Effort toward Characterization of Selected Lunar Sites for the Radiometric Calibration of Solar Reflective Bands

Fangfang Yu[1], Xi Shao[1], Xiangqian Wu[2]
Masaya Takahashi[3] and Arata Okuyama[3]

1: ERT, Inc@NOAA/NESDIS/STAR
2: NOAA/NESDIS/Center for Satellite Application and Research (STAR)
3: Japan Meteorological Agency (JMA)/meteorological Satellite Center (MSC)

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Acknowledgement

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- JMA for the Himawari-8 AHI lunar observation data and AHI L1B data
- JAXA, Japan NIES and AIST for the SELENE/LALT and SELENE/SP data
- Dr. Hyelim Yoo for the help to plot the AHI DCC data

Background

- **GOES-R Advanced Baseline Imager (ABI)**
  - On-board calibration for both solar reflective and infrared bands
  - First NOAA GEO satellite with solar diffuser for the on-board solar reflective band calibration. No Solar Diffuse Stability Monitoring (SDSM) system
  - To be launched in Nov. 2016
- **JMA Himawari-8 Advanced Himawari Imager (AHI) was launched in Oct. 2014 and became operational since early July 2015**
  - VNIR LUT updated once so far, in early June 2015
- **ABI and AHI instruments**
  - Similar optics design
  - Same on-board calibration algorithms
    - VNIR: SD + deep space
    - IR: Blackbody + deep space
  - Similar spectral bands
    - 6 NVIR + 10 IR
  - Similar spatial resolution
    - 0.5km, 1km, and 2km
  - Similar temporary resolution
    - AHI: 10 minutes / full disk
    - ABI: 15 minutes / full disk

ABI and AHI band central wavelength and the spatial resolution

Band		Spatial Res.	AHI (μm)	ABI (μm)
1	Visible (VIS)	1 km	0.47	0.47
2			0.51	
3 / 2		0.5 km	0.64	0.64
3	Near Infrared (NIR)	1 km	0.86	0.865
4		2 km		1.378
5		2 km	1.6	1.61
6			2.3	2.25
7	Infrared (IR)	2 km	3.9	3.90
8			6.2	6.19
9			6.9	6.95
10			7.3	7.34
11			8.6	8.5
12			9.6	9.61
13			10.4	10.35
14			11.2	11.2
15			12.4	12.4
16			13.3	13.3

Lunar Calibration

- **The moon is an extremely stable solar diffuser**
  - No atmospheric absorption/scattering
  - No vegetation/water ….
  - Relatively flat spectrum
  - Yet with strong directional reflectance

- **Challenges in the lunar calibration**
  - Accurate physical model to characterize the bi-directional reflectance function (BRDF) of the lunar surface
    - Phase angle
    - libration
  - Accurate calculation of the satellite measurement

Lunar Irradiance and Radiance Calibration

- **Lunar irradiance calibration is currently widely used**
  - Most popular physical model: USGS ROLO (GSICS GIRO) model
    - Works very well for the trending study when the phase angle range is small, successful at some LEO instruments (e.g. SeaWIFS, MODIS, VIIRS…)
    - Relative accuracy is phase angle dependent with possible residual of libration correction – Challenge for the GEO instruments as the moon can appear at the FOR at large range of phase angles
    - Relatively large absolute calibration uncertainty
  - Uncertainty in the satellite irradiance estimates
    - Oversampling factors, out-of-field energy (MTF, cross-talking, straylight, etc) and detector noise
- **Lunar radiance calibration can be an alternative method**
  - Use of relatively spectral/spatial uniform sites at the lunar surface
    - Minimize the phase and libration effects on the physical model
    - Minimize the effects of out-of-field radiance and oversampling factors on the satellite measurement
  - Challenges:
    - Accurate image-to-image registration
    - Accurate BRDF model is still required

Objectives

- **Explore the feasibility of lunar radiance calibration for the ABI/AHI solar reflective bands**

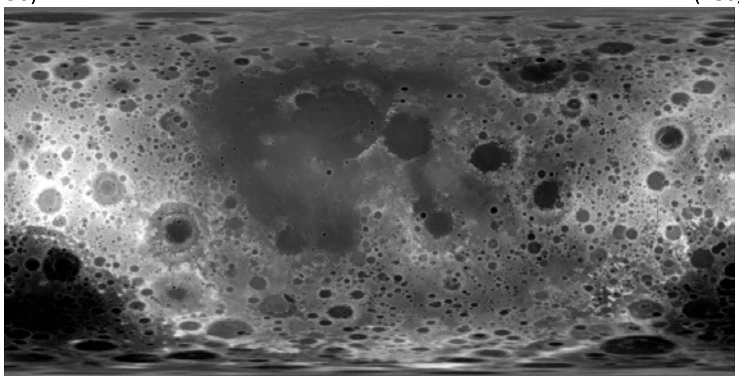
- **Take the first look at the preliminary results, identify the issues/challenges, and improve the corresponding algorithm(s)**

Outline

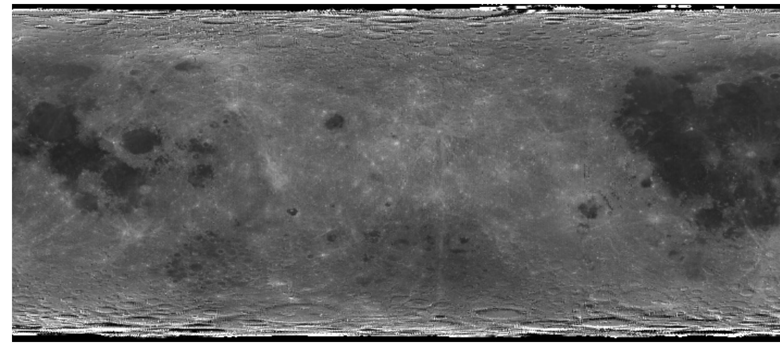
- **Potential targets identified with lunar orbital satellite data**
  - SELENE LALT (Laser ALTimeter) – high spatial resolution elevation data
  - SELENE SP (Spectral Profiler) – high spectral resolution data
- **Target verification with Earth orbital satellite data**
  - AHI data
  - SIFT method for automatic image-to-image registration for images with similar phase angle
  - Hybrid method to register all the images to the reference image
- **Preliminary results of the feasibility study with AHI data**
  - Albedo variations at the selected sites
  - AHI VNIR instrument degradation analysis – first look
- **Summary**

SELENE (Kaguya) Data to Select the Target Areas

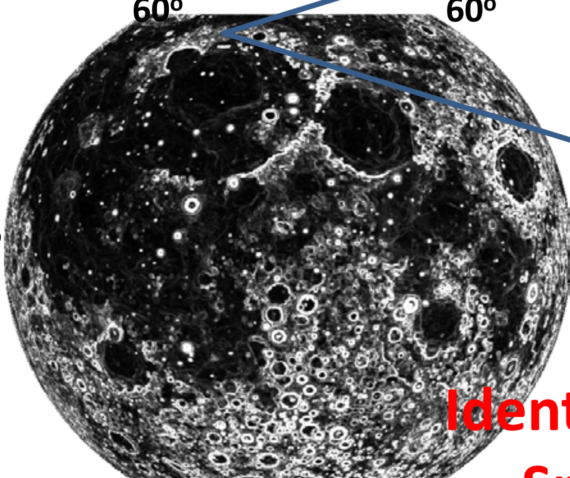
SELENE/LALT

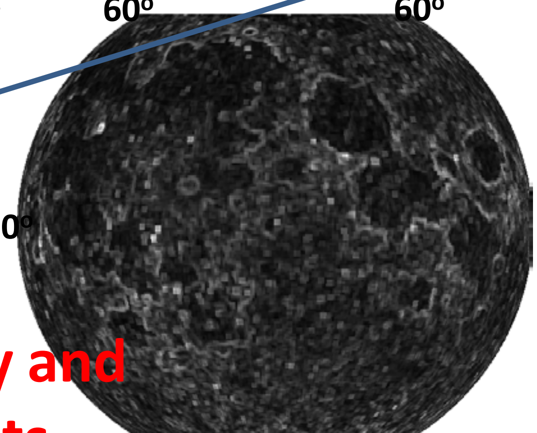


SELENE/SP



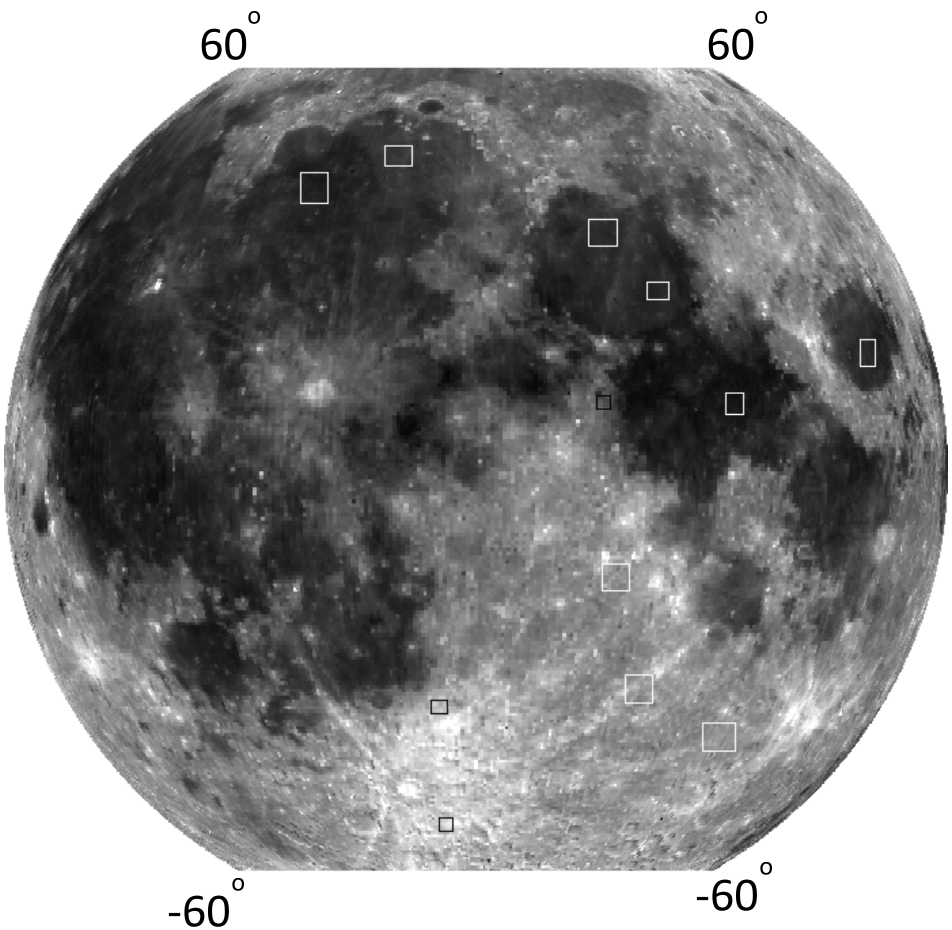
1. Re-project the near side of lunar surface products from cylindrical onto plane projection with selenographic coordinate at 5km/grid spatial resolution at Equator
2. Generate the Coefficient of Variation (CoV) of the topographic and radiometric products
3. Combine the CoV maps





