DESIS: Overview and Calibration

Emiliano Carmona for the DESIS Ground Segment Team

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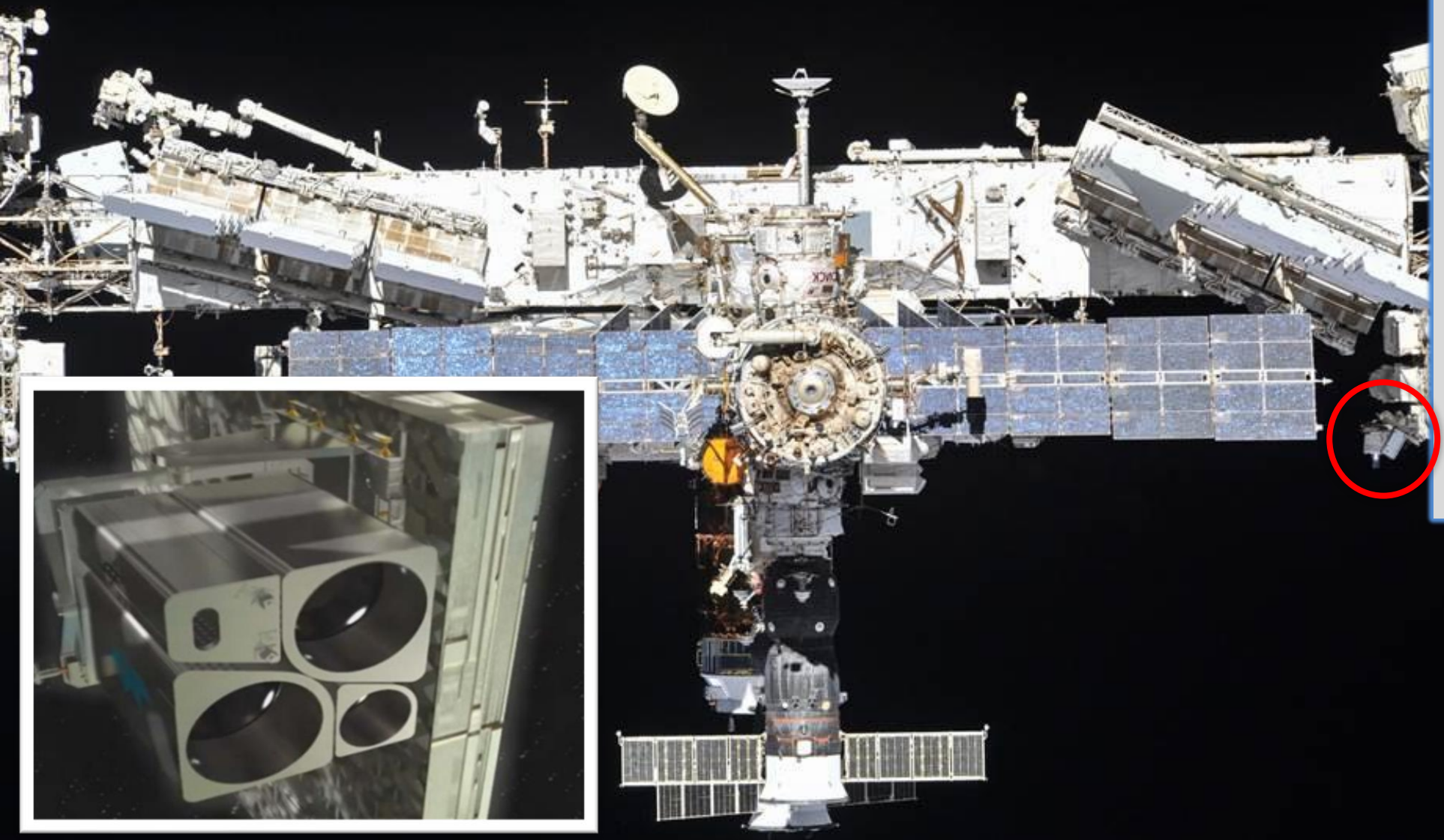
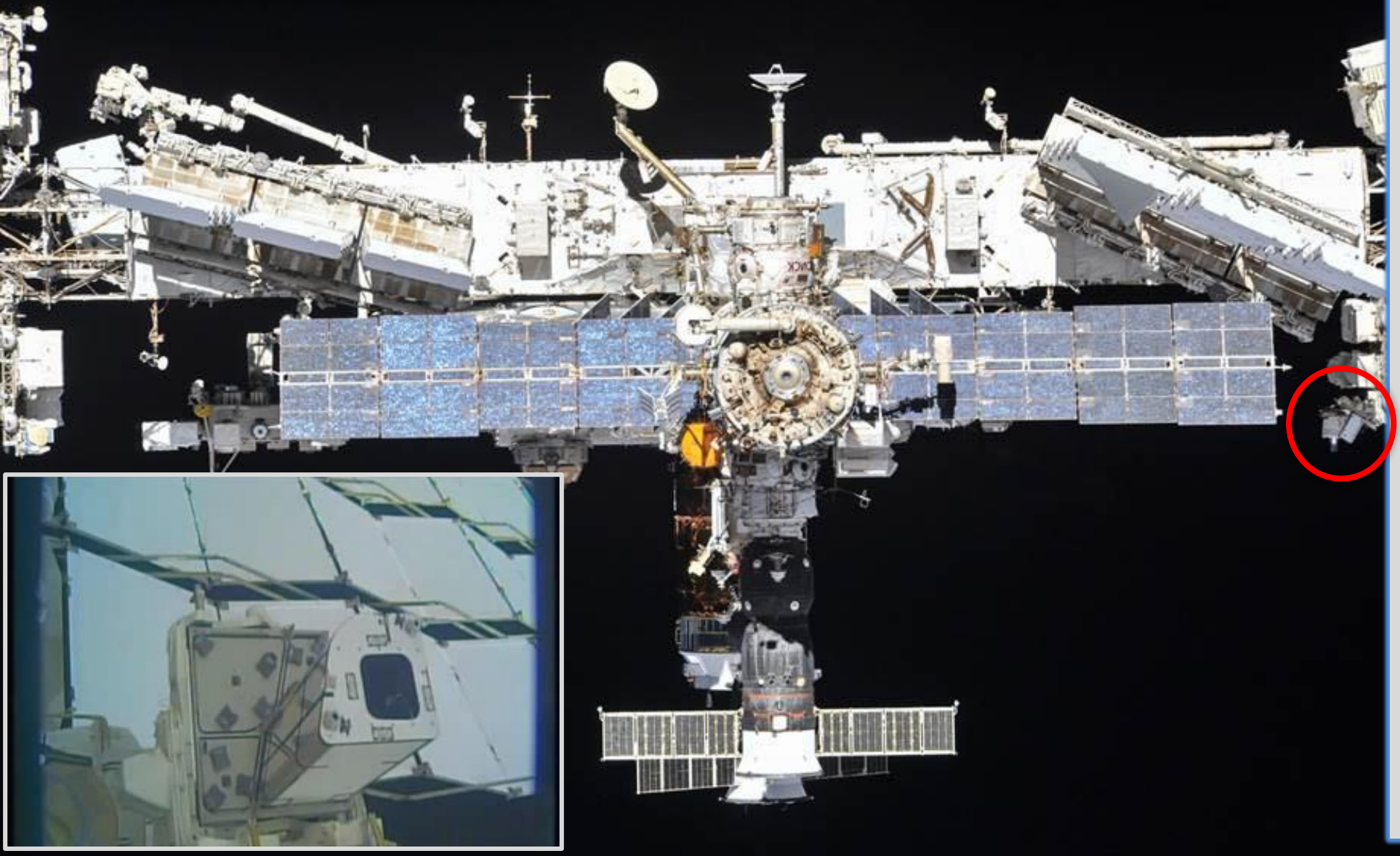
DESIS, MUSES and ISS



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, MUSES and ISS



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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

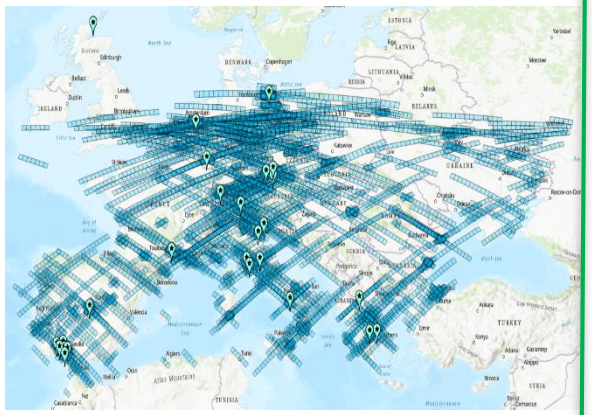
29.09.–01.10.2021

1st DESIS User Workshop (online)

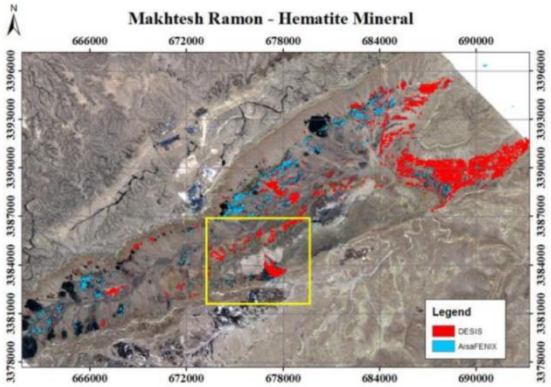
Design, Implementation, Test | Commissioning | Operations

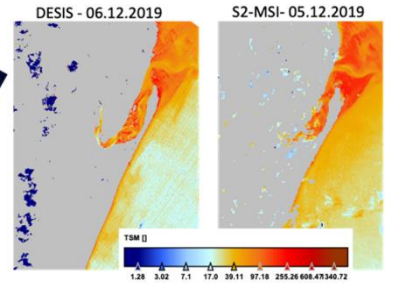
Since 2018 **~130.400** scenes processed and archived

~23.000 scenes in USA



~8.600 scenes in Europe





DLR

DESIS Data Products

Archive

L1A Raw Data
(prepared for selection & ordering & processing)

Analysis Ready Data

L1B Top-Of-Atmosphere (TOA) Radiance

L1C Geocoded & Orthorectified

L2A Bottom-of-Atmosphere (BOA) Reflectance

Data Tasking and Access to Data Archive for Scientific* purposes

Tasking new DESIS data

A proposal is requested to understand the basic research question and the amount of data that will be ordered

Proposal Process

1. Proposal evaluation
2. **TBE TCloud portal**: Task L1A data
3. Get notification from Tcloud
4. Order your data via **DLR EOWEB Portal**
5. Download data (L1B, L1C, L2A) via EOWEB Portal

Order archived data

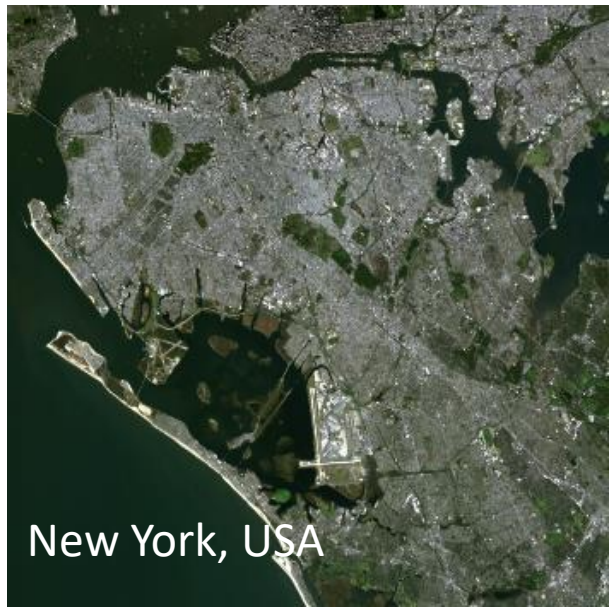
Can be ordered without restrictions

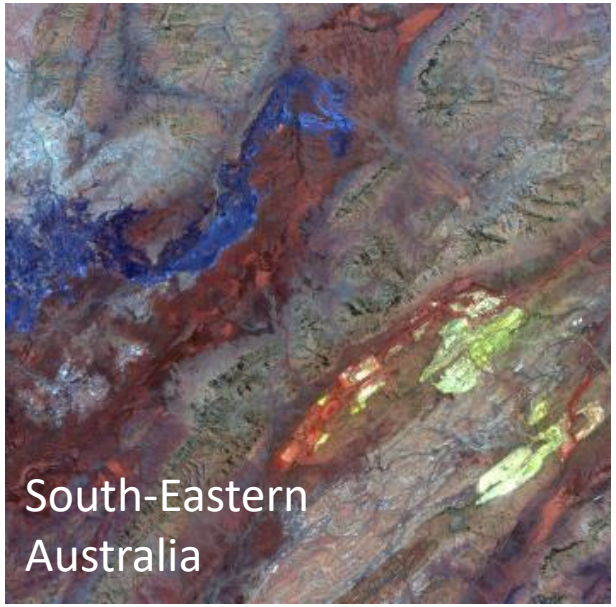
Only DESIS EOWEB Portal account required

