# An Overview of USGS-NASA Landsat Science Team Activities During 2018

*Christopher J. Crawford, ASRC Federal InuTeq/U.S. Geological Survey Earth Resources Observation and Science Center, cjcrawford@contractor.usgs.gov*
*Thomas R. Loveland, U.S. Geological Survey, Earth Resources Observation and Science Center, loveland@usgs.gov*
*Jeffery G. Masek, NASA's Goddard Space Flight Center, jeffrey.g.masek@nasa.gov*
*Michael A. Wulder, Canadian Forest Service, Pacific Forestry Centre, Natural Resources Canada, mike.wulder@canada.ca*

**Introduction**

Two meetings of the U.S. Geological Survey (USGS)-NASA Landsat Science Team (LST) took place in 2018. The USGS Earth Resources Observation and Science (EROS) Center hosted the winter meeting, which took place February 21-22 in Sioux Falls, SD. The University of Colorado-Boulder hosted the summer meeting, which was held August 8-10 in Boulder, CO.

The objectives of the winter LST meeting were to introduce the new 2018-2023 LST members, review LST member roles and responsibilities, receive status updates on Landsat 7 and Landsat 8 mission operations, review Landsat 9 development progress, and establish science team priorities for the LST's five-year term.

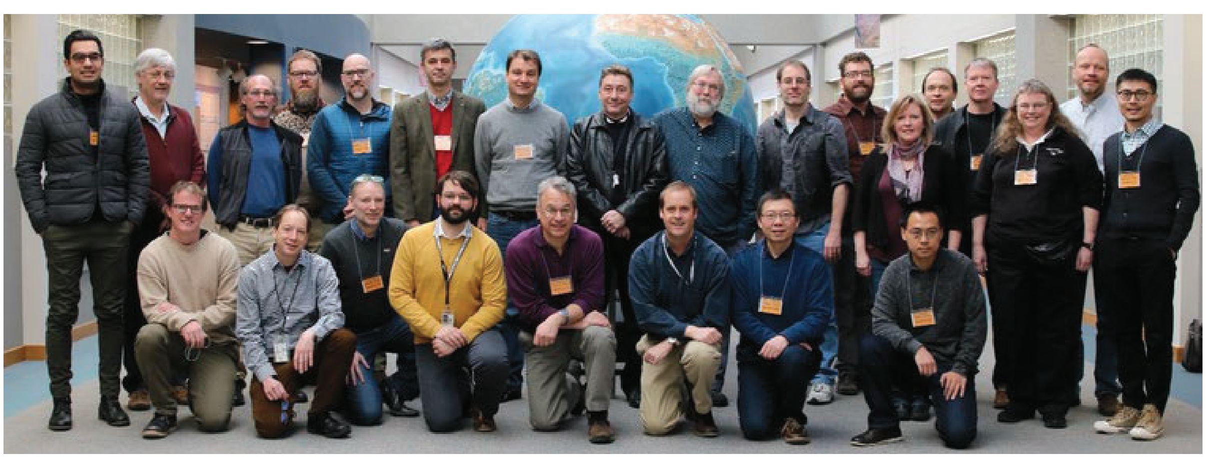
The summer LST meeting objectives included review of Landsat's no-cost, nondiscriminatory-access data policy, status updates on Landsat data product evolution, future archive collection and reprocessing plans, Landsat calibration/validation (cal/val) activities, and identifying LST synergy with NASA's Multi-Source Land Imaging Program (MuSLI). Meeting participants also toured Ball Aerospace, located in Boulder, where Landsat 9's Operational Land Imager Two (OLI-2) is being built.

This article begins with a brief review of the Landsat mission to-date followed by a short synopsis of the USGS–NASA LST's makeup, role, impact, and contributions to the Landsat program. Next, the 2018-2023 USGS–NASA LST is introduced, and its key responsibilities to the Landsat program are described. The article finishes with summaries of both winter and summer LST meetings that took place during 2018. The USGS-NASA LST meetings are open and transparent and all meeting materials are publicly accessible at *https://landsat.usgs.gov/landsat-science-teams*.

**Review of the Landsat Mission to Date**

The Landsat mission began in July 1972 with the launch of Landsat 1 (1972-1978), formerly known as Earth Resources Technology Satellite (ERTS-A or ERTS-1), carrying Multispectral Scanner (MSS) and Return Beam Vidicon (RBV) sensors. The MSS system continued with Landsat 2 (1975-1978) and Landsat 3 (1978-1983), and provided visible-to-near-infrared (VNIR) multispectral coverage.

