
# DESIS Calibration: Status and Results after 4 Years of Operation

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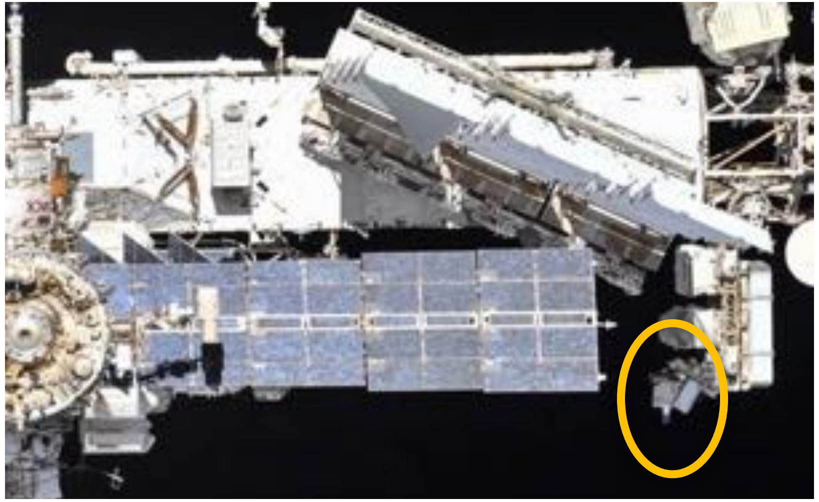
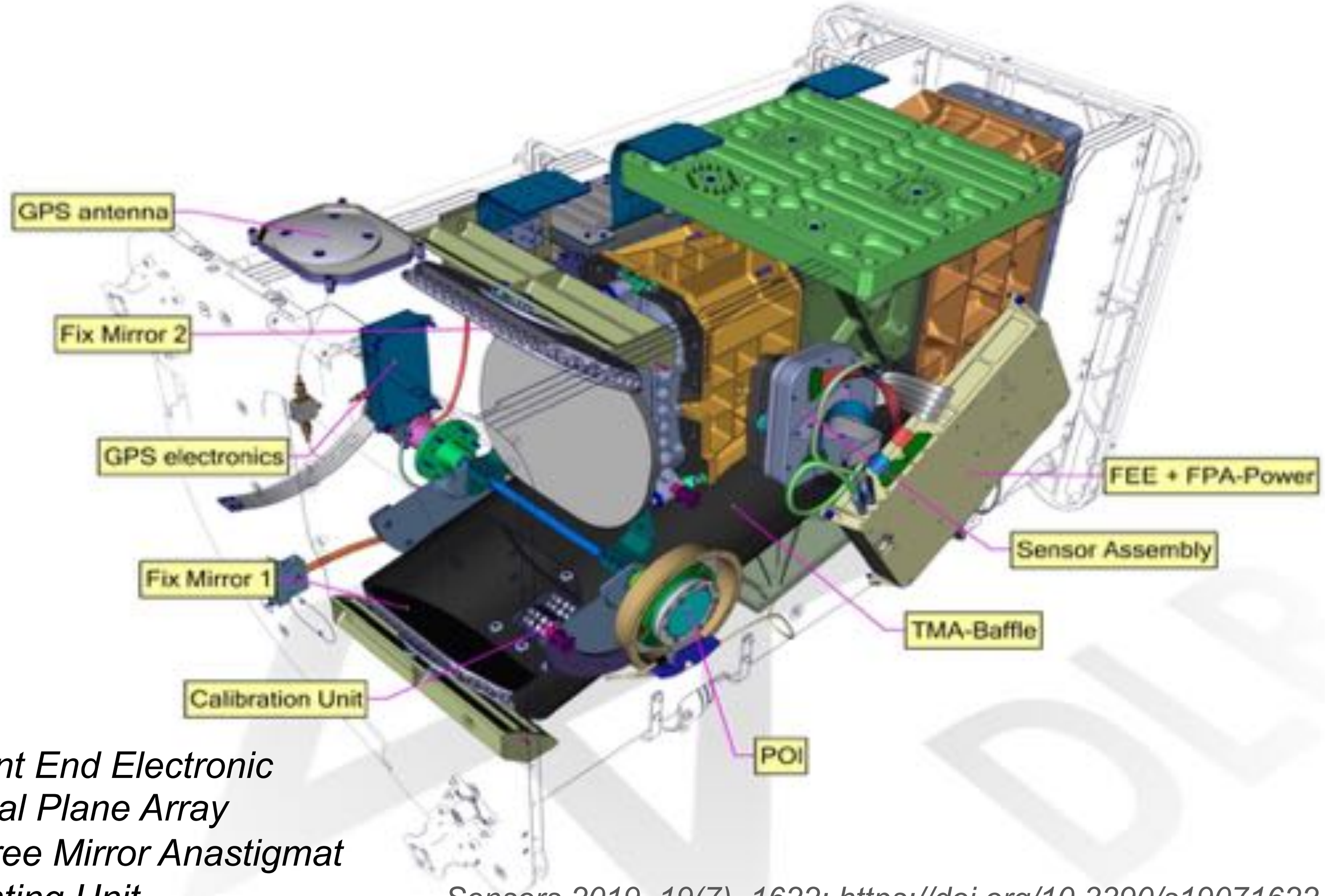
DLR



# DESIS Instrument

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




| 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 |

**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

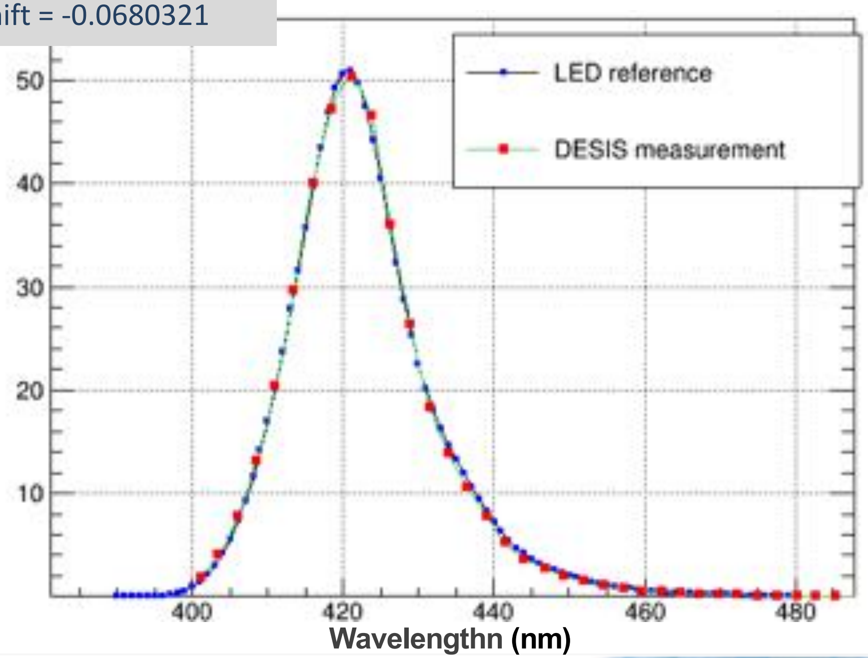
- Equipped with 9 different types of LEDs. It allows to measure signal with different LED types
- 1 Calibration measurement every 1 or 2 weeks for 3 years
- It allows for precise spectral stability measurements:

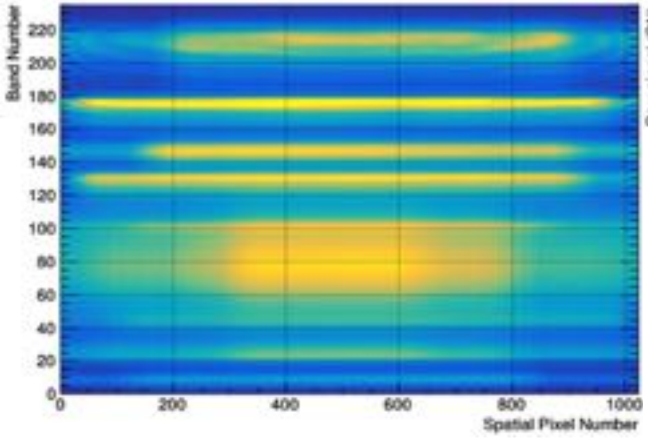
**Fit parameters**

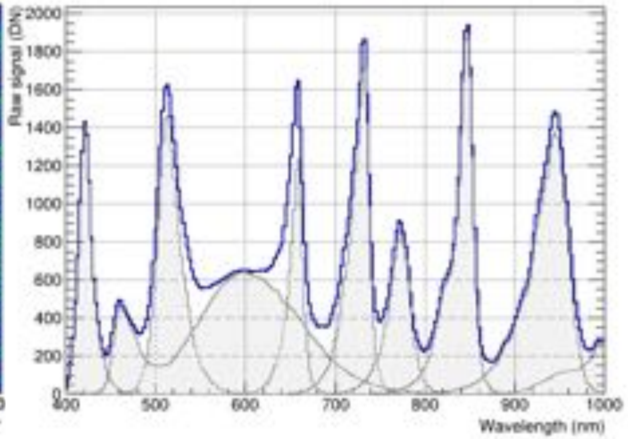
Normalization = 0.996495

Spectral_shift = -1.25566 (nm)

