An overview of the Landsat Data Continuity Mission

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ABSTRACT

The Landsat Data Continuity Mission (LDCM) is the follow-on mission to Landsat 7 and will be the eighth mission in the Landsat series. The mission is in development via an interagency partnership between the National Aeronautics and Space Administration (NASA) and the Department of Interior (DOI) / United States Geological Survey (USGS). The LDCM satellite will carry two earth-observing sensors, the Operational Land Imager (OLI) to collect image data for nine spectral bands in the reflective portion of the spectrum and the Thermal Infrared Sensor (TIRS) to collect coincident image data for two thermal spectral bands. The LDCM ground segment will control the satellite and will receive, process, archive, and distribute the science data collected by the OLI and TIRS instruments. The USGS Earth Resources Observation & Science Center (EROS) will distribute LDCM data products at no cost to requestors. The mission objective is to continues the Landsat program's collection, archive, and distribution of multispectral imagery affording global, synoptic, and repetitive coverage of the Earth's land surfaces at a scale where natural and human-induced changes can be detected, differentiated, characterized, and monitored over time. The LDCM launch readiness date is currently December, 2012.

Keywords: Landsat, data archive, continuity, NASA, USGS

1. INTRODUCTION

The Landsat program has collected and archived multispectral digital images of the global land surface since the launch of Landsat 1 in 1972. Two Landsat satellites remain in operation. Landsat 5 remarkably continues to collect and transmit data from one of its sensors, the Thematic Mapper (TM), 26 years after its 1984 launch with a three year design life. The most recently launched Landsat satellite, Landsat 7 launched in 1999, continues to collect and transmit data from its sole instrument, the Enhanced Thematic Mapper-Plus (ETM+), although the data is now compromised by a 2003 failure of a component of the ETM+ optical system, the scan line corrector. The ages and problems with these two satellites create urgency with respect to the development and launch of the next Landsat mission, the Landsat Data Continuity Mission (LDCM).

The development of the LDCM has been delayed by a couple alternative implementation strategies that were explored and ultimately abandoned by the U.S. government. The current strategy is to develop and launch a dedicated LDCM satellite as a "free-flyer." In late 2005 the Executive Office of the President directed the National Aeronautics and Space Administration (NASA) and the Department of Interior (DOI) / United States Geological Survey (USGS) to implement this strategy through an interagency partnership. The two organizations subsequently agreed on roles and responsibilities with the agreement modeled on the partnership leading to the successful development and operation of Landsat 7. NASA is responsible for the development, launch, and initial check-out of the LDCM space segment and oversees the integration of the entire mission architecture. DOI/USGS is responsible for development of the ground system and will assume responsibility for satellite and ground system operations following the check-out period. Together, the partnership is striving for a December, 2012 launch date with operational data collection beginning in early 2013 in advance of the Northern Hemisphere growing season.

The goal of the LDCM, consistent with U.S. law and government policy, is to continue the collection, archive, and distribution of multispectral imagery affording global, synoptic, and repetitive coverage of the Earth's land surfaces at a scale where natural and human-induced changes can be detected, differentiated, characterized, and monitored over time. As the successor to Landsat 7 and the earlier Landsat satellites, the intent is to provide data into the future that is sufficiently consistent with previous Landsat data to allow the detection and quantitative characterization of changes in or on the land surface of the globe. Specific mission objectives include: collect and archive moderate resolution (circa 30 m ground sample distance) multispectral image data affording seasonal coverage of the global landmass for a continuous period of not less than 5 years; ensure that LDCM data are sufficiently consistent with data from the earlier Landsat missions in terms of acquisition geometry, calibration, coverage characteristics, spectral characteristics, output product quality, and data availability to permit studies of land cover and land use change over multi-decadal periods; and distribute LDCM data products to the general public on a nondiscriminatory basis and at no cost to the users. The mission will provide Landsat data to the USGS National Satellite Land Remote Sensing Data Archive (NSLRSDA) at USGS Earth Resources Observation & Science Center (EROS) for at least 5 years. This archive constitutes the longest continuous record of the Earth's surface as seen from space and is an irreplaceable resource for understanding the changing land surface and its impact on climate change, the economy, society, and national security.

