Landsat and What Comes Next

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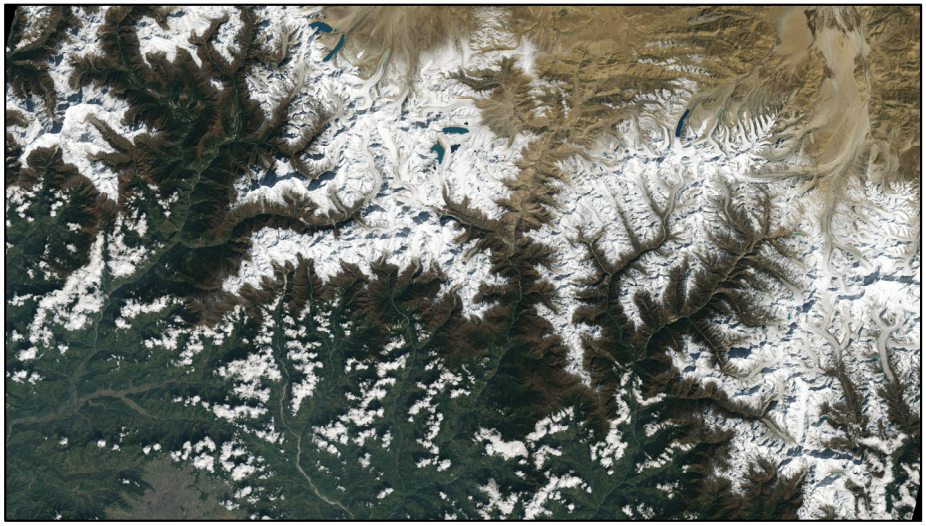
U.S. Department of the Interior
U.S. Geological Survey

Landsat 9 launch; Photo credit: NASA

Presentation Topics

- (1/3) Current Landsat science mission status, data products, and research and development priorities
- (2/3) Landsat Next mission synopsis
- (3/3) Landsat Next science overview and expected application benefits



Landsat 9 first light image over Himalayas; Illustration source: NASA SVS

Landsat 8 image over Lake Superior Apostle Islands, Wisconsin
Illustration source: USGS

USGS NASA

Landsat Mission Overview

- Observe Earth's surface to map, analyze, quantify, and interpret natural and human-induced variability and change in the terrestrial environment
- Force behind decades of Earth science discovery and development – highly cited spaceborne data record in the peer review scientific literature
- *See* Wulder et al. (2022). Fifty years of Landsat science and impacts. *Remote Sensing of Environment*, 280, 113195

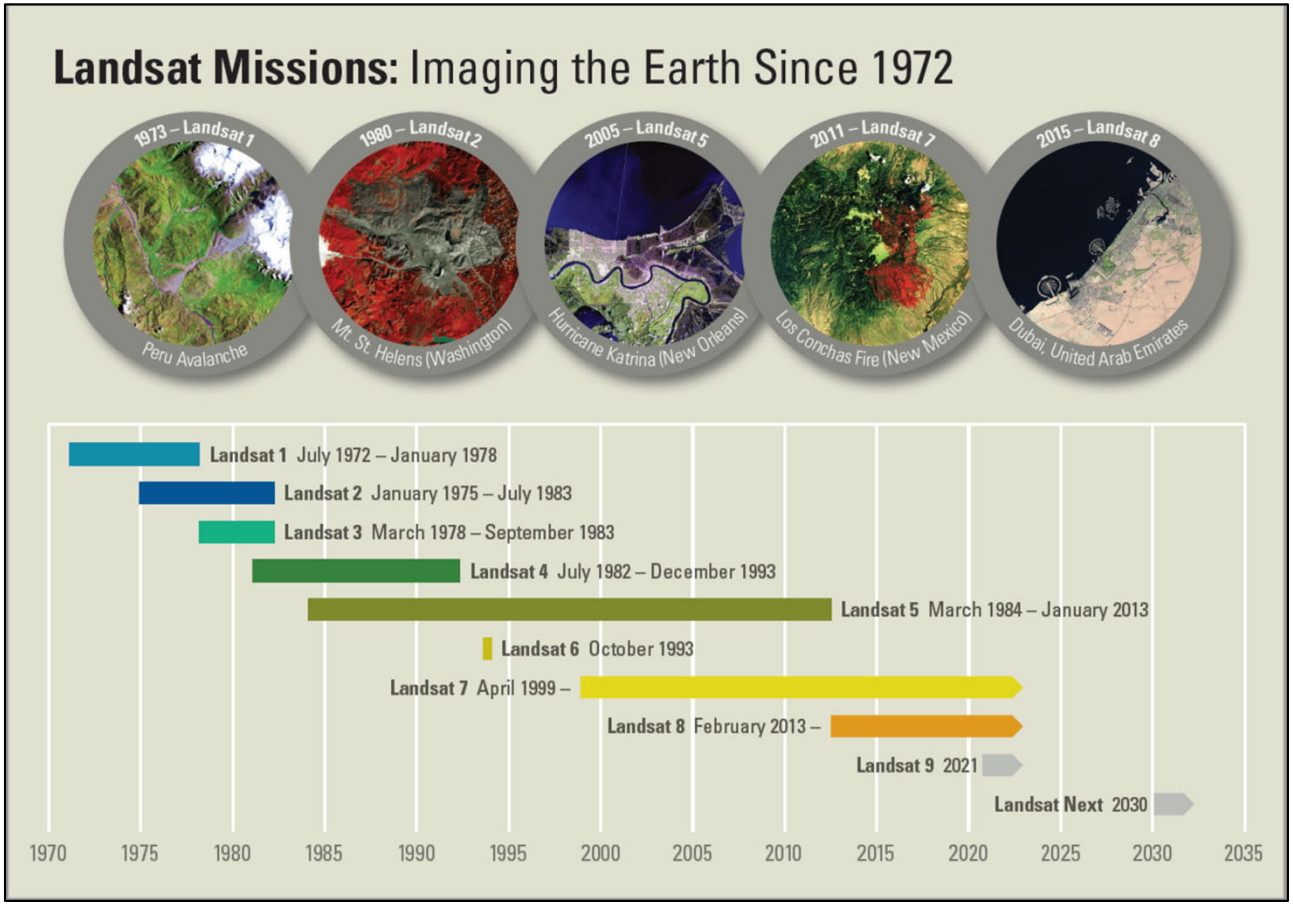


Illustration Source: USGS

NASA/USGS Landsat Mission Partnership

- NASA and USGS partner to provide independently funded joint agency mission(s)
- NASA is responsible for the space segment including instruments, spacecraft, launch, and on-orbit checkout
- USGS is responsible for building and delivering the ground segment, operating the observatories after commissioning and mission handover phases, and provisions science data products via archiving, processing, and open access distribution
- Both NASA and USGS participate jointly in science, calibration/validation, and communications/outreach activities

