Supported by:

Federal Ministry
for Economic Affairs
and Climate Action

on the basis of a decision
by the German Bundestag

OPERATIONAL DATA QUALITY CONTROL AND INSTRUMENT MONITORING FOR THE SPECTRAL, RADIOMETRIC AND GEOMETRIC DATA PROPERTIES WITHIN THE ENMAP GROUND SEGMENT

1st EnMAP User Workshop
October 10 – 11, 2023

M. Bachmann, M. Schneider, B. Gerasch, S. Holzwarth, M. Habermeyer, M. Pato, E. Carmona
... and many others from the whole EnMAP team
EnMAP Ground Segment, Processor and Calibration Segment
German Aerospace Center (DLR), Earth Observation Center, Oberpfaffenhofen

Data Quality Control

- Generation of **QC-related metadata and flags**
  - L2A „Land“ product fulfilling CEOS Analysis Ready Data CARD4L requirements
  - Automatically generated for each product
  - Updated in processed products

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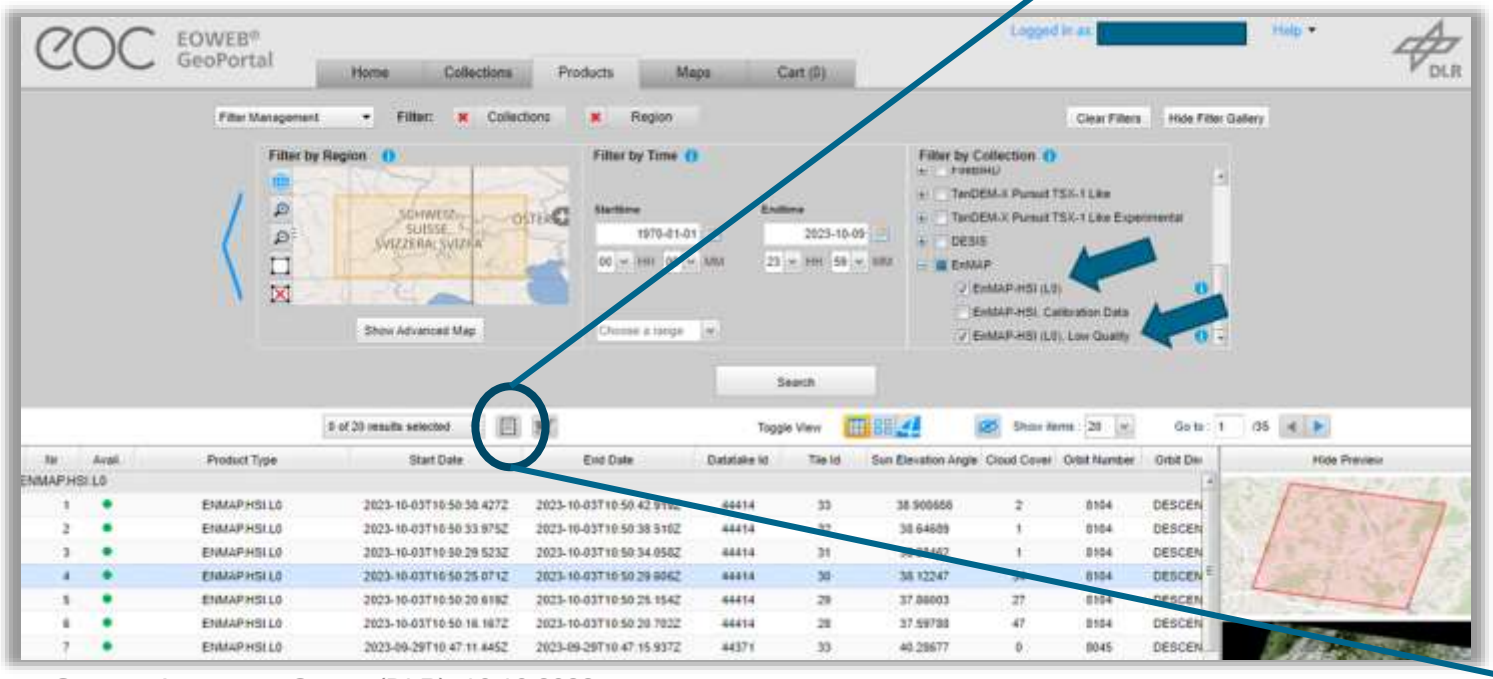

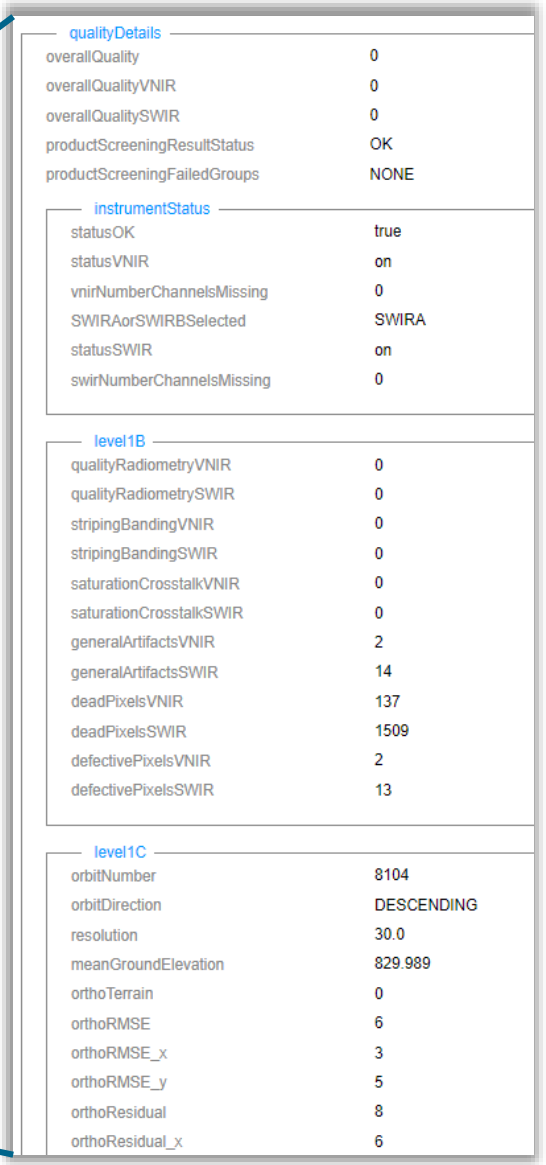

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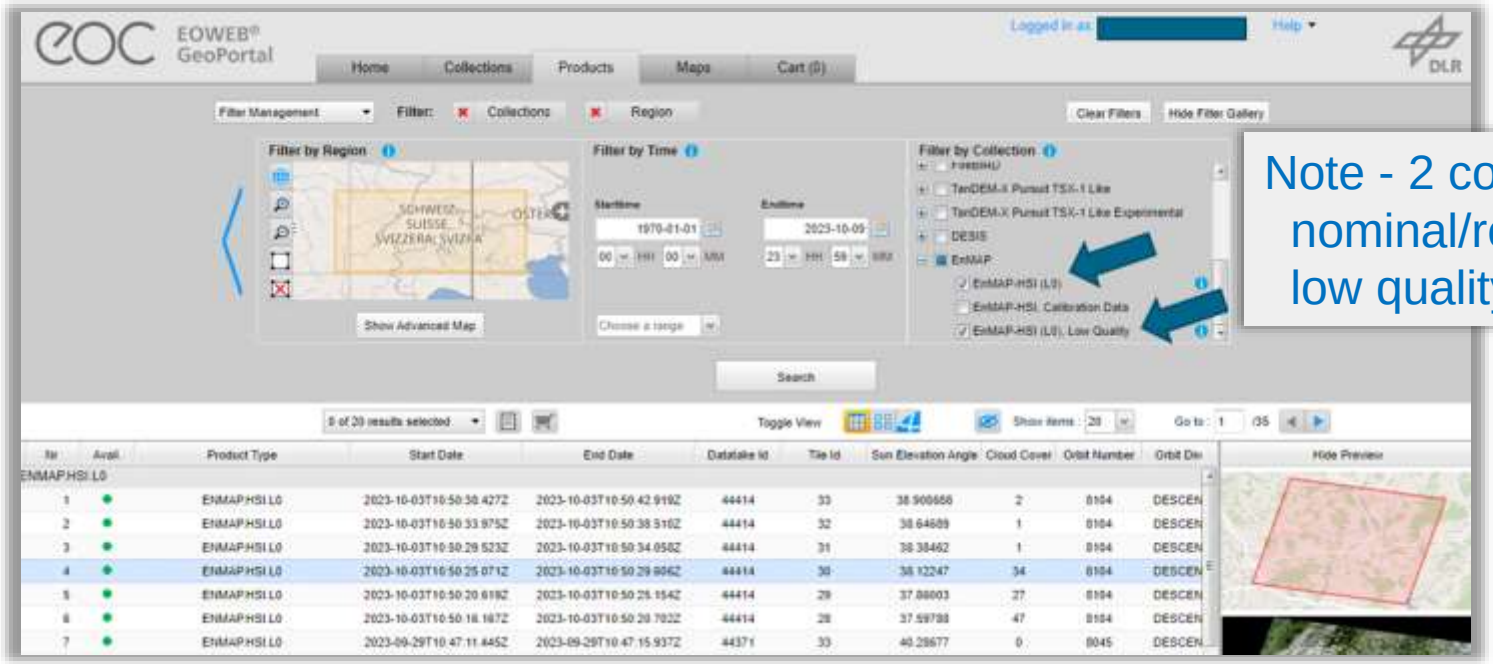

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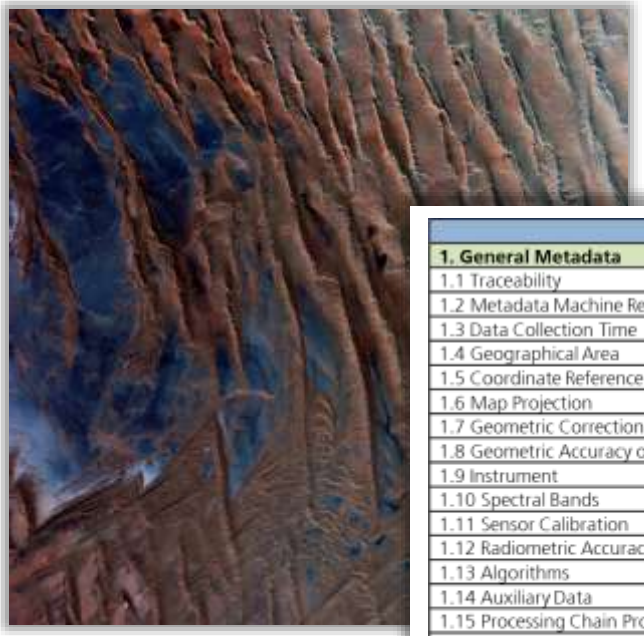