2. MISSION ARCHITECTURE

The LDCM architecture consists of two major segments: the Space Segment and the Ground System. NASA is responsible for implementing the Space Segment and its major component is the satellite observatory. USGS is responsible for integrating the elements of the ground system including the Ground Network Element (GNE), the Mission Operations Element (MOE), and the Data Processing and Archive System (DPAS).

2.1. The Satellite Observatory

The LDCM observatory will consist of the spacecraft bus and its payload of two Earth observing sensors, the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS). The spacecraft bus and the OLI are being procured through private vendors selected via competitive processes. NASA GSFC is building TIRS. Both sensors will be delivered to the spacecraft bus vendor for integration as the observatory. OLI and TIRS will collect the LDCM Science Data. The two sensors will coincidently collect multispectral digital images of the global land surface including coastal regions, polar ice, islands, and the continental areas. The spacecraft bus will store the OLI and TIRS data on an onboard recorder and will transmit data to ground receiving stations.

2.1.1. The Spacecraft Bus

NASA awarded a contract for the LDCM spacecraft to General Dynamics Advanced Information Systems (GDAIS) in April 2008. Orbital Science Corporation subsequently acquired the spacecraft division of GDAIS in April 2010. Orbital Sciences Corporation has thus assumed responsibility for the design and fabrication of the LDCM spacecraft bus, integration of the government furnished instruments, satellite-level testing, on-orbit satellite check-out, and continuing on-orbit engineering support. They also will provide a spacecraft/observatory simulator. The contract includes fabrication and testing of the spacecraft with mission specific design modifications; generation of interface control documents, instrument and full spacecraft integration; testing, shipment to the launch site, launch vehicle integration support and on-orbit checkout.

A successful spacecraft critical design review was held in October 2009. The design notably includes a 3.14 Terra-bit solid-state data recorder and an earth-coverage X-band antenna. The X-band antenna will transmit OLI and TIRS data either in real time or played back from the data recorder. Assembly of the spacecraft bus has begun following the design review.

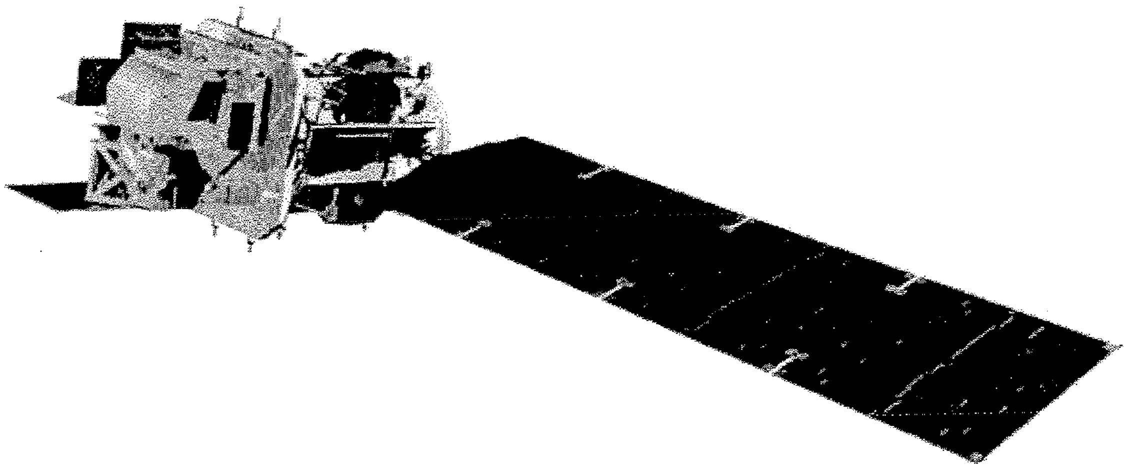

Figure 1. Drawing of the LDCM Satellite Observatory (courtesy of Orbital Sciences Corporation)

2.1.2. The Operational Land Imager (OLI)

NASA awarded Ball Aerospace and Technology Corporation a contract for the Operational Land Image (OLI) in July 2007. The OLI will collect digital image data for nine shortwave spectral bands (Table 1) across a 185 km swath from the LDCM observatory. The OLI will provide a 30 m spatial resolution for eight of the spectral bands and 15 m spatial resolution for a panchromatic band (Table 1). Seven of the OLI spectral bands compare closely to the shortwave spectral bands collected by the Enhanced Thematic Mapper-Plus (ETM+) aboard Landsat 7. OLI will provide data for two new bands: a blue spectral band (Band 1) added principally to provide ocean color data for coastal regions and a shortwave infrared band (Band 9) added to aid the detection of cirrus clouds in OLI images. OLI will quantize raw image data to 12-bits and is required to produce data with signal-to-noise ratios as good as or better than ratios given in Table 2.