Vertical_shift = -0.0680321

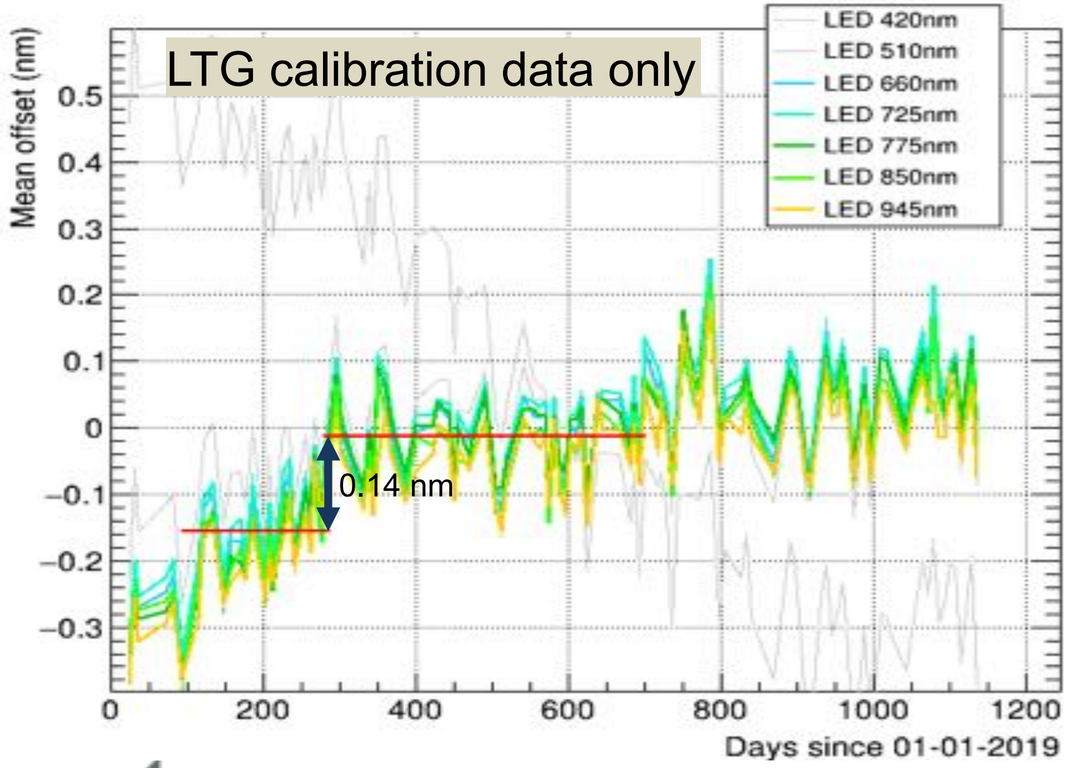


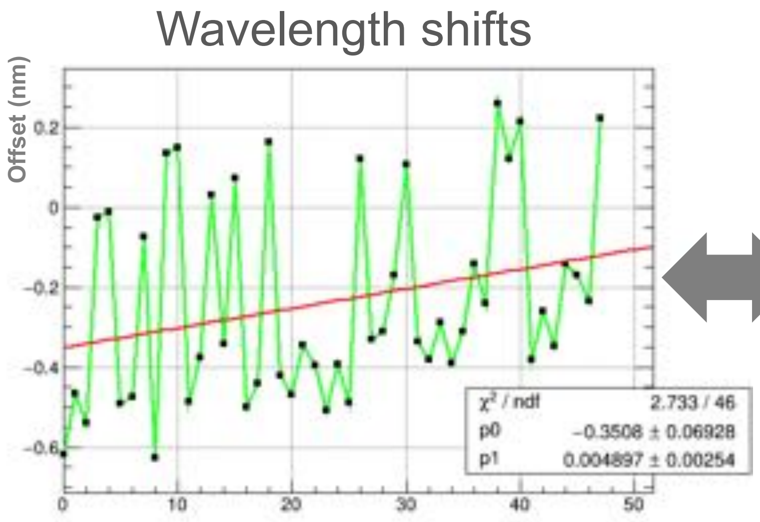



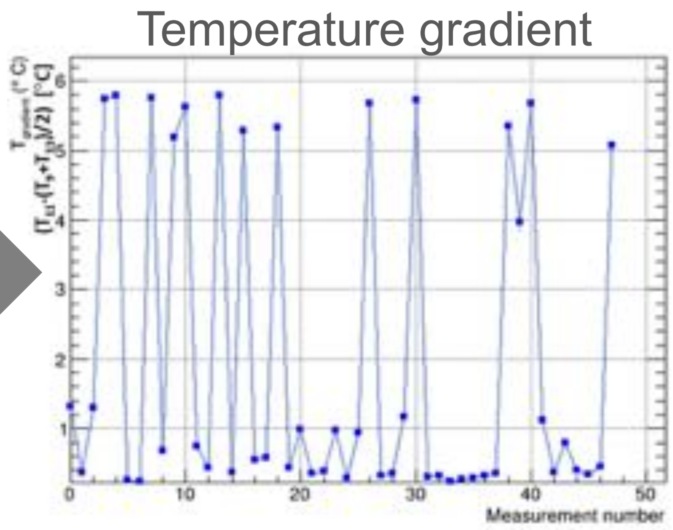



# Spectral Calibration Results

- 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)

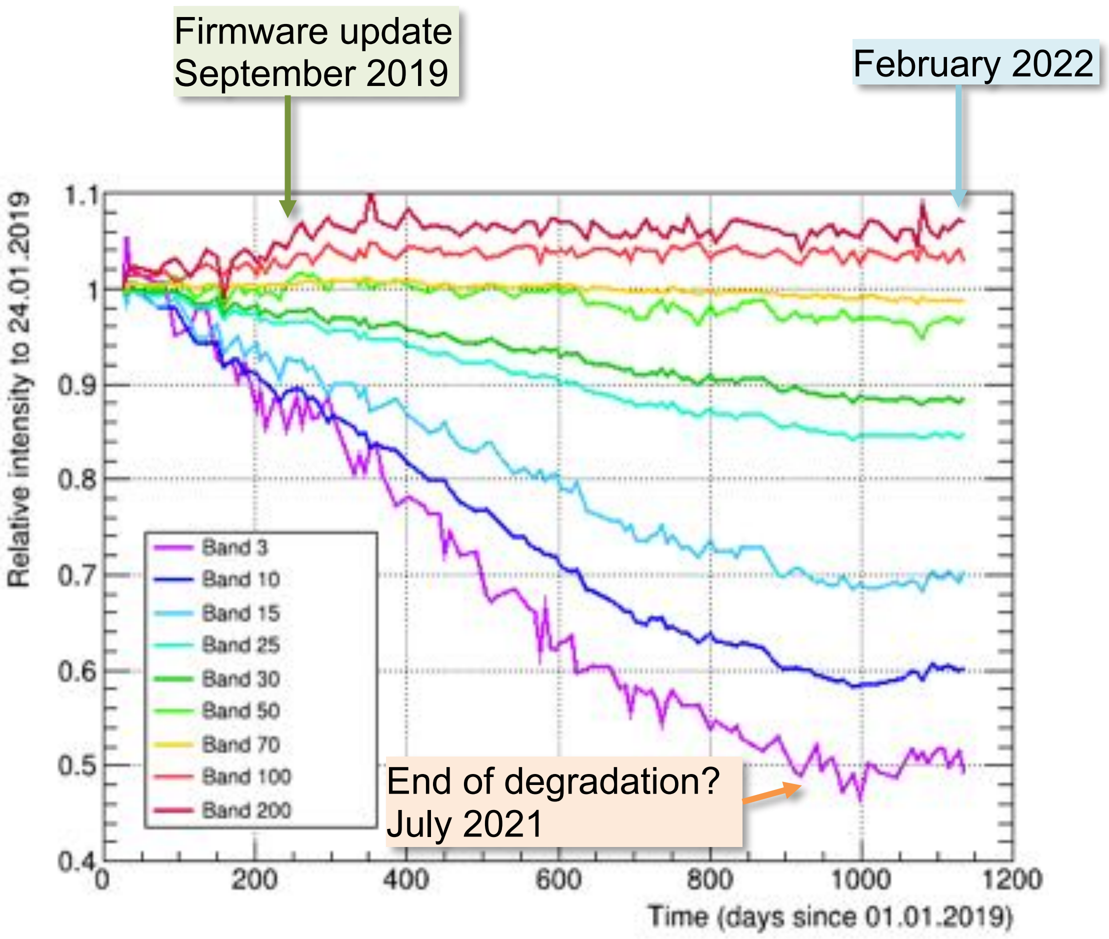



- After stabilization, RMS ~0.1 nm for one of the two states

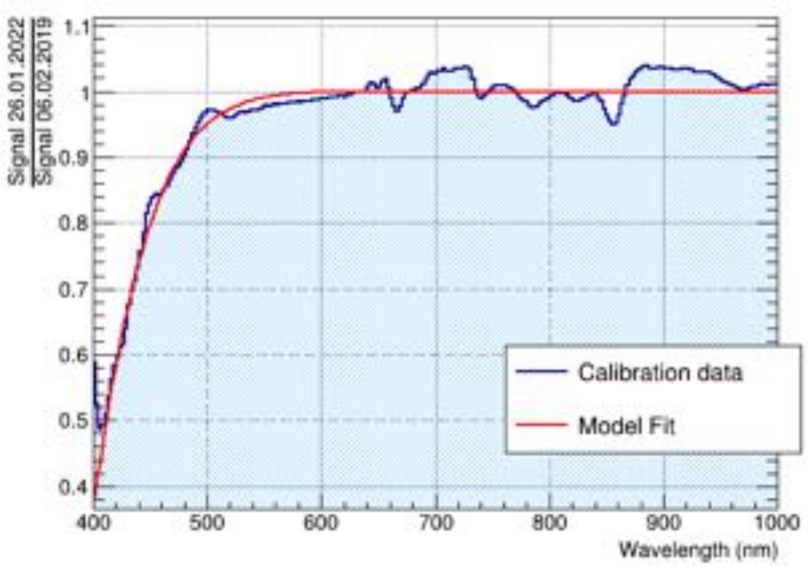
# Calibration Unit Long Term Data




- 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:

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

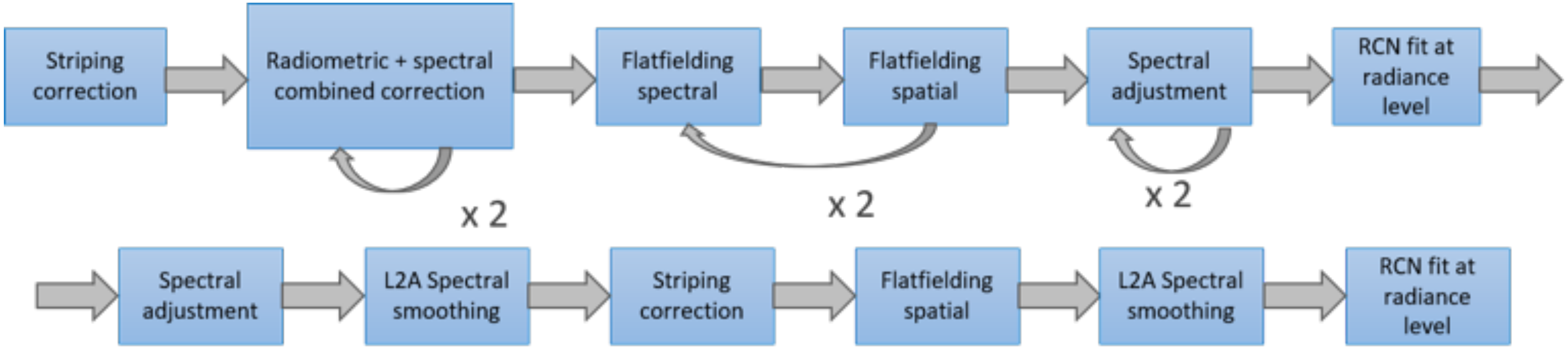
- Where x is wavelength and A, $\mu$, $\sigma$ are 3 parameters fitted from the calibration data
- Small discrepancies in first 2 bands and across-track