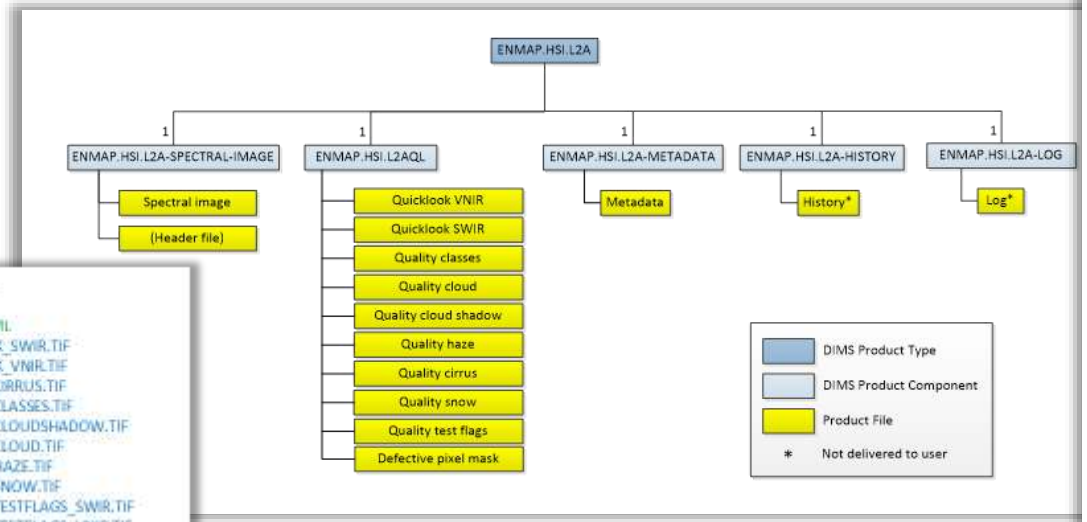

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ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-METADATA.XML
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ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_PIXELMASK_VNIR.TIF
ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_CIRRUS.TIF
ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_CLASSES.TIF
ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_CLOUDSHADOW.TIF
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ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-AUX_DATA_VNIR.OUT
ENMAP01-____L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-DM.TGZ

	Threshold	Target
1. General Metadata		
1.1 Traceability	n.a.	no
1.2 Metadata Machine Readability	ok	ok
1.3 Data Collection Time	ok	no
1.4 Geographical Area	ok	ok
1.5 Coordinate Reference System	ok	ok
1.6 Map Projection	ok	ok
1.7 Geometric Correction Methods	n.a.	ok
1.8 Geometric Accuracy of the Data	n.a.	ok
1.9 Instrument	ok	ok
1.10 Spectral Bands	ok	ok
1.11 Sensor Calibration	n.a.	no
1.12 Radiometric Accuracy	n.a.	no
1.13 Algorithms	ok	partially
1.14 Auxiliary Data	ok	no
1.15 Processing Chain Provenance	n.a.	no
1.16 Data Access	ok	ok
1.17 Overall Data Quality	n.a.	ok
2. Per-Pixel Metadata		
2.1 Metadata Machine Readability	ok	ok
2.2 No Data	ok	ok
2.3 Incomplete Testing	ok	ok
2.4 Saturation	ok	partially
2.5 Cloud	ok	ok
2.6 Cloud Shadow	ok	ok
2.7 Land/Water Mask	n.a.	ok
2.8 Snow/Ice Mask	n.a.	ok
2.9 Terrain Shadow Mask	n.a.	no
2.10 Terrain Occlusion	n.a.	no
2.11 Solar and Viewing Geometry	ok	no
2.12 Terrain Illumination Correction	n.a.	no
2.13 Aerosol Optical Depth Parameters	n.a.	tbd
3. Radiometric and Atmospheric Corrections		
3.1 Measurement	ok	no
3.2 Measurement Uncertainty	n.a.	partially
3.3 Measurement Normalisation	n.a.	no
3.4 Directional Atmospheric Scattering	ok	ok
3.5 Water Vapour Corrections	ok	ok
3.6 Ozone Corrections	n.a.	ok
4. Geometric Corrections		
4.1 Geometric Correction	ok	ok

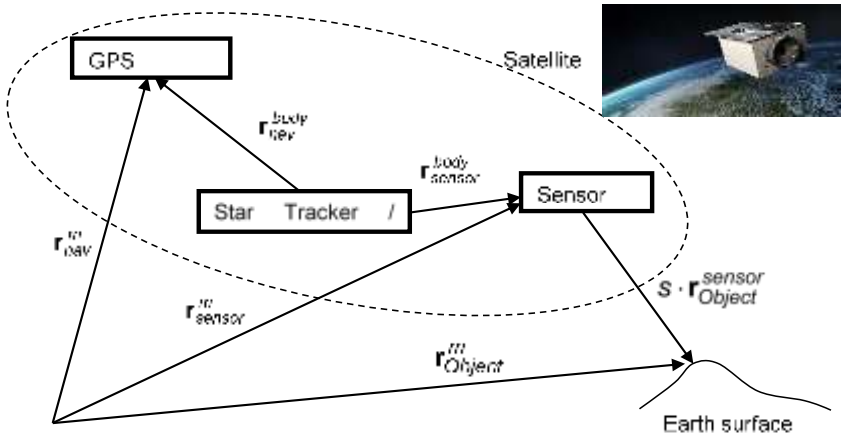
CEOS CARD4L

- Geometric Data Properties

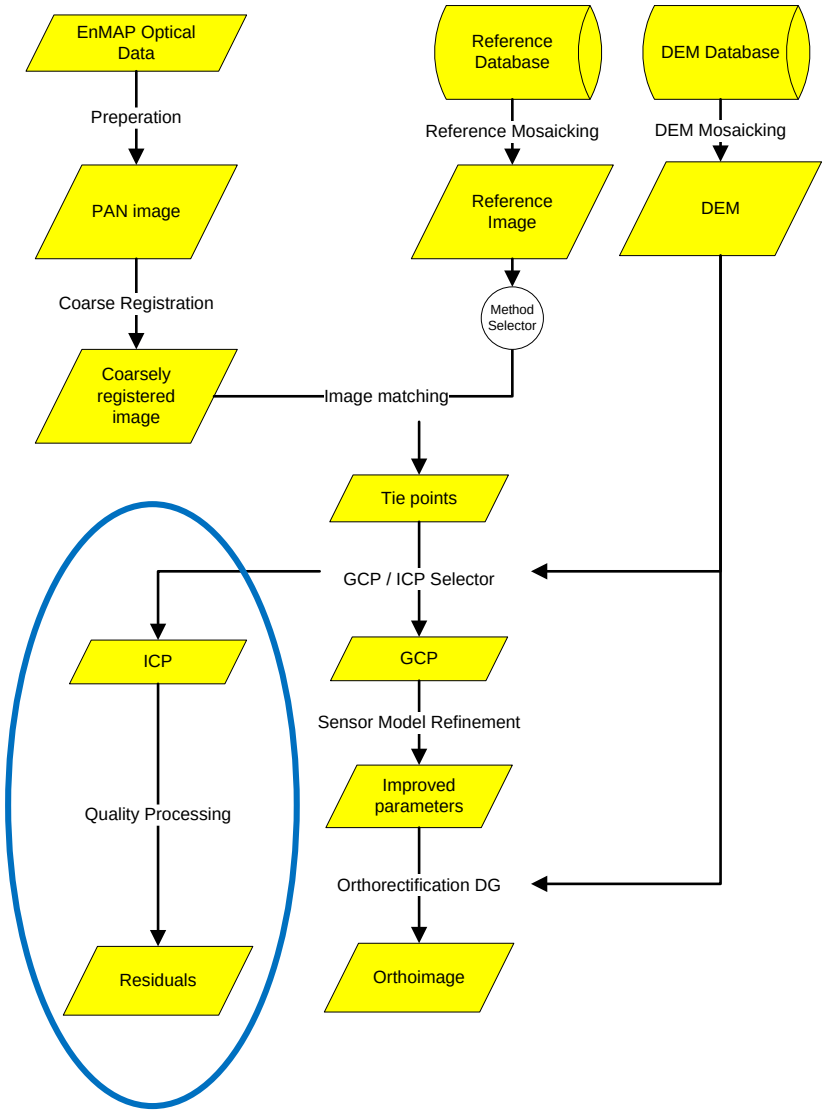
Dubai Palm Jumeirah
UAE

Geometric Processing

- Extraction/interpolation of orbit and attitude data
- Extraction of DEM from DEM database (Copernicus GLO-30)
- Extraction of reference image from database (custom built Sentinel-2 database)
- Matching of EnMAP image to reference image and improvement of sensor model
- RPC generation
- RMSE calculation
- Orthorectification of image and merging of VNIR and SWIR images



$$r_{object}^{ECR}(t) = r_{HSI}^{ECR}(t) + s \cdot R_{STS}^{ECR}(t) \cdot R_{HSI}^{STS} \cdot r_{object}^{HSI}$$

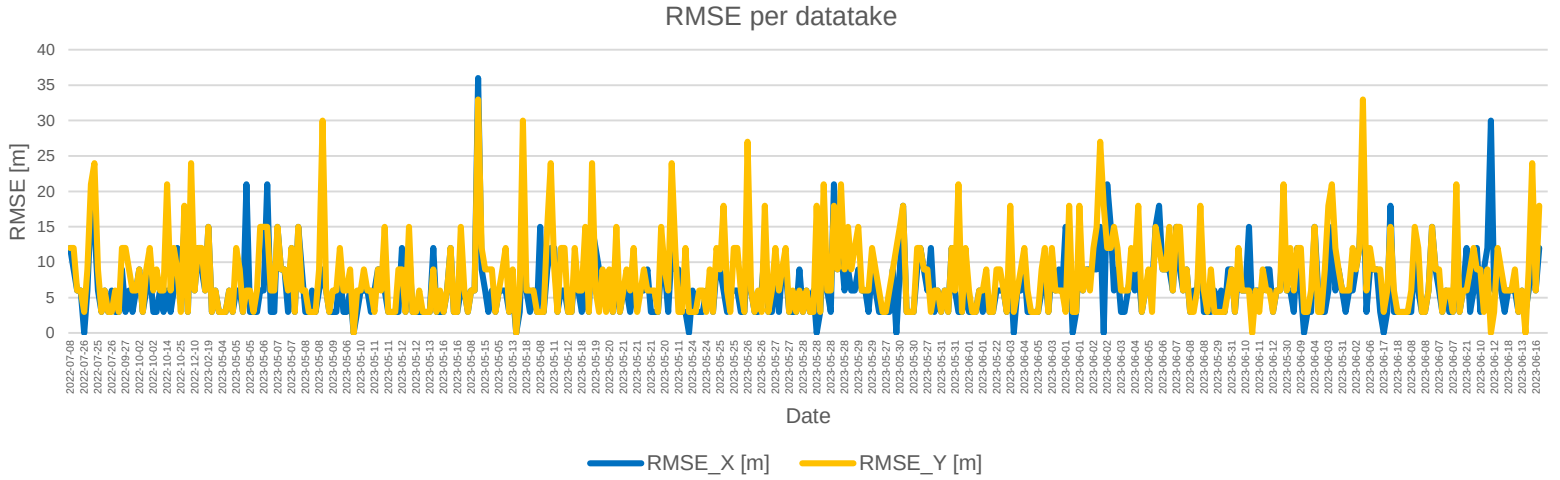


Geometric Performance

- 01.08.2022 (CP) Fix of attitude processing
  - Improvement of absolute geolocation (w/o matching)
- 20.09.2022 (CP) Boresight Calibration
  - Improvement of absolute geolocation (w/o matching)
- 03.11.2022 (end of CP) 1st Geometric Calibration
  - Improvement of absolute geolocation (w/o matching)
  - Improvement of VNIR/SWIR co-registration (~0.8 pix -> ~0.4 pix)
- 11.02.2023 (OP) 2nd Geometric Calibration
  - Improvement of VNIR/SWIR co-registration (~0.4 pix -> ~0.15 pix)
- 29.03.2023 (OP Processor update (v01.02.00)
  - Improvement of VNIR/SWIR co-registration (~0.15 pix -> ~0.06 pix)
- 05.05.2023 (OP) Processor update (v01.03.01)
  - Improvement of geolocation accuracy

