Enhancing Inter-sensor SI Traceability and Image Data Exploitation with Specular Array Calibration (SPARC)

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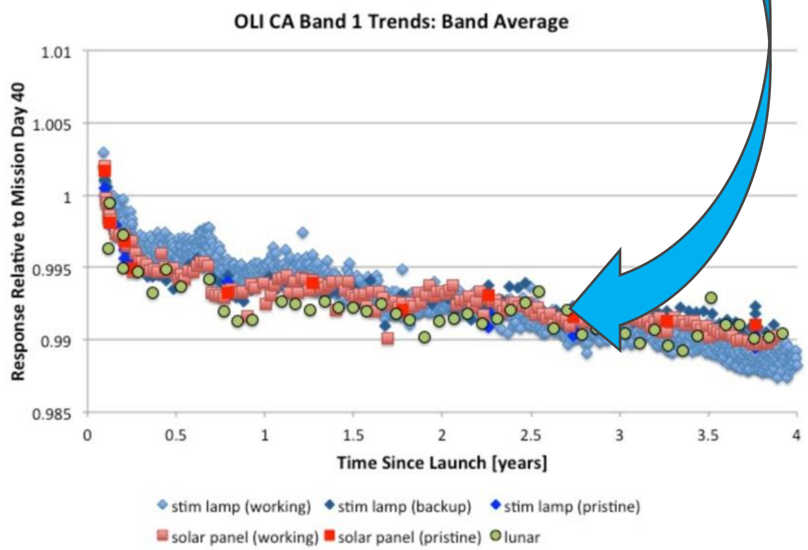
Overview

- Vicarious Specular Array Calibration (SPARC) targets provide a way for a sensor in-flight to record the direct solar irradiance as an absolute intensity reference imbedded within an operational earth scene collect
- The SPARC targets have a nearly constant BRDF without off-nadir foreshortening simplifying response characterization
- The sensor under calibration responds in the same way as a solar radiometer where the only atmospheric parameter that needs to be characterized is transmittance
- Thus the satellite can be calibrated to determine a spectral zero airmass response constant (ZARC) that can be used to track the radiometric stability of and between sensors systems on the same radiometric scale
- The implementation of the SPARC method in Labsphere’s FLARE network makes this capability readily available to evaluate repeatability and reproducibility within a virtual constellation important to creating interoperable data sets

Potential new trend line using FLARE

Response Trending Landsat 8



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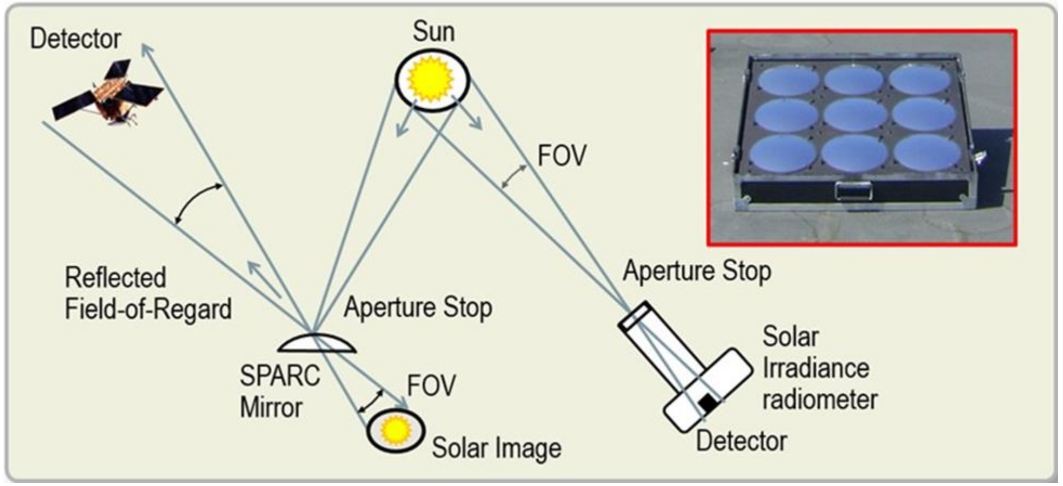
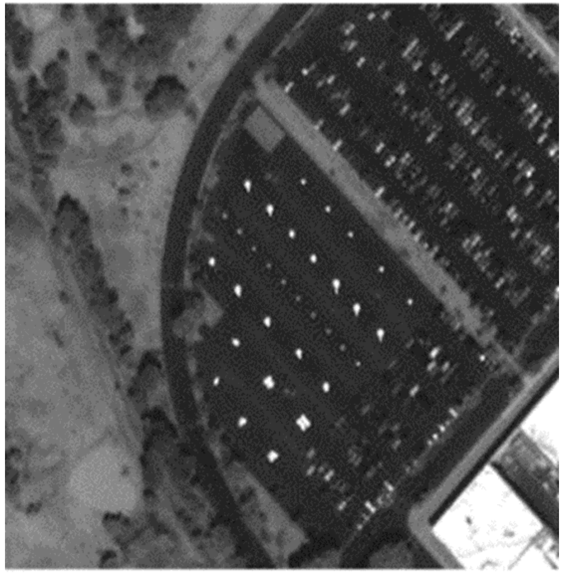
Conceptualizing The SPARC Vicarious Method

- The Specular Array Calibration (SPARC) method allows any earth observing sensor to be calibrated to the solar spectral constant just like a solar radiometer.
- The mirror acts as a Field-of-View (FOV) aperture stop allowing the sun to be imaged directly as an absolute reference.





- The curvature of the spherical mirror scales down the brightness of the sun to an intensity that does not saturate the sensor focal plane.
- Number of mirrors controls dynamic range response

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Are Natural Lambertian-like References the Best Way to Go?

