Landsat 9: Status and Plans

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ABSTRACT

The Landsat 9 mission, currently under development and proceeding towards a targeted launch in late 2020, will be very similar to the Landsat 8 mission, launched in 2013. Like Landsat 8, Landsat 9 is a joint effort between NASA and USGS with two sensors, the Operational Land Imager 2 (OLI-2), essentially a copy of the OLI on Landsat 8 and the Thermal Infrared Sensor 2 (TIRS-2), very similar to the TIRS on Landsat 8. The OLI-2, like OLI, provides 14-bit image data, though for Landsat 9, all 14 bits will be retained and transmitted to the ground. The focal plane modules to be used for OLI-2 were flight spares for OLI and are currently being retested by Ball Aerospace. Results indicate radiometric performance comparable to OLI. The TIRS was a class C instrument, with a 3-year design lifetime, and therefore had limited redundancy. TIRS-2 will be a class B instrument, with a 5-year design lifetime, like OLI (and OLI-2), necessitating design changes to increase redundancy. The stray light and Scene Select Mechanism (SSM) encoder problems observed on orbit with TIRS have also instigated a few design changes to TIRS-2. Stray light analysis and testing have indicated that additional baffles in the TIRS-2 optical system will suppress the out-of-field response. The SSM encoder problems have not been definitively traced to a route cause, though conductive anodic filament growth in the circuit boards is suspected. Improved designs for the encoder are being considered for TIRS-2. The spare Focal Plane Array (FPA) from TIRS is planned for use in TIRS-2; FPA spectral and radiometric performance testing is scheduled for September of this year at NASA's Goddard Space Flight Center.

Keywords: Landsat, Operational Land Imager 2, Thermal Infrared Sensor 2

1. INTRODUCTION

The routine observation of the Earth's surface at moderate resolutions began with the launch of the Earth Resources Technology Satellite (ERTS) 1 in July of 1972. This satellite, later renamed Landsat 1, began the 40-year plus history of the Landsat program. Landsat 9, currently under development and planned for launch in late 2020, is the latest in this series. The full history of the Landsat program is depicted in Figure 1.

The Landsat 9 program was initiated in early 2015. A key difference from earlier Landsat missions is that Landsat 9 is not just a single mission, but is the first flight element of the Administration's Sustainable Land Imaging (SLI) program. SLI provides for a continuous series of missions into the foreseeable future to ensure the continuity of this operational system. Landsat 9 will essentially be a rebuild of Landsat 8 based on the same high level (level 1) requirements. The only exception to the Level 1 requirements is that the thermal imaging capability is now part of the baseline science, meaning, in essence, that the thermal imager needs to be built to the same level of reliability as the spacecraft and reflective band imager. For Landsat 8, the thermal imager was built to a lower level of reliability (risk class C in NASA parlance) than the rest of the mission (risk class B). Meeting the higher level of reliability requires some redesign of the thermal imager, primarily in the area of electronics redundancy.

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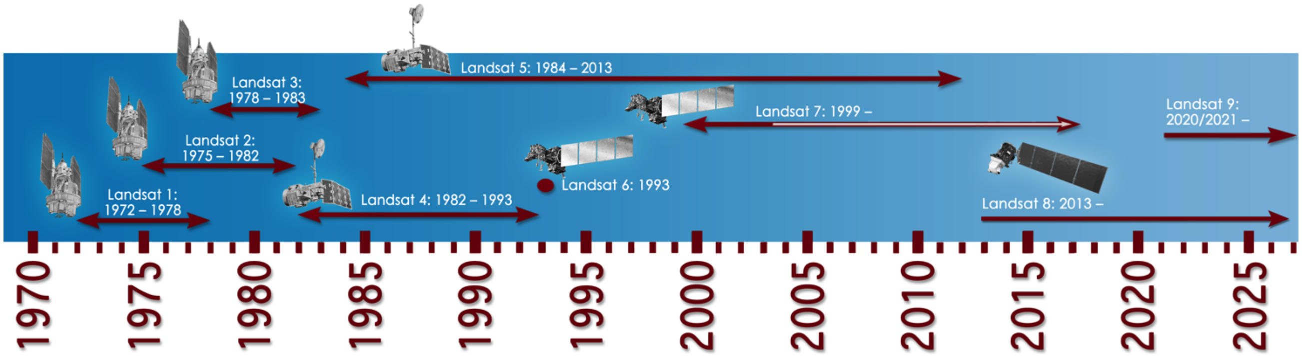

Figure 1. The Landsat project history[1]

Landsat 9, like Landsat 8 will be a joint effort between NASA and USGS, with NASA responsible for the space segment (instruments and spacecraft) and launch segment and USGS responsible for the ground segment: mission operations center, operations (after commissioning), data processing and archive and the ground network (ground stations and antennas). Though the lead for each segment is defined, both organizations will be involved in all elements. NASA's role diminishes after commissioning, though science and calibration/validation efforts continue on the NASA side as well as support for anomaly resolution.

