Using the Moon for MODIS and VIIRS Reflective Solar Bands Calibration Inter-Comparison

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Outline

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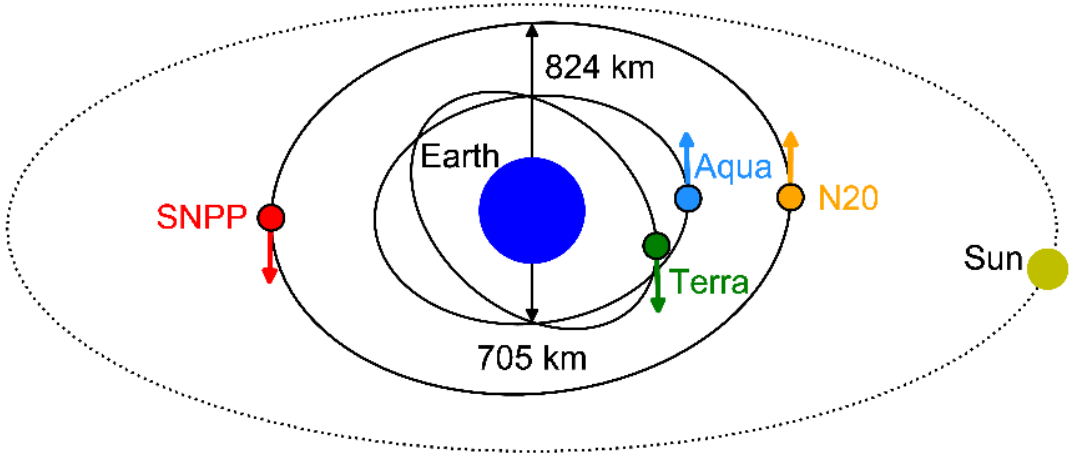
- MODIS and VIIRS Lunar Calibration
- Lunar Calibration Inter-comparisons
- Results and Discussion
- NOAA-21 VIIRS First Lunar Observations
- Conclusions

Introduction

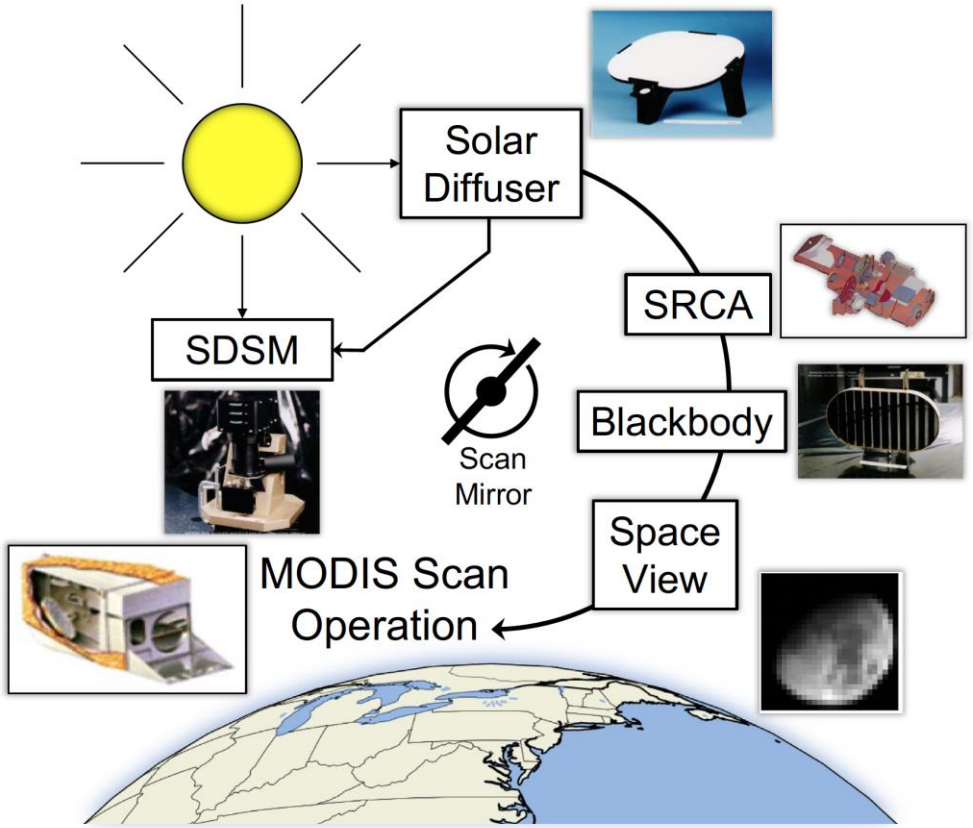
- MODIS (Terra/Aqua) and VIIRS (SNPP/N20/N21) are multi-spectral Earth-observing instruments, covering wavelengths from visible to long-wave infrared.
- For reflective solar bands (RSB) calibration, each instrument uses an on-board solar diffuser (SD) with an associated SD stability monitor (SDSM).
- The Moon has also been used for MODIS and VIIRS RSB on-orbit calibration and has a long history as a calibration target for the LEO remote sensing instruments and more recently for the GEO instruments.
- The Moon as an inter-comparison target:
  - Observable by many instruments
  - No overpass time constraints
  - No atmospheric correction
  - View-geometry corrections (lunar model).



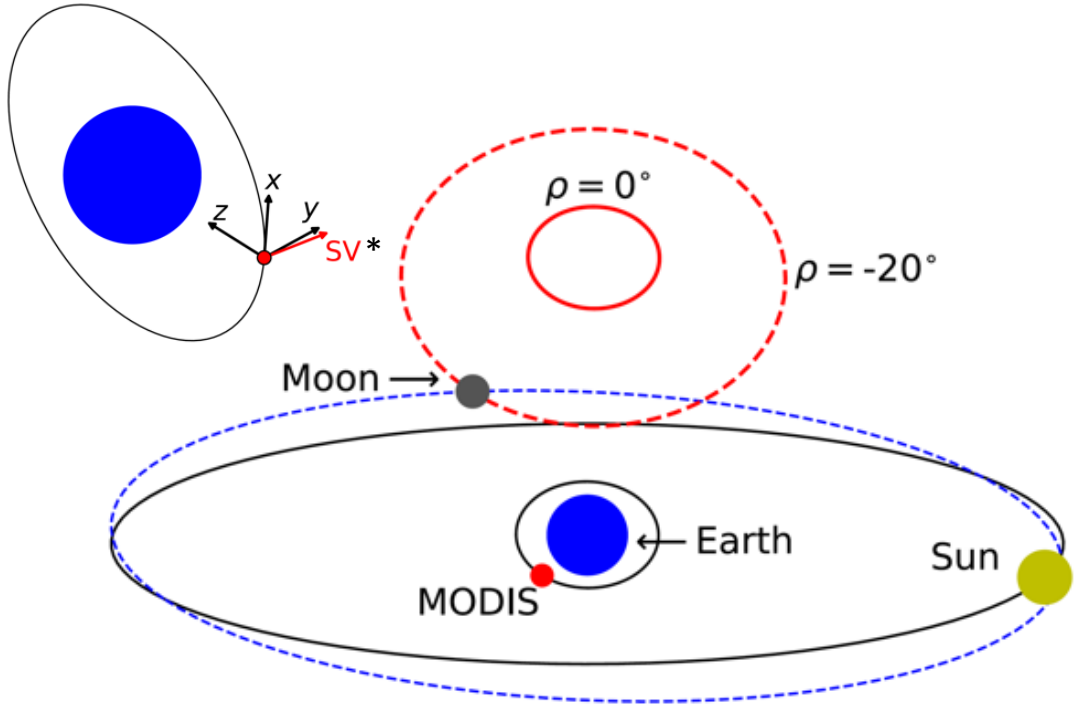
See backup slide for details on MODIS/VIIRS spectral bands and their on-orbit calibration

MODIS and VIIRS Lunar Calibration

- MODIS and VIIRS share the same calibration strategies
  - No SRCA in VIIRS
  - VIIRS SV and SD have the same AOI
- Lunar observations are scheduled on a near-monthly basis for a fixed phase angle range.
  - The Moon is observed through the space-view (SV) port via a spacecraft roll maneuver.
  - A data section rotation is performed



Lunar Observation Geometry



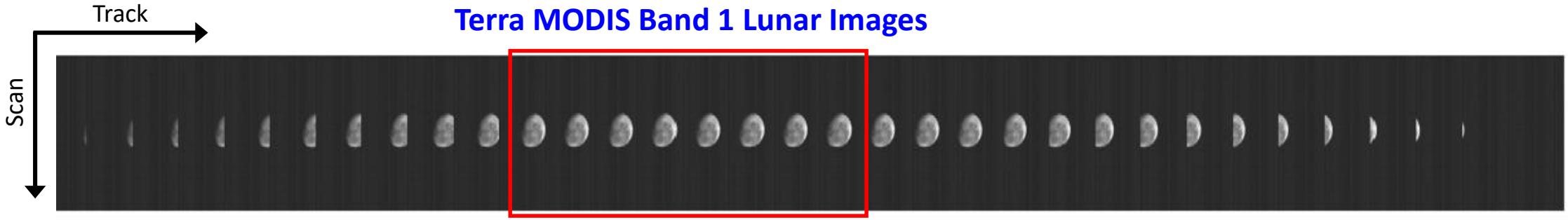
Inst.	Launch Year	Phase Range+	Roll Range	# Events^
Terra	1999	55° to 56°	-20° to 0°	221
Aqua	2002	-55° to -56°	-20° to 0°	208
SNPP	2011	-50.5° to -51.5°	-14° to 0°	92
N20	2017	-50.5° to -51.5°	-14° to 0°	41

+ Some events fall outside of this range
^ Number of scheduled Moon events as of January 1, 2023.

