Landsat Data Continuity Mission

Continuously Observing Your World

In an era when receipt of images and data from low-Earth-orbiting satellites is more or less "routine," it's hard to remember that a few short decades ago this was not the case. As the first land-observing satellite program, Landsat laid the foundation for modern space-based Earth observation. Today, Landsat offers the longest near-continuous data record of Earth's land surface as observed from space.

Laura Rocchio
"Chronicling the Landsat Legacy"
The Earth Observer, *November – December 2011, Vol. 23, Issue 6, pp. 4 – 10.*

Acknowledgments

Landsat Program
landsat.gsfc.nasa.gov
landsat.usgs.gov

Landsat Data Continuity Mission
ldcm.gsfc.nasa.gov

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Image Credit: NASA

Key Landsat Characteristics

- Landsat satellites provide an unparalleled record of Earth's varying landscapes.
- Landsat's 30-meter resolution—about the size of a baseball diamond—is ideal for measuring both natural changes and human impacts on land.
- The consistency of Landsat's digital image data from sensor to sensor and year to year makes it possible to trace land cover changes from 1972 to the present and into the future with LDCM.

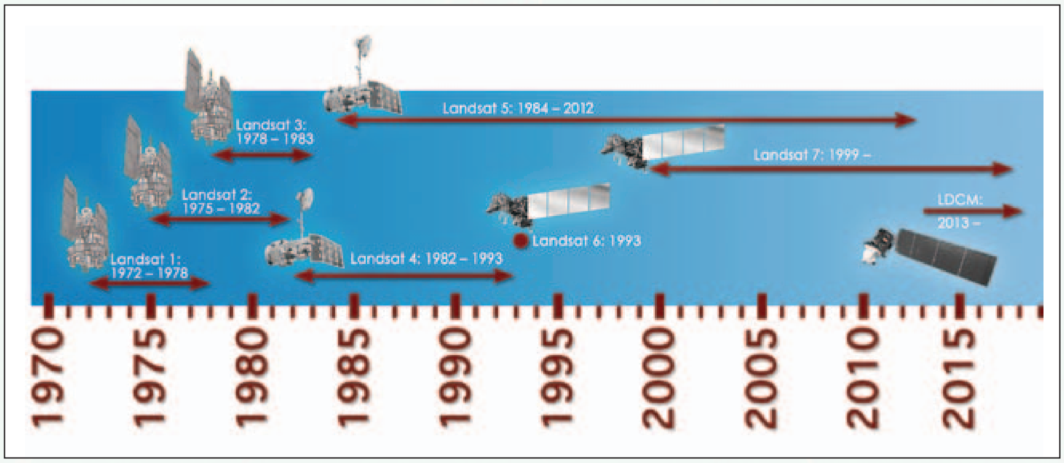
The Landsat Legacy

Prior to 1972, the idea of using satellite data for land monitoring, mapping, or exploration was a visionary concept. The Landsat Program—a series of Earth-observing satellite missions jointly managed by NASA and the United States Geological Survey (USGS)—has revolutionized the way humans view and study our planet. The data series, which began in 1972, is the longest continuous record of changes in Earth's surface as seen from space and Landsat has been the only satellite system designed and operated to repeatedly observe the global land surface at moderate resolution. The Landsat Data Continuity Mission (LDCM) will continue the legacy of Landsat's rich, global, medium-resolution archive.

Landsat Science

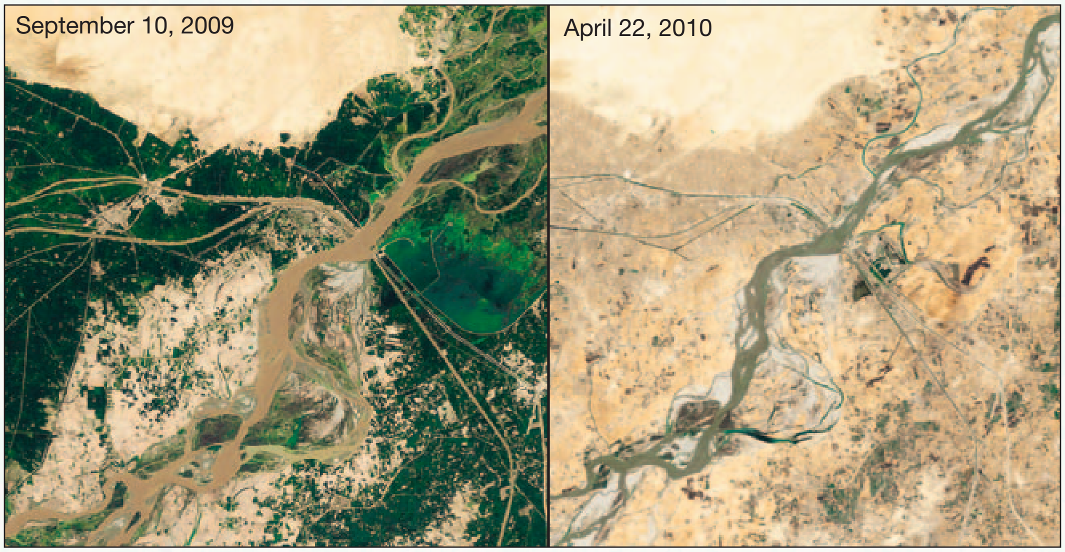
Landsat data have helped to improve our understanding of Earth. Thanks to Landsat, today we have a better understanding of surface features as diverse as coral reefs, glaciers, and tropical forests.

Landsat imagery fills an important scientific niche. Landsat's near-polar orbit allows nearly the entire Earth to fall within view once every 16 days. Its 185-kilometer (115-mile) wide orbital swaths are broad enough



Credit: NASA

This graphic depicts the eight satellites that make up the Landsat series. Beginning with Landsat 1, launched in 1972, this graphic shows the operational life span of each satellite. Landsat 6 was lost in a launch failure in 1993. Note that Landsat 5 Thematic Mapper operations ended in 2011. LDCM will be renamed Landsat 8 when it reaches orbit.



Credit: NASA's Earth Observatory

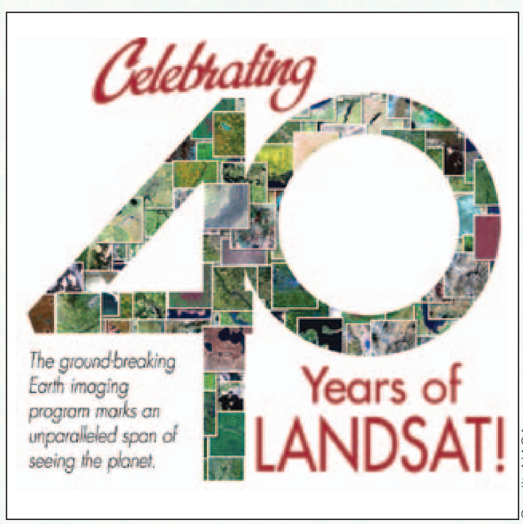
These natural-color images, captured by the Thematic Mapper on the Landsat 5 satellite, show seasonal changes in vegetation along a small portion of the Indus River around the Guddu Barrage on September 10, 2009 (left), and April 22, 2010 (right). The Indus River typically crests in July and August. The barrage, or dam, diverts water from the Indus for irrigation and by September, lush vegetation carpets the land on either side of the river.

for global coverage every season of the year. With a spatial resolution of 30-meters (98-feet), images acquired by Landsat are detailed enough to characterize human-scale processes such as urban growth, agricultural irrigation, and deforestation.

By establishing baseline knowledge of Earth's land areas over the last half century, Landsat enables scientists to evaluate environmental change over time. Through 40 years of continuous coverage, the Landsat series of Earth-observation satellites has become a fundamental global reference for scientific issues related to land use and natural resources. For example, Landsat holds the distinction of being the only satellite record that is both long and consistent enough to track land-cover changes related to climate change at the scale of cities and farms.

