EnMAP mission overview: Data Quality Control

M. Bachmann, M. Schneider, S. Holzwarth, M. Habermeyer, M. Pato, E. Carmona

EnMAP Ground Segment, Processor and Calibration Segment
German Aerospace Center (DLR), Earth Observation Center, Oberpfaffenhofen

Infrared and Visible Optical Sensors (IVOS) 35
CEOS, Working Group on Calibration and Validation (WGCV)
Oberpfaffenhofen, 27.09.2023

Federal Ministry for Economic Affairs and Climate Action

DLR

Outline

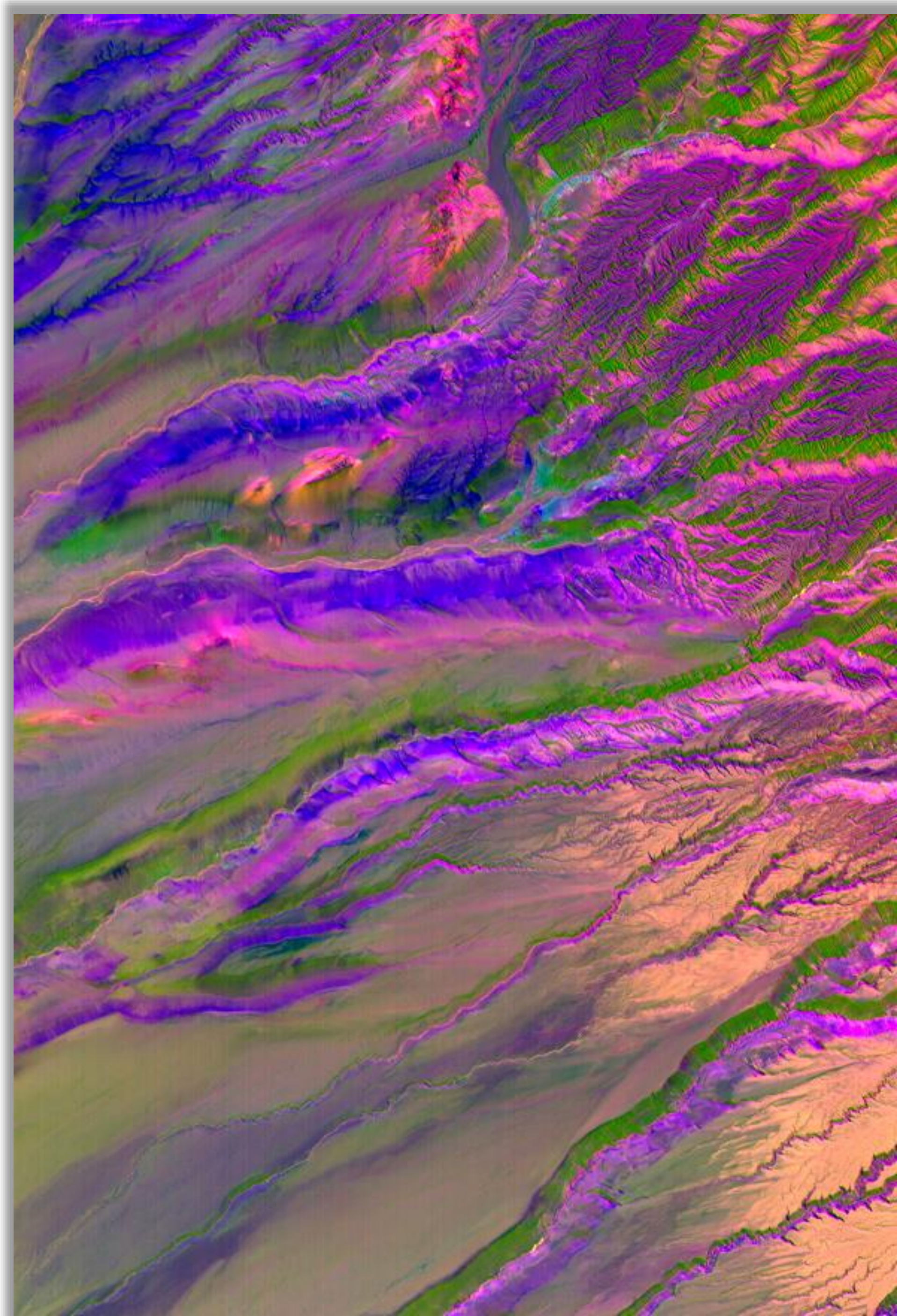
EnMAP mission overview:

▪ Mission status	Miguel Pato	Miguel.FigueiredoVazPato@dlr.de
▪ In-orbit calibration	David Marshall Ingram	David.Marshall@dlr.de
▪ Data quality control	Martin Bachmann	Martin.Bachmann@dlr.de

EnMAP GS manager:	Emiliano Carmona
EnMAP PCV team:	
▪ Processors	Peter Schwind, Miguel Pato (L0/L1B), Mathias Schneider (L1C), Raquel de los Reyes (L2A), Maximilian Langheinrich (L2A)
▪ Calibration	David Marshall Ingram, Helge Witt
▪ Quality control	Martin Bachmann, Martin Habermeyer, Stefanie Holzwarth, Mathias Schneider
▪ Instrument monitoring	Birgit Gerasch

EnMAP DataQC

Lucinda Jetty, Australia (CIR)



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

… a big thank you to the Cal/Val community !

DLR

Remote Sensing of Environment 294 (2023) 113632

Contents lists available at ScienceDirect

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Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

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The EnMAP imaging spectroscopy mission towards operations

Tobias Storch [a,*], Hans-Peter Honold [e], Sabine Chabrillat [g,h], Martin Habermeyer [a], Paul Tucker [e], Maximilian Brell [g], Andreas Ohndorf [d], Katrin Wirth [d], Matthias Betz [e], Michael Kuchler [e], Helmut Mühle [a], Emiliano Carmona [a], Simon Baur [e], Martin Mücke [e], Sebastian Löw [d], Daniel Schulze [d], Steffen Zimmermann [d], Christoph Lenzen [d], Sebastian Wiesner [d], Saika Aida [d], Ralph Kahle [d], Peter Willburger [d], Sebastian Hartung [b], Daniele Dietrich [a], Nicolae Plesia [a], Mirco Tegler [b], Katharina Schork [a], Kevin Alonso [a], David Marshall [a], Birgit Gerasch [c], Peter Schwind [a], Miguel Pato [a], Mathias Schneider [a], Raquel de los Reyes [a], Maximilian Langheinrich [a], Julian Wenzel [f], Martin Bachmann [a], Stefanie Holzwarth [a], Nicole Pinnel [a], Luis Guanter [i], Karl Segl [g], Daniel Scheffler [g], Saskia Foerster [g], Niklas Bohn [g,l], Astrid Bracher [j], Mariana A. Soppa [j], Ferran Gascon [k], Rob Green [l], Raymond Kokaly [m], Jose Moreno [n], Cindy Ong [o], Manuela Sornig [p], Ricarda Wernitz [p], Klaus Bagschik [p], Detlef Reintsema [p], Laura La Porta [p], Anke Schickling [p], Sebastian Fischer [p]

Acknowledgments

This research was supported by the DLR Space Agency with funds of the German Federal Ministry of Economic Affairs and Climate Action on the basis of a decision by the German Bundestag (50 EE 0850, 50 EE 1923 and 50 EE 2108).

We would like to thank all principal investigators of the validation sites and people involved in carrying out the in-situ validation measurements: R. Kokaly (USGS): Black Rock Playa Zero; E. Ben-Dor & D. Heller (TAU): Amiaz Plain & Makhtesh Ramon; C. Ong (CSIRO): Pinnacles; B. Brede (GFZ) & N. Origo (NPL): Barrax; T. Schmid (CIEMAT): Camarena; R. Milewski (GFZ): Berlin-Tegel; T. Hank & M. Wocher (LMU): Munich-Isar; P. Gege, I. Somlai, S. Plattner, & M. Niroumand-Jadid (DLR), M. Zeising & L. Alvarado (AWI), M. Gomes (MARE): Lake Constance; M. Brasciani & C. Giradino (CNR-IREA): Lake Trasimeno; T. Schröder (CSIRO): Lucinda Jetty Coastal Observatory; V. Brando (CNR) & the HYPERNETS project (RBINS, TARTU, SU, CNR, NPL, GFZ, CONICET), G. Zibordi & B. Bulgarelli (AERONET-OC): Aqua Alta Oceanographic Tower. Our special thanks go to the RadCalNet teams at CNES, NPL, NASA and University of Arizona for valuable additional support, in particular to A. Meygret and M. Farges (CNES) for EnMAP-specific BRDF (Bidirectional Reflectance Distribution Function) simulations.

