Lunar Calibration Inter-comparison for S-NPP, NOAA-20, and NOAA-21 VIIRS

Jack Xiong[a], Truman Wilson[b], Amit Angal[b], and Junqiang Sun[b]

[a]Sciences and Exploration Directorate, NASA Goddard Space Flight Center, Greenbelt, MD, USA
[b]Science Systems and Applications Inc., 10210 Greenbelt Road, Lanham, MD, USA

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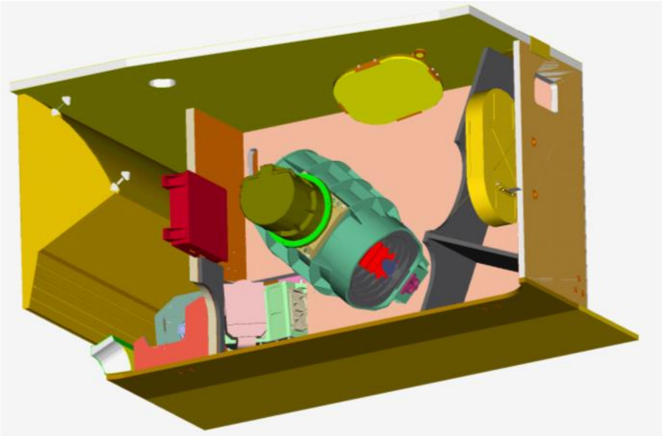
Outline

- VIIRS Instrument and Lunar Calibration
- Lunar Calibration Inter-comparisons
- Results and Discussion
- Conclusions

VIIRS Instrument

- **Visible Infrared Imaging Radiometer Suite (VIIRS)**
  - 22 spectral bands: 14 reflective solar bands (RSB), 7 thermal emissive bands (TEB), and 1 day night band (DNB)
  - S-NPP: launched on Oct 28, 2011
  - JPSS-1: launched on Nov 18, 2017 (N-20)
  - JPSS-2: launched on Nov 10, 2022 (N-21)
  - JPSS-3: launch in 2033 (currently in spacecraft I&T)
  - JPSS-4: launch in 2027 (currently in sensor TVAC)



VIIRS

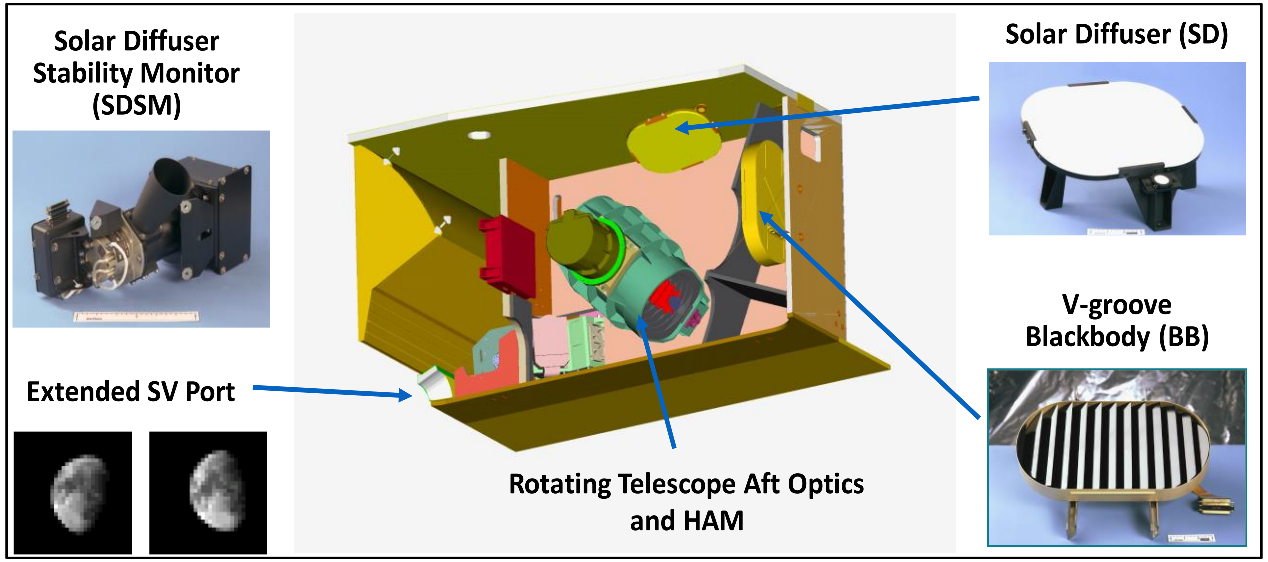
JPSS-2 launch on Nov 10, 2022

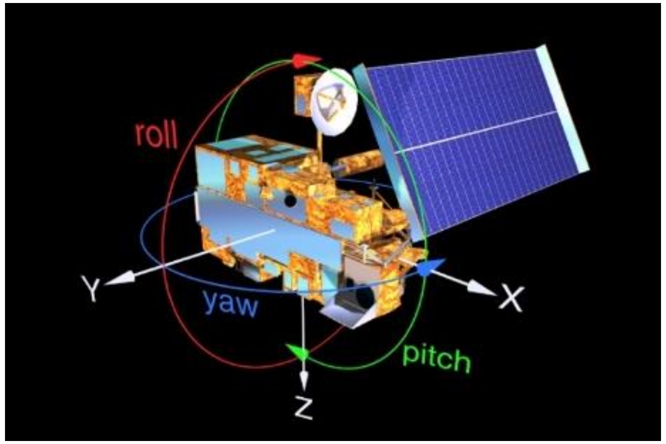
	Band	λc(nm)	Δλ(nm)	Spatial Resolution (m)
VisNIR	DNB	700	400	750
	M1	412	20	750
	M2	445	18	750
	M3	488	20	750
	M4	555	20	750
	M5	672	20	750
	I1	640	80	375
	M6	746	15	750
	M7	865	39	750
	I2	865	39	375
SMWIR	M8	1240	20	750
	M9	1378	15	750
	M10	1610	60	750
	I3	1610	60	375
	M11	2250	50	750
	I4	3740	380	375
	M12	3700	180	750
	M13	4050	155	750
LWIR	M14	8550	300	750
	M15	10763	1000	750
	I5	11450	1900	375
	M16	12013	950	750