2. INSTRUMENT PAYLOAD

Like Landsat 8, Landsat 9 will carry two instruments, the second Operational Land Imager (OLI-2) and the second Thermal Infrared Sensor (TIRS-2). To the extent possible OLI-2 will be a rebuild of OLI. TIRS-2, in addition to the added redundancy needed for a class B instrument, will have a few additional design changes to correct some performance issues observed on TIRS.

2.1 OLI-2

OLI-2 will look a lot like OLI[2] and will be built by Ball Aerospace under contract to NASA. The only design changes will be those necessitated due to parts obsolescence, standards changes, requirements changes or where low risk changes can significantly improve schedule or cost.

Key parts of OLI-2 already exist, e.g., a complete spare set of Focal Plane Modules (FPMs) was built as part of the OLI effort. These FPMs were radiometrically retested during the summer of 2016 and showed comparable performance to the FPMs flown on OLI. As such, comparable integrated instrument level performance is expected with OLI-2.

As indicated, the design of OLI-2 matches OLI (Figure 2). Light from the Earth enters the aperture and is reflected off of four mirrors before reaching the focal plane. The focal plane is made up of 14 FPMs. Each FPM contains 494 detectors for each of the 8 spectral bands and 988 detectors for the panchromatic band. The FPMs are aligned in a staggered configuration (odd and even FPMs offset with overlap in the across track direction) to build up the full 15° FOV in a pushbroom configuration. Butcher-block filters built up of strips of each band's spectral filter sit on top of the FPMs to provide spectral selection.

The analog signals from the OLI detectors are digitized to 14 bits in the focal plane electronics. For Landsat 8, although the OLI data were 14 bits, only 12 bits were accepted by the spacecraft electronics and transmitted to the ground. Usually the 12 most significant bits were kept, though for the shutter closed data, used to measure the detector dark levels, the least significant bits were kept. At low signals, OLI data are quantization noise limited, so this strategy provided better estimates of the instrument biases. For Landsat 9, recognizing that the OLI data were quantization noise limited, and the value improved Signal to Noise Ratio (SNR) would provide to dark targets, e.g., vegetation in the visible, polar targets at low solar elevation angles, and coastal water, all 14 bits will be retained for all targets (Earth, calibration, etc.). Figure 3 provides estimates of the improvement in SNR of OLI data (based on measured OLI performance). Note 20-30% improvement in VIS bands SNR for vegetation and water in summer, up to 45% improvement in VIS bands at lowest radiances (e.g., low sun angle data) and small improvements, circa 5% or less, at high radiance levels.

