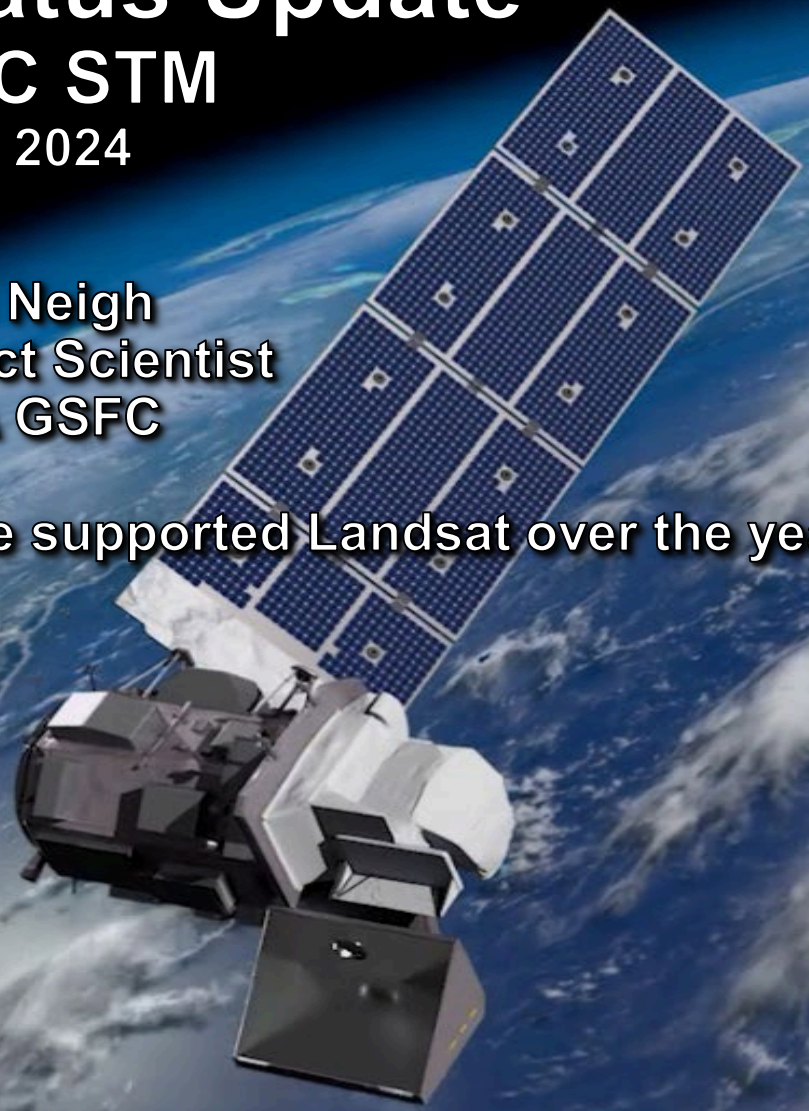
Landsat Status Update

LCLUC STM

April 2024

Chris Neigh
L8/9 Project Scientist
NASA GSFC

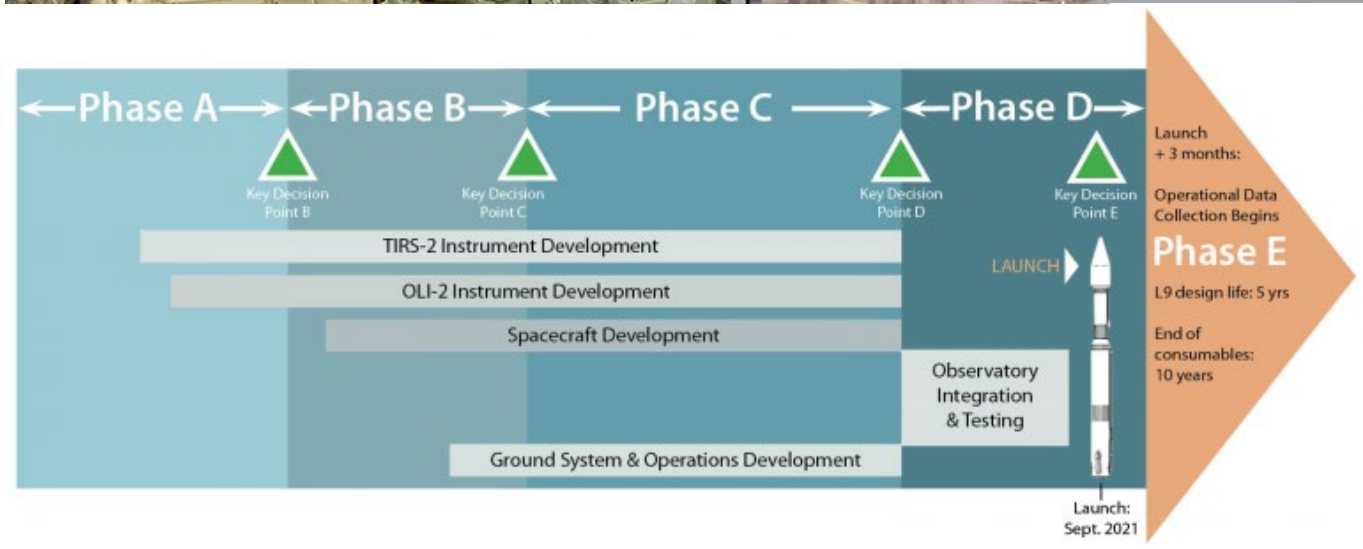
+ many, many other people who have supported Landsat over the years…



Landsat 9 Overview

L9 OLI-2 7/24/22
https://landsat.visibleearth.nasa.gov/

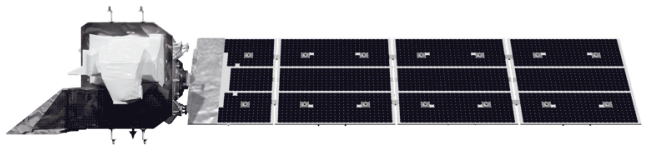
Under budget and ahead of schedule!



https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-mission-details/

Level 1 Requirements Overview

Science Requirements



- 5-year mission life
- Seasonal coverage of global land mass
- Heritage Landsat 4-8 orbit (705 km)
- Image anywhere once every 16 days
- Simultaneously collect images for 9 reflective spectral bands (15/30m), and 2 thermal infrared bands (120m)
- Produce and distribute Level 1 data products:
    - orthorectified, band-to-band registration
    - at-aperture spectral radiance uncertainty of <5% (reflective) or <2% (thermal IR)

Mission Data Requirements

- Operate to collect and archive at least 400 scenes per day, with no changes that would preclude heritage Landsat 8 collection rate (740 scenes/day).
- Generate and distribute at least 400 Level 1 data products per day
- Nondiscriminatory access to Landsat 9 data
- Publicly release data processing algorithms
- Support a Landsat Science Team

Mission & Spacecraft Performance

- Category 1 Project, Risk Category B mission
- 5 year on-orbit spacecraft design life
- 10 years of consumables, reserves for controlled reentry

Launch Requirements

- Risk Category 3 expendable launch vehicle

Education and Public Outreach

- Prepare and execute Public Outreach Plan

All L9 Level 1 Requirements have been met and exceeded

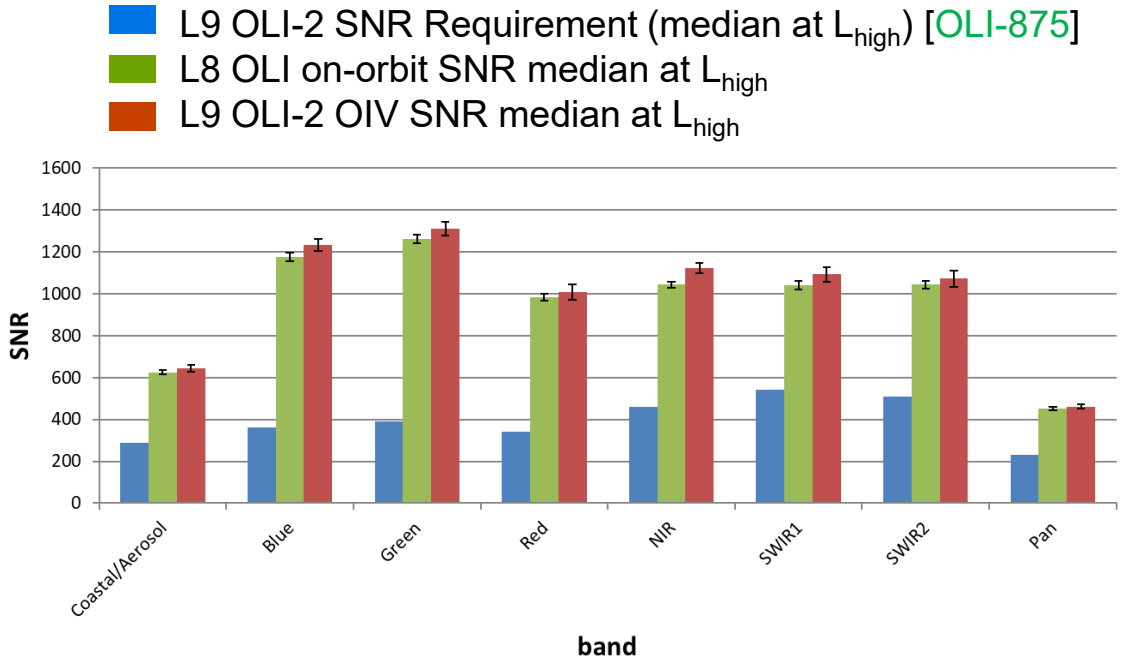
Science Benefits of Landsat 9 over 8

- **OLI-2 data transmitted as 14-bits (vs. 12-bits for Landsat 8)**
  - SNR for dark targets improved by 25-30%
  - Provides more accurate aquatic reflectance, and improved water quality & coastal ocean color products
  - Potential additional benefits for dark vegetation pigments
- **TIRS stray light problems mitigated**
  - More accurate atmospheric corrections become feasible via split window techniques using both channels
- **Two observatories with "state of the art" radiometry providing data every 8-days**

OLI and OLI-2 SNR Performance

#	Band	SNR Requirement@ $L_{Typical}$	Typical Radiance Level, $L_{Typical}$	L8 OLI SNR (12 bit) Median Performance	L9 OLI-2 SNR (14 bit) Median Performance
1	Coastal Aerosol	130	40	232	263
2	Blue	130	40	355	442
3	Green	100	30	296	366
4	Red	90	22	222	268
5	NIR	90	14	199	249
6	SWIR 1	100	4	261	314
7	SWIR 2	100	1.7	326	367
8	Pan	80	23	145	162
9	Cirrus	50	6	162	173

OLI-2 Signal to Noise Ratio (SNR) Requirements and Performance. Requirements were exceeded by ~2-3×. Both instruments have 14 bit A/D converters and have similar performance when all 14 bits are used. Landsat 8 downlinks 12 bits and Landsat 9 downlinks 14 bits giving transmitted OLI-2 data higher SNR.



