The Moon as a CEOS Radiometric Stability Standard — a Proposal

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Introduction — Motivation

Climate-quality EO data from solar-band radiometers require calibration stability of 1% over a decade (e.g. NISTIR 7047 — surface albedo).

- tracking performance changes in sensors and on-board calibration hardware at this level is a significant challenge at these wavelengths

The Moon presents a source of solar-reflected radiance that can be viewed by all Earth-orbiting spacecraft instruments.

- The lunar surface is exceedingly aged, thus providing favorable reflectance properties**:**
  - smooth reflectance spectrum
  - ★ photometric stability better than one part in10^8 per year (Icarus <u>130</u>, 323-327)

- The inherent stability of the Moon is key to its use as a calibration source
  - allows durable modeling of its variations in brightness (phase, non-uniformity, **...**)

  *** lunar calibration is realized through use of a photometric model ***

  - enables precise sensor response trending using a series of Moon observations
  - enables back-calibration using past observations
  - enables cross-calibration of instruments having similar passbands

Background —Lunar Model Development

To attain adequate precision in the prediction capability of a lunar model, an extensive set of basis observational data is needed.

- >4.5 years, to capture the Moon's periodic behavior (JAOT 13, 360-375)

- Acquisition of an observational dataset, and substantial advances in lunar model development have been accomplished by the lunar calibration program at the US Geological Survey in Flagstaff, Arizona, under NASA sponsorship

The USGS lunar model (ROLO model) involves the quantity of spectral irradiance.

- derived from spatial integration of Moon images (Astronom. J. 129, 2887-2901)
- advantage of increased signal-to-noise resulting from sample (pixel) summation

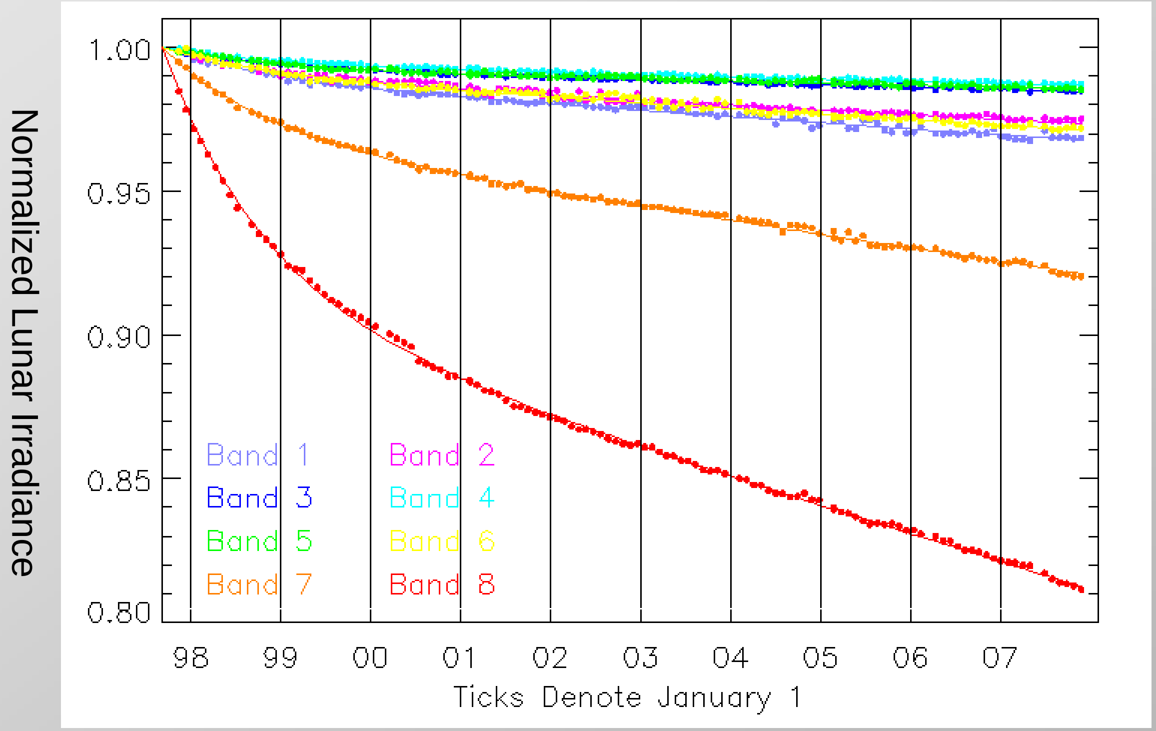
- The model was developed empirically; observational data were fitted to ~1% mean absolute fit residual
- This fit residual value (~1%) is an indicator of the model relative precision for predicting the variations in the Moon's brightness over the full range of geometric variables (phase and lunar libration)
  - effectively independent of the absolute scale

Capability of Lunar Calibration

Sensor performance trending (calibration stability) — the SeaWiFS example

- Comparison of a series of Moon observations against the lunar model reveals changes in sensor response over time
- SeaWiFS has observed the Moon >180 times, ~monthly since 1997

SeaWiFS Moon Observations/Model Comparisons



The series of SeaWiFS Moon observations, corrected by USGS lunar model results, show monotonic degradation trends in all 8 bands

