Radiometric and Geometric Performance of Sentinel 2A Compared to Landsat 8

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U.S. Department of the Interior
U.S. Geological Survey

Radiometric Analyses

- Methodology:
  - Use near-simultaneous collection of Sentinel 2A MSI and Landsat 8 OLI over Pseudo Invariant Calibration Site (PICS)
    - Libya 4 WRS2 Path 181 Row 40, S2A Tile 34RGT (~98x48km)
  - Two sets of data were used
    - S2A and L8 data collected 4 days apart, 30Dec15 and 03Jan16
    - S2A and L8 data collected 6 days apart, 29Jan16 and 04Feb16
    - Hyperion data for spectral adjustment collected 30Dec15 and 03Feb16
  - Apply spectral band adjustment factor (SBAF)
  - Compute TOA reflectance from selected ROIs
  - Compare TOA reflectance only for similar S2A/L8 bands

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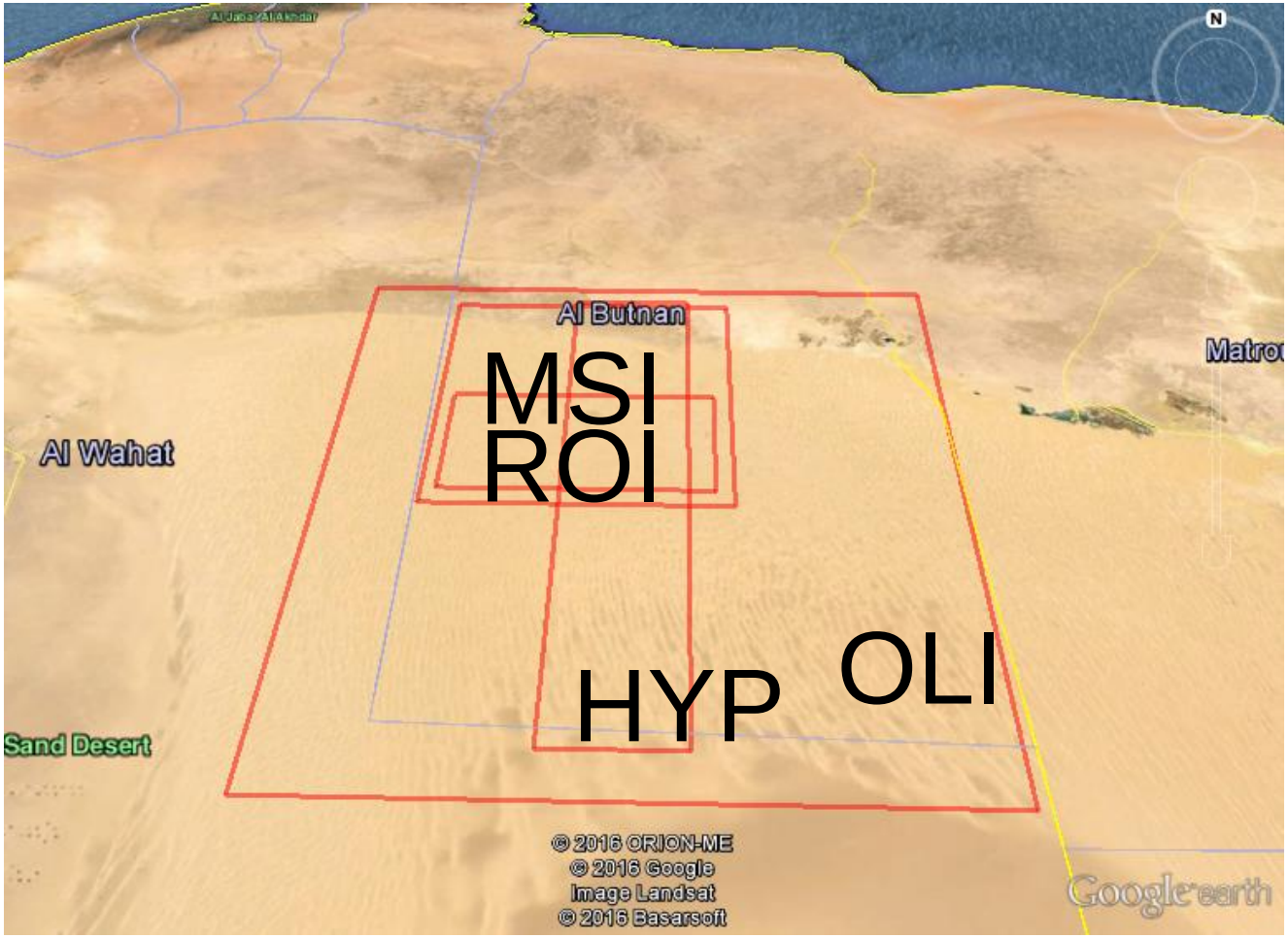
Footprints over Libya 4



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Calculation of TOA Reflectance

