



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



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
 - Available already in archived L0 products:



The screenshot shows the EOWEB GeoPortal interface. At the top, there are navigation tabs: Home, Collections, Products, Maps, and Cart (0). Below the navigation, there are filter management options for Collections and Region. A map view shows a region in Switzerland. To the right of the map, there are filters for Time (Start: 1970-01-01, End: 2023-10-09) and Collection (TanDEM-X Pursuit TSX-1 Like, DESIS, ENMAP). The ENMAP collection is expanded, showing ENMAP-HSI (L0), ENMAP-HSI Calibration Data, and ENMAP-HSI (L0), Low Quality. Below the filters is a search button. At the bottom, a table displays search results for ENMAP-HSI L0 products. The table has columns for Id, Avail, Product Type, Start Date, End Date, Datalake Id, Tile Id, Sun Elevation Angle, Cloud Cover, Orbit Number, and Orbit Dir. A blue circle highlights the 'Toggle View' icon in the table header.

Id	Avail	Product Type	Start Date	End Date	Datalake Id	Tile Id	Sun Elevation Angle	Cloud Cover	Orbit Number	Orbit Dir
1	●	ENMAP-HSI L0	2023-10-03T10:50:38.4272	2023-10-03T10:50:42.9192	44414	33	38.900658	2	8104	DESCEN
2	●	ENMAP-HSI L0	2023-10-03T10:50:33.9752	2023-10-03T10:50:38.5102	44414	32	38.646803	1	8104	DESCEN
3	●	ENMAP-HSI L0	2023-10-03T10:50:29.5232	2023-10-03T10:50:34.0582	44414	31	38.392947	1	8104	DESCEN
4	●	ENMAP-HSI L0	2023-10-03T10:50:25.0712	2023-10-03T10:50:29.6062	44414	30	38.139091	0	8104	DESCEN
5	●	ENMAP-HSI L0	2023-10-03T10:50:20.6192	2023-10-03T10:50:25.1542	44414	29	37.885236	27	8104	DESCEN
6	●	ENMAP-HSI L0	2023-10-03T10:50:16.1672	2023-10-03T10:50:20.7022	44414	28	37.631380	47	8104	DESCEN
7	●	ENMAP-HSI L0	2023-09-29T10:47:11.4452	2023-09-29T10:47:15.9372	44371	33	40.28677	0	8045	DESCEN

qualityDetails	
overallQuality	0
overallQualityVNIR	0
overallQualitySWIR	0
productScreeningResultStatus	OK
productScreeningFailedGroups	NONE

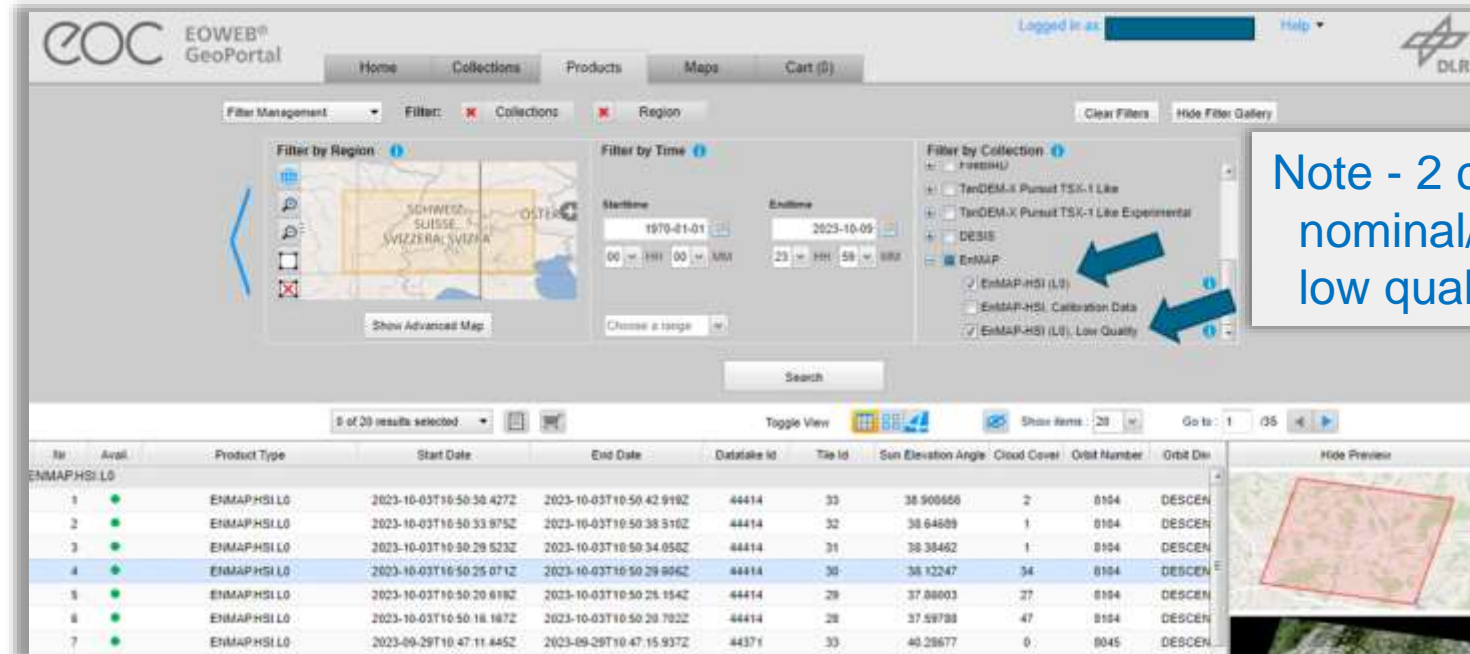
instrumentStatus	
statusOK	true
statusVNIR	on
vnirNumberChannelsMissing	0
SWIRAorSWIRBSelected	SWIRA
statusSWIR	on
swirNumberChannelsMissing	0

level1B	
qualityRadiometryVNIR	0
qualityRadiometrySWIR	0
stripingBandingVNIR	0
stripingBandingSWIR	0
saturationCrosstalkVNIR	0
saturationCrosstalkSWIR	0
generalArtifactsVNIR	2
generalArtifactsSWIR	14
deadPixelsVNIR	137
deadPixelsSWIR	1509
defectivePixelsVNIR	2
defectivePixelsSWIR	13

level1C	
orbitNumber	8104
orbitDirection	DESCENDING
resolution	30.0
meanGroundElevation	829.989
orthoTerrain	0
orthoRMSE	6
orthoRMSE_x	3
orthoRMSE_y	5
orthoResidual	8
orthoResidual_x	6

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
 - Available already in archived L0 products:



The screenshot shows the EOWEB GeoPortal interface. At the top, there are navigation tabs: Home, Collections, Products, Maps, and Cart (0). The main area is divided into several sections: Filter Management, Filter by Region (showing a map of Switzerland), Filter by Time (with start and end date pickers), and Filter by Collection (listing various data collections). A search button is located below the filters. Below the filters, there is a table with 7 rows of data. The table has columns for #, Avail, Product Type, Start Date, End Date, Datalake Id, Tile Id, Sun Elevation Angle, Cloud Cover, Orbit Number, and Orbit Dir. The first row is highlighted in blue.