Landsat is valued all over the world as the gold standard of land observation.

No other civilian satellite program, in our nation or in any other country, comes close to having the historical length and breadth, the continuity, and the coverage of the Landsat archive.

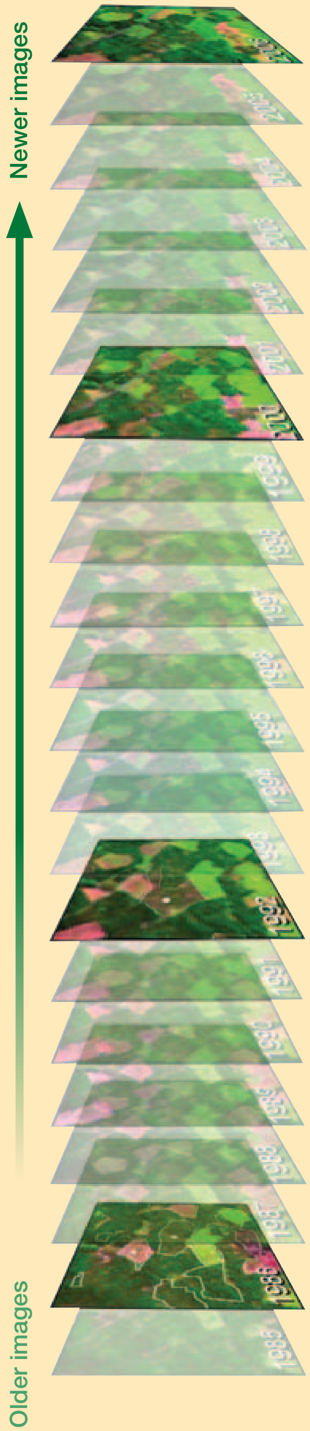


Credit: NASA

The knowledge gained from 40 years of continuous data contributes to research on climate, carbon cycle, ecosystems, water cycle, biogeochemistry, and changes to Earth's surface, as well as our understanding of human effects on land surfaces.

LDCM

The Future of Landsat Satellites



Credit: NASA

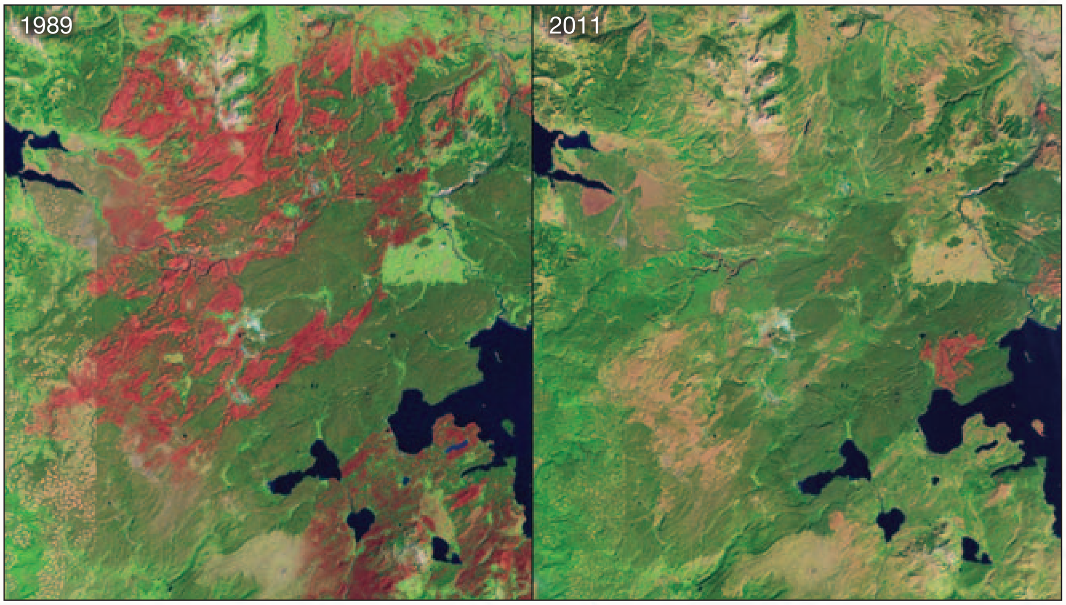
Data from LDCM will be referenced to the same coordinate system as Landsat 4, Landsat 5, and Landsat 7 to allow easy comparison between images.

Credit: Orbital Sciences Corp.

The LDCM observatory consists of the spacecraft bus with the instruments mounted on top in this photo.

The Landsat Data Continuity Mission (LDCM), a collaboration between NASA and the United States Geological Survey (USGS), is the eighth satellite in the Landsat series and is the future of Landsat satellites. It is poised to expand, improve, and advance the unique and highly beneficial long-term record of Earth's landscapes, while maintaining the high-value heritage of its six Landsat predecessors.

Following launch, the LDCM satellite will be renamed Landsat 8. The system will consist of two major segments: the observatory and the ground system. The observatory consists of the spacecraft bus and its payload of two Earth-observing sensors, the Operational Land Imager (OLI), and the Thermal Infrared Sensor (TIRS). OLI and TIRS will collect data jointly to provide coincident images of the global land surface including coastal regions, polar ice, islands, and the continental areas. In addition, LDCM will follow the same sequence of fixed ground tracks (also known as paths) as the Landsat 4, Landsat 5, and Landsat 7 satellites. This will allow all of the science data from LDCM to be referenced to the same coordinate system, continuing the decades-long data record.



Credit: NASA's Earth Observatory

The two Landsat images above show the aftermath of the 1988 Yellowstone National Park wildfires. The 1989 image [left] shows burn scars in bright red while the 2011 image [right] shows recovery as green vegetation develops within the burned areas. The instruments onboard LDCM will provide valuable data that can be used to answer questions about Earth's changing surface including the land surface conditions before and after disasters such as fires, floods, tornadoes, and hurricanes.

The spacecraft bus will store the OLI and TIRS data on an onboard solid-state recorder and then transmit the data to ground receiving stations. The ground system will also provide the capabilities necessary for planning and scheduling the operations of the LDCM observatory and the capabilities necessary to manage and distribute the science data.

The LDCM spacecraft, built by Orbital Sciences Corporation, has a design life of 5 years, but carries sufficient fuel for 10 years of operations. The spacecraft will orbit from north to south during the day, crossing the equator at about 10:00 AM local time, and will fly 705 kilometers (438 miles) above Earth.

Each Landsat pixel represents a quarter of an acre—making the images ideal for identifying land use patterns. In the image at right, taken by Landsat 7 on May 28, 2003, small, blocky shapes of towns, fields, and pastures can be seen surrounding the graceful swirls and whorls of the Mississippi River near Memphis, Tennessee.

Credit: NASA/USGS

LDCM Characteristics

Altitude: 705 km (438 mi)

Inclination: 98.2º ± 0.15º

Speed: 7.6 km/sec (4.7 mi/sec)

Orbit duration: 99 minutes

Orbits per day: 14

Views entire Earth: 16 days

Design life: 5 years

Fuel life: 10 years

NASA helped lead engineers from Orbital Sciences Corporation through a series of mission readiness tests and mechanical tests to validate that the LDCM observatory can survive the launch environment. This image was taken on August 7, 2012 at Orbital Sciences Corporation in Gilbert, Arizona.

Evolutionary Advances

Technology and Performance

Landsat sensors enable us to see beyond what our human eyes alone can see, not only because the satellite's perspective on Earth comes from an orbit of 705 kilometers (438 miles), but also because the sensors record light reflected and emitted from Earth's surface in specific infrared wavelengths as well as visible ones.

