Monitoring Sentinel-2 MSI Radiometric Stability and Calibration with Landsat-8 OLI

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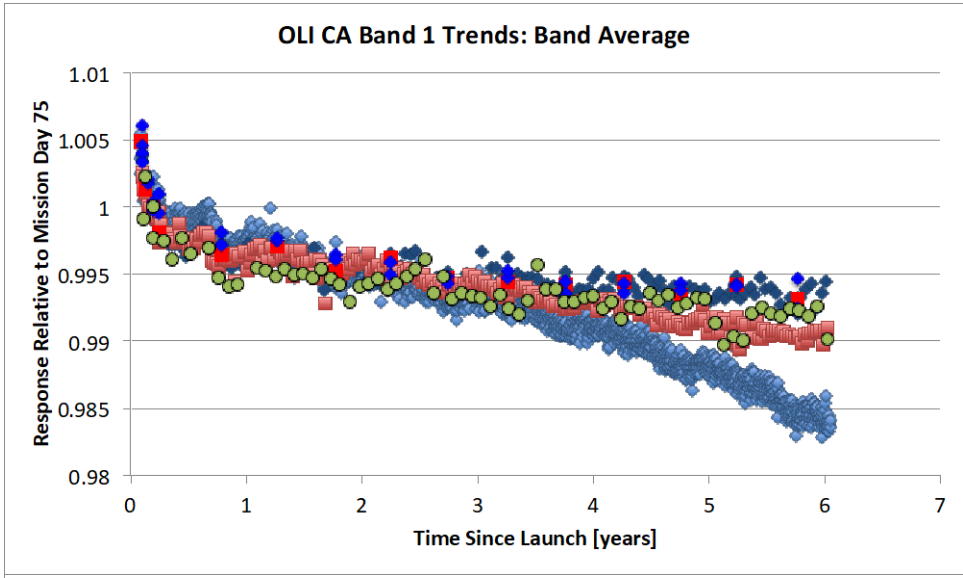
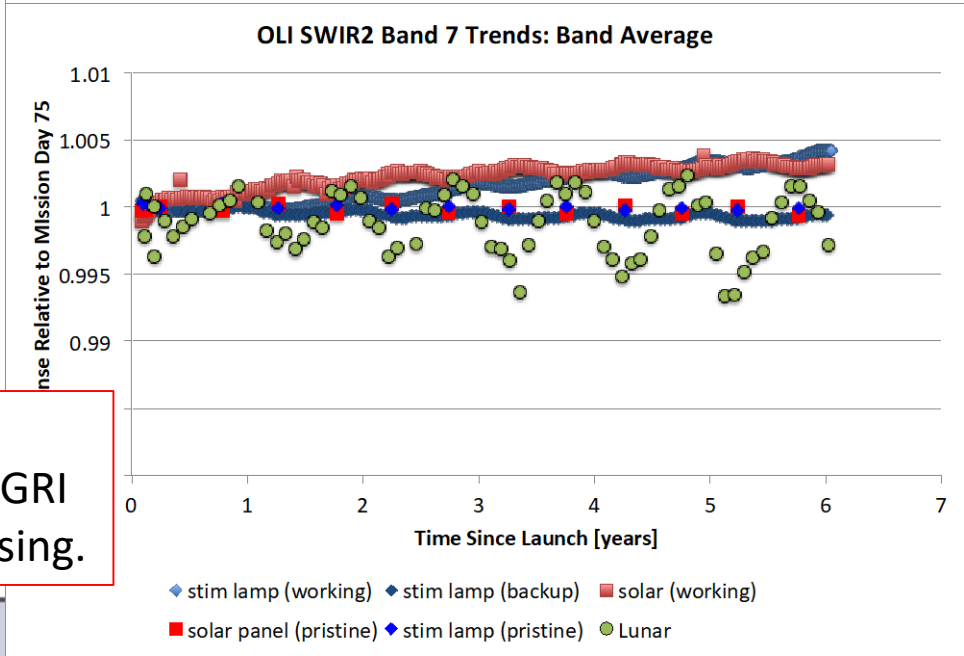
Landsat-8 OLI Calibration Status

- Radiometric calibration monitored by a suite of on-board calibrators
  - Three pairs of lamps
  - Two solar diffuser panels
  - Maneuvers to look at the moon
- Augmented by
  - Vicarious ground measurements
  - PICS
- OLI has been stable to within 1.5% since launch based on best assessment of data
  - Radiometric calibration updates have been made for drift in responsivity in CA and Blue bands
- Collection-2 processing will be started in Fall 2019, but no major radiometric or g

13 Mar 2019: CORRECTION
The USGS does plan to include the GRI for control in Collection-2 reprocessing.





Monitoring MSI with OLI

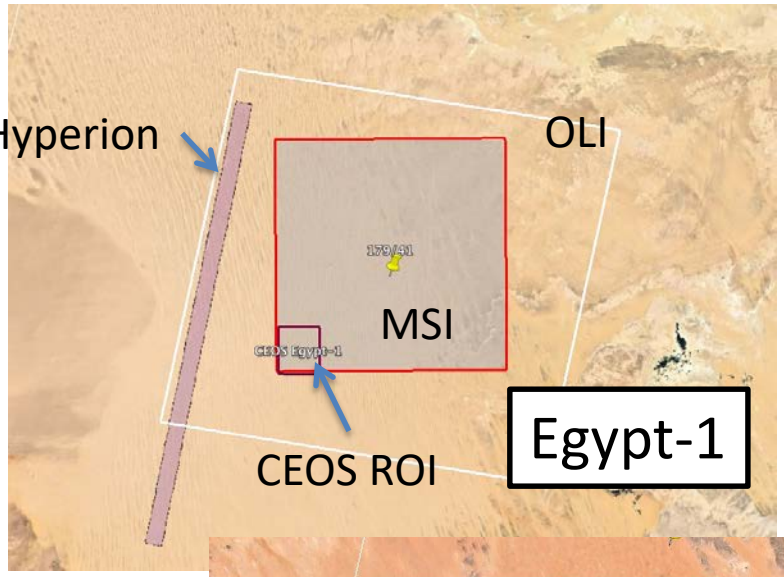
- Desert site cross-calibration
  - Acquisitions within 20 minutes
    - S2A: Libya-4, Algeria-3
    - S2B: Algeria-5, Egypt-1
- Lifetime trending to monitor for drift
    - Libya-4, Sudan-1, Algeria-3, Algeria-5, Egypt-1

