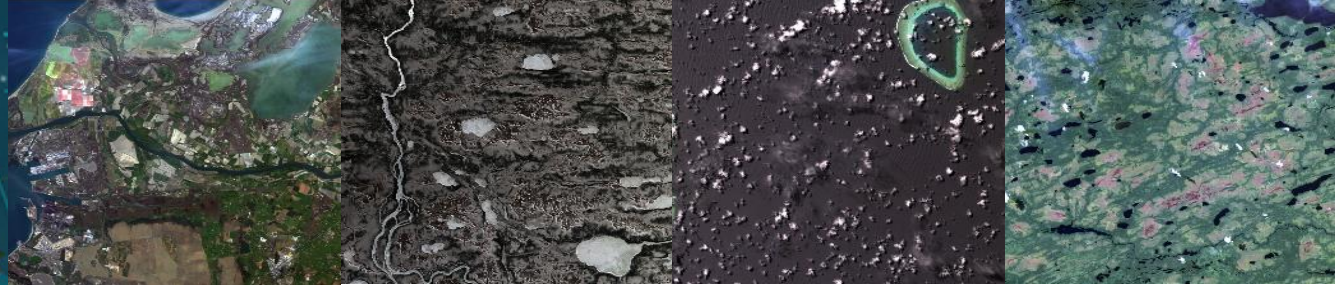


19 – 21 OCTOBER 2022 📍 FRASCATI, ITALY

2ND WORKSHOP ON INTERNATIONAL COOPERATION IN SPACEBORNE IMAGING SPECTROSCOPY



DESIS Calibration: Status and Results after 4 Years of Operation

Emiliano Carmona¹, Kevin Alonso¹, Martin Bachmann², Raquel De Los Reyes¹, Uta Heiden¹, David Marshall¹, Rupert Mueller¹

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(2) DLR German Aerospace Center, German Remote Sensing Data Center, Oberpfaffenhofen, Germany

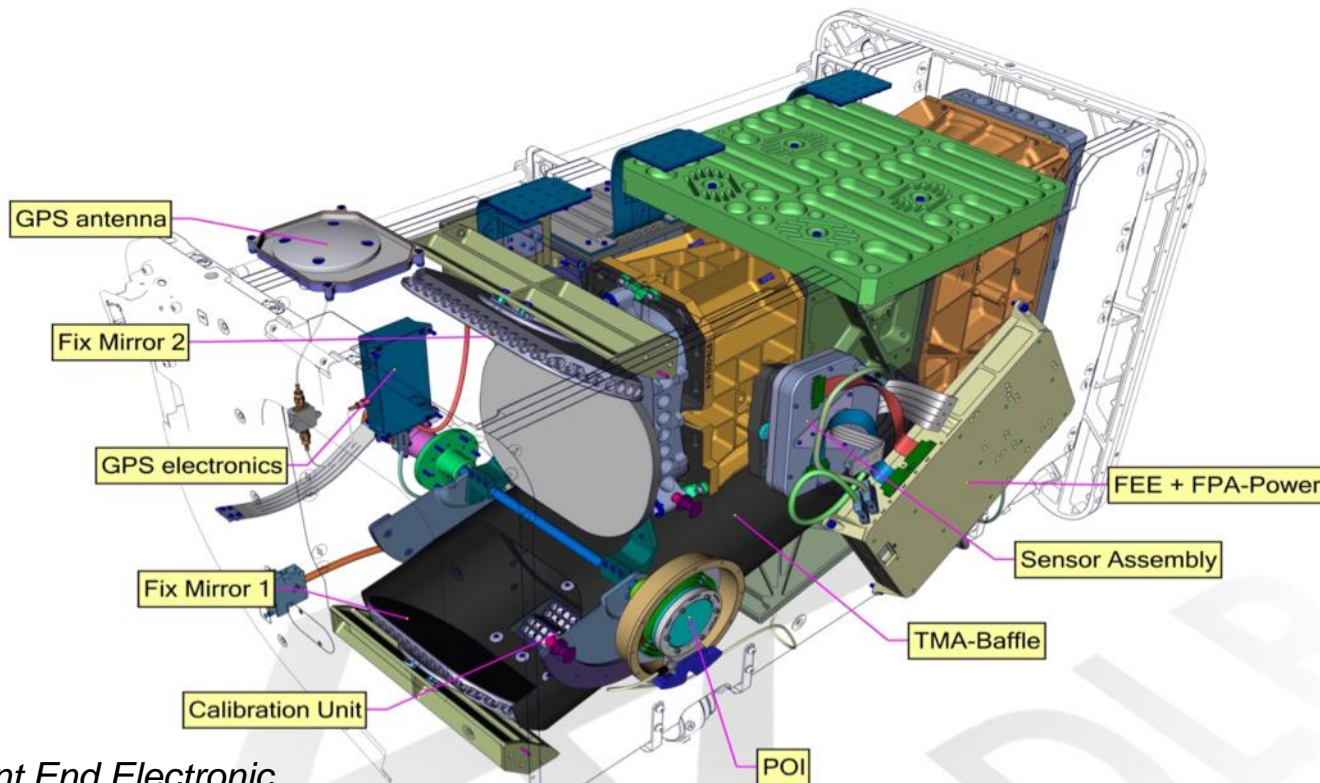
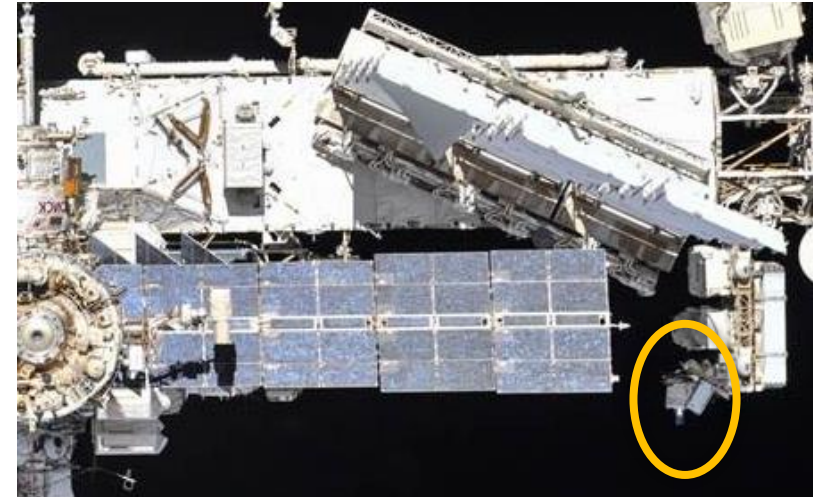


Knowledge for Tomorrow



DESI Instrument

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



Mission Instrument	MUSES/DESI
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

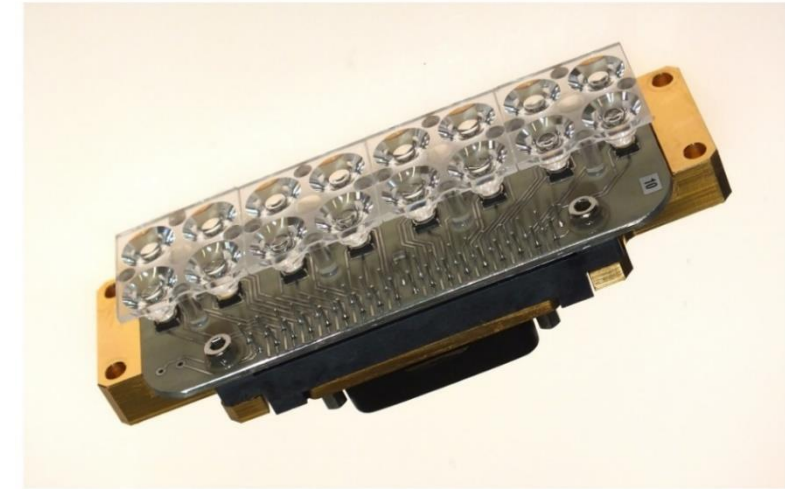
FEE: Front End Electronic
FPA: Focal Plane Array
TMA: Three Mirror Anastigmat
POI: Pointing Unit

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



Calibration unit

- Equipped with 9 different types of LEDs. It allows to measure signal with different LED types
- 1 Calibration measurement every 1 or 2 weeks for 3 years
- It allows for precise spectral stability measurements:

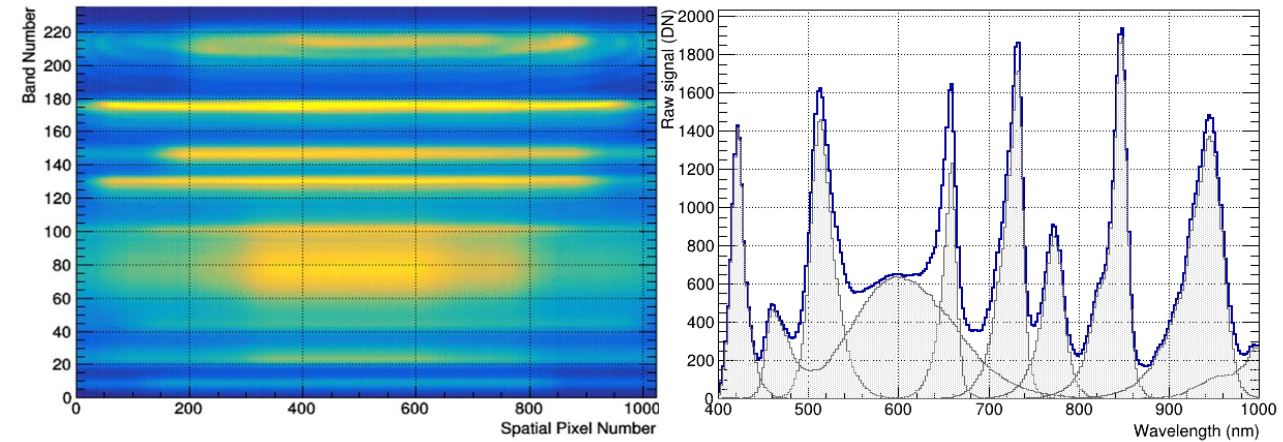
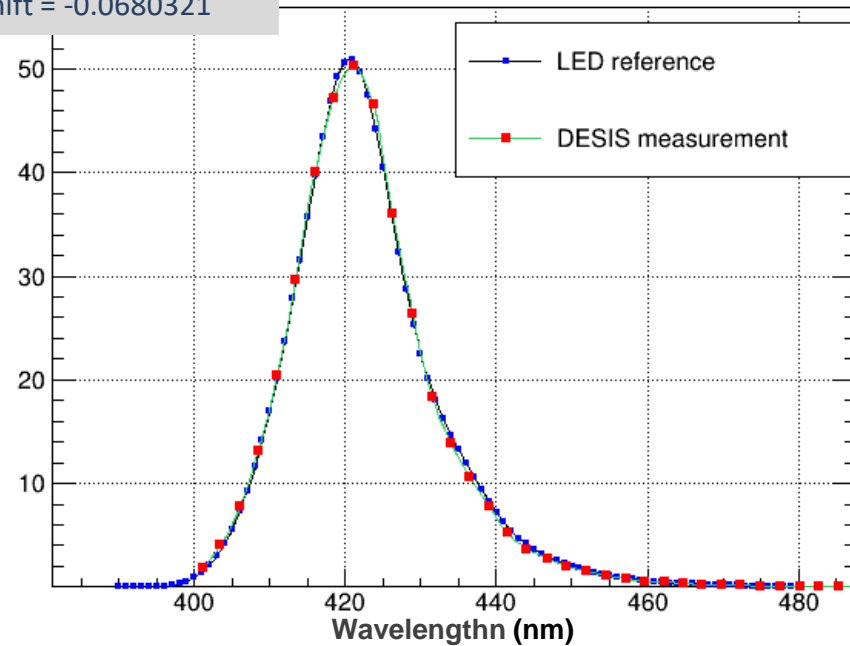