Identify the Topographically and Spectrally Uniform Targets

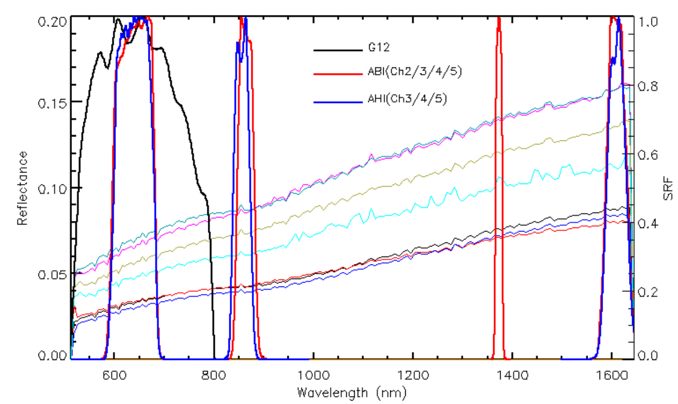
Combined CoV from SELENE Data



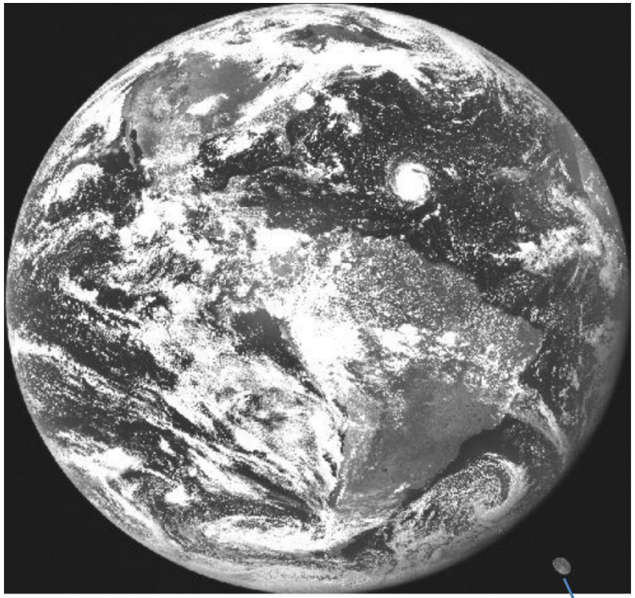
Favorable Conditions

- **Spatially Uniform – for flat moon surface. No impacts of vegetation and atmosphere**
  - **SELENE/Laser Altimeter (LALT) for lunar global topography**
- **Spectrally Uniform**
  - **SELENE/SP for spectral variation**
- **Sufficiently Large – tolerant to INR uncertainty**
  - **Different spatial resolutions at different bands**
- **Closer to the center**
  - **More data opportunity for model development**
- **Both dark (low elevation) and bright (high elevation) sites – bright sites to increase SNR**
- **Apollo 16 site for absolute calibration**
- **Weighting for these favorable conditions**

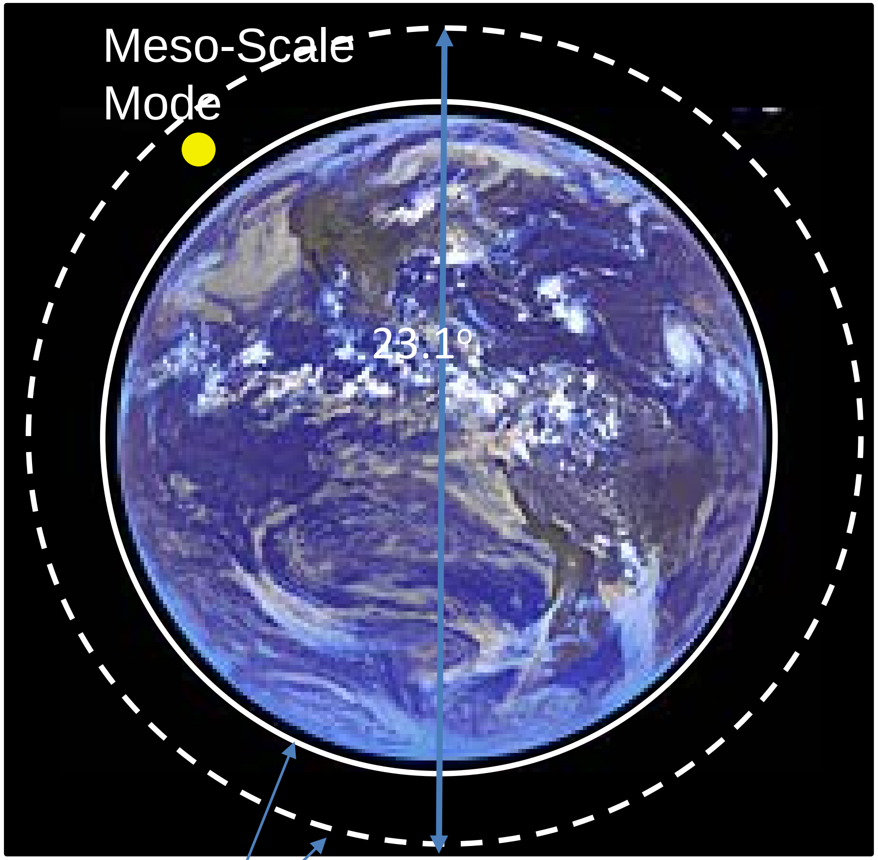
SELENE SP spectra of lunar surface and the GOES-12, GOES-R ABI, H8 AHI spectral response functions



Lunar Appearance in ABI Field of Regard (FOR)



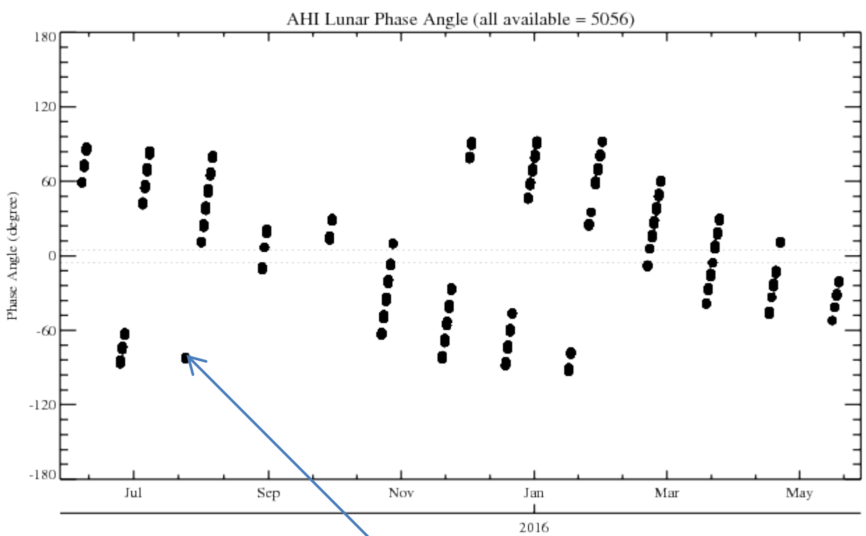
GOES-12 Observation

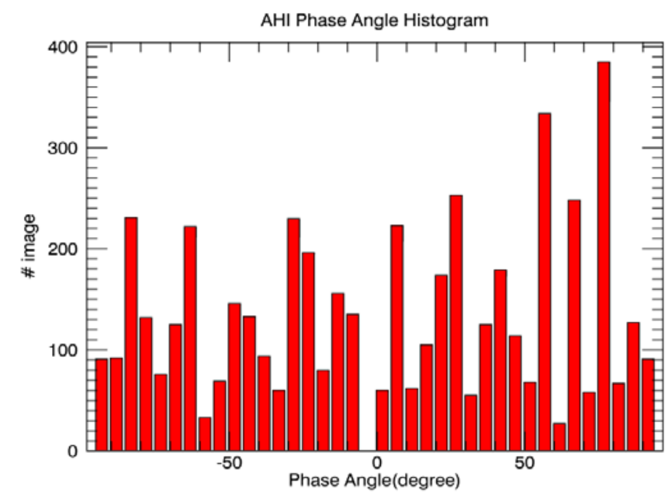


GOES-R ABI: Moon's appearance within the annular ring between Earth's limb margin and the outer boundary of the ABI's field of regard

H8 AHI Lunar Data

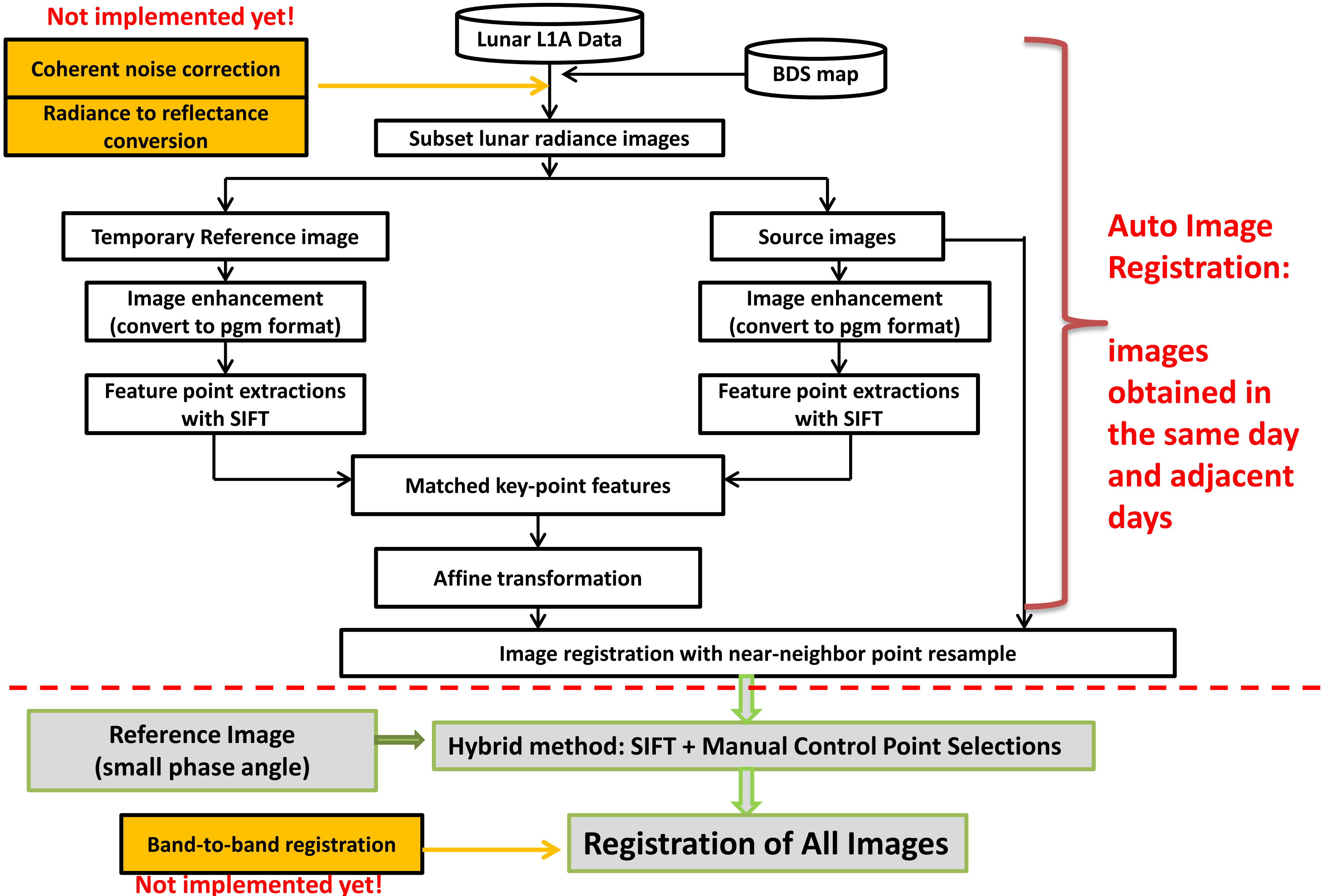
- **Verify the sites with earth orbital satellite data**
  - **AHI data**
  - **June 2015 – May 2016**
    - **>5, 000 images no-occulted images**