State of the Landsat Collection 2 consolidated global data archive

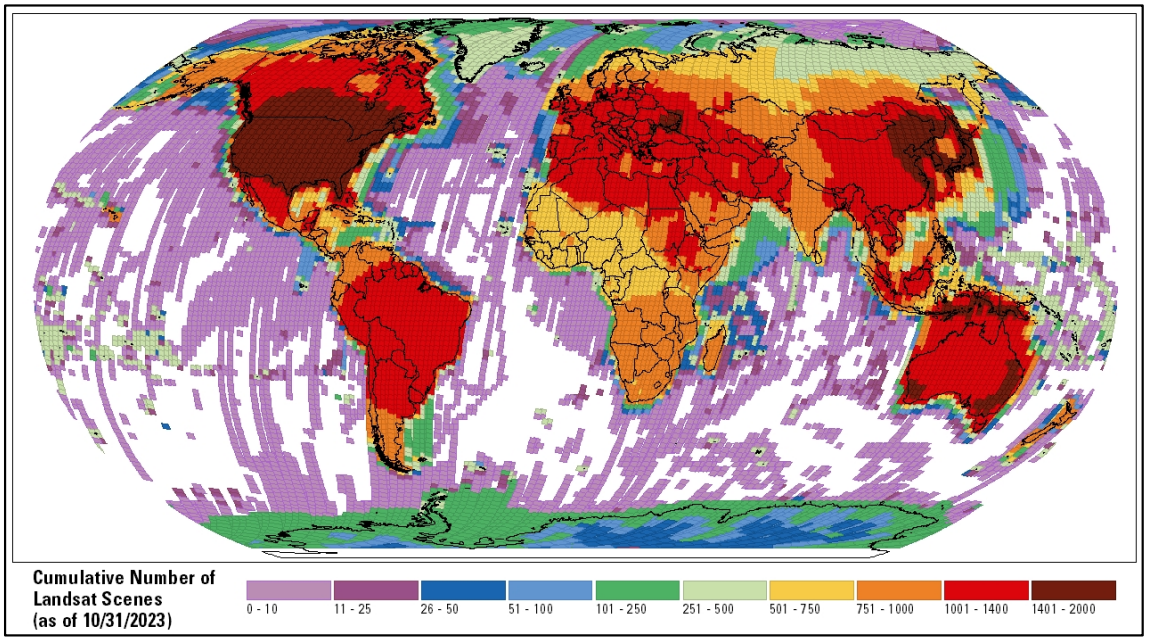


Illustration source: USGS

Landsat 8 and Landsat 9 Science Operations

- Landsat 8 launched February 10, 2013; 10+ years on-orbit
- Landsat 9 launched September 27, 2021; 2+ years on-orbit
- Both observatories carry multispectral visible to shortwave-infrared (VSWIR) Operational Land Imager (OLI)s and dual channel Thermal Infrared Sensors (TIRS) acquiring imagery coincidentally
- Sun-synchronous near-polar orbit global survey missions acquiring all landmasses and nearshore coastal regions
- Selected nighttime imaging of volcanoes, active wildland fires, urbanization, and polar twilight

Landsat 8 and Landsat 9 together acquire ~1500 images per day

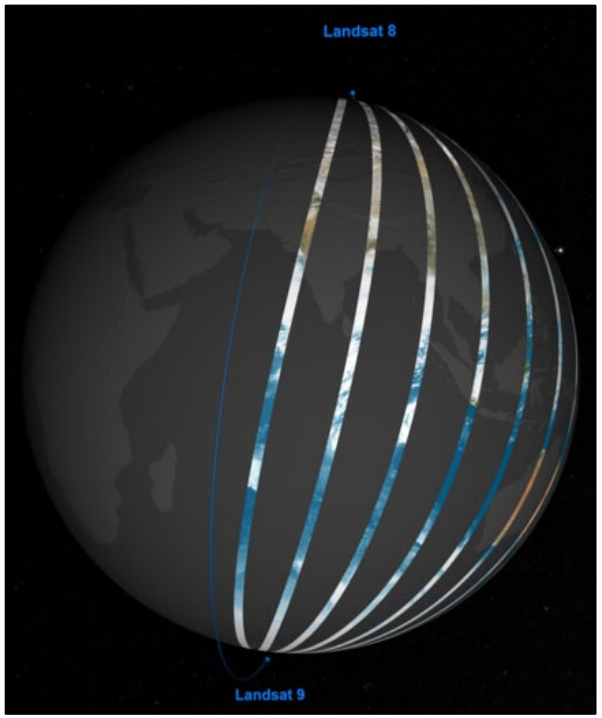


Illustration source: NASA SVS

See Masek et al. (2020). Landsat 9: Empowering open science and applications through continuity. *Remote Sensing of Environment.* 248, 11968

Landsat Ground Network and International Partners

- Utilization of international ground station partners, Australia and Germany, to downlink and transfer data to USGS EROS in Sioux Falls
- USGS/NASA/European Commission (EC), and European Space Agency (ESA) engage in quadrilateral transatlantic cooperation in space around Landsat and Sentinel-2 series missions
- Cooperation includes future missions, product generation, calibration/validation, and data access/discovery architectures