Dual gain: M1-M5, M7, M13

VIIRS Lunar Calibration (RSB)

- **On-board Calibrators**
  - Solar diffuser (SD) and SD stability monitor (SDSM)
  - Space view (SV)
- **Lunar Calibration**
  - Through SV port (roll maneuvers)
  - Data sector rotation





Inst.	Launch	Phase Range+	Roll Range	# Events^
S-NPP	2011	-50.5° to -51.5°	-14° to 0°	99
N-20	2017	-50.5° to -51.5°	-14° to 0°	48
N-21	2022	-50.5° to -51.5°	-14° to 0°	5

+ Some events fall slightly outside of this range
^ Number of scheduled Moon events as of Aug 20, 2023.

Lunar Calibration Inter-comparison: Lunar Irradiance

- Lunar calibration inter-comparisons among different sensors is performed using their measured lunar irradiances.
- For VIIRS, the Moon is visible in the SV for many scans. Only scans with the full lunar disk visible (marked in red) are used for inter-comparison.

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

N: Number of scans

S,D: Scan, Detector

dn: Background-subtracted signal

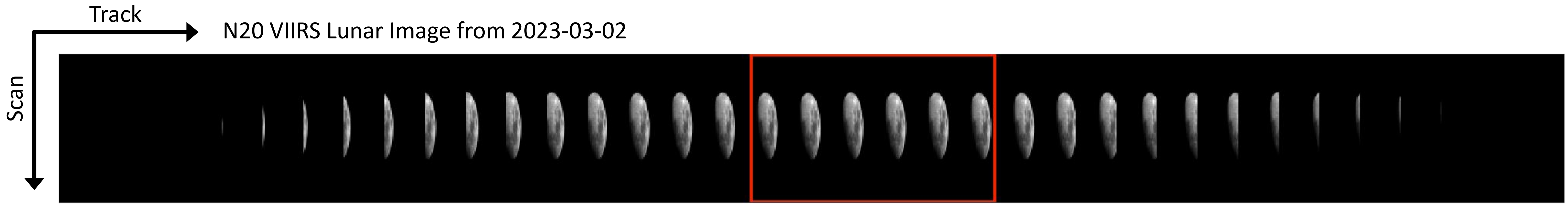
RVS: Response Versus Scan Angle

ω: Detector Solid Angle

c_i: Pre-launch calibration coefficients

F: F-factor derived from SD data

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

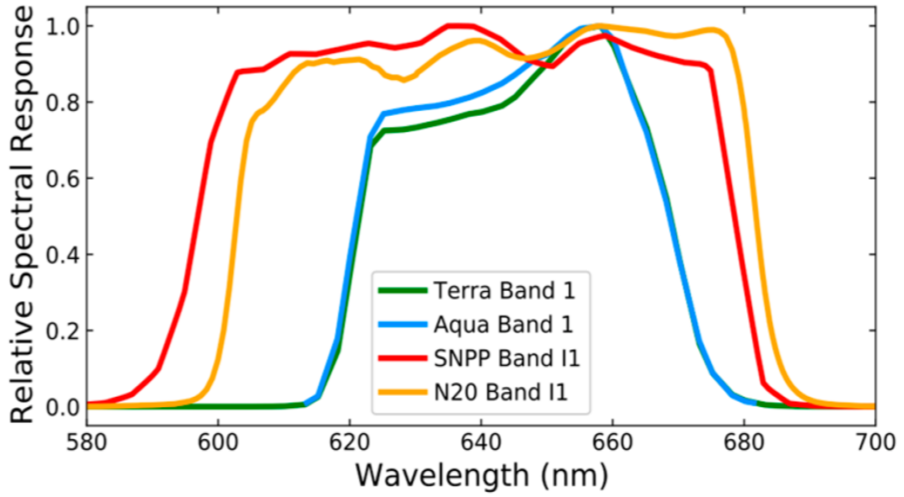


Lunar Calibration Inter-comparison: Lunar Model Reference

- For a simple calibration inter-comparison, the measured irradiance from sensor A is normalized by the predicted value from the lunar model and then compared to that from sensor B.
- Different VIIRS builds may have slightly different relative spectral response (RSR) for the same spectral band.
- Ratios of the measured data to the lunar model allow for comparison between instruments.

