whispers
Athens, Greece
Oct 31 - Nov 02 2023

2nd DESIS User Workshop

13th Workshop on Hyperspectral Image and Signal Processing : Evolution in Remote Sensing

Calibration of the DESIS Instrument

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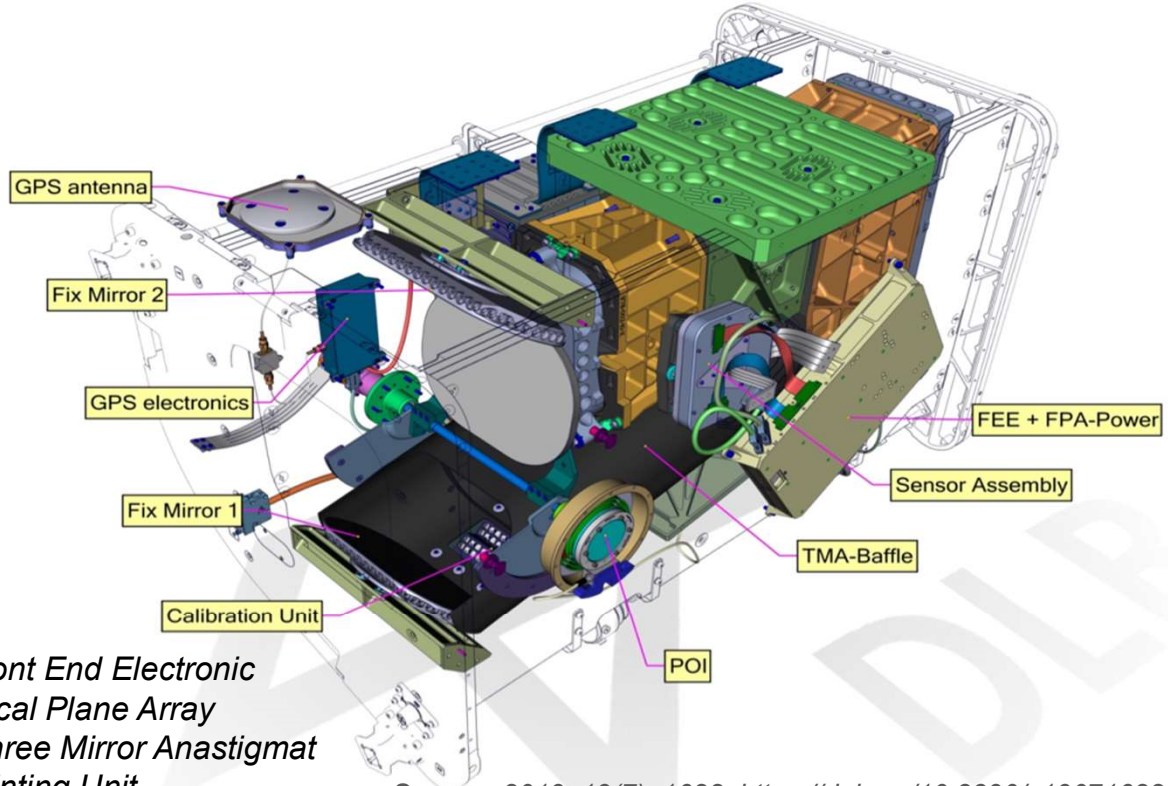
Mission Introduction

DESIS Instrument

- Hyperspectral instrument consisting of a Three-Mirror-Anastigmat (TMA) telescope combined with an Offner-type spectrometer



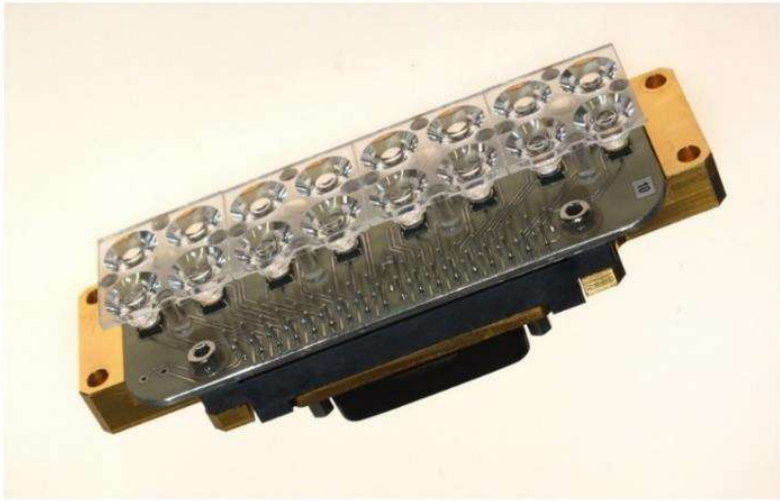
FEE: *Front End Electronic*
FPA: *Focal Plane Array*
TMA: *Three Mirror Anastigmat*
POI: *Pointing Unit*

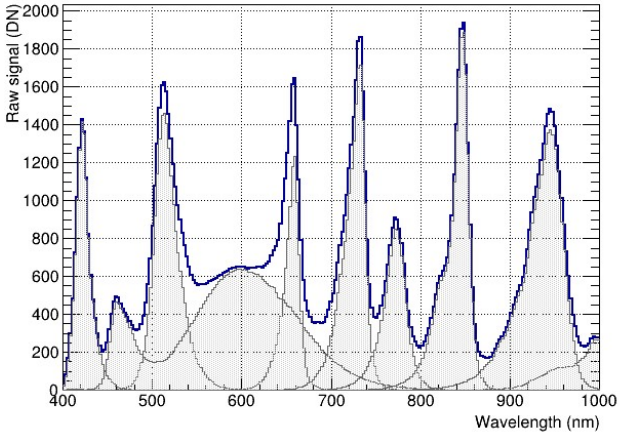
Sensors 2019, 19(7), 1622; https://doi.org/10.3390/s19071622

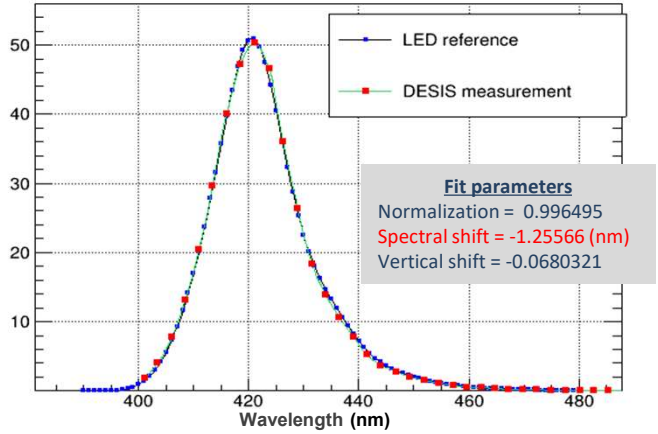
Mission Instrument	MUSES/DESIS
Target lifetime	2018-2023
Off-nadir tilting (across-track, along-track)	-45° (backboard) to +5° (starboard), -40° to +40° (by MUSES and DESIS)
Spectral range	400 nm to 1000 nm
Spectral Sampling (res., acc.,bands)	2.55 nm, 0.5 nm, 235 bands. Binning: 118 , 79 , 60 bands
Spectral response	Gaussian shape, 3.5 nm FWHM
Software Binning (sampling distance, number bands)	Binning 2 (5.1 nm, 118 bands) Binning 3 (7.6 nm, 79 bands) Binning 4 (10.1 nm, 60 bands)
Radiometry (res., acc.)	13 bits, ~10%
Spatial (res., swath)	30 m, 30 km (@ 400 km)
SNR (signal-to-noise)	195 (w/o bin.) / 386 (4 bin.) @ 550 nm
Instrument (mass)	93 kg
Capacity (km, storage)	2360 km per day, 225 GBit

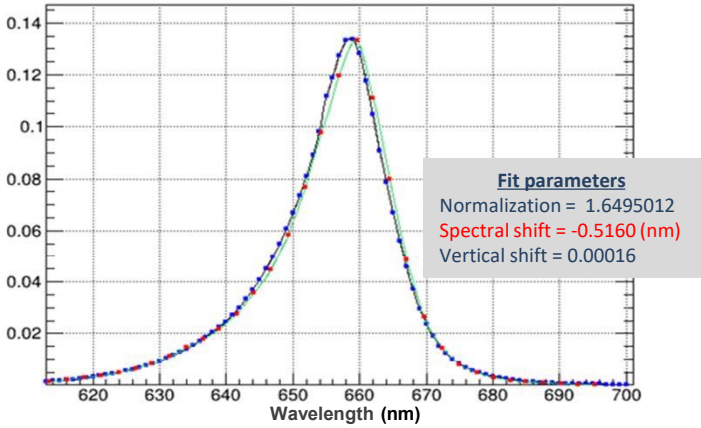
Calibration unit

- Equipped with 9 different types of LEDs. It allows to measure signal with different LED types. Calibration measurement every week for 5 years
- It allows for precise spectral stability measurements. Jumps of 0.5 nm in all LEDs, correlated with different temperature gradients inside DESIS. Corrected during processing. Residual RMS ~0.1 nm for each of the two states



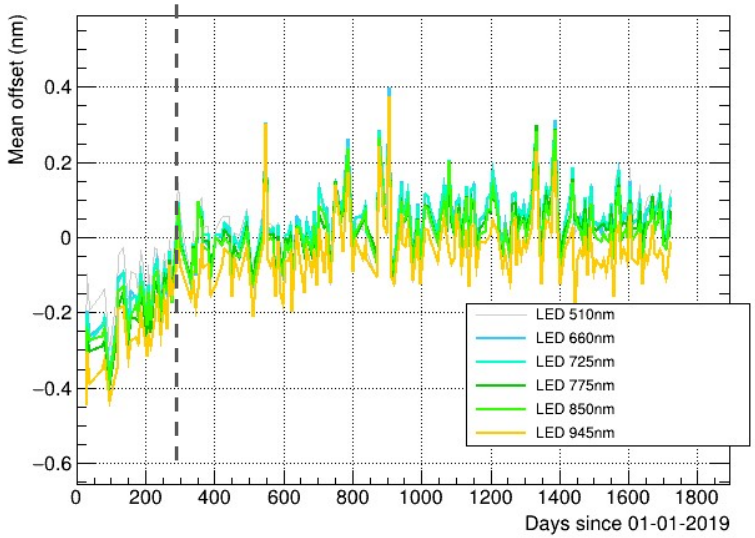






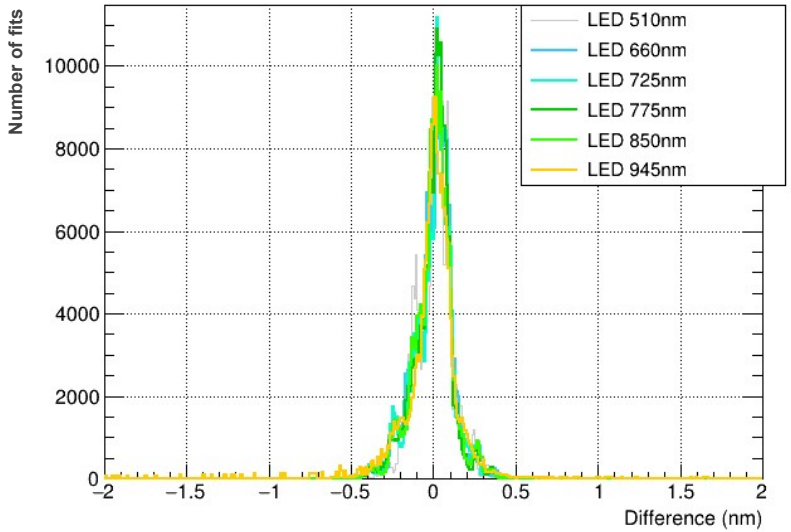
Spectral Calibration

- **Global shift**: based on LED calibration measurements, sensor experiments global shifts. Change of trend in September 2019. More stable since then.



