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Characterization of JPSS Solar Diffuser Stability Monitor Response to Sun Angle of Incidence

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Abstract

The Visible/Infrared Imaging Radiometer Suite (VIIRS) is a key sensor on the Suomi National Polar-orbiting Partnership (NPP) satellite launched on October 28, 2011 as well as the upcoming Joint Polar Satellite System (JPSS). VIIRS collects radiometric and imagery data of the Earth's atmosphere, oceans, and land surfaces in 22 spectral bands spanning the visible and infrared spectrum from 0.4 to 12.5 mm. Radiometric calibration of the reflective bands in the 0.4 to 2.5 mm wavelength range (M1 – M11, I1 – I3) range is performed by measuring the sunlight reflectance from Solar Diffuser Assembly (diffuser is Spectralon™). Spectralon™ is known to solarize due to sun UV exposure at the blue end of the spectrum (~0.4 – 0.6+ mm) as seen by laboratory tests as well as on orbit data from MODIS. VIIRS uses a SDSM (Solar Diffuser Stability Monitor) to monitor the change in the Solar Diffuser reflectance in the 0.4 – 0.94 mm wavelength range and provide a correction to the calibration constants. The SDSM measures the ratio of sun light reflecting from the Solar Diffuser to a direct view of the sun. The intensity of the light reaching the SDSM in both Solar Diffuser view and sun view is a function of the sun's angle of incidence. The error in the Solar Diffuser to sun view in the SDSM ratio due to response due to sun angle of incidence translates into an error in the Solar Diffuser reflectance correction. Thus the SDSM response variation with sun angle of incidence has to be characterized.

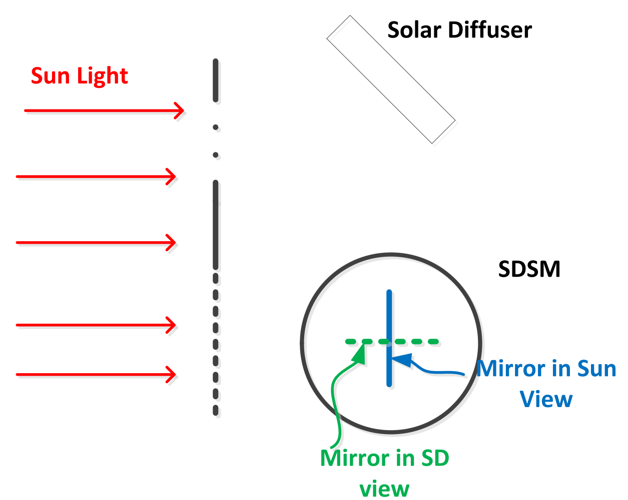
The sun angle of incidence of variation for the Solar Diffuser view is measured by measuring the BRDF of the Solar Diffuser as a function of angle of incidence. This paper presents the test equipment developed and the results for the complete SDSM relative response to sun angle of incidence in sun view for Flight J1 for JPSS. The relative response to the sun angle of incidence was performed with an uncertainty better than 0.5%. The test required developing a source to simulate the sun including parameters such as a 0.5° extended collimated source with sufficient intensity for adequate signal to noise on the SDSM detectors. The source also needed to have adequate stability to characterize the angular response with acceptable repeatability. Details of the equipment as well as typical results for Flight J1 for JPSS will be presented.

Outline

- Solar Diffuser Stability Monitor (SDSM) purpose
- SDSM Response to Sun Angle of Incidence Requirements
- Test Equipment Description
- Measurement Results
  - Comparison with Suomi NPP on orbit SDSM

VIIRS Reflective Band Calibration: Use of Solar Diffuser Stability Monitor (SDSM)

- Sunlight reflected from a **S**olar **D**iffuser (Spectralon®) is used to provide the VIIRS Sensor a known radiance source for radiometric calibration of the reflective bands (400 – 2300 nm)
- Spectralon® reflectance is known to degrade on exposure to UV due to the presence of contaminants
- Solar Diffuser Stability Monitor (SDSM) monitors the Spectralon® solarization by
  - Using a 3 position fold mirror to sequentially view a dark scene, direct sunlight, and illumination from SDA
  - Direct sunlight is attenuated to keep radiance within dynamic range of SDSM's detector/amplifier combination
  - Change in ratio of Solar Diffuser reflectance to direct sun view is a measure of SDA degradation
- Ratio of SD view to sun view needs to be known within 0.65%
- Ratio needs to be corrected for variation due to sun angle of incidence on SDSM



Spectralon® on orbit reflectance degradation: Aqua MODIS, Terra MODIS, and NPP VIIRS

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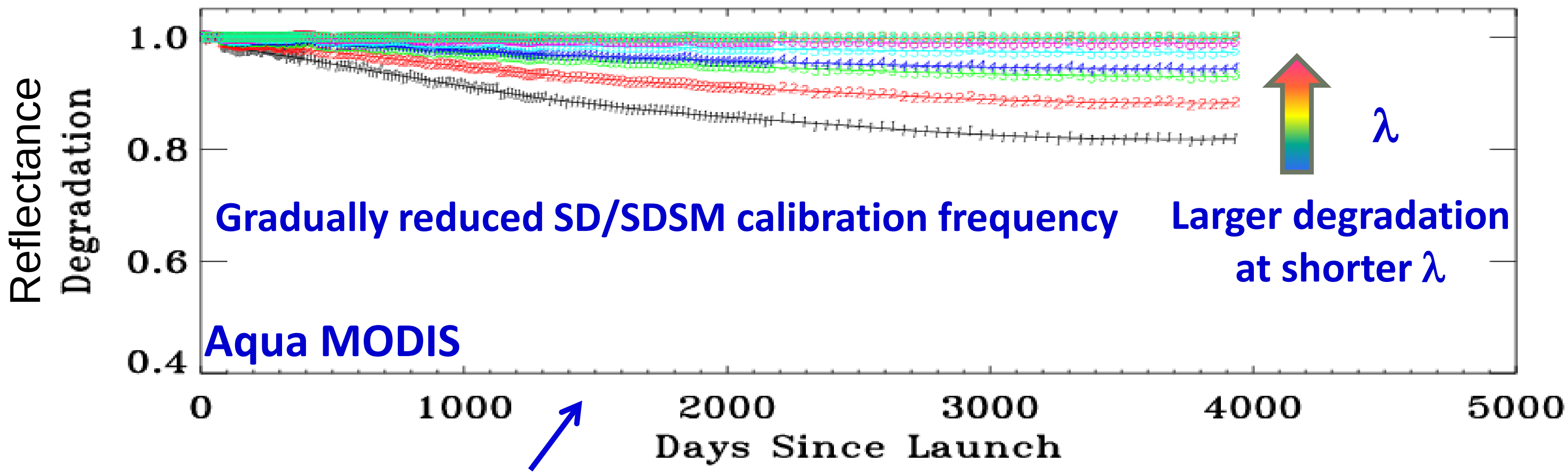
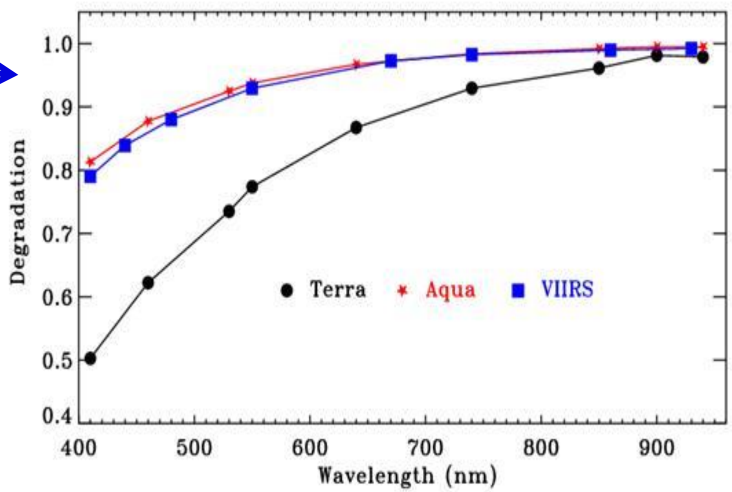


