

LANDSAT

9



Earth From Space

Tracking Decades of Change

To access Landsat data, visit <https://www.usgs.gov/landsat>

For nearly half a century, the Landsat mission has shaped our understanding of Earth. Since the launch of the first Landsat satellite in 1972, the mission has gathered and archived more than 8 million images of our home planet's terrain, including crop fields and sprawling cities, forests and shrinking glaciers. These data-rich images are free and publicly available, leading to scientific discoveries and informed resource management.

The continuous flow of Landsat data has enabled researchers to monitor global land cover for more than 48 years. With each pixel recording data on an area the size of a baseball infield, 98 feet (30 meters) across, Landsat images are detailed enough to detect both natural and human-caused changes to the landscape.

More than 18,000 peer-reviewed research papers have used Landsat data. The mission helps deter-

mine the health of global crops and the extent of agricultural irrigation. It allows organizations to detect deforestation in remote areas of the globe and quantify the impact of wildfires. It also feeds efforts to improve wildlife habitat and prepare for natural disasters.

The Landsat mission, a partnership between NASA and the U.S. Geological Survey (USGS), has provided the longest continuous record of Earth's land surfaces from space. The consistency of Landsat's land-cover data from sensor to sensor and year to year makes it possible to trace land-cover changes from 1972 to the present, and it will continue into the future with Landsat 9. With better technology than ever before, Landsat 9 will enhance and extend the data record to the 50-year mark and beyond.

Continuing the Landsat Legacy

Building on the Landsat Legacy. Prior to 1972, the idea of using satellite data for land monitoring, mapping, or exploration was a novel concept. The Landsat Program—a series of Earth-observing satellite missions jointly managed by NASA and USGS—has revolutionized the way humans view and study our planet. This graphic depicts the 9 satellites that make up the Landsat series. Landsat 6 was lost in a launch failure in 1993. Landsat 7 and 8 are still operational, and Landsat 9 will continue the legacy of the Landsat missions' rich, global archive.