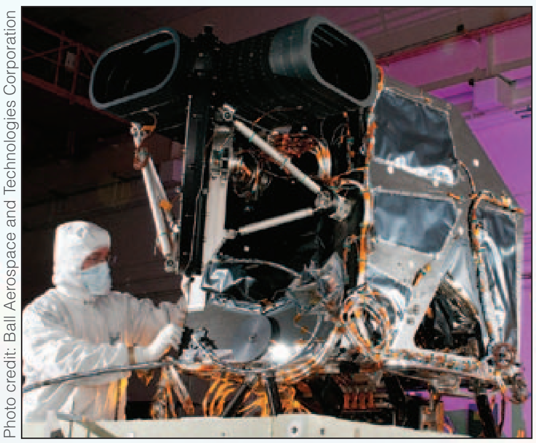


Photo credit: Ball Aerospace and Technologies Corporation

The new OLI design, built by the Ball Aerospace & Technologies Corporation, is expected to be more reliable than earlier Landsat instruments (e.g., the Thematic Mapper and Enhanced Thematic Mapper-Plus) and provide improved performance.

The two science instruments aboard LDCM—the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS)—represent evolutionary advances in sensor technology and performance. OLI and TIRS will measure Earth's surface in the visible, near infrared, shortwave-infrared, and thermal infrared with a moderate resolution between 15 and 100 meters—depending on spectral wavelength. The distribution of observed energy across these spectral wavelengths reveals information about the reflecting and emitting surfaces.

To make it possible for scientists to compare new Landsat images to Landsat images taken in the past, engineers had to design the next Landsat satellite to measure roughly the same spectral bands as previous Landsat satellites. In addition, the OLI provides two new spectral bands—one tailored especially for detecting cirrus clouds and the other for coastal zone observations. TIRS will collect data for two additional narrow spectral bands in the thermal region, formerly covered by only one wide spectral band on Landsats 4–7 to measure Earth's thermal energy (i.e., heat).

LDCM is also required to return 400 scenes per day (150 more scenes per day than required of Landsat 7) to the USGS data archive, increasing the probability of capturing cloud-free scenes for the global landmass.

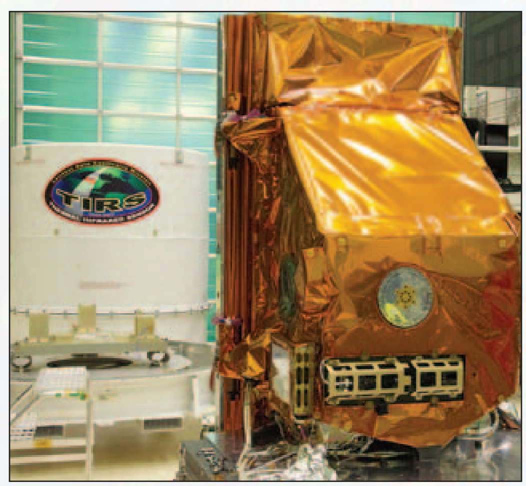
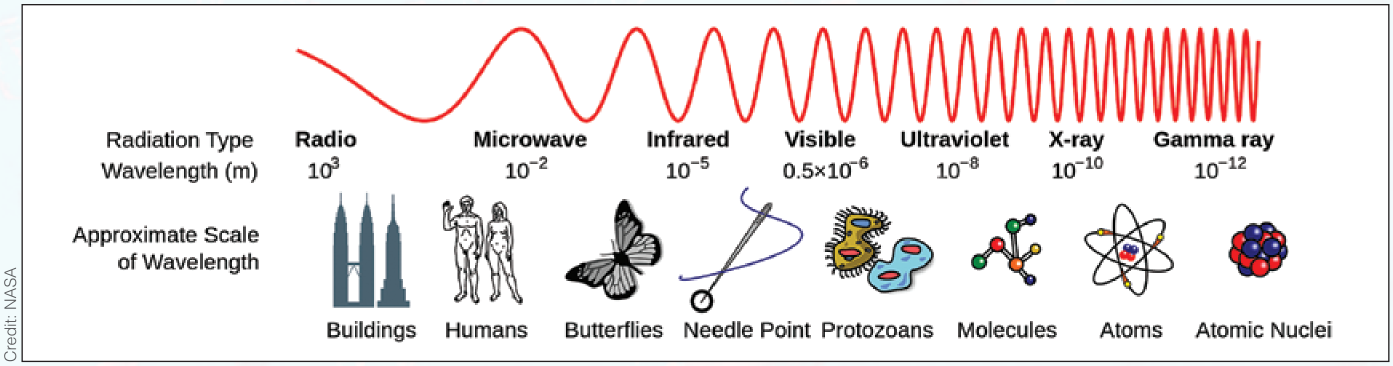


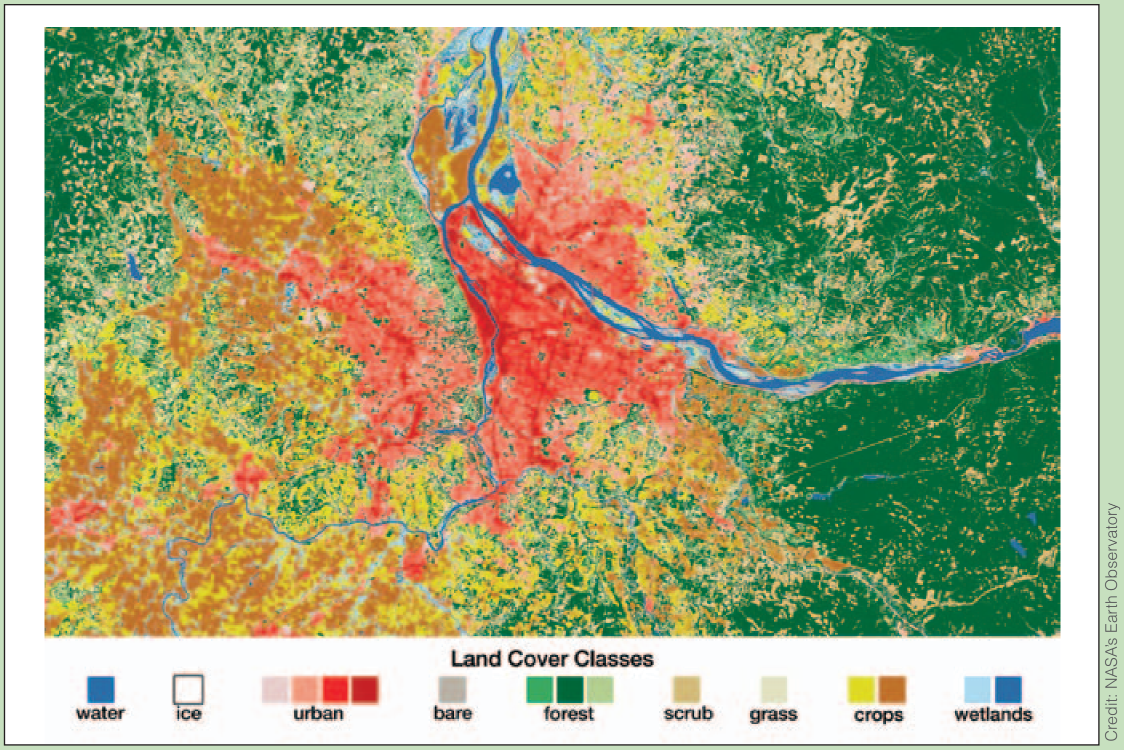
Photo credit: NASA

The TIRS instrument, built in-house at NASA's Goddard Space Flight Center, uses a new technology that is sensitive to two thermal infrared wavelength bands—an advancement over the single thermal band data collected by previous Landsat satellites.