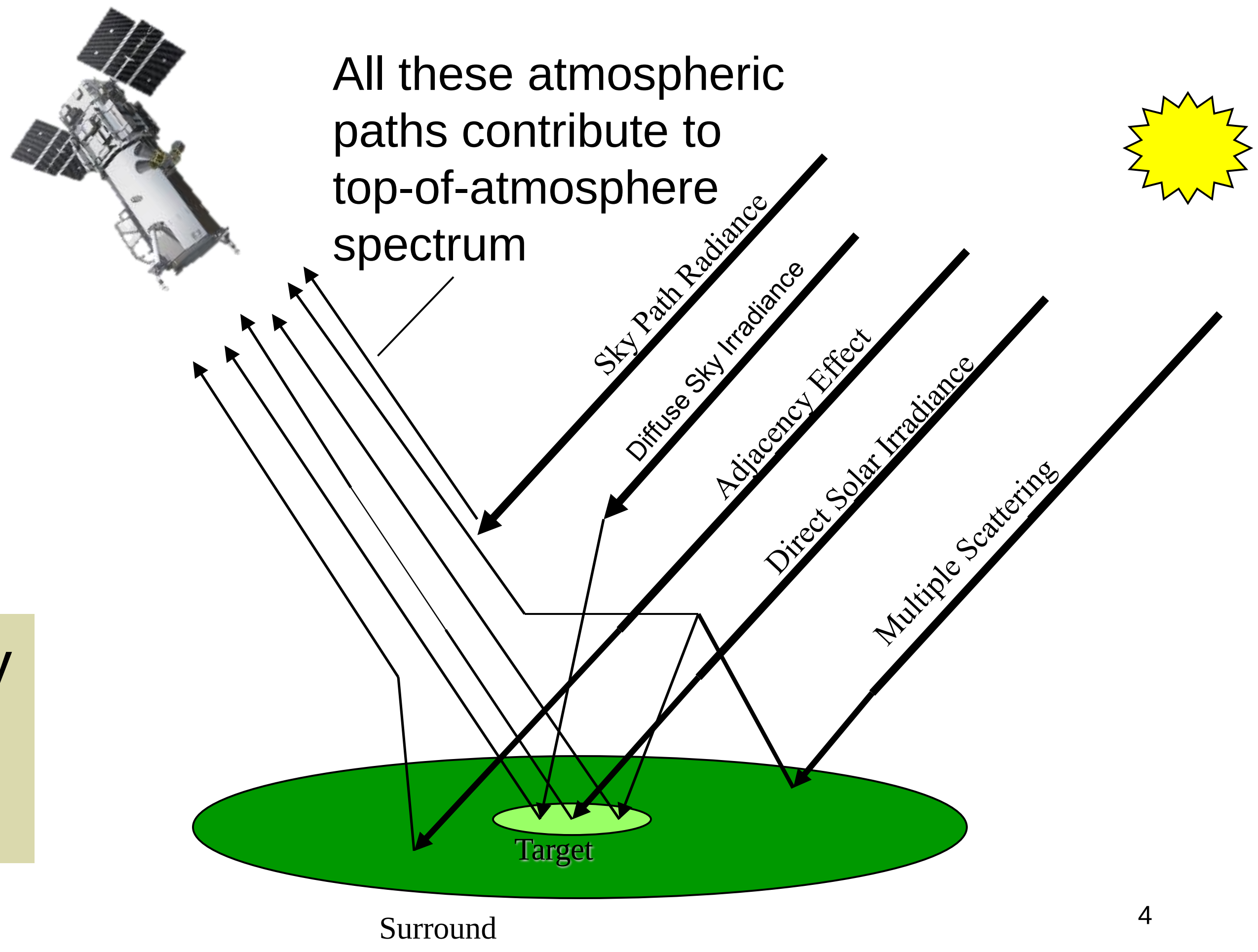
The upwelling calibration signal by Lambertian-like surfaces are influenced by all sources within the illumination hemisphere of the target including the surround

All must be measured or modeled to predict the at-sensor radiance for calibration

Each adds an error source to the at-sensor radiance

Is there an alternative approach that potentially reduces these errors?

Specular reflectance creates an intensity source for calibration that can be designed to greatly reduce these effects



Specular Array Calibration (SPARC) Method Significantly Reduces Atmospheric Effects on At-Sensor Calibration Radiance

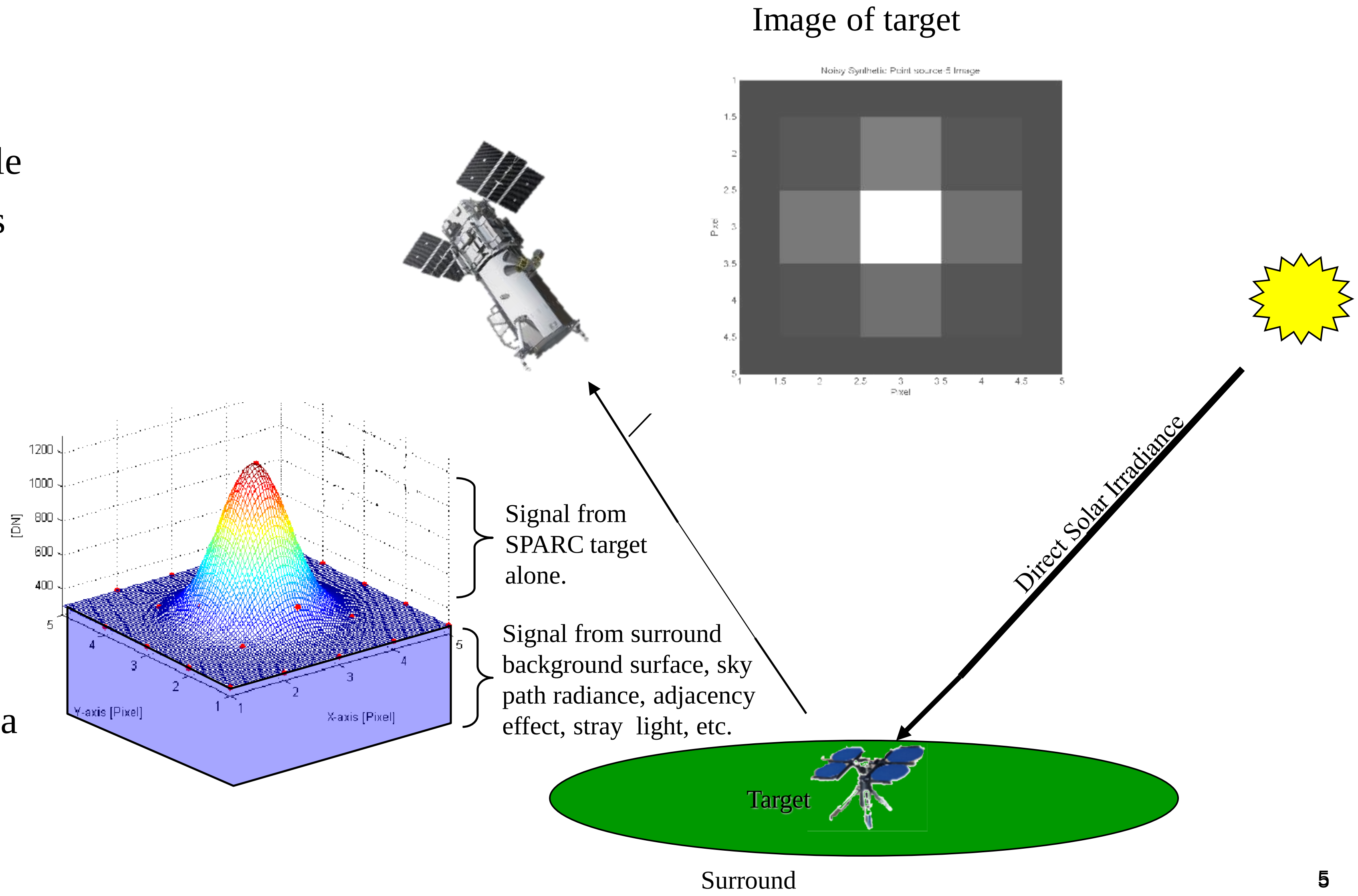
Target signal embedded in a uniform area is elevated above the low spatial frequency background and is separable

Background and atmosphere becomes a bias and is subtracted out based on image data alone

Sensor response to target is the integrated Digital Number (DN) contained in the point response function (PRF)

