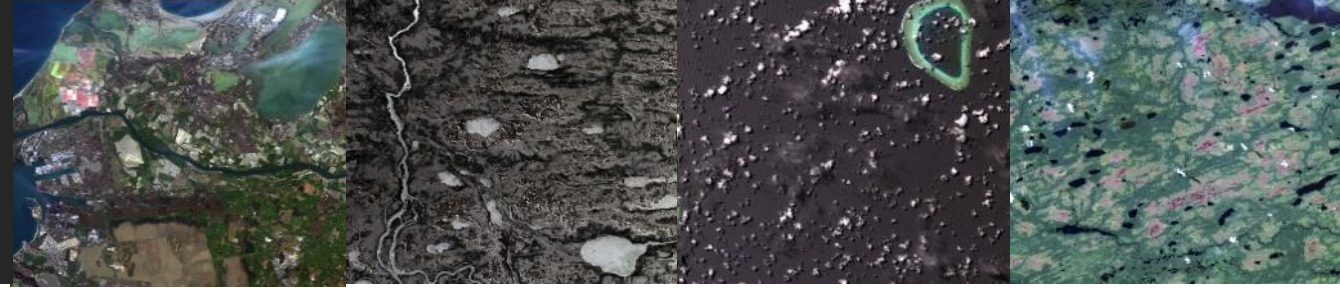
CEOS WGCV IVOS 35
Oberpfaffenhofen, Germany
27 September 2023



The DESIS Spaceborne Hyperspectral Instrument Calibration

E. Carmona[1], M. Bachmann[2], R. de los Reyes[1], D. Marshall[1], R. Müller[1]

[1] Remote Sensing Technology Institute, DLR, Oberpfaffenhofen, 82234 Wessling, Germany
[2] German Remote Sensing Data Center, DLR, Oberpfaffenhofen, 82234 Wessling, Germany

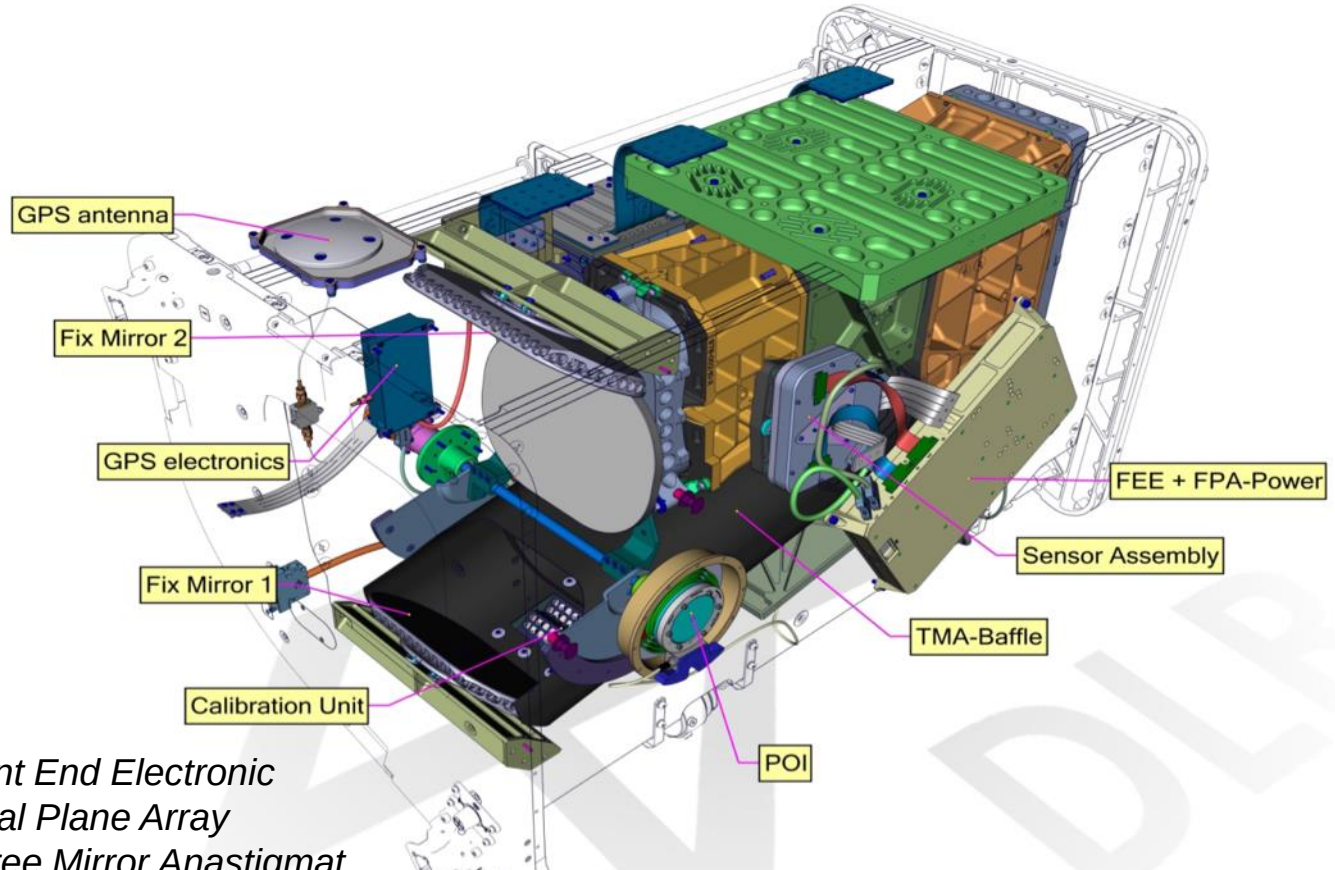
DLR

Teledyne

Mission Introduction

DESIS Instrument

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



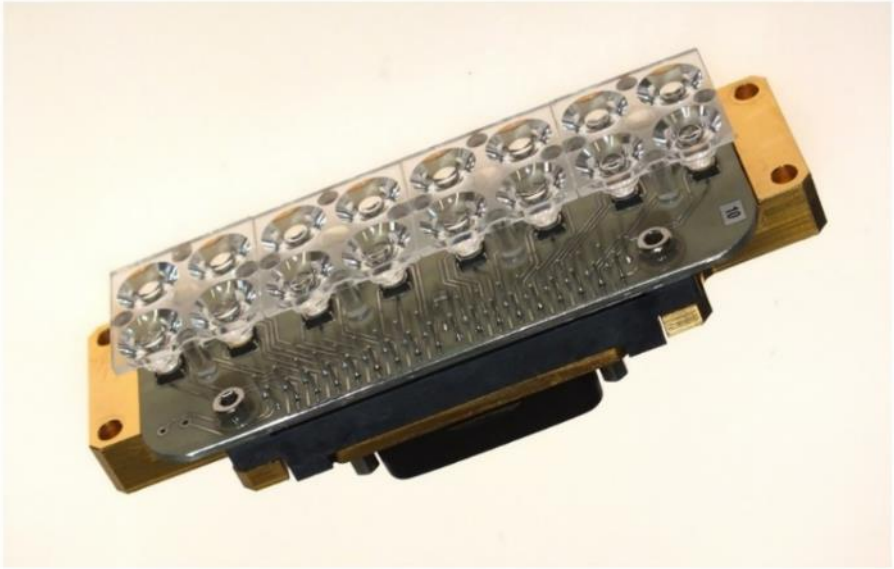
FEE: *Front End Electronic*
FPA: *Focal Plane Array*
TMA: *Three Mirror Anastigmat*
POI: *Pointing Unit*

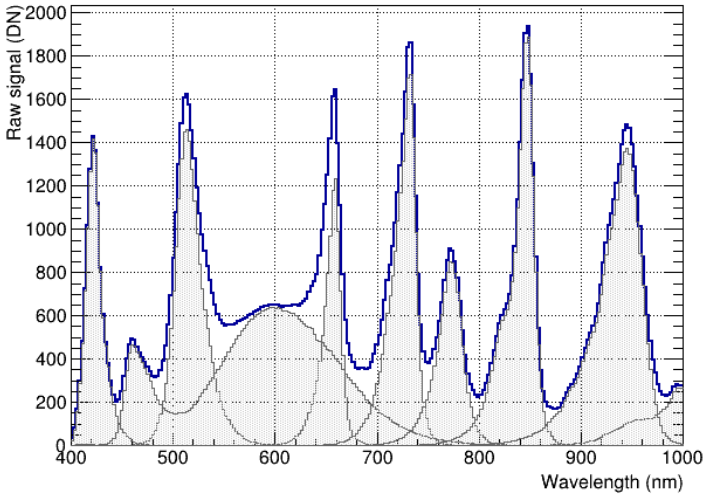
Sensors 2019, 19(7), 1622; https://doi.org/10.3390/s19071622

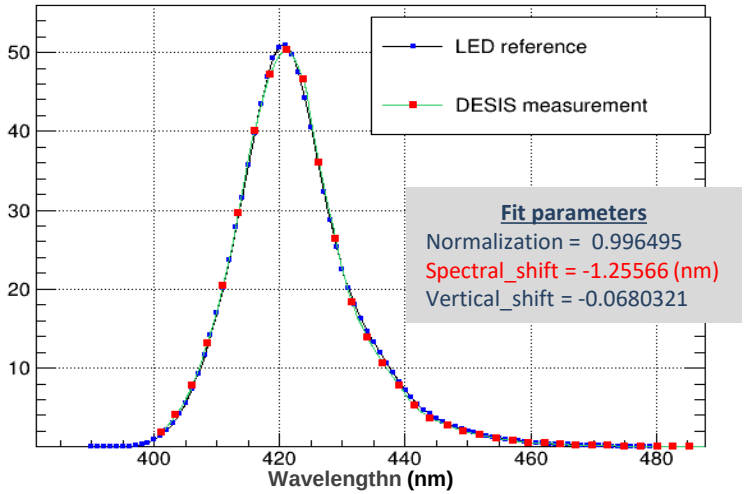
Mission Instrument	MUSES/DESIS
Target lifetime	2018-2023
Off-nadir tilting (across-track, along-track)	-45° (backboard) to +5° (starboard), -40° to +40° (by MUSES and DESIS)
Spectral range	400 nm to 1000 nm
Spectral Sampling (res., acc.,bands)	2.55 nm, 0.5 nm, 235 bands. Binning: 118 , 79 , 60 bands
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

