Pre-launch Radiometric Characterization of the Operational Land Imager 2 (OLI-2)

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Imagery Credit: USGS/NASA Landsat
Overview

- Facilities
- Noise Characterization
- Non-Uniformity Characterization
  - Of the calibration source
  - Of spectral non-uniformities using GLAMR data
- Non-Linearity
  - Using varying integration times
- Stability
Radiometric, Spectral, and Polarization Characterization done together

- The Calibration Test Station (CATS) put the instrument inside a vacuum chamber with sources outside the window
  - Large integrating sphere (radiometric characterization/calibration)
  - Integrating Sphere with large sheet polarizer (polarization)
  - NASA provided GLAMR source (tunable lasers pumping a sphere)

![Diagram showing CATS setup with OLI-2, GLAMR Sphere, and Rotating Polarizer in front of window.](image-url)
CATS Enables Use of Multiple Sources
CATS is well suited for characterization of OLI-2

- This test setup allowed for efficient radiometric characterization in 3 domains:
  - Radiometric, Spectral and Polarization
- The design of CATS addressed several challenges:
  - OLI-2 15° cross track field of view
  - Tight spatial uniformity requirements
  - Solar illumination of the diffusers by the heliostat, inside the chamber
  - Practical sizes of the:
    - DSS
    - Heliostat beam size
- The test set was designed to cover the field of view in segments by rotating about the OLI-2 entrance pupil.
- The forward location of the OLI-2 entrance pupil had several benefits for test and allowed:
  - Rotation of OLI-2 inside the chamber to illuminate any desired portion of the field of view, without bumping into the chamber walls.
Death Star Source (DSS)

- The DSS is a 40 in. BaSO4 integrating sphere with 14 in. aperture.
  - The DSS covers the dynamic range of all OLI-2 bands.
- Two internal diodes (one Si, one Ex-InGaAs) view the sphere wall.
  - Each diode can be filtered to have a spectral response corresponding to an OLI spectral band.
  - Each diode/filter combination is roughly calibrated by the sphere software.
  - One diode actively controls the sphere output while the other passively monitors it.
  - The current from one diode is used to control a variable attenuator on a set of low power bulbs.
- To select an output radiance the operator requests a band and radiance and the sphere controls bulb combinations and aperture position.
  - Knowledge of the DSS output radiance is based on the diode set-points, not the combination of bulbs used.
- OLI-2 viewed 2x more radiance levels than OLI and each radiance level was controlled in band.
  - This greatly increases (180 vs 49) the number of levels required
- Extensive pre-CATS characterization allowed efficient testing.
Heliostat Brings Sunlight into the same Thermal Vacuum Chamber

- The Heliostat is a Three Mirror Relay
  - First Mirror is on a rotation stage programmed to track the sun
  - Second Mirror angles the beam through the roof
  - Third Mirror directs the beam into the Ball 10 chamber
  - Second and Third Mirrors are aligned so that the beam is perpendicular to the chamber window

Tracking Mirror on roof

Third mirror outside of chamber and closed chamber port
Stages Allow Calibration of the Entire FOV With In the Ball-10 Spatial Constraints

Axes
Z : Chamber Long Axis
Y: Chamber Short Axis
X : Y x Z (Vertical)

Look Left

Look Straight

Look Right
Stages Allow Mapping of the DSS Non-Uniformity and Observation of the Heliostat in Ball-10
SNR Data Show OLI-2 is close to Shot Noise Limited

- OLI-2 easily meets its noise specifications.
Uniformity is Measured Using a Continuous Scan for OLI-2

- By azimuthally scanning the DSS with OLI-2 at 21 elevations from $-1^\circ$ to $+1^\circ$ we can create a map of it’s non-uniformity, as viewed by OLI-2.
Each image is a map of the central 2° by 2° region the DSS used for radiometric characterization.
8 of 9 Bands Show Comparable Non-Uniformity