Figures courtesy of Jack Xiong (NASA/GSFC)

- Aqua MODIS data shows time dependent change in reflectance for detectors 1 – 9 wavelengths 400 – 950 nm wavelength region normalized to time zero
- Degradation is maximum at the blue end with virtually no degradation at the red end of the wavelength range for Aqua, Terra, and VIIRS (figure on right)



On Orbit Spectralon® shows spectrally dependent reflectance degradation

SDSM Description and Requirements

- Solar Diffuser Stability Monitor (SDSM) is a ratio instrument that measures the reflectance of the SD relative to a 'constant' source: sun
- As SD solarizes, reflectance drops at the blue end of the spectrum with minimal changes at ~900 nm
- SDSM takes the ratio of the SD reflectance to signal from the sun: as signal from sun nominally constant, ratio is a correction factor for the calibration constants used for VIIRS
  - Use of ratio technique minimizes accuracy and stability requirements for SDSM
- Ratio depends on terms specific to the SD signal and terms specific to the sun view through the aperture array
- Knowledge of ratio needed is better than 0.65% for all SDSM specific contributions to the ratio
- Presentation is characterization of SDSM response change with sun angle of incidence

$$\frac{P_{SD\ View}}{P_{Sun\ View}} = \frac{\cos\varphi_{\mathrm{sd\_sun}} \times \mathrm{T}_{\mathrm{SD\_SAS}} \times \mathrm{BRDF}_{\mathrm{SD}} \times \Omega_{\mathrm{SD\_SDSM}}}{\cos\theta \times \mathrm{T}_{\mathrm{SDSM\_AA}}}$$

SDSM has tight knowledge response requirement

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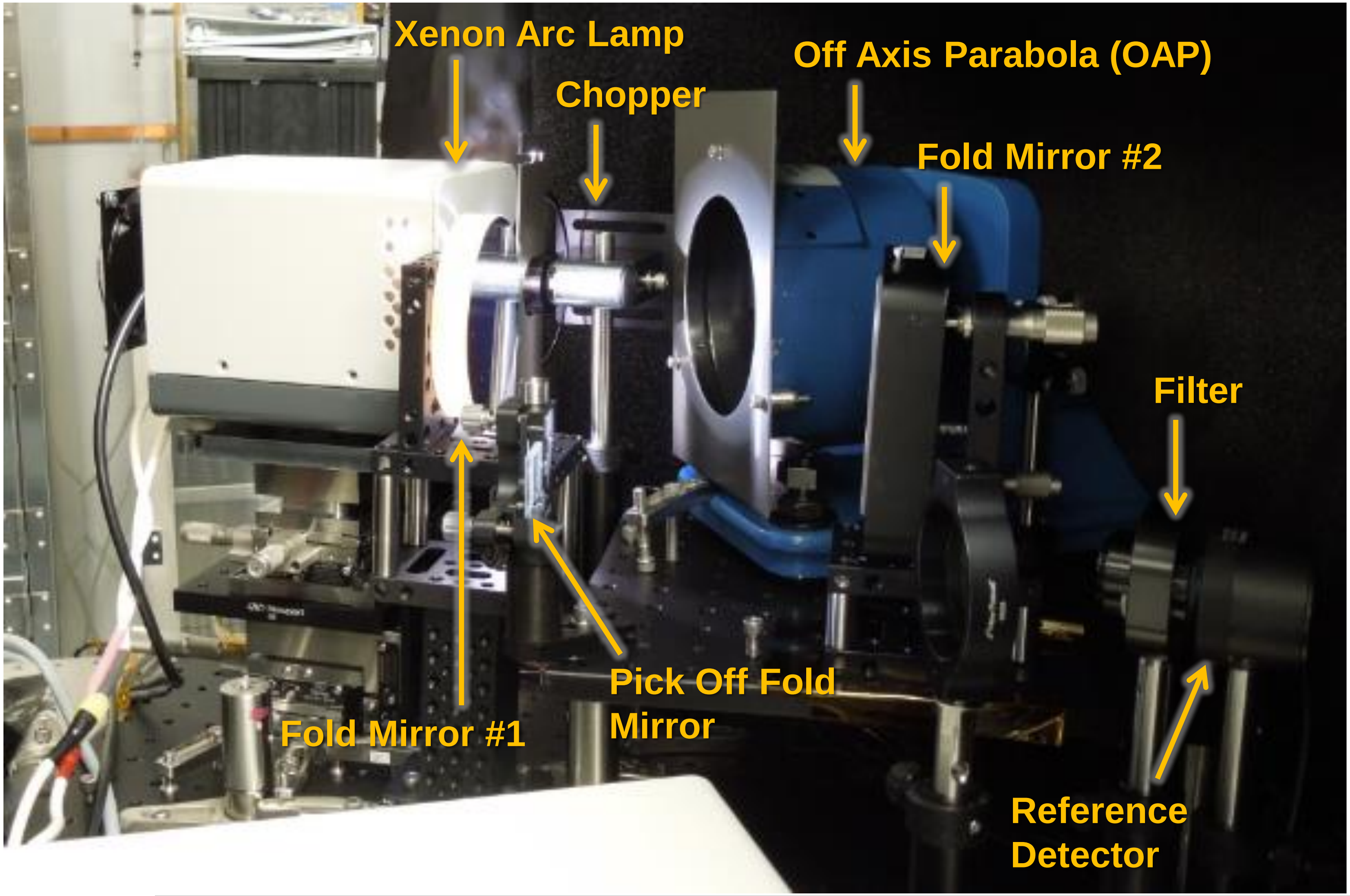
Test Characterization Requirements