Fit parameters

Normalization = 0.996495

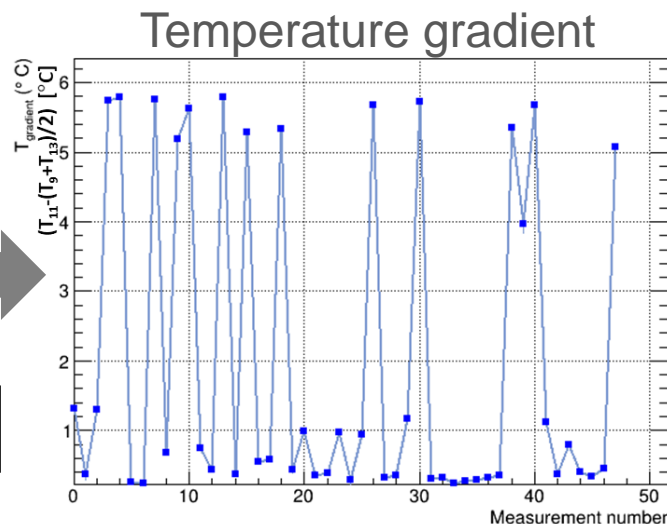
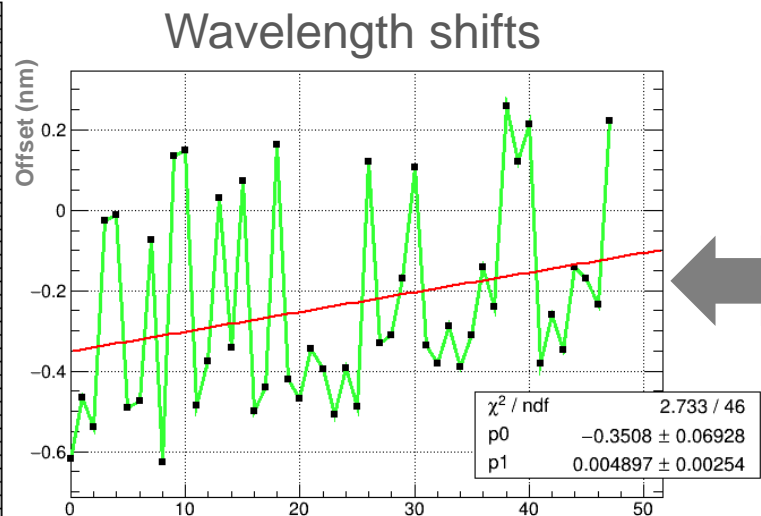
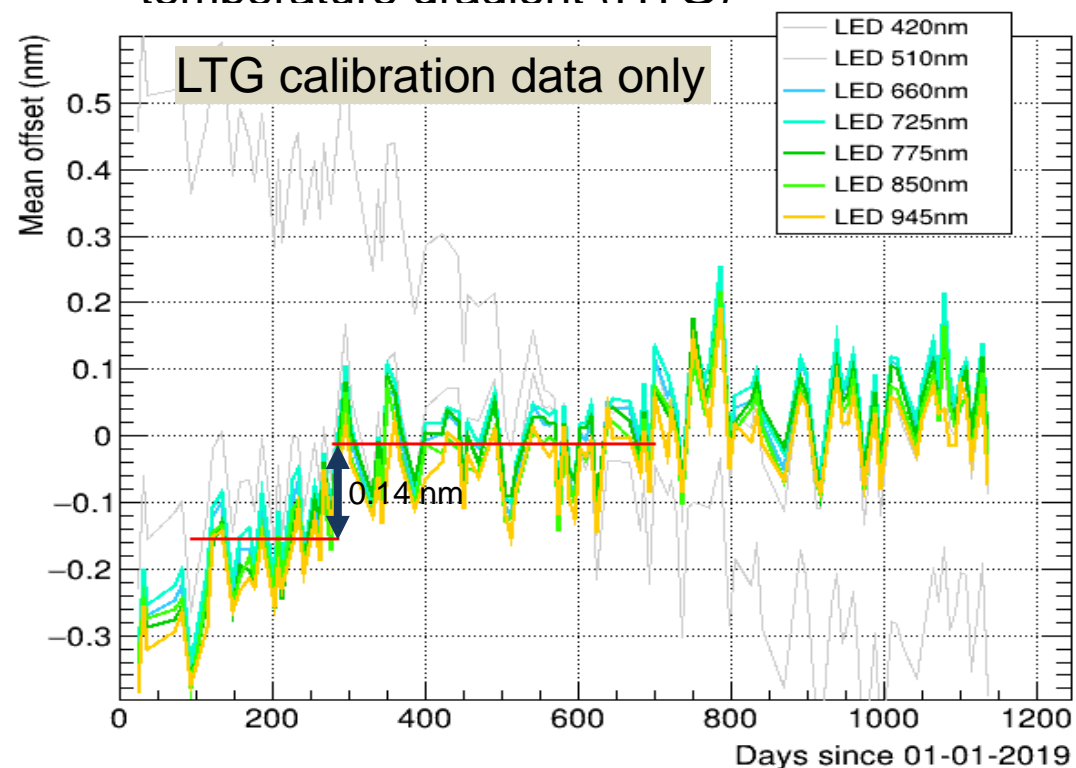
Spectral_shift = -1.25566 (nm)

Vertical_shift = -0.0680321



Spectral Calibration Results

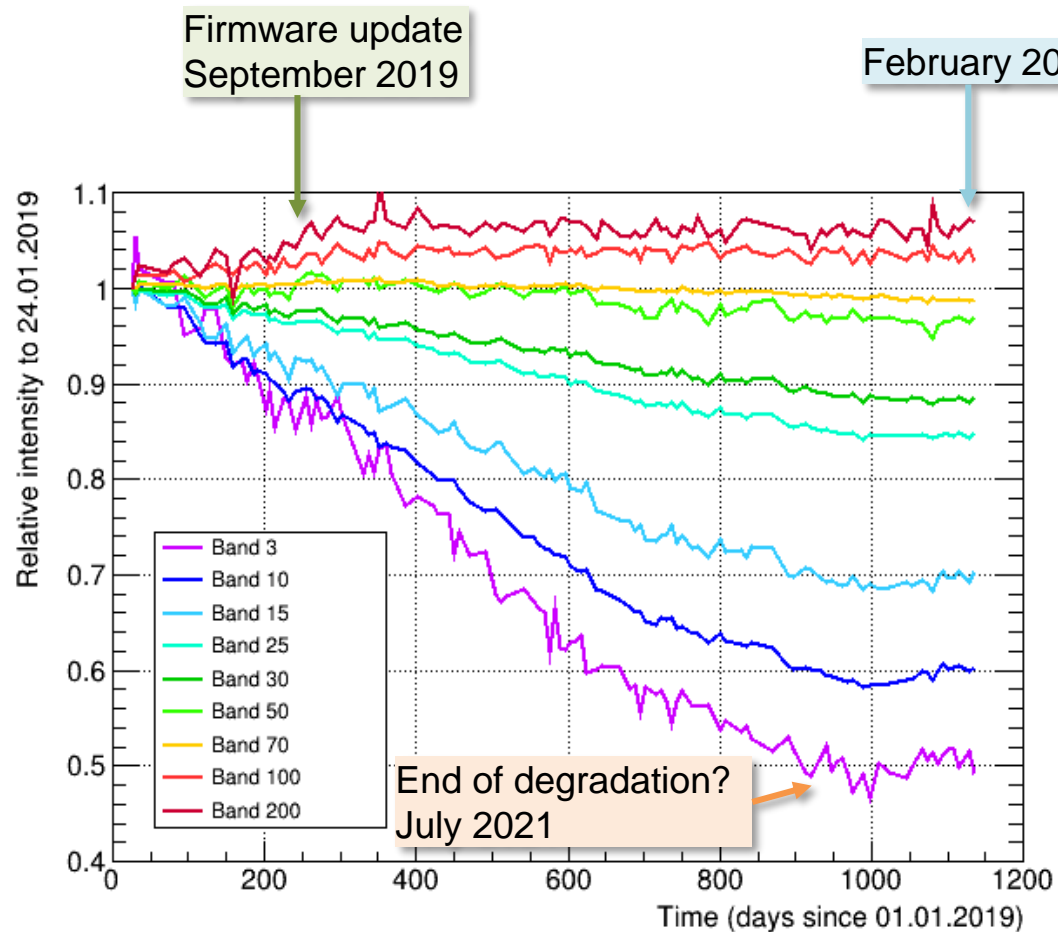
- Mostly obtained from on-board Spectral Calibration. Very precise measurement of LEDs profile provides accurate values
- Observed simultaneous jumps of 0.5 nm in all LEDs and all pixels across-track. Correlated with different temperature gradients inside DESIS sensor. Two populations: low-temperature gradient (LTG) and high-temperature gradient (HTG)



- After stabilization, RMS ~0.1 nm for one of the two states



Calibration Unit Long Term Data



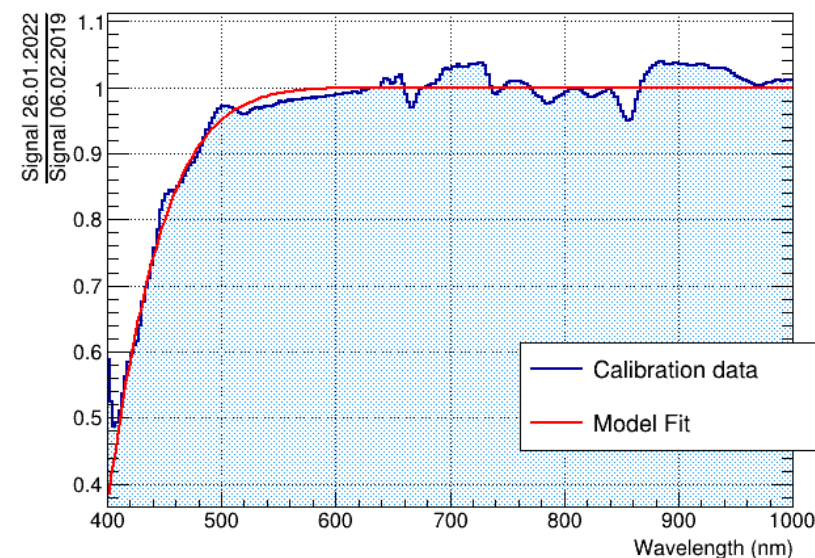
- First bands show a fast degradation reaching 50% of initial performance 1000 days after reference point. The decrease is very close to linear.

- Good approximation for this decrease with a gaussian fit:

$$\text{Decrease 1000 days} = \frac{A}{\sigma} * \exp\left(-\frac{(x - \mu)^2}{2\sigma^2}\right)$$

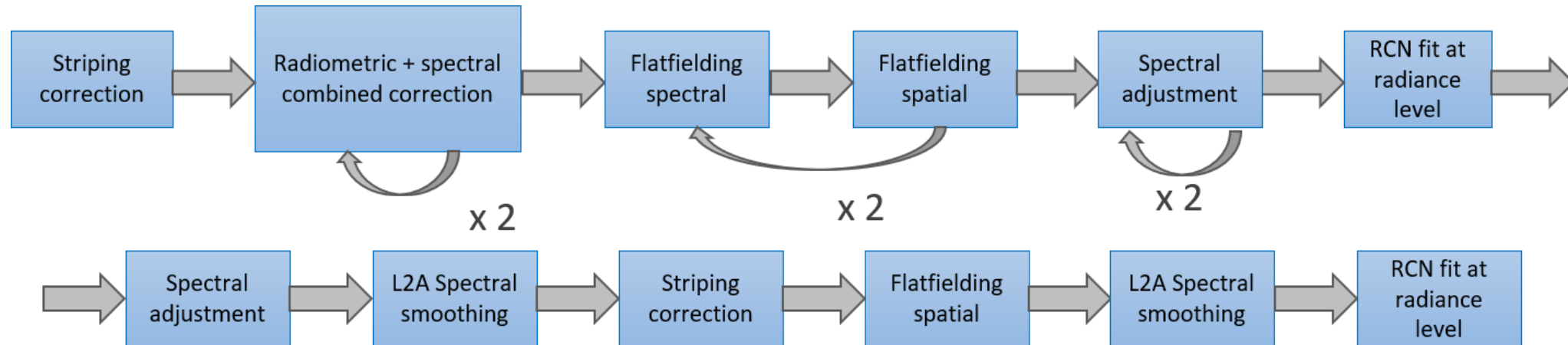
- Where x is wavelength and A, μ , σ are 3 parameters fitted from the calibration data

- Small discrepancies in first 2 bands and across-track



Vicarious Calibration Concept

- Two main goals:
 1. Consistent relative response in spatial and spectral direction of the sensor (use uniform scene images)
 2. Correct absolute radiance scale (use RadCalNet reference data)
- Use a sequence of configurable steps to achieve both goals:

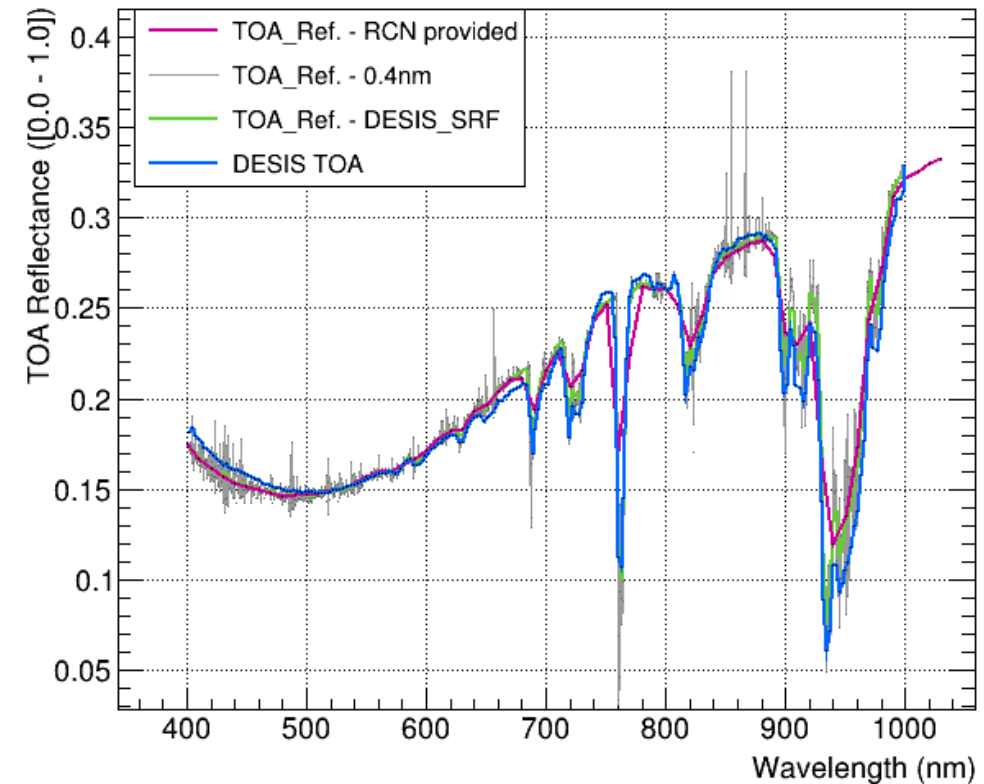
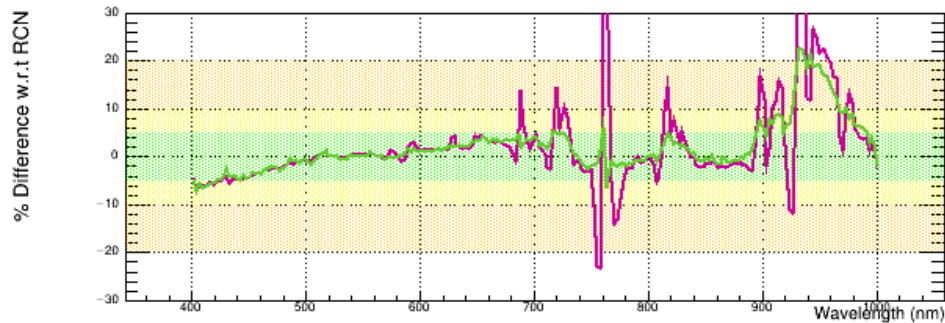