Table 1. OLI Spectral Band and Spatial Resolution Specifications

#	Band	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)	Center Wavelength (nm)	Spatial Resolution
1	Coastal	433	453	443	30 m
2	Blue	450	515	482	30 m
3	Green	525	600	562	30 m
4	Red	630	680	655	30 m
5	NIR	845	885	865	30 m
6	SWIR 1	1560	1660	1610	30 m
7	SWIR 2	2100	2300	2200	30 m
8	Panchromatic	500	680	590	15 m
9	Cirrus	1360	1390	1375	30 m

Table 2. OLI Saturation Radiance and Signal-to-Noise Ratio Specifications

#	Band	Saturation Radiances (W/m^2 sr µm)	Radiance Level for SNR (W/m^2 sr µm)		SNR Requirements	
			Typical, $L_{Typical}$	High, L_{High}	At $L_{Typical}$	At L_{High}
1	Coastal	555	40	190	130	290
2	Blue	581	40	190	130	360
3	Green	544	30	194	100	390
4	Red	462	22	150	90	340
5	NIR	281	14	150	90	460
6	SWIR 1	71.3	4.0	32	100	540
7	SWIR 2	24.3	1.7	11	100	510
8	Panchromatic	515	23	156	80	230
9	Cirrus	6.0	N/A	88.5	9	N/A

The OLI employs a pushbroom sensor design incorporating a focal plan with long arrays of photosensitive detectors (Figure 2). A four-mirror anastigmatic telescope will focus incident radiation onto the focal plane while providing a 15-degree field-of-view covering a 185 km across-track ground swath from the nominal LDCM observatory altitude of 716 km. Periodic sampling of the across-track detectors as the observatory flies forward along the ground tracks will form the multispectral digital images. The detectors are divided into 14 modules arranged in an alternating pattern along the centerline of the focal plane. Data will be acquired from over 6000 across-track detectors for each spectral band with the exception of the 15 m panchromatic band that requires over 12000 detectors. The spectral differentiation will be achieved by interference filters arranged in a "butcher-block" pattern over the detector arrays in each module. Silicon PIN (SiPIN) detectors will collect the data for the visible and near-infrared spectral bands (Bands 1 to 4 and 8) while Mercury-Cadmium-Telluride (MgCdTe) detectors will be used for the shortwave infrared bands (Bands 6, 7, and 9). The OLI also contains internal stimulation lamps and an external mechanism with solar diffuser panels for radiometric calibration.

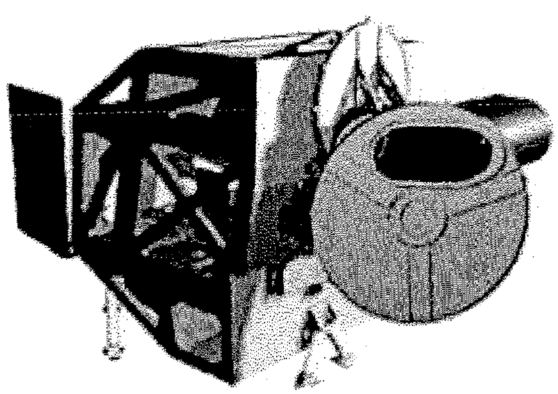

Figure 2. Drawing of the Operational Land Imager (courtesy of Ball Aerospace and Technology Corporation)

2.1.3. The Thermal Infrared Sensor (TIRS)

NASA Goddard Space Flight Center (GSFC) is building the Thermal Infrared Sensor (TIRS). TIRS will collect digital images for two thermal (longwave) bands with a spatial resolution of 100 m (Table 3). In comparison, the ETM+ collects data for one thermal band with a 60 m spatial resolution along with data for six 30 m shortwave bands and one 15 m panchromatic band. The TIRS data will be quantized to 12 bits with Table 4 providing TIRS dynamic range and noise-equivalent-change-in-temperature specifications.