- Sun is an extended (0.5°) collimated source with ~5600K black body spectral distribution so that source assembly must be
  - Collimated for all SDSM wavelengths (400 – 950 nm)
  - “Extended”: not a point source
  - Adequate power density over the entire spectral range 400 – 950 nm to have adequate signal to noise for all bands simultaneously
  - Uniform power density over illuminated region reaching the detectors
- SDSM needs to be rotated in both ‘azimuth’ and ‘elevation’ over range of use angles
  - Pivot point selection for azimuth and elevation rotation defines size of beam where power uniformity is needed
- Angle of incidence range is -15° to +2° in azimuth and -4° to +2° in elevation
  - Need to measure at enough angle pairs to characterize response variation

Need to simulate sun and move SDSM relative to source

Sun simulation light source assembly



Collimated extended source assembly with Xe lamp

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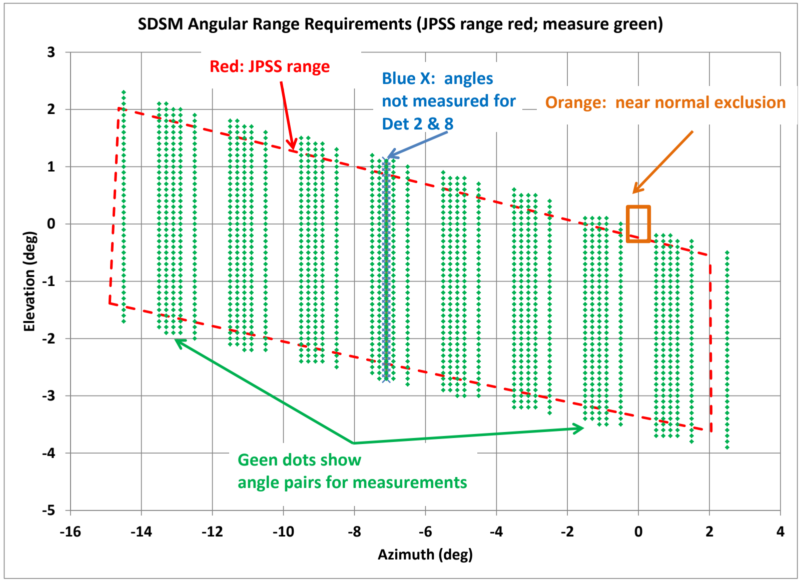
Sun Angle of incidence Range Measured

- Requirement is to construct response characterization over sun angles of incidence
  - a. Declination: 15.0 to 18.5 degrees, where 'declination' is defined as the angle between the projection of the Solar-view vector on the X-Z plane and the X-axis. The angle is positive towards the Z-axis.
  - b. Azimuth: 13.6 to 31.1 degrees, where 'azimuth' is defined as the angle between the projection of the Solar-view vector on X-Y plane and the X-axis. The angle is positive towards the negative Y-axis.

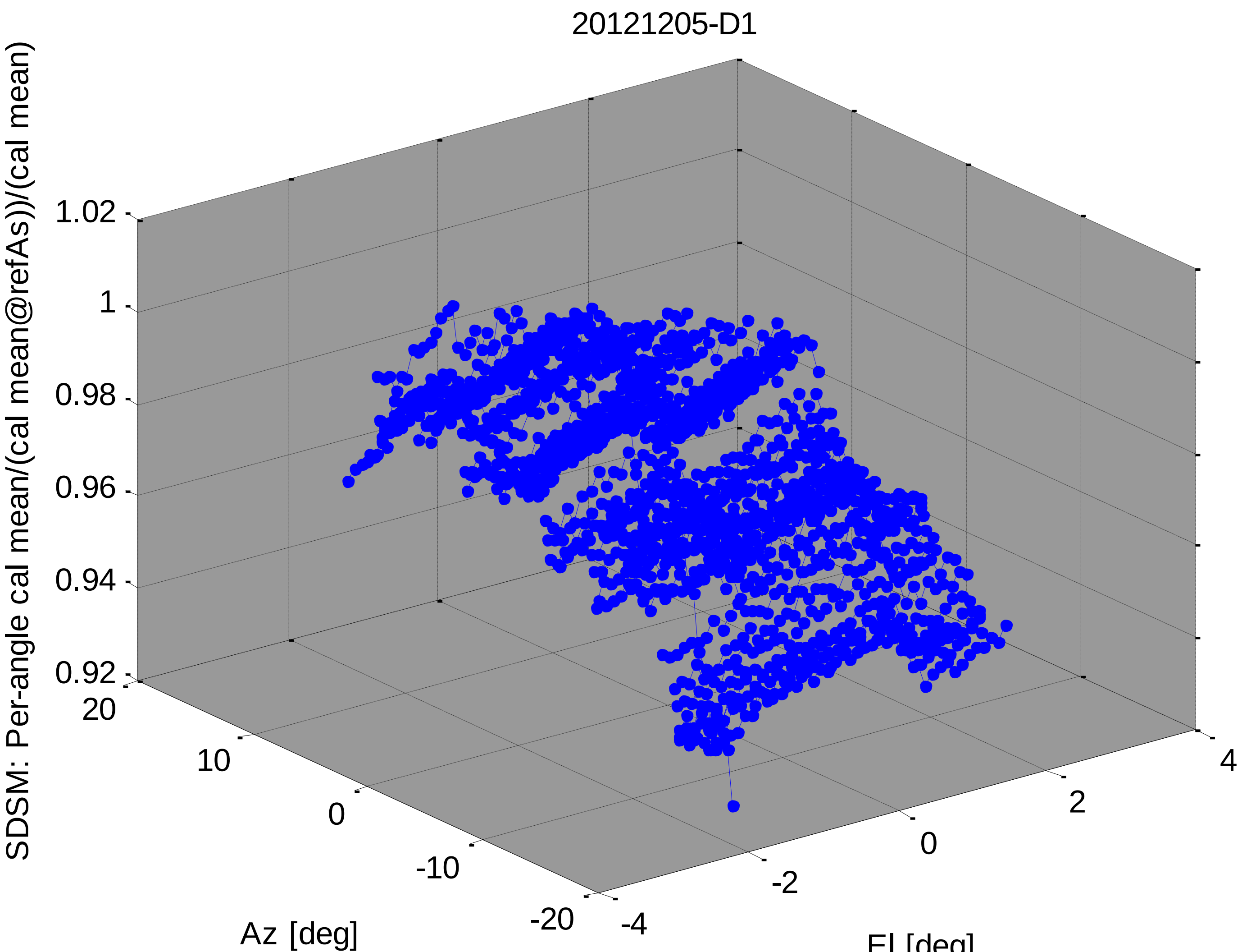
    Characterization region outline shown in red