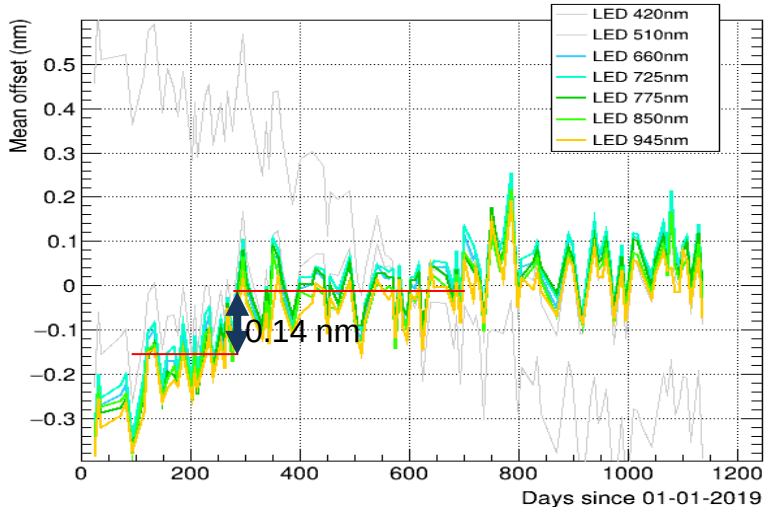
Calibration unit

- 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





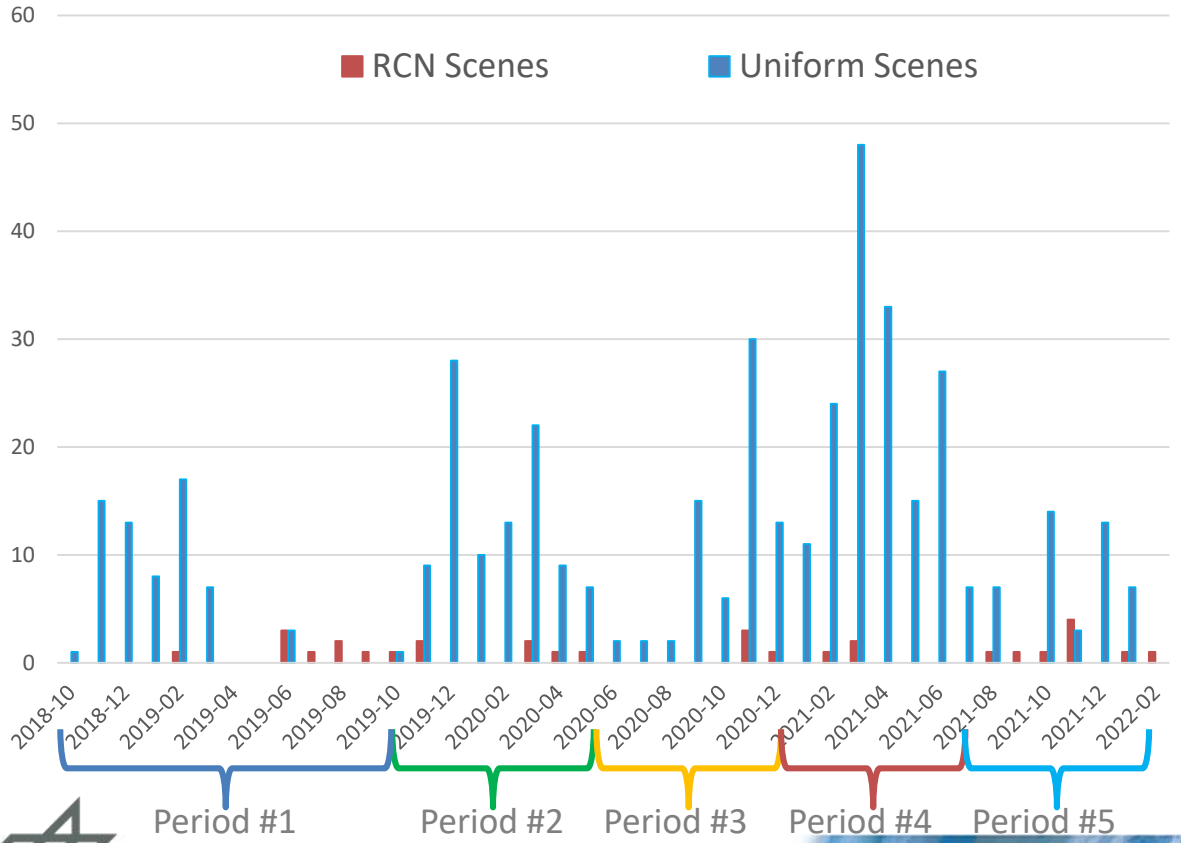


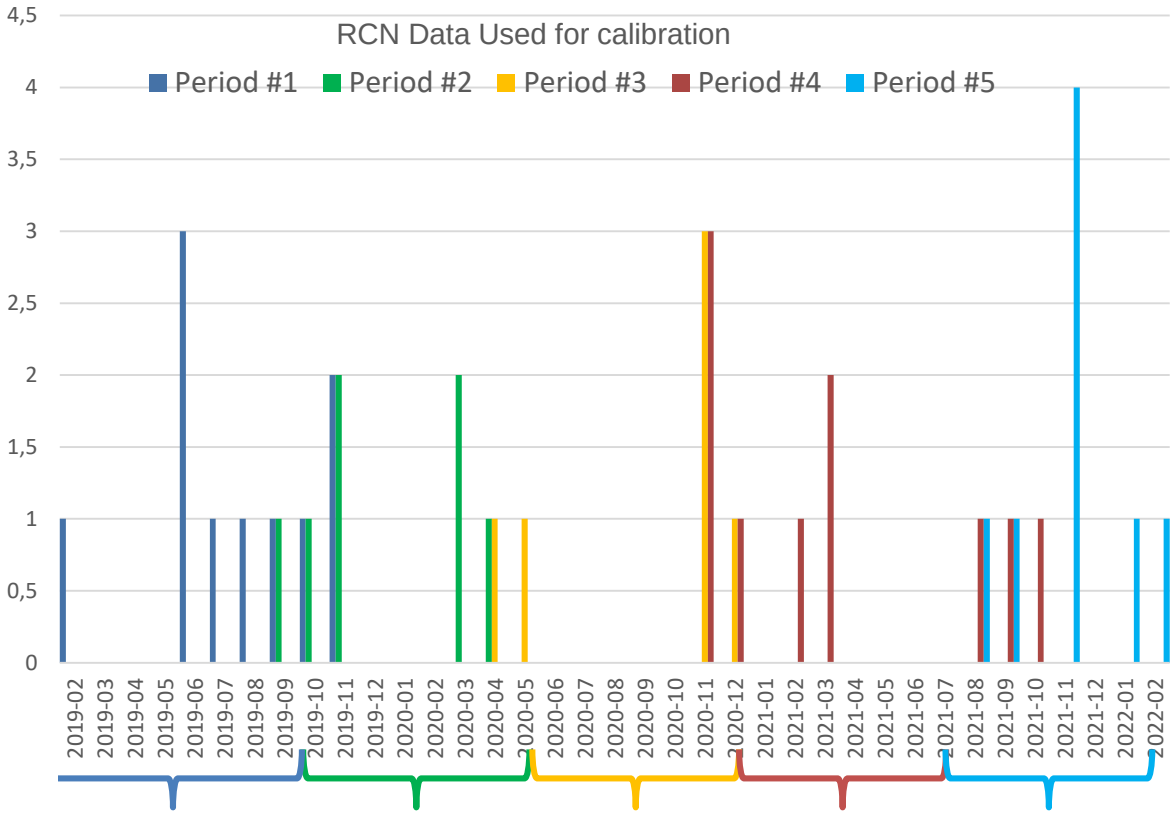


Vicarious calibration data

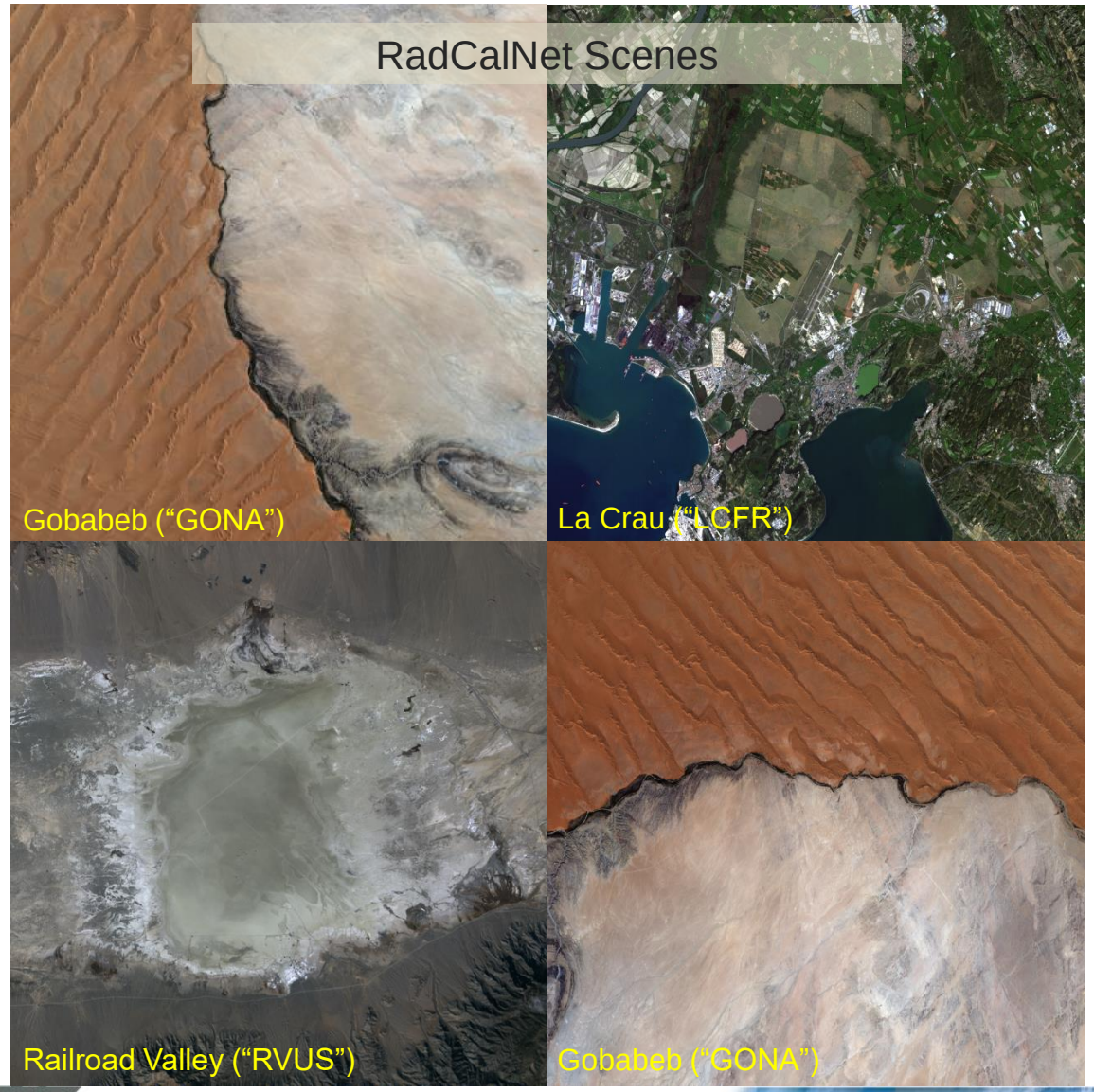
"Vicarious calibration of the DESIS imaging spectrometer", E. Carmona et al., IGARSS2021

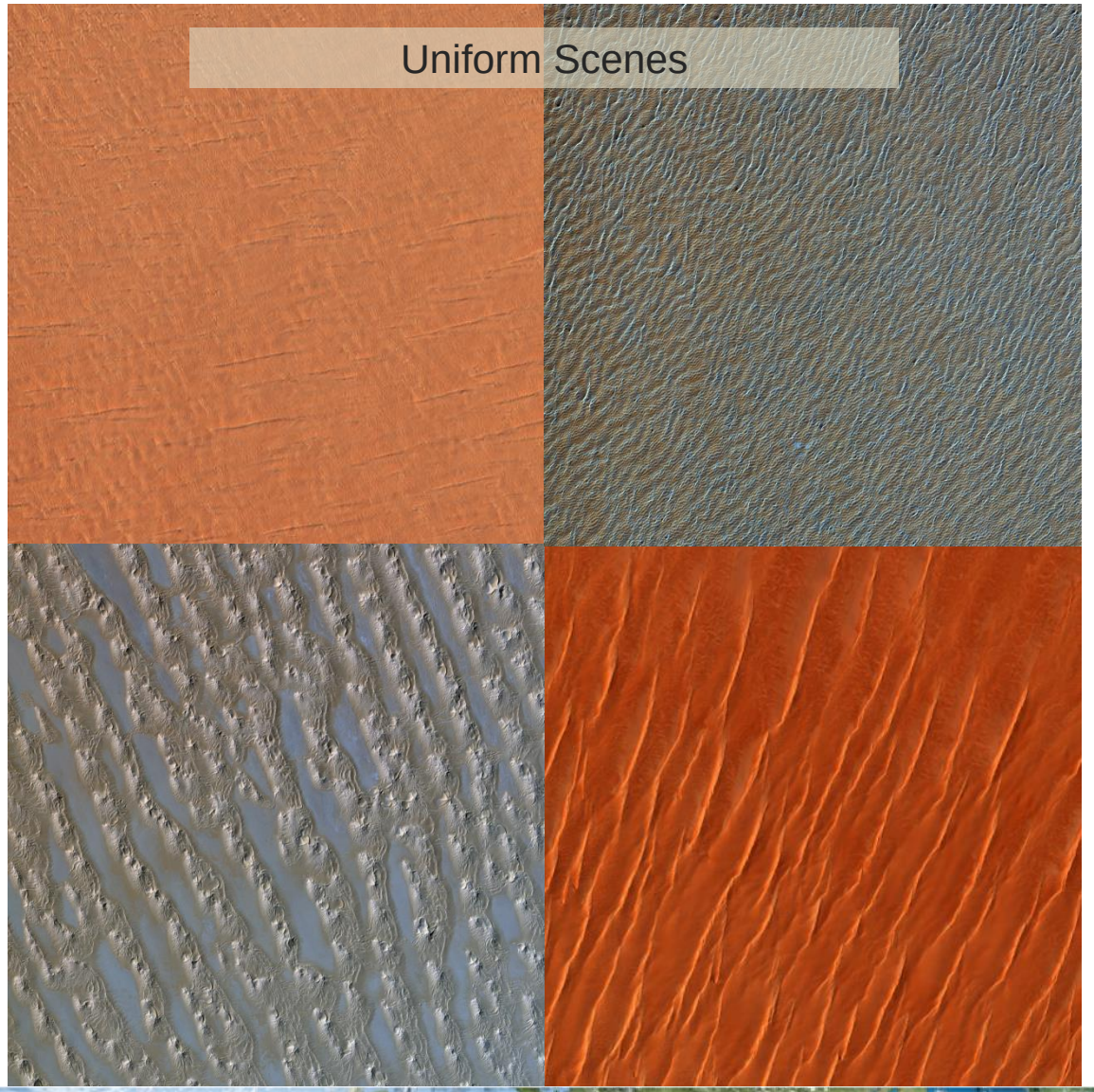
- Input scenes not evenly distributed in time
- Particularly challenging to have abundant good quality Radcalnet (RCN) scenes
- Calibration updates arrive several months after data acquisition