* VIIRS shows the opposite relationship in roll angle vs SV trace size as its SV is on the opposite side of the y-axis

For MODIS and VIIRS, the Moon is visible in the SV for many scans. Only scans with the full lunar disk visible are used for intercomparison (below, red).

Terra MODIS Band 1 Lunar Images



Lunar Irradiance Calculation

- Lunar observations can be used to track on-orbit changes in sensor responses (stability monitoring) as well as for calibration inter-comparisons among different sensors.
- MODIS and VIIRS use similar but ***slightly different*** equations (*MODIS: linear; VIIRS: quadratic calibration approach*) to compute the lunar irradiance

MODIS

$$I = \frac{1}{N}\frac{\sum_{S,D}^{N} m_1 E_{sun} dn^*_{moon} \omega}{\pi \mathrm{RVS}_{SV}}$$

N: Number of scans
S,D: Scan, Detector
dn: Background-subtracted signal
RVS: Response versus scan angle
ω: Detector solid angle
E_{sun}: Solar spectral irradiance
m_1: Calibration coefficient

$$m_1 \propto \rho_{SD} \cos(\theta) / dn^*_{SD}$$

VIIRS

$$I = \frac{1}{N}\frac{\sum_{S,D}^{N} F \omega \sum_i c_i dn^i_{moon}}{\mathrm{RVS}_{SV}}$$

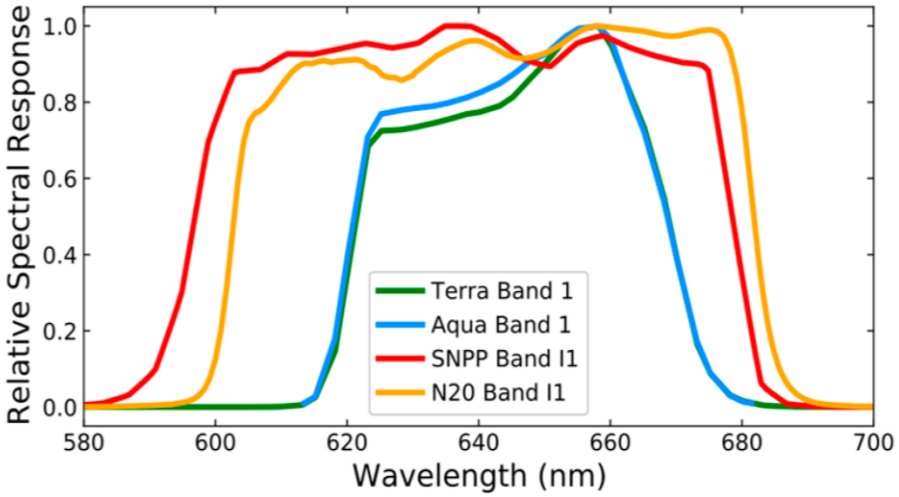
N: Number of scans
S,D: Scan, Detector
dn: Background-subtracted signal
RVS: Response Versus Scan Angle
ω: Detector Solid Angle
c_i: Pre-launch calibration coefficients
F: F-factor derived from SD data

$$F \propto \rho_{SD} \cos(\theta) E_{SUN} / c^i dn^i_{SD}$$

Lunar Calibration Inter-comparisons

- For a simple calibration inter-comparison, the measured irradiance from sensor A is first divided by the predicted value from the ROLO and then compared to that from sensor B.
- MODIS and VIIRS have many bands with near matching wavelengths, their relative spectral response, however, could be slightly different even between the same model instrument on different platforms.
- Ratios of the measured data to the ROLO model allow for comparison between instruments.

$$R_{A/B} = \frac{I_{meas,A}}{I_{model,A}} \Big/ \frac{I_{meas,B}}{I_{model,B}}$$

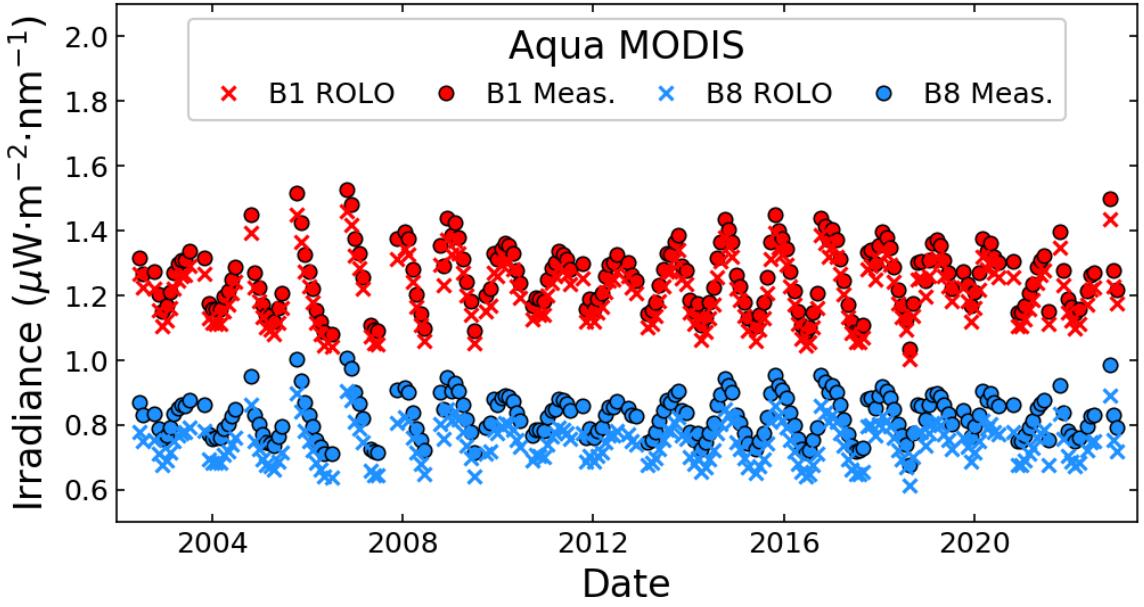


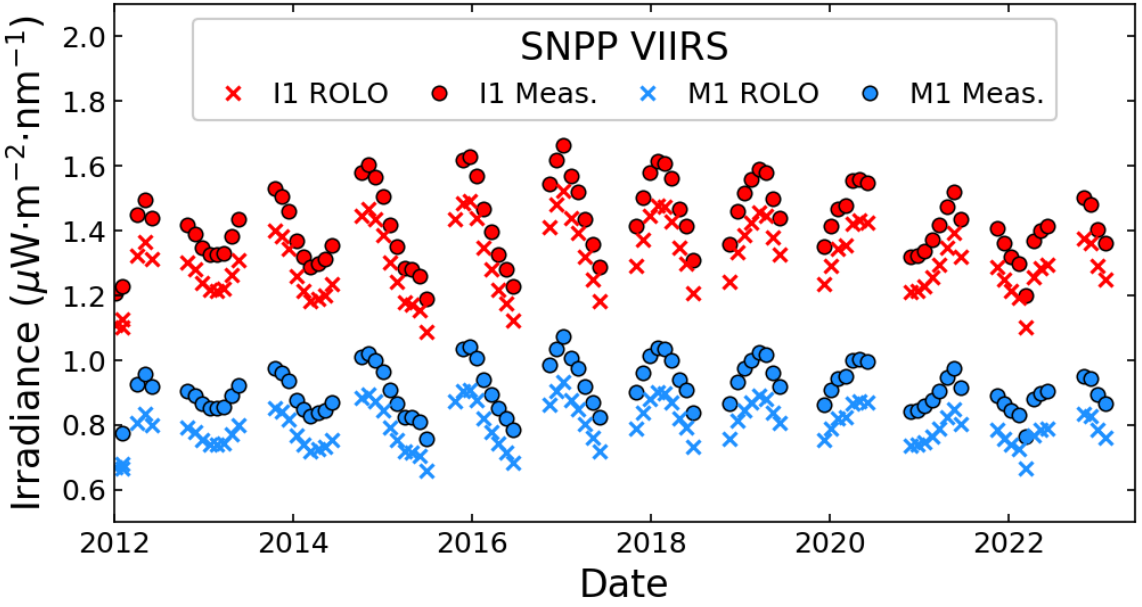
- **Sensor specific solar spectrum also needs to be considered.**

Xiong, X., J. Sun, and W. Barnes, "Inter-comparison of On-orbit Calibration Consistency between Terra and Aqua MODIS Reflective Solar Bands Using the Moon," *IEEE GRSL*, 5(4), 778-782, 2008

Comparison to the ROLO Model

- Individual lunar observations have varying geometry, particularly the Sun-Moon/Moon-Sensor distances.
- The ROLO model is used to predict the irradiance using the observation geometry of each event, which accounts for the lunar phase and libration angles in addition to the Sun-Moon/Moon-Sensor distances.
- There are biases between the measured and model results, but by normalizing to the model, the variation in the measured irradiance data is significantly reduced.





