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Improving Spatial and Temporal Coverage in Earth Observations through Inter-Sensor Data Harmonization

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Abstract

Data harmonization in remote sensing enhances the quality and utility of image data allowing unified big data to emerge from multiple sensors having different spatial and spectral properties. It works toward creating a single source of truth about targets of interest. A path to implementation will allow civil and commercial sensors to work together improving spatial and temporal coverage with current assets and then merge seamlessly with future sensors and constellations. Differences in design and function of various optical remote-sensing systems can be minimized by imaging reference ground sites containing targets designed specifically for radiometric, spectroscopic and spatial performance assessment among disparate sensors. The process allows difference in characteristics to be effectively identified revealing information for improved data integration. In this presentation we describe applications toward harmonization using an affordable, autonomous, and responsive ground site target configuration and operation for supporting vicarious calibration and sensor performance assessment of Earth-imaging satellites and constellations. The Specular Array Calibration (SPARC) method, is an adaptable in-flight calibration system that uses ground-based convex mirrors to create small reference targets capturing radiometric, spatial, spectral, geometric, and temporal characteristics of individual sensors for transforming distinct sensors and constellation into a harmonious Earth-monitoring system. The approach minimizes inaccuracies and inconstancies between data sources by equalizing radiometric content through a common traceability path and characterizing spatial effects impacting data interoperability.

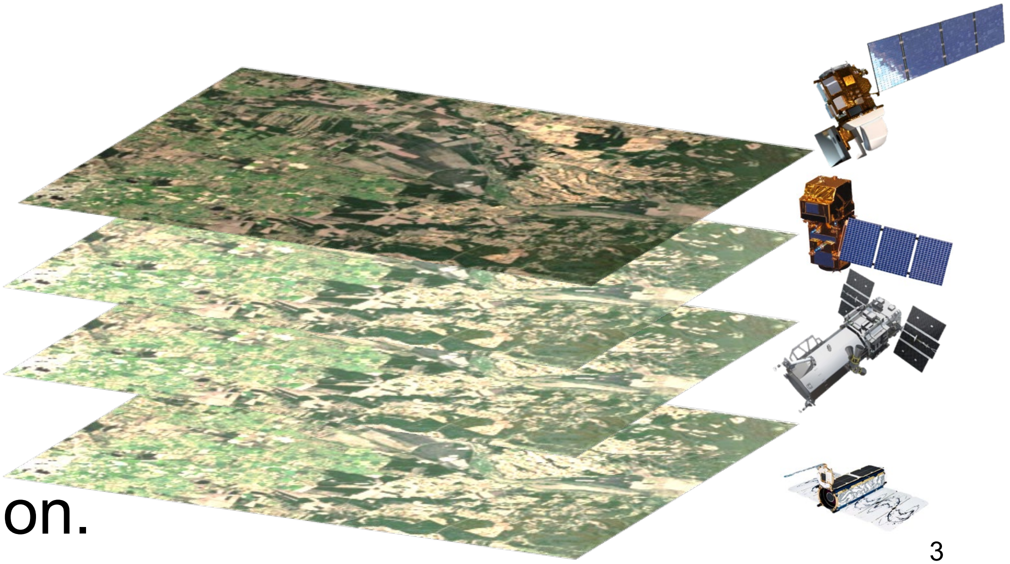
Making Data More User-friendly and Accessible

Interoperability of data– Combining data from multiple sensors into a single seamless time series.

Data harmonization – Sensor-specific radiometric, spatial, spectral and geometric differences in design and function are adjusted and removed

Goal - to create data sets vacant of sensor-specific biases providing absolute information about scene content.

Measurable Objective - The integration and combination of consistent and comparable data greatly increases spatial and temporal information density – providing the general user community accessible avenues for new analysis and exploitation.



Harmonization Illustrated by Landsat-Sentinel-2 (HLS) Reflectance Product Analysis Process

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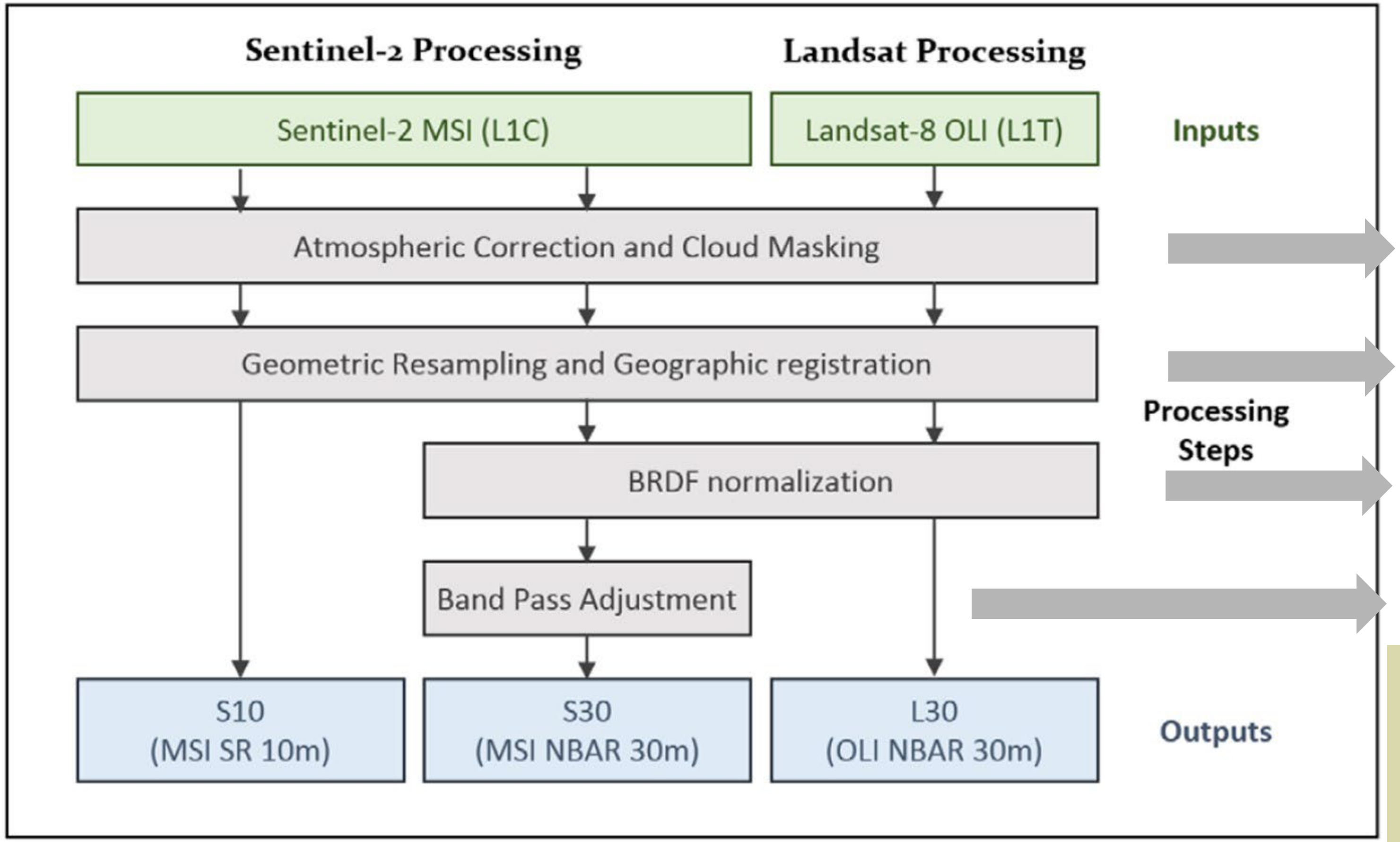
HLS processing flowchart