Mean co-registration accuracy: ~ 0.06 pix

Mean geolocation accuracy with GCP: ~ 8 m
Mean geolocation accuracy without GCP: ~ 30-50 m



=> 1 year of data

Geometric Performance

- 01.08.2022 (CP) Fix of attitude processing
  - Improvement of absolute geolocation (w/o matching)
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    pix -> ~0.06 pix)
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  - Improvement of geolocation a

Highest geometric performance → Metadata tag archivedVersion >= 01.03.00

Mean co-registration accuracy: ~ 0.06 pix

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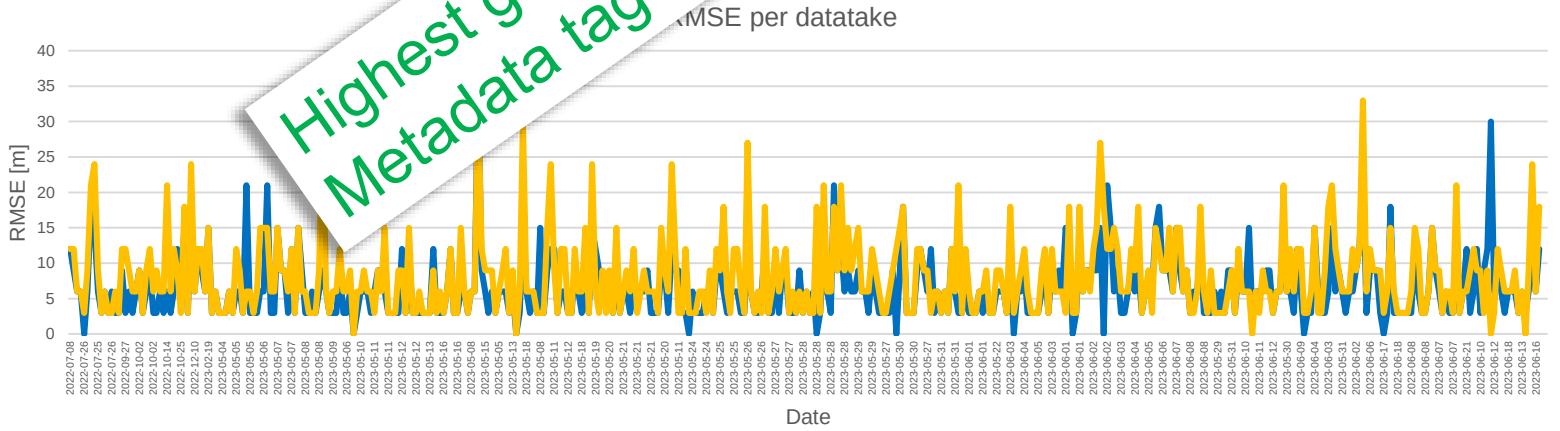
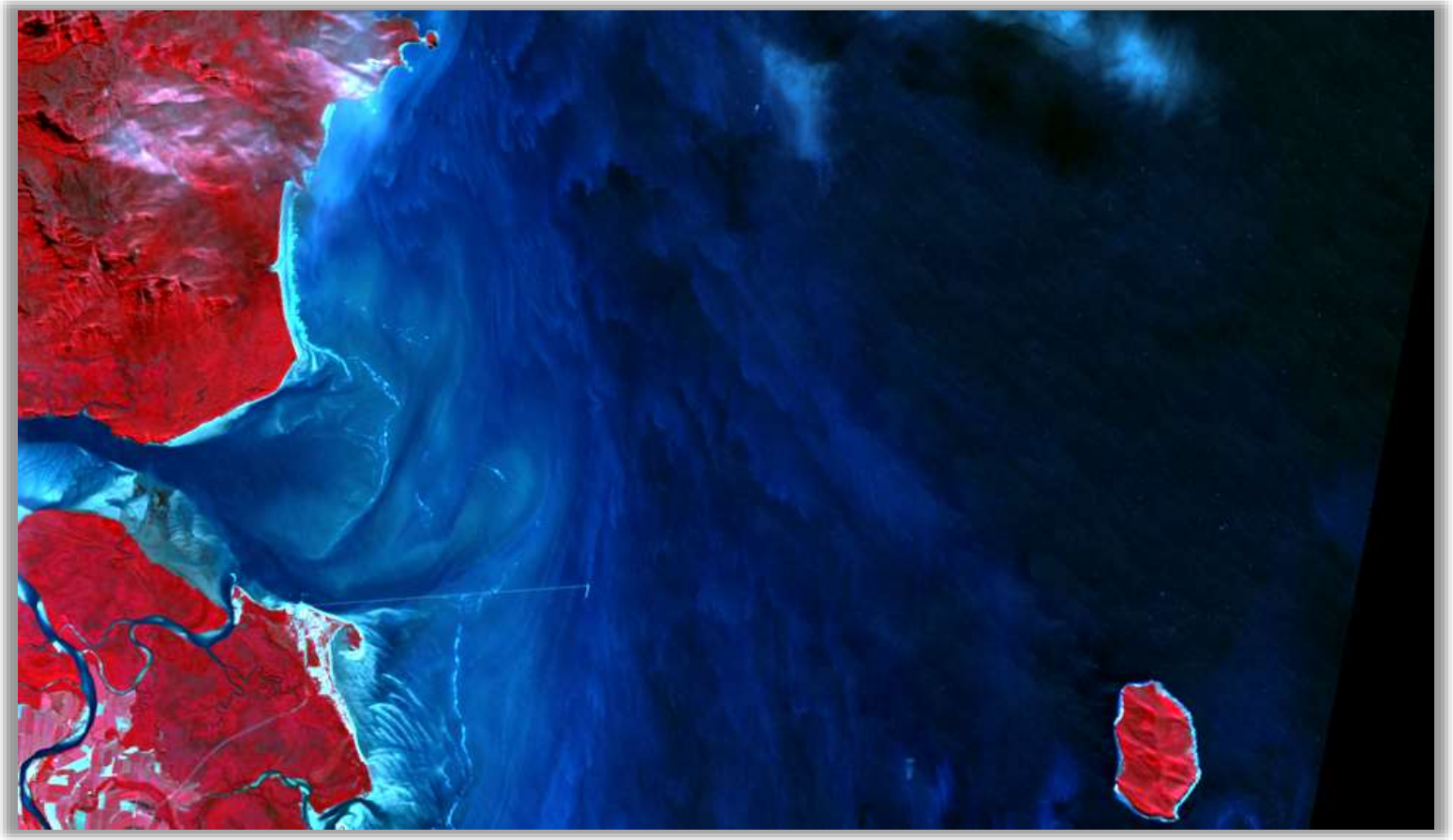


=> 1 year of data

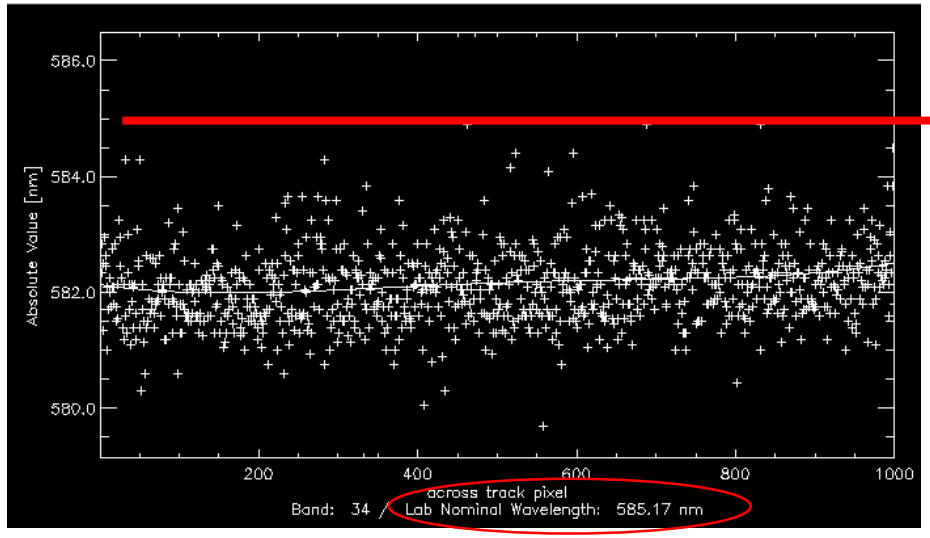
- Spectral Data Properties



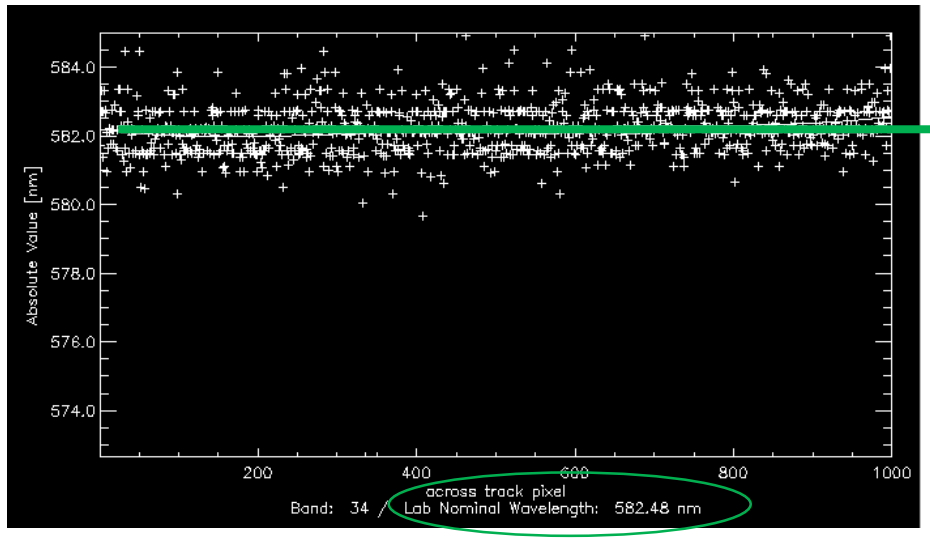
Lucinda Jetty, Australia (CIR)

