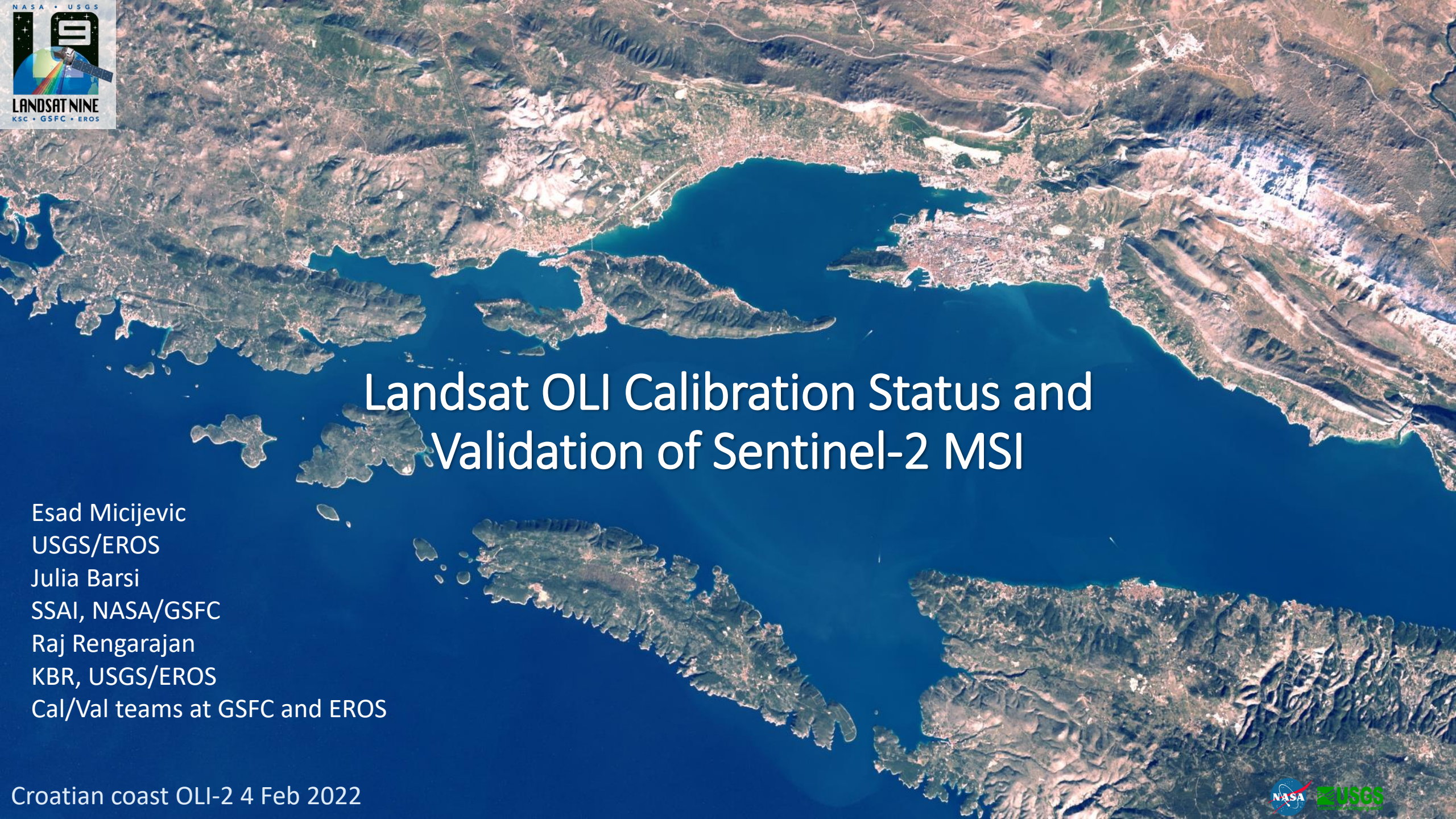

Landsat OLI Calibration Status and Validation of Sentinel-2 MSI

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USGS/EROS
Julia Barsi
SSAI, NASA/GSFC
Raj Rengarajan
KBR, USGS/EROS
Cal/Val teams at GSFC and EROS

Croatian coast OLI-2 4 Feb 2022

Outline

- Landsat Status
  - Radiometric stability
  - Solar diffuser stability
- Radiometric cross-calibration of MSI with Landsat
- Radiometric stability monitoring using PICS
- Co-registration Assessment of Archived Landsat-8 and Sentinel-2 orthorectified products
- Summary

Landsat Mission Status

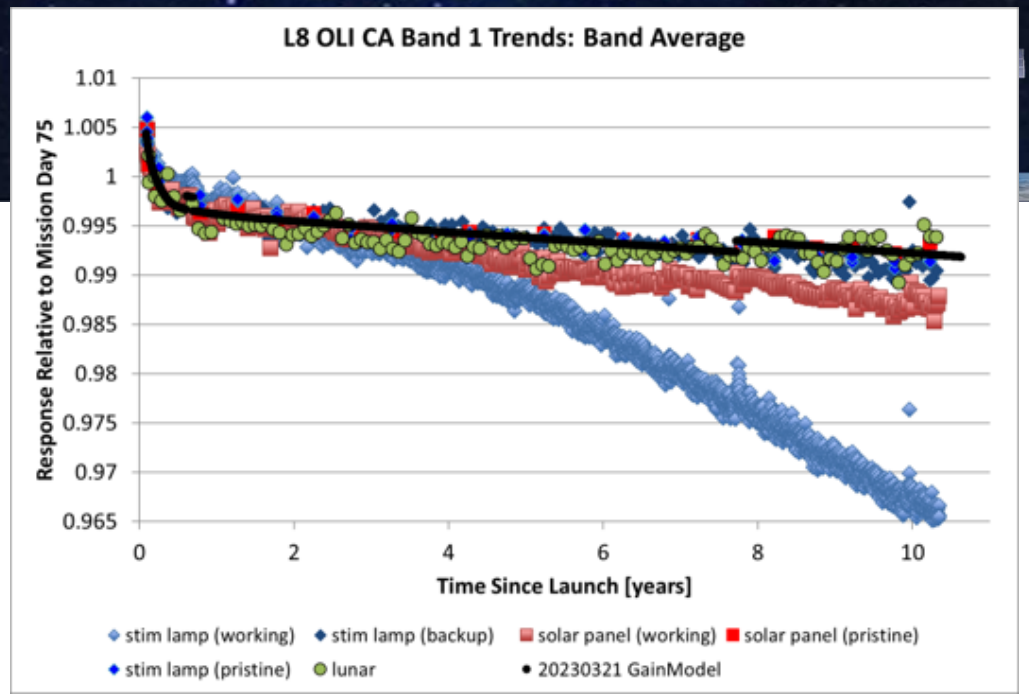
- Landsat-9 launched 2 years ago
  - Spacecraft transmits all 14-bits of OLI data to improve radiometric accuracy for dark targets
  - L9 TIRS does not have the stray light feature present in L8 TIRS
  - Both instruments are performing to better than requirements
- Landsat-8 launched 10 years ago
- Landsat-7 ETM+ still operating
  - Mean equatorial crossing time as of Sep 2023: 07:55 am
  - nominal science mission has ended
  - Data are still being acquired and distributed
- Landsat mission ground station at EROS celebrated 50-year anniversary this year.

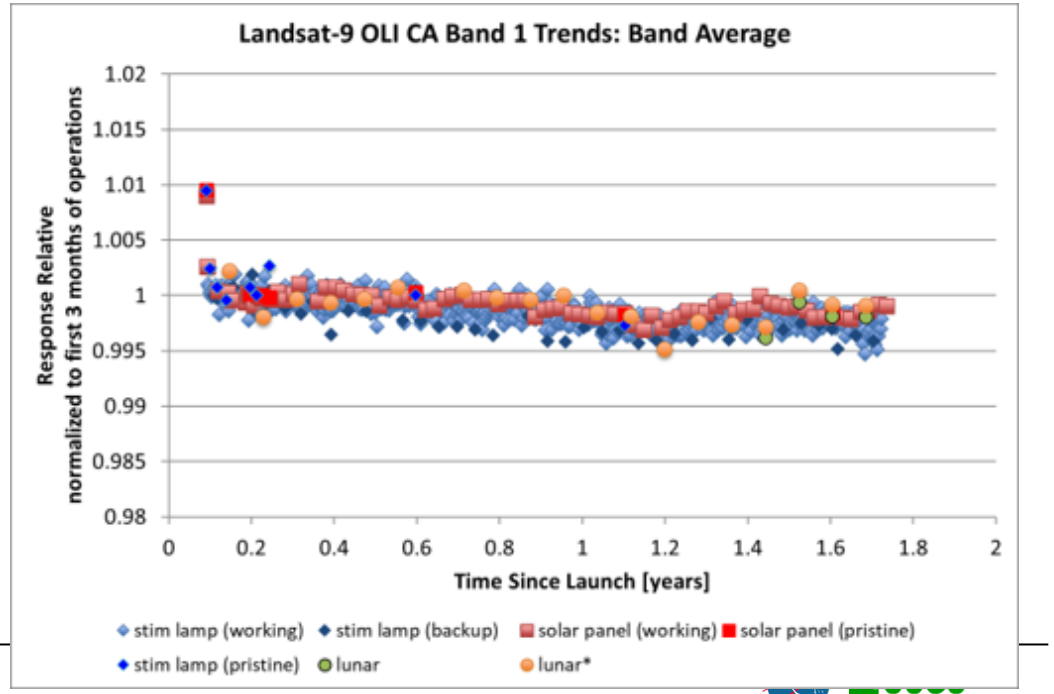
A 1970 site selection graphic indicating the best site for an antenna to receive Landsat signal when the satellite is acquiring data over the continental US.

Picture of USGS/EROS 50th celebration

Landsat OLI Radiometric Calibration Status

- Radiometric calibration is 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
- Landsat-8 OLI has been stable to with ~1.3% since launch based on best assessment of on-board calibrators data
  - The absolute calibration of CA (Band 1) and Blue (Band 2) is actively adjusted to account for drift. The other bands are largely unchanged.
- Landsat-9 OLI has been more stable since launch than OLI was
  - The exponential decay in CA seen in OLI is not apparent
  - On-board calibration is stable to better than 0.2% across all bands
- UNDERFLY update #1: Landsat-9 OLI radiometric calibration was updated in Jan 2022 to account for radiometric offset between L8 OLI and L9 OLI. L9 archive was reprocessed before the release of data to public.
- UNDERFLY update #2: Further study indicated small adjustments to the radiometric offset would be beneficial. Entire L9 archive was reprocessed to account for the change in March 2023.