Beginning with the Landsat 4 mission (1982-1993), the MSS sensor was accompanied by an additional Thematic Mapper (TM) sensor as well as initiation of thermal infrared (TIR) measurements. The changes from Landsat 3 to 4 (in particular, moving from MSS to TM) with improved radiometry, additional spectral coverage [e.g., adding shortwave infrared (SWIR—sometimes called middle infrared) and TIR] as well as increases in spatial resolution, resulted in a significant advancement in Landsat sensor design and resultant information content. The shift from MSS, with 60-m (~197-ft) spatial resolution, to TM, with 30-m (~98-ft) spatial resolution, provided sufficient detail to enable human interactions with the Earth's surface to be characterized over large areas and monitored through time.



The 2018-2023 USGS-NASA Landsat Science Team. **Photo credit:** USGS EROS

Landsat 5 (1984-2011) also had a TM, which was nearly identical to the TM on Landsat 4 and which remained in a science-imaging orbit for a remarkable 28 years and 10 months. The TM sensor also provided additional SWIR multispectral coverage as well as one TIR spectral band.

The subsequent improvements to Landsat sensors described below have built upon the successful TM design, keeping key elements to enable continuity of measurements (e.g., orbital characteristics, 30-m spatial resolution) but leaving opportunity for improvement (e.g., adding additional spectral bands, improved radiometry). At this point, the next step in Landsat sensor development came with the Enhanced Thematic Mapper (ETM), which, as its name implies, was an enhanced version of TM that added a VNIR panchromatic spectral band, and low- and high-gain modes for the TIR spectral band.

Landsat 6 (launched in 1993) had an ETM onboard; unfortunately, the satellite failed to reach orbit. In 1999 Landsat 7 was launched, with the Enhanced Thematic Mapper Plus (ETM+) onboard. The Landsat 7 ETM+ has been in operation with stable on-orbit performance for ~20 years—well beyond its 5-year design life. Landsat 7 was the first system to carry full- and partial-aperture solar calibrators to monitor sensor health and performance. The Landsat 7 ETM+ sensor has multispectral VNIR, SWIR, and TIR coverage. In May 2003 Landsat 7 experienced a failure with the Scan Line Corrector (SLC), resulting in a status described as *SLC-off,* whereby there are systematic, zig-zag, data gaps along the image edges. Since initial discovery of the SLC-off failure and subsequent characterization of the malfunction as permanent, many approaches for mitigating the issue have been developed and documented.

Landsat 8 (2013-present), known as the Landsat Data Continuity Mission (LDCM) during development, was launched in February 2013 and carries two sensors, the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS). Landsat 8 OLI has significantly improved radiometry over prior Landsat sensors. Ultrablue and infrared cirrus spectral bands were added to OLI to enhance coastal and fresh water remote sensing science, improve capabilities to compensate for atmospheric effects, and increased cloud detection accuracy. Landsat 8 TIRS measures emitted thermal radiance in two spectral regions to enable more accurate atmospheric characterization and compensation with the intent of improving the fidelity of surface temperature retrievals. The upcoming Landsat 9 will be nearly identical to Landsat 8 and will carry two sensors, the OLI-2 and TIRS-2.[1] The launch date for Landsat 9 is targeted for December 2020. Planning is now underway for a Landsat 9 follow-on.

[1] Landsat 9 will fly near-identical copies of the OLI and TIRS instruments that were flown on Landsat 8. The TIRS instrument will be upgraded to a risk class B implementation, whereas no changes are planned for OLI. With respect to the Landsat 9 project, these instruments will be referred to as OLI-2 and TIRS-2.

**Landsat: Recent Accomplishments**

Over the past decade, the Landsat program has achieved several notable benchmarks. First, in January 2008, the USGS and NASA decided to open the full Landsat image archive for public access on a nondiscriminatory, no-cost basis. This change in Landsat's data policy has ushered in a new era of Landsat data uses and applications while also revolutionizing the way Landsat has been woven into scientific discovery, economic prosperity, and public policy for management of land and water resources across a range of scales. Second, the Landsat Global Archive Consolidation (LGAC) initiative, an effort to recover historical imagery from past Landsat sensors archived at international cooperator ground stations around the globe, has doubled the size of the Landsat image archive on a global scale. Third, the Landsat image archive has undergone a transition to collections-based processing, which facilitates greater data traceability, accuracy, management, and distribution of analysis-ready data where image products are continuously growing and evolving. Collections also enable reprocessing of the entire archive in a systematic and transparent manner when improvements to data consistency and quality are possible (e.g., improved geometric control, updated radiometric processing).