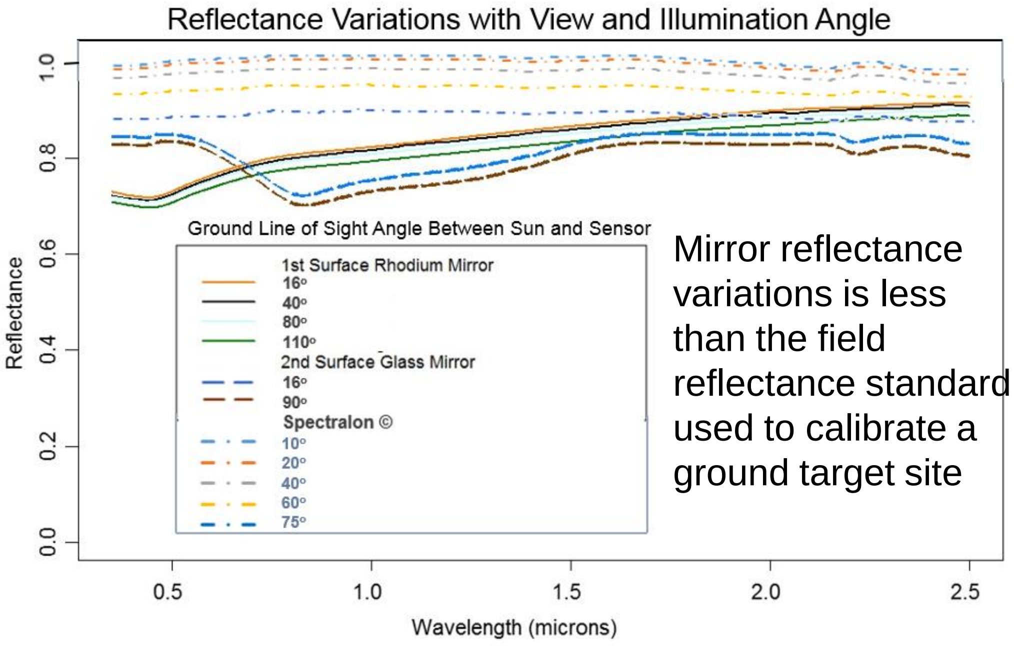
Atmospheric effects reduce to transmittance only

Another bonus is that sensor specific stray light effects also subtract out as a bias



SPARC Validation of Surface Reflectance Products

- Specular targets provide reflectance uncertainty knowledge in the field <0.5% (~0.2% in the Lab)
- Almost negligible BRDF effects with spherical mirrors (small but accurately known variation with angle of incidence, θ_i^m)



Mirror reflectance variations is less than the field reflectance standard used to calibrate a ground target site

- No foreshortening effects on calibration signal with off-nadir image geometry
- Broadband mirror reflectance is spectrally flat, comparable to Lambertian tarps and panels
- Identical SPARC targets can be reproduced at multiple sites

A SPARC target in a scene provides a nearly constant upwelling intensity and BRDF in-scene reflectance reference

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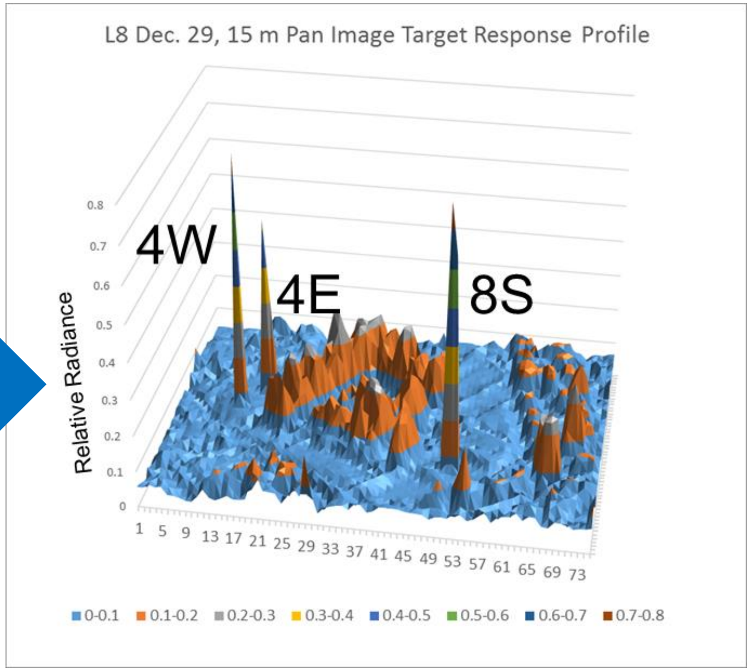
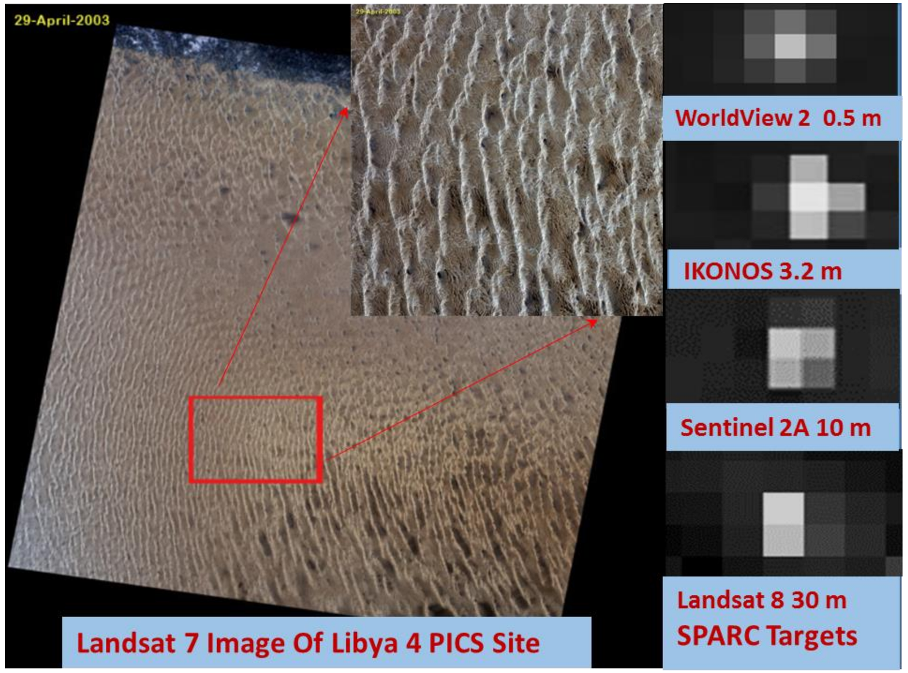
SPARC provides a Reference Target that has the Same Spatial Appearance Independent of the Sensor GSD

Landsat 8 Pan image of SPARC targets

SPARC target images are spatially consistent





- The desire is to apply a consistent calibration methodology to each constellation member
- The calibration reference area of interest for PICS sites are difficult to standardize for varying GSD
- SPARC targets area of response integration is defined consistently by the sensor’s PRF, independent of the GSD

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SPARC Radiative Transfer Equations Predicting At-sensor Intensity and Radiance

TOA Intensity (Sensor Independent)

$$I(\lambda,\theta_r)_{TOA} = \tfrac{1}{4}\rho(\lambda,\theta_r)\tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)E_o(\lambda)R^2$$

Watts/(sr micron)/mirror

At-Sensor Radiance/Mirror (sensor and collection geometry specific)

$$L_{at-sensor}(\lambda,\theta_r) = \rho(\lambda,\theta_r)\tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)E_o(\lambda)\frac{R^2}{4GSD(x)GSD(y)}$$

Watts/(m^2 sr micron)/mirror

$\rho(\lambda,\theta_r)$ = Mirror specular reflectance at the reflectance angle θ_r

$\tau_{\downarrow}(\lambda)$ = Sun to ground transmittance

$\tau_{\uparrow}(\lambda)$ = Ground to sensor transmittance

$E_o(\lambda)$ = Solar spectral constant
R = Mirror radius of curvature (m)
GSD = Line-of-site ground sample distance (m), cross-scan and along-scan

Because SPARC targets are intensity sources, the apparent at-sensor radiance depends on sensor line-of-sight Ground Sample Distance (GSD).