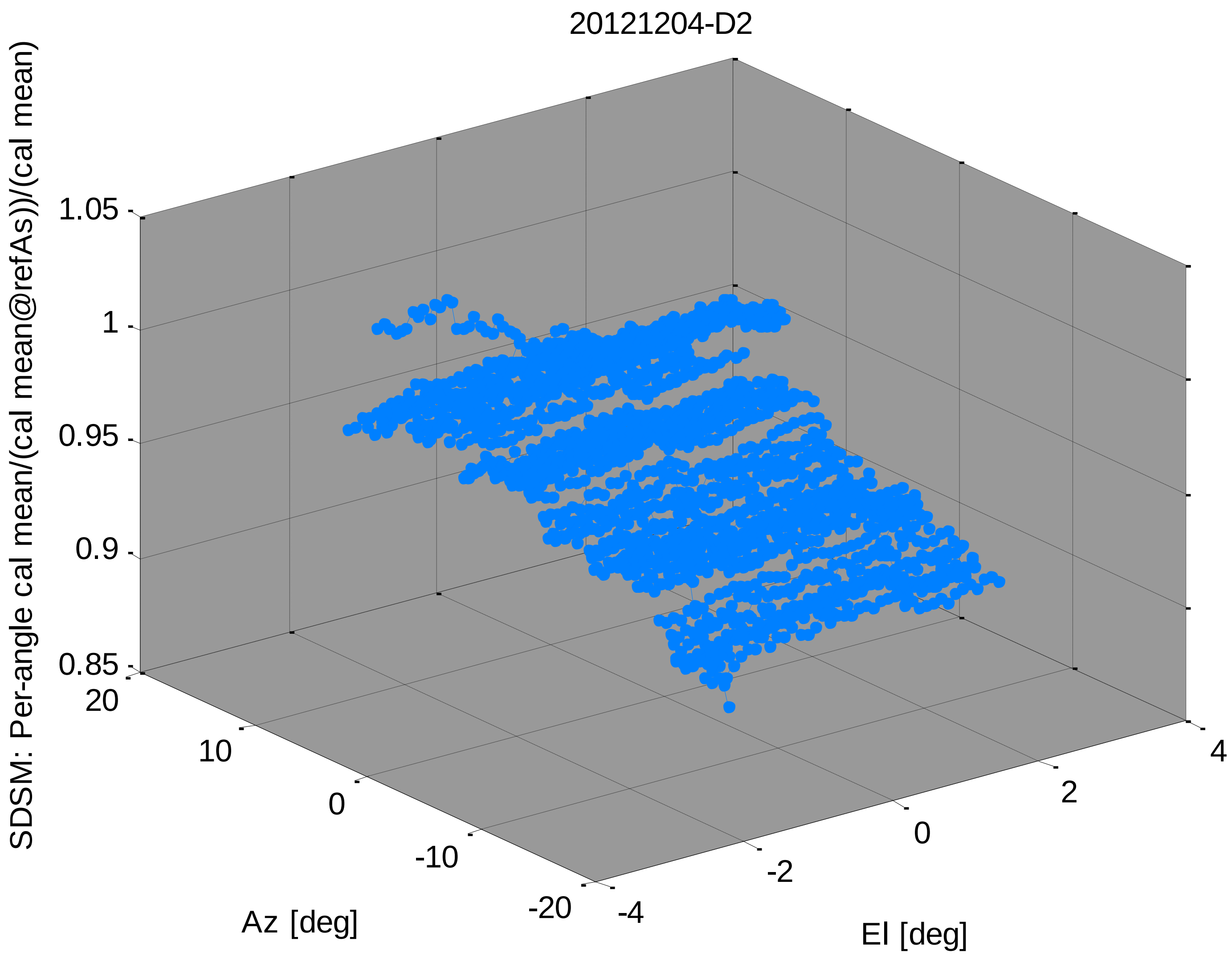
- Data was taken over the specified regions of red outline at the green dots location
- Sampling density was selectively done with higher density over angular regions where throughput is changing

Sufficient Sampling of Response Surface to Interpolate

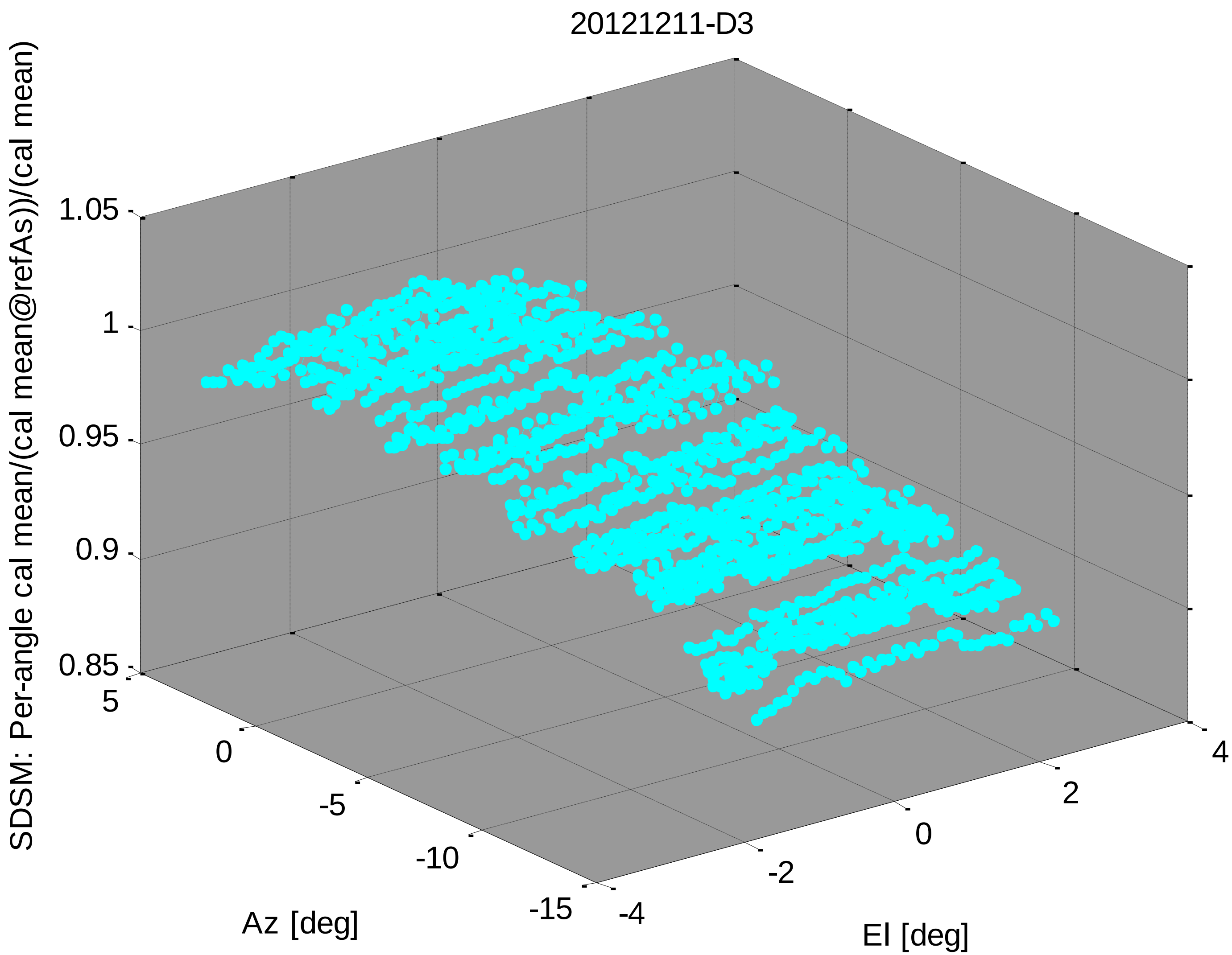
Band 1 (412 nm) Angle Dependent Response