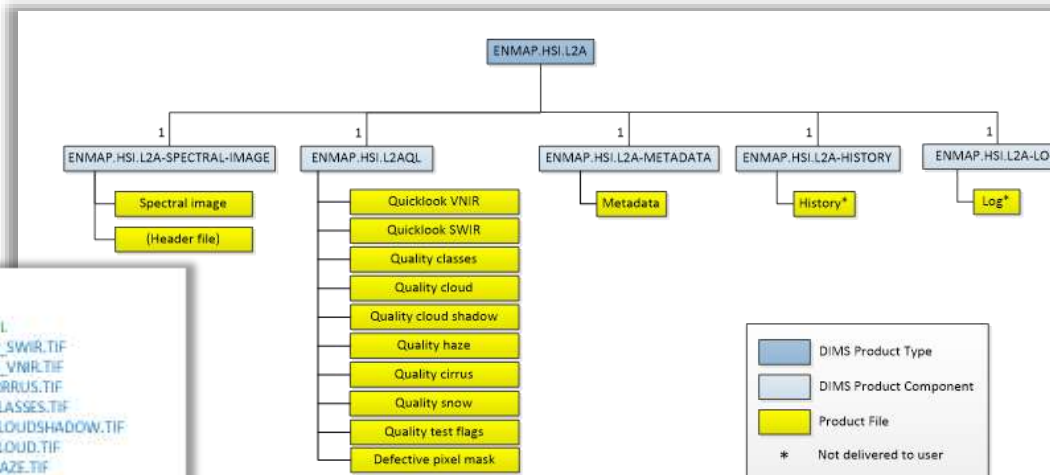
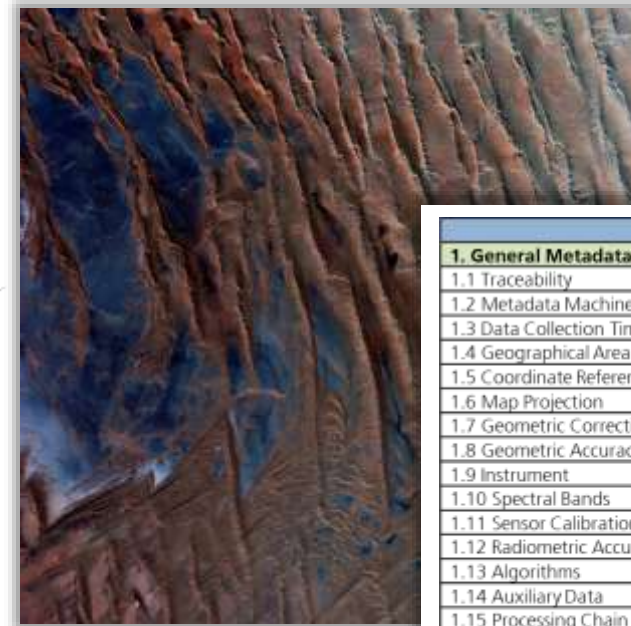
#	Avail	Product Type	Start Date	End Date	Datalake Id	Tile Id	Sun Elevation Angle	Cloud Cover	Orbit Number	Orbit Dir
1	●	ENMAPHSI L0	2023-10-03T10:50:58.427Z	2023-10-03T10:50:42.919Z	44414	33	38.900658	2	8104	DESCEN
2	●	ENMAPHSI L0	2023-10-03T10:50:53.975Z	2023-10-03T10:50:38.510Z	44414	32	38.646803	1	8104	DESCEN
3	●	ENMAPHSI L0	2023-10-03T10:50:29.523Z	2023-10-03T10:50:34.058Z	44414	31	38.384462	1	8104	DESCEN
4	●	ENMAPHSI L0	2023-10-03T10:50:25.071Z	2023-10-03T10:50:29.896Z	44414	30	38.12247	34	8104	DESCEN
5	●	ENMAPHSI L0	2023-10-03T10:50:20.819Z	2023-10-03T10:50:25.154Z	44414	29	37.88803	27	8104	DESCEN
6	●	ENMAPHSI L0	2023-10-03T10:50:18.187Z	2023-10-03T10:50:20.792Z	44414	28	37.59798	47	8104	DESCEN
7	●	ENMAPHSI L0	2023-09-29T10:47:11.445Z	2023-09-29T10:47:15.937Z	44371	33	40.28677	0	8045	DESCEN

Note - 2 collections:
nominal/reduced &
low quality data

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
 - Available already in archived L0 products:



```

ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-HISTORY.XML
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-LOG.XML
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-METADATA.XML
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_PIXELMASK_SWIR.TIF
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
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_CLOUD.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_HAZE.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_SNOW.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_TESTFLAGS_SWIR.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_QUALITY_TESTFLAGS_VNIR.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_SWIR.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-QL_VNIR.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-SPECTRAL_IMAGE_SWIR.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-SPECTRAL_IMAGE_VNIR.TIF
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-VC_DATA_SWIR.BIN
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-VC_DATA_VNIR.BI
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-AUX_DATA_SWIR.OUT
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-AUX_DATA_VNIR.OUT
ENMAP01- L0-DT0000000001_20220427T092849Z_006_V010001_20220428T145024Z-DIM.TGZ
    
```

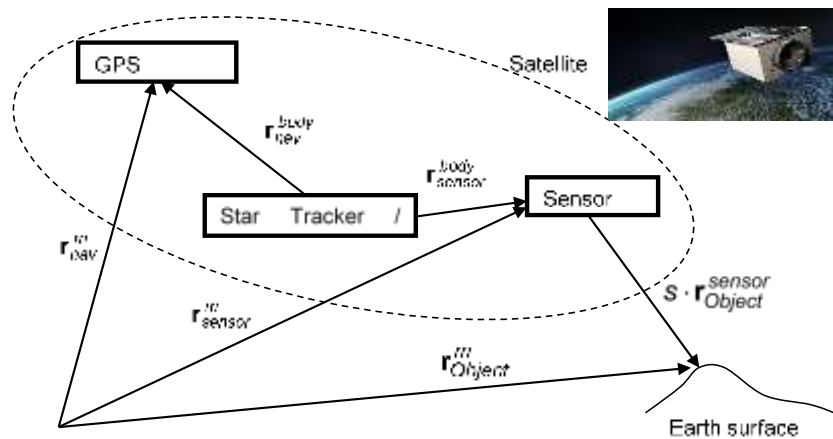
	Threshold	Target
1. General Metadata		
1.1 Traceability	n.a.	no
1.2 Metadata Machine Readability	ok	ok
1.3 Data Collection Time	ok	no
1.4 Geographical Area	ok	ok
1.5 Coordinate Reference System	ok	ok
1.6 Map Projection	ok	ok
1.7 Geometric Correction Methods	n.a.	ok
1.8 Geometric Accuracy of the Data	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

