

LANDSAT DATA CONTINUITY MISSION CALIBRATION AND VALIDATION

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ABSTRACT

The primary payload for the Landsat Data Continuity Mission (LDCM) is the Operational Land Imager (OLI), being built by Ball Aerospace and Technologies, under contract to NASA. The OLI has spectral bands similar to the Landsat-7 ETM+, minus the thermal band and with two new bands, a 443 nm band and 1375 nm cirrus detection band. On-board calibration systems include two solar diffusers (routine and pristine), a shutter and three sets of internal lamps (routine, backup and pristine). Being a pushbroom opposed to a whiskbroom design of ETM+, the system poses new challenges for characterization and calibration, chief among them being the large focal plane with 75000+ detectors. A comprehensive characterization and calibration plan is in place for the instrument and the data throughout the mission including Ball, NASA and the United States Geological Survey, which will take over operations of LDCM after on-orbit commissioning. Driving radiometric calibration requirements for OLI data include radiance calibration to 5% uncertainty (1 σ); reflectance calibration to 3% uncertainty (1 σ) and relative (detector-to-detector) calibration to 0.5% (1 σ). Driving geometric calibration requirements for OLI include band-to-band registration of 4.5 meters (90% confidence), absolute geodetic accuracy of 65 meters (90% CE) and relative geodetic accuracy of 25 meters (90% CE). Key spectral, spatial and radiometric characterization of the OLI will occur in thermal vacuum at Ball Aerospace. During commissioning the OLI will be characterized and calibrated using celestial (sun, moon, stars) sources and terrestrial sources. The USGS EROS ground processing system will incorporate an image assessment system similar to Landsat-7 for characterization and calibration. This system will have the added benefit that characterization data will be extracted as part of the normal image data processing, so that the characterization data available will be significantly larger than for Landsat-7 ETM+.

INTRODUCTION

Beginning with Landsat-1 in 1972 and continuing through Landsat-7 ETM+ in 1999, the Landsat program has evolved. One part of the evolution is the increased emphasis on the scientific utility of the data and the requisite increased requirements for instrument and data characterization, calibration and validation. This trend is continuing with LDCM, the next mission in the Landsat sequence. The enhancements of the Landsat-7 system, e.g., more on-board calibration hardware and an image assessment system and personnel, have been retained and improved, where required, for LDCM. Aspects of the calibration requirements are spread throughout the mission, including the instrument and its characterization, the spacecraft, operations and the ground system. This paper provides an overview

of the key calibration requirements and how they will be met by the LDCM system. Detailed information on the geometric implications of the differences between ETM+ and OLI are provided in Storey et al (2008).

The LDCM project includes space and ground segments. The space segment consists of the LDCM spacecraft and its payload(s). The payload of interest for this paper is the Operational Land Imager (OLI), which images the Earth in the visible to short-wave portion of the spectrum. This sensor is being designed and built by Ball Aerospace and Technologies Corp (BATC). A Thermal Infrared Imaging Sensor (TIRS) is still under consideration for inclusion on LDCM; a decision on this sensor had not been made at the time of this writing. Although not specifically discussed here, the cal/val requirements placed on the TIRS instrument are similar to those placed on the OLI instrument. The spacecraft is being designed and built by General Dynamics Advanced Information Systems. The ground segment receives and sends data to the spacecraft via the Ground Network Element, controls and monitors the space segment via the Mission Operations Element, and processes, archives and distributes the science data via the Data Processing and Archive Segment (DPAS).

The OLI instrument has similar spectral bands to the Landsat-7 ETM+ sensor. It includes new coastal aerosol (443 nm) and cirrus detection (1375 nm) bands, though it does not have a thermal infrared band. With its pushbroom design, as opposed to 16 detectors per multispectral band and 32 detectors per band for the panchromatic band for the ETM+, the OLI has about 6500 active detectors per multispectral band and 13000 detectors for the panchromatic band. These detectors are organized as blocks ~500 multispectral (1000 panchromatic) detectors wide within 14 focal plane modules (FPMs) that make up the focal plane assembly. Each module has its own butcher-block assembly spectral filter. This provides significantly improved signal to noise performance, but significantly complicates the process of radiometrically matching the detectors responses. Similarly, the lack of a scan mirror removes the need for knowledge of its movement, but requires knowledge of the detectors locations across a much larger focal plane. At the time of this writing the OLI is completing its Critical Design Review (CDR) so few additional changes in the design are expected. Also, due to the compressed schedule of the OLI, parts of the instrument have already completed fabrication, including the optical bench and telescope mirrors.