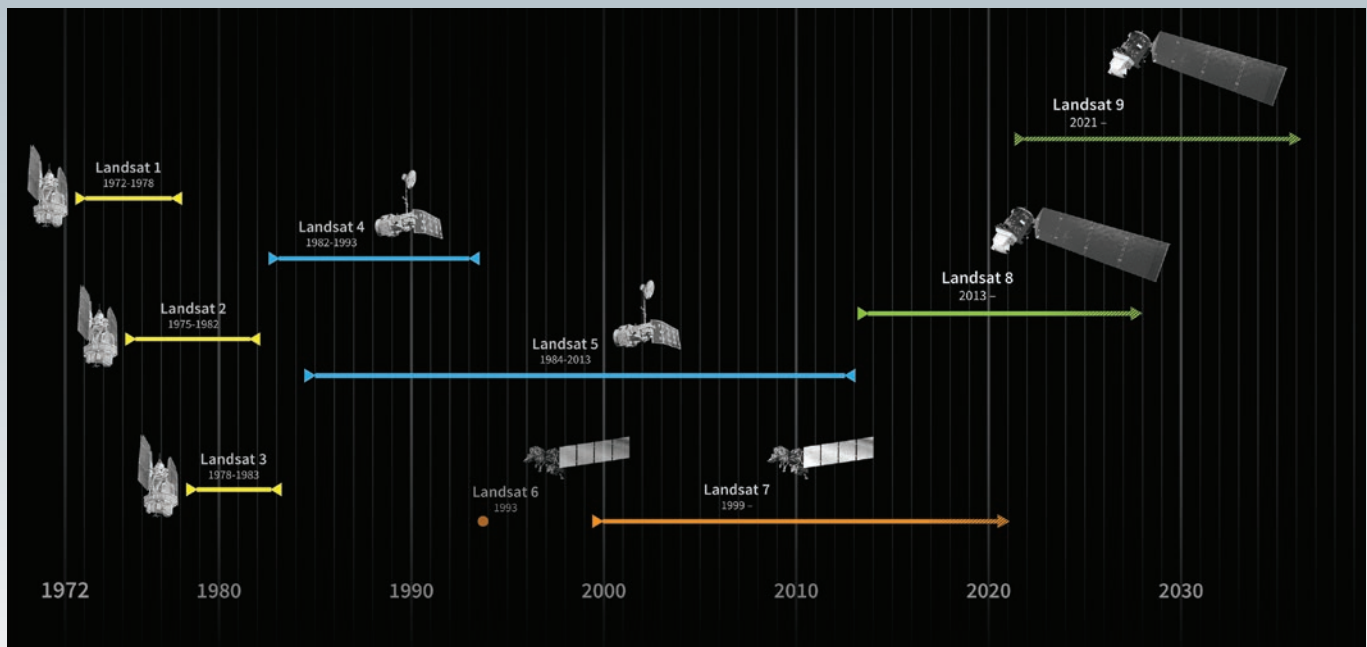


Image credit: NASA

Landsat 9

The newest Landsat satellite strikes a balance: Using state-of-the-art technology, Landsat 9 will collect the highest quality data ever recorded by a Landsat satellite, while still ensuring that these new measurements can be compared to those taken by previous generations of the Earth-observing satellite.

The new satellite will add more than 700 scenes of Earth to the mission's archive each day. A near-polar orbit will allow the satellite's sensors to image almost the entire planet every 16 days. When Landsat 9 joins Landsat 8 in orbit, the two satellites together will be able to image each swath of the globe every eight days.

Landsat 9 will carry two instruments that largely replicate the instruments on Landsat 8: the Operational Land Imager 2 (OLI-2) and the Thermal

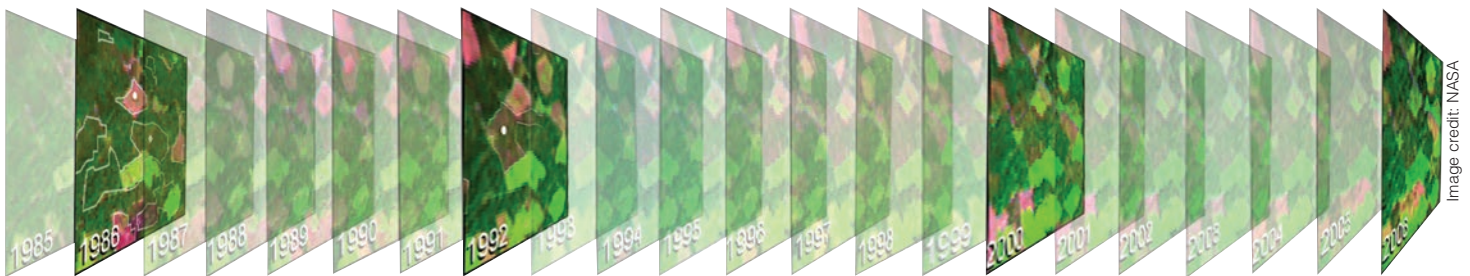
Infrared Sensor 2 (TIRS-2). OLI-2 and TIRS-2 are optical sensors that detect 11 wavelengths of visible, near infrared, shortwave infrared, and thermal infrared light as it is reflected or emitted from the planet's surface. Data from these instruments are processed and stored at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota—where decades worth of data from all of the Landsat satellites are stored and made available for free to the public.

As Earth's population approaches 8 billion people, Landsat 9 will continue to provide consistent and impartial data about the changing land cover and land use of our planet, and enable enhanced studies of the footprint of the growing population.



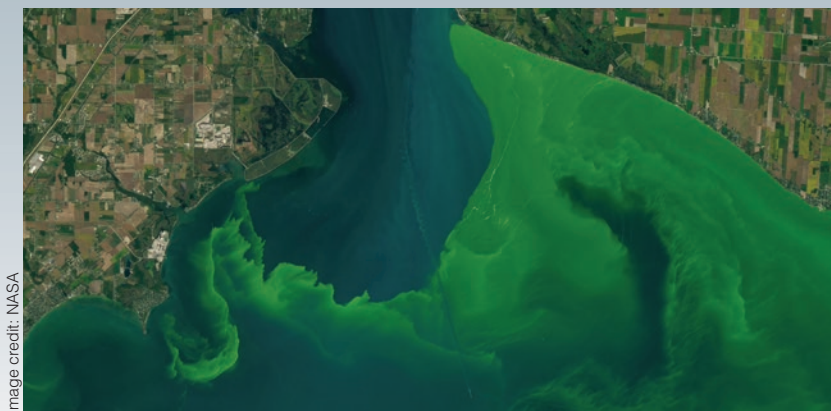
Older images

Newer images



Landsat 9 will have the same resolution as its predecessors, and the data will be precisely mapped to the globe so that researchers can study how each individual pixel—each parcel of land—changes over time.

