Using the Moon for Cross Comparisons Between Instruments

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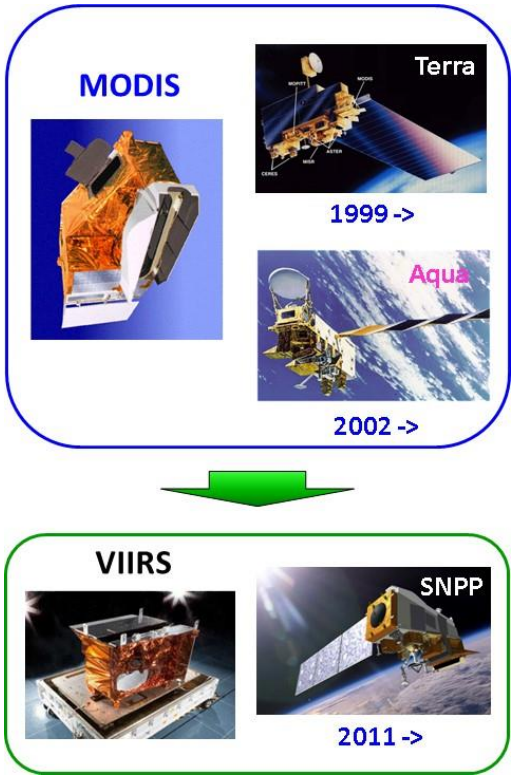
Introduction

- **The need for cross-comparisons between instruments**
  - Long-term and consistent data records using observations from multiple earth-observing instruments
- **Various approaches**
  - SNO, DCC, PICS, RadCaTS, …
- **Using the moon for cross-comparisons between instruments**
  - Pros and cons (see Tom Stone's presentations)

- **Examples using MODIS and VIIRS** (from Xiong et al, SPIE 2017)

Calibration Inter-comparisons Using Lunar Observations

- **MODIS and VIIRS Lunar Observations**
  - Regularly scheduled at the "same" phase angles for each instrument
  - Support for instrument on-orbit calibration
  - Many applications, including calibration inter-comparison



- **Calibration Inter-comparison**
  - Using integrated lunar irradiance
  - Normalizing sensor measured lunar irradiance to model predicated lunar irradiance

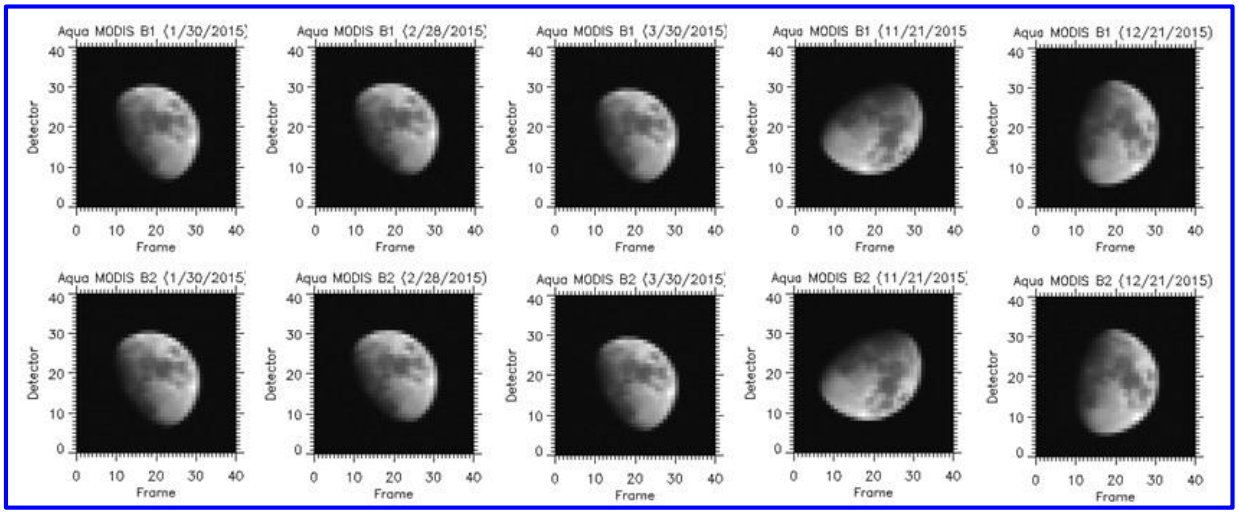
$$(I_{Meas\_Sensor\text{-}A} / I_{Model\_Sensor\text{-}A}) / (I_{Meas\_Sensor\text{-}B} / I_{Model\_Sensor\text{-}B})$$

