Landsat Science Team: 2017 Winter Meeting Summary

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Introduction

The winter meeting of the NASA-U.S. Geological Survey (USGS) Landsat Science Team (LST) was held January 10-12, 2017, at Boston University. LST co-chairs **Tom Loveland** [USGS's Earth Resources Observation and Science Center (EROS)—*Senior Scientist*], **Jim Irons** [NASA's Goddard Space Flight Center (GSFC)—*Deputy Director, Earth Sciences Division*], and **Curtis Woodcock** [Boston University—*Professor* and *LST Co-Leader*] welcomed the participants to the three-day meeting. The group immediately and enthusiastically recognized Woodcock's receipt of the *2016 Pecora Award*. Loveland summarized the primary meeting objectives to identify priorities for future Landsat measurements and to begin identifying next-generation Landsat products. He also discussed USGS's plans to issue a request for proposals for membership on the 2018-2023 LST (i.e., the next five-year term). Irons stressed Landsat's bipartisan support but cautioned against complacency when looking toward future capabilities. Meeting presentations are available at *https://landsat.usgs.gov/landsat-science-team-meeting-jan-10-12-2017*.

With the current LST nearing the end of its five-year term (2012-2017), **Mike Wulder** [Canadian Forest Service—*LST Member*], **David Roy** [South Dakota State University—*LST Co-Leader*], and **Curtis Woodcock** led a discussion of the major impacts of the 2012–2017 LST on relevant activities—these are summarized in *The Legacy of the Second (2012–2017) Landsat Science Team* on page 22.

Tim Newman [USGS Land Remote Sensing Program—*Program Coordinator*] and **David Jarrett** [NASA Headquarters—*Earth Science Missions Program Executive*] updated the LST on Landsat's programmatic status. Newman discussed planning for Landsat 9 and Sustainable Land Imaging (SLI) capabilities. He also reviewed Landsat's role in supporting the growing commercial imagery market, which includes developing network-cloud access to data and processing services, and multimission calibration. Jarrett then discussed the need to consider all options for Landsat configurations beyond Landsat 9.

NASA Land Cover and Multi-Source, Land-Imaging Activities

Garik Gutman [NASA Headquarters—*Land Cover and Land Use Change (LCLUC) Program Manager*] summarized the LCLUC program's vision that includes developing periodic global inventories of land use and land cover and the research projects associated with this vision. He focused his discussion on the Multi-Source Land Imaging (MuSLI) initiative to link Sentinel-2[1] and Landsat observations to map and monitor land-surface properties. **Jeff Masek** [GSFC—*Chief of the Biospheric Sciences Laboratory*] provided a detailed view of research leading to harmonized Landsat and Sentinel-2 data products. He explained that the goal is to create seamless, near-daily, 30-m (~98-ft) surface reflectance products by integrating Landsat 8 and Sentinel-2 data along with atmospheric corrections, spectral and bidirectional reflectance distribution function (BRDF) adjustments, and regridding. Preliminary products for selected areas are available for review at *https://hls.gsfc.nasa.gov*.

Tom Loveland and **Garik Gutman** concluded the session by discussing the relationship between the MuSLI and LST. Each team has a different focus for its activities: The LST seeks to ensure science-quality Landsat data while the MuSLI emphasizes synergy between Landsat and data from the European Sentinel missions. However, they overlap on two important issues: assessing data quality requirements and processing approaches. Because of these common areas of interest, the two teams plan to begin meeting with each other at least once a year.

Sentinel-2 Status

Benjamin Koetz [European Space Agency—*Sentinel-2 Exploitation Engineer*] summarized the status of Sentinel-2a and launch plans for Sentinel-2b.[2] Sentinel-2a's performance is exceeding most specifications, and absolute geolocation, multispectral registration, absolute radiometric uncertainty, and signal-to-noise ratio (SNR) measured performance are excellent. Multitemporal registration circular error is the only mission requirement not yet met, but full performance is expected once the global reference image is completed. Ten-day coverage is currently being acquired for Europe, Africa, and

[1] A series of Earth-observation missions have been or will be developed under the European Space Agency's Sentinel programme. Sentinel-2 provides high-resolution optical imaging for land services (e.g., imagery of vegetation, soil and water cover, inland waterways, and coastal areas). Sentinel-2 will also provide information for emergency services. Sentinel-2a was launched on June 23, 2015, from ESA's Spaceport in French Guiana.