# 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:

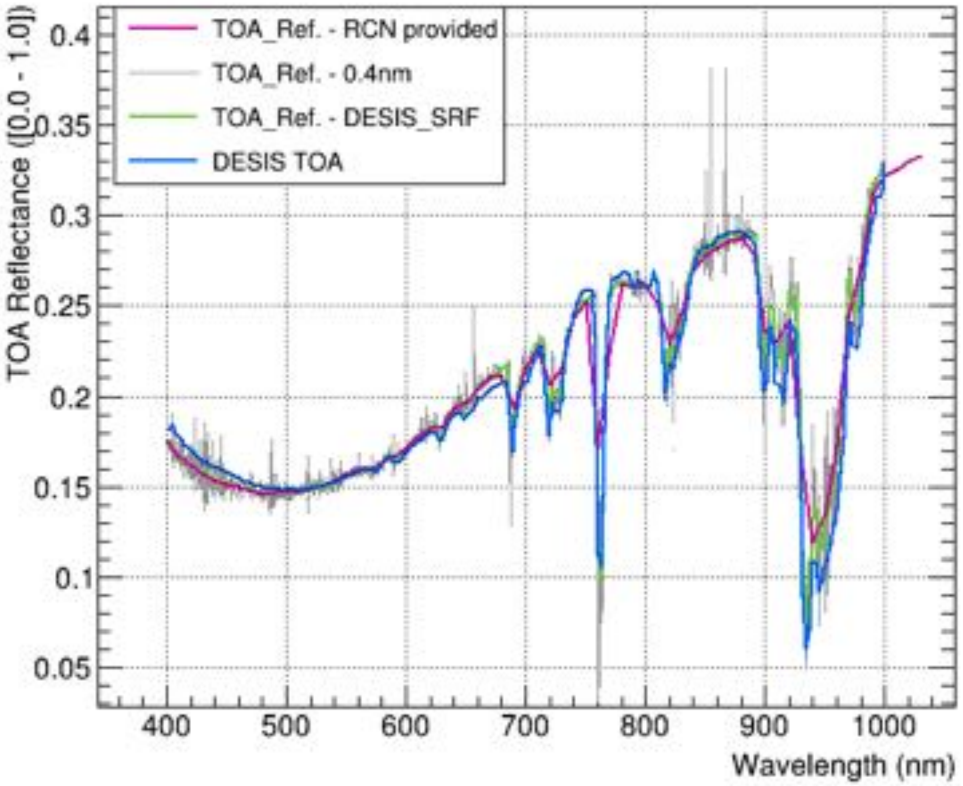



- Original sequence of steps followed on first ground-to-space calibration. Newer calibration updates require simpler sequences

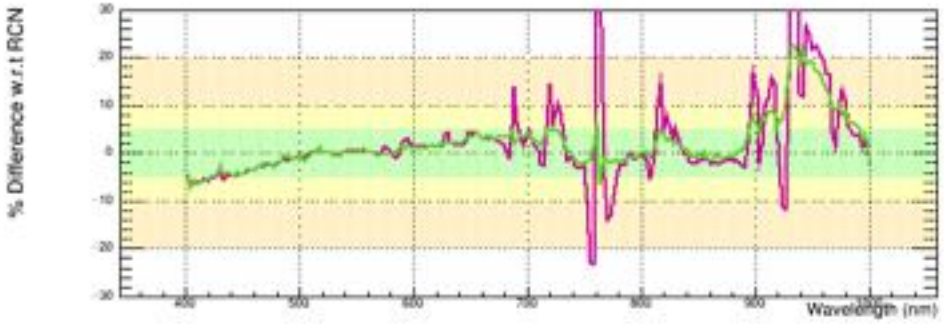
# Absolute radiometric scale

- 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



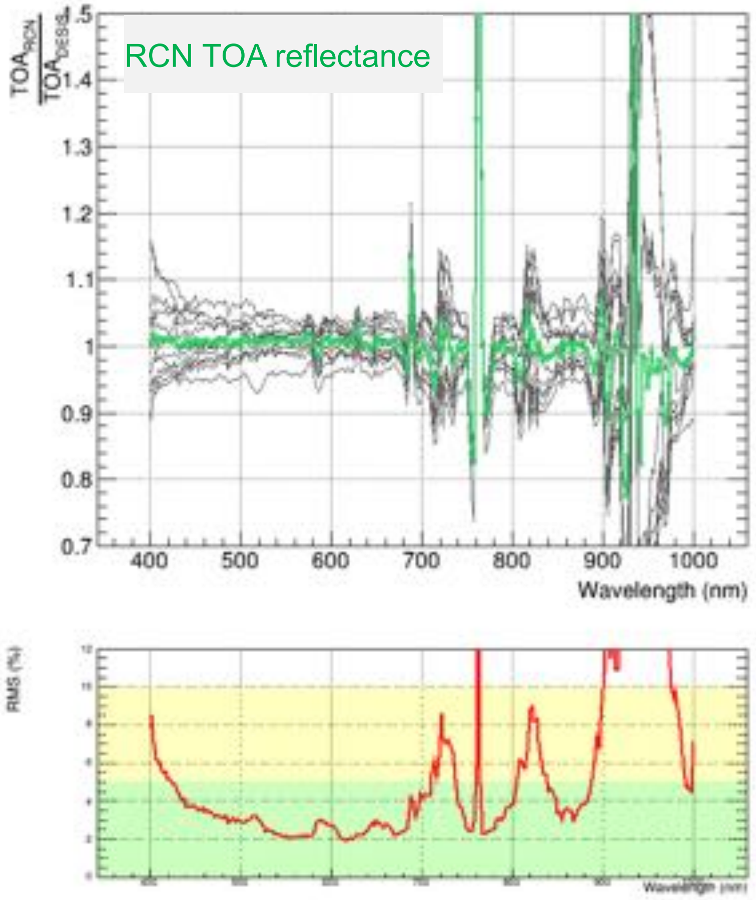

- Compute deviations of DESIS w.r.t. both references:

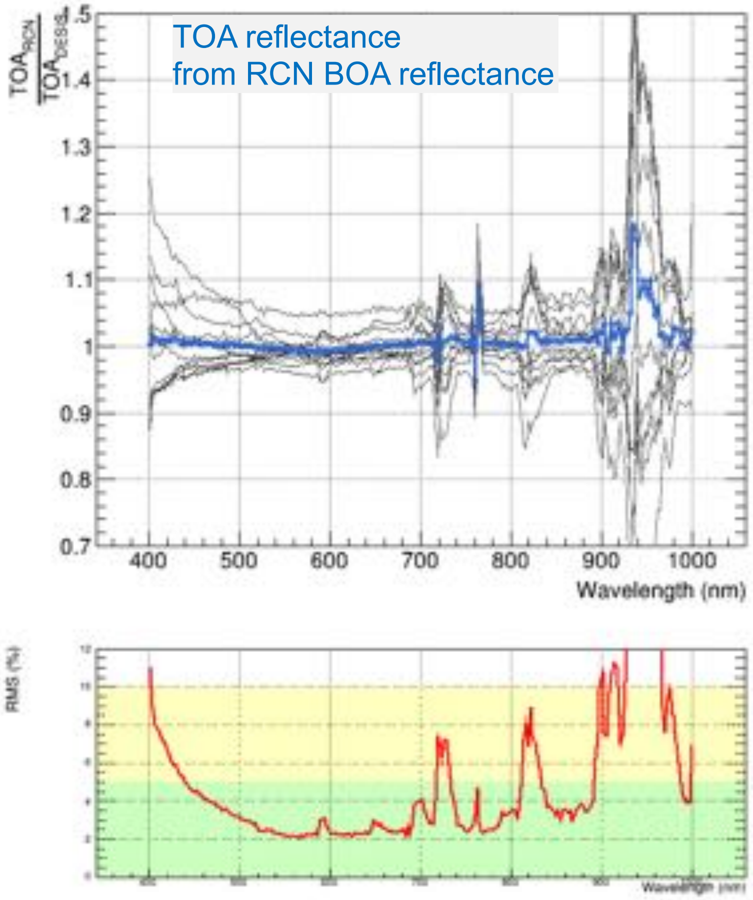



- Compute radiometric coefficient updates based on observed deviations

# 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

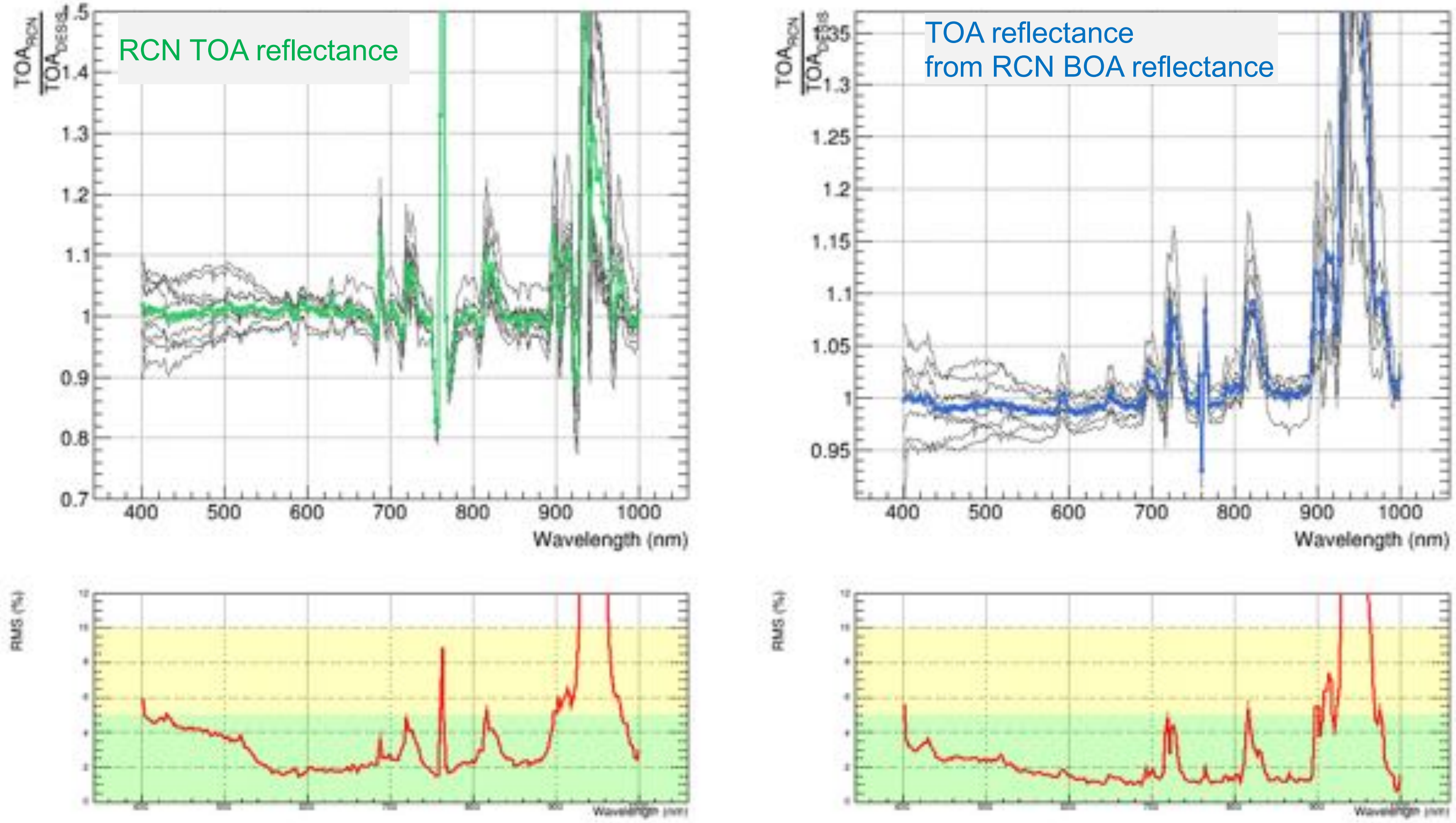



- Similar results as seen in other periods
- After calibration bias is corrected, but RMS below 500 nm is significant larger than above 500 nm