<table>
<thead>
<tr>
<th>Band</th>
<th>Name</th>
<th>CW</th>
<th>NU</th>
</tr>
</thead>
<tbody>
<tr>
<td>#</td>
<td>string</td>
<td>um</td>
<td>#</td>
</tr>
<tr>
<td>1</td>
<td>CA</td>
<td>0.443</td>
<td>0.07%</td>
</tr>
<tr>
<td>2</td>
<td>Blue</td>
<td>0.482</td>
<td>0.09%</td>
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<tr>
<td>3</td>
<td>Green</td>
<td>0.562</td>
<td>0.05%</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>0.655</td>
<td>0.07%</td>
</tr>
<tr>
<td>5</td>
<td>NIR</td>
<td>0.865</td>
<td>0.19%</td>
</tr>
<tr>
<td>6</td>
<td>SWIR1</td>
<td>1.610</td>
<td>0.08%</td>
</tr>
<tr>
<td>7</td>
<td>SWIR2</td>
<td>2.200</td>
<td>0.48%</td>
</tr>
<tr>
<td>8</td>
<td>Pan</td>
<td>0.590</td>
<td>0.12%</td>
</tr>
<tr>
<td>9</td>
<td>Cirrus</td>
<td>1.375</td>
<td>0.07%</td>
</tr>
</tbody>
</table>

- SWIR-2 (2.2 μm) is out of family.
- This is probably due to sensitivity to thermal variation caused by cooling lines on the back of the sphere.
OLI-2 Characterizes Images Non-Uniformity with Three Metrics

- The non-uniformity of the OLI-2 spectral response contributes to each metric.
The OLI-2 specification mandates evaluation of flat-fielding quality against several scene spectra.

Variations in spectral response are caused by:
- Variation in angle of incidence of illumination on the filters.
- Spatial variation of the response of the filters.

Because:
- The spectral response of each detector varies slightly,
- Each band is required to report band-weighted radiance with a single weighting function (RSR)

When calibrating against a spectrum (DSS) that is not the same as the scene (solar, vegetation, soil). There is unavoidable per-detector:
- Radiometric error
- Non-uniformity
GLAMR Allows Detailed Characterization of Spectral Errors

- Knowledge of … :
  - the calibration source (DSS) spectrum
  - the scene spectral content
  - RSR for each detector

- ... Allows calculation of the radiometric error associated with each detector.

- These errors are small relative to our radiometric specifications...

- … However the detector to detector variation in these errors introduces significant non-uniformity errors.
The Streaking Metric Evaluates High Spatial Frequency (detector to detector) Non-Uniformity
Banding is largely driven by discontinuities in illumination geometry at the focal plane module boundaries.
The Full Field of View (FFOV) Metric Evaluates Low Spatial Frequency Non-Uniformity

- **FFOV Non-Uniformity** is driven by all effects.

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**FFOV NU DSS to Soil**

**FFOV NU to Vegetation**

**FFOV NU to Sun**

**FFOV NU Residual**
No single set of calibration coefficients can eliminate spectrally induced radiometric error for all scenes.

The spectral non-uniformities are significant contributors to the overall OLI-2 non-uniformity budgets.

Given knowledge of spectral non-uniformities we can adjust calibration coefficients to minimize non-uniformity errors for the scenes of interest, or create special coefficients for particular scenes.

This potentially has several consequences:

- It improves the OLI-2 reported performance.
- It allows for the possibility of tuning calibration coefficients for scenes (such as Oceans and Ice) where:
  - Scene spectral content is spatially uniform
  - Scene spatial content is also uniform and hence de-striping is of interest
Varying Integration Times At A Variety of Signal Levels Allows Detailed Evaluation of Linearity
OLI-2 Can Monitor Linearity On-Orbit w/Variable Integration Time

- On-orbit OLI-2 can observe the diffuser at varying integration times.
- OLI-2 has a 16 day radiometric stability requirement.
- Since radiometric instability is expected to be driven by thermal variation as opposed to time, per-se, we evaluated performance by modifying the chamber shroud temperature to simulate the range of on-orbit operating temperatures.
  - This provided a more stringent test case than just examining images taken by OLI-2 in the chamber 16 days apart.
  - It expedited testing.
Summary

- OLI-2 is complete; on schedule for December 2020 launch
  - Minimal changes from OLI
  - Maintained strong emphasis on calibration and characterization
- Characterization and Calibration testing is complete
  - Results are comparable or better to OLI
    - Spectral and spatial uniformity characterizations more complete
    - Linearity measured more precisely
    - More NIST traceable radiance levels
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