Table 3. TIRS Spectral Band and Spatial Resolution Specifications

Band #	Band	Center Wavelength (nm)	Minimum Lower Band Edge (nm)	Maximum Upper Band Edge (nm)	Spatial Resolution (m)
10	Thermal 1	10800	10300	11300	100
11	Thermal 2	12000	11500	12500	100

Table 4. TIRS Saturation Radiance and Noise-Equivalent-Change-in-Temperature (NEΔT) Specifications

Band #	Saturation Temperature (K)	Saturation Radiance (W/m^2 sr µm)	NEDT at 300K
10	360K	20.5	0.4K
11	360K	17.8	0.4K

The TIRS will also be a pushbroom sensor employing a focal plan with long arrays of photosensitive detectors (Figure 3). TIRS will employ cryogenically-cooled quantum-well-infrared-photodetector (QWIP) arrays divided into three modules arranged in an alternating pattern along the centerline of the focal plane. These modules will provide over 1850 cross-track detectors per spectral band. TIRS will be the first spaceflight instrument to use QWIP arrays. A four-element refractive telescope will focus incident thermal energy onto the focal plane while providing a 15-degree field-of-view matching the 185 km across-tack swath of the OLI. A scene select mirror will flip the field-of-view between nadir (earth), an internal blackbody, and a deep space view for on-orbit radiometric calibration. The TIRS critical design review is scheduled for the end of April 2010.

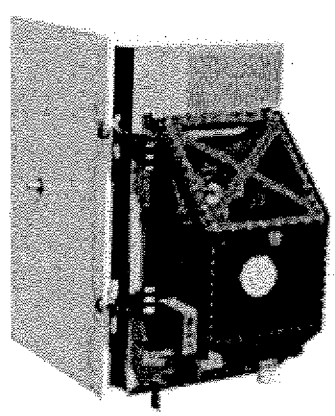

Figure 3. Drawing of the Thermal Infrared Sensor (TIRS)

2.2. The Ground System

USGS will develop an LDCM Ground System providing the capabilities necessary for planning, scheduling and operations of the LDCM Space Segment and the capabilities necessary to manage the science data following transmission from the spacecraft. Embedded within the Ground System is the real time command and control sub-system for real-time operations of the Space Segment, known as the Mission Operations Element (MOE). A vendor under contract to NASA (with USGS and NASA funding) is implementing the MOE subsystem. The Mission Operations Center (MOC) will house the MOE, and at launch the primary MOC will reside physically at NASA GSFC.

The USGS will also develop the Data Processing and Archive System (DPAS) that will ingest, process, and archive all LDCM science and mission data returned from the LDCM observatory. The DPAS will also provide a public Web interface to allow users to search for and receive data products. The DPAS is located at the USGS Earth Resources Observation and Science (EROS) Center near Sioux Falls, South Dakota. USGS successfully conducted a Ground System critical design review in March 2010.

2.2.1. The Mission Operations Element (MOE)

LDCM data collection will be scheduled daily by the MOE within the MOC. The MOE will send commands to the satellite once every 24 hours via S-band communications from a network of ground receiving and transmitting stations, the Ground Network Element (GNE). The daily schedule will be driven by a Long Term Acquisition Plan (LTAP-8) that sets priorities for collecting data along the satellite ground paths covered in a particular 24-hour period. OLI and TIRS will collect data jointly to provide coincident images of the same surface areas. The MOE will nominally schedule the collection of 400 OLI and TIRS scenes per day where each scene will be a digital image covering a 185-by-180 km surface area. The objective of scheduling and data collection will be to provide cloud-free coverage of the global landmass on a seasonal basis.

The MOE commands will also schedule the transmission of data from the observatory's X-band antenna to the GNE network of stations that receive the mission data for delivery to the Data Processing and Archive system (DPAS). In addition, data will be transmitted to a network of international stations operated or under the sponsorship of foreign governments referred to as International Cooperators (ICs). The GNE will consist of three stations: one at USGS EROS in Sioux Falls, South Dakota; one at Gilmore Creek, Alaska; and one at Svalbard, Norway. The GNE sends all 400 scenes collected daily to the DPAS at USGS EROS in Sioux Falls, SD.