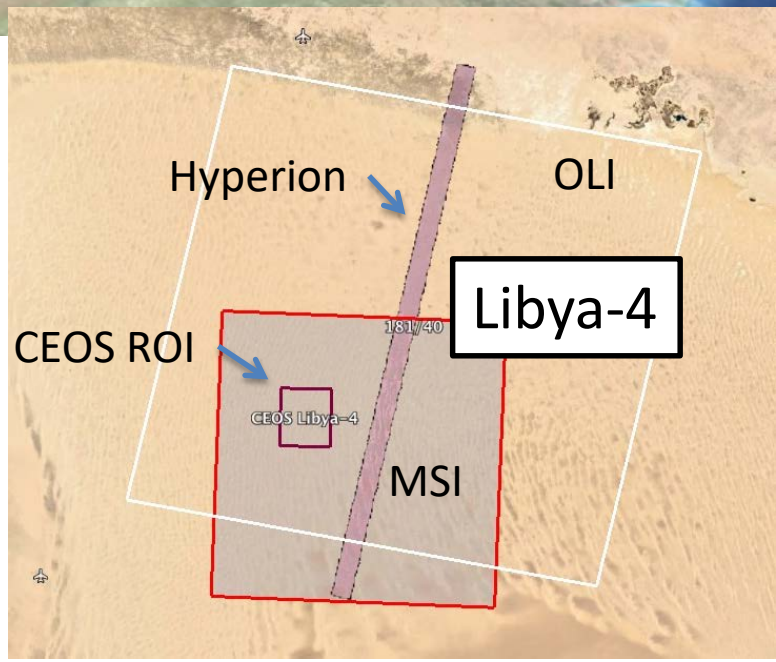
- Note: In this work, I'm only covering bands that MSI and OLI have in common: 1, 2, 3, 4, 8A, 11, 12
  - Recall that there is significant overlap in the spectral bandpasses of the instruments

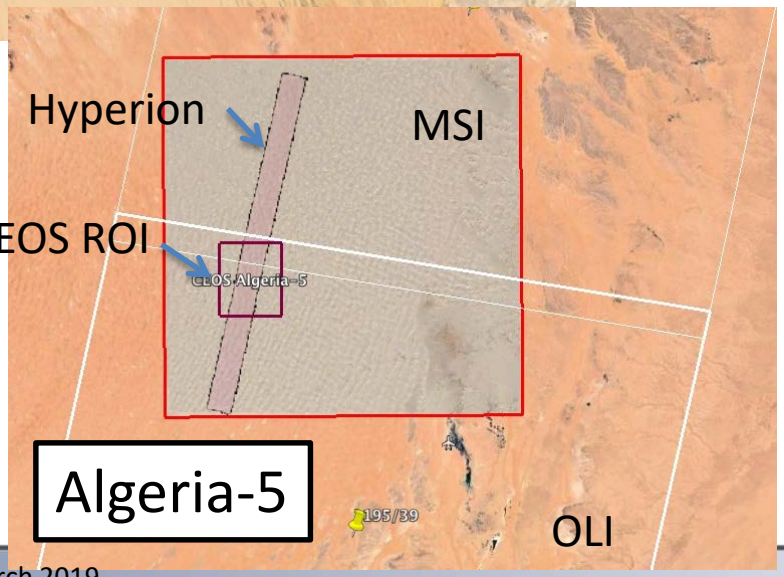
Cross Calibration with OLI

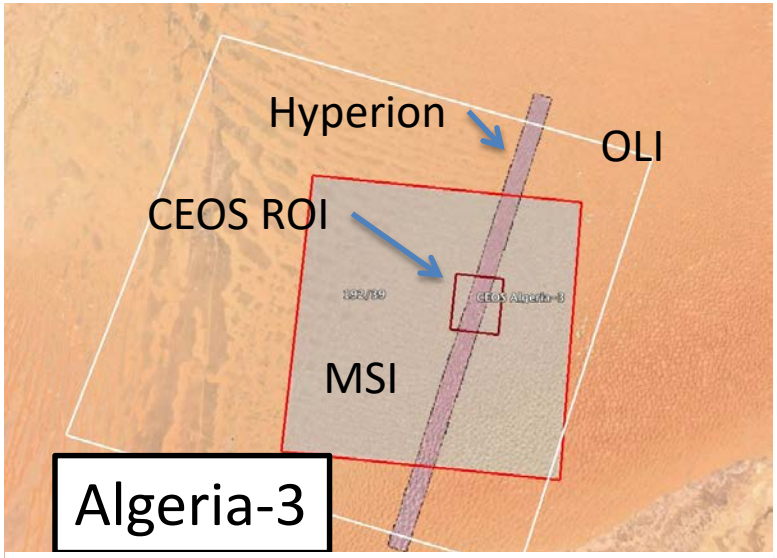
- Use MSI and OLI data over Pseudo Invariant Calibration Sites (PICS)
  - More than 95% overlap between acquisitions so view angles are within a couple of degrees
  - All Sentinel data retrieved from scihub or EarthExplorer.
    - Includes data processed with v2.01-2.07 of processing system.
  - All OLI processed by Collection-1 processing system
- Extract Region of Interest from images
  - CNES defined region, ~20x20km
- Compute TOA reflectances for both
- Apply Spectral Band Adjustment Factor (SBAF) to make MSI reflectances “OLI-like”
  - Makes use of Hyperion data
- Compare reflectances directly

PICS Regions









Exact regions defined in the backup slides

Reflectance Calculation

- For each band:
- OLI TOA reflectance

$$\rho_{OLI} = \frac{M * Q_{cal} + A}{cos\theta}$$

  - Where:
    - ρ_{OLI} is top-of-atmosphere reflectance
    - M and A are reflectance scaling factors in metadata
    - Q_{cal} is image digital count
    - θ is solar zenith angle (90-solar elevation angle from metadata or for ROI)

- MSI TOA reflectance

$$\rho_{MSI} = \frac{Q_{cal}}{QUANTIFICATION\_VALUE}$$

  - Where:
    - ρ_{MSI} is top-of-atmosphere reflectance
    - Q_{cal} is image digital count
    - QUANTIFICATION_VALUE is provided in the metadata