- Geometric Data Properties

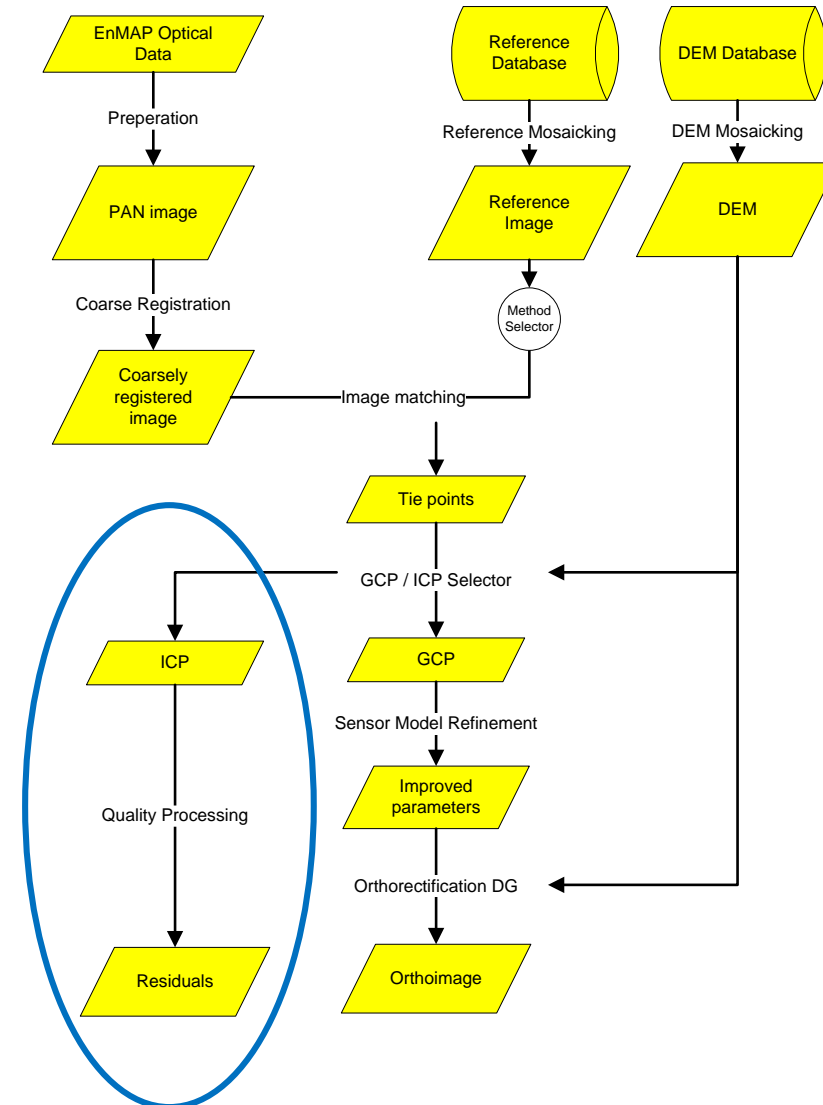


Geometric Processing

- 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



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



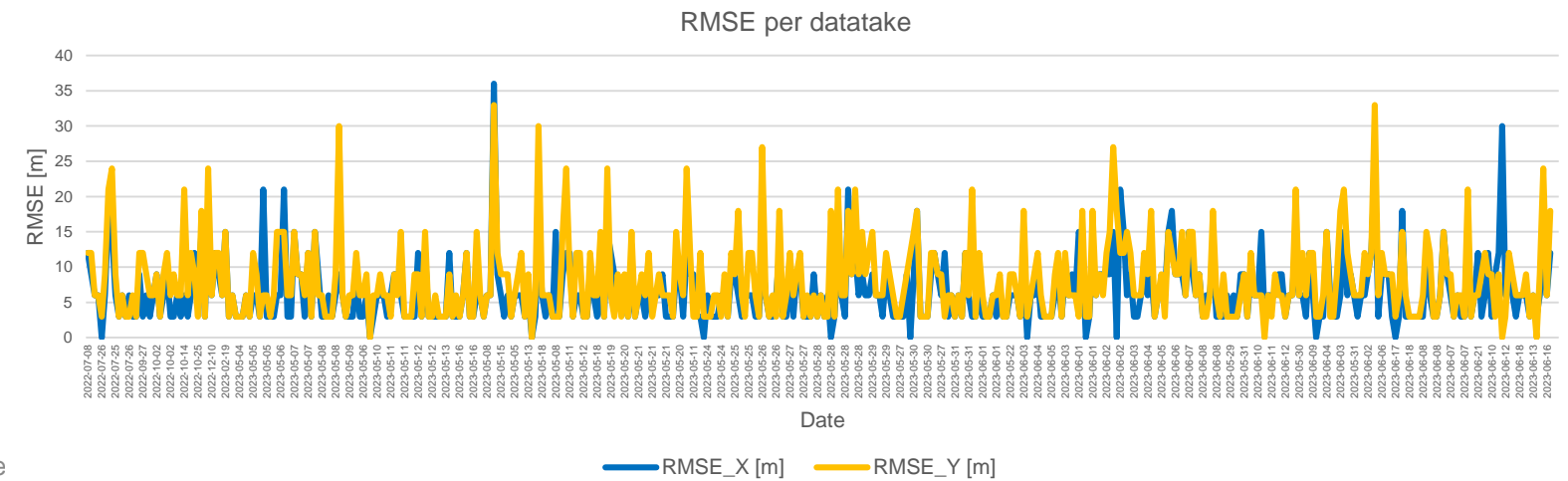
Geometric Performance



- 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

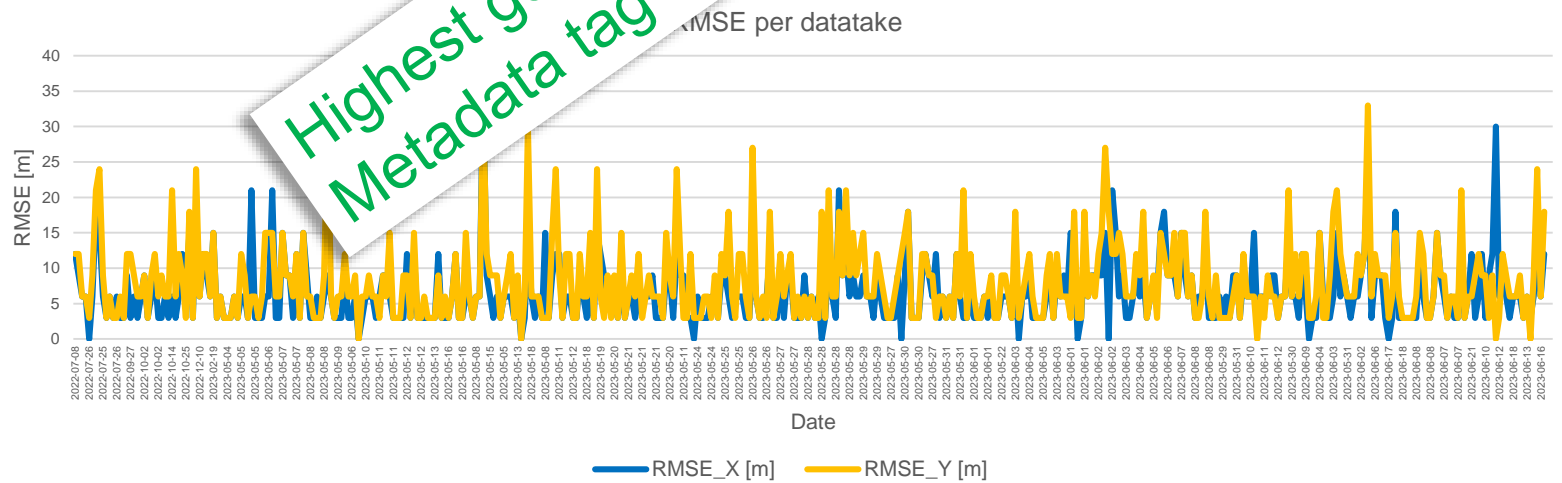


- 01.08.2022 (CP) Fix of attitude processing
 - Improvement of absolute geolocation (w/o matching)
- 20.09.2022 (CP) Boresight Calibration
 - Improvement of absolute geolocation (w/o matching)
- 03.11.2022 (end of CP) 1st Geometric Calibration
 - Improvement of absolute geolocation (w/o matching)
 - 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 (v01.03.00)
 - Improvement of geolocation



Highest geometric performance →
Metadata tag archived Version >= 01.03.00

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

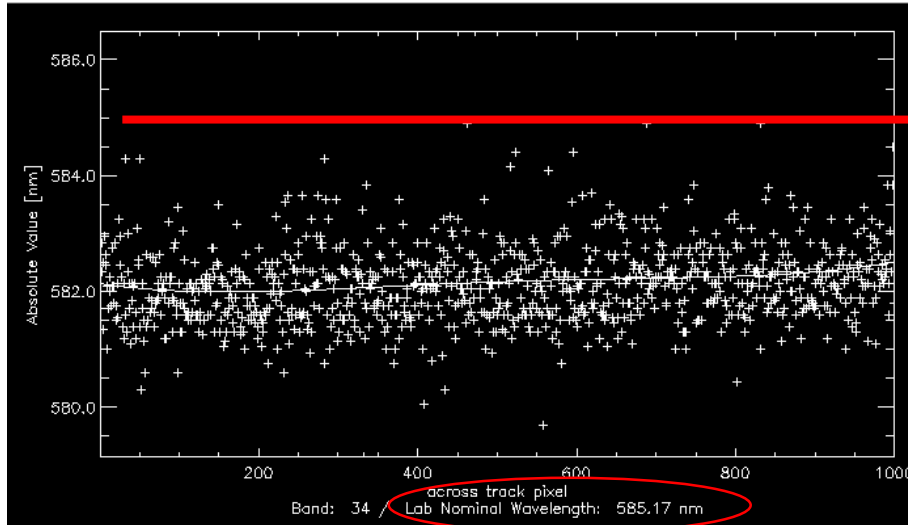
- Spectral Data Properties



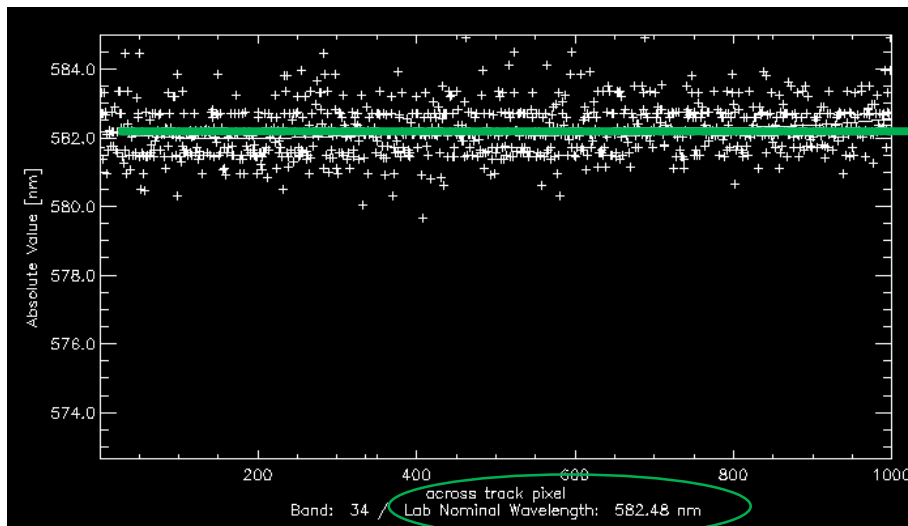
Lucinda Jetty, Australia (CIR)

Spectral Pre- to Post-Launch Changes

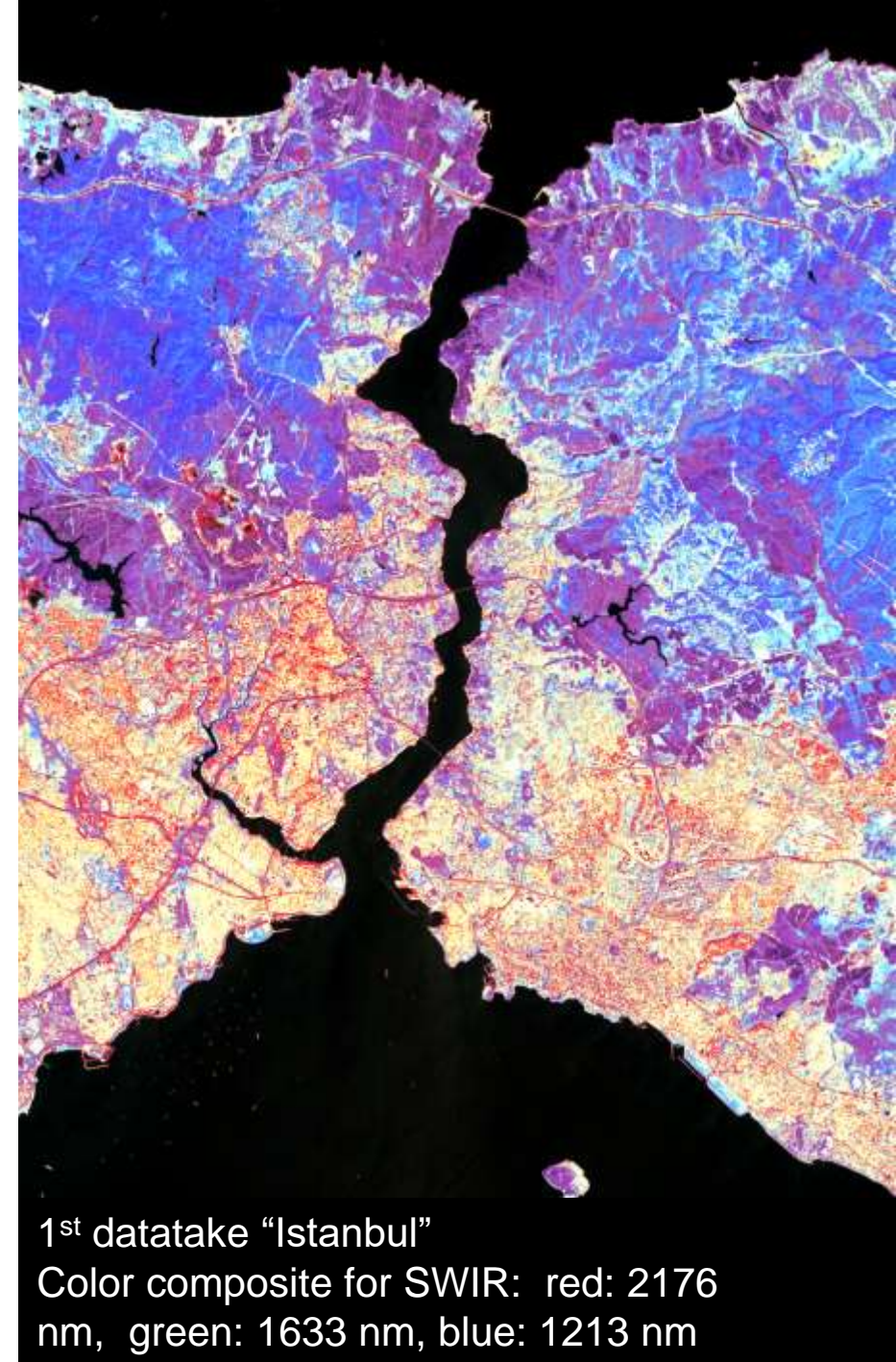
Results from spectral validation for pre- to 1st post-launch calibration tables