Moon tracing event, each has +10 to +100 images

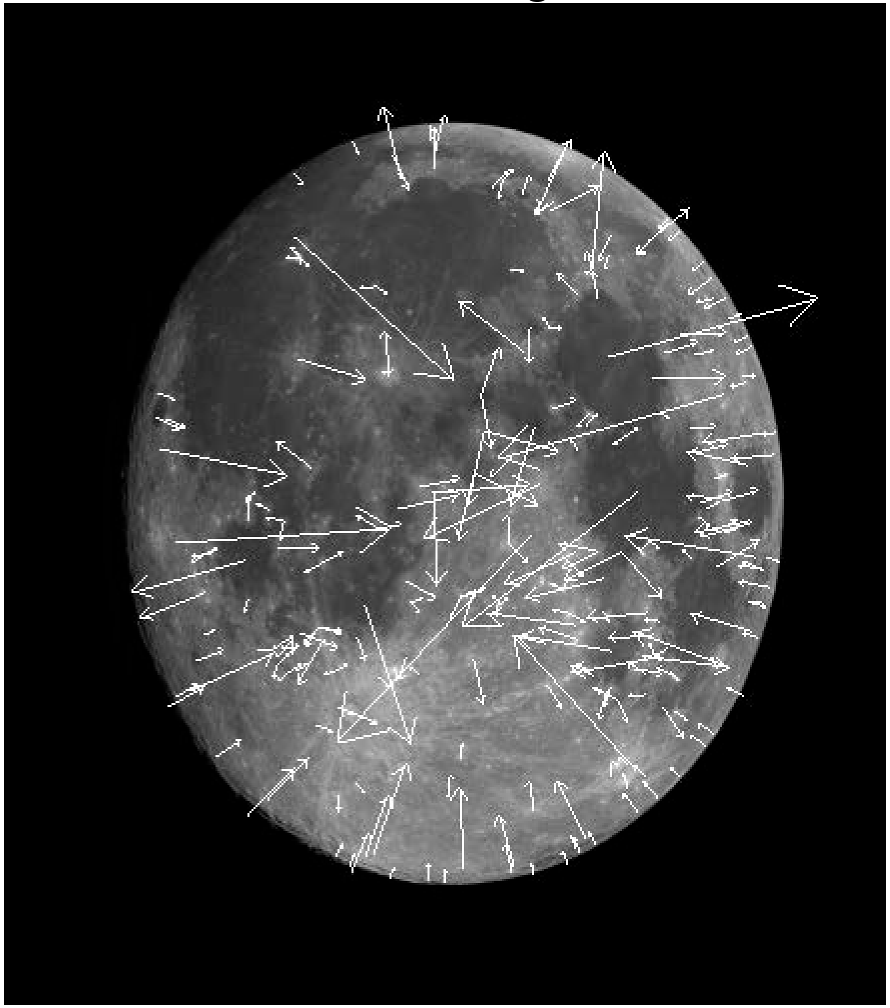
Image Registration



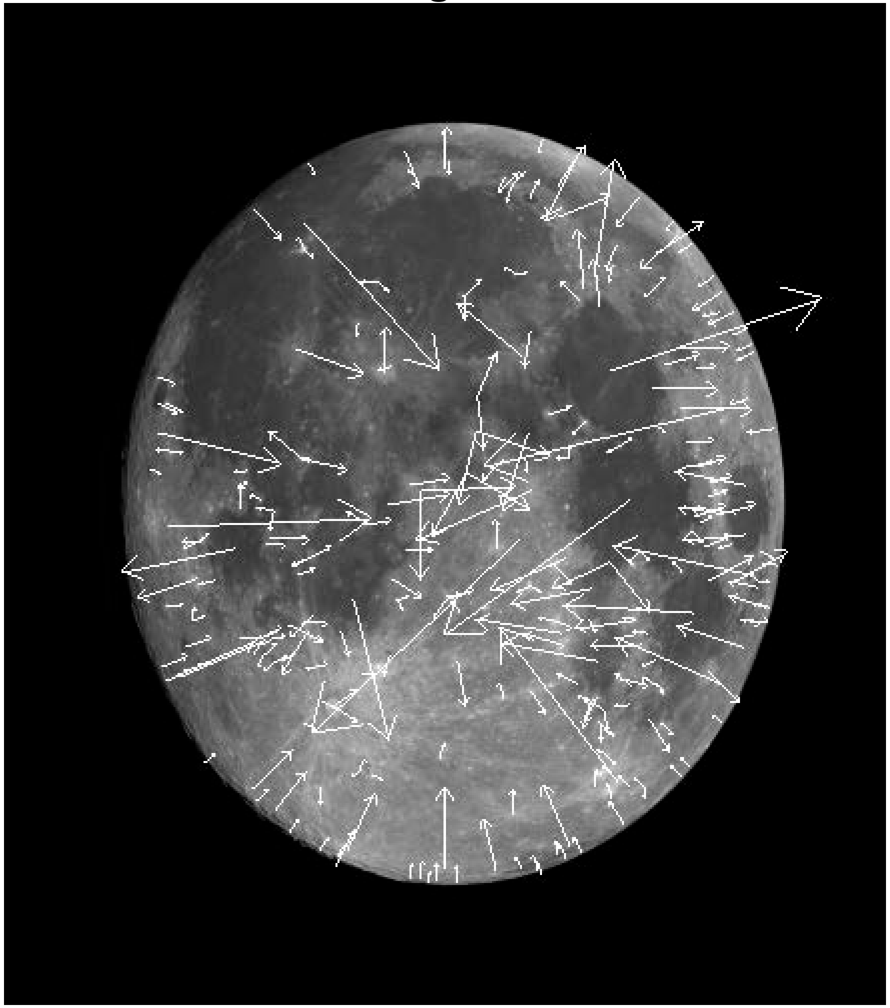
Keypoint Features - B1 as example

Scaled Invariant Feature Transform (SIFT)

Reference image



Source image



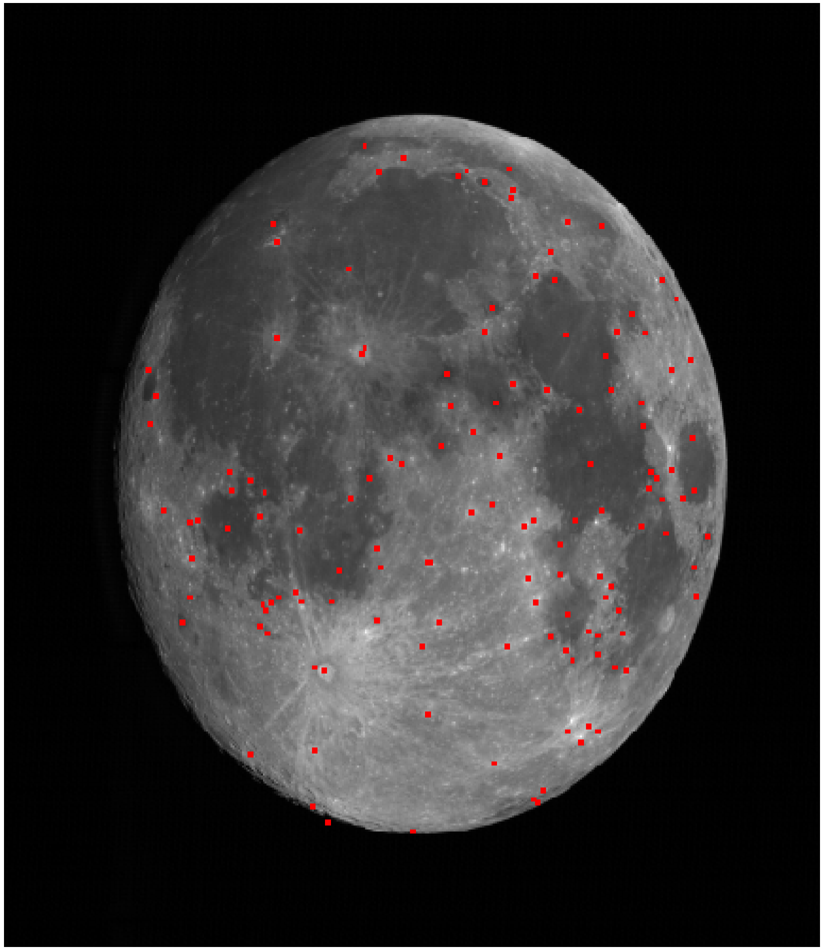
Lowe, D. 2004, *International Journal of Computer Vision*, 60, 91-110

Sub-pixel accuracy for the extracted key-point features

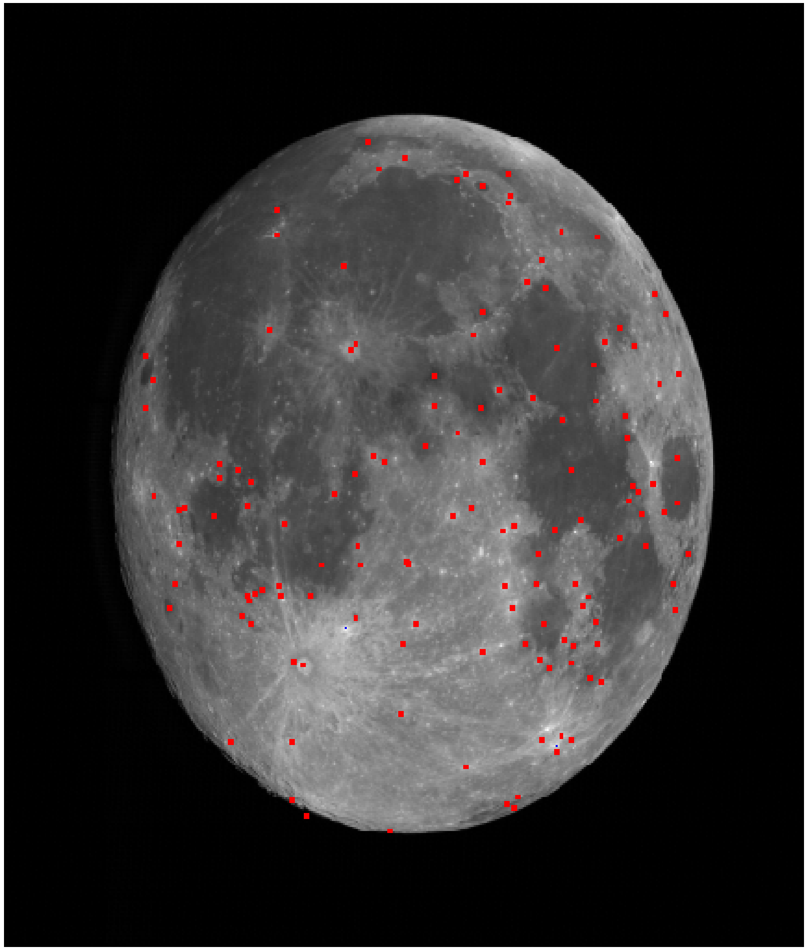
Extraction of Matched Key-points

Images in one moon tracing event

Reference image

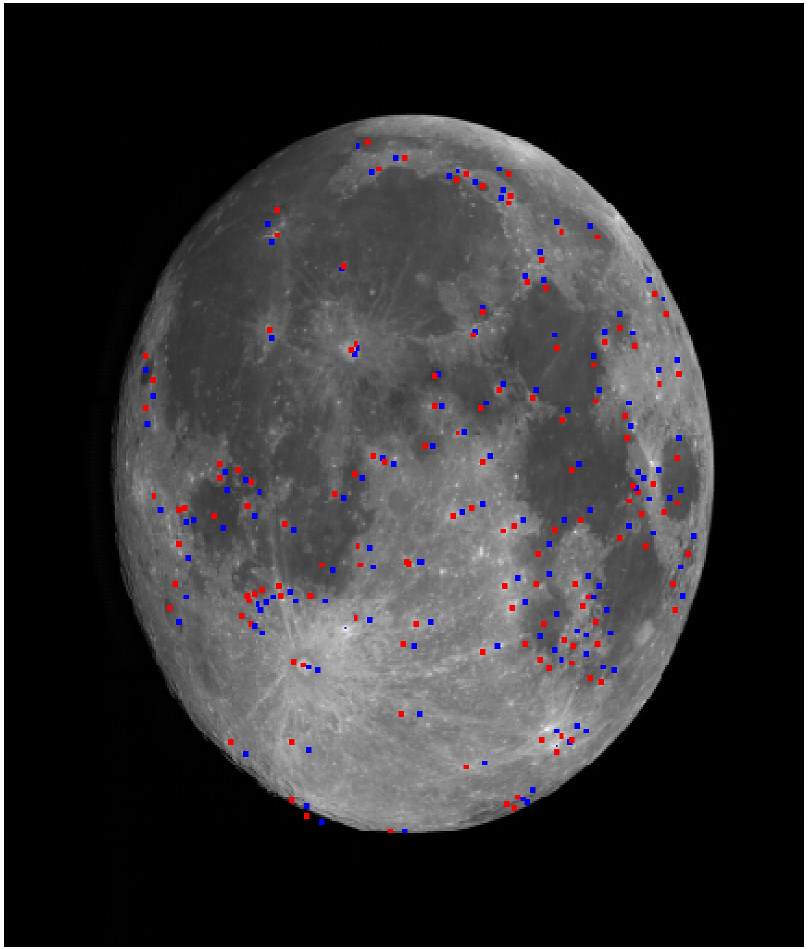


Source image



Euclidean distance to select the matchups of key-points

Matched Key-points (Example)