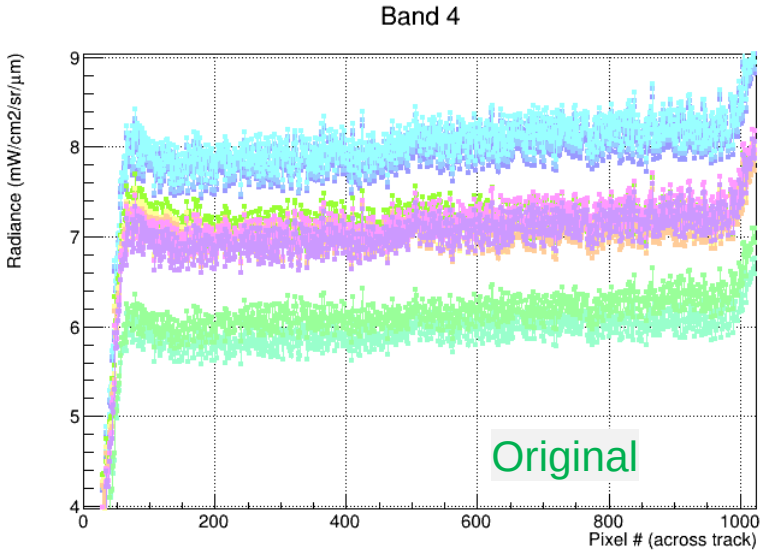
Vicarious calibration Input data

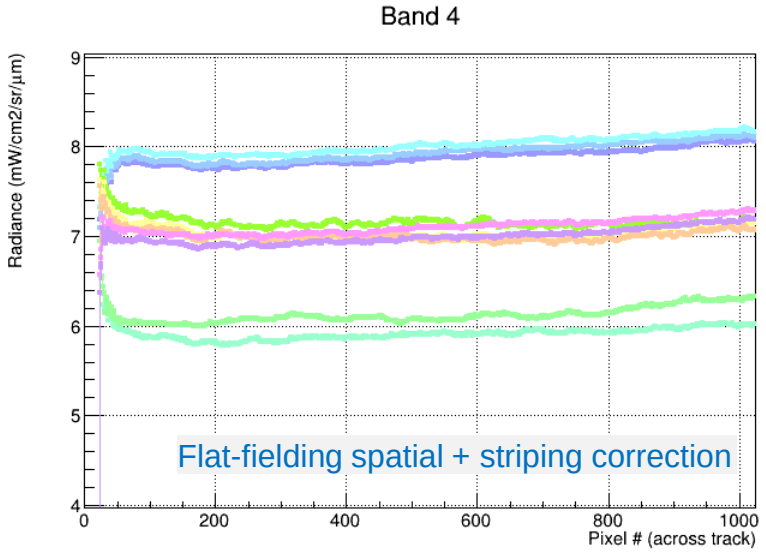




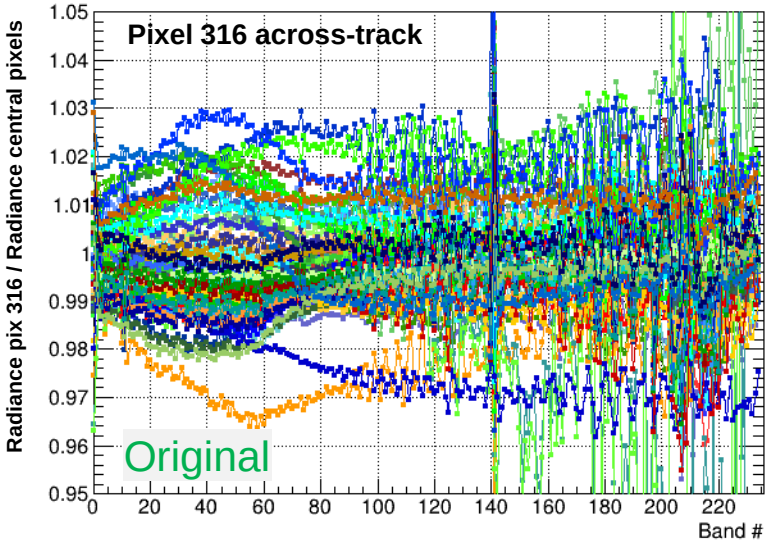
Correction Steps II: Flat-fielding

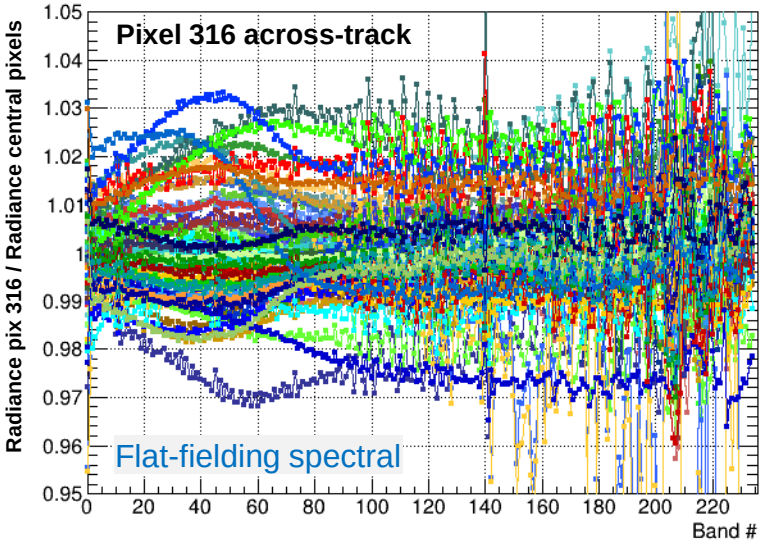
- **Flat-fielding spatial**: In homogeneous scenes all pixels across-track shall have the same value within a band





- **Flat-fielding spectral**: In homogeneous scenes all across-track pixels shall deliver the same spectra as the central pixels

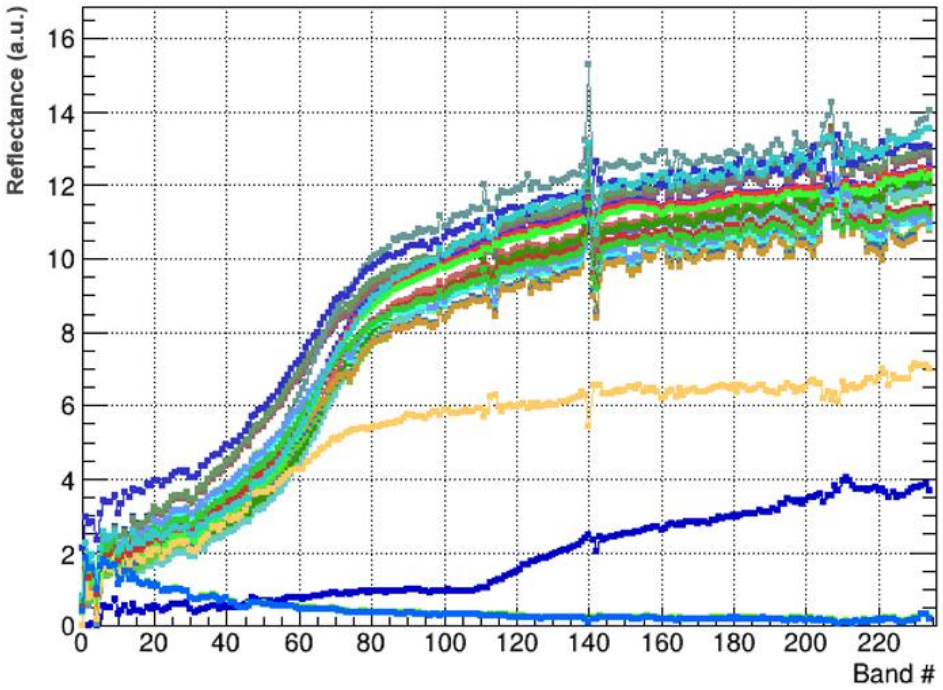




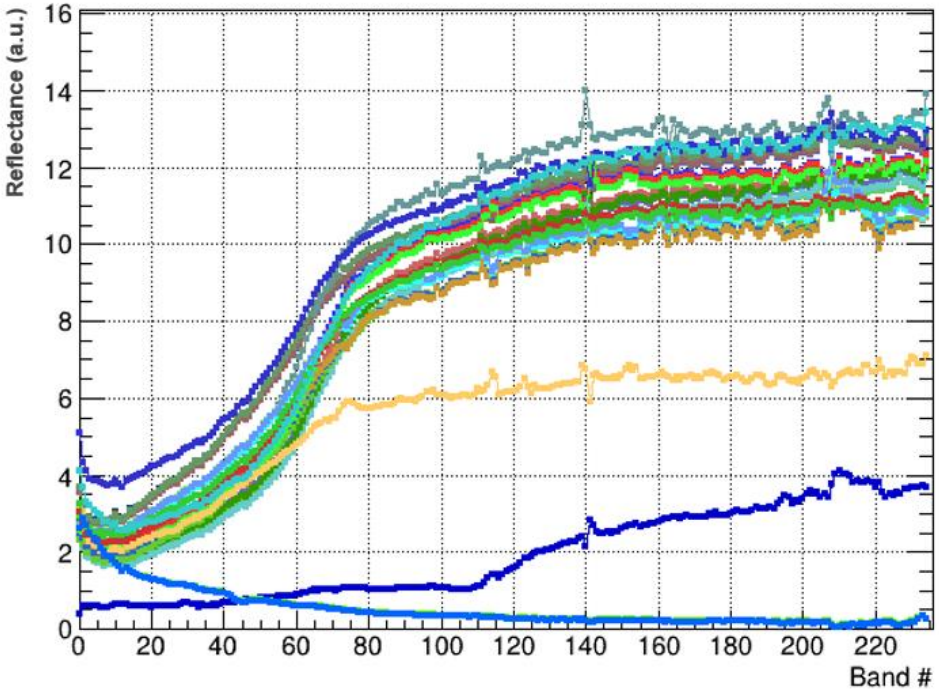
Correction Steps III: L2A spectral smoothing

- 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

Before



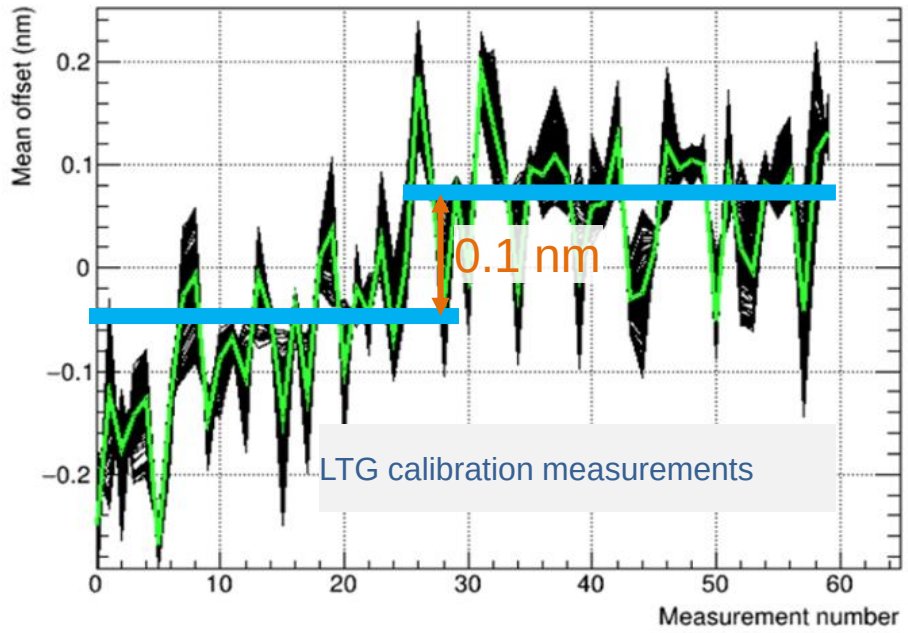
After



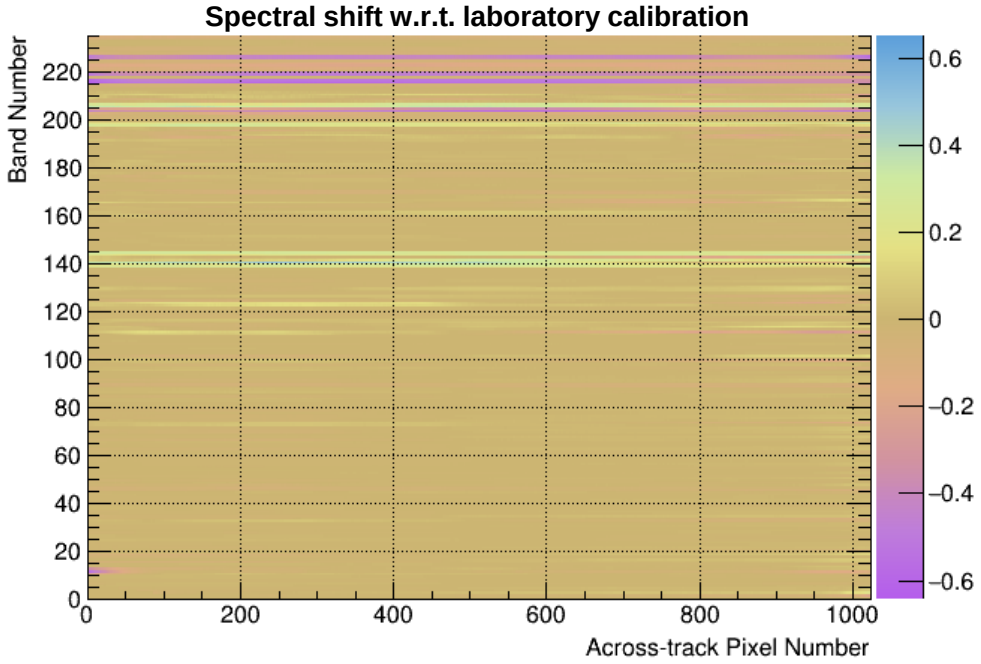
Correction Steps IV: Spectral adjustment vicarious

- Spectral calibration very difficult to obtain in-flight. Only small adjustments on central wavelengths possible

- **Global shift**: based on LED calibration measurements. Change of trend in September 2019. More stable since then. 0.10 nm shift included in calibration update