Continuing the Legacy of Tracking Water Quality



Spotting Algal Blooms from Space. Harmful algal blooms can cause big problems in coastal areas and lakes across the United States. When toxin-containing aquatic organisms multiply and form a bloom, it can sicken people and pets, contaminate drinking water, and force closures at boating and swimming sites. With limited resources to monitor these often-unpredictable blooms, water managers are turning to data from Landsat and other Earth-observing satellites. With its medium resolution, Landsat can gather data on smaller lakes than other satellites can, allowing scientists to track water quality information from more than 60% of the U.S. lakes and reservoirs, or more than 170,000 waterbodies. The image here shows a green algal bloom in western Lake Erie, taken by Landsat 8's Operational Land Imager on September 26, 2017.

Operational Land Imager 2 (OLI-2)



OLI-2 is being built and assembled by Ball Aerospace and Technologies Corporation. **Photo credit:** Ball Aerospace and Technologies Corporation

The OLI-2 instrument will produce stunning images of our home planet—algae swirling in the North Sea, teal melt ponds on a bright white glacier, checkerboards of crop fields stretching for miles—but the data behind these images will tell scientists and land managers so much more.

Within the OLI-2 instrument are thousands of detectors, aligned in rows. These detectors are sensitive to light reflecting off Earth's surface in nine different wavelengths, including visible, near-infrared and short-wave-infrared light. With data from these bands, either alone or in combination, Earth's surface is revealed.

For example, healthy plants reflect near-infrared light, so strong signals in that band, relative to others, provide scientists with information about growing vegetation. Information from the shortwave infrared bands can help ecosystem managers identify regions that have been scarred by wildfires. Visible light bands revealing subtle color variations in lakes can help water managers identify potentially harmful algae blooms.

Several of these bands replicate the wavelengths detected by previous Landsat instruments—allowing Landsat 9 to maintain continuity with decades of previous observations. The Landsat 8 OLI instrument introduced two new bands: one that detects cirrus clouds and one that has improved observations of coastal waters and aerosols. Landsat 9 will downlink 14-bit data from OLI-2, as compared with 12-bit data from Landsat 8 OLI, leading to improved observations of darker regions, such as forests and coastal waters.

OLI-2 will have a 98-foot (30-meter) spatial resolution across most of its spectral bands, meaning each pixel represents an area about the size of a baseball infield. Altogether, the sensors cover a swath 115 miles (185 kilometers) wide. This combination of a wide swath and moderate resolution allows OLI-2 to cover large areas, while still providing fine enough resolution to distinguish individual agricultural fields, forest plots or housing developments—important information for urban planners, land resource managers and commodity analysts.

Continuing the Legacy of Disaster Response

Burned Area Emergency Response Maps. Before wildfires stop smoldering, forest restoration specialists are on the job. They analyze maps created using Landsat satellite data, called Burned Area Emergency Response maps, to determine where a burn destroyed vegetation and exposed soil—and to identify where to focus emergency restoration efforts. These maps can save federal agencies as much as \$7.7 million annually in post-fire costs, according to a 2019 study. Fire managers analyze before and after images from the near-infrared band, which reflects strongly from healthy vegetation, and the shortwave-infrared band, which reflects strongly from exposed ground, to identify scorched areas. The images below show the location of the 2013 Silver Fire in New Mexico. The “before” image [left] is a false-color Landsat 8 image acquired May 28, 2013. The “during” image [middle] shows the location of the fire (bright red dot) and burn scar (dark red) on June 13, 2013, while the fire was still growing. The image on the right is an example of a Burned Area Emergency Response map created using Landsat data, showing areas with high (red), moderate (yellow) and low (green) severity burns. Fire managers use maps like these to direct restoration resources.