- Finetune based on atmospheric features during vicarious calibration

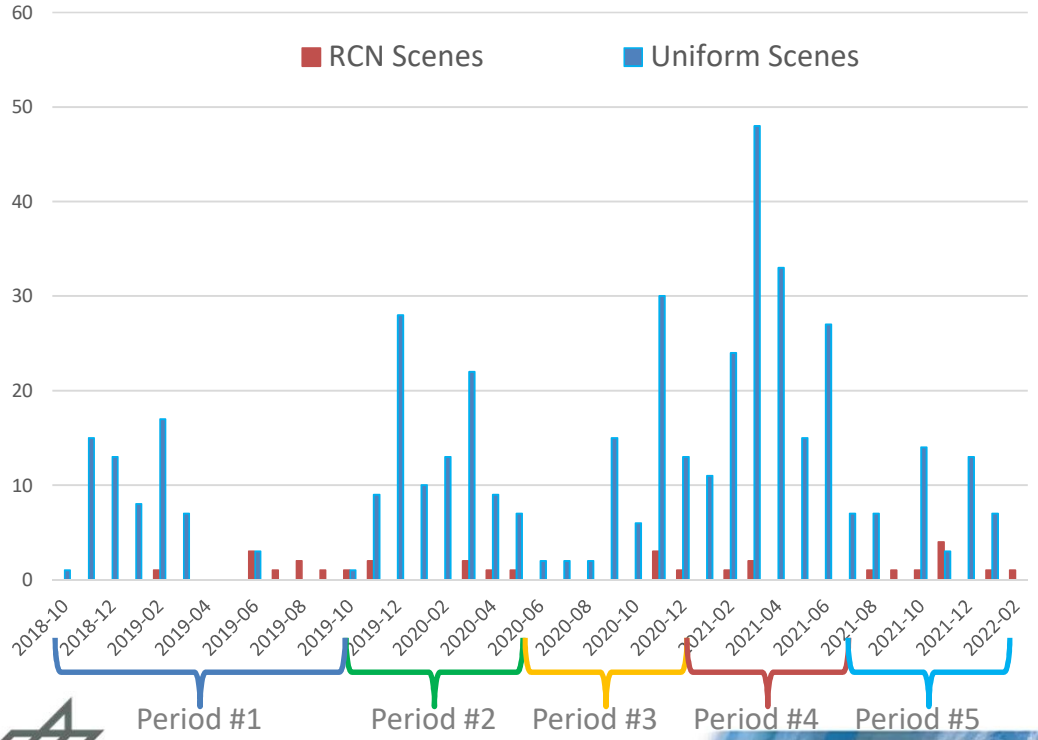
- **Spectral stability**: based on LED calibration, spectral stability **0.11 – 0.12 nm**, within one mode

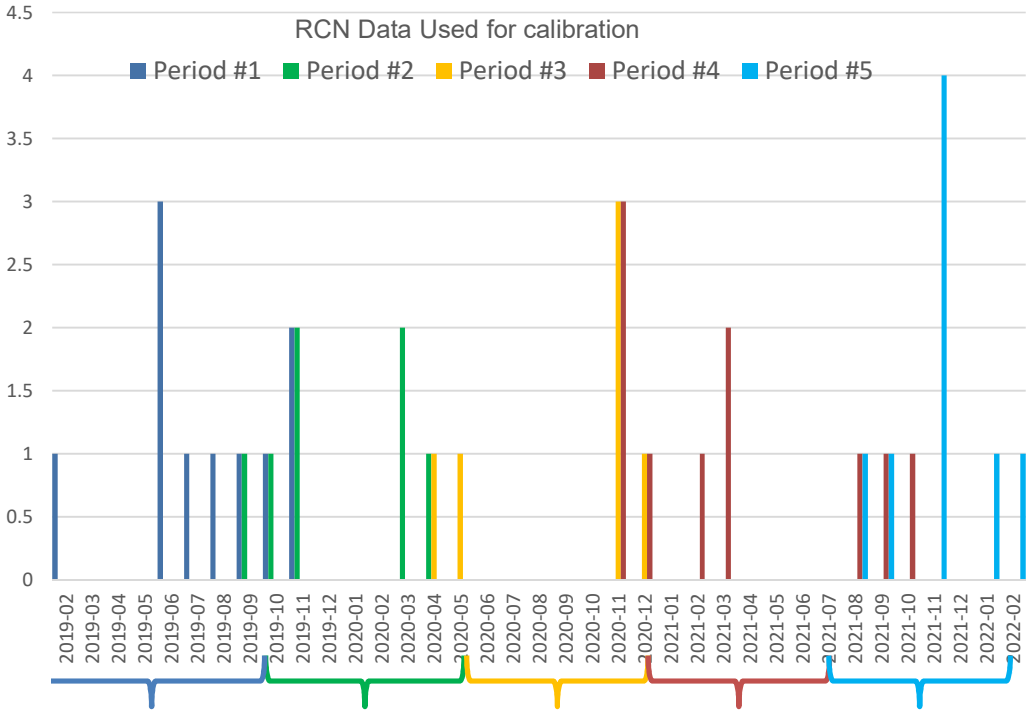


- 2 Modes observed associated to temperature gradients in the optical system. Jump of **0.5 nm** between modes. Corrected during smile correction step

Radiometric Vicarious calibration

- Input scenes not evenly distributed in time
- Particularly challenging to have abundant good quality Radcalnet (RCN) scenes
- Calibration updates arrive several months after data acquisition

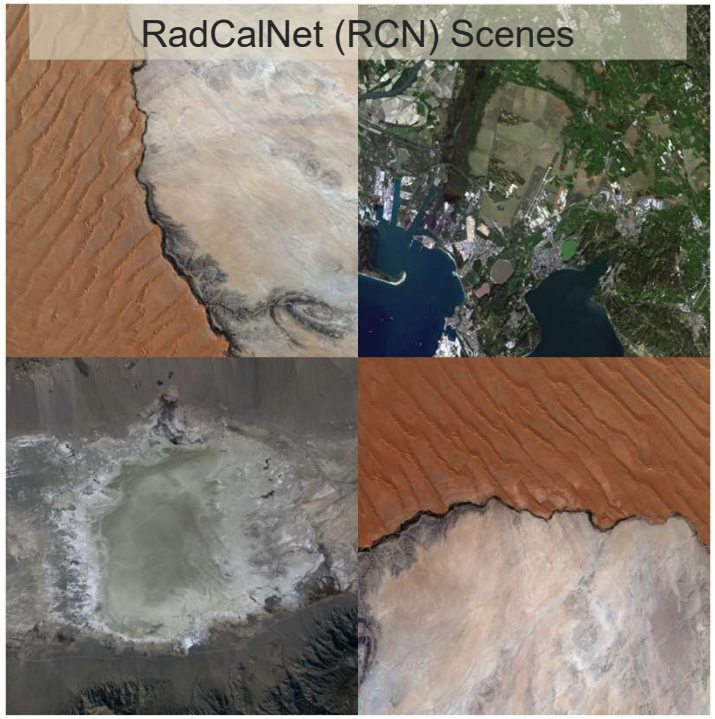




DESIS Vicarious Calibration

Obtain consistent relative response in spatial and spectral directions:

- Flat response on homogenous input
- Smooth pixel to pixel transitions
- Consistent behavior across-track



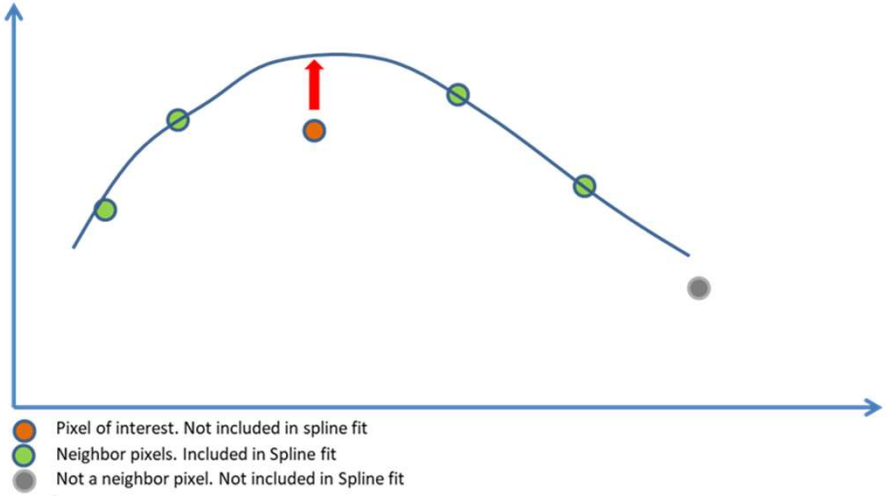
Obtain absolute radiance scale

Correction Steps I: Radiometric adjustments

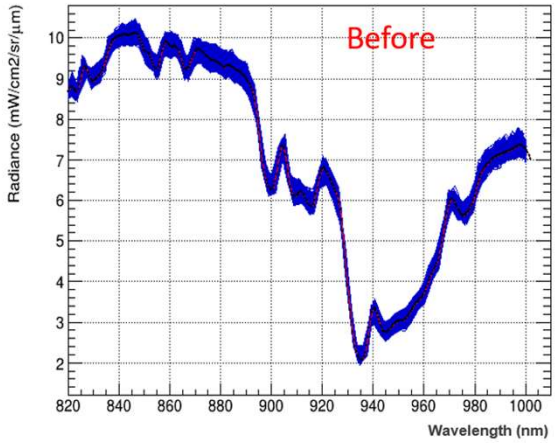
- Most steps performed with uniform scenes with L1B products averaged in the along-track direction
  - 235 bands × 1024 spatial pixels

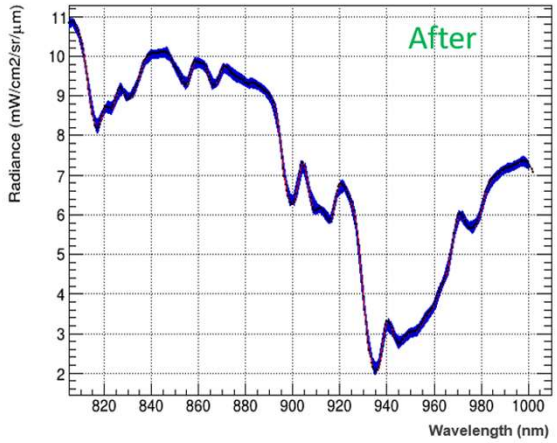
- Most corrections are performed after smile correction (confusion of spectral and radiometric corrections)

- **Striping correction**: Compute adjustment to radiometric coefficient using spline fits. Use iterative process until convergence



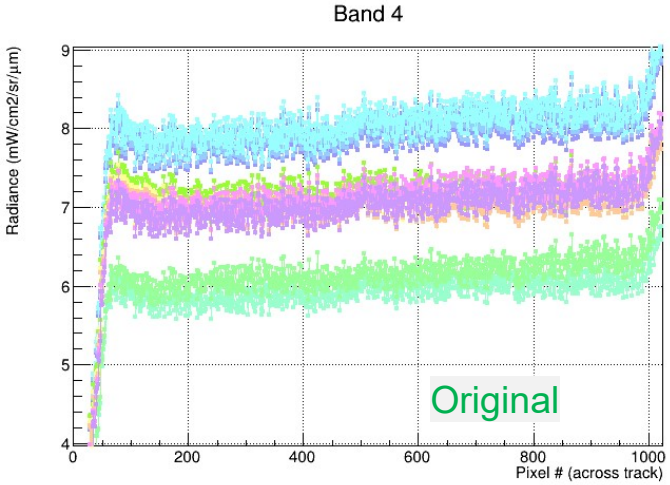
- **Rad./Spc. correction**: Use all pixels across track in one single spectrum. Compute minimum deviation to common spectrum

