Lunar Calibration Analysis of Landsat-8 OLI Images of the Moon

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Landsat-8, briefly

- LDCM spacecraft launched 11 February 2013, 10:02 a.m. PST
  - became operational 30 May 2013 — flight operations handed off to USGS; renamed Landsat-8
  - Sun-synchronous orbit at 705 km altitude; 10:00 a.m. descending node crossing time; 16-day repeat cycle
  - payload: Operational Land Imager (OLI) and Thermal InfraRed Sensor (TIRS)

- OLI instrument
  - pushbroom imager; 185 km cross-track swath
  - sensor array consisting of 14 focal plane modules (FPMs), each:
    - 8 monochromatic bands: 442 nm to 2200 nm; 30 meter resolution
    - one panchromatic band: 600 nm, 143 nm width; 15 m resolution
OLI focal plane array

Strip filters

Along-track direction

Image courtesy of Ball Aerospace & Technologies Corp.
OLI on-orbit calibration methods

• Closed shutter — twice per orbit
• Stimulation lamps — once per day
• Solar diffuser panel — once per week
• Vicarious ground sites — by opportunity
• Views of the Moon — once per month
  — phase angle between 6° and 9°, primarily after Full Moon
  — raster scan over focal plane array
    • executed by spacecraft attitude maneuvers
    • starting over the Antarctic, through eclipse portion of orbit
    • scan at constant rate in along-track direction for 30 to 40 seconds; Moon is imaged in about 8 seconds
    • requires two orbits to scan all 14 FPMs; repeat FPM07 or FPM08
Lunar Scan Pattern Across OLI Focal Plane

Y (radians)

0.15  0.10  0.05  0.00  -0.05  -0.10  -0.15

-0.10

-0.08

-0.06

-0.04

-0.02

0.00

0.02

0.04

0.06

0.08

0.10

Band 8  Band 9
Example OLI image of the Moon — 27 March 2013

Level L1R image: radiometrically corrected, geometrically raw
  • approx. 8.25x oversampled

The same data at level L1G: geometrically corrected (incl. rotation)
Lunar Calibration, briefly

Comparison of radiometric measurements of the Moon’s brightness taken by instruments against a reference standard. The reference is provided by computations of a lunar model. An analytic model is required to accommodate the observation geometry of any view of the Moon made by the sensor.

To date, the only fully-capable model for lunar calibration is the USGS (ROLO) model of lunar spectral irradiance.

• built from the measurement database acquired by the Robotic Lunar Observatory (ROLO) between March 1996 – Sept. 2003
• the model kernel is spatially-integrated lunar disk reflectance — a function of only phase angle and the lunar librations

ROLO was a proof-of-concept project for lunar calibration. The accuracy and stability of current on-orbit sensors has revealed limitations and residual dependencies in the ROLO lunar model.
Measurements of lunar irradiance from images

Realized by summation of radiance pixels:
• background (dark, bias) subtracted
• detector artifacts removed
• selected pixels on the Moon’s disk

For this OLI analysis, used L1R image data
• (currently) pre-launch calibration from BATC
• selection of on-Moon pixels by pixel level →
• accounting for oversampling:
  — summation includes all pixels
  — direct scaling factor to measured irradiance
  — oversampling determined from spacecraft attitude telemetry and image frame rate

\[
I = \Omega_p \sum_{i=1}^{N_p} L_i
\]

\(L_i = \) pixel radiance
\(\Omega_p = \) pixel solid angle
\(N_p = \) # of pixels on Moon
OLI line-of-sight (LOS) for lunar scan

27 March 2013, FPM07; LOS relative to center of focal plane
Lunar radiometric (irradiance) comparisons

- Measurements from images scaled by the oversampling factor
- Lunar model computed for the particular geometry of each observation for each sensor and band spectral response
  - fundamental quantities of phase angle and lunar libration state
  - corrections for Sun–Moon and Moon–Observer distances
  - spectral convolution of lunar reflectance, band spectral response and solar irradiance to generate irradiances for direct comparison

For this OLI analysis, all FPMs and bands processed individually

- 16 observation datasets from 26 March 2013 to 13 June 2014
  - two months missed: safe-hold event (Sept. 2013) and special TIRS Moon observations (Feb. 2014)

- results presented as ratios of measured to modeled irradiance
  - mean values and range over all FPMs for each OLI band
Lunar irradiance comparisons — spectral trend

Vertical bars represent range over FPMs and acquisitions
Lunar irradiance comparisons — time series

Vertical bars represent range over FPMs
Lunar irradiance comparisons — time series

OLI Lunar Comparison Trends - NIR and SWIR Bands

Vertical bars represent range over FPMs
OLI lunar and solar calibration temporal trends

Both series normalized to ~70 days after launch (orange line)

CA band shows decreasing trend, < 1% (note scale), tracked by lunar results
OLI lunar and solar calibration temporal trends

Both series normalized to ~70 days after launch (orange line)

Green band shows slight increasing trend, ~0.5%, tracked by lunar results
Conclusions

• OLI sensors show on-orbit temporal response stability within 1%
  — solar diffuser and lunar comparisons follow similar trends
  — this lunar analysis is still work in progress; results presented here
    have treated the FPMs collectively

• Moon imaging by OLI produces high-quality lunar radiometry
  — across-track sampling: ~250 pixels Moon diameter
  — along-track: >8x oversampling, evaluated using spacecraft attitude
    telemetry
  — lunar irradiance comparisons have shown some limitations of the
    current lunar model

Uncertainties in using the Moon as a calibration reference are in
the model, not the Moon itself, which is knowable to high accuracy
— demonstrates a need for new lunar measurements
— e.g. measurement project initiated by NIST (C. Cramer CALCON 2013)