The electromagnetic spectrum is the range of traveling waves of energy that include short gamma and x-ray, ultraviolet light, microwaves, and long radio waves. Human eyes are adapted to see a narrow band of this spectrum called visible light. Using satellite sensors to detect multiple spectral band combinations, scientists can "tune in" to study various aspects of land cover in ways they cannot from a photograph. Soils, different plant types, plant health, the presence of water, bare rock, ice, and many other types of land cover each leave their "signatures" in the electromagnetic spectrum and scientists can observe and analyze these patterns to detect changes in the land surface.

Sensing a Wealth of Scientific Data



Landsat satellites can characterize land cover in units about the size of a baseball diamond. Assembling millions of these measurements results in maps like this that show different land cover types surrounding Portland, Oregon from January 1 to December 31, 2001. Landsat can distinguish between these different land cover types because it detects not just visible light, but also infrared. Trees, crops, water, and city landscapes all reflect light differently throughout the growing season. This spectral signature allows scientists to determine what kind of land cover exists in each pixel. In this case, colors are assigned to each land cover type. Shades of red indicate urban areas, while shades of green indicate different types of forest. This map is from the National Land Cover Database 2001, which was assembled from observations by the Enhanced Thematic Mapper-Plus on Landsat 7.

OLI

Advanced Sensor Technology

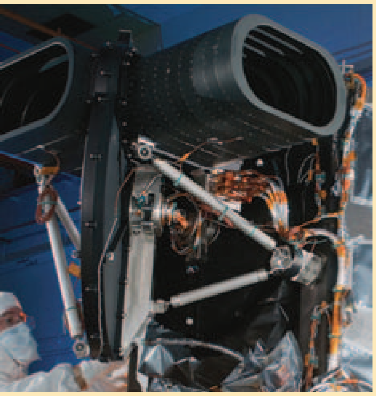


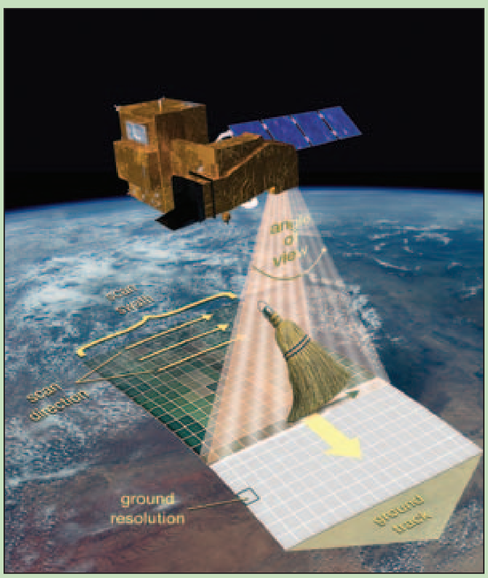
Photo credit: Ball Aerospace and Technologies Corp.

Inside the cleanroom, technicians wear protective suits, nicknamed "bunny suits," to prevent dirt, dust, and other contaminants from coming in contact with the instrument parts. Engineers at Ball Aerospace & Technologies Corp. built OLI.

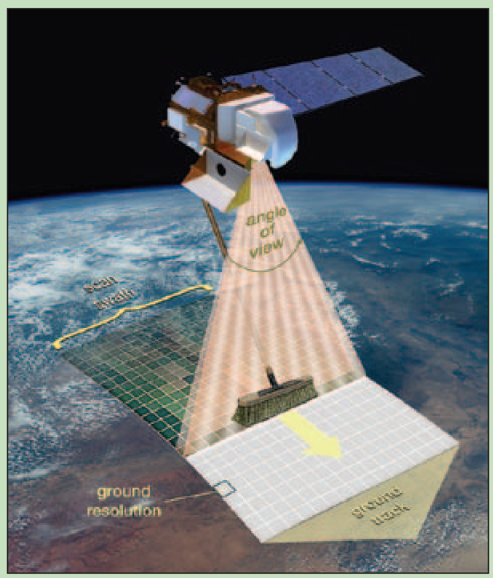
Photo credit: Ball Aerospace and Technologies Corp.

The Operational Land Imager (OLI) advances Landsat sensor technology using an approach demonstrated by the Advanced Land Imager sensor flown on NASA's experimental Earth Observing-1 (EO-1) satellite. Earlier Landsat satellites carried "whiskbroom" sensors that employed scan mirrors to sweep the instrument's field of view across the surface swath width and transmit light to a few detectors. The OLI, in contrast, is a "pushbroom" sensor that will use long detector arrays, with over 7000 detectors per spectral band, aligned across its focal plane to view across the swath. This "pushbroom" design results in a more sensitive instrument providing improved land surface information with fewer moving parts. Its images will have 15 meter (49 feet) panchromatic and 30 meter (98 feet) multi-spectral spatial resolutions (including visible, near infrared, and shortwave-infrared) along a 185 kilometer (115 miles) wide swath, covering wide areas of Earth's landscape while providing sufficient

Whiskbroom vs. Pushbroom Sensors

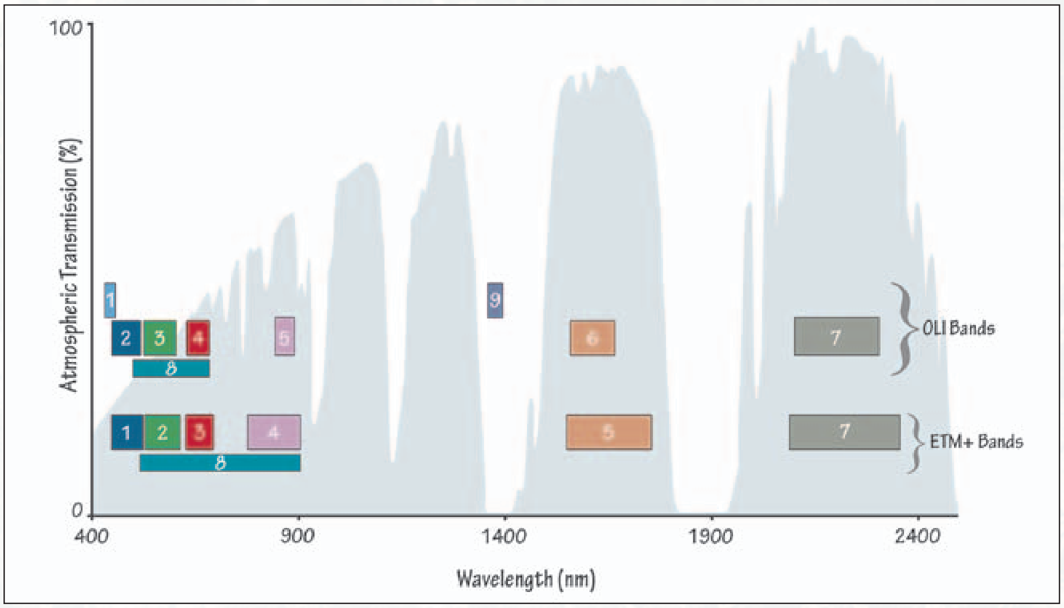


Previous Landsat sensors (i.e., the Multispectral Scanner System, Thematic Mapper, and Enhanced Thematic Mapper-Plus) used mirrors that swept back and forth, across the swath like a "whiskbroom" to collect data. This sensor design requires fast-moving parts, which are subject to wear.



New technologies allow OLI to view across the entire swath at once, building strips of data like a "pushbroom." The advantages are that pushbroom sensors require fewer moving parts and are more sensitive than whiskbroom sensors.

Image credits: NASA



Credit: NASA

This graph compares the portions of the electromagnetic spectrum that Landsat 7's Enhanced Thematic Mapper-Plus (ETM+) observed (lower row) to the parts of the spectrum that LDCM's OLI will observe (upper row). Note that OLI will detect two new spectral bands labeled 1 and 9 in the upper row.

resolution to distinguish features like urban centers, farms, forests, and other land cover.