Xiong et al, GRSL, 2009 on Terra and Aqua MODIS

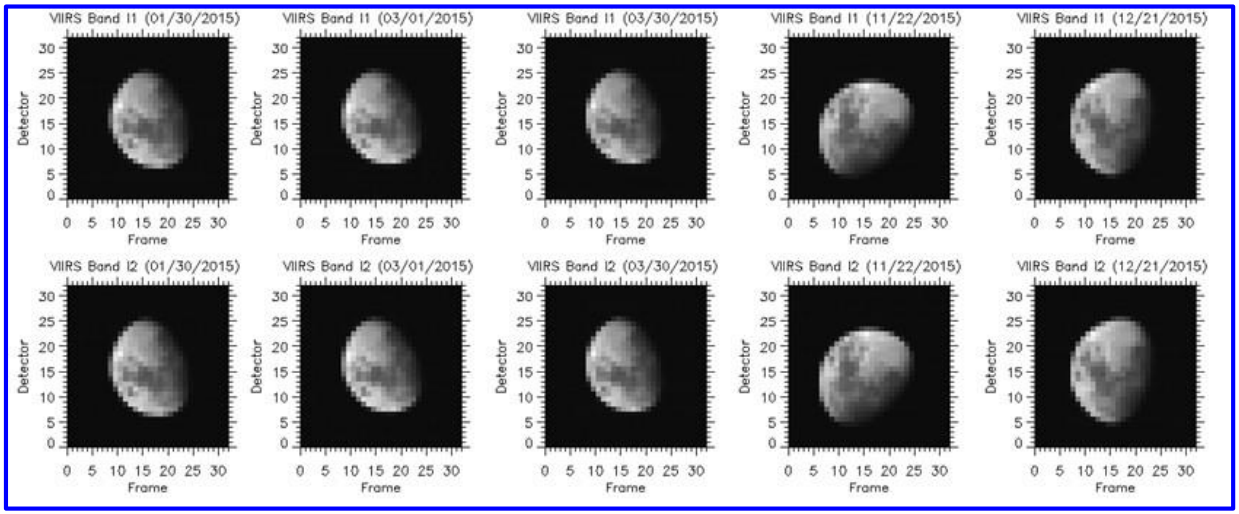
Xiong et al, SPIE 2014, 2015 on MODIS and VIIRS with PLEIADES (different approaches)

MODIS and VIIRS Lunar Observations (Images)

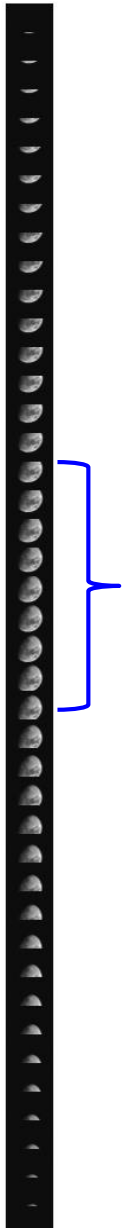
Aqua MODIS B1 and B2 (1/30, 2/28, 3/30, 11/21, 12/21/2015)



S-NPP VIIRS I1 and I2 (1/30, 3/1, 3/30, 11/22, 12/21/2015)