- **L8 OLI TOA reflectance**
  - $\rho_\lambda = \frac{M_\rho * Q_{cal} + A_\rho}{\sin \theta}$
  - **Where,**
    - ρ_λ**= Top-of-Atmosphere Reflectance**
    - M_ρ**= Reflectance multiplicative scaling factor for the band (REFLECTANCEW_MULT_BAND_n from the metadata)**
    - A_ρ**= Reflectance additive scaling factor for the band (REFLECTANCE_ADD_BAND_N from the metadata)**
    - Q_{cal}**= Level 1 pixel value in DN**
    - θ **= Solar Elevation Angle (from the metadata)**
- **S2A MSI TOA reflectance**
  - $\rho_\lambda = \frac{Q_{cal}}{QUANTIFICATION\_VALUE}$
  - **Where,**
    - ρ_λ**= Top-of-Atmosphere Reflectance**
    - Q_{cal}**= L1C pixel value in DN**
    - $QUANTIFICATION\_VALUE$ **is provided in metadata**

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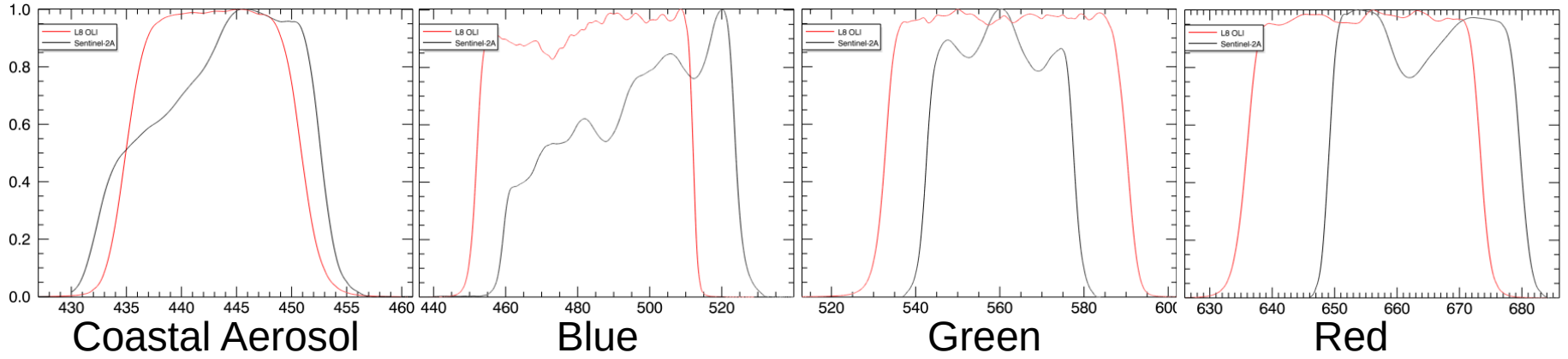
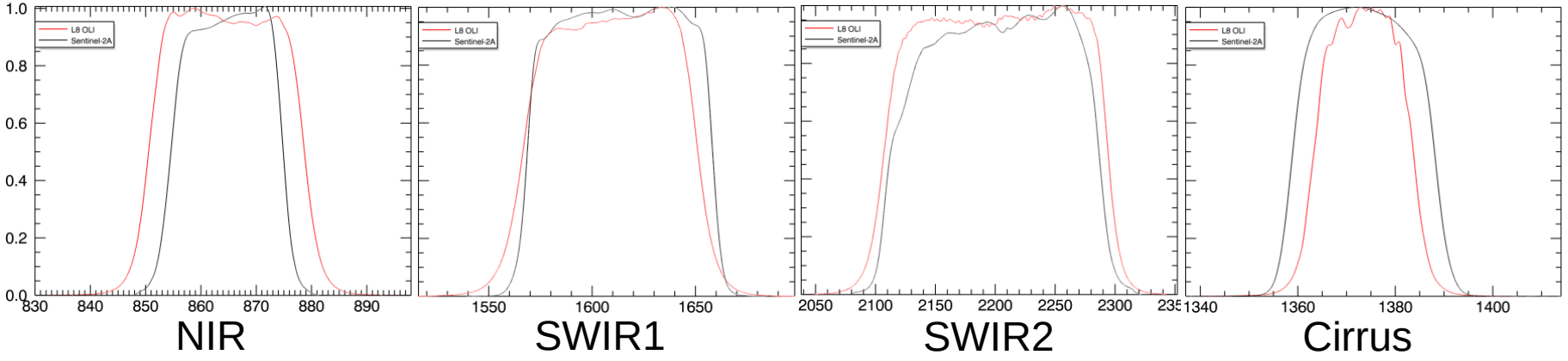
Relative Spectral Response