The OLI was designed to have a five-year lifespan and will detect the same spectral bands as earlier Landsat instruments (that is, the Thematic Mapper and Enhanced Thematic Mapper-Plus sensors) with the exception of a thermal infrared band. In addition to seven heritage Landsat multispectral bands (six of which have been refined) OLI will add two new spectral bands—a blue "coastal" band (band 1) and a shortwave-infrared "cirrus" band (band 9). These new bands will, respectively, help scientists measure water quality and help detect high, thin clouds that have previously been difficult to see in Landsat images.

Credit: NASA's Earth Observatory

New technologies will allow OLI to use a blue band (band 1) to detect ocean color near coastal zones. This new band will help scientists measure chlorophyll concentrations (i.e., ocean color) in coastal regions. Most of the chlorophyll comes from phytoplankton, tiny plant-like organisms that live in surface waters. Such analyses can be helpful when attempting to use remote sensing to examine water quality.

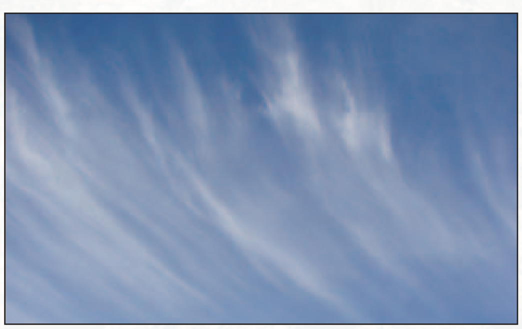
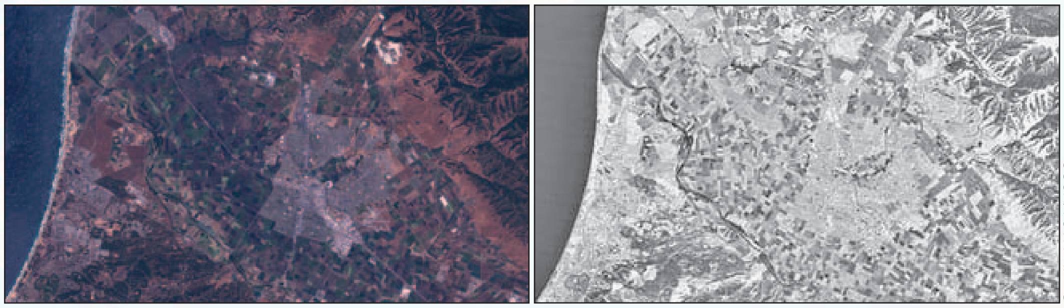


Photo credit: Doug McAbee

High, thin cirrus clouds can be hard to detect in satellite images. Both the clouds and their shadows can interfere with measurements. OLI's new shortwave-infrared band (band 9) will be able to detect these clouds better than previous Landsat sensors because it measures light in a short-wave infrared band particularly sensitive to the presence of cirrus clouds.

TIRS's Thermal Band Detection

Taking Earth's Temperature



Credit: NASA/USGS

These Landsat-5 images depict the region surrounding Salinas, California in true color [left] and thermal infrared [right]. In the true color image, different types of agricultural fields (shades of green) surround the town of Salinas (shades of gray and white). In the thermal infrared image, warmer temperatures appear in bright shades (e.g., the town of Salinas), and cooler temperatures appear darker (e.g., some agricultural fields and the ocean).

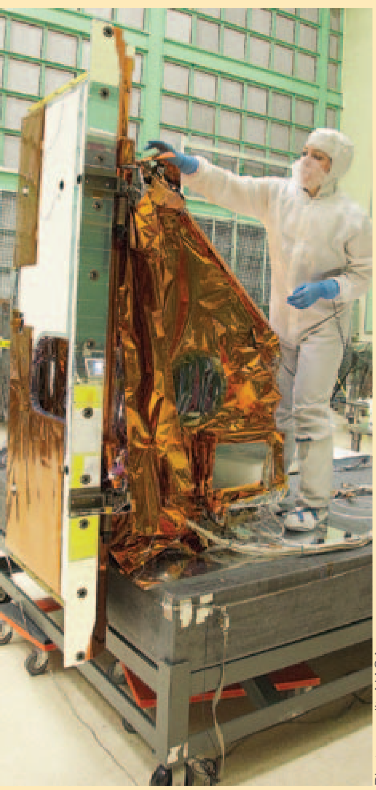


Photo credit: NASA

A technician reaches across the instrument to affix the corners of a multi-layer insulation blanket to the TIRS instrument.

Everything on Earth emits thermal infrared radiation, or heat. Physics tells us that the amount of emitted radiation is proportional to the object's temperature. The Thermal Infrared Sensor (TIRS) was added to the LDCM payload when it became clear that state water resource managers rely on the highly accurate measurements of Earth's thermal energy obtained by LDCM's predecessors—the Thematic Mapper on Landsat 5 and Enhanced Thematic Mapper-Plus on Landsat 7—to track how land and water are being used. The decision, however, came late. Engineers had less than four years to design and build TIRS so they turned to a new technology called Quantum Well Infrared Photodetectors (QWIPs) that NASA's Goddard Space Flight Center (GSFC) helped develop.

QWIPs are made from material that is compatible with silicon processing, meaning that the same tools that facilities use to make computer chips can be used to build QWIPs. QWIPs are very reliable, uniform, and well suited to TIRS requirements. The engineers at GSFC knew how to work with QWIPs and willingly took up the challenge to build TIRS in the short time available.

The QWIPs design operates on the complex principles of quantum mechanics. Gallium arsenide semiconductor chips trap electrons in an energy state "well" until the electrons are elevated to a higher state by thermal infrared light of a certain wavelength. The elevated electrons create an electrical signal that can be measured and recorded to create a digital image.

Previous Landsat satellites measured land surface temperature using a single thermal band to detect long wavelengths of light emitted by Earth. The QWIPs on TIRS, however, detect two segments of the thermal infrared spectrum, both falling within an atmospheric transmission window, to produce better estimates of surface temperature than can be retrieved from a single thermal band. These wavelengths, called thermal infrared, are well beyond the range of human vision.

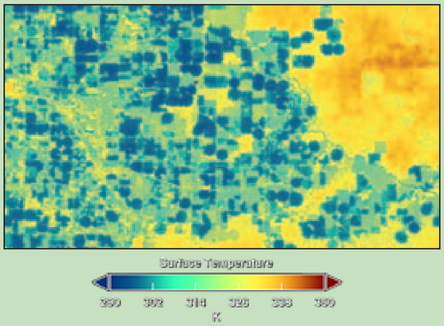
Like OLI, TIRS is also a pushbroom sensor with a 185-kilometer (115-mile) cross-track field of view. With a spatial resolution of 100 meters (328 feet) across, the TIRS spatial resolution is deemed sufficient for water consumption measurements over fields that use center-pivot irrigation—particularly across the U.S. Great Plains.

A major difference between OLI and TIRS specifications is that TIRS requires only a three-year design life. This relaxation was specified to help expedite the TIRS development. The designers were able to save schedule through more selective redundancy in subsystem components rather than the more robust redundancy required for a five-year design life.

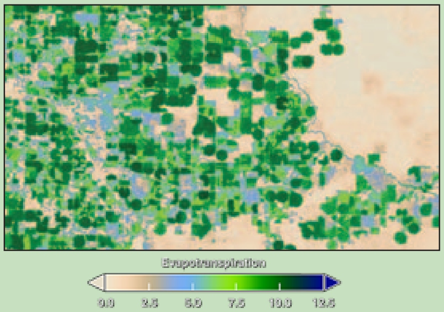
The Value of TIRS on LDCM

In the last ten years a team of scientists working with the Idaho Department of Water Resources developed a method that uses Landsat data to figure out how much water was being used by agricultural fields. They used the thermal infrared band that can measure temperature differences on the surface that correspond to water use by plants. The system, called Mapping EvapoTranspiration at High Resolution and Internalized Calibration, or METRIC, uses the thermal data to calculate water use on a field-by-field basis, and is used in some form in eleven states across the Western United States. When an earlier design of LDCM did not include a thermal infrared band, the Western States Water Council advocated for its inclusion. The TIRS on LDCM carries two thermal bands instead of one, and will continue the thermal band observations collected by previous Landsat satellites.