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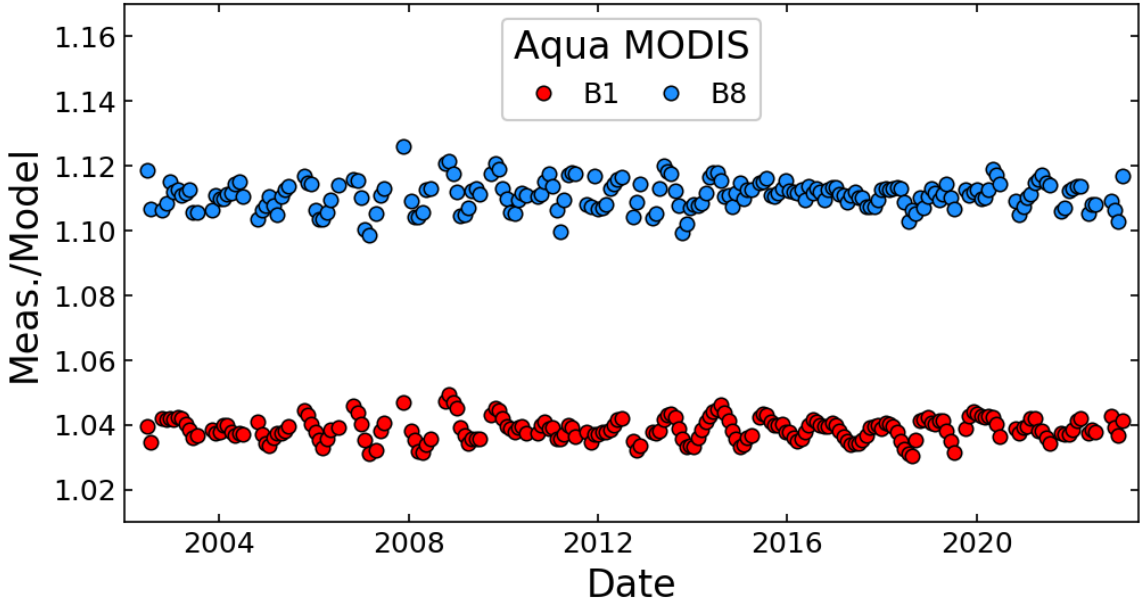
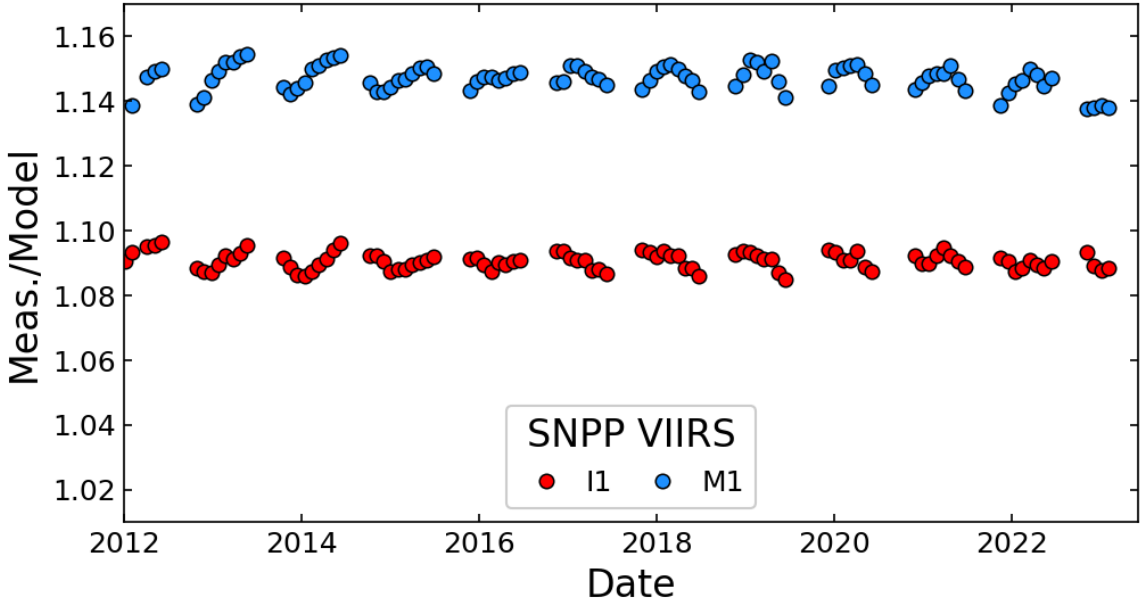
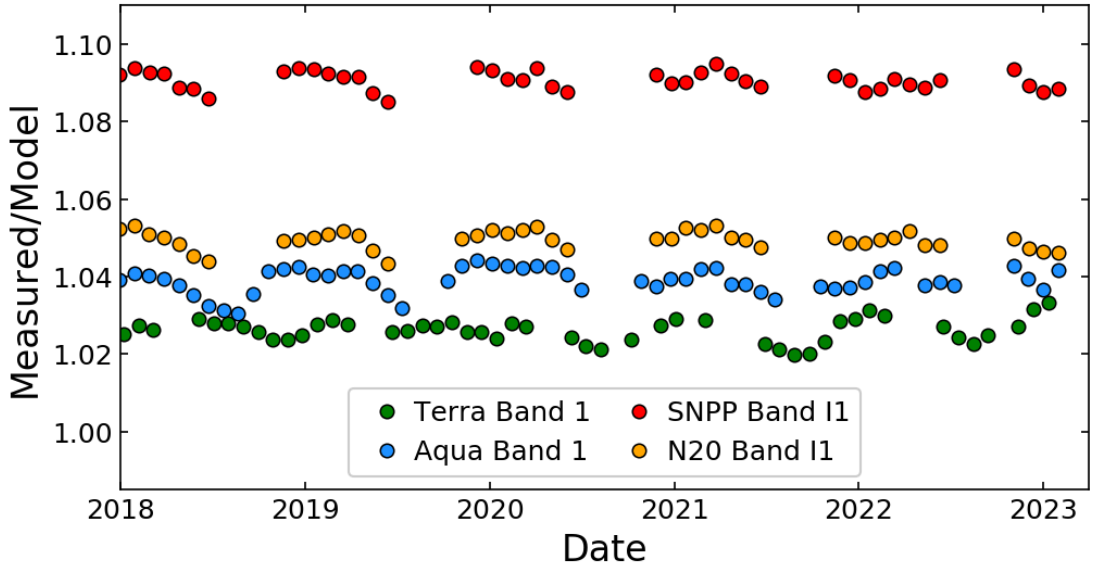
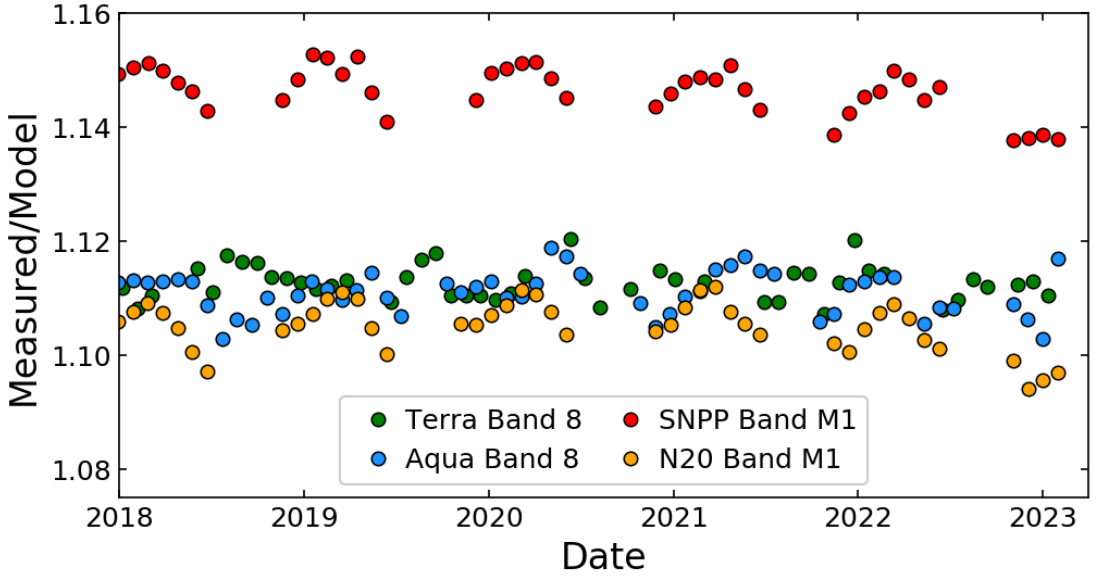
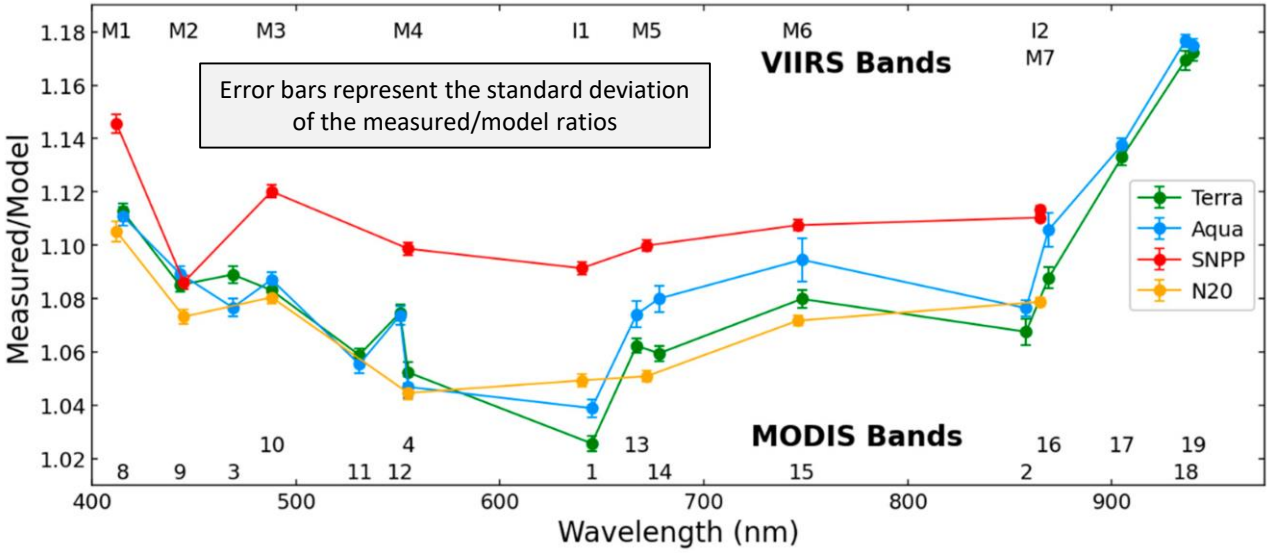