And last but not least the authors thank the five reviewers for their valuable suggestions.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

… a big thank you to the Cal/Val community !

DLR

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For updates, please check:
https://www.enmap.org/mission/
=> Quaterly Reports

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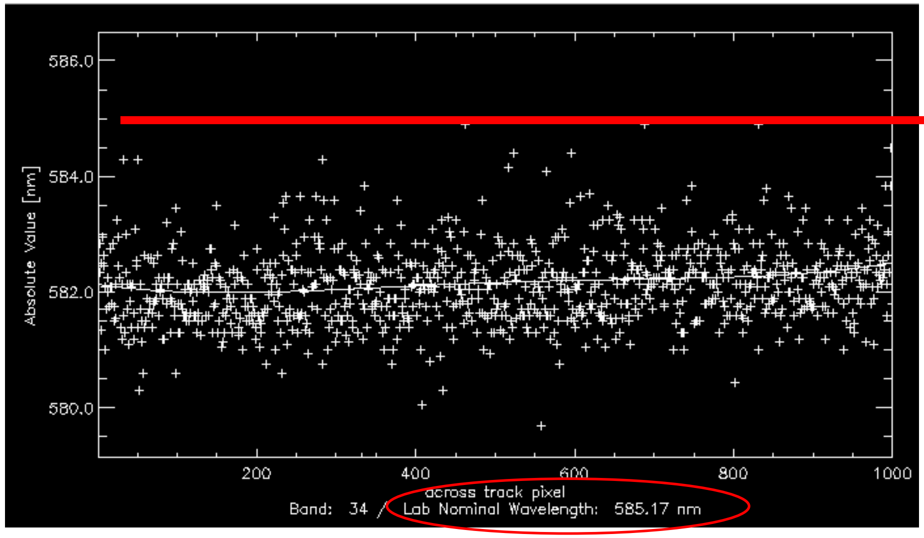
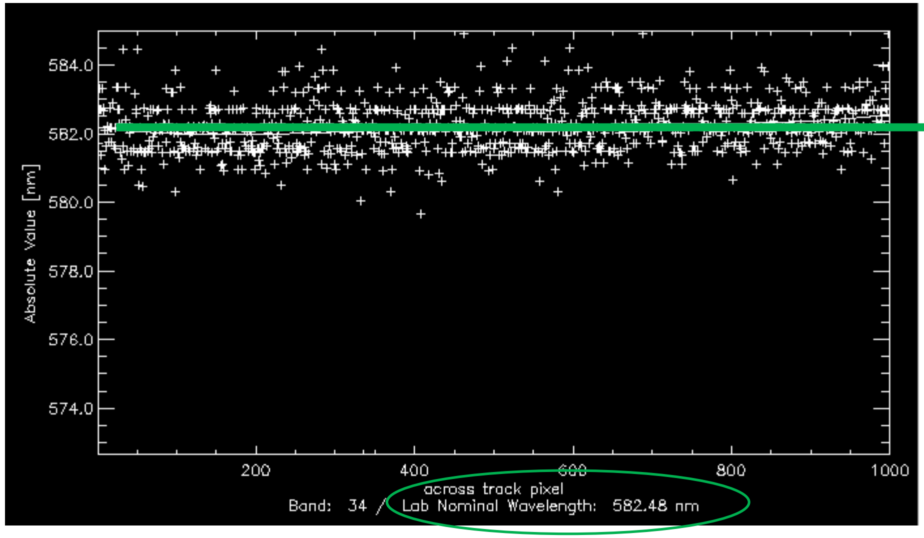
Spectral Pre- to Post-Launch Changes

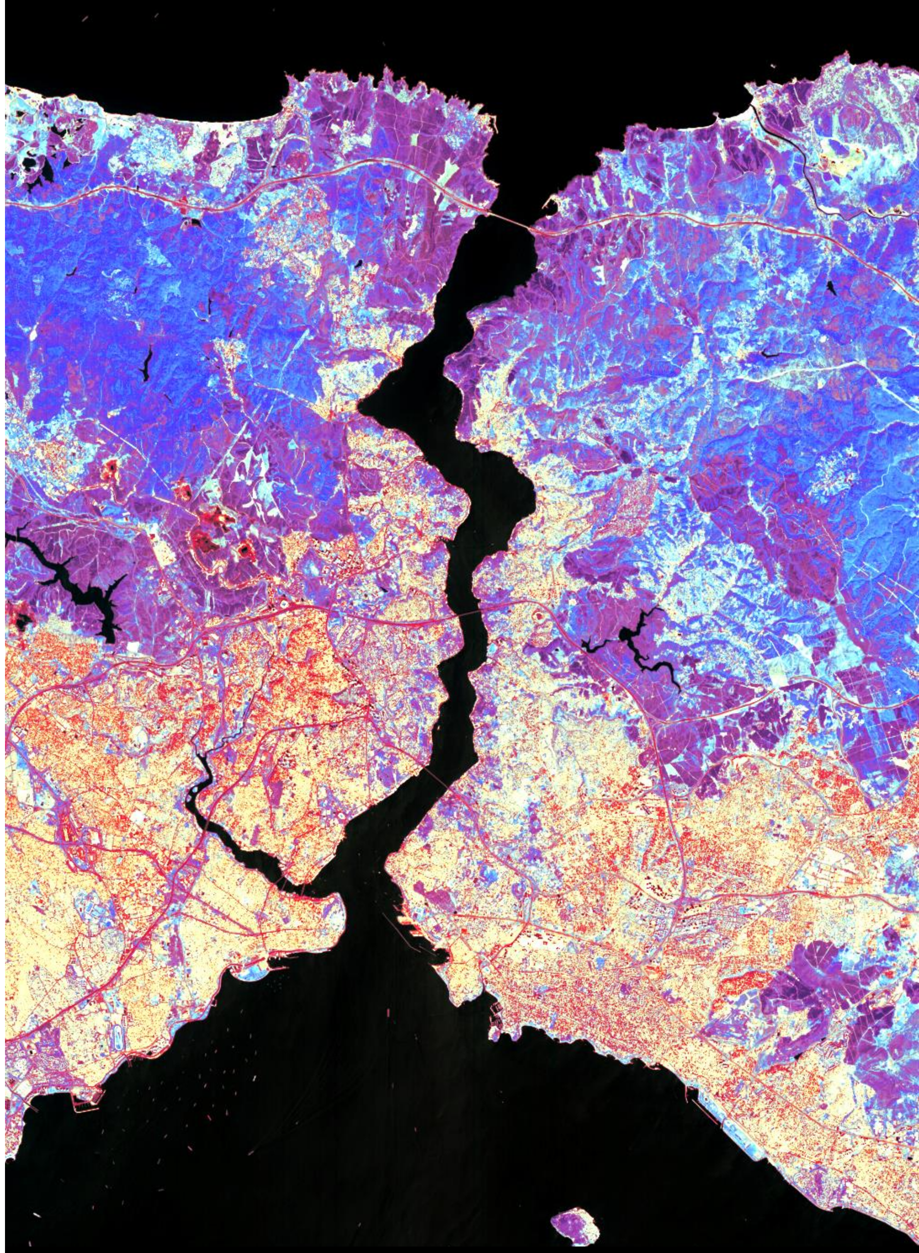
Results from spectral validation for pre- to 1st post-launch calibration tables