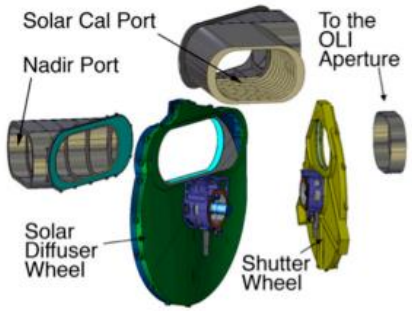




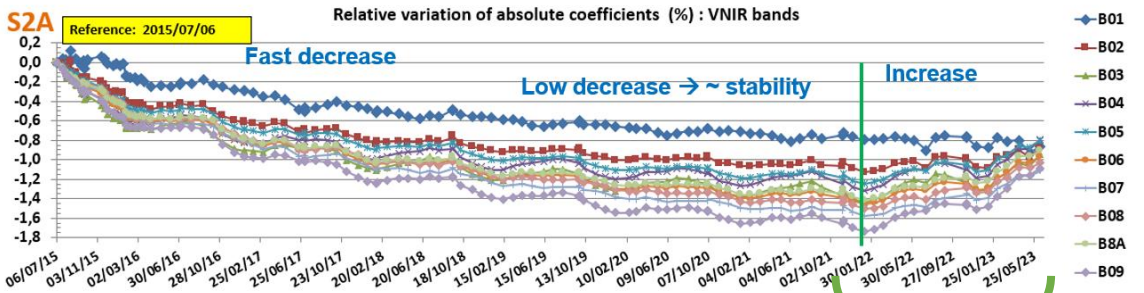
Solar Diffuser Stability

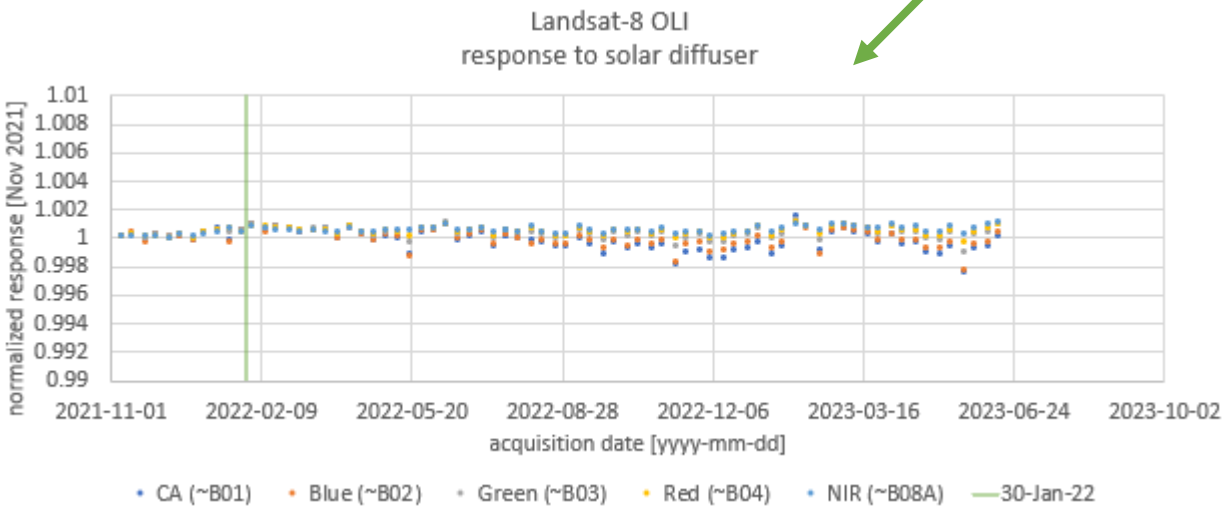
- June 2023: questions about S2 increase in response to solar diffuser
- OLI instruments have two solar diffusers

Working panel is used ~weekly
Pristine panel is used semi-annually
Diffusers are stowed inside the Calibration Assembly when not in use.



- None of the OLI diffusers indicates solar change of the magnitude indicated by the Sentinel plot



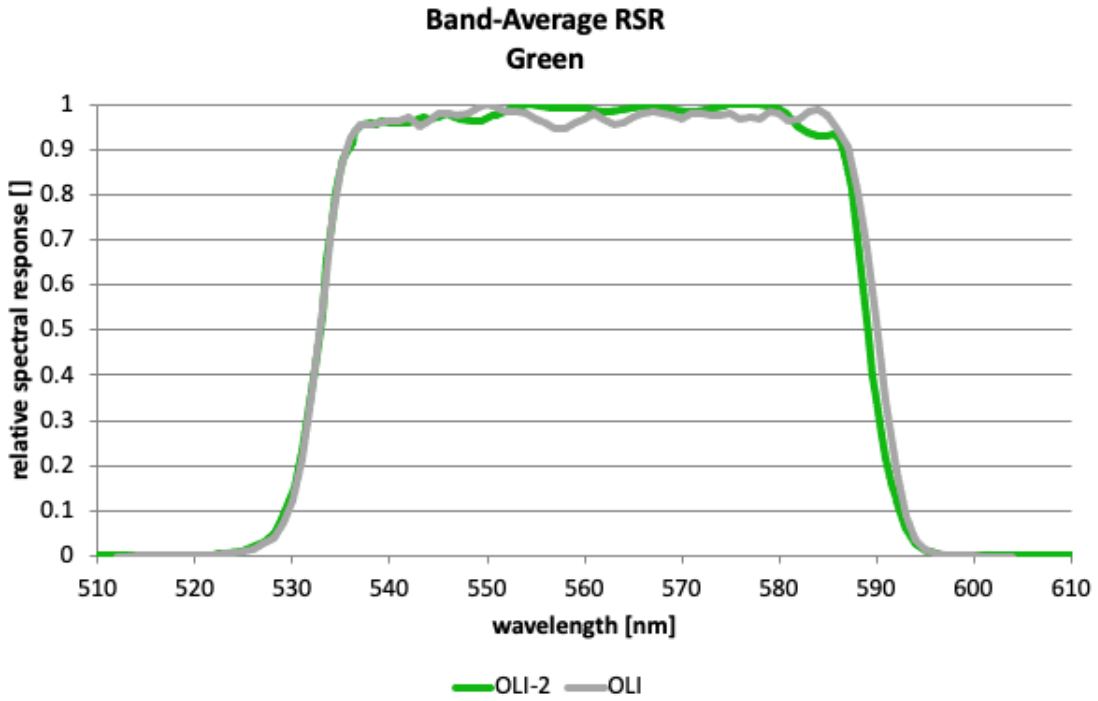


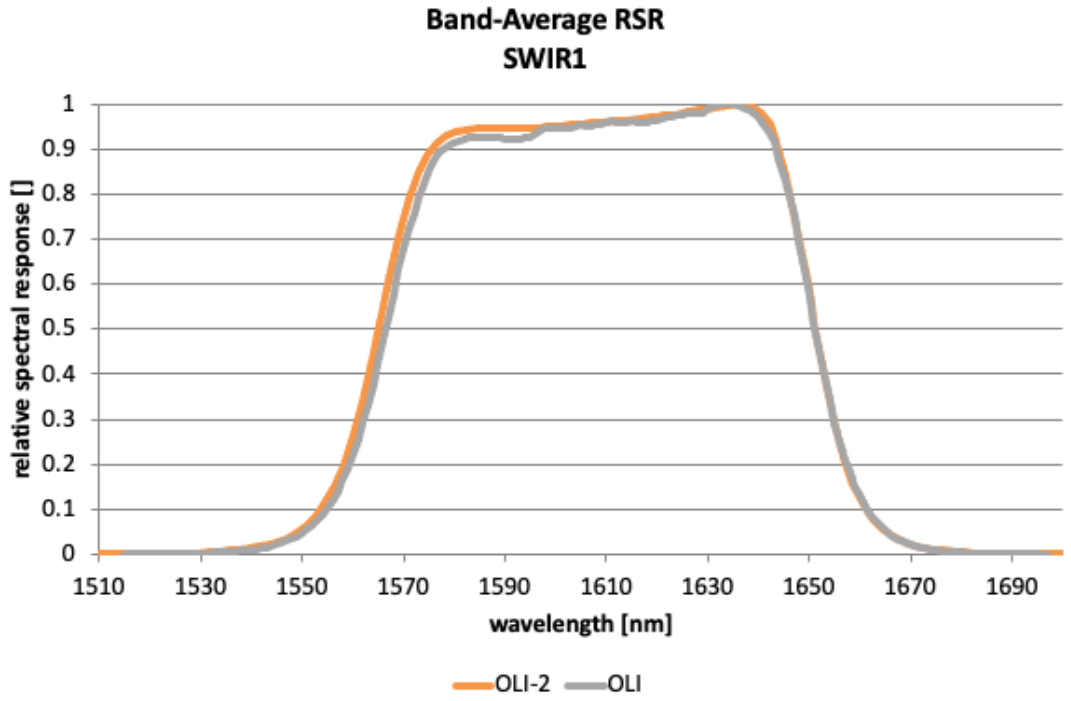
Landsat Relative Spectral Response

- L8 and L9 OLI spectral curves available at the NASA/GSFC and USGS websites

  https://landsat.gsfc.nasa.gov/satellites/landsat-9/landsat-9-instruments/oli-2-design/oli-2-relative-spectral-response
  https://landsat.usgs.gov/spectral-characteristics-viewer

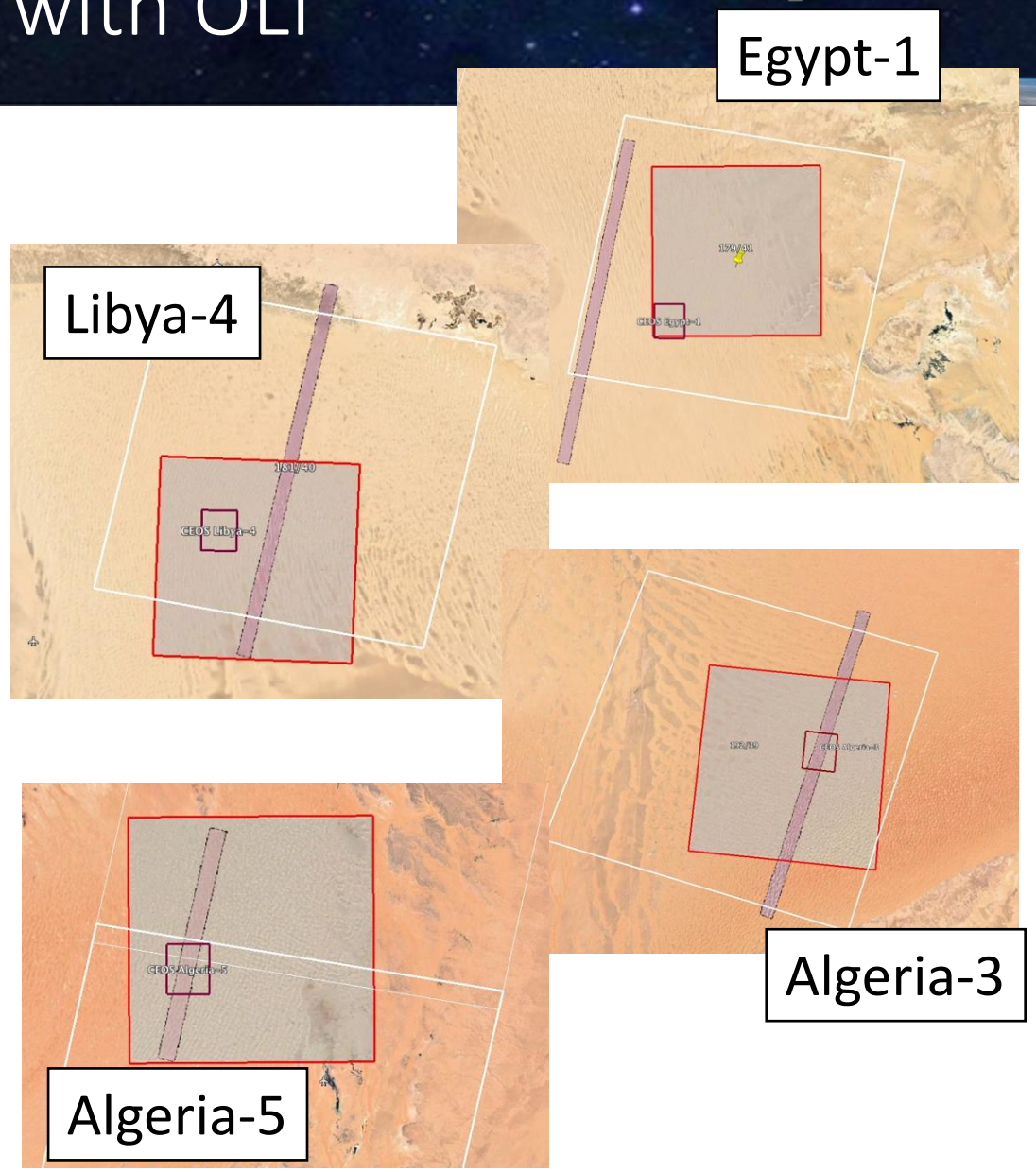
- OLI and OLI-2 are close spectral matches given the spectral filters and the detectors came from the same production lots