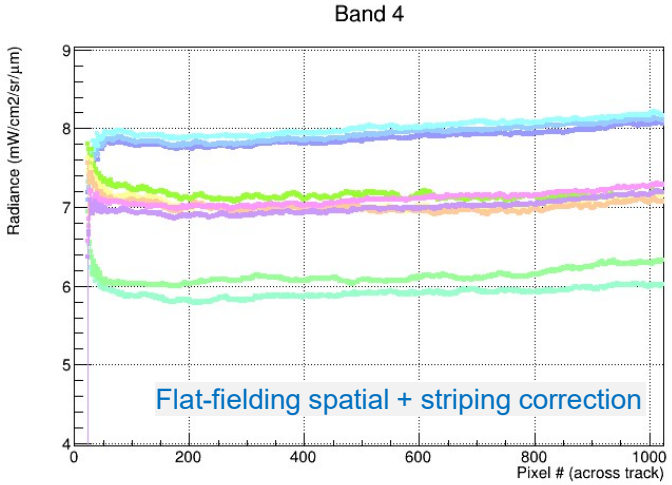


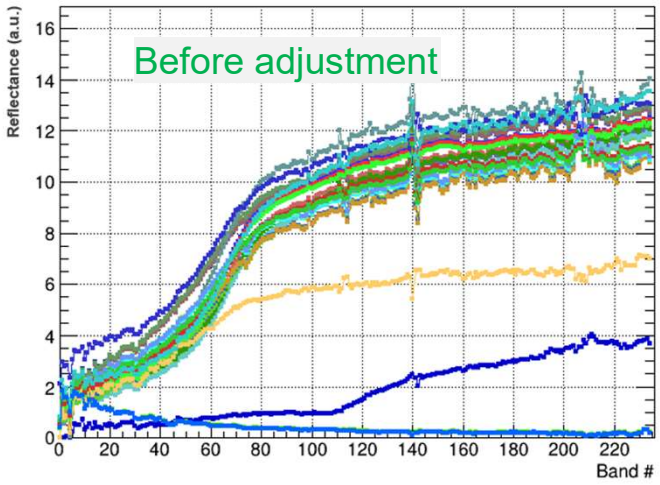


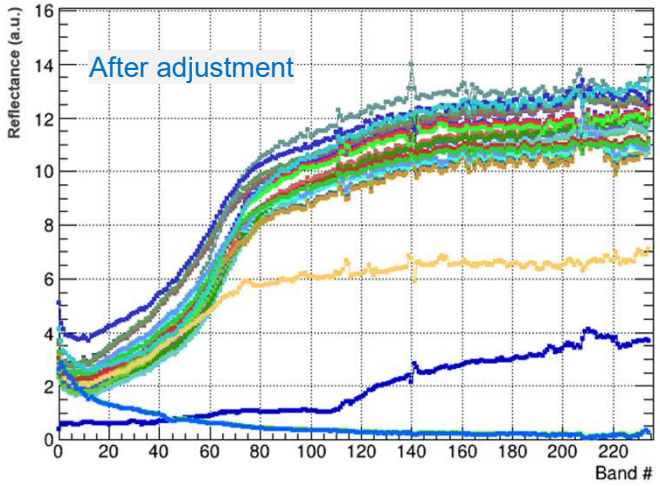
Correction Steps: Flat-fielding

- **Flat-fielding spatial**: In homogeneous scenes all pixels across-track shall have the same value within a band
- **Flat-fielding spectral**: In homogeneous scenes all across-track pixels shall deliver the same spectra as the central pixels
- **L2A Smoothing**: Adjust radiometric coefficients to reduce band to band fluctuations in L2A products for all pixels across-track



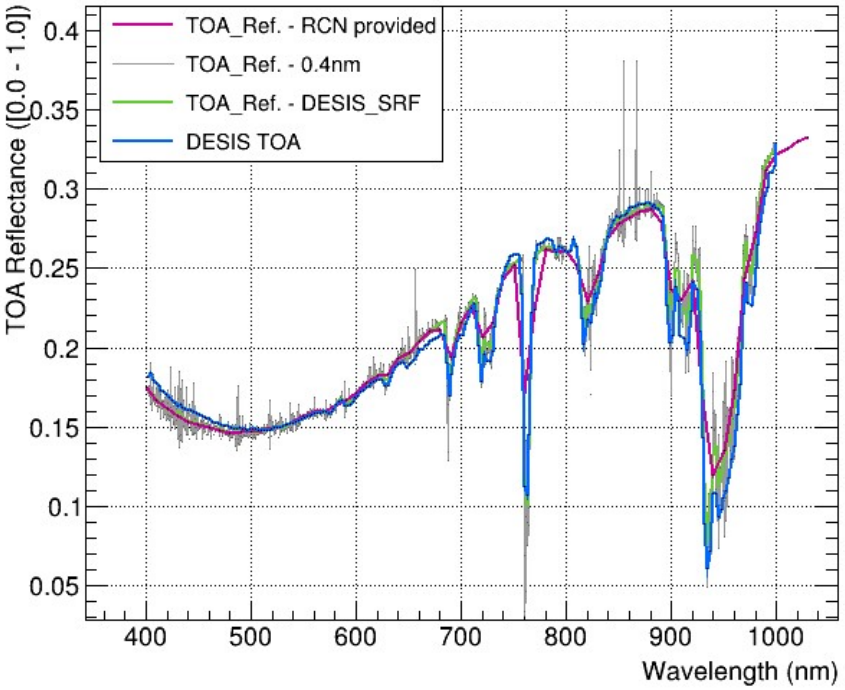


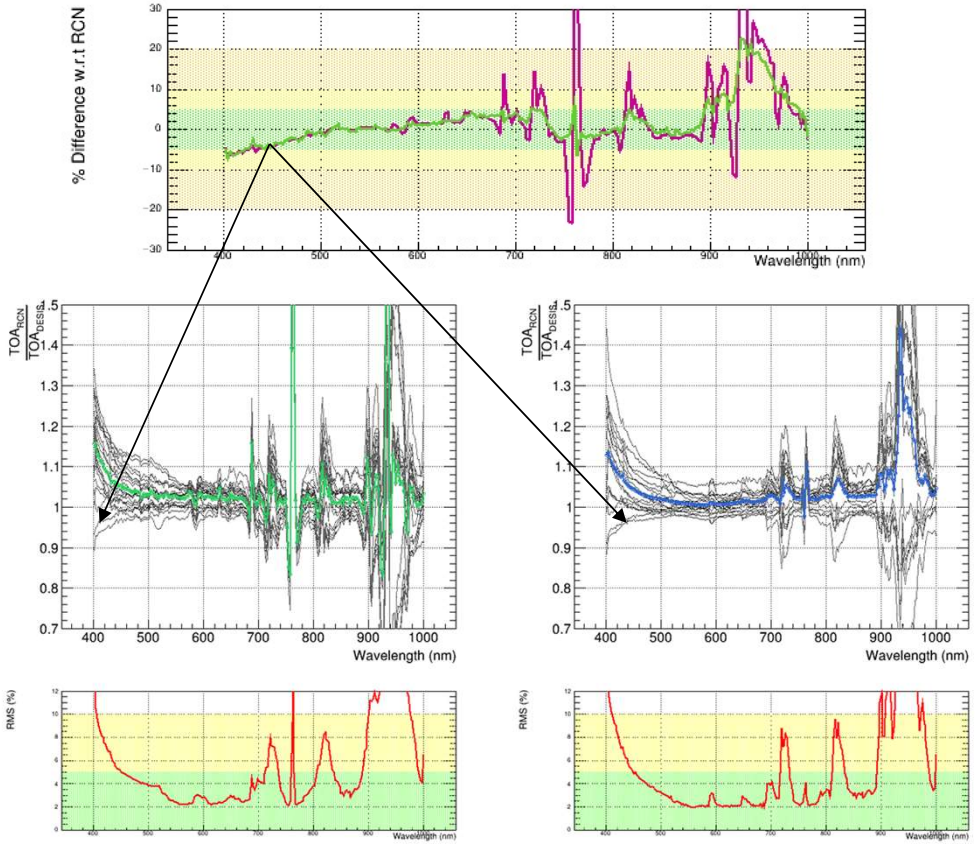




Vicarious Calibration

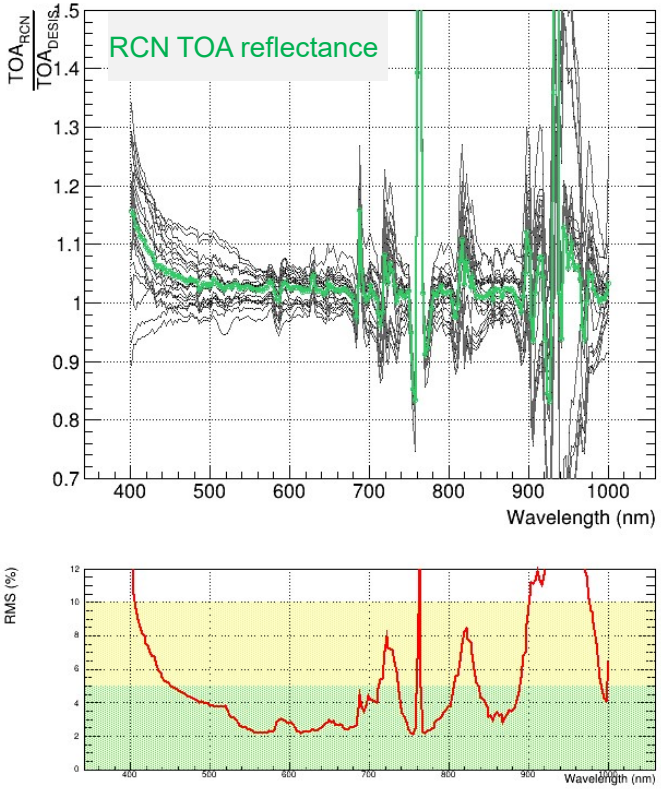
- Use flat-fielding over uniform areas for pixel-to-pixel relative adjustment. Use RadCalNet sites for absolute calibration

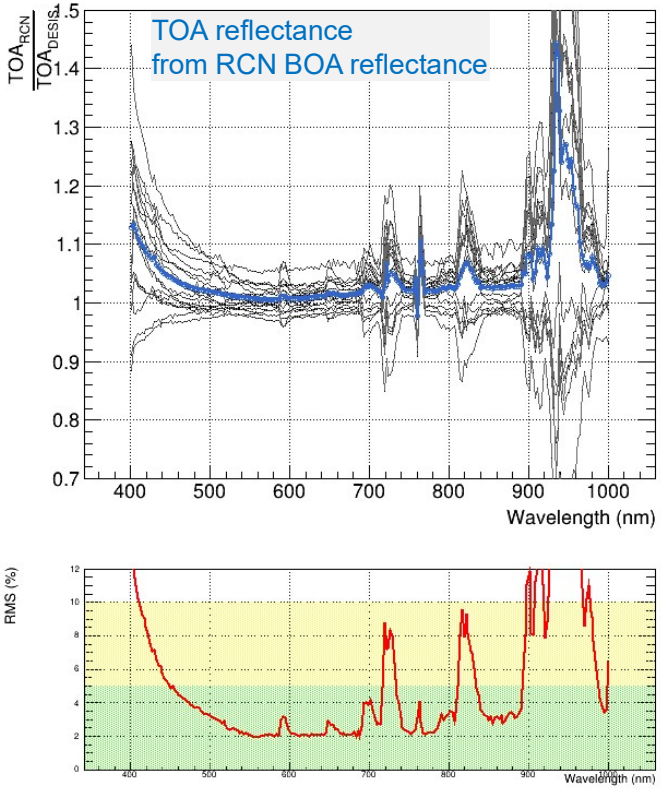




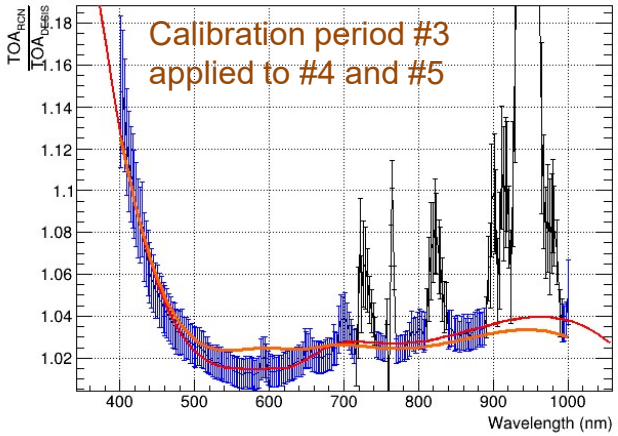
Latest Vicarious calibration data

- New calibration periods continue using baseline vicarious calibration
- Data in **periods #4** and **#5** with calibration for period #3:



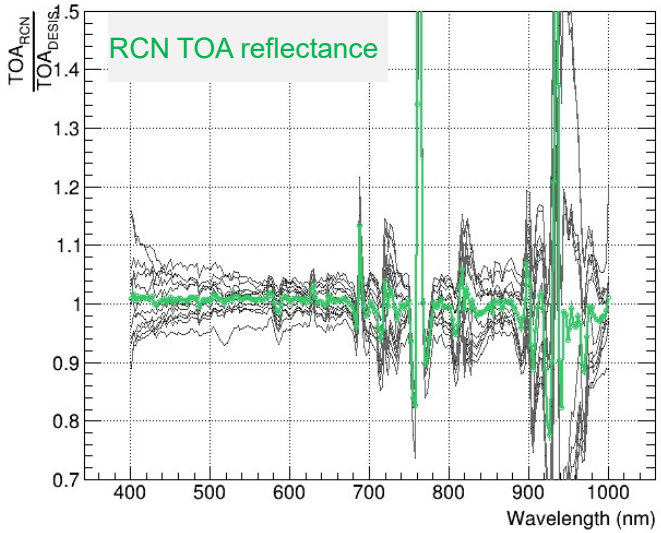


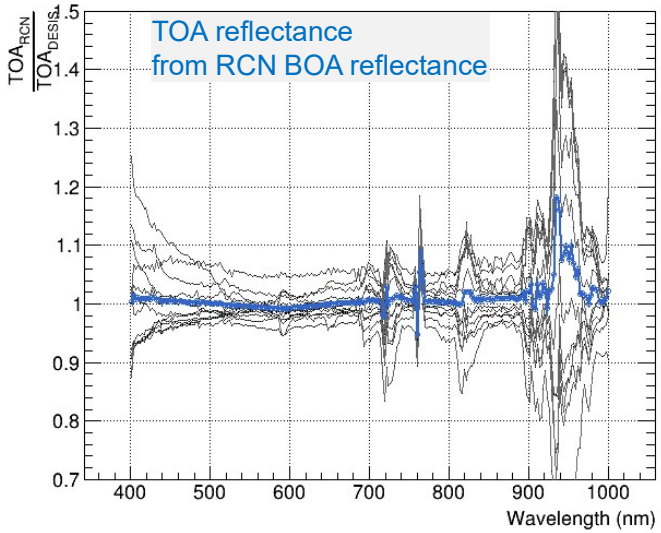
- Large variation of calibration below 500 nm as seem in other periods
- Magnitude is smaller

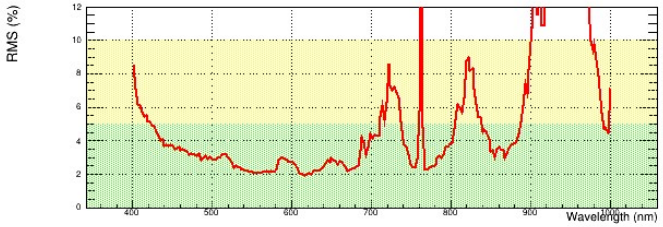


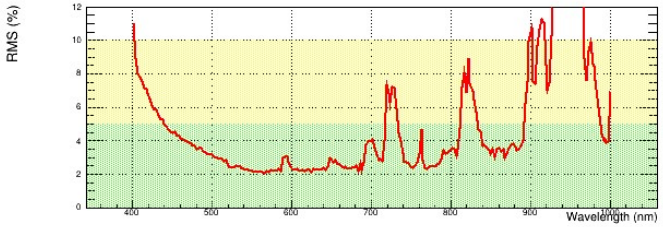
Latest Vicarious calibration data

- New calibration periods continue using baseline vicarious calibration used in DESIS
- Data in **period #4** calibrated with calibration in period #4:





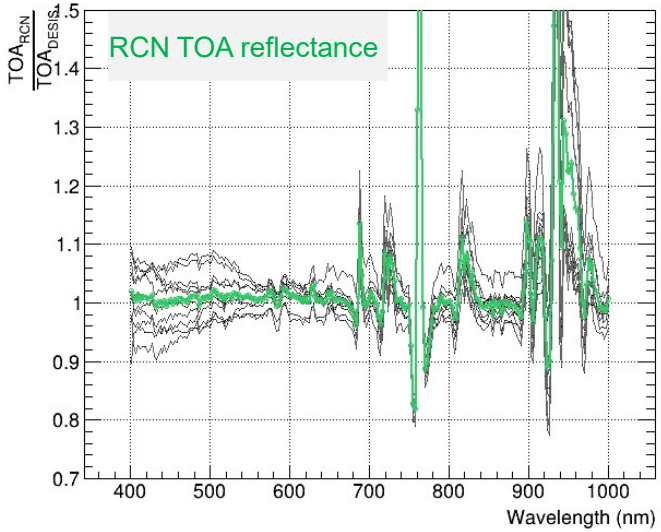


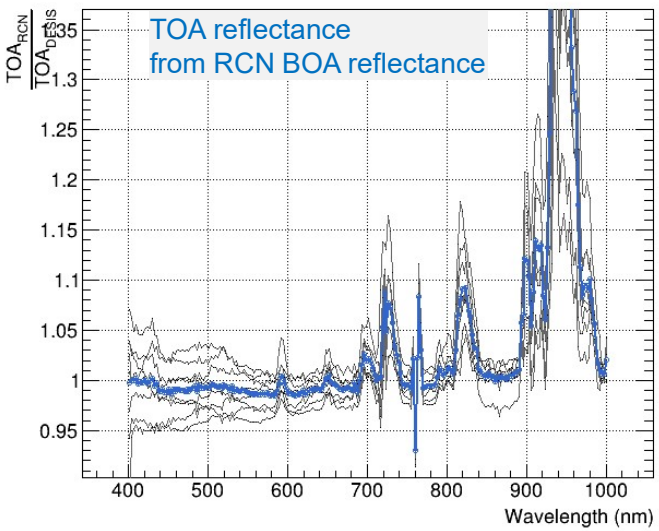


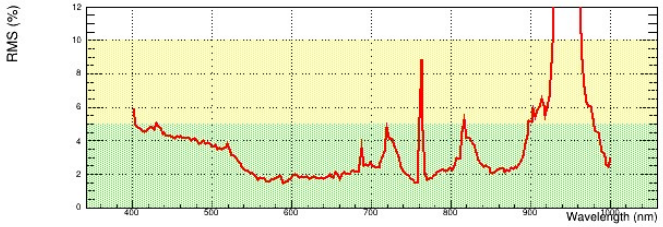
- Similar results as seen in other periods
- After calibration bias is corrected, but as usual RMS below 500 nm is significant larger than above 500 nm

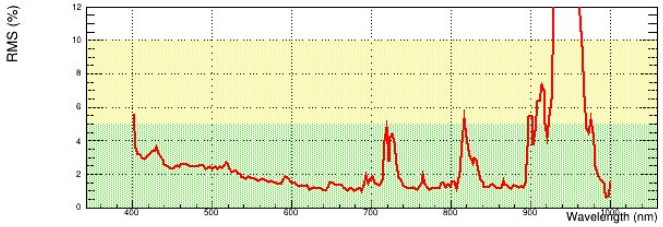
Latest Vicarious calibration data

- New calibration periods continue using baseline vicarious calibration used in DESIS
- Data in **period #5** calibrated with calibration in period #5:





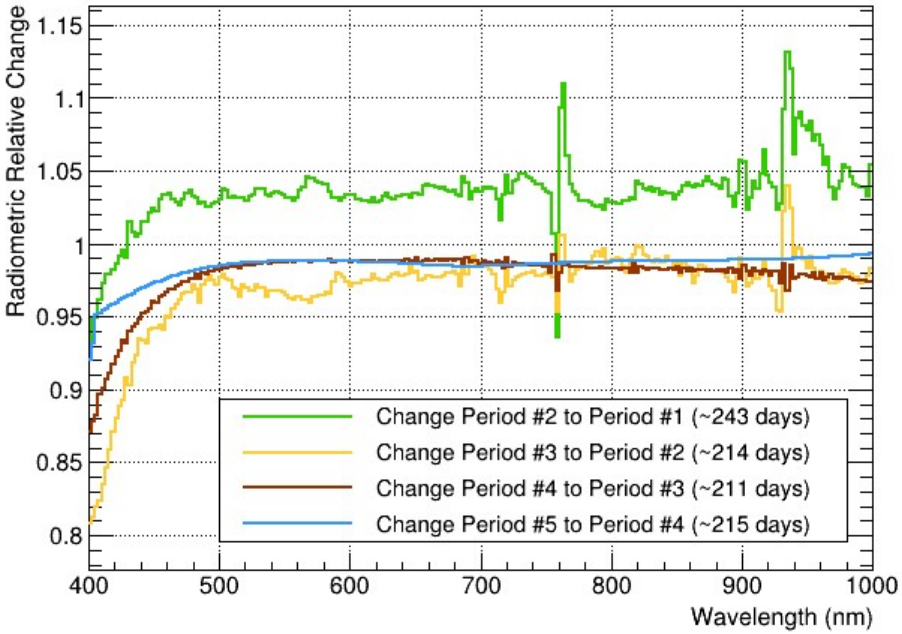


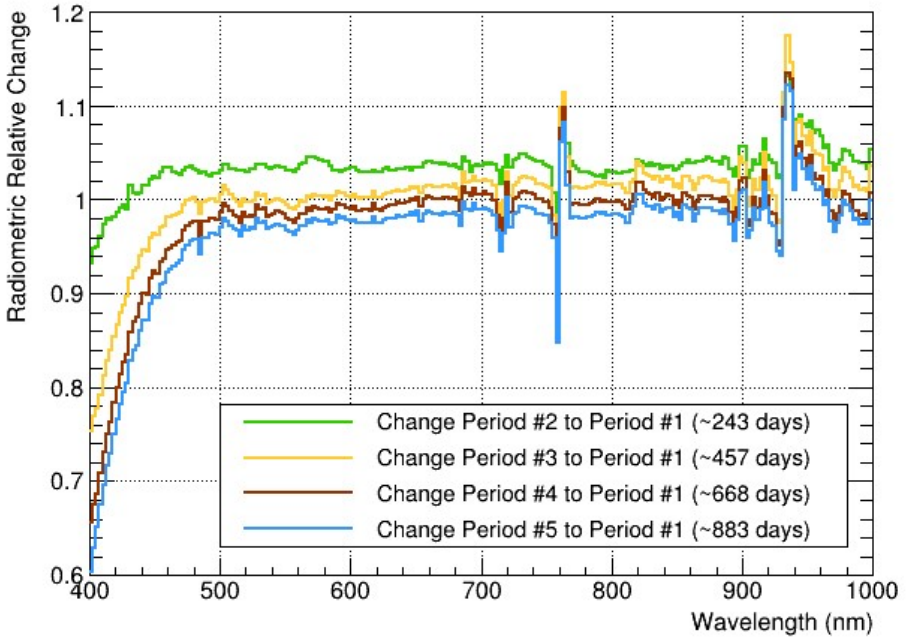


- For the first time different behavior below 500 nm
- More stable during Period #5, reduced RMS compared to all previous periods
- Degradation below 500 nm is reduced

Vicarious Calibration

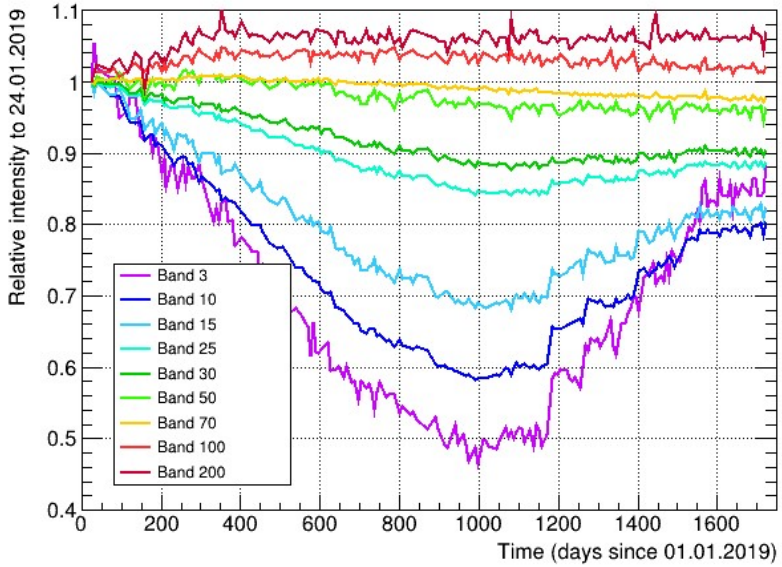
- Radiometric calibration shows high variability for wavelengths above 480 nm for data until July 2021
- More stable (better than 3.4% / year) for wavelengths above 500 nm