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

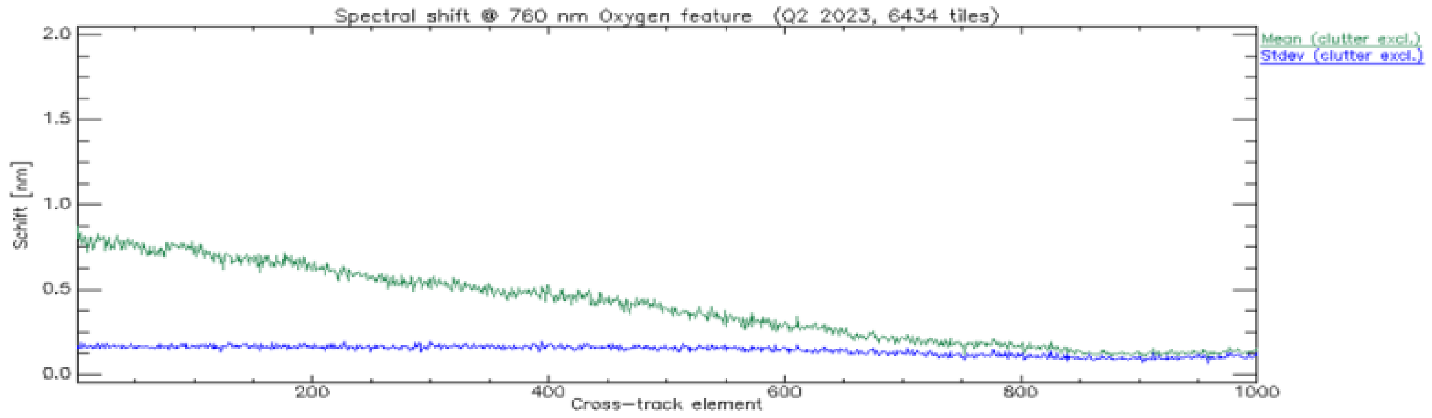


Figure 7-18 **VNIR estimated spectral shift at 760 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles**

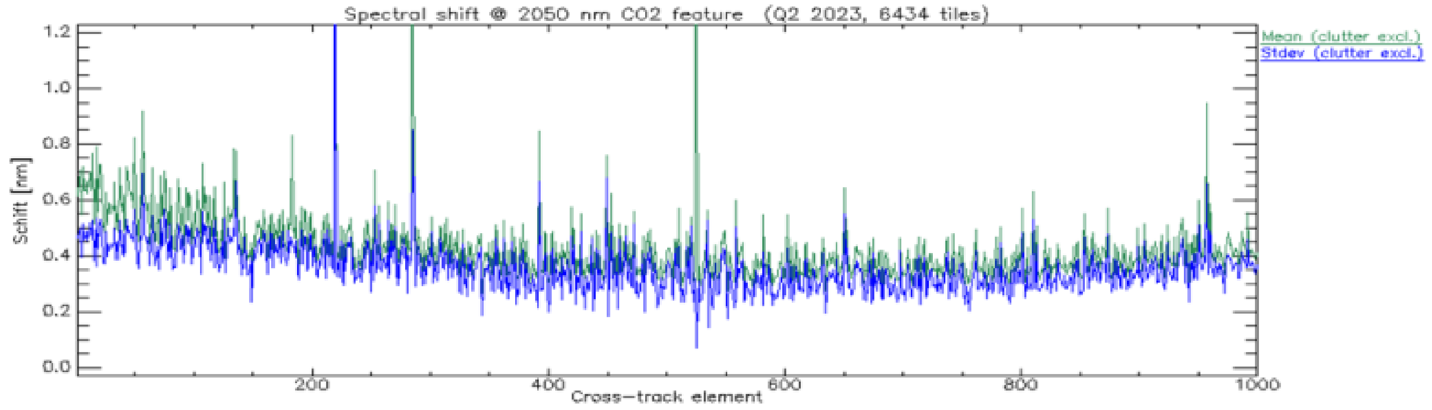


Figure 7-19 **SWIR estimated spectral shift at 2050 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles)**

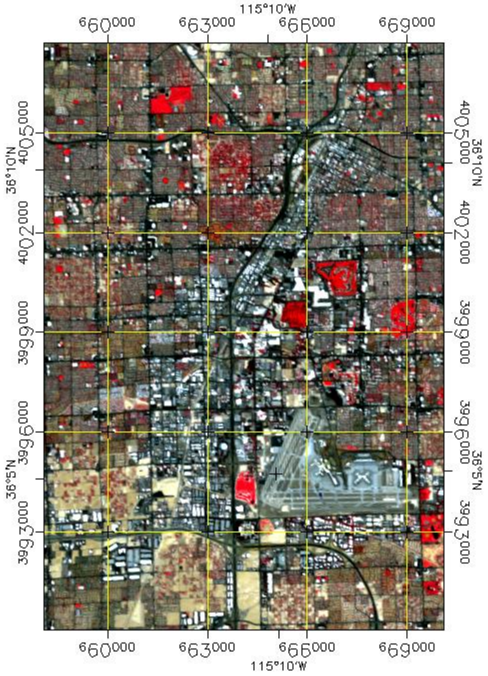
Approach:
fit of normalized TOA_rad to range of simulated spectrally shifted atm. absorption features of O2 @760 nm, CO2 @ 2060 nm

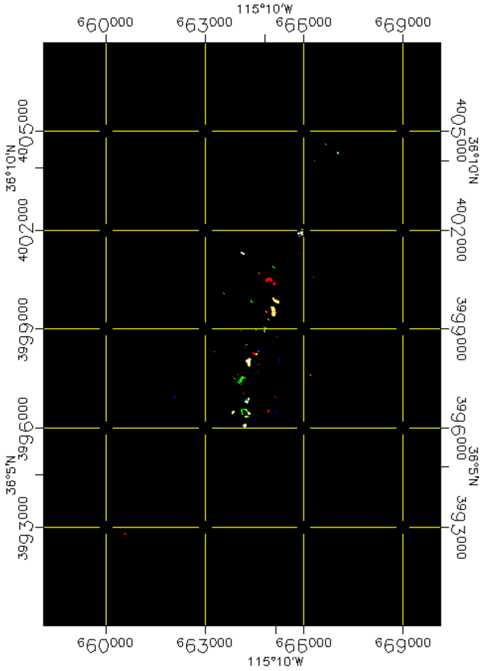
Result:
Overall good agreement with OBCA and interactive analysis

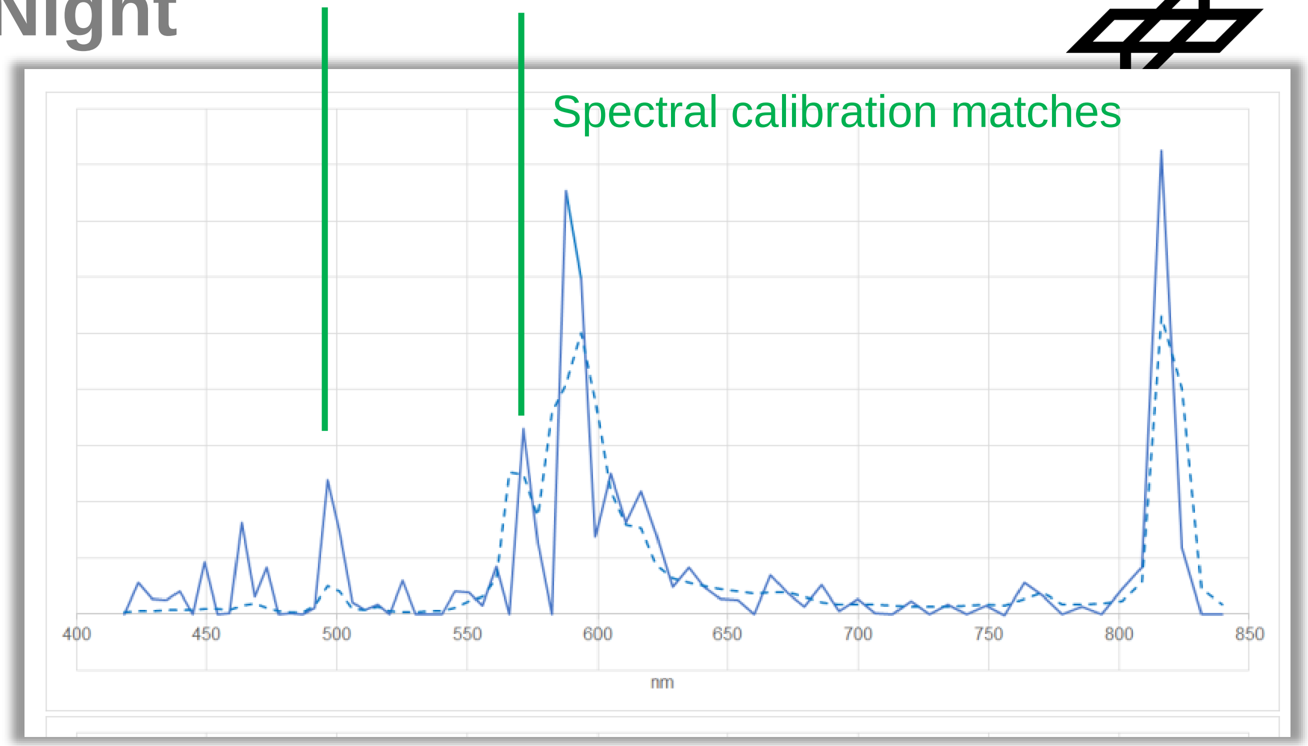
Figures:
Examples for EnMAP VNIR @ 760 nm expressed as stdev @ 1 sigma
Top: Q4 2022, 2770 image tiles
Bottom: Q2 2023, 6434 image tiles

