Summary of the Final Activities of the 2018–2023 Landsat Science Team

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Introduction

The Landsat Program celebrated its semicentennial on Saturday, July 23, 2022, with events on Capitol Hill and a Senate resolution designating the day as "Landsat 50th Anniversary Day" or **Landsaturday**. The milestone anniversary, which honored five decades of continuous Earth observations from space via a long-running partnership between NASA and the U.S. Geological Survey (USGS), was also commemorated throughout the year at conferences and meetings.[1] Following this landmark celebration, this article presents a highlight of the accomplishments and recent activities of those who have supported the Landsat Program, including the 2018–2023 Landsat Science Team (LST)—see **Photo 1** *below*.

For decades LST has been home to agency scientists and engineers, application specialists, members of industry, university professors, and researchers, who have contributed their scientific and technical expertise to ensure the continued success of the Landsat Program. Members have been pivotal in developing novel research and sound-science applications. The high-quality data and robust calibration standards resulting from their work define Landsat as the multispectral reference standard for terrestrial land observations.

LST members provide the relevant input to address the growing and diverse needs of Landsat data users. Among a wide range of tasks, they are responsible for providing recommendations about the radiometric and geometric quality of data and performance of new remote sensing instruments; defining innovative strategies, algorithms, and science products; and advancing methods for multidecadal and large-area land and aquatic change assessments. The 2018–2023 LST focused on ensuring that data from Landsat 9 was integrated into the Landsat archive and that future Landsat science requirements (e.g., Landsat Next) reflected evolving user needs while maintaining observational continuity with past and current Landsat missions.[2] The 2018–2023 LST also maintained Landsat

[1] See, for example, **NASA Participates in Pecora 22 Symposium and Celebrates Landsat 50th Anniversary**, in the November–December 2022 issue of *The Earth Observer*. [**Volume 34**, **Issue 6**, pp.4–9].

[2] To learn more about Landsat 9 in the context of the broader history of Landsat, see **The Legacy Continues: Landsat 9 Moves Landsat Toward a Golden Milestone**, in the July–August 2021 issue of *The Earth Observer* [**Volume 33**, **Issue 4**, pp. 4–12]. This article references other articles in The Earth Observer that discuss Landsat history.

