000 timeframe, the additional control should improve corrections in dynamic areas. The GCP update effort will be completed by late-2015.

John Dwyer [USGS EROS—*Landsat Project Scientist*] gave an update on progress in *Level-2 Products,* to provide surface reflectance and temperature products. Surface reflectance for all Landsat TM and ETM+ scenes are routinely available and provisional Landsat 8 OLI products were recently released. Artifacts in the OLI provisional products (e.g., "blockiness" near coastlines, inland water bodies, forested regions, and in areas of significant terrain change) are being investigated. Once these issues are resolved, the provisional label will be removed. Regarding surface-temperature products for TM, ETM+, and TIRS, the USGS, NASA/Jet Propulsion Laboratory, and RIT developers are continuing to work toward releasing surface temperature products. No release date has been set.

Dennis Helder [South Dakota State University—*Landsat Science Team*], **Brian Markham** [GSFC—*Landsat 8 Calibration Scientist*], **Joel McCorkel** [GSFC—*Landsat Science Team*] and **Jim Storey** provided a comprehensive Landsat calibration update on behalf of the Landsat calibration/validation team. Helder presented an analysis of Landsat 8 OLI radiometric performance since launch, and concluded that striping due to relative gain differences is largely not noticeable, but are most apparent in blue and SWIR bands. Vicarious methods of relative gain estimation perform similarly to onboard methods. Finally, the relative gains are changing slightly, but can be tracked using both diffuser and vicarious methods, and are being updated quarterly to minimize user impacts.

Markham showed radiometric stability statistics, and concluded that OLI is very stable, with the least stability in the coastal aerosol band (1% degradation over two years). Independent analysis shows that reflectance uncertainties are lower than those for radiance (~2% *versus* ~3%, respectively). The Landsat calibration/validation team recommends using OLI reflectance calibration, and advises propagating this calibration back to earlier Landsat sensors.

McCorkel summarized Climate Absolute Radiance and Refractivity Observatory (CLARREO)-sponsored design objectives for cross-calibration activities at the Aglodones Dunes test site in southern California using ground, airborne [Goddard's LiDAR, Hyperspectral & Thermal Imager(G-LiHT)], and satellite (Landsats 7 and 8) measurements. The data collected during 2015 will be used to improve satellite sensor inter-calibration.

Finally, **Storey** reviewed Landsat 8 geometric performance, and concluded that Landsat 8 meets or exceeds all requirements. Of note is that geolocation accuracy is measured at 18.1 m (~59 ft) circular error versus 29.2 m (~96 ft) circular error for the Landsat global land survey data.

One of the LST's priorities is improving the Landsat MSS record so that the full 43-year Landsat history can be used for land-change investigations. **Warren Cohen** [U.S. Forest Service—*Landsat Science Team*] and **Justin Braaten** [Oregon State University—*Graduate Research Assistant*] presented their perspectives on priorities for improving the MSS record. The radiometric relationship between MSS and other Landsat instrument measurements has been established due to the cross-calibrated work completed by **Dennis Helder** and colleagues. However, improving image geometry, cloud- and shadow-mask algorithms, developing surface reflectance algorithms, and defining standard cross-sensor spectral indices are needed. The LST concluded that more attention needs to be placed on improving the MSS record, and accepted Cohen and Braaten's recommendations for

priorities. The USGS was encouraged to assess the complexity of the improvements that are needed to increase the science value of the MSS record.

Sentinel-2 Investigations

Brian Markham and **John Dwyer** provided an update on NASA and USGS plans to establish synergy between Landsat and Sentinel-2. Markham summarized an ongoing technical exchange between the Landsat calibration/validation team and ESA's Sentinel-2 counterparts, addressing radiometric characteristics and performance between the Landsat 8 OLI and the Sentinel-2 Multispectral Instrument (MSI). Their objective is to support the synergistic use of Landsat and Sentinel-2 data and to facilitate calibration compatibility between the OLI and the MSI. Markham summarized relative spectral response and illustrated the similarities in SWIR bands and differences in the visible and near-infrared bands and discussed signal-to-noise ratio statistics between MSI and OLI. The group is currently trying to identify near-simultaneous orbital paths with similar view angles that can be used for cross-calibration.

Dwyer described the steps that USGS is taking to implement an initial capability for archiving and distributing all Sentinel-2 Level-1C format data (orthorectified TOA reflectance) from the USGS EROS long-term archive. Currently, planned capabilities will allow for an online disk cache of 360 days of Sentinel-2 imagery. Analysis is ongoing for providing reformatting that will make the Sentinel-2 imagery more consistent with Landsat Level-1T data.

Other Topics

Kass Green [Kass Green and Associates] summarized the activities of the Landsat Advisory Group (LAG). The LAG is part of the National Geospatial Advisory Committee and advises the federal government on the requirements, objectives, and actions of the Landsat Program as they apply to ongoing delivery of societal benefits for the U.S. and the Earth observation community, globally. The LAG recently updated their analysis of the value of Landsat and concluded that *"$350 million to over $436 million economic value of just one year of Landsat data far exceeds the multi-year total cost of building, launching, and managing Landsat satellites and sensors. It can be expected that these savings, and others not addressed here, will continue to accelerate."* Additional details are found at *www.fgdc.gov/ngac/meetings/december-2014/ngac-landsat-economic-value-paper-2014-update.pdf.*

Garik Gutman [NASA—*Land Cover Land Use Change (LCLUC) Program Manager*] summarized two LCLUC solicitations. Awards will be made this spring for Multi-Source Land Imaging research that address instrument characterization and cross-calibration, harmonization of data formats, standardization of the preprocessing algorithms, surface reflectance and derived products, and development of basic algorithms. He also identified some of the research already underway that contributes specifically to the synergistic use of Landsat and Sentinel-2 data. Finally, Gutman mentioned plans for a late-2015 solicitation addressing land-use and land-cover change research focused on South Asian topics.

Jeff Masek reviewed the effort of the Terrestrial Ecosystems Carbon Cycle Land Use/LandCoverChange and Biodiversity (TECLUB) study group. NASA established TECLUB to provide science input to the upcoming National Research Council Decadal Survey. The agency convened a group of experts and tasked them with identifying priority measurements needed to meet current and emerging science needs. A draft report is available at *cce.nasa.gov/cgi-bin/cce/teclub_comments.pl.*

Jim Nelson [USGS EROS—*Engineering and Development Manager*] introduced the EROS Architecture Study Team (EAST), which is tasked with providing a high-level concept for the systems architecture, infrastructure, and processes required to meet EROS Center strategic objectives. By summer 2015 EAST must define high-level concepts, considerations, assumptions, risks and benefits, and alternatives for the future EROS architecture and infrastructure that meets the needs of key EROS stakeholders and user communities. This requires consideration of new, cost-efficient technology, as well as potential interagency, international, and private-sector partnerships. NASA and NOAA representatives are contributing to EAST.

Tom Loveland gave a status report on the development of a special issue of *Remote Sensing of Environment* addressing Landsat 8 Science Results. Slated for publication in January 2016, the issue will contain 25 articles that address Landsat 8 performance, science, and applications advances, and the extension of the Landsat time series.

The next Landsat Science Team meeting will be held at the USGS EROS Center near Sioux Falls, SD, July 7-9, 2015. ■