- Original sequence of steps followed on first ground-to-space calibration. Newer calibration updates require simpler sequences



Absolute radiometric scale

- Use TOA Reflectance from RCN sites for estimation of absolute calibration
- Compare DESIS measurement against:
 - RCN measurement (10 nm)
 - DESIS team TOA calculation from RCN BOA
- Compute deviations of DESIS w.r.t. both references:

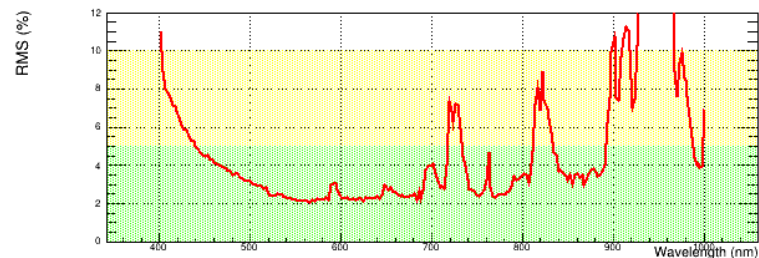
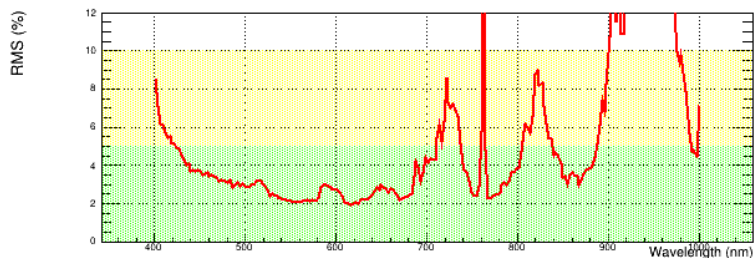
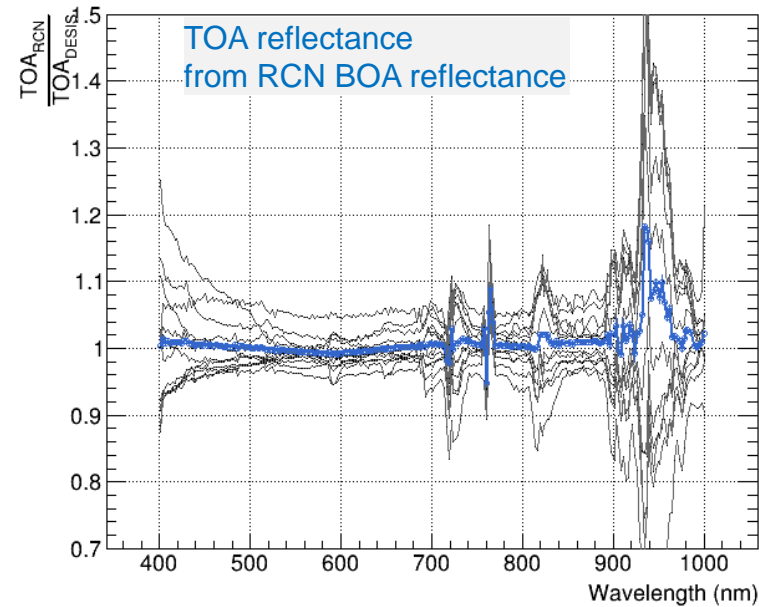
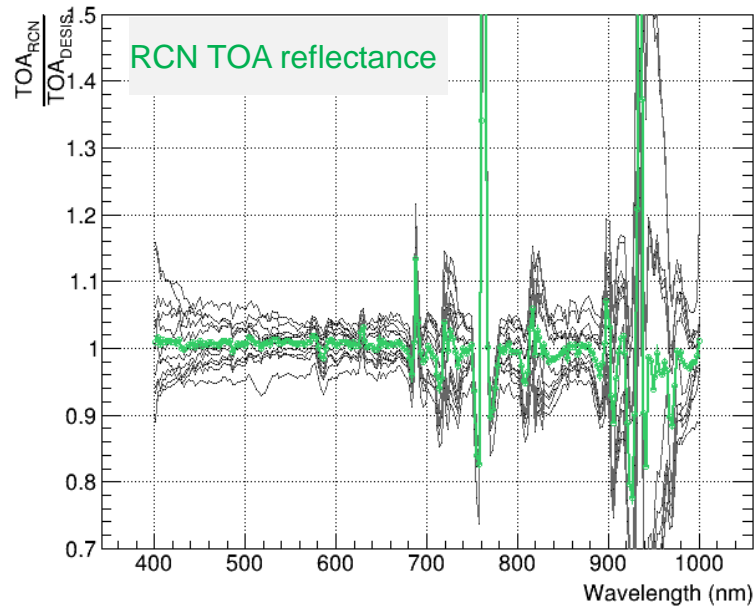


- Compute radiometric coefficient updates based on observed deviations



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**

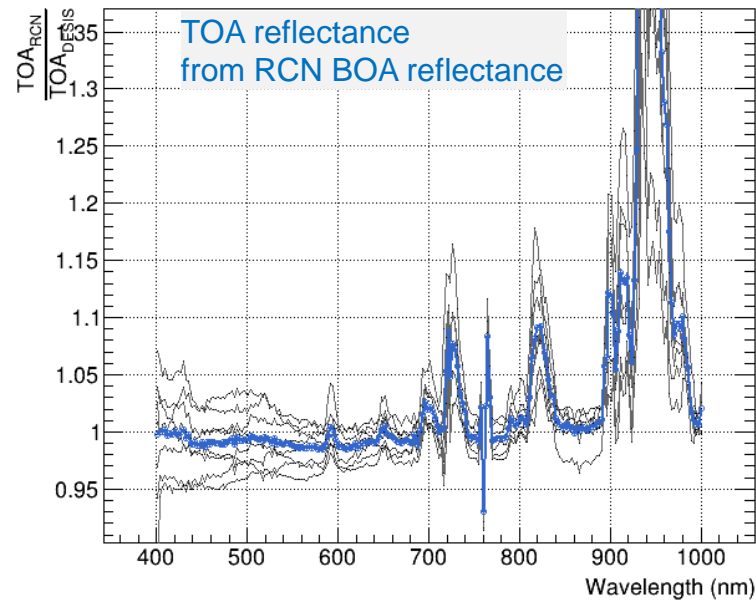
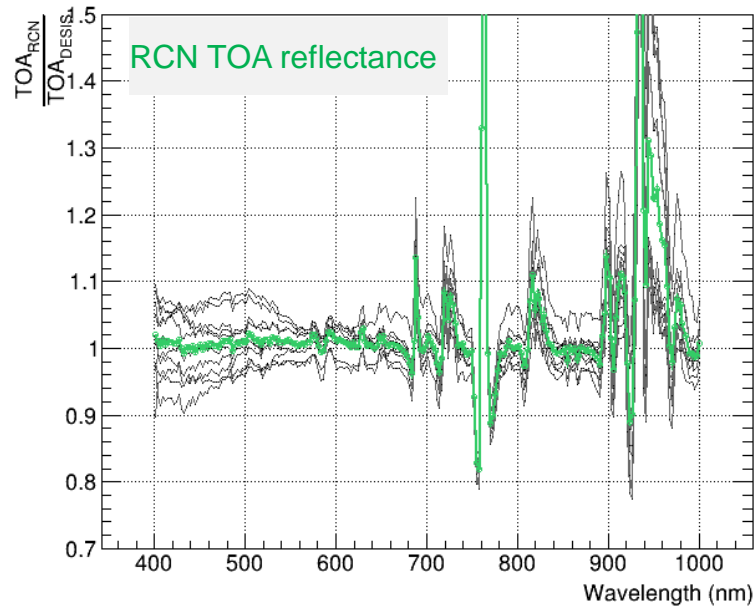


- Similar results as seen in other periods
- After calibration bias is corrected, but RMS below 500 nm is significant larger than above 500 nm

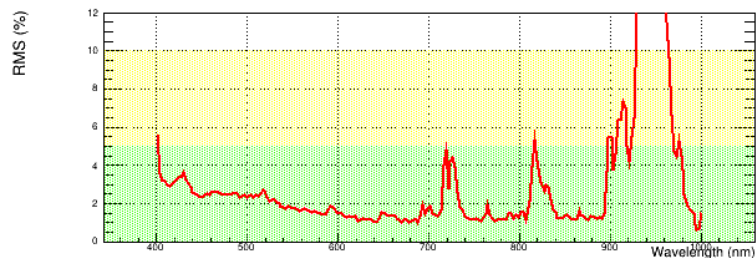
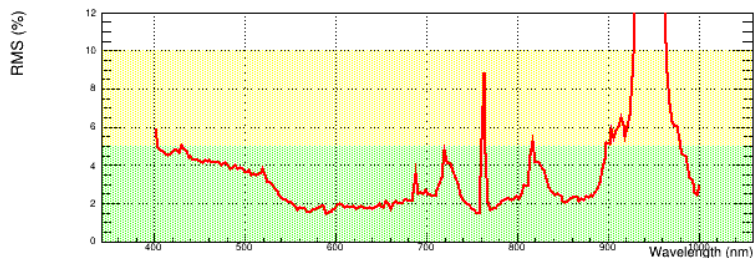


Latest Vicarious calibration data

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

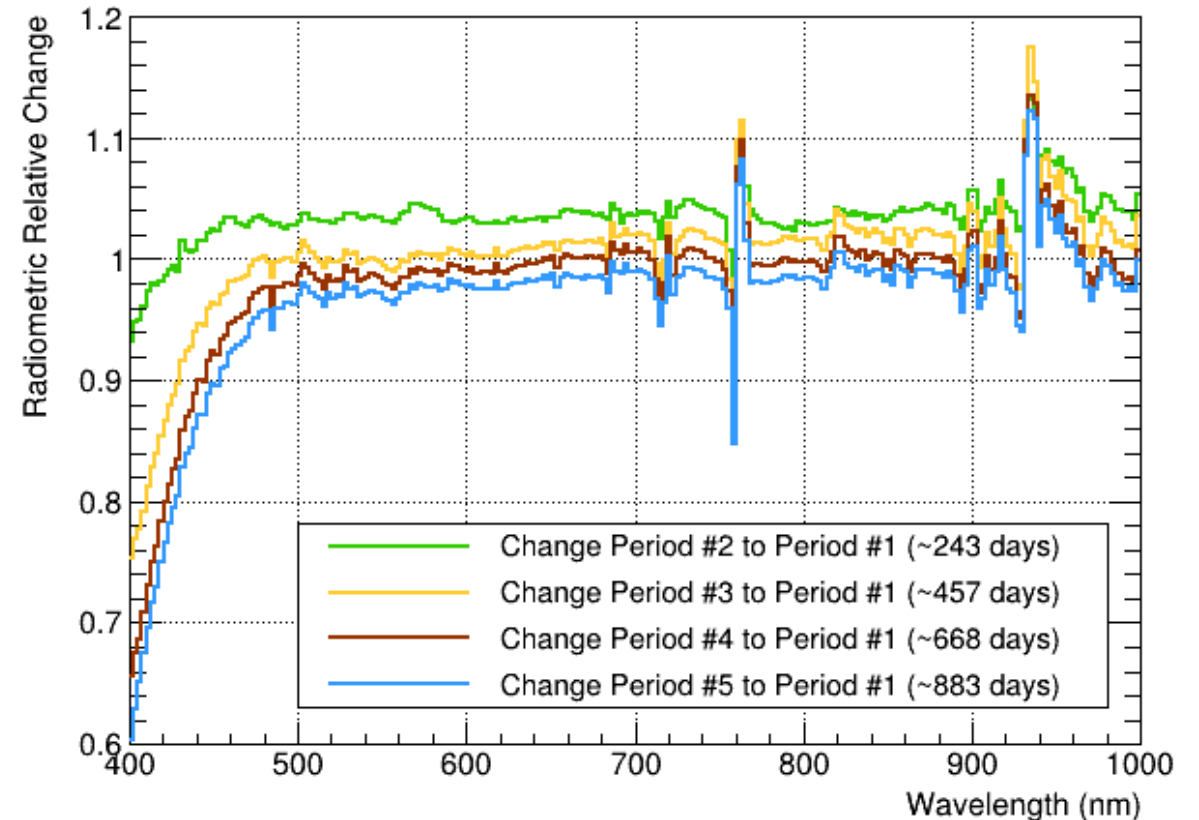


- As indicated by LED calibration data, no sign of degradation below 500 nm on Period 5 (starts 01.07.2022)