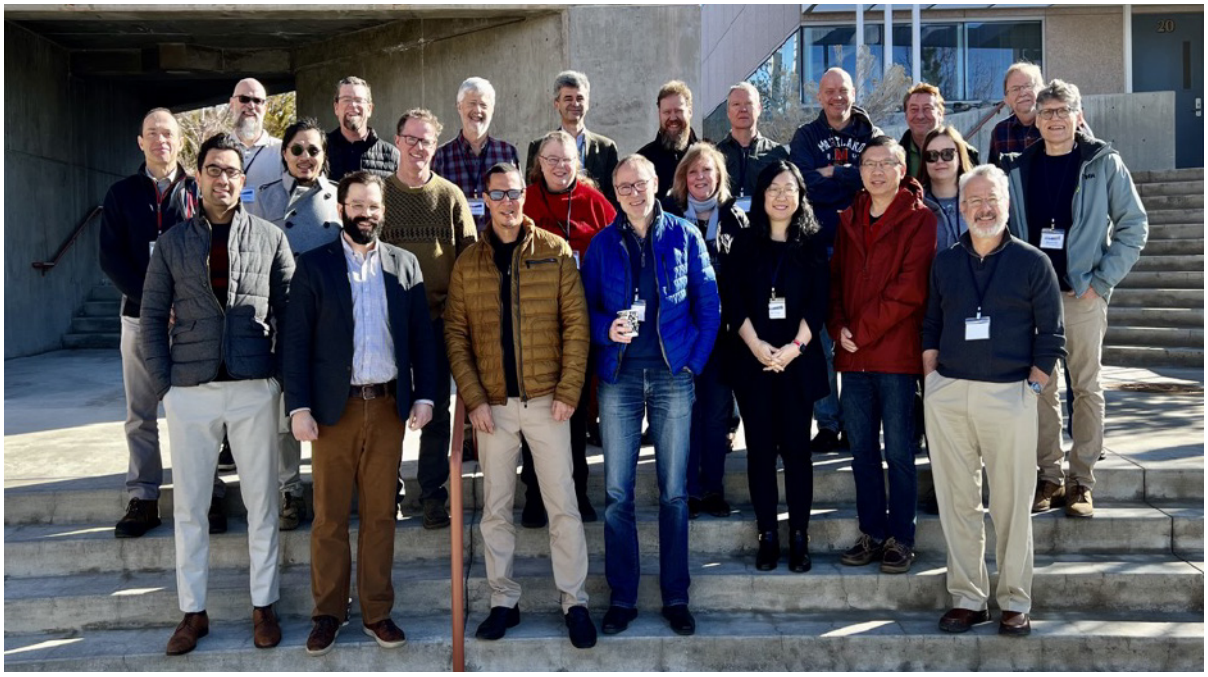

Photo 1. The Landsat Science Team at the 2023 Landsat Science Team Meeting held at the Desert Research Institute (DRI) in Reno, NV. **Photo credit:** Public Doman

compatibility with international and commercial data to enable new applications.

The 2018–2023 LST consisted of two agency cochairs, two academic coleads, and 21 other members. **Jeff Masek** [NASA's Goddard Space Flight Center (GSFC)—*Landsat Project Scientist*] served as the NASA cochair until his retirement in June 2022. **Chris Neigh** [GSFC—*Landsat Project Scientist*] assumed this position in July 2022. **Chris Crawford** [U.S. Geological Survey's Earth Resources Observation and Science (EROS) Center—*Landsat Project Scientist*] served as the USGS cochair. **David Roy** [Michigan State University (MSU)] and **Curtis Woodcock** [Boston University (BU)] served as the academic coleads. A complete list of **2018–2023 LST members** can be found on the Landsat mission website.

From the summer of 2020 to February 2022, the LST moved their biannual meetings to a virtual format due to the COVID-19 pandemic. In-person meetings resumed in August 2022. The remainder of this article provides an overview of the August 2022 and the February 2023 meeting. The article ends with a "Summary of the Final Recommendations of the 2018–2023 LST," on page 42. Meeting agendas, objectives, and presentations can be found at on the **Landsat mission website**.

August 2022 Meeting

The LST met at the USGS EROS Center in Sioux Falls, SD, from August 9–11, 2022, to regroup as the pandemic waned. The goals of this meeting were to honor LST members who had retired or passed away, update the team on Landsat 9 operations since launch, address forthcoming changes to Landsat Collection 2 (C2) Level-2 products, highlight science applications and advancements, and participate in the Landsat 9 Mission Transition Handover.

On the first day of the meeting, **Pete Doucette** [EROS—*Director*] gave opening remarks, acknowledged the original pioneers of the EROS and Landsat programs, and presented an update on EROS staffing and budgets. **Tim Newman** [USGS National Land Imaging (NLI) Program—*Program Coordinator*] reflected upon the fiftieth anniversary of Landsat and the launch of Landsat 9 on September 27, 2021; summarized the operations of Landsat 8; and discussed the status and future of the Sustainable Land Imaging (SLI) Program, including aspects of the updated NASA–Department of Interior (DOI) interagency agreement and plans for Landsat Next.

Chris Crawford joined **Keith Alberts** [EROS] in providing Landsat mission updates. Alberts outlined the status of the three operational missions and provided scene acquisition summaries. Crawford discussed the details of the extended Landsat 7 science mission, noting that Landsat 7 was lowered from 705 km (438 mi) to 697 km (434 mi) on April 6, 2022, and resumed science imaging on May 5, 2022. **Cody Anderson** [EROS] provided calibration and validation updates for data from instruments on Landsat 8 [Operational Land Imager (OLI) and Thermal Infrared Sensor [TIRS] and Landsat 9 [OLI-2 and TIRS-2] and called attention to recent publications about Landsat 9 cross-calibration with Landsat 8 and early on-orbit imaging performance. **Chris Engebretson** [EROS] discussed Landsat 9's initial data processing approach, postlaunch reprocessing events, and future reprocessing needs to incorporate first-year adjustments.

Saeed Arab [EROS/KBR, Inc.] presented details about the upcoming changes to Collection 2, Level-2 (L2) data. He discussed how the end of Moderate Resolution Imaging Spectroradiometer (MODIS) science observations will impact the Landsat 8/9 Land Surface Reflectance Code (LaSRC) Surface Reflectance product.[3] Arab indicated that the Visible Infrared Imaging Radiometer Suite (VIIRS)[4] Climate Modelling Grid (CMG) products can and will serve as an alternative source of ozone and water vapor data. He also referenced the upcoming processing changes to Landsat 8/9 Surface Temperature products as a result of plans to replace the Goddard Earth Observing System (GEOS)-FP IT system with a new system named GEOS-IT.