2.2.2. The Data Processing and Archive System (DPAS)

The DPAS will consist of several subsystems: Ingest (IS), Storage and Archive (SA), Subsetter (SS), Image Assessment (IAS), Product Generation (PGS), and User Portal (UP). The SA will receive, store, and archive the entire raw LDCM mission data sent from the GNE. The SA will perform all archive and storage functions in support of data ingest, image assessment, product generation, and data access through the User Portal. Mission data will be archived offline with an additional backup copy archived offsite.

The IS will process the OLI and TIRS file-based mission data into interval-based Level-0R archive (L0Ra) science data and will create the associated inventory metadata. The SS will subset the OLI and TIRS L0Ra data into Landsat scene equivalent Level-0R (L0Rp) data for distribution or the generation of Level-1 products and their associated metadata.

The PGS will process each Level 0Rp scene to radiometrically and geometrically correct the image data. The radiometric correction will transform raw OLI data to digital counts linearly scaled to top-of-the-atmosphere spectral reflectance and will transform raw TIRS data to digital counts linearly scaled to at-aperture spectral radiance. The geometric correction will resample the radiometrically corrected data to create orthorectified images of Earth's surface registered to a cartographic projection. The corrected digital images along with metadata will be referred to as Level-1T (L1T) data. The co-registered and terrain corrected OLI and TIRS data will be merged to create a single integrated Level-1 (L1T) data product. The PGS will routinely generate L1T products for each of the 400 scenes collected each day, as well as perform automated cloud cover and data quality assessments, and the results will stored in the IAS database for subsequent analysis and trending. The IAS will be used to perform OLI and TIRS data characterization, analysis, and trending, and the IAS will create the bias and calibration parameters required for Level-1 product generation. The User Portal will generate browse images from the L1T products at multiple resolutions for interactive display and at full spatial resolution for download. The OLI and TIRS Level-0R data are stored and managed separately online until they are merged and integrated during L1T product generation.

The L0Rp and L1T WRS-2 scenes will constitute the standard LDCM science data products. The general public will be able to search, browse, and order L0Rp and L1T scenes through the User Portal. The UP will electronically transmit ordered scenes to LDCM data users at no cost to the users

3. MISSION OPERATIONS CONCEPT

The fundamental LDCM operations concept is to collect, archive, process, and distribute science data in a manner consistent with the collection, archiving, processing, and distribution of science data from the Landsat 7 mission. To that end, the LDCM observatory will operate in a 716 km near-circular, near-polar, sun-synchronous orbit. The observatory will have a 16-day ground track repeat cycle with an equatorial crossing at 10:00 a.m. (+/- 15 minutes) mean local time during the descending node of each orbit. In this orbit, the LDCM observatory will follow a sequence of fixed ground tracks (also known as paths) defined by the second Worldwide Reference System (WRS-2). WRS-2 is a path/row coordinate system used to catalog the image data acquired from the Landsat 4, 5, and 7 satellites. These three satellites have all followed the WRS-2 paths and all of the science data are referenced to this coordinate system. The LDCM science data will likewise be referenced to the WRS-2 as part of the ground processing and archiving performed by the DPAS.

4. MISSION STATUS

The NASA Agency Management Council confirmed that the Landsat Data Continuity Mission is ready to proceed to the final design and fabrication phase of mission development following a December, 2009 review at NASA Headquarters. An approval to incorporate TIRS into the LDCM observatory payload along with the OLI was a notable outcome of this review. The confirmation followed the successful LDCM preliminary design review before an independent review board in July 2009.

The LDCM is now in the midst of the final design and fabrication phase. All major components of the mission architecture have been through successful critical design reviews with the exception of TIRS; the TIRS critical design review is scheduled for April 2010. The mission level critical design review before the independent board will follow soon after in May 2010. NASA and USGS are managing the LDCM implementation towards a December 2012 launch through this process. The launch will be aboard a United Launch Alliance Atlas-V launch vehicle.

5. SUMMARY

The Landsat program has provided an invaluable record of land cover and land use change for almost four decades. Continuing the record is critical to understanding the impacts of such change on climate, ecosystems, the environment, human health, the economy, society, and national security. The need to launch and operate the next Landsat satellite is urgent given the current states of Landsat 5 and Landsat 7. NASA and USGS are striving to launch and operate that satellite system, the LDCM, by December 2012 in order to prevent or minimize gaps in the coverage of the global land surface. The LDCM observatory, ground system, and mission operations concept will ensure the collection, archive, and distribution of the multispectral image data necessary to continue and improve upon the Landsat record.