# 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)

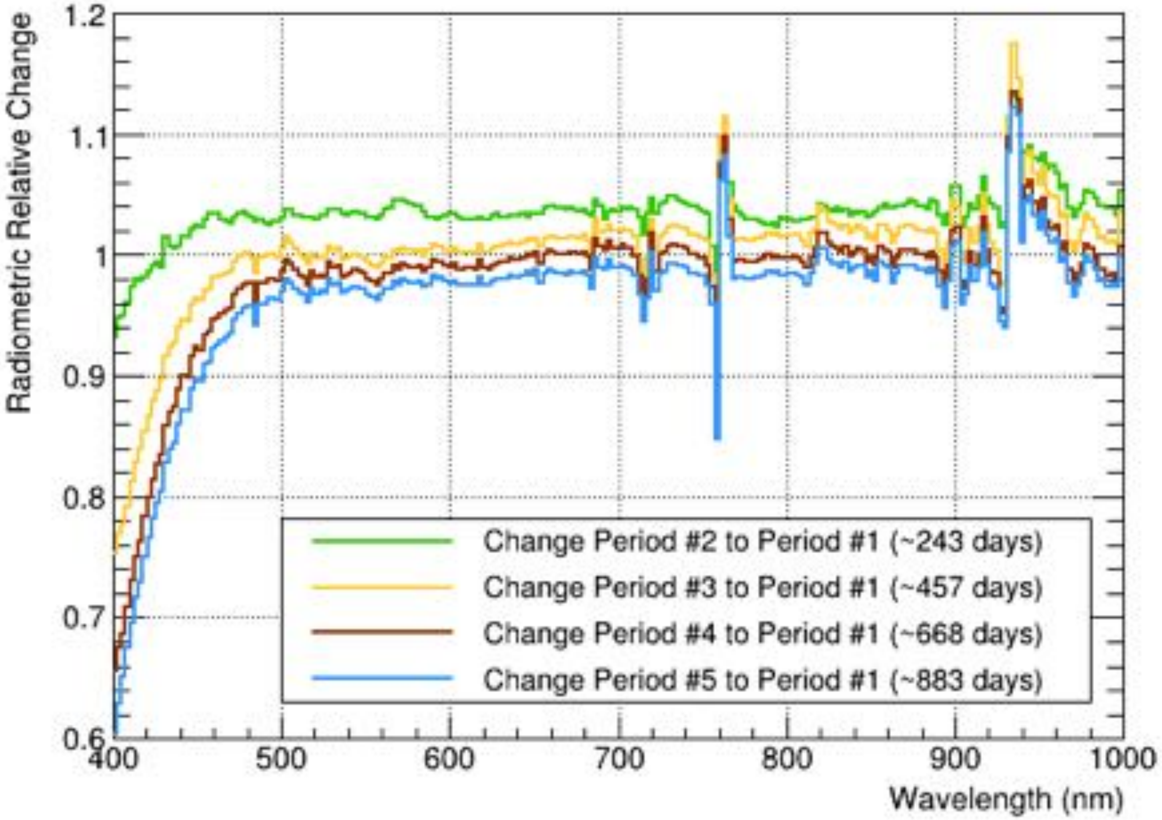
# Comparison with Radiometric update from Vicarious Calibration

- Unfortunately model does not seem to match well the data 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%



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- Unfortunately model does not seem to match well the data obtain in Vicarious calibration

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- Main similarity with LED data:
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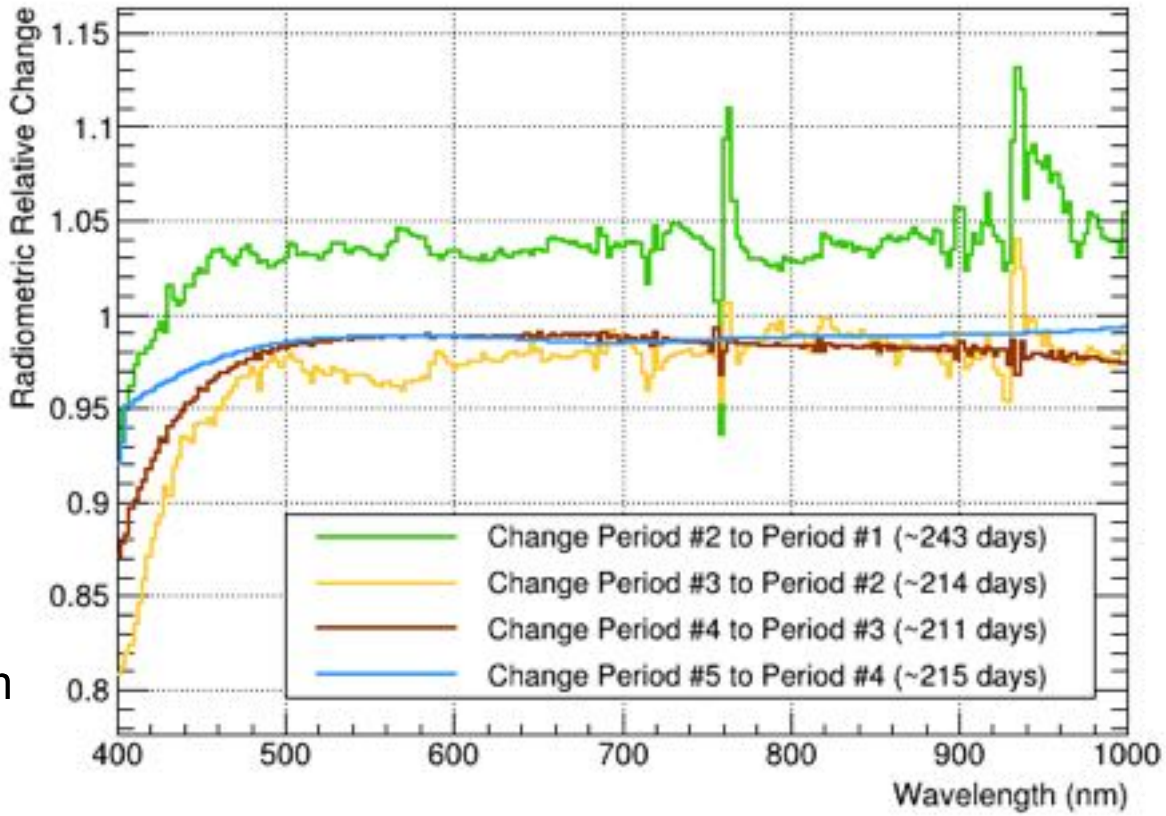
- Main differences are:
  - CAL data shows a maximum decrease down to 40% from the initial values, while the Vicarious data shows a maximum decrease down to 60%
  - CAL data does not reproduce decrease of ~2% between periods (3.4%/year) above 500 nm
  - CAL decrease below 500 nm is constant until July 2021, but vicarious results show different intensities for different periods



# Summary & Outlook

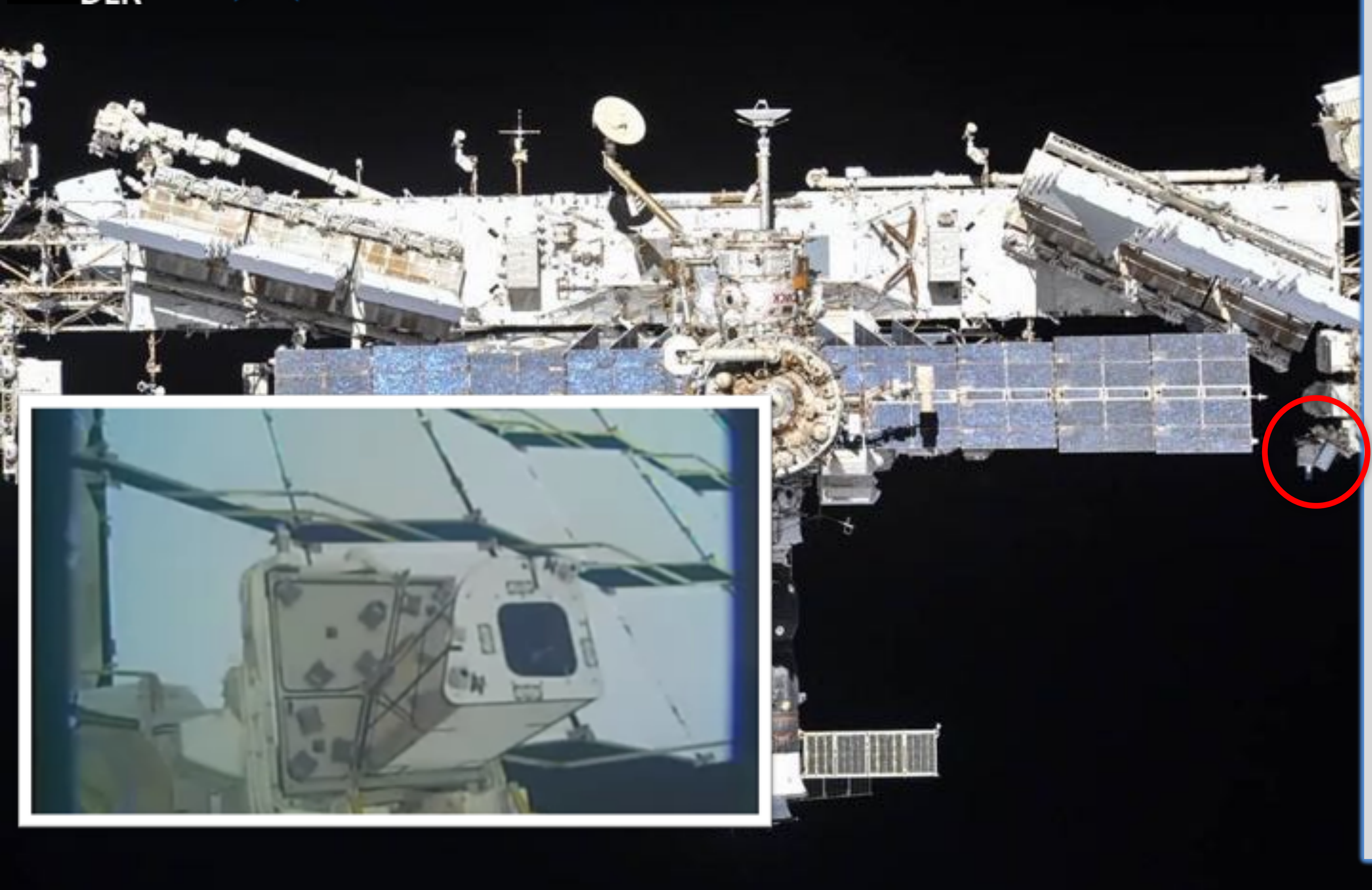
- Vicarious calibration is the baseline calibration method of the DESIS imaging spectrometer
- Fast change of radiometric performance below 500 nm in DESIS is challenging for this calibration method (~20% degradation / year)
- Above 500 nm the current calibration approach guarantees that difference between periods is ≤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 !