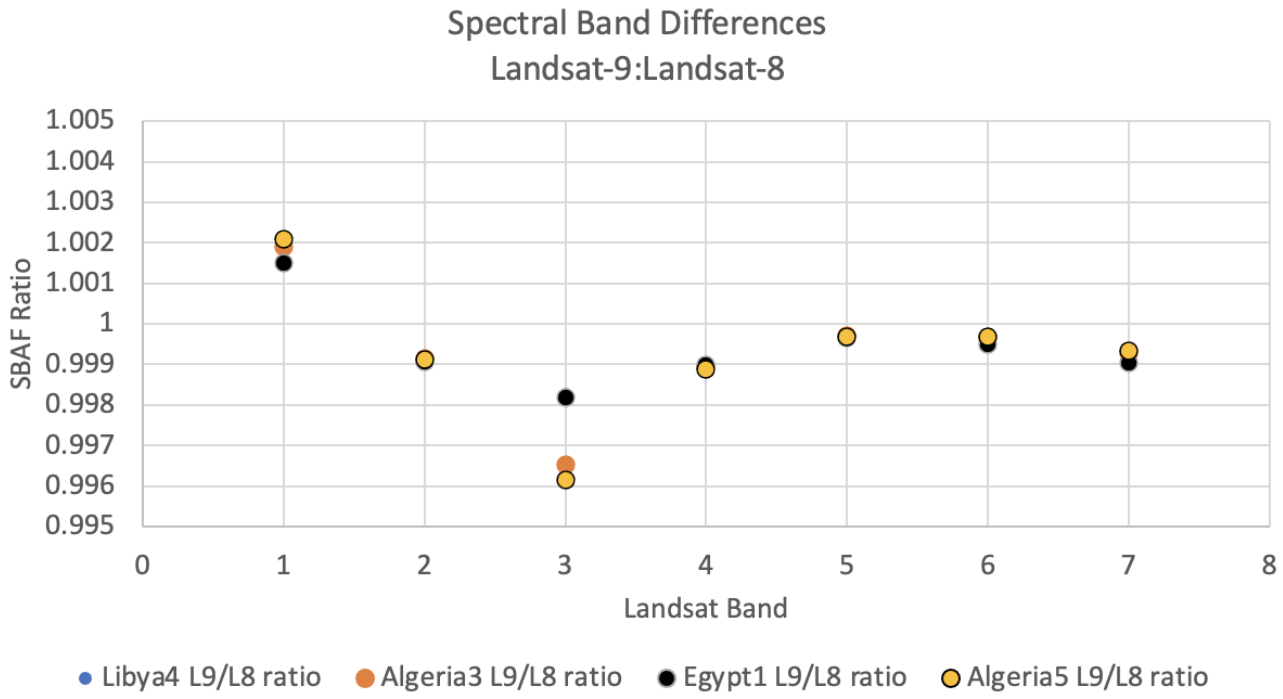
Monitoring MSI with OLI

- Familiar suite of PICS sites used to monitor Landsat-8 OLI, Landsat-9 OLI, Sentinel-2A MSI and Sentinel-2B MSI.
- CEOS 20x20km region of:
  - Libya-4
  - Egypt-1
  - Algeria-5
  - Algeria-3
- Apply Spectral Band Adjustment Factor to make MSI reflectances ”OLI-like”



Spectral Differences between OLIs

- Spectral differences are compensated for by using a region-specific Spectral Band Adjustment Factor
- New SBAFs have been calculated for Landsat-9 OLI and the MSIs
- There are larger differences in the Landsat Green bands between the Algeria desert sites and the dryer Libya/Egypt desert sites



Reflectance Calculation

- For each band:
  - OLI TOA reflectance
  - 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)

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

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

<v4

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

v4

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

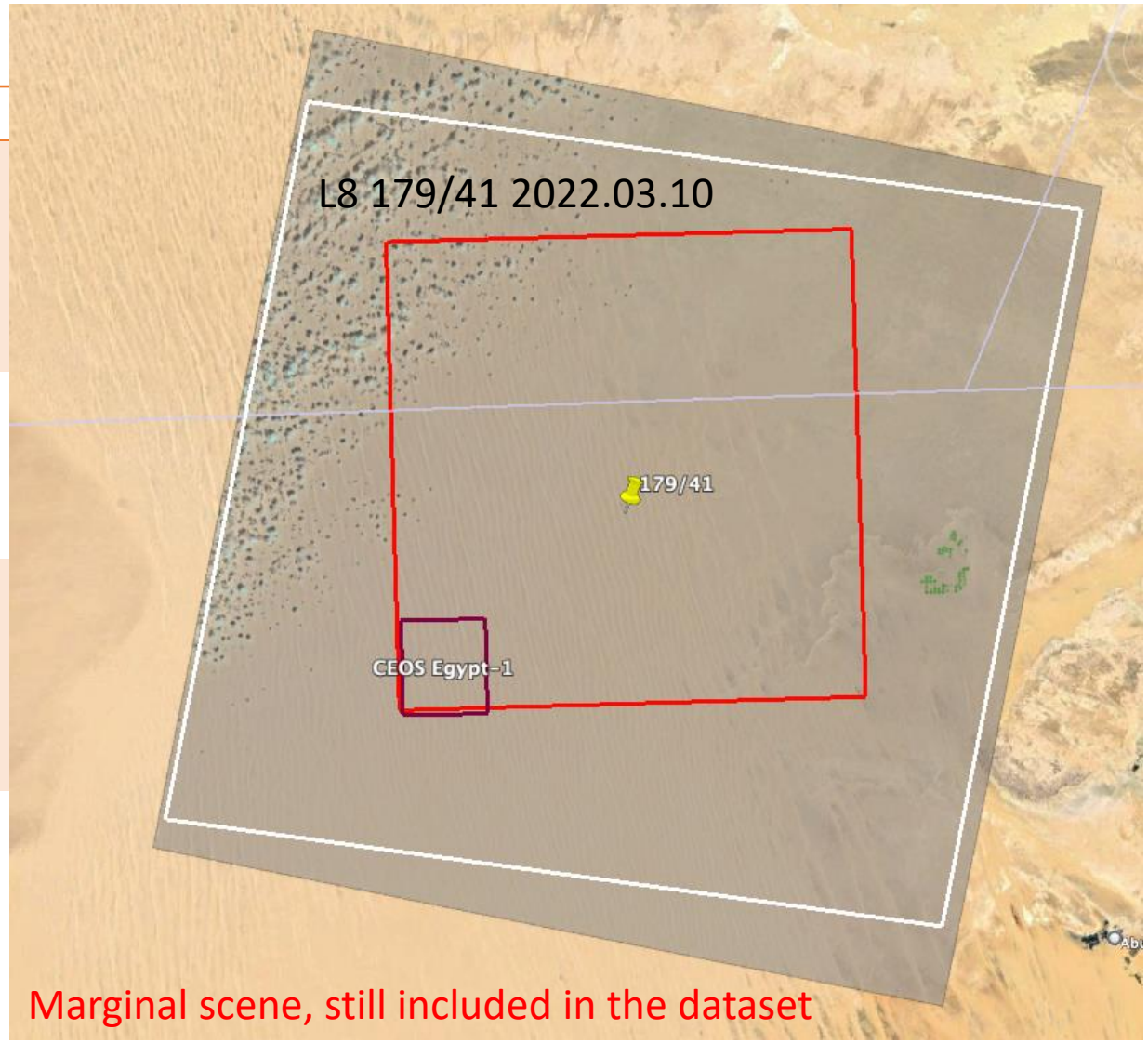
- Convert MSI TOA reflectance to OLI equivalent reflectance

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

Recent Coincident Pairs

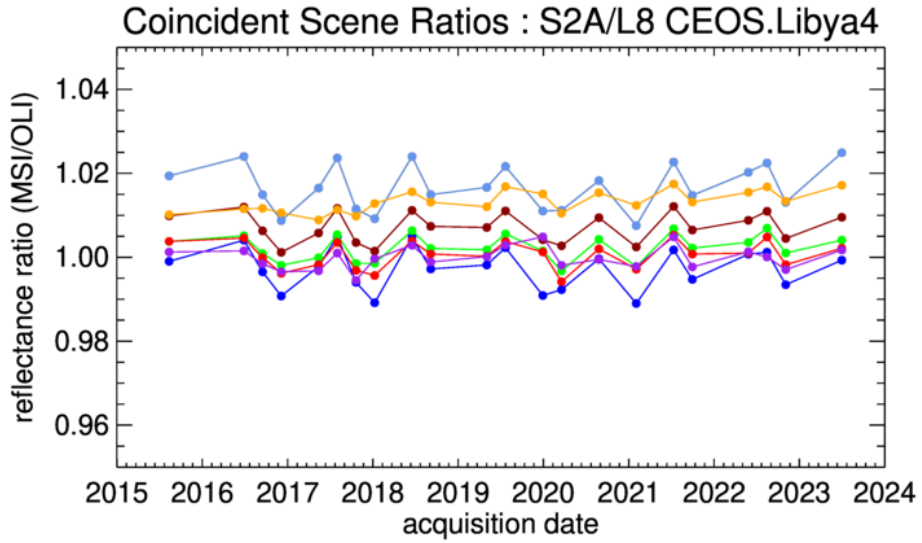
Cloud-free image pairs April 2022

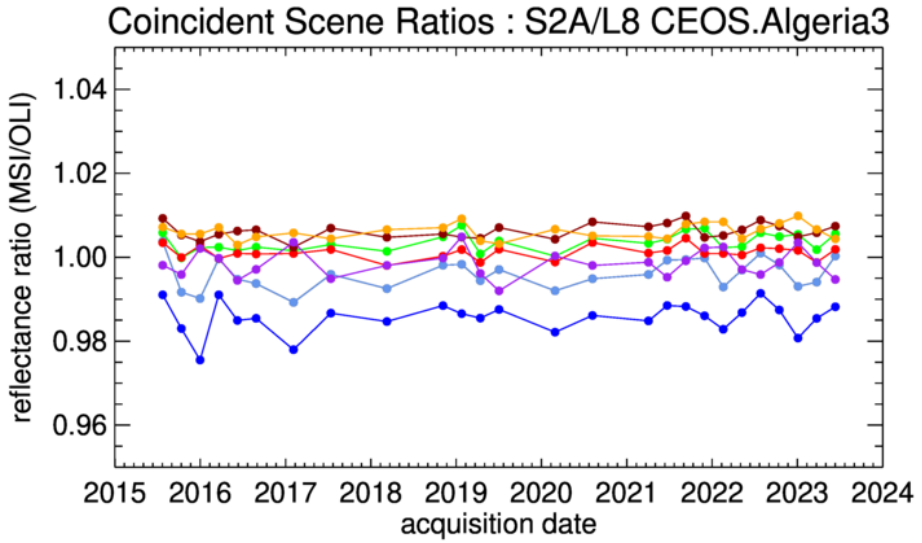
	Libya-4	Algeria-3	Egypt-1	Algeria-5
S2A-L8 (10)	2022.05.27 2022.08.15 2022.11.03 2023.07.01	2022.05.08 2022-07.27 2022.10.15 2023.01.03 2023.03.24 2024.06.12		
S2B-L9 (5)			2022.08.17 2023.01.24 2023.07.03	2022.11.05 2023.04.14
S2A-L9 (10)	2022.06.06 2022.09.24 2022.12.13 2023.03.03 2023.05.22 2023.08.10	2022.06.17 2022.09.05 2022.11.24 2023.07.22		
S2B-L9 (9)			2022.04.19 2022.07.08 2022.09.26 2022.12.15 2022.03.05 2023.05.24 2023.08.12	2023.05.24 2023.08.12