Spectral Pre- to Post-Launch Changes

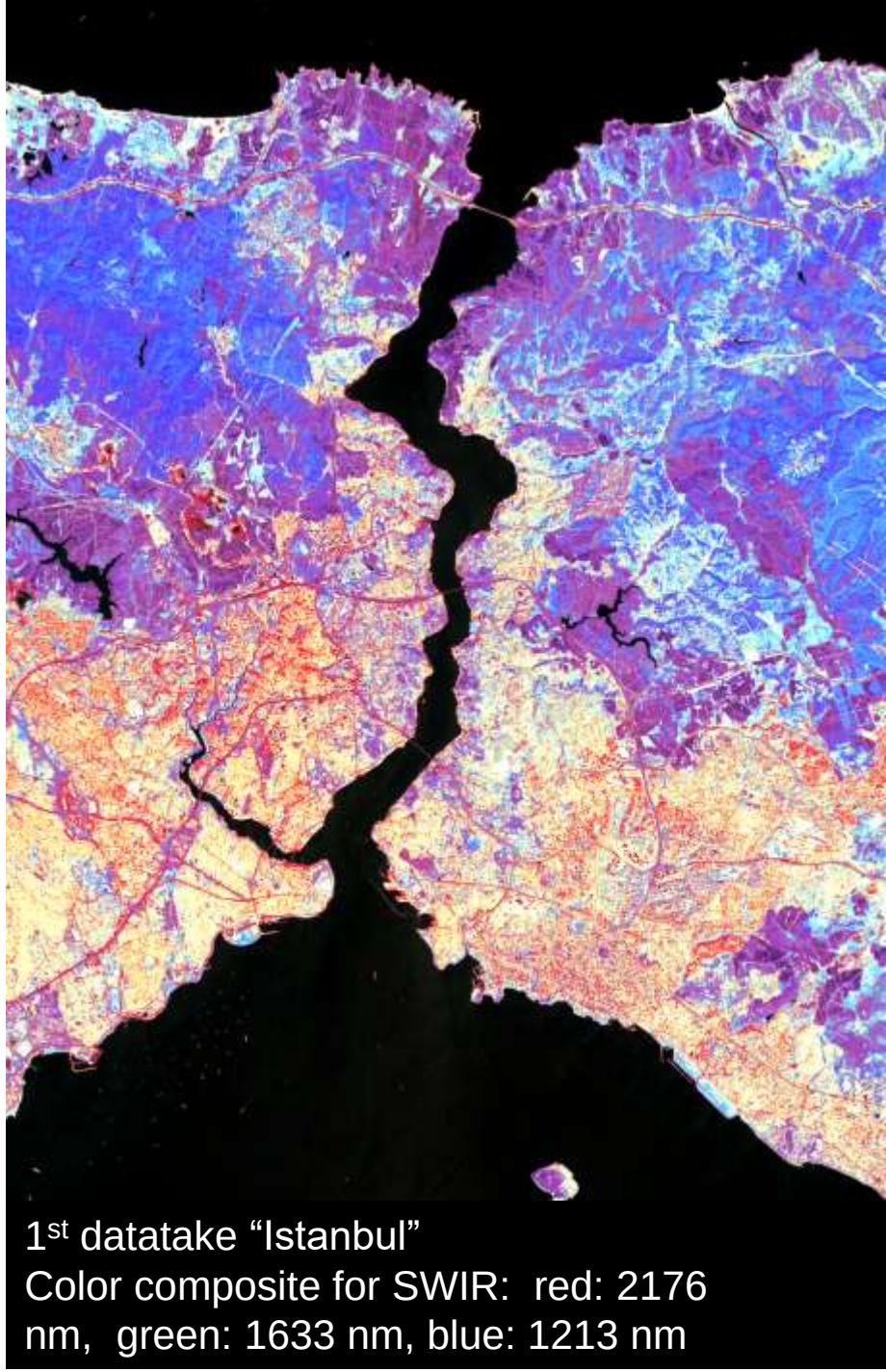
Results from spectral validation for pre- to 1st post-launch calibration tables



Nominal CW, pre-launch Cal. table



Nominal CW, updated Cal. table ✓



1st datatake “Istanbul”
Color composite for SWIR: red: 2176 nm, green: 1633 nm, blue: 1213 nm

Spectral Stability Estimation using all Earth Datatakes

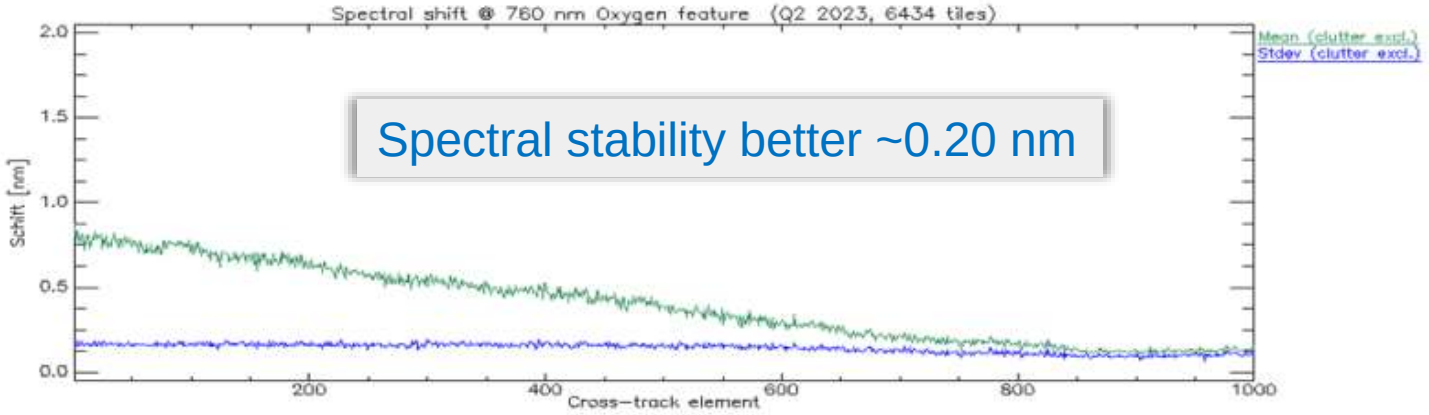


Figure 7-18 VNIR estimated spectral shift at 760 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles

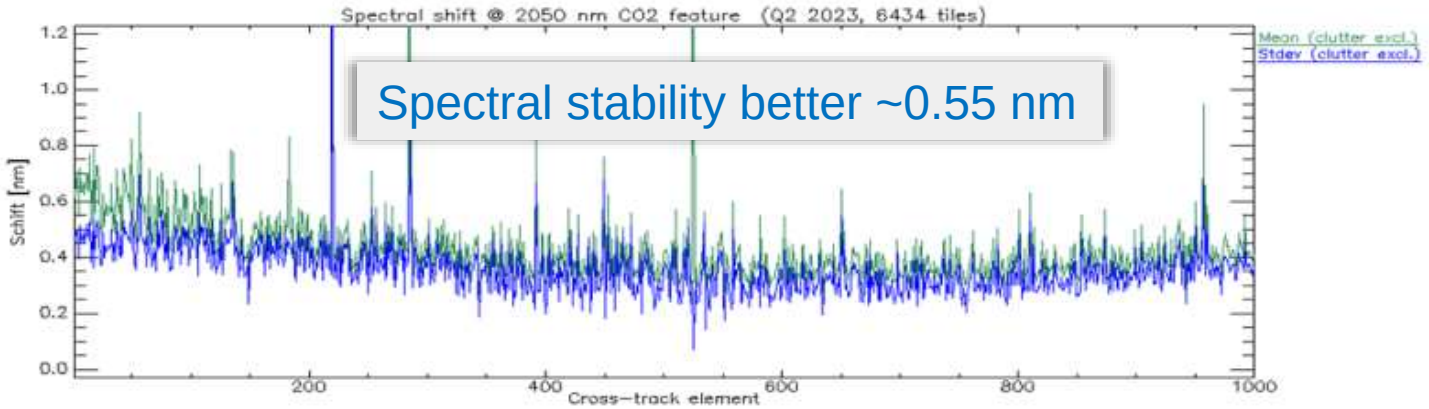


Figure 7-19 SWIR estimated spectral shift at 2050 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles)

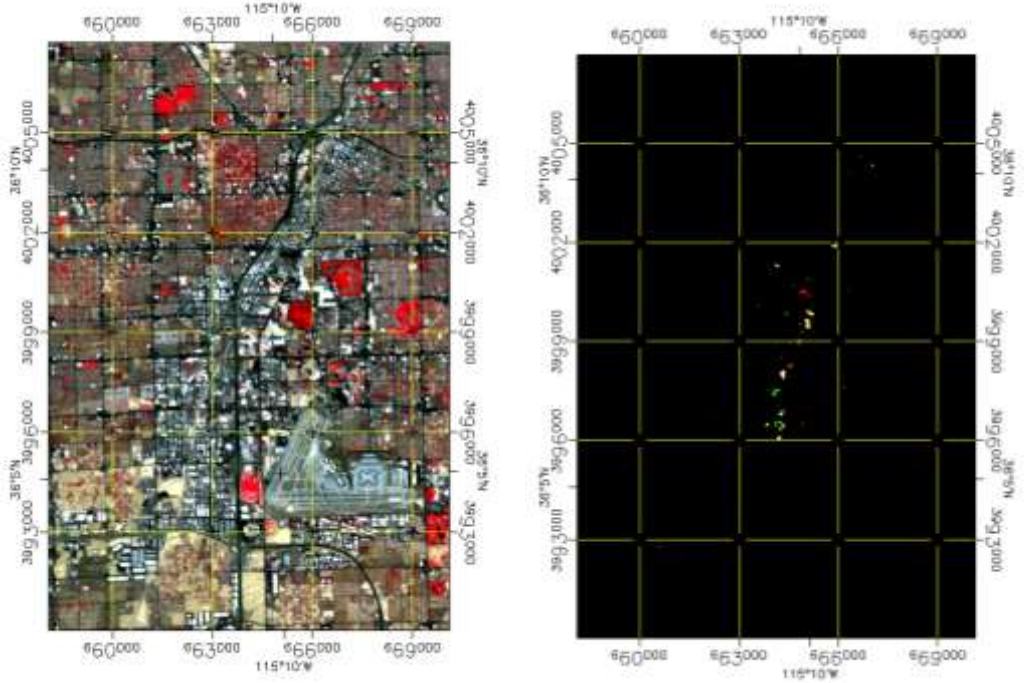
Approach:
fit of normalized TOA_rad to range of simulated spectrally shifted atm. absorption features of O2 @760 nm, CO2 @ ~2050 nm