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

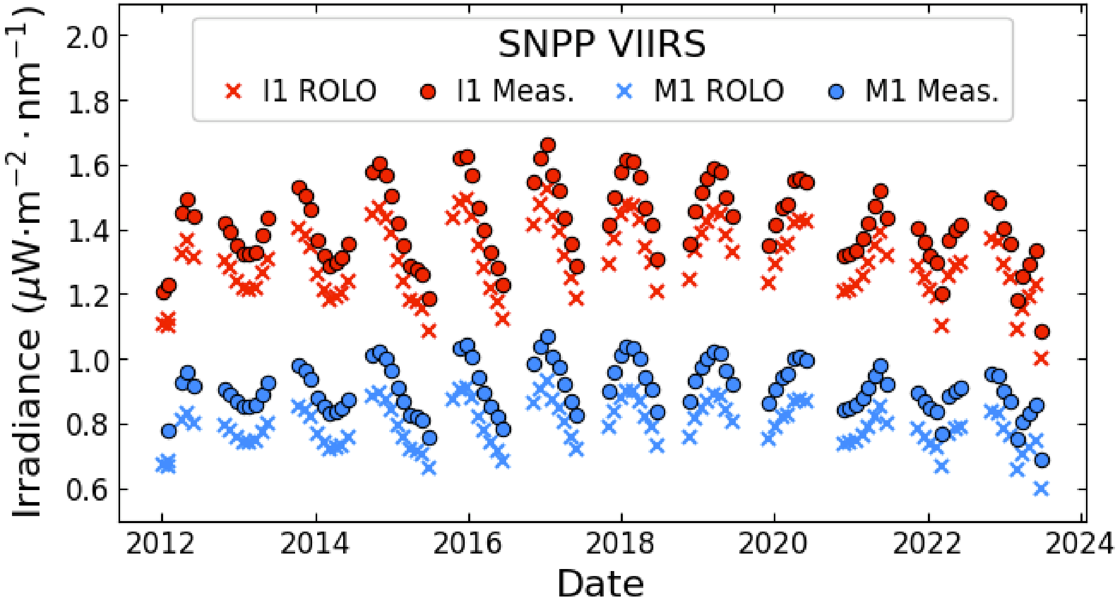
$$R_{A/B} = \frac{I_{meas,A}}{I_{model,A}} \Big/ \frac{I_{meas,B}}{I_{model,B}}$$

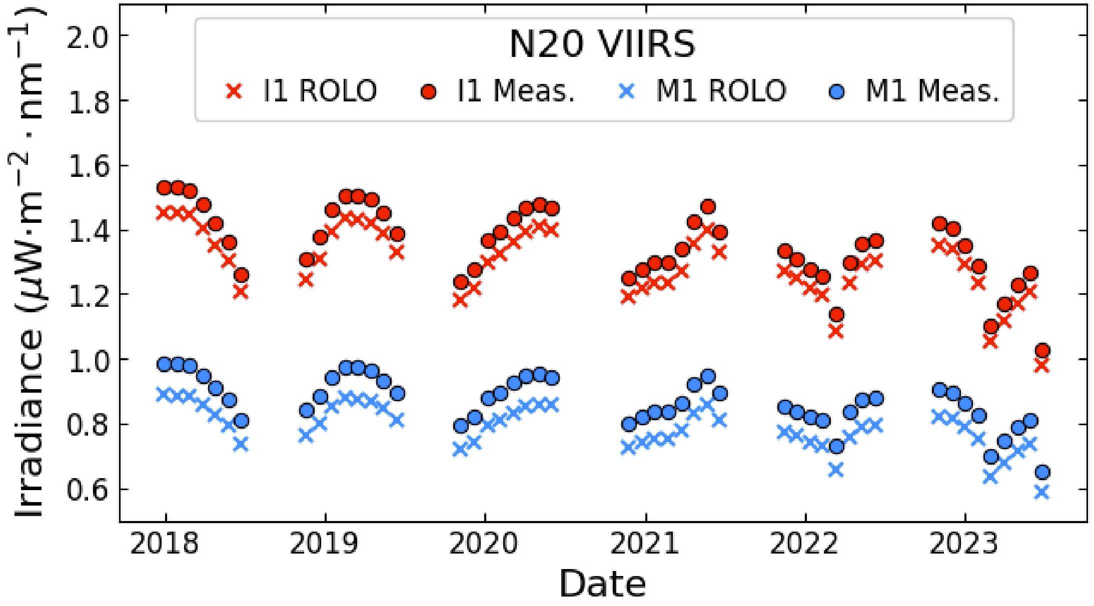


Xiong, X., J. Sun, and W. Barnes, "Inter-comparison of On-orbit Calibration Consistency between Terra and Aqua MODIS Reflective Solar Bands Using the Moon," *IEEE GRSL*, 5(4), 778-782, 2008

Results and Discussion: 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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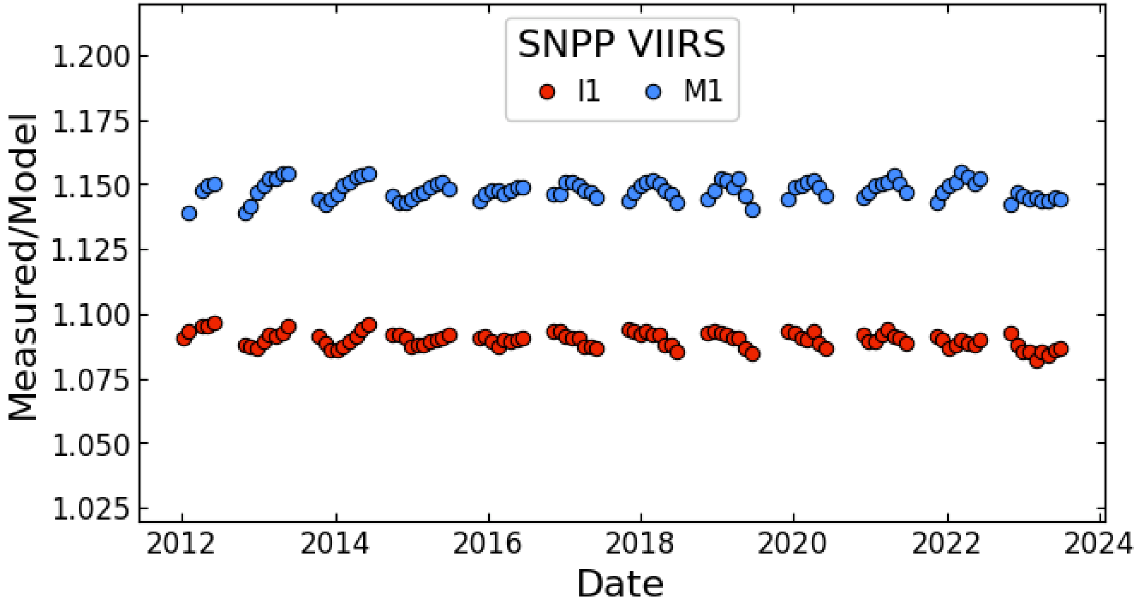