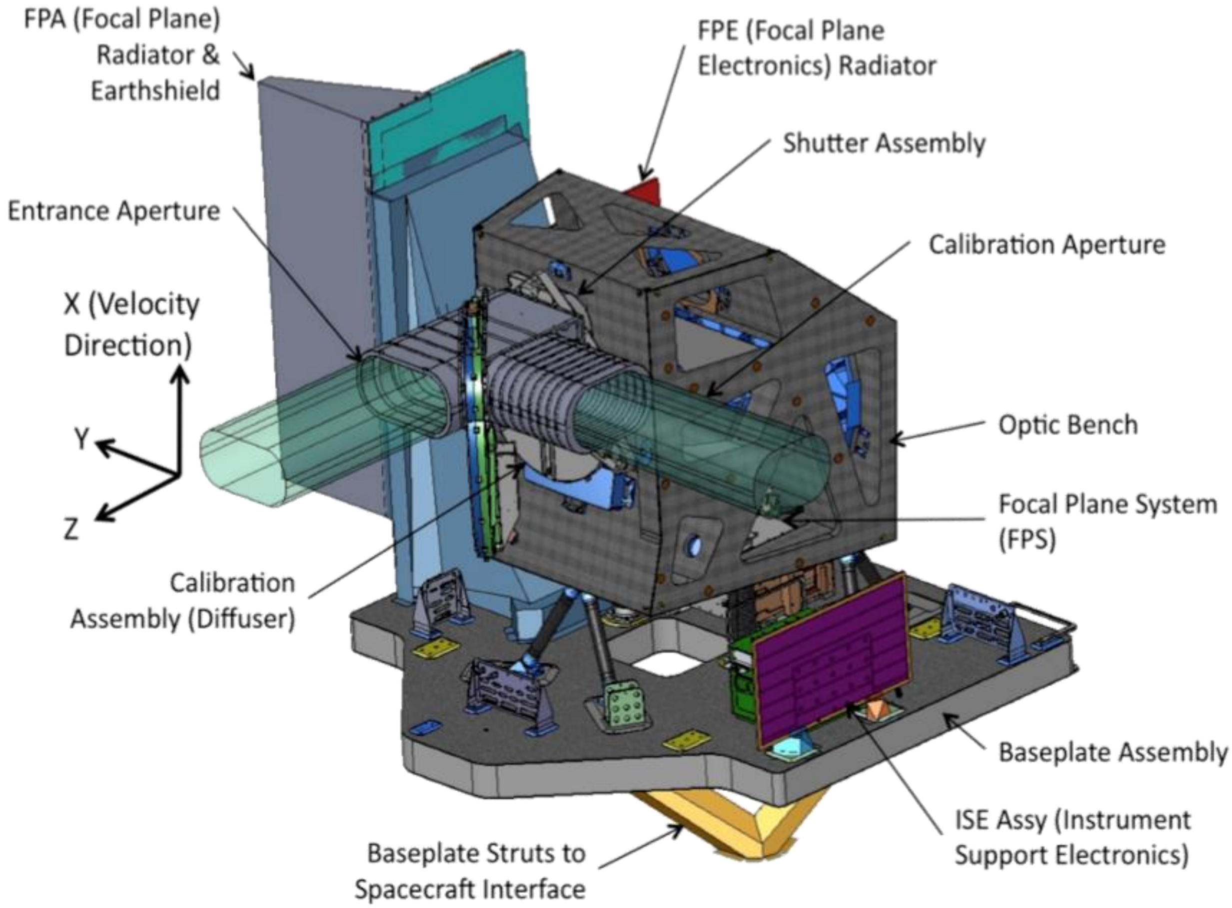

Figure 2. The Operational Land Imager (Ball Aerospace drawing).

There are changes for OLI-2 in the performance characterization and calibration program. Key among them is the use of the Goddard Laser for Absolute Measurement of Radiance (GLAMR) for the integrated instrument level spectral response characterization. GLAMR is the NASA/GSFC instance of the NIST-developed Spectral Irradiance and Radiance responsivity Calibrations using Uniform Sources (SIRCUS). GLAMR uses continuously tunable lasers coupled into an integrating sphere to provide monochromatic radiation. Standard reference detectors are used to provide absolute knowledge of the source radiance. GLAMR will allow spectrally characterizing all detectors (full field) using a uniform full aperture source. OLI had ~10% of detectors measured at instrument level using a double monochromator based system (partial aperture, small area on focal plane illuminated). In most portions of the spectrum the GLAMR will provide sufficient illumination for out of band (OOB) response characterization including crosstalk (due to flooded focal plane). OLI had OOB characterization only at the focal plane level. Additionally GLAMR will provide radiance uncertainties at the sub 1% level, allowing for validation of the OLI absolute radiance calibration.

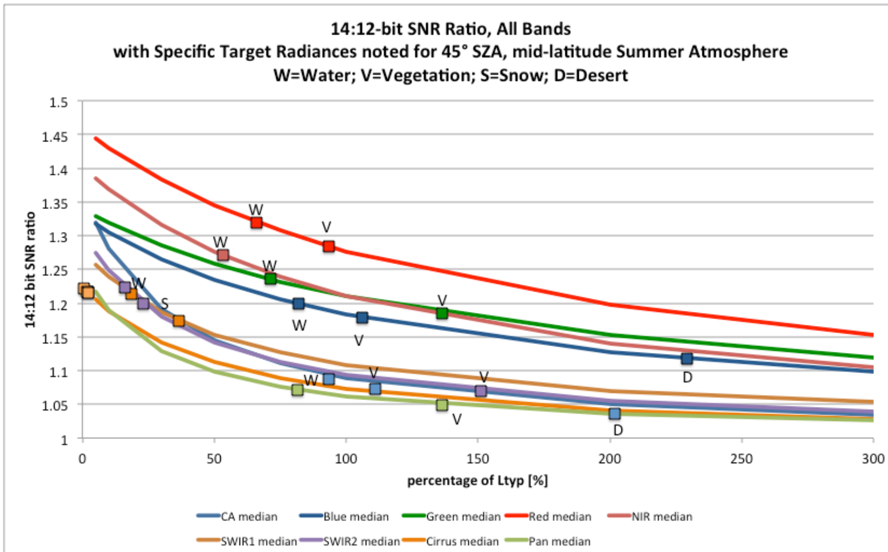

Figure 3. Measured OLI SNR improvement in going from 12 bit to 14 bit data as a function of radiance level. L_{typ} is the specified radiance for SNR performance requirements. Modeled Water (W), Vegetation (V), Snow (S) and Desert (D) target signal levels for 45° SZA and mid-latitude summer atmospheric conditions are shown for each band.