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

EnMAP – Las Vegas Lights at Night

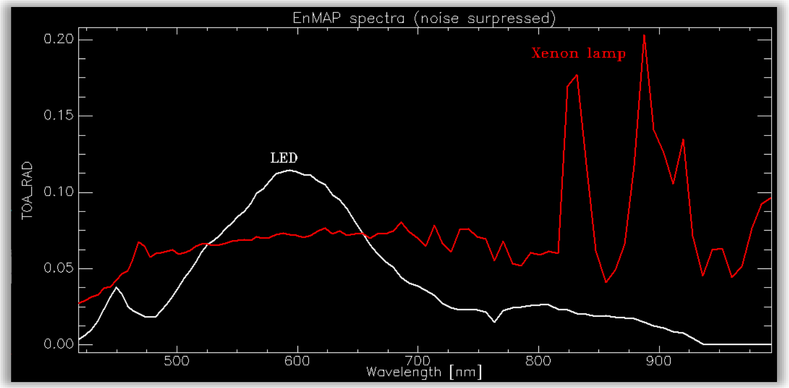






Actual TOA_rad EnMAP (solid) Vs. SpecLib by C. Elvidge
Example: HPS – high pressure sodium lamp

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

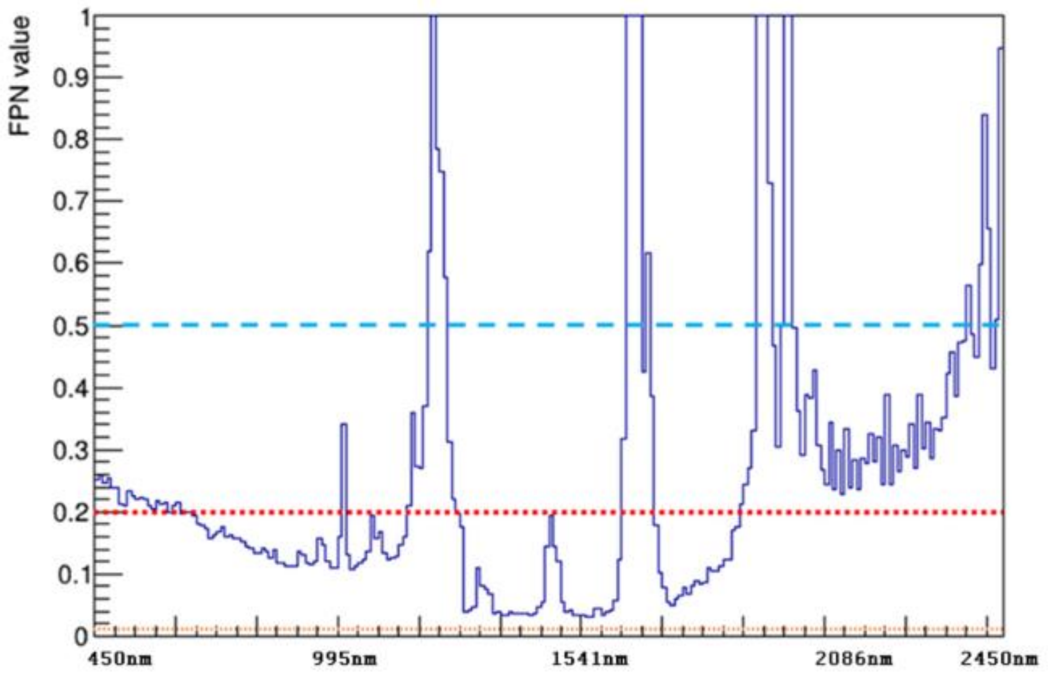
by Martin Bachmann and Tobias Storch *

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

* Author to whom correspondence should be addressed.

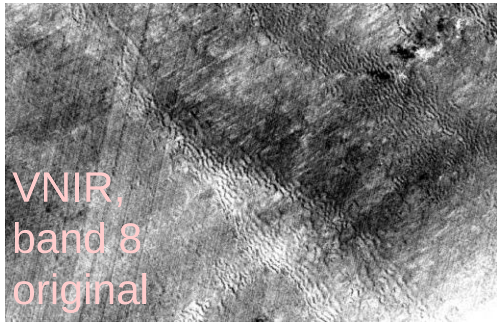
Remote Sens. **2023**, *15*(16), 4025; **https://doi.org/10.3390/rs15164025**

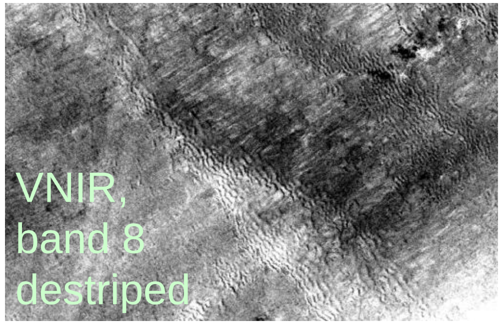
Striping / Fixed Pattern Noise



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

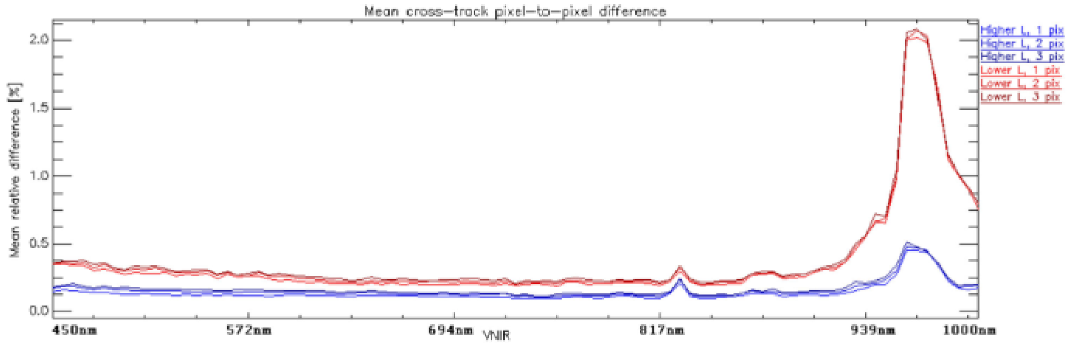
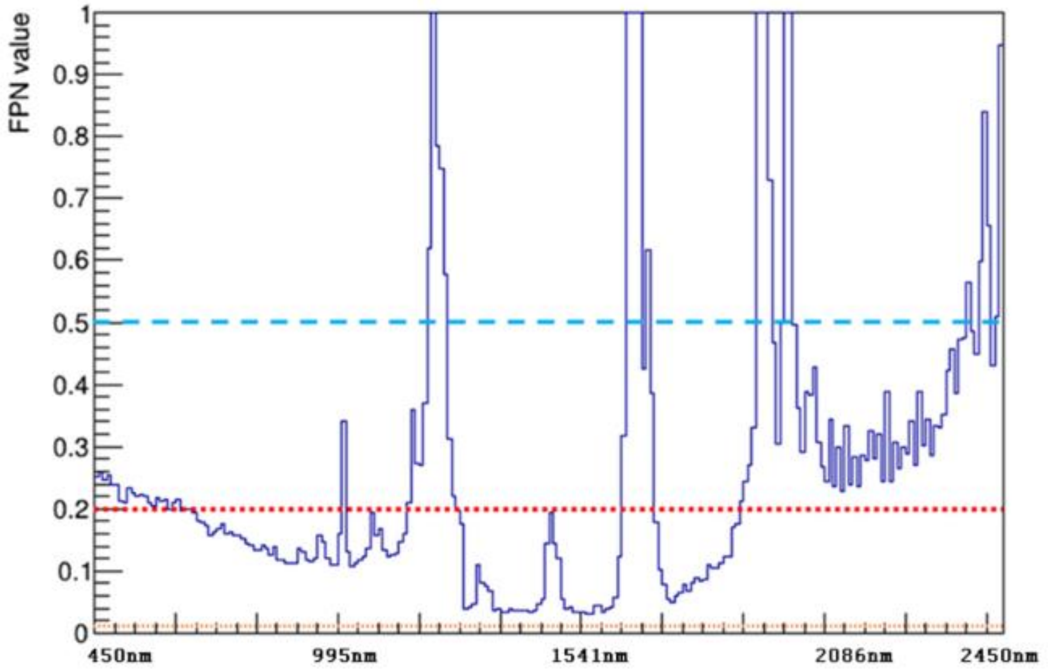


