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SPIE.

Event: SPIE Optical Engineering + Applications, 2020, Online Only

Landsat 9 Mission Update and Status

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ABSTRACT

Landsat 9 is currently undergoing testing at the integrated observatory level in preparation for launch from Vandenberg Air Force Base in 2021. Landsat 9 will replace Landsat 7 in orbit, 8 days out of phase with Landsat 8. Landsat 9 is largely a copy of Landsat 8 in terms of instrumentation, with an Operational Land Imager (OLI), model #2 and a Thermal Infrared Sensor (TIRS), model #2. The TIRS-2 is more significantly changed from TIRS with increased redundancy, as well as changes to the telescope baffling to improve stray light control and a revised scene select mirror encoder mechanism. Data quality of the Landsat 9 instruments is comparable to, or better than the Landsat 8 ones, with an increase to 14 bits of data transmitted and more detailed pre-launch characterization for OLI-2, and with more detailed characterization of the TIRS-2 pre-launch, in addition to the improved stray light control. The performance of the two instruments is summarized and compared to that of the Landsat 8 instruments.

Keywords: Landsat 9, Operational Land Imager 2, Thermal Infrared Sensor 2

1. INTRODUCTION

1.1 Landsat 9 Mission

The Landsat 9 mission will provide continuity in multi-decadal Landsat land surface observations to study, predict, and understand the consequences of land surface dynamics[1]. It is a core component of the Sustainable Land Imaging (SLI) program. The mission team includes NASA's Goddard Space Flight Center (flight system and checkout), United States Geological Survey (USGS) (ground system and operations) and NASA's Kennedy Space Center (launch services). The single satellite has a 5 year design life with a minimum of 10 years of consumables on board. Landsat 9 will be launched into the standard sun-synchronous 705 km orbit, providing 16 day global coverage by itself and 8 day global coverage in conjunction with Landsat 8. Landsat 9 will occupy the current location of Landsat 7, i.e., 8 days out of phase with Landsat 8.

The two instruments on Landsat 9 are the OLI-2 and the TIRS-2. OLI-2 is nearly identical to the OLI on Landsat 8 [2] and the TIRS-2 [3] is similar to the TIRS on Landsat 8 [4]. They will provide data in 11 spectral bands from the visible to the thermal infrared at spatial resolutions (in terms of Ground projected Instantaneous Field of View (GIFOV)) of 15 to 100 meters (Table 1). Both instruments are pushbroom, with approximately 7000 detectors per 30 meter band on OLI-2 (14000 for the pan band) and 1900 detectors per 100 meter band on TIRS. The OLI-2 was developed under contract by Ball Aerospace; the TIRS-2 was developed at Goddard Space Flight Center. The spacecraft was developed under contract by Northrop Grumman Space Systems (NGSS); integration and test of the observatory (combined spacecraft and instruments) is also under the NGSS contract. United Space Alliance is providing launch services under contract to Kennedy Space Center. The ground system is being developed by the USGS, leveraging existing contracts at the Earth Resources, Observation and Science (EROS) Center, with the exception of the Landsat Mission-satellite Operations Center (LMOC), which is being developed by General Dynamics Mission Systems.

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Earth Observing Systems XXV, edited by James J. Butler, Xiaoxiong (Jack) Xiong,
Xingfa Gu, Proceedings of SPIE Vol. 11501, 115010O · © 2020 SPIE
CCC code: 0277-786X/20/$21 · doi: 10.1117/12.2569748

1.2 Mission Status

The two flight instruments (Figure 1), TIRS-2 and OLI-2, have been delivered and mechanically integrated onto the spacecraft (Figure 2). As of this writing, the OLI-2 has been electrically integrated to the spacecraft and tested for functionality and TIRS-2 is in the process of electrical integration. After TIRS-2 integration, the first observatory level comprehensive performance test will be conducted, followed by Electromagnetic Interference/Electromagnetic Compatibility, Vibration and Thermal Vacuum/Thermal Balance Testing. Following observatory level testing completion, the observatory will be shipped to Vandenberg Air Force Base for launch on an Atlas-V 401 (Figure 2). All components on the Landsat 9 ground system, the Landsat Multi Satellite Operations Center (LMOC), the Ground Network Environment (GNE) including the ground stations and data collection and routing system, and the Data Processing and Archive System (DPAS) are on schedule for readiness by launch.