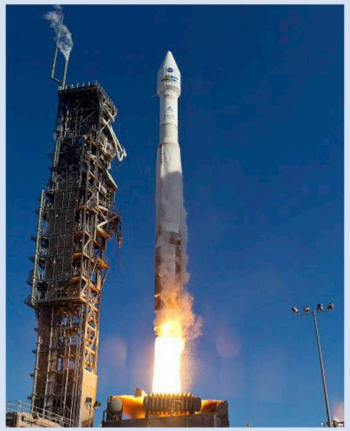
OLI-2 SNR 2-3x better than requirement.
16-day radiometric stability 5x better than requirements

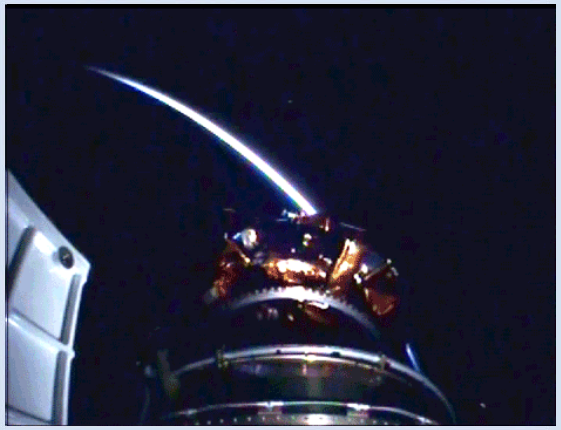
Masek, J. G.; Wulder, M. A.; Markham, B.; McCorkel, J.; Crawford, C. J.; Storey, J.; Jenstrom, D. T. Landsat 9: Empowering Open Science and Applications through Continuity. *Remote Sensing of Environment* **2020**, *248*, 111968. https://doi.org/10.1016/j.rse.2020.111968.


Landsat Mission Overview

The Landsat 9 Project is jointly managed by NASA & USGS

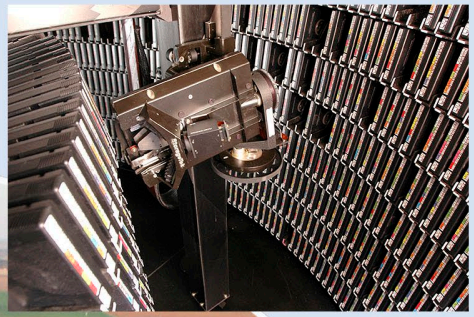
NASA builds, launches, and performs on-orbit checkout





Landsat 8 integration, launch, and separation from rocket

USGS manages the ground stations, conducts mission operations, and processes and distributes the data



BUILDING ON THE LANDSAT LEGACY

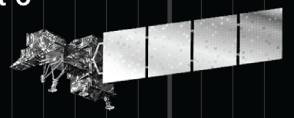
Landsat 4
1982 - 1993
MSS/TM

Landsat 1
1972 - 1978
MSS

Landsat 5
1984 - 2013
MSS/TM

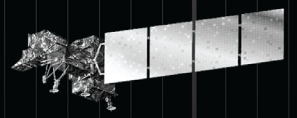
Landsat 2
1975 - 1982
MSS

Landsat 6
1993
ETM

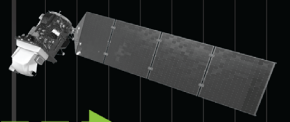


Landsat 3
1978 - 1983
MSS

Landsat 7
1999 - 2024
ETM+

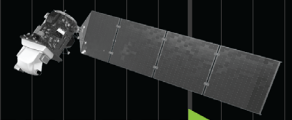


Landsat Next
2030 -



Landsat 9
2021 -
OLI-2/TIRS-2

Landsat 9
Collecting >700 new scenes per day.



Landsat 8
2013 -
OLI/TIRS

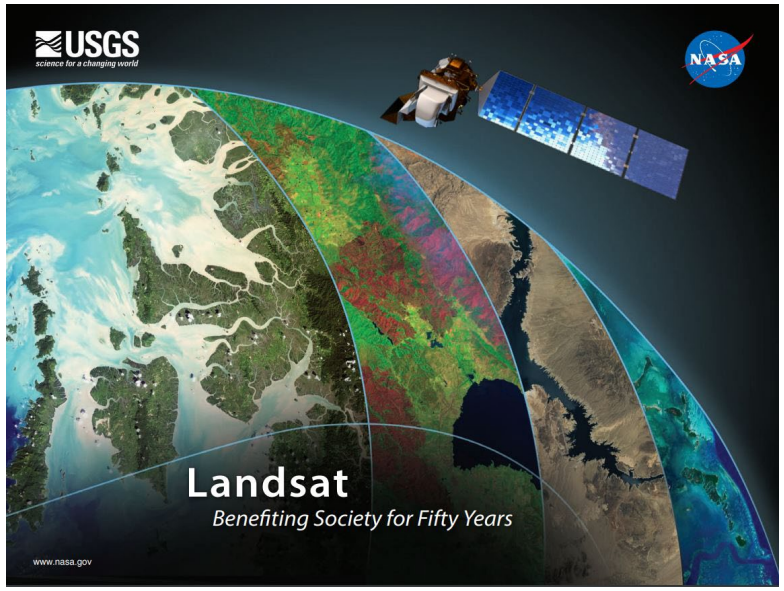
Landsat 8
Collecting >700 new scenes per day.

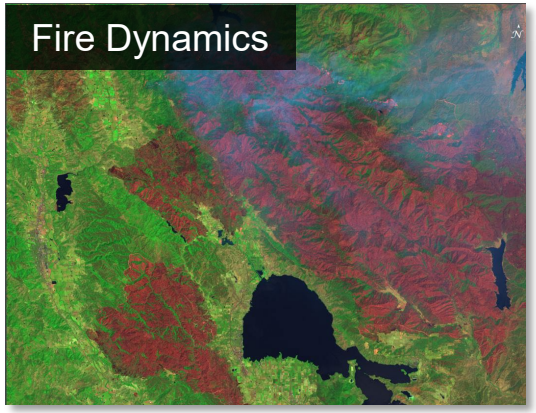
Landsat 7
Collected >400 scenes per day in extended mission ops, currently in storage orbit.

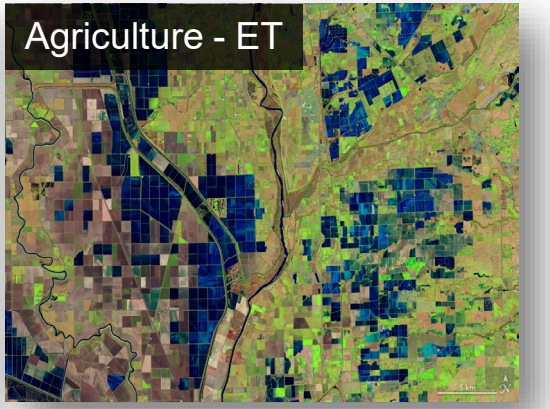
1970 1980 1990 2000 2010 2020 2030 2040

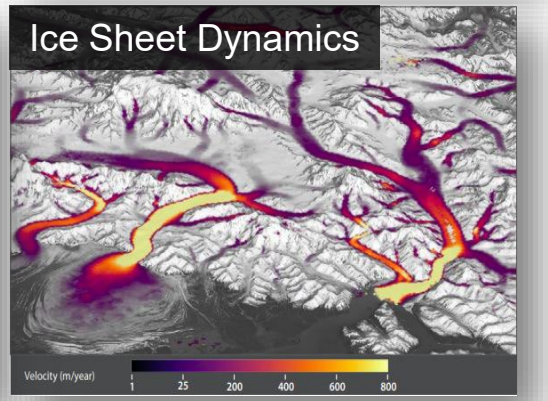
Landsat Applications and Societal Benefits

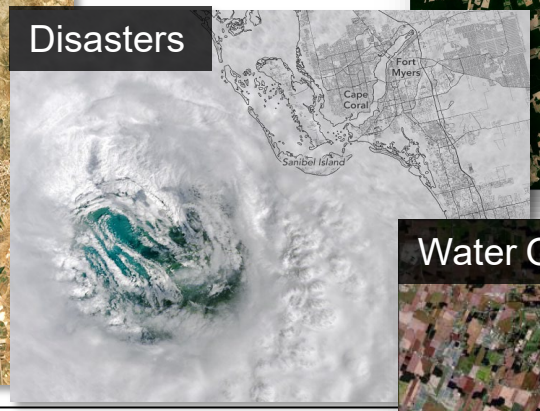
Landsat provides 50+ years of multispectral imagery supporting key science and societal benefit areas:











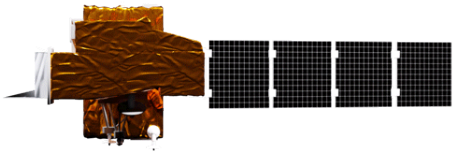
+ many more

https://landsat.gsfc.nasa.gov/benefits/


Landsat 7 Status

Landsat 7 Operations History

From Tom Cooke: Lead Ops/System Engineer Landsat 7; USGS/KBR/NASA Goddard Space Flight Center



- L7 has taken >2.8 million images of the Earth and safely deposited them into the global Landsat archive.
- L7 was running at approximately *450* scenes/day and downlinking them to sites around the world.
- The Flight Ops Team has conducted 244 orbit maintenance burns to control the orbit height/period, and 20 delta-inclination burns to control the orbit inclination and equatorial crossing time.
- L7 has suffered a few component issues but considering its advanced age >24 (Launched 4/15/99), it has held up extremely well.

-2002; Solar array circuit #14 failed. In 2008, it began producing power again!

-2003; Instrument (ETM+) scan line corrector failed.