# Extra


DLR

# DESIS, MUSES and ISS



**Teledyne** Brown Engineering (TBE, USA) and **DLR** have partnered to build and operate the DLR Earth Sensing Imaging Spectrometer (**DESIS**) 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

**DESIS**, 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

# DESIS – Timeline and Results

**2014 / 2015**

MUSES / DESIS Start Mission

**7. June 2017**

MUSES installation on ISS

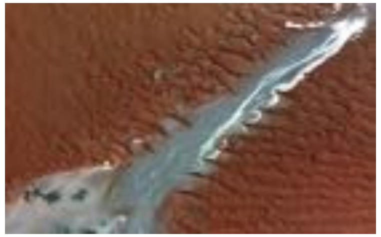
**29. June 2018**

DESIS 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

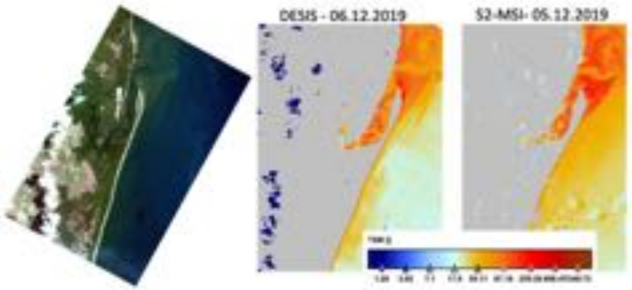
Since 2018 **~130.400** scenes processed and archived

~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

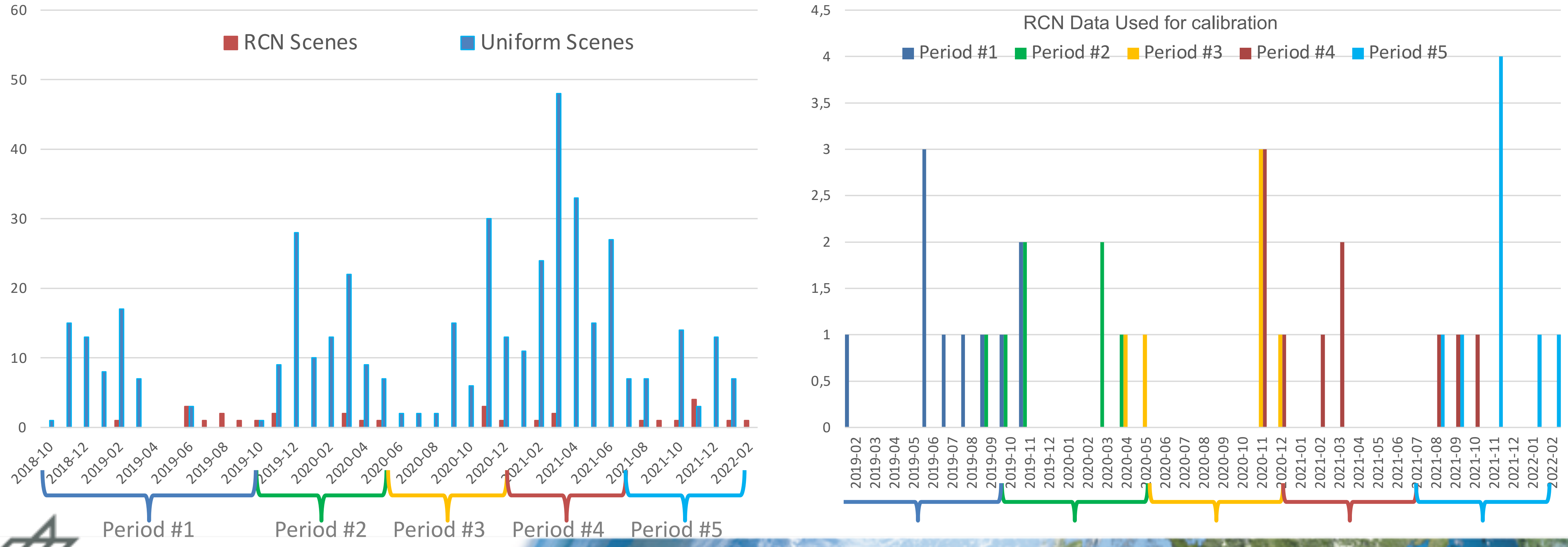

Obtain absolute radiance scale

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

# Vicarious calibration data

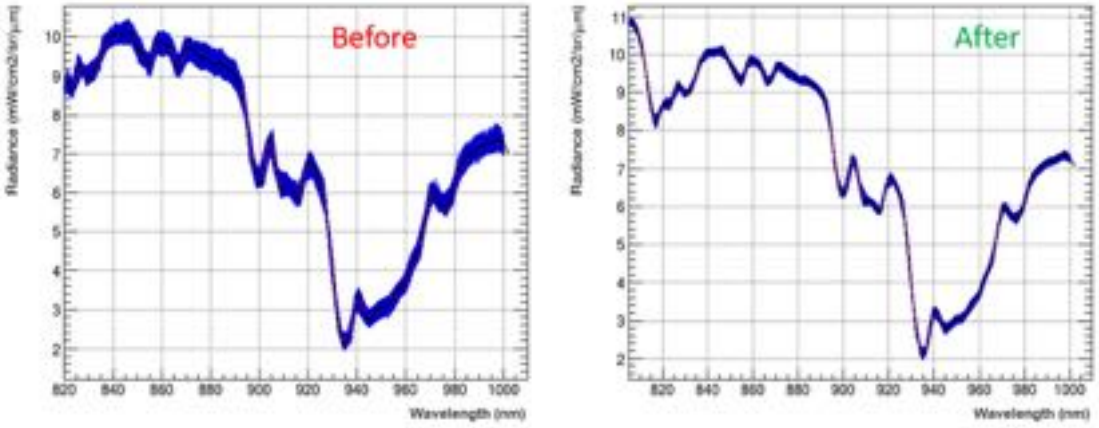
*“Vicarious calibration of the DESIS imaging spectrometer“, E. Carmona et al., IGARSS2021*

- 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

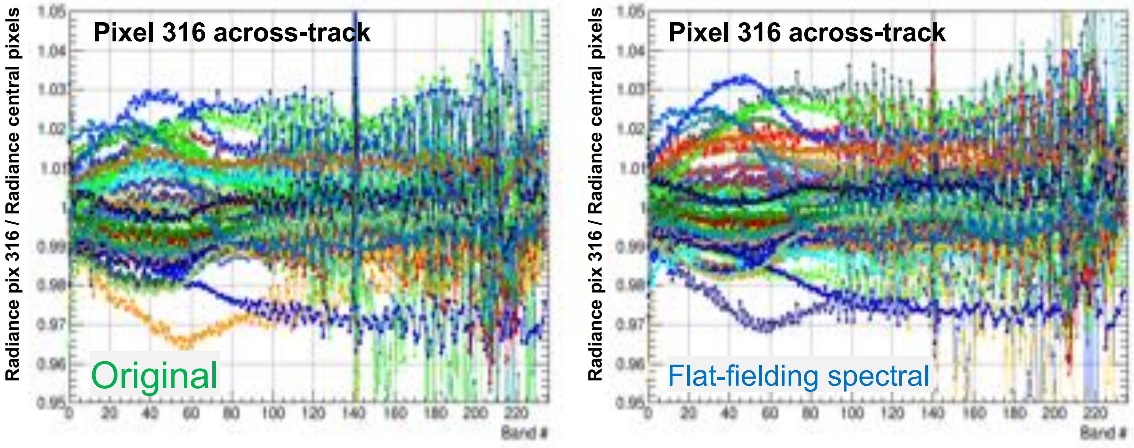


# Uniform Scenes Processing Steps

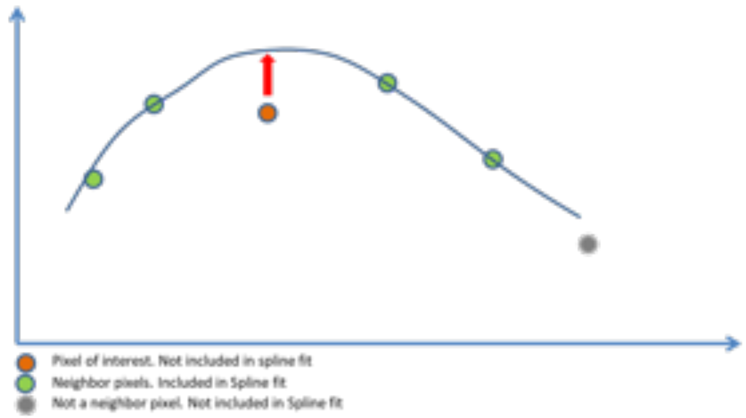
- Rad./Spc. Correction (before smile corr.)