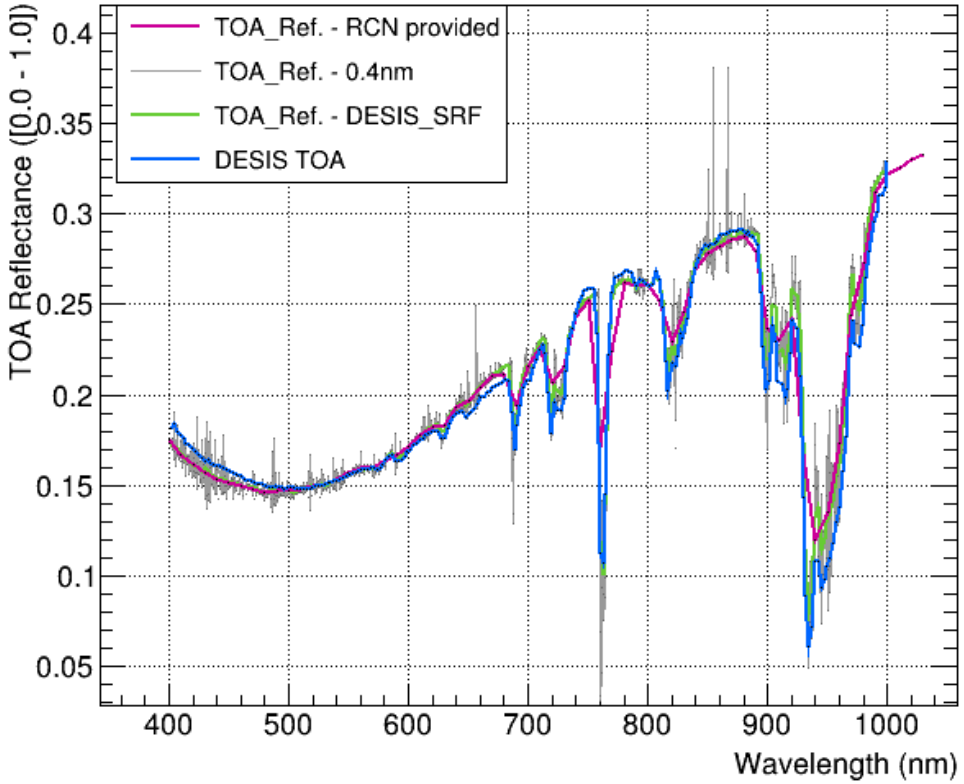
- **Spectral adjustment**: Certain L2A spectral features after calibration can only be fixed adjusting central wavelengths (around strong atmospheric absorption features)

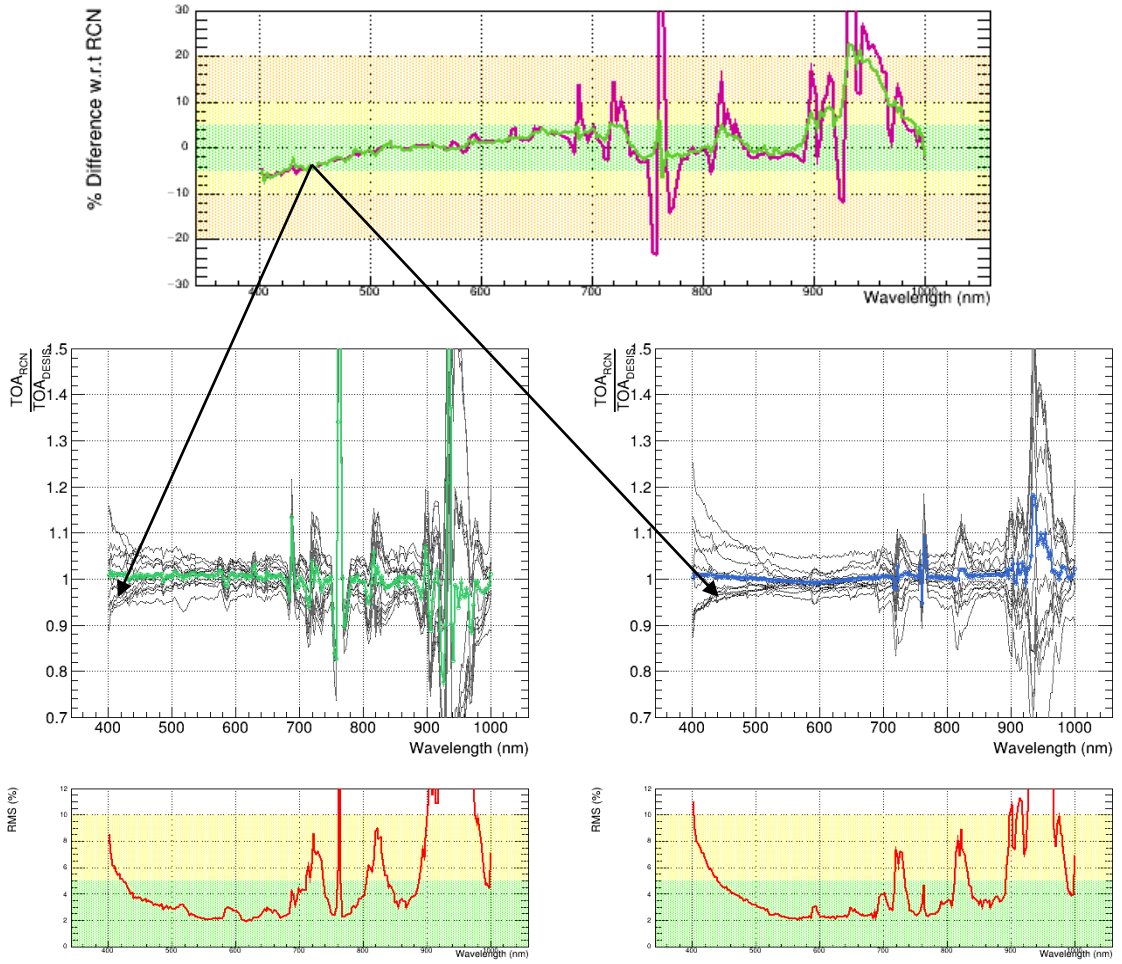


Mission Introduction

Vicarious Calibration

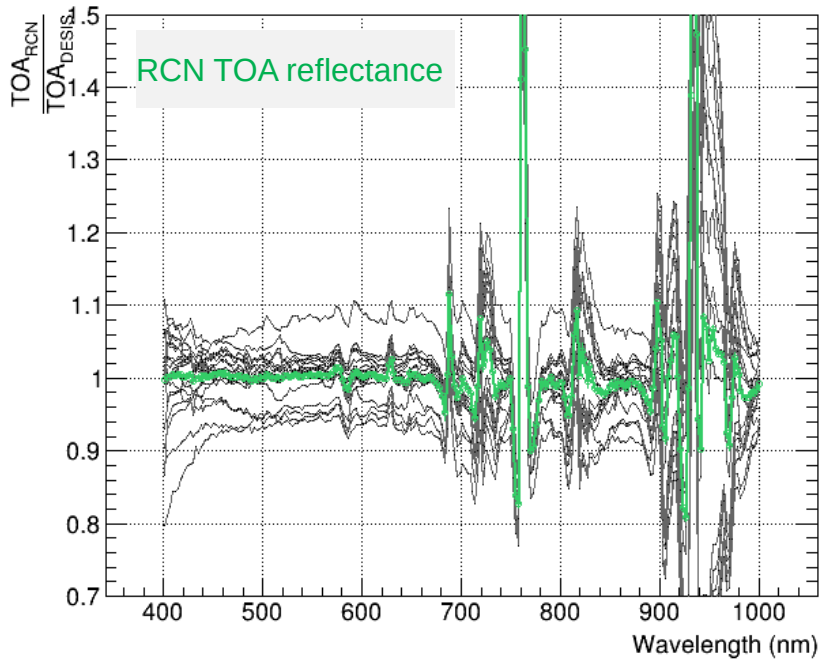
- Use flat-fielding over uniform areas for pixel-to-pixel relative adjustment. Use RadCalNet sites for absolute calibration