Result:
Overall good agreement with OBCA and interactive analysis

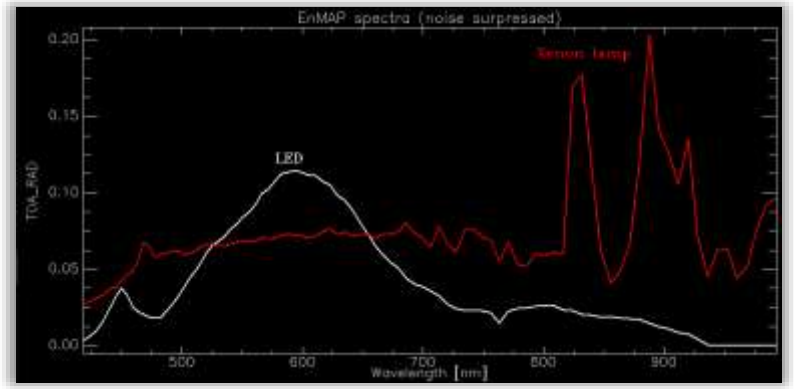
Figures:
Examples for EnMAP VNIR @ 760 nm
and EnMAP SWIR @ 2050 nm
expressed as stdev @ 1 sigma

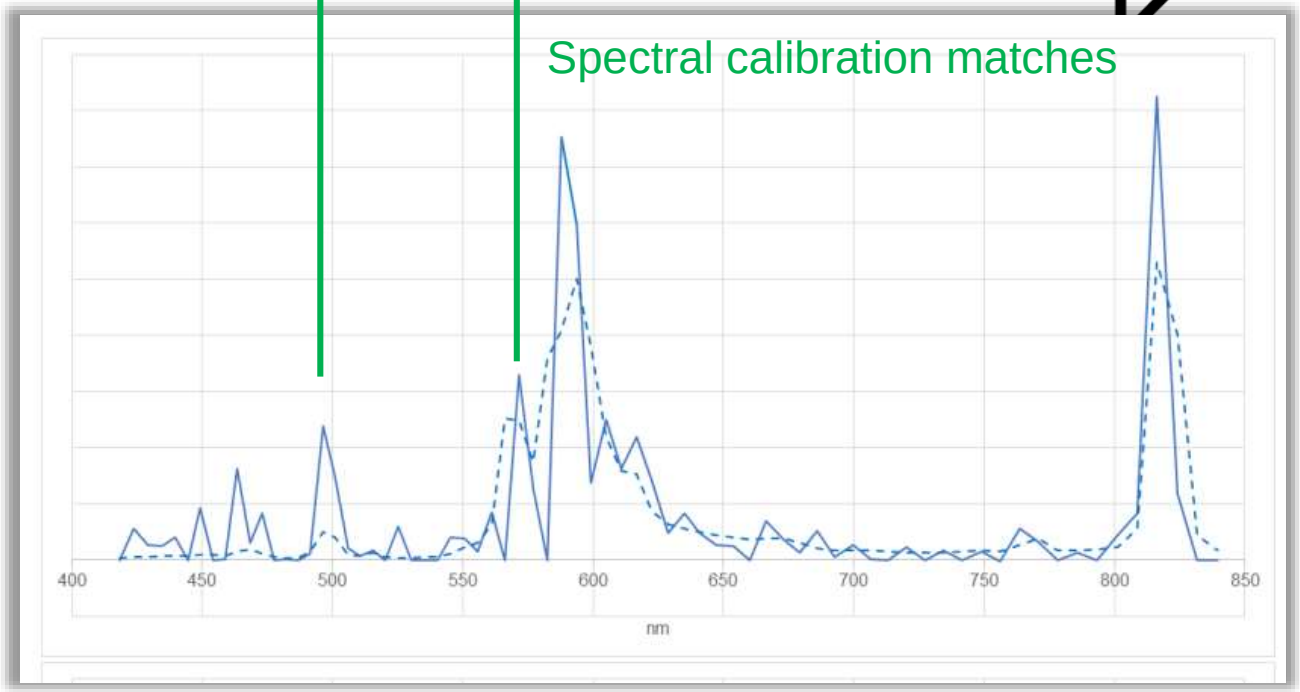
4th mission quarterly report – https://www.enmap.org/mission/

EnMAP – Las Vegas Lights at Night



EnMAP
top-left: CIR day
top-right: broad-band RGB night
right: night-time image spectra (noise-surpressed)





Actual TOA_rad EnMAP (solid) Vs. SpecLib by C. Elvidge
Example: HPS – high pressure sodium lamp

First Nighttime Light Spectra by Satellite—By EnMAP

by Martin Bachmann and Tobias Storch *

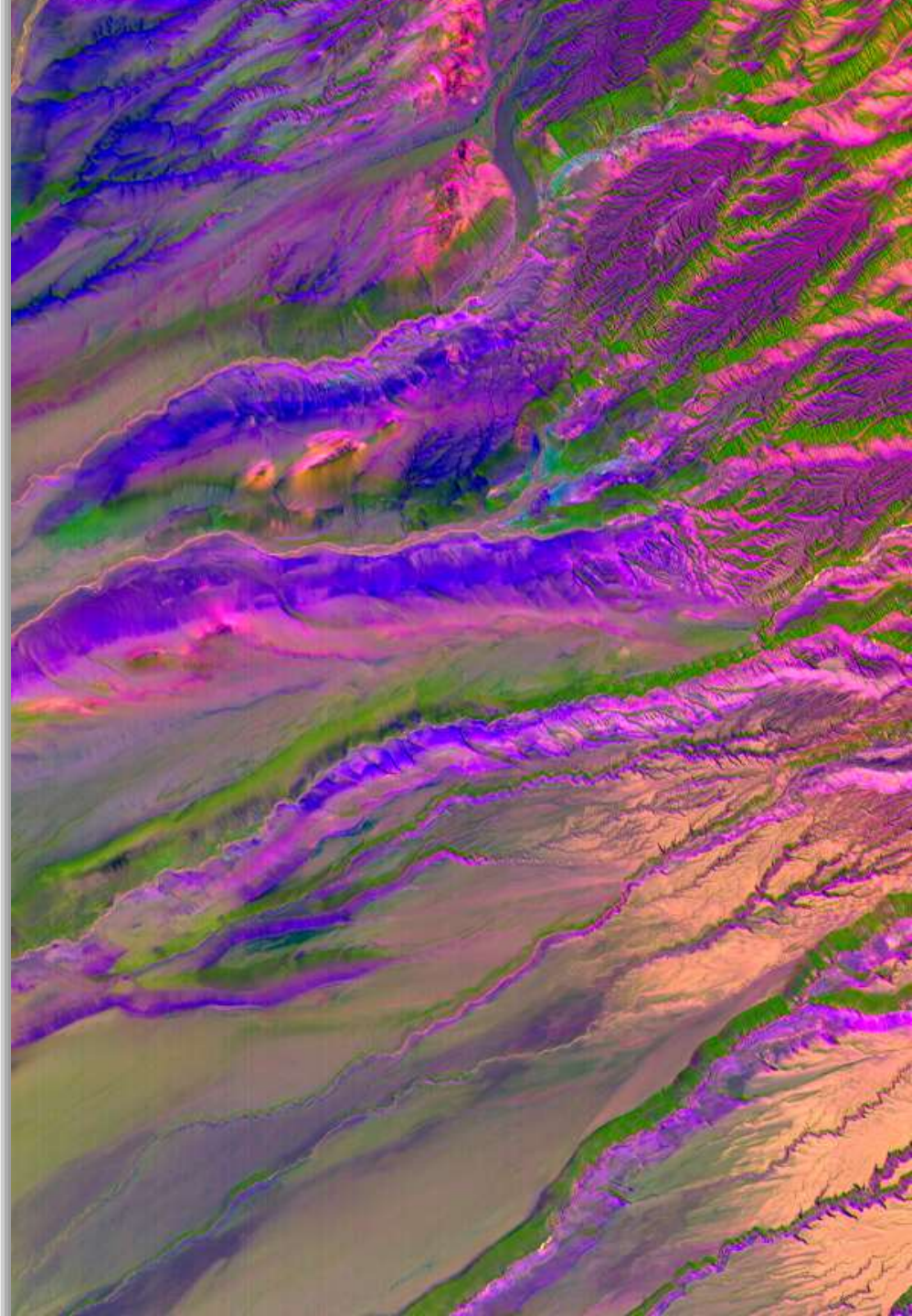
German Aerospace Center (DLR), Earth Observation Center (EOC), Münchener Str. 20, 82234 Weßling, Germany

* Author to whom correspondence should be addressed.

