Landsat—Earth Observation Satellites

Since 1972, Landsat satellites have continuously acquired space-based images of the Earth's land surface, providing data that serve as valuable resources for land use/land change research. The data are useful for a number of applications including forestry, agriculture, geology, regional planning, and education.

Landsat is a joint effort of the U.S. Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA). NASA develops remote sensing instruments and the spacecraft, then launches and validates the performance of the instruments and satellites. The USGS then assumes ownership and operation of the satellites, in addition to managing all ground reception, data archiving, product generation, and data distribution. The result of this program is an unprecedented continuing record of natural and human-induced changes on the global landscape.

In the mid-1960s, stimulated by U.S. success in planetary exploration using unmanned remote sensing satellites, the Department of the Interior, NASA, and the Department of Agriculture embarked on an ambitious effort to develop and launch the first civilian Earth observation satellite. Their goal was achieved on July 23, 1972, with the launch of the Earth Resources Technology Satellite (ERTS-1), which was later renamed Landsat 1. The launches of Landsat 2, Landsat 3, and Landsat 4 followed in 1975, 1978, and 1982, respectively. When Landsat 5 launched in 1984, no one could have predicted that the satellite would continue to deliver high quality, global data of Earth's land surfaces for 28 years and 10 months, officially setting a new Guinness World Record for "longest-operating Earth observation satellite." Landsat 6 failed to achieve orbit in 1993; Landsat 7 successfully launched in 1999. In April 2022, Landsat 7 lowered its orbit by 8 kilometers but will continue to provide data until September 2022. Landsat 8, launched in 2013, and Landsat 9, launched in 2021, continue the mission of acquiring global data (fig. 1).