Other changes in the instrument test plan include incorporation of additional testing of the OLI-2 radiance linearity at the focal plane electronics and integrated instrument level, removal of the step and stare spatial characterization and use of the continuous scanning methodology only (which worked better on OLI), and measurement of the spatial edge response of the OLI-2 at multiple focus positions.

2.2 TIRS-2

TIRS-2, like TIRS, will be built by NASA's Goddard Space Flight Center. It will largely be a rebuild of TIRS (Figure 4), but with the improved redundancy required for a risk class B instrument. The primary changes will be in the electronics, including Main Electronics Box (MEB) redundancy, Cryo-Cooler Electronics (CCE) redundancy and cross-strapped MEB and Focal Plane Electronics (FPE).

Like TIRS, light enters the Earth aperture, is reflected off the Scene Select Mirror (SSM), and goes through the four telescope refractive elements (Figure 5) to the focal plane. The focal plane is made up of three sensor chip assemblies, each with a filter bezel containing spectral filters for the two bands (Landsat band 10 and band 11). The spare focal plane assembly for TIRS will be used for TIRS-2 and several spare sensor chip assemblies from the TIRS program will be used for the TIRS-2 spare focal plane. The TIRS flight spare focal plane is scheduled for testing in the Fall of 2016; this testing will also incorporate spectral response testing, which was not done at this integration level for TIRS. This characterization will likely provide better spectral characterization of TIRS-2 than was obtained for TIRS. Based on earlier measurements, performance is expected to be similar to TIRS.

TIRS stray light performance was problematic[4]. Out-of-field ghosts at approximately 13° off axis (nominal field-of-view extends to ± 7.5°) contributed sufficient energy under average conditions to affect the absolute calibration by some 2% in band 10 and 4% in band 11; in worst case situations, these numbers could be double[4]. This response also varied between detectors, inducing scene dependent non-uniformity. These ghosts were traced to reflections off the lens 3 mounting structure (Figure 5). For TIRS-2, baffles are being added to the telescope in to suppress these ghosts. The new design will be independently analyzed and testing limitations with Ground Support Equipment (GSE) are being addressed. TIRS Calibration GSE cannot be placed close enough to TIRS at the integrated instrument level (with Scene Select Mirror (SSM) in place) to measure stray light/ghosts beyond about 10° off axis. The current plan for TIRS-2 calls for stray light testing at the telescope level in ambient with CO_2 laser and with the combined telescope and focal plane in thermal-vacuum (minus SSM and front baffles) with existing GSE, which will allow testing out to ~25° off axis. Additional review team involvement is planned to finalize testing plans.

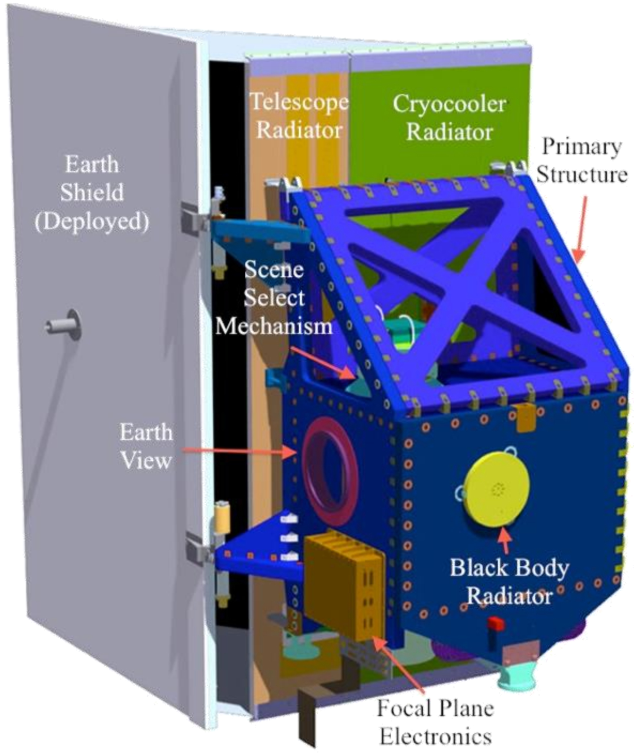

Figure 4. The Thermal Infrared Sensor (GSFC drawing).

