

Radiometric Calibration and Stability of the Landsat-8 Operational Land Imager (OLI)

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ABSTRACT

Landsat-8 and its two Earth imaging sensors, the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) have been operating on-orbit for 2 ½ years. The OLI radiometric calibration, which is monitored using on-board lamps, on-board solar diffusers, the moon and vicarious calibration techniques has been stable to within 1% over this period of time. The Coastal Aerosol band, band 1, shows the largest change at about 1% over the period; all other bands have shown no significant trend. OLI bands 1- 4 show small discontinuities in response (+0.1% to 0.2%) beginning about 7 months after launch and continuing for about 1 month associated with a power cycling of the instrument, though the origin of the recovery is unclear. To date these small changes have not been compensated for, but this will change with a reprocessing campaign that is currently scheduled for Fall 2015. The calibration parameter files (each typically covering a 3 month period) will be updated for these observed gain changes. A fitted response to an adjusted average of the lamps, solar and lunar results will represent the trend, sampled at the rate of one value per CPF.

Keywords: Landsat, radiometry, radiometric stability, calibration, OLI

1. INTRODUCTION

Landsat-8 continues the 40 plus year history of the Landsat program. It has been successfully collecting Earth imagery beginning shortly after its launch in February 2013. The OLI provides the reflective solar bands; the TIRS covers the thermal region. This paper will deal exclusively with the OLI sensor. Basic information for OLI is provided in table 1. More detailed information on the OLI, its pre-launch and early-on orbit performance is covered in the special issue of Remote Sensing (http://www.mdpi.com/journal/remotesensing/special_issues/landsat8).

Radiometric Monitoring and Calibration Methods

The OLI has multiple on-board calibration devices that are used in conjunction with observations of the moon and terrestrial targets to provide the radiometric calibration of the OLI and monitor its stability^{1, 2}. A shutter, three sets of tungsten halogen lamps controlled to constant current and two full aperture solar diffusers comprise the on-board systems. The shutter is closed once or twice an orbit and provides a dark reference. The lamps are used at different frequencies to help separate lamp changes from instrument changes: (1) the working set is used daily, (2) the backup set is used biweekly and (3) the pristine set is used semi-annually. The solar diffusers are similarly used at different frequencies: (1) weekly for the working diffuser and (2) semi-annually for the pristine diffuser.

The moon is imaged once a lunar cycle at a nearly constant phase angle. Each OLI focal plane module is scanned across the moon once (and one module is scanned twice) over the eclipse portion of two consecutive Earth orbits. The integrated lunar signal is compared to the ROLO – based lunar irradiance model³.

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Table 1. OLI spectral bands.

Band #	Band Name	Lower Band Edge (nm)	Upper Band Edge (nm)	IFOV (m)
1	Coastal Aerosol (CA)	435.0	451.0	30
2	Blue	452.0	512.1	30
3	Green	532.7	590.1	30
4	Red	635.9	673.3	30
5	Near Infrared (NIR)	850.5	878.8	30
6	Short Wave Infrared -1 (SWIR-1)	1566.5	1651.2	30
7	Short Wave Infrared -2 (SWIR-2)	2107.4	2294.1	30
8	Panchromatic (Pan)	503.3	675.7	15
9	Cirrus	1363.2	1383.6	30

2. RESULTS

On-board and Lunar-based results

In Figure 1 are shown the trends for each OLI band (excluding the Pan band) in terms of normalized band average response for each technique. All results are normalized to the date of the initial solar diffuser collects, though the normalization is not perfect due to noise in each set of measurements.

The key things to note in the plots are:

- 1) The consistency of the results from the different techniques. All techniques are consistent to within a few tenths of a percentage over the 2.5 years to date of the mission.
- 2) The stability of the OLI response. In the worst case, OLI band 1, the response has changed about 1% over the mission to date. All other bands are in the few tenths of percentage change.
- 3) Some divergence over time in the response to the working diffuser (used weekly) and the pristine diffuser (used semi-annually). The response to the working diffuser has increased a few tenths of a percent relative to the starting response and the pristine diffuser.
- 4) A small step like increase in response (0.1 to 0.2%) in the visible bands at about 0.6 years since launch followed by a recovery about a month later. The initial step increase occurred in conjunction with a power cycling of the OLI instrument.
- 5) Generally decreasing scatter in the trends with increasing wavelength, with the exception of the lunar trends, which are noisiest in the Cirrus and SWIR-1 bands. This noise is currently under investigation.