Results and Discussion



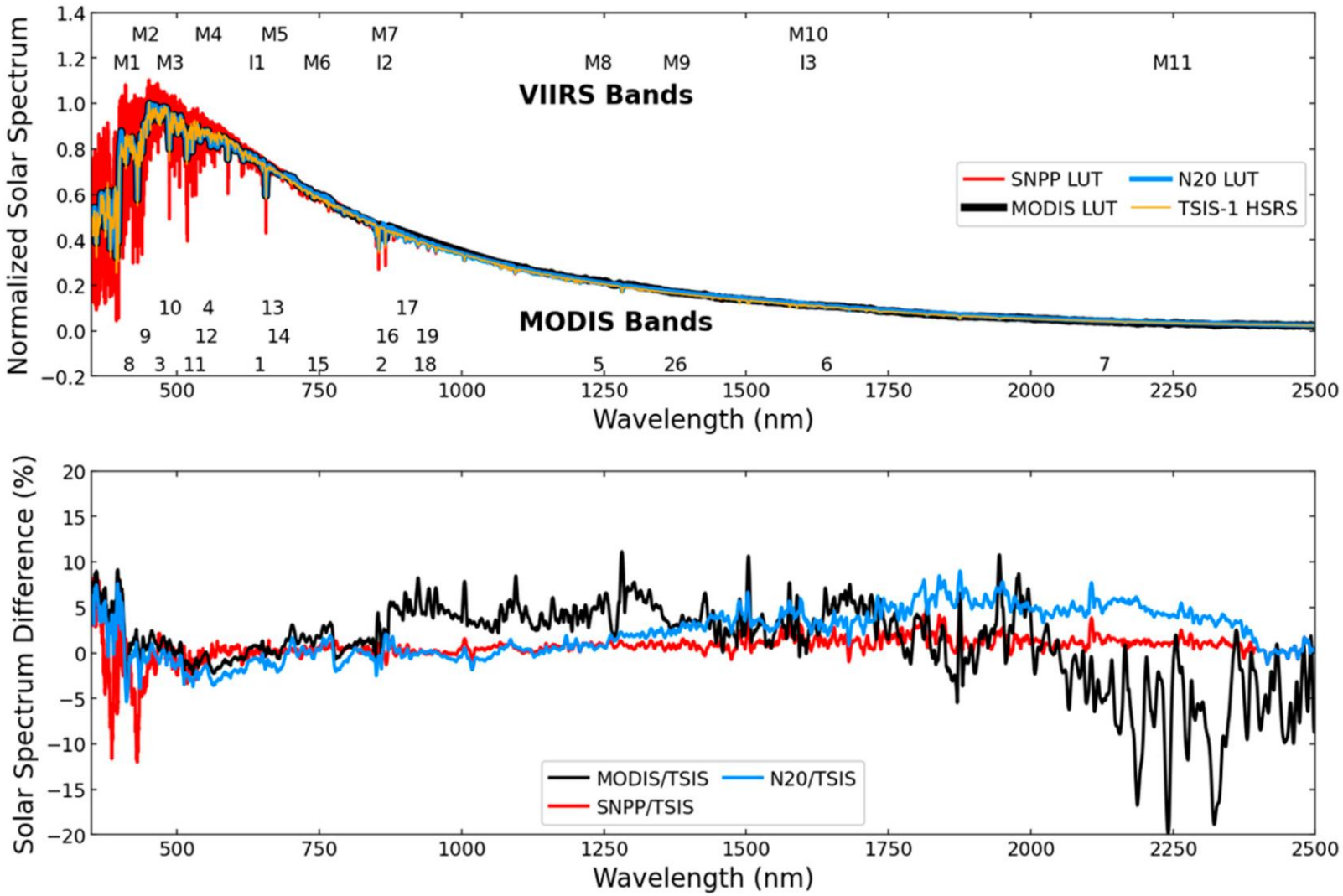




- Each instrument shows a similar trend versus wavelength, with the SNPP data showing a higher offset with the ROLO model.
- The MODIS NIR bands (17-19) show a greater bias, however this bias decreases when rederiving the measured data using the TSIS-1 Hybrid Solar Reference Spectrum (HSRS).

MODIS and VIIRS Solar Spectra

- Calibration for the MODIS and VIIRS instruments use different reference solar spectra which can causes differences in lunar calibration inter-comparison.
- Comparison to the TSIS-1 HSRS shows significant differences in certain wavelength ranges.
- Two approaches can be used to correct the calibration differences due to sensor specific solar spectrum
  - Apply a solar spectrum correction to the ratio data.
  - Re-derive the calibration coefficients using the TSIS-1 HSRS data.