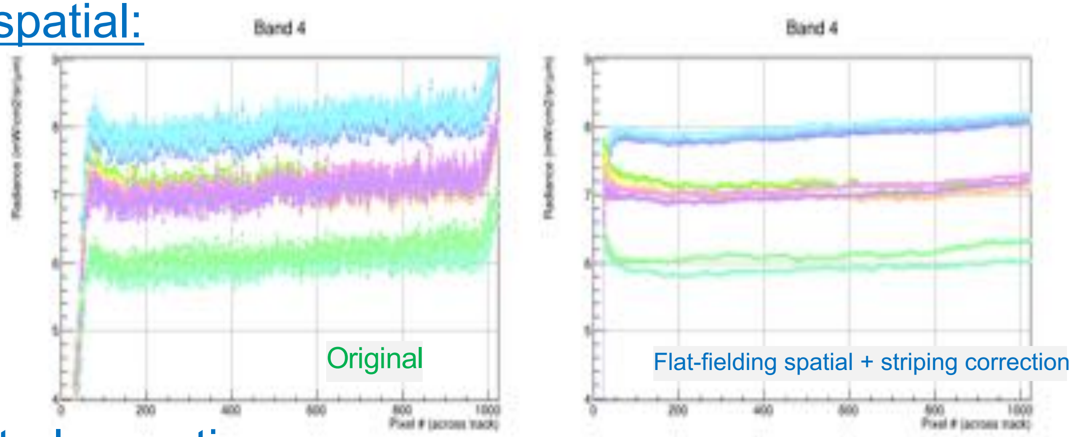

- Flatfielding spectral:



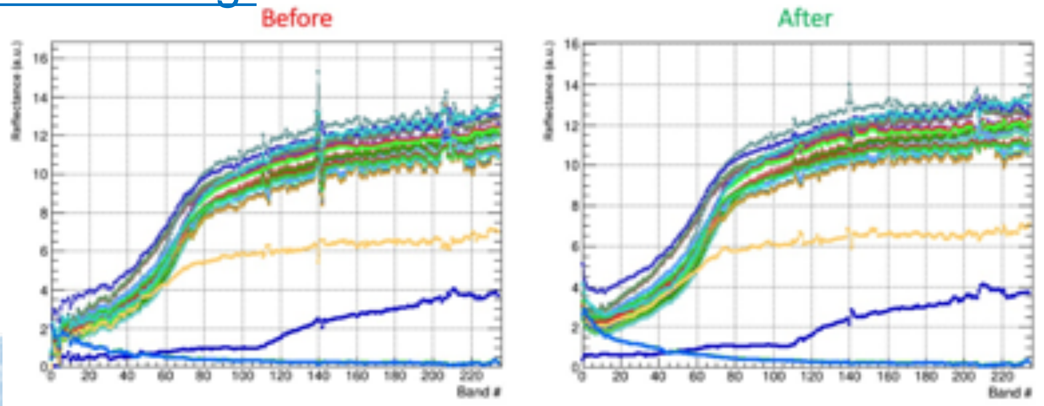

- Striping correction:




- Flatfielding spatial:

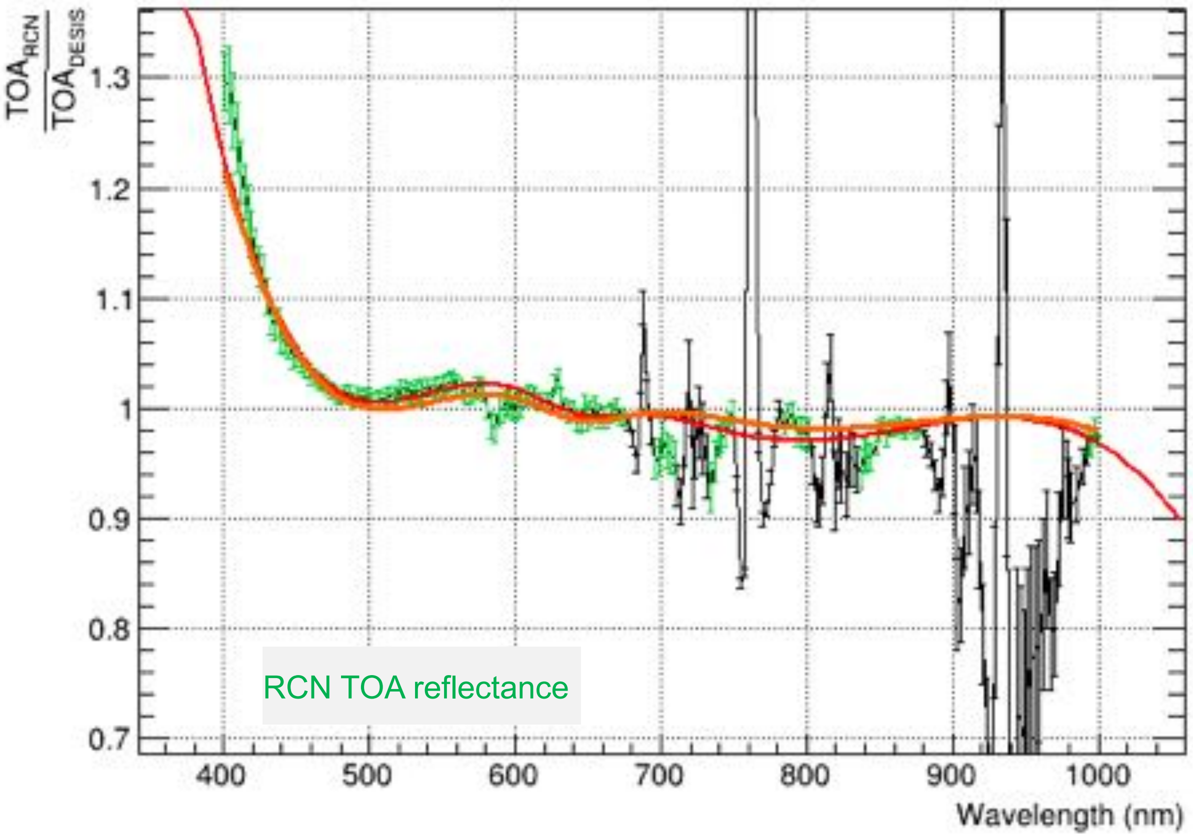


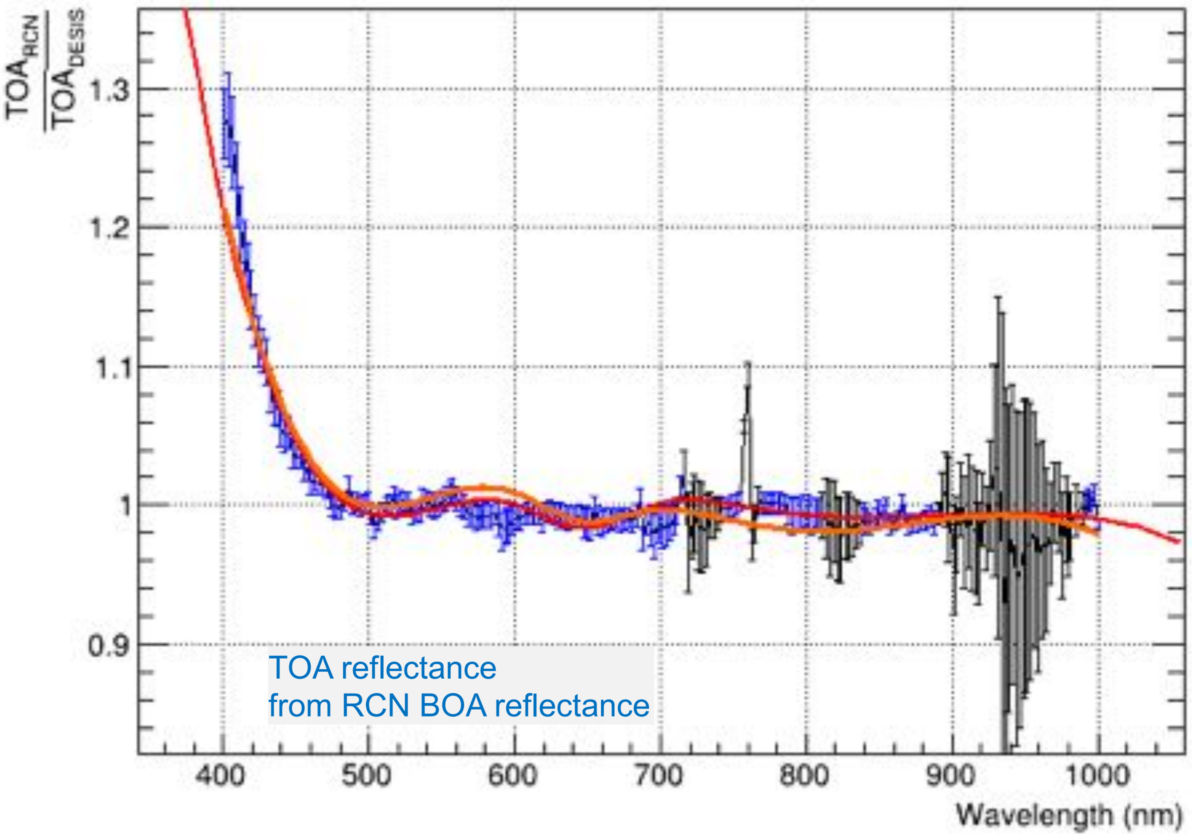

- L2A spectral smooting:



# Absolute radiometric scale

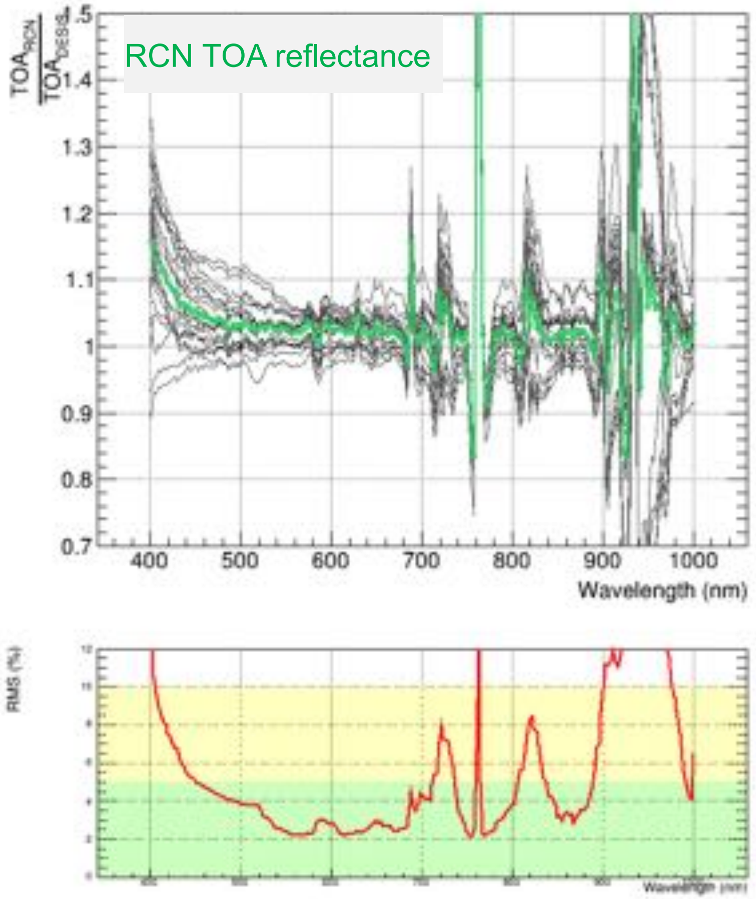
- Use selected "calibration" scenes from RCN and perform a fit to mean value (2 times in steps sequence) in order to obtain a per-band factor
- Use Average from 2 TOA reference data: RadCalNet provided (10 nm), DESIS calculated (DESIS resolution)