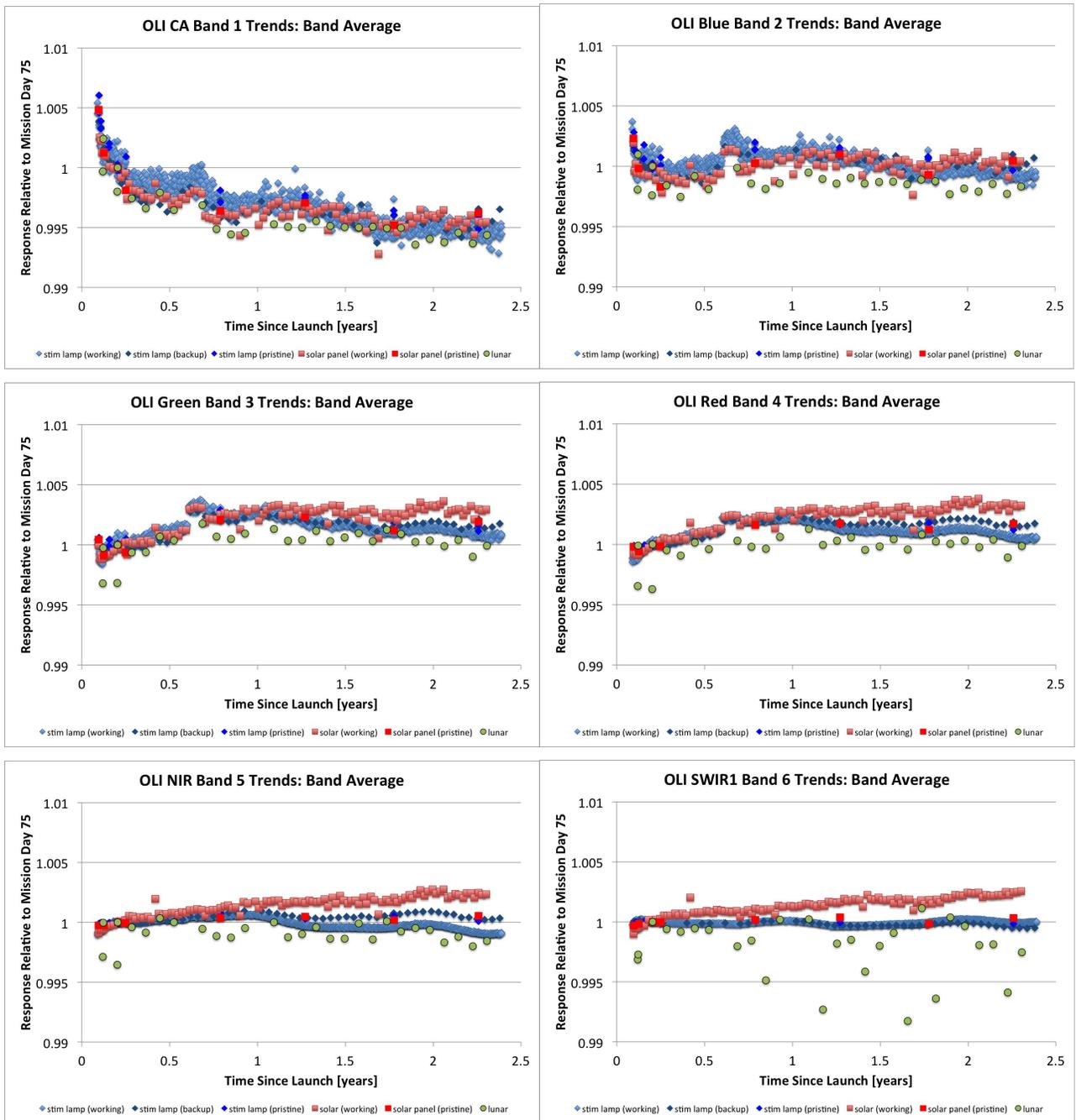


Figure 1a. OLI response trends to on-board calibrators and the moon

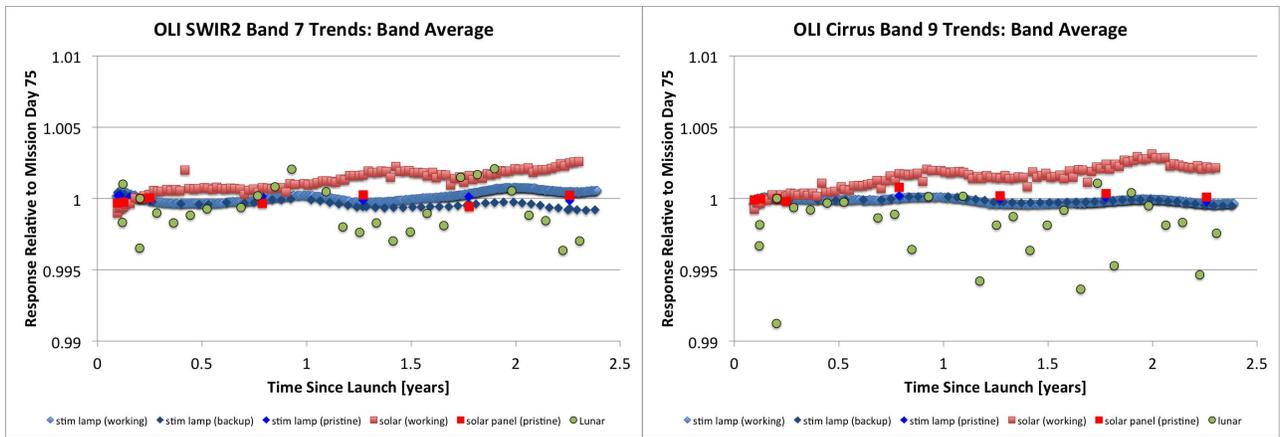


Figure 1b. OLI response trends to on-board calibrators and the moon

3. ANALYSIS AND DISCUSSION

Removal of Systematic Effects

The results strongly suggest a small brightening of the working solar diffuser over time, particularly in the SWIR bands. In order to come up with a good estimate of the instrument response change over time, all calibrator-related changes must be accounted for. An initial estimate of the brightening of the solar diffuser was determined by fitting a line to the ratio of the working solar diffuser response to the pristine diffuser response. Removing this linear effect, results in the change observed in Figure 2 for band 5 between the “solar diffuser working (original)” and “solar diffuser working”