Solar Spectra Correction

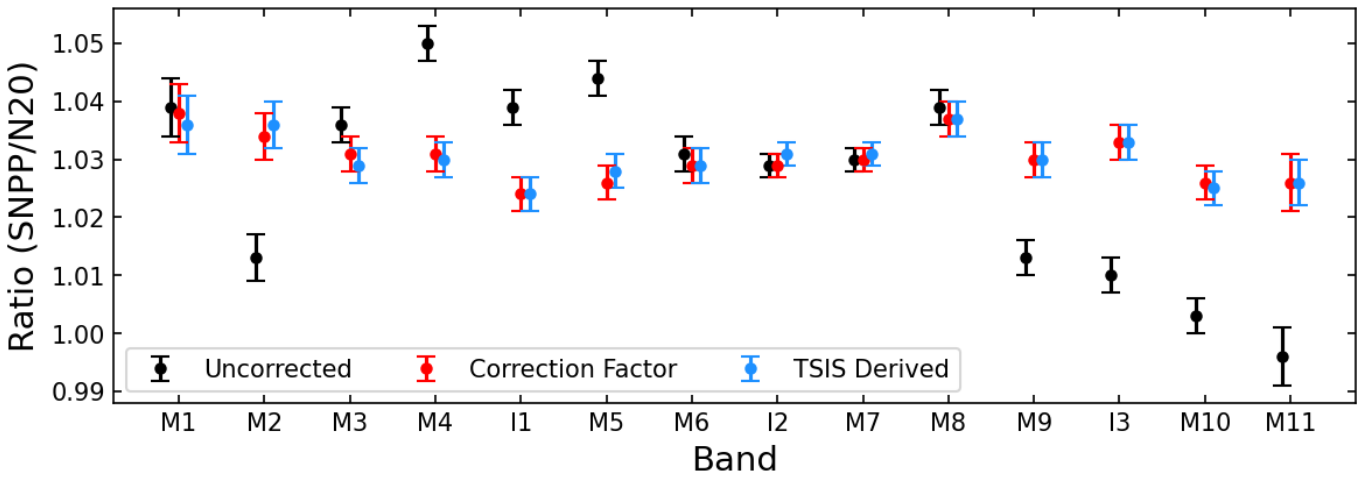
- Applying a simple solar spectral correction to the ratio produces nearly equivalent results to rederiving each instrument's calibration using the TSIS-1 HSRS data.
- The correction factor used to correct the ratio of Sensor A to Sensor B is given by

$$C_{A/B} = \frac{\int RSR_A(\lambda) E_{Sun_B}(\lambda) d\lambda / \int RSR_A(\lambda) d\lambda}{\int RSR_A(\lambda) E_{Sun_A}(\lambda) d\lambda / \int RSR_A(\lambda) d\lambda}$$

Xiong, X., J. Sun, A. Angal, T. Wilson, "Calibration Inter-Comparison of MODIS and VIIRS Reflective Solar Bands Using Lunar Observations," Remote Sens. 2022, 14(19), 4754

- It can be applied to the ratio as: $R^*_{A/B} = C_{A/B} \cdot R_{A/B}$

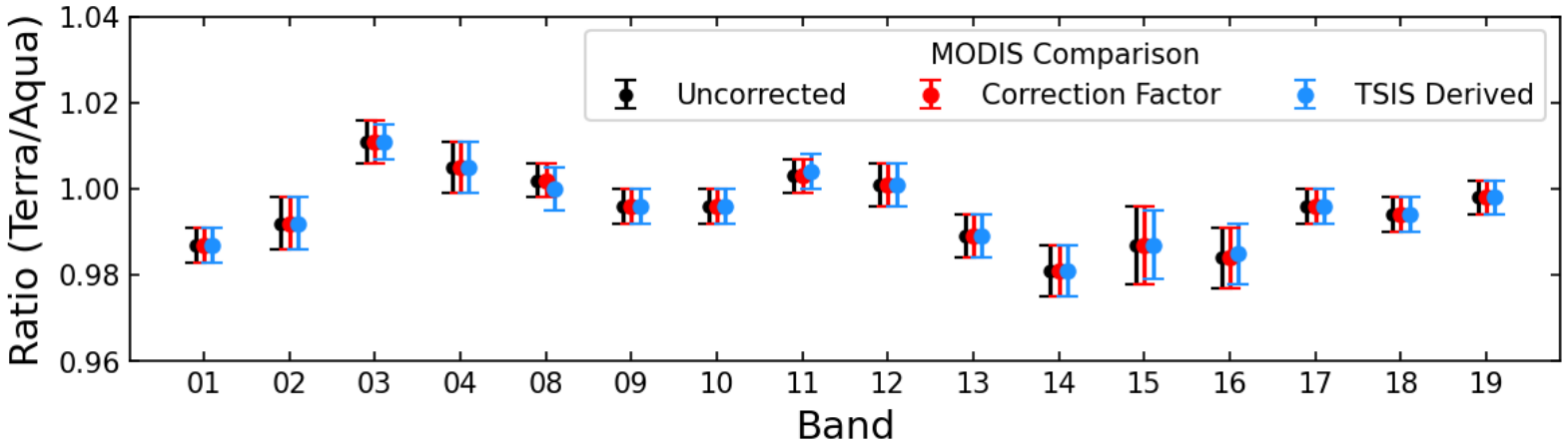
- For SNPP-to-N20 comparisons (right), the solar correction produces more consistent offsets between the bands.
- There is ~3% offset in the SNPP/N20 ratio due to unresolved calibration differences.



Error bars represent the combined standard deviations of the ratios

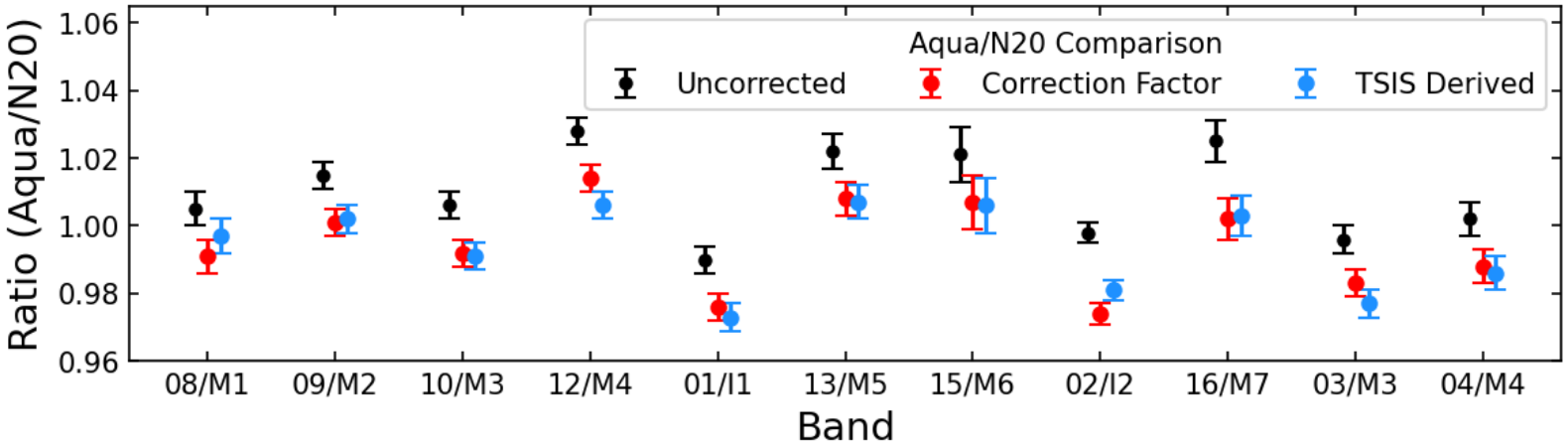
Solar Spectra Correction

For MODIS, the solar spectrum used is the same for both instruments, and therefore applying a correction factor has no impact. Negligible differences are seen using the TSIS data.



For the Aqua and N20, most matching bands agree to within 2%.