Finally, new Landsat 8 operations revisions to Landsat's long-term acquisition plan (LTAP) have been made possible in part by OLI's notable in-orbit instrument performance and advanced imaging capabilities. LTAP applies systematic, repeatable, science-based logic to Landsat's 16-day Earth imaging of all sun-lit global landmasses and near-shore coastal regions at a solar elevation angle of greater than 5°. As Landsat's image overlap increases substantially towards the poles (to ~80%), this effective increase in temporal imaging frequency is paying important dividends for advancing our understanding of high-latitude environments, e.g., how Greenland and Antarctic ice sheets are responding to global environmental change.

For nearly two-thirds of the various Landsat missions' lifetime, there have been two satellites operating in tandem to produce eight-day revisit equivalency. At present, ~1200 Landsat images are acquired daily: ~475 from Landsat 7 (following LTAP) and ~740 from Landsat 8 (with collection of nearly all possible terrestrial land mass opportunities, due to sufficiently large onboard recording and downlink capacity). Landsat 8 alone is adding ~500,000 images per year to the USGS EROS Landsat archive. With a nominal five-year sensor design life and approximate seven-year launch readiness as guiding principles for Landsat data continuity, the upcoming launch of Landsat 9 will ensure that Landsats 8 and 9 together sustain eight-day global imaging beyond 2025.

### The 2018–2023 USGS–NASA Landsat Science Team

The third 2018-2023 USGS-NASA LST—see *The Landsat Science Team* on page 22 to learn more about the LST—was selected and announced in late 2017—see **Table 1** for a list of principal investigators (PIs) and their affiliations.[2] For the 2018-2023 term, the LST will address five primary Landsat program topics, which include:

- Overseeing the end of the Landsat 7 mission and ETM+ science imaging;[3]
- overseeing the launch of Landsat 9 and evaluating OLI-2 and TIRS-2 data quality and potential science impacts;
- continuing to contribute to the process of defining science requirements for future Landsat sensors and missions;
- continuing to provide feedback on data product improvements as well as interoperability with data from other Earth-observing missions; and
- continuing to communicate the role of Landsat in understanding global land surface change and management of land and water resources.

### Winter Meeting

The winter meeting at USGS EROS was the first meeting of the new LST's 2018-2023 term. This two-day meeting was designed to familiarize the team members with each other, and brief them on the status and outlook of key Landsat program activities in 2018. The winter meeting objectives are summarized in the *Introduction* section of this article. The presentation content described below reflects the main elements that were addressed during the winter meeting.

The winter meeting opened with **Frank Kelly** [USGS EROS—*Director*] welcoming the new LST to the first gathering of the 2018-2023 term. He commented that LST PIs came to the meeting as individuals but would leave as a team. **Tom Loveland** [USGS EROS—*LST Co-Chair* and *Chief Scientist*] also welcomed the new 2018-2023 LST members, and then described the LST selection process; he followed with a description of Landsat's programmatic aims. Loveland reiterated that the LST should remain concentrated on the full Landsat archive and its utilization rather than approaching LST responsibilities from a single-mission perspective. He stated that the LST should work to expand Landsat's scientific impact and broaden its constituency. The LST team then acknowledged and applauded Loveland's years of dedicated service to the Landsat program and LST. Loveland confirmed his planned retirement from the USGS in March 2018, and then stated that **Christopher Crawford** [ASRC Federal/contractor to the USGS EROS—*Landsat Deputy Project Scientist* and *LST Co-Chair* (as of April 2018)] would transition into his LST co-chair role after working together on LST leadership activities since March 2017.

With the start of the new 2018-2023 LST, **Jeff Masek** [NASA's Goddard Space Flight Center (GSFC)—*LST Co-Chair* and *Landsat 9 Project Scientist*], who has served on four Landsat science teams starting with the

**Table 1.** The 2018-2023 USGS-NASA Landsat Science Team.

| Principal Investigators (PIs) | Affiliations |
|---|---|
| Martha Anderson | U.S. Department of Agriculture's (USDA) Agricultural Research Service (ARS) |
| Feng Gao | USDA ARS |
| Noel Gorelick | Google |
| Matthew Hansen | University of Maryland, College Park |
| Sean Healey | U.S. Forest Service |
| Patrick Hostert | Humboldt University of Berlin |
| Justin Huntington | Desert Research Institute |
| David Johnson | USDA's National Agricultural Statistics Service |
| Leo Lymburner | Geoscience Australia |
| Alexei Lyapustin | NASA's Goddard Space Flight Center (GSFC) |
| Nima Pahlevan | Science Systems and Applications, Inc. |
| Jean-François Pekel | European Commission Joint Research Centre (ECJRC) |
| Peter Strobl | ECJRC |
| Volker Radeloff | University of Wisconsin |
| David Roy | South Dakota State University |
| Ted Scambos | University of Colorado Boulder |
| Crystal Schaaf | University of Massachusetts Boston |
| Eric Vermote | GSFC |
| Curtis Woodcock | Boston University |
| Michael Wulder | Canadian Forest Service |
| Zhe Zhu | Texas Tech University |

[2] The accomplishments of the second (2012–2017) LST are summarized in a sidebar called "The Legacy of the Second (2012–2017) Landsat Science Team," which appears in the May–June 2017 issue of *The Earth Observer* [**Volume 29**, **Issue 3**, p. 22]— *https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/May%20June%202017%20color%20508.pdf#page=21*.