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

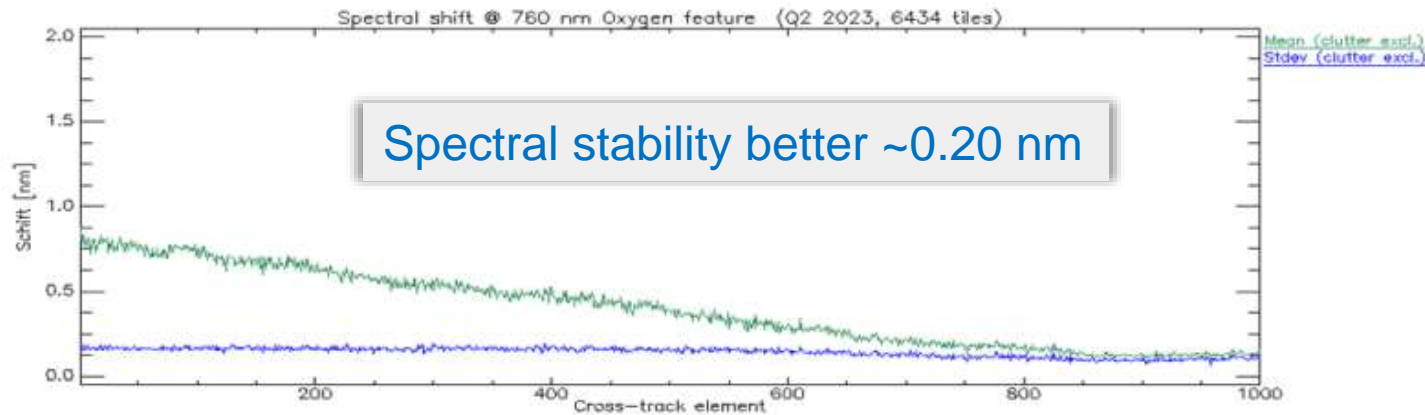


Figure 7-18 VNIR estimated spectral shift at 760 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles)

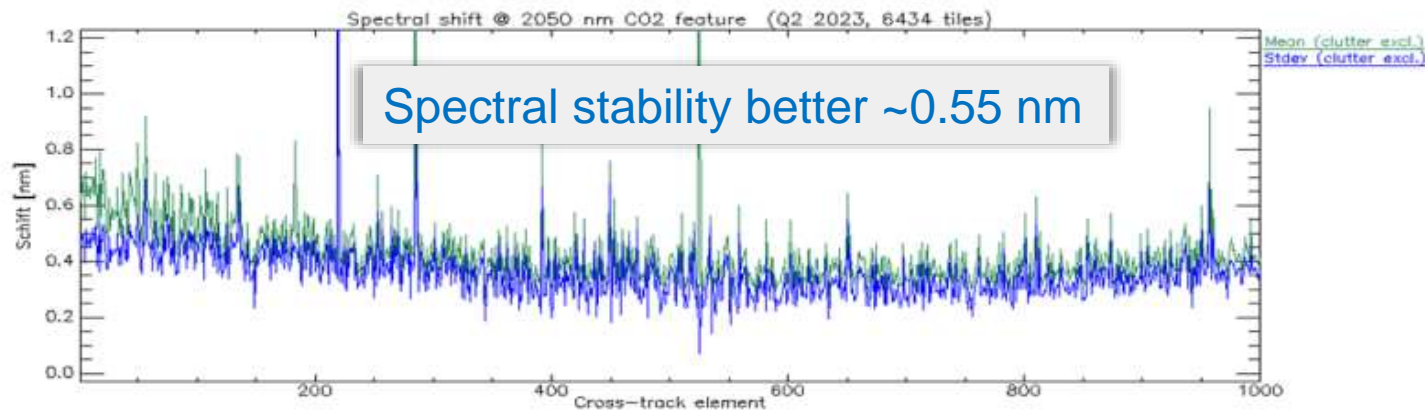


Figure 7-19 SWIR estimated spectral shift at 2050 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles)

Approach:

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

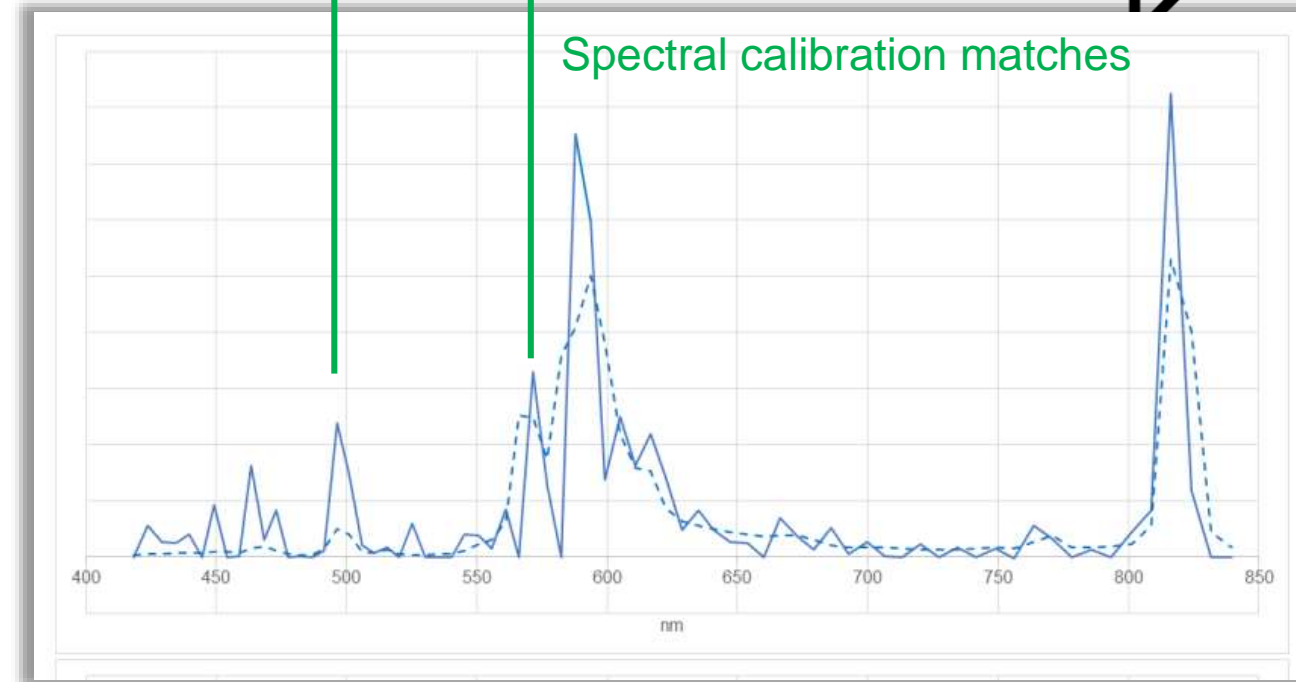
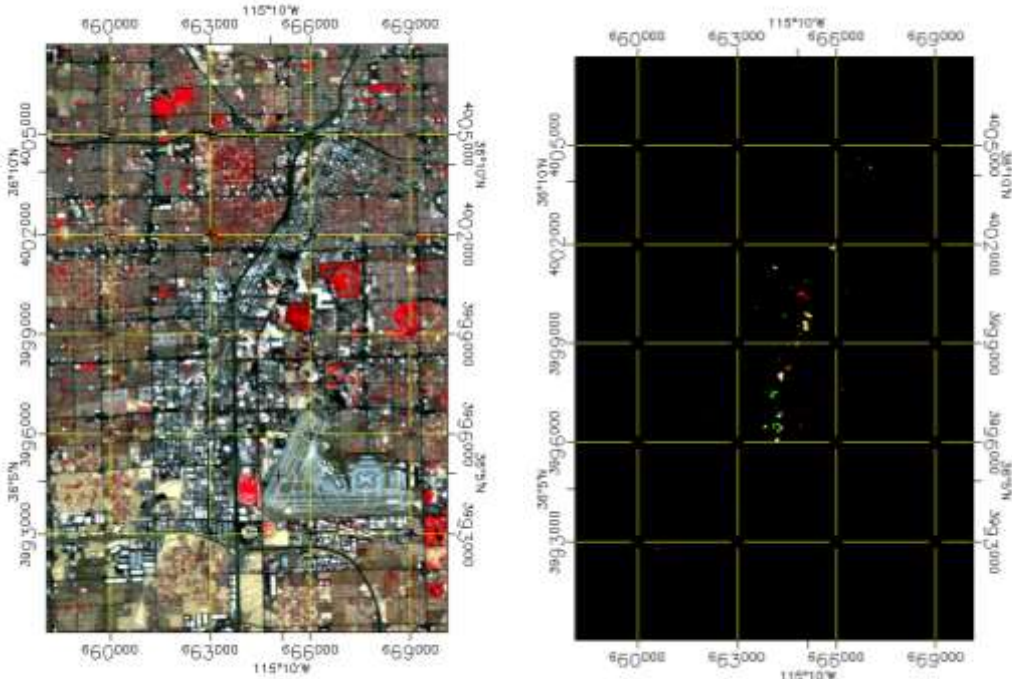
Result:

Overall good agreement with OBCA and interactive analysis

Figures:

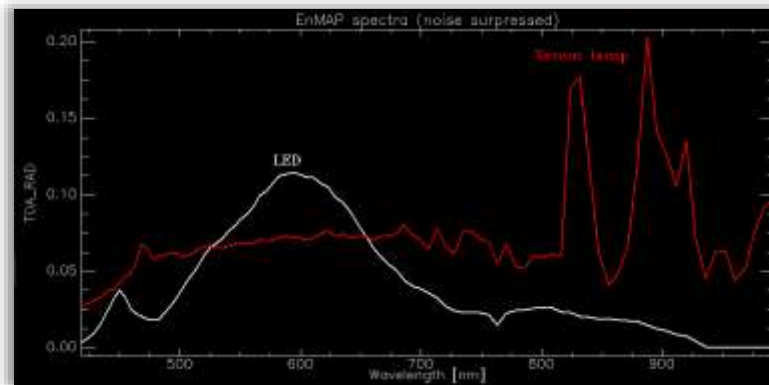
Examples for EnMAP VNIR @ 760 nm and EnMAP SWIR @ 2050 nm expressed as stdev @ 1 sigma

EnMAP – Las Vegas Lights at Night



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

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



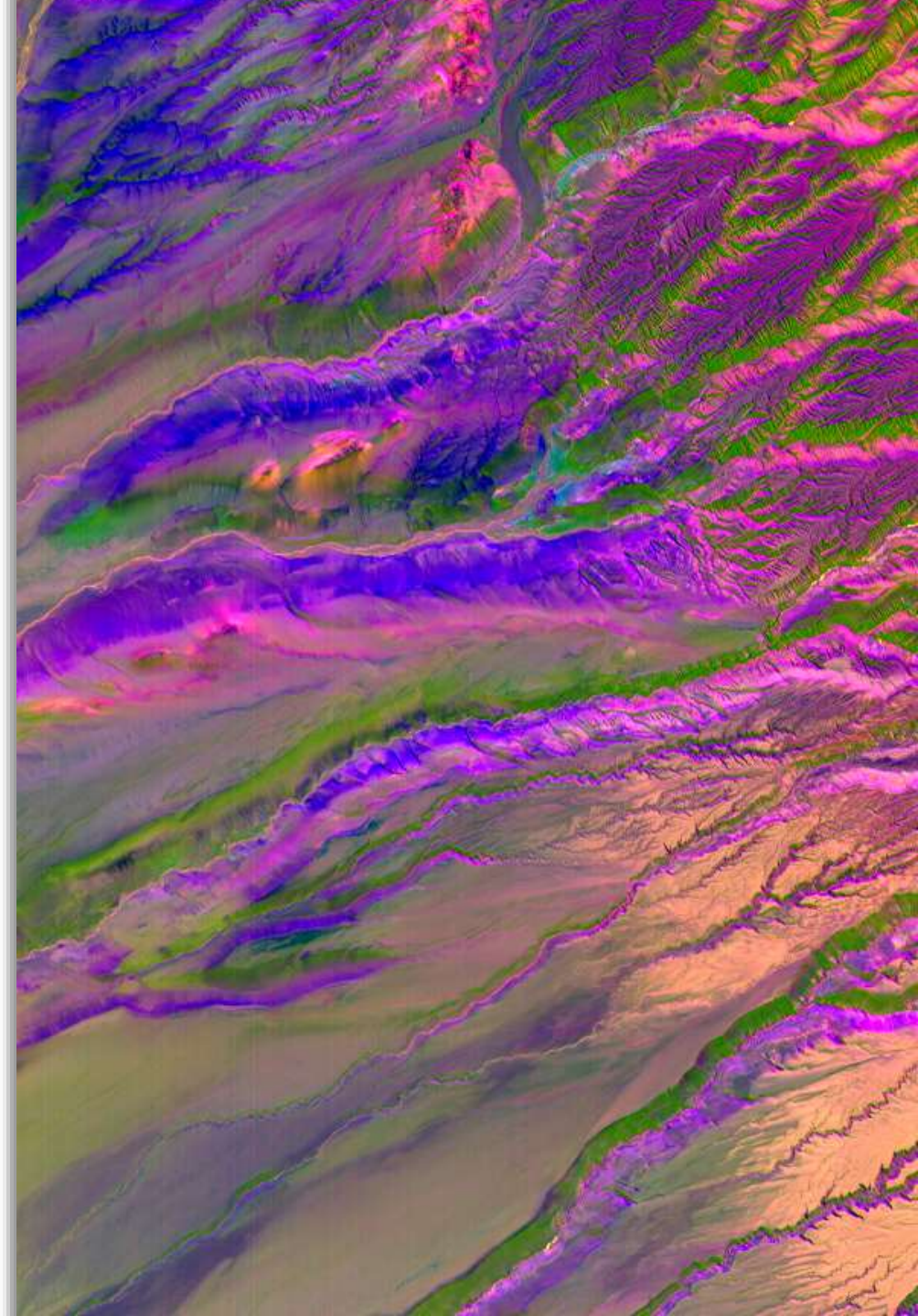
First Nighttime Light Spectra by Satellite—By EnMAP
 by Martin Bachmann and Tobias Storch *

German Aerospace Center (DLR), Earth Observation Center (EOC), Münchener Str. 20, 82234 Weßling, Germany
 * Author to whom correspondence should be addressed.

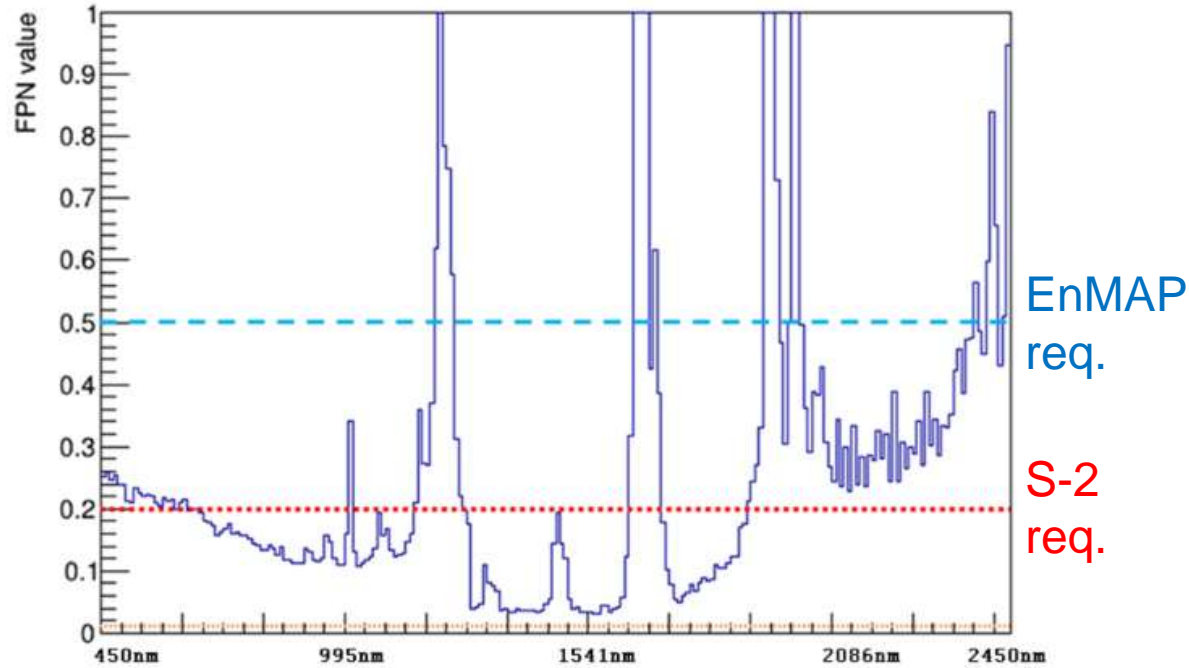
Remote Sens. **2023**, *15*(16), 4025; <https://doi.org/10.3390/rs15164025>