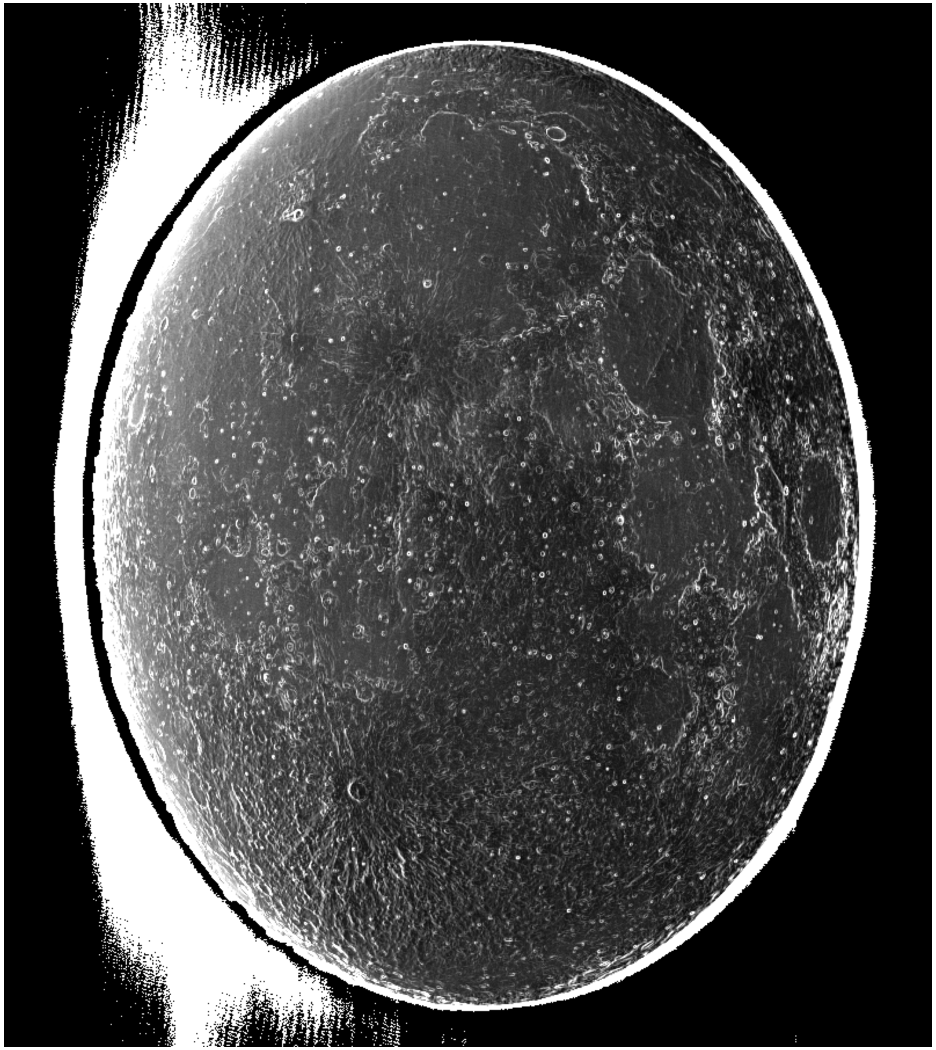
Distortion is not systematic!
- Linear affine transformation may not be sufficient to correct the image distortion

The number of matched key-points reduces and becomes clustered as absolute phase angle increases

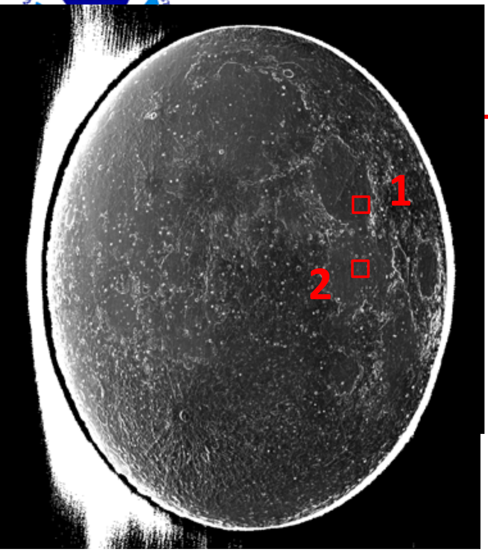
Blue: source image **Red: temporary reference image** image: temporary reference image

CoV of Radiance for Two Moon Tracing Events

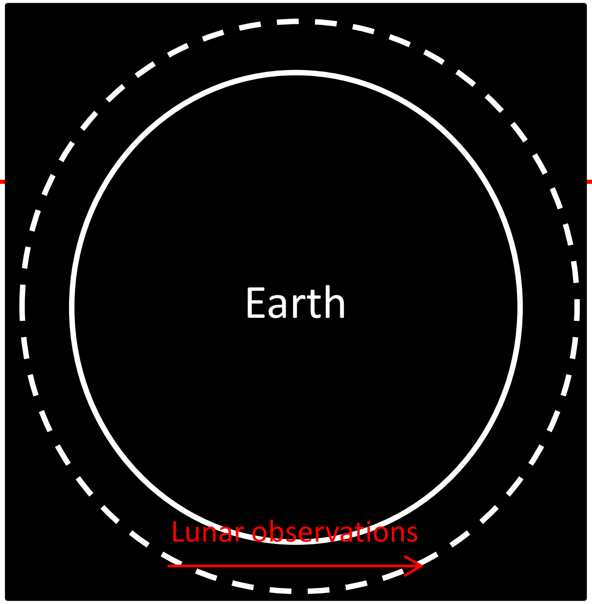
Phase angle = ~-10. degree, ~100 images



Phase angle = ~-75. degree, ~60 images

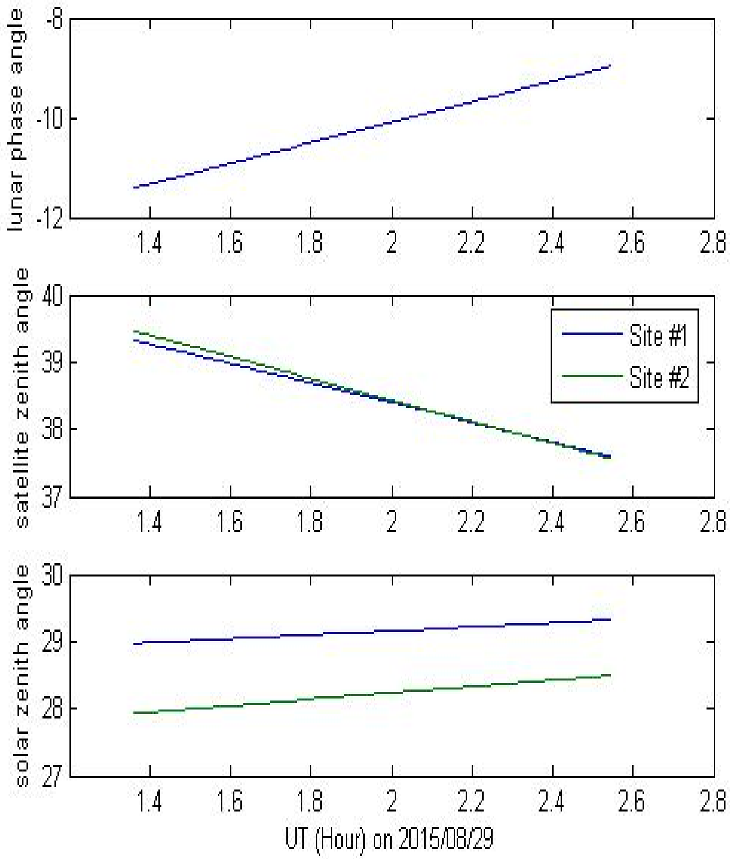


Viewing Geometry

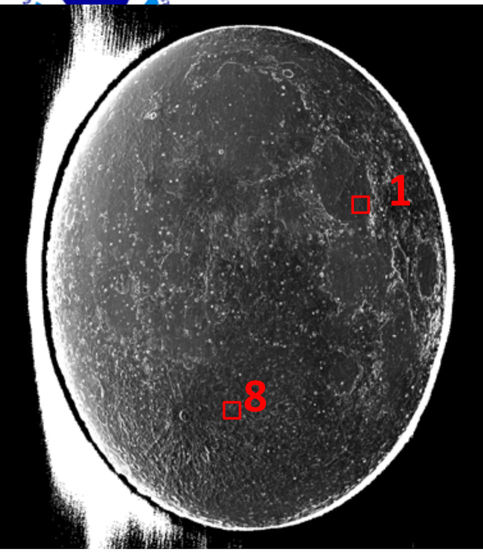


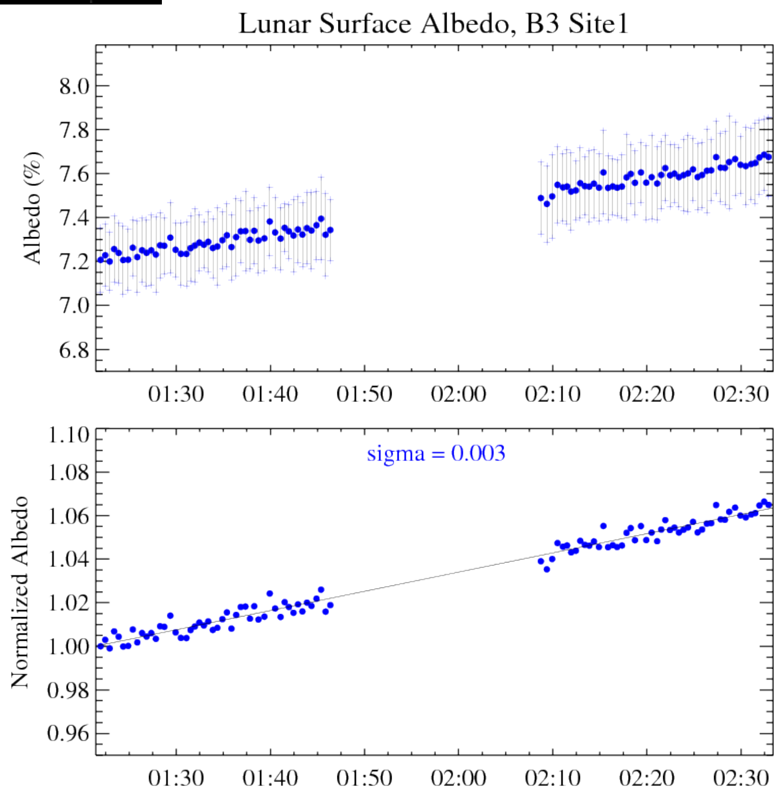
29 August 2015

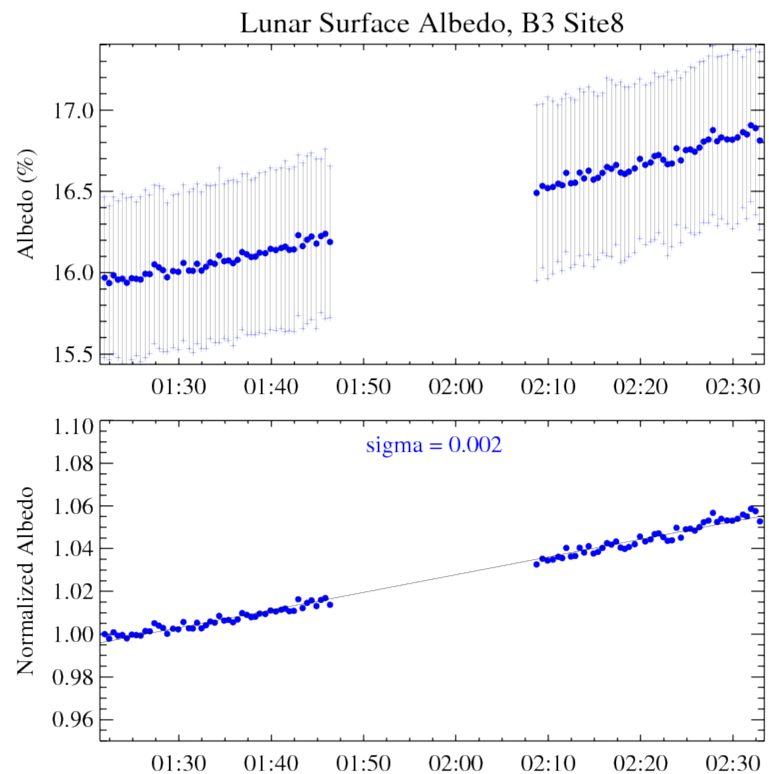
- **Phase angle: from <u>-11.5 to -9.0</u> [deg]**
- **100 observation / ~90 minutes**