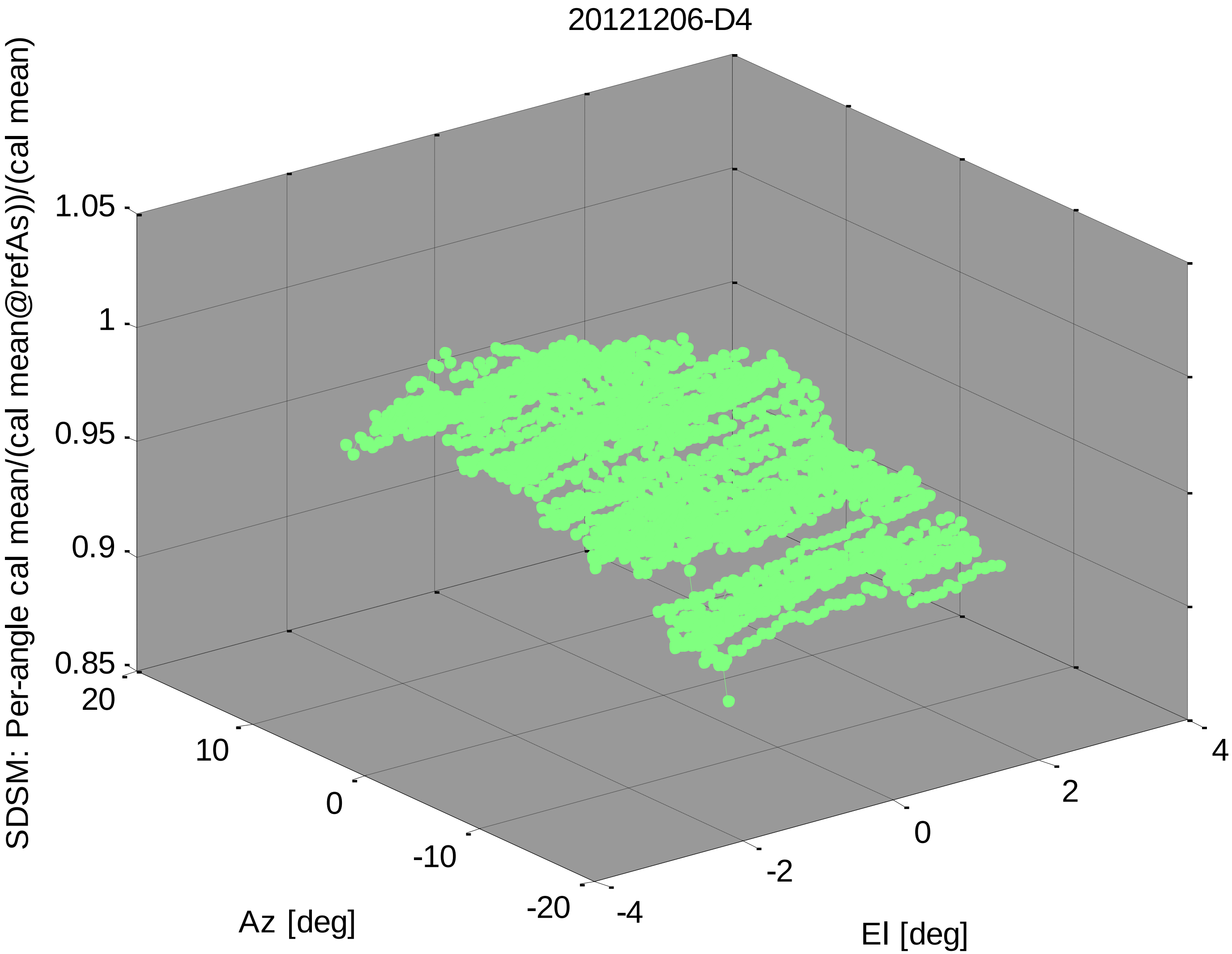
Band 2 (448 nm) Angle Dependent Response