After launch in 2021, there will be a 90 day commissioning period during which Landsat 9 will be activated and checked out. Both instruments will collect characterization and calibration data from on-board sources (lamps, shutters and black bodies) and celestial sources (Sun (reflected off on-board diffusers), Moon and deep space), along with ground-based geometric calibration sites, to confirm performance is as expected. Earth image data will be acquired on an increasing schedule so that the planned acquisition rate of ~750 scenes per day is achieved. Landsat 8 and Landsat 9 Earth image data will be acquired near simultaneously for several days to allow comparison and cross-calibration. After placement in its final orbit, 8 days out-of-phase with Landsat 8, and upon completion of its on-orbit checkout, Landsat 9 will be transitioned to operations under USGS control.

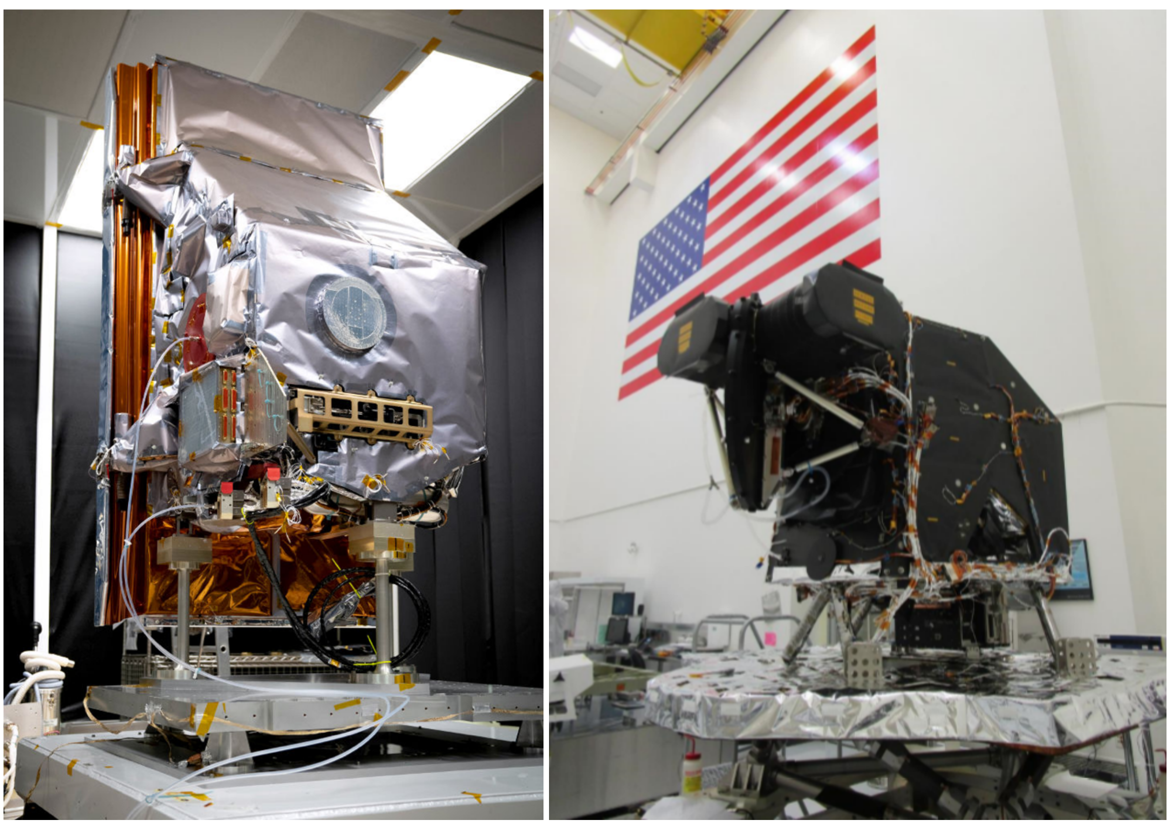

Figure 1. Completed TIRS-2 Instrument (left) and OLI-2 Instrument (right) prior to integration onto spacecraft.