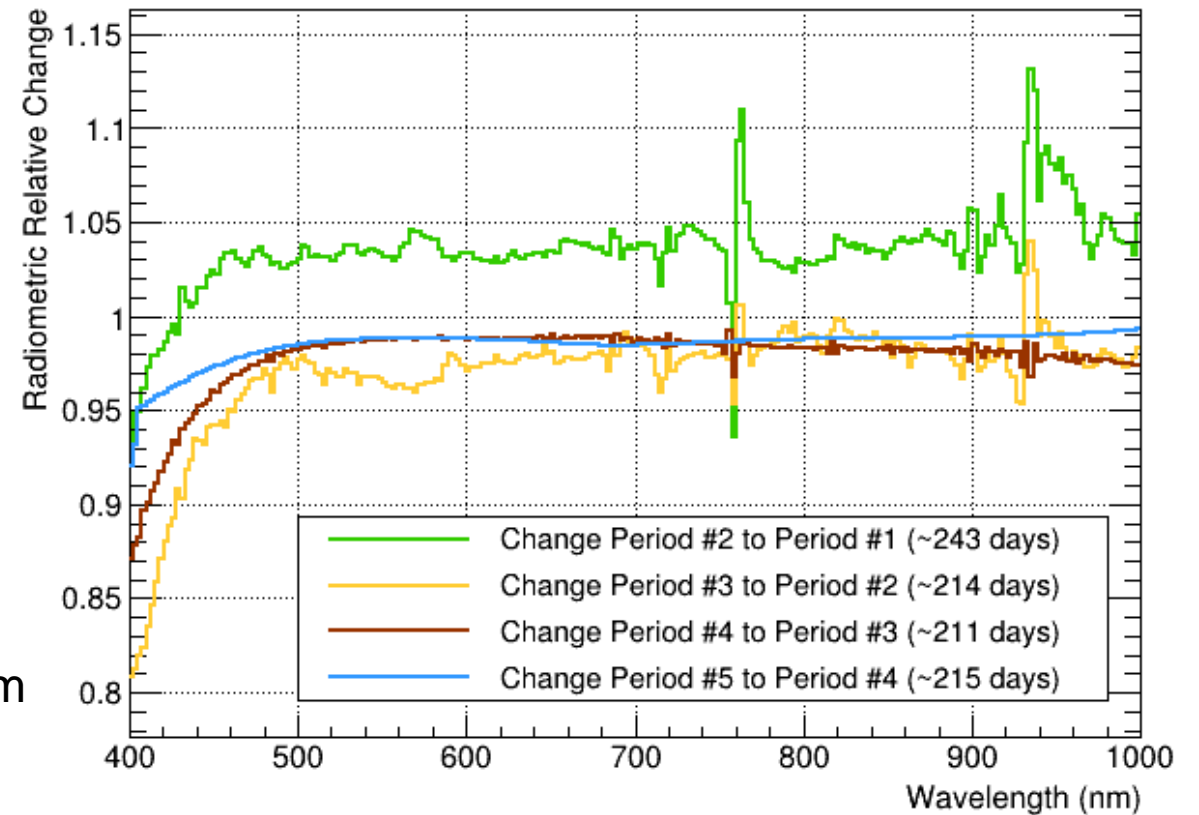
Comparison with Radiometric update from Vicarious Calibration

- Unfortunately model does not seem to match well the data obtained in Vicarious calibration
- The plot shows relative change of detector performance obtained from the Vicarious calibration
- Main similarity with LED data:
 - CAL data reproduces the fast decrease in performance below 500 nm
- Main differences are:
 - CAL data shows a maximum decrease down to 40% from the initial values, while the Vicarious data shows a maximum decrease down to 60%



Comparison with Radiometric update from Vicarious Calibration

- Unfortunately model does not seem to match well the data obtain in Vicarious calibration
- The plot shows relative change of detector performance obtained from the Vicarious calibration
- Main similarity with LED data:
 - CAL data reproduces the fast decrease in performance below 500 nm
- Main differences are:
 - CAL data shows a maximum decrease down to 40% from the initial values, while the Vicarious data shows a maximum decrease down to 60%
 - CAL data does not reproduce decrease of ~2% between periods (3.4%/year) above 500 nm
 - CAL decrease below 500 nm is constant until July 2021, but vicarious results show different intensities for different periods



Summary & Outlook

- Vicarious calibration is the baseline calibration method of the DESIS imaging spectrometer
- Fast change of radiometric performance below 500 nm in DESIS is challenging for this calibration method (~20% degradation / year)
- Above 500 nm the current calibration approach guarantees that difference between periods is $\leq 2\%$ (~3.4% / year)
- In order to improve the calibration under 500 nm, we developed a model to characterize the sensor behavior using the on-board spectral calibration data
 - Model reproduces well trends, but LED data are not accurate enough for radiometric calibration
- Evidence of no further degradation below 500 nm after August 2021 from LED data, confirmed with vicarious data



Thank you for your attention !



Knowledge for Tomorrow



Extra

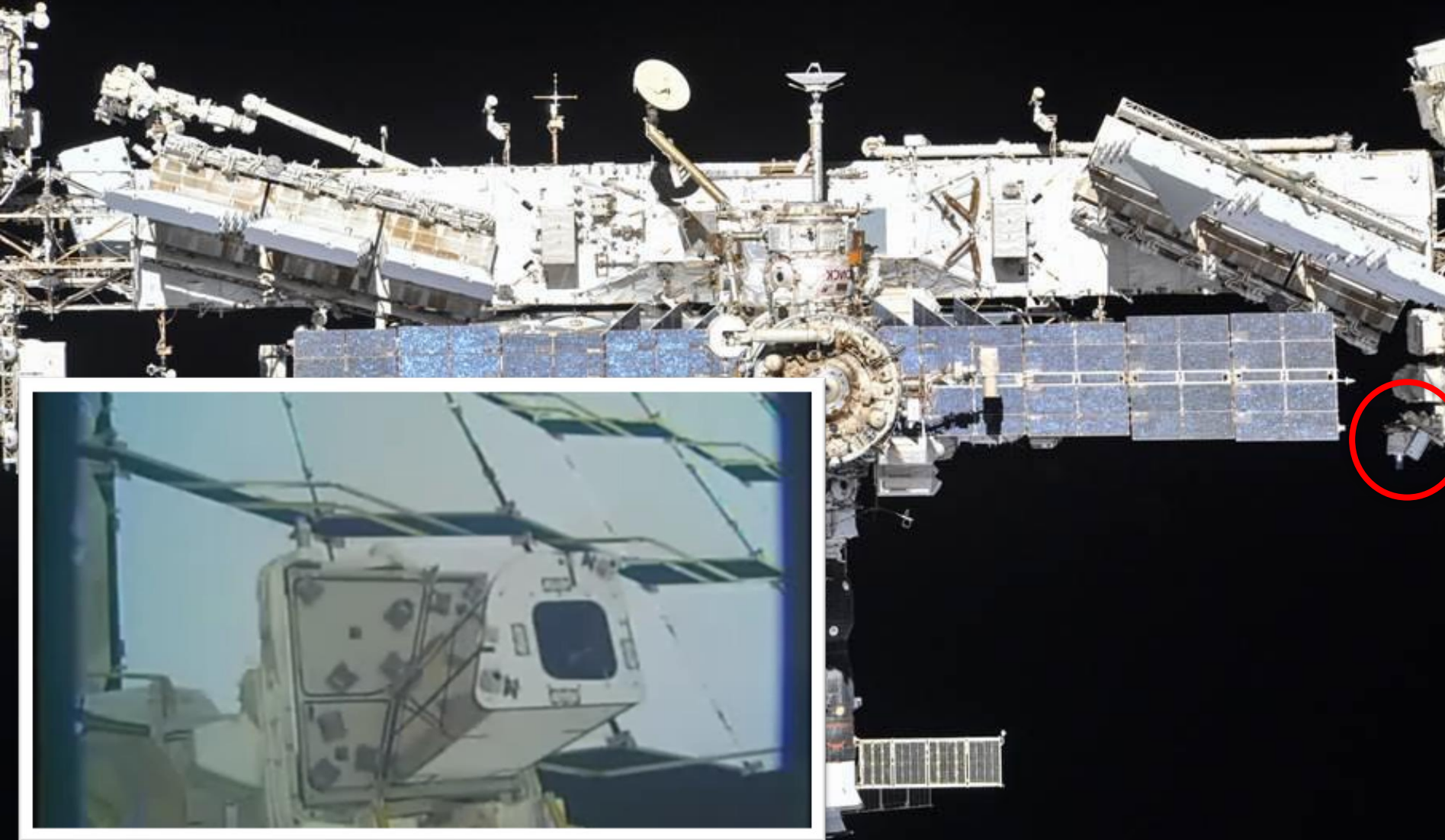


Knowledge for Tomorrow





DESI, MUSES and ISS



Teledyne Brown Engineering (TBE, USA) and **DLR** have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DESI**) from the Teledyne-owned Multi-User System for Earth Sensing (**MUSES**) Platform on the ISS

MUSES provides accommodations for two large and two small hosted payloads and provides **core services** for the instruments

DESI, the hyperspectral sensor developed by DLR, is the first payload of **MUSES**.

DLR also established the Ground Segment and licensed the SW processors to Teledyne running in an Amazon Cloud

DESI – Timeline and Results

2014 / 2015



MUSES / DESIS Start Mission

7. June 2017



MUSES installation on ISS

29. June 2018



DESI launch from Cape Canaveral to ISS via SpaceX Dragon

27.-28.08 2018



Installation of DESIS in MUSES

23. October 2019



@ IAC Washington Start operational Phase

29.09.–01.10.2021



1st DESIS User Workshop (online)

Design, Implementation, Test

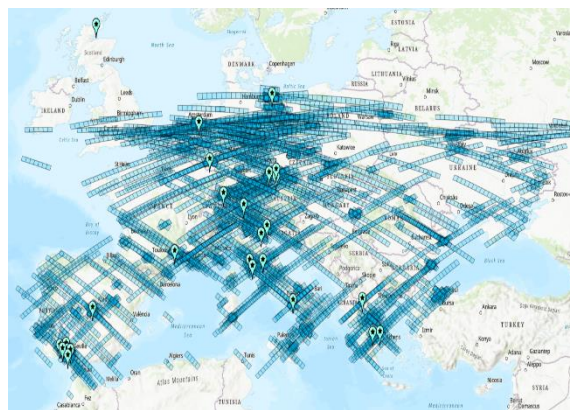
Commissioning

Operations

Since 2018 **~130.400** scenes processed and archived

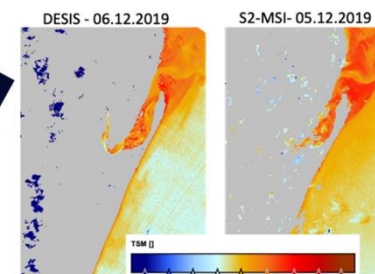
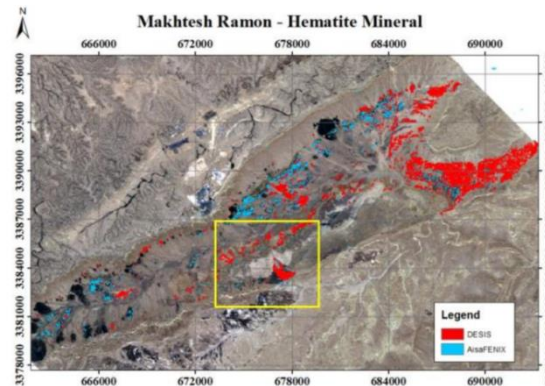


~23.000 scenes in USA

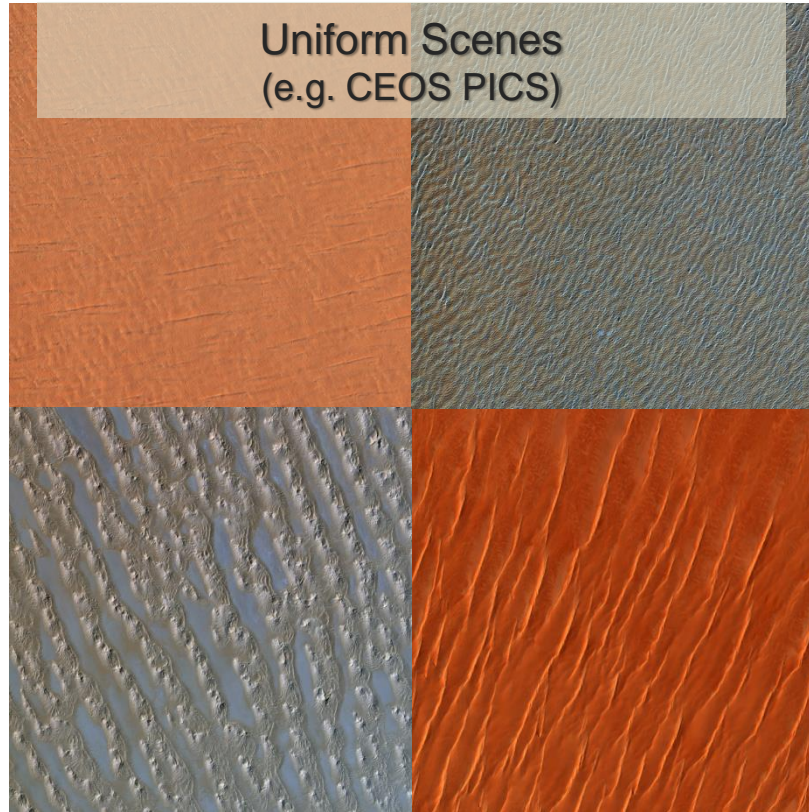


~8.600 scenes in Europe

First DESIS User workshop (September 2021)
Publication at The International Archives of the ISPRS