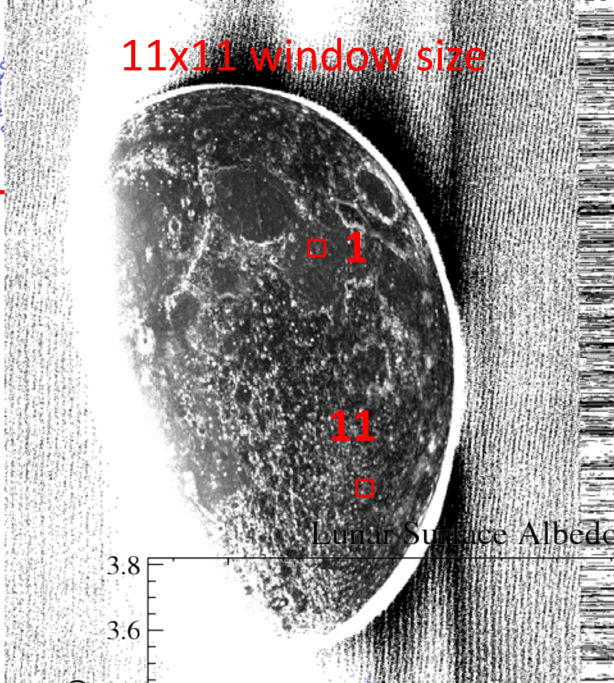


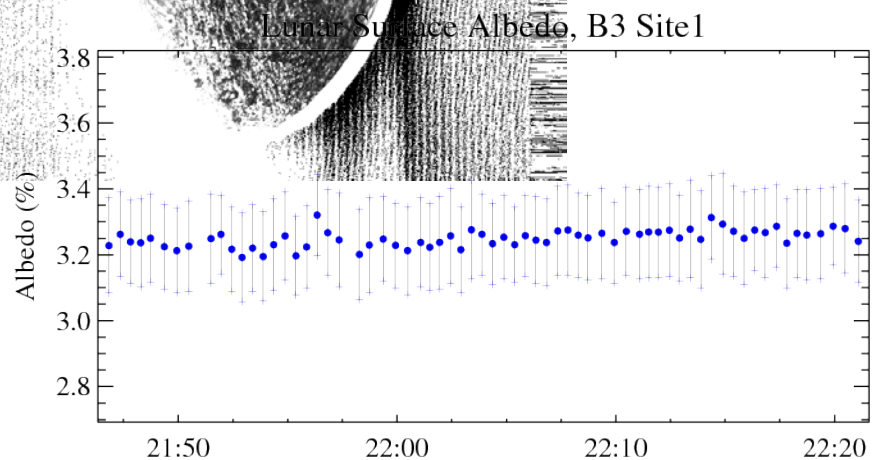
Site Radiance Extraction

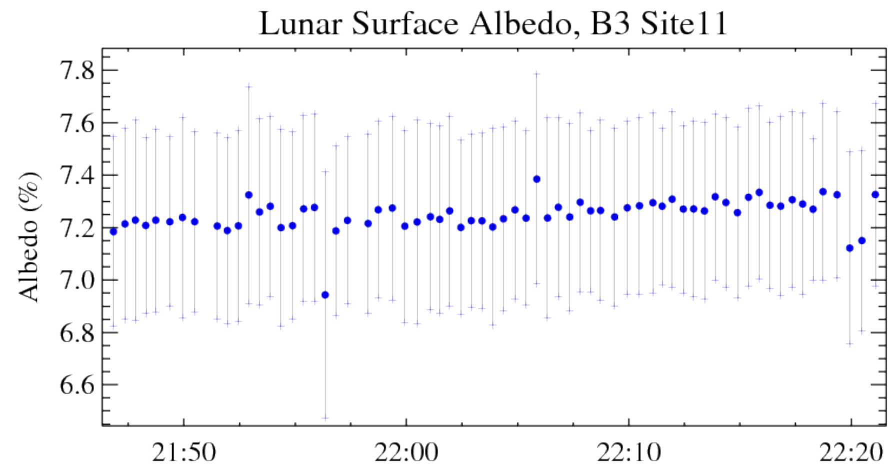


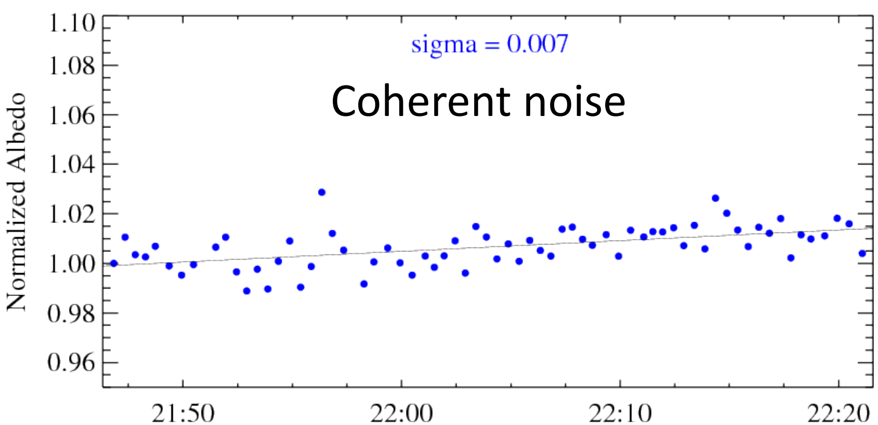


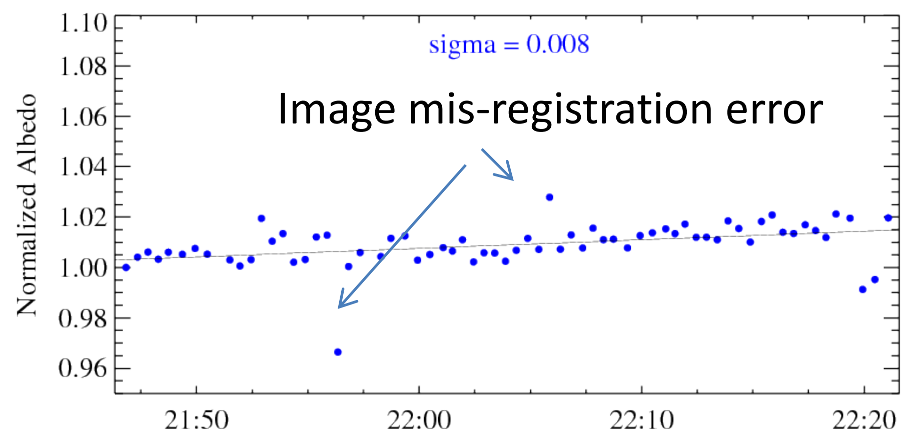



11x11 window size
1
11


Lunar Surface Albedo, B3 Site1
Albedo (%)
3.8
3.6
3.4
3.2
3.0
2.8
21:50
22:00
22:10
22:20


Lunar Surface Albedo, B3 Site11
Albedo (%)
7.8
7.6
7.4
7.2
7.0
6.8
6.6
21:50
22:00
22:10
22:20


sigma = 0.007
Coherent noise
Normalized Albedo
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
21:50
22:00
22:10
22:20


sigma = 0.008
Image mis-registration error
Normalized Albedo
1.10
1.08
1.06
1.04
1.02
1.00
0.98
0.96
21:50
22:00
22:10
22:20

Current Issues and Challenges

- Images obtained at different tracing events have various phase angles/libration, resulting in few and/or clustered matchups of key-points

- Manually add the matched control points
  - Result in relatively large registration error, especially for B5 and B6 (2km spatial resolution)

- Image distortion is not linear
  - Linear affine transformation is used in this study

- Certain registration error is thus expected for images between the tracing events. Effort is ongoing to develop an algorithm to increase the matched key-points across the illuminated lunar surface.

Data Processed so far….

- B1 (0.47um, 1km) and some B2 (0.51um, 1km) data, at various phase angles

- B5 (1.6um, 2km), B6 (2.3um, 2km)
  - Almost data: 5 < |Phase angle| < 45, July 2015 – May 2016

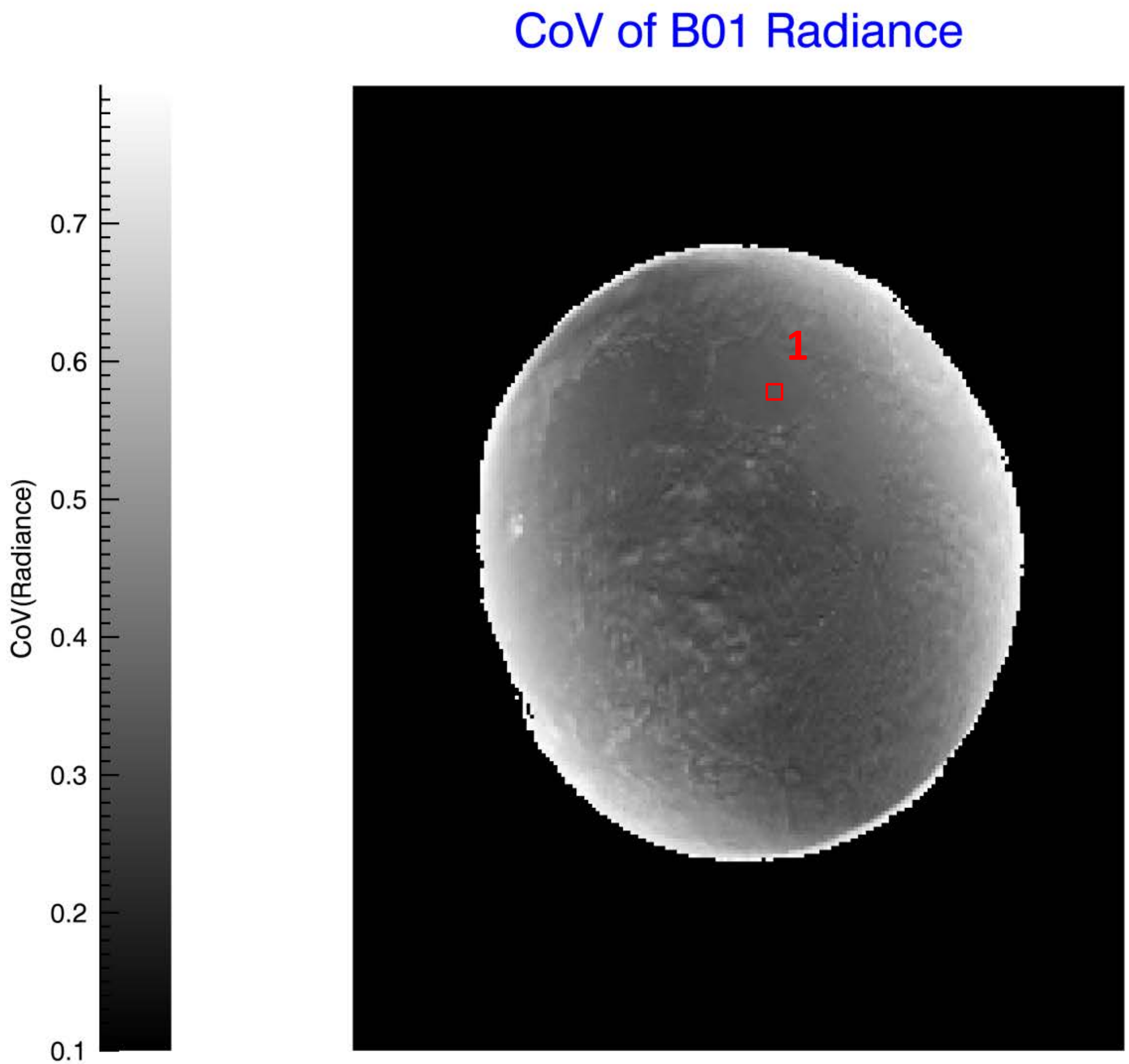
- Band to band registration is not strictly implemented yet.