- Convert MSI TOA reflectance to OLI equivalent reflectance

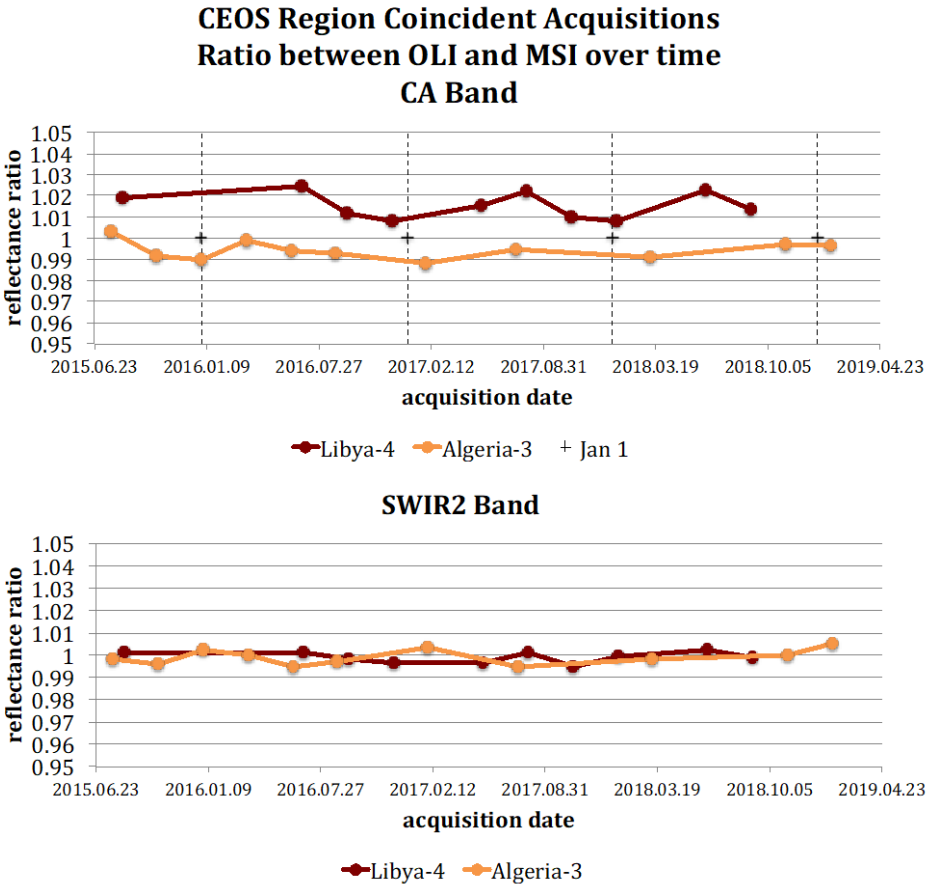
$$\rho'_{MSI} = \rho_{MSI} * SBAF$$

Cross Calibration Coincident Overpass Results Sentinel-2A

- Reflectance ratio:

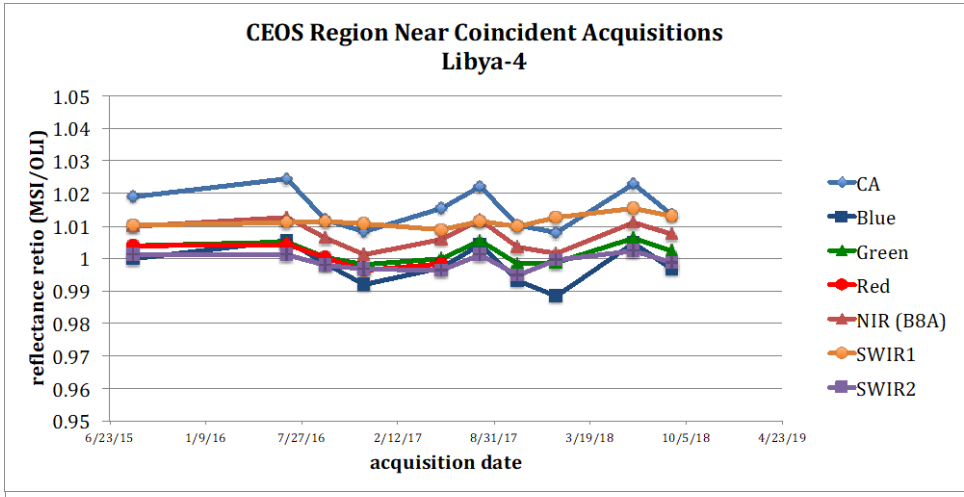
$$r = \frac{\rho'_{MSI}}{\rho_{OLI}}$$

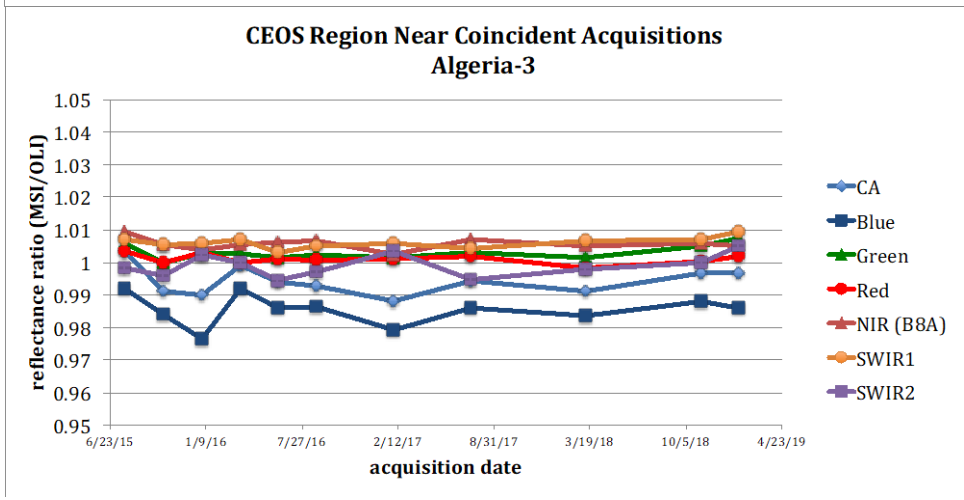
- Seasonal differences between the instruments for Libya-4 in the VNIR bands
- Offset between Algeria-3 and Libya-4 for CA and Blue
- Better agreement in all other bands



Cross Calibration Coincident Overpass Results Sentinel-2A

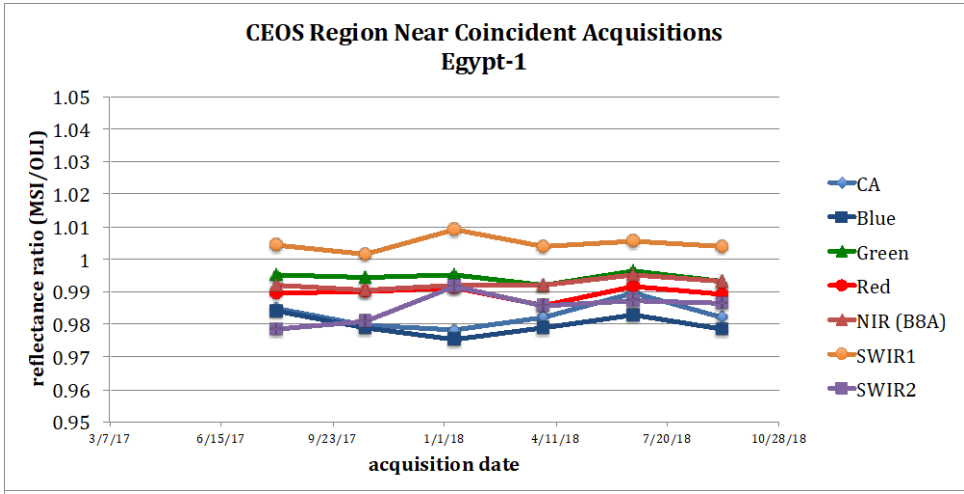
- OLI and MSI agree within 0.2% in Green, Red, and SWIR2, 0.7% in NIR (B8A) and 1.2% in SWIR1
- There are larger differences in the CA and Blue, of 0.5-1.5%.
  - However, within a site the results are consistent to within 0.6% (1σ).
- Not a significant change since last meeting