Harmonized Landsat-8 Sentinel-2 (HLS) Product User's Guide (http://hls.gsfc.nasa.gov/)

Inputs - orthorectified TOA reflectance data

Harmonization Addresses:

- Atmospheric Effects
- Resampling and Registration Errors
- View and Illumination BRDF Effects
- Band Specific Spectral Response

The same harmonization issues must be addressed in creating the original inputs through calibration

Data Harmonization is Only as Good as Its Starting Point – Sensor Calibration

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Radiometric, spatial, spectral, and geometric characterization and calibration of the specific optical remote-sensing satellites is seen as the necessary first step.

Harmonization towards interoperability must be based on a methodology that is not sensor specific ==>> Only calibration based on a common vicarious reference imaged by each interoperable sensor can achieve this!

Critical characteristics of an ideal vicarious calibration reference

- Minimal impact by atmospheric effects
- Well characterized spatial structure that avoids size of source effects
- Stable and/or known spectral reflectance over time (accessible throughout the year)
- Flat reflectance over the sensor’s spectral range
- Tests gain response over the sensor’s full dynamic range (multiple radiance levels)
- Minimal BRDF effects

A methodology best meeting the ideal characteristics minimizes the bias impact of a specific sensor optimizing data harmonization for interoperability

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

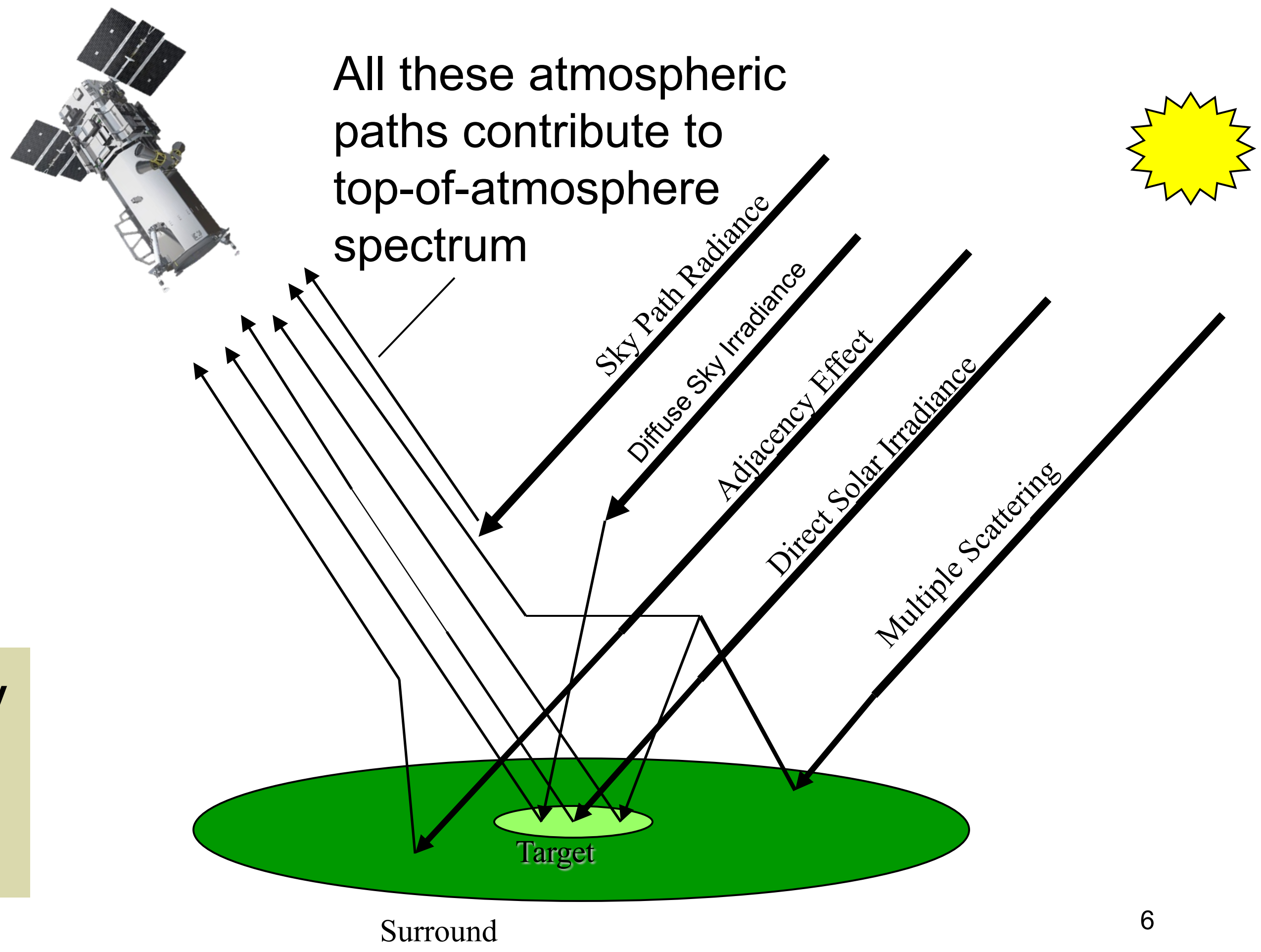
The upwelling calibration signal by Lambertian-like surfaces are influenced by all sources within the illumination hemisphere of the target and the surround