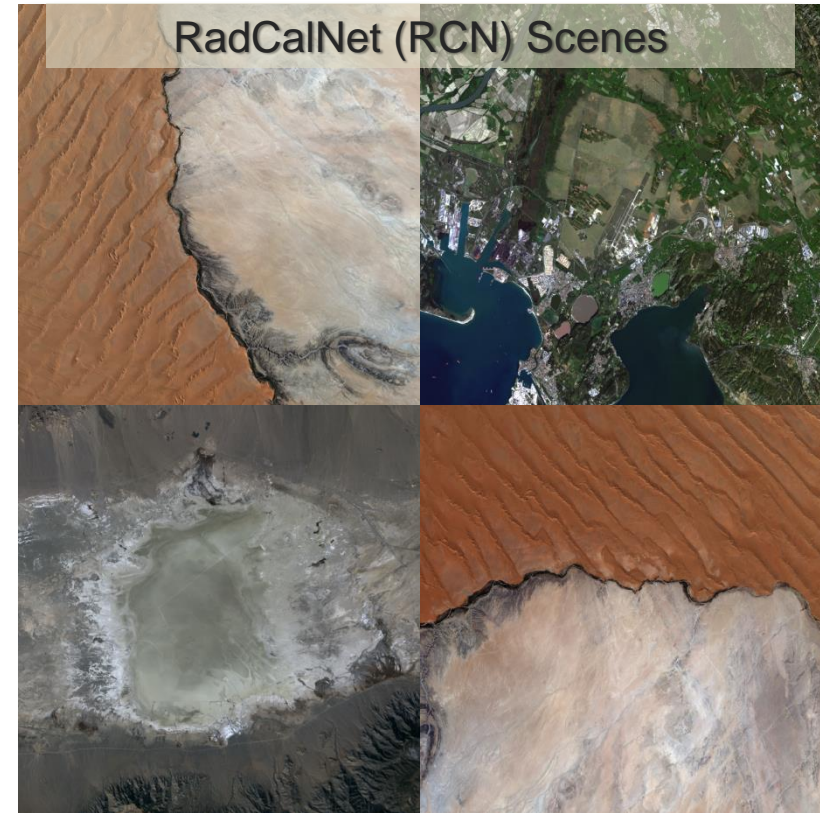


DESIS Vicarious Calibration



Obtain consistent relative response in spatial and spectral directions:

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



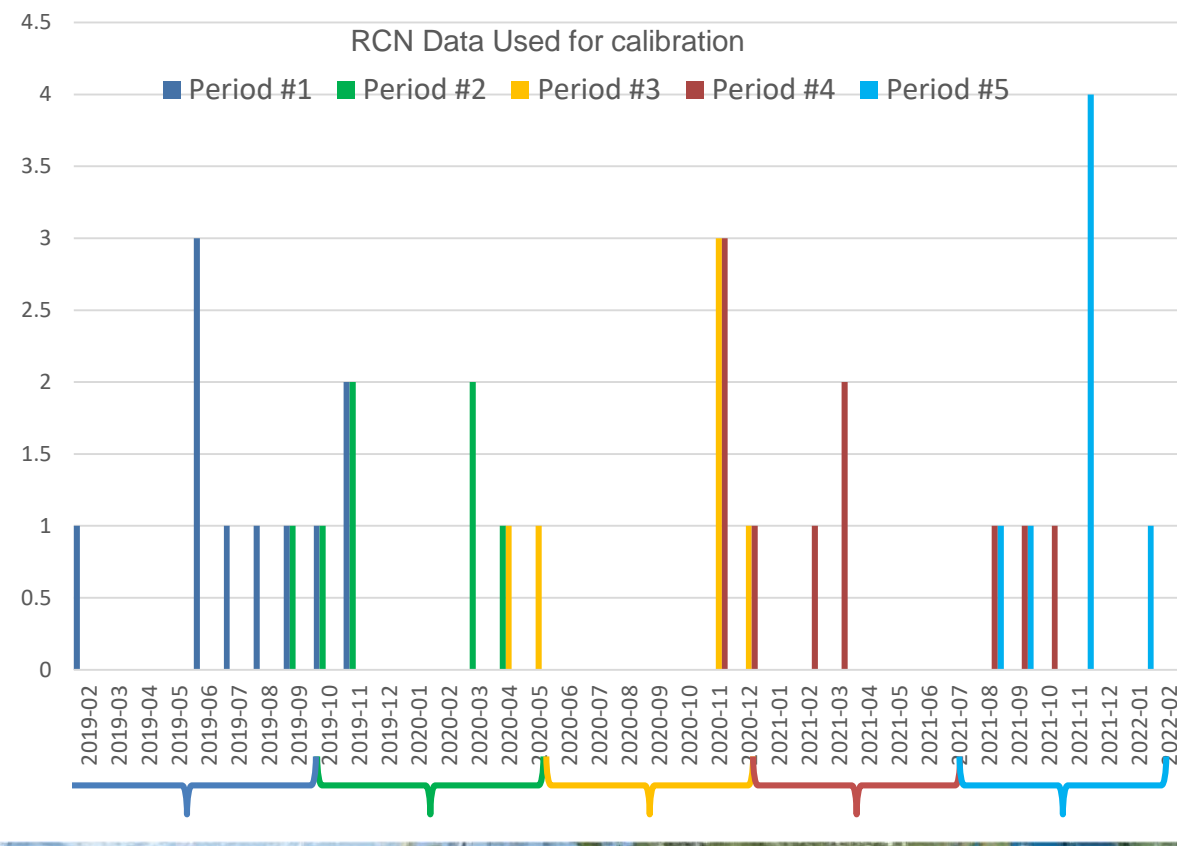
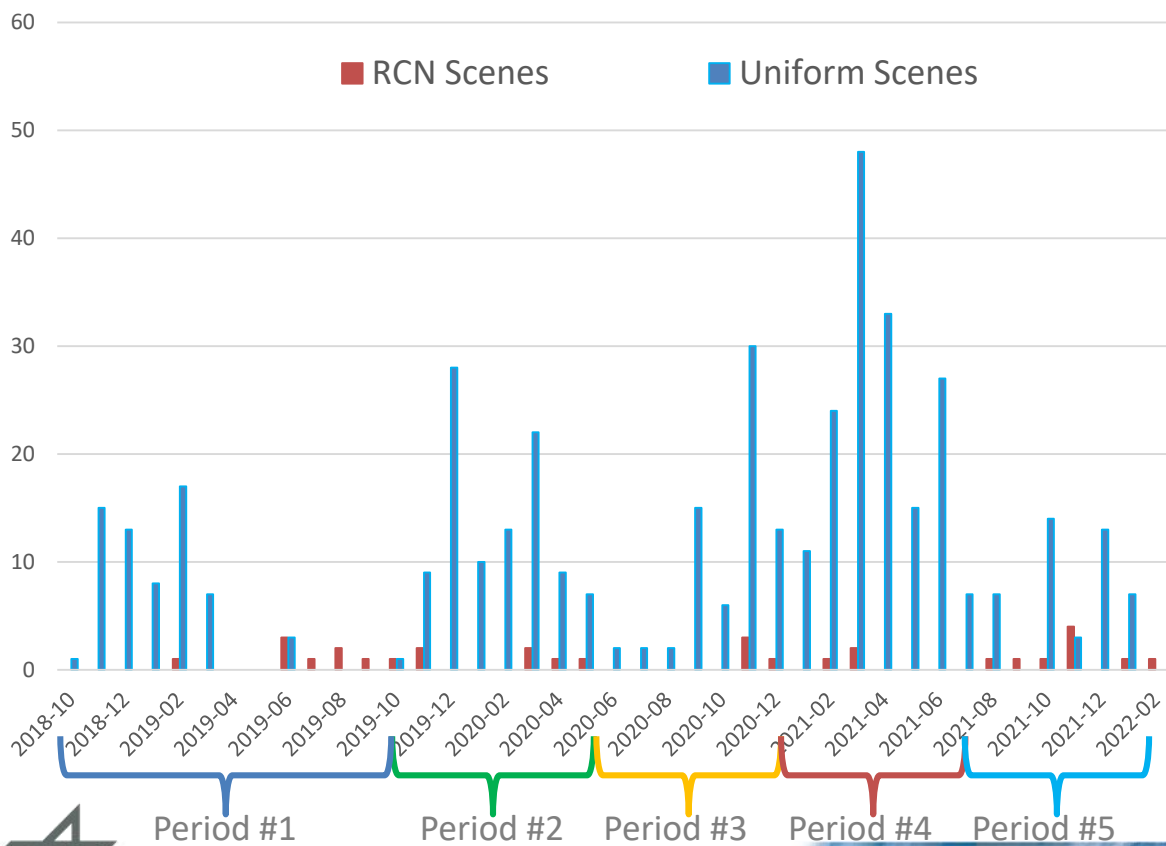
Obtain absolute radiance scale

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

Vicarious calibration data

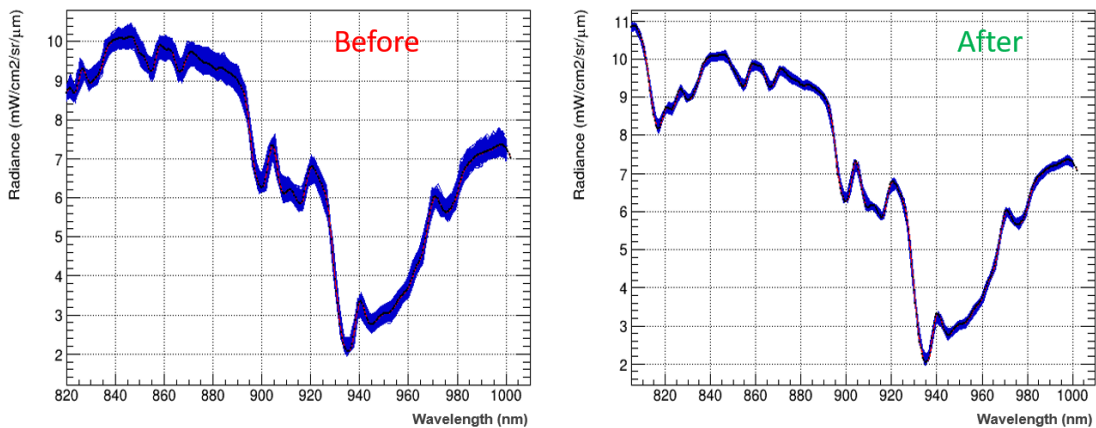
“Vicarious calibration of the DESIS imaging spectrometer”, E. Carmona et al., IGARSS2021

- 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

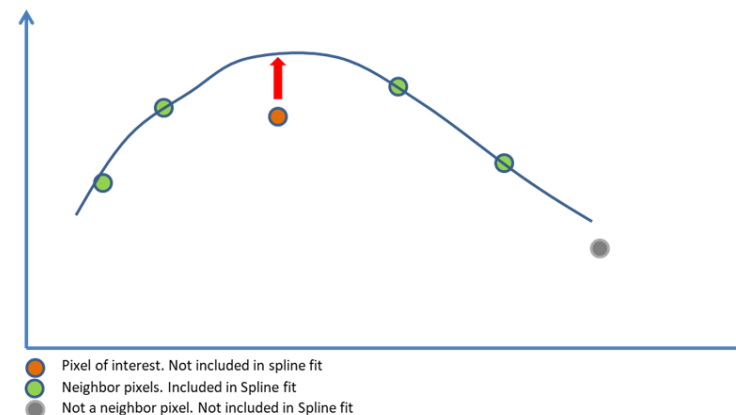


Uniform Scenes Processing Steps

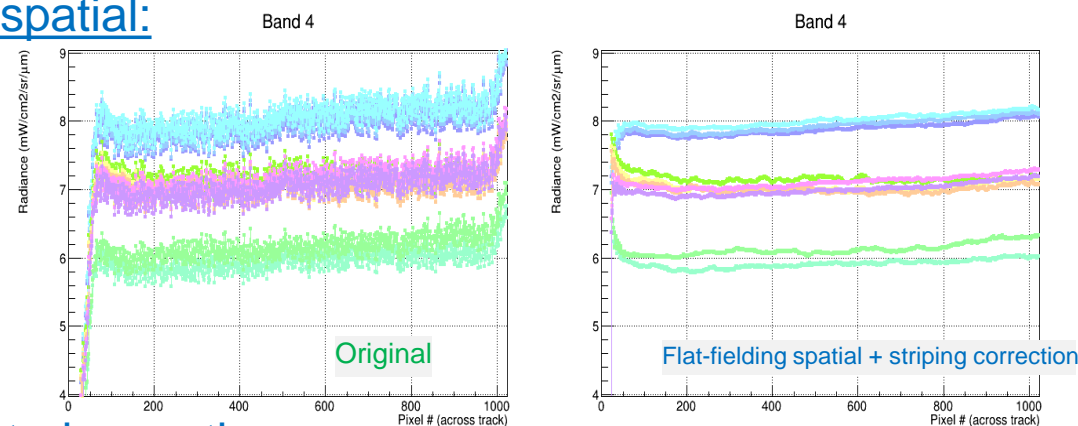
- Rad./Sp. Correction (before smile corr.)