These data were fitted with exponential/ polynomial functions (solid lines) to model the trends

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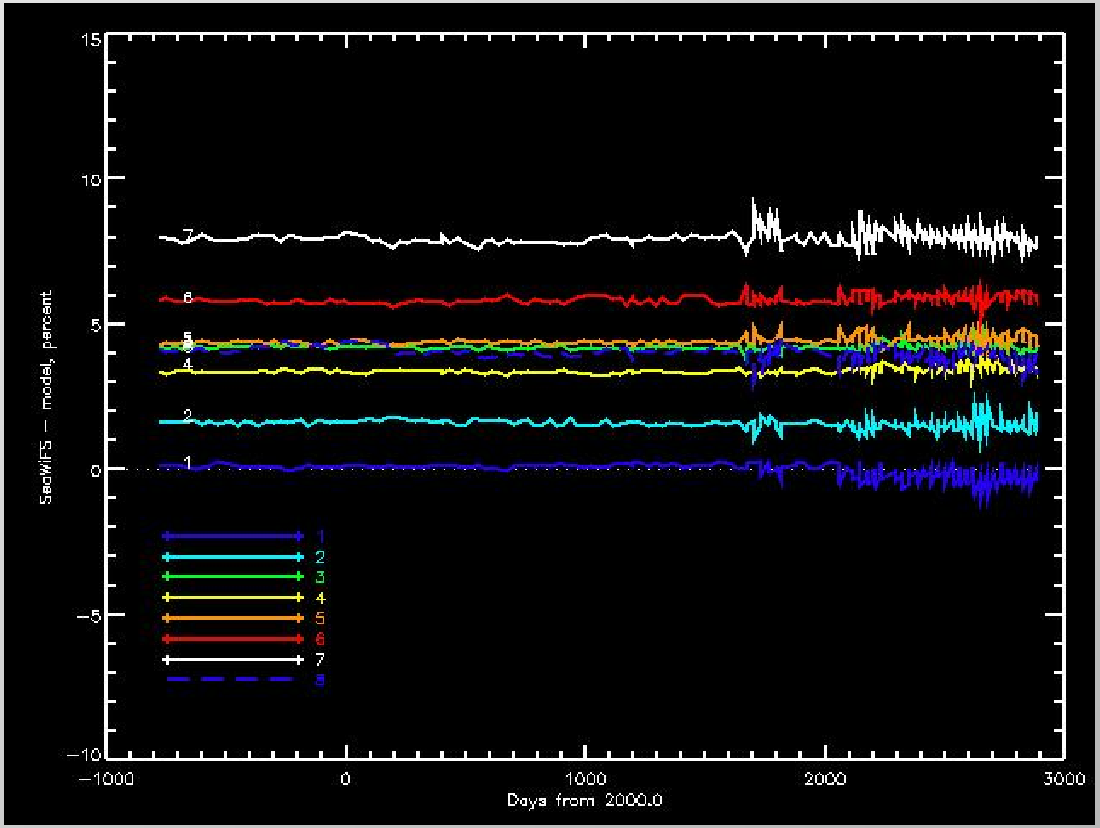
SeaWiFS Response Trending (calibration stability)

- Time-dependent calibration corrections were derived from fitting the lunar observation data — the corrected response trends for the SeaWiFS bands are flat to 0.05% per 1000 days (Applied Optics 43, 5838-5854)

SeaWiFS Observations/Lunar Model Comparisons

Discrepancy % (SeaWiFS / model – 1)



The distribution of the band plots shows the difference in absolute calibration of SeaWiFS and the lunar irradiance model

WGCV QA Requirements (DA-06-02)

The WGCV Quality Assurance strategy encompasses the need to evaluate sensor performance against an agreed reference.

- Calibration measurements and procedures need to demonstrate traceability to an internationally agreed reference standard (SI standards preferable)
- Documentation of the calibration activity provides evidence to support the claim of traceability

How lunar calibration fits into the WGCV QA strategy:

- The Moon provides an ultra-stable solar diffusing source that can be viewed by satellite instruments in orbit
- Deriving sensor radiometric stability from Moon observations requires a model and special methods — these have been established
- Comparison of lunar model results has a demonstrated capability to meet the calibration stability requirement for climate for solar-band instruments
- Underpinning this capability is the inherent stability of the Moon

• The Moon can provide a reference standard for radiometric calibration stability

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Proposed Recommendation

Given**:**

- Accompanying a calibration reference standard are documented procedures for its use
- An established technique exists that enables calibration stability with high precision using a time-series of observations of the Moon

It is proposed that the Moon should be a CEOS-endorsed reference standard for stability in calibration of radiometric instruments in the solar-reflectance wavelength range.

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Implications for Earth Observation Satellites

Flight operations

- scheduling dedicated observations of the Moon at regular intervals
  - recommended once per month (provides consistency in phase angle)
- post-launch check-out
  - recommended many observations, to establish baseline sensor response

Instrument and spacecraft design

- ability to view the Moon
  - preferably through nadir-view optics
    - for LEO spacecraft this normally requires an attitude maneuver
  - space-view port, e.g. MODIS
    - possible scan mirror angle dependency
    - implementing limited spacecraft roll adds view opportunities