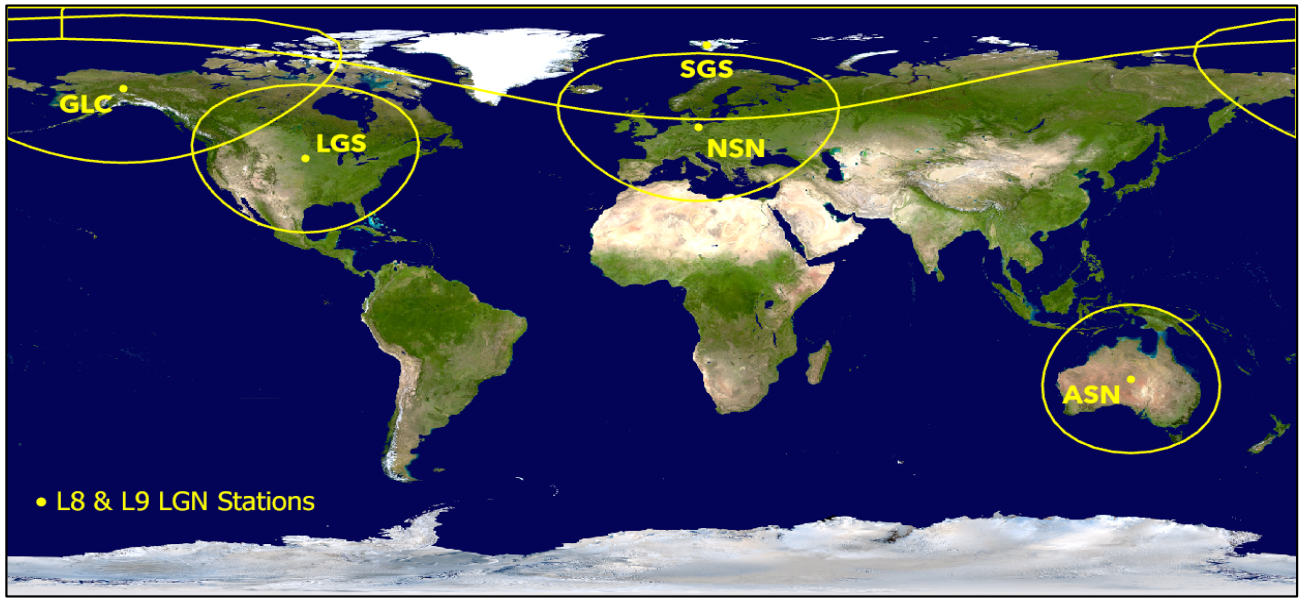


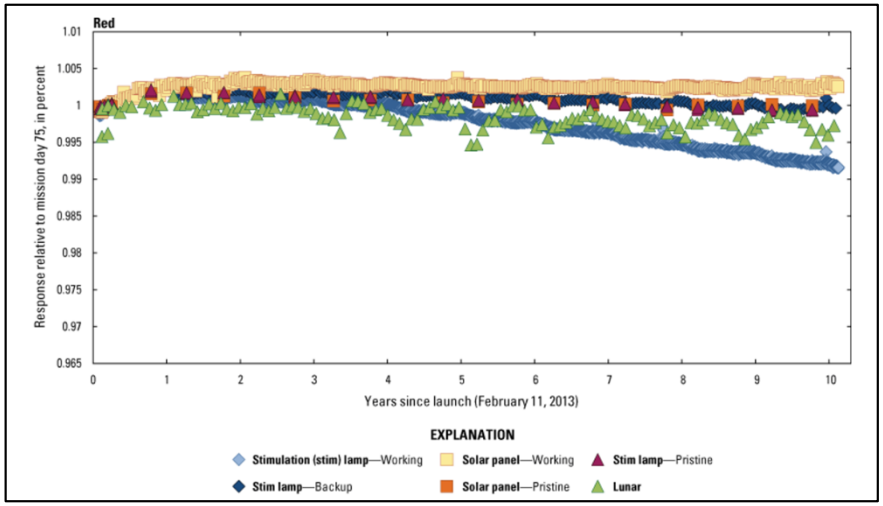
Illustration source: USGS

Alice Springs, Australia Photo credit: USGS

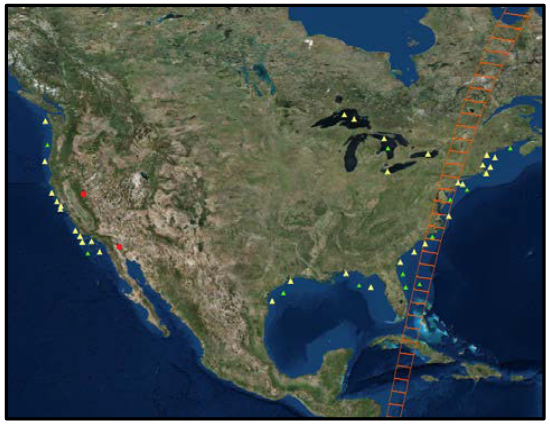
Neustrelitz, Germany Photo credit: USGS

Landsat Calibration and Validation Standards for Science

- OLI VSWIR responsivity is monitored using routine solar, stim lamp, and lunar calibration collects – the absolute instrument calibration is tied to the known on-board solar diffuser(s) reflectance
- TIRS responsivity is monitored using an on-board blackbody and the thermal absolute calibration is tied to coastal and inland buoys
- Routine OLI shutter and TIRS deep space calibration collections are conducted to monitor dark currents
- Earth Pseudo Invariant Calibration Sites (PICS) and ground-based vicarious networks are used for radiometric trending and instrument cross-calibration purposes
- OLI geometric calibration is maintained by an on-board global positioning system and globally distributed ground control sites



Haque et al. (2023). ECCOE Landsat Cal/Val Quarterly Report-Quarter 1

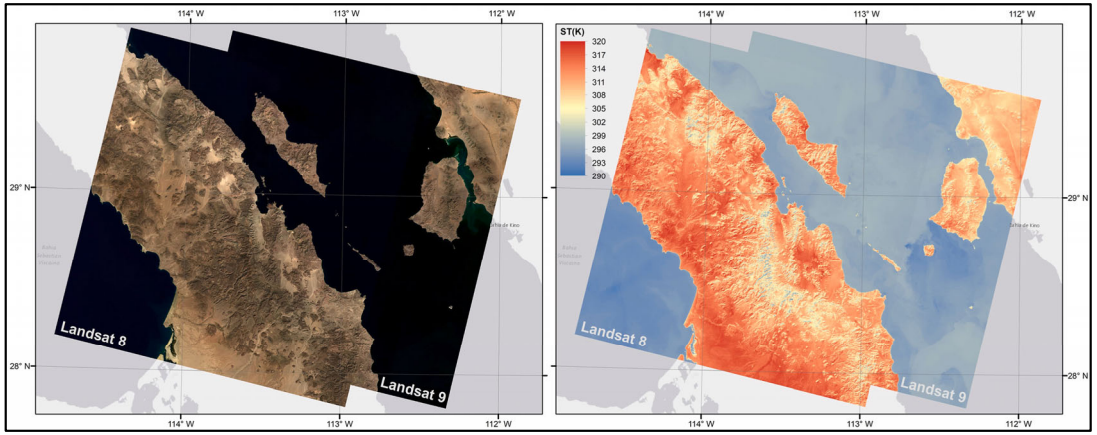


Buoy network for Landsat thermal calibration; Illustration source: USGS

Landsat Collection 2 Archive

- The Landsat consolidated global archive was reprocessed to a Collection 2 by the USGS in late 2020 using the commercial cloud
- The Landsat Collection 2 archive is a 50+ year record with >10 million images and > 9 petabytes
- Two key advancements: (1) updated global ground control for improved pixel geometry using Landsat 8 and ESA's Sentinel-2 Global Reference Image (GRI); (2) generation of global standard Level 2 atmospherically-corrected, geophysical surface reflectance and surface temperature products
- *See* Crawford et al. (2023). The 50-year Landsat Collection 2 archive. *Science of Remote Sensing.* 8, 100103