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 Affects on At-Sensor Calibration Radiance

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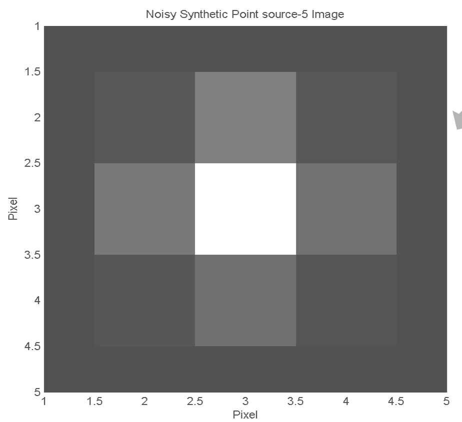
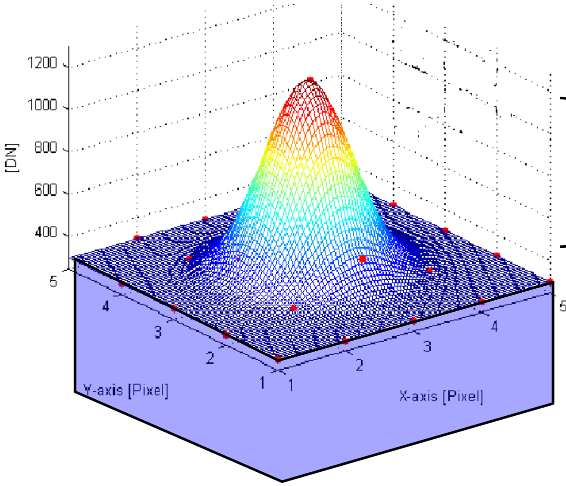
- Target signal embedded in a uniform scene is elevated above the low spatial frequency background (sky path radiance, adjacency effect, stray light, ect.) and is separable
- Background becomes a bias and is subtracted out based on image data alone
- Sensor response to target radiance is the integrated Digital Number (DN) contained in the PSF
- Atmospheric effects reduce to transmittance only which can be measured with a solar irradiance spectrometer coincident with the overpass
- Another bonus is that sensor specific stray light effects also subtract out as a bias

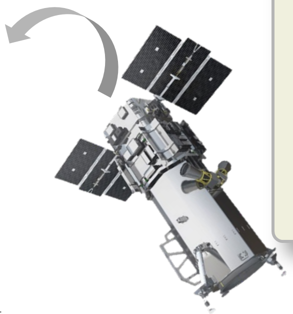
Image of target

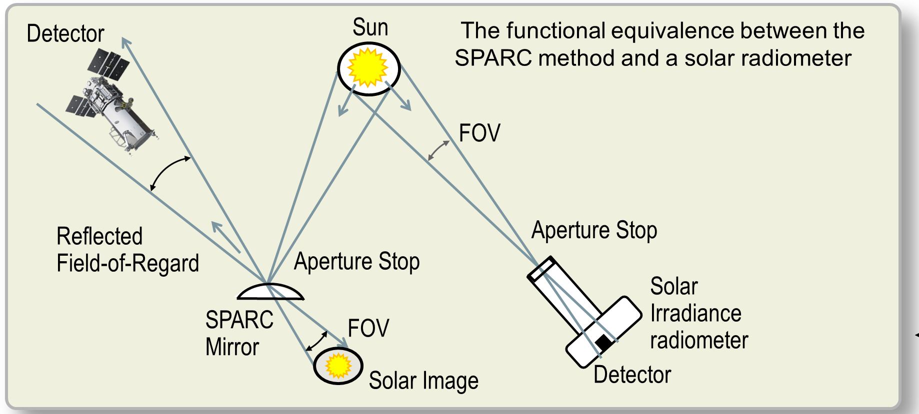


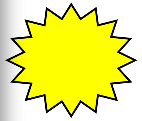


Signal from SPARC target alone.

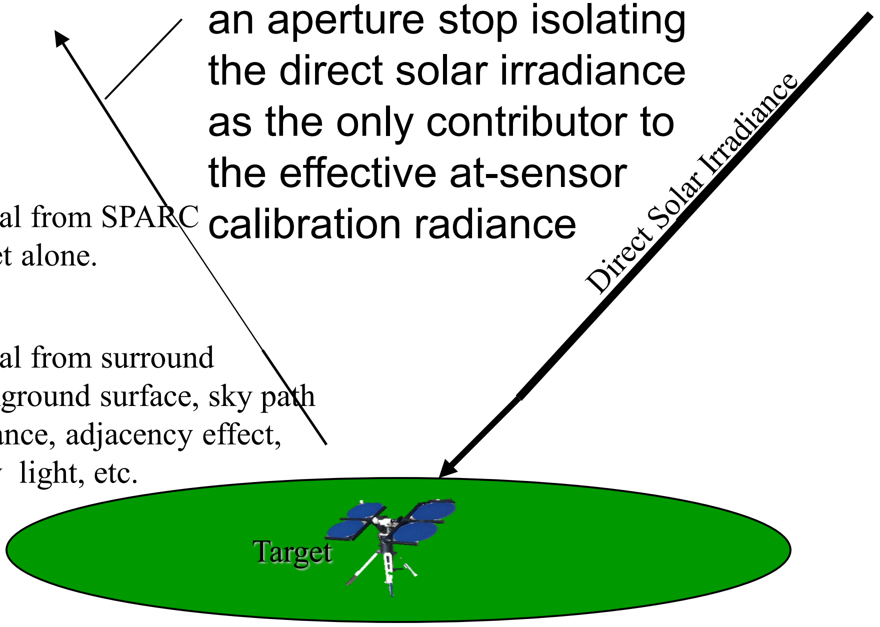
Signal from surround background surface, sky path radiance, adjacency effect, stray light, etc.