[2] **UPDATE:** Sentinel-2b was successfully launched on March 7, 2017, from ESA's Spaceport in French Guiana.

The Legacy of the Second (2012–2017) Landsat Science Team

The LST is selected to serve a five-year term and provide direction, research, and scientific and technical evaluations of issues affecting the active Landsat missions and the Landsat archive. The USGS–NASA cosponsorship of the LST began in 2006, and the first team therefore served through 2011. The LST members are representatives of the Landsat user community and offer perspectives that enhance or expand Landsat applications. As explained in the article text, the third team is expected to be selected later this year, to serve from 2018–2023.

The second LST has made several contributions that have directly influenced the future of Landsat, and has played a major role in ensuring Landsat continuity. In particular, Team members produced science statements that were used to define the Sustainable Land Imaging (SLI) framework. These statements addressed Landsat continuity, Landsat 9 capabilities, and Landsat synergy with international imaging systems (e.g., European Sentinel missions, India's Resourcesat). They also provided the scientific rationale for particular sensing features the SLI Architecture Study Team has recommended, exemplified by articulation of the science value of 12-bit radiometric resolution. The second LST also established the importance of the Landsat Global Archive Consolidation (LGAC) in producing new terrestrial Essential Climate Variables that make full use of the program's spatial and temporal coverage, multidecadal continuity, metadata, instrument calibration and cross-calibration, and data access.

The second LST has also made major contributions to the success of the Landsat 7 and 8 missions. For example, Team members provided science justification for revising the Landsat 7 and 8 acquisition schedules—nearly doubling the scenes obtained per day from ~650 to ~1200, which reduces emphasis on cloud avoidance—and advocated for increased daily imaging rates. The second LST also quantified the variability of Landsat 5 local overpass time, which was used to inform Landsat 7 end-of-life scenarios, and also documented the Landsat 8 science and product vision for terrestrial global change.

The second LST made numerous contributions to improving Landsat products. Team members developed algorithms to deal with cloud/shadow detection, data tiling, and land cover change mapping, which were incorporated into USGS's Landsat operational systems. Team members provided rationale, insight, and advice to help Landsat Collections provide users with access to the most up-to-date and traceable analysis-ready data (ARD). The second LST also provided a science motivation for bringing Multispectral Scanner (MSS) data in line with those from the Thematic Mapper (TM) and later Landsat instruments, and offered options to produce reliable, continuous, measurements across all Landsat missions. Team members demonstrated the importance of absolute calibration and they evaluated and recommended improvements to Landsat surface reflectance algorithms. They also characterized Landsat image radiometry—ensuring consistency across Landsat instruments and quality of climate variables (e.g., albedo) and developed the capacity to estimate biophysical parameters.

Finally, the second LST supported the expansion of Landsat science and applications. Team members supported the global applications community in using Landsat data by providing science, enhanced understanding, and evidence of the benefits of new Landsat capabilities and products. They also articulated novel scientific applications with notable insights into water resources and cryosphere systems. In addition, the second LST demonstrated the need for thermal data and advancements to improve mapping of vegetation phenology and stress over large areas, and increase the accuracy of required cloud and shadow detection and screening algorithms. Team members also communicated the advanced information content as a result of Landsat time series availability and contributed science leadership regarding use of time series data to characterize land-cover dynamics.

Greenland, and coverage of the rest of the world alternates between 10 and 20 days.[3] Full, global, 10-day coverage is expected sometime during 2017.

Patrick Griffiths [Humboldt University of Berlin] summarized his research involving the integration of Landsat and Sentinel-2 data for interannual time series studies of crop type and land-cover mapping, and documenting cover-specific phenology variables. While Griffiths reported some confusion between some crop types, the spatial consistency of the classifications benefited from 10-day composites, and the characterization of grassland and cropland phenology was promising.

[3] For the rest of the globe, areas are imaged roughly every other overpass, but it varies depending on the particular day and situation.