The LDCM spacecraft is a three axis stabilized platform. Key aspects of the satellite performance related to calibration and validation are pointing, stability and maneuverability. Pointing and stability affect geometric performance; maneuverability affects data acquisitions for calibration using the sun, moon and stars. For LDCM, an off nadir acquisition capability is included (up to 1 path off nadir) for imaging high priority targets. At this writing the LDCM spacecraft has completed its Systems Requirements Review.

The DPAS 's Image Processing Element (IPE) is where the science data are processed, radiometrically and geometrically corrected. During the data processing, statistics are generated that are used to characterize and calibrate the instrument and its data products. Certain scenes, e.g., scenes over well-characterized geometric sites are additionally characterized using the Image Assessment System, an offline portion of the image processing element.

BATC has primary responsible for the calibration and characterization of the OLI instrument and data during the pre-launch and on-orbit commissioning phase. BATC personnel work in conjunction with the Calibration and Validation Working Group (CVWG), which includes NASA and USGS personnel, which provides oversight and coordination of calibration and validation activities. Primary responsibility for OLI calibration and characterization transfers from BATC to the NASA/USGS calibration team at the end of commissioning with USGS leading these efforts during the operational phase of the mission. BATC, NASA and USGS develop the algorithms that are to be used for the calibration and characterization within the IPE of the ground system.

DERIVING CALIBRATION REQUIREMENTS

Radiometric

The absolute radiometric calibration requirements for OLI are given in Table 1. These requirements apply across the majority of the OLI dynamic range, with some relaxation at low radiance levels. The radiance requirement is the same as Landsat-7 ETM+; the reflectance calibration requirement is new.

Table 1. OLI Absolute Radiometric Calibration Requirements

Parameter	Requirement (1-sigma)
Radiance	5%
Top of Atmosphere (TOA) Reflectance	3% of actual TOA

Four relative radiometric calibration requirements were established for OLI to control the variability that can be present across the focal plane. These requirements control the high frequency detector-to-detector variations, referred to here as streaking, the variation between focal plane modules and localized lower frequency variation, referred to as banding and variation across the full field of view. In addition these requirements are applicable for three different spectra, a soil spectra and a vegetation spectra passed through simulated atmospheres and an exoatmospheric solar spectrum (Figure 1). The intention of including these spectra was to control the variation in spectral response across the focal plane as it impacts the ability to normalize the response across the focal plane. An instrument's data can be made to normalize very well in its response to only one target even with wide variation in spectral response across its focal plane.

Full Field of View: The standard deviation of all pixel column average radiances across the FOV within a band shall not exceed 0.25% of the average radiance.

Banding (1): The root mean square of the deviation from the average radiance across the full FOV for any 100 contiguous pixel column averages of radiometrically corrected OLI image data within a band shall not exceed 0.5% of that average radiance.

Banding (2): The standard deviation of the radiometrically corrected values across any 100 contiguous pixels column averages of OLI image data within a band shall not exceed 0.25% of the average radiance across the full FOV.

Note: The average radiance across the FOV is used here merely as a reference for deriving the magnitude of the 0.25%. The mean in the standard deviation calculation is, by definition, the mean of the 100 pixel columns and not the entire FOV mean.

Streaking: The maximum value of the streaking parameter within a line of radiometrically corrected OLI image data shall not exceed 0.005 for bands 1-7 and 9, and 0.01 for the panchromatic band.

The streaking parameter is defined by the following equation:

$$S_i = \left| \bar{L}_i - \frac{1}{2} (\bar{L}_{i-1} + \bar{L}_{i+1}) \right| / \bar{L}_i$$

Where:

\bar{L}_i is the average radiance of pixel column i;

\bar{L}_{i-1} and \bar{L}_{i+1} are similarly defined for the (i-1)th and (i+1)th pixel columns.