Aqua MODIS B1 image from March 30, 2015

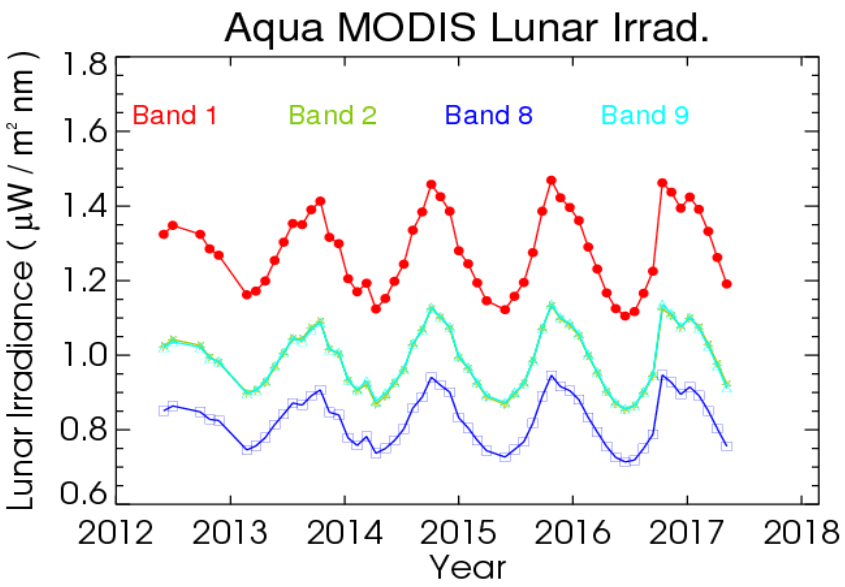


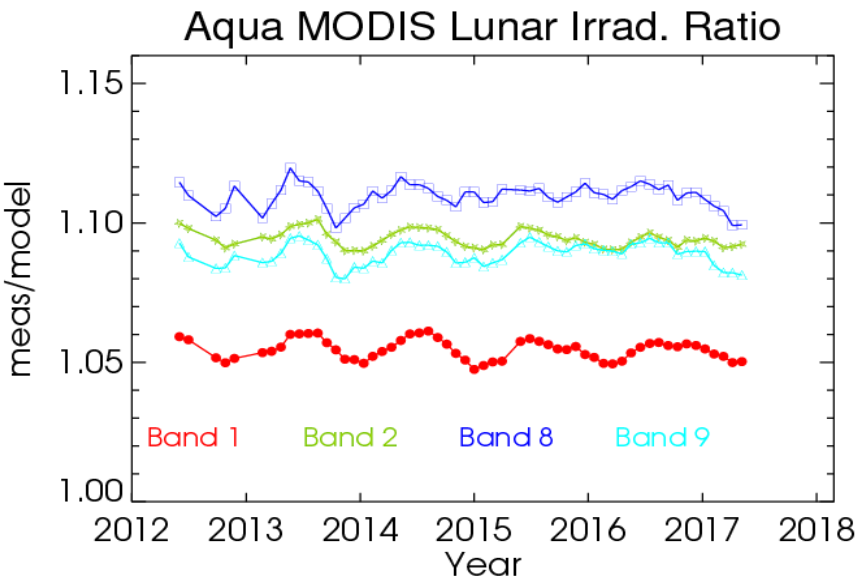
SNPP VIIRS I1 Image from March 30, 2015

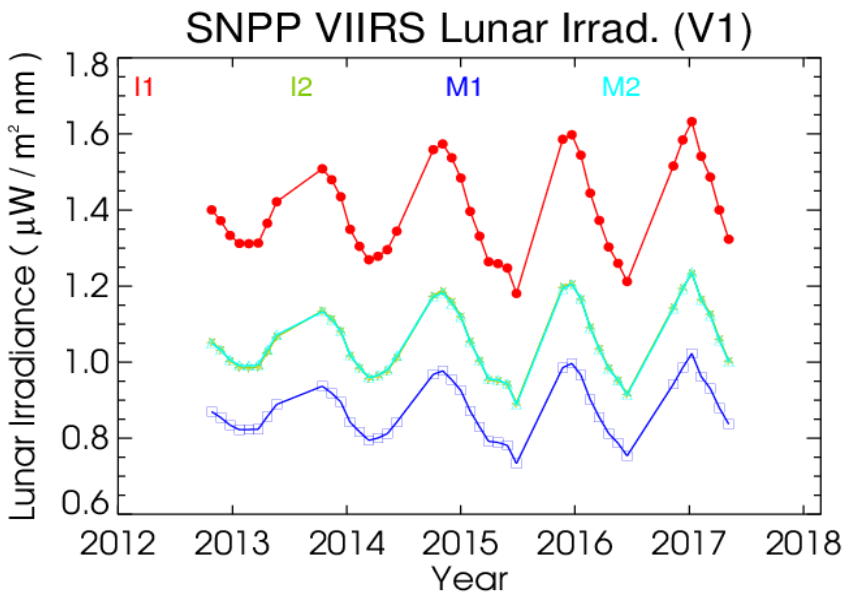
MODIS and VIIRS Spectral Bands (VIS/NIR)