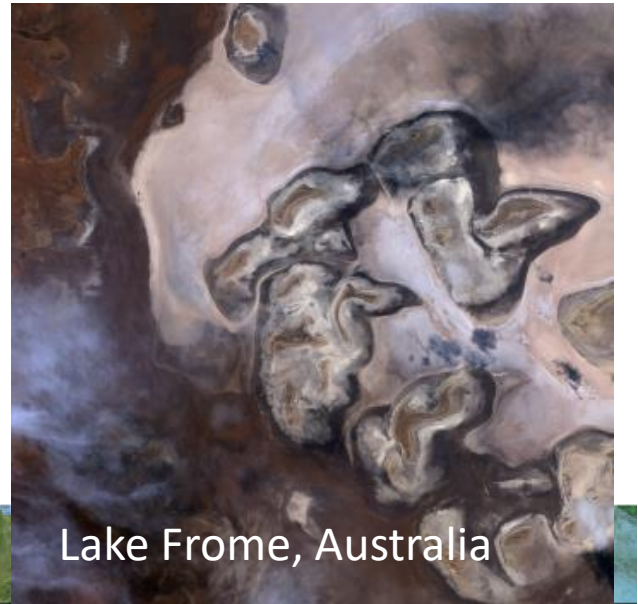
4. Order your data via **DLR EOWEB Portal**
5. Download data (L1B, L1C, L2A) via EOWEB Portal

***For Non-scientific activities contact Teledyne Brown Engineering for data access**

DESIS Image Impressions *(see official DESIS website)*

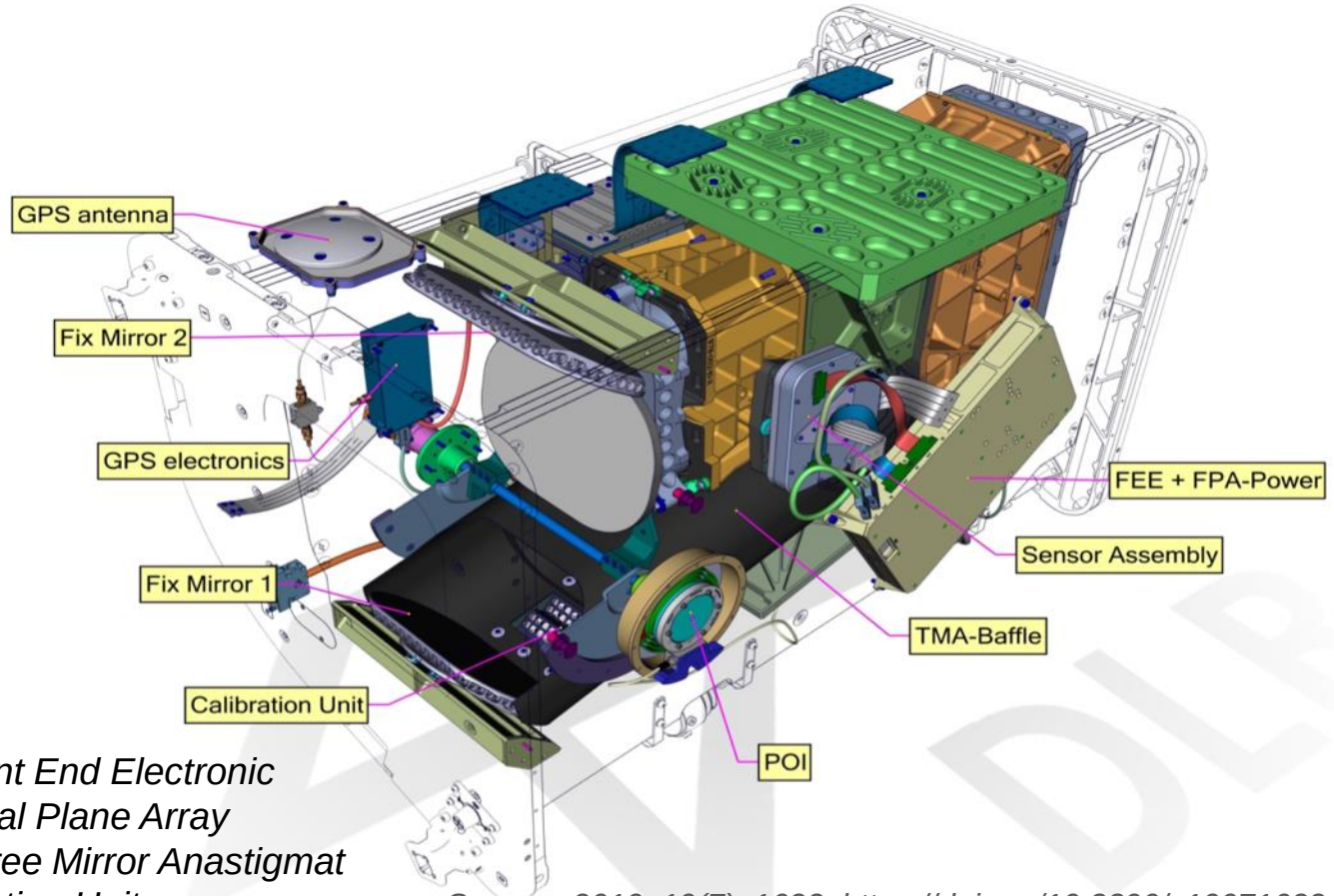






DESIS Instrument

- 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

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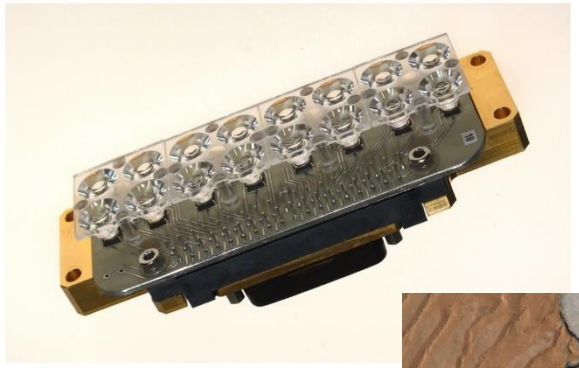
DESIS Calibration Concept

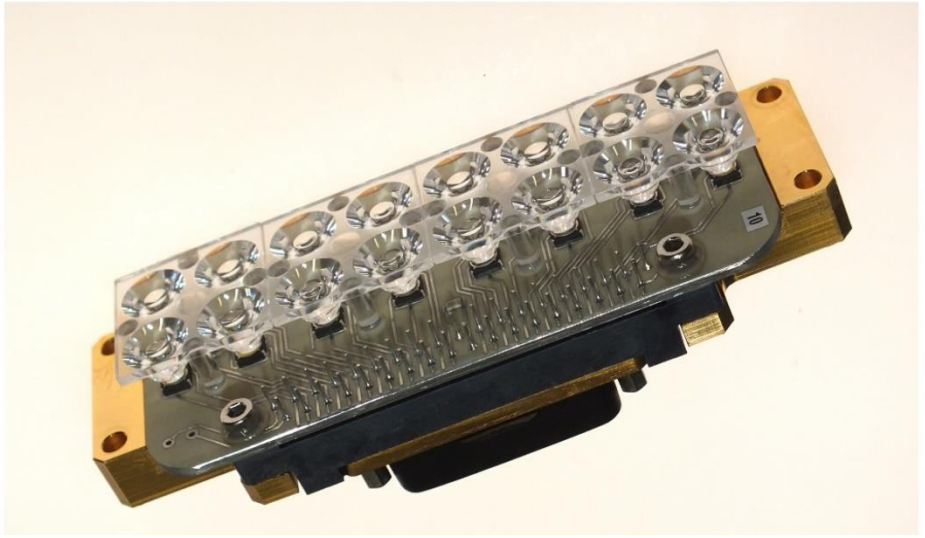
- Based on laboratory pre-launch calibration with updates over time for:
  - **Central wavelengths**: from on-board calibration unit + vicarious calibration
  - **Radiometric parameters**: from vicarious calibration
  - **Geometric parameters** (Bore-sight angles, POI offset): from vicarious calibration



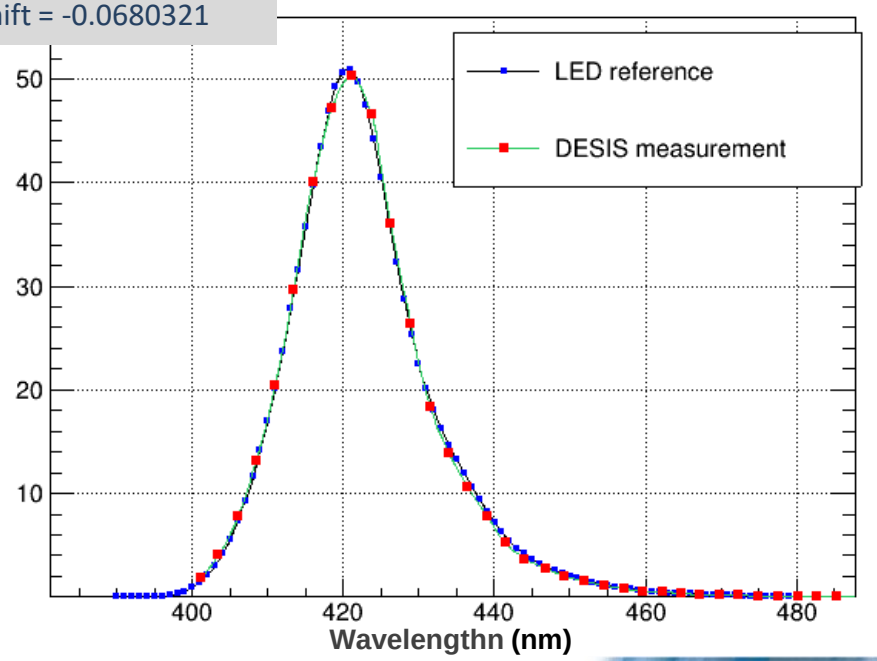
DESIS calibration unit
9 LEDs of different wavelengths

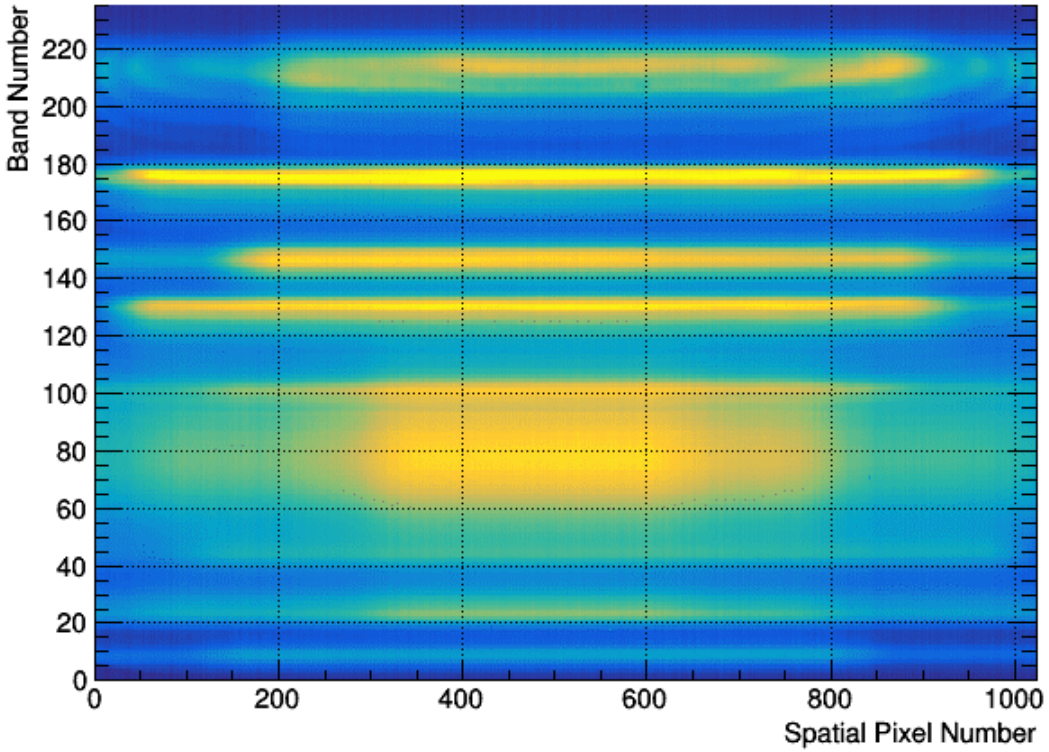
On Board Calibration Unit

- LED Bank with 9 different LED types (7 used for spectral calibration)
- Data from sensor can be fitted for different LED type



Fit parameters
Normalization = 0.996495
Spectral_shift = -1.25566 (nm)
Vertical_shift = -0.0680321