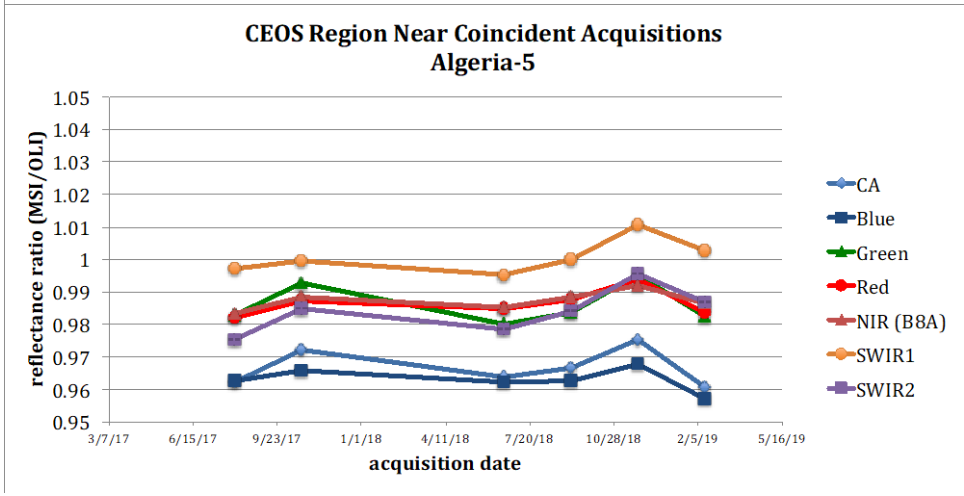




Cross Calibration Coincident Overpass Results Sentinel-2B

- OLI and S2B MSI do not agree as well.
- Green, Red, NIR, SWIR1, SWIR2 are different by 0.6-1.6%
- Differences in CA and Blue are between 1.7 and 3.7%.
  - Again, sites are different but within a site, the results are consistent to within 0.6% (1σ).



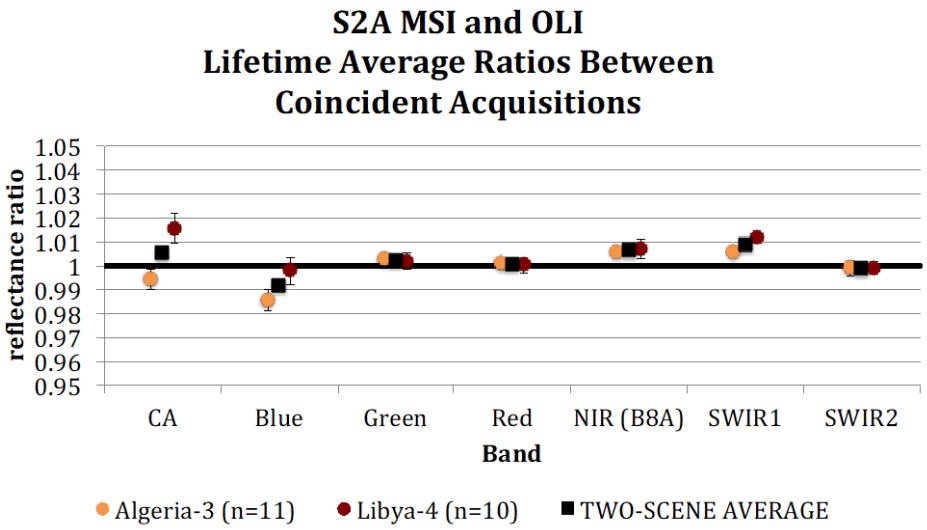


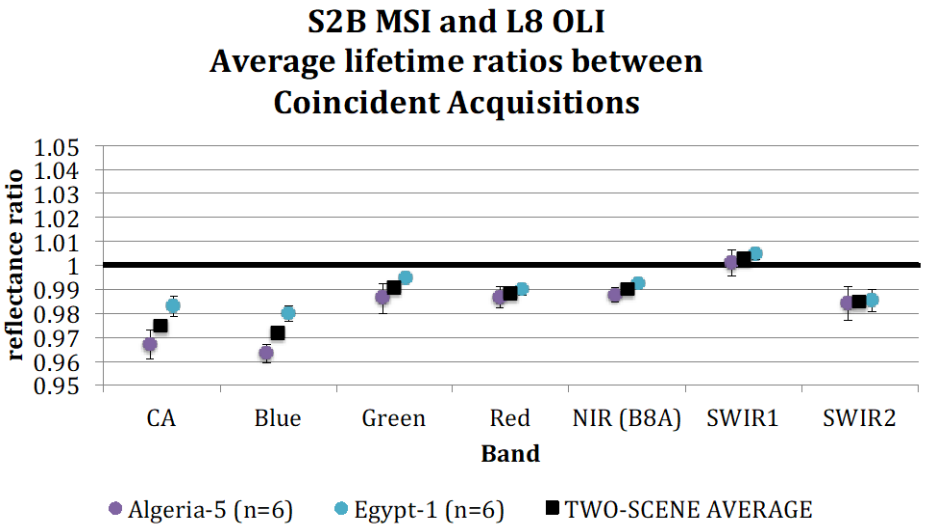
Cross Calibration Coincident Overpass Results Sentinel-2A and -2B

- Overall, the trends are holding since the last meeting

S2A scenes added since last meeting:
Algeria-3: +3
Libya-4: +2

S2B scenes added since last meeting:
Algeria-5: +4
Egypt-1: +3





PICS Lifetime Trending

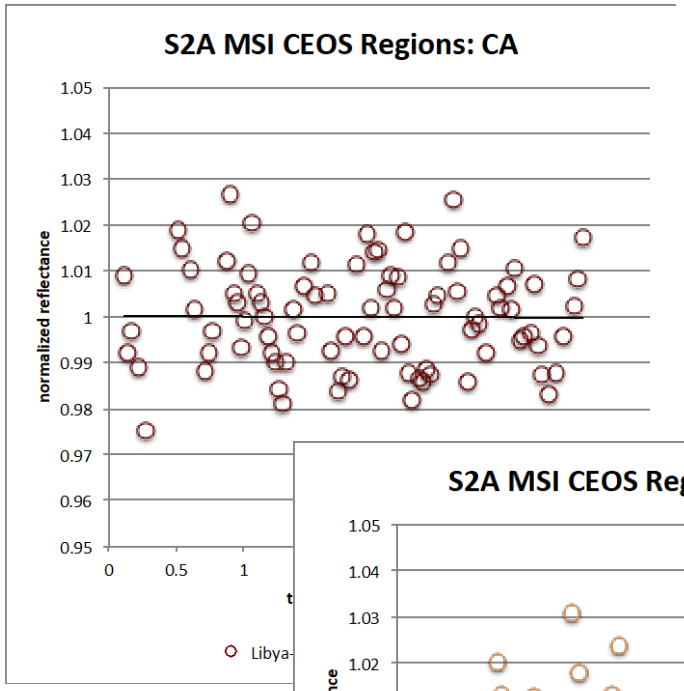
- Monitor stability of the instruments using PICS trends
  - Libya-4, Sudan-1, Algeria-3
  - **Added Algeria-5 and Egypt-1 to lifetime trending**
  - Generate trend for each site separately