The first day of the meeting concluded with a celebration of life that recognized the incredible contributions of **John Dwyer** and **Tom Loveland** [both from EROS]. **Dwyer**, who passed away on July 4, 2021, was the former USGS Landsat 8 Project Scientist and Science and Applications Branch Chief at EROS. After 39 years at the EROS, he retired in 2019. He was instrumental in establishing Landsat as an operational program, and he was proactive in increasing the breadth and depth of science applications through the development of the Land Satellites Data System (LSDS) Science Research and Development (LSRD) project team. Dwyer navigated through volumes of data with sophistication and intellect in unprecedented times. **Loveland**, who passed away on May 13, 2022, was the Chief Scientist and a research geographer at EROS—and longtime author of LST summaries for *The Earth Observer*. He dedicated his USGS career of public service to advancing the use of Earth observation data for natural resources management and scientific understanding. He became a globally recognized remote sensing scientist, received

[3] MODIS instruments fly on NASA's Earth Observing System Terra and Aqua platforms. Both mission will end in the next few years and plans are underway for continuity of MODIS data products.

[4] VIIRS instruments fly on the Suomi National Polar-orbiting Platform (Suomi NPP) and on the National Oceanic and Atmospheric Administration's (NOAA) -20 and -21 satellites.

a Pecora Award in 2018, and served as the USGS cochair of the LST from 2006–2018. Together, Dwyer and Loveland were an unmatched force. Their dedication, expertise, and contributions, which will live on in perpetuity, were appreciated and memorialized during the LST celebration.

During the second day of the meeting, several presenters shared their applied science projects and perspectives. For brevity, a few presentations have been selected that might be of particular interest to readers, however a **complete list of presentations** is available. **David Johnson** [USDA National Agriculture Statistics Service] gave a presentation on crop type mapping and discussed the need for and possibility of developing global crop datasets using temporally dense Landsat and Sentinel-2 composites and machine learning. **Noel Gorelick** [Google Switzerland] provided an overview of how the Google Earth Engine has used a decade of Landsat data, underscoring that a large percentage of registered users integrated Landsat data into their scripts and models.

Mike Wulder [Canadian Forest Service] discussed the use of Landsat data to map and monitor Canada's forested ecosystem. He emphasized that Landsat data has the required characteristics to develop high-quality land cover data products, support forest inventories, track disturbances, and generate carbon accounting budgets. **Curtis Woodcock** and his fellow BU researchers presented a framework for developing near real-time tropical forest disturbance models using fused data from multiple sensors, including those from Landsat and from the European Space Agency's Copernicus Sentinel-2 and Sentinel-1 missions.

The August 2022 meeting concluded with the Landsat 9 Mission Transition Handover Ceremony as administrators, EROS employees, scientists, researchers, faculty from South Dakota State University, and representatives from AmericaView and media outlets joined together to celebrate the official commencement of Landsat 9 operations. NASA transferred ownership and operational control of the Earth-observing satellite system to the USGS, and **Pete Doucette** signed the Landsat 9 Certificate of Readiness—see **Photo 2** *below*.

February 2023 Meeting

The 2018–2023 LST met for their final meeting at the Desert Research Institute (DRI) in Reno, NV from February 7–9, 2023. **Justin Huntington** [DRI] hosted the event and gave opening remarks about the history of the research facility and its involvement in managing Nevada's arid land resources. He emphasized the value of Landsat data in solving the hydrologic problems of the Intermountain West and Colorado Plateau through updates to agricultural models and perennial yield estimates.