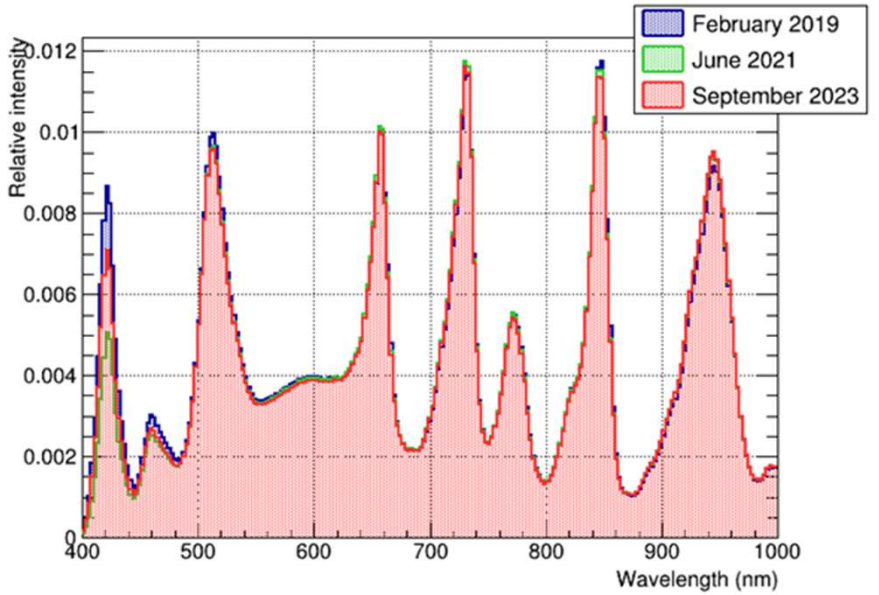




Crosscheck with Calibration Unit

- Change of behavior below 500 nm observable in August 2021. Degradation reduces
- More Stable until February 2022
- Rapid increase until December 2022 and more stable (again) since then
- Very stable in other wavelengths

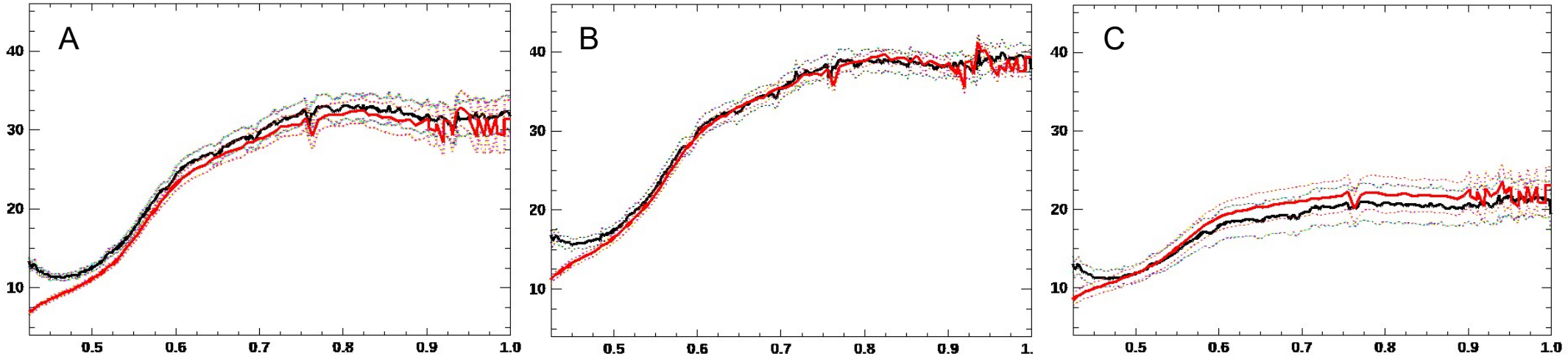


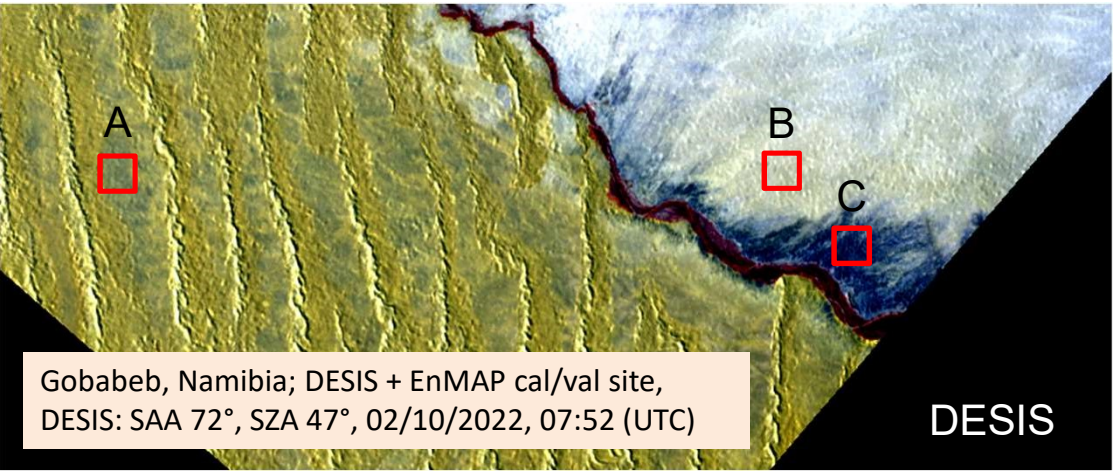


DESIS and EnMAP – L2A spectral comparison

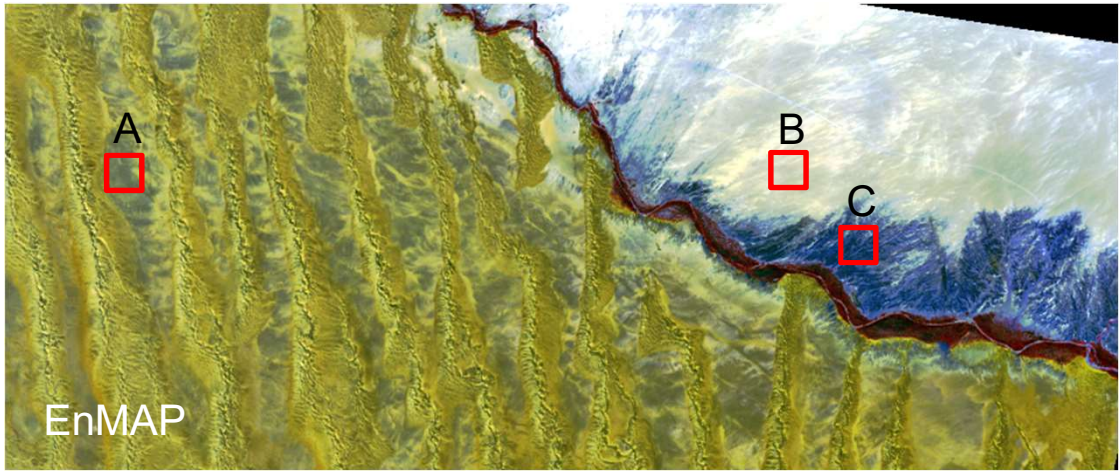
DESIS

EnMAP



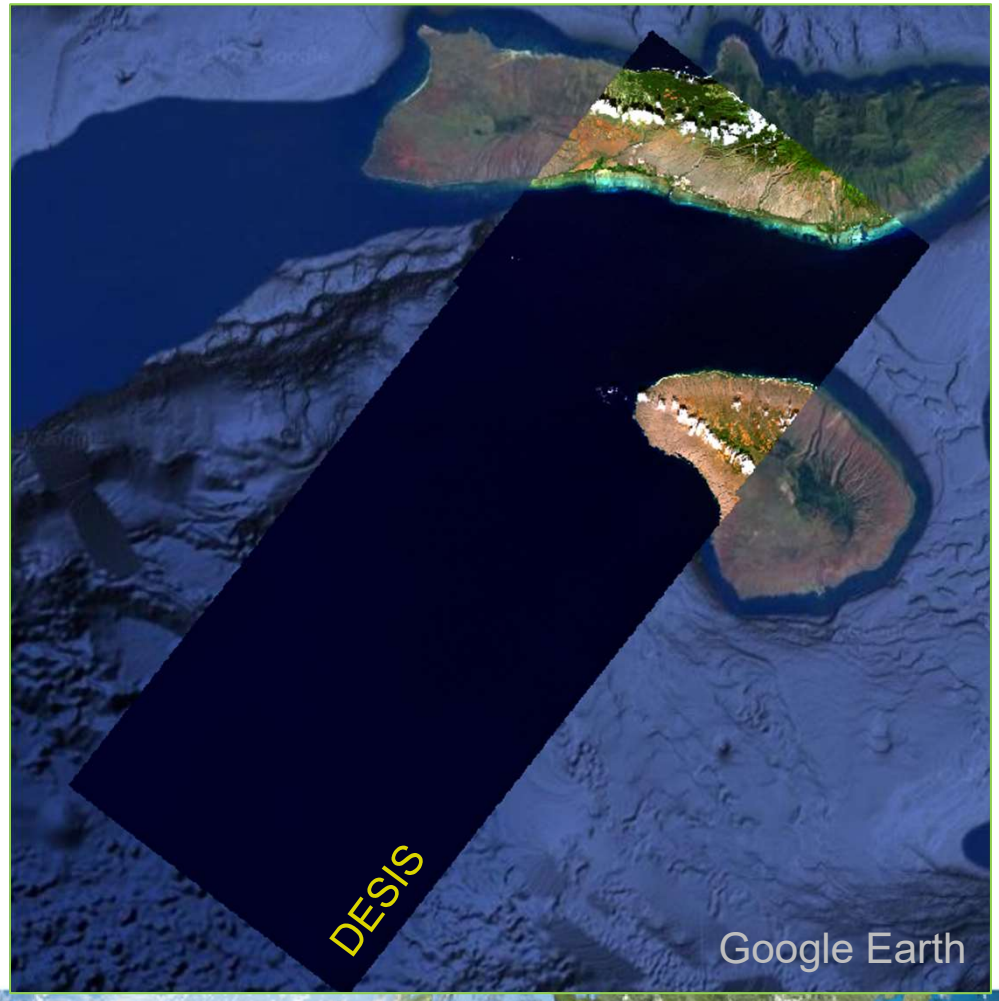


Gobabeb, Namibia; DESIS + EnMAP cal/val site,
DESIS: SAA 72°, SZA 47°, 02/10/2022, 07:52 (UTC)



L1C Processing (and Calibration)

- Orthorectification is performed individually for each DESIS product
- It requires support from automatically extracted Ground Control Points (GCPs) from each scene to improve results and achieve accuracy better than 1 pixel
- Sometimes it is not possible to obtain GCPs and the geometric accuracy reduces
- The image shows a datatake with 3 tiles. Only 1 contains GCPs