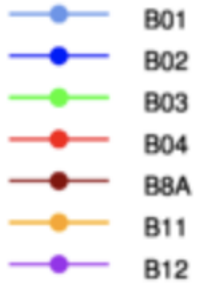


Cross Calibration Coincident Overpass Results
Sentinel-2A

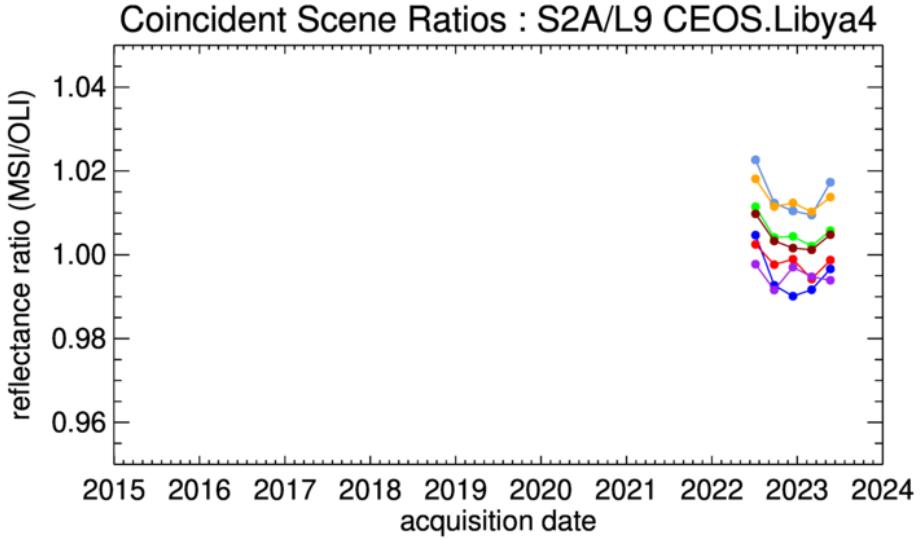
S2A MSI
L8 OLI

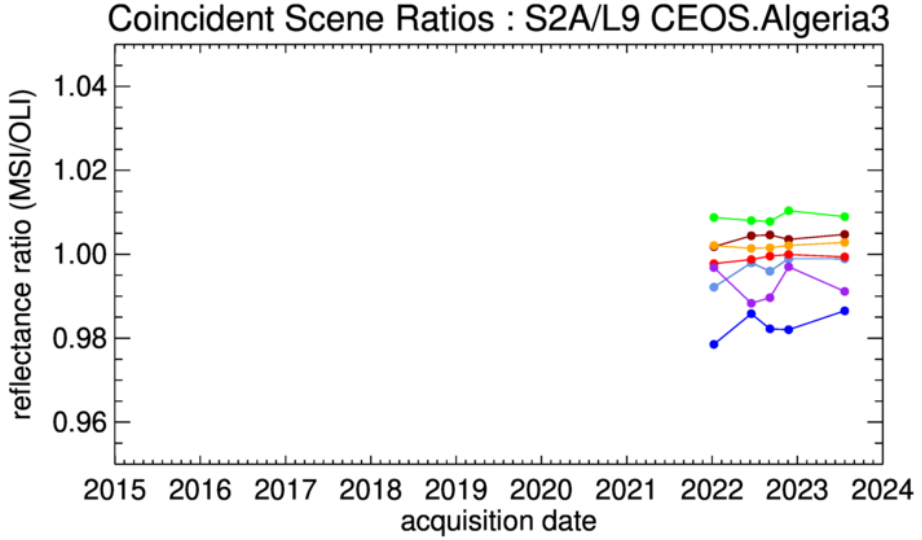






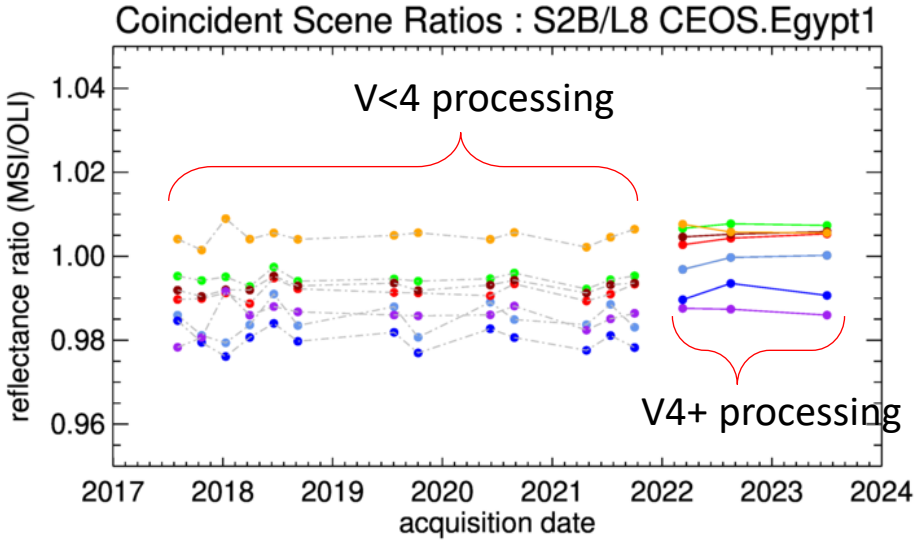
S2A MSI
L9 OLI-2

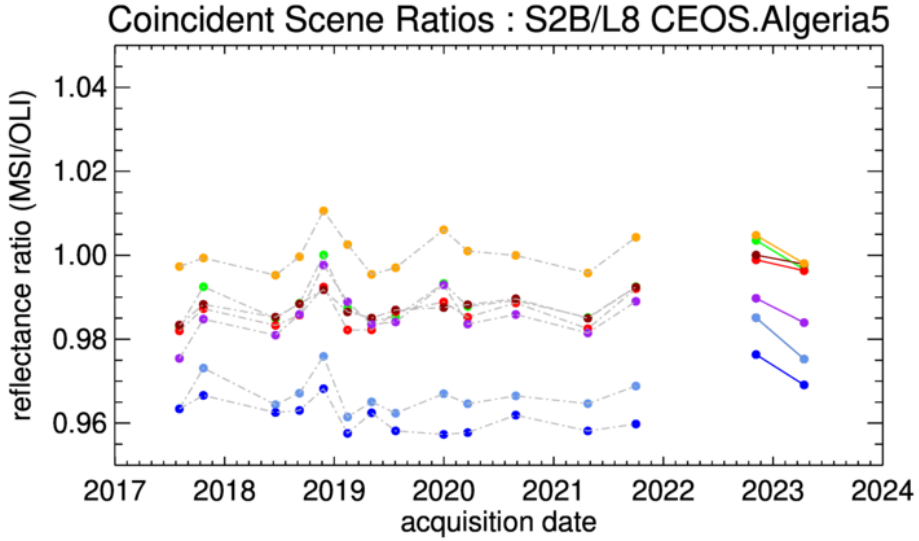


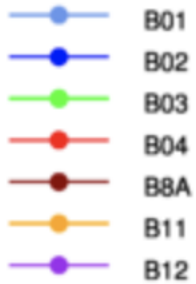


Cross Calibration Coincident Overpass Results
Sentinel-2B

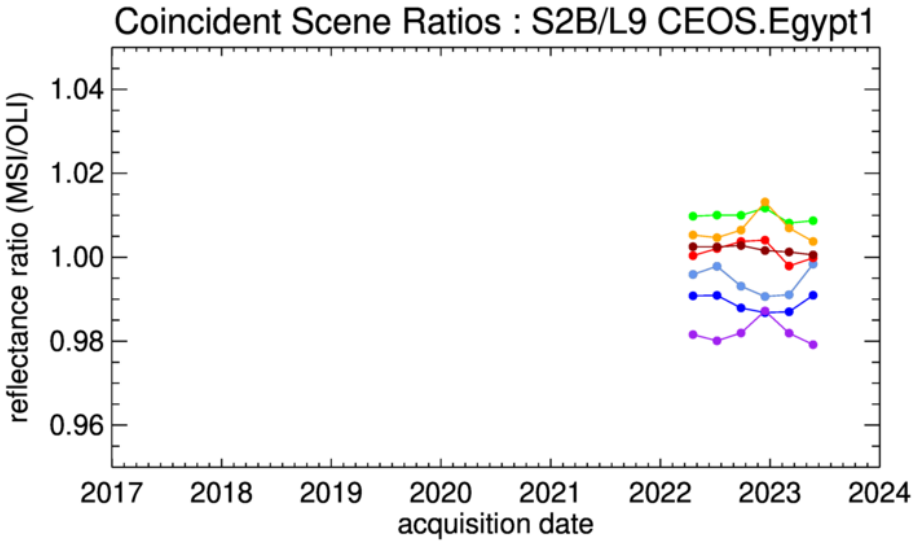
S2B MSI
L8 OLI

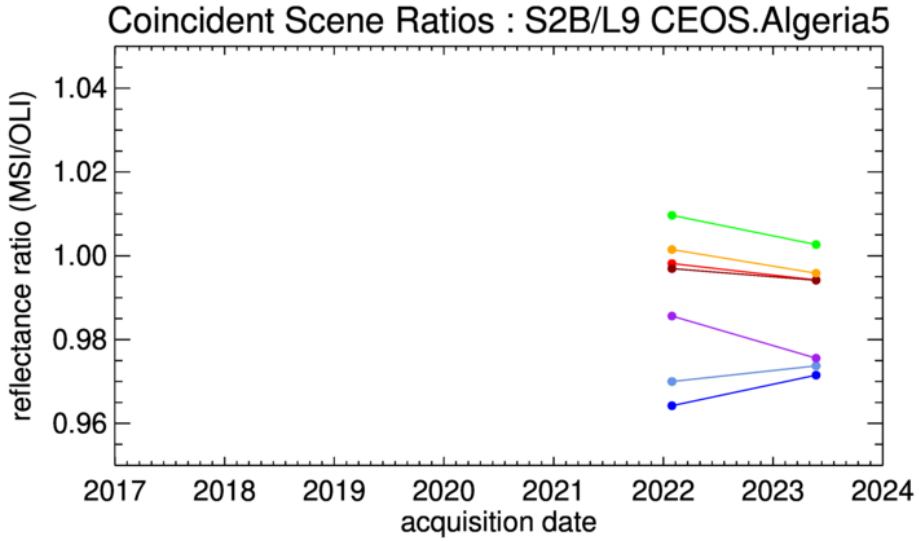






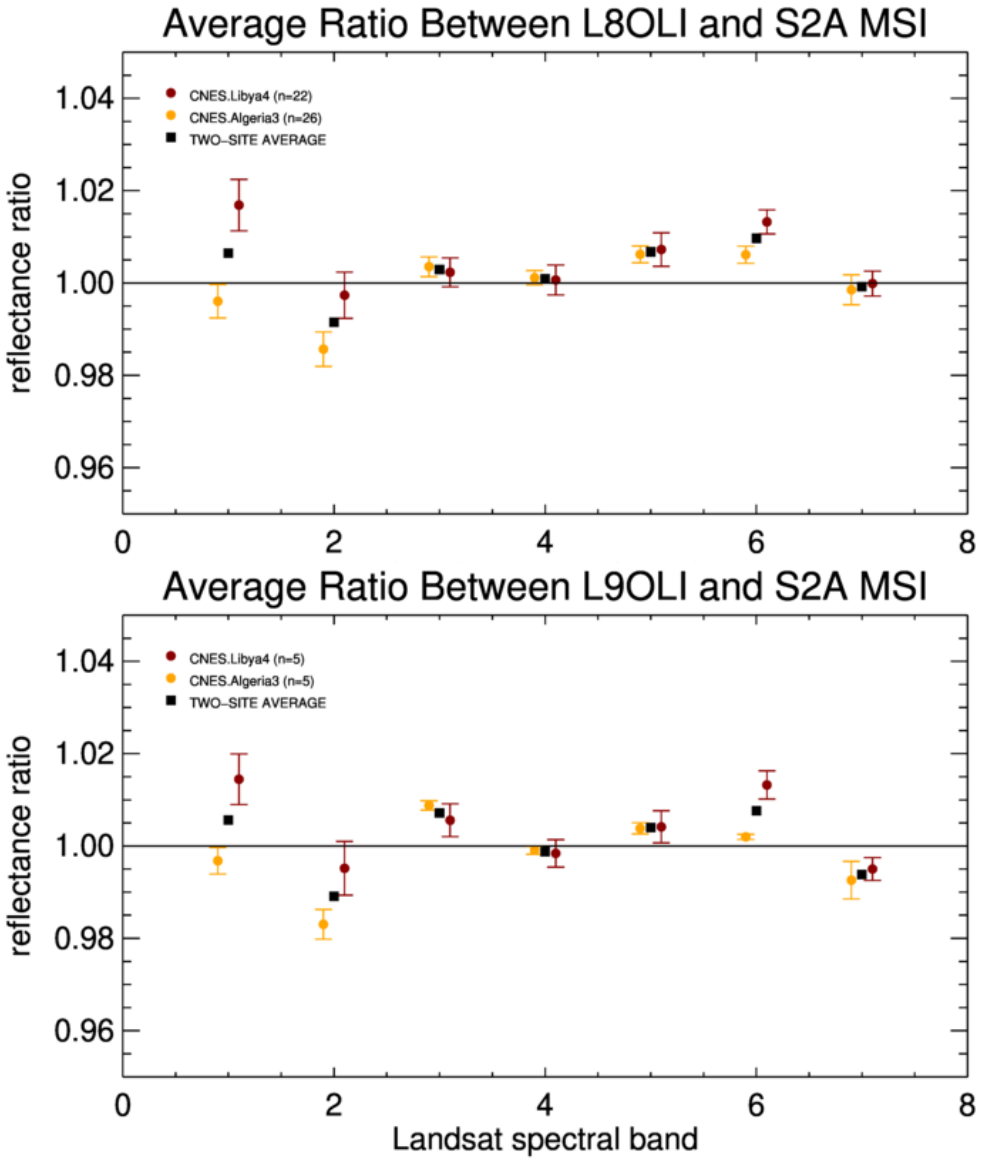
S2B MSI
L9 OLI-2





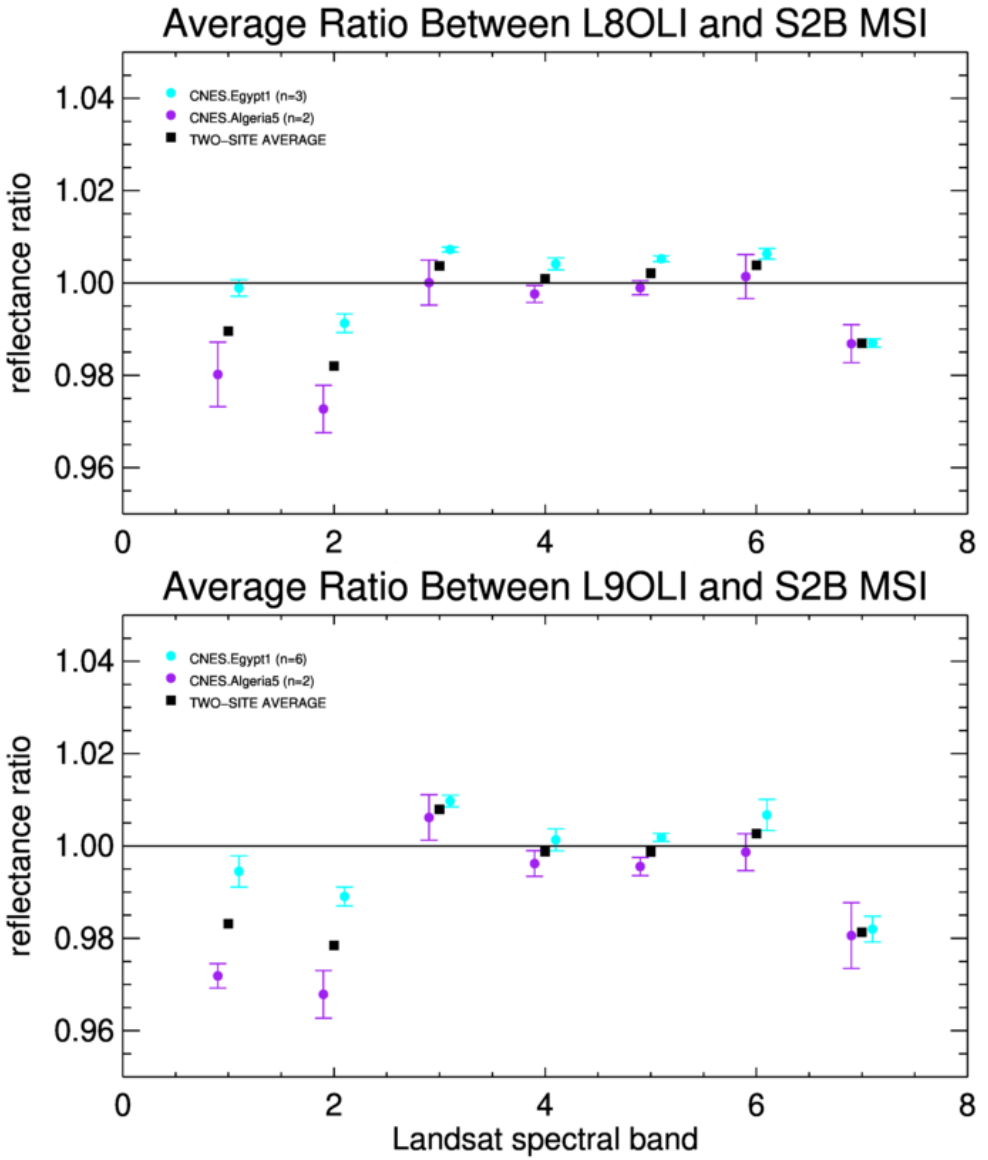
Cross Calibration Coincident Overpass Results
S2A Summary

- L8 and S2A agreement remains consistent with previous results
  - Green, Red, SWIR2 within 0.3%
  - NIR (B8A) within 0.7%
  - SWIR1 within 1.2%
  - No significant change since March 2021
- L9 and S2A is based on small dataset
  - General trends hold
- To be investigated: double ratio comparison between L8 and L9 using S2A as a reference