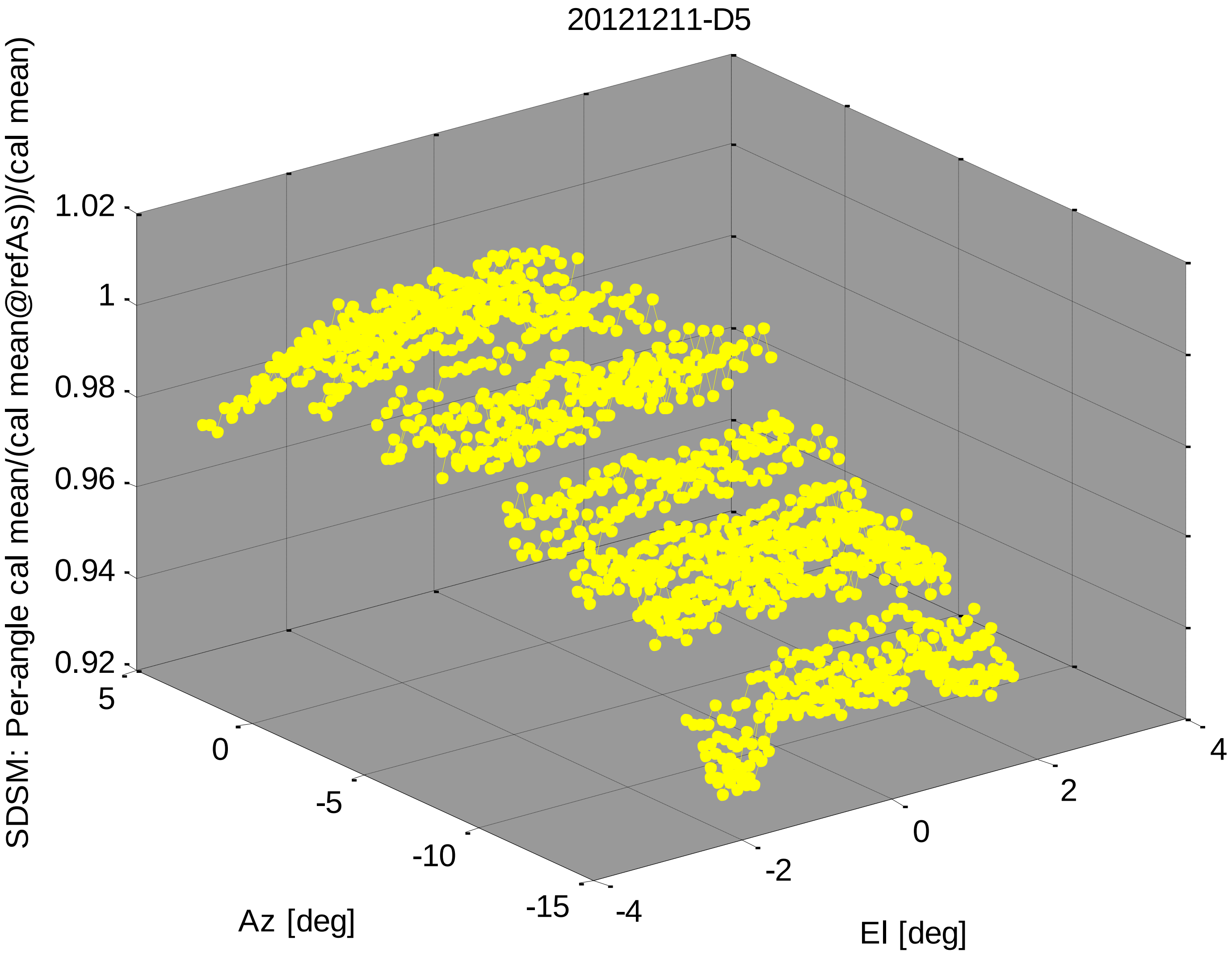
Band 3 (490 nm) Angle Dependent Response



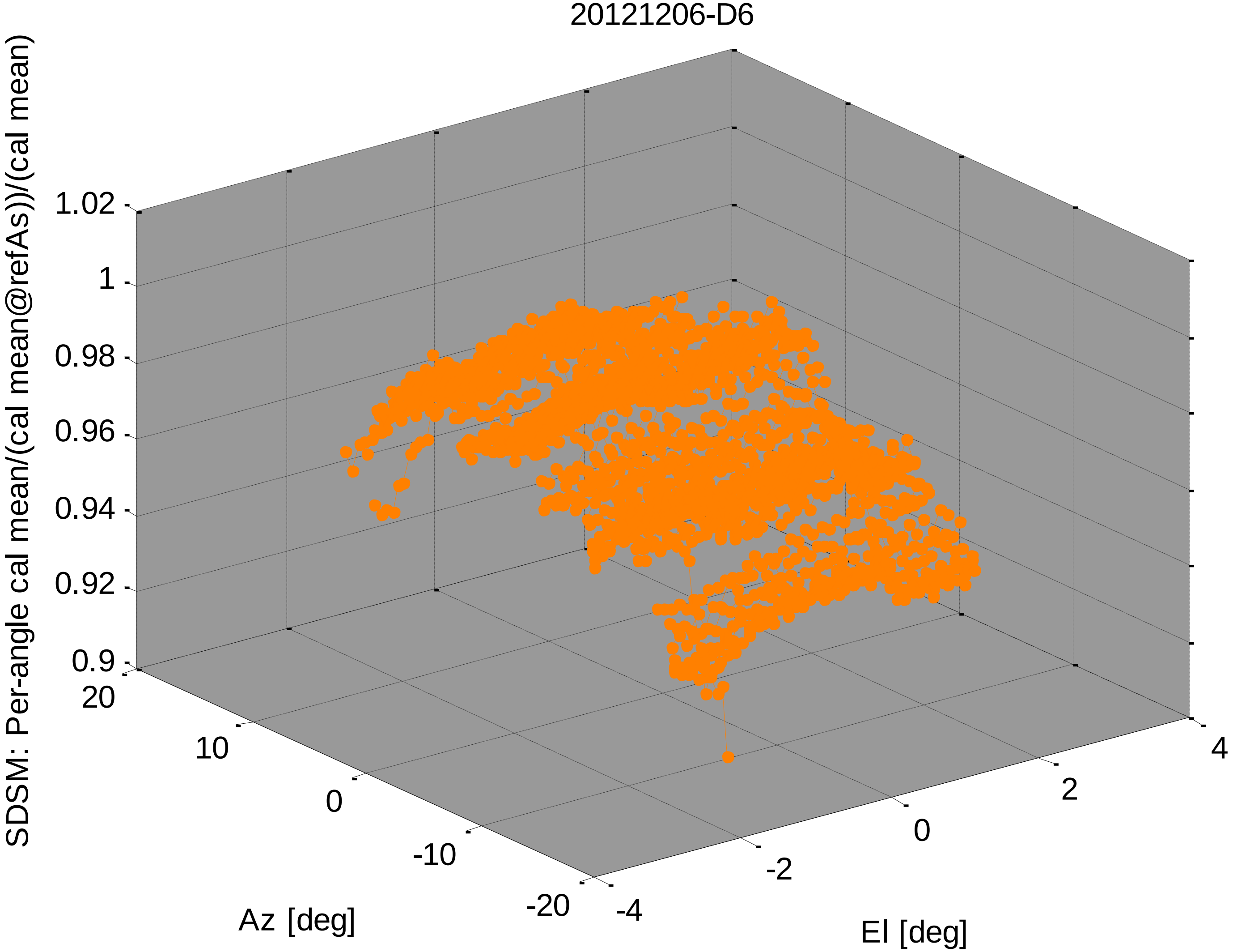
Band 4 (550 nm) Angle Dependent Response