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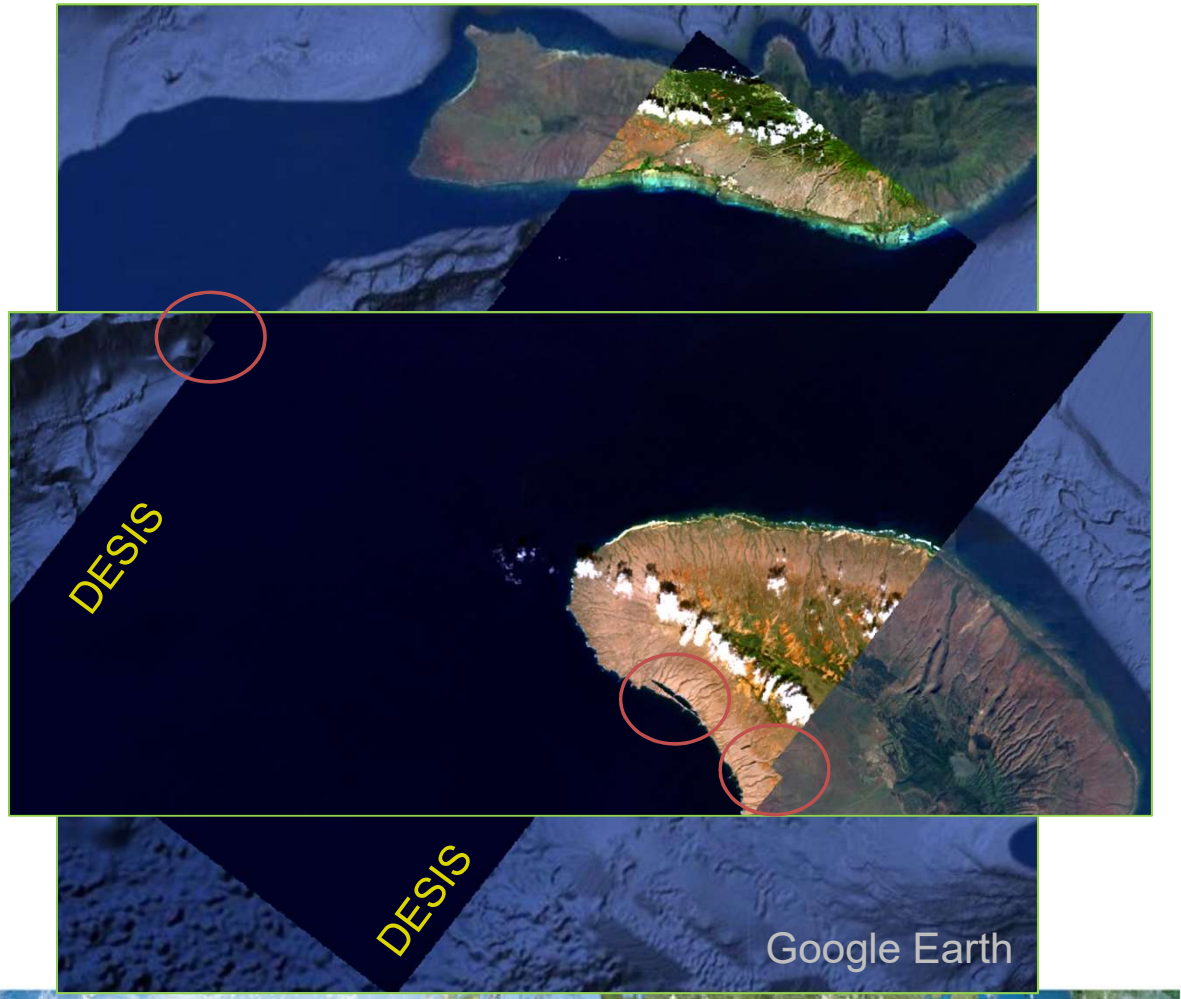
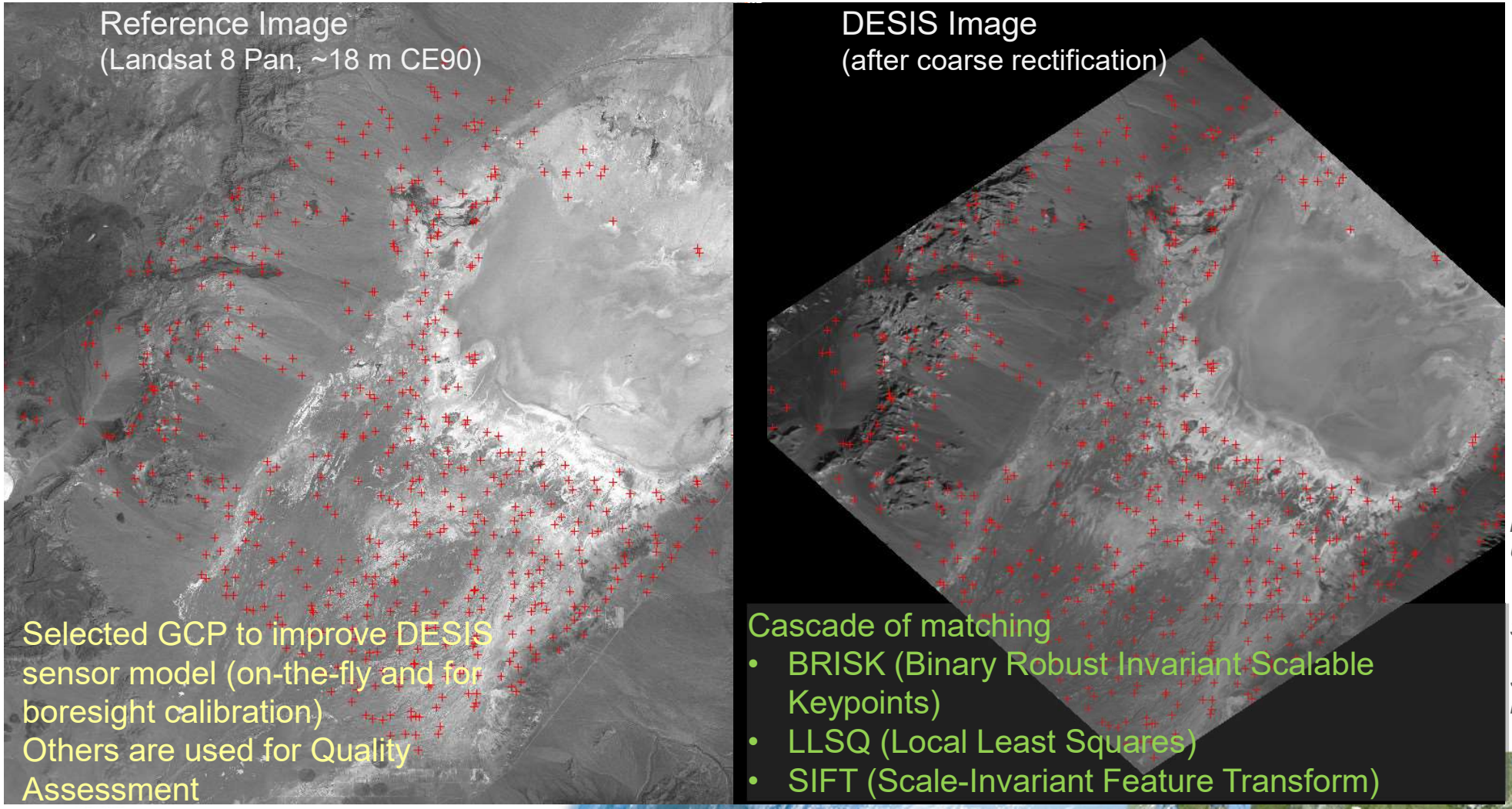


L1C Processing (and Calibration)



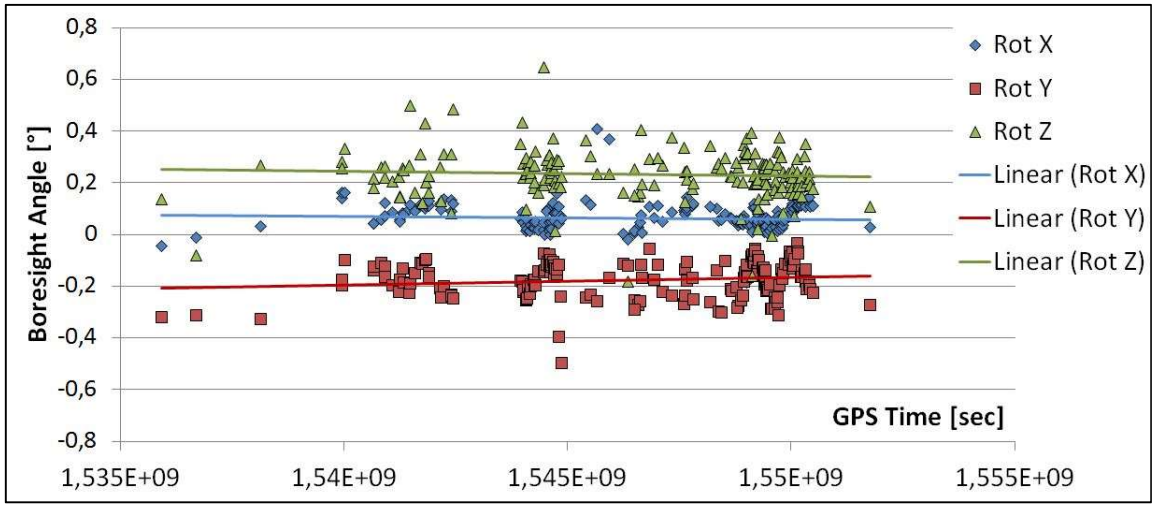
Railroad Valley, USA
13-12-2018
18:23:11 UTC
38.4467°N
115.7512° W
Sun: 64.14°, 160.58°
Incident Angle: 0.8°

Geometric performance

- Accuracy w.r.t. Reference in 177 scenes:
  - #GCP: average **210** per scene
  - #Control Points: average **969** per scene
- In case image matching works for a scene
  - RMSE (east) = **21.0 ± 5.9 m**
  - RMSE (north) = **21.4 ± 6.0 m**
- In case of no-matching, geolocation relies on boresight calibration:
  - RMSE ~289 m (across); ~496 m (along), but with peak values up to 1 km

Check in Metadata file the parameters "**orthoRMSE_x**" or "**orthoRMSE_y**". When value is **-1** it means that no matching could be achieved

- Boresight angles are stable over time:



- Recently updated boresight calibration with **date 01.03.2023**

Summary

- DESIS spectral calibration uses the calibration unit and vicarious calibaration. Spectral stability ~0.11 nm (RMSE) between measurements (after correction of temperature effects). Stable long-term.

- Vicarious calibration used for Radiometric calibration. Radiometric accuracy after adjustment to RCN ~4-5% (RMSE)

- An update of radiometric calibration is needed for data after February 2022, in particular below 500 nm. Calibration unit data shows a recovery of the sensitivity lost during the first 3.5 years of operation

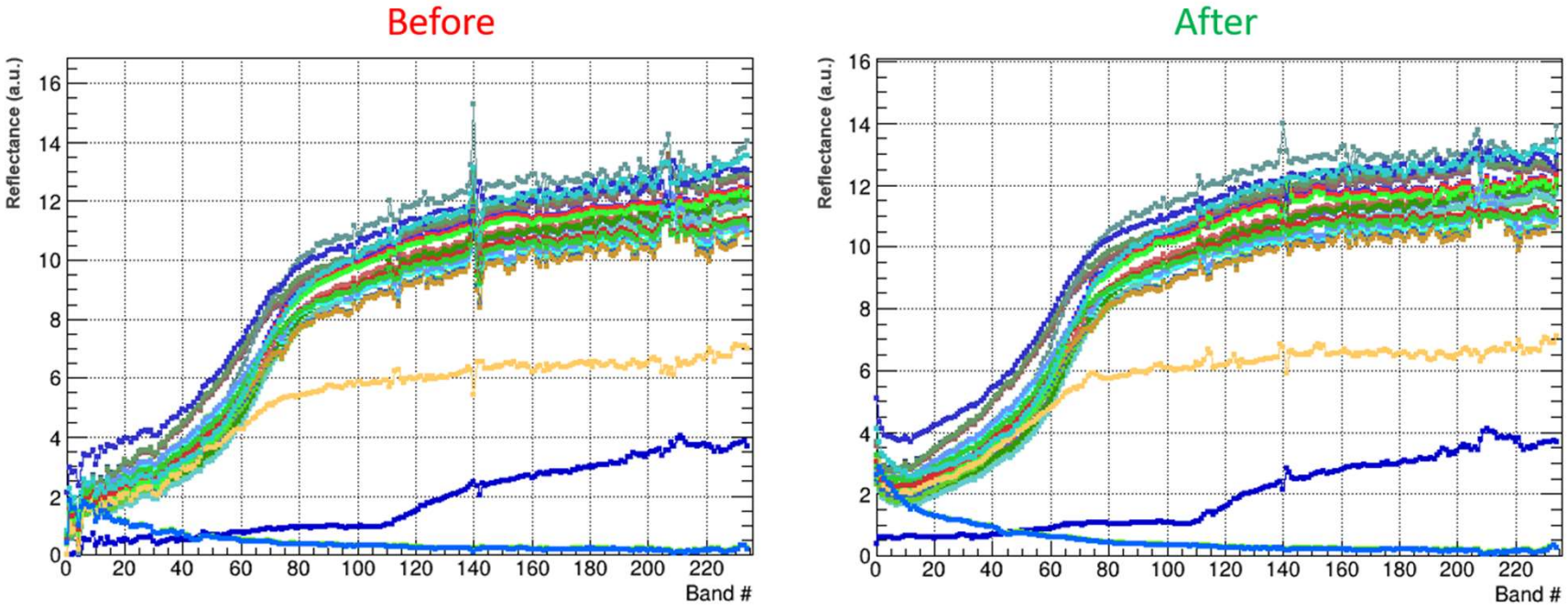
- Geometric performance very stable. Significant accuracy difference between products with GCP (RMSE ~21 m) and without GCPs (RMSE 300 m – 500 m)