  - Green and SWIR2 differences look out-of-family



Cross Calibration Coincident Overpass Results
S2B Summary

- L8 and S2A agreement : small data set, only includes data acquired after V4.0 processing
  - Green, Red, NIR (B8A) within 0.35%
  - CA, Blue better agreement
  - SWIR1 (B11) within 0.3% (no change)
  - SWIR2 (B12) within 1.3% (no change)
- L9 and S2B agreement : small data set
  - General trends hold
- Also look at using S2B as reference for L8/L9 double ratio

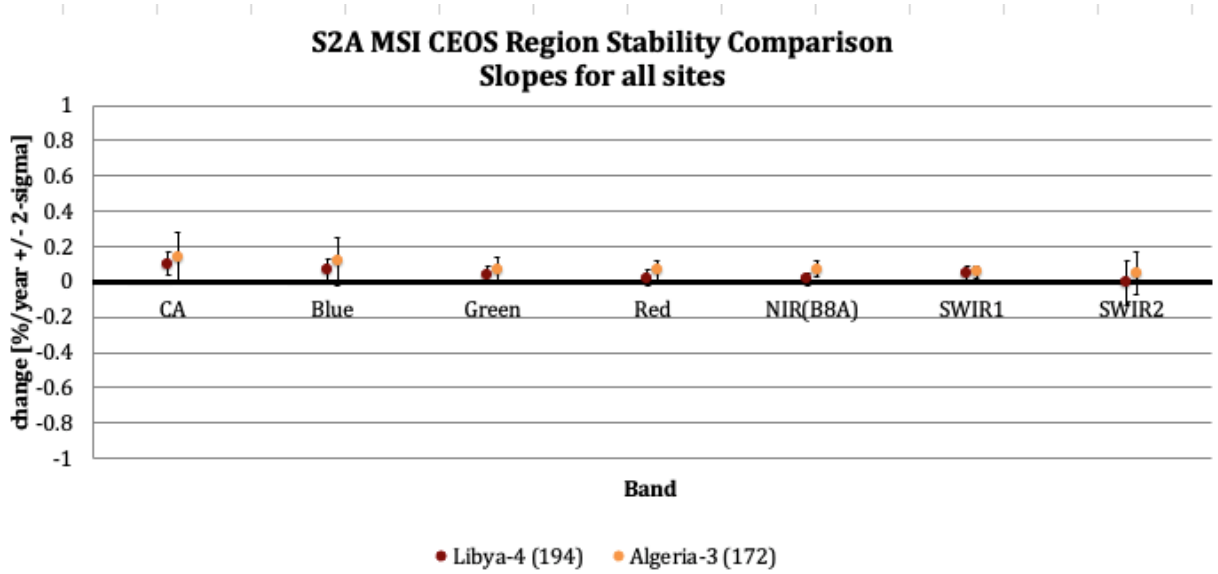


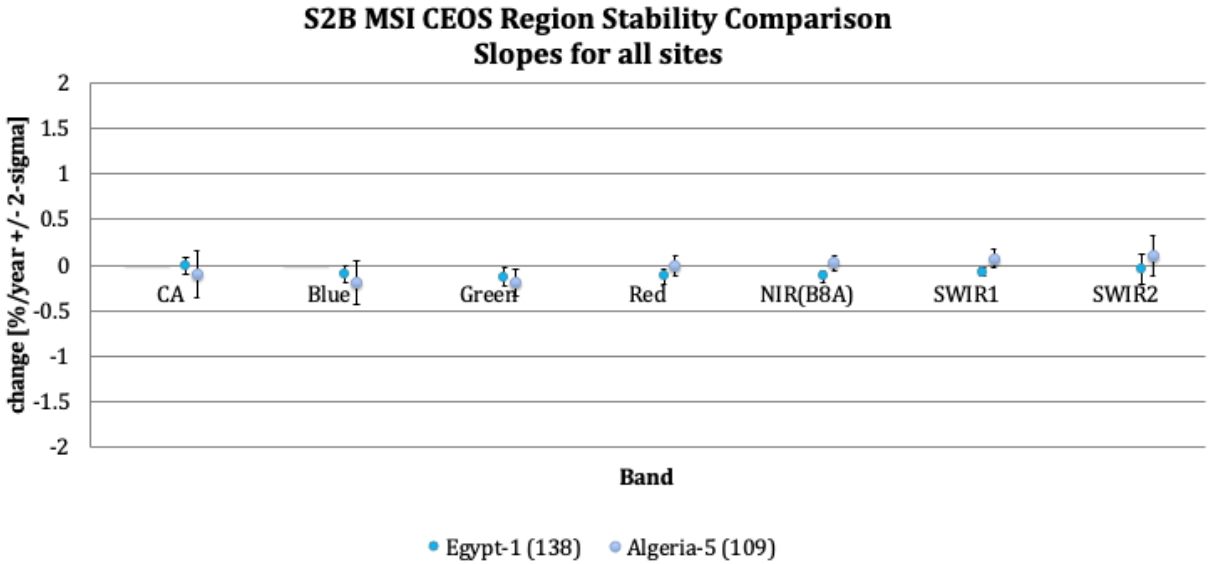
PICS Lifetime Stability Trending

- Plots only include the sites currently being updated
  - S2A: Only Libya-4 and Algeria-3
  - S2B: Only Egypt-1 and Algeria-5

- S2A MSI shows stability over desert sites within 0.1% per year.

- S2B MSI shows stability over desert sites to within 0.1% per year.





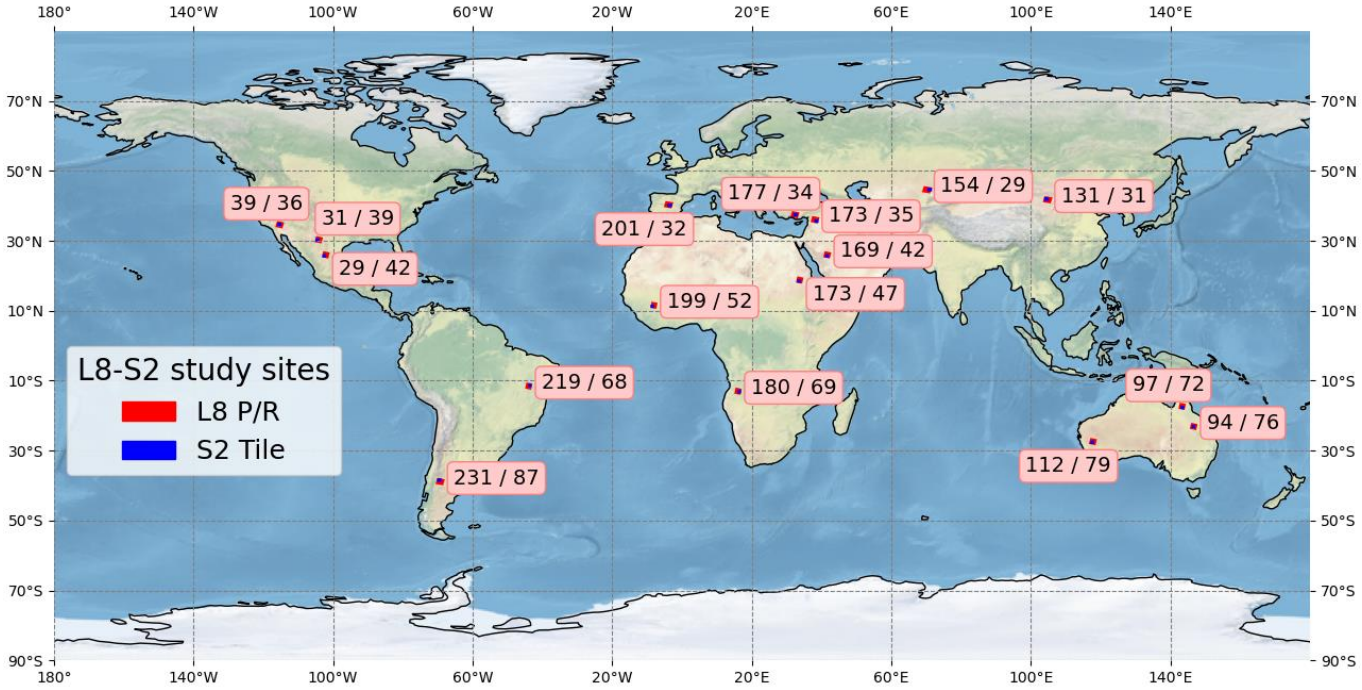
Background : Landsat and Sentinel-2 Archives