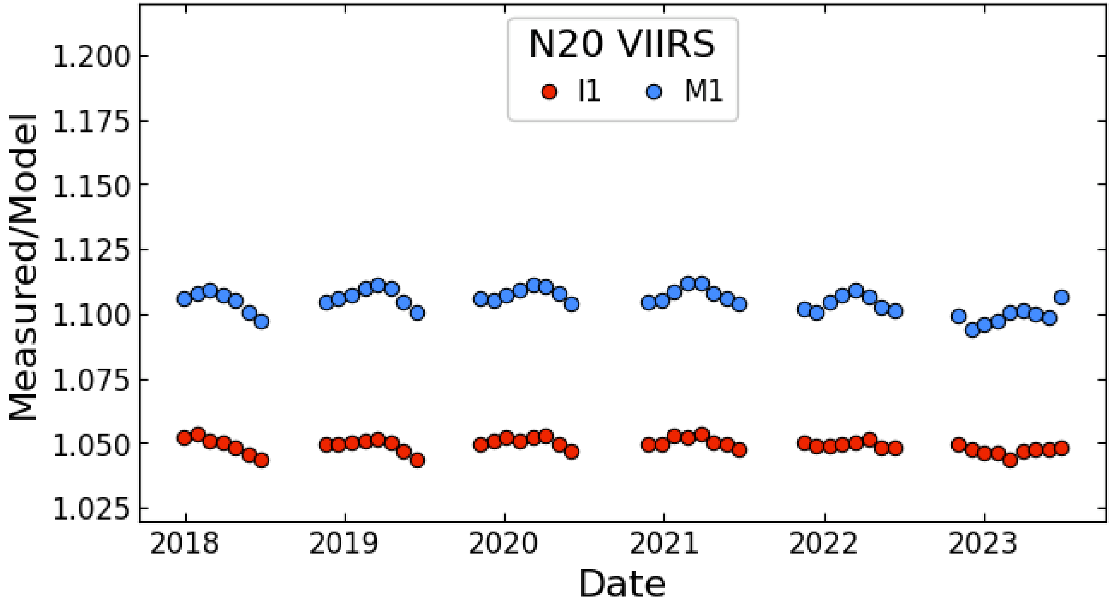

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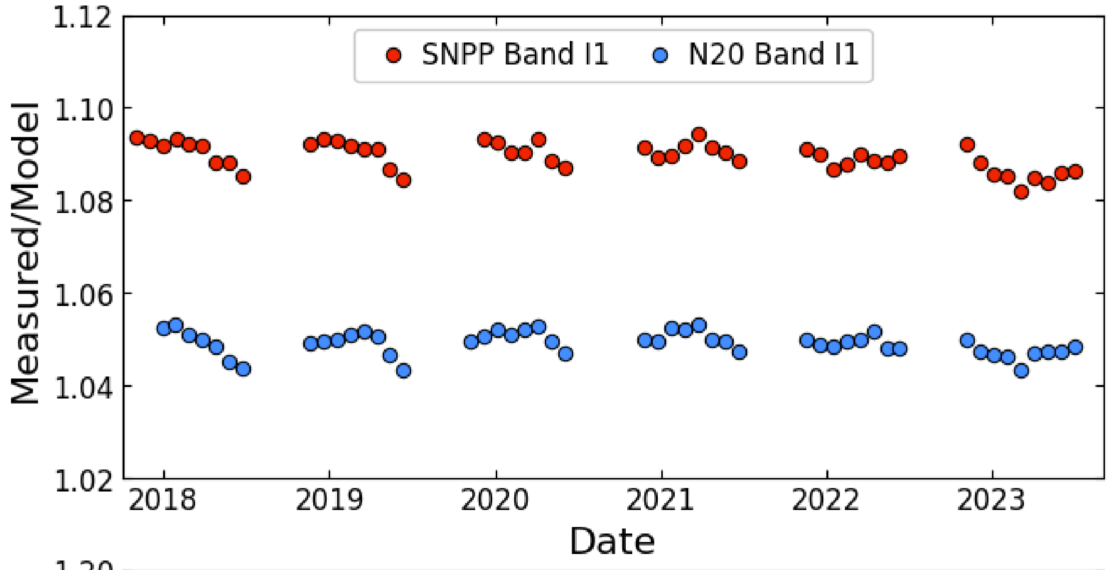