This real color image shows an agricultural region in Idaho. The round, green circles are individual irrigated farm fields. Information from Landsat bands 1, 2, and 3 (blue, green, and red bands) were combined to create this image. To our eyes, green fields of crops would all look similar, but Landsat "sees" things differently and reveals how these fields in Idaho differ in terms of the amount of water they consume.



Thermal measurements from Landsat satellites show that crops have different temperatures. This Landsat thermal band image shows the same agricultural region in Idaho on the same day. As growers irrigate farm fields, water evaporating from the soil and transpiring from the plants' leaves absorb energy and cool the fields.



Growing crops release water vapor through a process called transpiration and, as a result, the canopy cools. The crops transpiring more water register as cooler in this image showing evapotranspiration of the same agricultural region in Idaho on the same day (created by processing Landsat data with the METRIC).

Image credits: NASA's Earth Observatory

QWIPs Factoid

QWIPs are a new, lower-cost alternative to conventional infrared technology and NASA's Goddard Space Flight Center played a significant role in developing the technology.

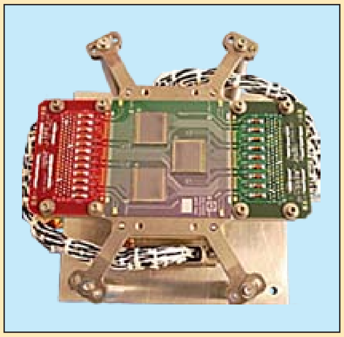
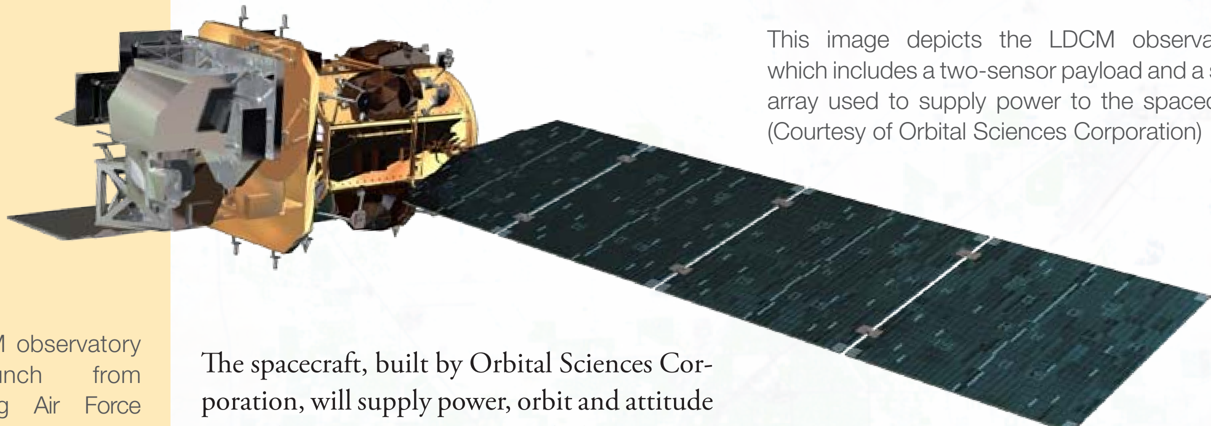


Photo credit: NASA

This is a photograph of the TIRS focal plane showing the QWIPs detector arrays. The three squares in the center of the circuit board are QWIPs arrays, which are gallium arsenide semiconductor chips. Each QWIP array contains 327,680 detectors.

Spacecraft Design



This image depicts the LDCM observatory, which includes a two-sensor payload and a solar array used to supply power to the spacecraft. (Courtesy of Orbital Sciences Corporation)

The LDCM observatory will launch from Vandenberg Air Force Base aboard an Atlas-V rocket, built by United Launch Alliance. NASA's Kennedy Space Center will support the launch. The USGS will take responsibility for LDCM mission operations after completion of the on-orbit checkout period.

Photo credit: Pat Corkery/United Launch Alliance

The spacecraft, built by Orbital Sciences Corporation, will supply power, orbit and attitude control, communications, and data storage for OLI and TIRS. The spacecraft consists of the mechanical subsystem (primary structure and deployable mechanisms), command and data handling subsystem, attitude control subsystem, electrical power subsystem, radio frequency (RF) communications subsystem, the hydrazine propulsion subsystem, and thermal control subsystem.

All the components, except for the propulsion module, will be mounted on the exterior of the primary structure. A 9.0 × 0.4 m (~29.5 x 1.3 ft) deployable solar array will generate power for the spacecraft components and will charge the spacecraft's 125 amp-hour nickel-hydrogen (Ni-H_2) battery. A 3.14-terabit solid-state data recorder will provide data storage aboard the spacecraft and an Earth-coverage X-band antenna will transmit OLI and TIRS data either in real time or played back from the data recorder. The OLI and TIRS will be mounted on an optical bench at the forward end of the spacecraft.

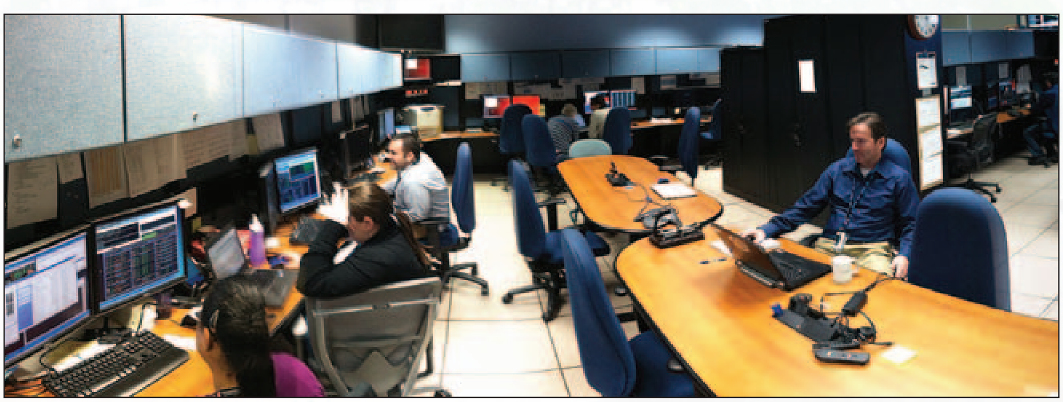


Photo credit: NASA

The USGS will manage LDCM flight operations from a mission operations center (MOC) at NASA's Goddard Space Flight Center where they will monitor the satellite 24 hours a day, 7 days a week. They will move the satellite if debris threatens it or if it drifts out of its ideal orbit.

Strength in Partnership

Photo credit: NASA

NASA Chief Scientist Waleed Abdalati, second from left, speaks during a joint NASA-USGS news conference, held to celebrate the fortieth anniversary of the launch of Landsat 1, at the Newseum, Monday, July 23, 2012, in Washington, DC. In cooperation with the U.S. Department of the Interior (DOI) and its science agency, the USGS, NASA will launch the LDCM spacecraft in early 2013. Anne Castle, Assistant Secretary for Water and Science, U.S. DOI, is at left and scientists Jeff Masek from NASA and Tom Loveland from the USGS look on.