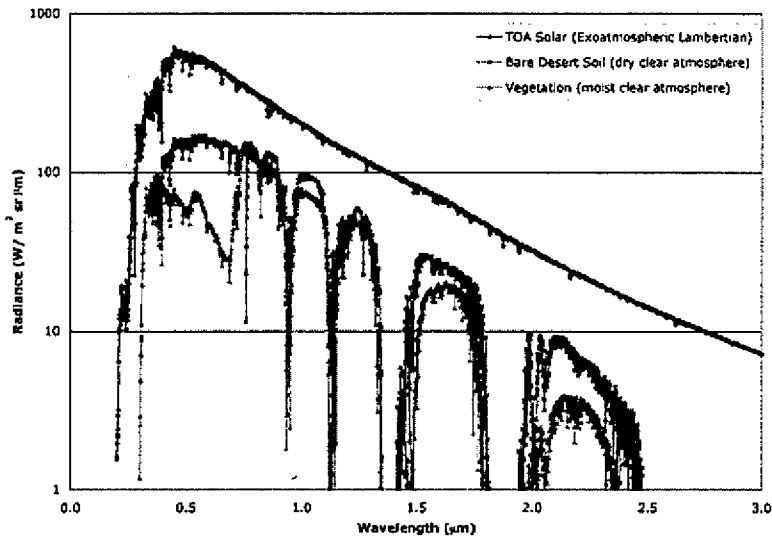


Figure 1. Top-of-atmosphere spectra used to control pixel-to-pixel uniformity

Geometric

Key geometric performance requirements are presented in Table 2. These requirements are on the final processed data and have allocations to both the OLI instrument as well as the LDCM spacecraft. Obtaining the band-to-band registration accuracy on a push-broom sensor like OLI requires terrain correction, so terrain correction will be part of the OLI geometric processing. Relative geodetic accuracy is specified after the removal of any constant offsets determined by the absolute geodetic accuracy evaluation.

Table 2. OLI Geometric Performance Requirements

Parameter	Requirement
Band-to-band registration	4.5 m (90% confidence)
Absolute geodetic accuracy	65 meters (90% circular error)
Relative geodetic accuracy	25 meters (90% circular error)

INSTRUMENT DESIGN AND ON-BOARD CALIBRATION DEVICES

The OLI instrument design is illustrated in Figure 2. It uses a four-mirror off-axis design with a front aperture stop. (Fig 2). The focal plane assembly (Fig 2) consists of 14 focal plane modules (FPM's). Each FPM contains detectors for each spectral band, silicon for the VNIR bands and HgCdTe for the SWIR bands and a butcher-block filter assembly to provide the spectral bands.

The calibration subsystem (Figure 3) consists of two solar diffusers, a working and a pristine and a shutter. When positioned so that the sun enters the solar lightshade, the diffusers reflect light diffusely into the instruments aperture and provide a full system full aperture calibration. The shutter, when closed, provides a dark reference. The two stim lamp assemblies are located at the front aperture stop. Each lamp assembly contains three lamps (per redundant configuration) that are operated at constant current and monitored by a silicon photodiode (Figure 4). The lamp signal goes through the full telescope system. Additionally, the OLI focal plane will include masked HgCdTe detectors, that is, detectors that will be blocked from seeing the Earth's radiance.

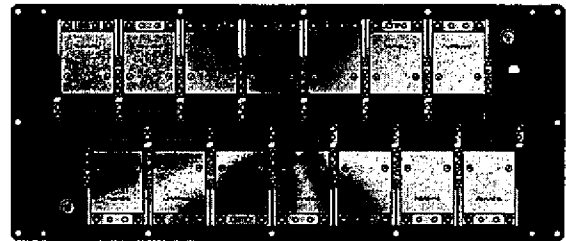
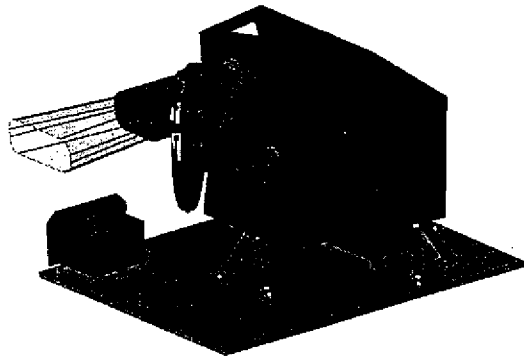


Figure 2. OLI instrument design (left) and OLI focal plane assembly design (right) illustrating 14 FPM's.