First Look at the Preliminary Results and Applications

- **Surface Uniformity**

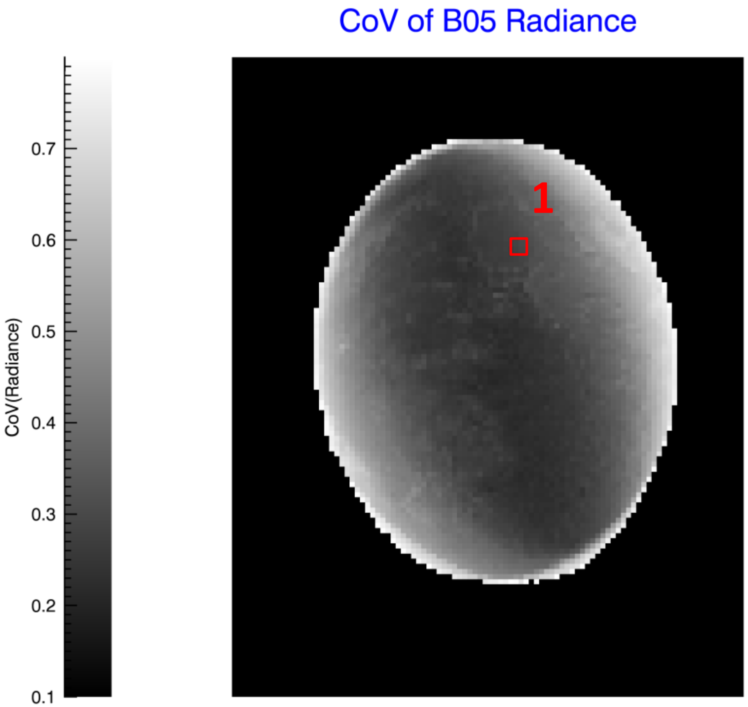
- **Time-series of band-to-band radiance ratio at given sites**
  - **Strict band-to-band registration not implemented yet**
  - **Manually selected area at different bands for this study**

Preliminary Results – Uniformity

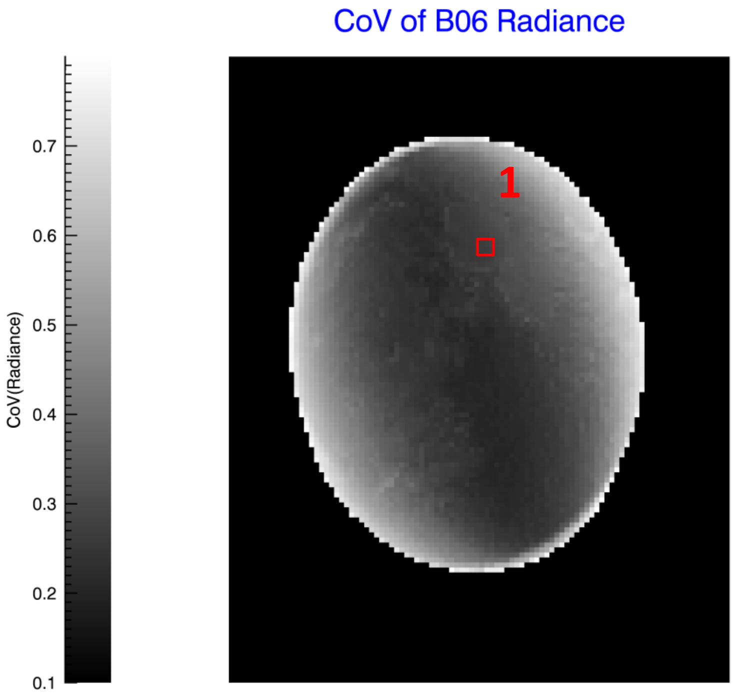


0.47um,
1Km

Uniformity for B5 and B6

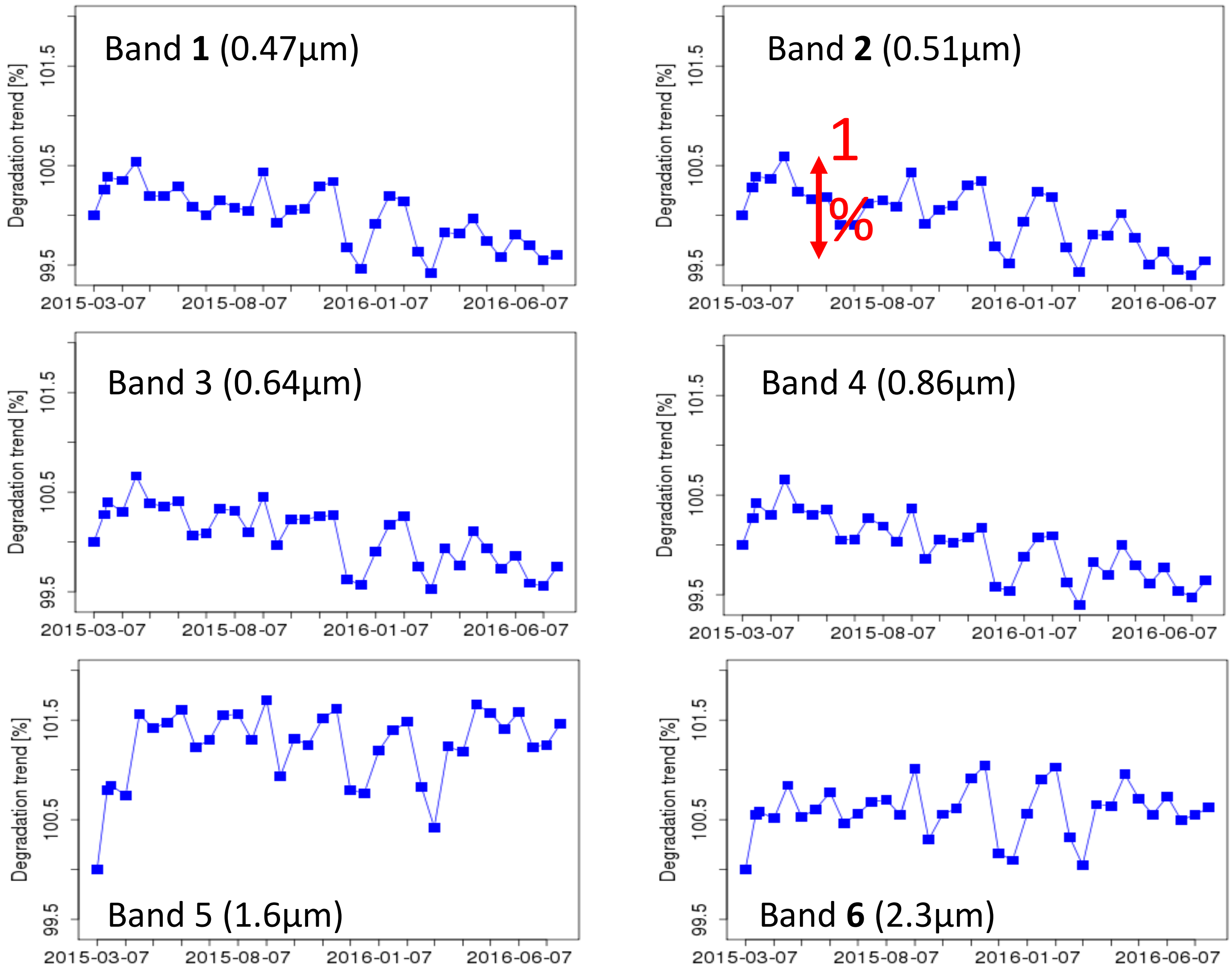


1.6um, 2km



2.3um, 2km

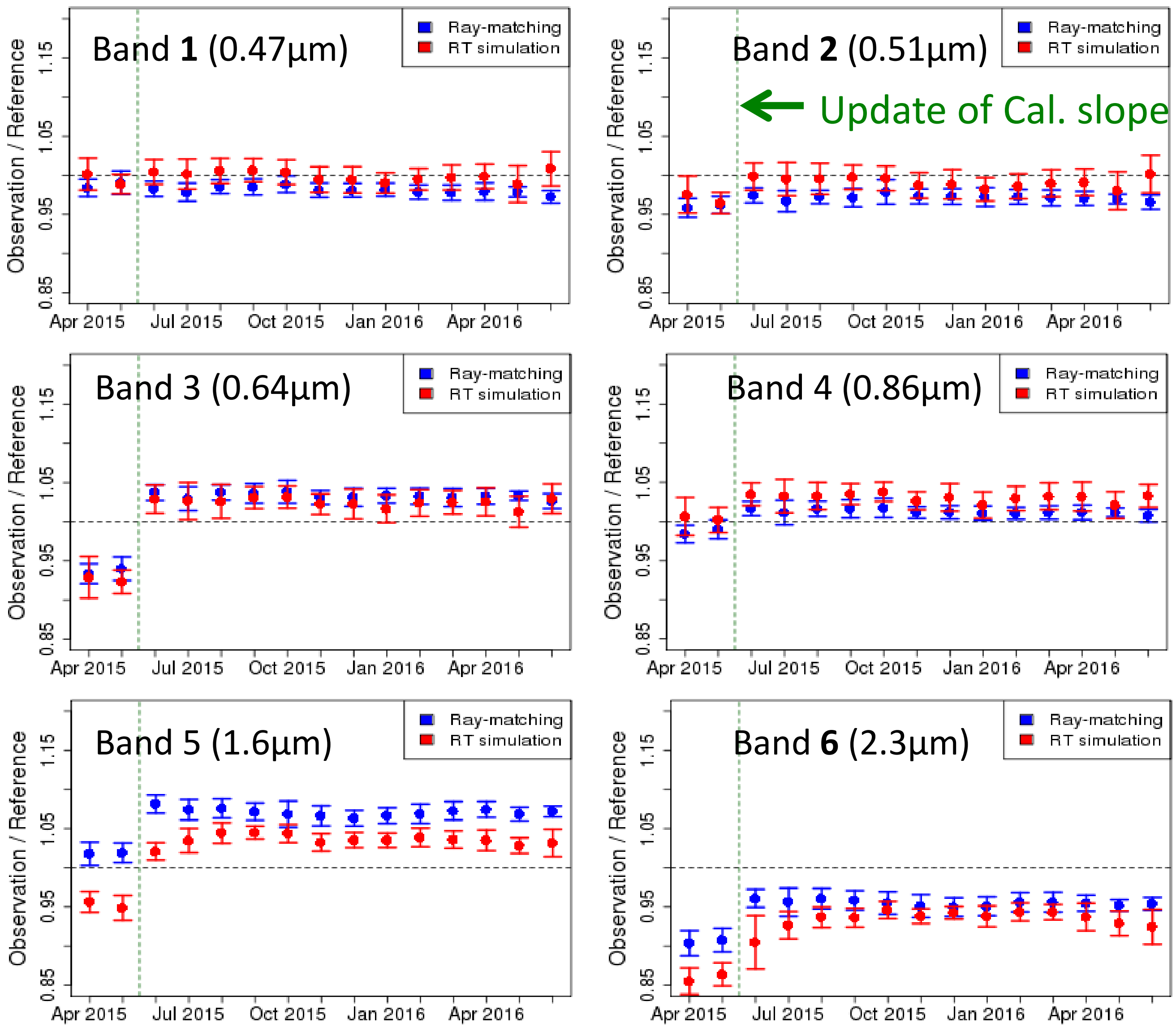
Inverse of AHI VNIR SD Derived Calibration Slope



The values are averaged over all the detectors and are normalized at the first observation on 7 March 2015.