Landsat tiled analysis ready data (ARD) concept



Landsat 8/9 Collection 2 surface reflectance and temperature images during November 2021 Landsat 9 ascent underfly campaign, Baja California, Mexico

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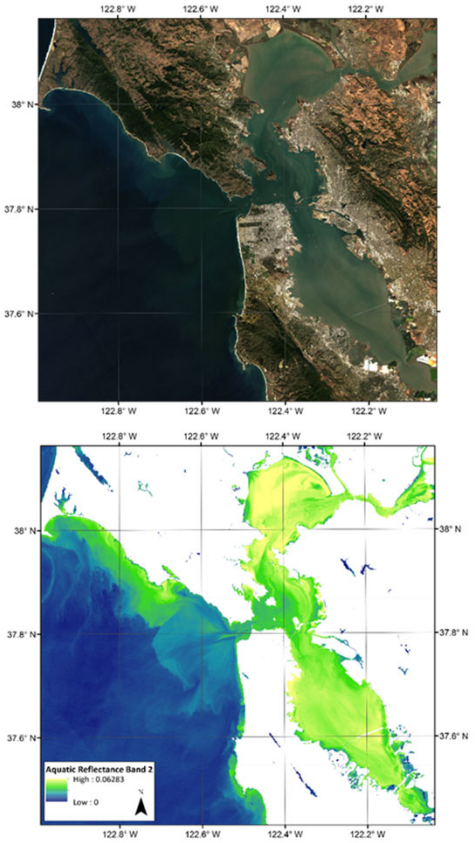
Official Landsat Collection 2 Data Access

- Available through the USGS legacy Earth Explorer interface including a bulk ordering capability (users do not pay for product downloads)
- Available through direct access to the USGS's Amazon Web Services (AWS) S3 bucket (users pay for compute and product egress)
- Available through USGS EROS's machine-to-machine (M2M) application programming interface (API) (users do not pay for download)
- More information: [Landsat Data Access (usgs.gov)]

Illustration source: USGS

Current Landsat Science Research and Development Priorities

- Collection 3 archive planning, research, and development scope, and implementation of Collection 2 lessons learned
- Infusion of a fully cloud-enabled science data processing system into the ground segment (e.g., archive and forward mode)
- Identification of advanced science processing algorithms for atmospheric correction, quality assurance, and uncertainty quantification
- Continued expansion of Landsat observational capabilities for coastal and inland aquatic disciplines
- Prepare for integration of Landsat Next science data into Collection 3



Example Collection 2 prototype Landsat 8 aquatic reflectance for San Francisco Bay, CA; Illustration source: USGS

Landsat 9 Follow-on Architecture Study, User Needs, and Science Community Input

- Between 2016 and 2018, the USGS National Land Imaging program conducted a future user needs survey and analysis with the Landsat community, US Federal Agencies, Landsat Advisory Group, Landsat Science Team, and terrestrial remote sensing Subject Matter Experts (see Wu et al. (2019). User needs for future Landsat missions. *Remote Sensing of Environment.* 231, 111214 & Wulder et al. (2019). Current status of the Landsat program, science, and applications. *Remote Sensing of Environment.* 225, 127-147)

- NASA and USGS conducted a Landsat 9 follow-on mission architecture study between 2018 and 2020 commissioned by the Sustainable Land Imaging (SLI) Steering Committee

- The NASA/USGS joint agency Landsat Next mission concept originated during 2020 and 2022 that included a NASA Request for Information (RFI) on Science mission requirements, space architecture trades and selection, a Mission Concept Review, and Pre-Phase A technical studies

Landsat Next Enables Emerging Science Application Benefits

Benefit Areas		Spatial (10/60m)	Temporal Ø day	Spectral (SS)
Agriculture	Mapping Cropland	✓		
	Crop Tillage and Soil Conservation		✓	✓
	Crop Growth and Health		✓	✓
	Water Consumption		✓	
Forest Monitoring	Deforestation	✓	✓	
	Forest Fires	✓	✓	
	Forest Health	✓	✓	✓
	Forest Inventory	✓	✓	✓
Water	Water Quality		✓	✓
Climate	Ice Dynamics	✓	✓	
	Urban Environments	✓	✓	
	Snow Hydrology		✓	✓
Minerals	Mineral Mapping	✓		✓

Information source: USGS/NASA

USGS NASA

Landsat Next Mission Synopsis

- Landsat Next is a joint mission being formulated, implemented, and operated by NASA and the Department of Interior (DOI) USGS
- Landsat Next is in Phase A development of a satellite mission that will acquire images of Earth's surface, thereby continuing uninterrupted data acquisition to assist land and water managers and policy makers to make informed decisions about natural resources and the environment
- This mission will continue the five plus decades of global survey data collection including open access product distribution currently provided by the Landsat series
- The mission is a component of the SLI Program conducted jointly by NASA and USGS of the DOI

Landsat Next spatial (10, 20, and 60 meters) and spectral (26 channels) science measurement requirements

	Band Name	Ground Sample Distance (m)	Center wavelength (nm)	Band width (nm)	Rationale
1	Violet	60	412	20	Improved aerosol retrieval; CDOM from inland/coastal water
2	Coastal Aerosol	20	443	20	Landsat
3	Blue	10	490	65	Landsat
4	Green	10	560	35	Landsat
5	Yellow	20	600	30	Leaf chlorosis, vegetation stress and mapping
6	Orange	20	620	20	Phycocyanin detection for Harmful Algal Blooms
7	Red 1	20	650	20	Phycocyanin, chlorophyll
8	Red 2	10	665	30	Landsat
9	Red Edge 1	20	705	15	LAI, Chlorophyll, plant stress (S2)
10	Red Edge 2	20	740	15	LAI, Chlorophyll, plant stress(S2)
11	NIR_Broad	10	842	115	10m NDVI (S2)
12	NIR1	20	865	20	Continuity (note-S2 narrower than L8)
13	Water vapor	60	945	20	Improved atmospheric correction for LST, SR (S2)
14	Liquid Water	20	985	20	Liquid water, water surface state
15	Snow/Ice 1	20	1035	20	Snow grain size for water resources
16	Snow/Ice 2	20	1090	20	Ice absorption, snow grain size
17	Cirrus	60	1375	30	Landsat
18	SWIR 1	10	1610	90	Landsat
19	SWIR 2a	20	2100	30	Subdivided for cellulose/crop residue measurement (Landsat)
20	SWIR 2b	20	2210	40	Subdivided for cellulose/crop residue measurement (Landsat/ASTER)
21	SWIR 2c	20	2260	40	Subdivided for cellulose/crop residue measurement (Landsat/ASTER)
22	TIR 1	60	8300	250	Mineral and surface composition mapping (ASTER)
23	TIR 2	60	8600	350	Emissivity separation, volcanos (SO2) (MODIS/ASTER)
24	TIR 3	60	9100	350	Mineral and surface composition mapping (ASTER)
25	TIR 4	60	11300	550	Surface temperature (Landsat), carbonates
26	TIR 5	60	12000	550	Surface temperature, snow grain size (Landsat)