The convex mirror acts as an aperture stop isolating the direct solar irradiance as the only contributor to the effective at-sensor calibration radiance



SPARC Radiometric Target Compact Size Allows Flexible and Reproducible Application at any Accessible Test or Study Site

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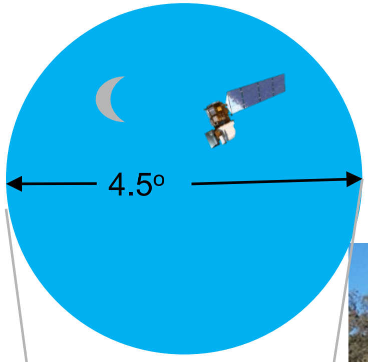
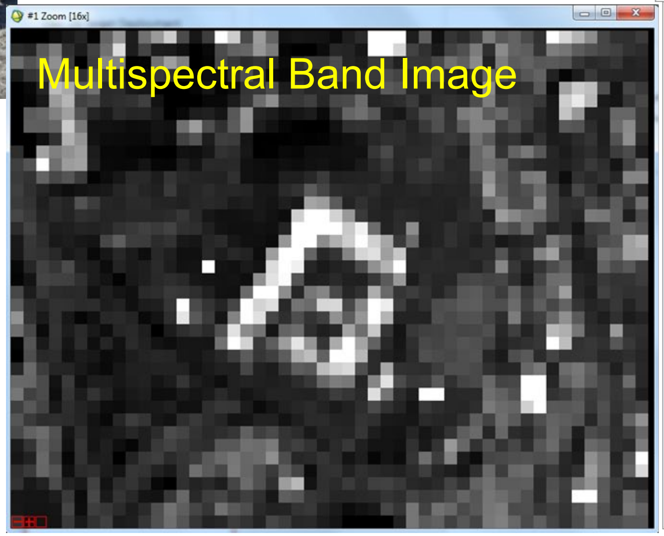
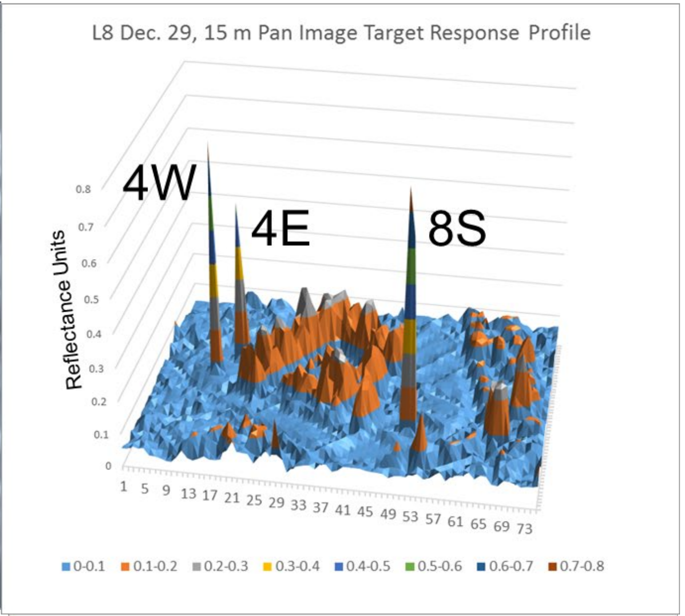
The reflected field- of-regard (FOR) produces a uniform illumination intensity across the sky
= 4.5 degrees

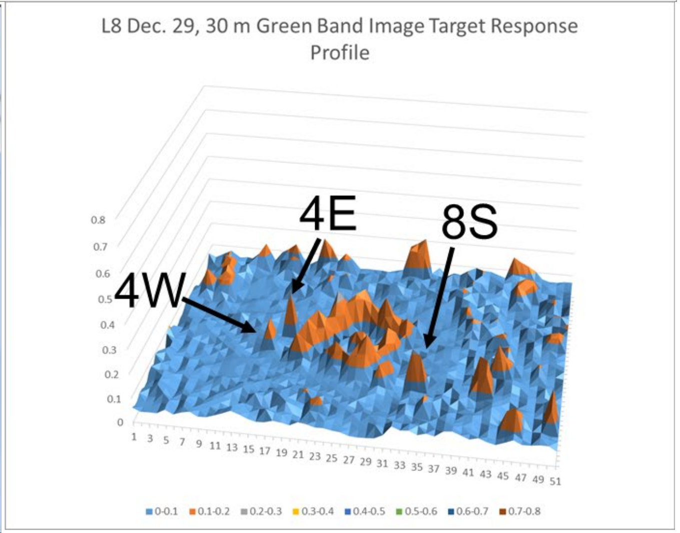


Deployed at alternate site

Portable system provides computer controlled pointing using an alt/az mount.