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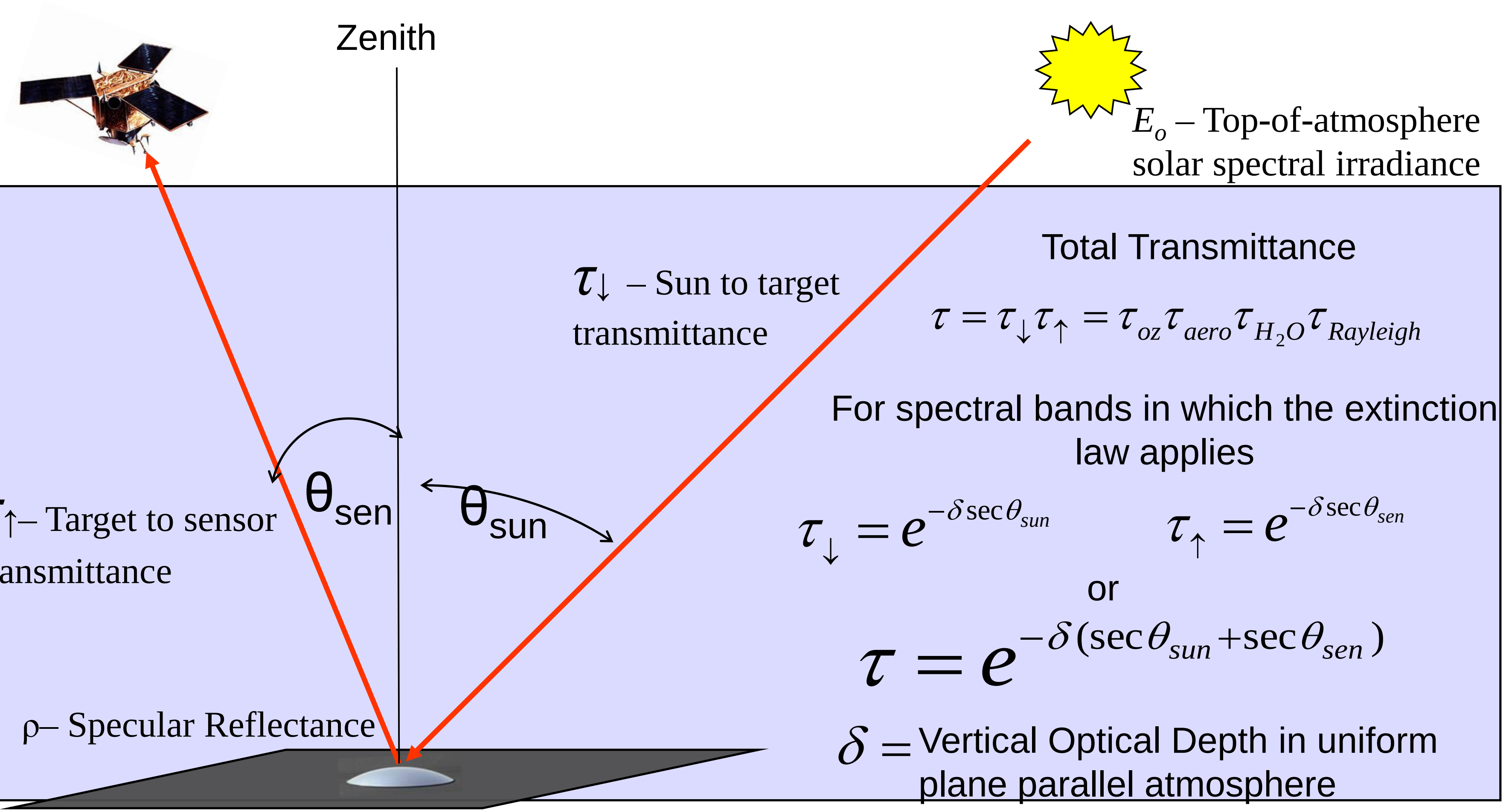
Transmittance Is The Only Atmospheric Component Affecting The Sensor Response To The Reflected Direct Solar Signal