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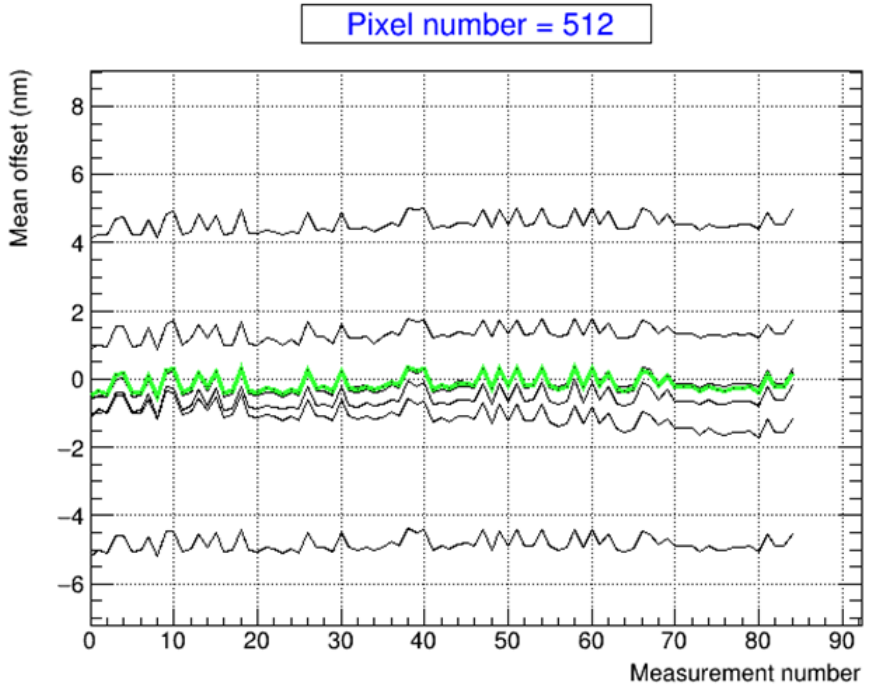
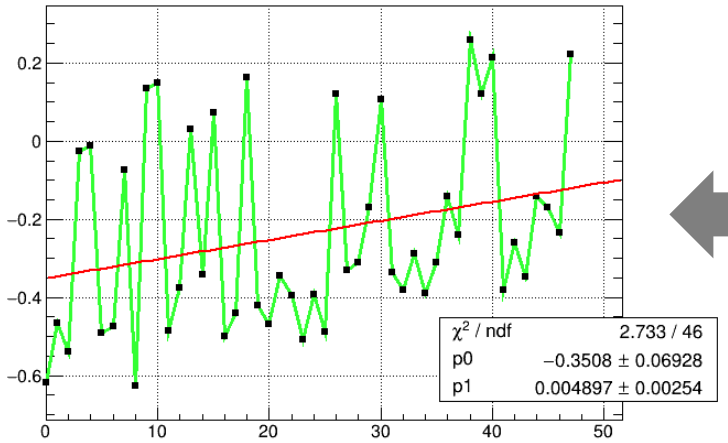
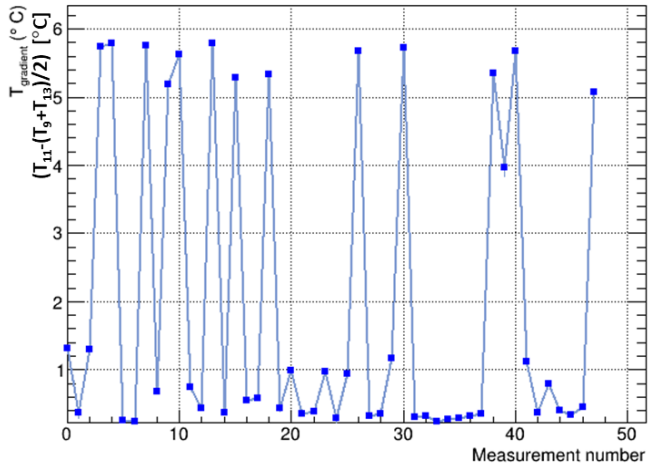
Spectral Calibration Unit Results

- 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)







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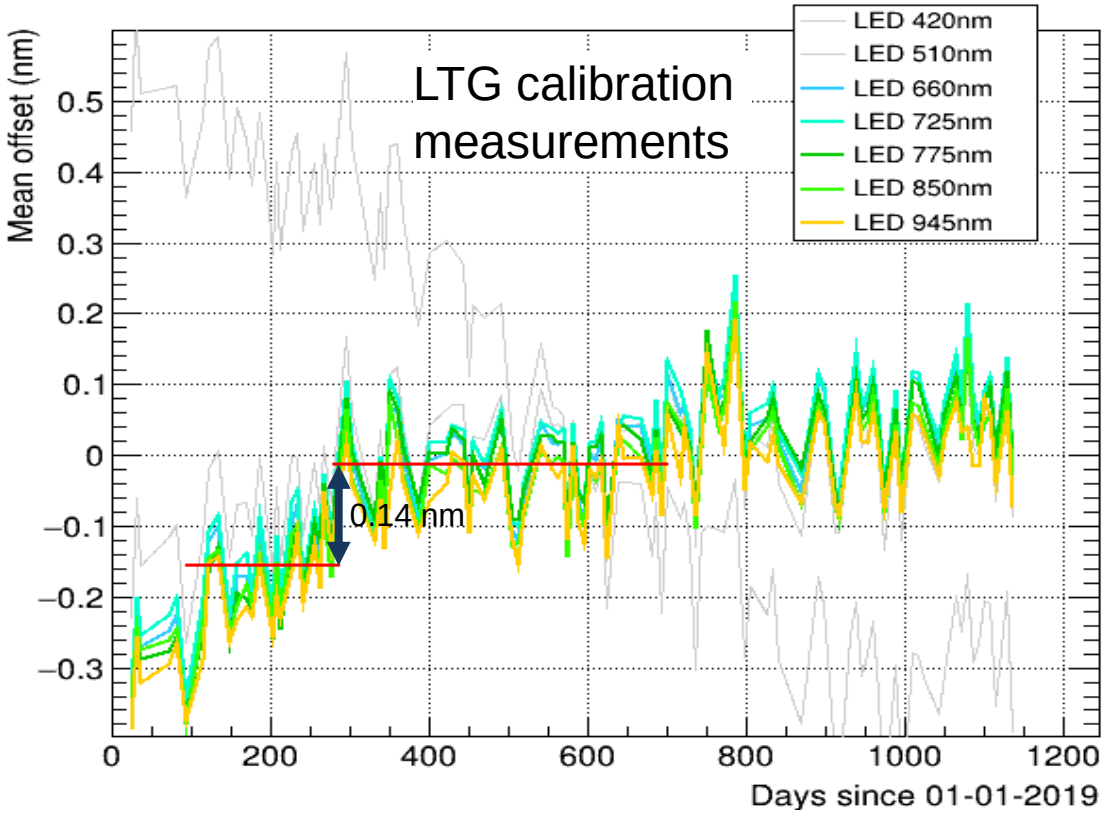
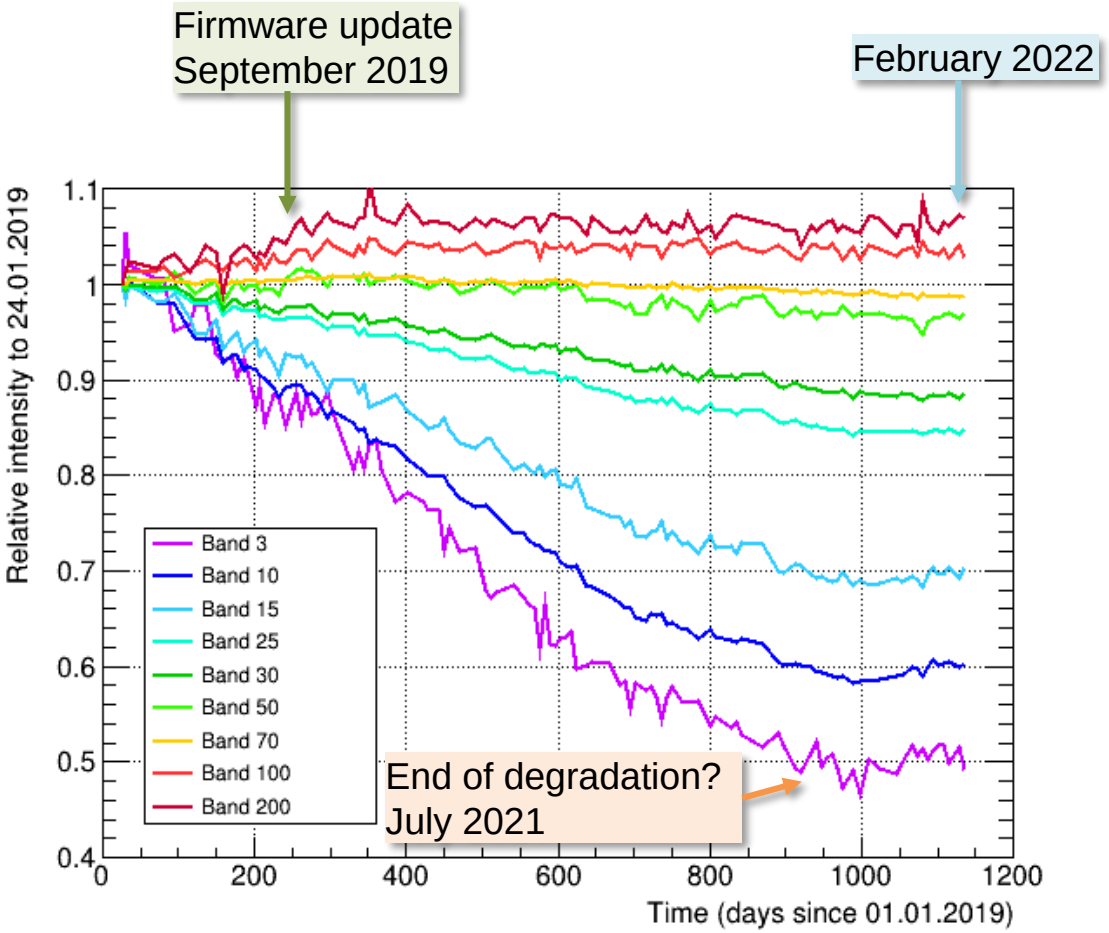
- Observed simultaneous jumps of 0.5 nm in all LEDs and all pixels across-track. Correlated with different temperature gradients inside DESIS sensor. Two populations: low-temperature gradient (LTG) and high-temperature gradient (HTG)
- Small gradient with time (0.2 nm / year) until September 2019 (Firmware update)
- For any of the two populations, RMS 0.10 nm. Most measurements within 0.10 nm, but small fraction of measurements can deviate as much as 0.3 – 0.4 nm
- A correction of the 0.5 nm jumps between populations implemented inside smile resampling



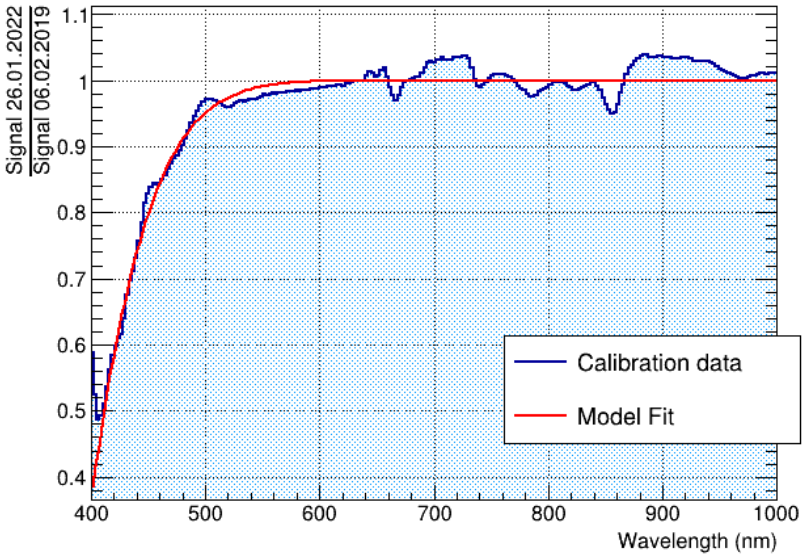
Other Calibration Unit Results



- 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:

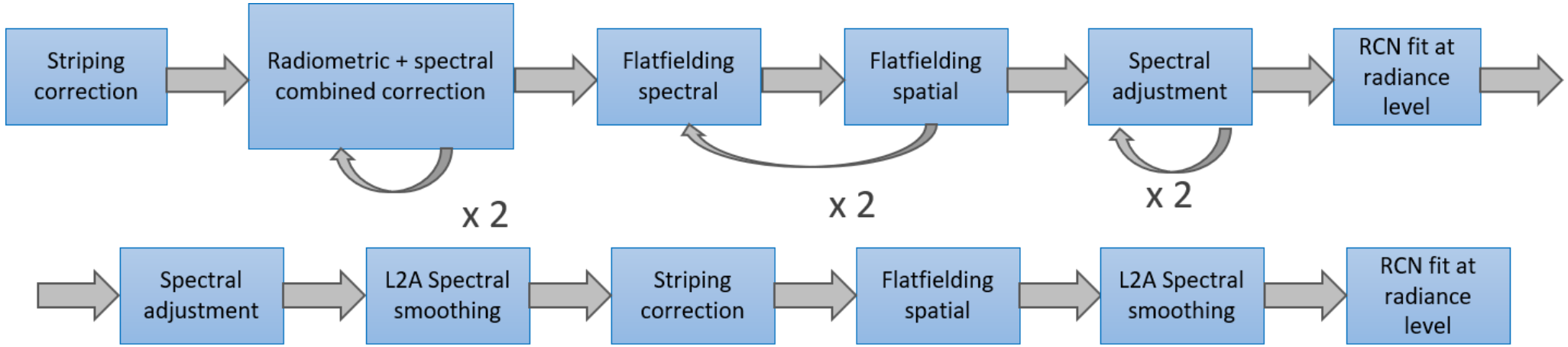
$$Decrease\ 1000\ days = \frac{A}{\sigma} * \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