Specular Reflectance Compared to Measured Lambertian Reflectance Factors In Vicarious Calibration

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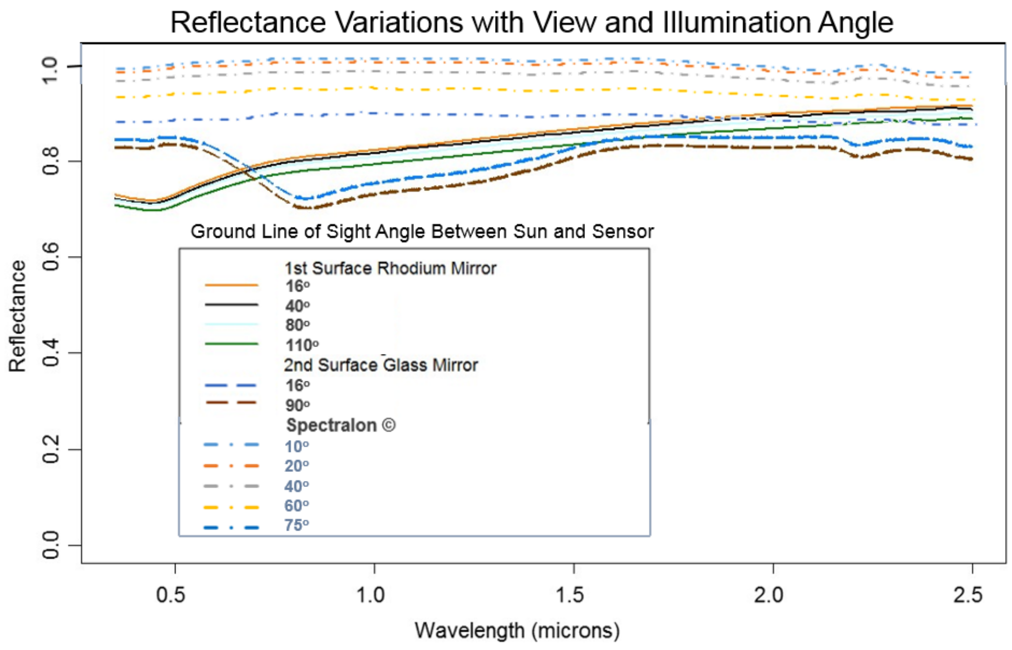
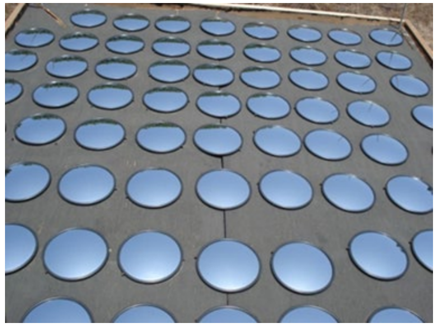
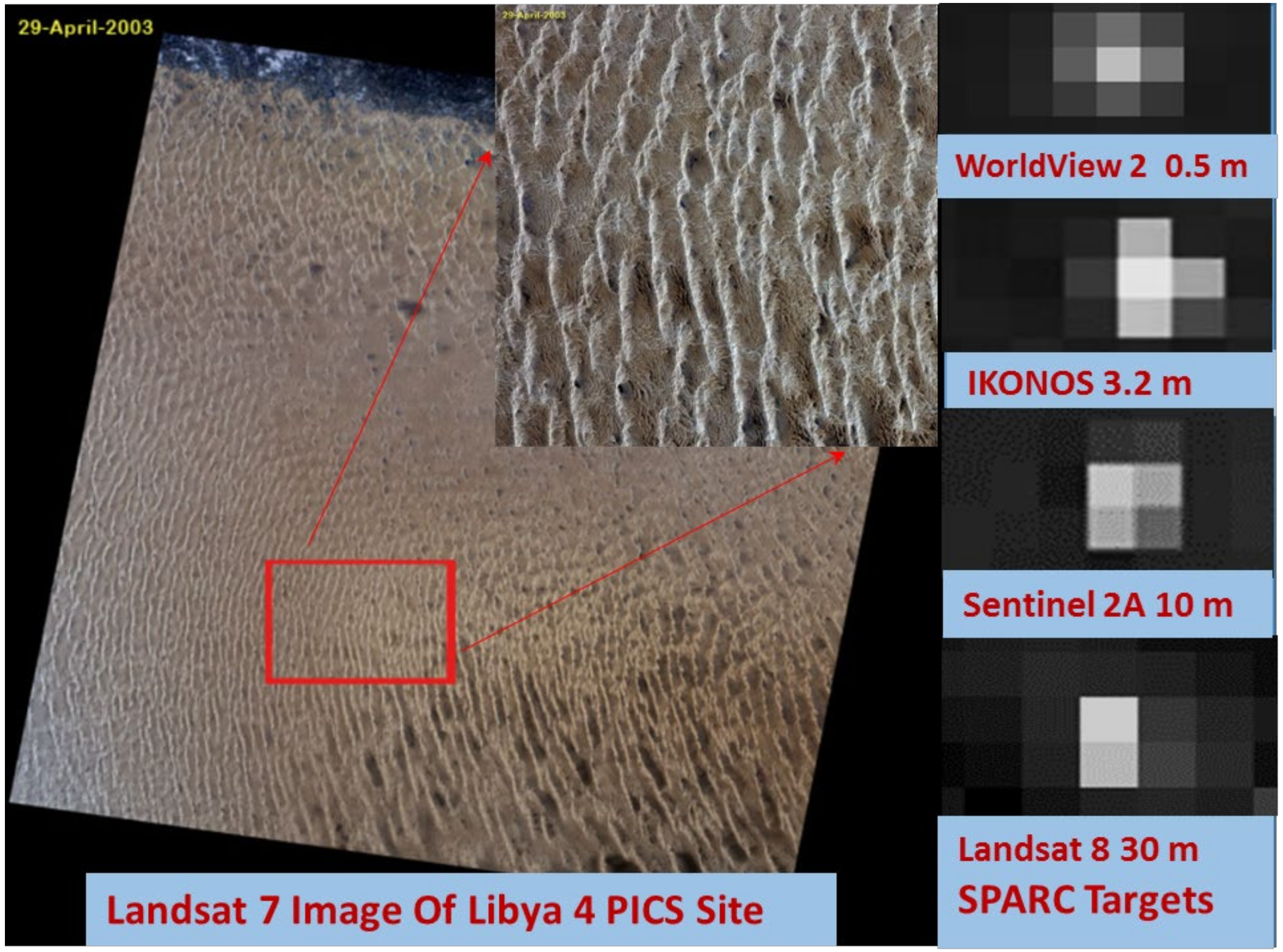
- Specular targets provide reduced reflectance uncertainty for calibration
  - Specular reflectance is measured in the lab with high accuracy and deployed as is in the field.
  - Reflectance factor of diffuse ground targets is based on a transfer in the field with a reflectance standard
- Almost negligible BRDF effects with spherical mirrors
  - Even less than the field reflectance standard used to calibrate a diffuse target site (see plot)
- No foreshortening effects on calibration signal
  - Mirrors maintain a stable intensity source over widely varying view and illumination geometries
- Mirror reflectance is spectrally flat, comparable to the reflectance transfer standard itself
- Identical targets can be reproduced at multiple sites