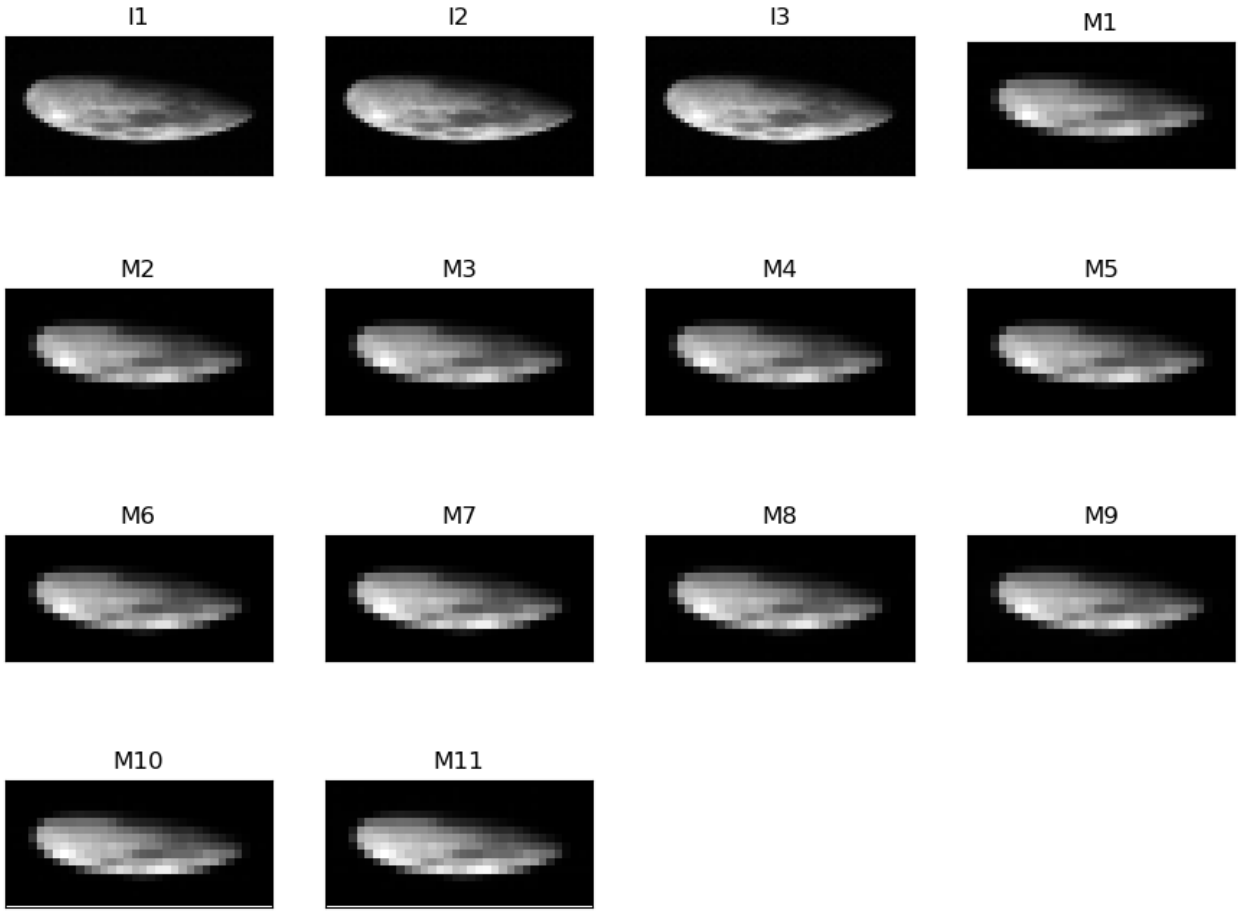
Some differences between the correction and the TSIS derived data are seen for some bands.

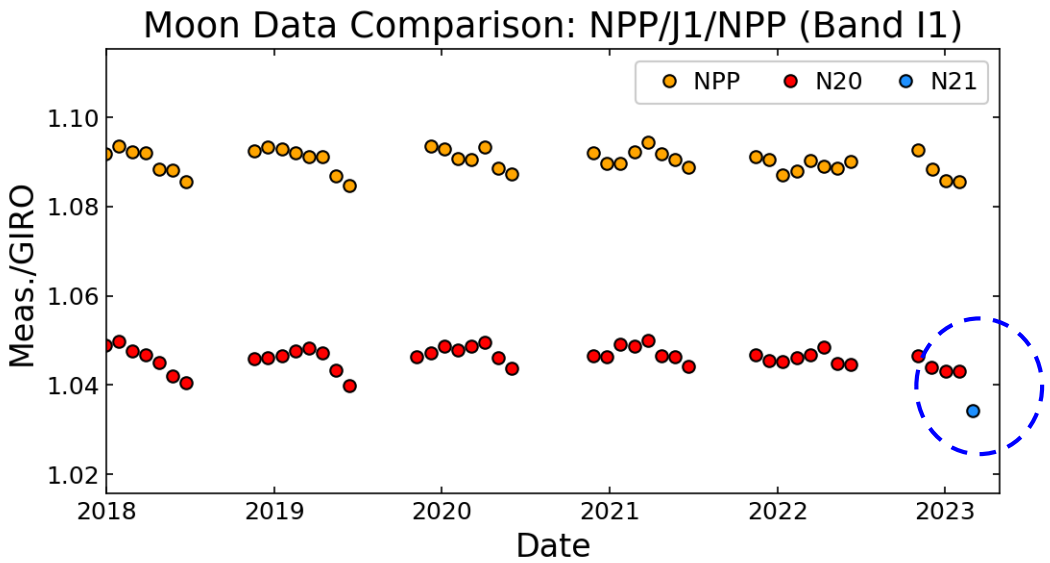


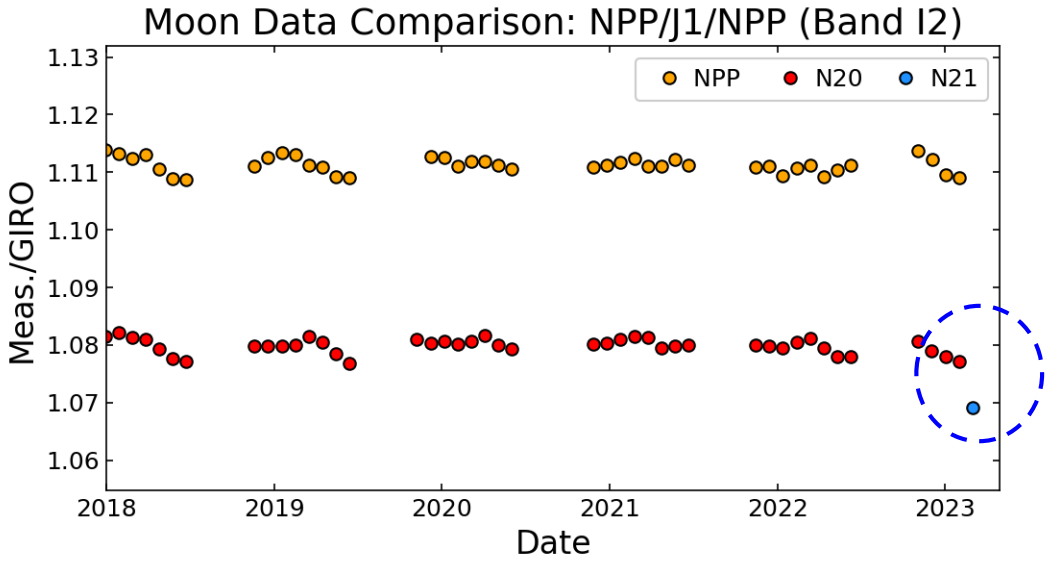
Error bars represent the combined standard deviations of the ratios