Figure 2. Landsat 9 observatory with integrated OLI-2 and TIRS-2 instruments (bagged) (left) and Atlas-V payload fairing for Landsat 9 (United Launch Alliance Photo) (right).

Table 1. Landsat 9 Spectral Bands and Spatial Resolutions

Band	Band Designation	Band Edges (nm)	GIFOV (m)
1	Coastal Aerosol (CA)	435 – 450	30
2	Blue	452 – 512	30
3	Green	533 - 589	30
4	Red	636 - 673	30
5	Near IR (NIR)	850 - 879	30
6	Short Wave IR 1 (SWIR 1)	1565 - 1651	30
7	SWIR 2	2105 – 2295	30
8	Panchromatic	503 – 675	15
9	Cirrus	1364 – 1384	30
10	Thermal 1	10450 - 11200	100
11	Thermal 2	11580 – 12500	100

2. TIRS-2 PERFORMANCE

2.1 Spectral Response

Like the Landsat 8 TIRS instrument, the relative spectral response of the Landsat 9 TIRS-2 instrument was calculated by measuring the spectral characteristics of each component contributing to the spectral response (detectors, filters and optics) as well as by direct measurement at the integrated instrument level. The process was improved for the TIRS-2 instrument level characterizations, providing higher signal levels and measurements at more locations across the focal plane. Figure 3 shows a comparison of the average TIRS-2 spectral responses and the TIRS spectral responses.

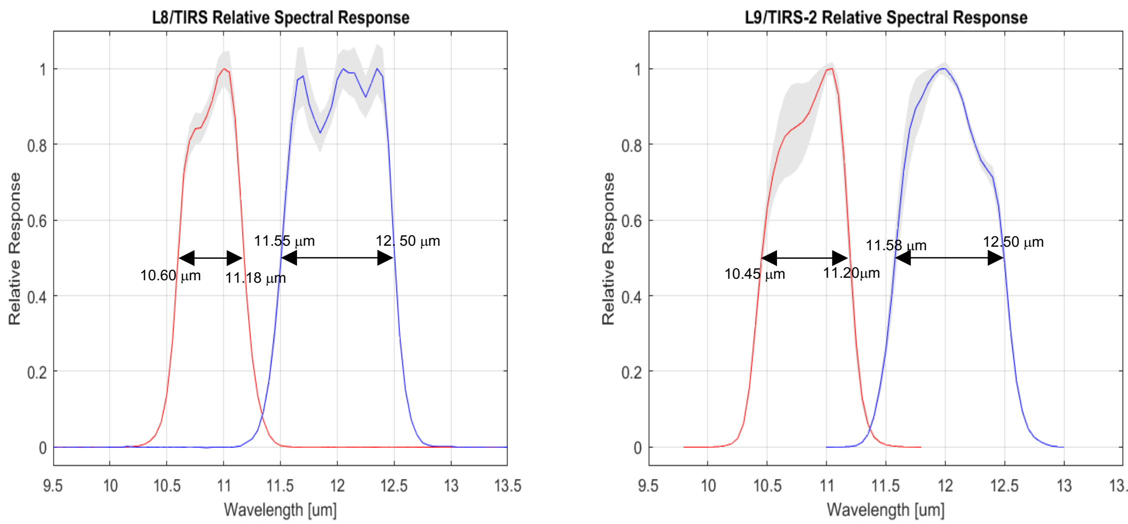

Figure 3. Landsat 8 TIRS band average spectral response (from component level measurements) and Landsat 9 TIRS band average spectral response (from integrated instrument level measurements). Shading shows ±1 sigma variation within the band. The Landsat 8 TIRS lower band edges were about 0.04 μm lower in the integrated instrument level measurements (the upper band edge was unchanged) – this difference has a marginal effect on the radiometric calibration.