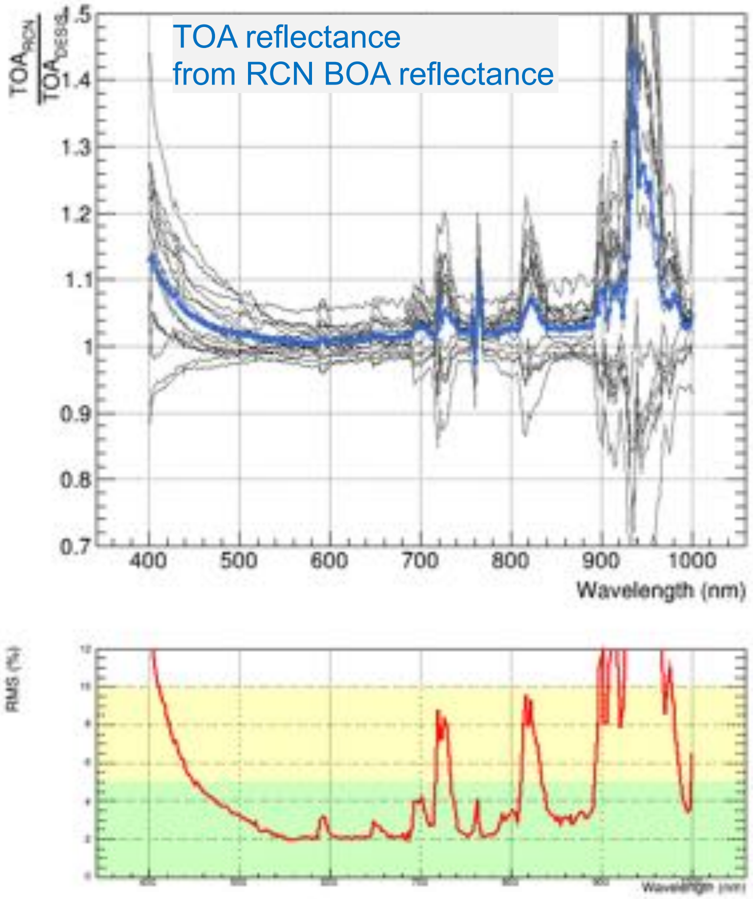


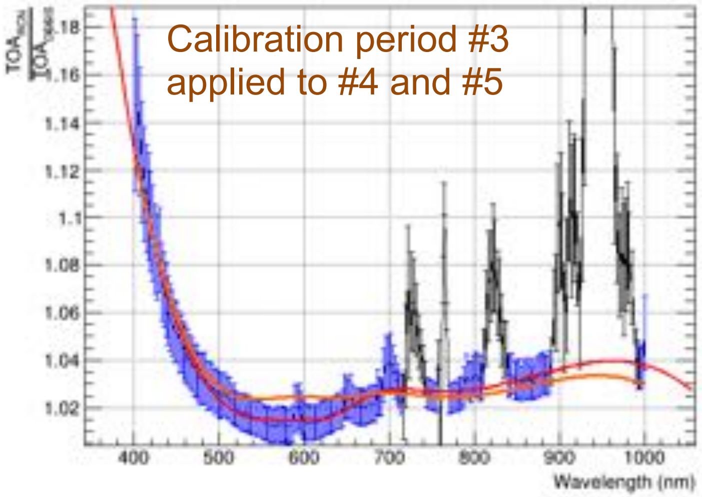
# Latest Vicarious calibration data

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



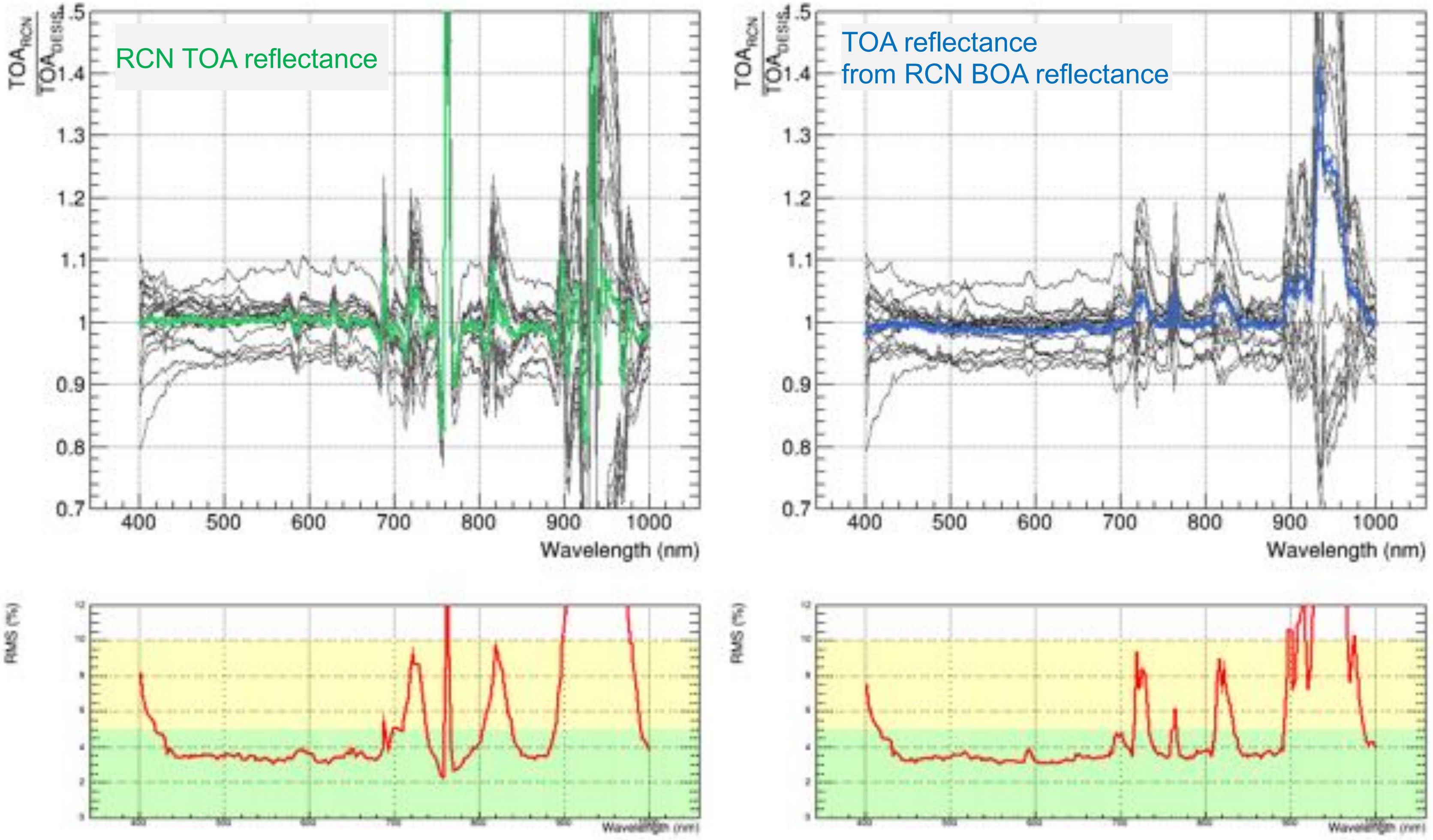




- Large variation of calibration below 500 nm as seem in other periods
- Magnitude is smaller