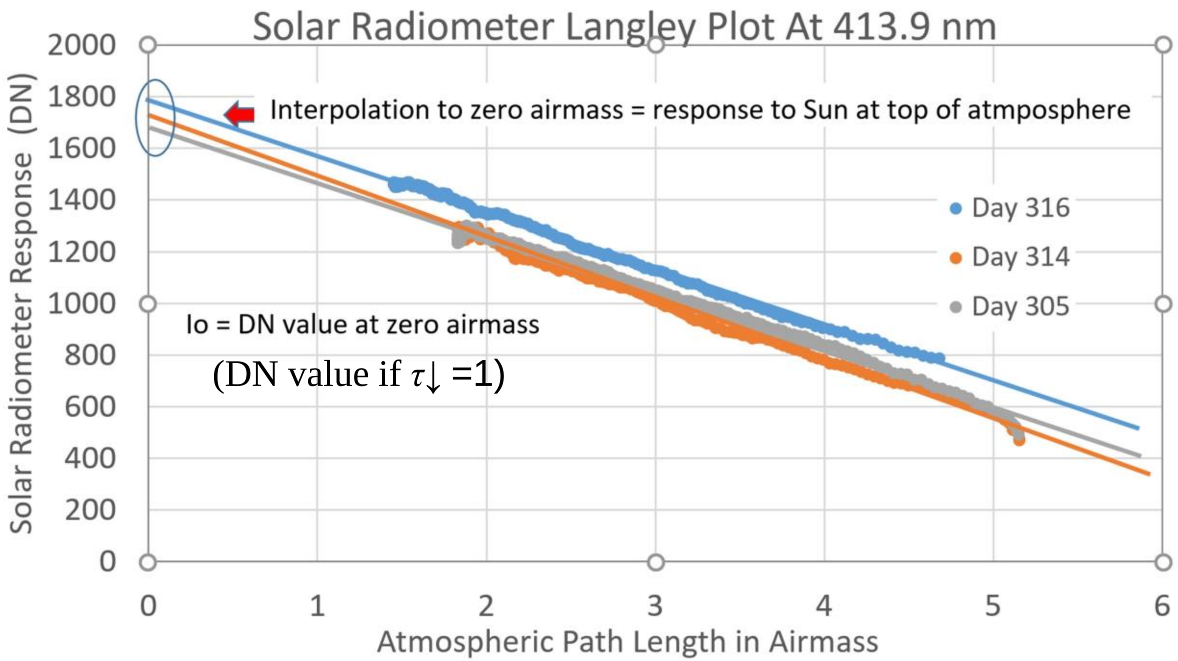


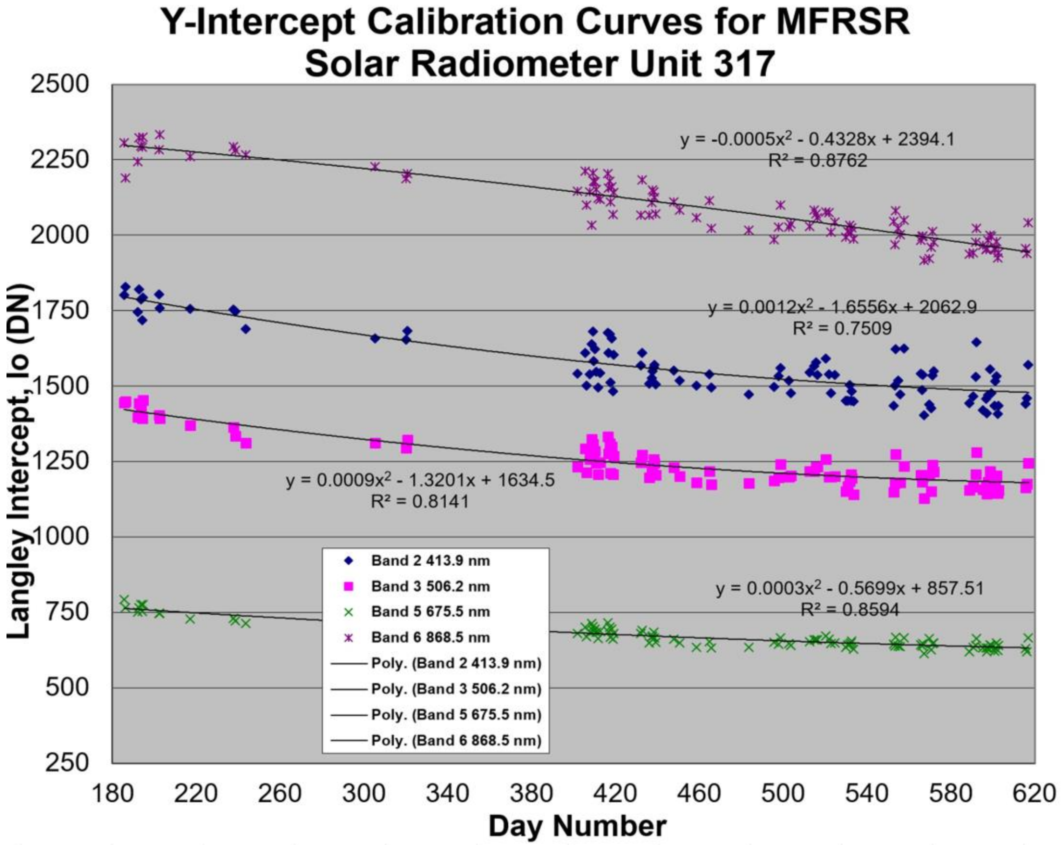
Outcome is the potential for the satellite to emulate a sun photometer/radiometer using SPARC reflectors

Imaging Sensor can be Calibrated Like a Solar Radiometer

- With a solar radiometer, calibration requires determining the top-of-atmosphere, zero airmass response (I_o) for each spectral band based on Langley plot analysis

  This is usually digital numbers representing a detector output as a function of solar airmass





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Zero Airmass Response Constant - DN_o

With SPARC, the equivalent calibration requires determining the “Zero Airmass Response Constant” (ZARC) for each spectral band.

This is the orbiting sensor digital number (DN) response to a solar illuminated SPARC reflector when the atmospheric transmittance = 1.

The response is the integrated (∑DN) over the image PRF of a SPARC reflector panel containing N identical mirrors.

- Setting $\tau_{\downarrow}$ =1 and $\tau_{\uparrow}$=1, the SPARC radiative transfer equation becomes

$$L_{at-sensor}(\lambda)_o = \rho(\lambda)E_o(\lambda)\left(\frac{R}{2GSD_o}\right)^2$$

GSD_o =Sensor’s Reference GSD
GSD_o (IKONOS Pan) = 0.8m
GSD_o (IKONOS MSI) = 3.2m

- Assuming a linear, bias subtracted response for the imaging sensor then

$$DN_o = g(\lambda)L_{at-sensor}(\lambda)$$

- The constant is fixed by sensor and mirror parameters, otherwise
- Or

$$DN_o(\lambda) = g(\lambda)\rho(\lambda)E_o(\lambda)\left(\frac{R}{2GSD_o}\right)^2$$

$$DN_o(\lambda)GSD_o^{\,2} = g(\lambda)\rho(\lambda)E_o(\lambda)\left(\frac{R}{2}\right)^2$$

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Zero Airmass Response Constant – DN_o (continued)

- In any atmosphere, when imaging a SPARC reflector, the DN/mirror response will be

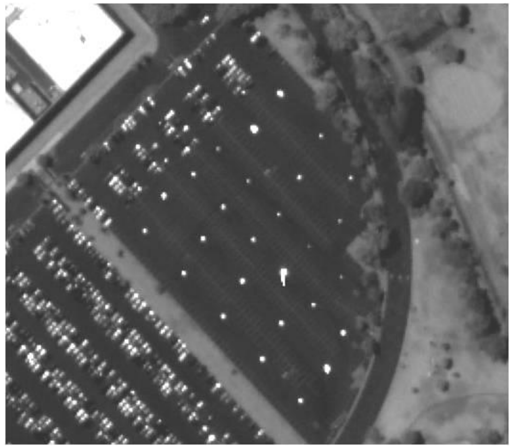
$$DN(\lambda) = g(\lambda)L_{at-sensor}(\lambda) = \tau_{\downarrow}(\lambda)\tau_{\uparrow}(\lambda)\underbrace{g(\lambda)\rho(\lambda)E_o(\lambda)\left(\frac{R}{2}\right)^2}_{= DN_0 GSD_o^2 \ (insert)}\frac{1}{GSD^2}$$

- Substituting

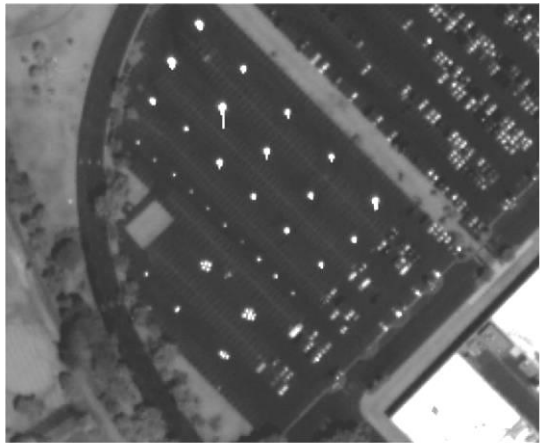
- The zero airmass response constant is derived in terms of the integrated SPARC target image response and the atmospheric transmittance measured at the target

$$DN_o(\lambda) == \frac{GSD^2 DN(\lambda)}{GSD_o^2 \tau_{\uparrow}(\lambda)\tau_{\downarrow}(\lambda)}$$

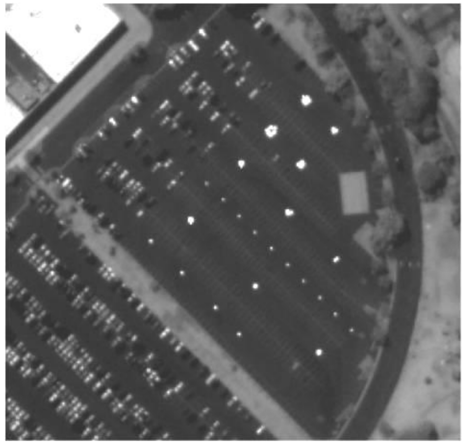
Validation: Sun Photometry Obtained With IKONOS