Information source: NASA/USGS

USGS NASA

See NASA Landsat Next website for more information: [Landsat Next | Landsat Science (nasa.gov)]

Landsat Next Mission Architecture and Parameters

- Landsat Next mission is a constellation of three identical observatories with equal orbit spacing
- Each observatory images the full swath required to achieve global coverage; three satellites are used to improve revisit
- Launch Readiness Date: ~November 2030
- The selected NASA/USGS joint agency mission architecture has been endorsed by Landsat user communities, including 12+ US Federal Agency users, and the recent Landsat Science Team
- This mission architecture improves Landsat's temporal, spectral, and spatial observational capabilities while maintaining historical Landsat data continuity

Parameter	Value
Mission Category	Category 2, Class B
Mission Life	5-years
Altitude	653 km Sun-synchronous
Inclination	~98 degrees
Orbital Separation	120 degrees
Mean Local Time Descending Node	10:10 AM +/- 5-min
Obs. Repeating Ground Track	18-day
Swath Width	164 km
Half Angle FOV	7.2 degrees

Information source: NASA Landsat Next Project

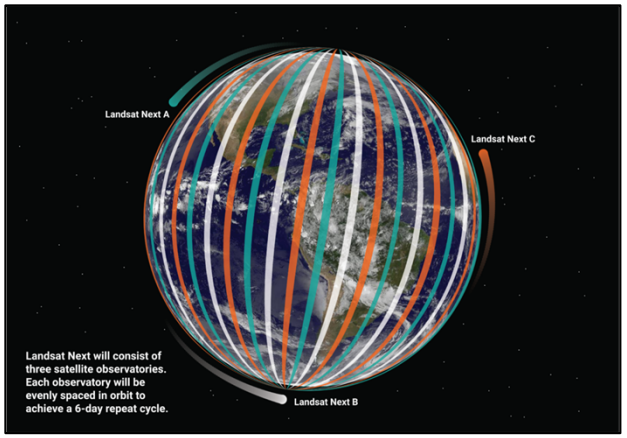
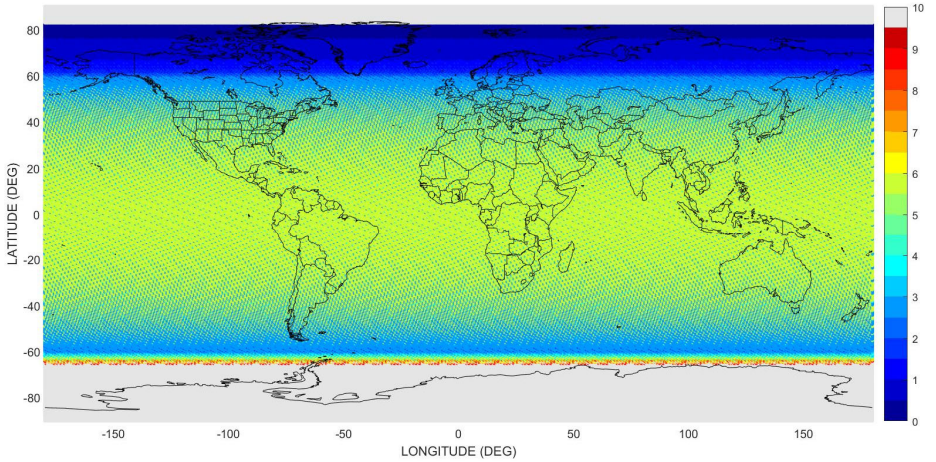


Illustration source: NASA SVS

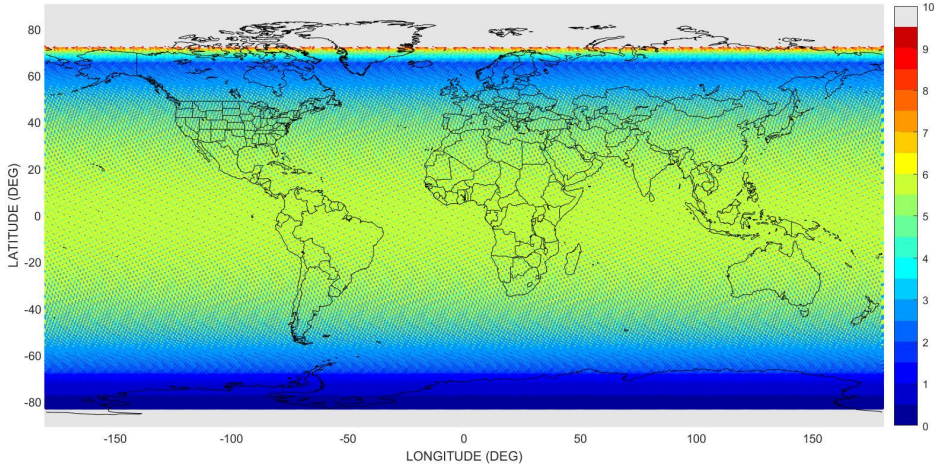
Landsat Next Constellation Imaging Concept

- The constellation architecture satisfies emerging Landsat user needs that maximizes resiliency
- With all three observatories operating, revisit is expected to be 6 days
- With two of three observatories operating, revisit is expected to be 9 days
- The mission architecture will move to a new 653 km World Reference System 3 (WRS-3) ground track imaging strategy
- The mission will maintain Landsat on-orbit calibration standards and Landsat's Long Term Acquisition Plan (LTAP) for global survey imaging

Frequency centered on NH Summer Solstice, source: NASA/USGS



Frequency centered on NH Winter Solstice, source: NASA/USGS



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Landsat Next Ground Segment Concept

(1) Multi-satellite Operations Center (MOC)

- Observatory command, telemetry, planning, scheduling, mission data management, health and safety, security, and trending

(2) Ground Network (GN)

- S-Band interface for command and telemetry, and Stored State Of Health (SSOH); Ka-Band interface for mission data capture from the observatory and data transfer to the cloud

(3) Data Processing and Archive System (DPAS)

- Ingest of mission data files from the ground stations; Level 0 product generation; storing and archiving the data; Level 1 and Level 2 product generation