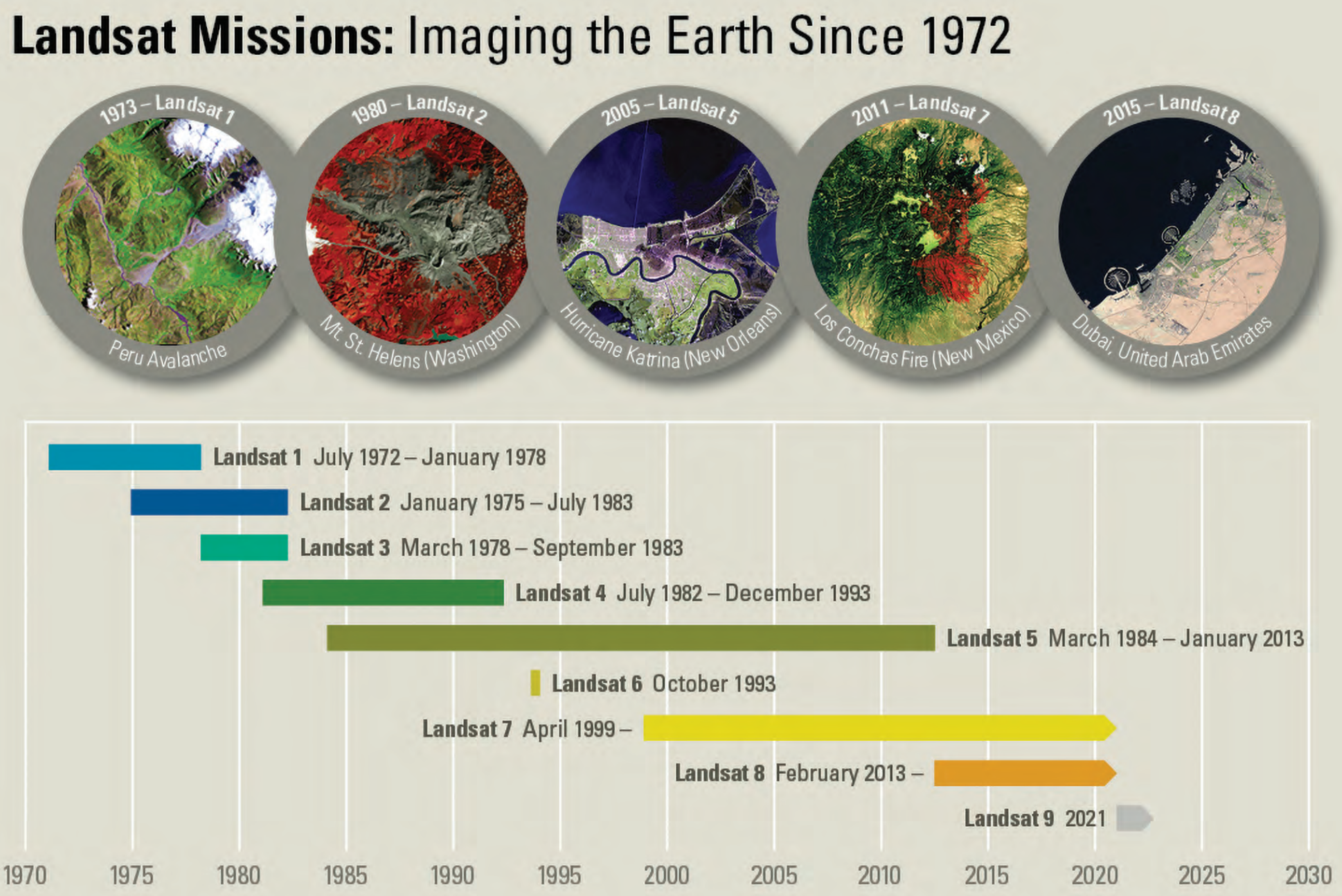

Figure 1. Timeline and history of the Landsat Missions, which started in 1972.

Satellite Acquisitions

The Landsat 8 and Landsat 9 satellites orbit the Earth at an altitude of 705 kilometers (438 miles) in a 185-kilometer (115-mile) swath, moving from north to south over the sunlit side of the Earth in a sun synchronous orbit. Each satellite makes a complete orbit every 99 minutes, completes about 14 full orbits each day, and crosses every point on Earth once every 16 days. Although each satellite has a 16-day full-Earth-coverage cycle, their orbits are offset to allow 8-day repeat coverage of any Landsat scene area on the globe. Between the two satellites, more than 1,500 scenes are added to the USGS archive each day. Landsats 4, 5, and 7 followed the same orbit as Landsats 8 and 9, whereas Landsats 1, 2, and 3 orbited at an altitude of 920 kilometers (572 miles), circling the Earth every 103 minutes, yielding repeat coverage every 18 days.

The Landsat Long Term Acquisition Plans (LTAPs) identify Earth imaging priorities that most effectively utilize both Landsat 8 and Landsat 9 data acquisitions. Information about the LTAPs is provided on the Landsat Missions website (https://www.usgs.gov/landsat-missions).

Sensors and Band Designations

The primary sensor onboard Landsats 1, 2, and 3 was the Multispectral Scanner (MSS), which collected data at a resolution of 80 meters in four spectral bands ranging from the visible green to the near-infrared (IR) wavelengths. Delivered Landsat MSS data are resampled to 60 meters (table 1). Return Beam Vidicon (RBV) instruments on Landsats 1, 2, and 3 acquired data that were recorded to 70-millimeter black and white film. RVB data are archived at the Earth Resources Observation and Science (EROS) Center and are available as film-only products.

Landsat 4 and Landsat 5 also carried the MSS, along with the Thematic Mapper (TM) sensor. The TM sensor included additional bands in the shortwave infrared (SWIR) part of the spectrum; improved spatial resolution of 30 meters for the visible, near-IR, and SWIR bands; and the addition of a 120-meter thermal IR band. Delivered Landsat 4 and Landsat 5 TM thermal data are resampled to 30 meters (table 1).

Landsat 7 carries the Enhanced Thematic Mapper Plus (ETM+), with 30-meter visible, near-IR, and SWIR bands; a 60-meter thermal band; and a 15-meter panchromatic band. Delivered Landsat 7 ETM+ thermal data are resampled to 30 meters (table 1). On May 31, 2003, unusual artifacts began to appear within the data collected by the ETM+ instrument. Investigations determined that the Scan Line Corrector (SLC), which compensates for the forward motion of the satellite to align forward and reverse scans necessary to create an image, had failed. Efforts to recover the SLC were unsuccessful, and without an operating SLC, 22 percent of the image data are missing, resulting in data gaps forming in alternating wedges that increase in width from the center to the edge of the image. Landsat 7 still acquires geometrically and radiometrically accurate data worldwide, and methods were established that allow users to fill the data gaps.