# 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



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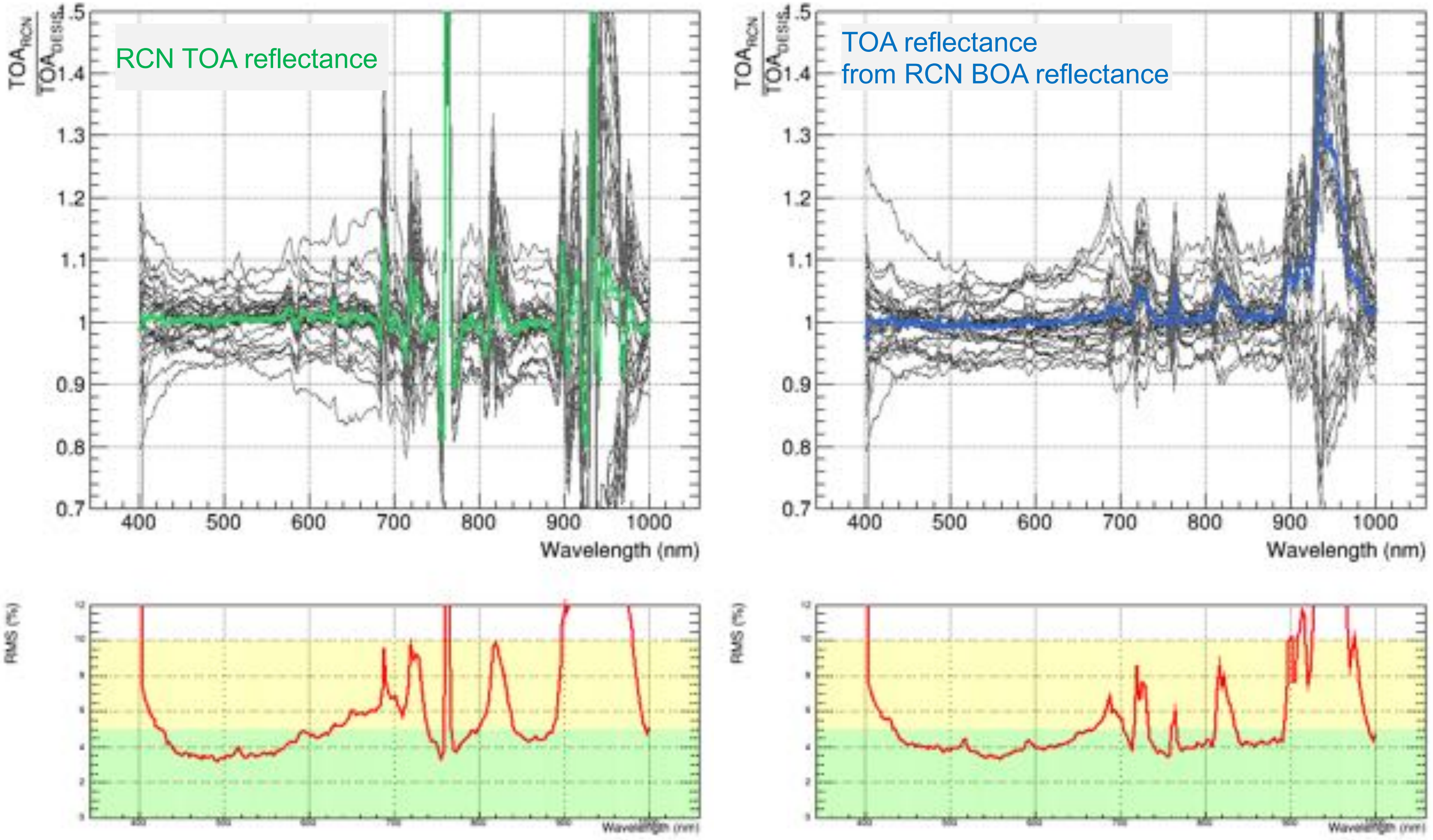
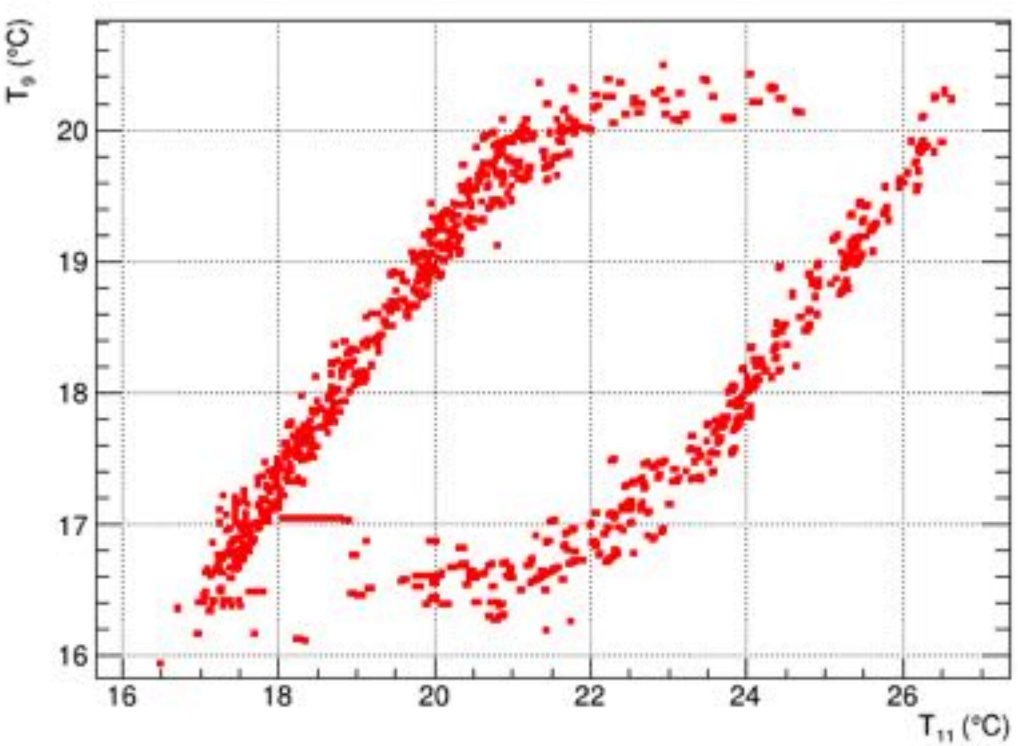
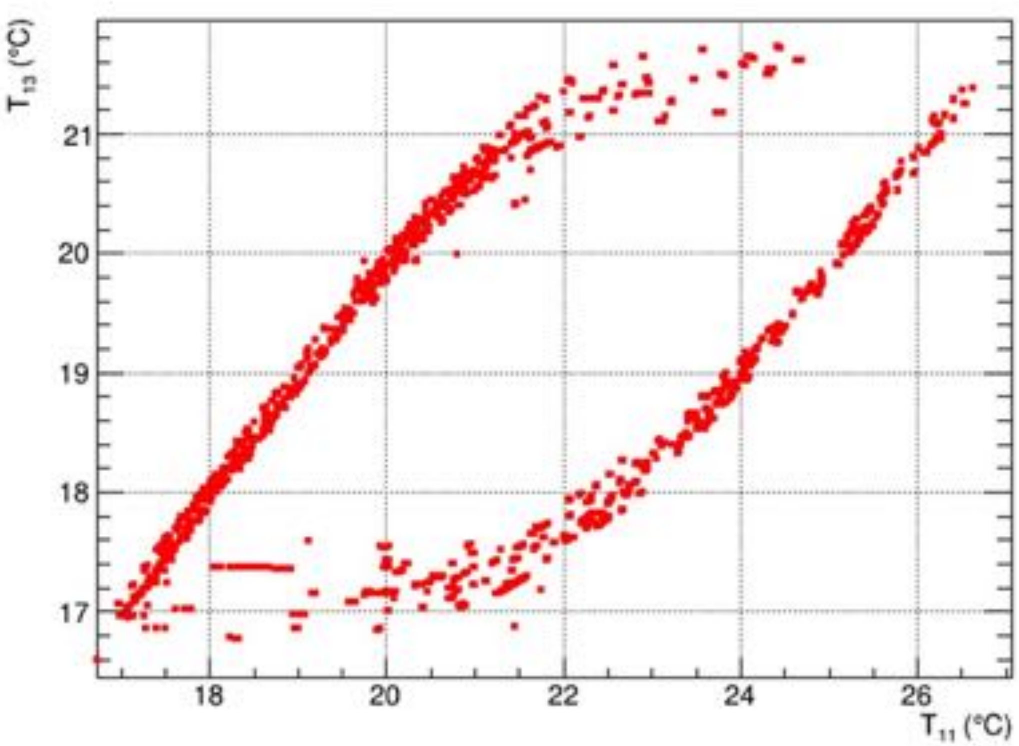
  - good atmospheric conditions
  - below 50 degrees Sun Zenith Angle
- These summary plots show **all** RCN scenes (**30** scenes)



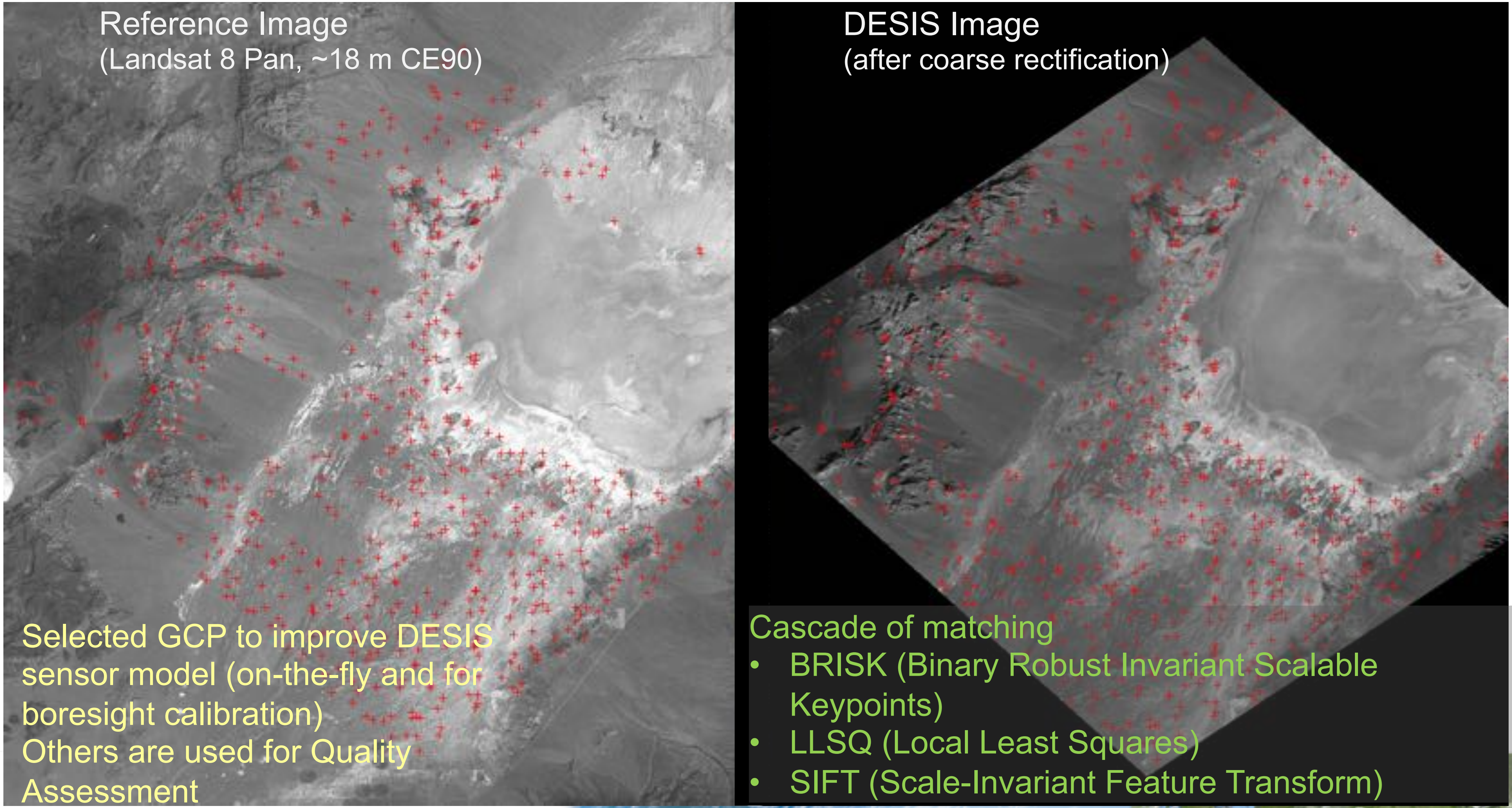
# Temperature gradients

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



# L1C Processing (and Calibration)




***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)

DESIS Image
(after coarse rectification)

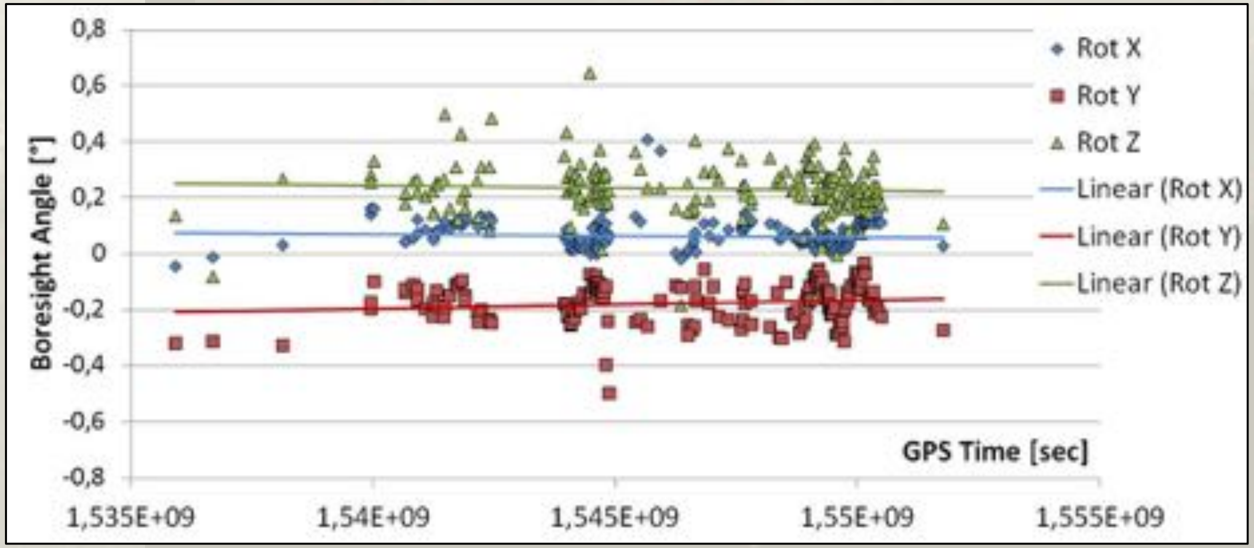
Accuracy w.r.t. Reference
177 scenes
#GCP: average 210 per scene
#Control Points: average 969 per scene

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*
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