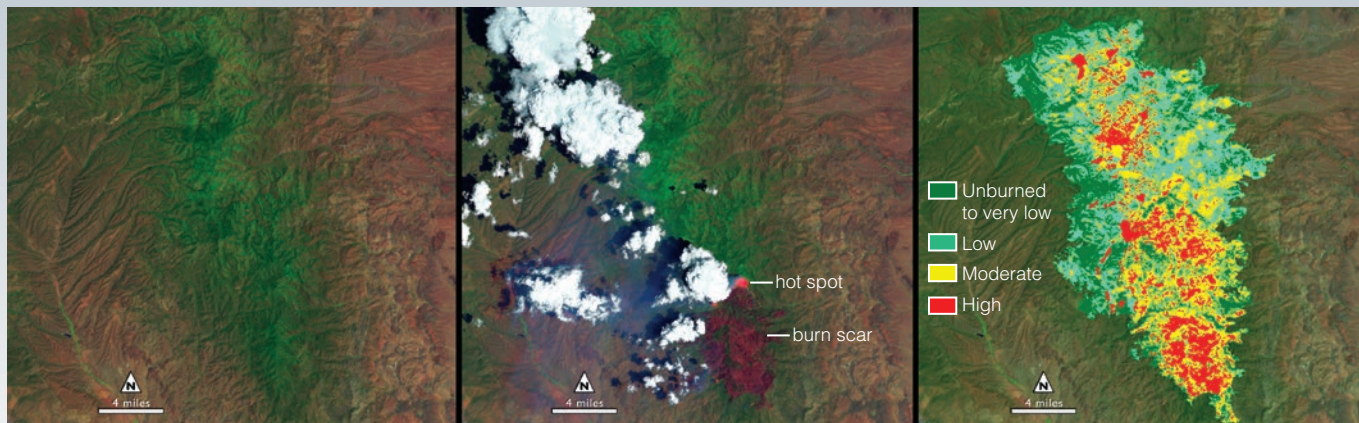


Image credit: USDA Forest Service, Burned Area Emergency Response Team

Thermal Infrared Sensor 2 (TIRS-2)

Whether it's a cornfield, a parking lot, or an iceberg, a surface emits thermal infrared radiation, or heat. By detecting radiation in two thermal wavelengths, Landsat 9's TIRS-2 instrument can measure the temperature of our planet's ground and water.

TIRS-2 uses thermal bands to detect subtle shifts in temperature—within a tenth of a degree Celsius. Its detectors are called Quantum Well Infrared Photodetectors, or QWIPs, and were developed at NASA's Goddard Space Flight Center in Greenbelt, Maryland. Thermal infrared radiation in a specific wavelength will excite electrons within the QWIPs, creating an electrical signal that is used to determine surface temperature.

Observing surface temperatures from space can be difficult, however, as atmospheric moisture and air temperature can skew the signals. The atmosphere affects each of the TIRS-2 thermal bands slightly differently, resulting in a thermal image from one of the bands that is slightly darker than the other. Computer programs can analyze that difference to compensate for atmospheric effects, creating a more accurate temperature record of Earth's surface.

TIRS-2 works on the same principles as the original TIRS on Landsat 8, but corrects a problem the first instrument had with scattered light inside the telescope. And while TIRS has a three-year design life, TIRS-2 is built with increased robustness and redundancy to last at least five years. TIRS-2, like OLI-2, is a “push-broom” sensor with arrays of detectors that line up to observe a field of view that is 115 miles (185 kilometers) across, with a resolution of 328 feet (100 meters).

Water resource managers, who use temperature measurements from the Landsat satellites to help track agricultural water use, advocated for the inclusion of the original TIRS on Landsat 8. Water in the soil, as well as water released from a plant's leaves as it undergoes transpiration, results in cooler temperatures over irrigated, healthy crops—which can be detected in TIRS data.

Scientists and resource managers have used Landsat thermal observations to locate the perimeters of active fires, since the thermal bands can penetrate smoke that might otherwise obscure the view. TIRS data can also be used to “see” in the polar night, tracking icebergs in winter when there is little visible light for other bands to detect.



Engineers at NASA Goddard work on TIRS-2, which will measure surface temperatures on Earth's surface from the Landsat 9 satellite. **Photo credit:** NASA

Continuing the Legacy of Ice Observations

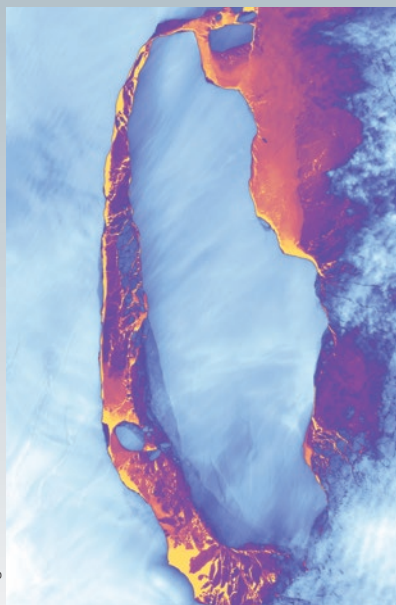
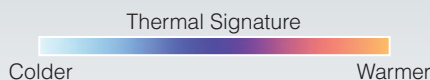