[3] The Landsat 7 observatory is running low on fuel, so performing an inclination maneuver to maintain ETM+'s science imaging orbit past July 2021 is no longer an option.

### The Landsat Science Team

As information needs proliferate and Landsat program elements became increasingly complex, the USGS, NASA, and other partners needed a mechanism to solicit feedback and gather informed advice on the Landsat program. To meet this need, the USGS created an advisory panel, the LST, that is cochaired by the USGS and NASA. The first USGS–NASA LST was constituted in 2006, followed by recompetes for membership in 2012 and 2017. The LST is composed of competitively selected principal investigators (PIs) through a peer-review process that draws from U.S. federal government agencies, universities, and the international community. LST members serve five-year terms and participate in a minimum of two science team meetings per calendar year. The LST meetings are organized around USGS and NASA agency briefings pertinent to Landsat programmatic priorities and directions, status updates on mission operations, data archive management and processing, calibration/validation activities, data product evolution, and topical content requiring deliberation, scientific advancements, and external recommendations. Unique to the LST forum, members share their experiences, insights, and scientific findings based on use of Landsat data at each meeting via oral presentations.

LST membership is a highly sought appointment and carries significant scientific and technical evaluation responsibilities to the Landsat program. LST measures of success include Landsat scientific innovation, productive and original scientific work (documented through citable publications), the ability to enhance Landsat's science and engineering capabilities, and contributions to future Landsat sensor and mission planning. LST members are expected to bring visibility to and promote the Landsat program across a broad range of scientific and application forums. LST members are and will continue to play an increasingly important role in defining interoperability standards for Landsat and other Earth-observing systems, while exploiting their Landsat-related research as PIs to inform requirements and capabilities for the next generation of Landsat sensors. The expectation is that this role will continue throughout the next decade and should remain central to the Landsat program basis and USGS-NASA partnership.

1996-2001 NASA Landsat 7 science team, assumed the NASA LST co-chair role taking over for **Jim Irons** [GSFC—*Director of the Earth Sciences Division*] who co-chaired the prior two USGS–NASA LSTs' with Tom Loveland. Masek encouraged the LST to look more broadly at the satellite land remote sensing landscape and work to reduce roadblocks for data usage. He emphasized the importance of sensor cross-calibration as well as exploitation of the TIR time series from Landsats 4-8 (a new USGS Landsat science data product). He reinforced Loveland's comments on prior LST accomplishments, and highlighted the fact that the LST has been behind many Landsat program advancements.

**Tim Newman** [USGS's National Land Imaging (NLI) Program—*Program Coordinator*] gave a Landsat status briefing from a USGS management perspective. He described how the USGS and its science strategy falls within the U.S. Department of Interior's (DOI's) organizational structure, as well as its responsibility for managing 20% of the U.S. land area. Newman articulated USGS science priorities for 2018 and beyond, and discussed how the NLI program and Landsat fit into and will inform that framework. The USGS currently has a strong emphasis on integrated predictive science for the twenty-first century that will focus explicitly on natural resource decision making; land and water management; and protection of public safety, health, and property. Newman underscored several NLI programmatic challenges including securing consistent funding for Landsat development, operations, and science; maintaining operational Landsat continuity; institutionalizing the NASA-USGS Sustainable Land Imaging (SLI) program; and maturing the requirements process to meet end-user satisfaction and federal civil community needs. He concluded by briefly mentioning planning activities for the Landsat 9 follow-on Architecture Study Team, requesting that the LST start thinking about how to leverage an existing and growing commercial image data stream to augment Landsat science and applications, and for the LST to remain active in providing guidance to the NLI and Landsat programs.