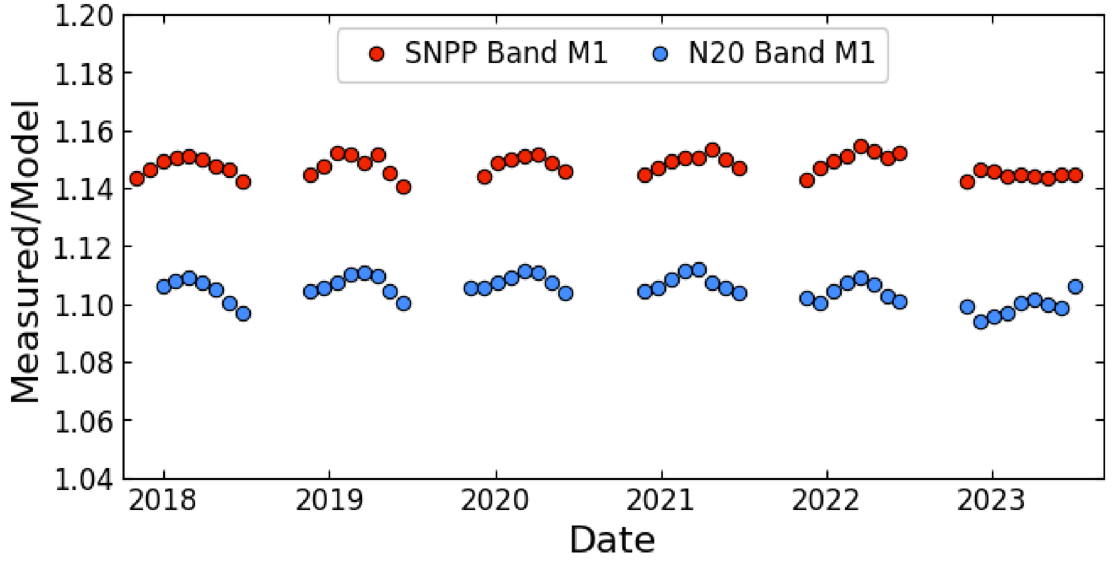

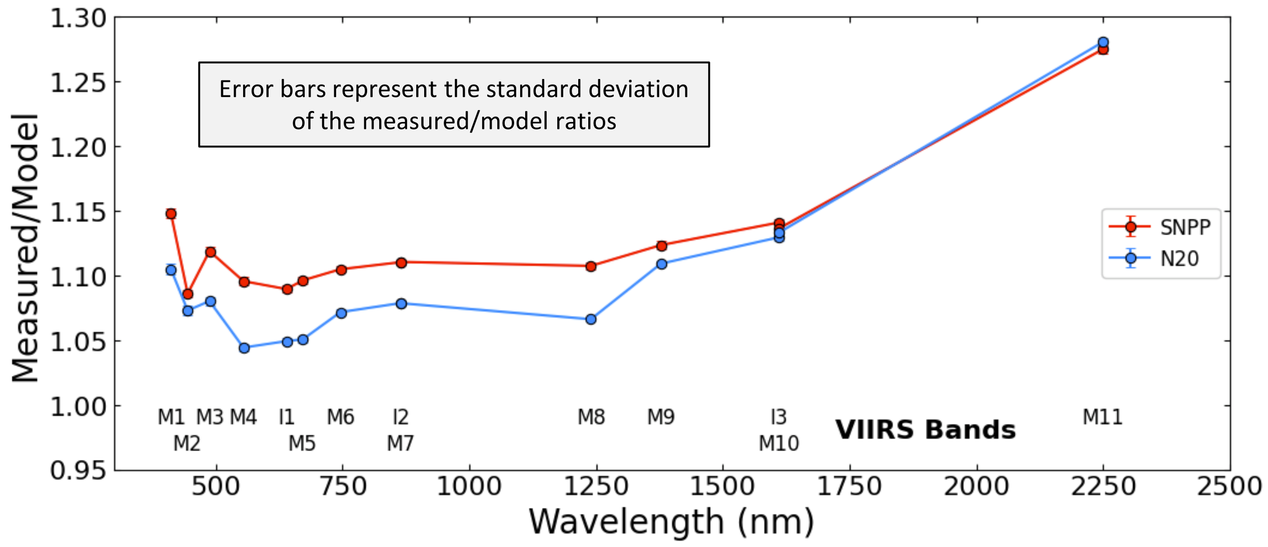

- Each instrument shows a similar trend versus wavelength, with the SNPP data showing a higher offset with the ROLO model, particularly at shorter wavelengths
- The bias between SNPP and N20 is a known issue that is currently under investigation.