-2004; Gyro #3 was shut off due to a sharp rise in output noise and a negative impact to the performance of gyros #1 and #2.

-2004; Primary fuel line heater failure.

-2005; Solar array circuit #6 failed.

-2007; ETM+ was placed into “Bumper mode” in response to wearing on the primary mirror turn-around spring bumpers.

-2013; Redundant fuel line heater failure. The team has a plan in place, to partially operate the failed heaters to keep the fuel lines in a safe thermal range.

-2014; The Remote Telemetry and Command box (RTC) autonomously failed from side A to side B.

-2014; A clock generator circuit in the power system autonomously failed over from the prime circuit to the redundant circuit.

-2019; calibration lamp #1 in the ETM+ failed, and a switch to lamp #2 was made.

-1999-2021; The solid-state recorder experienced anomalies ranging from memory boards shutting off to the controller locking up. These issues have caused a loss of science data at the time of the problem, but the FOT has always been able to recover the recorder to a functioning state, with minimal impact to long-term science objectives (Aside from slightly less storage space). The team has a plan in place, should it be needed, to recover some of the de-powered memory boards.

L7 Current Status and Orbit

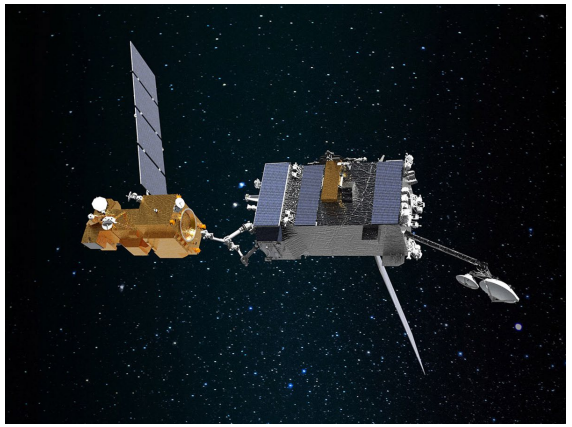
From Tom Cooke: Lead Ops/System Engineer Landsat 7; USGS/KBR/NASA Goddard Space Flight Center

During the first week of April 2022, L7 took a series of retrograde burns lowering L7 into a new orbit.

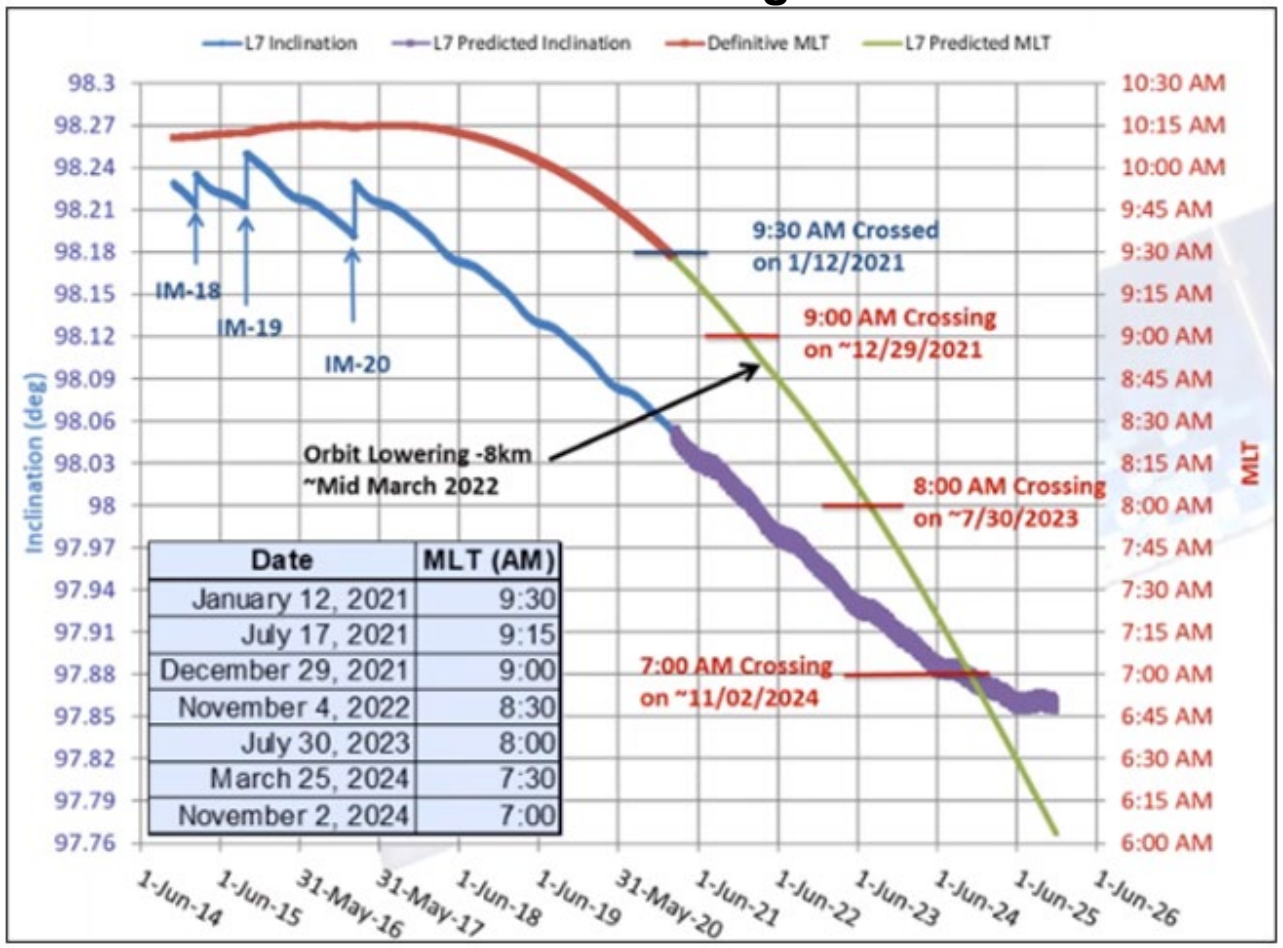
The new orbit was to support L7 extended mission operations:

L7 in preparation for supporting the OSAM-1 mission. OSAM-1 is a technology demonstration mission being developed by NASA, scheduled for launch in 2026. One of the OSAM-1 objectives is to rendezvous and dock with another spacecraft (in this case, L7), transfer fuel to the client spacecraft, and then release it.

- The L7 Flight Operations Team (FOT) has worked with the OSAM-1 team for several years now helping with information transfer, and operations development.
- Transition operations, sunline slewing, RF performance while in safe-hold, and many other aspects of the operation will be vetted during the test.



L7 MLT and b Angle



Date	MLT (AM)
January 12, 2021	9:30
July 17, 2021	9:15
December 29, 2021	9:00
November 4, 2022	8:30
July 30, 2023	8:00
March 25, 2024	7:30
November 2, 2024	7:00

https://www.usgs.gov/landsat-missions/landsat-7

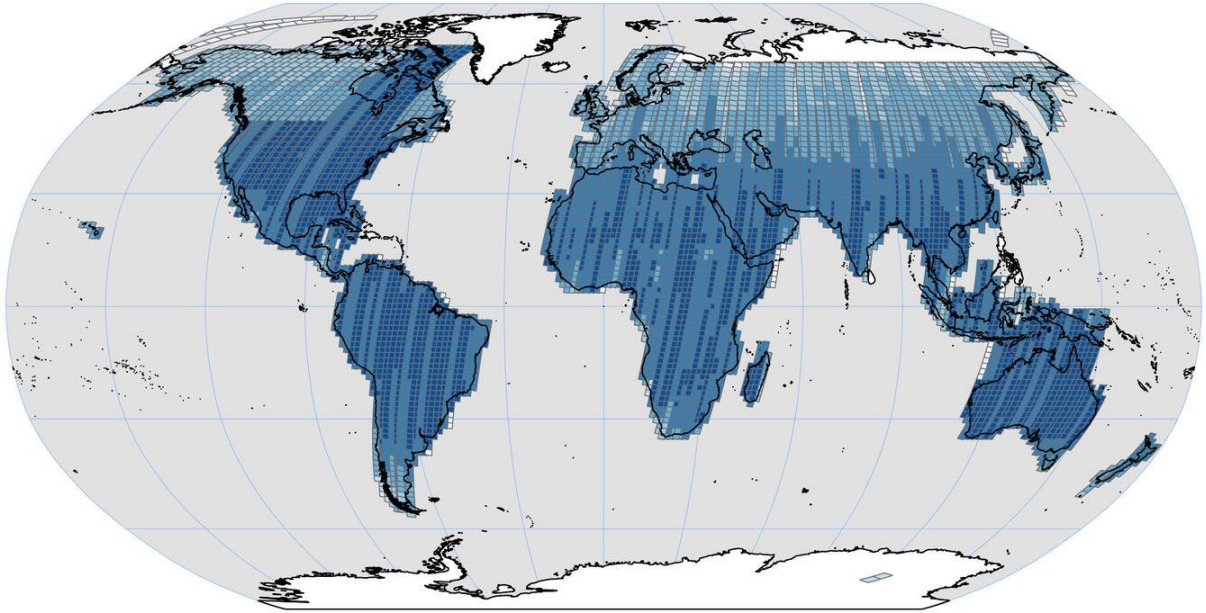
Landsat 7 Extended Science Mission

Landsat 7 satellite was lowered from the standard 705 kilometers (km) orbit to 697 km in April of 2022.

In the lower orbit, Landsat 7 is no longer on a repeating ground track, and data acquisitions were not aligned to the World Reference System-2 (WRS-2) used by Landsat 8 and Landsat 9. Additionally, Landsat 7 acquisition footprints have continually shifted in relation to the WRS-2 grid.

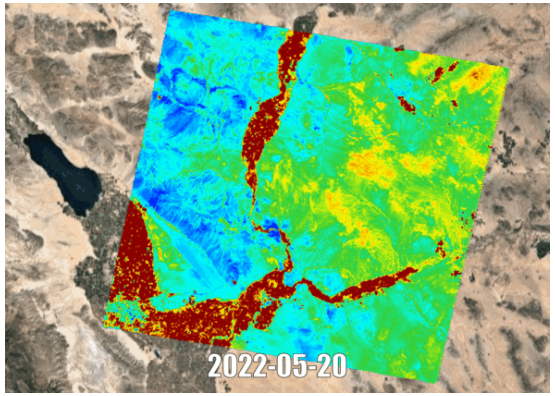
https://www.usgs.gov/landsat-missions/landsat-7-extended-science-mission

The ETM+ acquired about 450 images per day. Landsat 7 added over 175,000 scenes to the USGS Landsat archive from May 5, 2022 to January 19, 2024.