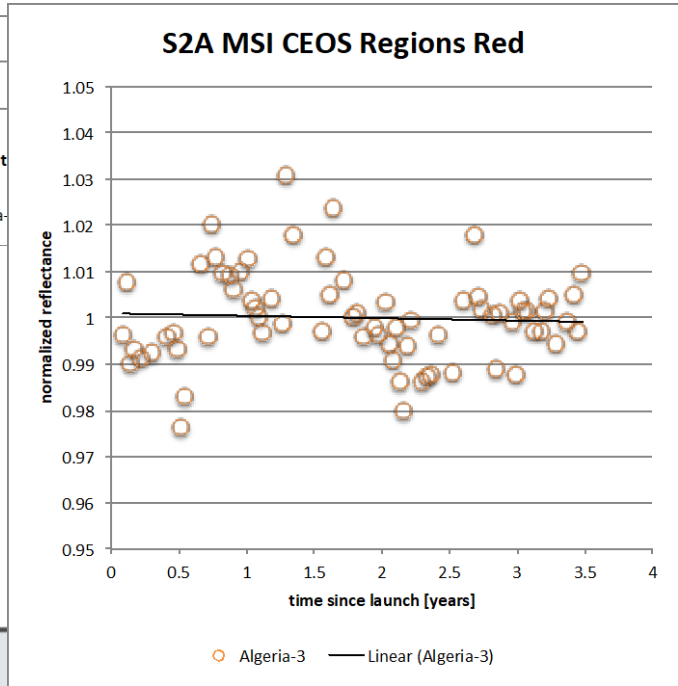
- ETM+ long-term calibration has been updated based on PICS trends
- OLI long-term stability is monitored with PICS

- Added S2B trending since last meeting

PICS Lifetime Trending

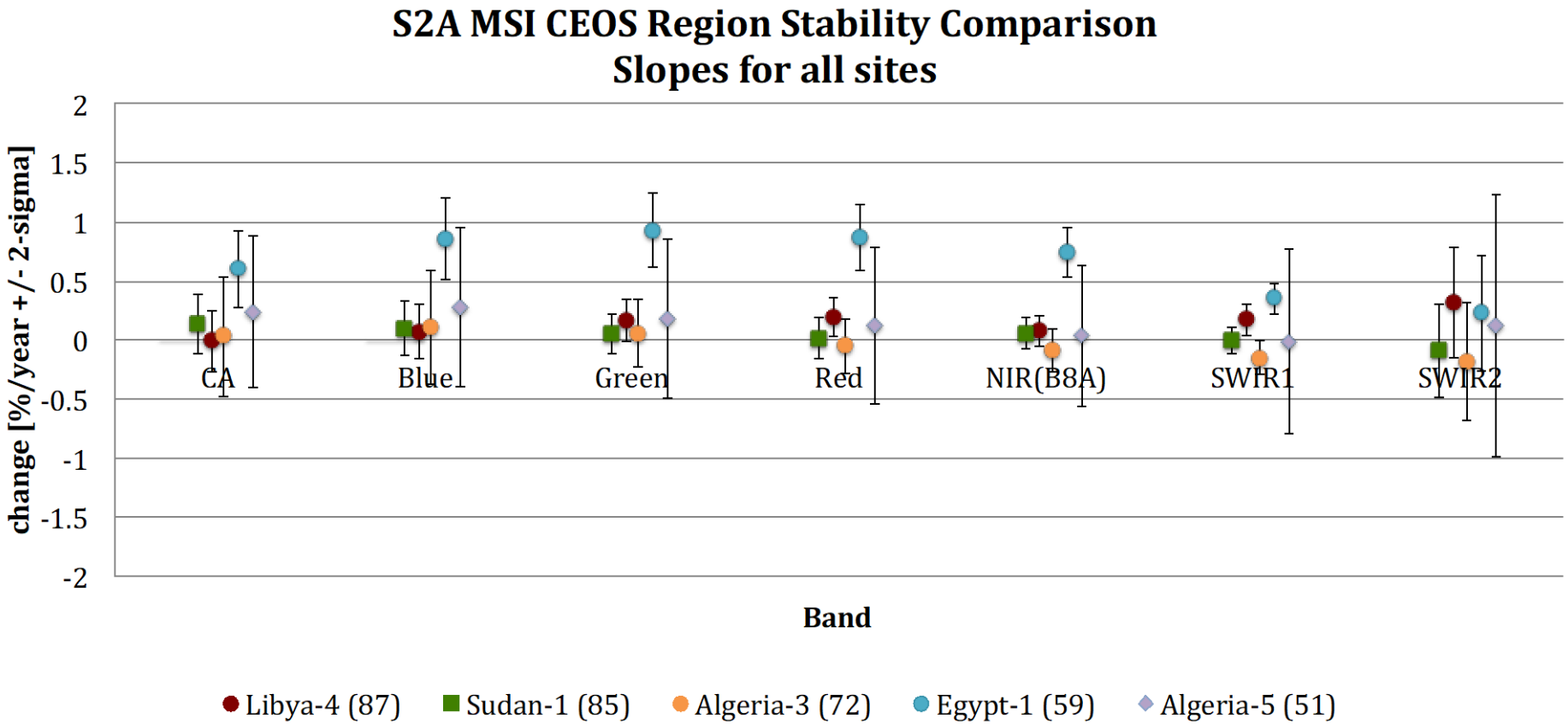
- For each site, accumulate all cloud-free region-of-interest averages
- Correct TOA reflectance for solar zenith angle
  - Empirical adjustment to normalize to a standard reference angle. Accounts for some of the seasonal differences.
- Normalize all site reflectance data to 1
- Calculate slope over time, determine 2-sigma uncertainty of slope