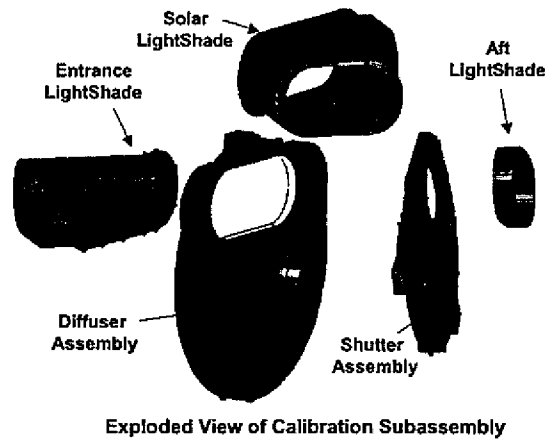
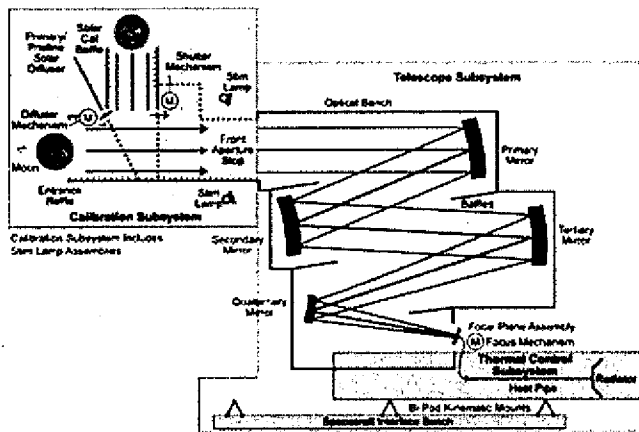


Figure 3. OLI block diagram (left) illustrating calibration subsystem in front of the telescope and blow-up of the calibration subsystem (right) illustrating solar diffuser and shutter assemblies.

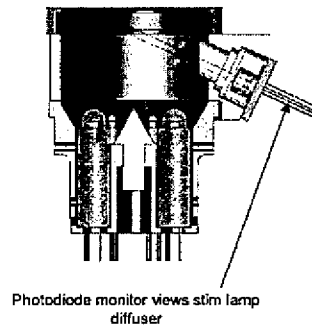


Figure 4. Stimulation Lamp assembly design showing bulbs (green) and photodiode monitor

PRE-LAUNCH CHARACTERIZATION AND CALIBRATION

An extensive pre-launch characterization and calibration program is planned for the OLI instrument on LDCM. Spectral characterization will occur at the component, assembly and integrated instrument level. The primary out-of-band spectral characterization will be performed at the FPM level, i.e., integrated detectors and filters. The primary in-band relative spectral response characterization will take place at the integrated instrument level in thermal vacuum. Spatial response characterization will also be performed at the integrated instrument level in thermal vacuum. A stray light test is planned for the telescope and a ghosting test is planned at the integrated instrument level.

Radiometric testing at the integrated instrument level in thermal vacuum includes absolute radiometric calibration using an external integrating sphere monitored by transfer radiometers. An integrated instrument level characterization of the diffuser reflectance and a heliostat-based transfer to orbit test are planned. Pre-launch geometric characterization is focused on determining the line of sight of each of the detectors to the instruments optical axis and this optical axis to an instrument alignment cube. Additionally the timing of the sampling of the detectors is characterized.

ON-ORBIT CALIBRATION ACQUISITIONS

During the commissioning phase and into operations special and normal acquisitions of OLI data will be used to characterize the OLI instrument and its data products.