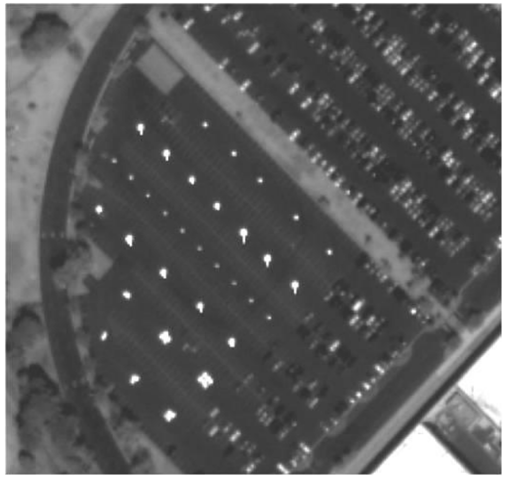
July 23



July 31

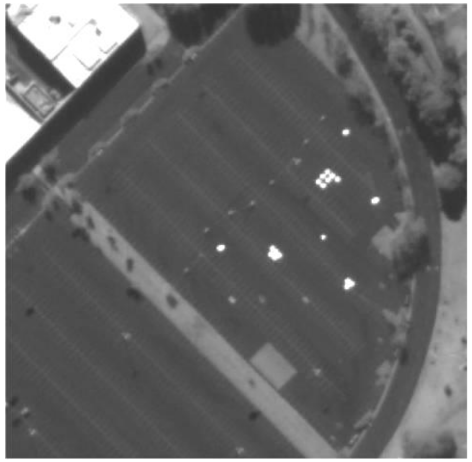


Sept 2



Sept 10

- Five overpass days
- Two collects per overpass
- 10 calibration points for determining an average DN_o.



Nov 15

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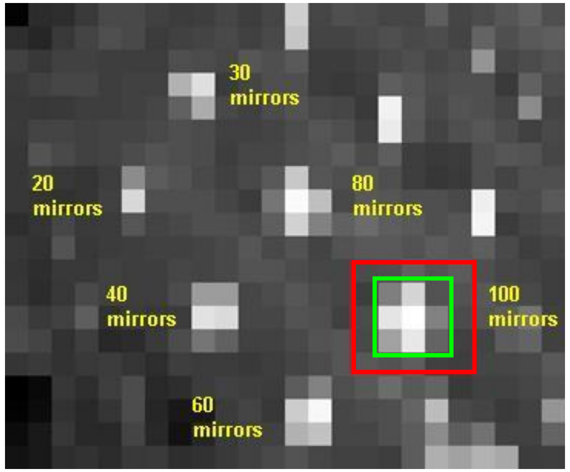
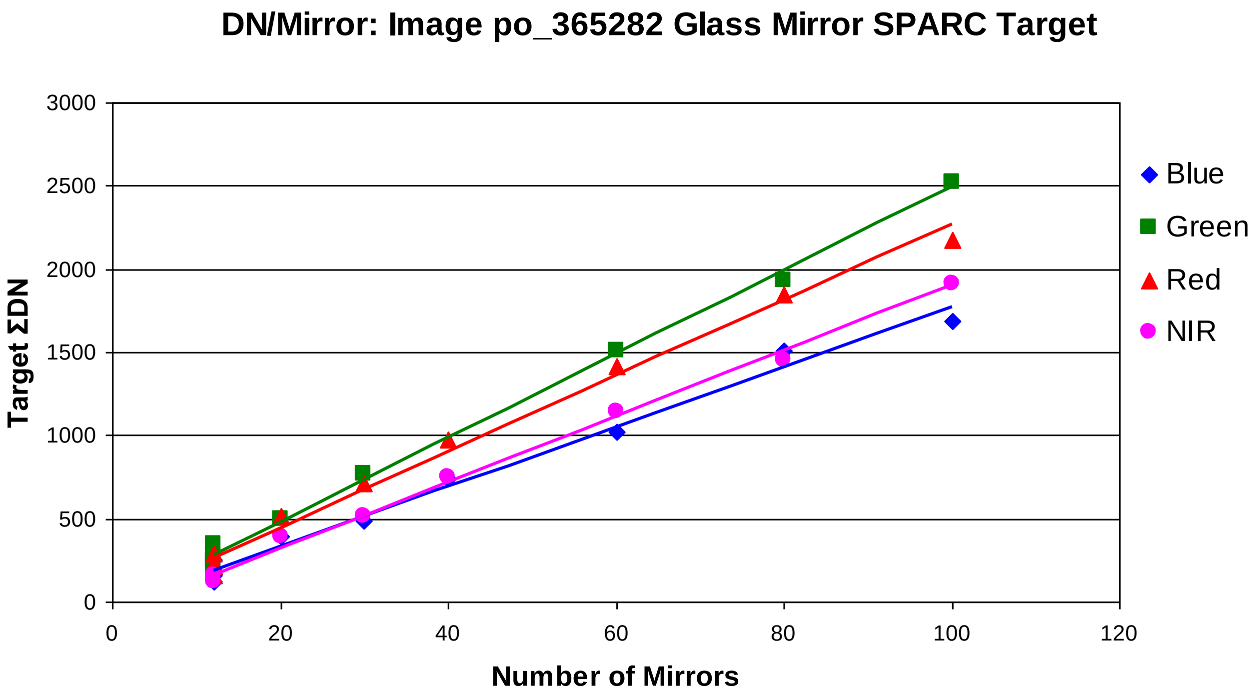
Image Analysis: Measurement of DN/Mirror



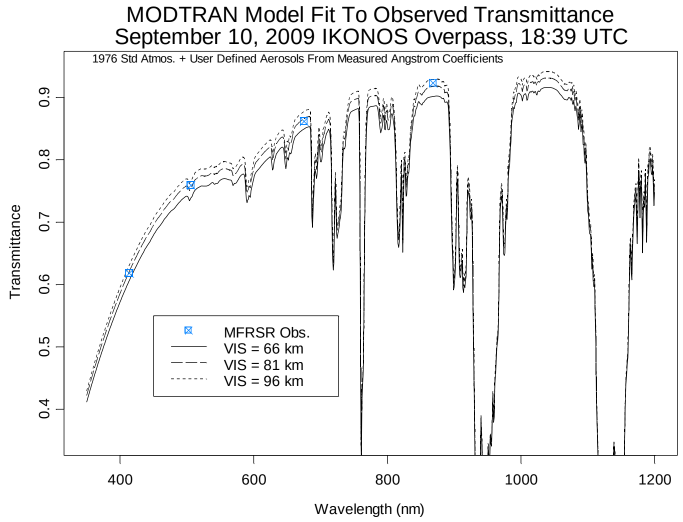


Spectral Band	Slope: DN/Mirror	R^2
Blue	17.9	0.9898
Green	25.2	0.9972
Red	22.8	0.9917
NIR	19.8	0.9965

Results for Sept. 10, 2009

IKONOS collect.