Remote Sens. **2023**, *15*(16), 4025; **https://doi.org/10.3390/rs15164025**

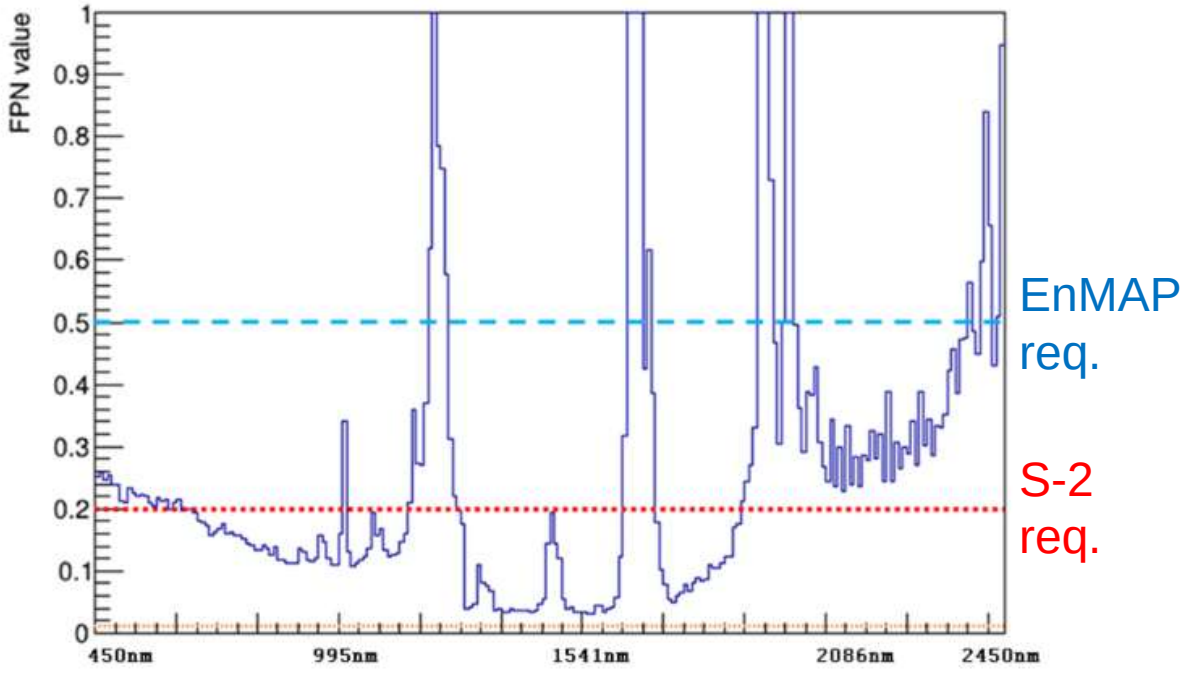
- Radiometric Data Properties

  and Data Artefacts



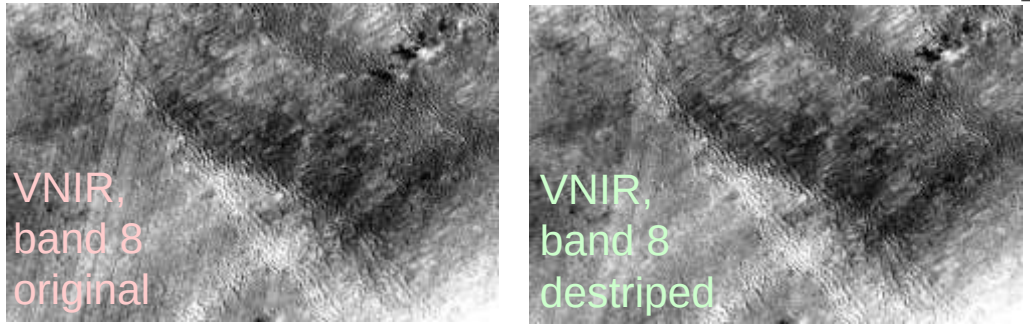
Desert Playa, Peru
(SWIR, PC-Transfo.)

Striping / Fixed Pattern Noise



Blue line: typical EnMAP FPN values; orange line: typical Sentinel-2 FPN values; dashed blue: EnMAP RNU requirement (0.5%); dashed red: Sentinel-2 FPN requirement (0.2%)

Figure 6-21 **Fixed Pattern Noise (FPN) analysis using methodology proposed for Sentinel-2**



De-striping processor – L1C product

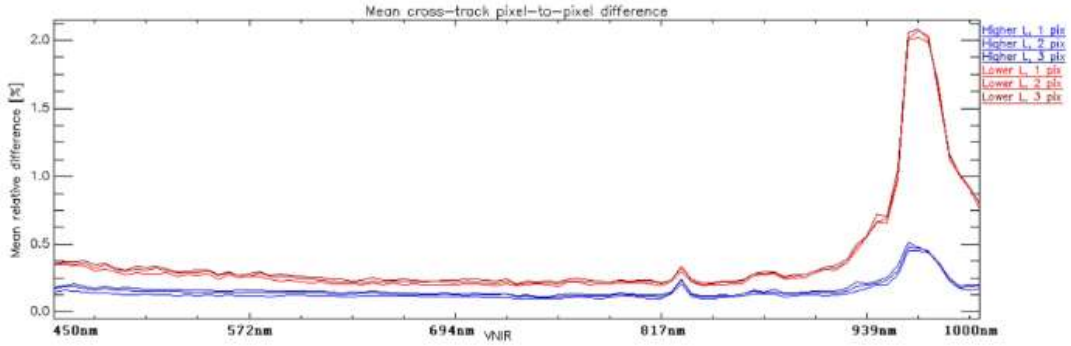
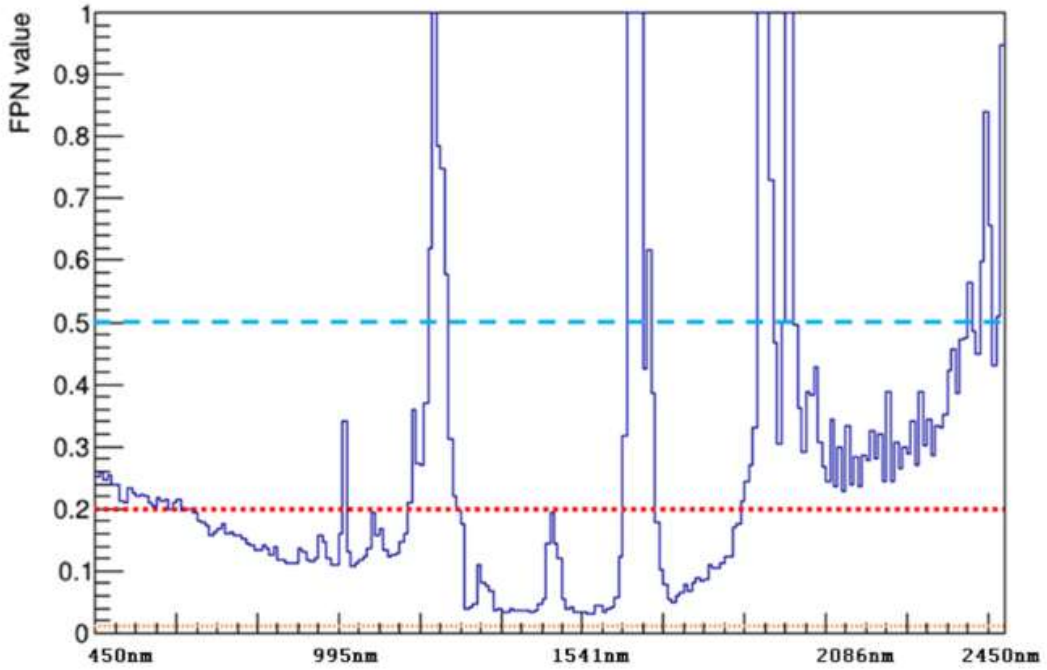


Figure 6-19 **VNIR mean cross-track pixel-to-pixel difference**

- Cross-track striping residual < 0.3% for most bands
- After user feedback, de-striping processor (scene-based) included

1st mission quarterly report – https://www.enmap.org/mission/

Striping / Fixed Pattern Noise



Blue line: typical EnMAP FPN values; orange line: typical Sentinel-2 FPN values; dashed blue: EnMAP RNU requirement (0.5%); dashed red: Sentinel-2 FPN requirement (0.2%)

Figure 6-21 Fixed Pattern Noise (FPN) analysis using methodology proposed for Sentinel-2

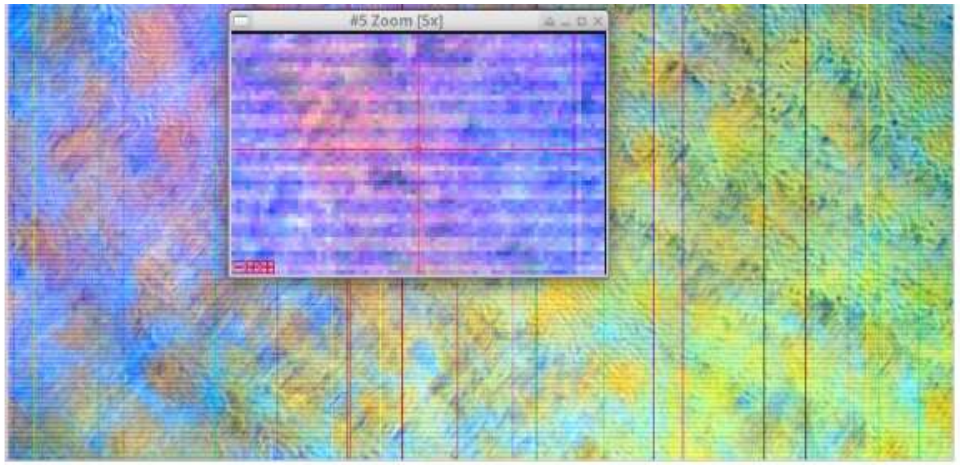


Figure 6-26 Principal Component Analysis (PCA) highlighting along-track striping

SWIR compressor µ-vibrations harmonics (@ 44 Hz, frame rate 230 Hz => 5.2 pix) magnitude well within requirements

1st mission quarterly report – https://www.enmap.org/mission/

Radiometric Offset of VNIR-SWIR Overlap

- Non-linearity effects, esp. at low radiance levels identified as root cause
- Improvements for CAL under investigation

- Geometric co-registration is <u>not</u> the root cause, as jump occurs also for spatially homogeneous areas.

  But co-registration errors can add on top of the radiometric effect.

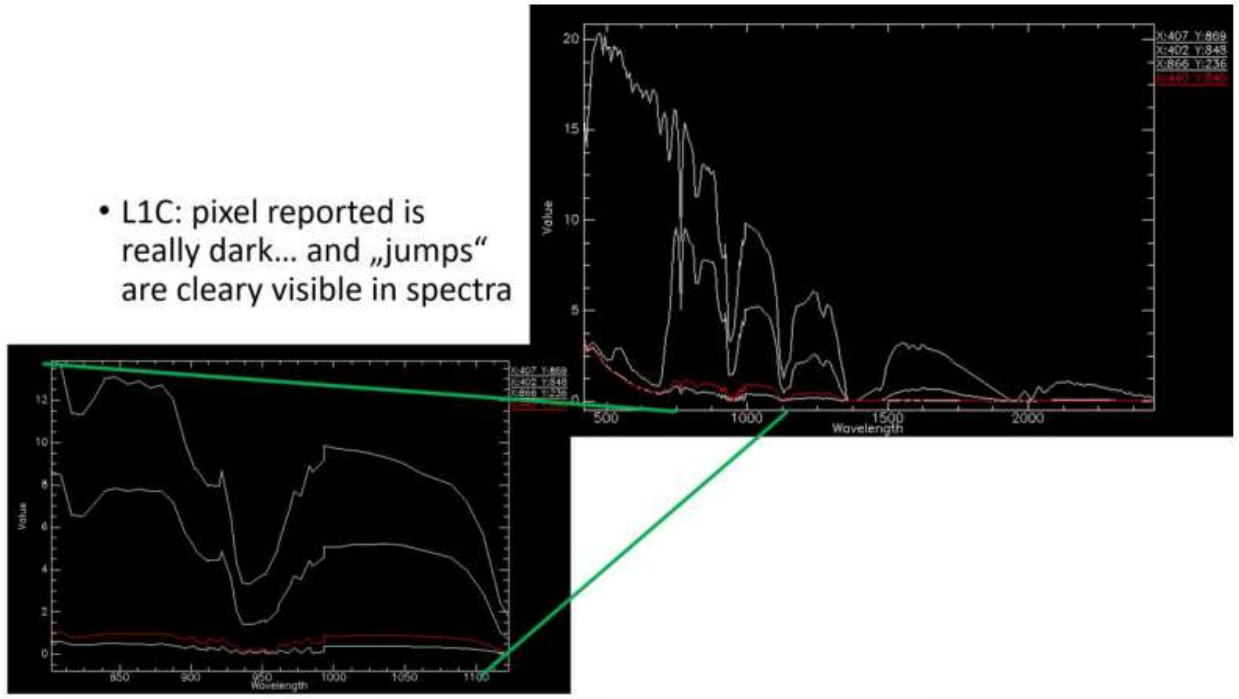


Figure 7-25 L1C radiance spectra of the reported pixel in comparison to spectra of other image locations.