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



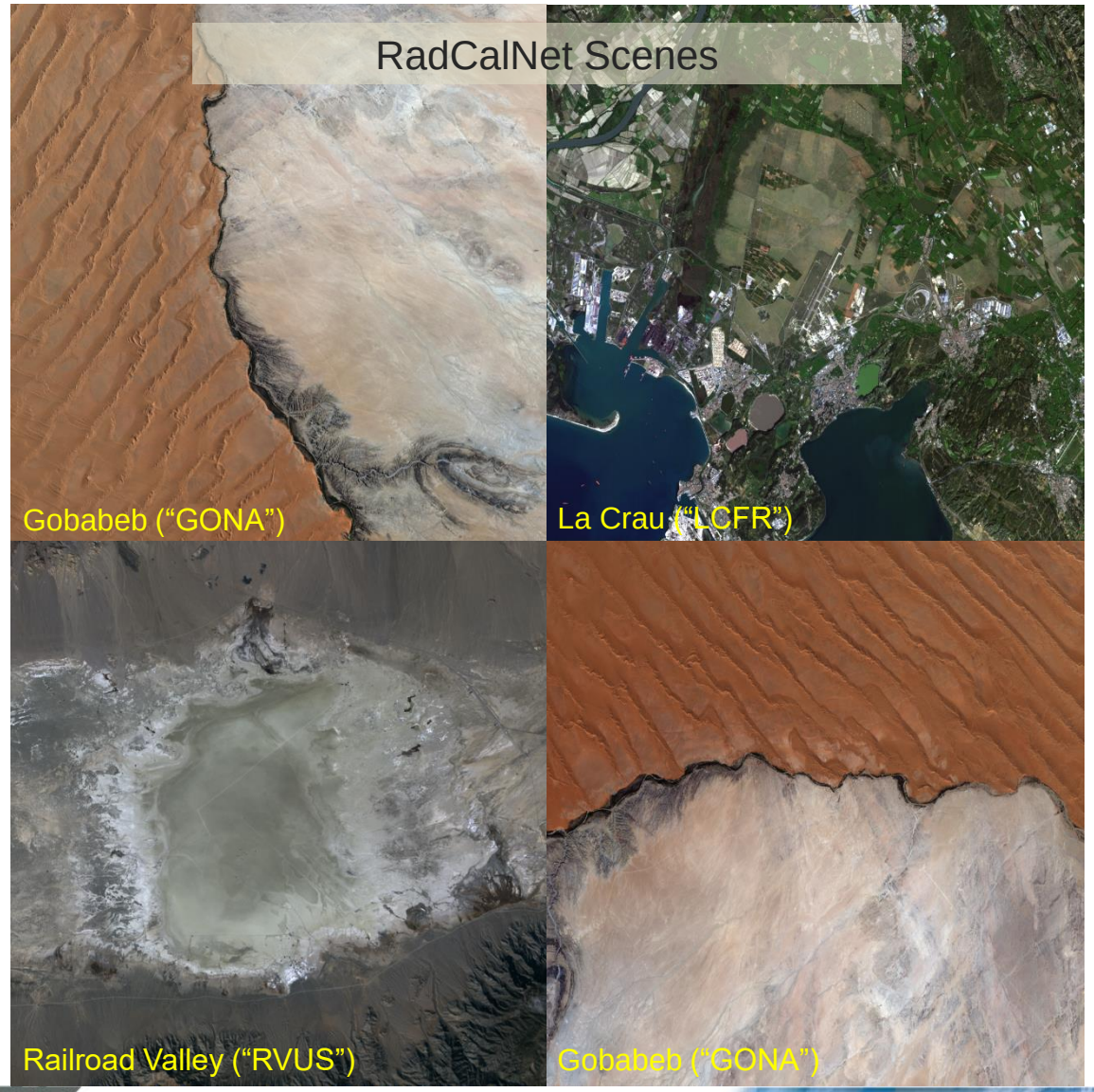
Vicarious Calibration Concept

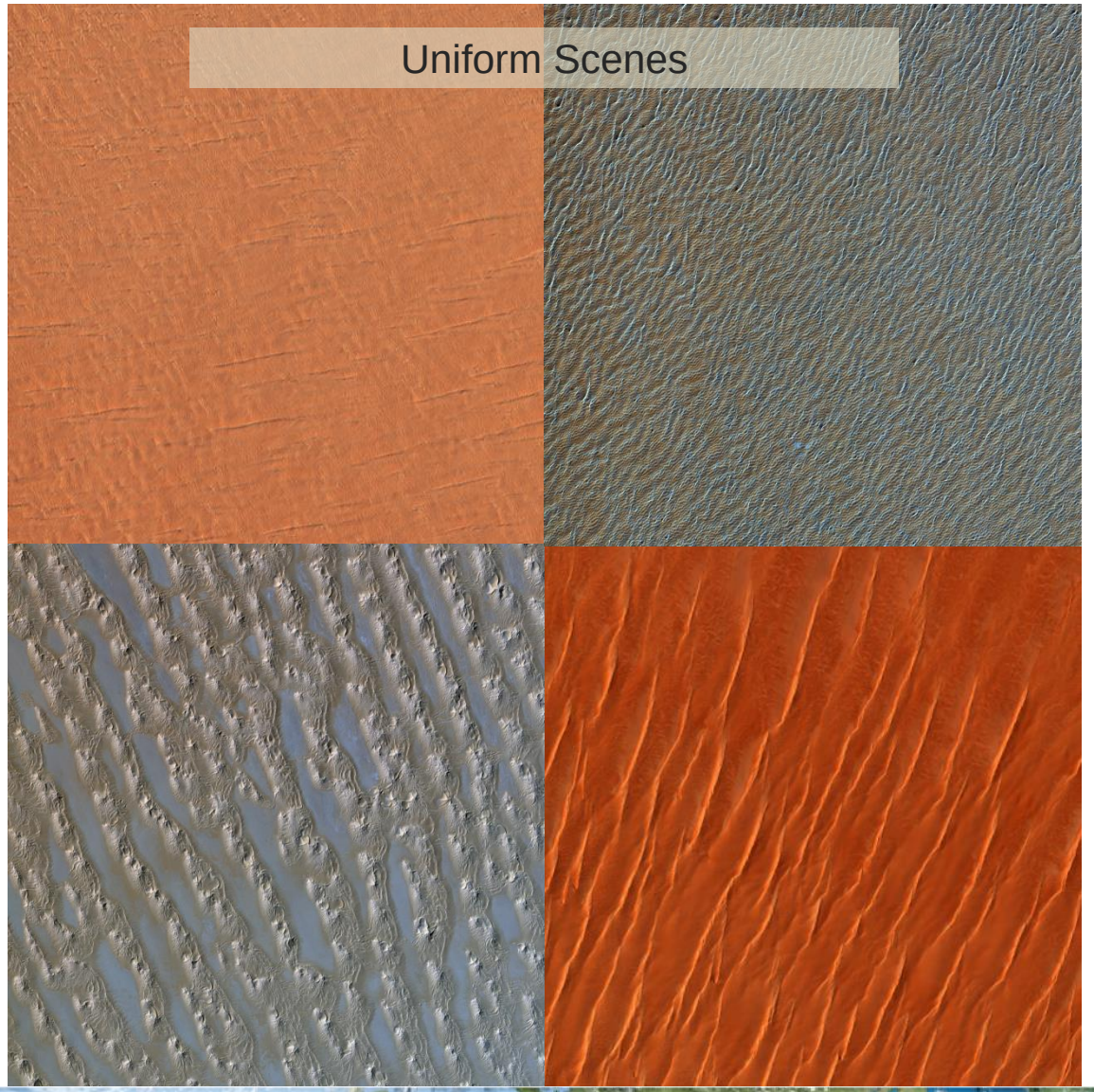
- Two main goals:
  1. consistent relative response in spatial and spectral direction:
     - Flat response on homogenous input
     - Smooth pixel to pixel transitions
     - Consistent behavior across-track
  2. Correct absolute radiance scale
- Use a sequence of configurable steps to achieve both goals:



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

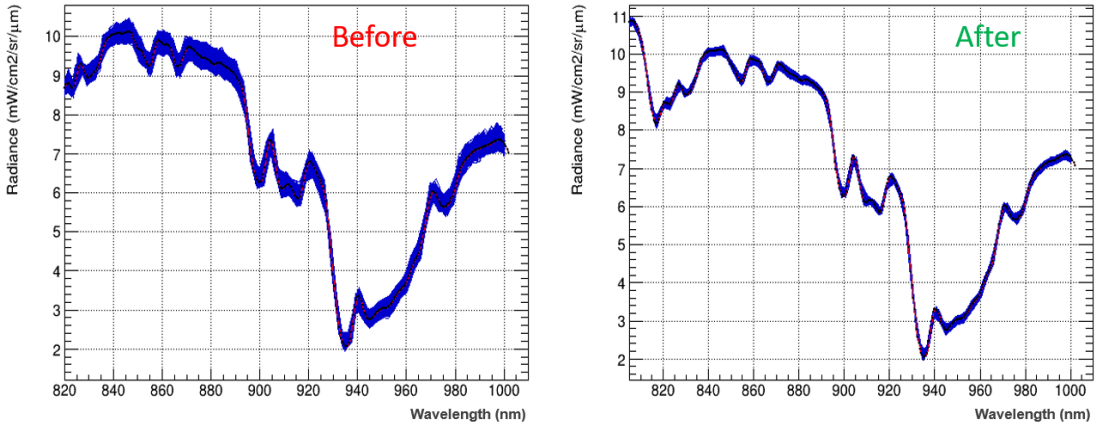
Vicarious calibration Input data



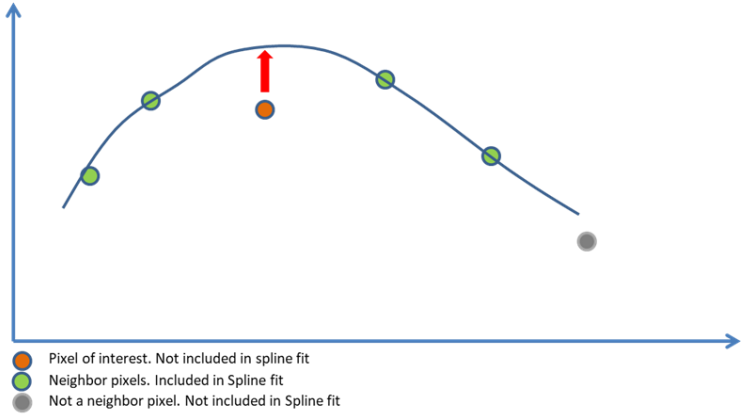


Uniform Scenes Processing Steps

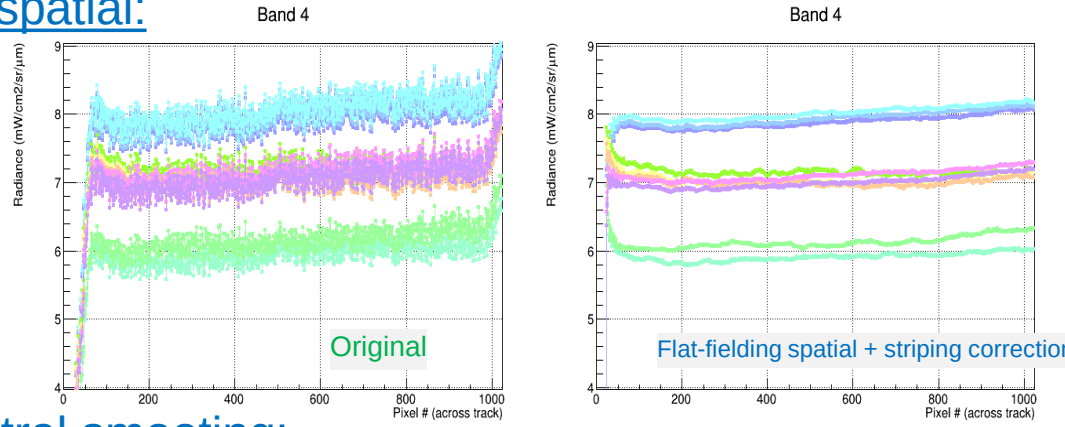
- Rad./Spc. Correction (before smile corr.)