- Radiometric Data Properties
and Data Artefacts

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

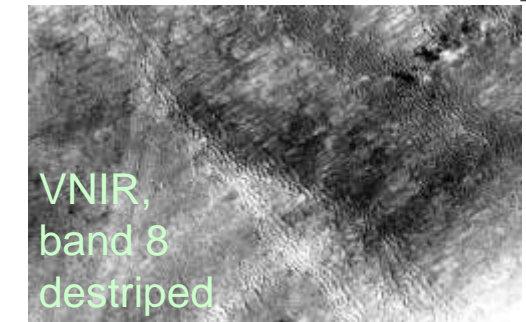
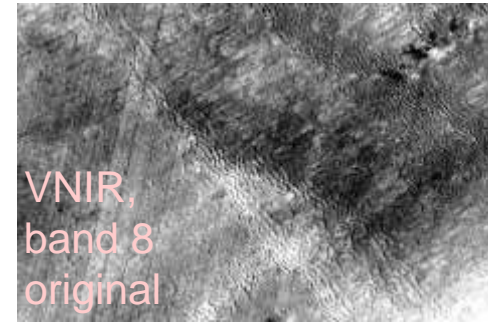


Striping / Fixed Pattern Noise



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

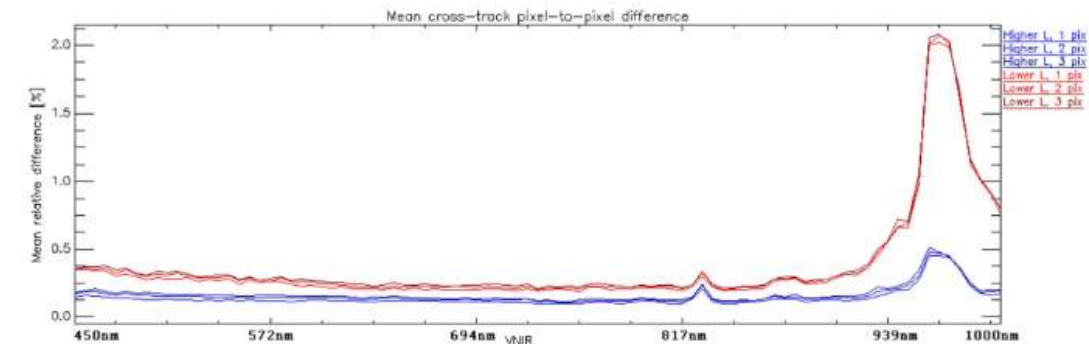
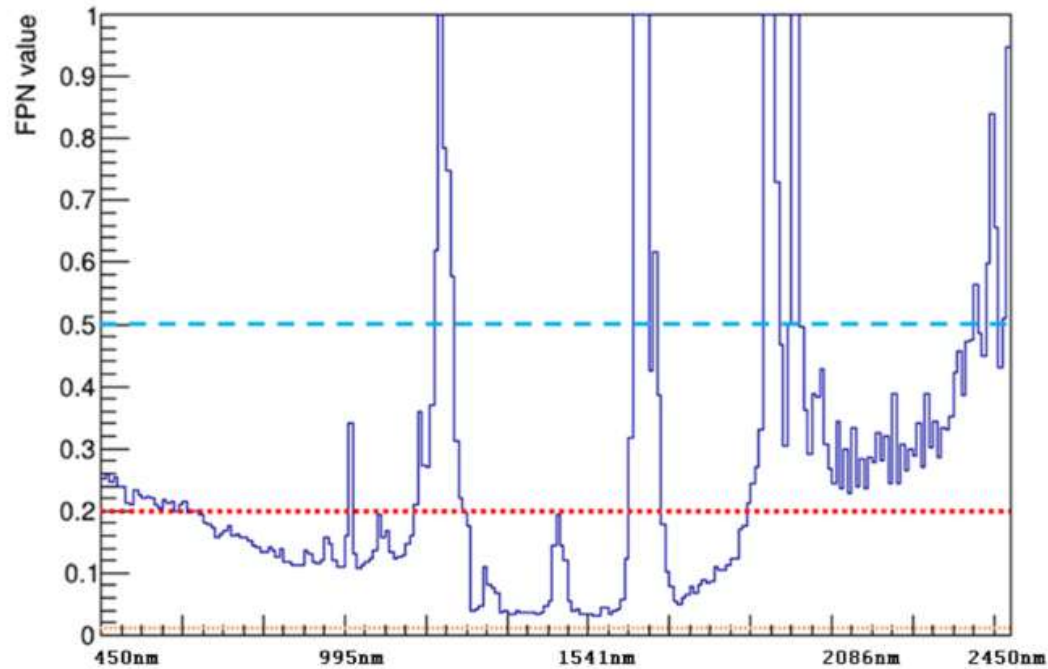


Figure 6-19 VNIR mean cross-track pixel-to-pixel difference

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

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

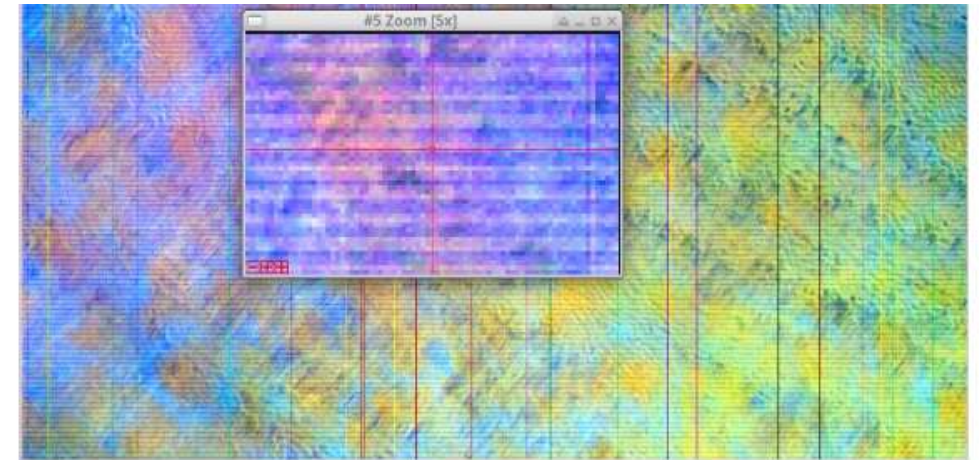


Figure 6-26 Principal Component Analysis (PCA) highlighting along-track striping

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

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 not the root cause, as jump occurs also for spatially homogeneous areas.
But co-registration errors can add on top of the radiometric effect.

- L1C: pixel reported is really dark... and „jumps“ are clearly visible in spectra

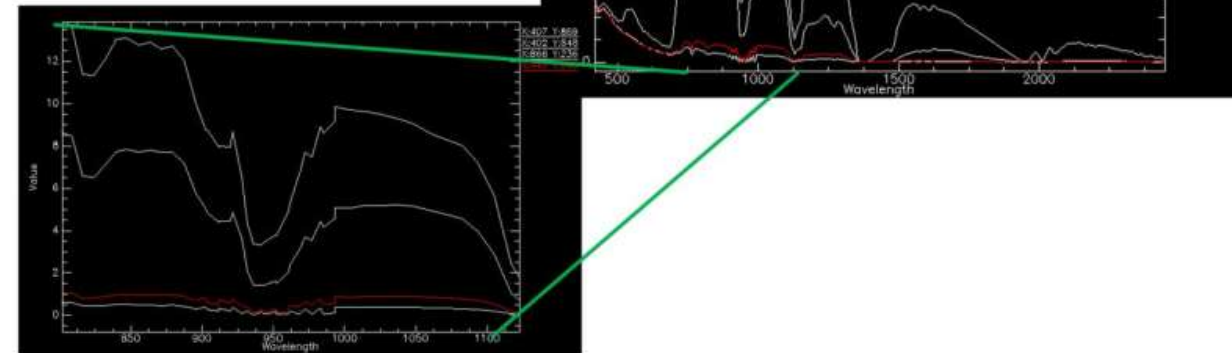


Figure 7-25 L1C radiance spectra of the reported pixel in comparison to spectra of other image locations.

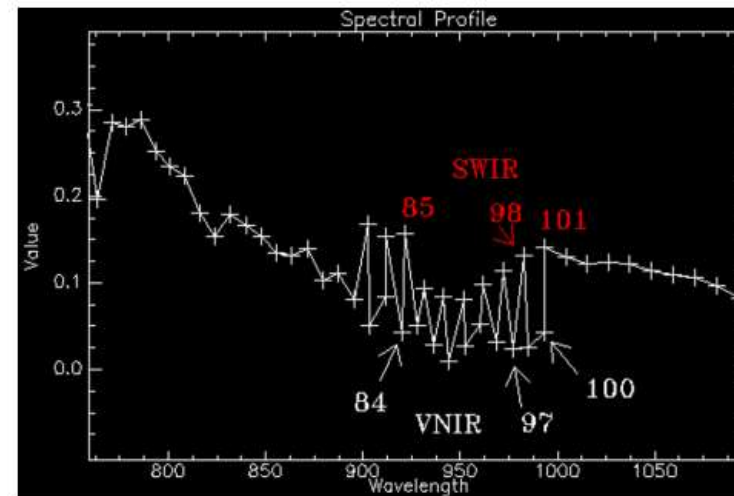


Figure 7-27 Illustration of VNIR-SWIR overlapping region using L1C data.