- **For Collection-2 release (Dec 2020), the Landsat ground reference dataset was updated using the Sentinel-2 Global Reference Image (GRI)**
  - The objective was to improve the co-registration between Landsat and Sentinel-2 terrain-corrected products
  - All Collection-2 Landsat products are produced using the updated Landsat ground reference
    - The entire Landsat archive was reprocessed to improve the absolute and relative accuracies of the Landsat products across all missions
- **Prior to 2021, all Sentinel-2 scenes were processed without using GCPs**
  - The GRI dataset was in the process of development prior to 2021
  - The Sentinel-2 processing system had to be modified to use the GRI dataset
- **Since March 2021, the Sentinel-2 processing system began processing orthorectified products using the GRI dataset**
  - Current baseline processes all data (forward acquisition) using the GRI dataset to improve the temporal registration accuracy
    - Backward processing of the older data is in progress and will be completed by the end of 2023 (or early 2024)

Comparison of Landsat-8 and Sentinel-2 products

- **Collection-2 Landsat-8 L1T products were compared with the existing Sentinel-2 L1C products to assess the co-registration error temporally**
  - Assessed over 17 sites (tiles) distributed globally

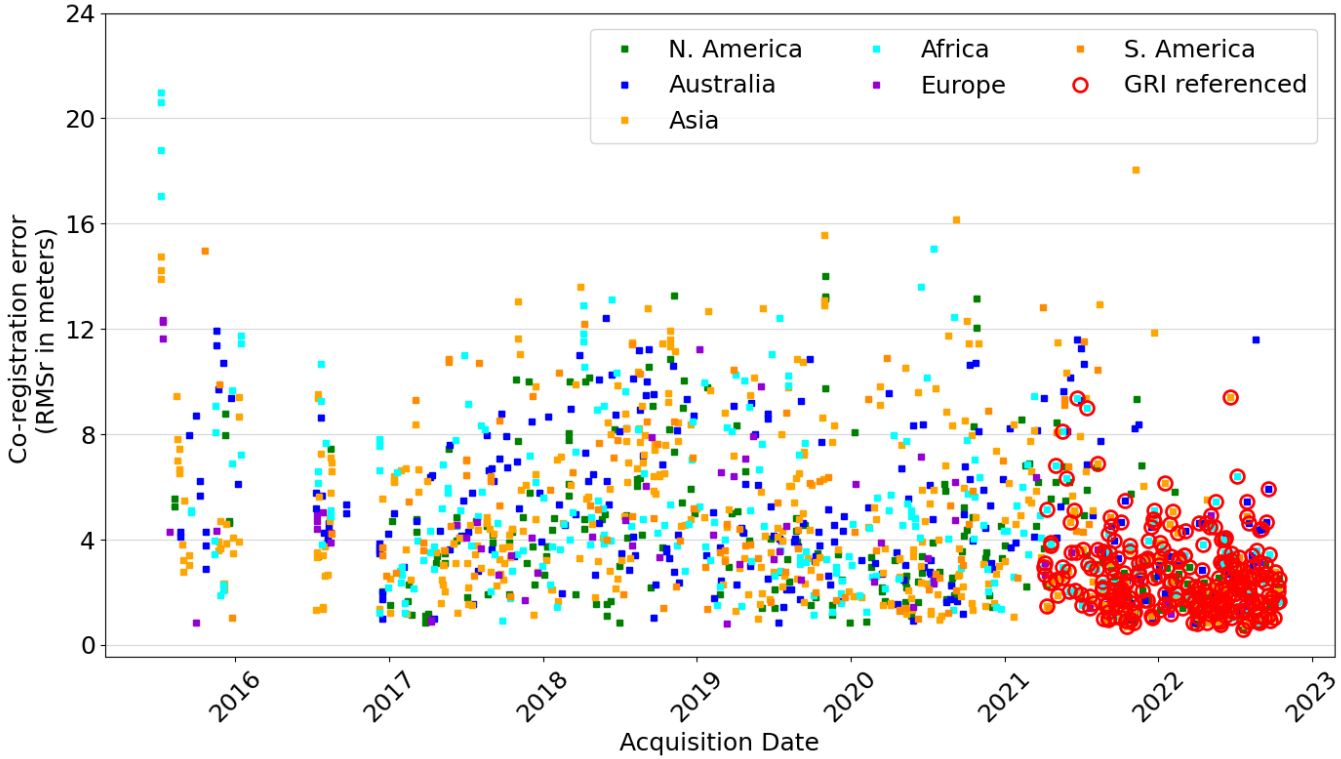
- A couple of tiles for each continent
- Cloud-free (less than 10%) L8 and S2 product pairs were used
- L8 products compared were within 32 days of acquisition (2 repeat cycles of L8) from S2 products to reduce seasonal or temporal differences
  - Reduces registration uncertainty
- Scenes acquired between 2015 - 2022 were compared
- Compared Band 8 of L8 with Band 4 of S2
- S2 Band 4 was resampled to 15 m to match L8 Band 8



Comparison of Landsat-8 vs. Sentinel-2 products

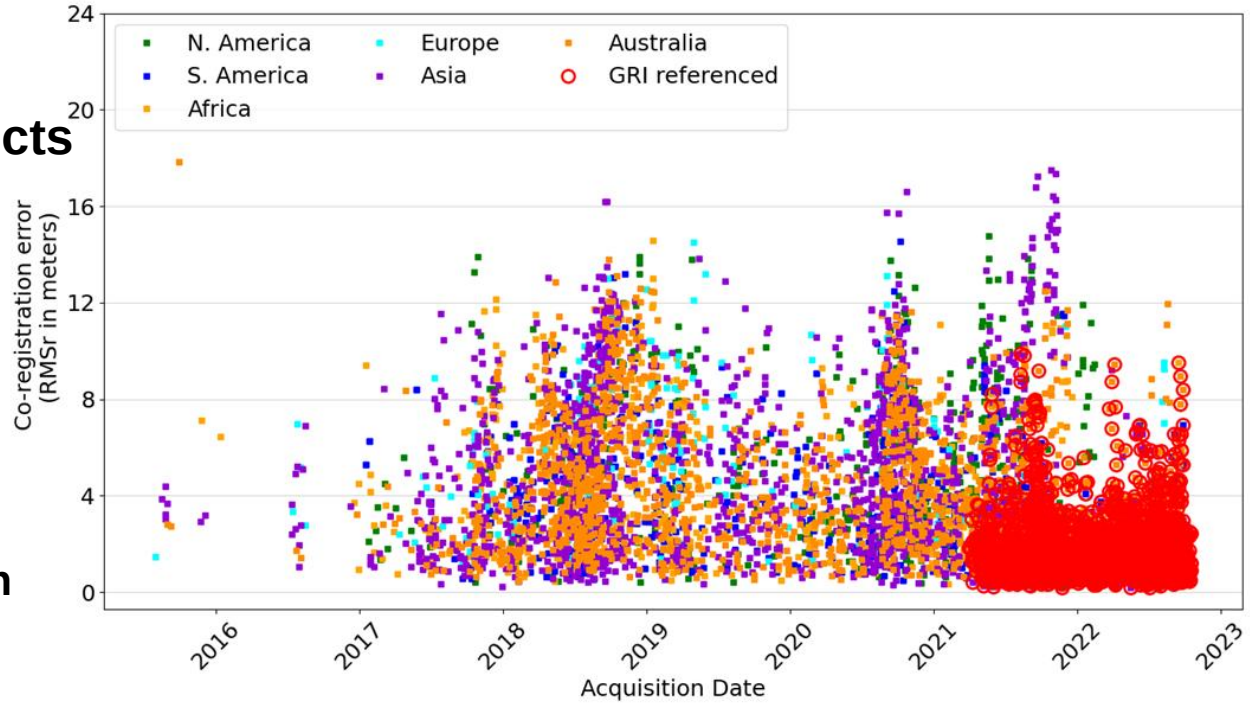
- **L8 vs. S2 products currently in the archive were compared**
  - S2A and S2B are considered as S2 products
  - 1378 scenes were compared, of which 272 were S2 scenes processed with GRI
    - Root Mean Square difference radial (RMSr): 3.0 m

- **Co-registration error between L8 and S2 orthorectified products**
  - Without GRI :
    - CE90: 9.4 m
    - Root Mean Square difference radial (RMSr): 6.2 m
  - With GRI :
    - CE90: 4.6 m
    - Root Mean Square difference radial (RMSr): 3.0 m



Comparison of Sentinel-2 vs. Sentinel-2 products

- **Sentinel-2 products currently in the archive were compared**
  - Temporal co-registration error was assessed for Sentinel-2 products over 17 tiles distributed globally
    - GRI vs. GRI (2084 scenes)
    - Non-GRI vs. Non-GRI (6994 scenes)
- **Co-registration error between S2 and S2 products**
  - Without GRI :
    - CE90: 8.8 m
    - Root Mean Square difference radial (RMSr): 5.8 m
  - With GRI :
    - CE90: 3.5 m
    - Root Mean Square difference radial (RMSr): 2.3 m
- **A similar comparison over the same geographic region showed very good co-alignment between Landsat orthorectified products**
  - L8 vs L8: 1.7 m (CE90: 3 m)
  - L8 vs L9: 1.7 m (CE90: 3 m)
  - This is expected as all the Landsat products use the same ground reference