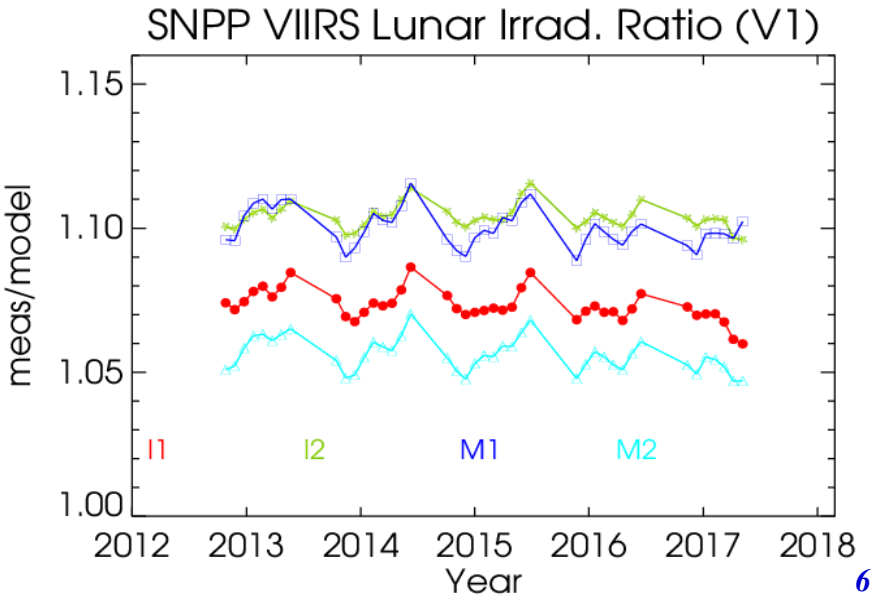
VIIRS Band	Spectral Range (um)	Nadir HSR (m)	MODIS Band(s)	Range	HSR
DNB	0.500 - 0.900				
M1	0.402 - 0.422	750	8	0.405 - 0.420	1000
M2	0.436 - 0.454	750	9	0.438 - 0.448	1000
M3	0.478 - 0.498	750	3 10	0.459 - 0.479 0.483 - 0.493	500 1000
M4	0.545 - 0.565	750	4 or 12	0.545 - 0.565 0.546 - 0.556	500 1000
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

Integrated Lunar Irradiance (Measured and Normalized)