Landsat 7 Extended Science Mission Scenes
5 May 2022 - 19 January 2024

1 - 8 | 9 - 15 | 16 - 22 | 23 - 29 | 30 - 36 | 37 - 44




Landsat Science

Landsat Collection 2 Publication

Science of Remote Sensing
Volume 8, December 2023, 100103

The 50-year Landsat collection 2 archive

Table 1.

Improved absolute geolocation accuracy using Landsat 8 Operational Land Imager (OLI) harmonized with European Space Agency (ESA) Global Reference Image (GRI) (Section 3.1)
New Digital Elevation Model (DEM) used for orthorectification with improved vertical accuracy (Section 3.1)
Improved radiometric calibration particularly for Landsat 5 and 8 (Section 3.2)
Inclusion of Landsat 9 observations (Section 3.2)
Global coverage Level 2 Surface Reflectance (Section 3.3) and Surface Temperature (Section 3.4) Landsat 4–9 products
Expanded Quality Assessment (QA) bits for Landsat 4–9 (Section 3.5)
Consistent bit design between Level 1 and Level 2 (Section 3.6)
Inclusion of per-pixel solar illumination and sensor viewing geometry (Section 3.6)
Expanded U.S. Analysis Ready Data (ARD) tile grid to cover more of the Aleutian Islands, Great Lakes, and certain coastal regions (Section 3.7)
Improved latency between acquisition and availability of Landsat 8 products (Section 4)
Direct Landsat access and analysis via commercial cloud (Section 4)

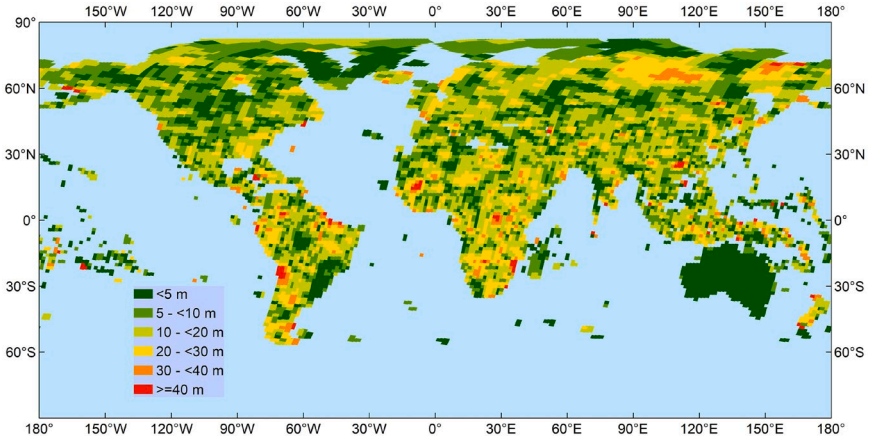


Fig. 1. Landsat WRS-2 path/row geolocation differences between the Collection 1 and Collection 2 Level 1 data products. The root-mean-square difference (RMSD) defined at each path/row are shown for Landsat 4–8.

Crawford, C. J.; Roy, D. P.; Arab, S.; et al. The 50-Year Landsat Collection 2 Archive. *Science of Remote Sensing* **2023**, *8*, 100103. https://doi.org/10.1016/j.srs.2023.100103.

Landsat Science Team 2018-2023

USGS Funded: Currently Landsat does not have a Science Team, the prior teams funding ended in June 2023.

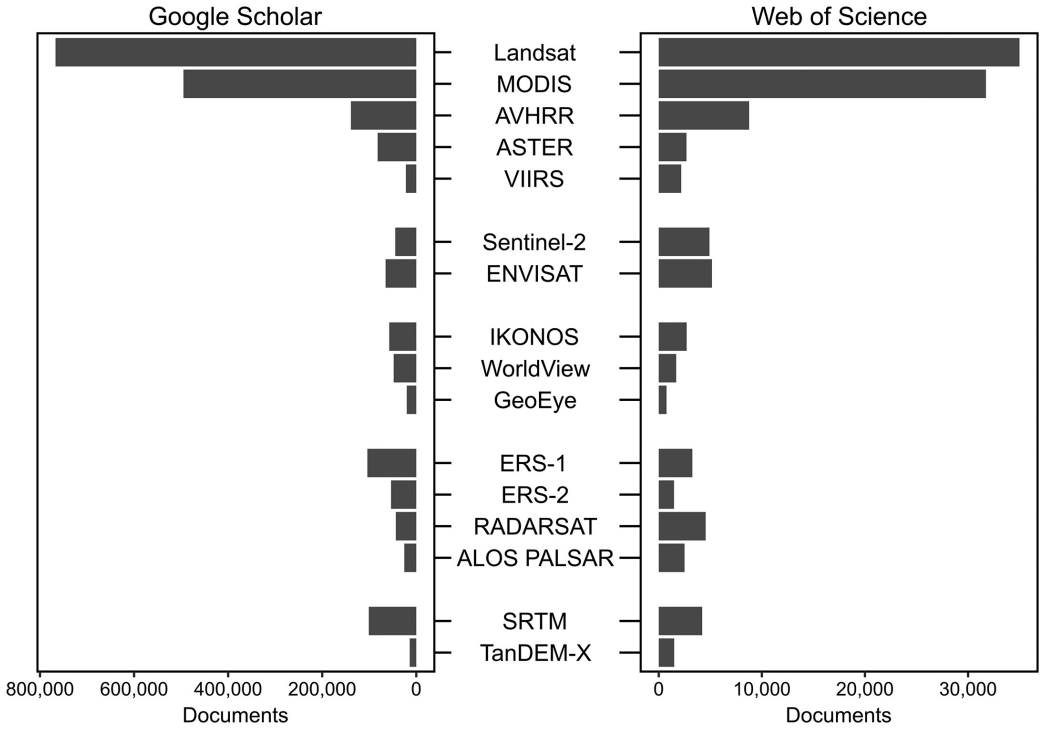
Summary of long-term recommendations from the final meeting

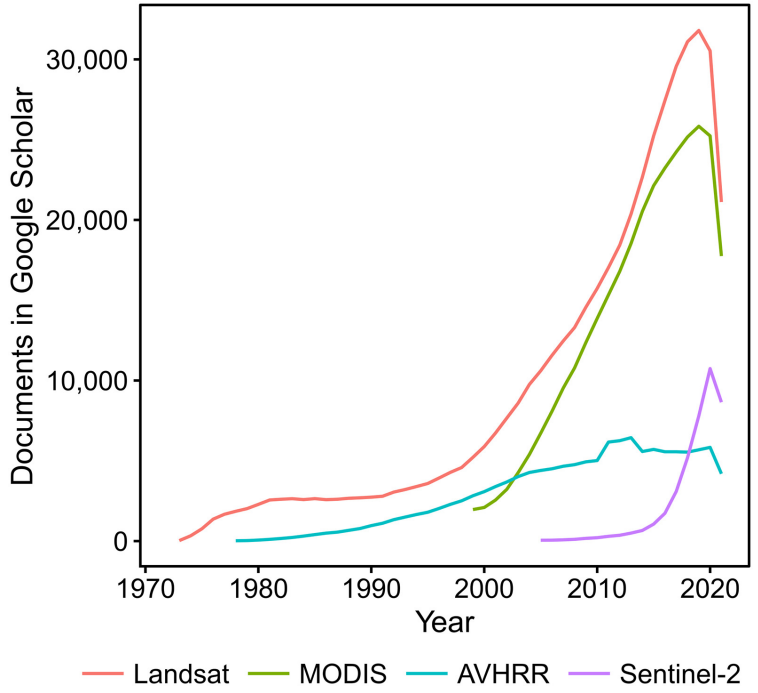
Desert Research Institute, Reno, NV, February 7-9, 2023:

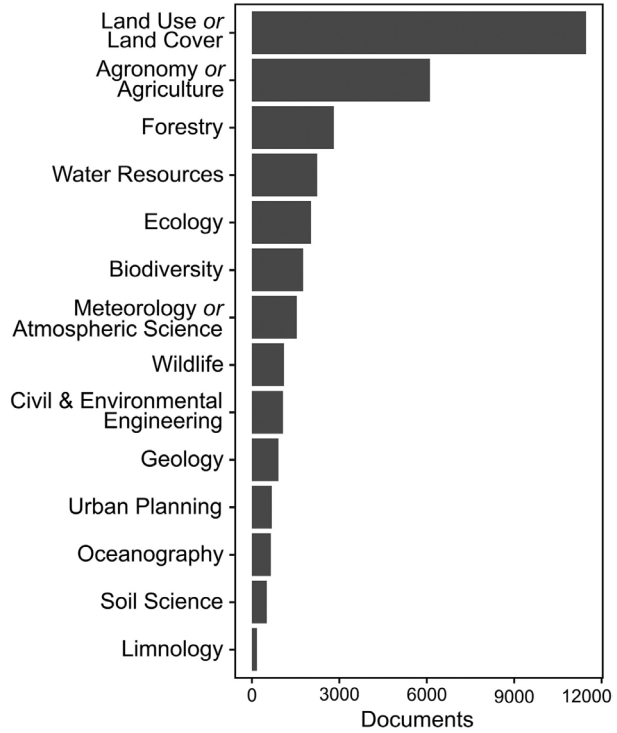
- Encourage long term archiving of all collections and input data at “golden tiles” – including preservation of the L0 and ancillary data – for long term science traceability/provenance.
- Bring MSS into the CONUS/Alaska/Hawaii ARD processing
- Consider ACIX and CMIX exercise outcomes to help guide future Landsat cloud and atmospheric correction algorithms.
- Include per-pixel uncertainty (defined in SI Units and not quantized into categorical classes) in future land surface reflectance and land surface temperature products.
- Include AOD (defined as a real number and not quantized into categorical classes) in future land surface reflectance products.
- Consider a mechanism for more open communication and harmonization of Landsat and ESA Sentinel-2 reprocessing concepts and schedules.
- Collection 3 R&D:
    - Land surface reflectance adjacency correction
    - Atmospheric correction of reflectance over inland and coastal water
    - Improve cloud and cloud shadow detection
    - Examine the impact of reducing the Tier-1 12m Root Mean Square Error (RMSE) geodetic accuracy criterion
    - Topographic correction of land surface reflectance and surface temperature
    - Global ARD
    - BRDF minimization – NBAR – should be invertible
    - Development of both LNext proxy (based on satellite data) and simulated (based on modelling e.g., DIRSIG) data sets to support LNext science algorithm development and code processing testing and feasibility studies

Neigh, C.S.R.; Crawford, C.J.; and McGinty E. (2023) Summary of the Final Activities of the 2018-2023 Landsat Science Team. *The Earth Observer*, **35** (5), 38-42. https://eospso.nasa.gov/earthobserver/sep-oct-2023

What has been the Impact of Landsat on Science?