**Doug Daniels** [USGS EROS/Aerospace Corp.—*Landsat Mission Manager*] gave a status briefing to the LST on Landsat 7 and Landsat 8 mission operations. There has been no change to the Landsat 7 observatory status or performance since the last LST in July 2017.[4] Daniels mentioned the NASA Restore-L servicing mission[5] to refuel Landsat 7 and said the USGS is working to understand the proposed strategy. He also briefly reviewed the Landsat 7 end-of-mission timeline, highlighted earlier in this article. The Landsat 8

[4] A summary of the Summer 2017 Landsat Science Team meeting can be found in the January–February 2018 issue of *The Earth Observer* [**Volume 30**, **Issue 1**, pp. 21-25—*https://eospso.gsfc.nasa.gov/sites/default/files/eo_pdfs/Jan_Feb_2018_color508_0.pdf#page=4*].

[5] The RESTORE-L mission is intended to demonstrate technologies for on-orbit rendezvous with inspection, repair, and refueling of a client satellite (Landsat 7 has been chosen as the target), all of which are vital for a future satellite servicing capability.

observatory has also experienced no change in status or performance, but did achieve the fifth anniversary of its launch on February 11, 2013.

**Chris Engebretson** [USGS EROS—*Landsat Science Data Processing Engineer*] reviewed Landsat archive statistics, Landsat Collection One status, Landsat Collection Two definitions and baselining efforts, and Landsat MSS 1-3 alignment with Landsats 4-8, and LGAC status. During Landsat Collection One processing, there were many Landsat TM and ETM+ scenes that had never undergone Level-1 processing. As a result, a shutter intrusion anomaly was identified in TM and ETM+ imagery appearing as what is referred to as *caterpillar tracks*. Engebretson summarized USGS efforts to understand, mitigate, and flag this data anomaly in Landsat quality assurance information during future collection-based reprocessing of the Landsat archive.

**Brian Markham** [GSFC—*Landsat Calibration Scientist*] gave an overview on Landsat cal/val activities and data usage recommendations, and provided Landsat 8 calibration and Landsat 9 performance updates. He described how Landsats 4-8 calibration is radiometrically tied to OLI's reflectance-based calibration. The MSS 1-3 calibration is being finalized by South Dakota State University (SDSU) and will be consistent with the Landsat 4-8 calibration. Markham stated that Landsat's radiometric uncertainty has been quantified in units of reflectance by sensor using desert pseudo-invariant calibration site (PICS) targets. Radiometric uncertainty has also been quantified for Landsats 4-8 TIR measurements using water as the calibration target. He pointed out that Landsat 8 OLI and TIRS continue to exceed radiometric and geometric expectations, with very stable on-orbit performance despite impacts of stray light on TIRS (i.e., band 11), which has been mitigated for using a postlaunch correction. For Landsat 9, OLI-2 and TIRS-2 instrument testing will follow similar protocols for OLI and TIRS, although OLI-2 spectral testing will be laser-based rather than monochromator-based, and TIRS-2 will undergo more extensive stray-light testing.

**Dennis Helder** [SDSU/USGS EROS—*EROS Calibration Center of Excellence (ECCOE) Director* and *Acting Landsat Calibration and Validation Manager*] presented information regarding the purpose of ECCOE and results from the first ECCOE cal/val workshop aimed at Landsat 8 and Sentinel-2 interoperability. ECCOE's vision is to be recognized as a leading national and international institution for improving the accuracy, precision, and efficiency of radiometric and geometric calibration and cross-calibration of optical remote sensing systems, to achieve the highest degree of data product interoperability. The first ECCOE cal/val workshop on Landsat 8 and Sentinel-2 interoperability was held at the PECORA20 meeting in November 2017. The workshop included a panel of experts from NASA, USGS, and European Space Agency (ESA) cal/val teams, as well as several LST members and international partners. Most of the proceedings from this workshop were made available to the broader remote sensing community.

**Brian Sauer** [USGS EROS—*Landsat 9 Project Manager* and *Landsat Development Manager*] offered an overview of Landsat 9 development status. Landsat 9 is a NASA–USGS partnership where NASA is responsible for the space segment, mission integration, launch, and on-orbit checkout, while the USGS is responsible for the ground system, flight operations, and data processing and distribution. Sauer summarized how Landsat 9 instrument development is progressing rapidly, with planned spacecraft integration in 2019. The Landsat 9 project has been making excellent progress against an aggressive development schedule with launch targeted for December 2020, and has been receiving high marks at each spacecraft, ground system, and mission-level review.

During the meeting, LST members had the opportunity to give oral presentations on their proposed Landsat science program contributions for the 2018-2023 term—see **Table 2** on page 24. To conclude the winter meeting, the LST reviewed prior achievements of the 2012-2017 LST, with an eye towards transition and setting new goals for the next five years. During the meeting, **Curtis Woodcock** [Boston University] and **David Roy** [SDSU] were elected by their fellow members as co-leads of the LST.