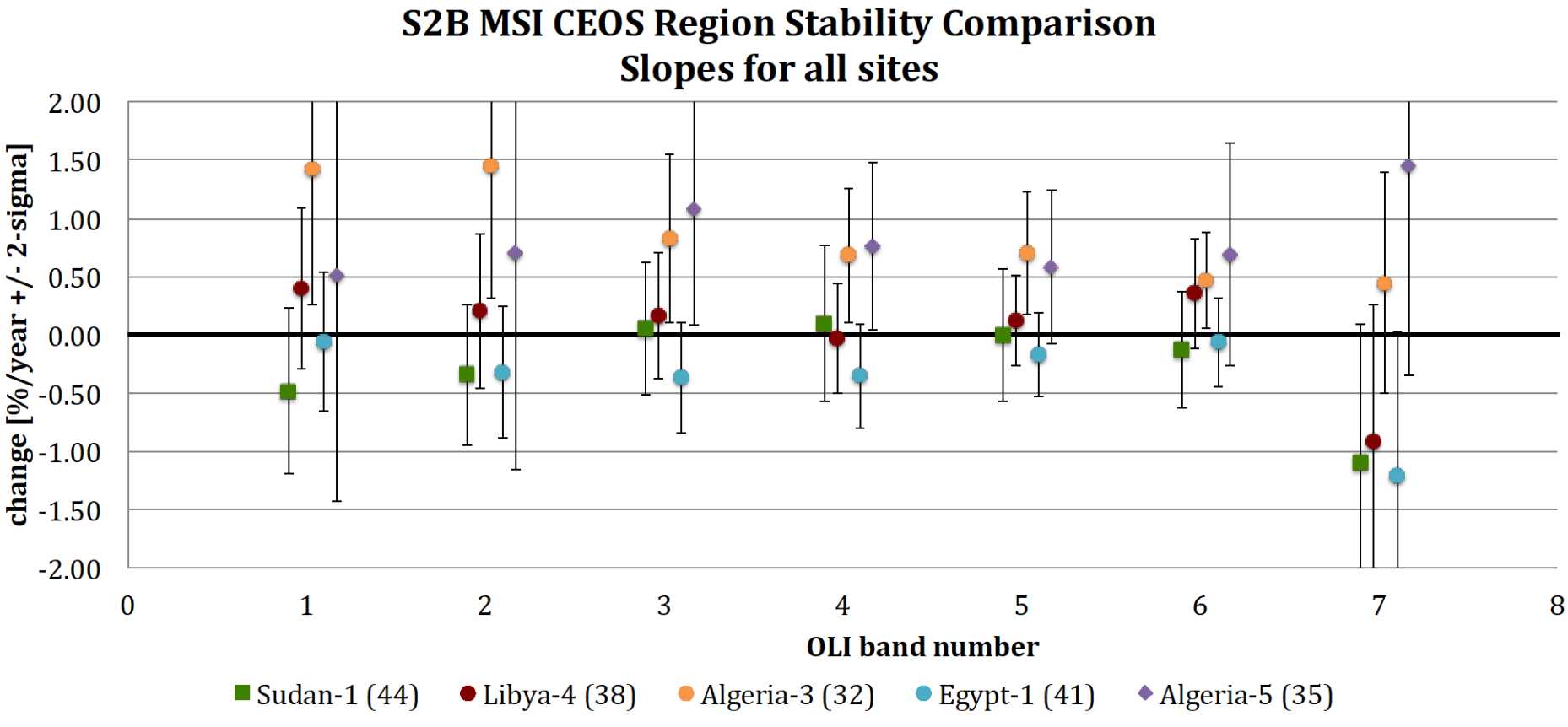
S2A PICS Lifetime Trending

- Trending over 3.5 years indicates S2A MSI is stable to within 0.5% based on my trusted sites
  - Egypt-1 is not stable but results are replicated by OLI



S2B PICS Lifetime Trending

- Have just under 2 years of data, so uncertainties are large.
- S2B patterns are not significantly different than OLI trends over the same time period



2018 Publications

- Julia A. Barsi, Bahjat Alhammoud, Jeffrey Czapla-Myers, Ferran Gascon, Md. Obaidul Haque, Morakot Kaewmanee, Larry Leigh & Brian L. Markham (2018) Sentinel-2A MSI and Landsat-8 OLI radiometric cross comparison over desert sites, European Journal of Remote Sensing, 51:1, 822-837, DOI: 10.1080/22797254.2018.1507613

- Helder, D.; Markham, B.; Morfitt, R.; Storey, J.; Barsi, J.; Gascon, F.; Clerc, S.; LaFrance, B.; Masek, J.; Roy, D.P.; Lewis, A.; Pahlevan, N. Observations and Recommendations for the Calibration of Landsat 8 OLI and Sentinel 2 MSI for Improved Data Interoperability. *Remote Sens.* **2018**, *10*, 1340

Conclusions

- Coincident overpasses of pseudo-invariant calibration sites allows for cross calibration with OLI
  - S2A MSI calibration is within 1% for most bands as compared to OLI. Larger difference of up to 1.5% remain in CA and Blue.
  - S2B MSI calibration is generally within 1.5% of OLI, though results appear to have a bias relative to S2A

- PICS lifetime trending
  - S2A MSI calibration is stable to within 0.5%
  - Results for S2B are generally consistent with OLI for the same time period.
    - Another year of data will be helpful

Landsat-9 OLI-2 Progress

- OLI-2 will effectively be a clone of OLI
  - Identical focal plane, telescope, spectral coverage
  - Primary difference is that the OLI-2 downlink will retain all 14-bits
- Build is complete
  - Instrument-level radiometric, spectral and spatial tests were completed Aug-Dec 2018
    - See GLAMR poster for details on spectral characterization
  - Performance is comparable to OLI based on preliminary assessments
- Delivery to spacecraft vendor scheduled for Summer 2019
- Launch scheduled for Dec 2020
- Will occupy the Landsat-7 orbit
  - 8-day coverage between Landsat-8 and -9
  - Landsat-7 will be moved