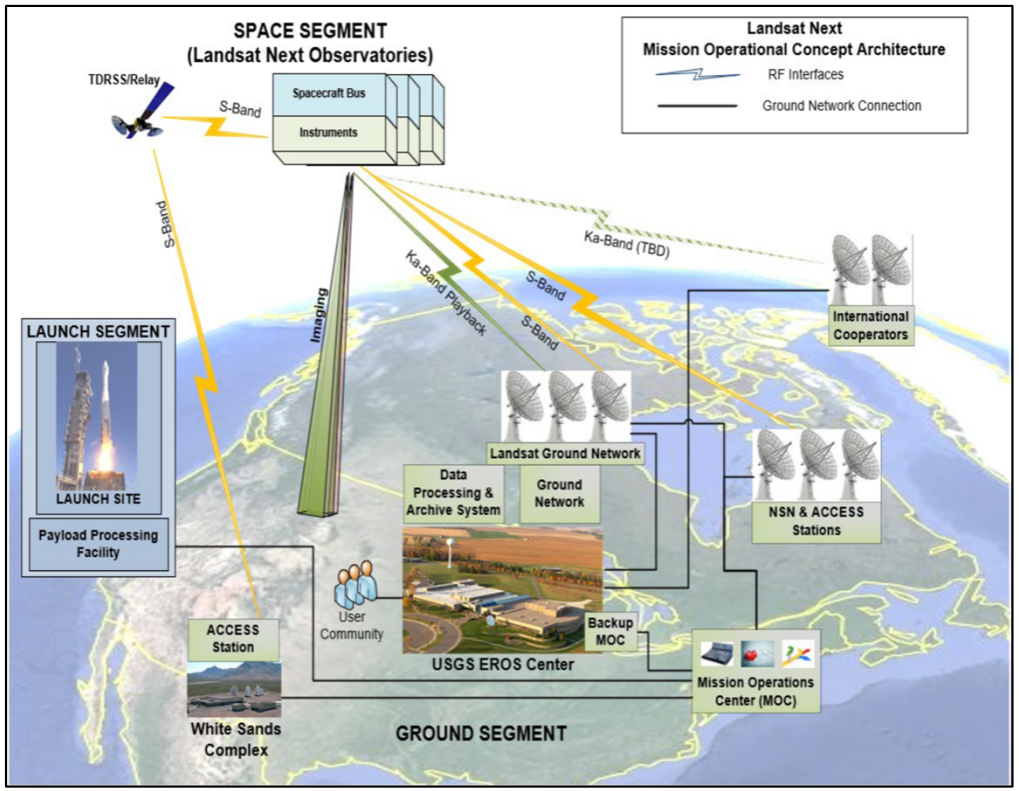
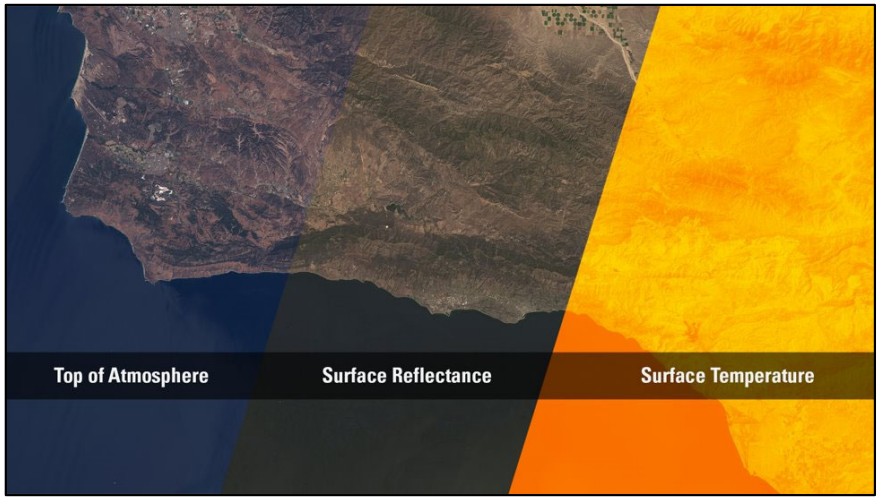


Illustration source: USGS

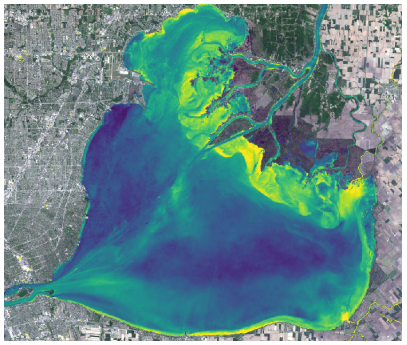
Landsat Next Science Data Roadmap

- Landsat Next science mission data products will include:
  - Level 1 Top of Atmosphere (TOA) calibrated data
  - Level 2 Surface Reflectance, Aquatic Reflectance, Surface Temperature, and Surface Emissivity geophysical quantities
- Landsat Next Level 2 science algorithms (i.e., atmospheric correction and quality assurance) for product generation will require evolution and advances to:
  - Leverage new atmospheric and surface spectral measures (e.g., aerosol, water vapor, emissivity)
  - Develop VSWIR and TIR algorithms by combining heritage and emerging techniques
- Landsat Next science mission data will be processed into the notional Collection 3 at time of Phase E operations



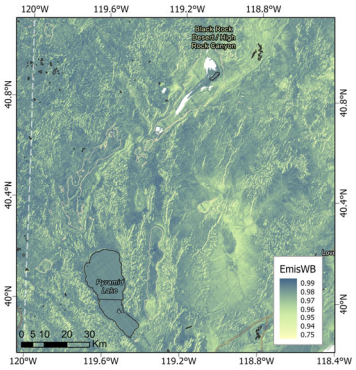
Landsat 8, California coast from Vandenburg to Ventura