SPARC Targets Avoids Systematic Interoperability Errors from Radiance Size of Source and Inter-sensor Registration Effects



SPARC targets look the same to all sensors

For extended radiance sources differences in sensor ground sample distance (GSD) introduce inter-sensor bias errors

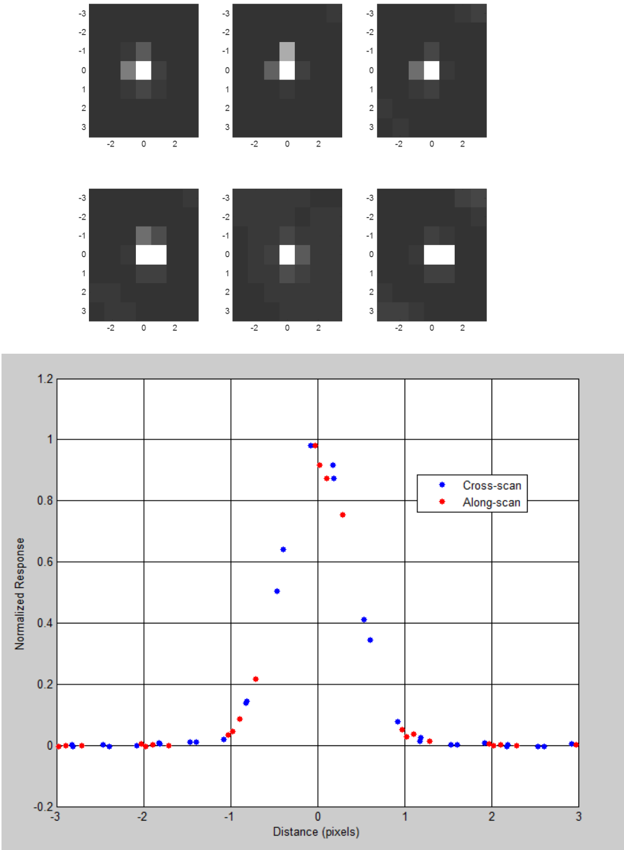
- Size of source (SSE) effects
- FOV limitations
- Reference area mismatch
- Registration errors

SPARC target energy distribution is independent of sensor GSD

- defined by the system PSF
- Relative image registration is not needed to compare responsivity and derive band adjustment factors.

The SPARC Method Offers an Innovative Calibration and Image Assessment Capability Using Vicarious Reference Targets

- An optimal calibration capability should not only deliver radiometric performance analysis but support a complete image assessment system (IAS)
- Processing can be incorporated as part of the ground station, data production and archiving architecture
- Key assessment attributes include:
  - Radiometric validation, updates, uncertainties and traceability over the sensors full dynamic range.
  - Spatial PSF and MTF characterization (Along-track & cross track differences)
  - Image quality analysis (Focus, jitter, data compression, focal plain uniformity)
  - Geometric calibration (camera model)
  - Band-to-band registration
  - Spectral band ratio trending and derivation of inter-sensor band difference coefficients
  - Validate product quality above Level 1 (System PSF performance, surface reflectance, NDVI …)
- Maintain updates of the sensor’s Calibration Parameter File (CPF)
- Monitor inter-sensor spatial performance for improved data harmonization
- Build databases to support detailed spatial, geometric and radiometric bulk trending for monitoring sensor degradation over the lifetime of each sensor and the effect on interoperability.



Oversampled PSF assessment of Landsat 8 using SPARC point targets

Detailed Analysis of the Full 2-D PSF Profile Important to Achieving Interoperability Using Data with Varying GSD

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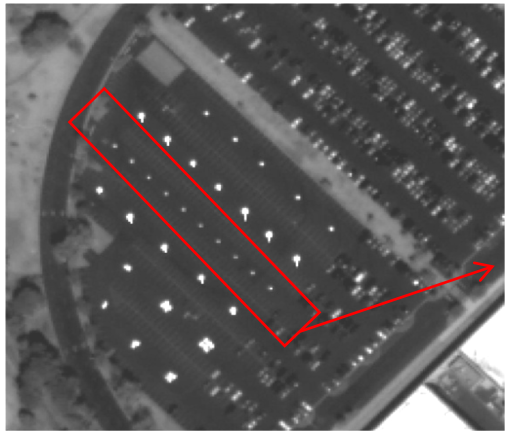
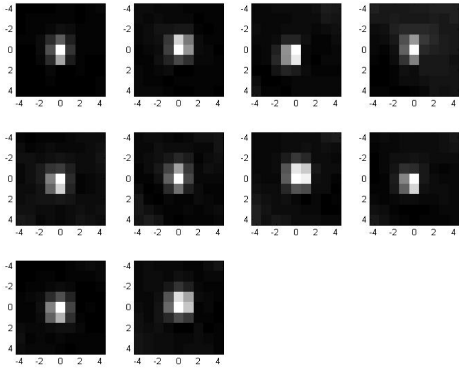
Analysis essential to provide end-users with meaningful per-pixel uncertainty estimates

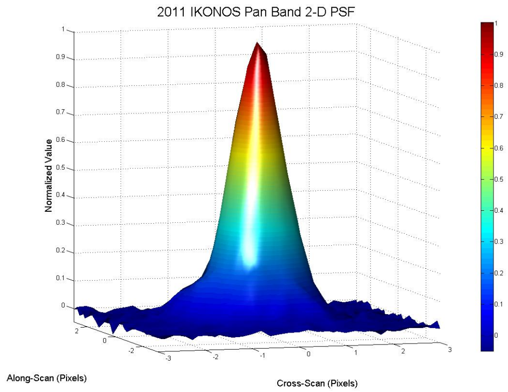
SPARC uses a grid of spherical reflectors to create an oversampled point spread function (PSF).