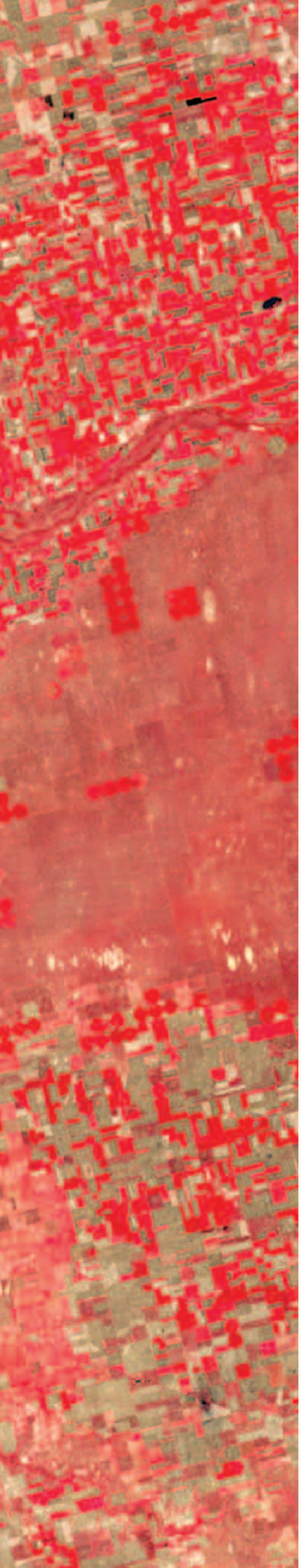
The fundamental LDCM operations concept is to collect, archive, process, and distribute science data in a manner consistent with the operation of the Landsat 7 satellite system. To that end, NASA and the USGS have well defined roles and responsibilities to carry out the mission.

NASA leads the development of the LDCM spacecraft and its two-sensor payload and is responsible for the launch. NASA also leads mission system engineering for the entire system and therefore acts as the system integrator with responsibility for mission assurance efforts through an on-orbit check out period.

The USGS leads the development of the ground system and will take responsibility for LDCM mission operations after completion of the on-orbit checkout period. Mission operations will include the scheduling of data collection along with receiving, processing, archiving, and distributing LDCM data. USGS program management for LDCM falls under the responsibility of the Land Remote Sensing Program, specifically Climate and Land-Use Change. Responsibility for ground system implementation and LDCM operations is assigned to the USGS Earth Resources Observation and Science (EROS) Center. EROS maintains the U.S. archive of data from all of the previous Landsat satellites.

Photo credit:USGS EROS Center

Receiving stations operated by USGS will collect data from LDCM. Data from LDCM will be processed and distributed at the USGS Earth Resources Observation and Science (EROS) Center in Sioux Falls, South Dakota.



The LDCM Ground System

The LDCM ground system includes all of the ground-based assets needed to operate the LDCM observatory. In simple terms, the LDCM ground system will perform two main functions: the first will be to command and control the LDCM observatory in orbit and the second will be to manage and distribute the data transmitted from the observatory.

The observatory is controlled by software commands that originate within the LDCM Mission Operations Center, or MOC, at NASA's Goddard Space Flight Center. A flight operations team at the MOC will operate two computer systems: the Collection Activity Planning Element (CAPE) and the Mission Operations Element (MOE). The CAPE will plan science data collection by building activity requests for the LDCM imaging sensors each day, while the MOE will translate the activity requests into software commands transmitted to the observatory.

The software commands are transmitted to the observatory from the antenna of the LDCM Ground Network Element (GNE). In return, the observatory transmits data back to the GNE. The GNE is composed of three nodes, one located at Gilmore Creek, Alaska, another at Svalbard, Norway, and the third at Sioux Falls, South Dakota. Each node in the GNE includes a ground station that will be capable of receiving LDCM X-band data. Additionally, each station provides complete S-band uplink and downlink capabilities.

Once data are transmitted from the observatory to the GNE, the GNE sends it to the Data Processing and Archive System (DPAS), which is located at the EROS Center in Sioux Falls, South Dakota, via the internet. The DPAS will archive the data and produce the LDCM data products for science and applications, as well as provide a data portal to the user community. The Hammers Company, Inc. developed the MOE.

An Invaluable Data Archive

Credit: NASA's Earth Observatory

The United States Department of Agriculture uses satellite data, including accurate estimates of total crop area provided by Landsat, to forecast commodities in the U.S. and the world food market.

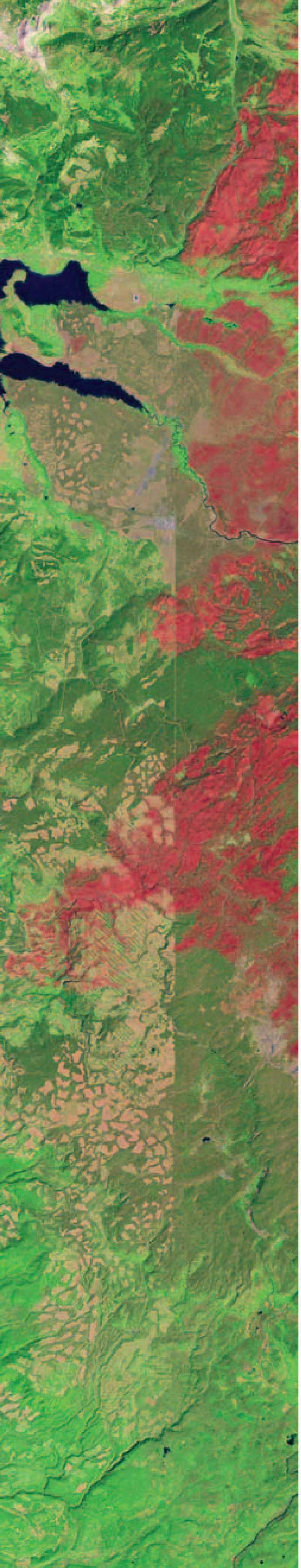
The USGS Earth Resources Observation and Science (EROS) Center has carefully maintained the treasured Landsat data archive for over four decades. The archive has well over 3.5 million images of Earth spanning the history of Landsat. New data from Landsat 7 are added daily, as there are regular downlinks from the spacecraft to several ground stations around the globe. In addition, new data constantly arrive from international ground station partners, who send newly acquired data in addition to their historical archives.

In April 2008, the USGS announced that all archived Landsat data would be made available to the public for free. In October 2008, Landsat 7 data were made available for no cost and in December 2008, Landsat 1-5 data were also made available at no cost. Since then, the USGS has experienced over a 100-fold increase in daily downloads (~2,000,000 images per year). In August 2009, the millionth free scene was downloaded; the following August, downloads hit three million; and in September 2012, free downloads surpassed nine million.

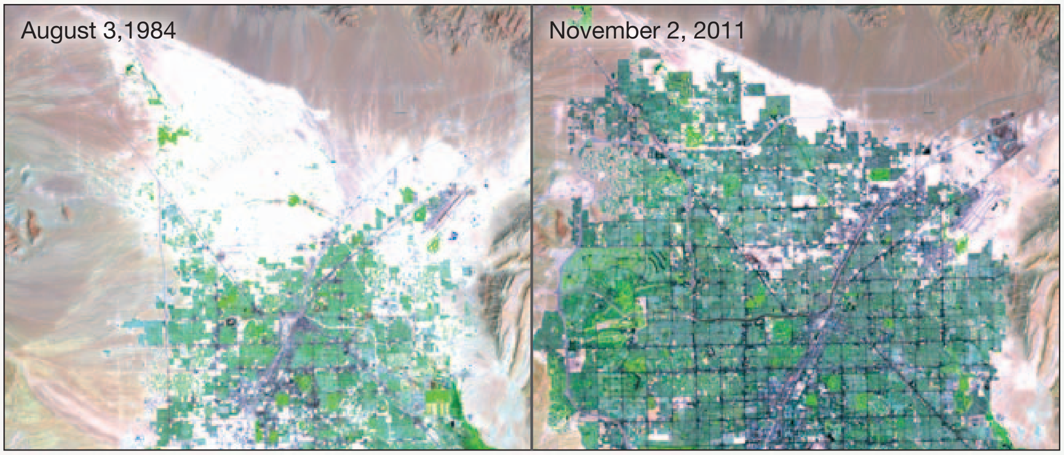
Free Landsat data, paired with today's powerful computer processing capabilities, have enabled large-scale, global-change studies that in the past were too costly to be conducted. The Landsat imaging dataset has led to improvements in human and biodiversity health, energy and water management, urban planning, disaster recovery, and agriculture and forestry monitoring.