Normal Earth Acquisitions

The OLI instrument will be scheduled to acquire a minimum of 400 World Reference System (WRS)-2 scenes per day. This will include all the available scenes over the continental United States plus scenes acquired elsewhere per the Long Term Acquisition Plan. As necessary, the non-US coverage will be supplemented by acquisitions over Geometric Super Sites, i.e., sites that have been characterized in terms of ground control and elevation using high resolution satellite or aircraft data and maintained by the Cal/Val team. Additionally radiometric sites, e.g., those historically used by Landsat-5 and -7 calibration teams and those recommended by the CEOS CVWG will be routinely acquired.

Dark acquisitions

A routine set of Earth acquisitions will be preceded and followed by closed shutter acquisitions. These acquisitions will provide pre and post dark level measurements for all the imaging detectors. The masked or blind HgCdTe detectors will be acquired during these dark and during the Earth acquisitions to provide information on the drift of the dark levels of these detectors between the shutter acquisitions. On occasion, longer dark collects will be performed to better characterize dark current drift and noise characteristics.

Lamp acquisitions

Once per day, during the closed shutter operations, the stimulation lamps will be activated. Current plans are to use the working lamps every day, the backup lamps approximately monthly and the pristine lamps twice per year. A lamp acquisition will be about 5 minutes in length.

Solar Diffuser acquisitions

Nominally weekly, the spacecraft will be maneuvered to have the sun directed into the solar view port. The working solar diffuser will be deployed and the shutter opened to record the light reflected off the solar diffuser. The pristine solar diffuser will be deployed less frequently, nominally every 6 months to check for any degradation in the working solar diffuser.

Lunar acquisitions

Once a lunar cycle at approximately a 7° lunar phase angle (near full moon) the LDCM spacecraft will be

maneuvered to image the lunar disk through the nadir (Earth) port of the OLI. Multiple passes will be performed so that the lunar signal can be viewed by a number of the FPM's. The lunar disk is approximately half a degree and each of the FPM's cover slightly more than 1 degree.

Other acquisitions

Plans are not finalized, but acquisitions of stars may be performed during the commissioning phase to aid in geometric characterization. Also, acquisitions of the Earth may be performed with the spacecraft rotated approximately 90° to its normal orientation, to image the same location on the Earth with "all" the detectors in an FPM. These data will be used to aid in detector-to-detector radiometric normalization.

IMAGE ASSESSMENT AND DATA PROCESSING

After receipt of the data on the ground, the standard Earth images will be processed to a standard Level 1Gt product, i.e., fully radiometrically and geometrically corrected. The radiometric processing will use the biases determined from the dark collects before and/or after the Earth acquisitions, the signals from the masked pixels (for the HgCdTe detectors) and a model (for the HgCdTe detectors) relating the masked pixels dark levels to the Earth imaging detectors dark levels. The gains will be predetermined using the solar diffuser results (absolute and relative gains) and trends from the lunar and lamp acquisitions. Geometric processing will use the attitude and ephemeris data provided by the spacecraft, alignment from pre-launch measurements as updated from post-launch geometric calibrations and digital terrain data to geolocate the data. Plans call for the standard product to be top-of-atmospheric reflectance, resampled to 30 meters (multispectral bands), 15 meters (panchromatic band) in a UTM projection. During routine processing statistics will be acquired from all scenes to provide data useful for the assessment and correction of artifacts like striping and banding.

Special acquisitions, e.g., solar and lunar acquisitions, long dark acquisitions, geometric super site collections will receive additional processing. Solar data will be used to derive absolute and relative radiometric gains; lunar data will be used to determine radiometric trends, spatial edge response characterization, and band to band registration; long dark acquisitions will be used to update the bias models, assess coherent noise and geometric super sites will be used to assess current geometric performance and update the geometric calibrations as required.

REFERENCES

Storey, J., K. Lee and M. Choate. 2008. Geometric performance comparison between the OLI and the ETM+. Proceeding from the PECORA 17 Conference, November 18-20, 2008. <http://www.asprs.org/Pecora17>