N21 VIIRS First Lunar Observations

Date	Time (UTC)	Roll Angle	Lunar phase
2023-03-02	01:28:26	-1.37°	-59.4°

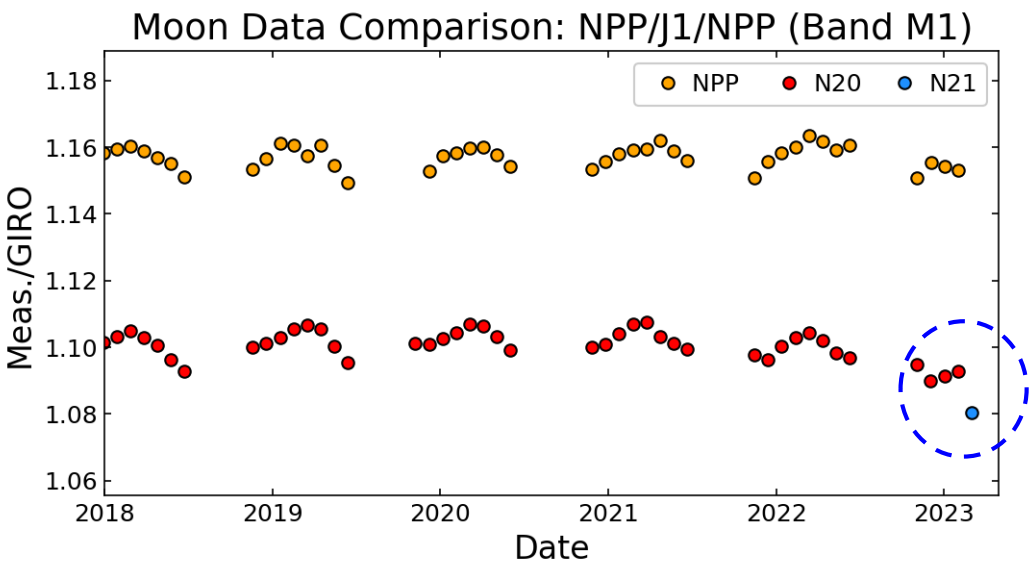


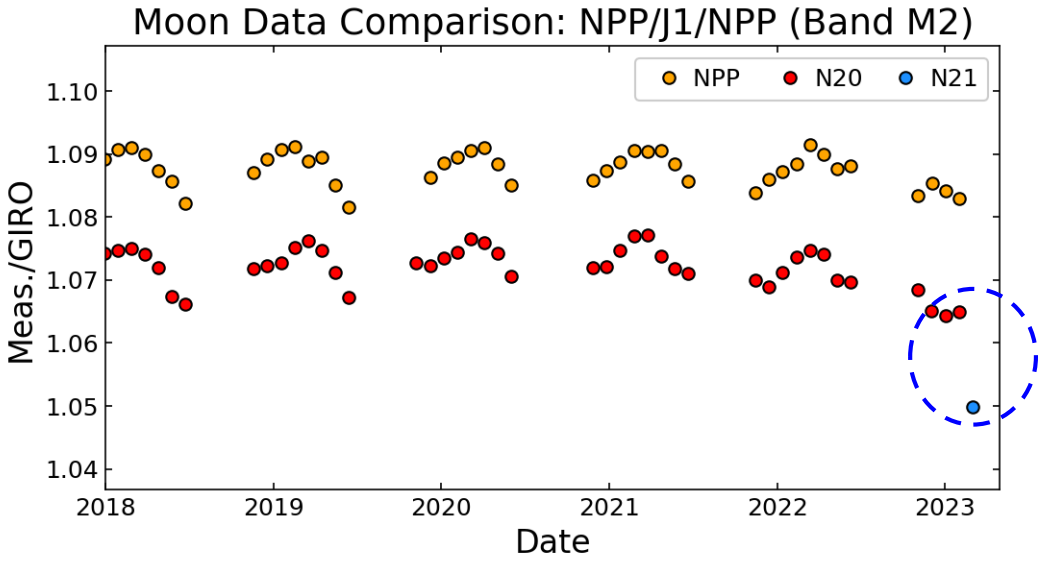


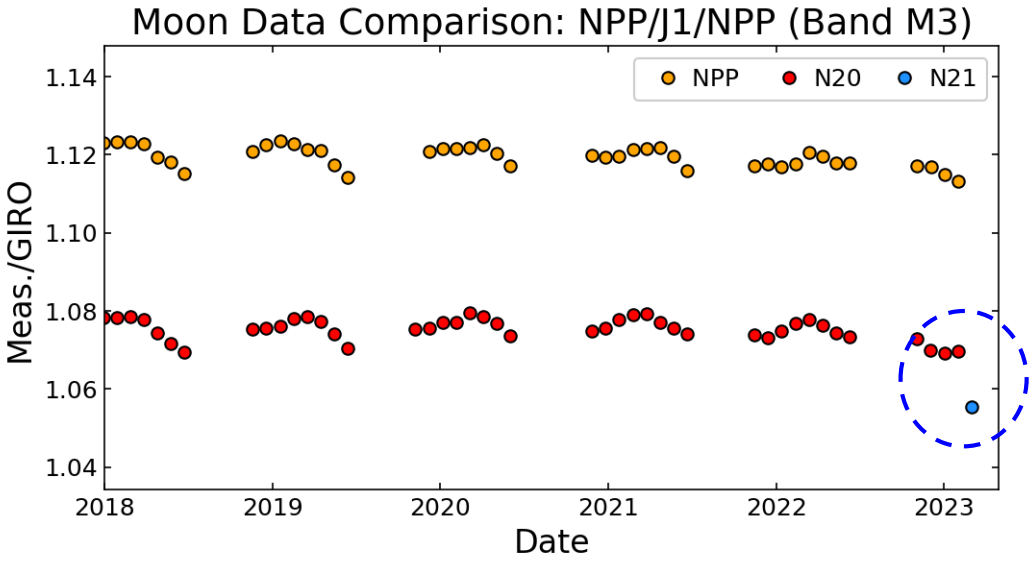


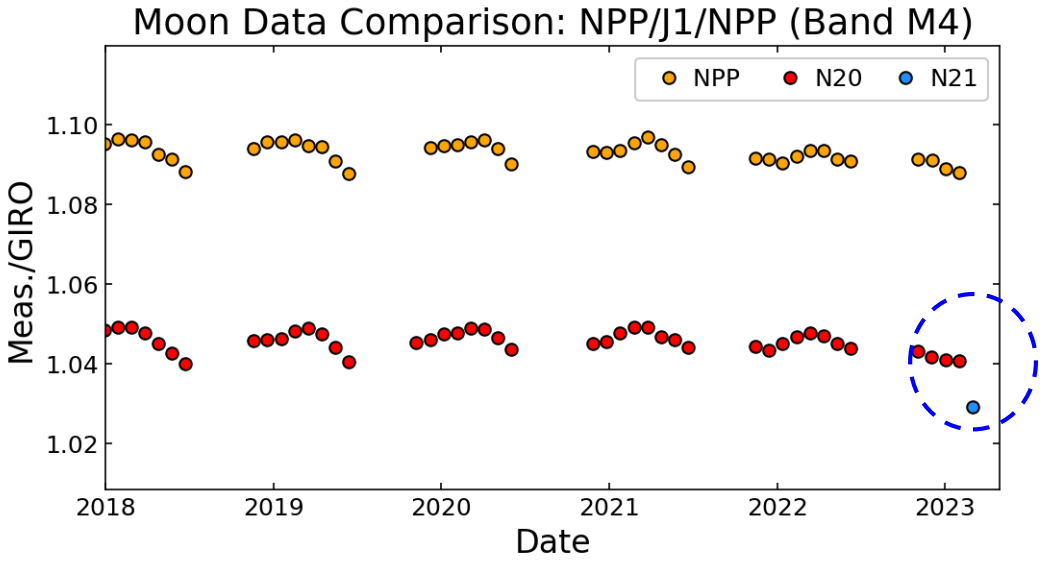
Preliminary Result

Preliminary Results (1st N21 Lunar Observations)









L1B LUTS: NPP (V3p3) N20 (V2.2) N21 (V0p2)

Conclusions

- The Moon has been used for calibration inter-comparisons between the MODIS and VIIRS instruments.
  - The ROLO model combined with a solar spectral adjustment factor put data from different instruments on the same scale.
  - The solar spectral adjustment also agrees well with the TSIS-1 HSRS derived inter-comparison results.
- The Terra/Aqua and Aqua/N20 comparisons agree well for most bands to within their combined uncertainties.
- The SNPP results show a bias of ~3% with N20.
  - This difference is also seen in other EV intercomparison studies.
  - **N21 agrees with N20 to within ~ 2% (preliminary results from 1st N21 lunar calibration)**
- Lunar calibration inter-comparison will be vital for evaluating future missions, such as VIIRS on JPSS-3/4, OCI on PACE, CPF instrument, …

Backup Slides

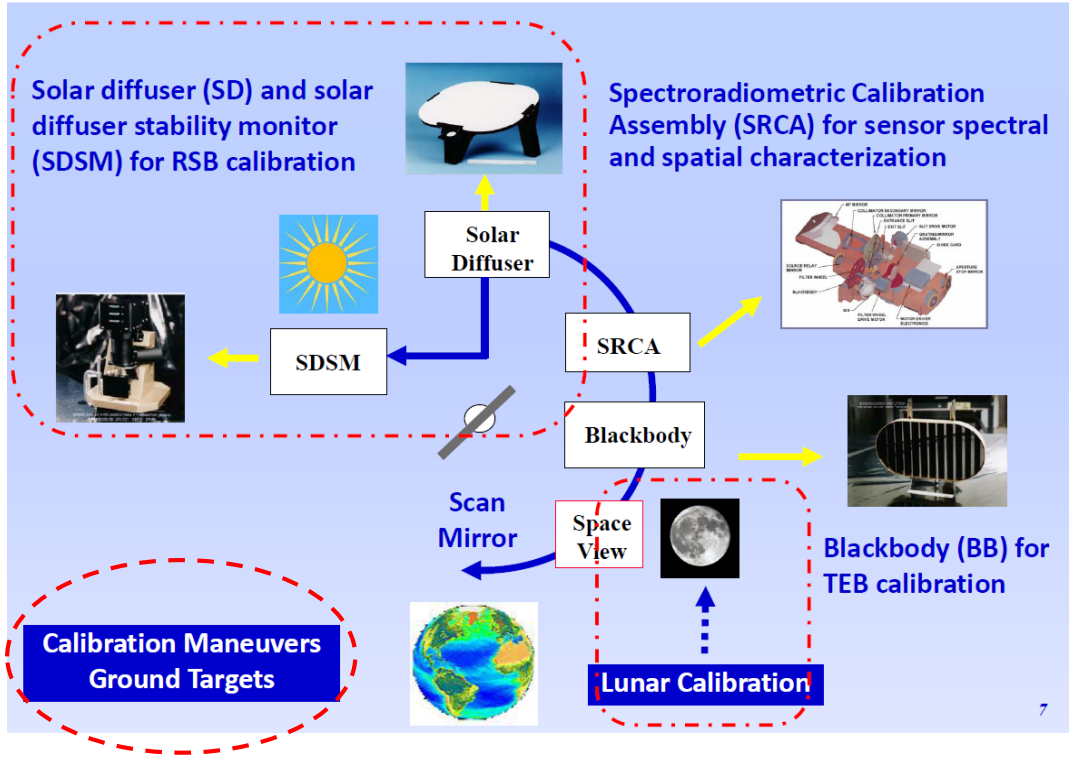
MODIS and VIIRS Spectral Bands and On-orbit Calibration