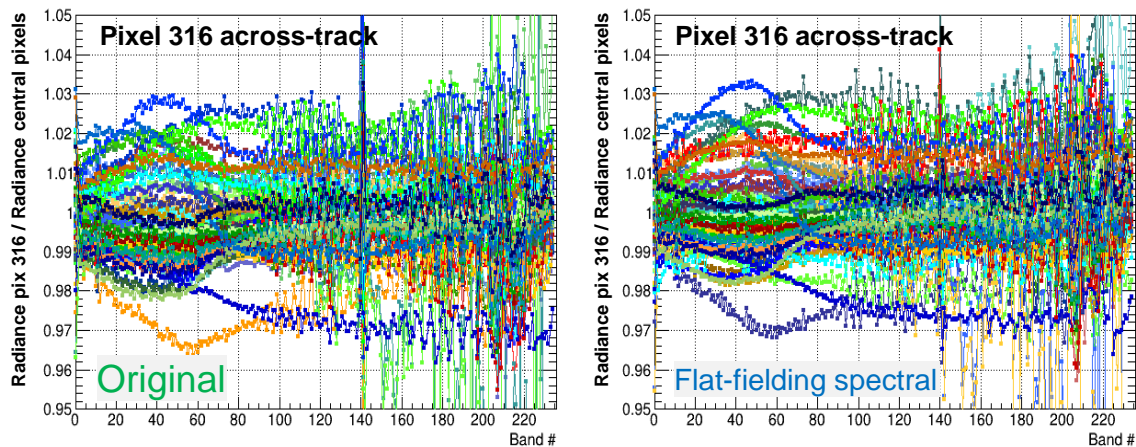
- Striping correction:



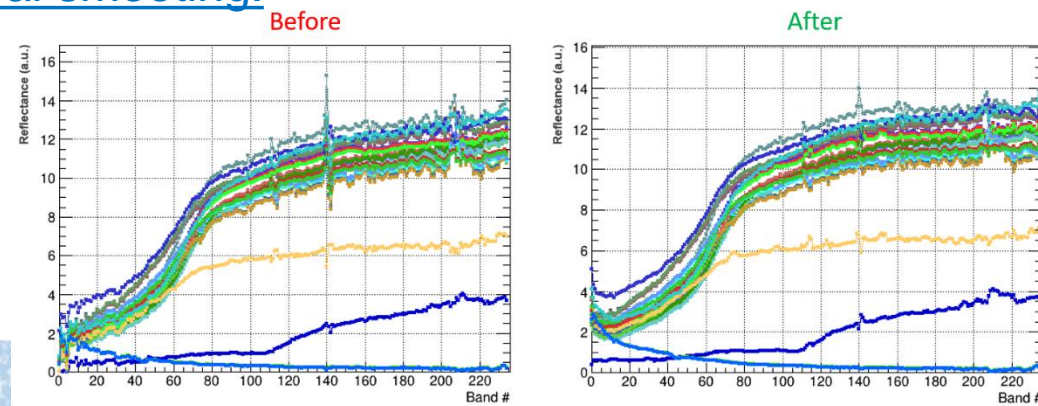
- Flatfielding spatial:



- Flatfielding spectral:

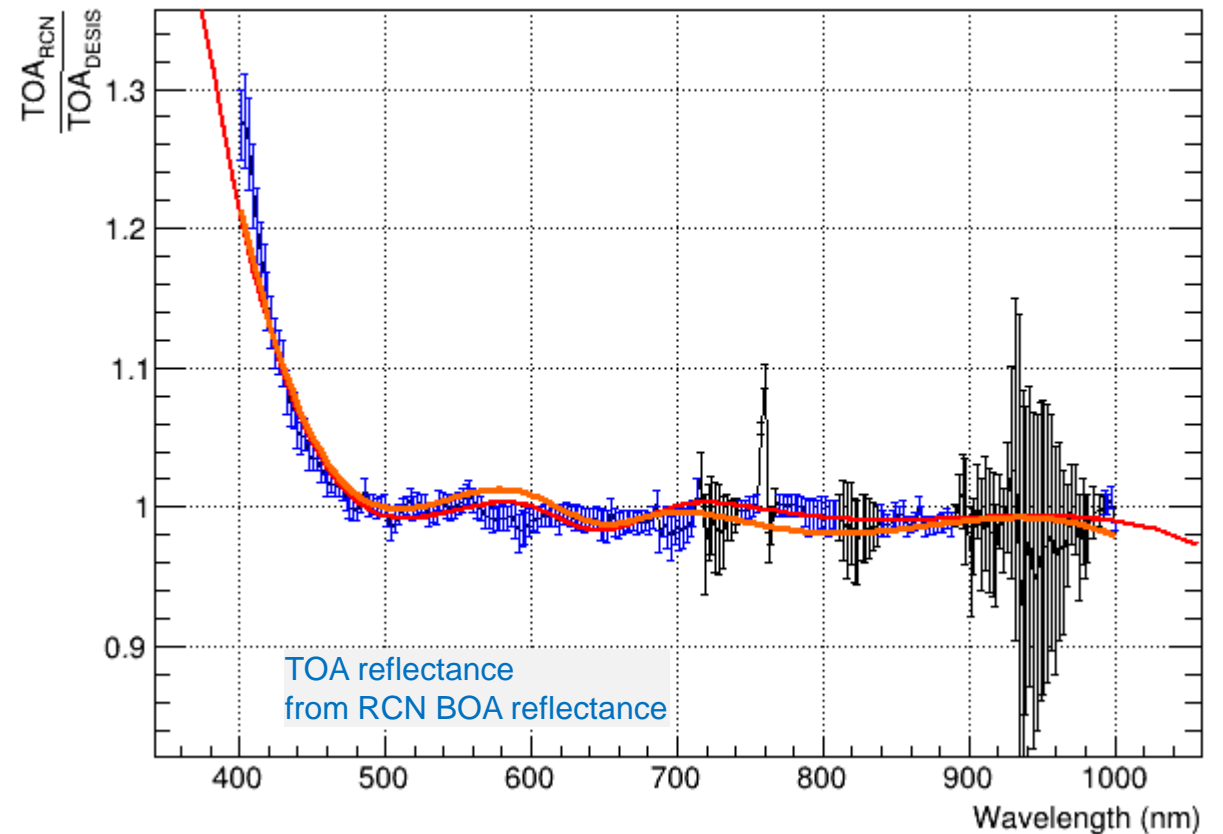
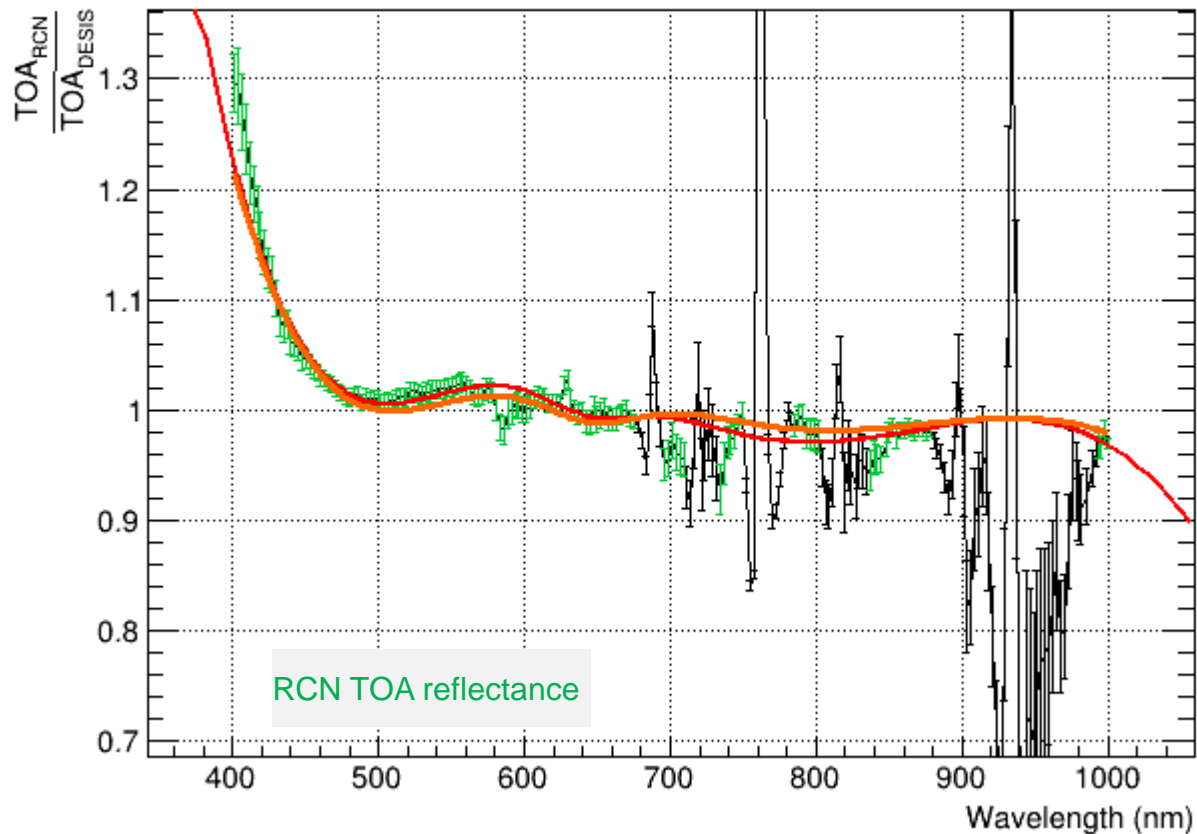


- L2A spectral smooting:



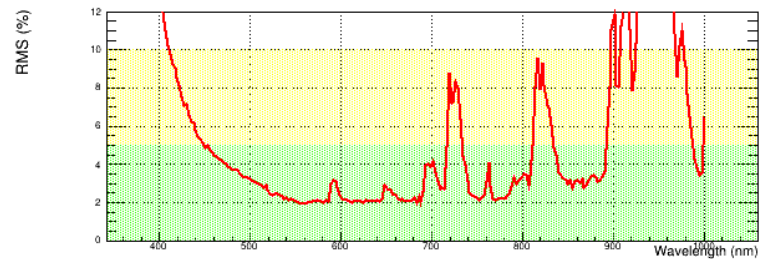
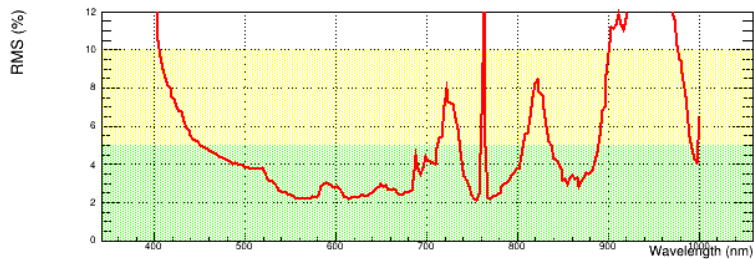
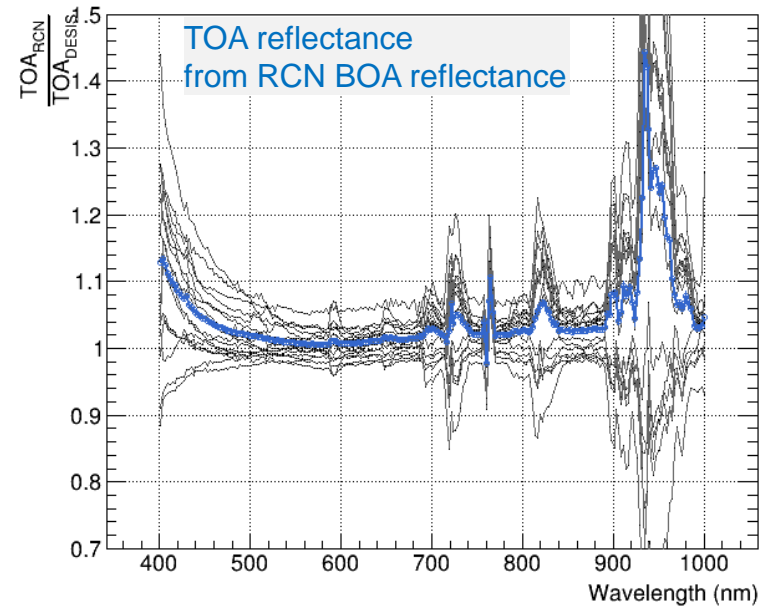
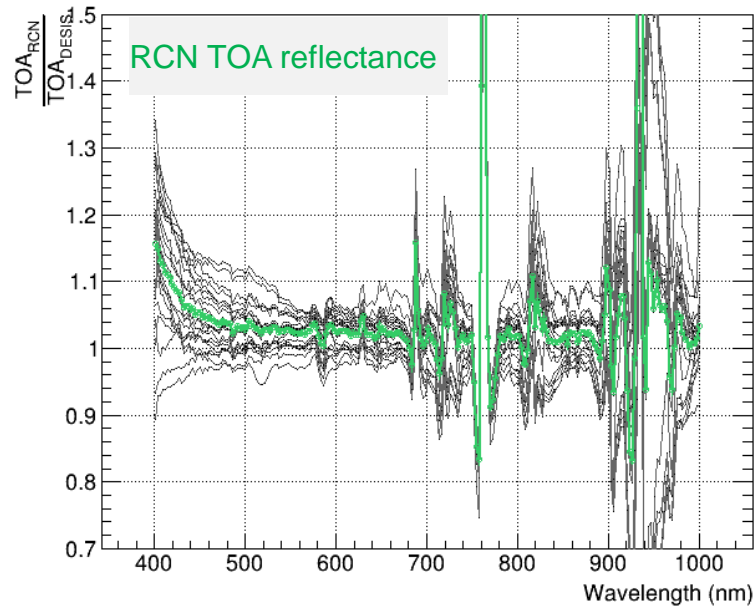
Absolute radiometric scale

- Use selected “calibration” scenes from RCN and perform a fit to mean value (2 times in steps sequence) in order to obtain a per-band factor
- Use Average from 2 TOA reference data: RadCalNet provided (10 nm), DESIS calculated (DESIS resolution)