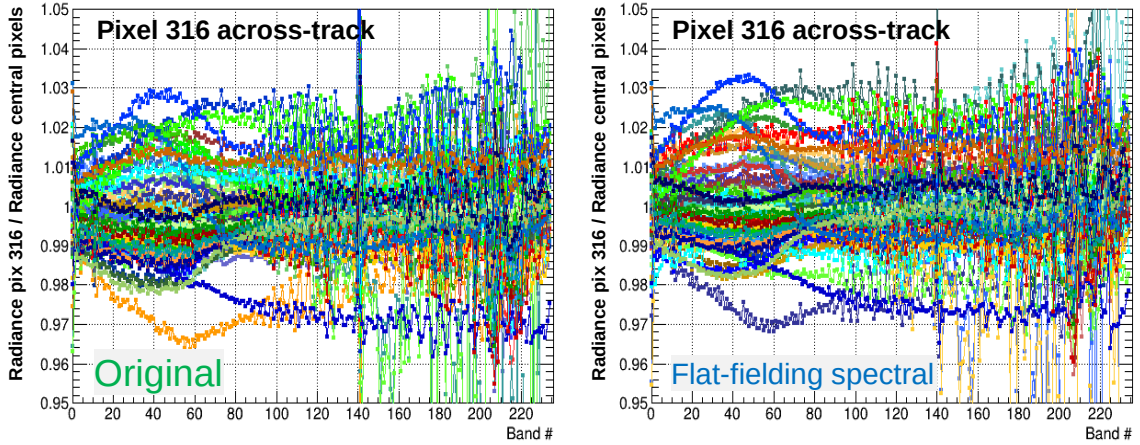
- Striping correction:



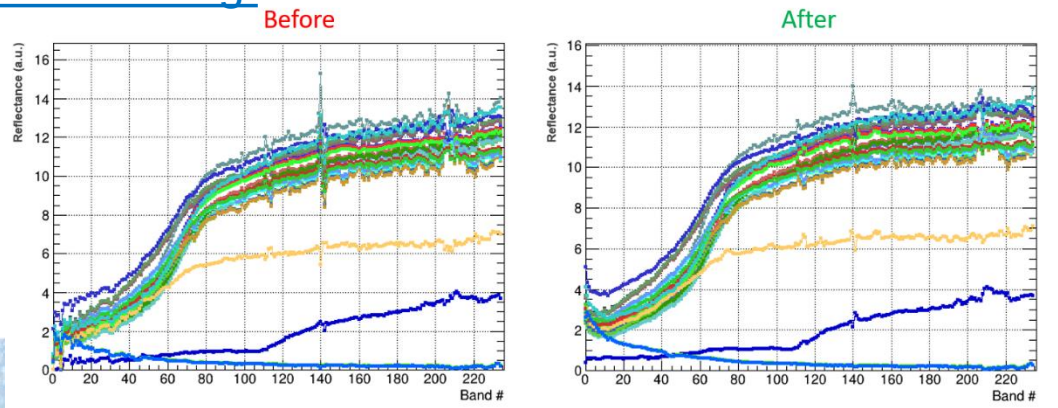
- Flatfielding spatial:



- Flatfielding spectral:



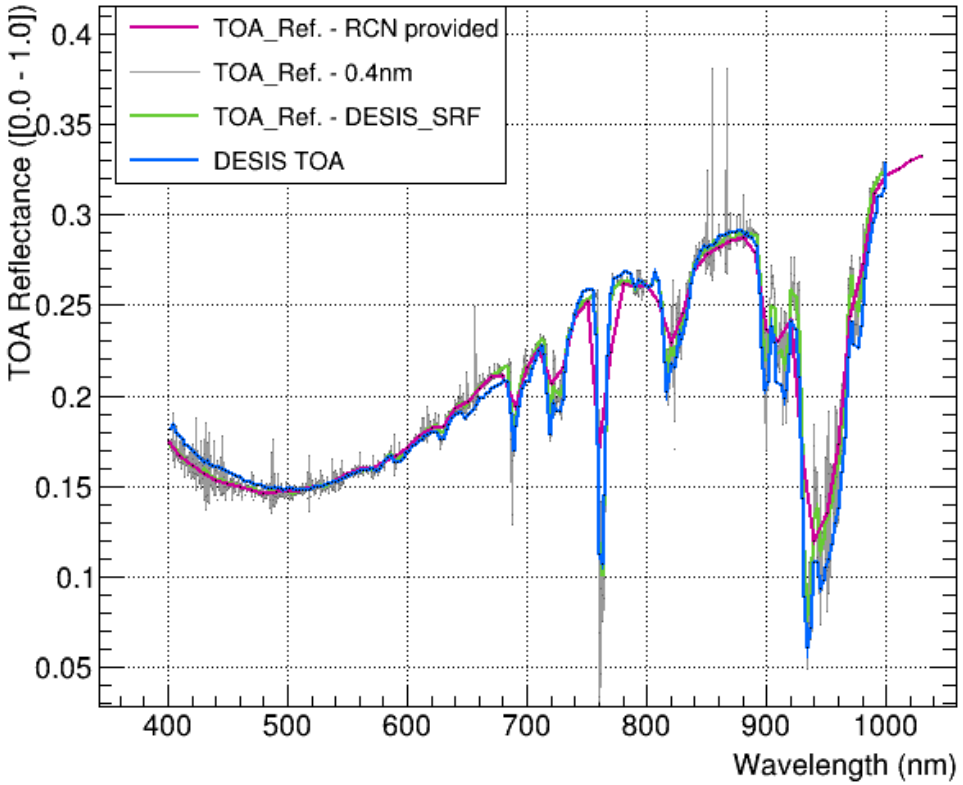
- L2A spectral smooting:



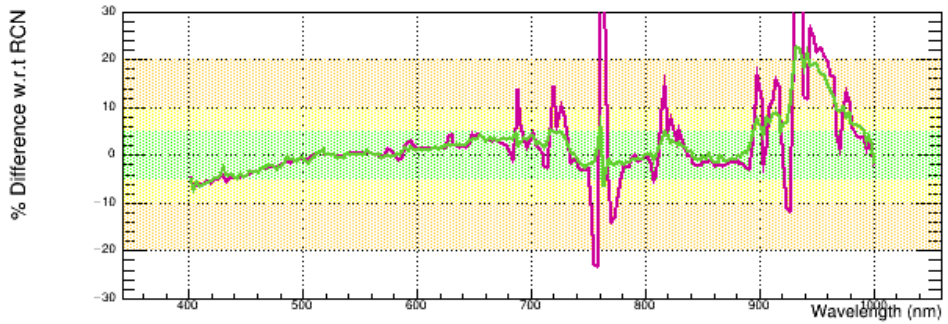
Absolute radiometric scale

- 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

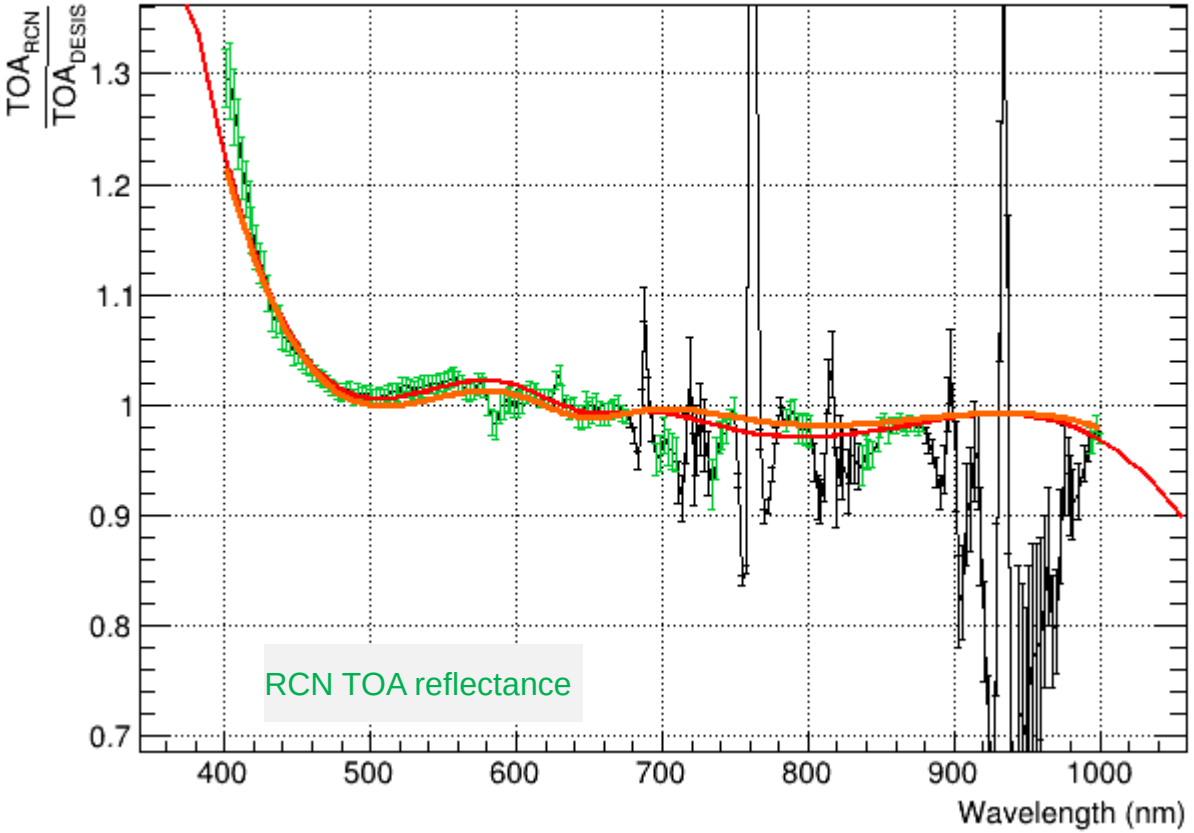


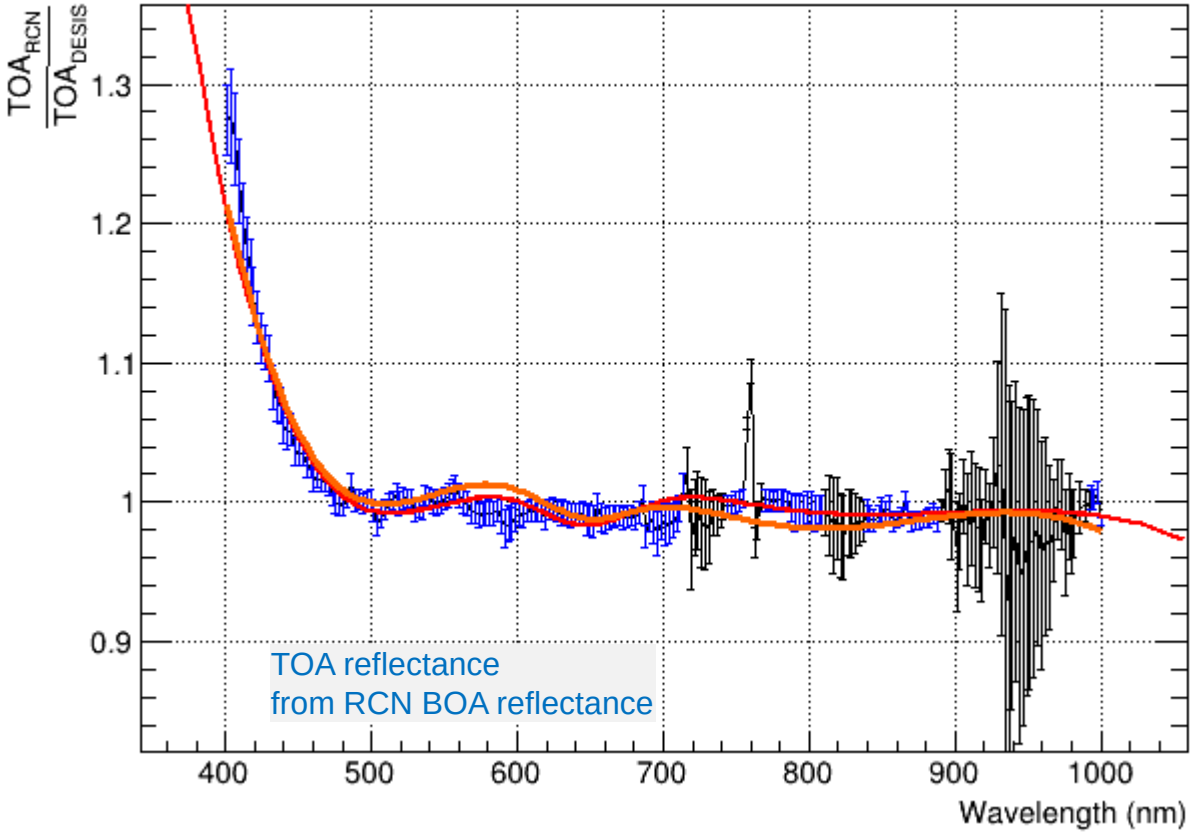
- Compute deviations of DESIS w.r.t. both references:



Absolute radiometric scale

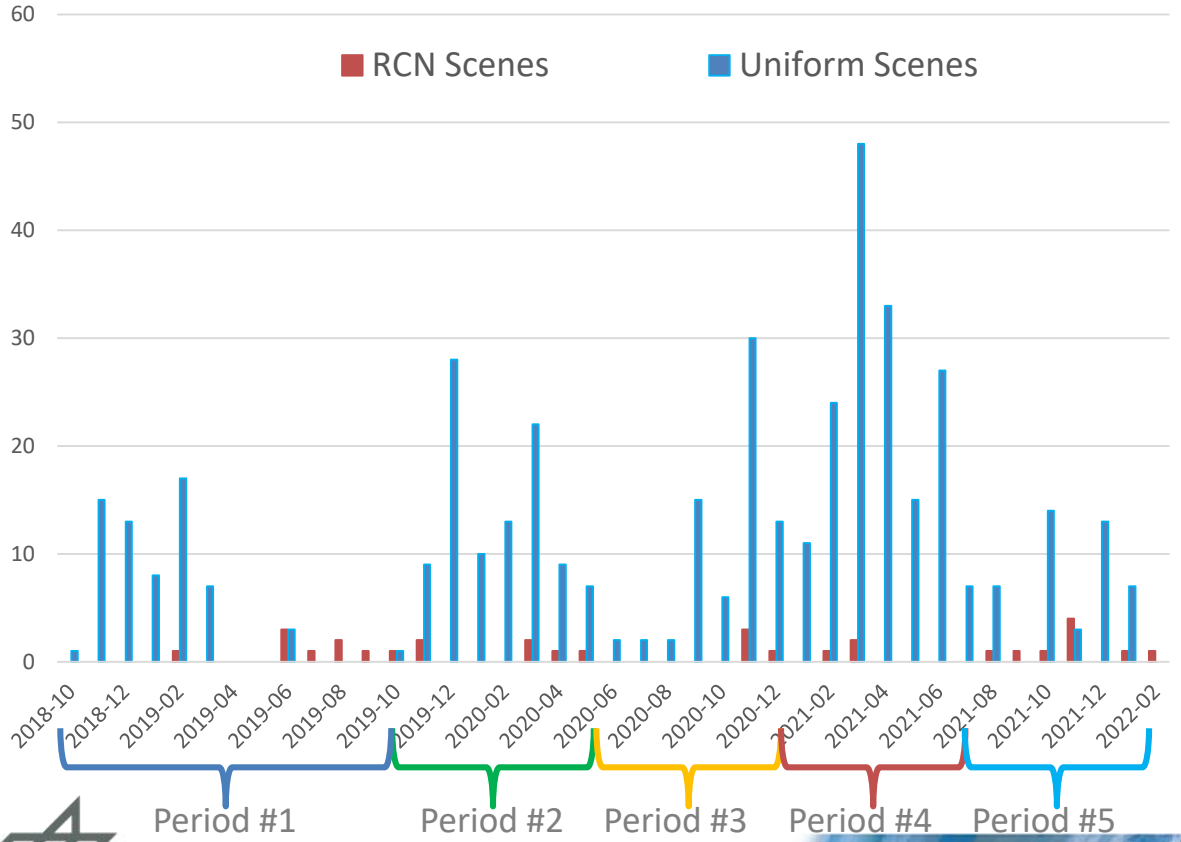
- Use selected “calibration” scenes from RCN and perform a fit to mean value (2 times in steps sequence) in order to obtain a per-band factor
- Use Average from 2 TOA reference data: RadCalNet provided (10 nm), DESIS calculated (DESIS resolution)

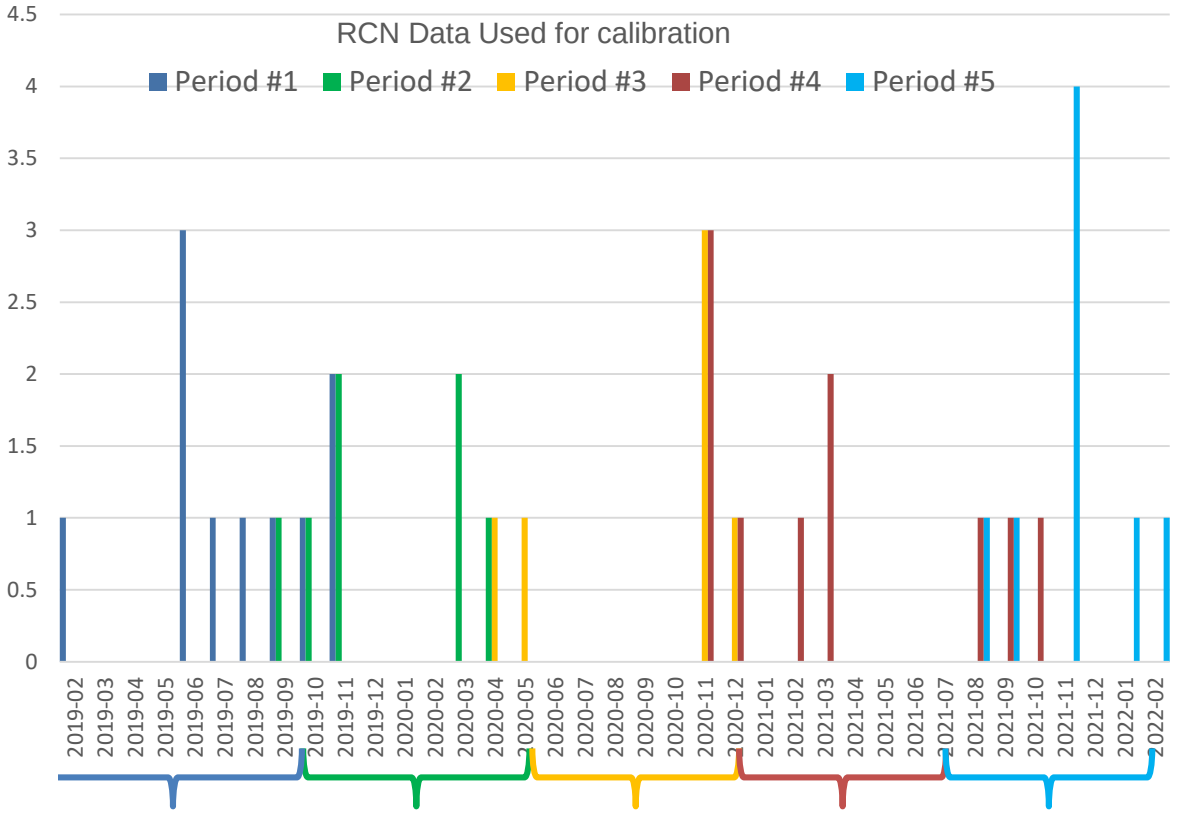




Vicarious calibration Periods

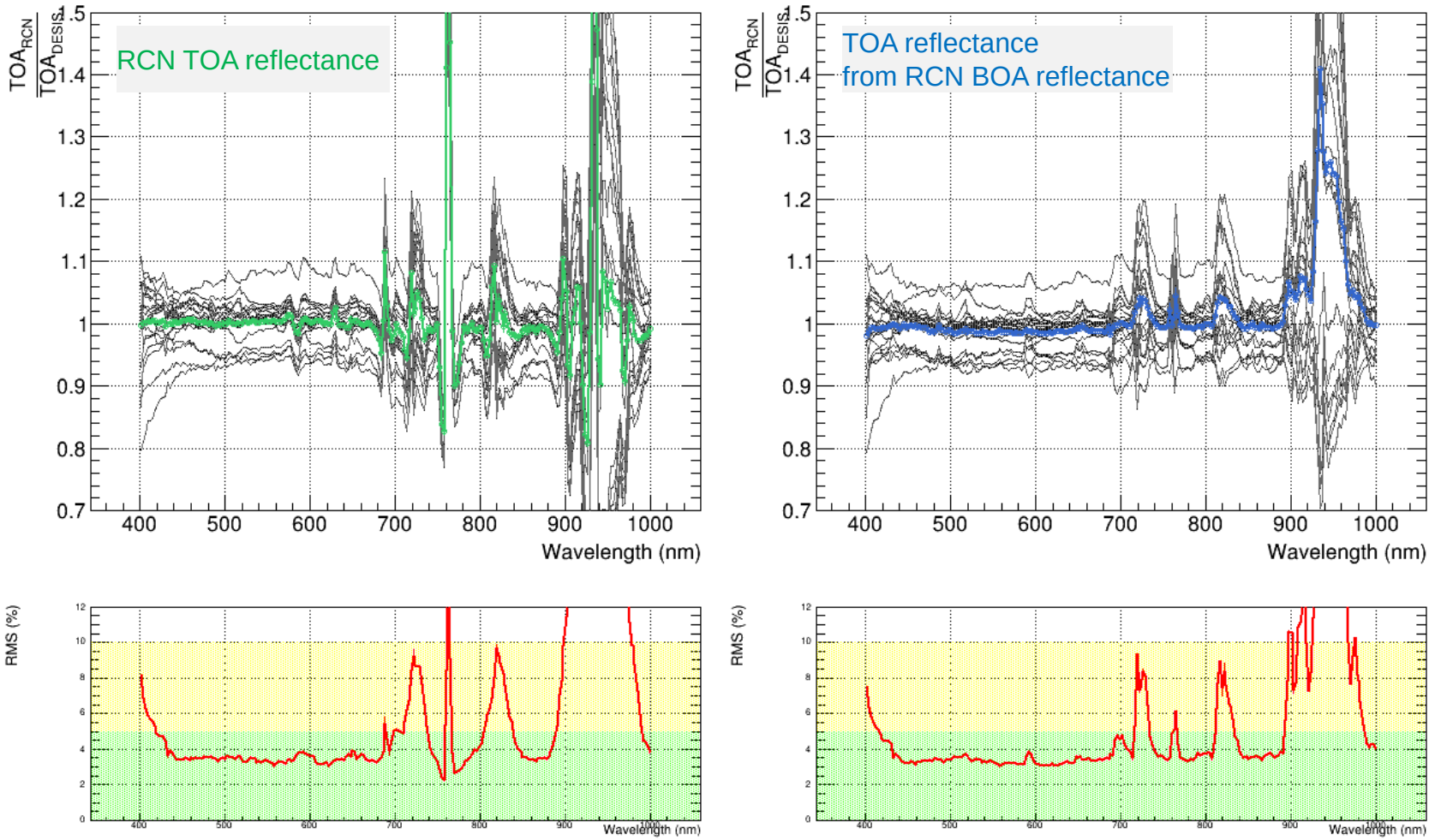
- Input scenes not evenly distributed in time
- Particularly challenging to have abundant good quality Radcalnet (RCN) scenes
- Calibration updates arrive several months after data acquisition





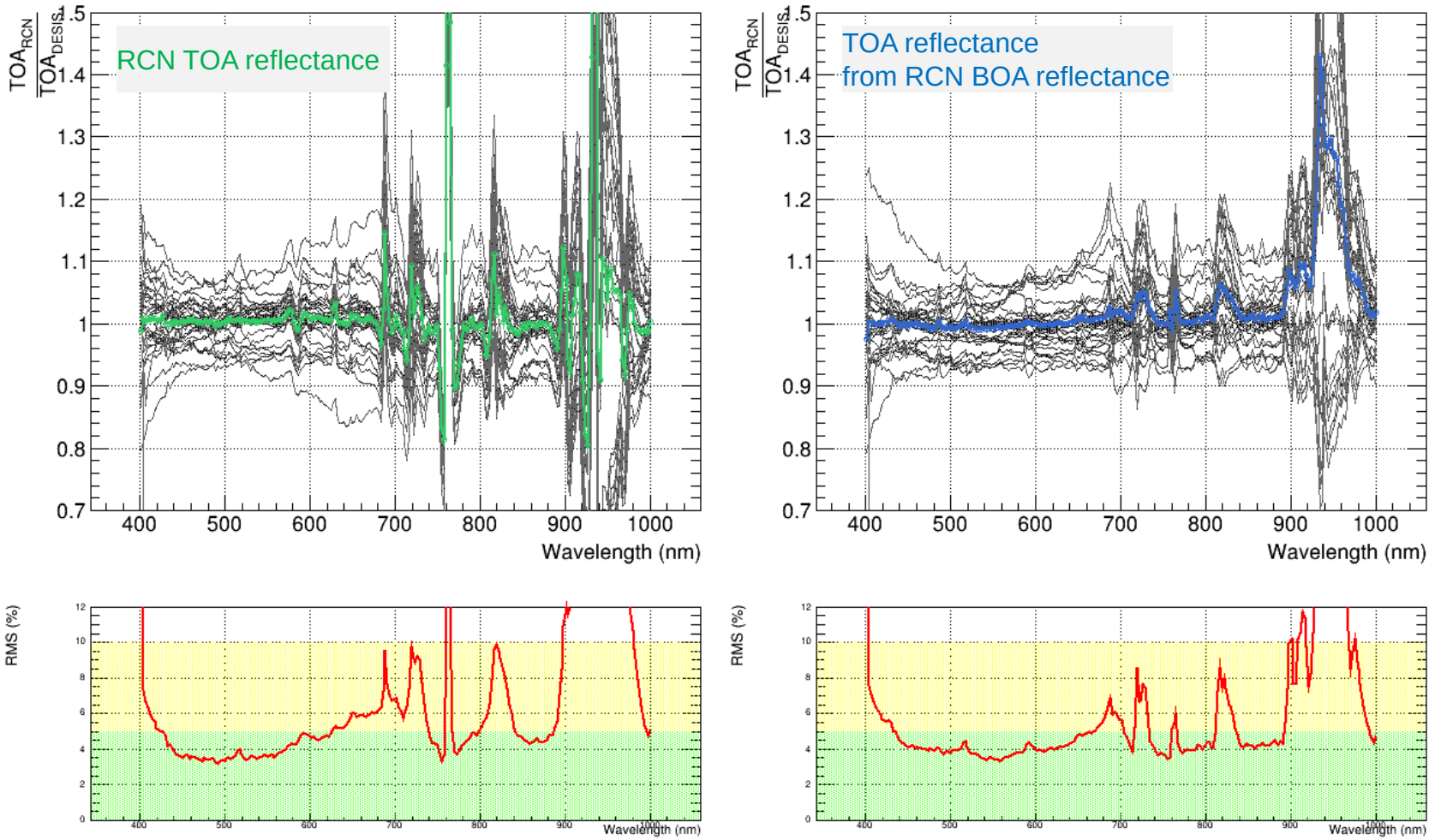
Results from 3 calibration periods: Calibration RCN Data Results