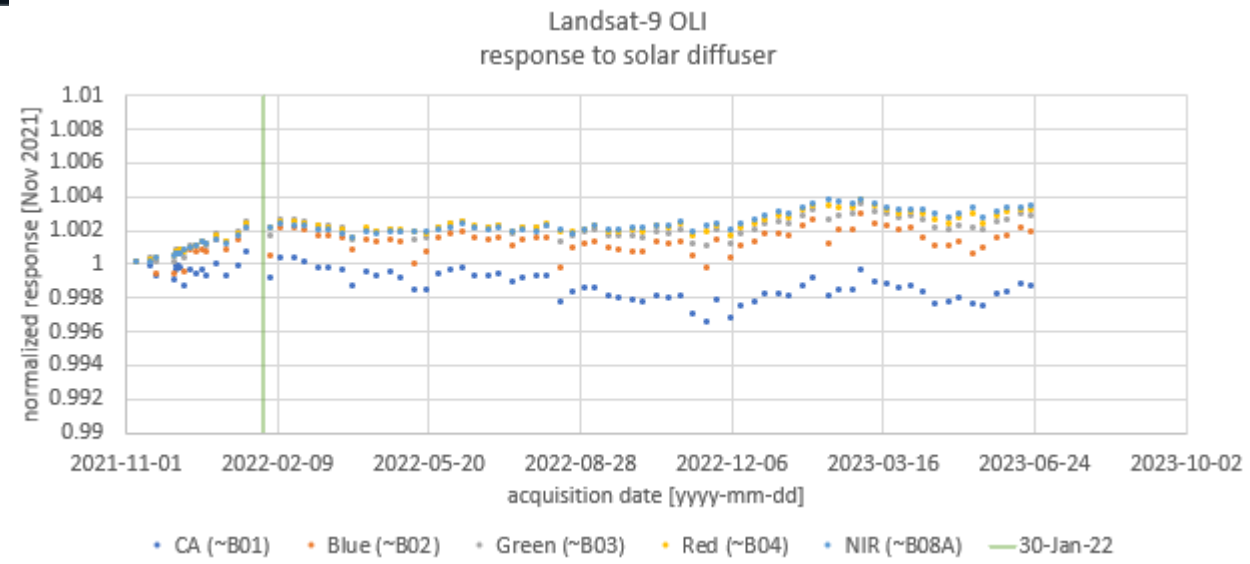
Summary

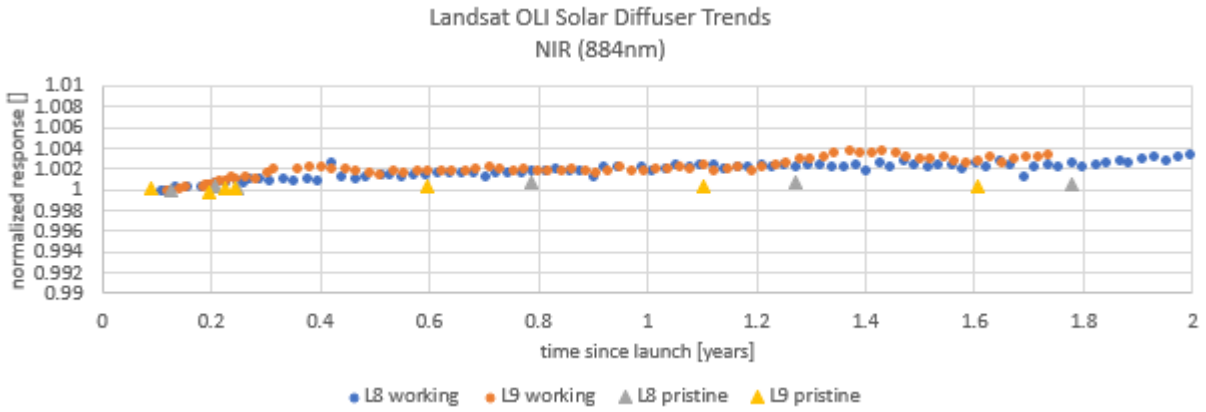
- Radiometry
  - **All four instruments are exhibiting excellent radiometric performance**
    - Agreement generally better than 1%
  - Landsat-9 OLI radiometric calibration was adjusted to better agree with Landsat-8 OLI; all publicly available products have been processed with the adjusted calibration
  - Coincident overpasses of pseudo-invariant calibration sites allow for cross calibration of MSI with OLI
    - The radiometric offset between S2A and S2B has been eliminated
    - Look at using S2A and S2B as reference for L8/L9 comparison
  - PICS lifetime trending
    - S2A MSI calibration is stable to within 0.1%
    - S2B MSI calibration is stable to within 0.1%
- Geometry
  - When GRI is used in the Sentinel-2 processing system, the Landsat-8 (and Landsat-9) orthorectified products are registered with the S2 products to better than 3 m
    - 4.6 m (CE90)
  - A similar assessment for Sentinel-2 data, when GRI is used, showed a very good co-alignment between orthorectified products
    - 3.5 m (CE90)
  - Small co-registration errors between L8 and S2 products will benefit the remote sensing community in time-series analysis without a need for additional registration and resampling
  - The ECCOE quarterly report publishes these comparisons for the specific quarter
  - This geometry study has been submitted to the RSE journal (currently under review)

backup

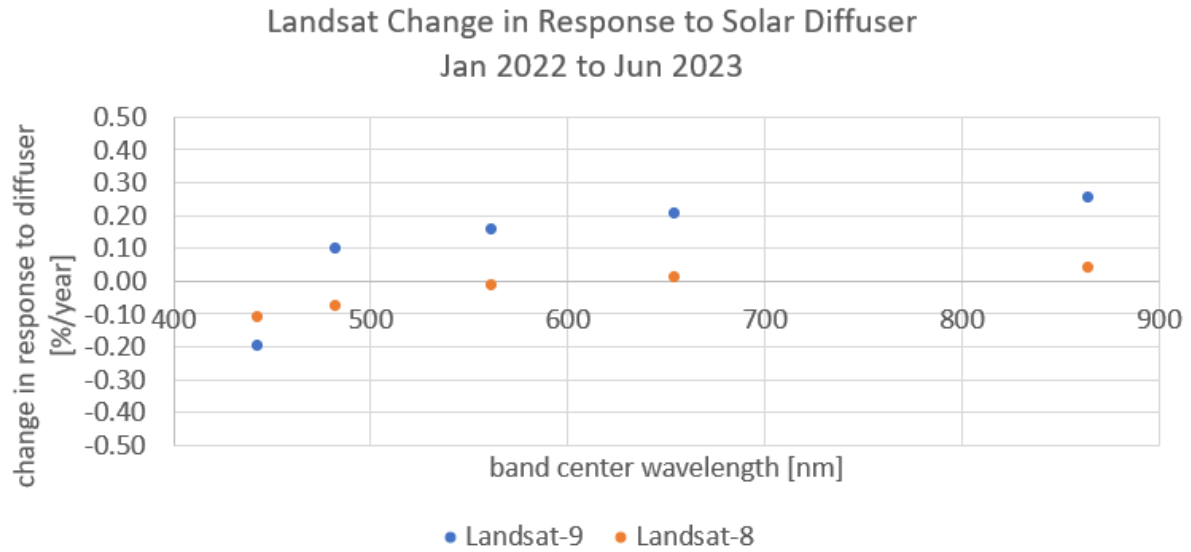
Solar Diffuser Stability

- Landsat-8 response to diffuser has changed significantly since launch, but since Jan 2022, has changed less than 0.1%.
- Landsat-9 response to diffuser has changed as much as 0.3%, but that is expected based on the early lifetime trends of Landsat-8
- Pristine diffuser on both instruments indicate no