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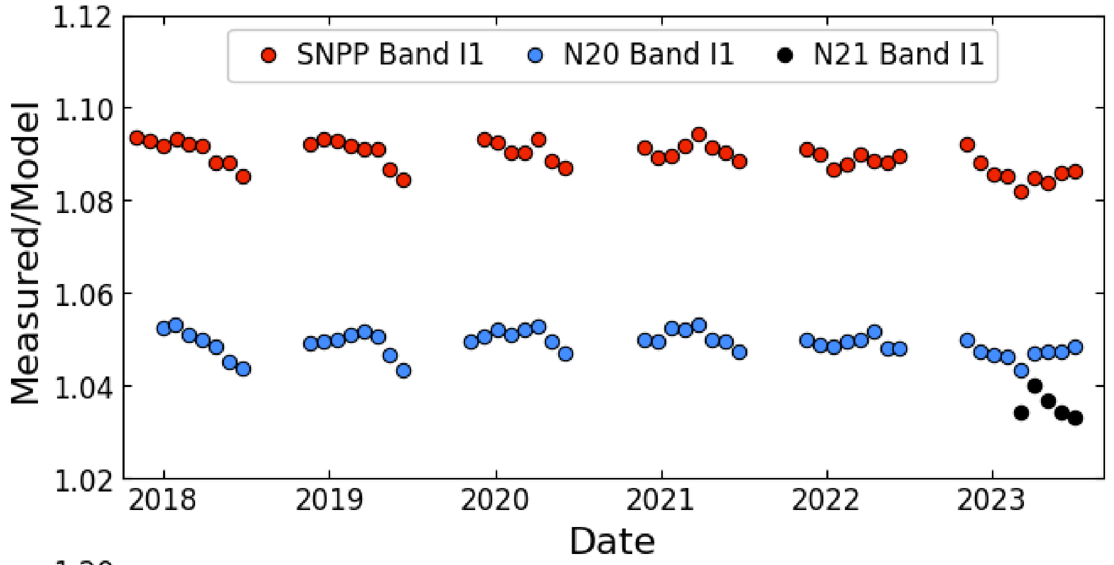
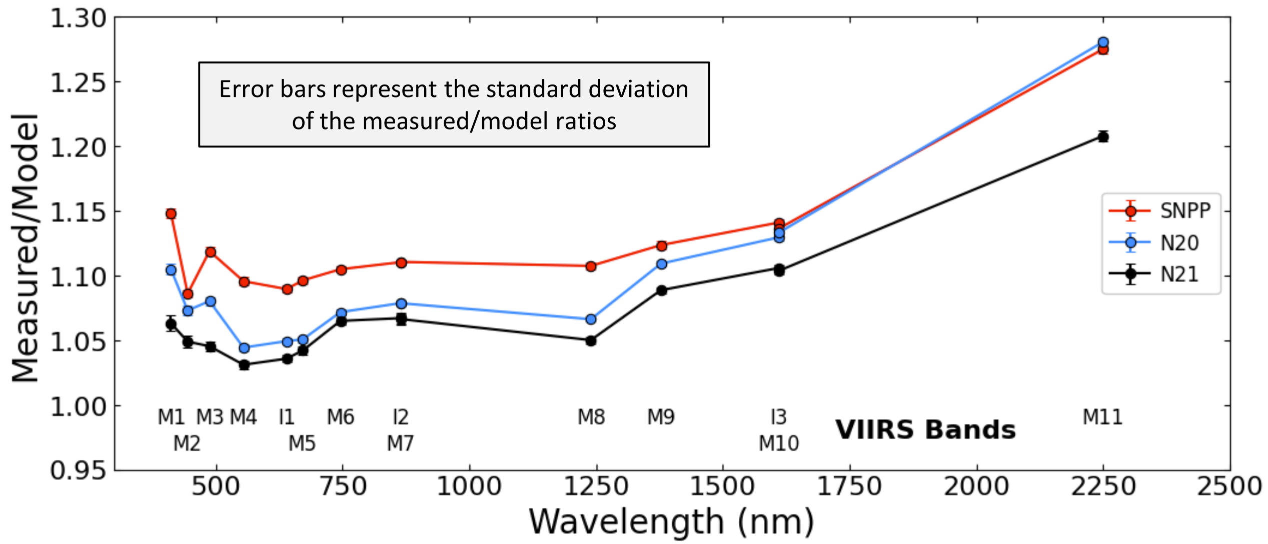
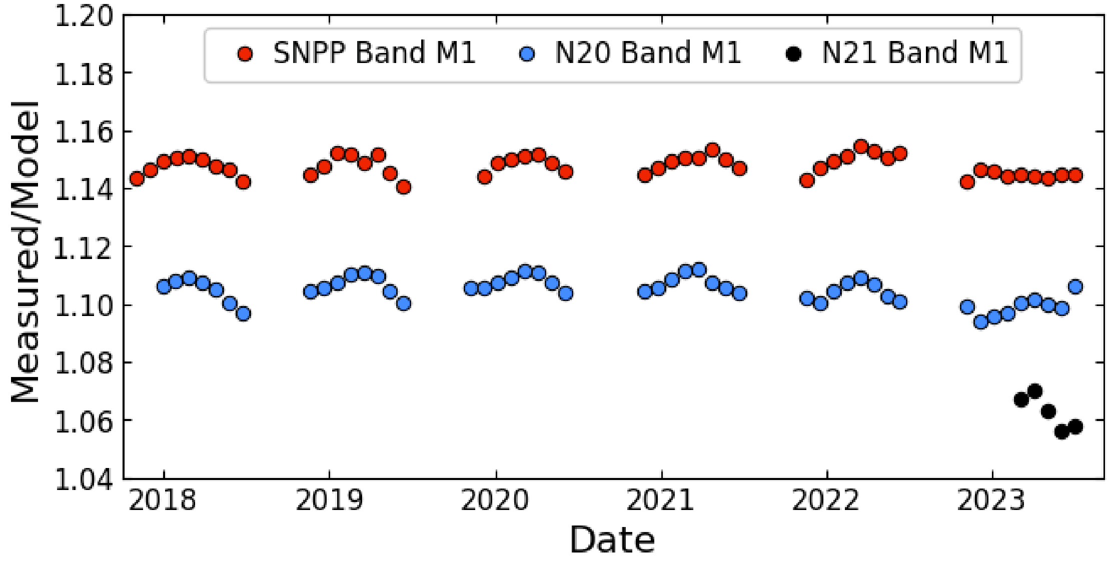