Image credit: NASA

Tracking Ice in Polar Darkness. Under the cloak of Antarctica's polar night, a massive iceberg calved from the Larsen C Ice Shelf in July 2017. Despite the lack of sunlight, thermal images from Landsat 8's TIRS instrument were able to tell the story of how a chunk of ice about the size of Delaware broke loose from the Antarctic Peninsula. On September 16, 2017, the TIRS instrument on Landsat 8 took this false-color image of the berg, showing the relative warmth or coolness of the surfaces, allowing scientist to track its split and movement. Light blue and white colors are the coldest surfaces, including the ice shelf and thick iceberg. Purples reveal areas of thin sea ice, and regions of mixed water, ice, and snow called mélangé. The yellows and oranges indicate the warmest surfaces, such as the open water between the shelf and berg.



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Launch and Operations



On February 11, 2013, at 1:02 p.m. Eastern Standard Time (10:02 a.m. Pacific Standard Time), an Atlas V rocket successfully carried the Landsat Data Continuity Mission (LDCM)—later renamed Landsat 8—into orbit from Vandenberg Air Force Base in California. **Photo credit:** NASA

Landsat 9 will launch from Vandenberg Air Force Base in California, in a United Launch Alliance Atlas V rocket. It will go into a near-polar orbit at an altitude of 438 miles (705 km) above Earth, travelling 16,760 miles per hour (26,972 km per hour).

The two instruments aboard Landsat 9 are integrated onto a spacecraft bus built by Northrop Grumman Space Systems. The spacecraft—which has a design similar to the one used for Landsat 8—provides the satellite with power, orbit control, propulsion, navigation, communications, data storage and more.

Four solar panels will deploy after launch, to charge the spacecraft's battery. A data recorder onboard

will store up to 4 terabits of data, before the data are transmitted to one of three ground stations—either in Gilmore Creek, Alaska; Svalbard, Norway; or Sioux Falls, South Dakota.

The data are archived at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, which also generates the data products used by scientists, resource managers and other users. This is one element of the Landsat 9 ground system—the other consists of the Mission Operations Center (MOC) at NASA Goddard, which issues software commands to control the satellite observatory and direct science data collection.

Continuing the Legacy of Helping Farmers

Using Landsat Data to Track Regional Crop Changes. From major crops like corn and wheat, to regional crops like rice and citrus, the U.S. Department of Agriculture (USDA) tracks America's farmland with the help of data from Landsat satellites. Landsat satellites see detail at the human scale, about the size of a baseball diamond, and can image individual farm fields. The agency's Cropland Data Layer program started in 1997 in North Dakota, as an experiment. Other states became interested and the program grew. Landsat's detailed view, combined with on-the-ground surveys and other tools, allows the USDA to tally crop type and acreage, county by county, and state by state for the contiguous U.S. At the end of each year, the USDA releases a cropland data layer. This effort began in 2009 and continues today. The 2018 map, below, shows several different agricultural patterns, including a patchwork of corn (in yellow) and soybeans (in green) in the Midwest, and the diversity of crops in California's central valley. With a decade of these maps, farmers and others can see how agriculture changes through the years.