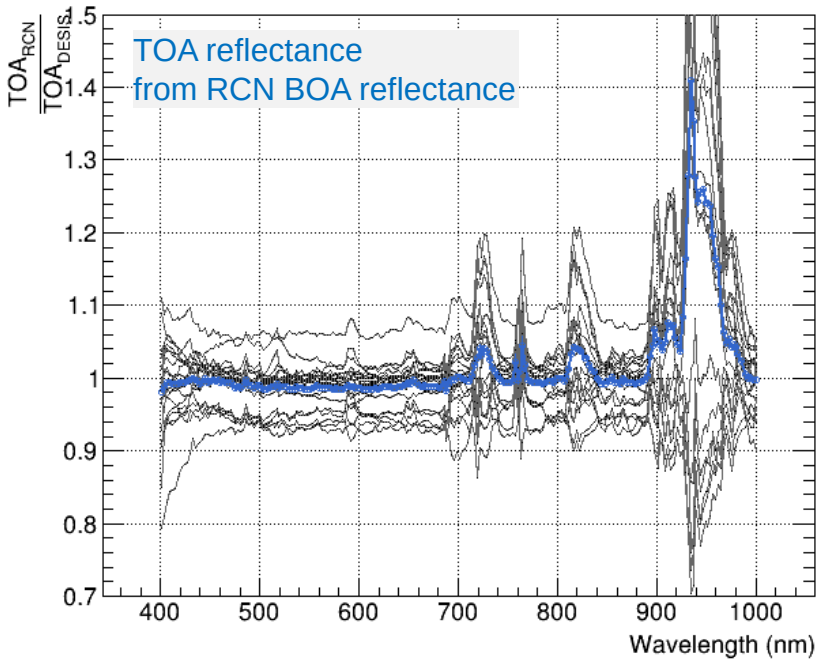


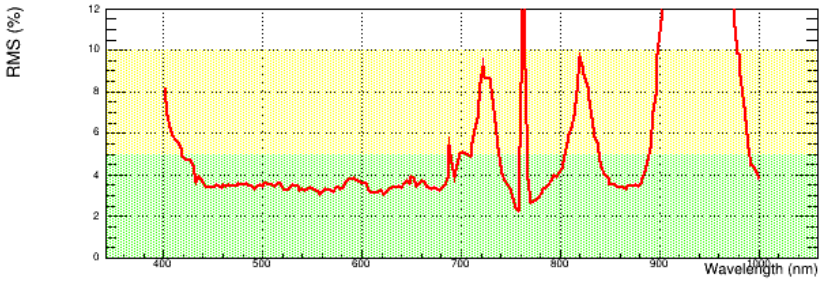


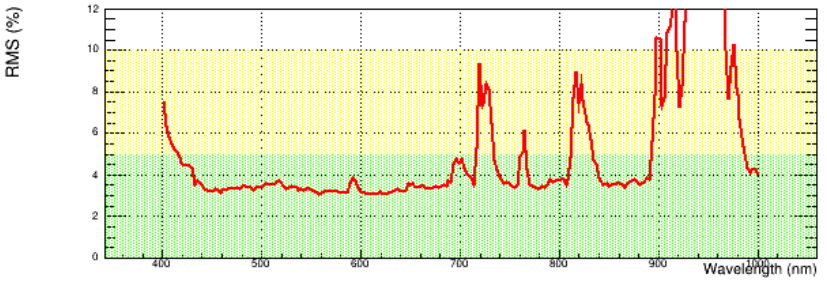
Results from 3 calibration periods

- 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



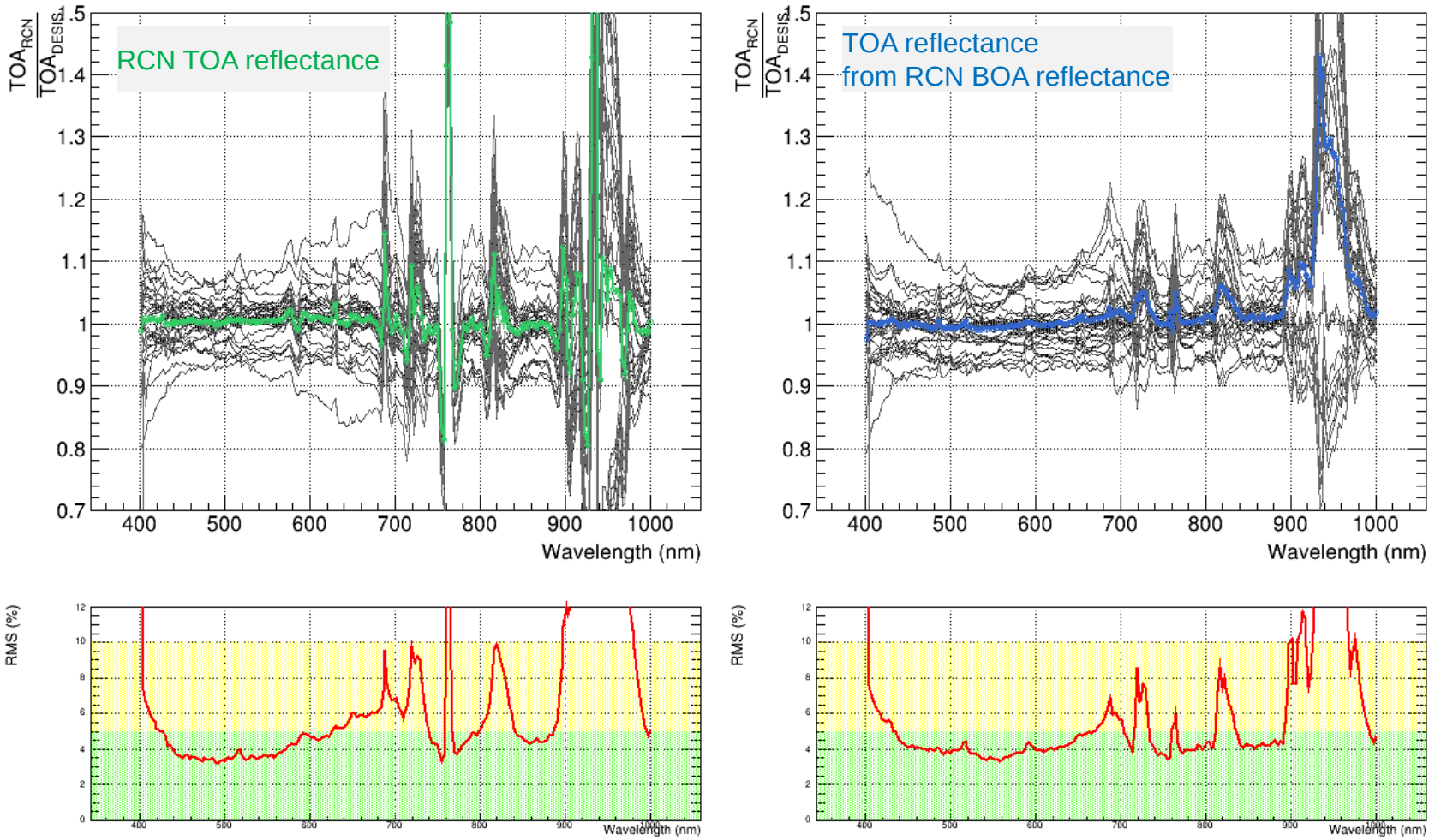






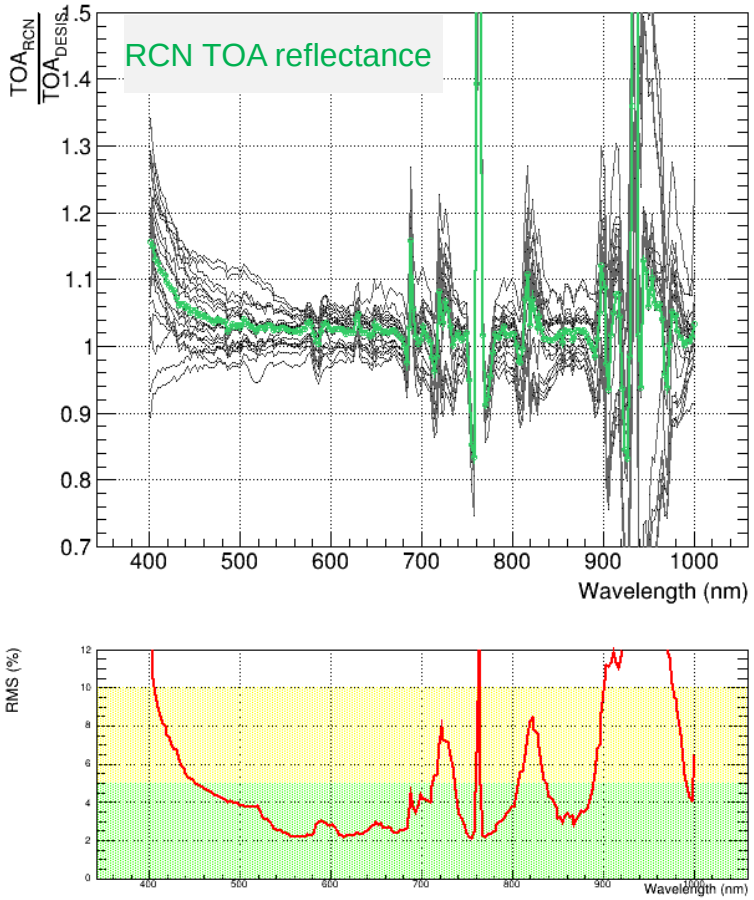
Results from 3 calibration periods: All RCN Data Results

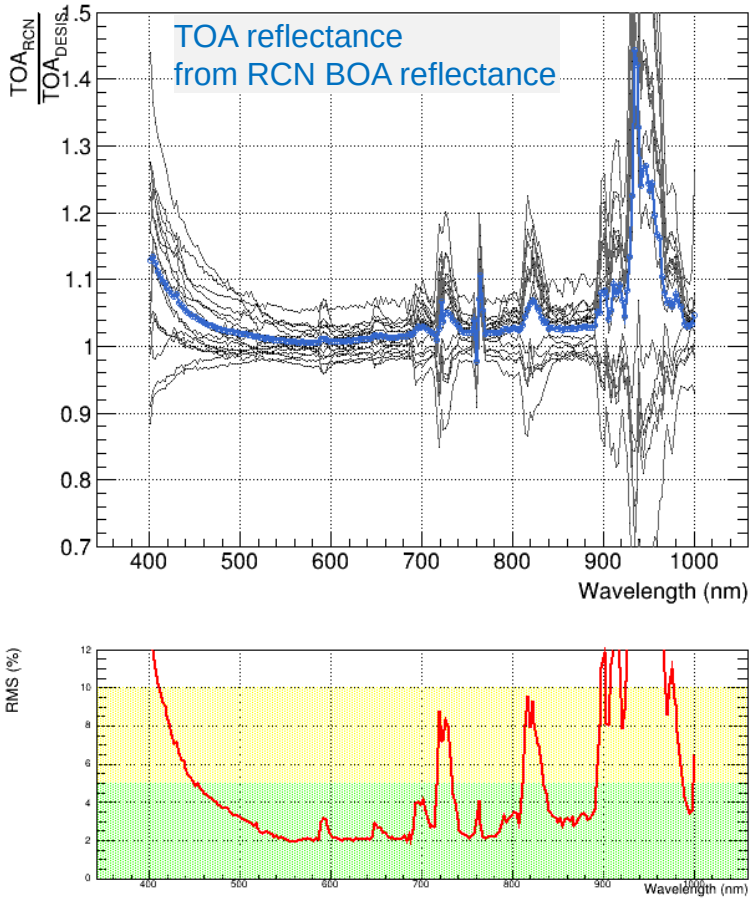
- Absolute calibration adjusted with RCN data for 3 different periods
- Absolute calibration uses only part of RCN scenes (19)
  - good atmospheric conditions
  - below 50 degrees Sun Zenith Angle
- These summary plots show **all** RCN scenes (**30** scenes)



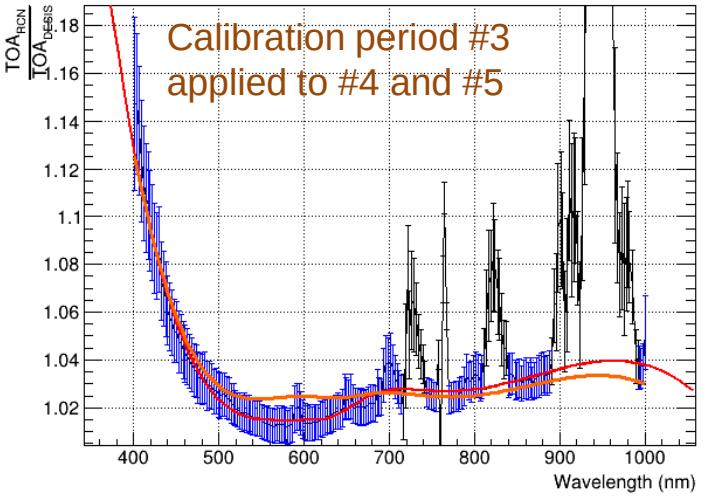
Latest Vicarious calibration data

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



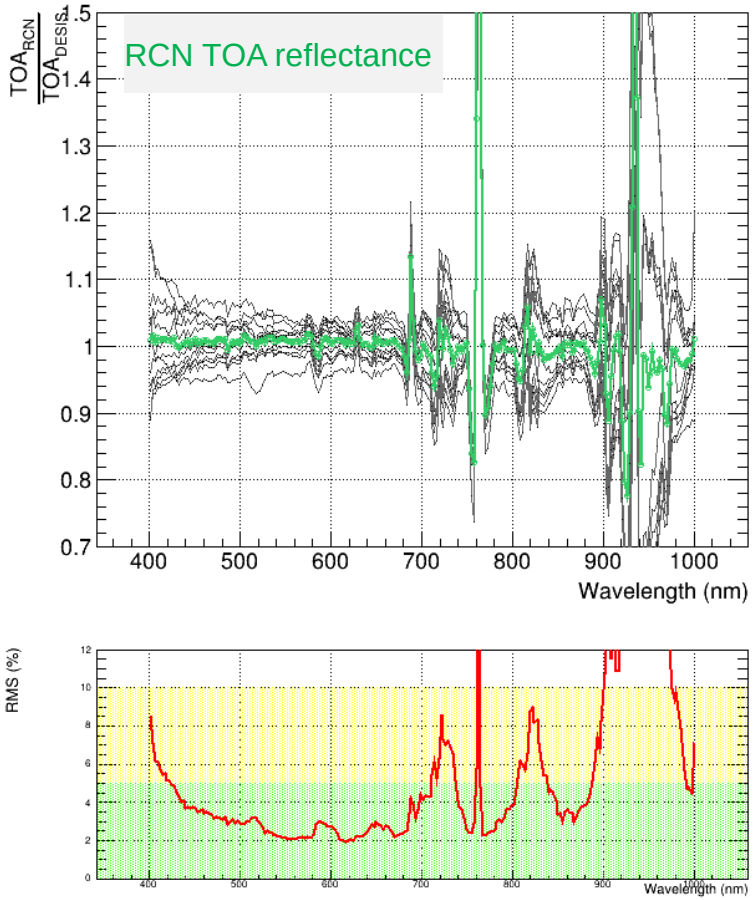


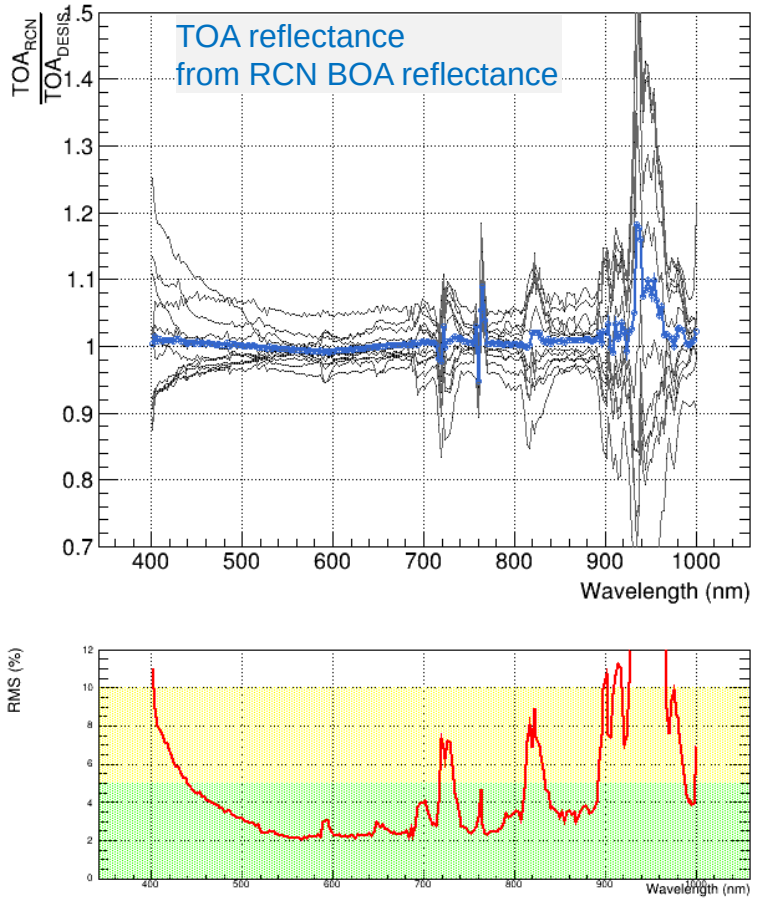
- Large variation of calibration below 500 nm as seem in other periods
- Magnitude is smaller



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 (preliminary):