2.2 Noise

TIRS-2 noise levels are comparable to TIRS, being 50 to 80 mK across the range of typical Earth surface targets (Table 2). For both TIRS instruments, the noise measurements were made in thermal vacuum observing an external blackbody.

Table 2. Landsat 8 TIRS and Landsat 9 TIRS-2 Average Noise Equivalent Temperatures (1 sigma in K) at three scene temperatures

Instrument	Band	270K	300K	320K
L8 TIRS	10	0.06	0.05	0.05
	11	0.06	0.05	0.05
L9 TIRS-2	10	0.05	0.05	0.05
	11	0.08	0.07	0.06

2.3 Stray Light

Stray light was a particular challenge for Landsat 8 TIRS and required a post-launch correction in the operational image processing system. The Landsat 8 TIRS stray light contribution to image signal was larger in the Thermal 2 band (~12 μm). As shown in Figure 4, the stray light contribution could be as high as 8% of the signal in the center Sensor Chip

Assembly (SCA-C). Significant redesign and improved testing conducted on the Landsat 9 TIRS-2 led to reduction in the stray light by more than an order of magnitude across much of the field of view, though there may still be a significant contribution towards the edges of the field of view. The correlation of the stray light model with the pre-launch measurements was not as good as expected and pre-launch measurements across the full field of view were not feasible prior to launch; the edge of field results may be overestimated by the model shown. During the commissioning phase, scans of the moon with TIRS-2 are planned to more completely map out the stray light response and determine whether stray light correction would improve performance.

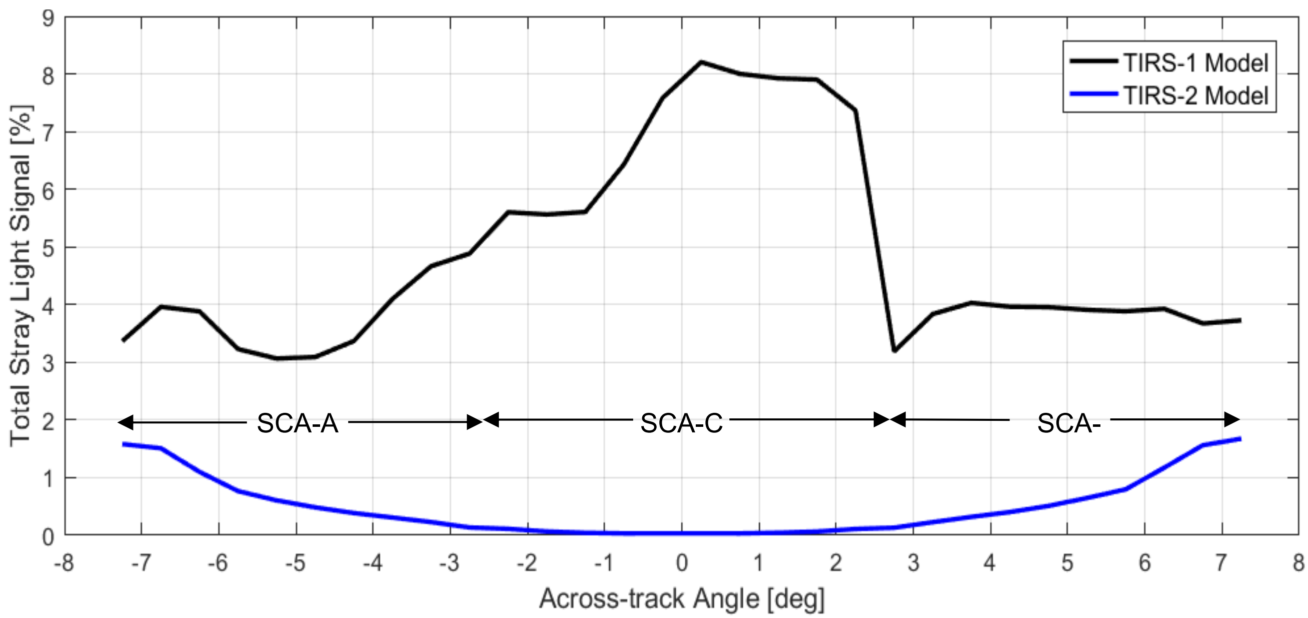

Figure 4. TIRS and TIRS-2 Thermal 2 band (12 μm) stray light contributions across the field of view. The field of view is composed of three Sensor Chip Assemblies (SCA).