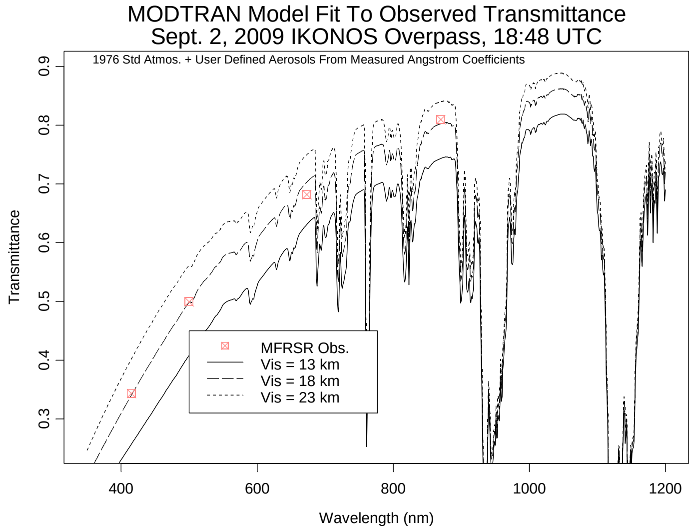
Band Integrated Atmospheric Transmittance



Clearest Day

Sept. 10, 2009

Vis = 81 km



Haziest Day

Sept. 2, 2009

Vis = 18 km

Sept. 10, 2009		
Image po_365282		
	$\tau_{\downarrow}(\lambda)$	$\tau_{\uparrow}(\lambda)$
Pan	0.7841	0.8093
Blue	0.7357	0.7656
Green	0.7773	0.8032
Red	0.8279	0.8476
NIR	0.8332	0.8498
Sept. 2, 2009		
Image po_364249		
	$\tau_{\downarrow}(\lambda)$	$\tau_{\uparrow}(\lambda)$
Pan	0.6427	0.6779
Blue	0.4748	0.5239
Green	0.5667	0.6117
Red	0.6687	0.7048
NIR	0.7087	0.7389

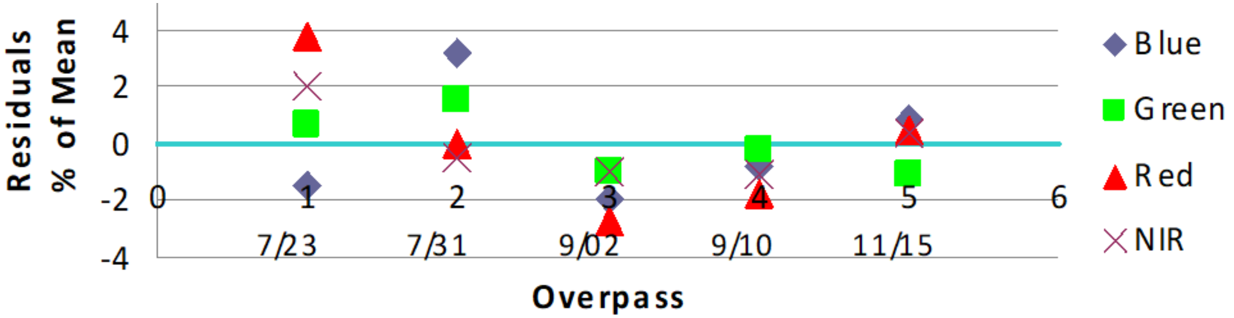
Zero Airmass Response Constant (ZARC) from Individual Images

Results from 10 images for 5 overpasses over 4 months

	Overpass Average					Individual Images				
Date	DN_0 - Pan	DN_0 - Blue	DN_0 - Green	DN_0 - Red	DN_0 - NIR	DN_0 - Pan	DN_0 - Blue	DN_0 - Green	DN_0 - Red	DN_0 - NIR
23-Jul	558.41	36.15	47.04	40.67	32.32	554.14	38.07	45.57	39.94	31.30
23-Jul						562.67	34.23	48.51	41.39	33.33
31-Jul	585.63	37.92	47.43	39.13	31.51	597.59	39.59	45.94	37.50	30.76
31-Jul						573.68	36.26	48.91	40.76	32.25
2-Sep	575.45	36.00	46.28	38.08	31.36	567.98	36.37	47.22	36.99	30.83
2-Sep						582.93	35.62	45.34	39.16	31.89
10-Sep	592.12	36.39	46.63	38.46	31.32	608.58	36.42	46.16	37.21	32.02
10-Sep						575.66	36.37	47.10	39.71	30.62
15-Nov	552.15	37.02	46.19	39.32	31.77	508.28	36.45	45.88	38.77	31.15
15-Nov						596.02	37.60	46.51	39.87	32.40

Values adjusted to Sun/Earth Distance = 1AU

Overpass Average Residuals from Mean



IKONOS Demonstration of Radiometric Stability Measurements Using SPARC

Reproducibility of Zero Airmass Response Constant (ZARC)

		DN_o - Pan	DN_o - Blue	DN_o - Green	DN_o - Red	DN_o - NIR
Average	DN_o	572.75	36.70	46.71	39.13	31.66
Std Deviation		17.17	0.79	0.52	0.99	0.41
Std Deviation	%	3.00	2.15	1.11	2.54	1.29

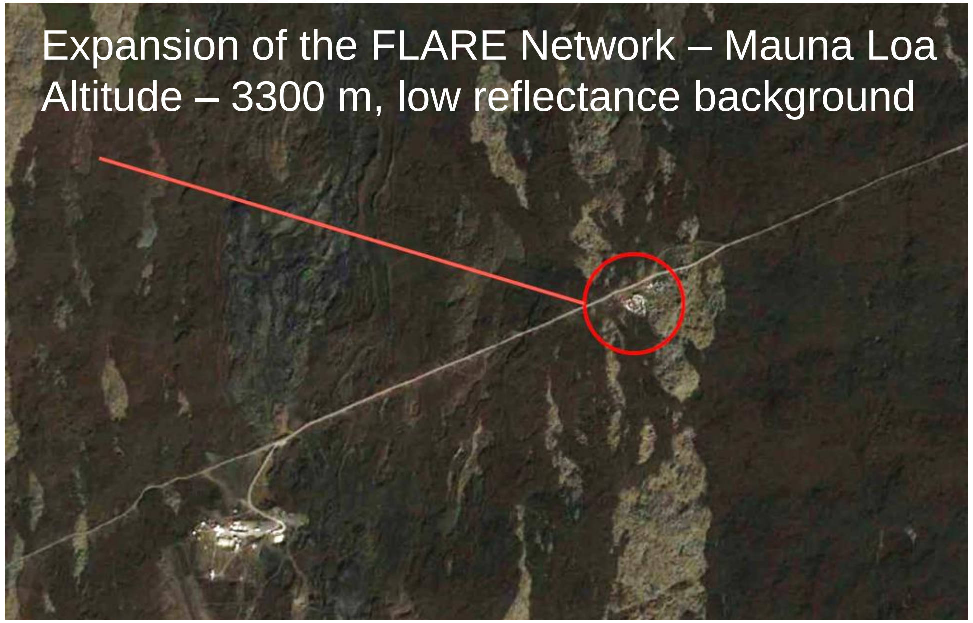
DN_o calculations from band integrated transmittance and Image measured *DN/Mirror*

$$DN_o(\lambda) = \frac{GSD^2 DN(\lambda)}{GSD_o^2 \tau_\uparrow(\lambda)\tau_\downarrow(\lambda)}$$