Figure 6-19 **VNIR mean cross-track pixel-to-pixel difference**

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

1st mission quaterly 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**

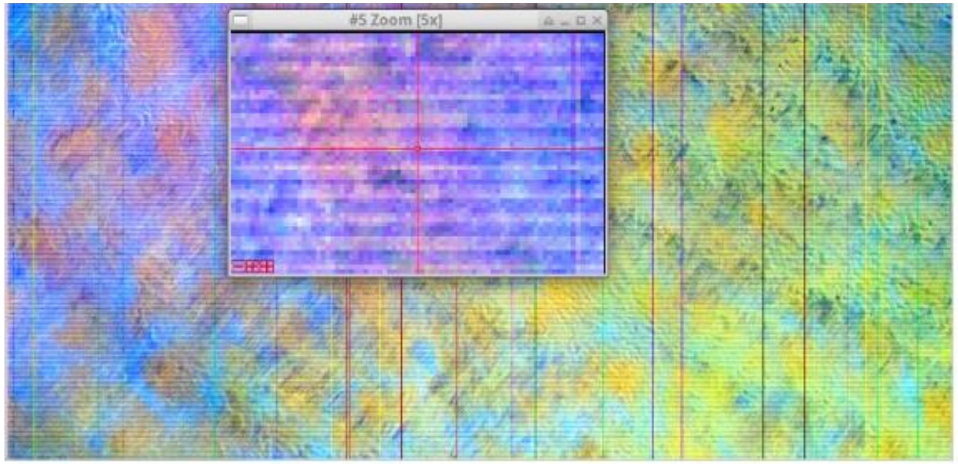


Figure 6-26 **Principal Component Analysis (PCA) highlighting along-track striping**

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

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Radiometric offset of VNIR-SWIR overlap for dark targets

- Non-linearity effects at low radiance levels idetified as root cause
- Improvements for CAL under investiagtion
- Geometric co-registration is not the root cause, as jump occurs also for spatially homogeneous areas

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

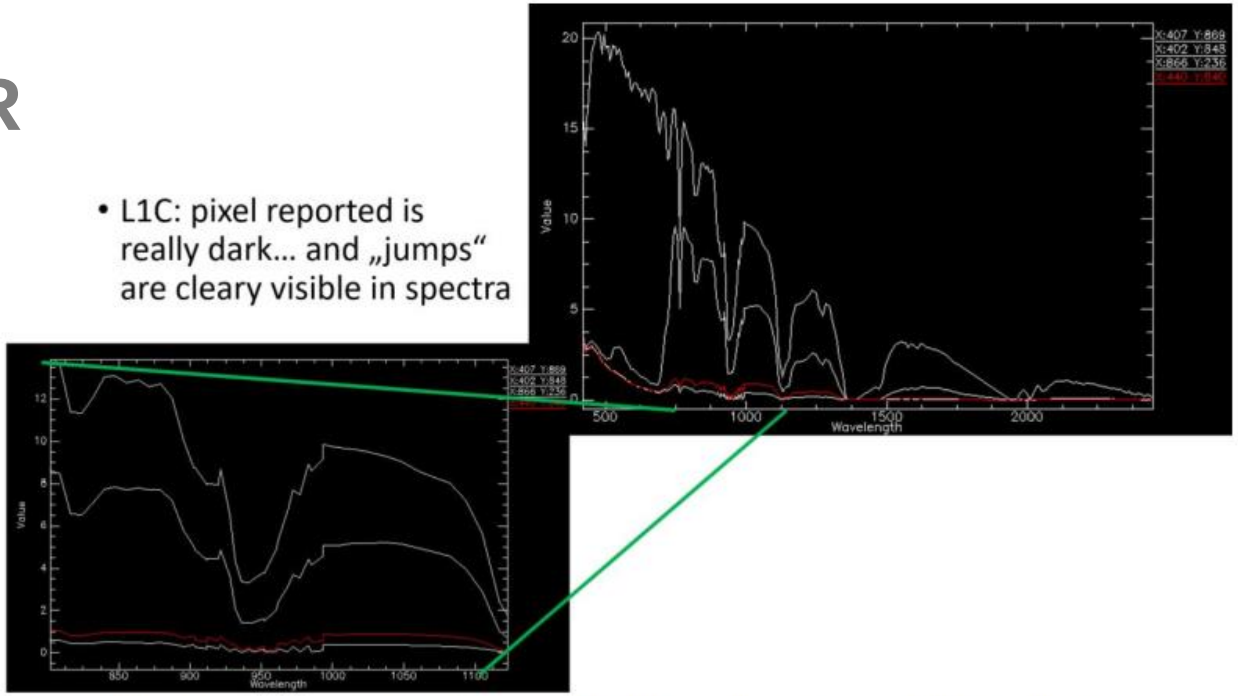


Figure 7-25 L1C radiance spectra of the reported pixel in comparison to spectra of other image locations.

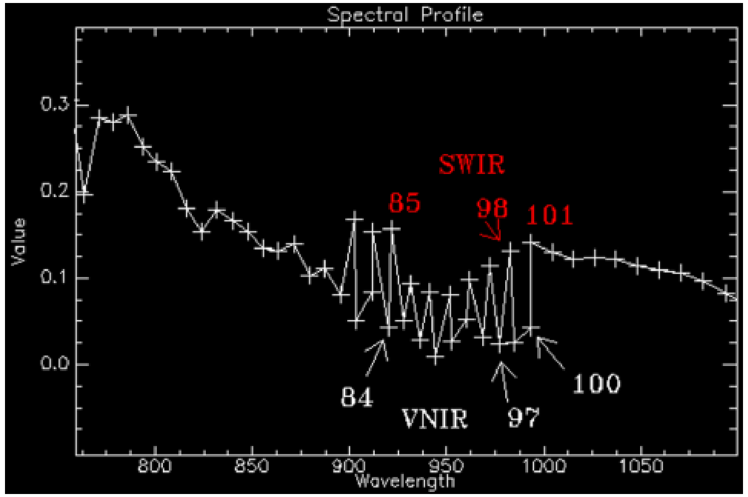


Figure 7-27 Illustration of VNIR-SWIR overlapping region using L1C data.

4th mission quaterly 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

1st mission quaterly 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 VNI
  - 230:1 @ 2200 nm (requirement: >150:1 for SWI
- **Dead pixels** (in orbit, total):
  - VNIR: 137 (0.2%)
  - SWIR: 1784 (1.2%)
- **Saturation level**: see plot