Band 5 (674 nm) Angle Dependent Response



Band 6 (745 nm) Angle Dependent Response



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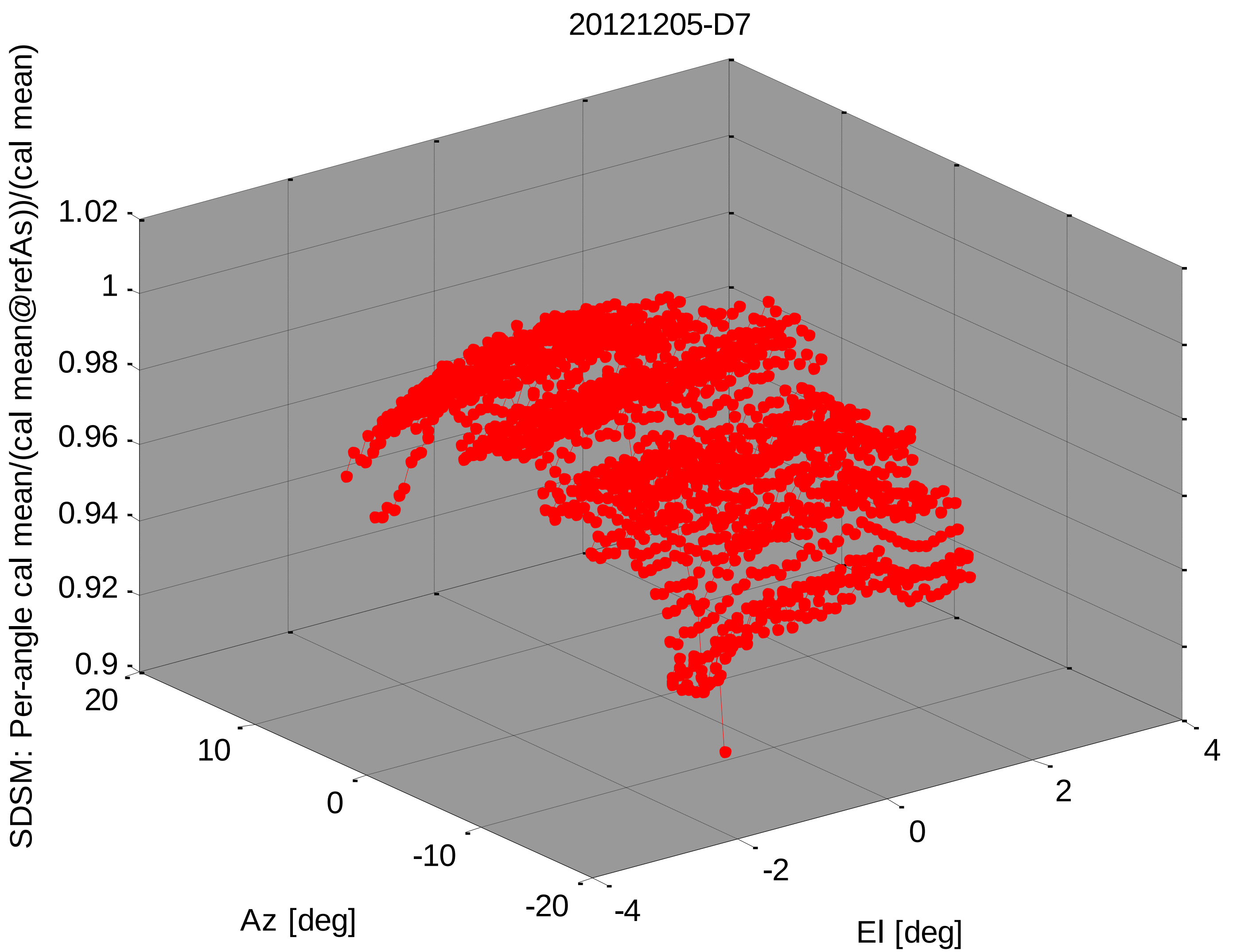
Band 7 (868 nm) Angle Dependent Response



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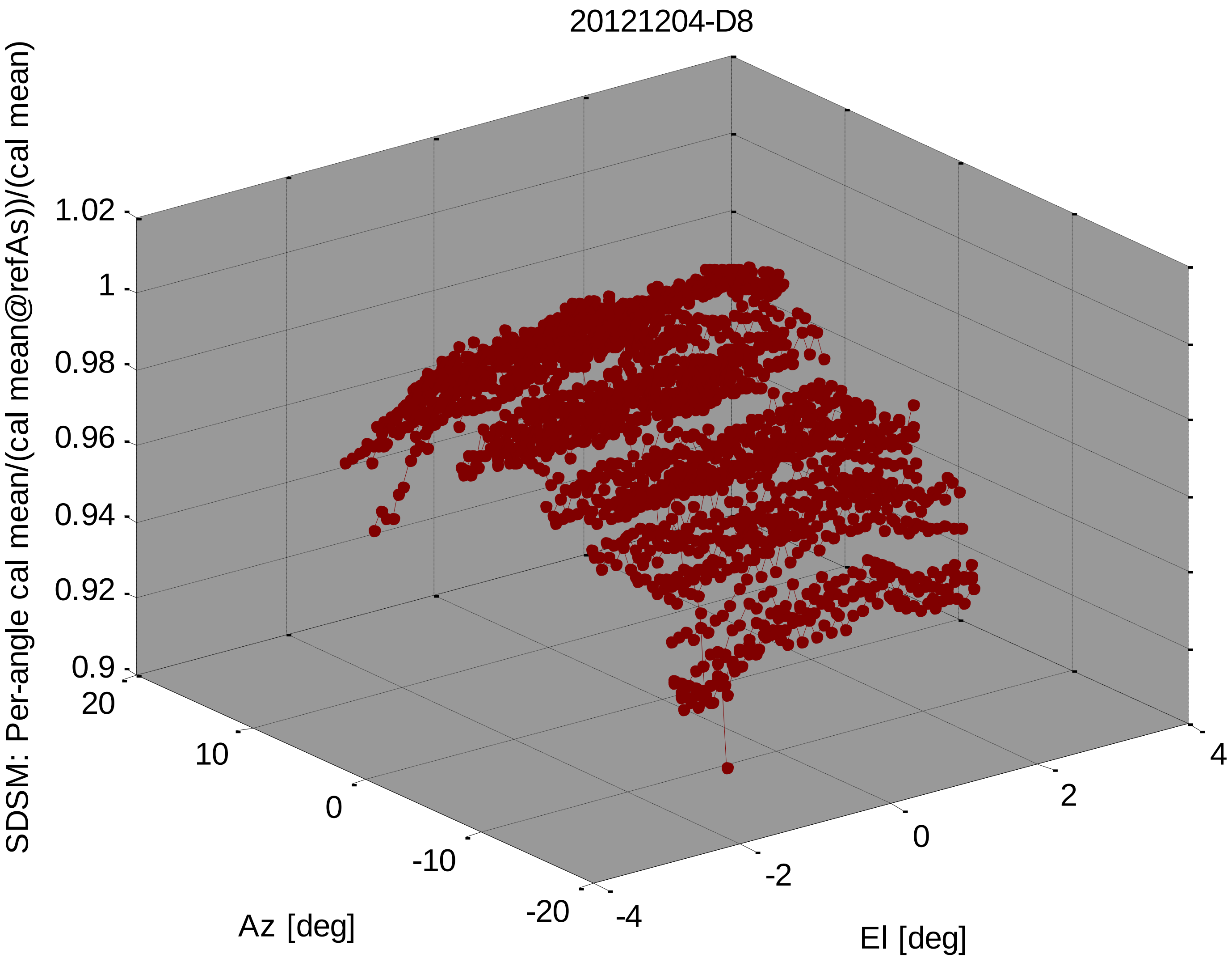
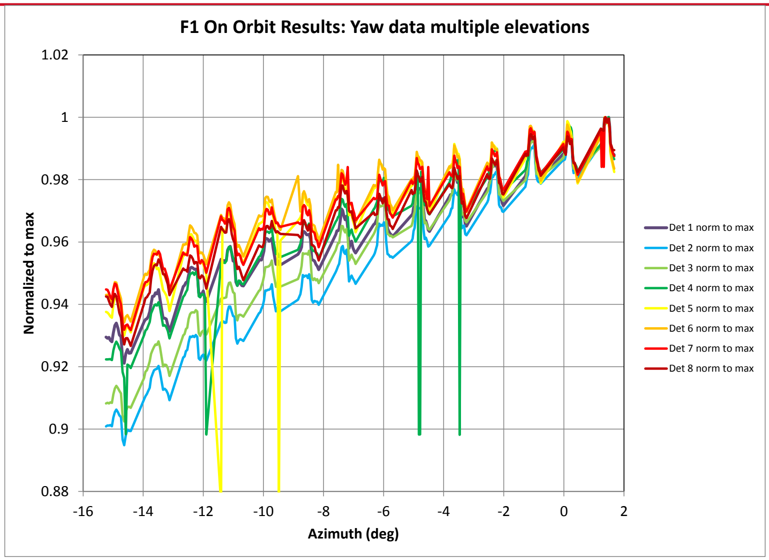
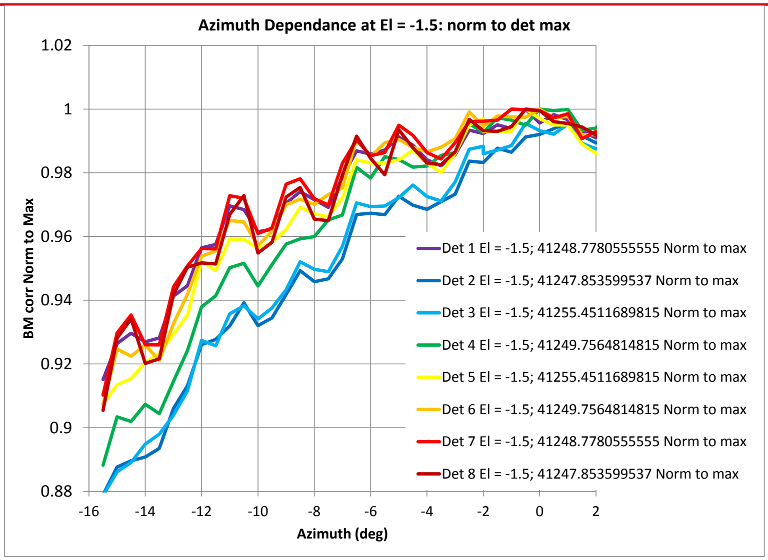
Band 8 (921 nm) Angle Dependent Response