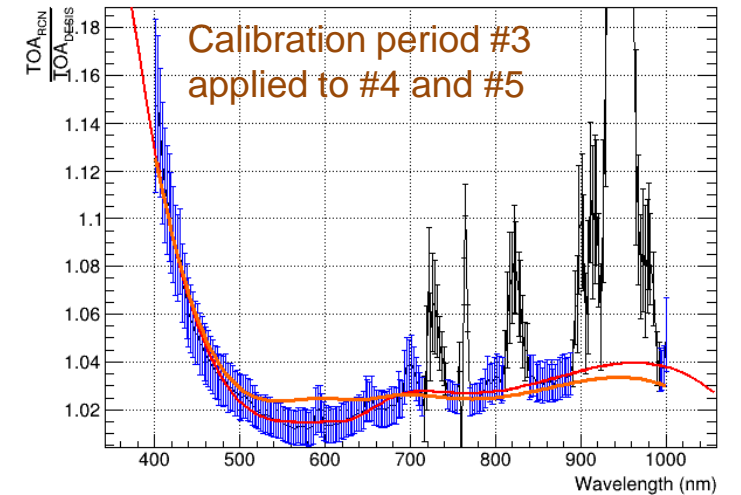


Latest Vicarious calibration data

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

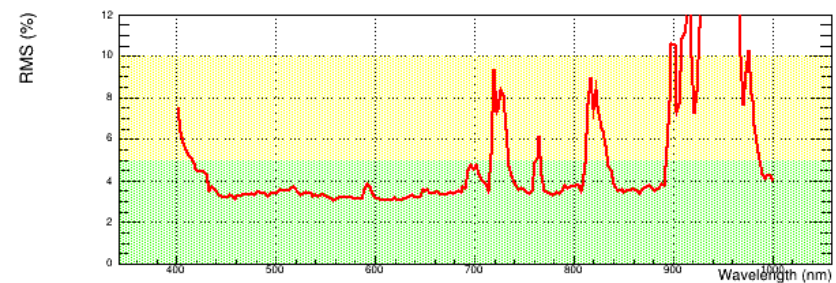
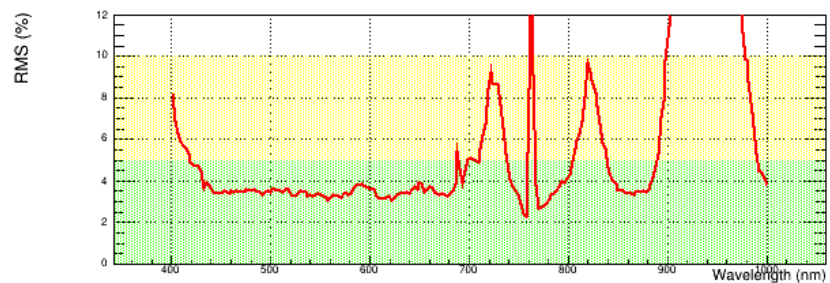
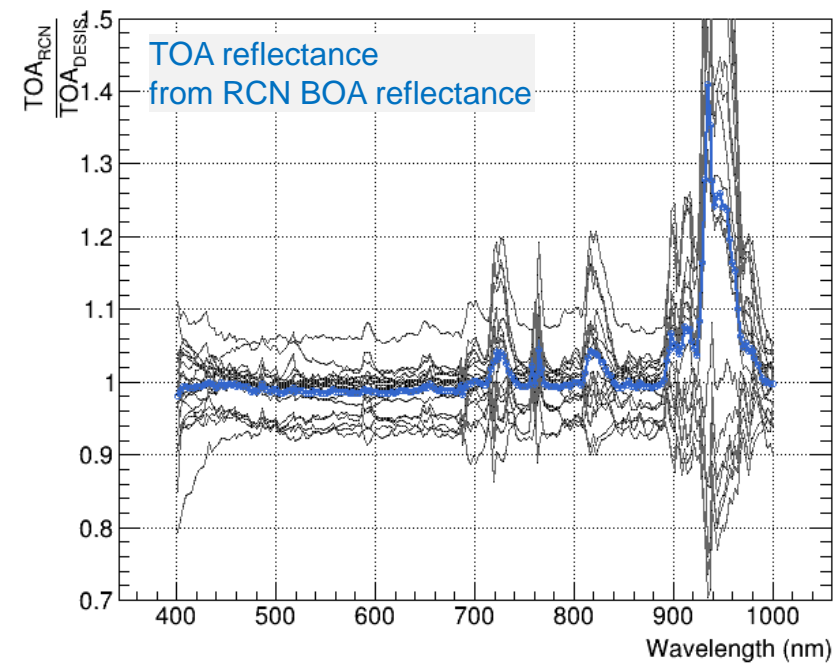
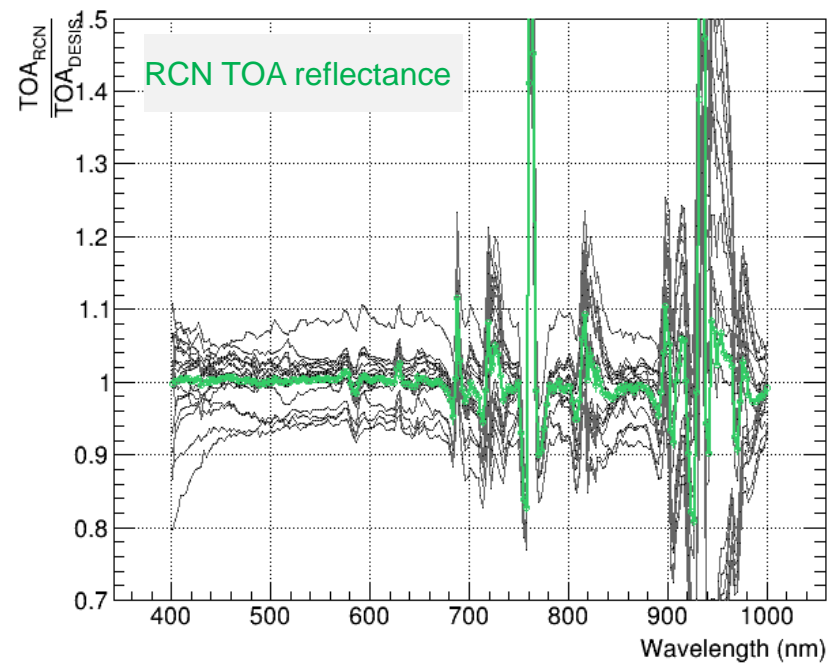


- Large variation of calibration below 500 nm as seen in other periods
- Magnitude is smaller



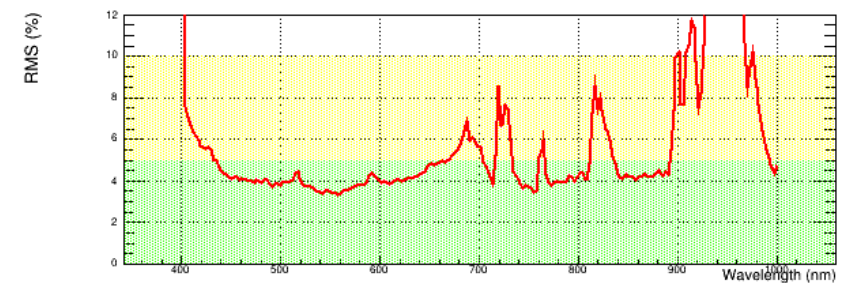
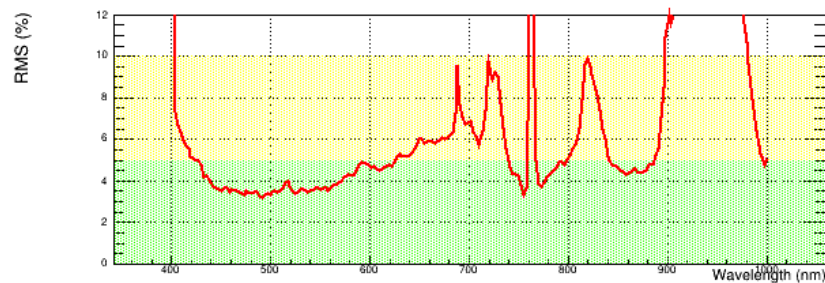
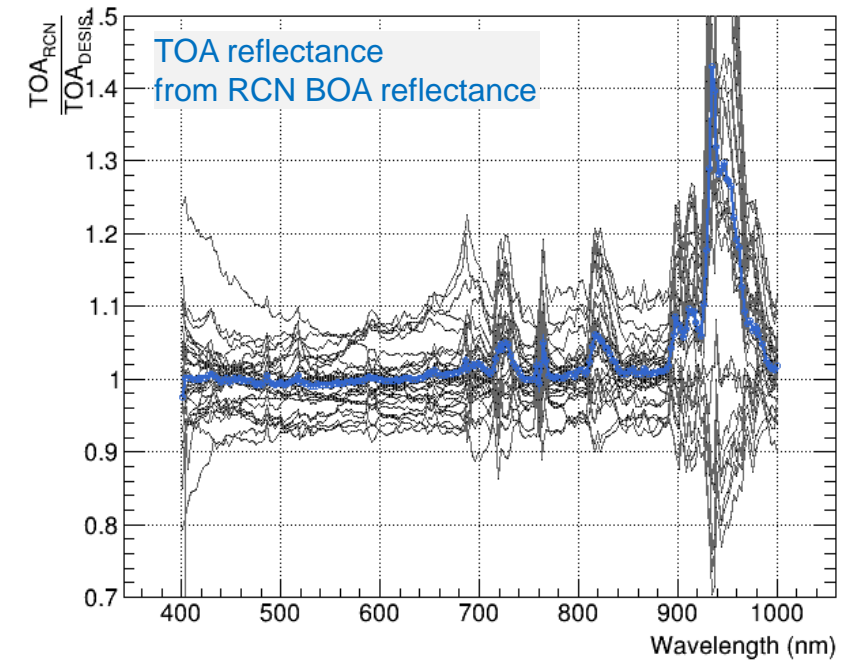
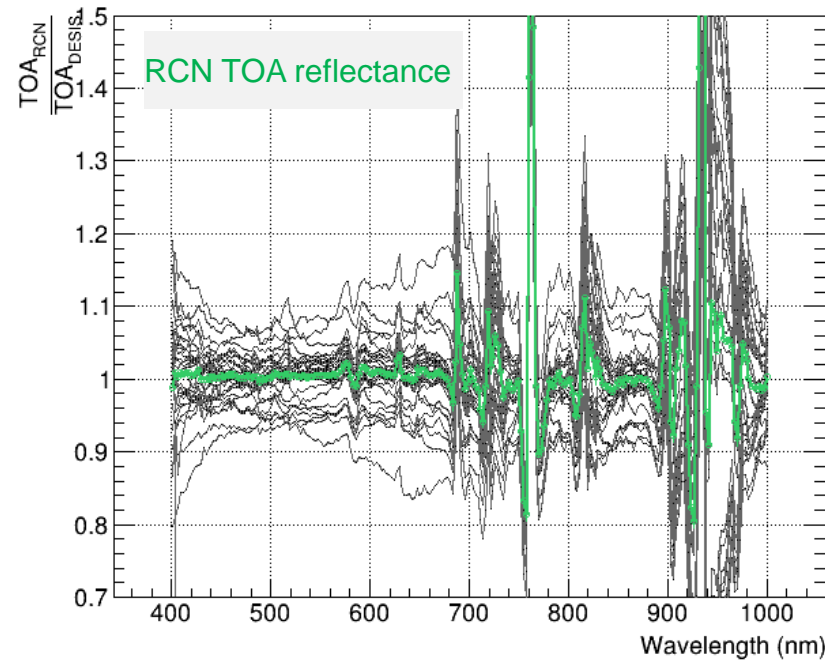
Results from 3 calibration periods: All RCN Data Results

- 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 **19** RCN scenes used for calibration