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Spectral Band Adjustment

- Hyperion data over the test area was used to estimate Spectral Band Adjustment Factors (SBAF)
  - $SBAF = \frac{\rho_1(\lambda)}{\rho_2(\lambda)} = \frac{\frac{\int \rho_T(\lambda) RSR_1(\lambda) d\lambda}{\int RSR_1(\lambda) d\lambda}}{\frac{\int \rho_T(\lambda) RSR_2(\lambda) d\lambda}{\int RSR_2(\lambda) d\lambda}}$
  - **Where,**
  - $\rho_T(\lambda)$ **is TOA reflectance of the target area estimated from TOA reflectance seen by Hyperion collection over Libya 4 dated 7/28/2015 and 9/7/2015**
  - $\rho_1(\lambda)$ **and** $\rho_2(\lambda)$ **are simulated TOA reflectance of OLI and MSI, respectively**
  - $RSR_1(\lambda)$ **and** $RSR_2(\lambda)$ **are relative spectral responses of OLI and MSI, respectively**

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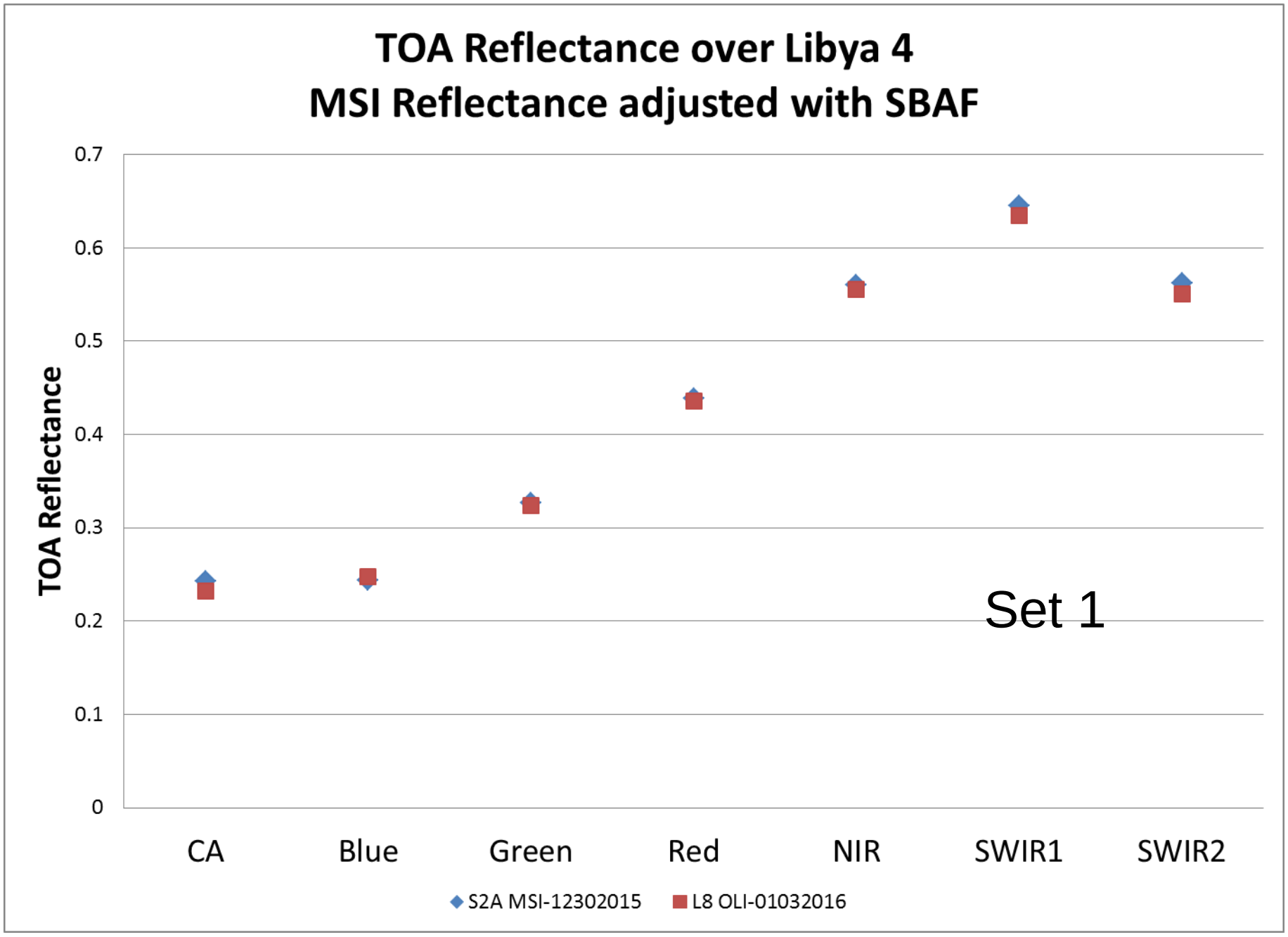
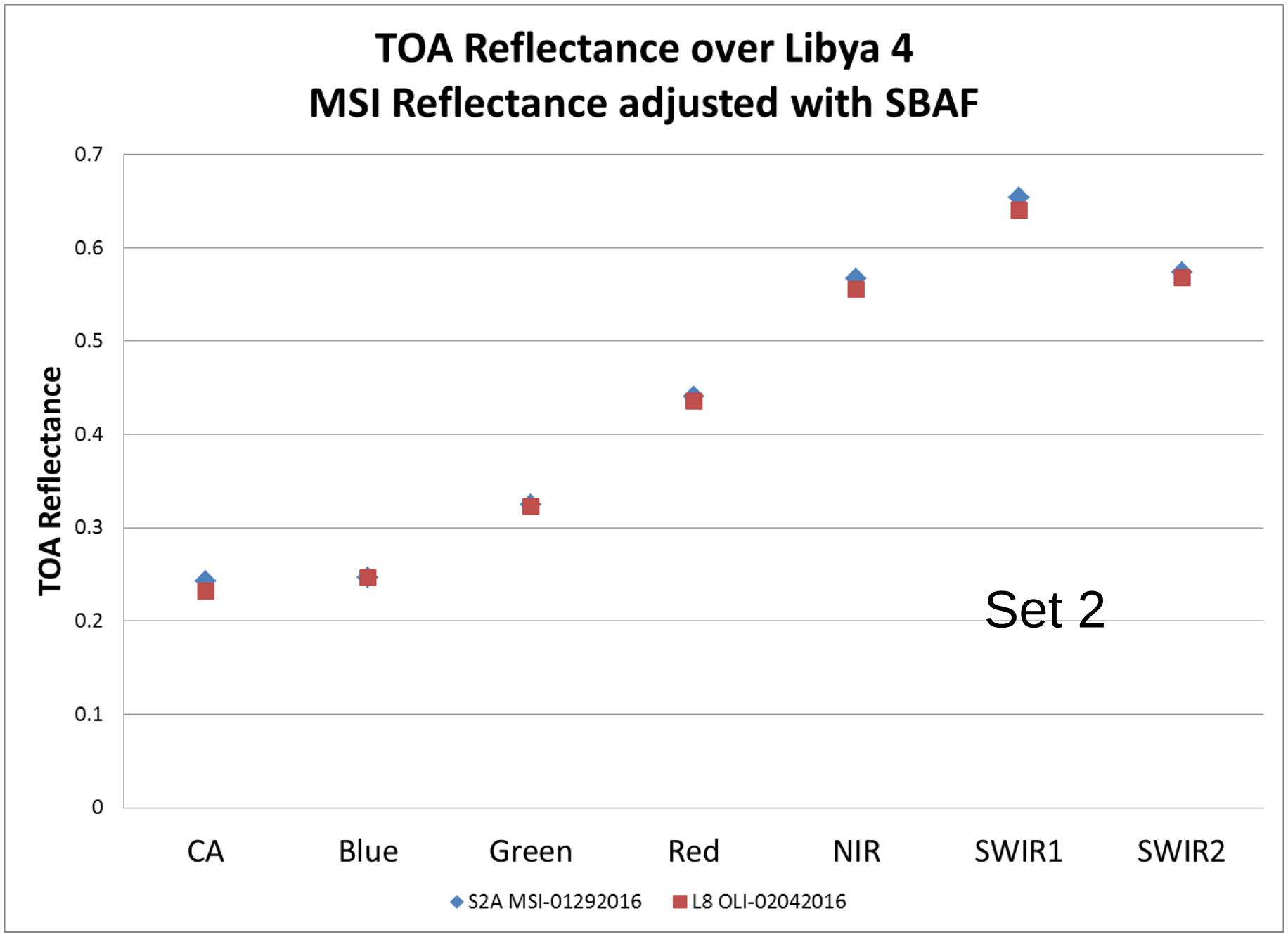