- 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



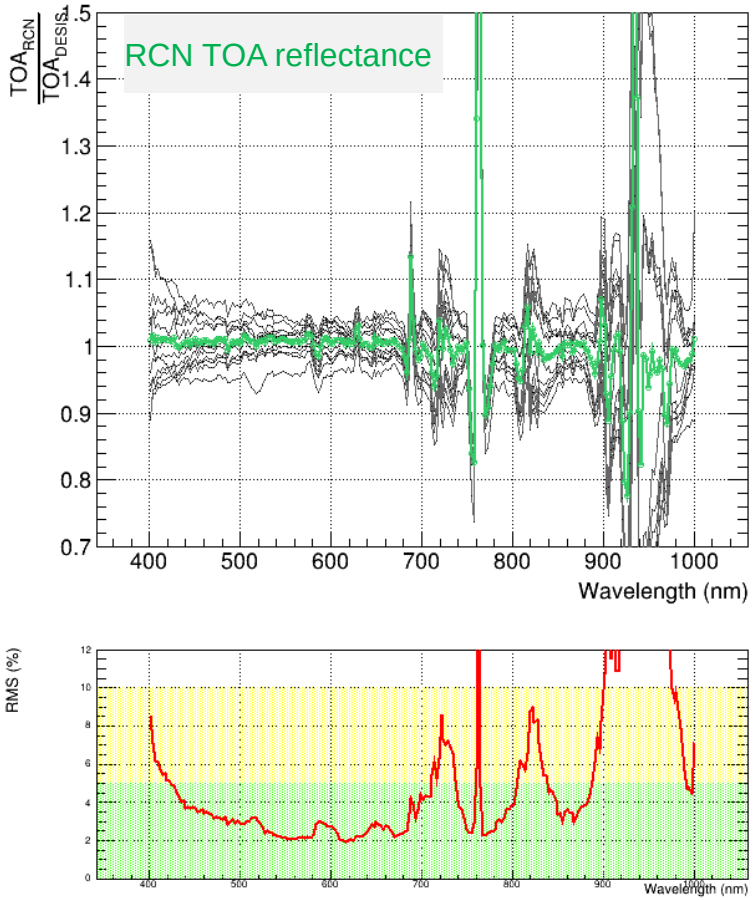
Results from 3 calibration periods: All RCN Data Results

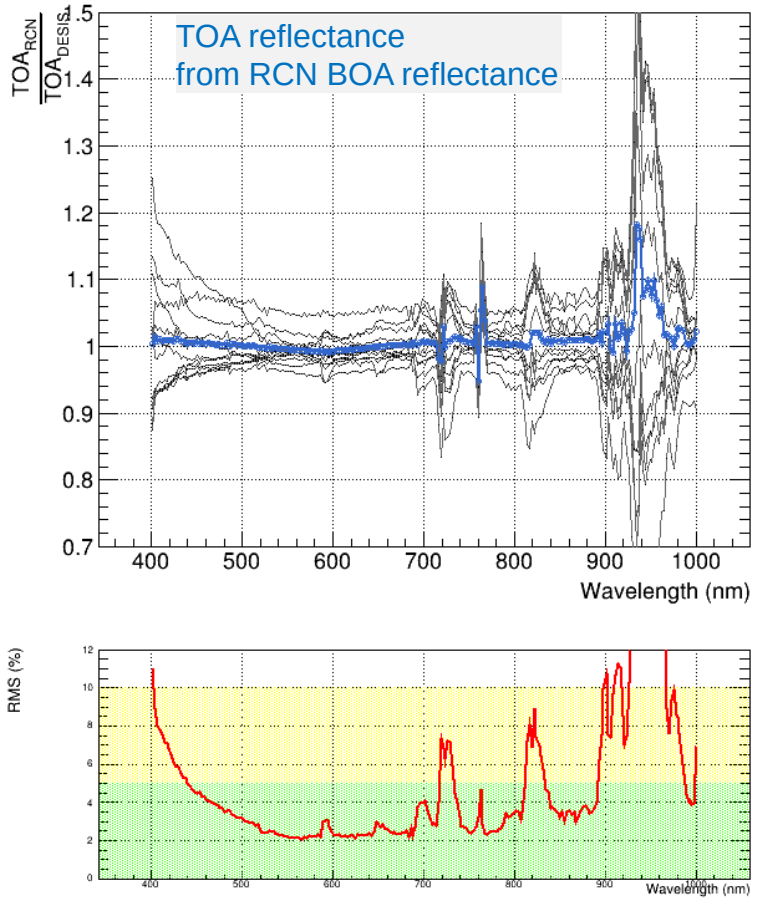
- Absolute calibration adjusted with RCN data for 3 different periods
- Absolute calibration uses only part of RCN scenes (19)
  - good atmospheric conditions
  - below 50 degrees Sun Zenith Angle
- These summary plots show **all** RCN scenes (**30** scenes)



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):

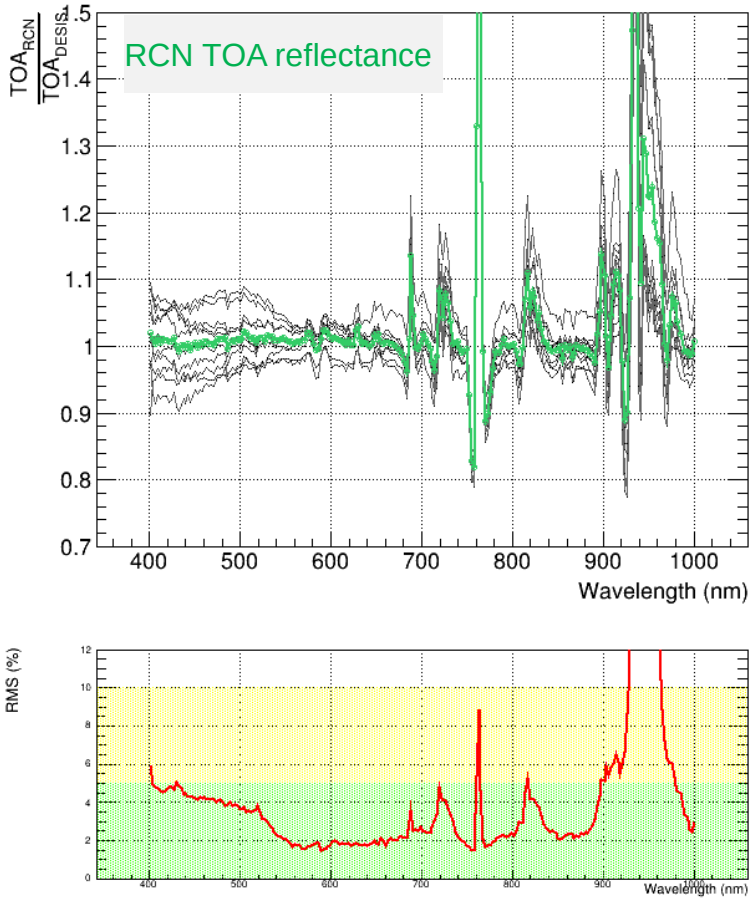


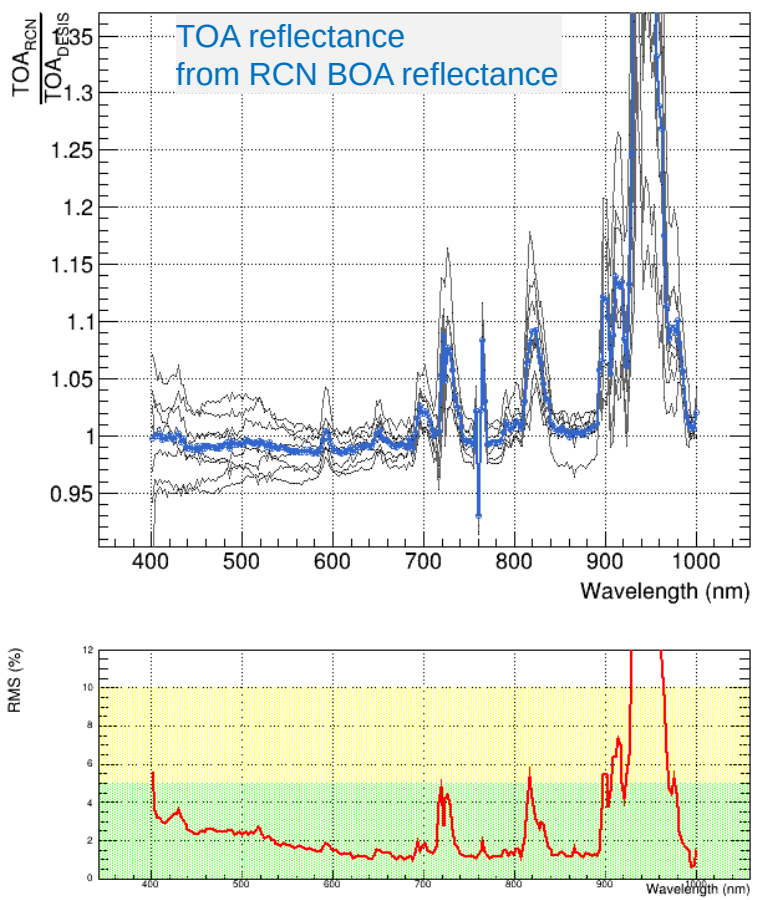


- Similar results as seen in other periods
- After calibration bias is corrected, but RMS below 500 nm is significant larger than above 500 nm

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):



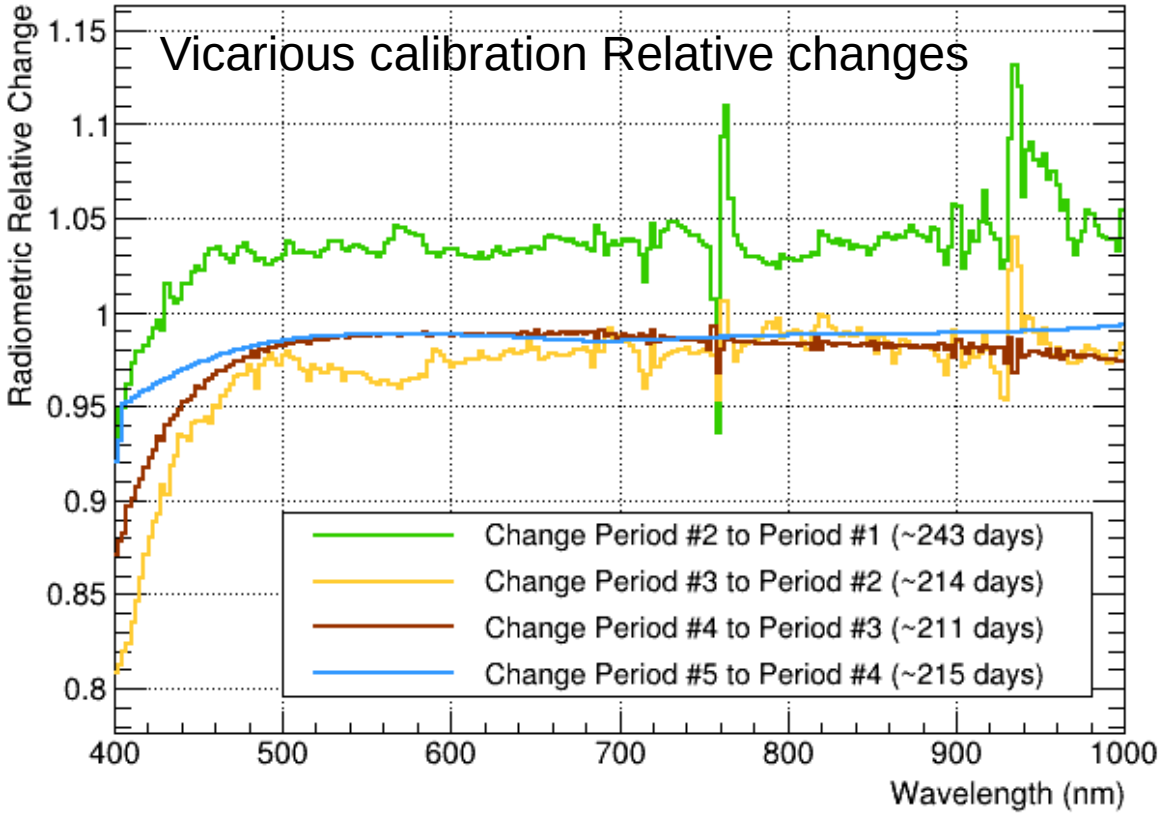


- As indicated by LED calibration data, no sign of degradation below 500 nm on Period 5 (starts 01.07.2022)
- LED calibration data seem to reproduce well the trends, but not the actual intensity of the effect
- Not accurate enough for model, but probably accurate about change of behavior in July 2021