Landsat 8, launched on February 11, 2013, and Landsat 9, launched on September 27, 2021, each have two sensors: the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). OLI collects data with a spatial resolution of 30 meters in the visible, near-IR, and SWIR wavelength regions, and a 15-meter panchromatic band, which provides data compatible with products from previous missions. OLI also has a deep blue band for coastal-aerosol studies and a band for cirrus cloud detection (table 1). TIRS has two thermal bands, which were designed to allow the use of split-window surface temperature

Table 1. Display and comparison of the bands and wavelengths of each Landsat sensor. Instrument-specific relative spectral response functions can be viewed and compared using the U.S. Geological Survey Spectral Viewer tool: https://landsat.usgs.gov/spectral-characteristics-viewer.

[OLI, Operational Land Imager; TIRS, Thermal Infrared Sensor; ETM+, Enhanced Thematic Mapper Plus; TM, Thematic Mapper; MSS, Multispectral Scanner; --, not applicable]

Band designations	Landsat band wavelength comparisons All bands 30-meter resolution unless noted									
	L8–9 OLI/TIRS		L7 ETM+		L4–5 TM		L4–5 MSS*		L1–3 MSS*	
Coastal/Aerosol	Band 1	0.43–0.45	--	--	--	--	--	--	--	--
Blue	Band 2	0.45–0.51	Band 1	0.45–0.52	Band 1	0.45–0.52	--	--	--	--
Green	Band 3	0.53–0.59	Band 2	0.52–0.60	Band 2	0.52–0.60	Band 1	0.5–0.6 *	Band 4	0.5–0.6 *
Panchromatic	Band 8**	0.50–0.68	Band 8 **	0.52–0.90	--	--	--	--	--	--
Red	Band 4	0.64–0.67	Band 3	0.63–0.69	Band 3	0.63–0.69	Band 2	0.6–0.7 *	Band 5	0.6–0.7 *
Near-Infrared	Band 5	0.85–0.88	Band 4	0.77–0.90	Band 4	0.76–0.90	Band 3	0.7–0.8 *	Band 6	0.7–0.8 *
Near-Infrared	--	--	--	--	--	--	Band 4	0.8–1.1 *	Band 7	0.8–1.1*
Cirrus	Band 9	1.36–1.38	--	--	--	--				
Shortwave Infrared-1	Band 6	1.57–1.65	Band 5	1.55–1.75	Band 5	1.55–1.75				
Shortwave Infrared-2	Band 7	2.11–2.29	Band 7	2.09–2.35	Band 7	2.08–2.35				
Thermal	Band 10 T1	10.60–11.19	Band 6 T2	10.40–12.50	Band 6 T2	10.40–12.50				
Thermal	Band 11 T1	11.50–12.51	--	--	--	--				

* Acquired at 80 meters, resampled to 60 meters

** 15-meter (panchromatic)

T1 = Thermal (acquired at 100 meters, resampled to 30 meters)

T2 = Thermal (acquired at 120 meters, resampled to 30 meters)

Table 2. The bands of each Landsat satellite and descriptions of how each band is best used.

[--, not applicable]