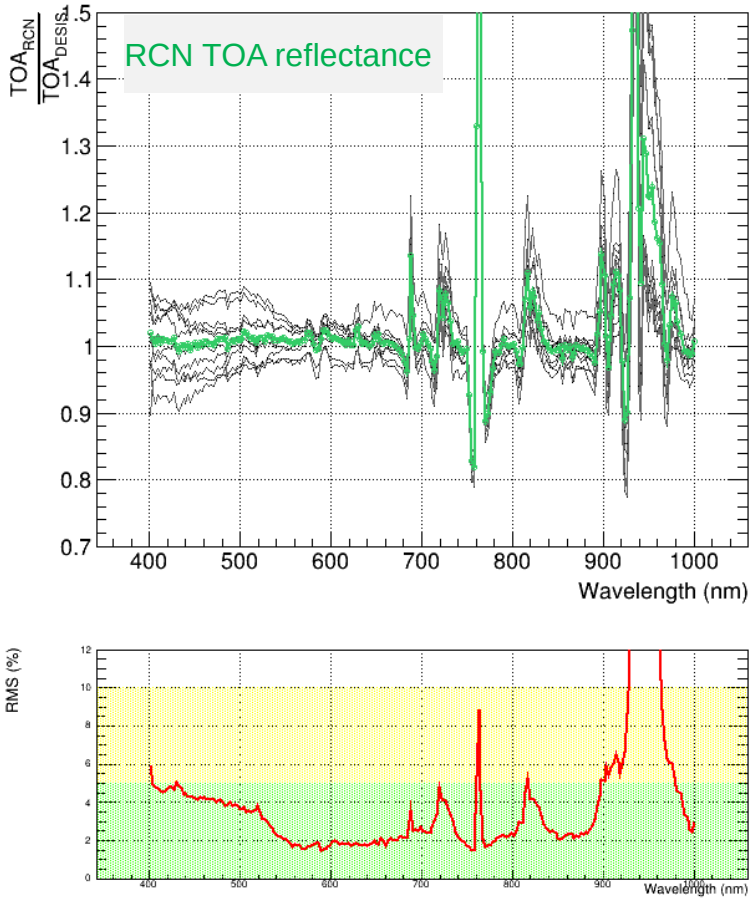


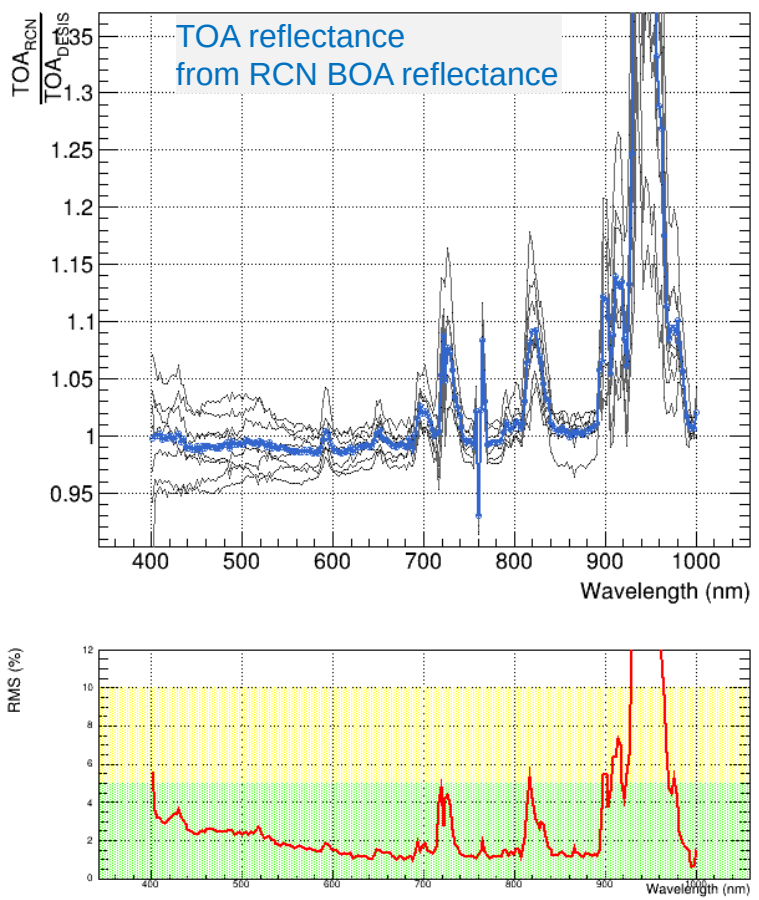


- Similar results as seen in other periods
- After calibration bias is corrected, but as usual RMS below 500 nm is significant larger than above 500 nm

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 (preliminary):

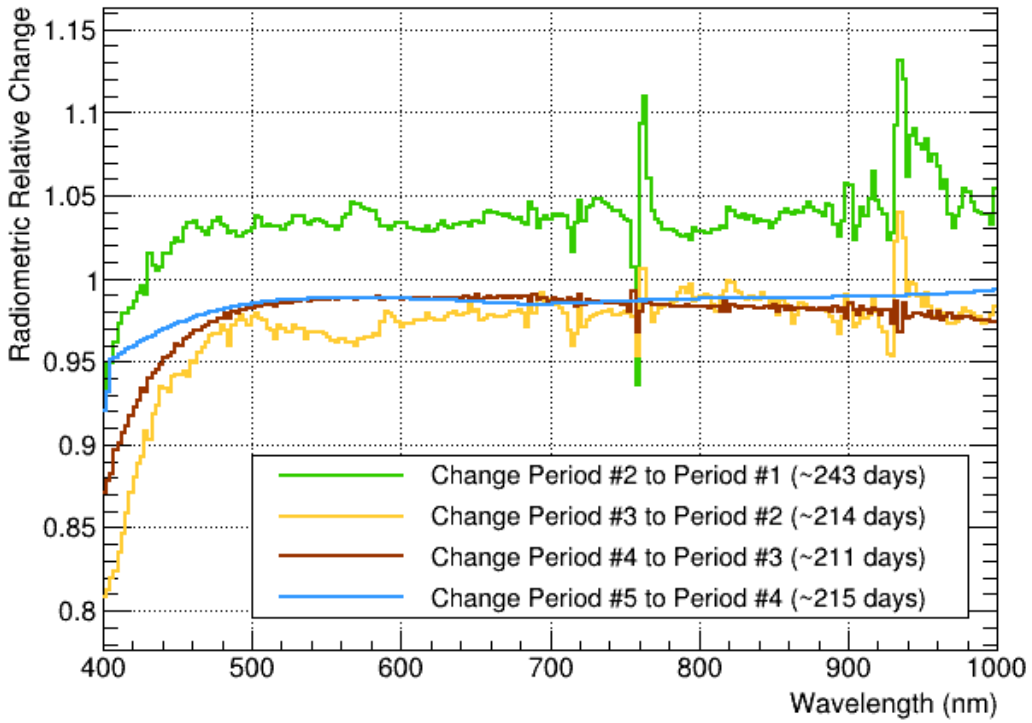


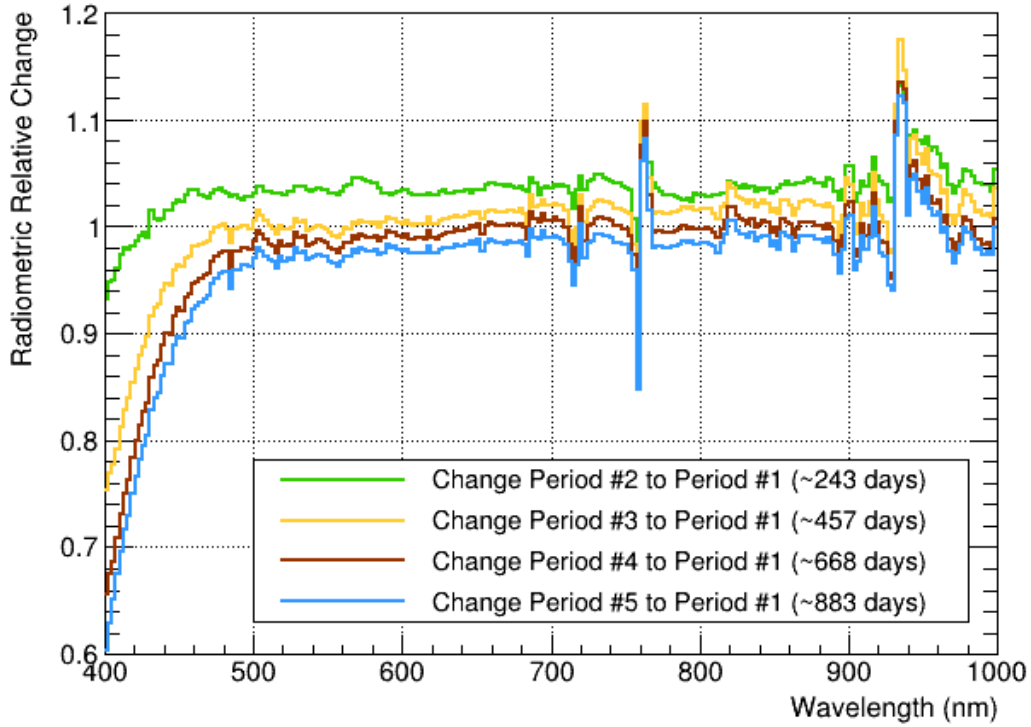


- For the first time different behavior below 500 nm
- More stable during Period #5, reduced RMS compared to all previous periods
- Degradation below 500 nm is reduced

Vicarious Calibration

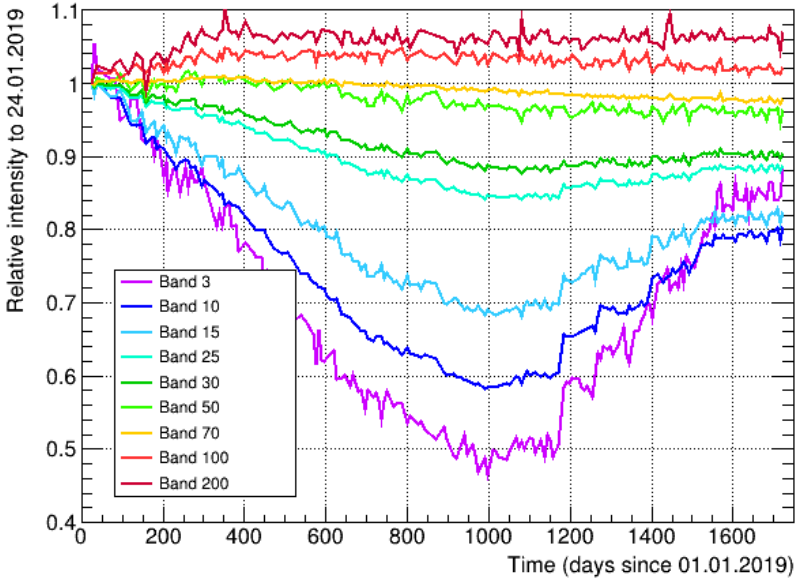
- Radiometric calibration shows high variability for wavelengths above 480 nm for data until July 2021
- More stable (better than 3.4% / year) for wavelengths above 500 nm