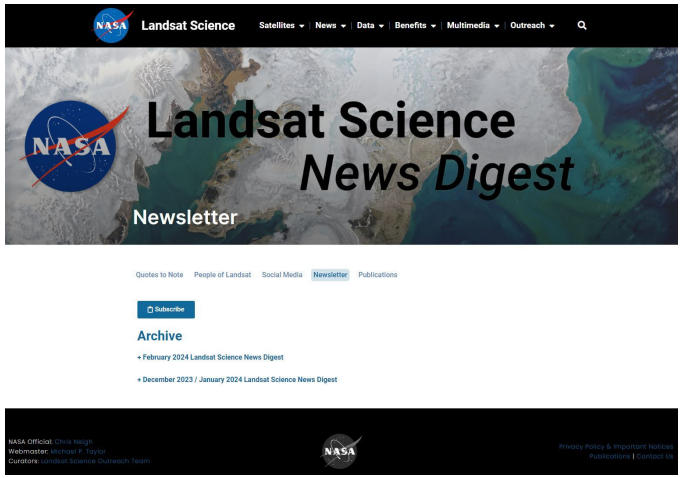


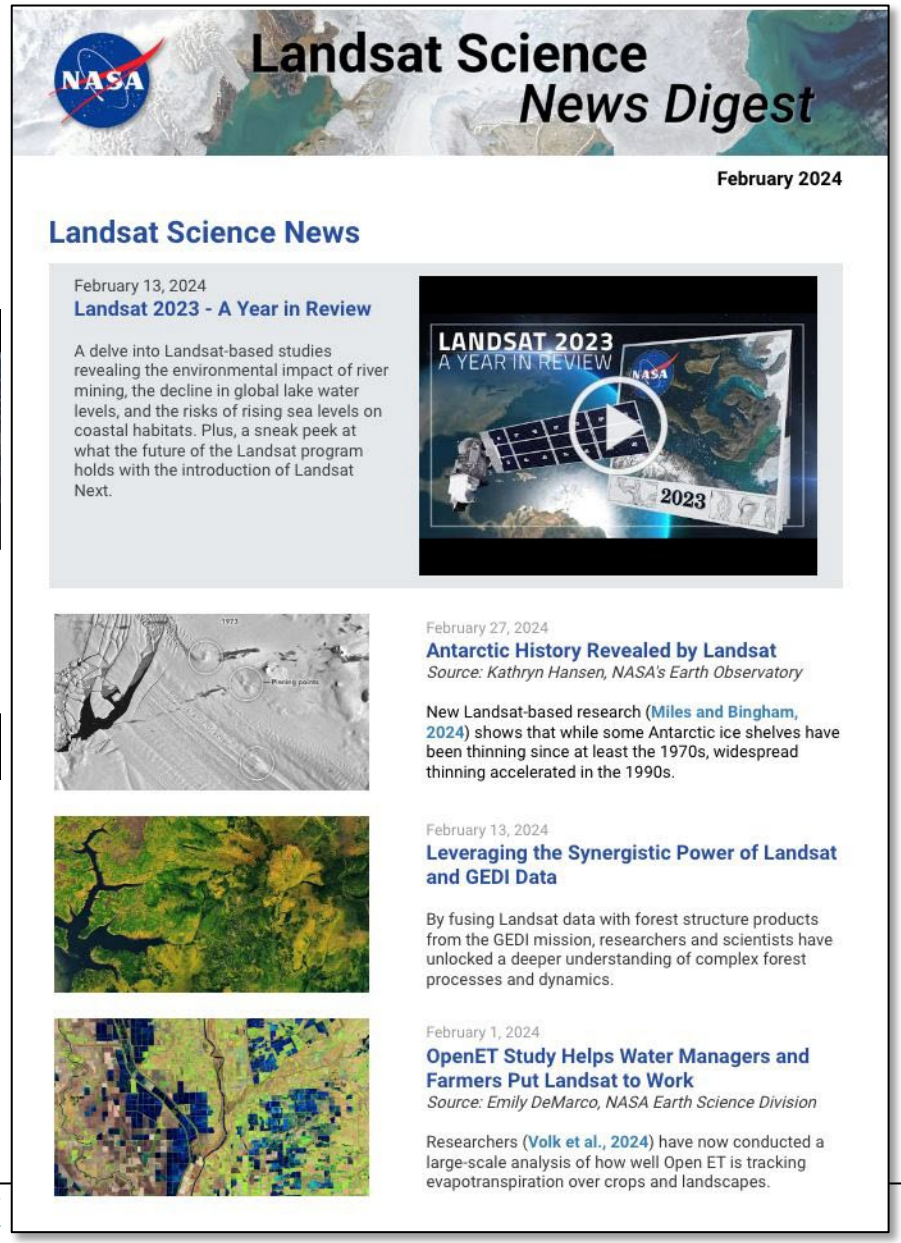
>1,600 Peer reviewed Landsat publications per year.

Wulder, M. A.; et al. Fifty Years of Landsat Science and Impacts. *Remote Sensing of Environment* **2022**, *280*, 113195. https://doi.org/10.1016/j.rse.2022.113195.


Landsat Communications
and Public Outreach

Landsat Science News Digest





Summary of the newsletter sections:

Any news articles published to our website during the given month.

NASA Earth Observatory: Select Landsat Images from the given month. Picked at team's discretion based on what is compelling both story-wise and visually.

Reaching Out: Any outreach briefs published to our site for the given month.

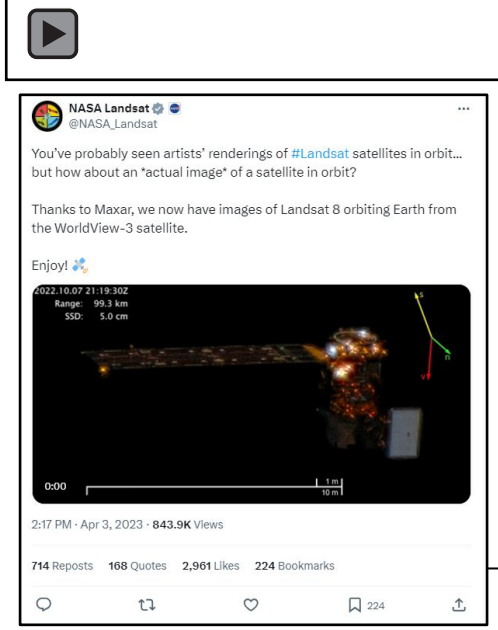
Publication Spotlight: A Landsat-based journal article selected by (L8/9 Project Scientist).

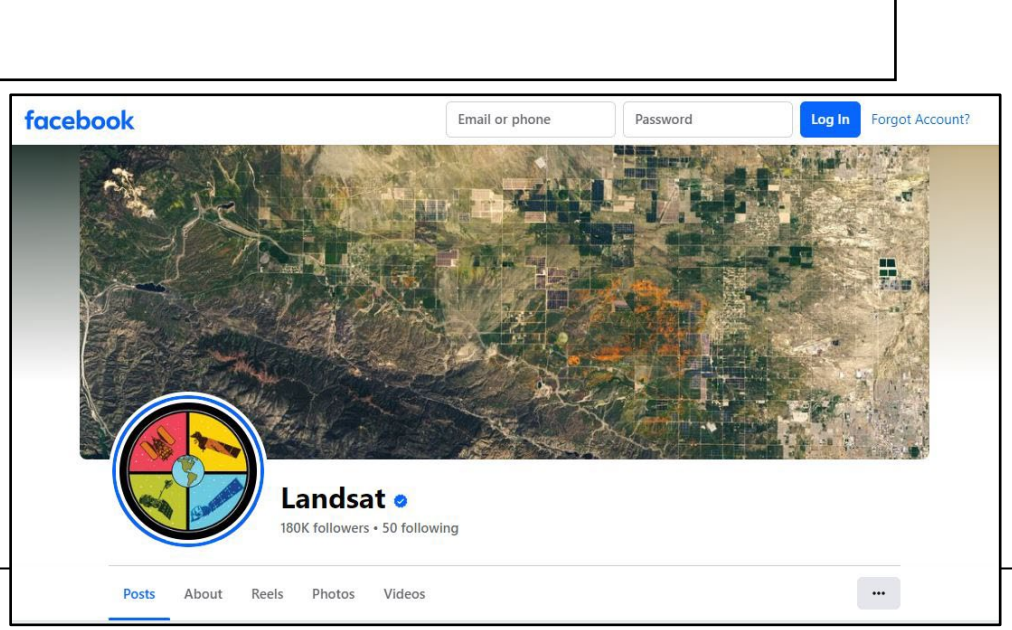
Upcoming Outreach Events: Any outreach activities (or meetings) coming up in next month or two.

In Case You Missed It: Anything else interesting from the month that doesn't fit into above sections.

https://landsat.gsfc.nasa.gov/news/newsletter/

Landsat Communications Outreach – Social Media





Have you seen an actual image of an orbiting satellite before?

On October 7, 2022, Maxar's WorldView-3 satellite snapped this sequence of images showing Landsat 8 in orbit. The distance between the satellites ranges from between 91.4 to 129.9 km (56.8 to 80.7 miles). The orientation arrows provide Sun, Nadir, and Velocity information. The resolution of the Landsat 8 images in this sequence varies from 4.6 to 6.5 cm (SSD stands for Space Sample Distance).