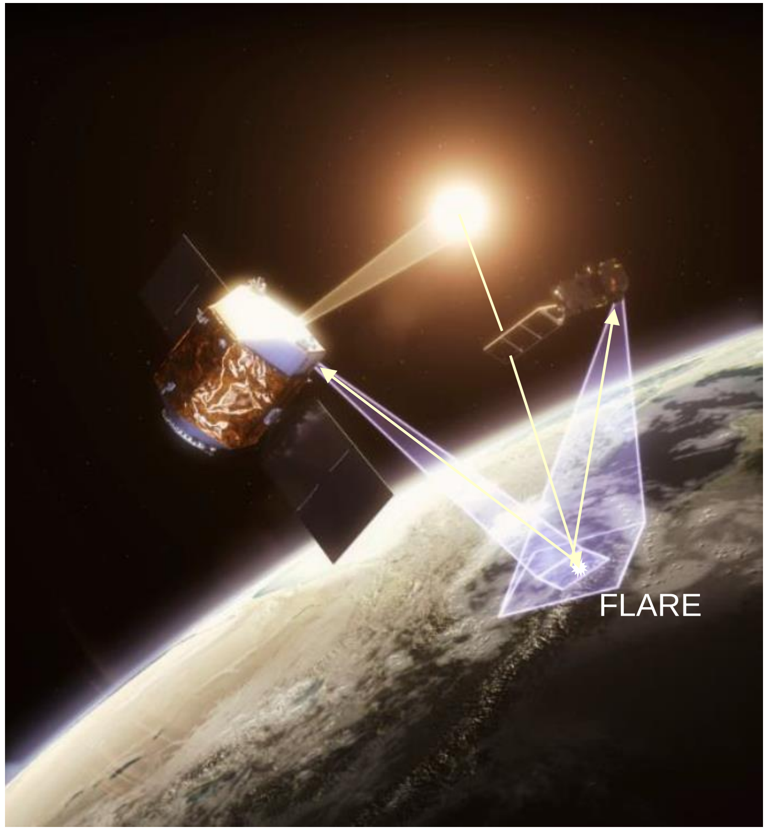
Results indicate that MSI ZARC can be tracked to better than 2.5% for SPARC targets at sea level

Placing targets at high altitude for better transmittance accuracy knowledge will significantly increase the ZARC precision

Potential to achieve <1% DN_o precision with a high altitude FLARE reference target.



Tracking DN_o – Assessment of Sensor Stability and Multi-Sensor Interoperability.

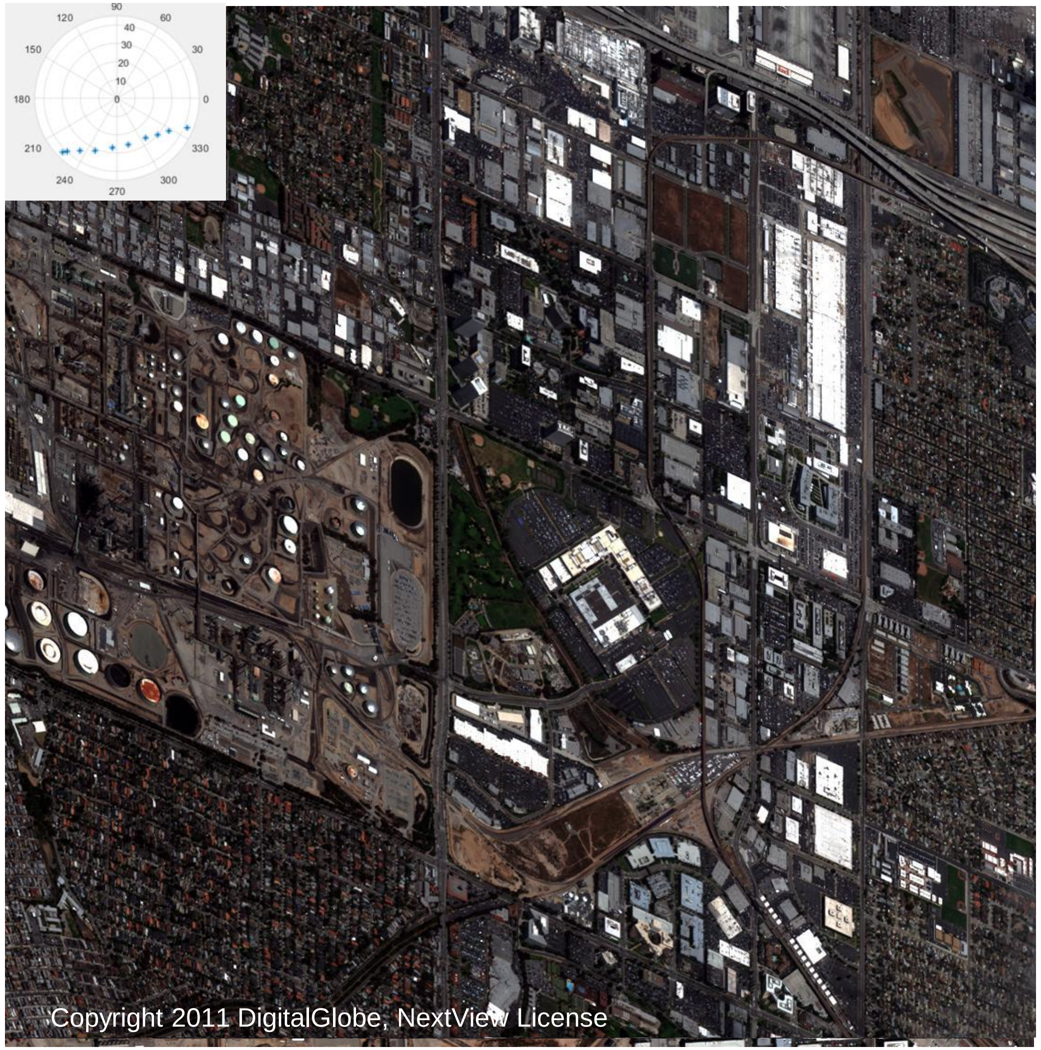


Cross-comparison of the ZARC sensor band response between satellites does not require simultaneity of collects when imaging a SPARC/FLARE target to evaluate relative stability and interoperability

- Any overpass of a SPARC/FLARE target provides an opportunity to measure the ZARC (DN_o) for any sensor in their solar reflective spectral bands
- ZARC, as a measure of sensor response can be tracked to monitor sensor radiometric stability.
- Tracking the ratio of ZARC values for similar bands between two sensors provides a parameter on a common radiometric scale for evaluating interoperability performance.
- TRUTHS, a UK-led operational Earth Observation mission, will initiate a space based calibration observatory providing a primary SI reference.
- **TRUTHS will act as a fiducial reference to cross-calibrate other sensors but must do so by imaging a common ground target.**
- **The Labsphere FLARE vicarious network provides such reference targets establishing a robust vicarious traceability path between these systems and temporal interoperability knowledge**

Moving from Analysis Ready Data to “Exploitation Ready Data”

- CEOS (the Committee on Earth Observation Satellites) established requirements for basic CEOS Analysis Ready Data for Land (CARD4L) surface reflectance products
- However, the current processing requirements allow topographic and BRDF effects to be ignored resulting in potential product artifacts that may impact general analysis of normalized BRDF images
- Any image acquired with a SPARC/FLARE network reference in the scene links the image to the sensor’s ZARC calibration providing a constant BRDF reference to generate topographic 3D spectral data
- The process allows generation of passive 3D point clouds providing full exploitation of surface facets using BRDF spectral libraries
- (≡ Exploitation Ready Data or ERD)



More to come on ERD

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