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



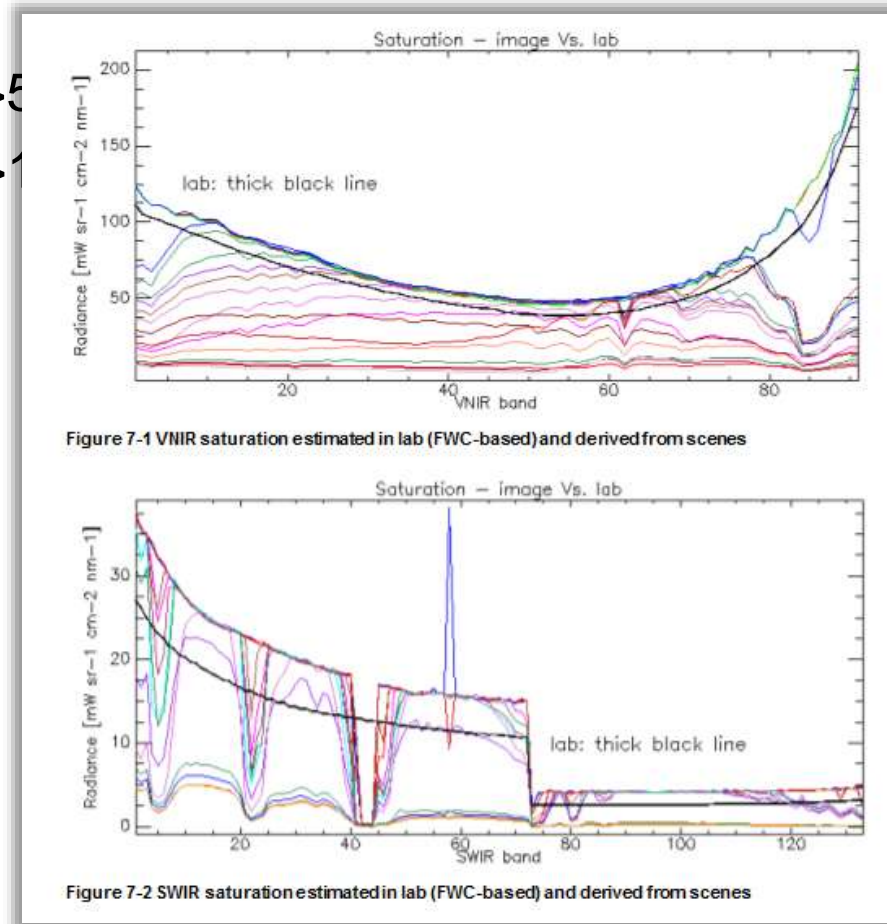
- Estimated **SNR** (30% reflectance, 30° sun incidence angle, 21 km visibility, target 500 m above sea level)
 - 620:1 @ 495 nm (requirement: >500:1 for VNIR, low gain)
 - 230:1 @ 2200 nm (requirement: >150:1 for SWIR, high gain)
- **Dead pixels** (in orbit, total):
 - VNIR: 137 (0.2%)
 - SWIR: 1784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



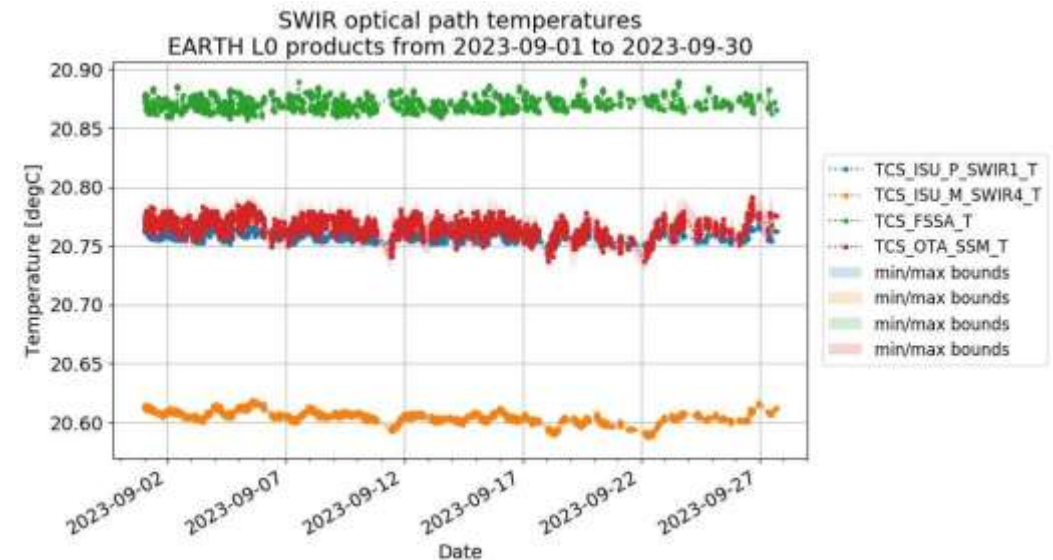
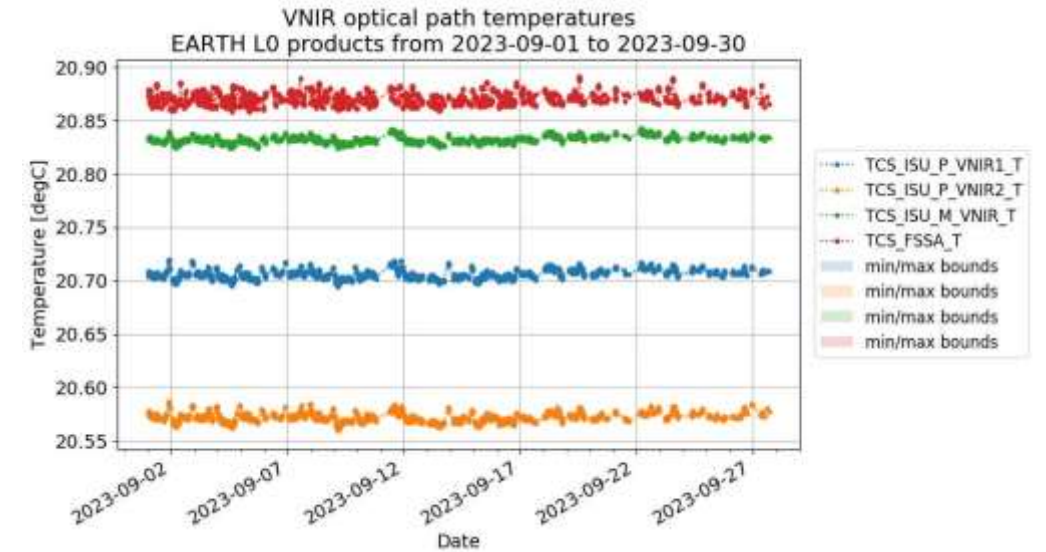
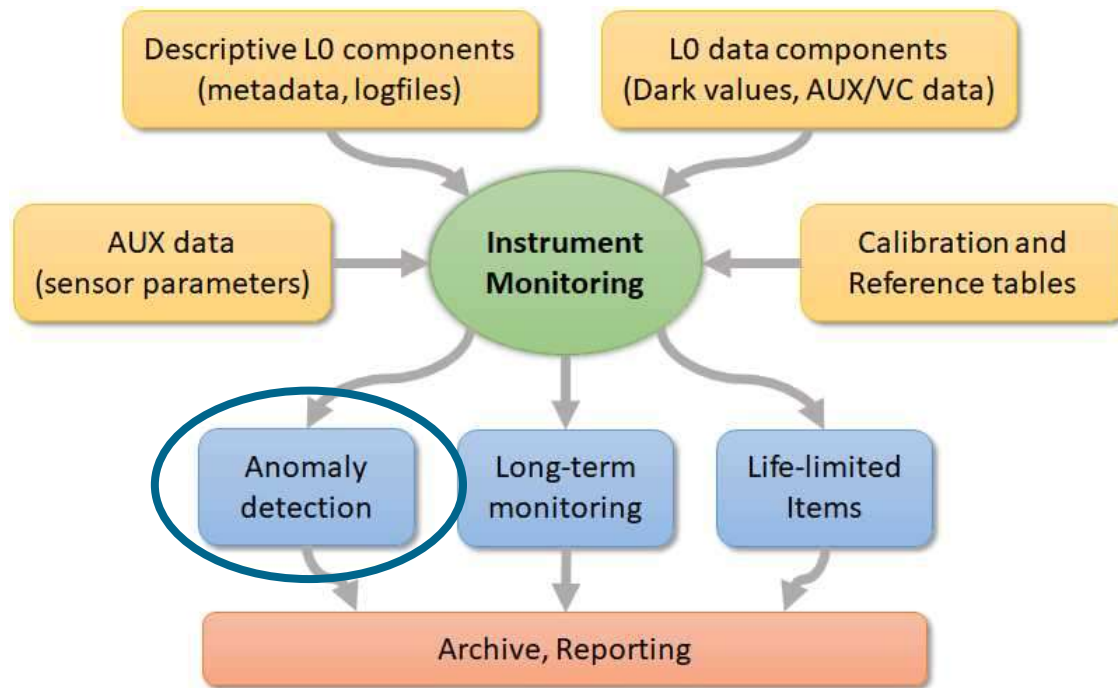
Other Parameters