Landsat 9 Development Status

Del Jenstrom [GSFC— *Landsat 9 Project Manager*] and **Jim Nelson** [USGS—*Landsat 9 Project Manager*] provided an update on the status of Landsat 9 development. Jenstrom reported that Ball Aerospace and Technologies Corporation in Boulder, CO, is making significant progress with Operational Land Imager-2 (OLI-2) detector-module testing, focal-plane assembly construction, and other fabrication activities. Meanwhile, GSFC is working to develop the Thermal Infrared Sensor-2 (TIRS-2) and has redesigned the telescope to include baffles that mitigate the *stray-light* issues that impacted Landsat 8's TIRS.[4] Orbital ATK in Gilbert, AZ, was awarded the Landsat 9 spacecraft contract; initial reviews have already been held. Launch vehicle procurement is expected this summer (2017). Nelson reported that the ground-system requirements review took place recently; at the conclusion of the review, the panel approved the Landsat 9 Ground System team to proceed to the Preliminary Design Review (PDR) stage. The Landsat 9 launch is tentatively scheduled for December 2020.

Landsat 7 and 8 and Archive Status

Brian Sauer [USGS EROS—*Landsat Sustaining Engineering Project Manager*] gave an update on Landsat 7 and 8 and the Landsat archive. Landsat 7 is performing nominally and collecting about 430 scenes per day. Now in its eighteenth mission year, end-of-life planning is underway. However, maintaining eight-day imaging with Landsat 8 is a top priority and the USGS is working to extend the mission until the launch of Landsat 9. Because of fuel limitations, by the fall of 2020 Landsat 7's orbit will degrade to an orbital mean local time between 9:15 and 9:30 AM. The NASA Restore-L mission has targeted Landsat 7 to demonstrate in-orbit refueling capabilities. Restore-L calls for a refueling mission following the end of the Landsat 7 science mission in late 2020. Landsat 7 would descend to a lower orbit, pair with the Restore-L spacecraft, and be refueled.[5] Options for a refueled Landsat 7 include de-orbiting to meet or exceed the 25-year re-entry guideline established in U.S. Space Policy, thus extending the Landsat 7 science mission and enhancing cross-calibration between Landsat 8 and 9, or extending the science mission in the event of a Landsat 9 failure.

Sauer also reported that Landsat 8 systems are working nominally, with up to 740 scenes acquired each day. OLI performance continues to exceed requirements, and the TIRS alternate operations concept established after the 2015 scene-select mirror encoder issue is providing useful thermal imagery.[6]

The Landsat archive has grown to more than 6.7 million scenes from Landsats 1–8, and the number of scenes distributed to users worldwide exceeded 17.4 million for Fiscal Year 2016—nearly double the number of scenes distributed in Fiscal Year 2015. The LGAC activity has added nearly 4.1 million scenes. LGAC is approximately 62% complete, with 71% of the scenes new to the archive.

Landsat Product Improvements

Dennis Helder [South Dakota State University] gave a review of research on radiometric calibration across the entire Landsat record. Historically, the USGS applied radiance-based calibration using solar exoatmospheric-irradiance values (ESUN). Different sources have defined different ESUN values for the same Landsat instrument. Enhanced Thematic Mapper Plus (ETM+) ESUN values published in a 2009 *Remote Sensing of Environment* paper by Gyanesh Chander, Brian Markham, and Dennis Helder,[7] have been used by many, but the authors advise against using those values due to differences in calculated irradiance. Helder described research on reflectance-based calibration that uses Landsat 8 OLI top-of-atmosphere (TOA) reflectance as the basis for calibrating the Landsat archive and to minimize uncertainties due to solar model differences. Ensuing discussion led to LST members endorsing the use of reflectance-based calibration, and recommending their routine implementation.

Brian Sauer gave an update on implementing Landsat data collection management. By definition, data collections have well-characterized radiometric quality, are cross-calibrated among the different Landsat sensors, and are assigned to different tiers based on data quality. Tier-1 data are suitable for time-series analysis and have root mean square error (RMSE) in georegistration accuracy of less than 12 m (~39 ft). Tier-2 and real-time data have georegistration-accuracy RMSE exceeding 12 m. Collection 1 processing of all U.S. Landsat 4–7

[4] Thermal energy from outside the normal field of view (*stray light*) has affected the data collected in Landsat 8 TIRS Bands 10 and 11. This varies throughout each scene and depends upon radiance outside the instrument field of view. Band 11 is significantly more contaminated by stray light than Band 10. Details about Landsat 8 TIRS stray light can be found in Appendix A of the Landsat 8 Data User Handbook, accessible online at *https://landsat.usgs.gov/sites/default/files/documents/Landsat8DataUsersHandbook.pdf*.