Suomi NPP F1 On Orbit Comparison with J1 Measurements





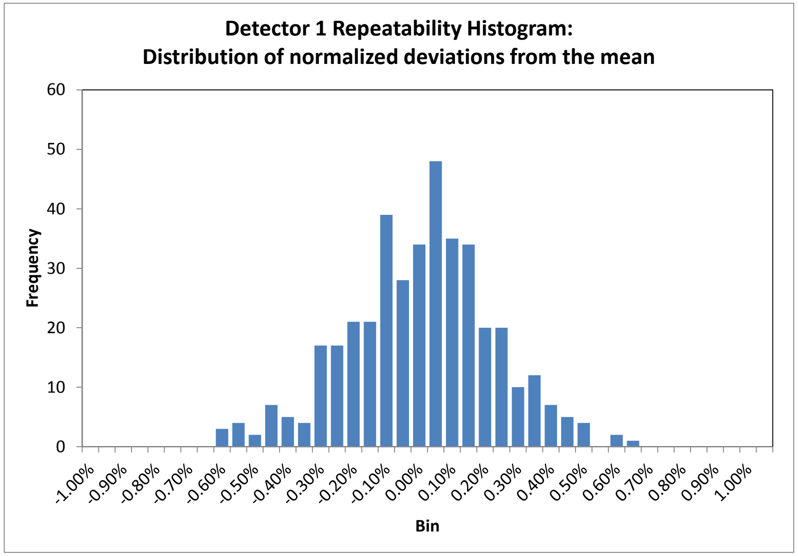
NPP on orbit data courtesy Jeff McIntire, Sigma Space Co.

- **Left figure: NPP SDSM solar azimuth dependence from yaw maneuvers**
- **Right figure: J1 SDSM laboratory measurements varying azimuth fixed elevation = -1.5**
- **Both figures show the same overall angular dependence with similar periodic features**
- **Both figures show a similar spectral dependence of SDSM response to ‘sun’ view**
- **Laboratory testing with sun simulator (for J1) is similar to on orbit measurements (NPP) where the SDSM response to the sun is viewed**
  - **Exact match not expected due to manufacturing variations**

Lab test of SDSM simulates on orbit performance

Measurement Repeatability

- Repeatability assessed for a given detector by calculating deviation from the mean at each angle setting for repeat scans over different days and with different bulbs
- Figure on right shows histogram of deviations for Detector 1 (similar performance for other detectors)
- Combining statistics for all scans, variation of deviation ranges from 0.21% to 0.29%
- Overall error includes other terms and discussed in companion Calcon presentation “JPSS VIIRS reflective band radiometric calibration uncertainty updates” by E. Kim et. al.



Detector	1	2	3	4	5	6	7	8
# scans	10	12	10	18	10	18	10	12
Repeatability	0.22%	0.24%	0.25%	0.21%	0.26%	0.23%	0.23%	0.29%

Measurement repeatability is <0.30%

Summary

- SDSM is used to measure the changing reflectance of the Solar Diffuser at the blue end of the spectrum due to solarization
- Test equipment including a sun simulator including collimation with reflective components, extended source, similar spectral power density, and power uniformity over beam was developed to measure the SDSM response to the sun in 'as use' configuration for ALL detectors
- Measurement scheme was developed to obtain repeatable measurements with an overall knowledge error <0.4% consistent with overall ratio knowledge requirement of 0.65%
- Measured results are comparable to on-orbit results observed on NPP

SDSM response to sun characterized to better than 0.4%