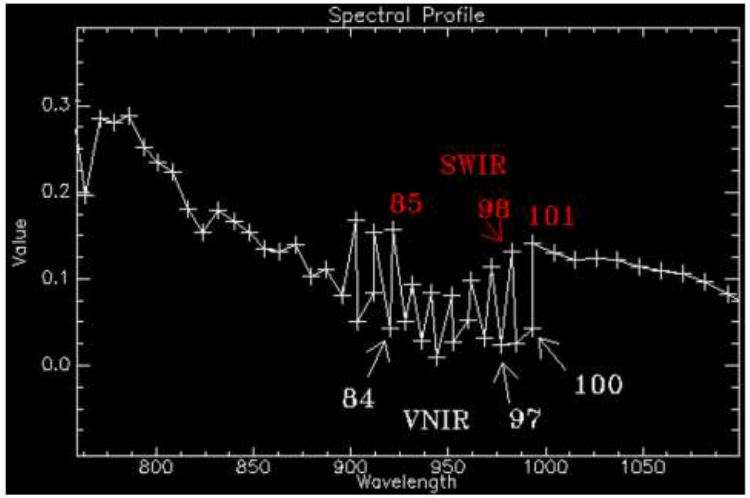


Figure 7-27 Illustration of VNIR-SWIR overlapping region using L1C data.

4th mission quarterly report – https://www.enmap.org/mission/

Other Parameters

- Estimated **SNR** (30% reflectance, 30° sun incidence angle, 21 km visibility, target 500 m above sea level)
  - 620:1 @ 495 nm (requirement: >500:1 for VNIR, low gain)
  - 230:1 @ 2200 nm (requirement: >150:1 for SWIR, high gain)

Other Parameters

- Estimated **SNR** (30% reflectance, 30° sun incidence angle, 21 km visibility, target 500 m above sea level)
  - 620:1 @ 495 nm (requirement: >500:1 for VNIR, low gain)
  - 230:1 @ 2200 nm (requirement: >150:1 for SWIR, high gain)
- **Dead pixels** (in orbit, total):
  - VNIR: 137 (0.2%)
  - SWIR: 1784 (1.2%)

From lab + update using OBCA:
0 dead (no recovery possible)
1 border pixel
2 hot
3 cold
4 flickering
5 stuck
6 readout noise defect
7 linearity defect
8 PRNU defect
9 DSNU defect

From scene:
#10 low radiance
#11 high radiance
#12 maximum radiance value
#13 anomalous pixels

Other Parameters

- Estimated **SNR** (30% reflectance, 30° sun incidence angle, 21 km visibility, target 500 m above sea level)
  - 620:1 @ 495 nm (requirement: >5
  - 230:1 @ 2200 nm (requirement: >1
- **Dead pixels** (in orbit, total):
  - VNIR: 137 (0.2%)
  - SWIR: 1784 (1.2%)
- **Saturation level**: see plot

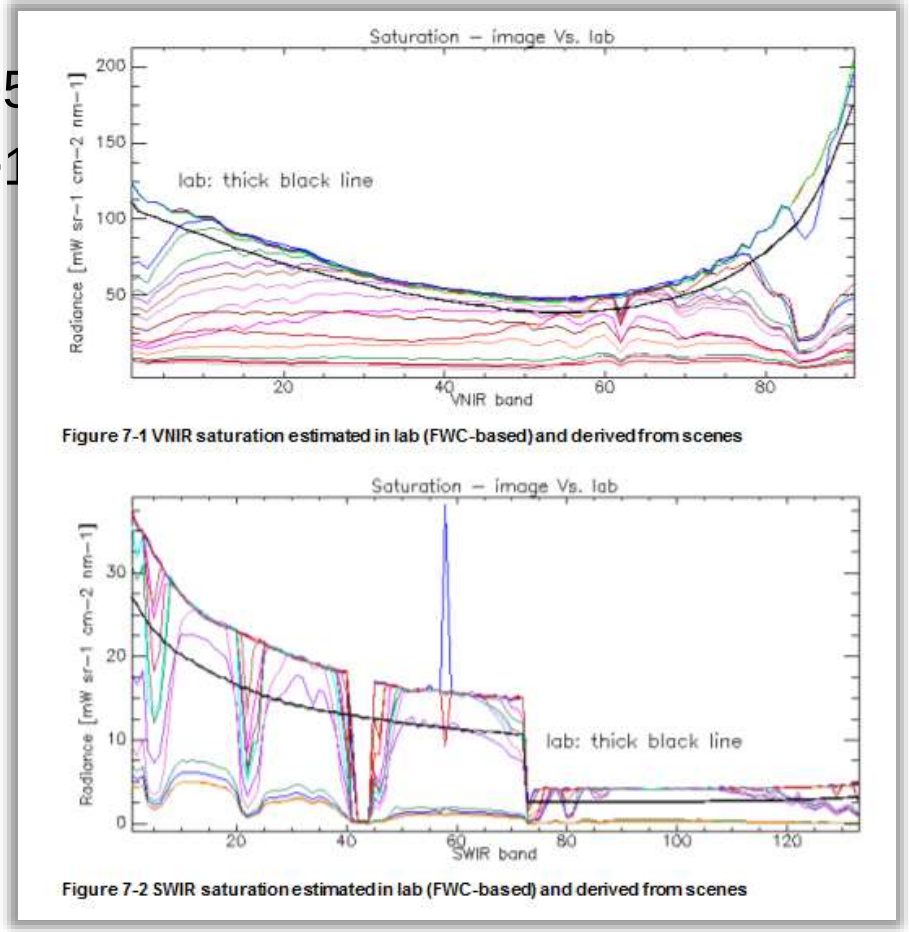


Figure 7-1 VNIR saturation estimated in lab (FWC-based) and derived from scenes

Figure 7-2 SWIR saturation estimated in lab (FWC-based) and derived from scenes

1st mission quarterly report – https://www.enmap.org/mission/

Other Parameters

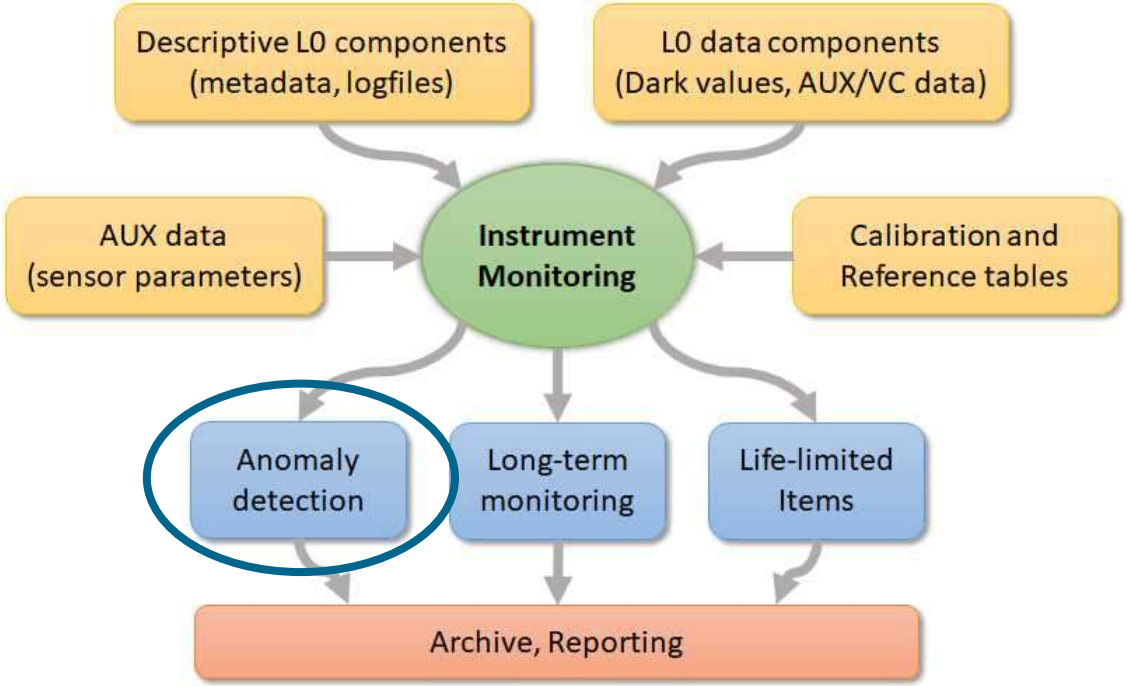
- Estimated **SNR** (30% reflectance, 30° sun incidence angle, 21 km visibility, target 500 m above sea level)
  - 620:1 @ 495 nm (requirement: >500:1 for VNIR, low gain)
  - 230:1 @ 2200 nm (requirement: >150:1 for SWIR, high gain)
- **Dead pixels** (in orbit, total):
  - VNIR: 137 (0.2%)
  - SWIR: 1784 (1.2%)
- **Saturation level**

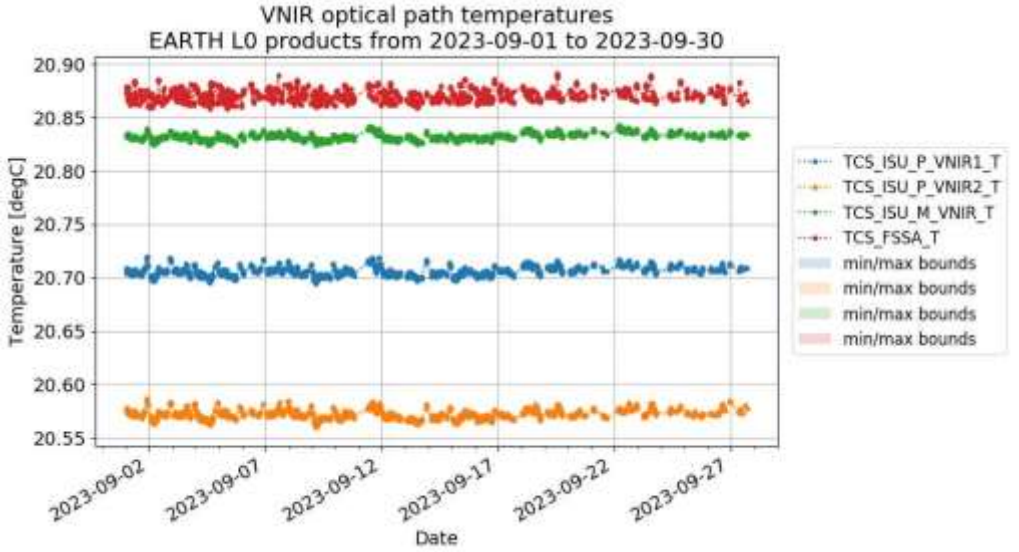
Figure 6-23 Fringing of the VNIR, Principal Component-transformed data