Courtesy of JMA

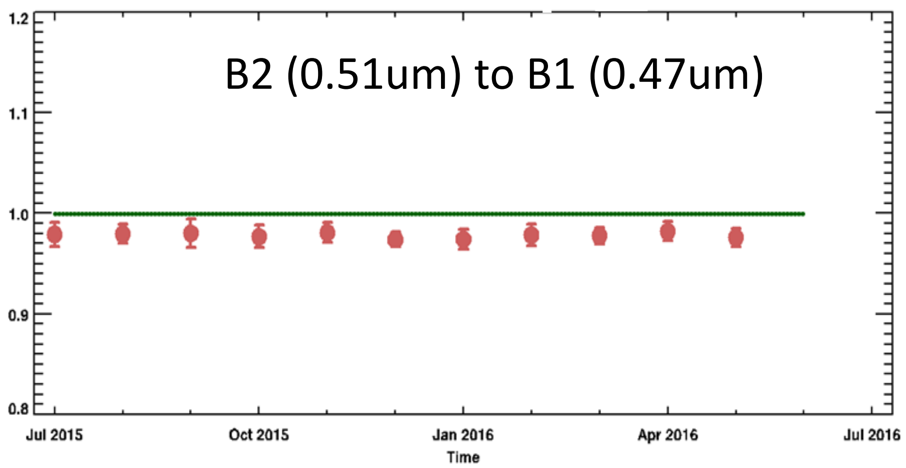
JMA's AHI Earth Data Quality Monitoring

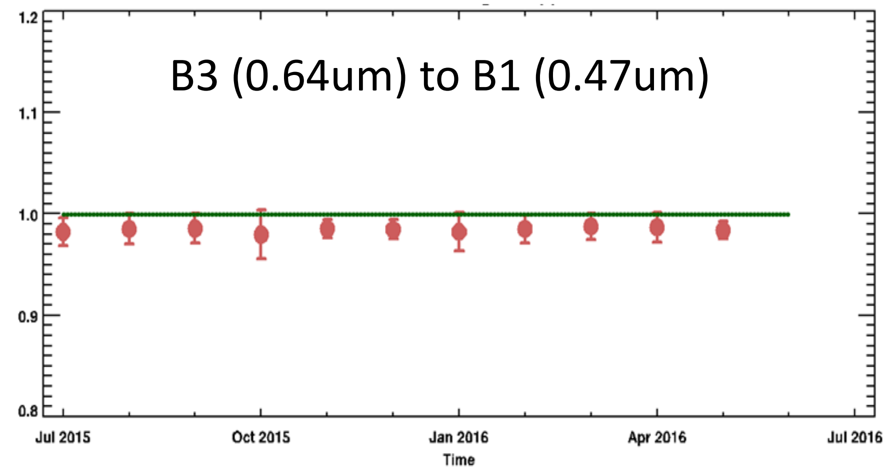


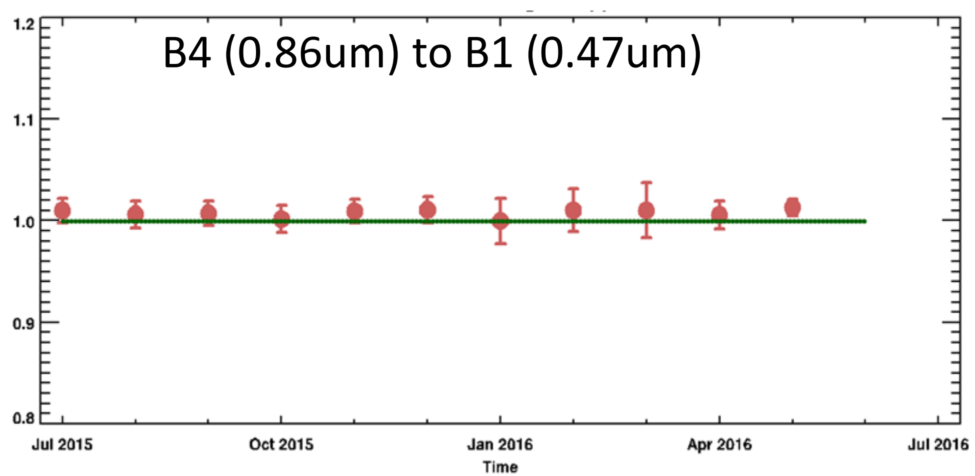
Does the solar diffuser degrade faster than the instrument?