**Summer Meeting**

The summer meeting at the Cooperative Institute for Research in Environmental Sciences (CIRES) on the campus of University of Colorado Boulder was the second meeting of the current LST's term. This meeting offered an opportunity for the team to learn about the status of the DOI's requested review of the Landsat data policy, plans for Collection Two processing of the Landsat archive in preparation for Landsat 9 launch, and to firm up key LST recommendations for Landsat 10 and beyond, to support Landsat's next architecture study. Specific meeting objectives are outlined in the *Introduction* section of this article. The presentation content below is intended to describe the core elements of the summer meeting and to reduce redundancy in information provided for the winter meeting section of this article.

**Waleed Abdalati** [University of Colorado Boulder—*CIRES Director*] and **Ted Scambos** [University of Colorado Boulder—*National Snow and Ice Data Center (NSIDC)* and *LST Member*] opened the summer meeting by welcoming the LST to CIRES. In his opening remarks, Abdalati reiterated the importance of Landsat and the LST to both science and USGS–NASA agencies, emphasizing the need to turn data into value. **Christopher Crawford** and **Jeff Masek** also welcomed the LST to the second meeting of the 2018-2023 term, and briefly reviewed the summer meeting's objectives.

**Table 2.** Winter Landsat Science Team member presentations.

| LST PI | Presentation Title* |
|---|---|
| Martha Anderson and Feng Gao | Characterizing Crop Water Use, Phenology, and Yield at Field Scales Using Multisensor Data Fusion |
| Noel Gorelick | Driving Cloud-Based Usage of Landsat with Google Earth Engine |
| Matthew Hansen | Generating Time-Series Maps that Accurately Reflect Land Change Area: A Strategy for Global Land Monitoring |
| Sean Healey | Landsat Science and Applications in the U.S. Forest Service |
| Patrick Hostert | Synergies Between Future Landsat and European Satellite Missions, from Land Cover to Land Use |
| Justin Huntington | Towards the Development and Integration of Landsat Evapotranspiration Ensembles and Climate Data for Enhanced Water and Land Management Decision Support |
| David Johnson | Leveraging Analysis-Ready Landsat Products for Use in Crop Production Estimation |
| Leo Lymburner | Digital Earth Australia |
| Alexei Lyapustin | Advanced Atmospheric Correction of Landsat 8/Sentinel-2 Data Using the Multiangle Implementation of Atmospheric Correction (MAIAC) Algorithm |
| Nima Pahlevan | Landsat/Sentinel-2 Constellation for Monitoring Aquatic Systems Across the U.S. |
| Jean-François Pekel and Peter Strobl | Copernicus–Landsat Convergence, Architecture, and Applications |
| Volker Radeloff | Landsat Data for Biodiversity Science and Conservation |
| David Roy | Pathfinding Near-Real-Time, Moderate-Resolution, Land-Surface Monitoring: Looking Forward to an Operational Landsat 9/10 Sentinel-2A/2B Era |
| Ted Scambos | Landsat and the Cryosphere: Tracking Interactions Between Ice, Snow, and the Earth System |
| Crystal Schaaf | Global 30-m Snow and Snow-Free Land Surface Albedo from Landsat and MODIS/VIIRS |
| Eric Vermote | Maintenance and Refinement of the Land Surface Reflectance Code (LaSRC) for Landsats and Sentinel-2s |
| Curtis Woodcock | New Opportunities Using the Landsat Temporal Domain: Monitoring Ecosystem Health, Condition, and Use |
| Michael Wulder | Integrating Time and Space with Landsat to Learn from the Past, Monitor the Present, and Prepare for the Future |
| Zhe Zhu | Toward Near-Real-Time Monitoring and Characterization of Land-Surface Change for the Coterminous U.S. |

*Some of these presentations were given by a co-investigator on the PI's research team.

**Eric Ianson** [NASA Headquarters—*Associate Director for Flight Programs*] presented a broad overview of NASA's Science Mission Directorate and its satellite mission portfolio. He then described missions specific to NASA Earth Science and summarized NASA's plans to address recommendations from the 2017 Decadal Survey.[6] He emphasized Landsat 9's role in SLI to ensure continuity of the 46+ year Landsat record, and then highlighted that the SLI program constitutes 8% of NASA's flight program budget that includes advanced technology investments and demonstrations as well as full instrument concepts to inform Landsat's next architecture.

**Tim Newman** provided an update on the USGS's NLI priorities and highlighted that the NASA–USGS Landsat 10 Architecture Study Team (AST) that will soon kick off is the highest 2018-2019 programmatic priority. He articulated how the Landsat 10 AST would draw from a variety of information sources on requirements and capabilities to address Landsat science and application user needs, and then confirmed his commitment to measurement continuity and backwards compatibility with the Landsat archive. Newman concluded by mentioning that the Landsat 10 AST would be considering a trade space that leverages existing international satellite systems and commercial small- and cube-satellite concepts.