Backup slides

Data sources

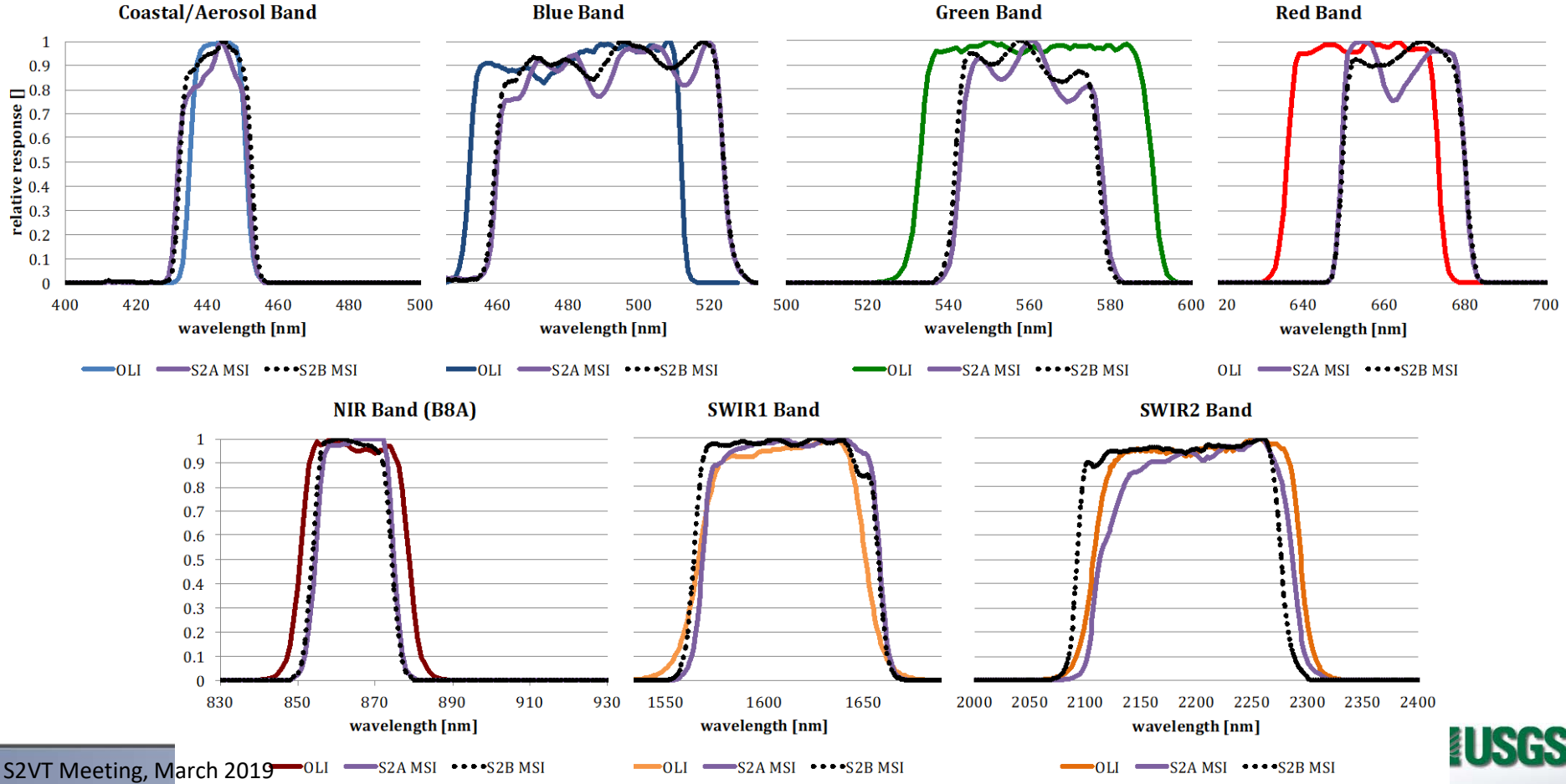
- Sentinel-2 data
  - Scihub, Processing versions 2.01 - 2.06
- Landsat-8 OLI data
  - USGS, Processing version Collection 1
- Test sites: CEOS pseudo-invariant calibration sites
  - Libya-4, Sudan-1, Algeria-3, Algeria-5, Egypt-1
- No additional measurements were performed

Data sources

Site	Center (latitude, longitude)	CEOS site corners (latitude, longitude)	Landsat Path/Row	Sentinel Tile
Libya-4	28.55, 23.39	28.65, 23.29 28.65, 23.49 28.45, 23.49 28.45, 23.29	181/40	34RGS
Sudan-1	21.9, 28.0	22.00, 27.90 22.00, 28.10 21.80, 28.10 21.80, 27.90	177/45	35QNE, 35QPE
Algeria-3	30.32,7.66	30.42, 7.56 30.42, 7.76 30.22, 7.76 30.22, 7.56	192/39	32RLU
Algeria-5	31.02, 2,23	31.12, 2.13 31.12, 2.33 30.92, 2.33 30.92, 2.13	195/39	31RDQ
Egypt-1	27.12, 26.1	27.22, 26.0 27.22, 26.2 27.02, 26.2 27.02, 26.0	179/41	35RML

OLI, MSI Spectral Overlap

- MSI Bands have significant spectral overlap with OLI bands
- S2A v3 RSRs has improved overlap in CA, Blue bands



SBAF Results

- Hyperion region is not the same as the CNES region but is contained within the same Landsat scene.
  - Only limited dates available
  - Acquisition time is changing as the EO-1 orbit degrades.
  - EXAMPLE of acquisition times:

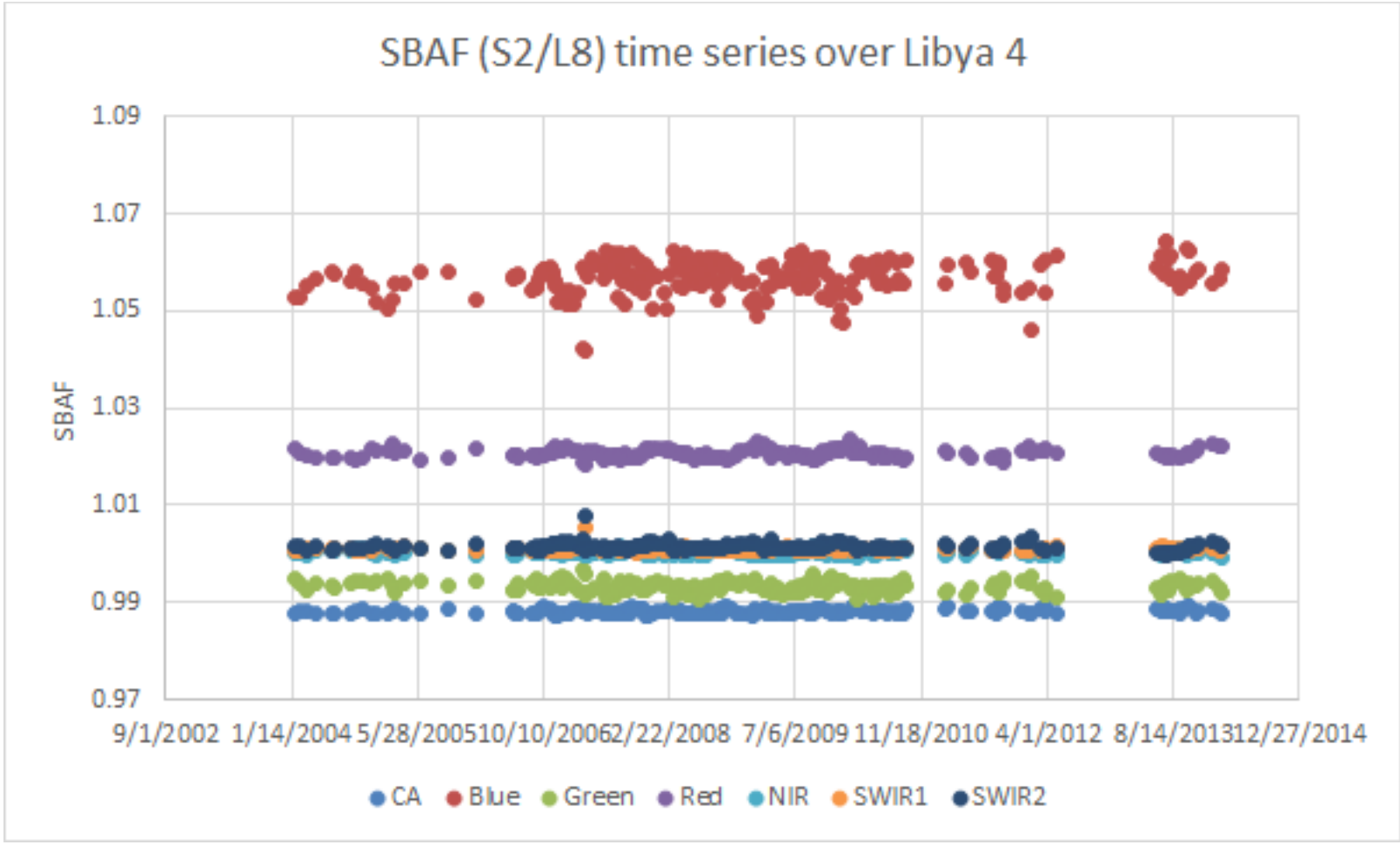
Site	Hyperion Acquisition Date	Hyperion Acquisition Time (UTC)	Typical OLI Acquisition Time (UTC)
Libya4	28 Jul 2015	07:20	08:55
Libya4	7 Sep 2015	07:28	
Sudan1	6 Oct 2015	06:58	08:32
Algeria3	10 Aug 2013	09:26	10:02
Algeria3	21 Jan 2014	09:19	