Band name	Uses of Landsat bands: L8–9 OLI/TIRS	L7 ETM+	L4–5 TM	L4–5 MSS	L1–3 MSS	Description of use
Coastal/Aerosol	Band 1	--	--	--	--	Coastal areas and shallow water observations; aerosol, dust, smoke detection studies.
Blue (B)	Band 2	Band 1	Band 1	--	--	Bathymetric mapping; soil/vegetation discrimination, forest type mapping, and identifying manmade features.
Green (G)	Band 3	Band 2	Band 2	Band 1	Band 4	Peak vegetation; plant vigor assessments.
Red (R)	Band 4	Band 3	Band 3	Band 2	Band 5	Vegetation type identification; soils and urban features.
Near-Infrared (NIR)	Band 5	Band 4	Band 4	Band 3	Band 6	Vegetation detection and analysis; shoreline mapping and biomass content.
	--	--	--	Band 4	Band 7	
Shortwave Infrared-1 (SWIR-1)	Band 6	Band 5	Band 5	--	--	Vegetation moisture content/drought analysis; burned and fire-affected areas; detection of active fires.
Shortwave Infrared-2 (SWIR-2)	Band 7	Band 7	Band 7	--	--	Additional detection of active fires (especially at night); plant moisture/drought analysis.
Panchromatic (PAN)	Band 8	Band 8	--	--	--	Sharpening multispectral imagery to higher resolution.
Cirrus	Band 9	--	--	--	--	Cirrus cloud detection.
Thermal (T)	Band 10	Band 6	Band 6	--	--	Ground temperature mapping and soil moisture estimations.
	Band 11			--	--	

retrieval algorithms. Because of larger calibration uncertainty associated with Landsat 8's band 11, it is recommended that users refrain from using band 11 data.

A Quality Assessment (QA) band is also included in Landsat 8 and 9 data products. This file contains information that improves the integrity of science investigations by indicating which pixels could be affected by instrument artifacts or cloud contamination.

Applications of Landsat Data

Landsat data support a vast range of applications in areas such as global change research, agriculture, forestry, geology, land cover mapping, resource management, water, and coastal studies. Specific environmental monitoring activities such as deforestation research, understanding pyroclastic flows, and understanding the effects of natural disasters all benefit from the availability of Landsat data. In recent years, Landsat data are also used to track oil spills and to monitor mine waste pollution.

Table 2 lists Landsat bands and describes the use of each band to help users determine the best band combinations to use in data analysis.

The consistency of Landsat data acquisitions through the years and the richness of the archive, combined with the no-cost data policy, allow users to exploit time series of data over extensive geographic areas to establish long-term trends and monitor the rates and characteristics of land surface change (fig. 2).

Landsat Data Products and Processing

The USGS delivers high quality systematic, geometric, radiometric, and terrain corrected data to users worldwide. Nearly 150 million Landsat images have been downloaded since the USGS adopted the free and open Landsat policy in December 2008.

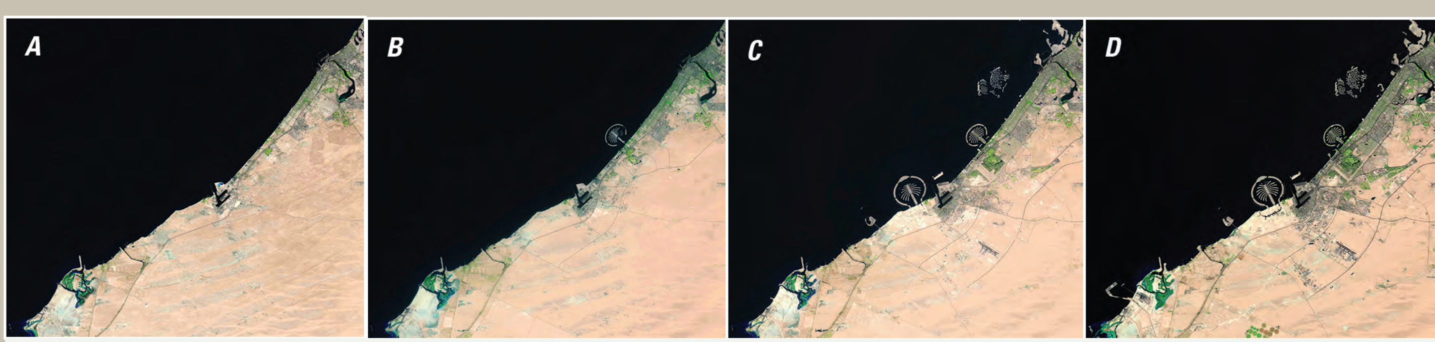

Figure 2. Landsat images showing expanding archipelagos along the coast of Dubai, United Arab Emirates. *A*, October 1998 (Landsat 5); *B*, May 2003 (Landsat 7); *C*, May 2008 (Landsat 5); and *D*, May 2015 (Landsat 8).