+ Aquatic



Landsat 9, Lake St Clair, MI

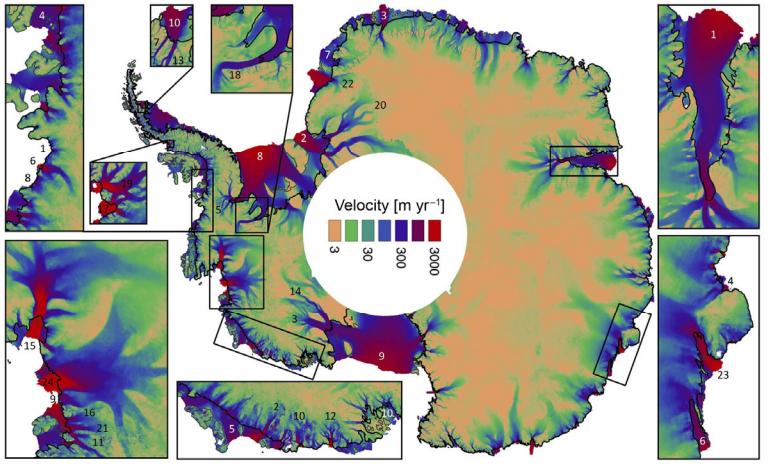
+ Emissivity



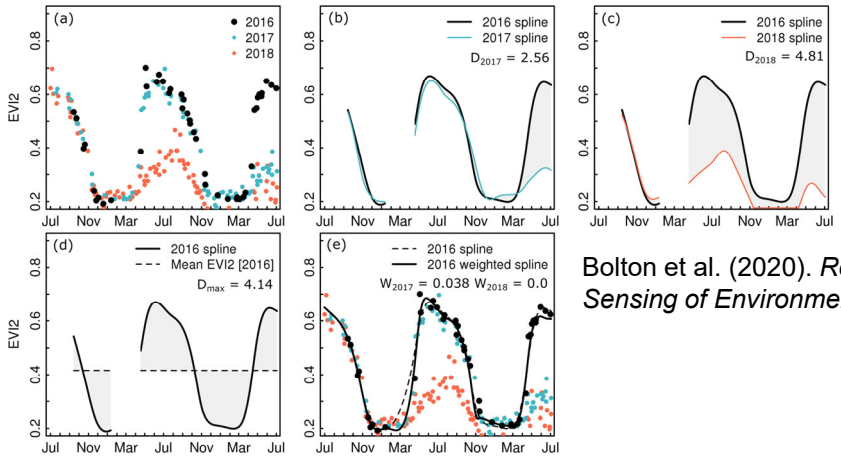
ECOSTRESS, northwest NV

Landsat Next's Increased Temporal Frequency for Science

- Landsat Next's increased temporal frequency at 6 days will simply offer more opportunities for cloud-free imaging
- Landsat Next's increased temporal frequency enables mapping, analysis, and quantification of rapidly changing surface phenomena such as snow cover, ice dynamics, water extent, and wildland fire
- Landsat Next's increased temporal frequency will substantially advance phenology mapping of vegetation, ecological disturbance or land surface change, agriculture cropping and yield, and aquatic biology



Gardner et al. (2018). *Cryosphere*



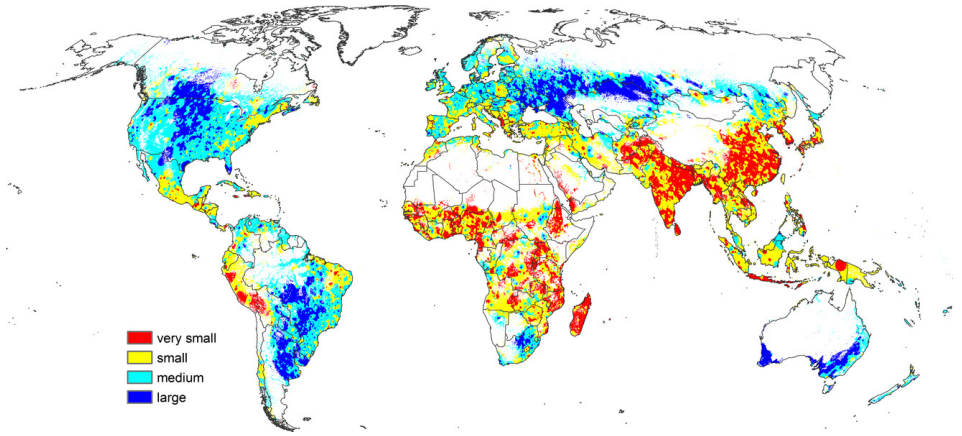
Bolton et al. (2020). *Remote Sensing of Environment*

USGS NASA

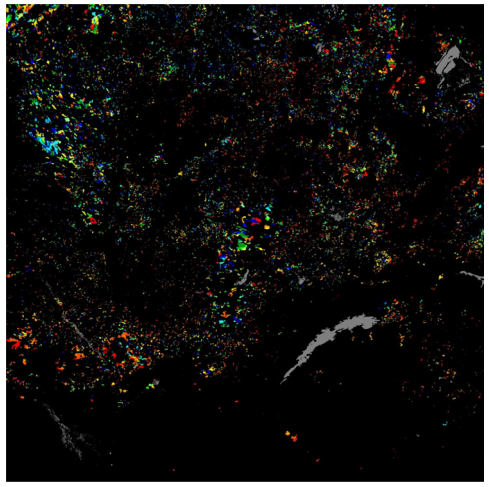
Landsat Next's Higher Spatial Resolution for Science

- Landsat Next's higher VSWIR 10/20 meter spatial resolution advances delineation of smaller agricultural parcels, within field agricultural cropping processes and yield patterns, and smaller burned area mapping for greenhouse gas emission quantification
- Landsat Next's higher VSWIR 10/20 meter spatial will resolve land surface cover type more discriminately, support vegetation structure and forest inventory analysis, and more precise deforestation accounting
- Landsat Next's higher TIR spatial resolution at 60 meters will sharpen retrieval of evapotranspiration quantities at the field scale and identify hot spots within urban heat islands

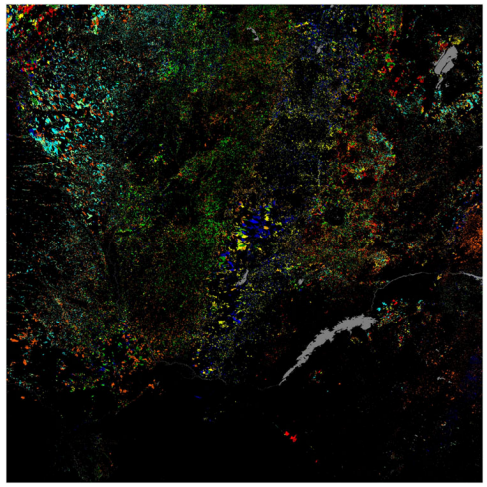
A global map of agricultural field size; Fritz et al. (2015). *Global Change Biology*



MODIS 500 m Burned Area



Landsat 8/Sentinel-2 30 m Burned Area



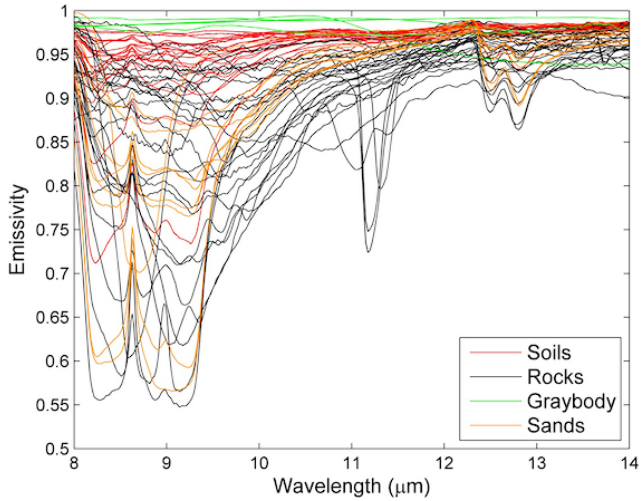
Roy et al. (2019). *Remote Sensing of Environment*