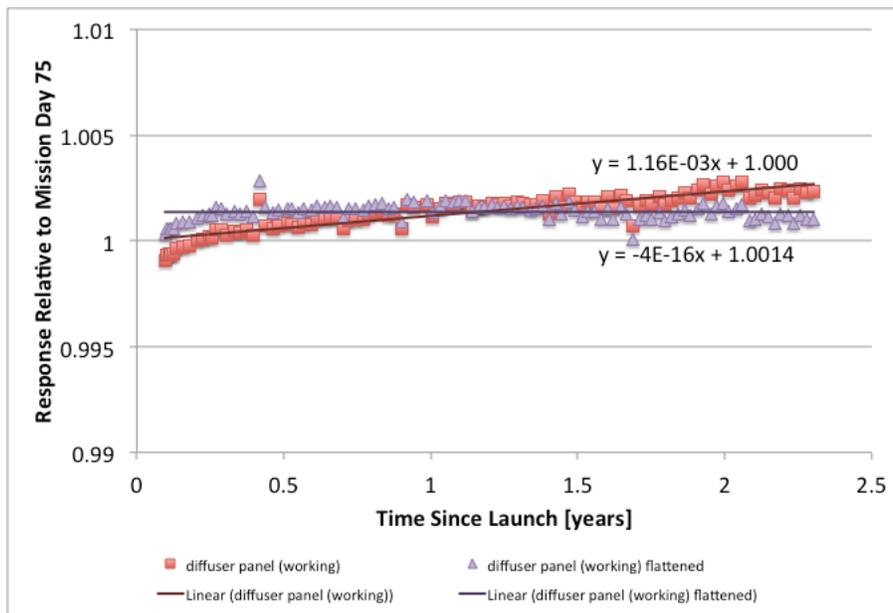


Figure 2. OLI Band 5 responses to working diffuser before and after adjustment for working diffuser “brightening”

Another systematic effect in the trends, though believed to be in the actual instrument response, as opposed to a calibrator change (as it shows up in the response to all calibrators), is the discontinuity at about year 0.6 and the recovery about a month later. The working diffuser data are used to determine the magnitude of the change and that amount is removed from all calibrators' time series in order to better fit a function to the overall series. The discontinuity is put back into the final gain model, on top of the functional form.