TOA Reflectance over Libya 4
MSI Reflectance adjusted with SBAF
TOA Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CA
Blue
Green
Red
NIR
SWIR1
SWIR2
Set 1
S2A MSI-12302015
L8 OLI-01032016


TOA Reflectance over Libya 4
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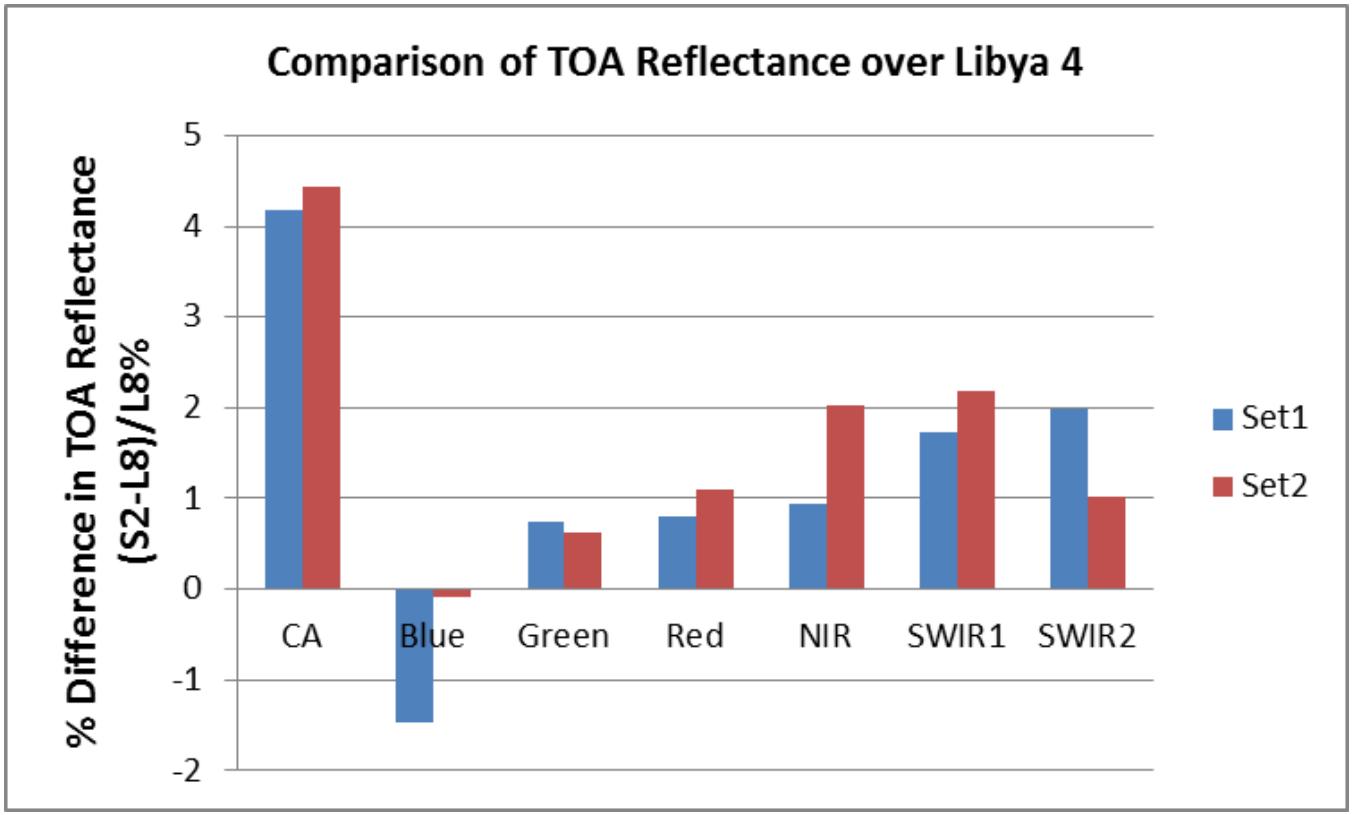
TOA Reflectance
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
CA
Blue
Green
Red
NIR
SWIR1
SWIR2
Set 2
S2A MSI-01292016
L8 OLI-02042016

Difference in TOA Reflectance (Set 1 & 2)



%Difference in TOA Reflectance (S2-L8)/L8%							
Band	CA	Blue	Green	Red	NIR	SWIR1	SWIR2
Set1	4.182	-1.478	0.740	0.804	0.935	1.721	1.979
Set2	4.430	-0.078	0.633	1.104	2.024	2.183	1.020

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Radiometry Conclusions

- **Radiometric characterization of Sentinel2A MSI was performed in comparison to Landsat 8 OLI data using acquisitions over PICS Libya4**
- **Based on the test calibration sites the TOA reflectance between S2A MSI and L8 OLI agree within 5% for all similar reflective bands**
  - **Maximum difference found in CA band (4.3%)**
  - **Minimum difference found in green band (0.74%)**
- **Note that some of the test data sets were not simultaneous acquisitions and atmospheric differences between MSI, OLI and Hyperion acquisition times were not accounted for**

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Geometric Analyses Performed

- **Sentinel-2A MSI L1C data geometric performance was assessed with respect to 3 characteristics:**
  - **Geometric Accuracy Assessment**
  - **Image Registration Accuracy**
  - **Band Registration Accuracy**
- **The MSI L1C data were preprocessed for compatibility with Landsat 8 geometric characterization tools.**
  - **Performance was assessed relative to Landsat 8 requirements, not S2A MSI requirements.**