[5] To learn more about Restore-L, visit *https://sspd.gsfc.nasa.gov/restore-L.html*.

[6] On November 1, 2015, TIRS experienced a condition related to the instrument's ability to accurately measure the location of the Scene Select Mirror (SSM). A new approach for determining the exact position of the SSM through analysis of instrument telemetry data was implemented to provide the information needed to regularly update the line of sight model that is used for geometric correction and alignment of TIRS and OLI data.

[7] Chander, G., Markham, B.L., and Helder, D.L., 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. *Remote Sensing of Environment*, 113, 893-903.

data was completed in October 2016, and processing of data for the rest of the world was completed in February 2017. Landsat 8 processing is now underway, with priority given to images of the U.S.; the processing should be completed by June 2017. For Collection 1, 70% of Landsat 7 Enhanced Thematic Mapper Plus (ETM+) data and 57% of Landsat 4 and 5 Thematic Mapper (TM) data meet Tier-1 specifications.

Ron Morfitt [USGS EROS—*Landsat 8 Calibration and Validation Lead*] reviewed research on algorithms for processing Landsat Multispectral Scanner (MSS) data and Landsat TM scenes missing payload correction data (referred to as *noPCD*). MSS algorithm development includes filling missing Level-0 scans and improving reflectance calibration and image geometry. Approximately 375,000 noPCD scenes lack the attitude and ephemeris data needed to accurately georegister pixels. At this point, the development team is working toward having both MSS and noPCD processing capabilities in place later in 2017.

John Dwyer [USGS EROS—*Landsat Project Scientist*] gave an update on Landsat atmospheric correction and surface reflectance processing. New releases of Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) algorithms, used to generate Landsat 4–7 surface reflectance products, were recently completed, using per-pixel, solar-zenith-angle corrections and quality-assurance-band pixel-quality attributes. The Landsat 8 Surface Reflectance Code (LaSRC) is also being improved to address aerosol retrievals over water, using per-pixel solar-azimuth and -zenith angles, and quality attributes. Development of Landsat 4–8 land surface temperature products for North America continues.

To end this session, **Brian Sauer** and **John Dwyer** summarized the development of Landsat analysis-ready data (ARD) products. Landsat ARD products are consistently processed to the highest scientific standards needed for direct use in applications. ARDs consist of TOA, surface reflectance, and surface temperature data that are consistently processed, gridded to a common cartographic projection, and accompanied by appropriate metadata to enable further processing while retaining traceability of data. Generation of Landsat 4–8 ARD products for the U.S. is underway and will be completed by September 2017. Landsat 4–7 data will be processed first, followed by those for Landsat 8.

Future Landsat Requirements and Capabilities Discussion

The LST is firmly committed to the idea that future Landsat missions absolutely must advance measurement capabilities while preserving continuity with earlier missions and constraining program costs. With this guiding premise in mind, the LST is working to define the science drivers and future capabilities for Landsat 10 and beyond. Five specific areas of investigation are underway: continuity issues, acquisition temporal frequency, spatial resolution and geometry, radiometric resolution and SNR, and spectral bands. Breakout groups were established to identify preliminary capabilities in each of the five areas. Each group reviewed their preliminary results and developed plans to produce a consensus recommendation. A report on recommended capabilities and the supporting science justification will be finalized at the next LST meeting.

The LST's efforts benefit from the USGS Requirements, Capabilities, and Analysis for Earth Observation (RCA-EO) project.[8] **Greg Snyder** [USGS—*RCA-EO Project Manager*] summarized the status of their effort to document user requirements for federal programs. Through interviews with federal stakeholders, the RCA-EO project is working to document environmental parameters and measurement attributes associated with a wide range of applications. The collective results are being analyzed to identify potential capabilities for future Landsat missions.