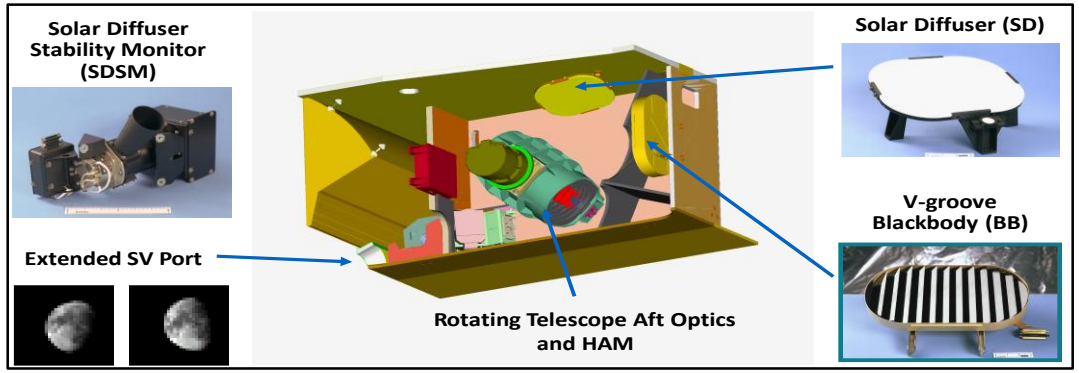
VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
I1	0.600 - 0.680	375	1	0.620 - 0.670	250
M5	0.662 - 0.682	750	13 or 14	0.662 - 0.672 0.673 - 0.683	1000 1000
M6	0.739 - 0.754	750	15	0.743 - 0.753	1000
I2	0.846 - 0.885	375	2	0.841 - 0.876	250
M7	0.846 - 0.885	750	16 or 2	0.862 - 0.877 0.841 - 0.876	1000 250
M8	1.230 - 1.250	750	5	SAME	500
M9	1.371 - 1.386	750	26	1.360 - 1.390	1000
I3	1.580 - 1.640	375	6	1.628 - 1.652	500
M10	1.580 - 1.640	750	6	1.628 - 1.652	500
M11	2.225 - 2.275	750	7	2.105 - 2.155	500
I4	3.550 - 3.930	375	20	3.660 - 3.840	1000
M12	3.660 - 3.840	750	20	SAME	1000
M13	3.973 - 4.128	750	21 or 22	3.929 - 3.989 3.929 - 3.989	1000 1000
M14	8.400 - 8.700	750	29	SAME	1000
M15	10.263 - 11.263	750	31	10.780 - 11.280	1000
I5	10.500 - 12.400	375	31 or 32	10.780 - 11.280 11.770 - 12.270	1000 1000
M16	11.538 - 12.488	750	32	11.770 - 12.270	1000

1 DNB (0.5-0.9 μm)

14 RSB (0.4-2.3 μm)

7 TEB (3.7-12 μm)





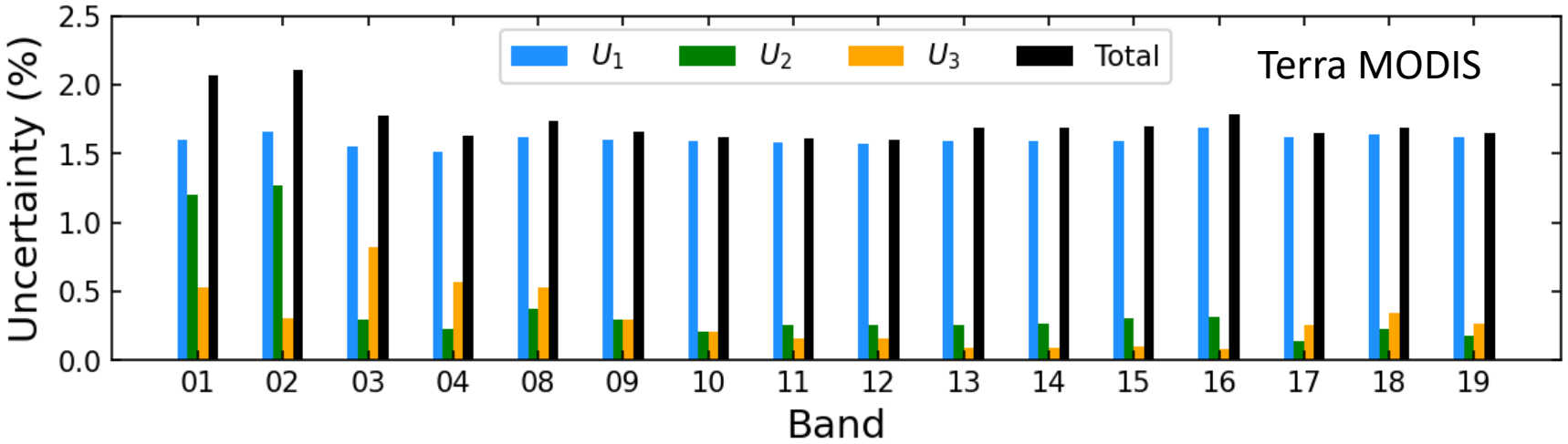
Dual Gain for M1-M5, M7, M13

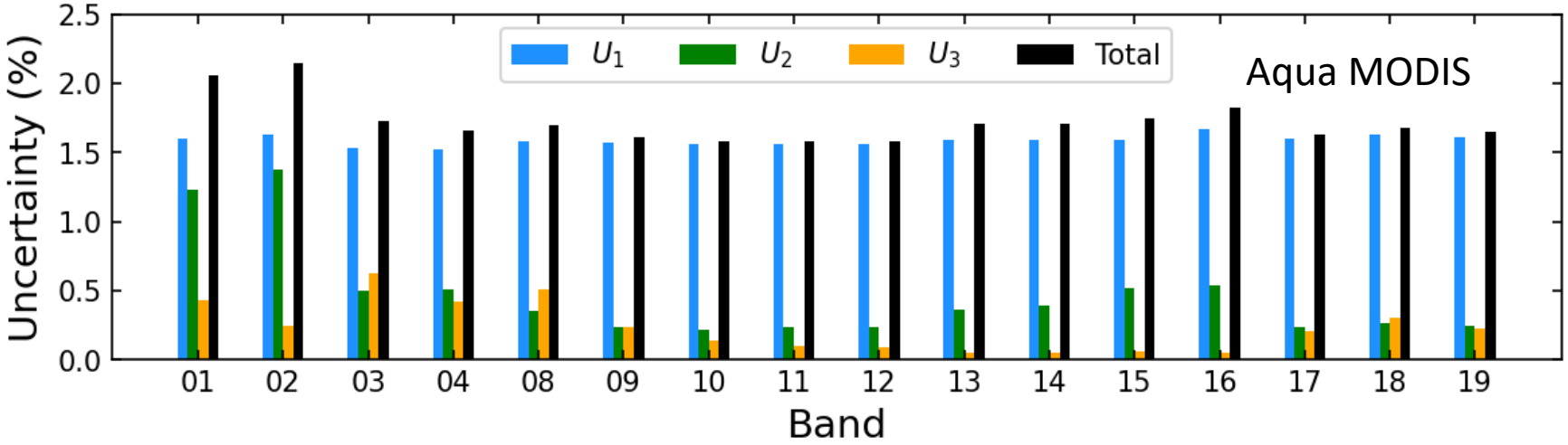
DNB

LWIR PC bands 33-36

MODIS Lunar Irradiance Uncertainty

- U_1: SD BRF, SD degradation, SD Screen transmission, m_1
- U_2: RVS
- U_3: Instrument temperature, detector noise
- Total: Root mean square of the U_1, U_2, and U_3 terms





VIIRS Lunar Irradiance Uncertainty

- U_1: SD BRF, SD degradation, SD Screen transmission
- U_2: c_i, on-orbit F-factor
- U_3: Instrument temperature, detector noise
- Total: Root mean square of the U_1, U_2, and U_3 terms