After Maxar's WorldView-2 satellite was hit by a non-tracked piece of space debris in 2016, Maxar used another one of its satellites to image WorldView-2 and assess the amount of damage—it was minimal. With the density of satellites and space debris both growing, Maxar realized that other commercial and government satellite operators may also need similar satellite imaging services for better space domain awareness. This technology could help identify space objects, assess on-orbit collision risks, aid satellite maneuver planning, and monitoring of end-of-life deorbiting and deactivated satellites.

As of December 2021, Maxar holds a license for non-Earth imaging (NEI) of Low Earth Orbit (LEO) satellites. The Landsat 8 images were taken as a demonstration of this technology.

https://landsat.gsfc.nasa.gov/article/satellite-sees-satellite-landsat-8-in-orbit/

Landsat Communications and Public Outreach

nature

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nature › articles › article

Article | Published: 23 August 2023

A global rise in alluvial mining increases sediment load in tropical rivers

Evan N. Dethier ✉, Miles Silman, Jimena Díaz Leiva, Sarra Alqahtani, Luis E. Fernandez, Paúl Pauca, Seda Çamalan, Peter Tomhave, Francis J. Magilligan, Carl E. Renshaw & David A. Lutz

Nature **620**, 787–793 (2023) | Cite this article

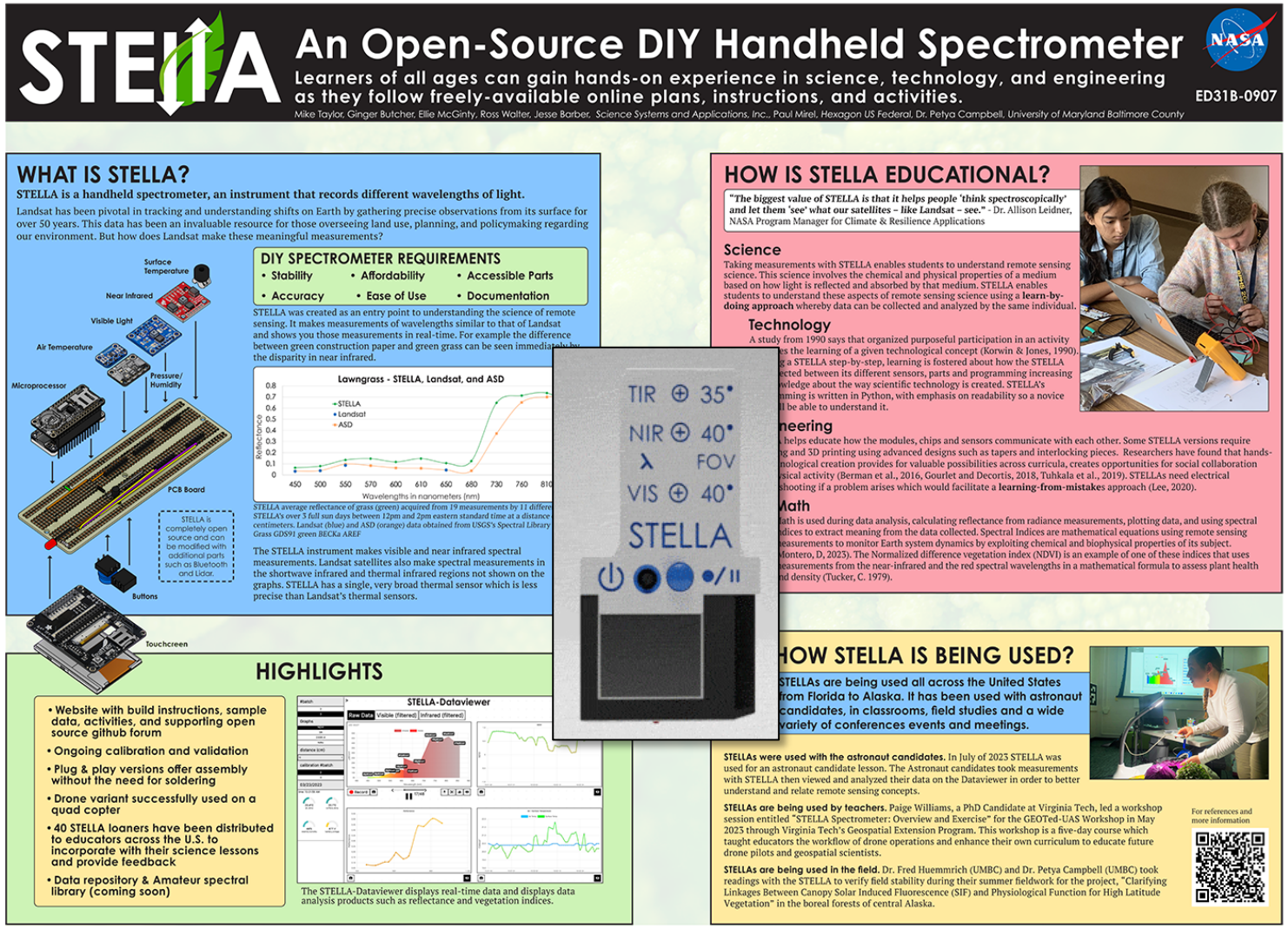
4514 Accesses | **5** Citations | **297** Altmetric | Metrics

Example of LCLUC research communicated through Landsat Communications Team to the public:

Landsat Staff Producer/Videographer: Chris Burns – Translates LCLUC research to be consumed by the masses
https://www.youtube.com/watch?v=xMEUC77xcMo

DIY Spectrometer - STELLA

STELLA (Science and Technology Education for Land/Life Assessment):
A portable low-cost do-it-yourself (DIY) instrument that support science education and outreach through scientific engagement and inquiry.



https://landsat.gsfc.nasa.gov/stella/

"It's a very nice engagement tool – more than just images, it gets into the quantitative aspect of satellite data. It provides insight into the scientific process – how to think analytically. It also provides teachable moments about uncertainty in measurements – and appreciation of calibration and validation of NASA data."

Summer 2023 - Astronaut candidates test STELLA devices outside during a hands-on activity in an Earth science class intended to lend a more personal perspective on how satellites operate. Credits: NASA / Allison Leidner


Landsat Cal/Val

Landsat 9 Calibration and Validation Team

NASA/GSFC

- Kurtis Thome Co-Lead *
- Brian Markham Co-Lead **
- Ed Kaita/SSAI Lead
- Julia Barsi/SSAI (GLAMR Test Lead)
- Libo Ding/SSAI *
- Lawrence Ong/SSAI **
- Raviv Levy/SSAI
- Jeff Miller/KBR
- Phil Dabney/Instrument Scientist
- Jeffrey Pedelty Ball/NGSS on-site rep

USGS/EROS

- Cody Anderson Co-Lead (radiometry)
- Michael Choate Co-Lead (geometry)*
- Jim Storey - Geometry Lead ** (on call)
- Esad Micijevic/KBR
- Obaidul Haque/KBR
- Pat Scaramuzza/KBR
- Alex Denevan/KBR
- ECCOE Vic Cal Team

VENDORS/PROVIDERS

- OLI-2 – Ball Leads
  - Geir Kvaran (Radiometry Lead)
  - Kip Gwin (Geometry Lead)
- TIRS-2 – GSFC Leads
  - Joel McCorkel (Calibration Lead/GLAMR)

UNIVERSITY GRANTS/GOV'T COLABORATORS

- Rochester Institute of Technology-Leads
  - Matt Montanaro (TIRS-2 and CVT)
  - Aaron Gerace (vicarious cal and Level 2 Val)
- University of Arizona - Leads
  - Stuart Biggar (Ball OLI-2)
  - Jeff Czapla-Myers (Vicarious cal and Level 2 Val)
- South Dakota State University- Leads
  - Larry Leigh * (Vicarious cal and Level 2 Val)
  - Dennis Helder **
- NASA/JPL-Lead
  - Simon Hook (Vicarious cal and Level 2 Val)

LDCM/L8 pre-launch/commissioning heritage

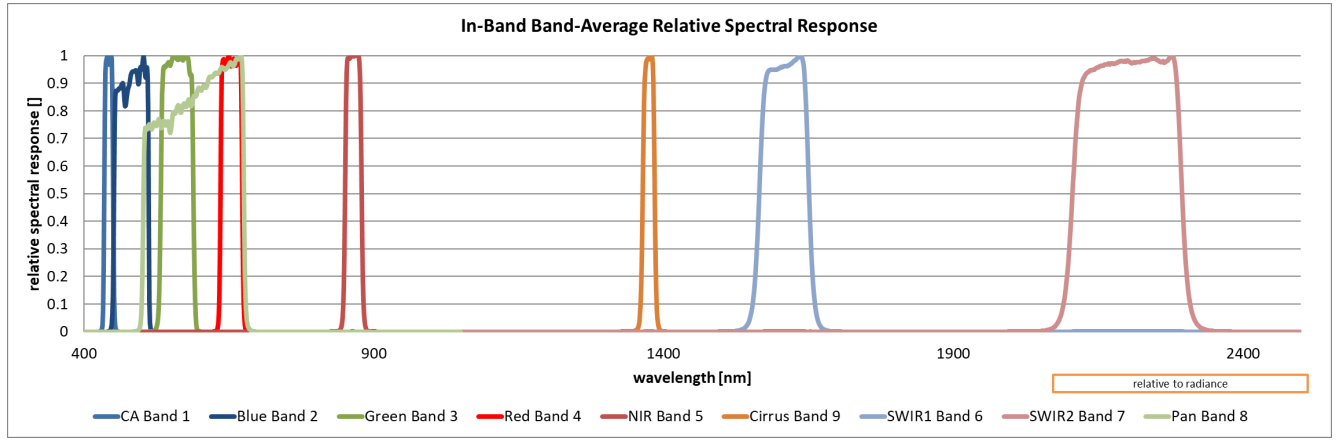
- * Succession replacements
- ** Retired or part-time

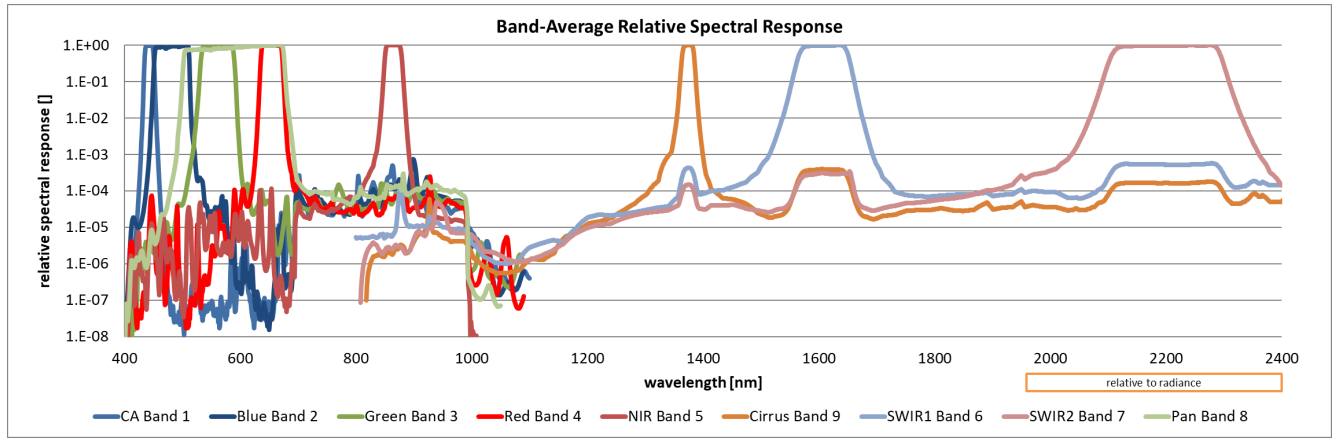
- Cal/val team has been operating together on Landsats 8 and 9 for >15 years and will continue in like fashion moving forward.
- NASA Phase E (Science & Data Analysis) provides NASA support for ongoing Cal/Val and communications/outreach.