Tim Newman presented an NLI Program summary, highlighted the Senate resolution (S. Res. 721) that

Photo 2. NASA, DOI, and USGS officials pose with a key symbolizing the longstanding NASA–USGS Landsat partnership's goal of "Unlocking Answers, Revealing Our Changing Earth," after signing the Landsat 9 Certificate of Readiness. They include [*left to right*]: **Mike Egan** [NASA HQ—*Program Executive*], **Cathy Richardson** [NASA GSFC—*Deputy Director for Flight Projects Directorate*], **Pete Doucette** [USGS—*EROS Director*], **Tanya Trujillo** [DOI—*Assistant Secretary for Water and Science*], **Paul TenHaken** [*Mayor of Sioux Falls*], and **David Applegate** [USGS—*Director*]. **Photo credit:** Ginger Butcher/SSAI

celebrated Landsat's Fiftieth anniversary, provided Landsat mission updates, and discussed the SLI Program, including second phase activities and budgets. The Landsat mission updates in the Resolution focused on the extended science mission of Landsat 7, the tenth anniversary of Landsat 8 (February 11, 2023), and the continued operations of Landsat 9. **Mike Egan** [NASA—*Flight Program Executive (FPE)*] discussed the status of Landsat Next and the future phases of the SLI Program, including the need for a new architecture study team and a technological assessment for future Landsat missions.

Pete Doucette presented an update on EROS, including the upcoming fiftieth anniversary of the EROS in August 2023. He also presented an organizational overview and gave an update on funding resources and distributions. In terms of Landsat operations, he discussed the receiver anomaly issues associated with Landsat 8, station keeping and risk mitigation maneuvers, and cloud-hosting solutions for Landsat data.

Saeed Arab and **Tom Maiersperger** [EROS] gave an overview of the known issues associated with Landsat C2, L2 data, including those impacting the quality of Landsat 8/9 Land Surface Reflectance Code (LaSRC), Landsat 4–7 Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) Surface Reflectance, and Landsat 4–9 Surface Temperature. The presenters acknowledged that the USGS is working to fully characterize and document these issues, identify the impacts on final data products, and develop procedures and algorithms to improve data archive processing.

On the second day of the meeting, **Bruce Cook** [GSFC—*Landsat Next Project Scientist*], **Jim Pontius** [NASA GSFC—*Landsat Next Project Manager*], and **Brian Sauer** [EROS—*Landsat Next Project Manager*] presented a comprehensive overview of the Landsat Next mission concept, objectives, and status. The presenters emphasized that the mission will markedly increase scientific performance, employ rigorous calibration techniques, and ensure the sustainability of long-term mission operations. They further outlined important milestones, including the successful completion of the Mission Concept Review, advancement into Phase A, the release of the Landsat Next Instrument Suite (LandIS) Request for Proposal, and upcoming integration and ground system studies. More information is available on the **Landsat Next** website.

Chris Engebretson and **Doug Daniels** [EROS—*Landsat Next Chief Engineer*] provided a summary of the key technical challenges associated with Landsat Next—including increased data volumes and compression techniques, westward tilt trade studies, and high-latitude observational density. They addressed the need to identify an optimal data downlink capacity, compression scheme, and image acquisition strategy during Phase A activities.

Eric Vermote [NASA GSFC] provided an update on atmospheric correction over land, focusing on the validation of the LaSRC algorithm. **Nima Pahlevan** [GSFC/Science Systems and Applications, Inc. (SSAI)] continued with an update on atmospheric correction over water. He highlighted the challenges of aquatic remote sensing and the need for a global multi-mission framework to support validation practices and the development of harmonized aquatic science products. **Zhe Zhu** [University of Connecticut] and **Sergii Skakun** [University of Maryland] discussed cloud detection and masking procedures, including the Function of Mask (Fmask) and Cirrus cloud mask (Cmask) algorithms. They further summarized the results of the Cloud Mask Intercomparison eXercise (CMIX), an international collaborative effort that compares cloud detection algorithms.

Glynn Hulley [NASA/Jet Propulsion Laboratory (JPL)] and **Martha Anderson** [USDA Agriculture Research Service (ARS)] gave an update on the status and issues of Landsat L2 Surface Temperature products, noting that C2 interpolation methods introduce blockiness and emissivity artifacts. They suggested that future processing methods will be able to integrate global emissivity datasets from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) on Terra, the ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station (ECOSTRESS), and the Combined MODIS/ASTER Emissivity over Land (CAMEL), to reduce artifacts and improve coverage in regions with persistent clouds.

At the close of the second day, **Lin Yan** [MSU] identified the need to improve Landsat 1–5 Multispectral Scanner (MSS) data processing to enhance geometric correction. He stressed the value of developing new algorithms to increase the feasibility of including MSS data in the Analysis Ready Data (ARD) products. He explained how an updated transformation (i.e., radial-basis-function) can be employed to increase the percentage of well-registered MSS images. **David Roy** offered some concluding remarks about the need for long-term consistent multi-sensor global ARD products and demonstrated some global Web-Enabled Landsat Data (WELD) ARD prototypes.