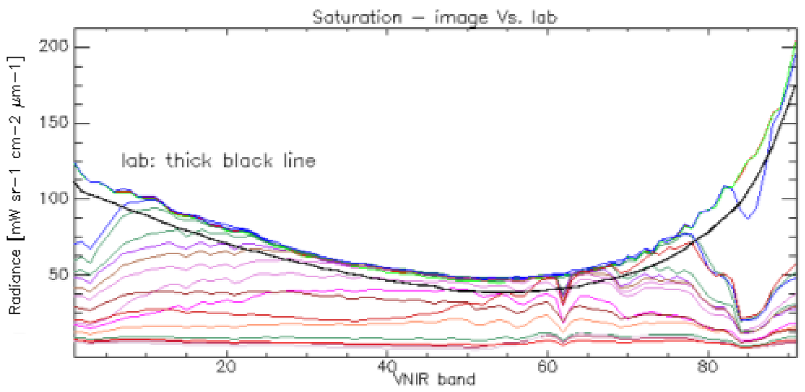


Figure 7-1 VNIR saturation estimated in lab (FWC-based) and derived from scenes

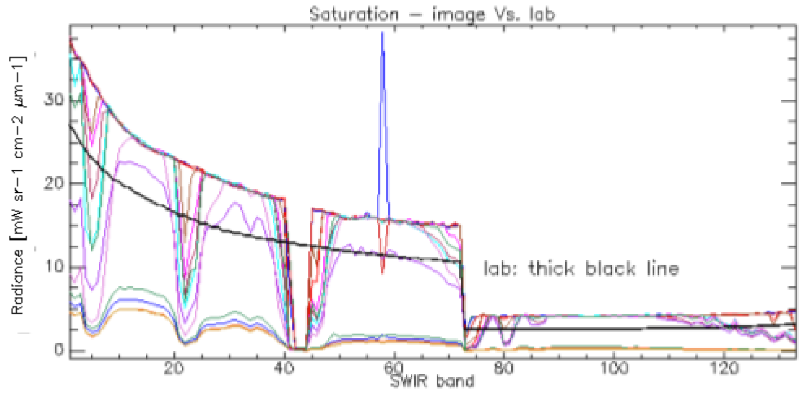


Figure 7-2 SWIR saturation estimated in lab (FWC-based) and derived from scenes

1st mission quaterly 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**

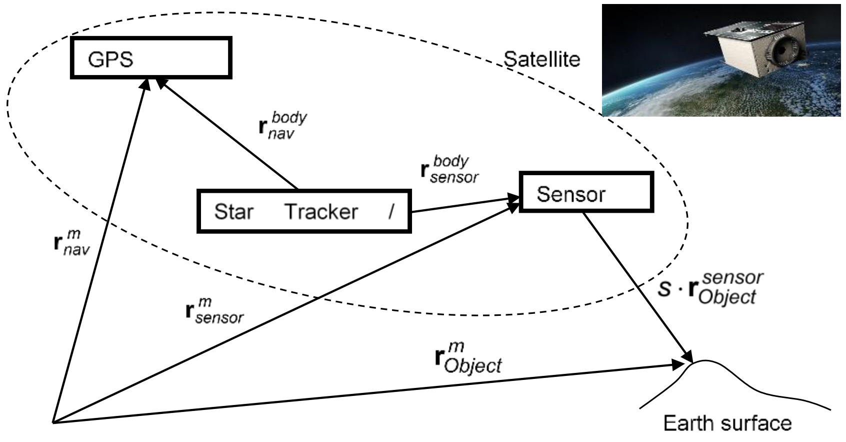
Figure 6-23 Fringing of the VNIR, Principal Component-transformed data

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

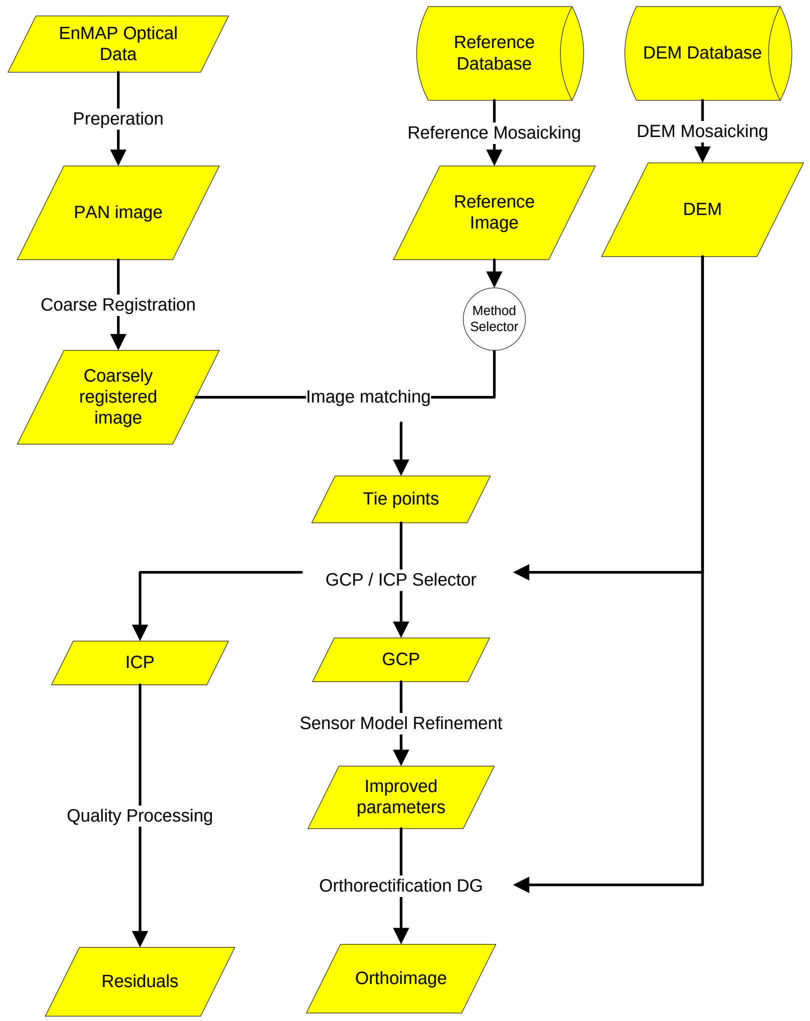
1st mission quaterly report – https://www.enmap.org/mission/

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



$$r^{ECR}_{object}(t) = r^{ECR}_{HSI}(t) + s \cdot R^{ECR}_{STS}(t) \cdot R^{STS}_{HSI} \cdot r^{HSI}_{object}$$