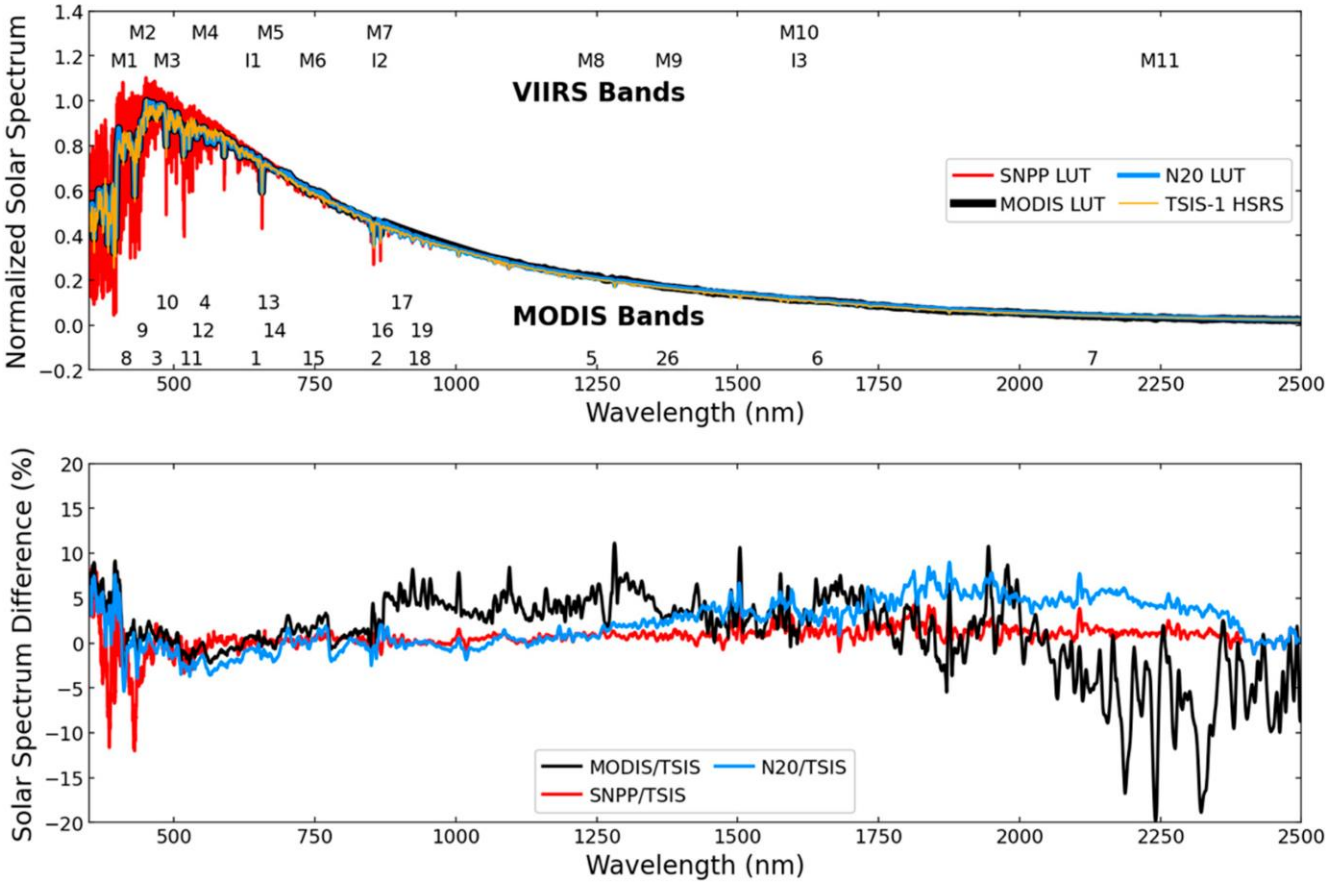




- Each instrument shows a similar trend versus wavelength, with the SNPP data showing a higher offset with the ROLO model, particularly at shorter wavelengths.
- The bias between SNPP and N20 is a known issue that is currently under investigation.
- The N21 data shows a lower bias compared to ROLO than SNPP and N20 for all wavelengths.

Results and Discussion: Sensor Solar Spectrum

- Different sensors may use different reference solar spectra which can causes differences in lunar calibration inter-comparison.
  - N21 uses the same solar spectra as N20.
- Comparison to the TSIS-1 HSRS shows significant differences in certain wavelength ranges for both MODIS and VIIRS.
- To correct for 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.