Landsat 9 Calibration and Validation

Landsat 9 Pre-launch, Commissioning, and Early On-Orbit Imaging Performance

Barsi, J. A.; Donley, E.; Goldman, M.; Kampe, T.; Markham, B. L.; McAndrew, B.; McCorkel, J.; Morland, E.; Pedelty, J. A.; Pharr, J.; Rodriguez, M. R.; Shuman, T. M.; Stutheit, C.; Sushkov, A. B. Prelaunch Spectral Characterization of the Operational Land Imager-2. *Remote Sensing* **2024**, *16* (6), 981. https://doi.org/10.3390/rs16060981.
11 Mar 2024



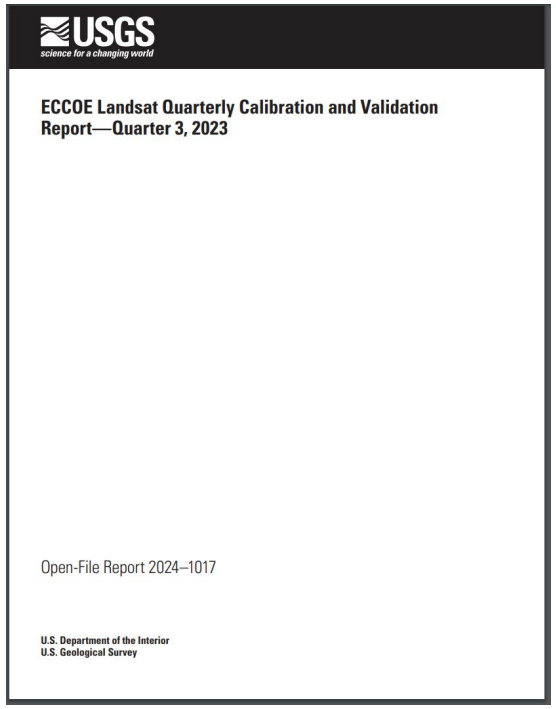


GLAMR at Ball Aerospace with three OLAF tables located in a room adjacent to the TVAC chamber with OLI-2. GLAMR is a system of tunable lasers that cover 350–2500 nm which are fiber-coupled to a 30 in integrating sphere permanently monitored by NIST-traceable radiometers. GLAMR allowed the spectral characterization of every detector (70,000) of the OLI-2 focal plane in nominal imaging conditions.

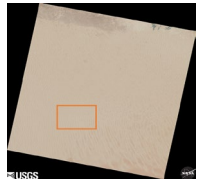
https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-instruments/oli-2-design/oli-2-relative-spectral-response/

Landsat 7 Calibration and Validation

Fig. 90 Landsat 7 Collection 2 surface reflectance trends for the Libya 4 PICS



https://doi.org/10.3133/ofr20241017
https://pubs.usgs.gov/



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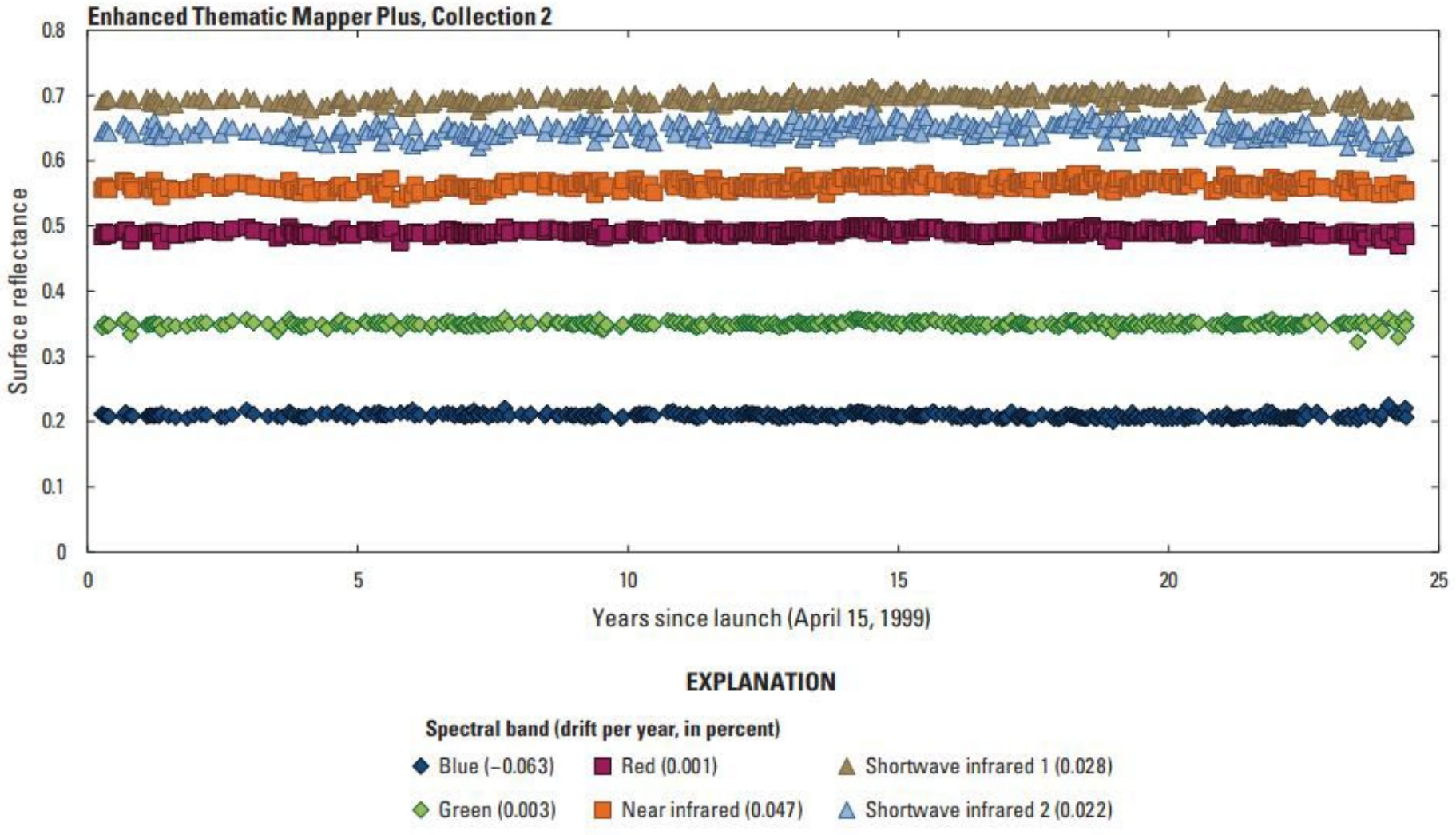
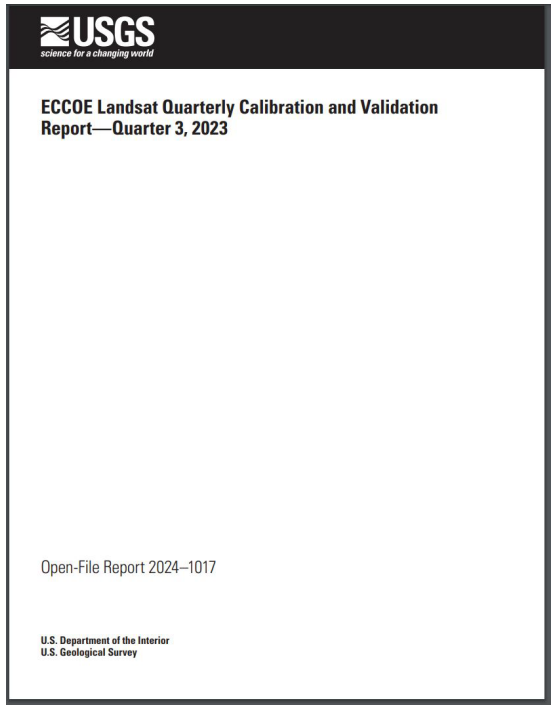
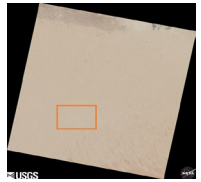


https://www.usgs.gov/publications/eccoe-landsat-quarterly-calibration-and-validation-report-quarter-3-2023