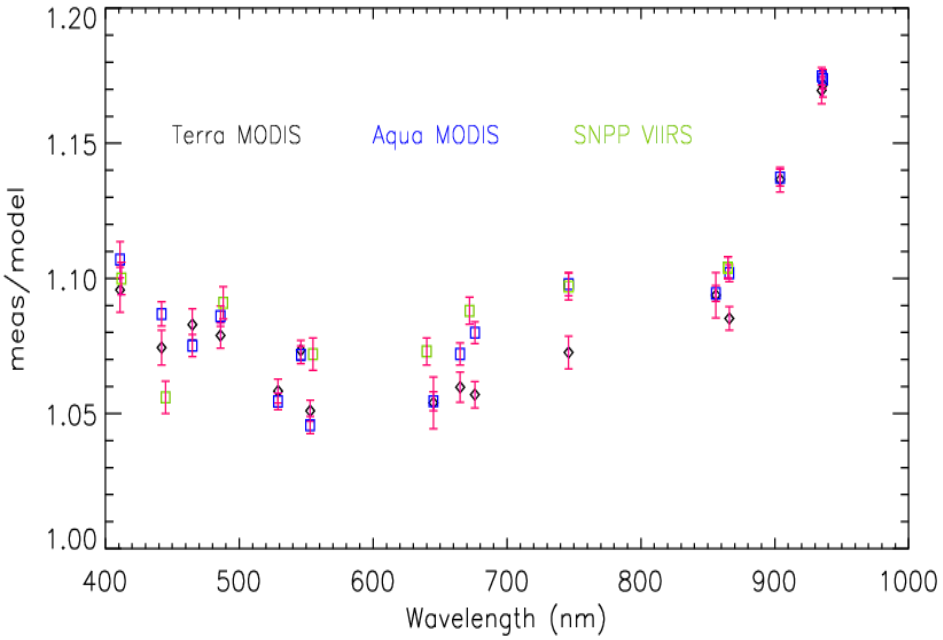




MODIS and VIIRS Lunar Irradiance (Normalized)

Data: 2012-2017		S-NPP VIIRS		Aqua MODIS		VIIRS/A-MODIS	
MODIS	VIIRS	Nom	STD	Nom	STD	Ratio	STD
8	M1	**1.100**	0.006	**1.107**	0.007	**0.994**	0.009
9	M2	**1.056**	0.006	**1.087**	0.004	**0.972**	0.007
10	M3	**1.091**	0.006	**1.086**	0.004	**1.004**	0.007
12	M4	**1.072**	0.006	**1.072**	0.003	**1.000**	0.007
1	I1	**1.073**	0.005	**1.055**	0.003	**1.018**	0.006
13	M5	**1.088**	0.005	**1.072**	0.004	**1.015**	0.006
15	M6	**1.097**	0.005	**1.098**	0.004	**0.999**	0.006
2	I2	**1.104**	0.004	**1.094**	0.003	**1.009**	0.005
16	M7	**1.104**	0.004	**1.102**	0.003	**1.002**	0.005

Results from MODIS bands 3, 4, 11, 18, and 19 are also included



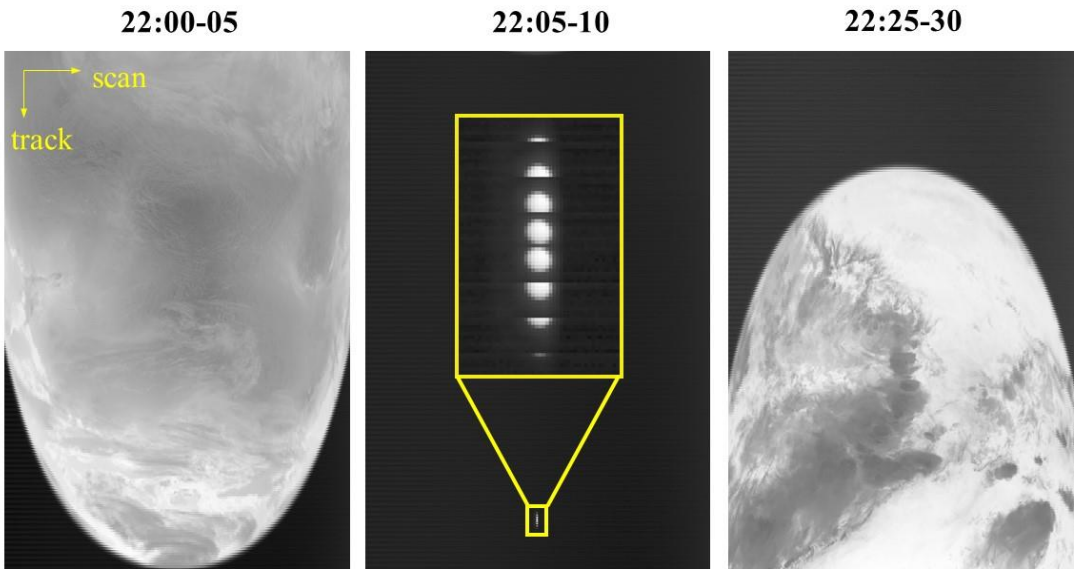
$$I_{Meas\_Sensor} / I_{Model\_Sensor}$$

$$\frac{(I_{Meas\_Sensor\text{-}A} / I_{Model\_Sensor\text{-}A})}{(I_{Meas\_Sensor\text{-}B} / I_{Model\_Sensor\text{-}B})}$$