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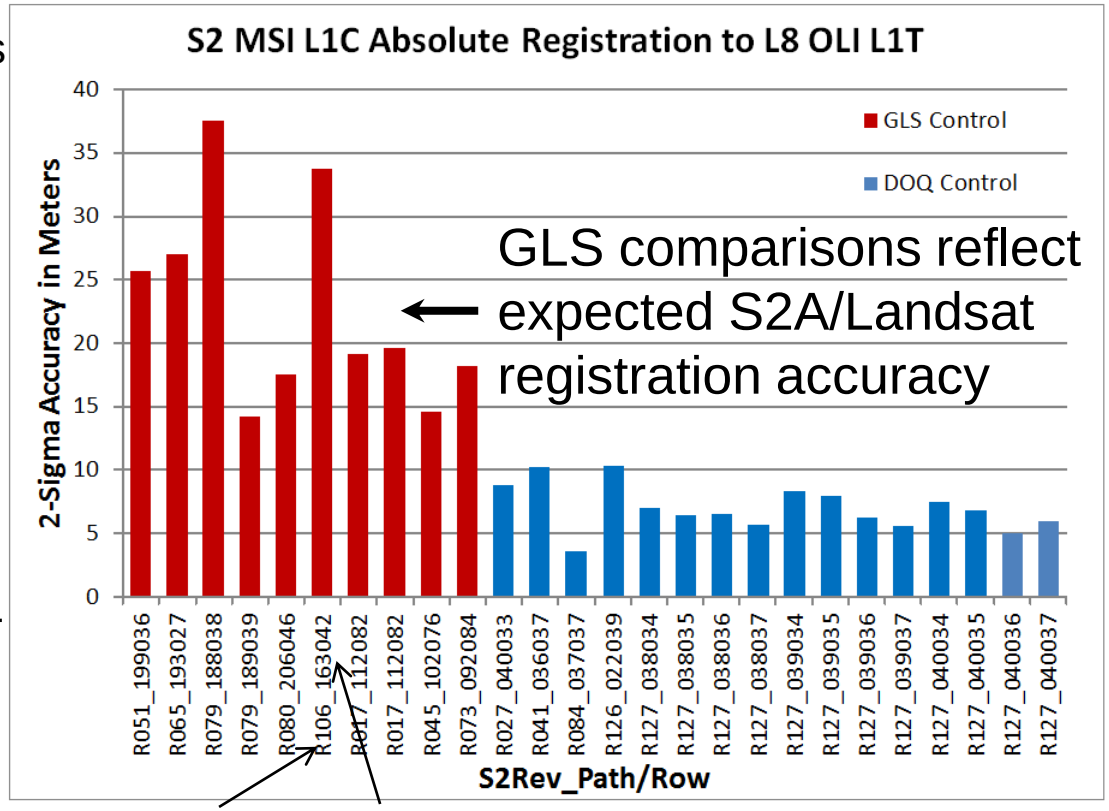
Absolute Geolocation

- **Compared MSI L1C products to ground control points (GCP) from two sources:**
  - **Global Land Survey – global but only accurate to ~38 meters CE90.**
  - **Digital Orthophoto Quad – available at calibration sites but accurate to ~3 meters CE90.**

- Global Land Survey (GLS) results (shown in red) are dominated by GCP error.
- Digital Orthophoto Quad (DOQ) results (shown in blue) show accuracy of 8.0 meters 2σ, well within Landsat requirements.
- Although based upon a small data sample, the DOQ results did suggest a small (~4 meter) cross-track bias.



Relative orbit_Landsat path/row

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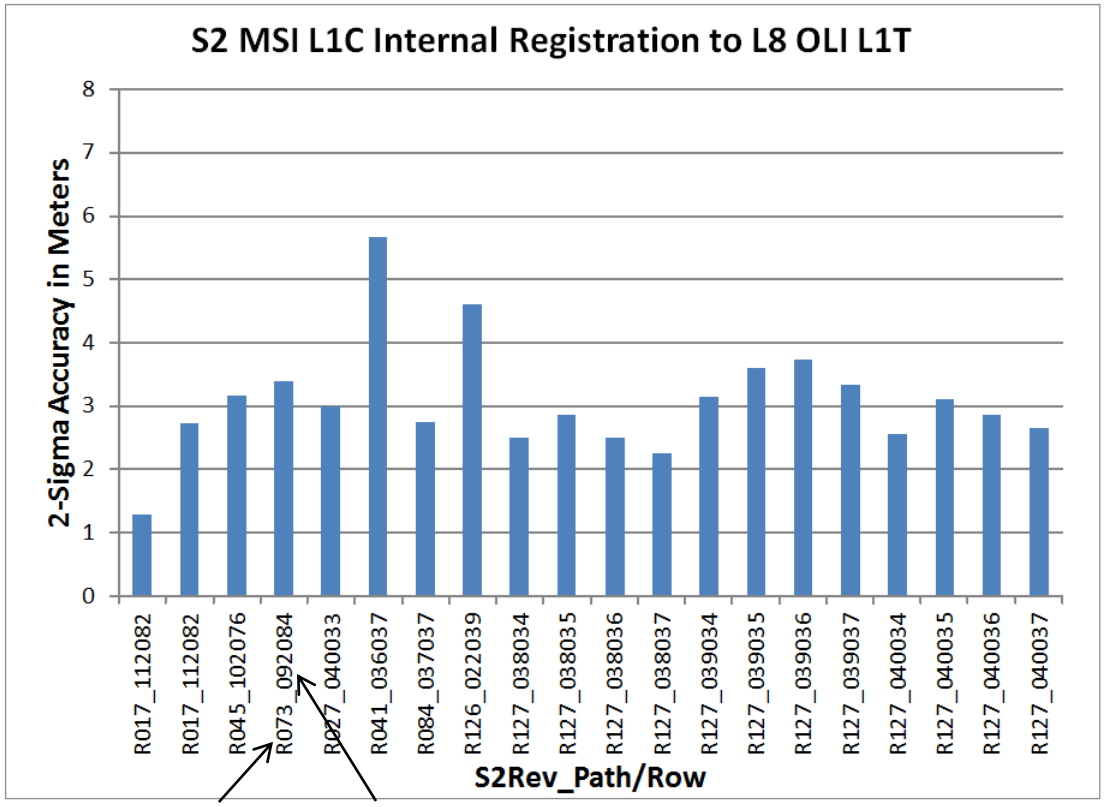
Initial Results
Internal Geometry