There are additional systematic effects in the data, i.e., the overall decrease in the band 1 response with time shown by all calibrators, which is what we want to model and correct for and some oscillatory effects, which do not necessarily occur in all calibrator trends, so it is unclear whether these should be attributed to the instrument or not. These oscillations are small, circa $\pm 0.1\%$, so the impact on the fitting process is small.

The lunar data is filtered to only include positive phase angle data. The first and third lunar points from shown in Figure 1 are removed.

Fitting and Combining the Estimates

Beginning with band average time series signal data after removing the effects noted above for each of the OLI's six calibrators (working/backup/pristine lamps, working/pristine diffuser, moon), each series is independently fitted. The fitting functions considered for the data are linear, exponential, and exponential plus linear. The fitting procedure starts with a linear model, tests for the significance of the fitting parameters and the randomness of the residuals and then proceeds to more complicated fits. The process continues until random residuals are achieved, the process runs out of options, or the analyst deems the fit satisfactory. Figure 3 illustrates an exponential plus linear model fit to the CA working lamp response.

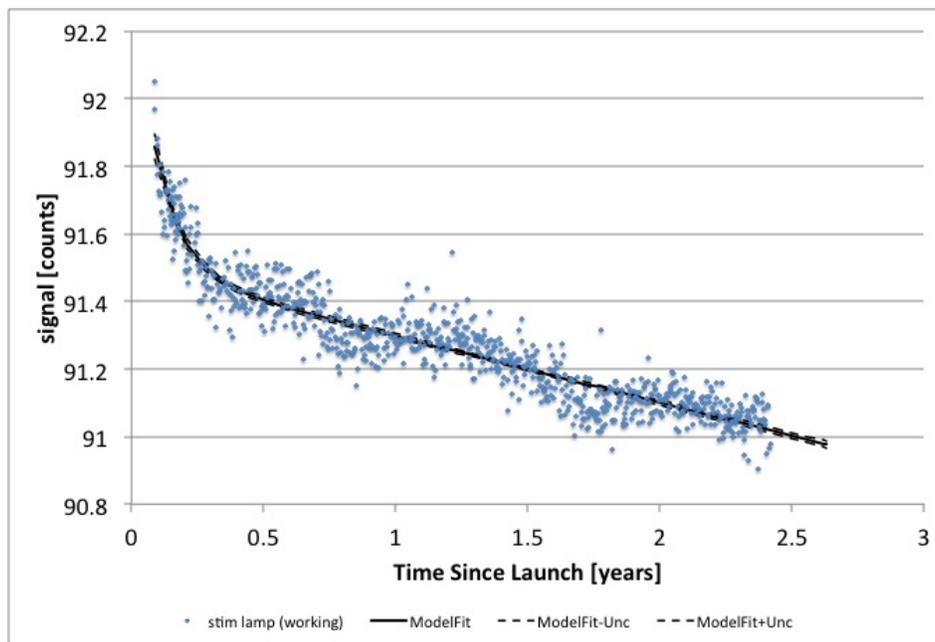


Figure 3. OLI Band 1 Exponential plus linear fit to the working lamp response

Using the fitting parameters for the given model for each calibrator, daily model values and uncertainties are calculated. The regularly gridded time series makes it easier to compare each calibrator. The model fit time series are normalized to '1' at the time of the initial on-orbit solar calibration, the current on-orbit absolute reflectance calibration reference for OLI (Figure 4).

A daily weighted average of the model values based on the uncertainties is calculated as well as a straight average. If more than three of the calibrators agree within the uncertainties with the working lamp model fit, then the weighted average is determined to be the new gain model. If even a single quarter does not agree, then the straight average is used as the new gain model. This was the case for the OLI CA band (Figure 5).