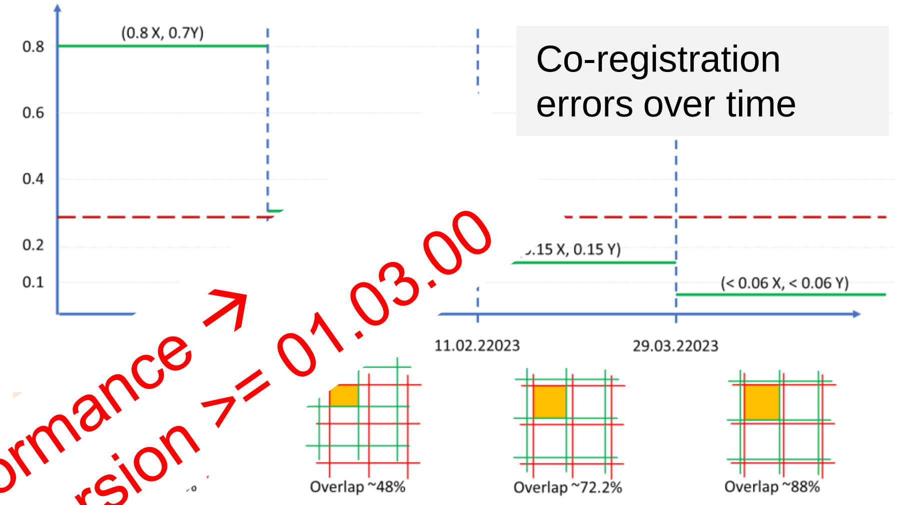


Geometric Performance

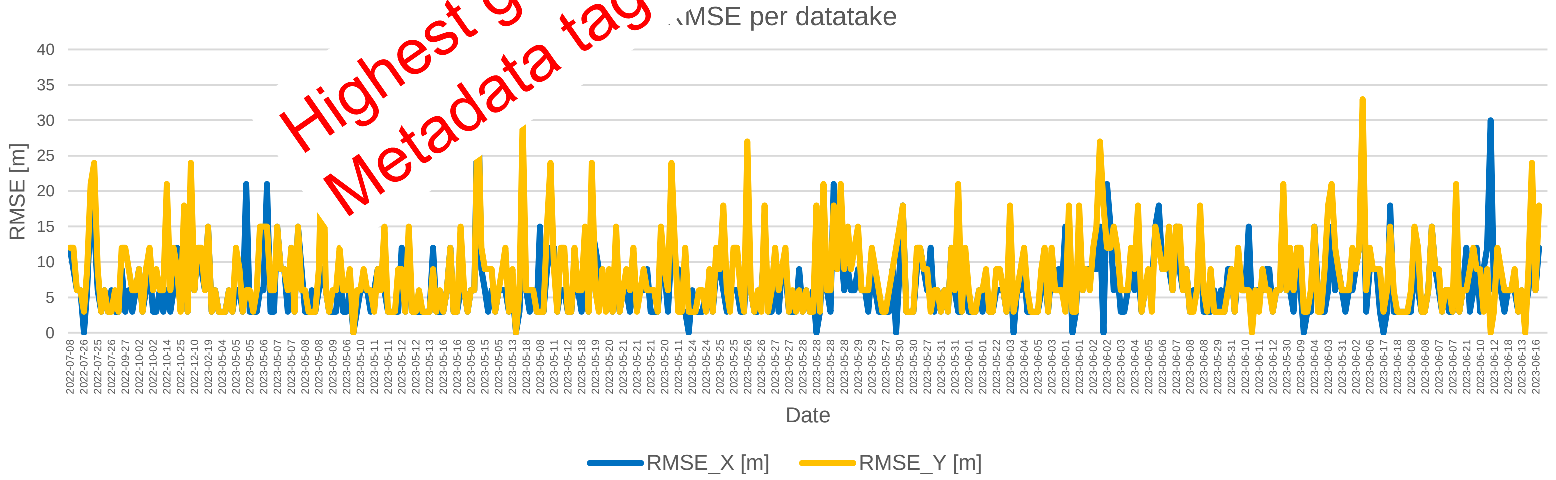
- 01.08.2022 (CP) Fix of attitude processing
  - Improvement of absolute geolocation (w/o matching)
- 20.09.2022 (CP) Boresight Calibration
  - Improvement of absolute geolocation (w/o matching)
- 03.11.2022 (end of CP) 1st Geometric Calibration
  - Improvement of absolute geolocation (w/o matching)
  - 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-registrati… pix -> ~0.06 pix)
- 05.05.2023 (OP) Processor update (v01…
  - Improvement of geolocation …

Highest geometric performance →
Metadata tag archivedVersion >= 01.03.00

Co-registration errors over time



Mean geolocation accuracy with GCP: ~ 8 m
Mean geolocation accuracy without GCP: ~ 30-50 m
Mean co-registration accuracy: ~ 0.06 pix



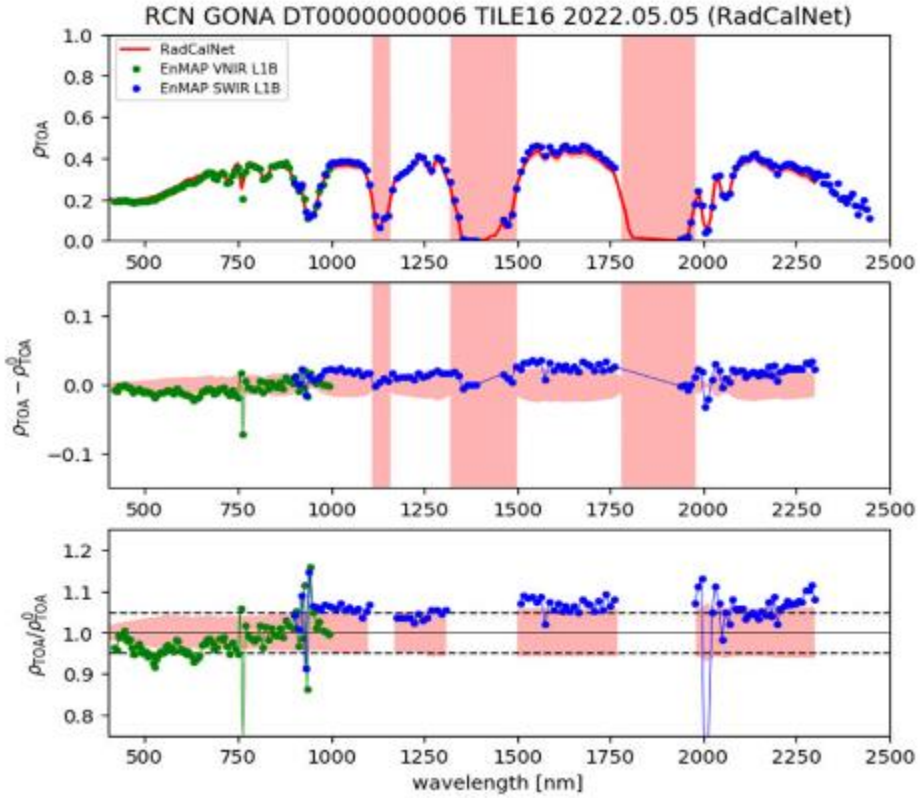
L1B TOA_rad & L2A BOA_ref validation

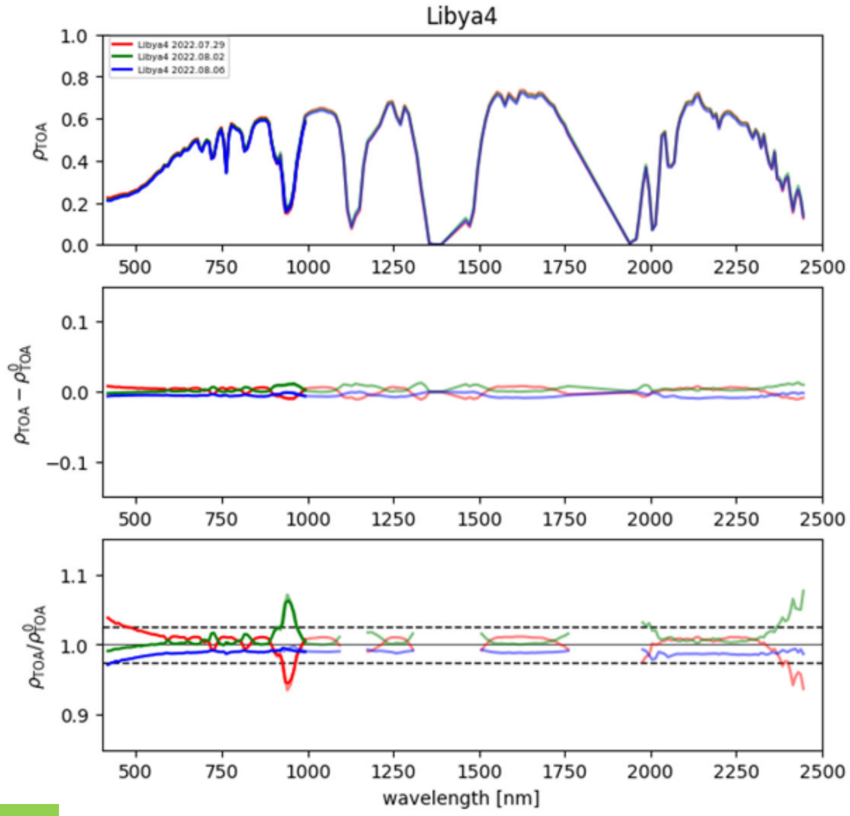
- Independent validation lead by GFZ
  - See presentation by Max Brell

Additionally within the GS @ DLR:

- Routine EnMAP overpasses over RadCalNet and PICS
  - For EnMAP „only“ validation / DESIS: radiometric calibration
  - Examples: see next slide
- Airborne & field campaigns at Panzerwiese site (north of Munich)
  - 2 HySpex campaigns, ASD & SVC spectrometers + Microtops
    => calibration lab. tour by A. Baumgartner

TOA_RAD Vicarious Validation
Examples for RadCalNet & PICS





Radiometric accuracy @ TOA_ref w.r.t. RadCalNet
- 1.02 ± 0.06 (1σ) for VNIR
- 1.07 ± 0.04 (1σ) for SWIR