Landsat Level-1 data are processed to standard parameters, which include cubic convolution resampling, north-up (map) orientation, Universal Transverse Mercator (UTM) map projection (Polar Stereographic for Antarctic scenes), and World Geodetic System (WGS) 1984 datum. Data are delivered in Cloud Optimized Georeferenced Tagged Image File Format (GeoTIFF) (COG) in compressed files for faster downloads. The number and sizes of data files vary based on the sensor. Full resolution "natural" color composite Joint Photographic Expert Group (.jpg) files of Landsat images (named Full Resolution Browse Images) are also available to download for easy use in presentations and visual interpretation.

Recognizing the need for new climate information products to meet national and international requirements in accordance with the Global Climate Observing System (GCOS), USGS scientists developed higher level science products to support time series of observational data with sufficient length, consistency, and continuity to record effects of climate change. Visit https://www.usgs.gov/landsat-missions/landsat-science-products for more information on the various science products (fig. 3).

Obtaining Landsat Data Products

Landsat Level-1 data and science products held in the USGS archives are available for download at no charge and with no restrictions from EarthExplorer (http://earthexplorer.usgs.gov), GloVis (http://glovis.usgs.gov), the LandsatLook Viewer (http://landsatlook.usgs.gov), or through the commercial cloud. Bulk downloading capabilities are available by accessing the EarthExplorer Help menu.

For more information about how to search and download Landsat data and science products, please visit https://www.usgs.gov/landsat-missions/landsat-data-access.

Landsat Science Teams

The Landsat Science Teams provide technical and scientific input to USGS and NASA and help ensure the success of the Landsat program while providing science support on issues including data acquisition, product access and format, and science and applications opportunities. As recognized national and international leaders in land remote sensing, members of the teams evaluate issues of importance to all Landsat users. The teams are funded by the USGS and co-chaired by the USGS and NASA. Meeting agendas and presentations are posted on the Landsat Missions Web site (https://www.usgs.gov/landsat-missions/landsat-science-teams).

For More Information

Questions about Landsat operations, data products, and data access can be directed to:

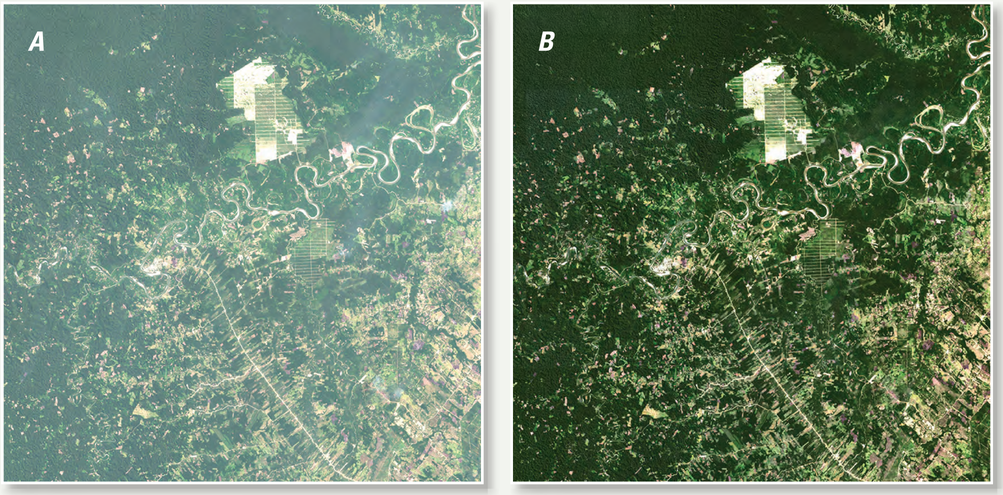

Figure 3. Landsat 8 images acquired May 11, 2014, showing a portion of rain forest in Peru, and displaying the differences in *A*, standard Level-1 data and *B*, surface reflectance (SR) data.

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Visit http://www.usgs.gov for more information about the USGS and https://www.usgs.gov/programs/national-land-imaging-program for specifics about the Land Remote Sensing Program.

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