Photo credit: Joe Zlomek/morguefile.com

In the western United States, approximately 80-90 percent of freshwater is used for agriculture. These arid states use Landsat satellite data products to measure and make management decisions on water distribution to preserve this scarce resource.



A Growing Data Record for a Growing World



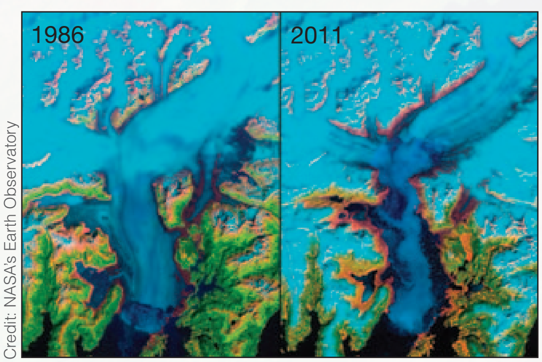
Credit: NASA's Earth Observatory

Tracking urban growth. Over the years of the Landsat program, the desert city of Las Vegas has gone through a massive growth spurt. The outward expansion of the city over the last quarter of a century is shown here with two false-color Landsat 5 images (August 3, 1984, and November 2, 2011). The dark purple grid of city streets and the green of irrigated vegetation grow out in every direction into the surrounding desert. These images were created using reflected light from the shortwave-infrared, near-infrared, and green portions of the electromagnetic spectrum (Landsat 5 Thematic Mapper bands 7,4,2).

Landsat observations have found increasingly wide acceptance within the science and applications communities over the program's lifetime. Every day, Landsat provides essential information for decision makers to support decisions about people and economies in the places we live and work.

Photo credit: Kevin A. Connors

Helping to locate sources of energy.



Credit: NASA's Earth Observatory

Conducting climate research. This image pair shows the retreat of Alaska's Columbia Glacier between 1986 [left] and 2011 [right].

As one measure, the Science Citation Index records well over 9,200 peer-reviewed articles making use of Landsat data since 1972, with significant increases in these citations over time. Similar discussions are found throughout the popular science literature.

Early applications of Landsat were largely confined to the remote sensing science community and often reported on new pathfinding uses of remote sensing. Today,

Photo credit: Andrea Booher/FEMA

Monitoring and mitigating the impacts of natural disasters.

use of Landsat data has evolved, and it is not only a fundamental data source for addressing basic science questions, but it also has come into its own as a valuable resource for decision makers in such diverse fields such as agriculture, forestry, land use, water resources, and natural resource exploration.

Over the past four decades, Landsat has also played an increasing role in diverse applications such as human population census, growth of global urbanization, and loss of coastal wetlands. As human populations increasingly dominate Earth's land areas, understanding changes in land cover and land use from year to year becomes increasingly important for both decision makers and human occupants of Earth. LDCM's evolutionary advances in technology and performance will continue the legacy of Landsat's invaluable data archive and provide new perspectives of our planet for years to come.

Credit: Landsat 5, NASA/USGS

Photo credit: Teresa Prendusi/USDA

Protecting ecosystems and biodiversity. Over the past century, the Blackwater Wildlife Refuge in Maryland has lost nearly 5,000 acres of tidal marsh, much of it to sea-level rise.

Resources

www.nasa.gov/landsat

ldcm.gsfc.nasa.gov

landsat.gsfc.nasa.gov

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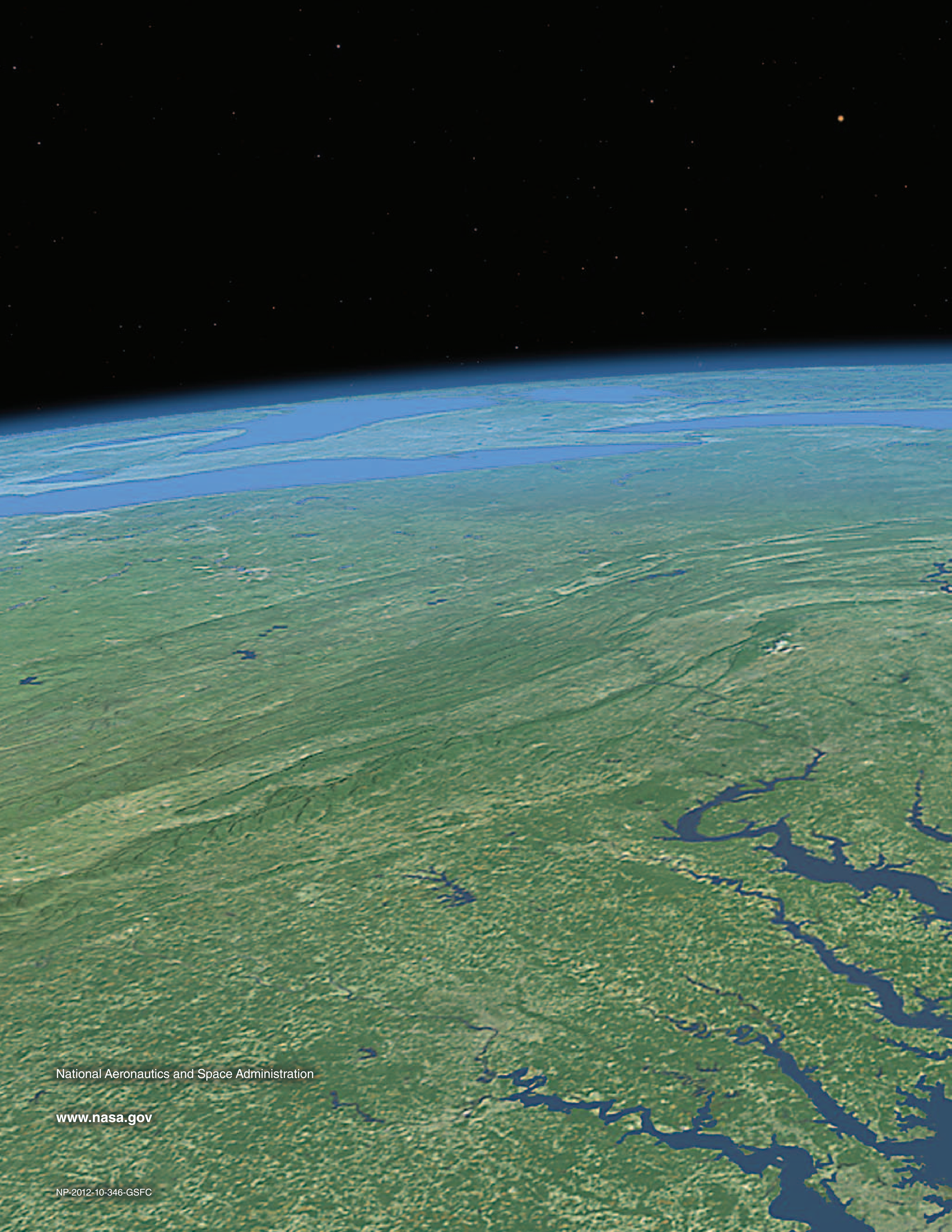

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