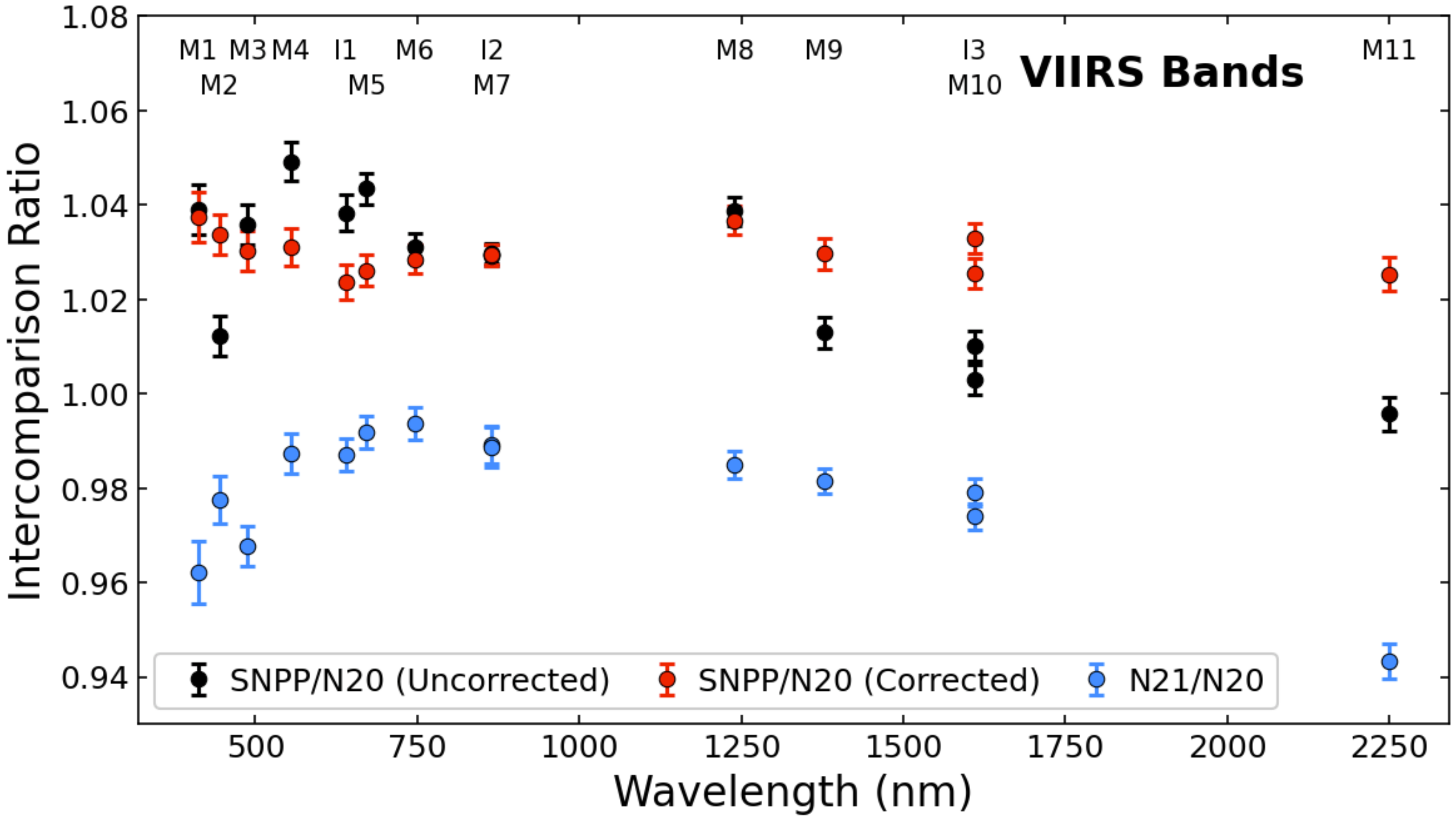


$$C_{A/B} = \frac{\int RSR_A(\lambda)E_{Sun_B}(\lambda)d\lambda / \int RSR_A(\lambda)d\lambda}{\int RSR_A(\lambda)E_{Sun_A}(\lambda)d\lambda / \int RSR_A(\lambda)d\lambda}$$

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

Intercomparison Ratios

- For SNPP/N20, the solar spectra correction makes the bias more consistent across all wavelengths.
- N21/N20 does not require a solar spectra correction.
- The N21 calibration shows higher differences at the shortest and longest wavelengths.



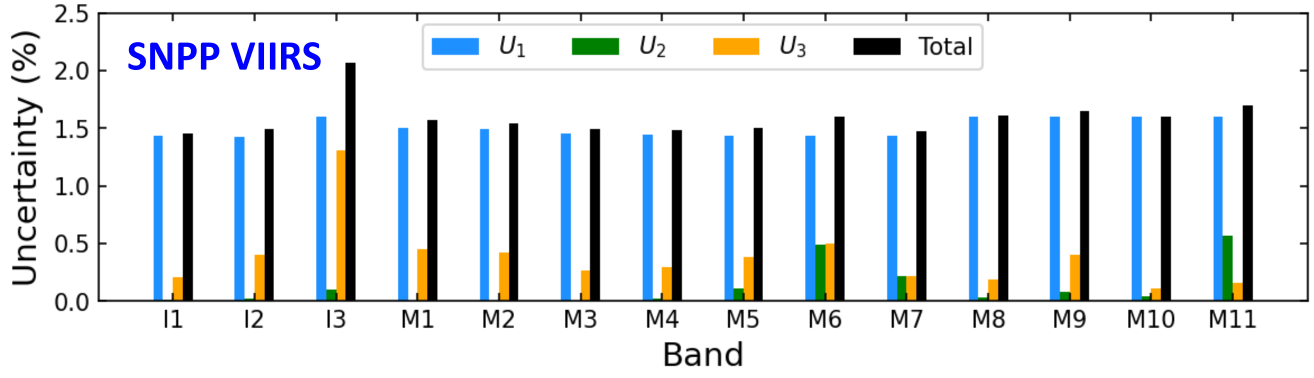
Results and Discussion: Calibration Uncertainty

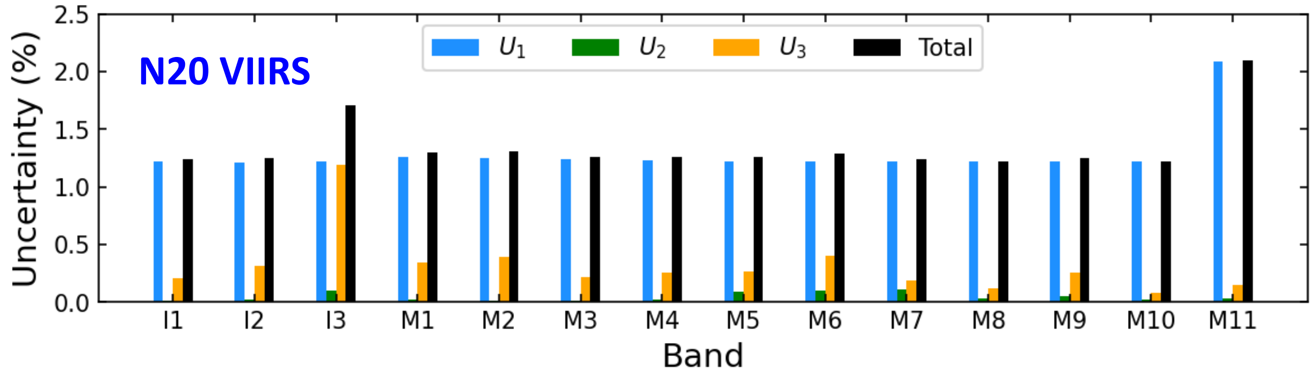
Key contributors to the lunar calibration inter-comparison uncertainty

- Calibration uncertainty of sensors involved
- Small residual differences in the lunar model if different phase/libration angles involved

Key factors for high quality and accurate calibration inter-comparison

- Calibration traceability
- Pre-launch calibration (RSR)
- Use of the same reference solar spectrum





- 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

Conclusions

- The Moon has been used for (RSB) calibration stability monitoring and calibration inter-comparisons for S-NPP, N-20, and N-21 VIIRS instruments.
  - The ROLO model combined with a solar spectral adjustment factor put data from different instruments on the same scale.
- The SNPP results show a bias of ~3% with N-20 in the VIS/NIR region.
  - This difference is also seen in other EV inter-comparison studies.
- The N-21 results show a good agreement with N-20 in the VIS/NIR region
  - Large difference (2-4%) seen in the SWIR region - likely due to J2 (or N-21) pre-launch BRDF characterization.
- Lunar calibration inter-comparison will be vital for evaluating future NASA/NOAA missions, such as VIIRS on JPSS-3/4, OCI on PACE, CPF instrument, and missions from other agencies, both domestic and international.