Landsat Next's Expanded Spectral Sampling for Science

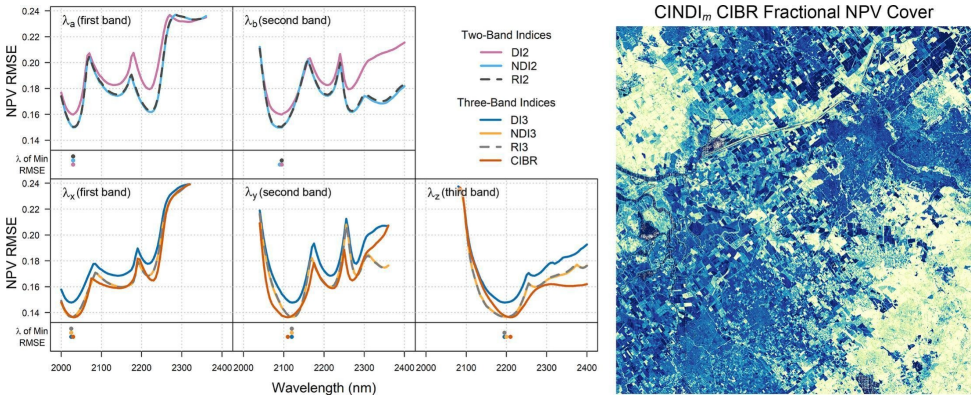
- Landsat Next's expanded VSWIR spectral sampling with the addition of 10 channels will advance autonomous land and aquatic atmospheric correction capabilities (i.e., 412 nm for aerosols, 945 nm for water vapor)

- Landsat Next's expanded TIR spectral sampling with three additional channels will enable simultaneous retrieval of surface emissivity, more accurate temperature, and mineral surface composition

- Landsat Next's expanded VSWIR spectral sampling enables emerging science applications such water quality and detection of potentially harmful algal blooms, snow and ice sheet hydrology, non-photosynthetic vegetation/soil minerology/agricultural crop residue, and vegetation health



Hulley et al. (2012). *JGR-Atmospheres*



Dennison et al. (2023). *Remote Sensing of Environment*

Landsat Mission Takeaways

- Landsat is US flagship optical Earth observing mission that now exceeds 50+ years of systematic and continuous global surface measurements at human scales that is unparalleled worldwide
- Coincident, global survey VSWIR and TIR optical imaging from Landsat at 30 to 120 meters ground sampling remains unique among its satellite mission class
- Landsat Next builds on these observing characteristics by providing heritage continuity, synergy with other Earth observing optical missions, and expands scientific and application capabilities towards discovery while also meeting reliable operational data needs

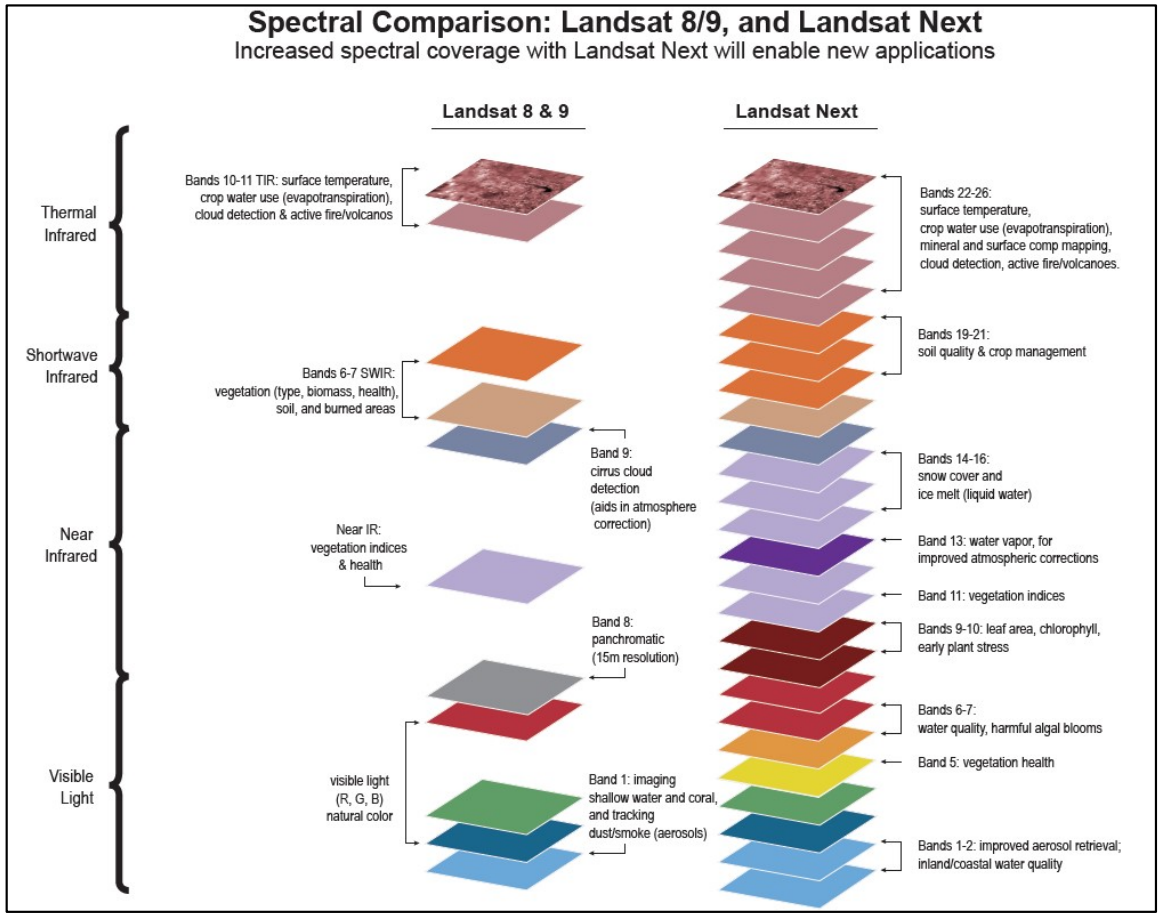


Illustration source: USGS/NASA

Acknowledgements

NASA/USGS joint agency Landsat and Landsat Next Project Teams; USGS Core Science Systems Mission Area leadership; USGS National Land Imaging Program leadership and staff; USGS Earth Resources Observation and Science (EROS) Center leadership and staff

USGS Landsat Mission Website: Landsat Missions | U.S. Geological Survey (usgs.gov)
NASA Landsat Mission Website: Landsat Science (nasa.gov)

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Landsat Flight Operations Team; Photo credit: USGS