Comparison between CAL Unit and Vicarious Calibration

- Model derived from CAL unit data does not match well the data obtain in Vicarious calibration

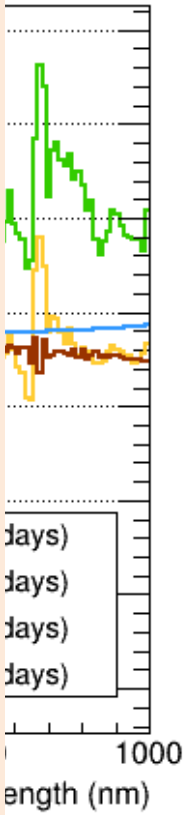
- Main similarity with LED data:
  - CAL data reproduces the fast decrease in performance below 500 nm
  - End of degradation <500 nm after July 2021
- Main differences are:
  - CAL data shows a maximum decrease down to 40% from the initial values, Vic. data maximum decrease is 60%
  - CAL data does 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



Comparison with Radiometric update from Vicarious Calibration

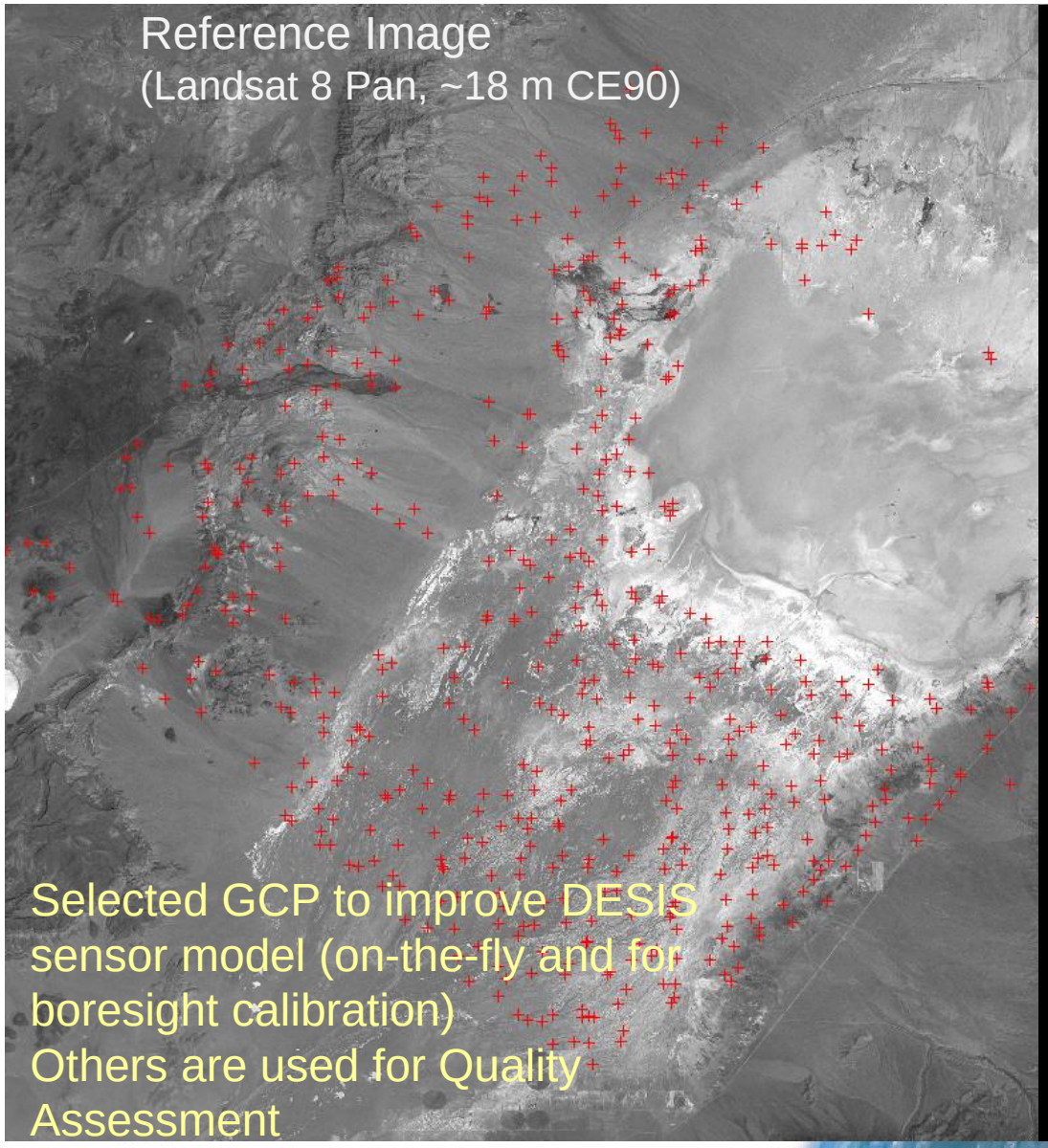
- Unfortunately m
- The plot shows
- Main similarity v
  - CAL data re
    performanc
  - End of deg
- Main difference
  - CAL data s
    to 40% fror
    decrease is
  - CAL data d
    ~2% betwe
  - CAL decrea
    July 2021,

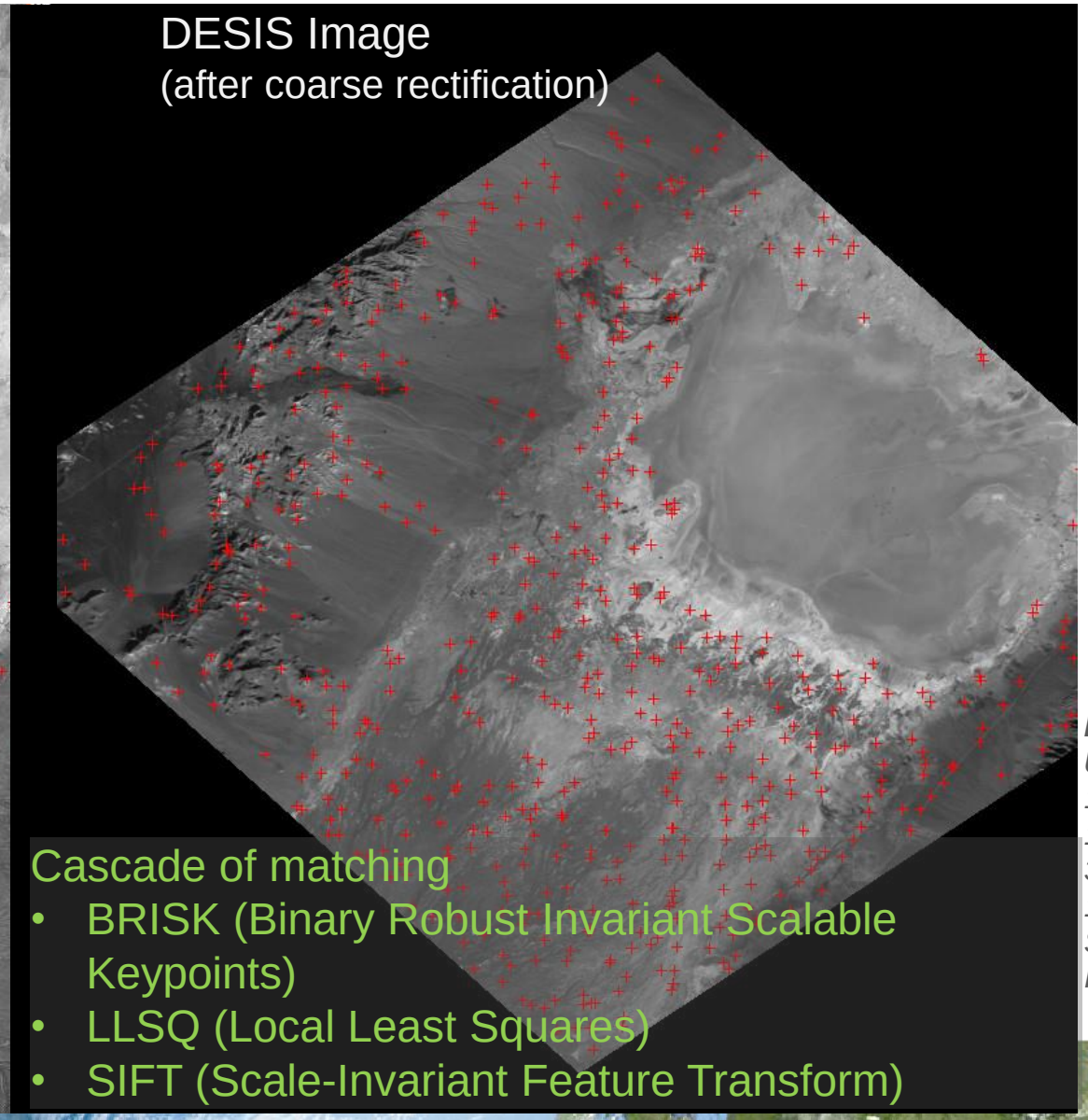
- Baseline for radiometric calibration is
- Difficult to match RCN data with radiometric results from CAL unit (difficulties known since start of mission)
- Good news that DESIS shall be more stable since July 2021 below 500 nm
- Results in agreement with independent study by:
  - S2, L8 crosschecks performed by TBE/I2R
  - ECCOE system characterization “System Characterization Report DLR Earth Sensing Imaging Spectrometer (DESIS)”, USGS LSDS-2011, version 1.0
  - Shrestha, M., Helder, D., & Christopherson, J. (2021). DLR Earth Sensing Imaging Spectrometer (DESIS) Level 1 Product Evaluation Using RadCalNet Measurements. Remote Sensing, 13(12), 2420. doi:10.3390/rs13122420



DLR

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)

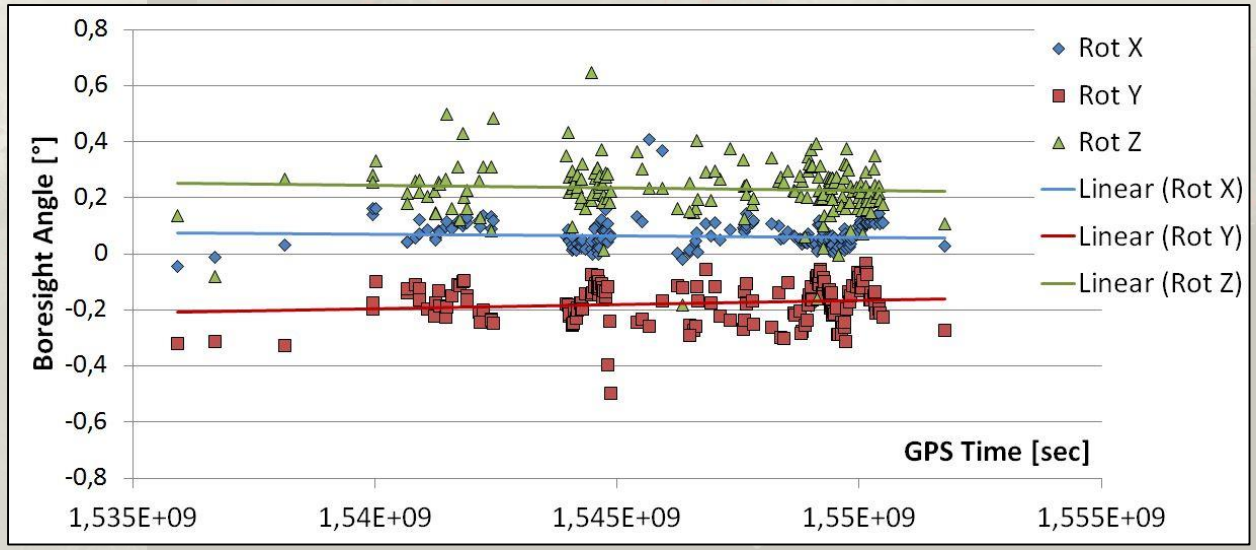
Accuracy w.r.t. Reference
177 scenes
- #GCP: average 210 per scene
- #Control Points: average 969 per scene

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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38.4467°N
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Thank you !

More DESIS information at:

- *Sensors 2019, 19(7), 1622; https://doi.org/10.3390/s19071622*
- *Sensors 2019, 19(20), 4471; https://doi.org/10.3390/s19204471*
- *IGARS 2021, Vicarious Calibration of the DESIS Imaging Spectrometer*

DLR

Comparison with Radiometric update from Vicarious Calibration

- Unfortunately model from CAL unit does not 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%