SBAF Results

- Hyperion acquisitions used for SBAF

Region	Date range	N	MSI ViewAngle (zenith)	OLI ViewAngle (zenith)
Libya-4	2015.06.04 – 2016.10.27	17	5.72	3.22
Algeria-3	2013.08.10, 2014.01.21	2	5.56	3.72
Sudan-1	2015.10.06	1		
Algeria-5	2012.02.20 – 2013.02.02	5		
Egypt-1	2015.06.28 – 2016.08.14	8		

SBAF Stability



Spectral Band Adjustment Factor

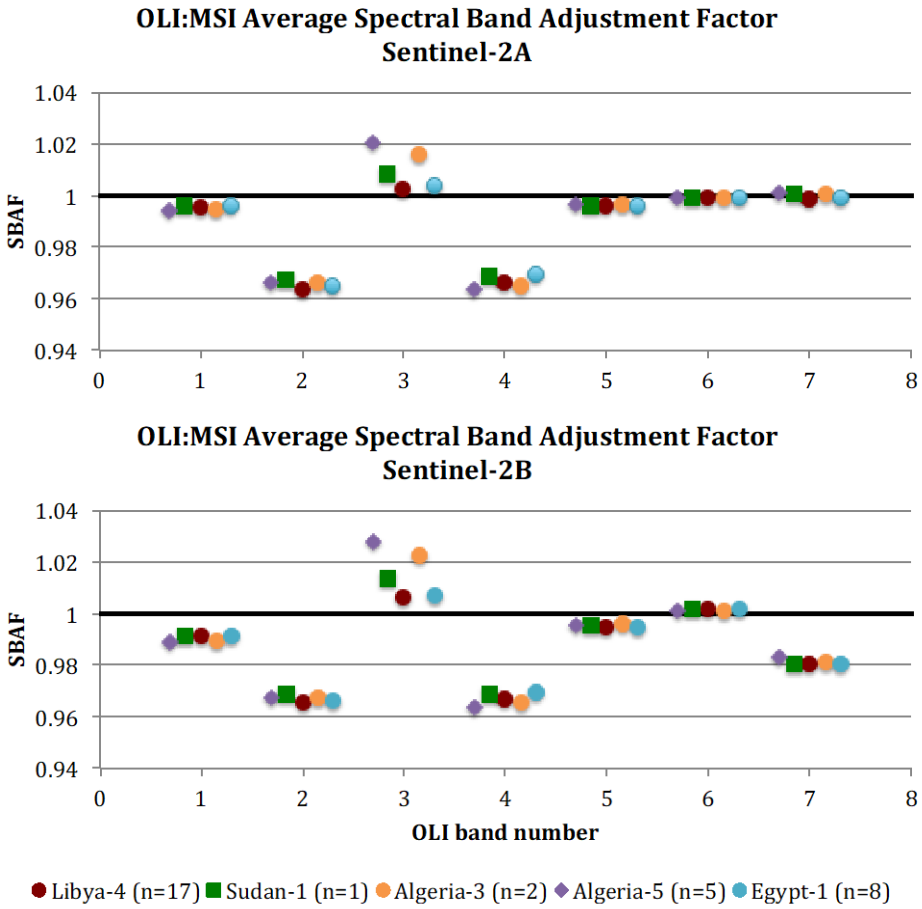
- To compare MSI reflectances to OLI reflectances, convert MSI reflectances to equivalent OLI reflectances through Hyperion

$$SBAF = \frac{\hat{\rho}_{OLI}}{\hat{\rho}_{MSI}} = \frac{\frac{\int \rho_H(\lambda) RSR_{OLI}(\lambda) d\lambda}{\int RSR_{OLI}(\lambda) d\lambda}}{\frac{\int \rho_H(\lambda) RSR_{MSI}(\lambda) d\lambda}{\int RSR_{MSI}(\lambda) d\lambda}}$$

- where:
  - $\rho_H(\lambda)$ is TOA reflectance of the target area from Hyperion
  - $\hat{\rho}_{OLI}$ and $\hat{\rho}_{MSI}$ are simulated TOA reflectances
  - $RSR_{OLI}(\lambda)$ and $RSR_{MSI}(\lambda)$ are the relative spectral responses

SBAF Results

- Robustness of SBAF depends on the availability of cloud-free Hyperion data
  - EO-1 has been decommissioned, so there will be no new Hyperion data
- SBAF is calculated per-band, per-target. SBAFs are not transferrable to other targets.
- S2A SBAFs have been recalculated with the v3 RSRs.
- Four bands have spectral differences of less than 1%. Blue and Red bands have significant spectral differences (4.5%). Green difference is more variable across regions (1-3%)



Near Simultaneous Overpasses

- Using orbital models, find scenes where OLI and MSI have good overlap
  - Same day acquisition
  - More than 95% of OLI frame is covered by MSI swath
  - Similar view angles

Site	OLI Image Time (average)	MSI Image Time (predicted by orbital model)	MSI View Angles (average Blue band) Zenith/Azimuth	OLI View Angles (average Blue band) Zenith/Azimuth
Libya-4 34RGS	08:54	09:12	5.73/ 97.63	3.25/ 102.06
Algeria-3 32RLU	10:02	10:22	5.56/ 277.72	3.72/ 277.96