On the second evening, at an organized dinner, the LST recognized **Jim Irons** [GSFC—*Director Emeritus Earth Sciences Division*] and **Jeff Masek** for their valuable contributions to the Landsat Program. **Irons**, who retired in 2022, dedicated his career to studying the Earth as an integrated system. Among his many achievements and positions, he served as Landsat 7 Deputy Project Scientist from 1992–1999, Landsat 8 Project Scientist from 1999–2021, and agency cochair

for the 2012–2017 LST. **Masek**, a research scientist with interests in forest dynamics and advanced remote sensing analysis, served as Landsat Data Continuity Mission (LDCM) Deputy Project Scientist from 2001–2010, Landsat 9 Project Scientist from 2010–2022, and colead of the LST from 2018–2022. He also led the LEDAPS project that utilized Landsat data to compile the first 30-m (~98-ft) resolution map of North American forest disturbance.

On the third and final day of the meeting, LST led a discussion about data quality improvements, Landsat Collection 3 priorities, and Landsat Next science requirements. The dialogue consisted of a solid recommendation to rectify C2, L2 Surface Reflectance, and Surface Temperature product issues as well as reprocess Landsat 9 data with the latest calibration coefficients. EROS completed reprocessing of Landsat-9 data in May 2023. The L2 Surface Reflectance and Surface Temperature products will be addressed in the future with Collection 3 (C3). There was another suggestion to align the processing of the Harmonized Landsat Sentinel-2 (HLS) data with Landsat Surface Reflectance improvements and Sentinel-2 updates. For the future C3, several team members encouraged the development of improved cloud detection algorithms and the integration of Landsat MSS into the CONUS/Alaska/Hawaii ARD products.

Final Recommendations of the 2018-2023 LST

As the 2018–2023 LST concluded its work, they recommended prioritizing the following three recommendations to propel the Landsat Program into the future and ensure a high-quality data archive.

Within 6-months. The LST recommended focusing on rectifying issues (i.e., atmospheric overcorrection and emissivity artifacts) with the C2, L2 products.

Within one year. The LST recommended focusing on feasibility investigations, developing decision-making frameworks, and analyzing data quality improvements. These efforts should include two investigations: (1) to evaluate the inclusion of Antarctic regions in the C2, L2 Surface Temperature product and (2) to assess the inclusion of cloud shadow data over water classes to support Cloud Mask algorithm validation. In addition, the LST suggested that a process be outlined when making mid-collection changes. Lastly, the LST encouraged a formal policy discussion about the use of *golden tiles*—locations that represent the range of atmospheric and surface conditions that can be used to evaluate land and aquatic science products and quantify data discrepancies between Landsat collections.

Beyond one year. The LST recommended a focus on data quality enhancements and research and development activities. In addition, MSS in ARD data processing should be included and the cloud and atmospheric correction algorithms through international collaborations (e.g., CMIX) refined. Myriad research and development activities were recommended for C3 to address needs, priorities, and improvements. Specific activities should evaluate adjacency corrections; atmospheric correction over inland and coastal waters; cloud and cloud shadow detection; geodetic accuracy criterion; topographic correction using the Copernicus DEM (COP-DEM); Landsat global ARD; and *bidirectional reflectance distribution function* (BRDF)[5] minimization. One final recommendation was made to develop two *Landsat Next datasets*—a proxy dataset based on satellite data and simulated dataset based on modeling—to support Landsat Next science algorithm development and code for processing data.

Conclusion

The LST meetings provide a public forum for discussing the state and future of the Landsat Program. With over 50 years of Earth observations, the Landsat data archive provides the most comprehensive and continuous record of terrestrial land, coastal, and aquatic monitoring data. It serves as an indispensable medium-resolution, Earth-observation resource for evaluating human impacts and environmental changes. With Landsat Next planning and formulation underway, the Landsat Program will march toward a new era of remote sensing through innovative technologies and expanded observational capabilities. ■

[5] The *bidirectional reflectance distribution function* (BRDF) defines how light is reflected at an opaque surface. In remote sensing it's used for correction of view and illumination angle effects (e.g., in image standardization and mosaicking), for deriving albedo, for land cover classification, for cloud detection, and for atmospheric correction.