- **Compared MSI L1C products to OLI reference images (at 15m GSD) corrected using DOQ ground control points.**
  - **Mean offsets mirrored results from DOQ GCPs.**
  - **Standard deviations reflect internal geometric consistency.**

- Image registration results show internal consistency between MSI and OLI of 3.3 meters 2σ, well within Landsat image registration accuracy requirements.
- Absolute geolocation and image registration results indicate that MSI L1C data meet Landsat L1T positional accuracy requirements.



Relative orbit_Landsat path/row

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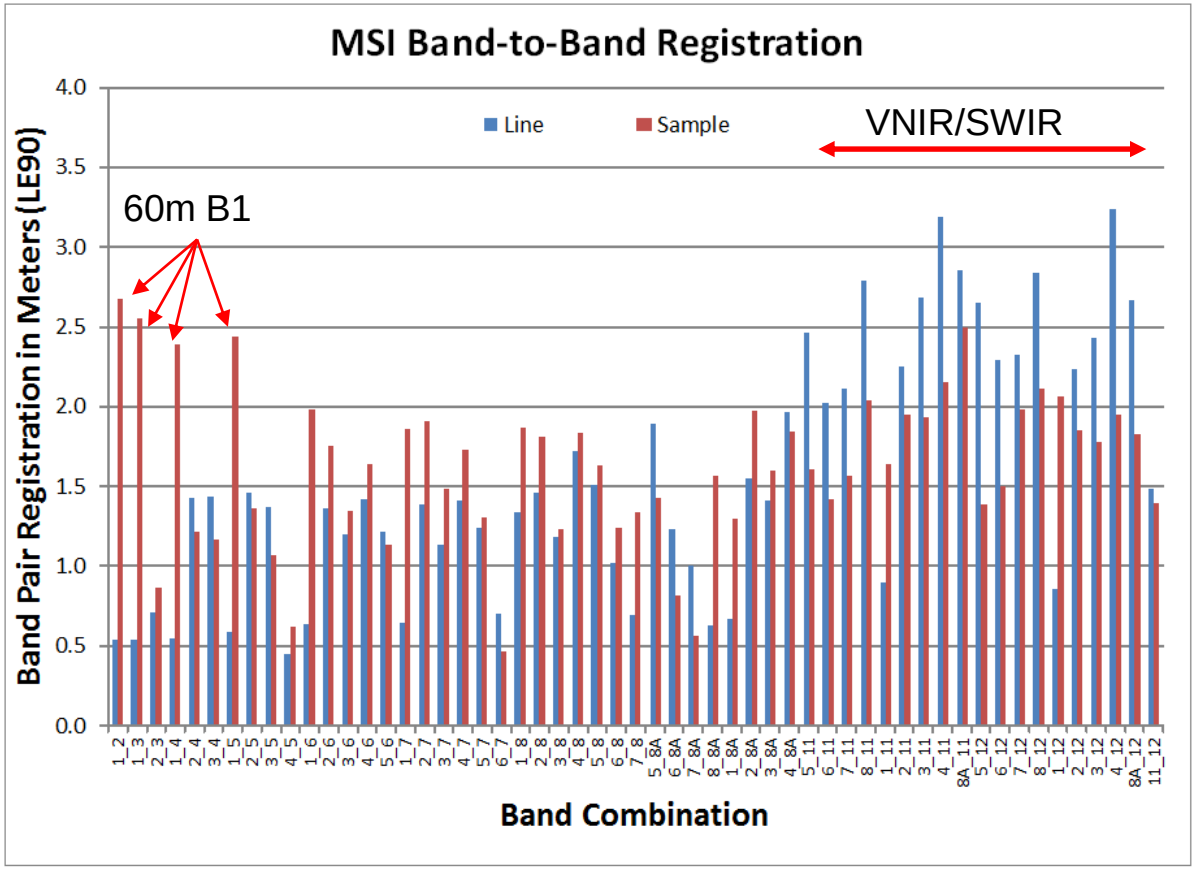
Initial Results
Band-to-Band Registration

- **MSI bands 1, 2, 3, 4, 5, 6, 7, 8, 8A, 11, and 12 measured pairwise after conversion to uniform 20m pixel size.**

- Worst band-pair worst direction registration is 3.24 meters LE90 (B4 to B12), well within Landsat requirements.
- VNIR/SWIR registration shows poorer performance than VNIR/VNIR or SWIR/SWIR.
- Although based upon a small data sample, the results suggest a small (~0.9 meter) common along-track offset in both SWIR bands.