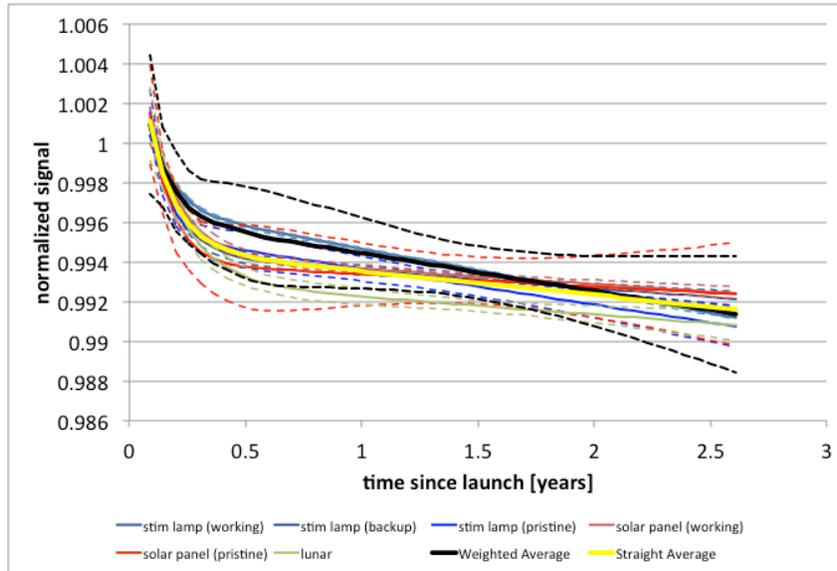


Figure 4. OLI Band 1 Fits and uncertainties to all calibrators as well as weighted average and straight averages

The maximum change in the gain model is calculated for determining whether the CPFs should be updated. The threshold for change is 0.2%. This change is determined based on the gain model before the safe-hold discontinuity is added back into the time series. If the maximum change in the gain model is greater than the threshold, then the data are converted back to absolute gains and quarter-average per-FPM gains are calculated and output them to a file to be put into updated CPFs. The new CPF's are used for processing when the decision to perform a reprocessing has been reached.

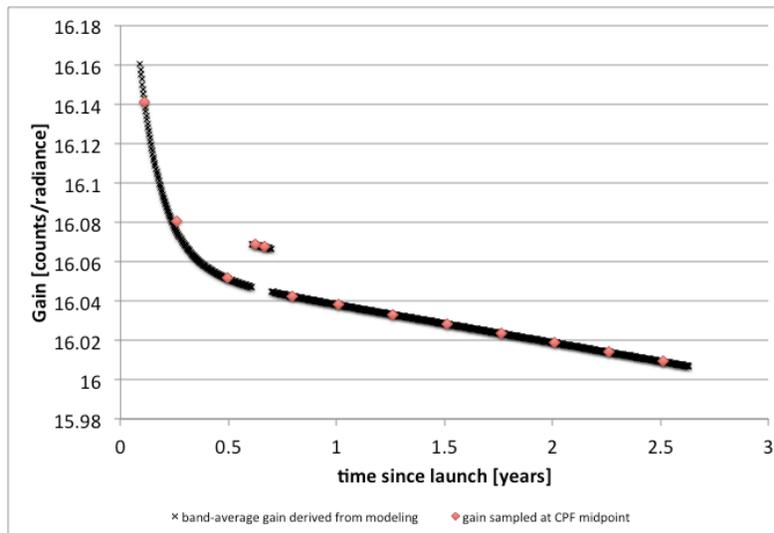


Figure 5. OLI Band 1 Gain Model based on average trend with discontinuity inserted.

The gain fitting strategy is regularly executed when new calibrator results become available. If a previously determined model is available for each calibrator, the algorithm will test the latest time series against the previous model. If the new data (the last data point) is within the uncertainty of the previous model, the previous model will be used in lieu of generating a new fit. If a previous model doesn't exist or no longer fits the data, the algorithm steps through the fits until the function passes a residual randomness test. The algorithm always starts with a linear fit regardless of what the form of the previous model was. If the algorithm gets to the exponential plus linear fit and the residuals still are not random, the algorithm will fall back to the linear fit. However, for the CA band, the fit is currently forced to be an exponential and linear regardless of the results of the randomness test, per the analyst's discretion (Figure 3).

4. SUMMARY AND CONCLUSIONS

All indications are that the OLI instrument is very stable. This based on its response to its on-board calibration devices and regular imaging of the lunar disk. Only the Coastal Aerosol band (band 1) shows a definitive trend over time, amounting to about a 1% change since launch. This trend has flattened since a larger initial rate of change and is now changing at about 0.1%/year. All the visible bands show a show jump in response (0.1 to 0.2%) coincident with a power cycling of the instrument about 7 months post launch that returned to normal about a month later. A weighted average of the responses of all the calibrators was used to estimate the CA band trend. This trend, sampled at 1 value per calibration parameter (typically 1 quarter of a year in applicability), will be used to process the data with the next reprocessing cycle, currently slated for the fall of 2015.

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