3. OLI-2 PERFORMANCE

3.1 Spectral Response

The spectral responses of both of the OLIs were measured at the integrated instrument level. For the Landsat 8 OLI, a traditional monochromator based system was used to measure a sampling of detectors. For the Landsat 9 OLI-2, a tunable laser based system, the Goddard Laser for Absolute Measurement of Radiance (GLAMR) was used [5] and all detectors were measured. Average spectral response parameters are shown in Table 3.

Table 3. Landsat 8 OLI and Landsat 9 OLI-2 Band Spectral Bandpasses

		Landsat 8 OLI				Landsat 9 OLI-2			
#	Band	Mean Band Center (nm)	St Dev Band Center (nm)	Mean Band Width (nm)	St Dev Band Width (nm)	Mean Band Center (nm)	St Dev Band Center (nm)	Mean Band Width (nm)	St Dev Band Width (nm)
1	CA	443.0	0.2	16.0	0.0	442.8	0.1	15.5	0.1
2	Blue	482.1	0.1	60.1	0.2	481.9	0.1	59.9	0.3
3	Green	561.4	0.1	57.4	0.0	561.0	0.1	56.5	0.2
4	Red	654.7	0.1	37.6	0.1	654.3	0.2	36.9	0.4
5	NIR	864.7	0.2	28.2	0.3	864.6	0.3	28.8	0.1
6	SWIR 1	1608.9	0.3	84.7	0.8	1608.2	0.4	86.1	0.5
7	SWIR 2	2200.7	0.5	186.7	0.4	2200.2	0.4	189.4	0.6
8	Pan	589.5	0.2	172.4	0.2	589.3	0.1	172.5	0.3
9	Cirrus	1373.5	0.3	20.3	0.1	1374.1	0.2	20.9	0.1

3.2 Noise

The OLI-2 noise was measured at 20 of radiance levels per band, generated by the integrating sphere used for radiometric calibration. Noise levels at each of these radiance levels were calculated and fit to an equation of the form:

Noise = SQRT ($A + B*L_\lambda$), where L_λ is the spectral radiance and A and B are fitting coefficients,

and calculated for the "typical" spectral radiances listed in the requirements documents. Both OLI and OLI-2 have 14 bit A/D converters, but the Landsat 8 spacecraft truncates the OLI data to 12 bits; The Landsat 9 spacecraft retains the full 14 bits. The two sensors are comparable in terms of noise performance, but the transmitted data for OLI-2 has higher SNR at lower radiance levels due to the reduced quantization noise from the 14 bits (Table 4).

Table 4. Landsat 8 OLI and Landsat 9 OLI-2 Median Signal to Noise Ratios (SNR) at the specified "typical" spectral radiance ($L_{typical}$)

Band	$L_{typical}$ (W/m^2 sr µm)	L8 OLI SNR (12 bit)	L9 OLI-2 SNR (14 bit)
1	40	232	262
2	40	355	441
3	30	296	365
4	22	222	268
5	14	199	249
6	4	261	316
7	1.7	326	368
8	23	145	161
9	6	162	173

4. SUMMARY

Landsat 9 is proceeding to launch in 2021. Upon commissioning on orbit, high quality reflective and thermal infrared Earth images will be collected by the Landsat 8 and 9 sensors on nearly all sunlit Earth Land masses every 8 days to allow continued long-term assessment of land surface dynamics. In conjunction with the Sentinel 2 MSI data which are collected every 5 days over the Earth's land surface, coverage will be provided every few days.

5. ACKNOWLEDGMENTS

The Landsat 9 project is large effort including participants across multiple federal agencies and numerous contractors. All of them are critical to the success of the mission. We would like to particularly thank Boryana Efremova for performing analyses to assess the uncertainties in the TIRS spectral response measurements and their impact on radiometric calibration.

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