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Expected Landsat/Sentinel-2 Registration

- **The Landsat GLS framework is not being used to constrain the Sentinel-2 geometric reference image (GRI) framework.**
  - **Registration accuracy will thus depend upon the absolute accuracies of the two systems.**
- **The RSS of the GLS (25m RMSEr) and GRI (10m 2σ) accuracies predicts ~37m 2σ registration.**
- **Landsat / Sentinel misregistration of up to several MSI pixels can be expected.**
  - **Better registration is highly desirable and will be demanded by the science community.**
  - **Provides motivation to improve the GLS while making it consistent with the Sentinel-2 GRI framework.**

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GCP Improvement Phase 4
Landsat/Sentinel Harmonization

- **Planning global readjustment of the GLS using L8 data with sparse ties to Sentinel-2 GRI.**
  - **Block areas of up to ~1000 scenes are practical.**
- **Blocks will be designed and run unconstrained (based upon L8 geometry) prior to GRI completion.**
  - **Allows time consuming block layout and scene selection processes to begin immediately.**
- **MSI control will be added when available to support a second, constrained triangulation solution.**
  - **Some MSI control will be withheld to test the triangulation.**
  - **Validate using OLI-MSI image registration measurements.**

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Geometric Harmonization Summary

- **Propose global re-triangulation of the GLS (outside Australia) to improve consistency with Sentinel-2 MSI framework.**
  - **Australian GLS has already been registered to the AGRI reference provided by Geoscience Australia.**
- **Schedule will depend upon availability of Sentinel-2 reference images (GRI).**
  - **Blocks will be worked as GRI become available but will not be released until all are complete.**
- **Updates should mostly be subpixel but will still require complete archive reprocessing / new collection when complete.**

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Backup Charts

Analysis Methods

- **Developed software to convert JPEG2000 L1C tiles to the HDF5 internal format used for Landsat 8 image assessment to facilitate use with existing tools.**
  - **Adjust ground sample distance (GSD), mosaic tiles, convert format.**
  - **Two types of GSD adjustment were used:**
    - **Resample 10m/20m/60m MSI bands to corresponding OLI bands at 15m/30m pixel Landsat product geometry to make "Landsat-like" products for geolocation assessment.**
    - **Convert 10m/20m/60m samples to 20m by pixel aggregation (10m) and replication (60m) for band registration assessment.**
  - **The Landsat 8 HDF5 format is limited to 11 bands so MSI bands 9 and 10 were not assessed.**

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Preprocessed MSI Data

- **The GCP and reference image assessments were performed on "Landsat-like" WRS-2 image units (example image window shown below):**

MSI 4:3:2 @ 30m for R051_199/036

OLI 4:3:2 @ 30m for 199/036

- **All tiles from the same UTM zone for each product were combined in a single mosaic for band registration assessment.**
  - **MSI bands 1, 2, 3, 4, 5, 6, 7, 8, 8A, 11, and 12 were converted to 20m GSD for band-to-band registration assessment.**

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Observations

- **Based upon examination of a set of 9 S2A MSI L1C data sets acquired over Europe, Africa, and North America, the MSI L1C data appear to meet all key Landsat geometric performance requirements. In particular:**
  - **Absolute geolocation accuracy – S2A MSI data could be used in conjunction with Landsat 8 OLI data to improve the accuracy of the GLS ground control point framework. Once the MSI global reference image infrastructure is complete we will need to investigate methods for harmonizing the MSI and GLS geometric references.**
  - **Internal geometric accuracy – S2A MSI data exhibit minimal internal distortion. Residual MSI/OLI offsets should be low frequency biases inherited from the GLS framework.**
  - **Band-to-band registration – S2A MSI L1C band registration appears to be similar to or slightly better than L8 OLI performance, including MSI bands 5, 6, and 7 which have no corresponding OLI band.**
- **S2A MSI data will be geometrically consistent and interoperable with L8 OLI data once residual issues with the Landsat GLS control framework (and possibly with the GLS digital elevation model at high latitudes) are resolved.**

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Sentinel-2 Geometric Reference

- **Sentinel-2 will use a set of global reference images (GRI) to ensure multi-temporal registration.**
- **This reference is being established through a series of continental-scale triangulation blocks of MSI data.**
  - **Highly accurate high-resolution Pleiades imagery is being used as control.**
  - **There is no explicit tie to the (less accurate) GLS.**
- **These blocks will be rolled out over the next ~year.**
  - **Europe is first with other regions to follow.**
  - **Timing will depend upon availability of suitably cloud-free MSI imagery.**

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List of Test Scenes

	Satellite	Scene / Tile	Path/Row / Relative Orbit	Acquisition Date	ROI
Set 1	L8	LC81810402016003LGN00	181/40	1/3/2016	ul_lat=29.319147 ul_lon=23.115119 lr_lat=28.866501 lr_lon=24.109045
	S2A	T34RGT	R007	12/30/2015	
	Hyp	EO1H1810402015364110K0_1T	181/40	12/30/2015	
Set 2	L8	LC81810402016035LGN01	181/40	2/4/2016	
	S2A	T34RGT	R007	1/29/2016	
	Hyp	EO1H1810402016034110K1_1T	181/40	2/3/2016	

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