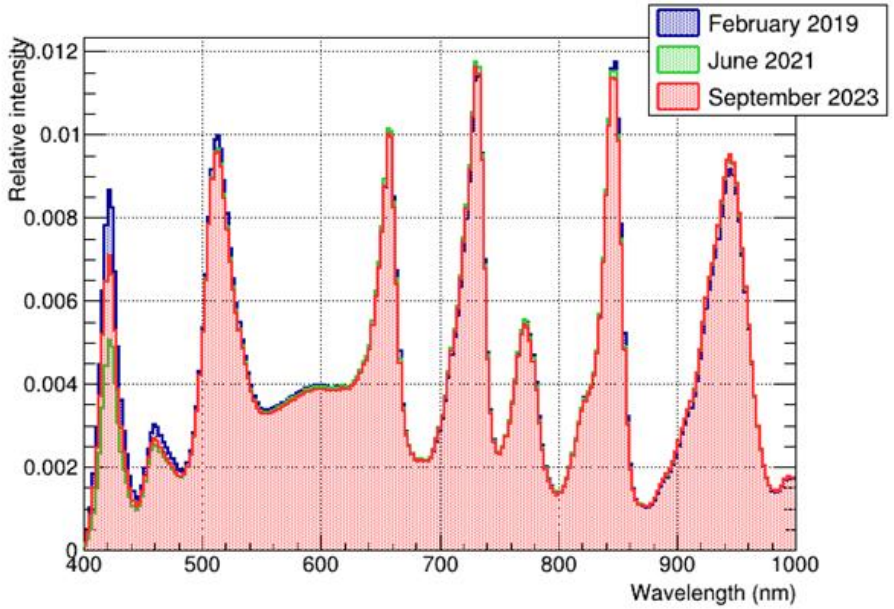


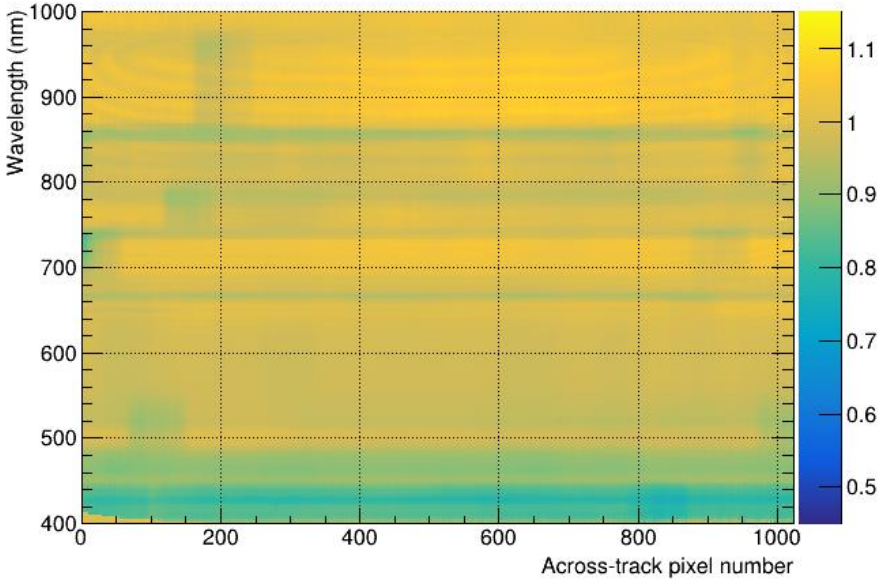


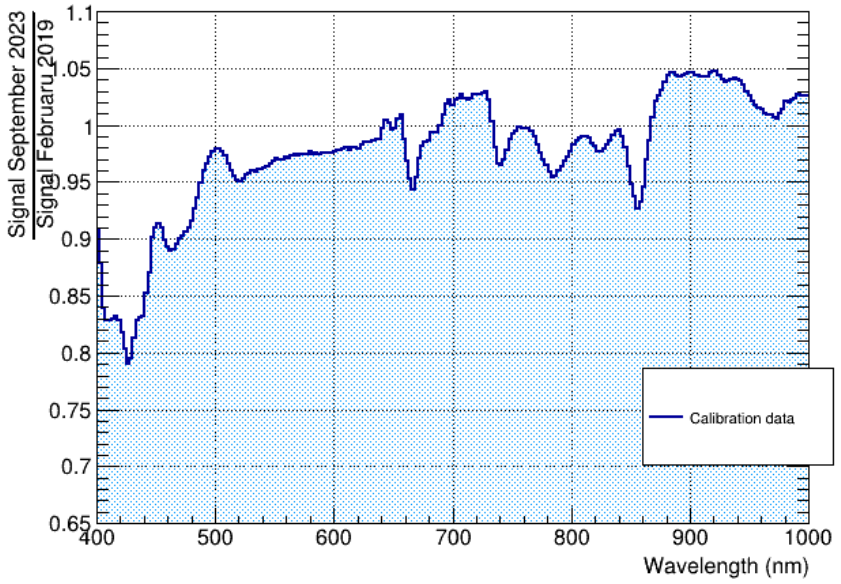
Crosscheck with Calibration Unit

- 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





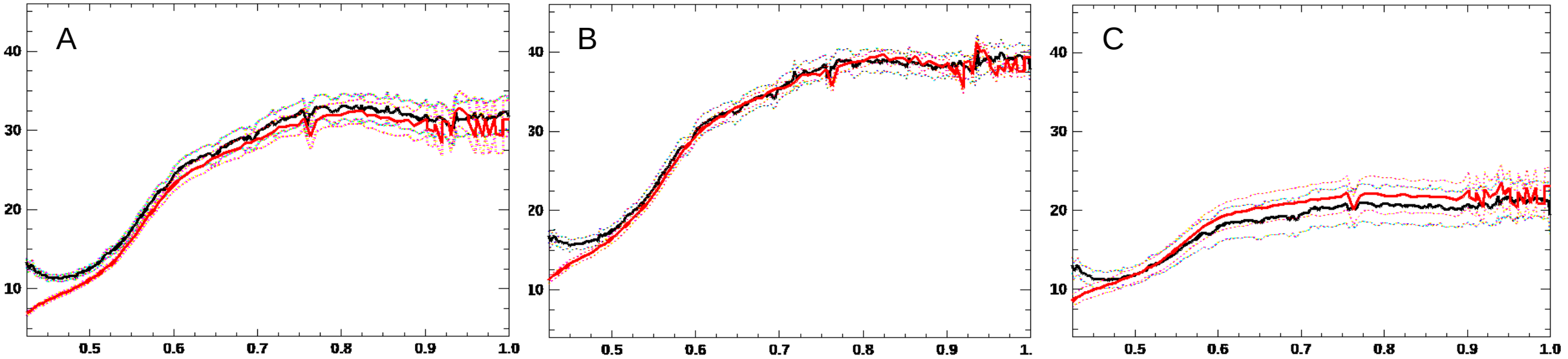


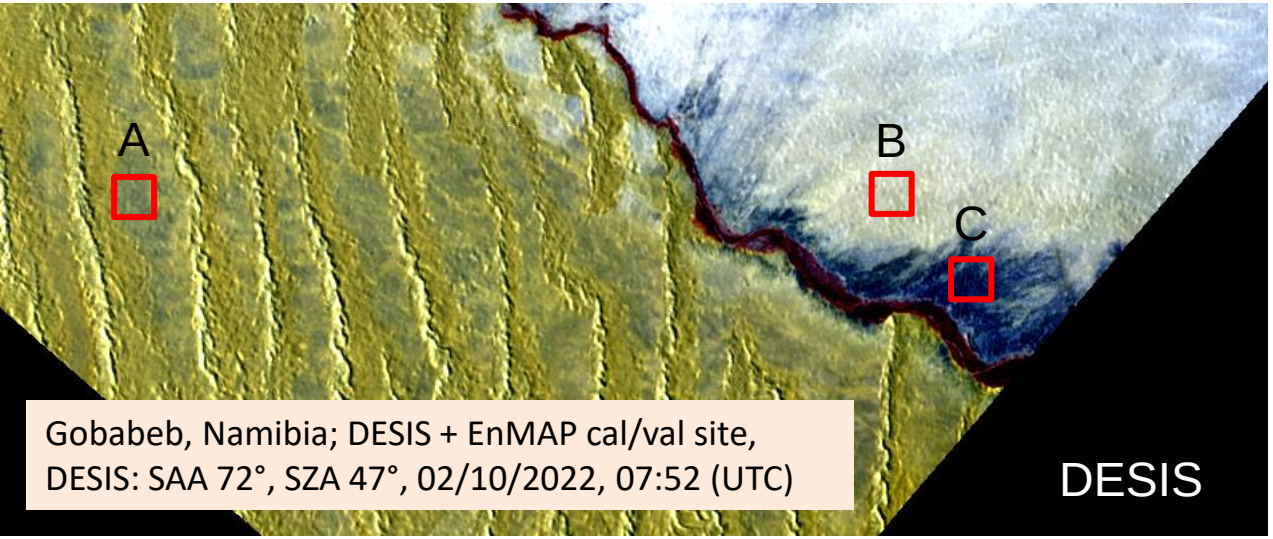


DESIS and EnMAP – spectral comparison

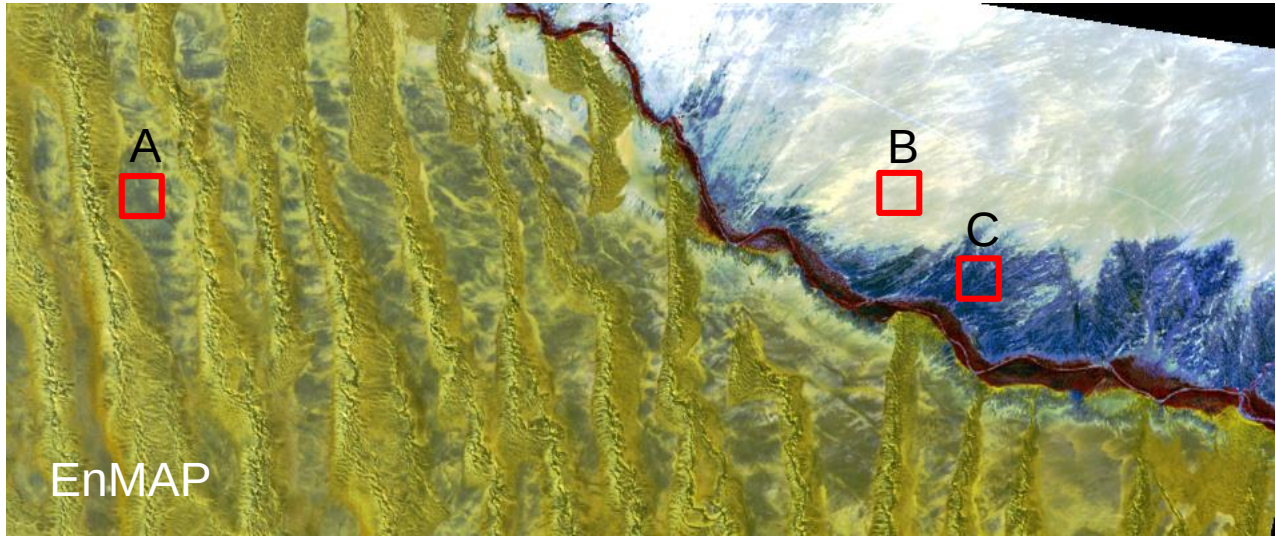
DESIS

EnMAP





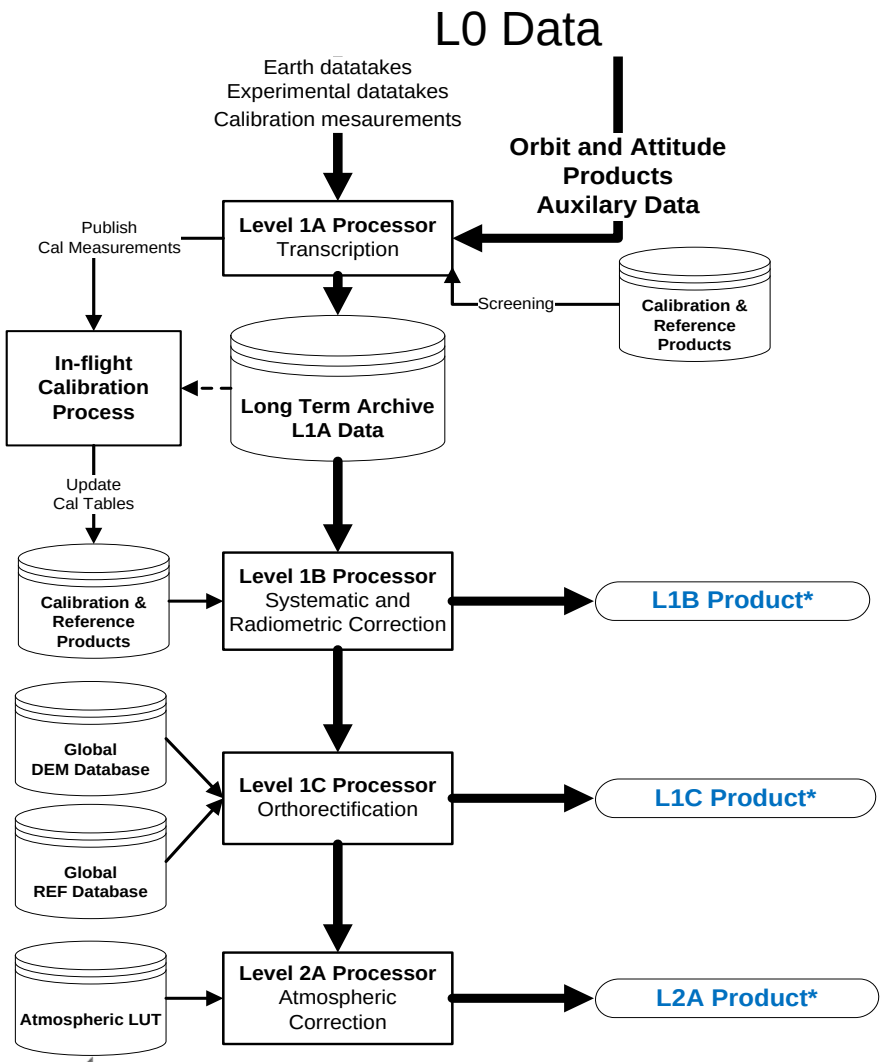
Gobabeb, Namibia; DESIS + EnMAP cal/val site,
DESIS: SAA 72°, SZA 47°, 02/10/2022, 07:52 (UTC)



Extra

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 – 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

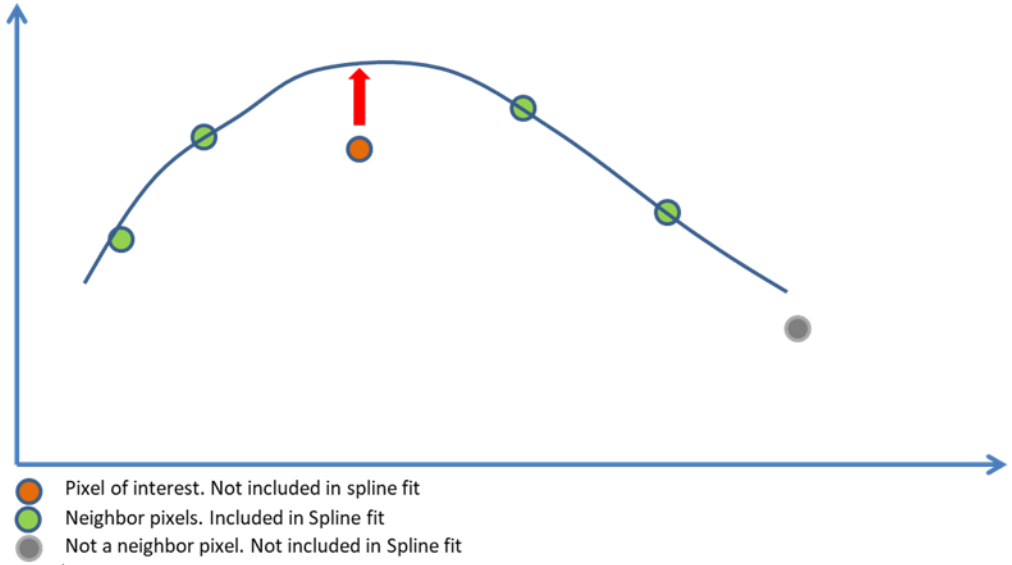
*** Delivery Product**

Correction Steps I: Radiometric adjustments

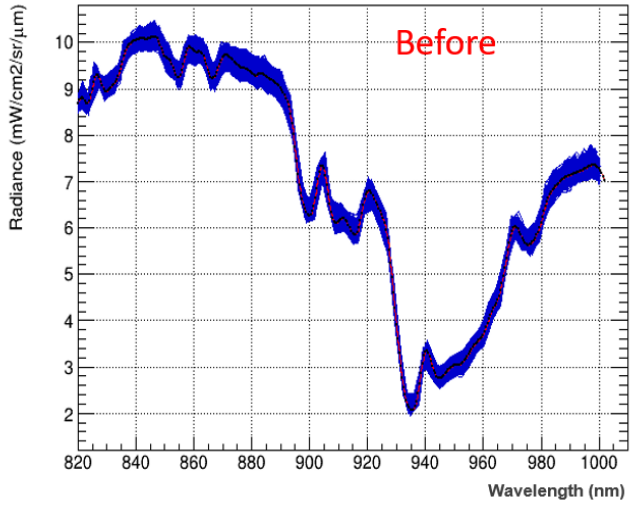
- Most steps performed with uniform scenes with L1B products averaged in the along-track direction
  - 235 bands × 1024 spatial pixels