Courtesy of JMA

AHI DCC Band-to-Band Reflectance Ratio

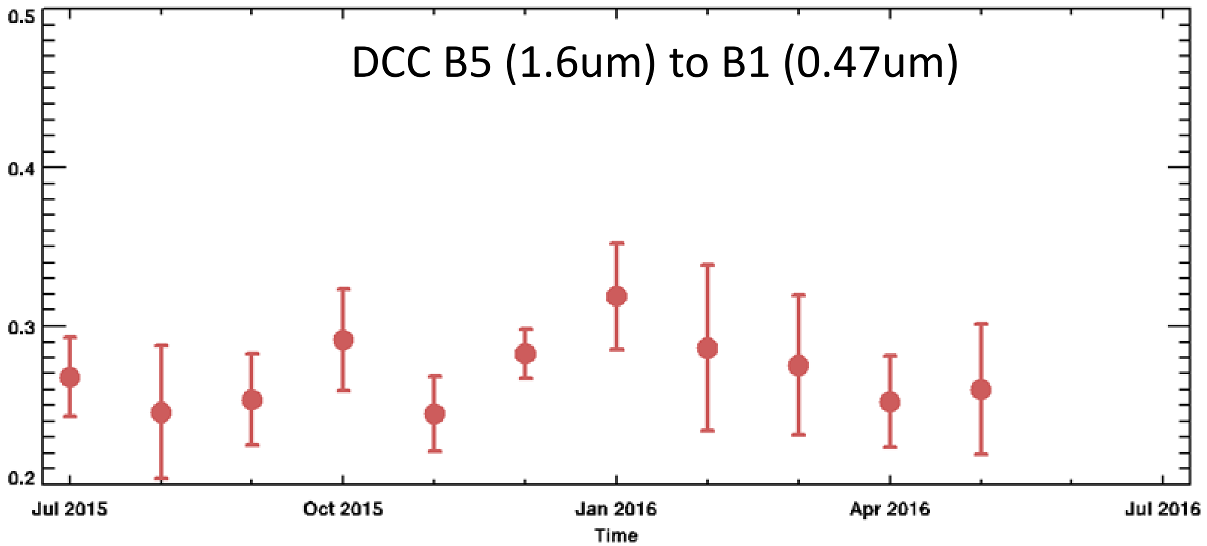


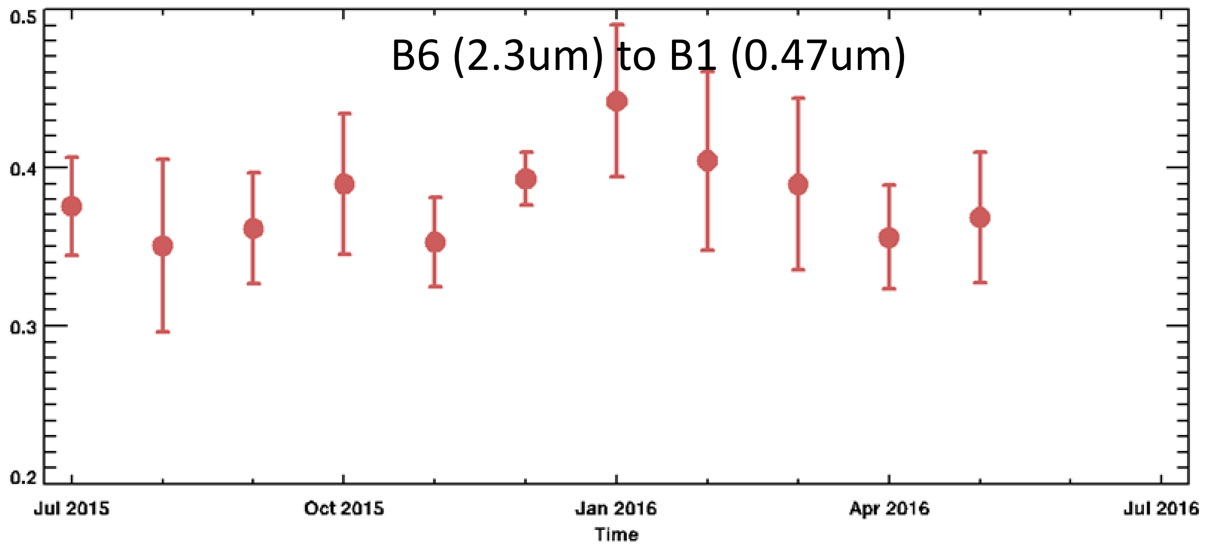




The three short-wavelength bands degrade at similar rate

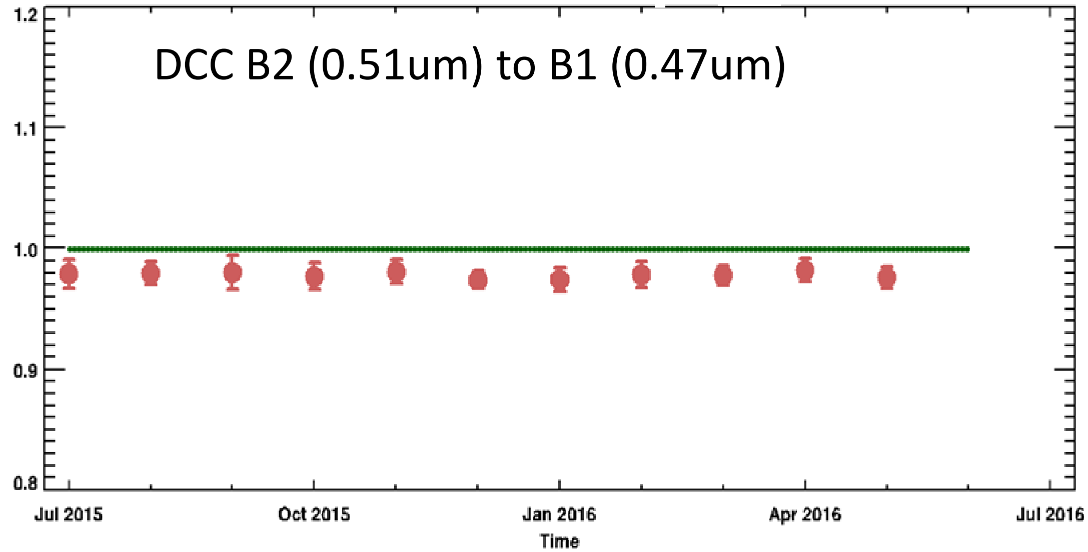
AHI DCC Band-to-Band Reflectance Ratio

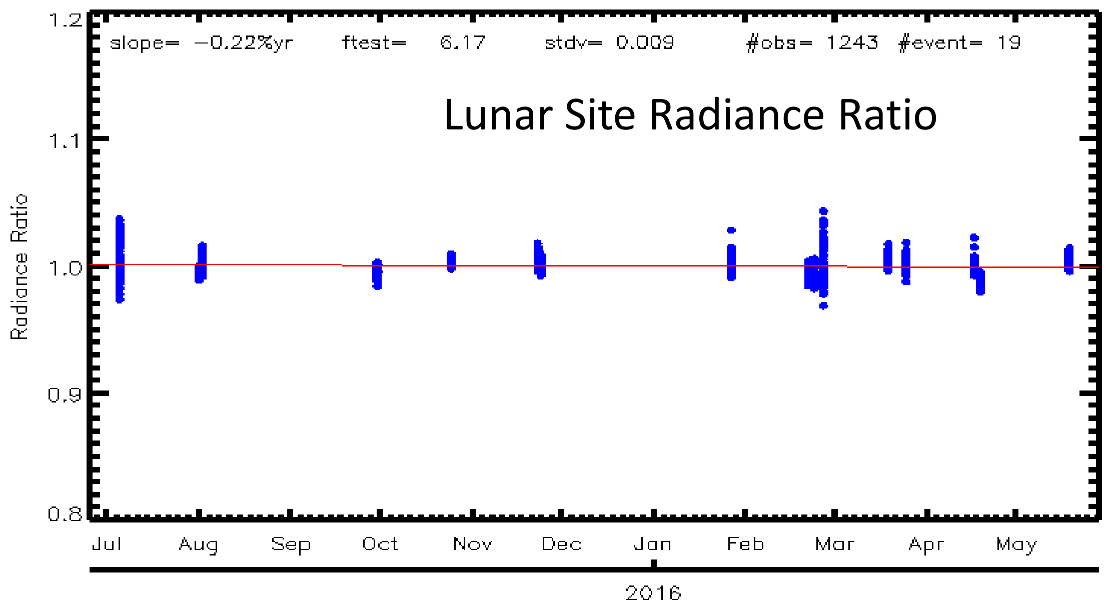




No apparent trending, yet with larger uncertainty and apparent seasonal variation

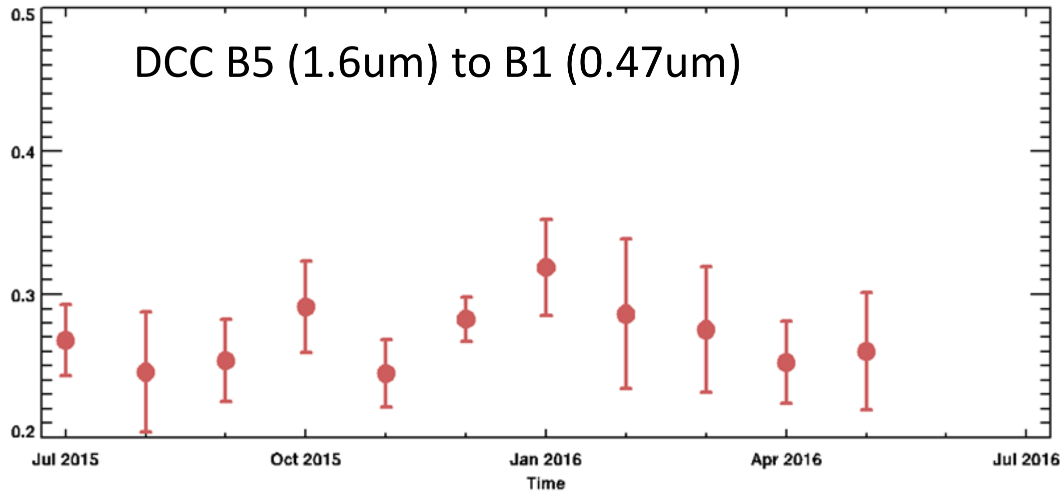
DCC Reflectance vs. Lunar Radiance B2B Ratio



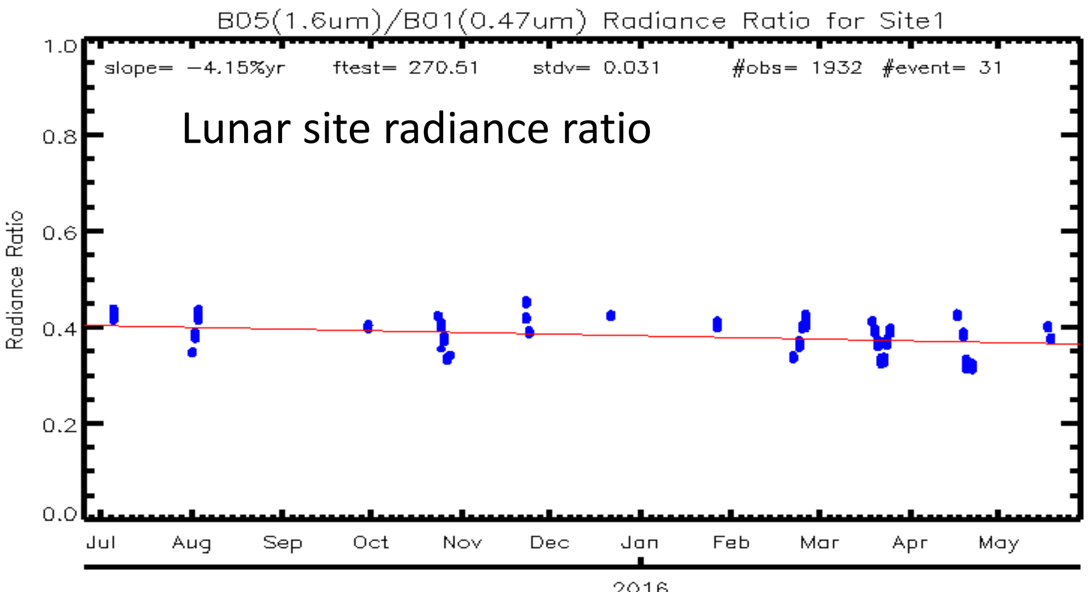


Again, B1 and B2 degrade at the similar rate

DCC Reflectance vs. Lunar Radiance B2B Ratio

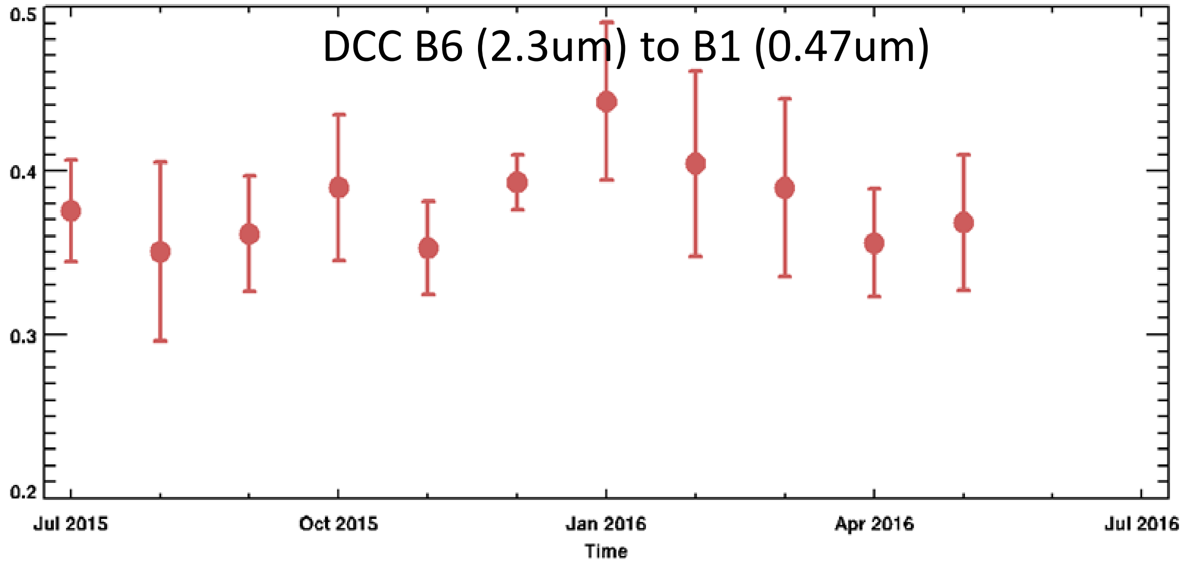


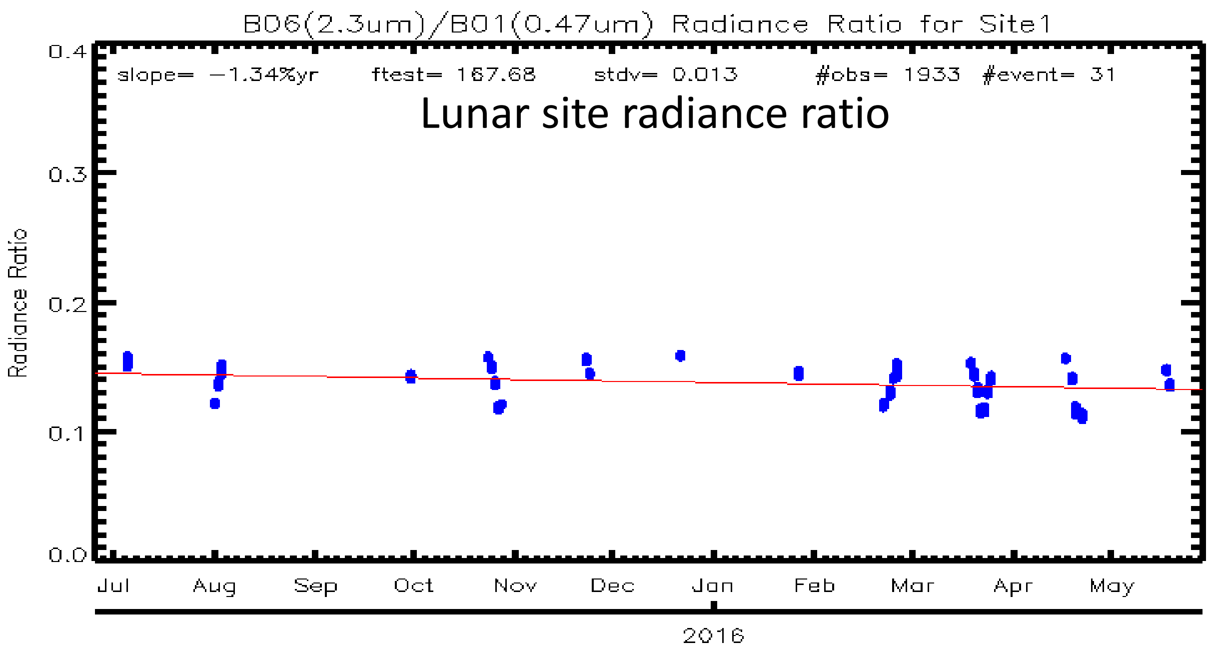
Need more (longer) Earth observation data to compensate for the seasonal variation.



- Small uncertainty within each moon tracing event
- Relatively large uncertainty between the moon tracing events
- Need to process more lunar images with improved registration algorithm

DCC Reflectance vs. Lunar Radiance B2B Ratio





Summary

- **Both the lunar and earth orbital satellite data show large uniform area at low elevation region**
- **The two moon tracing event images show encouraging early results to develop the BRDF model with H8 AHI data**
  - **1-sigma of albedo variation < 1% at both low and high albedo sites**
- **More (longer) earth observation data and more lunar images to be processed with improved registration algorithm are needed to confidently detect the AHI instrument degradation**
  - **Longer period to compensate for the seasonal variation in the Earth observation data**
  - **Improved image registration algorithm to reduce the error between the moon tracing events**
- **Accurate image-to-image registration is the key to the success of lunar radiance calibration**
  - **Increase the matched key-points across the illuminated lunar surface**
- **Effort is also ongoing for the coherent noise correction**