Other Reports

Frank Avila [National Geospatial Intelligence Agency—*Landsat Advisory Group (LAG) Vice Chair*] gave an update on LAG activities. LAG is part of the Department of Interior's National Geospatial Advisory Committee and contributes to the requirements, objectives, and actions of the Landsat Program. The LAG is currently investigating several topics, including the roles of smallsats in Earth observations, the feasibility and utility of temporal data cubes (e.g., ARDs) in monitoring global change and projecting future land variables, and data-continuity-mission enhancements.

Rick Lawrence [Montana State University—*Professor and AmericaView*[9] *Liaison*] gave an update on AmericaView's plans to survey its constituents on future Landsat requirements. They intend to use the approach developed by the RCA-EO team. Lawrence also summarized AmericaView-sponsored research on classification accuracy. While classification tree and support vector machines generally performed best, there was significant variability in results depending on the specific tests conducted.

Summary of Boston Area Remote Sensing Activities

Meeting co-hosts **Curtis Woodcock**, **Crystal Schaaf** [University of Massachusetts, Boston—*LST Member*]

[8] To learn more about RCA-EO, visit *https://remotesensing.usgs.gov/rca-eo/rcaeo*.

[9] AmericaView is a nationwide consortium for remote sensing education, research, and geospatial applications. To learn more, visit *https://americaview.org*.

Table. Summary of Landsat-related remote sensing activities in the Boston area.

Presenter [Affiliation]	**Topic**
Zhan Li [University of Massachusetts, Boston (UMass)]	Landsat/Sentinel surface albedo comparisons
Angela Erb [UMass]	Studying changes in albedo from boreal fire scars
Yan Liu [UMass]	Studying California savanna and grassland phenology
Peter Boucher [UMass]	Monitoring salt marshes
Farouk El-Baz [Boston University (BU)]	Monitoring Egypt's deserts
Eli Melaas [BU]	Studying boreal and temperate forest phenology
Damien Sulla–Menashe [BU]	Tracking boreal forest greening and browning
Jordan Graesser [BU]	Monitoring the changing scale of South American agriculture
Pontus Olofsson [BU]	SilvaCarbon* capacity building
Paulo Arevalo [BU]	Columbian Amazon change area estimates
Damien Sulla–Menashe [BU]	Monitoring deforestation with synthetic aperture radar/optical fusion
Xiaojing Tang [BU]	Near-real-time monitoring of forest change
Eric Bullock [BU]	Developing postprocessing approaches for time-series structure break detection
Stephan Estal [BU]	Conducting global assessments of protected area effectiveness

*SilvaCarbon is a U.S. technical coordination program to enhance capacity worldwide in monitoring and managing forest and terrestrial carbon. To learn more, visit *http://silvacarbon.org*.

and their student and faculty colleagues gave presentations showcasing a number of ongoing research projects where Landsat data are being used to study topics of interest to the LST—see **Table**.

Finally, **Valerie Pasquarella** [University of Massachusetts, Amherst], a Boston University alumnus, presented her research on monitoring northeastern forest dynamics using Landsat time-series data, and **Zhe Zhu** [Texas Tech University—*Assistant Professor*] presented his work on classifying change agents using Landsat time series.

Conclusion

The Boston meeting gave the LST a chance to reflect on the status of the Landsat program. Landsat 7 and 8 are acquiring more imagery than ever, Landsat 9 is authorized and proceeding toward a December 2021 launch date, and planning for Landsat 10 and beyond is underway. The LGAC initiative has doubled the size of the Landsat archive and new Landsat product specifications are being implemented. With Landsat applications growing in number and impact, the value of Landsat continues to grow. The attendees all agreed that this is an unprecedented time in Landsat's long history.

The next Landsat Science Team meeting will be held July 11-13 2017 at the USGS EROS Science Center in Sioux Falls, SD. ■

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Articles, contributions to the meeting calendar, and suggestions are welcomed. Contributions to the calendars should contain location, person to contact, telephone number, and e-mail address. Newsletter content is due on the weekday closest to the 1st of the month preceding the publication—e.g., December 1 for the January–February issue; February 1 for March–April, and so on.

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