Landsat 8 Calibration and Validation

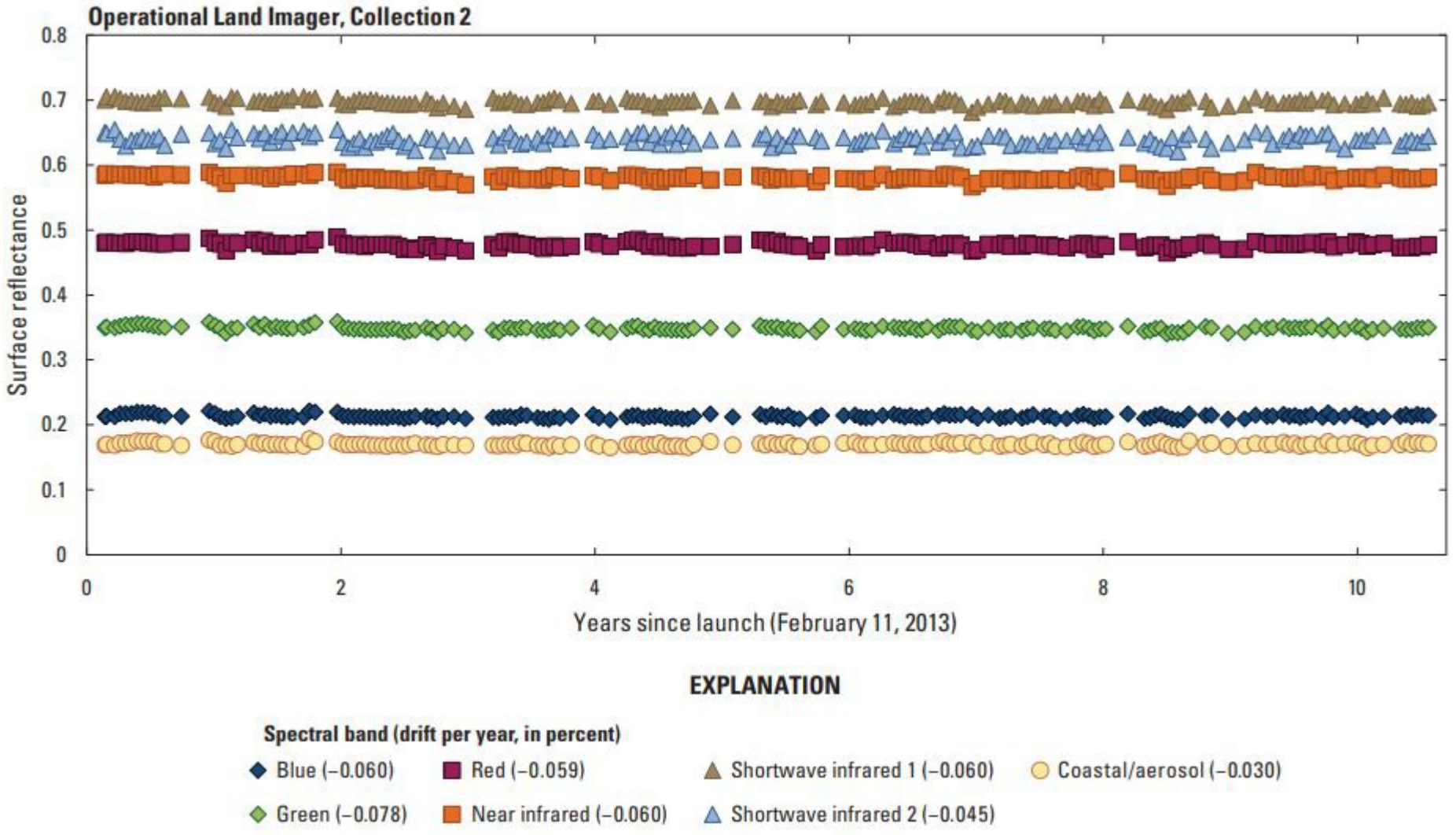


https://doi.org/10.3133/ofr20241017
https://pubs.usgs.gov/



L8 p181r40 7/27/20

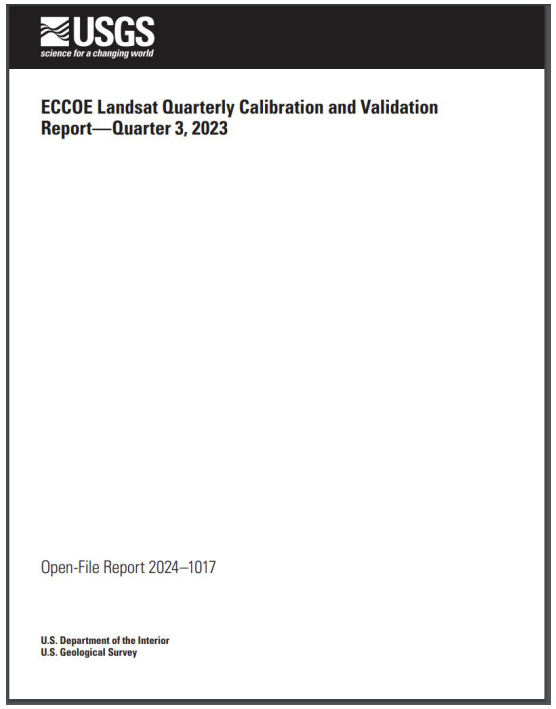
Fig. 91 Landsat 8 Collection 2 surface reflectance trends for the Libya 4 PICS



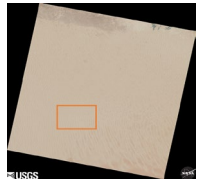
https://www.usgs.gov/publications/eccoe-landsat-quarterly-calibration-and-validation-report-quarter-3-2023

Landsat 9 Calibration and Validation

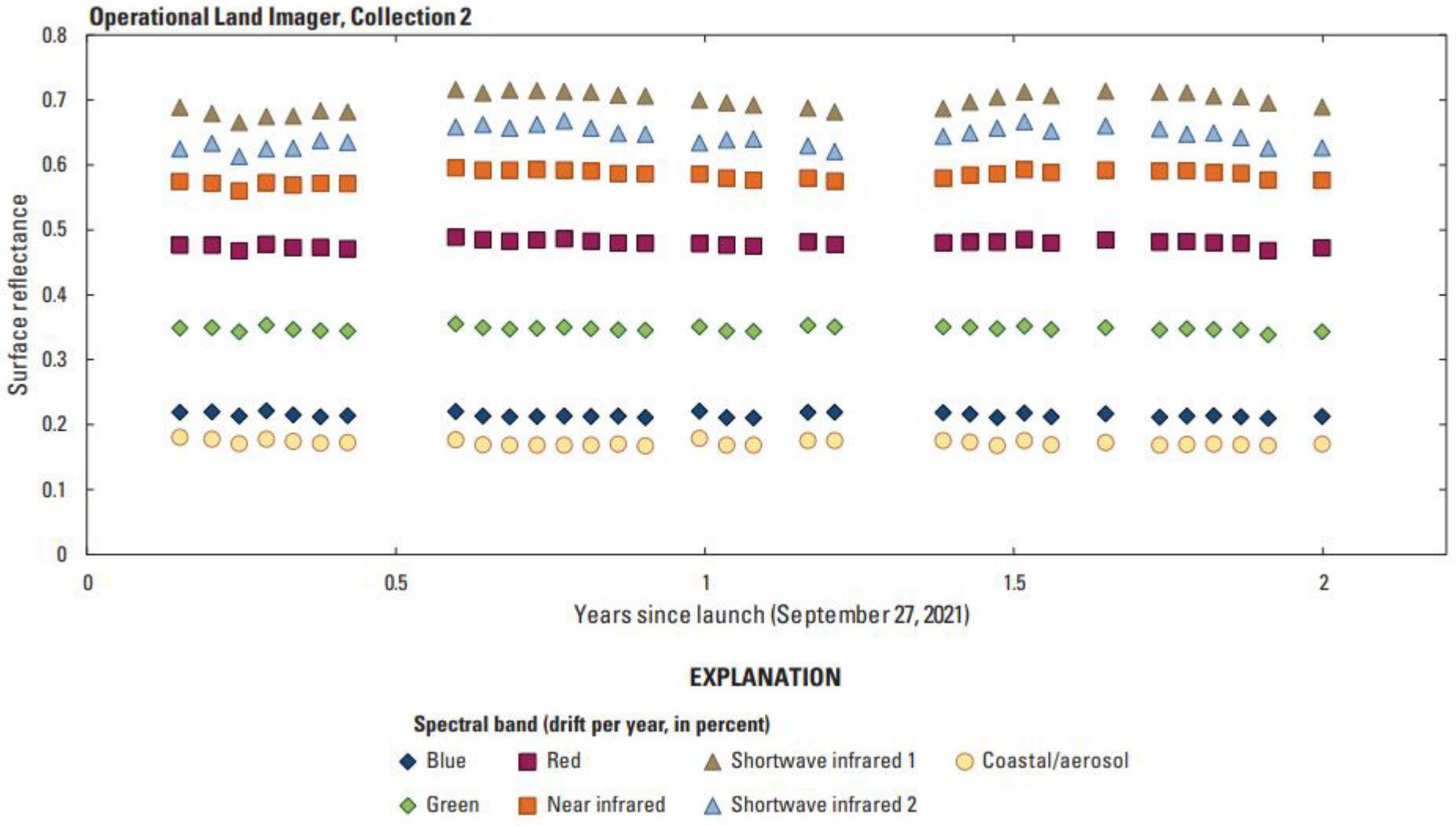
Fig. 92 Landsat 9 Collection 2 surface reflectance trends for the Libya 4 PICS



https://doi.org/10.3133/ofr20241017
https://pubs.usgs.gov/



L8 p181r40 7/27/20



https://www.usgs.gov/publications/eccoe-landsat-quarterly-calibration-and-validation-report-quarter-3-2023

Summary / Conclusion

- **All systems are nominal for L8 and L9, L7 is reaching end of life.**
- **Landsat 9 radiometric and geometric performance is excellent from a Cal/Val perspective.**
  - Spacecraft, ground system, and instruments continue to improve on L8 capabilities
  - Imagery looks great and performance exceeds requirements and, in many cases, by a significant margin
  - >1,400 images per day are collected by L8 and L9, the highest rate to date
- **On-orbit characterization of OLI-2 and TIRS-2 radiometric and geometric performance has confirmed and demonstrated that the all evaluated requirements are being met.**
- **Opportunities exist to share your high-profile Landsat based research through our communications team!**
- **Cal/Val Team continues for the duration of the mission as joint USGS/NASA effort.**
  - Will continue to monitor performance, characterize and update calibration parameters and algorithms as required to improve data products
  - Short term radiometry will be to continue evaluating on-orbit calibration data sets for trending information
  - Short term geometry efforts will be continued evaluation of geolocation accuracy and OLI-2 and TIRS-2 registration

https://landsat.gsfc.nasa.gov/
https://www.usgs.gov/core-science-systems/nli/landsat
https://earthexplorer.usgs.gov/