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



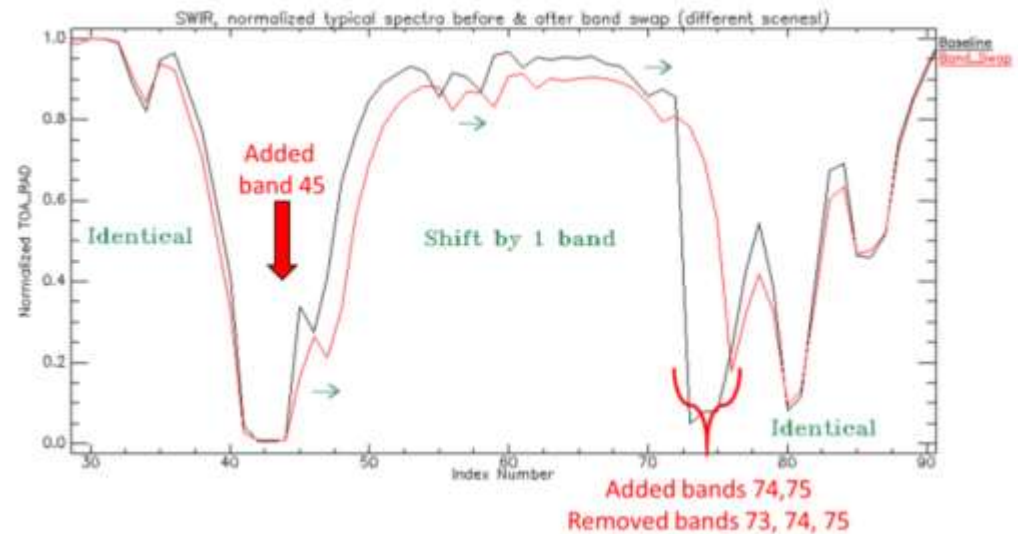
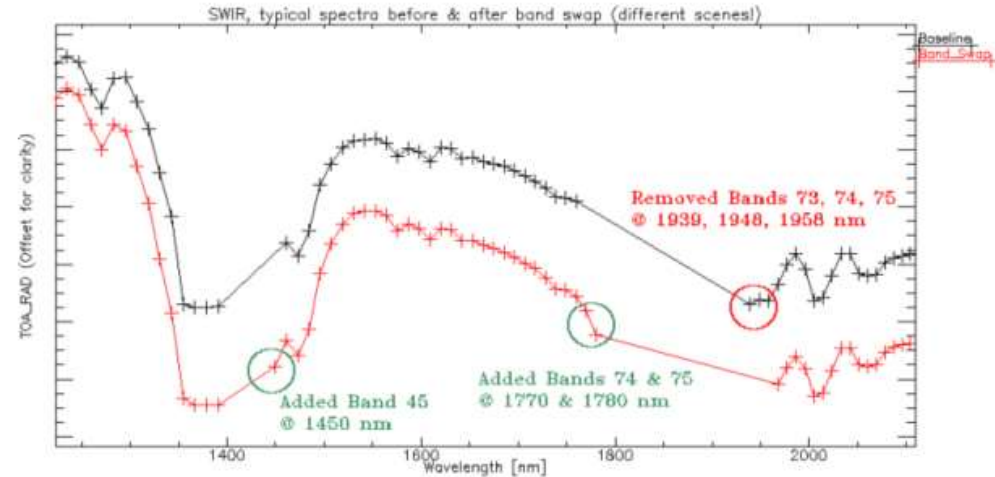
Figure 6-23 Fringing of the VNIR, Principal Component-transformed data

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

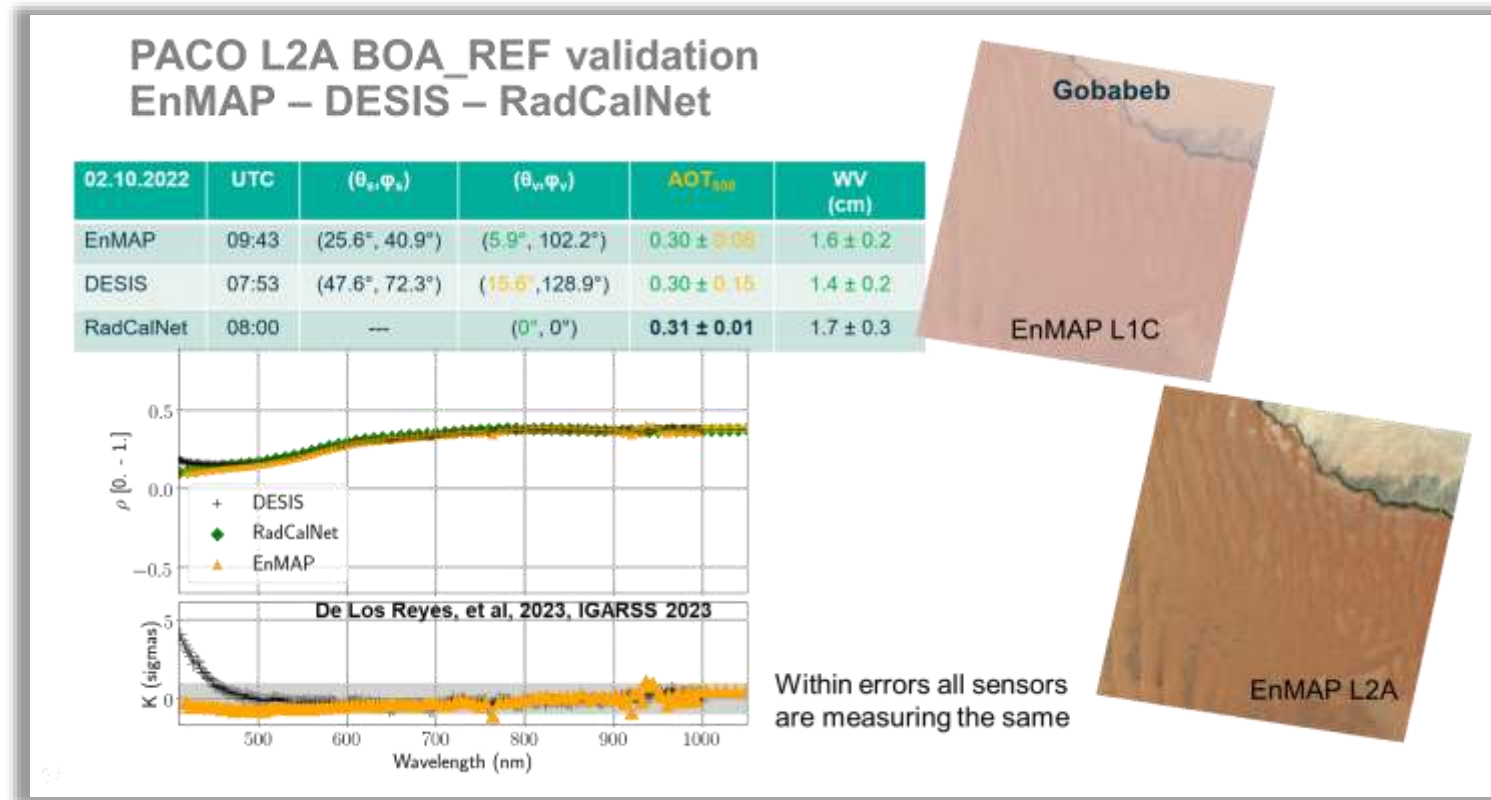


L1B TOA_rad & L2A BOA_ref Validation

- Independent validation lead by GFZ
 - [see presentation by Max Brell](#)

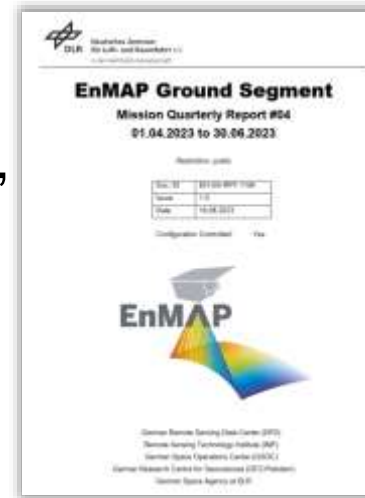
Additionally within the GS @ DLR:

- 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/>

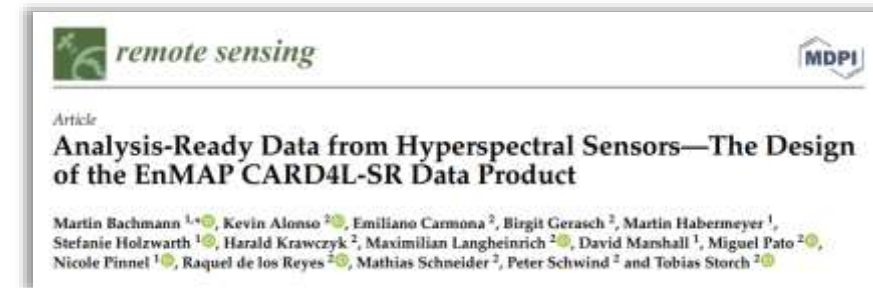


and



- 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/>

Supported by:



on the basis of a decision by the German Bundestag