Lunar Deep Space Calibration

Terra Spacecraft Pitch Maneuvers:

- April 14, 2003
- August 5, 2017



Band	λ (μm)	2003_D	2003_R	Ratio	2017_D	2017_R	Ratio	R/R (%)
1	0.647	1.037	1.027	**1.009**	1.047	1.046	**1.002**	**1.007**
2	0.857	1.077	1.075	**1.003**	1.079	1.094	**0.986**	**1.017**
3	0.466	1.099	1.088	**1.010**	1.099	1.084	**1.014**	**0.996**
4	0.554	1.063	1.054	**1.008**	1.056	1.050	**1.006**	**1.003**
8	0.412	1.107	1.105	**1.002**	1.116	1.097	**1.018**	**0.984**
9	0.442	1.102	1.082	**1.019**	1.100	1.074	**1.024**	**0.995**
10	0.487	1.085	1.087	**0.998**	1.068	1.075	**0.994**	**1.004**
11	0.530	1.063	1.062	**1.001**	1.033	1.055	**0.979**	**1.022**
12	0.547	1.080	1.077	**1.002**	1.060	1.070	**0.991**	**1.011**
17	0.904	1.137	1.139	**0.998**	1.125	1.140	**0.987**	**1.011**
18	0.935	1.177	1.175	**1.002**	1.160	1.172	**0.990**	**1.012**
19	0.936	1.174	1.172	**1.002**	1.160	1.175	**0.988**	**1.015**

Discussion

- **Sensor Calibration Traceability and Uncertainty**
  - Calibration differences: offsets and variations (systematic and random)
- **Calibration Coefficients or LUTs (Versions) and Data Collections**
  - Calibration consistency and stability
- **Detector IFOV**
  - Specified, measured, and changes on-orbit
- **Lunar Models**
  - Consistent reference
- **Impact of Sensor Performance and Characteristics**
  - Crosstalk, stray light, polarization
- **Others**
  - Background subtraction
  - Over-sampling factor if applicable

Summary and Future Work

- **Lunar observations can be used effectively to track sensor calibration stability and to examine calibration consistency among sensors**
  - Current lunar models (e.g. ROLO, GIRO) can do a fairly good job
  - Lunar models with improved accuracy are needed to move beyond from sensor inter-comparison to sensor inter-calibration
- **MODIS and VIIRS lunar observations have been used to support their on-orbit calibration and assess their calibration consistency**
  - The differences are generally smaller than their combined calibration uncertainties (not surprised with current design requirements)
  - Question: How to do better? What is good enough?
- **A number of factors need to be examined further**
  - Improved approach
  - Additional lunar observations
- **Joint effort to extend beyond MODIS and VIIRS**
  - Revisited SeaWiFS results (Eplee)
  - Received sample results from OLI (Ong)
  - Reviewed Terra pitch lunar calibration results from ASTER

2003 Comparison

SeaWiFS				MODIS				
Band No.	Wavelength (nm)	Measured I µW/m^2/nm	Model I µW/m^2/nm	Band No.	Wavelength (nm)	Measured I µW/m^2/nm	Model I µW/m^2/nm	Ratio
1	412	1.790	1.757	8	412	1.805	1.714	0.97
2	443	2.190	2.130	9	442	2.143	2.026	0.97
				3	466	2.465	2.316	
3	490	2.574	2.437	10	487	2.526	2.319	0.97
4	510	2.589	2.458	11	530	2.617	2.463	0.99
5	555	2.776	2.631	12	547	2.704	2.523	0.98
5	555	2.776	2.631	4	554	2.663	2.539	1.01
				1	647	2.596	2.512	
6	670	2.744	2.556	1	647	2.596	2.512	1.04
7	765	2.480	2.266					
8	865	2.009	1.886	2	857	1.974	1.855	1.00
				17	904	1.912	1.705	
				18	935	1.822	1.574	
				19	936	1.815	1.572	

How about now?