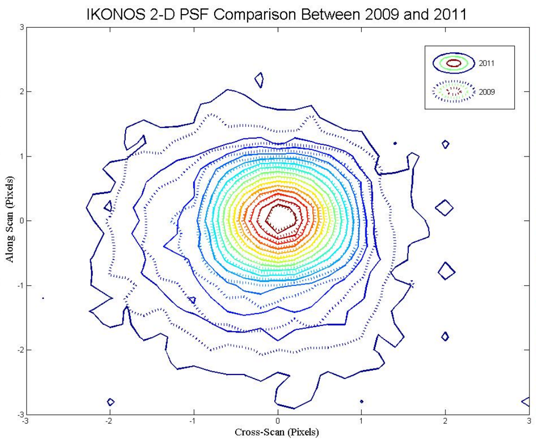
IKONOS Image Of point targets



Extracted images have different pixel phasing



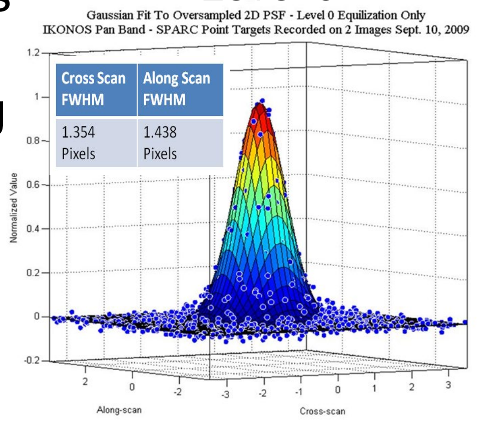
After centroiding, images are combined to reveal oversampled 2-D PSF Profile



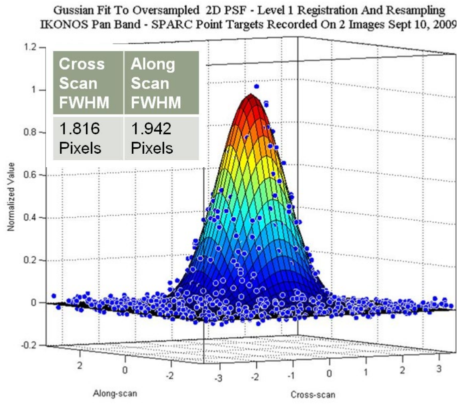
2-D PSF based on images taken two years apart show similar asymmetric profile

Analysis evaluates the image quality at each step along the image processing chain in the harmonization process

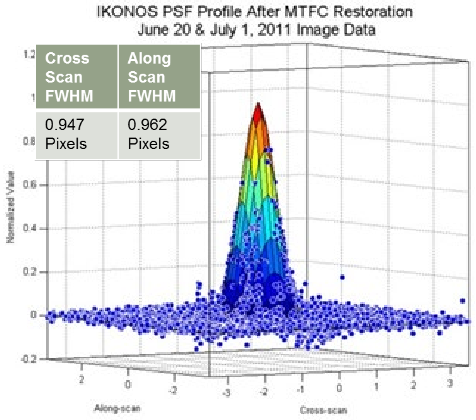
Level 0



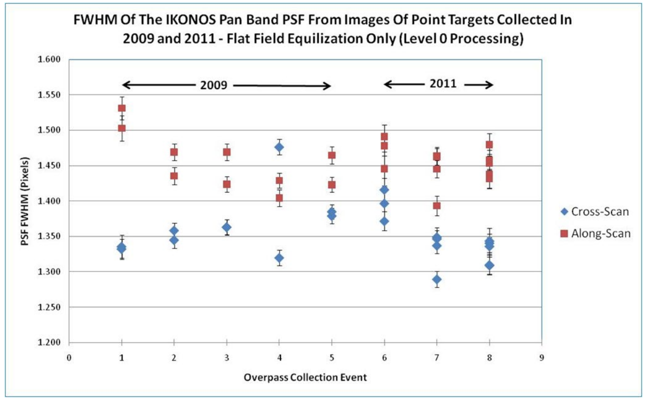
Level 1 (Resampled)