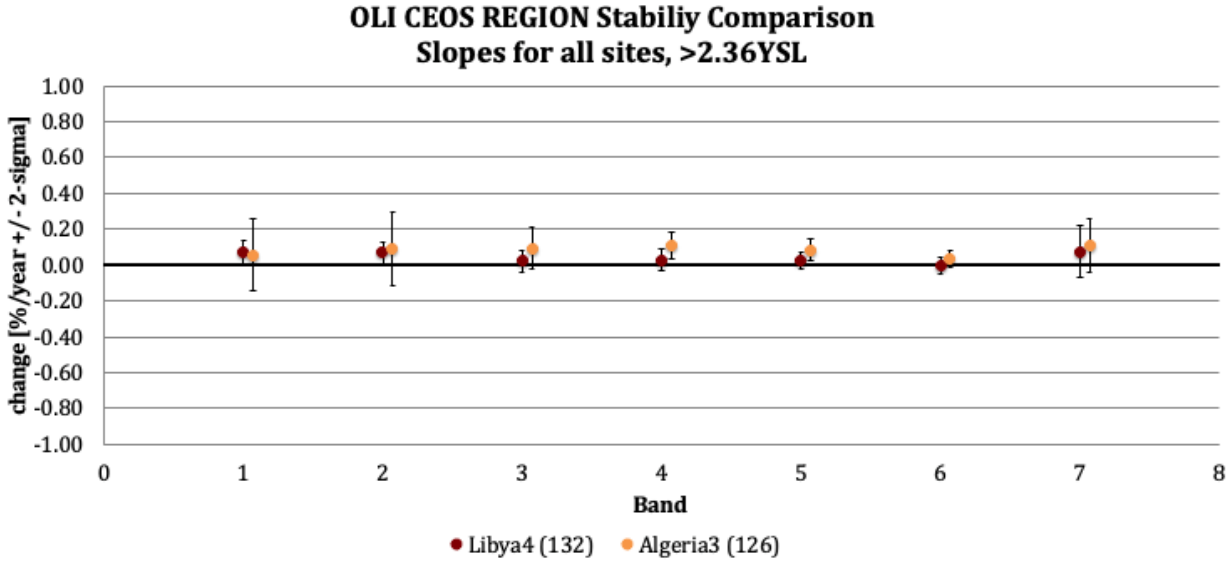


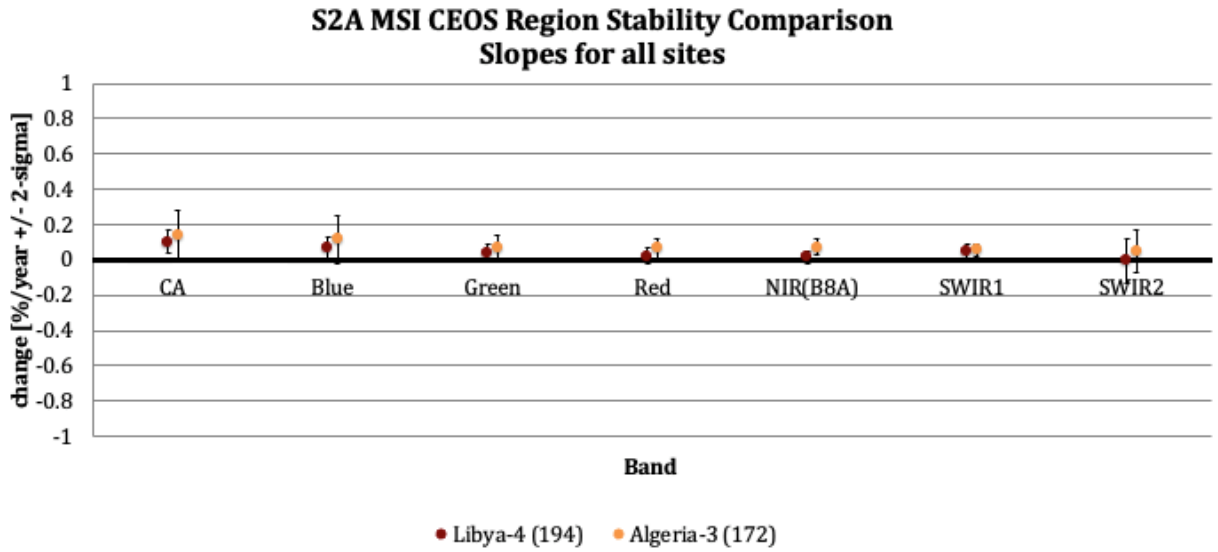


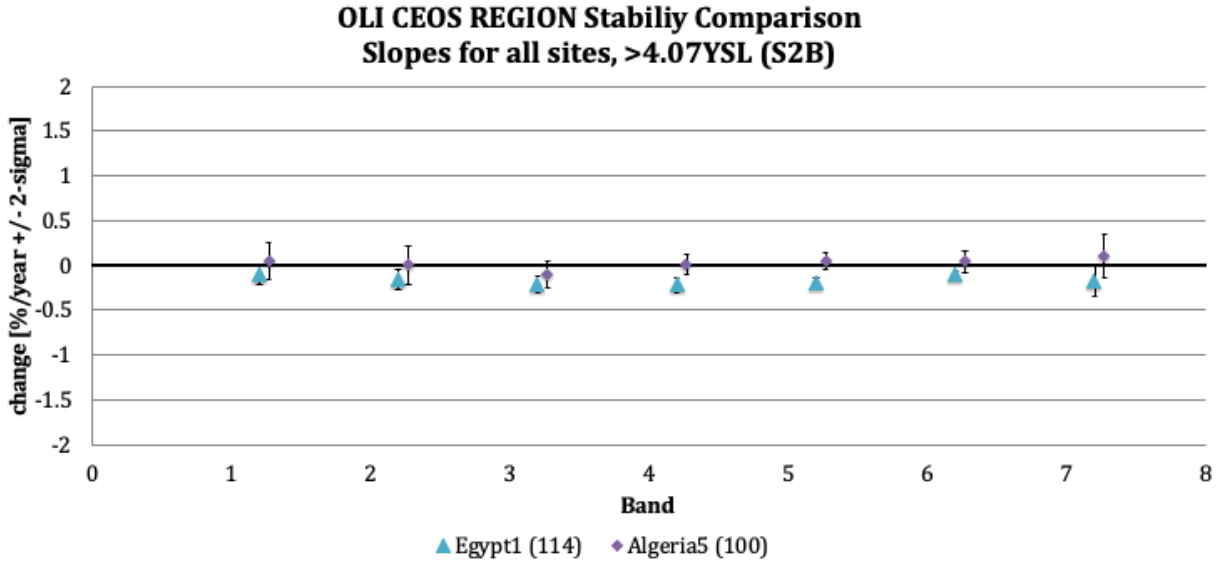
LandsatSolarTrendingSinceNov2021.xlsx

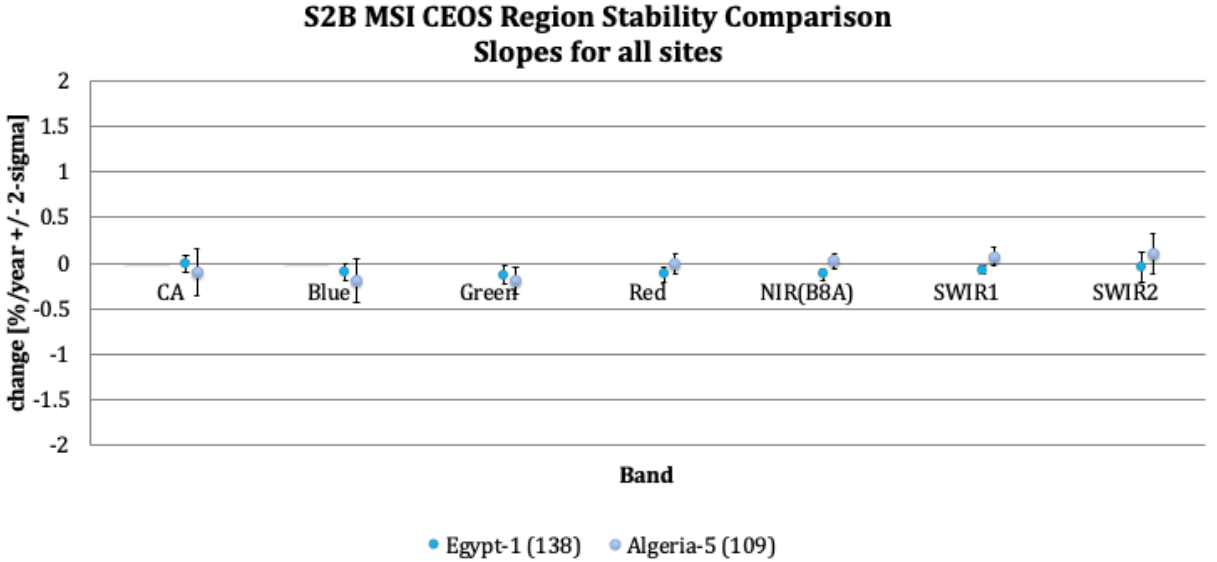

Landsat Change in Response to Solar Diffuser
Jan 2022 to Jun 2023
change in response to diffuser [%/year]
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
400
500
600
700
800
900
band center wavelength [nm]
Landsat-9
Landsat-8

PICS Lifetime Trending
Landsat-8 and Sentinel-2

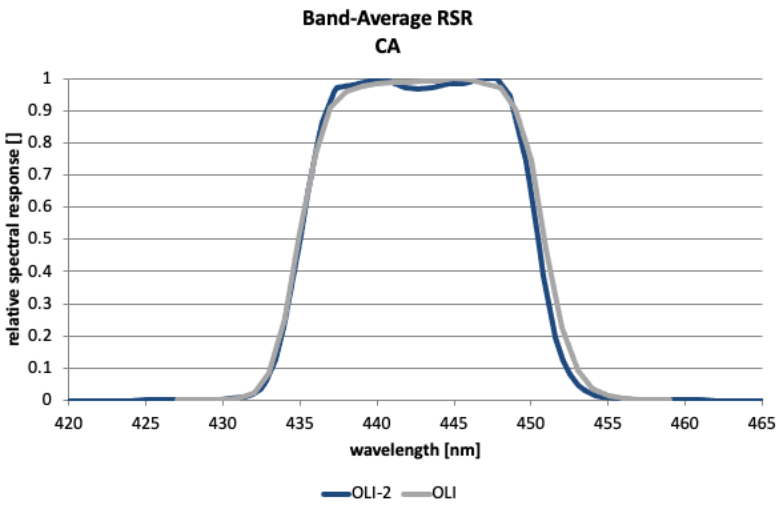


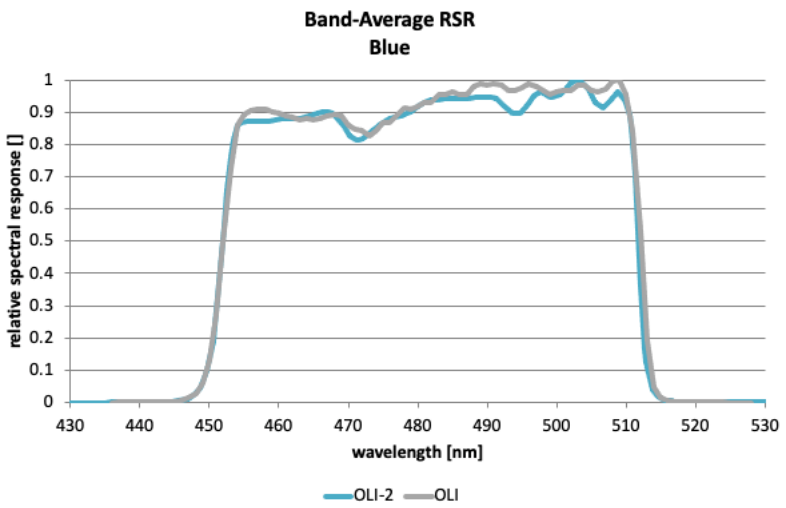


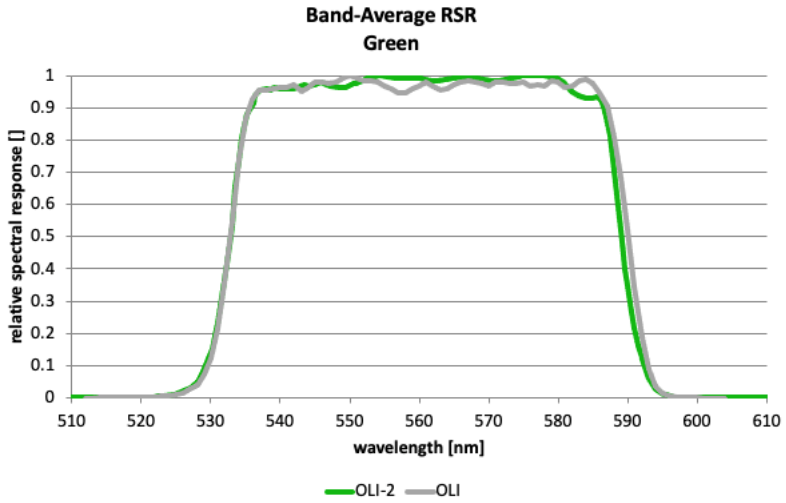


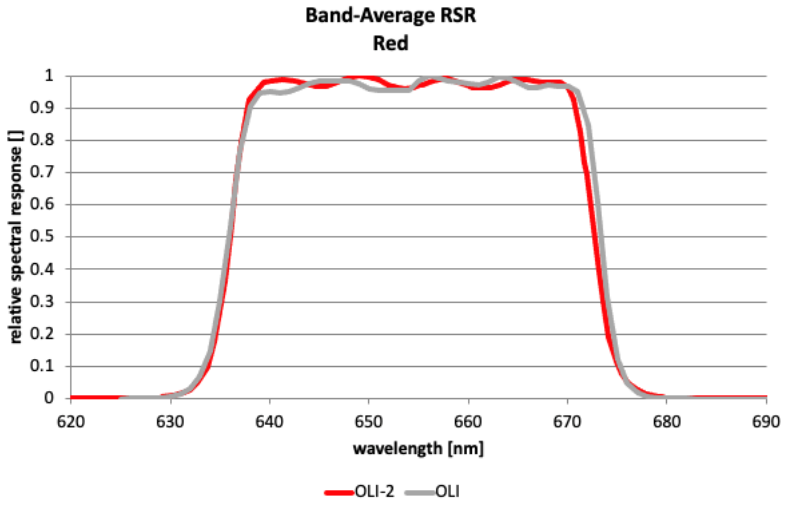


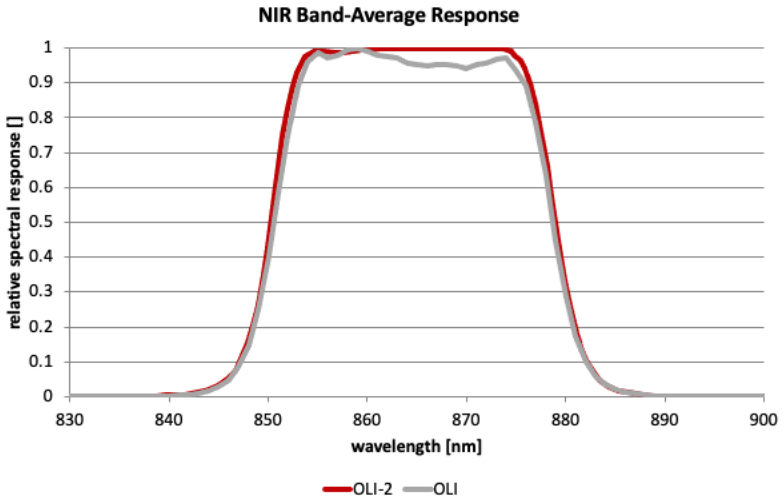
Landsat OLI RSRs



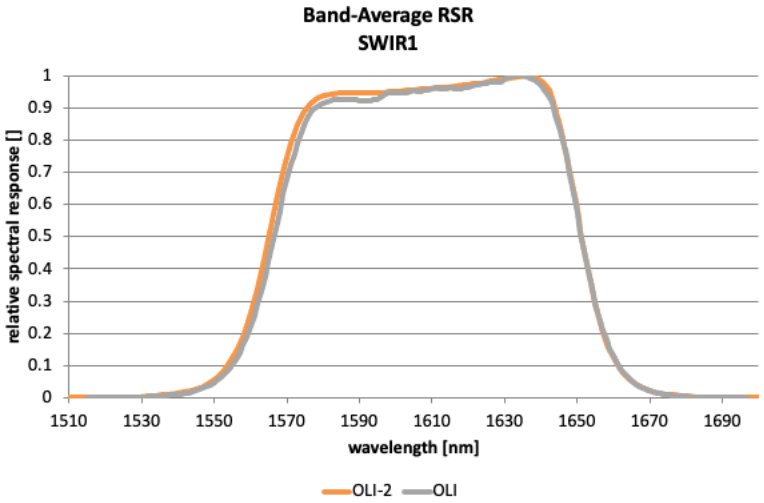


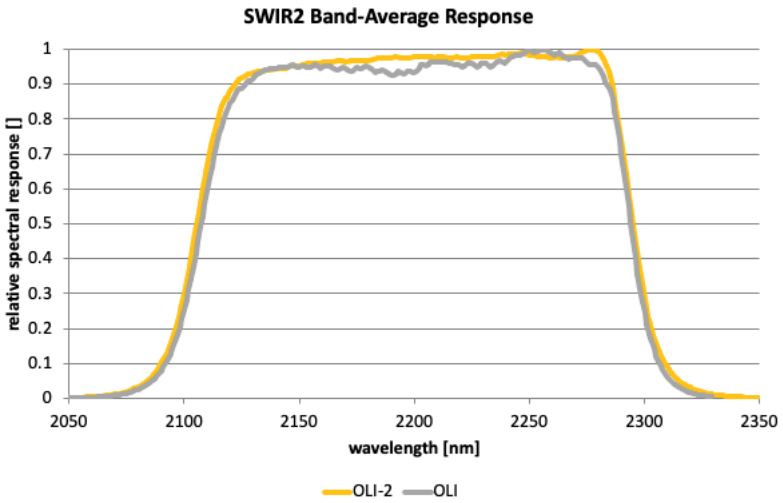






Landsat OLI RSRs





Zoom of the Sentinel-2 vs. Sentinel-2 plot, time range beginning from 2021

- Co-registration error between S2 and S2 products
  - Without GRI: 5.8 m (RMSr), With GRI: better than 2.3 m (RMSr)