DLR - Earth Observation Center – DESIS
https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/
EOWEB GeoPortal (Catalogue DLR)
https://eoweb.dlr.de/egp/
DLR
Teledyne

Extra

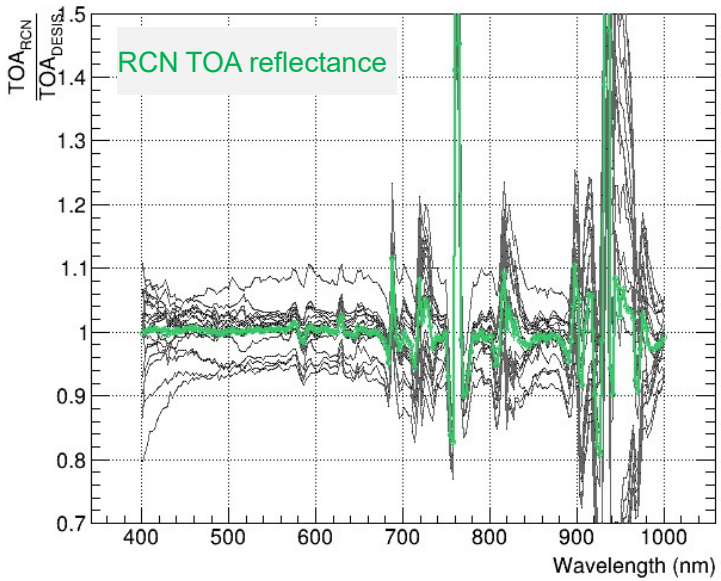
Correction Steps: L2A spectral smoothing

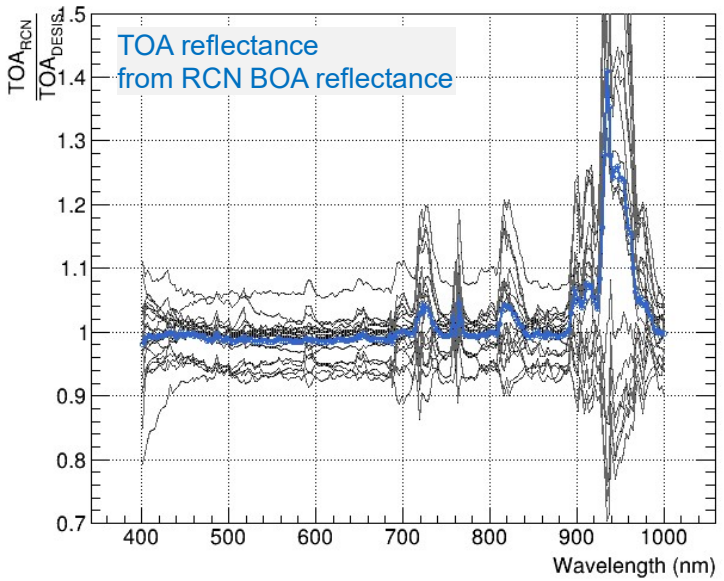
- Fine tuning of individual pixels radiometric factors obtained using L2A data to avoid atmospheric features
- Compute correction to minimize pixel to pixel fluctuations. Effect visible at lower wavelengths. Fluctuations at larger wavelengths dominated by spectral calibration errors and etaloning/fringing effect in the detector



Results from 3 calibration periods

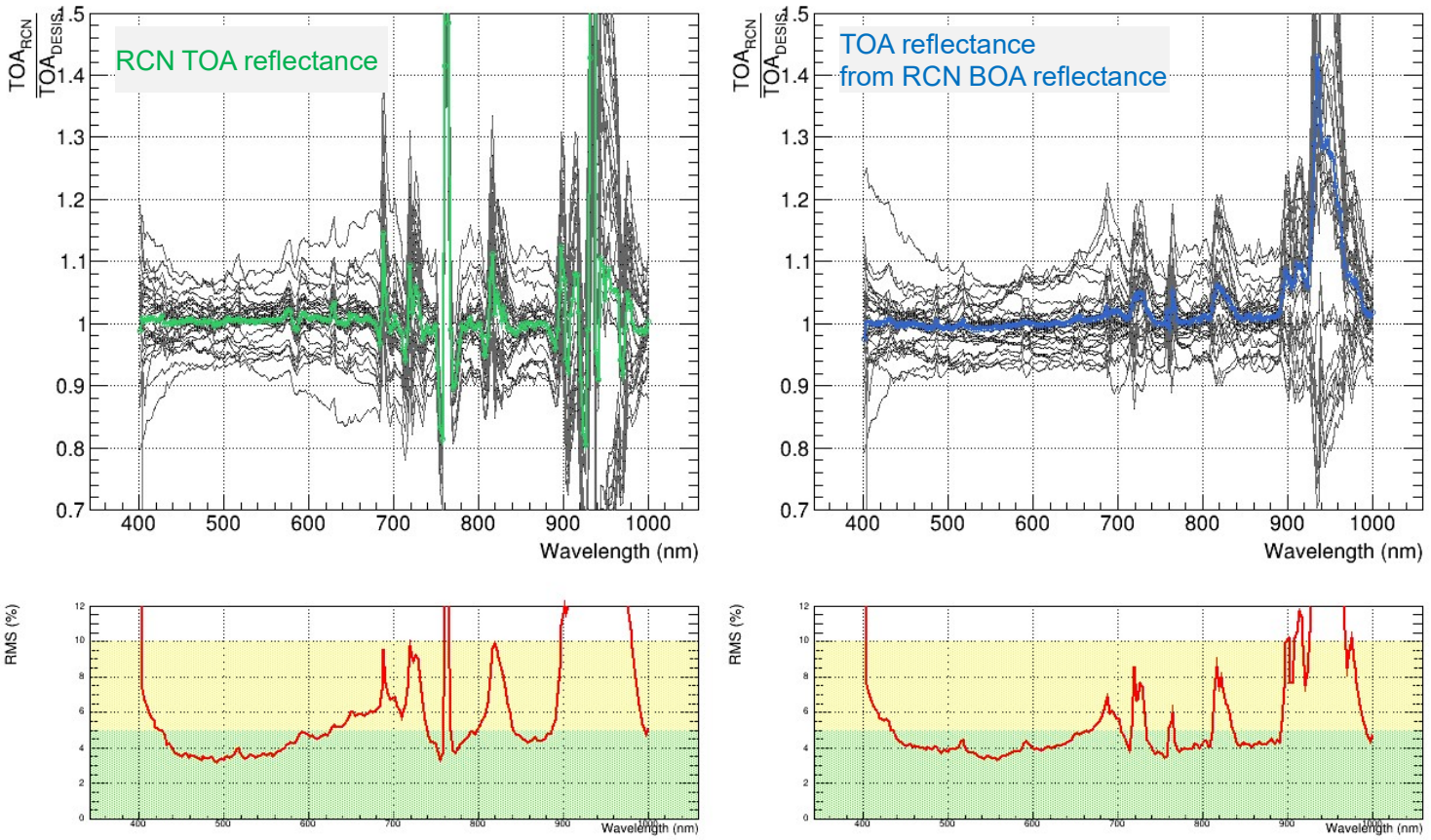
- Absolute calibration adjusted with RCN data for 3 different periods
- Absolute calibration uses only part of RCN scenes (19)
  - good atmospheric conditions
  - below 50 degrees Sun Zenith Angle
- These summary plots show **19** RCN scenes used for calibration





Results from 3 calibration periods: All RCN Data Results

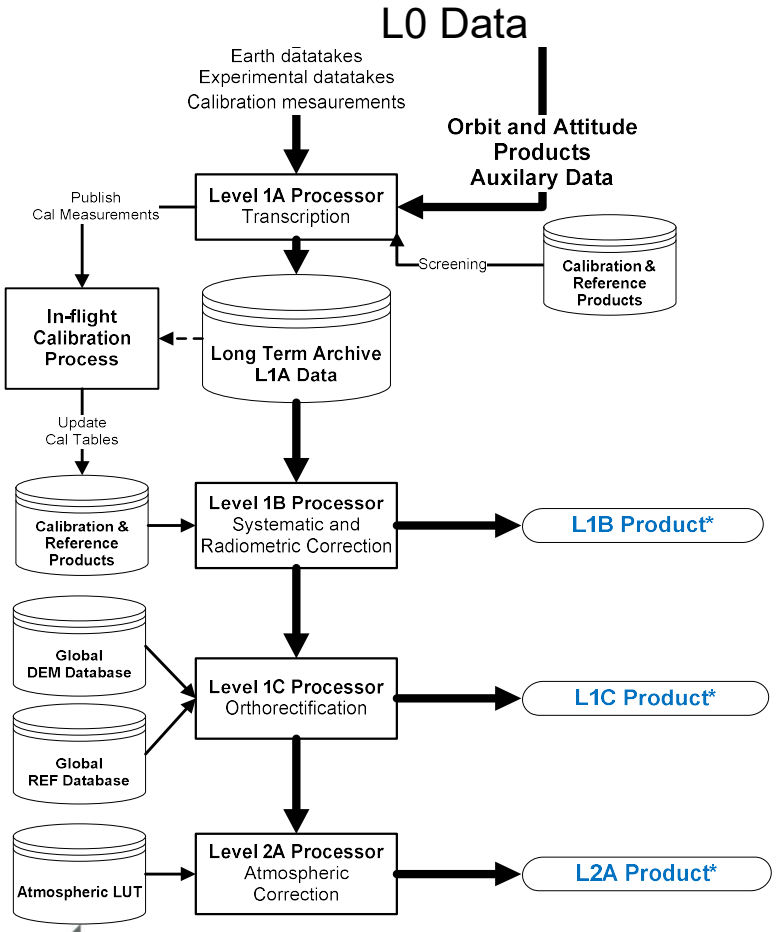
- Absolute calibration adjusted with RCN data for 3 different periods
- Absolute calibration uses only part of RCN scenes (19)
  - good atmospheric conditions
  - below 50 degrees Sun Zenith Angle
- These summary plots show **all** RCN scenes (**30** scenes)



Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESIS) Sensors 2019, 19(20), 4471; https://doi.org/10.3390/s19204471

DESIS Data Products

DESIS – Operational processors (DLR + Amazon Cloud)



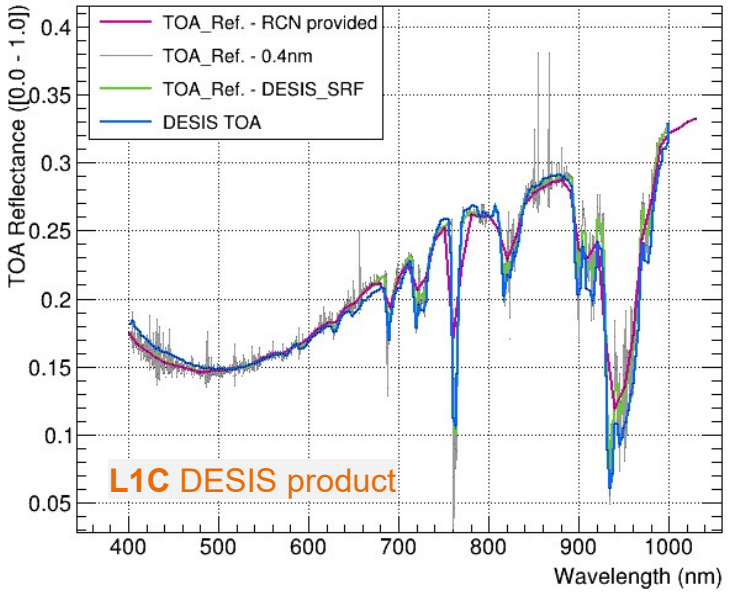
Products:

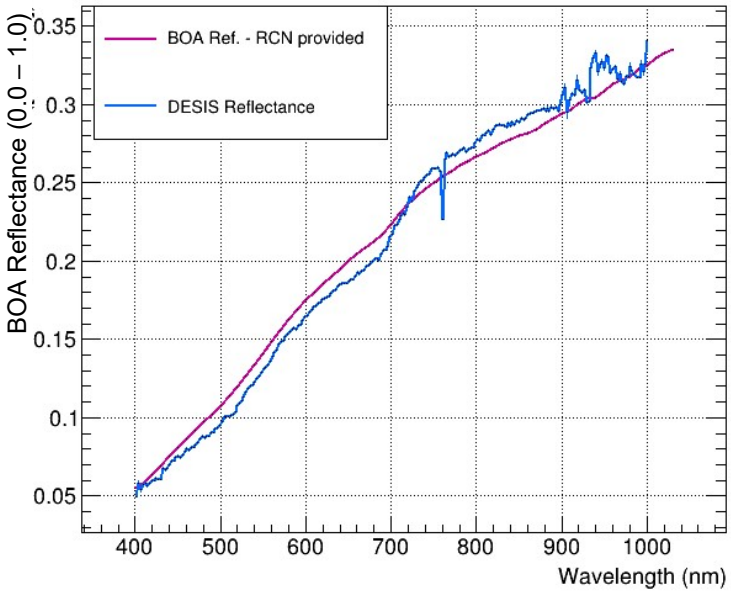
- **Level 0 (L0)**
  - Raw data (Datatakes up to 100 tiles 30x30 km², trajectory files, DC)
- **Level 1A (L1A)**
  - Tiled images, browse image, metadata, quality flags <= archived
- **Level 1B (L1B)***
  - Top of Atmosphere (TOA) radiance ($W \cdot m^{-2} \cdot sr^{-1} \cdot \mu m^{-1}$)
  - Systematic and radiometric correction (rolling shutter, smile, …)
  - All metadata attached for further processing
- **Level 1C (L1C)***
  - Level 1B data ortho-rectified, re-sampled to a specified grid
  - Global DEM (SRTM, 1arcsec), sensor model refinement using global reference image (Landsat-8 PAN with acc. 18m CE90)
- **Level 2A (L2A)***
  - Ground surface reflectance (i.e. after atmospheric corrections)
  - With and w/o terrain correction

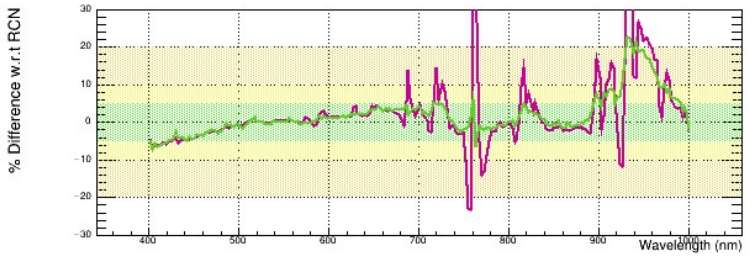
*** Delivery Product**

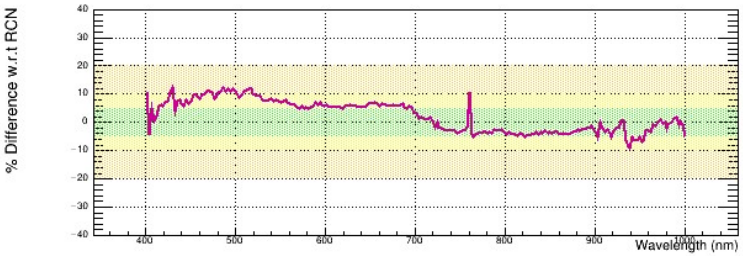
Results First Vicarious calibration (2018-10 – 2019-09)

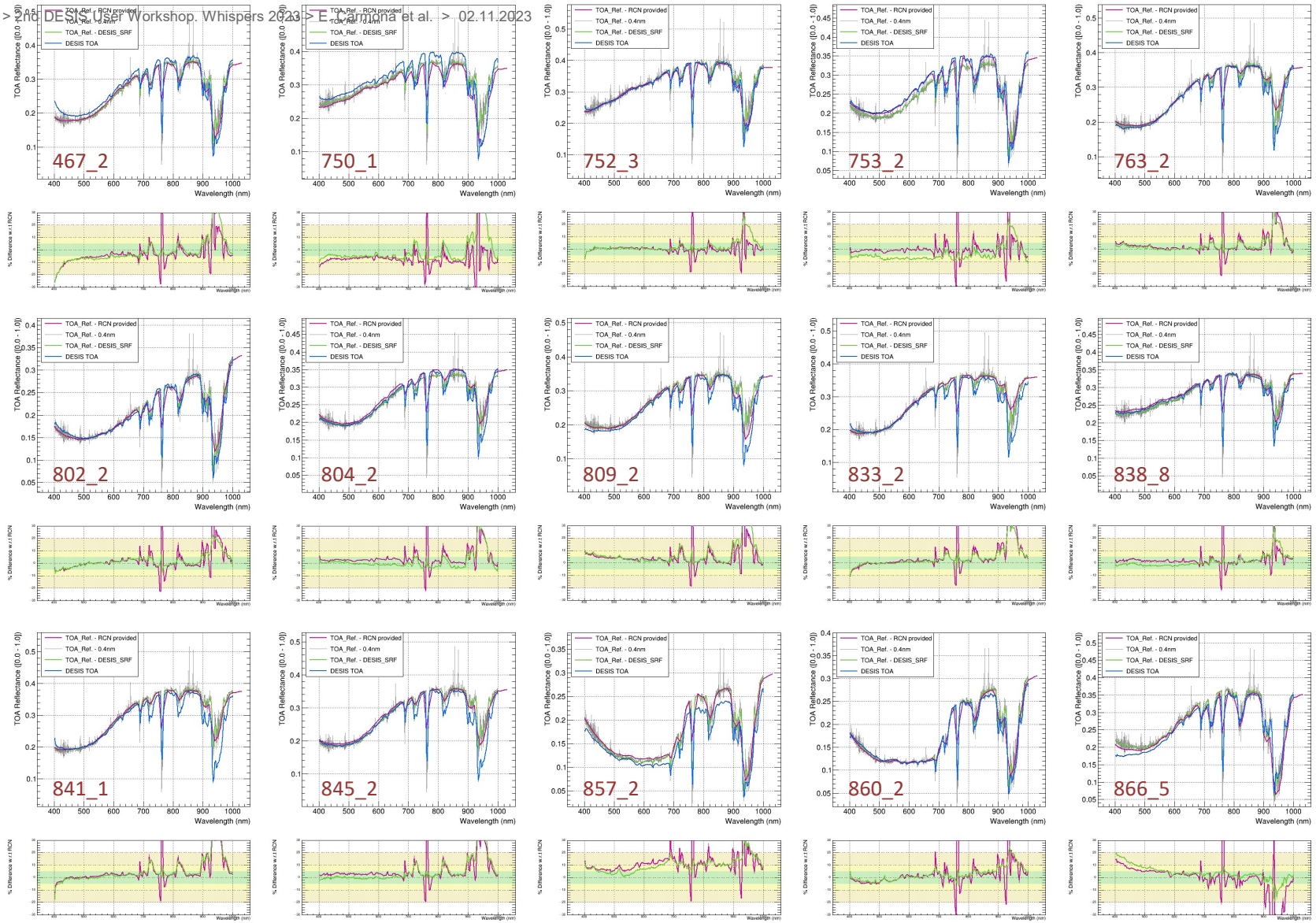
- Crosscheck using independent scene from RCN LCFR
  - TOA reflectance (left, 2 references)
  - BOA reflectance (right, 1 reference)

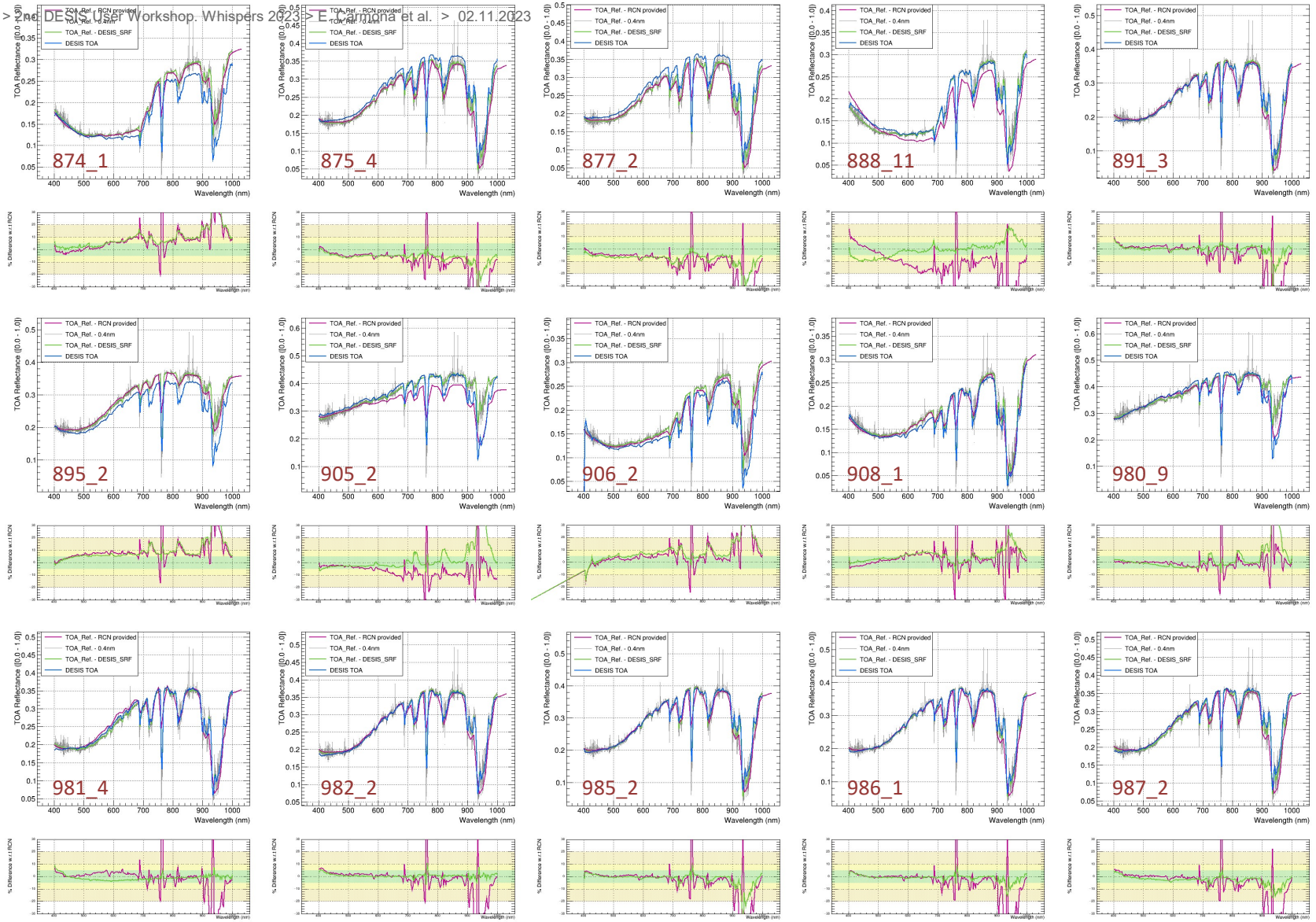









TOA_Ref. - RCN provided
TOA_Ref. - 0.4nm
TOA_Ref. - DESIS_SRF
DESIS TOA
TOA Reflectance ((0.0 - 1.0))
Wavelength (nm)
% Difference w.r.t RCN
467_2
750_1
752_3
753_2
763_2
802_2
804_2
809_2
833_2
838_8
841_1
845_2
857_2
860_2
866_5


874_1
875_4
877_2
888_11
891_3
895_2
905_2
906_2
908_1
980_9
981_4
982_2
985_2
986_1
987_2
TOA_Ref. - RCN provided
TOA_Ref. - 0.4nm
TOA_Ref. - DESIS_SRF
DESIS TOA
TOA Reflectance ((0.0 - 1.0))
Wavelength (nm)
% Difference w.r.t RCN