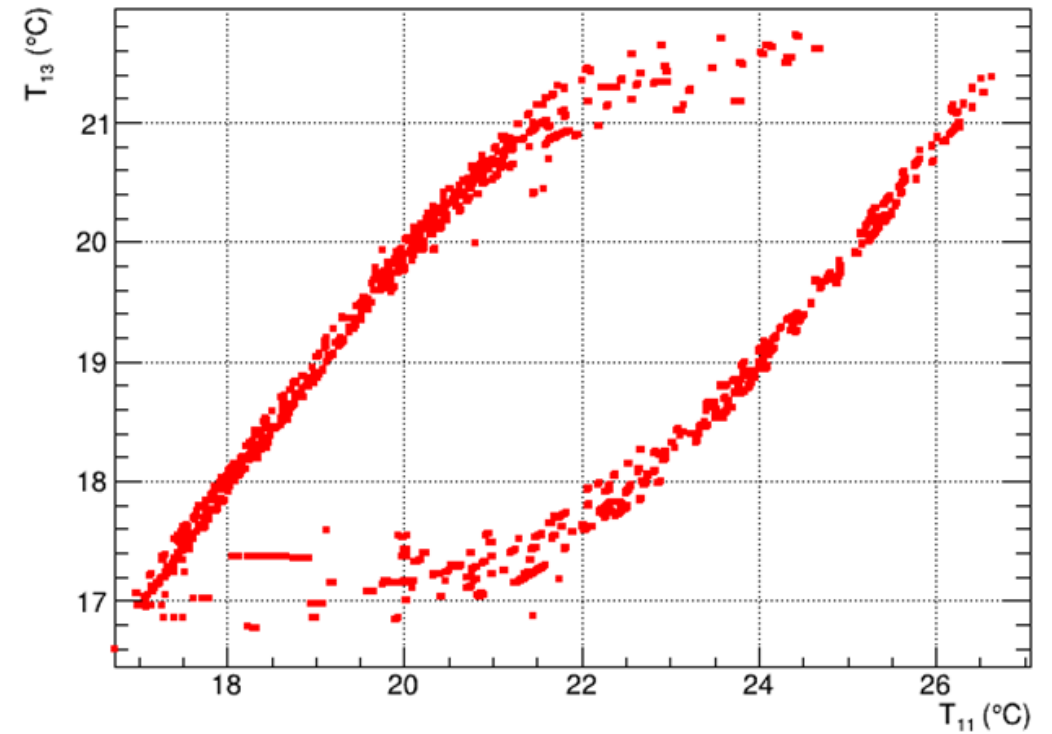
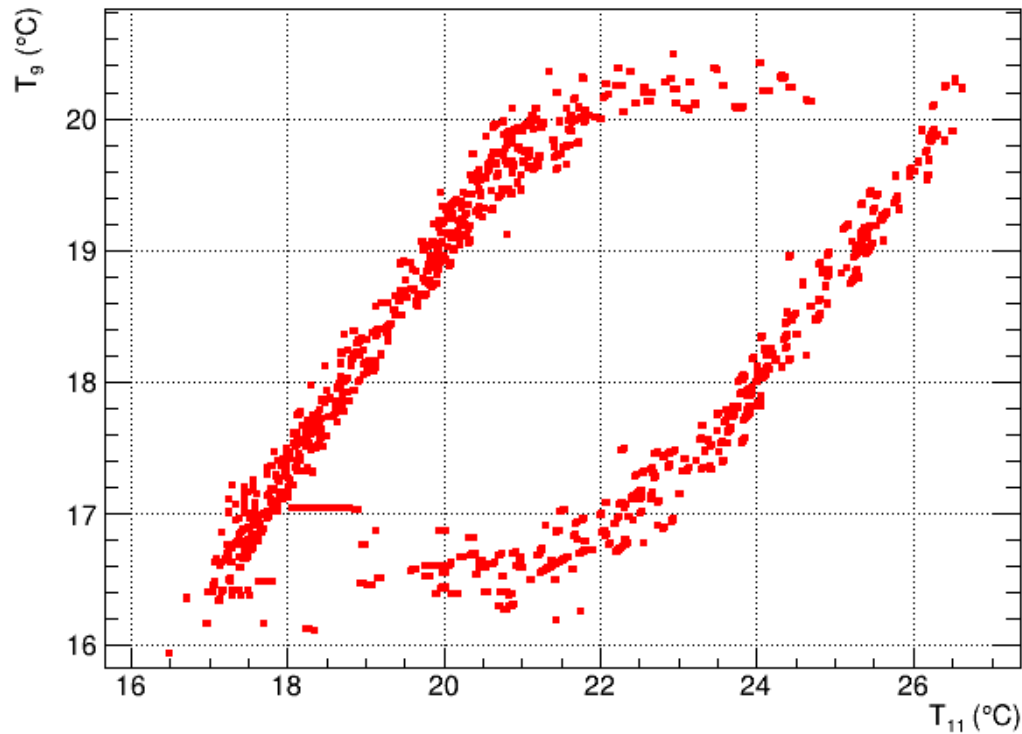
Results from 3 calibration periods: All RCN Data Results

- 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)



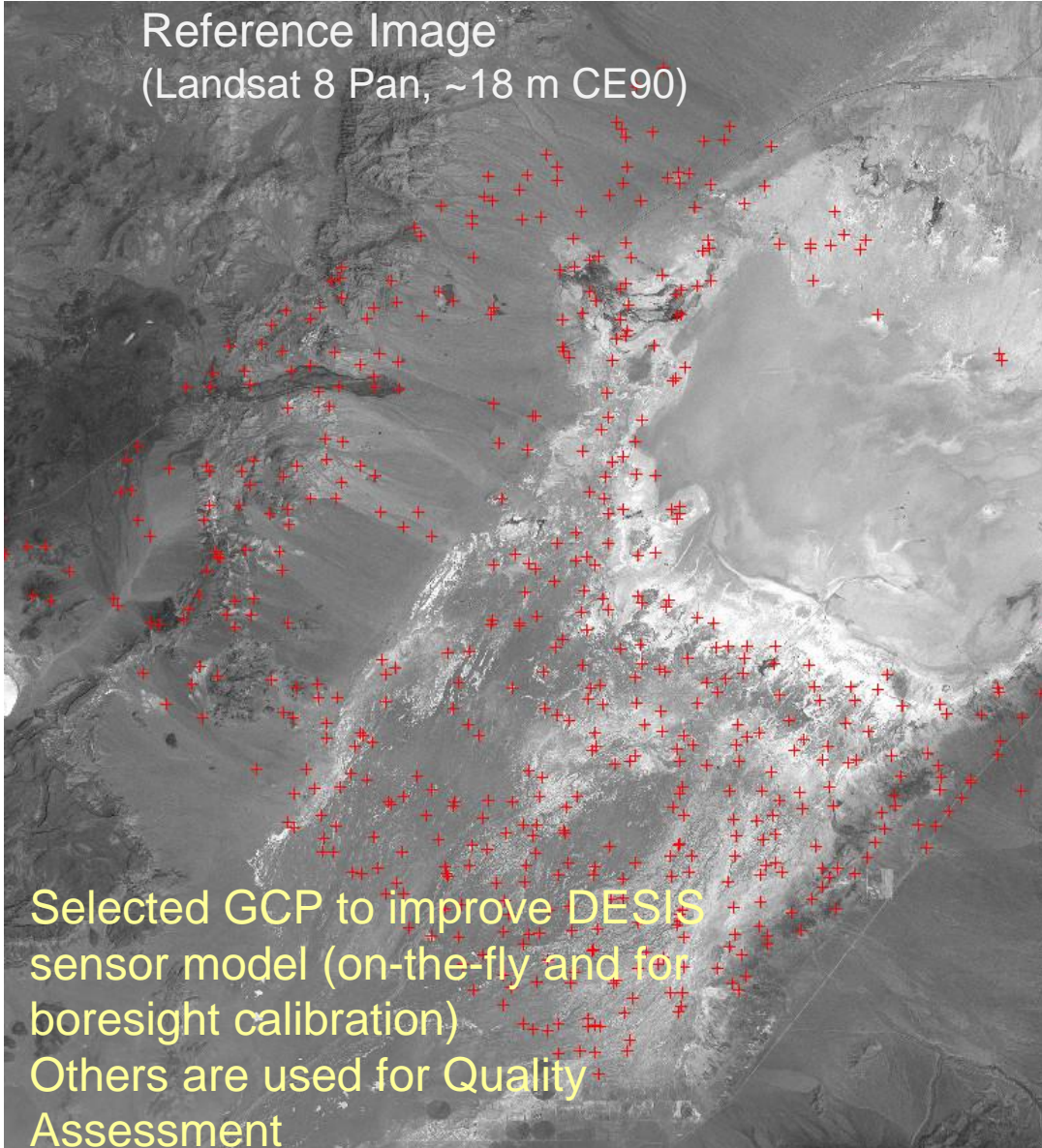
Temperature gradients

- Relationship between temperature values used to compute temperature gradients for spectral correction



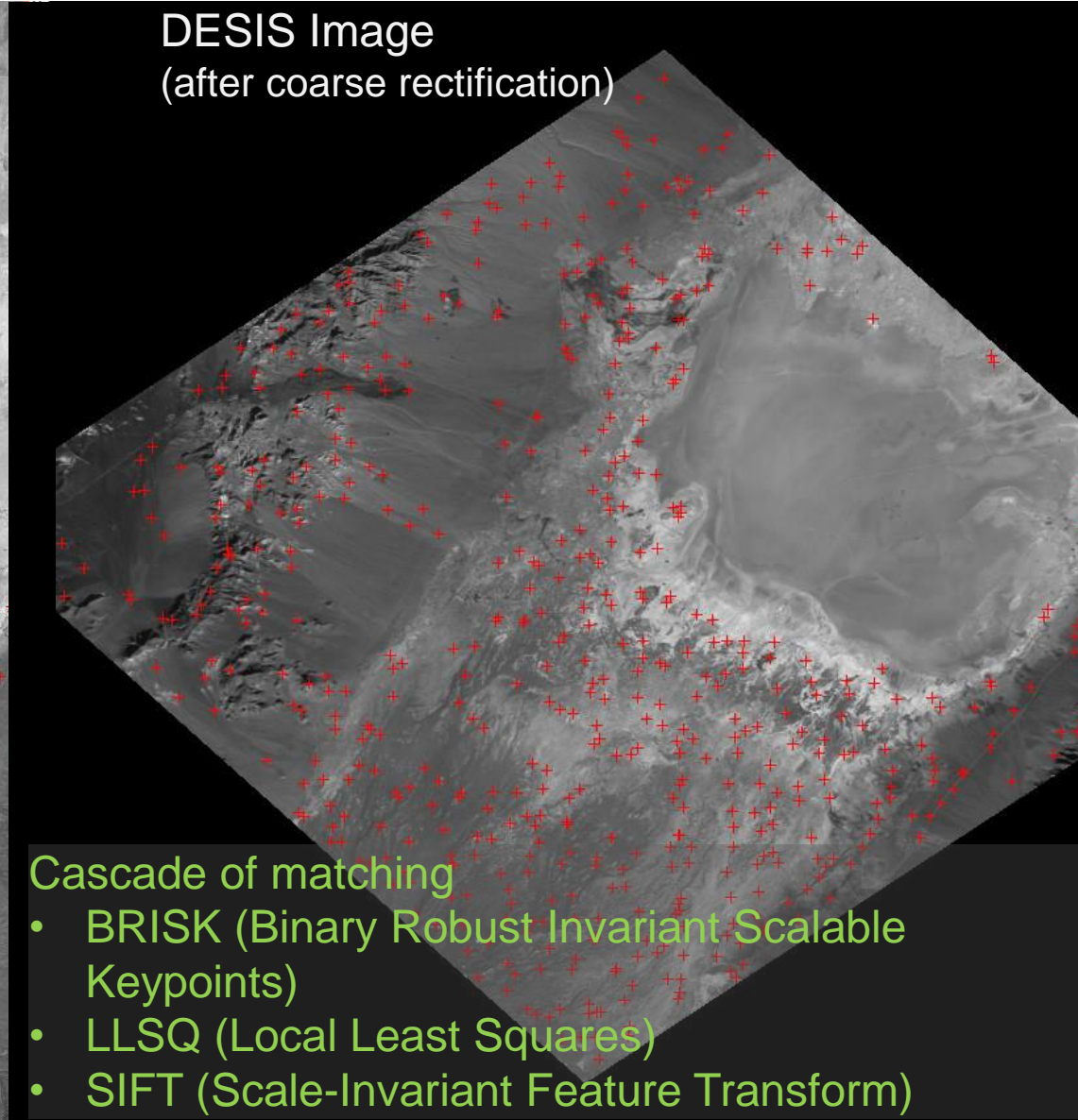
L1C Processing (and Calibration)

Reference Image
(Landsat 8 Pan, ~18 m CE90)



Selected GCP to improve DESIS sensor model (on-the-fly and for boresight calibration)
Others are used for Quality Assessment

DESIIS Image
(after coarse rectification)



Cascade of matching

- BRISK (Binary Robust Invariant Scalable Keypoints)
- LLSQ (Local Least Squares)
- SIFT (Scale-Invariant Feature Transform)

**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°



L1C Processing (and Calibration)

Reference Image
(Landsat 8 Pan, ~18 m CE90)

DESIIS Image
(after coarse rectification)

Accuracy w.r.t. Reference

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**

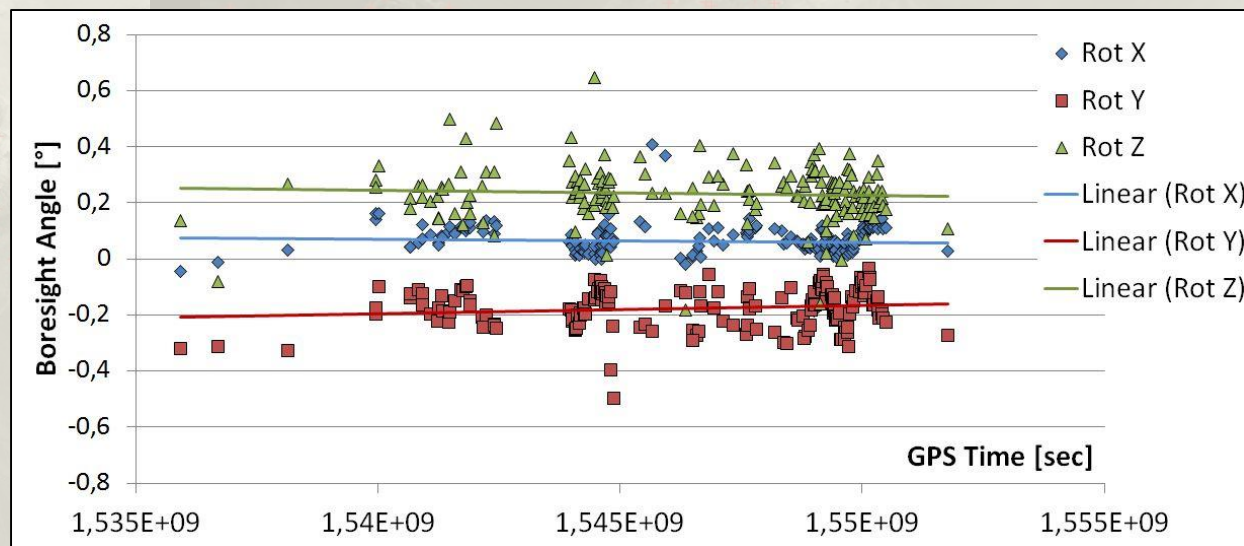
RMSE (north) = **21.4 ± 6.0 m**

In case of no-matching values rely on boresight calibration:

RMSE ~289 m (across); ~496 m (along), but with peak values up to 1 km

Boresight angles are stable over time:

Check parameters “orthoRMSE_x” or “orthoRMSE_y”. When value is -1 it means that no matching could be achieved



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°