Level 1 + MTFC

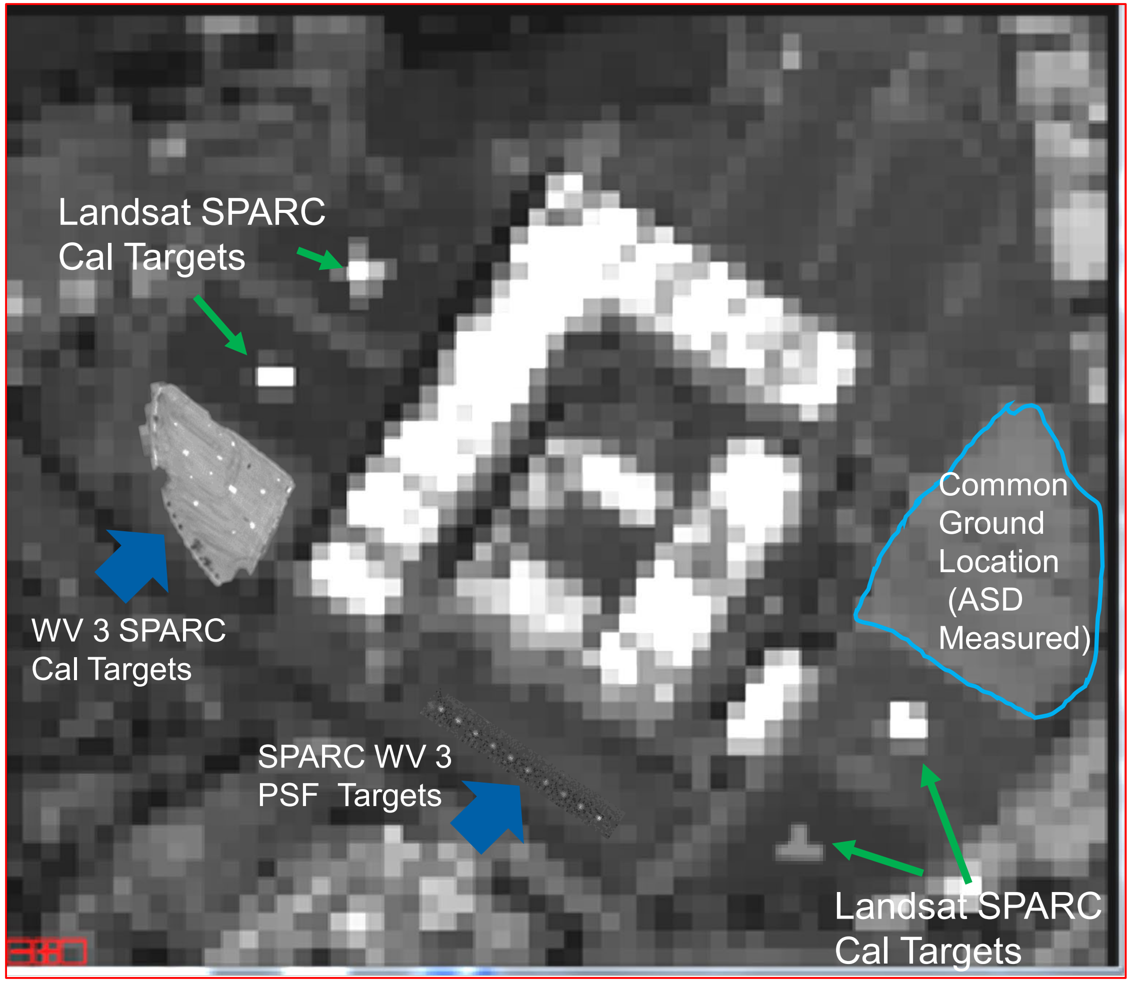


PSF FWHM Temporal Variability



Robust Methodology Places All Sensors a Common Radiometric Scale

SPARC Vicarious Intersensor Calibration



- SPARC targets produce, for all sensors under calibration, identical spectral profiles for deriving band gain coefficients on a consistent radiometric scale.
- Calibration performance can be validated against a common ground location allowing the derivation of band difference correction factors if desired.
- **However, the accurate hyperspectral knowledge of SPARC reflectance references allow precise performance comparison of similar and dissimilar bands. Do we want to loose potentially important spectral information surface cover types by applying a band “correction” factor?**

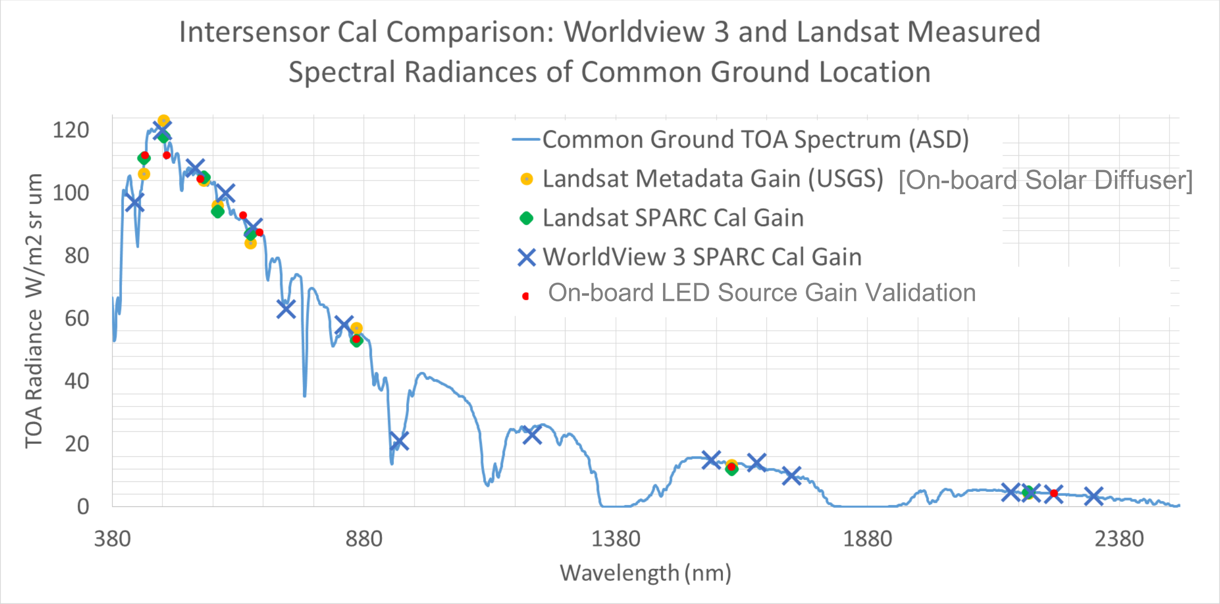


Illustration Only

Conclusion

The move to interoperability and analysis ready data (ARD) through an effective harmonization processing starts with a calibration process that facilitates improved performance knowledge with minimum artifacts that the harmonization process will need to adjust and remove

The SPARC method, based on creating intensity sources using convex mirrors, provides a process with many advantages for improving current and future efforts in achieving the worthwhile goal of data interoperability.