[6] The 2017-2027 Decadal Survey for Earth Science and Applications from Space (ESAS 2017) is intended to help shape science priorities and guide agency investments into the next decade. The survey, sponsored by NASA, NOAA, and the USGS, is driven by input from the scientific community and policy experts. To read the report, visit *http://sites.nationalacademies.org/DEPS/ESAS2017/index.htm*.

**Frank Avila** [National Geospatial Intelligence Agency (NGA)—*Senior Scientist* and *Landsat Advisory Group (LAG) Chair*] provided an update on the LAG's efforts to evaluate the potential for fee recovery for Landsat data use at the request of the DOI. The LAG provides advice to the federal government through the Department of the Interior's National Geospatial Advisory Committee (NGAC) on requirements, objectives, and actions of the Landsat program. In the past, the LAG has authored several reports on the value of Landsat data (see *www.fgdc.gov/ngac/key-documents*). Currently, the LAG is exploring a variety of cost-sharing models for access to Landsat data in addition to retaining the free and open data policy. Avila mentioned that USGS conducted a study on Landsat users' willingness to pay for data access, including a dollar value assignment per image. This earlier work is being revisited as part of the LAG's fee-recovery evaluation activities. The LAG expects to have a final report on Landsat data-fee recovery recommendations by spring 2019.

After Avila's presentation, the LST discussed Landsat's data policy. An important point that came up was that NASA does not charge for its Earth observation data and thus, if Landsat's current data policy was to change, it would be the only Earth observation data source with an associated access fee. The LST will draft an official position on Landsat's data policy. During the meeting's science presentations, each LST member was asked to address the importance of free and open data for their PI research and for their respective science and application community.

On the second day, **James Reilly** [USGS—*Director*] attended the meeting and took the opportunity to introduce himself to the LST by offering a short biography about his Landsat experience and awareness of its value to Earth Science. LST members had the chance to introduce themselves individually to the Director, noting their institutional affiliations and Landsat areas of expertise.

**Del Jenstrom** and **Brian Sauer** gave a brief update on the status of the Landsat 9 development schedule. Key takeaways were that the launch date has been set for December 15, 2020, and that the final ground system critical design review is scheduled for September 2018.

**Dennis Helder** reported on outcomes from the Landsat Science Interface Panel (SIP) meeting that occurred on August 7, 2018, at CIRES, prior to the LST meeting. The Landsat SIP is intended to improve communication between different elements of the Landsat program by bringing together Landsat cal/val, project science, and a subgroup of LST members to address emergent issues that crosscut cal/val and science domains. The SIP discussed the status of efforts to gain access to the Sentinel-2 global reference image (GRI) to improve Landsat 8's geodetic registration. They also discussed temporal latency challenges for distribution of Landsat 8 TIRS surface temperature products. Currently, two algorithms are under consideration: a single-channel inversion based on model radiative transfer and Modern-Era Retrospective analysis for Research and Applications 2 (MERRA-2) reanalysis data ingest, and a split-window algorithm that exploits Landsat 8 TIRS dual channels centered at 10.8 and 12.0 µm.

**Steve Labahn** [USGS EROS—*Land Satellite Data Systems Manager*] provided a briefing on current plans for Landsat data product improvements as well as preparation for Collection Two processing of the Landsat data archive. It is anticipated that approximately one year after the launch of Landsat 9, there will be a need to reprocess Landsat 9 data to incorporate postlaunch calibration adjustments. While the earliest possible date for Collection Two processing to begin is September 2019, how the timelines for Collection Two processing and Landsat 9 reprocessing align is under consideration. After some discussion, the LST recommended that the timing of Collection Two processing should minimize impacts to the user community while also enabling Landsat data products to evolve and improve.

**Brian Markham** gave an update on Landsat 8 OLI's performance from a cal/val perspective, with an emphasis on cross-calibration results with Sentinel-2 over desert PICS. Currently, Landsat 8 and Sentinel-2A cross-calibration differences are within 1.0% for all VNIR and SWIR spectral bands except blue and coastal aerosol, which are consistent within a PICS site but less so across sites. An initial Sentinel-2A and Sentinel-2B comparison over PICS sites reflect VNIR and SWIR differences around 1% that likely translate to greater differences between Landsat 8 OLI and Sentinel-2B than Sentinel-2A.