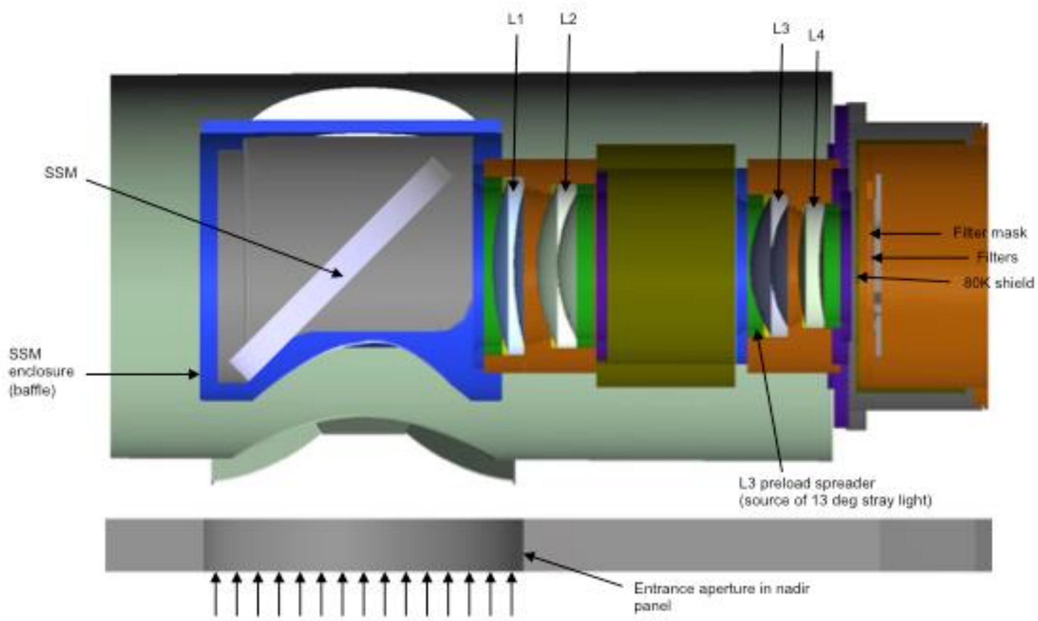

Figure 5. The Thermal Infrared Sensor Optical System (GSFC drawing)

Other design changes being incorporated into TIRS-2 include: (1) an improved scene select mirror position encoder to address the anomalous high currents observed on TIRS that led to a substantially reduced number of radiometric calibrations that rely on the SSM and (2) a change in the mount for the focal plane assembly to the telescope. On TIRS focusing was problematic and varied across the focal plane. The revised mount is designed for easier shimming and to induce less distortion across the focal plane.

3. MISSION DEVELOPMENT

As is typical for mission development, the instruments are the furthest along at this phase of the overall project. The spacecraft delivery order award is anticipated in Fall 2016, followed by spacecraft systems requirement review in early to mid 2017 and preliminary design review in mid to late 2017. The ground system will look very similar to the existing Landsat 8 ground system. USGS anticipates a Ground System Heritage Review in late 2016 along with a Landsat Mission Operations Contract Award in early to mid 2017. The overall mission preliminary design review is anticipated in mid 2017.

ACKNOWLEDGEMENTS

Landsat 9 is a joint project between NASA and the USGS, made possible by the contributions of government and contractor personnel too numerous to list here. Ball Aerospace is the key contractor for the OLI-2 instrument and the TIRS-2 cryocooler. Contractors for the spacecraft, launch vehicle and other aspects of the project have yet to be selected. Key project senior staff include:

Del Jenstrom, NASA project manager
Jim Nelson, USGS project manager
Jeff Masek, NASA project scientist
John Dwyer, USGS project scientist
Matthew Strube, NASA OLI-2 instrument manager
Phil Dabney, NASA instrument scientist
Jason Hair, NASA TIRS-2 instrument manager
Dennis Reuter, NASA TIRS-2 instrument scientist
Vicki Dulski, NASA observatory manager
Leanne Presley, Ball Aerospace OLI program manager
Ed Knight, Ball Aerospace OLI lead system engineer

These and many others are logical authors for this presentation of material.

Additional details on the project can be obtained at: http://landsat.gsfc.nasa.gov, and http://landsat.usgs.gov.

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