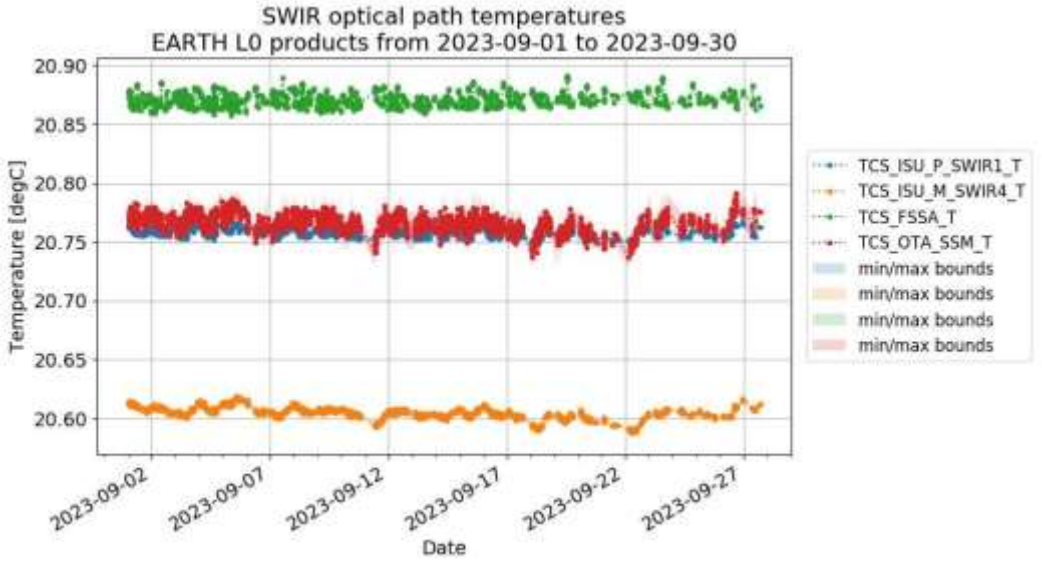
- **Fringing** in VNIR (CMOS detector) as expected

1st mission quarterly report – https://www.enmap.org/mission/

Instrument Monitoring



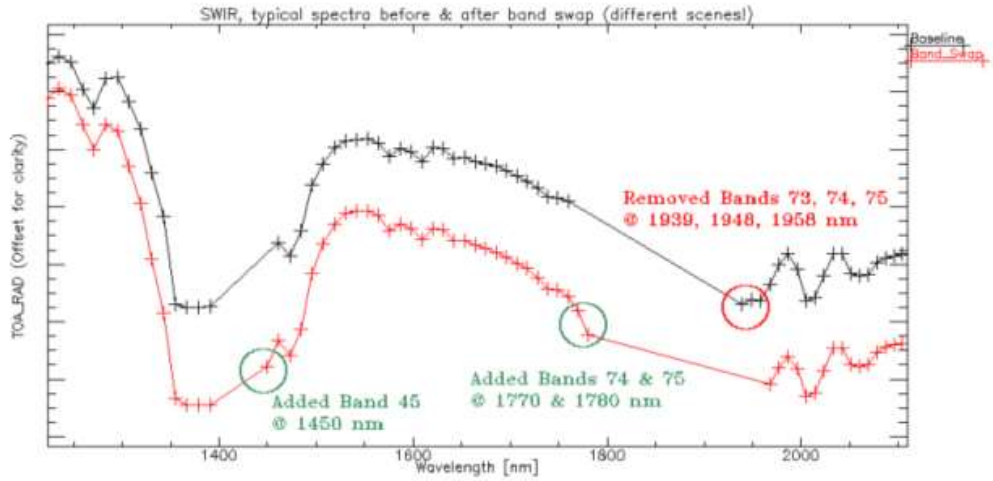


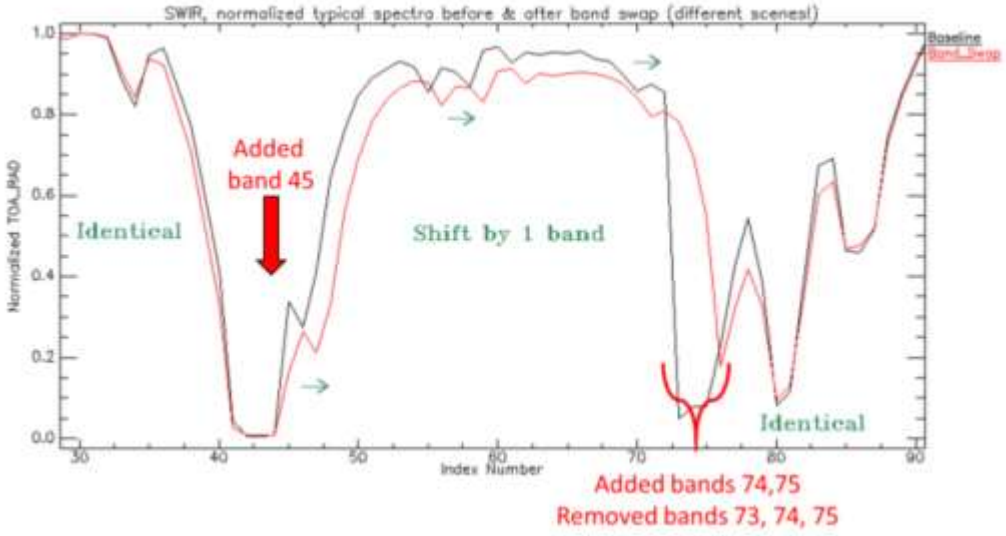


Changes in Instrument & Data Products

- SWIR band configuration changed on July 5, 2023,
  as requested by users & EnSAG

- Important:
  when addressing by band number (and not by wavelengths),
  then SWIR bands #45 to #75
  (full cube bands #136 to #167)
  are shifted by one band between periods before / after 05.07.2023



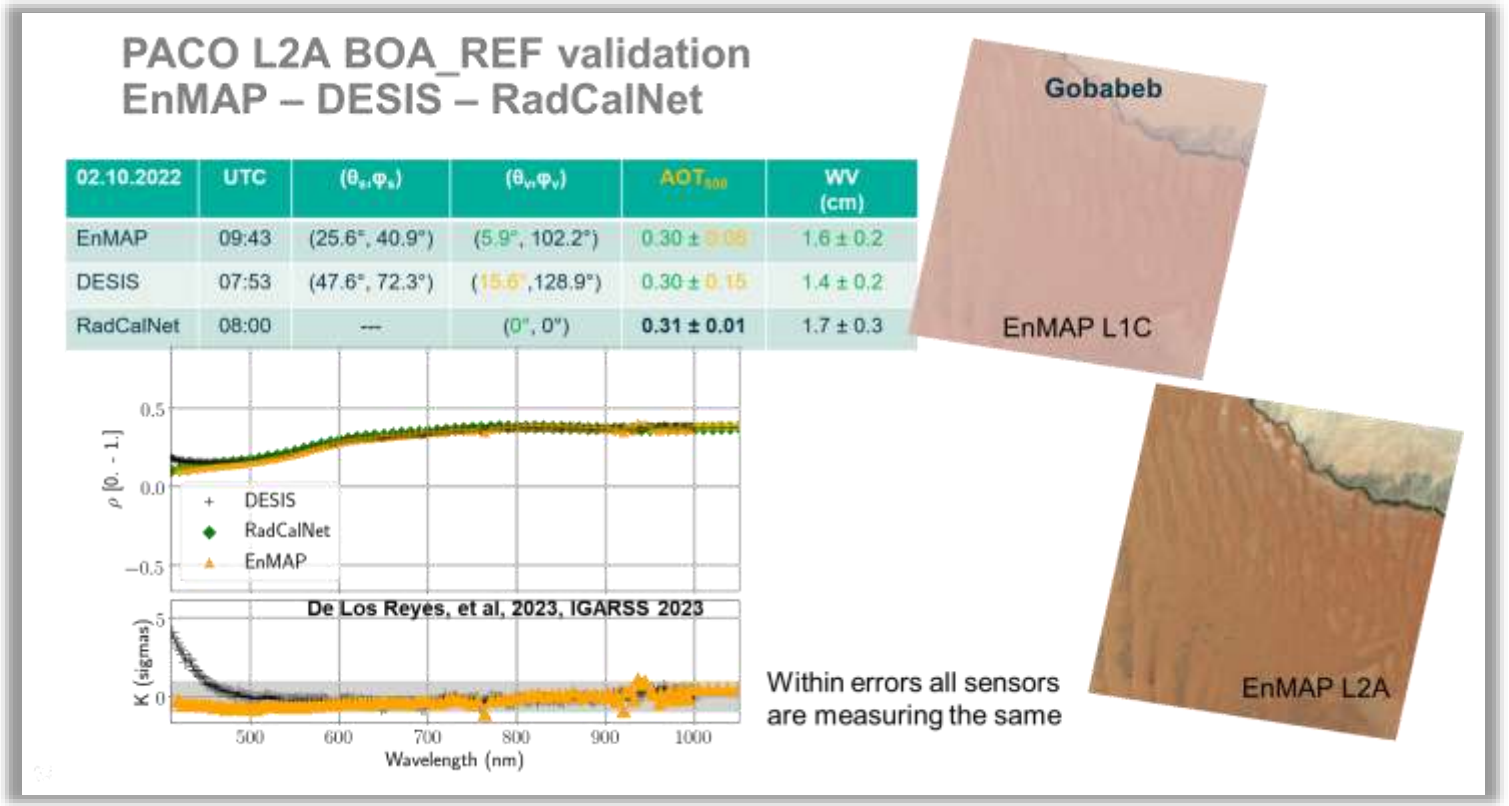


L1B TOA_rad & L2A BOA_ref Validation

- Independent validation lead by GFZ
  - ➢ see presentation by Max Brell

Additionally within the GS @ DLR:

- Routine EnMAP validation of TOA_rad & BOA_ref over RadCalNet and PICS
- Airborne & field campaigns at Panzerwiese site



Thank you for your attention

- For performance on the processing chain, data quality, external validation results, see Mission Quarterly Reports at: https://www.enmap.org/mission/

and

- For full description in QC-related metadata and flags https://www.enmap.org/data/doc/EN-PCV-ICD-2009-2_**HSI_Product_Specification**_Level1_Level2.pdf

and

- For any questions on data quality, please use the official contact form at https://www.enmap.org/contact/

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