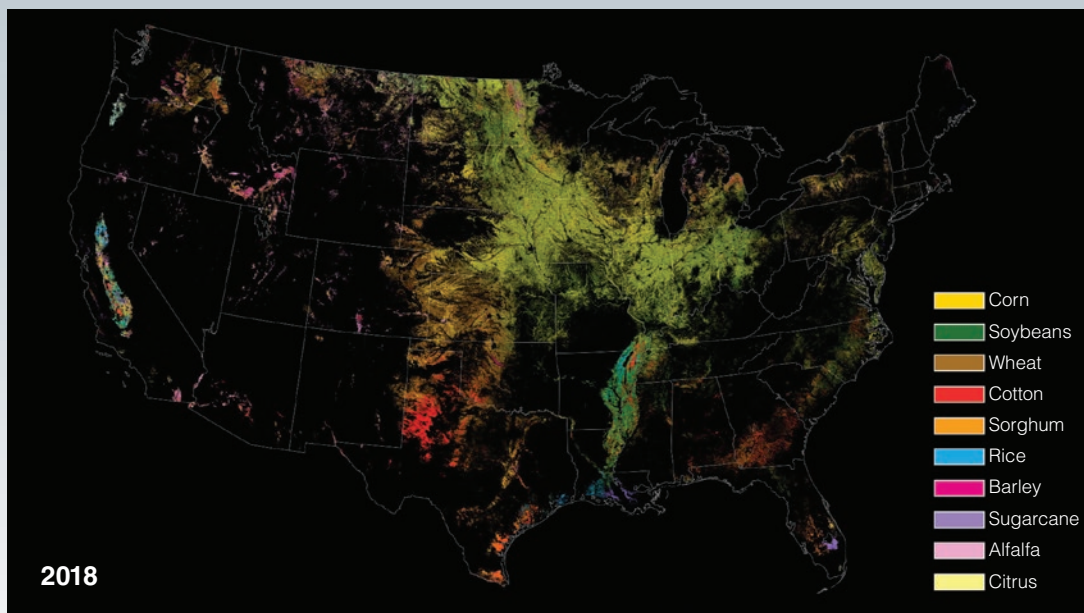


Image credit: NASA

An Invaluable Archive

To investigate how Earth has changed in the last half a century, look to Landsat. The mission's archive is a continuous data record of natural and human-caused changes to land, ice and water since 1972.

Containing more than 8 million images, the archive provides researchers and decision-makers with an essential tool to understand and manage our planet's food, water and forests.

The archive contains raw, newly acquired data, as well as refined products depicting burned areas, snow cover, surface reflectance, water and temperature. While the data exist in formats ready for experienced analysts and researchers, tools such as the USGS Global Visualization Viewer (GloVis, glovis.usgs.gov) and EarthExplorer (earthexplorer.usgs.gov) also allow individuals to view and search images directly from their web browsers.

In 2008, USGS made the entire Landsat archive free and available to the public. The archive is open for

people to investigate vast geographic areas and temporal spans—studies that were often cost-prohibitive before the archive opened. Since 2008, the number and complexity of studies using Landsat data has grown exponentially.

The advent of big data analysis and cloud computing have further unlocked the archive's power. By using cloud computing platforms and other powerful analysis tools, researchers can quickly and accurately look for patterns and changes across decades-long timeframes or large swaths of the globe.

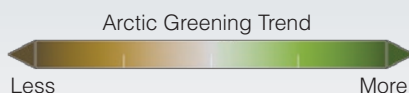
The Landsat archive gives researchers power to investigate questions about our changing world. With access to this one-of-a-kind archive, we can monitor our natural resources at local and global scales, and empower natural-resource managers to make informed decisions for the future.

To investigate how Earth has changed in the last half a century, look to Landsat.

Continuing the Legacy of Tracking Climate Change Impacts



Image credit: NASA



Landsat Reveals Greening Across North America's Arctic. The northern reaches of North America are getting greener, according to a NASA study that examined plant life across Alaska and Canada. In a changing climate, almost a third of the land cover—much of it Arctic tundra—is looking more like landscapes found in warmer ecosystems. With 87,000 images taken from Landsat satellites between 1984 and 2012, converted into data that reflects the amount of healthy vegetation on the ground, the researchers found that western Alaska, Quebec and other regions became greener over three decades. Rapidly warming temperatures in the Arctic have led to longer growing seasons for plants and changes to the soils. Grassy tundra changes to shrubland, and shrubs grow bigger and denser—changes that could impact regional water, energy and carbon cycles.



Landsat 9 Quick Facts

Mission Management and Operations: NASA's Goddard Space Flight Center manages the development of Landsat 9 through its launch and post-launch checkout. The USGS Earth Resources Observation and Science Center operates the satellite and manages the data archive.

Spacecraft Provider and Observatory Integration: Northrop Grumman Space Systems

OLI-2 Provider: Ball Aerospace

TIRS-2 Provider: NASA's Goddard Space Flight Center

Altitude: 438 miles (705 kilometers)

Orbit Duration: 99 minutes

Orbits per Day: 14

Images per Day: 700+

Coverage of Earth: Every 16 days

Launch Vehicle: United Launch Alliance Atlas V 401 rocket

Launch Site: Vandenberg Air Force Base, California

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