**Aaron Gerace** [Rochester Institute of Technology (RIT)] gave an overview of RIT's efforts to compare TIRS single-channel versus split-window algorithms for retrieving surface temperature over both land and coastal water targets. Both algorithms exploit a global emissivity database (GED) comprised of data from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on Terra and Aqua platforms, because ground-reference TIR data are sparse and often measured and integrated over broadband wavelengths that do not necessarily correspond to TIRS relative spectral response functions.

**Benjamin Koetz** [ESA] summarized ESA's current activities related to the Sentinel-2 program. He emphasized future Sentinel mission capabilities and efforts to develop a Landsat Surface Temperature Mission (LSTM) that is currently under consideration by the European Commission and an international advisory panel. He reiterated the importance for having close ties with the USGS-NASA Landsat program, and to continue to work towards data interoperability.

**Jeff Masek** provided a brief overview of NASA's MuSLI program, which is designed to exploit a range of U.S. and international Earth observation data including optical, thermal, and synthetic aperture radar measurements, to advance the remote sensing science of land cover and land-use change across multiple spatial and temporal scales. There is natural overlap between LST and MuSLI expertise, and it is anticipated that these distinct but complementary science teams will interact across a range of forums in the coming years to address key issues surrounding medium-resolution Earth observations from the Landsat-Sentinel virtual constellation.

During the meeting, LST members had the opportunity to give oral science presentations on their ongoing Landsat program contributions for the 2018-2023 term—see **Table 3**.

**Table 3**. Summer Landsat Science Team member presentations.

| LST PI | Presentation Title* |
|---|---|
| Martha Anderson | Use of Landsat Data in Real-Time Irrigation Management—and ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS) Update |
| Feng Gao | Values of High-Temporal and Spatial-Resolution Data for Crop Yield Assessment Over the U.S. Corn Belt Using Landsat, Sentinel-2, and MODIS |
| Noel Gorelick | Driving Cloud-Based Usage of Landsat |
| Matthew Hansen | Large-Area Land Monitoring Enabled by Freely Available, Long-Terrm Global Acquisitions of Landsat Imagery |
| Sean Healey | Landsat as the Wall-to-Wall Phase of a Hierarchical Global Forest Monitoring System |
| Patrick Hostert | Land Use 2.0: The Role of Dense Time Series and Phenometrics *(David Franz presented)* |
| Justin Huntington | Supporting Water and Land Management Through the Combined Use of Landsat, Climate Data, and Hydrologic Models |
| David Johnson | On Using the Landsat Archive to Map Crop-Cover History Across the U.S. |
| Leo Lymburner | Mapping the Mangroves and Intertidal Zones of the Australian Coast |
| Alexei Lyapustin | MAIAC Algorithm Development for Lansat 8/Sentinel-2 Processing: First Results |
| Nima Pahlevan | Global Long-Term Aquatic Studies with Landsat Archive |
| Jean-François Pekel and Peter Strobl | Aspects of Interoperability on Distributed Data Platforms |
| Volker Radeloff | Topographic Correction of Landsat Imagery in the Caucasus Mountains |
| David Roy | Land-Surface Monitoring at Long and Short Timescales |
| Ted Scambos | The Power of Free: Time-Series Landsat 8 Applications to Ice Sheets, Glaciers, and Snow |
| Crystal Schaaf | Landsat Albedo of Higher Latitudes *(Angela Erb presented)* |
| Eric Vermote | Maintenance and Refinement of the LaSRC for Landsats and Sentinel-2s |
| Curtis Woodcock | Time Series, Time Series, and More Time Series |
| Michael Wulder | Quantifying Forest Recovery: Spectral and Structural Insights from Landsat and Lidar Time Series |
| Zhe Zhu | Making Landsat Time Series Consistent for Monitoring Land Change |

*Some presentations were given by a co-investigator on the PI's research team, as indicated.

## Conclusion

The year 2018 brought about several changes to the LST configuration and the Landsat program more broadly, with successful and rapid development of the Landsat 9 mission. A new USGS–NASA LST was selected and announced for the 2018-2023 term in addition to other LST leadership transitions on both the USGS and NASA sides of the Landsat partnership. While the Landsat mission and program is arguably at its most stable point in its five-decade existence, activities in 2018 have opened new frontiers that the LST and Landsat program will need to address specifically across four core areas: Landsat 9 development, launch, and data integration; Landsat 8 and Sentinel-2 data interoperability; Landsat data product evolution and archive reprocessing; and the Landsat 10 architecture study. As always, the USGS–NASA partnership, the Landsat program, and the LST together possess the maturity and resolve to move ahead, with the understanding that measurement continuity and traceability are the most essential ingredients for the next generation of Earth observations from Landsat. ■