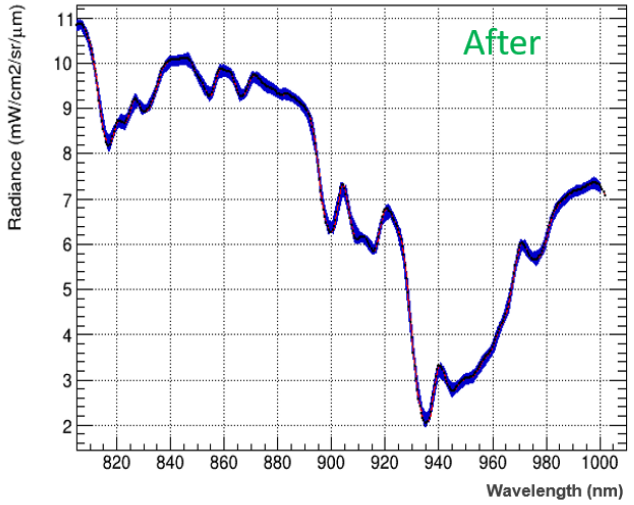
- Most corrections are performed after smile correction (confusion of spectral and radiometric corrections)

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



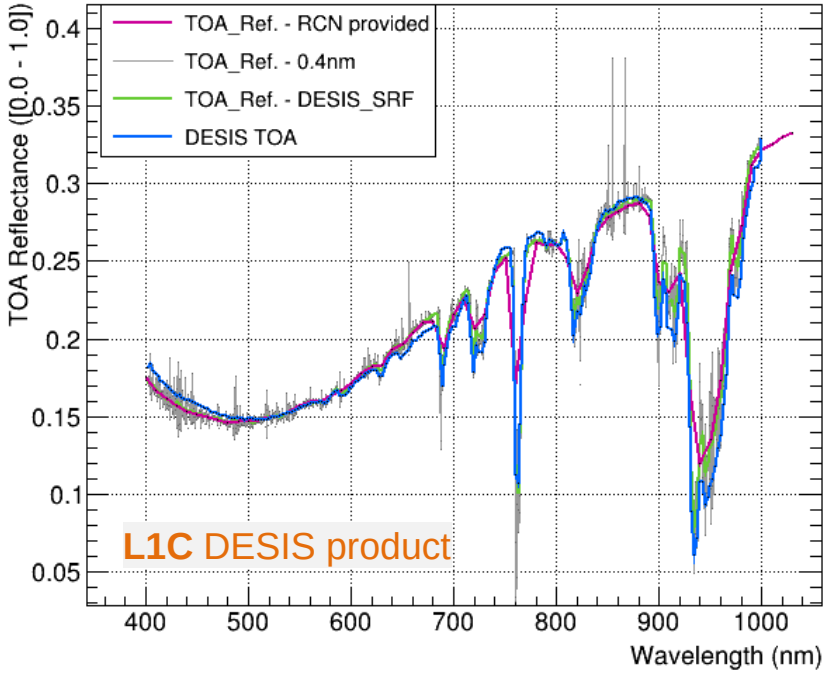
- **Rad./Spc. correction**: Use all pixels across track in one single spectrum. Compute minimum deviation to common spectrum

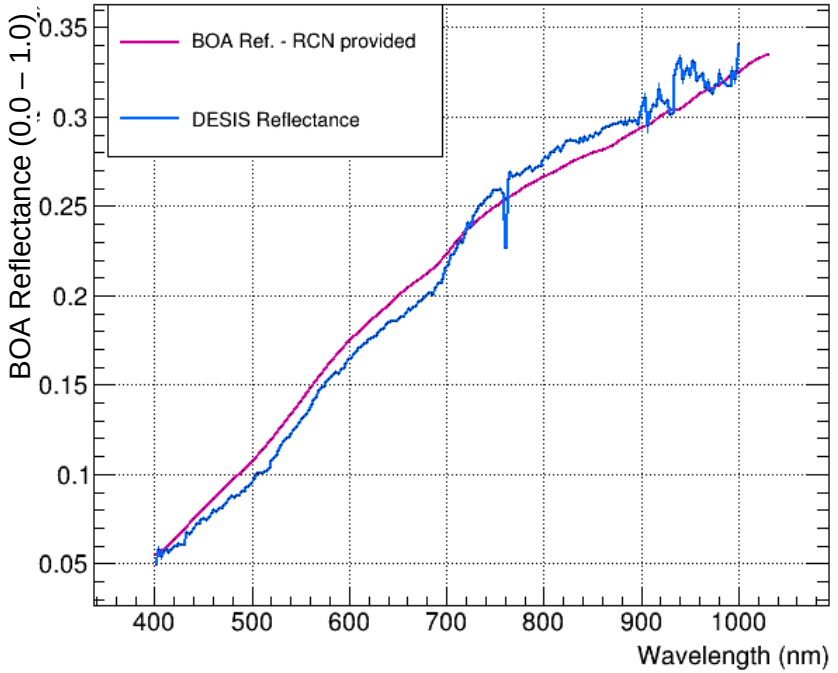


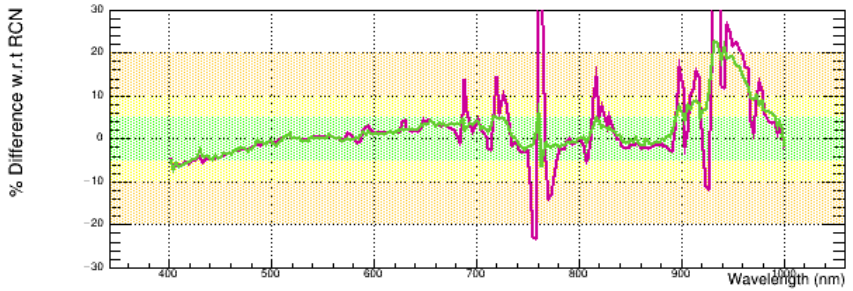


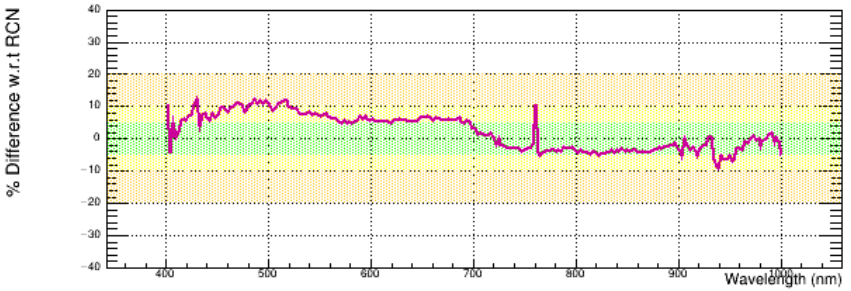
Results First Vicarious calibration (2018-10 – 2019-09)

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



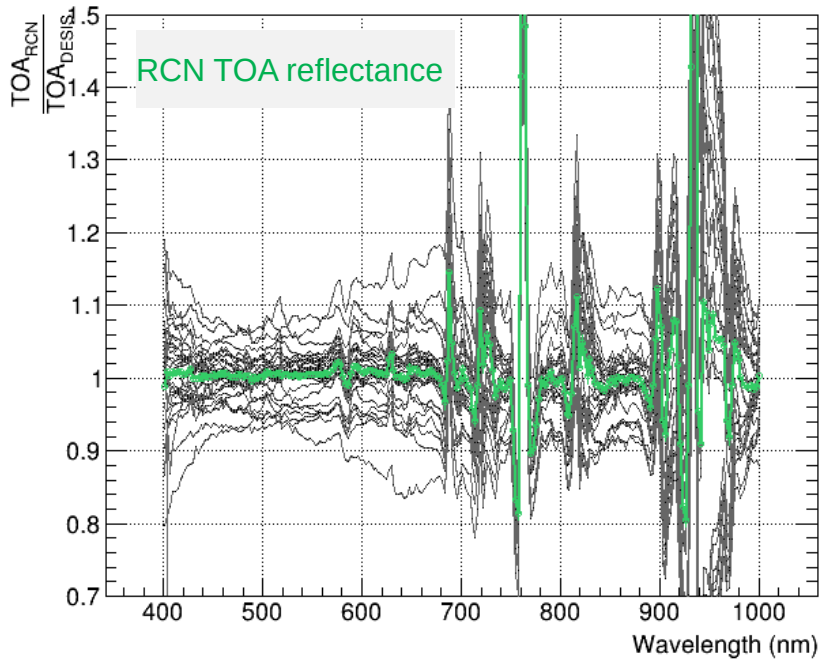


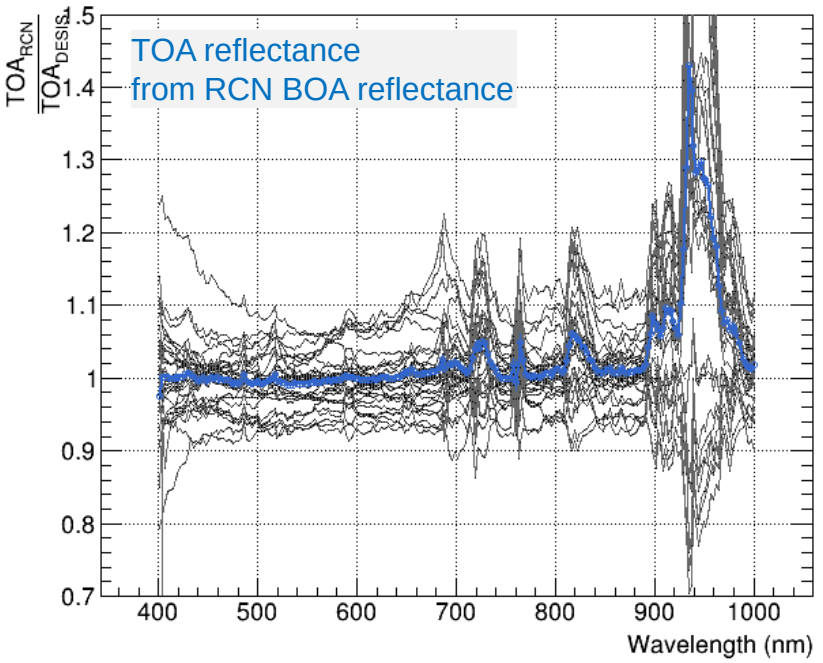


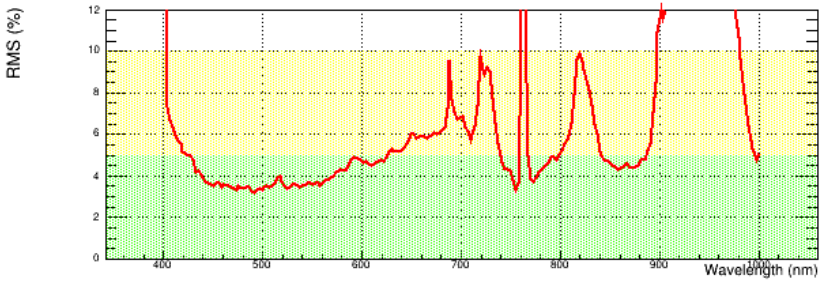


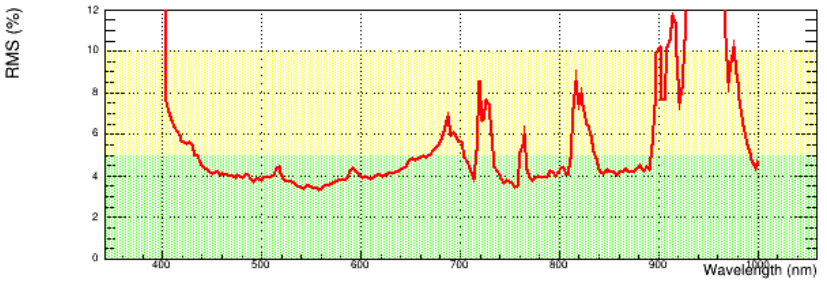
Results from 3 calibration periods: All RCN Data Results

- **Bias** is kept <1-2% on average
  - Limitation of the method, probably never better than 1-2%
  - Differences between the two TOA calculations ~1%
- **RMS** is typically ~4% outside strong absorption bands
  - Smaller for reduced Sun zenith range and good atmospheric conditions
- **Problematic area below 450 nm**:
  - Sensor not very stable
  - Degradation of up to ~20% / year at 400 nm









Crosscheck with Calibration Unit