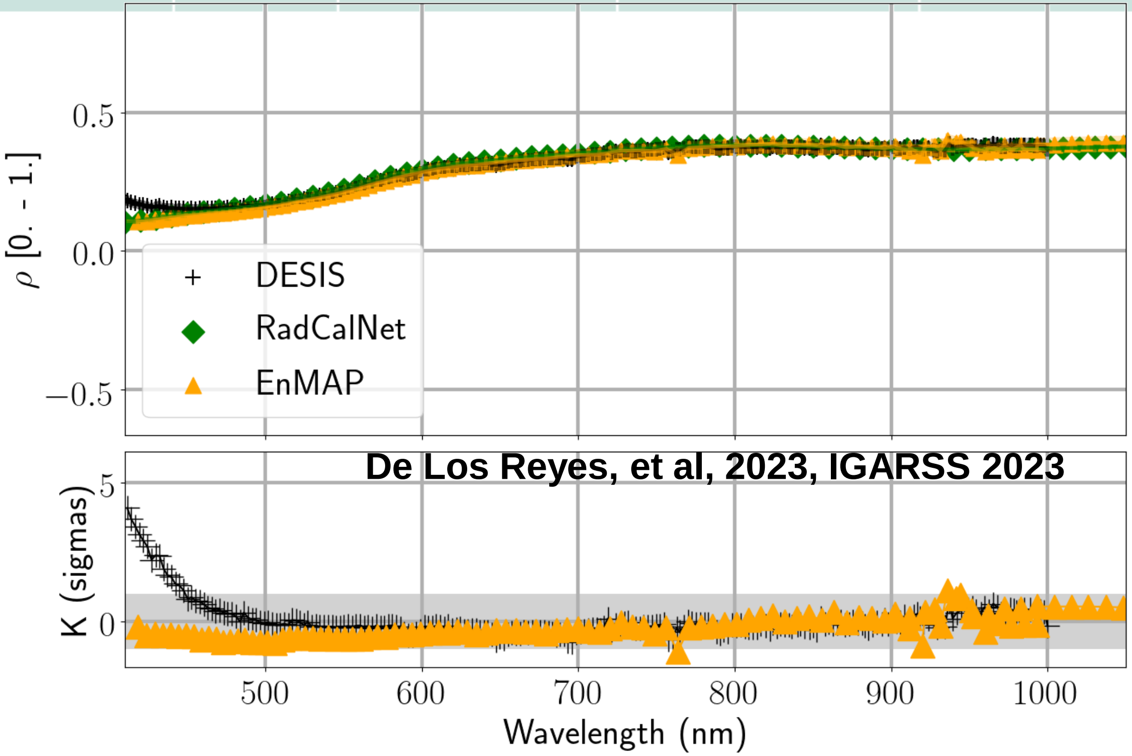
=> 5-10% (estimations during Commissioning Phase with old processor version, work in progress to investigate & separate sources of uncertainty)

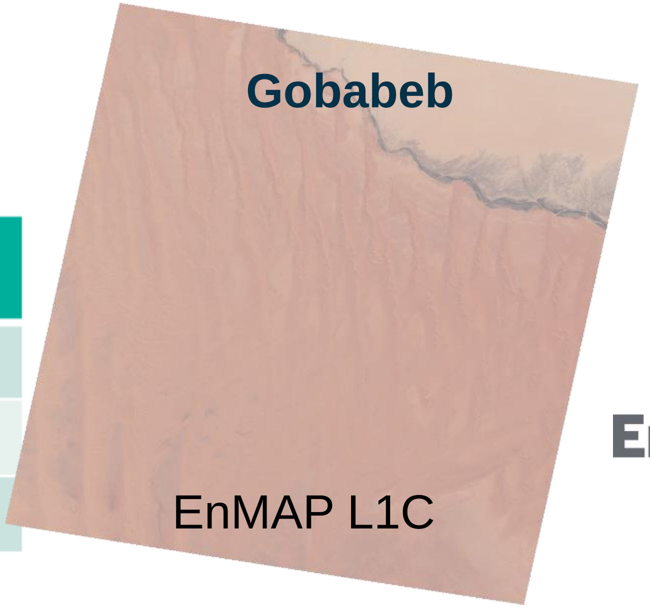
Radiometric stability w.r.t. PICS,

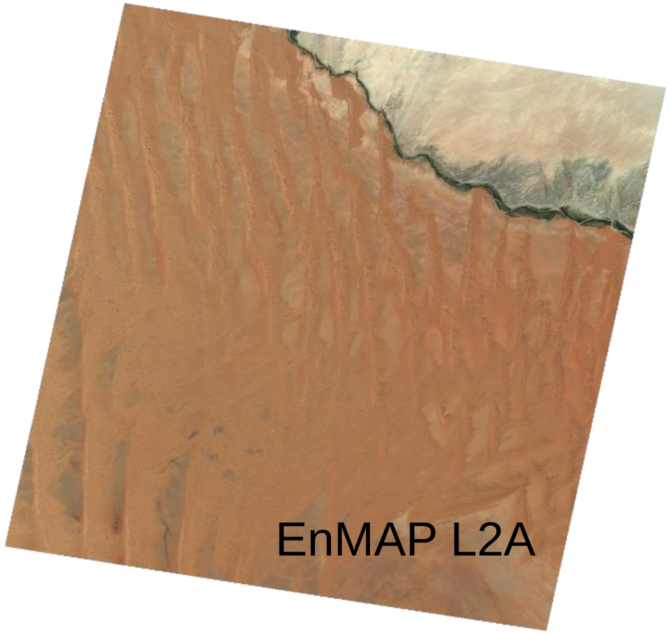
1st mission quaterly report – https://www.enmap.org/mission/

PACO L2A BOA_REF validation EnMAP – DESIS – RadCalNet

02.10.2022	UTC	(θ_s,φ_s)	(θ_v,φ_v)	AOT_{550}	WV (cm)
EnMAP	09:43	(25.6°, 40.9°)	(5.9°, 102.2°)	0.30 ± 0.08	1.6 ± 0.2
DESIS	07:53	(47.6°, 72.3°)	(15.6°,128.9°)	0.30 ± 0.15	1.4 ± 0.2
RadCalNet	08:00	---	(0°, 0°)	**0.31 ± 0.01**	1.7 ± 0.3







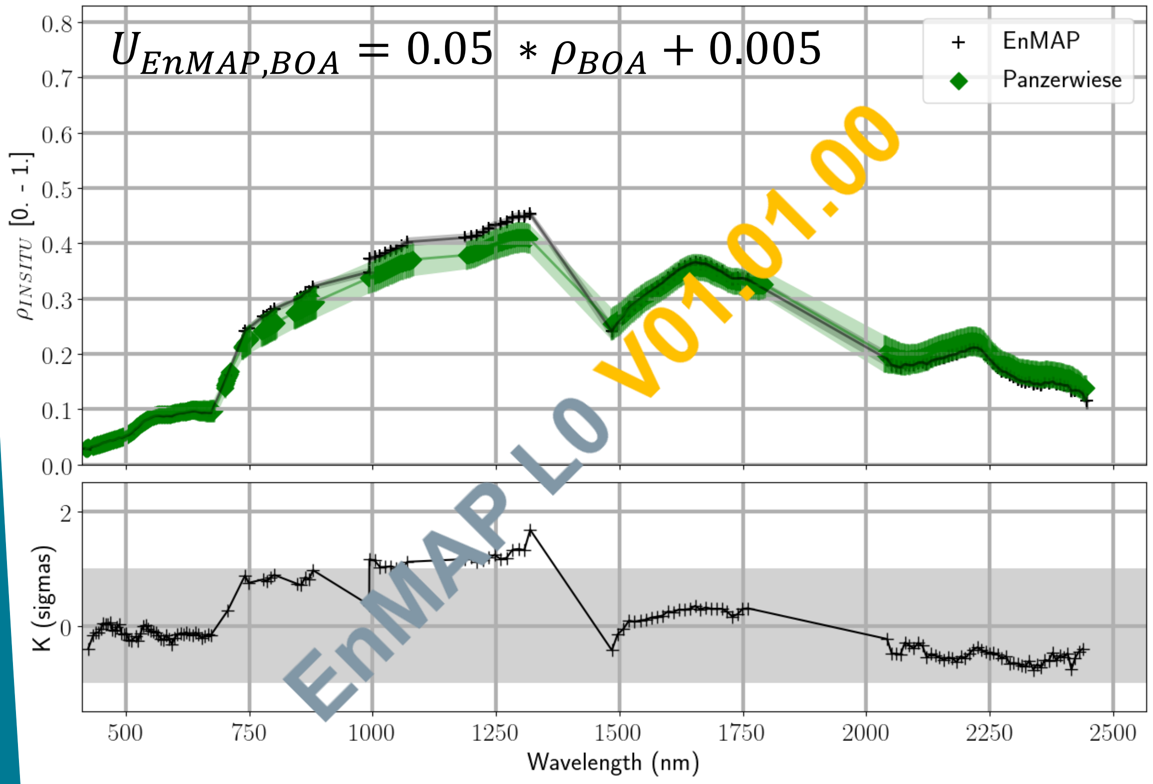
Within errors all sensors are measuring the same

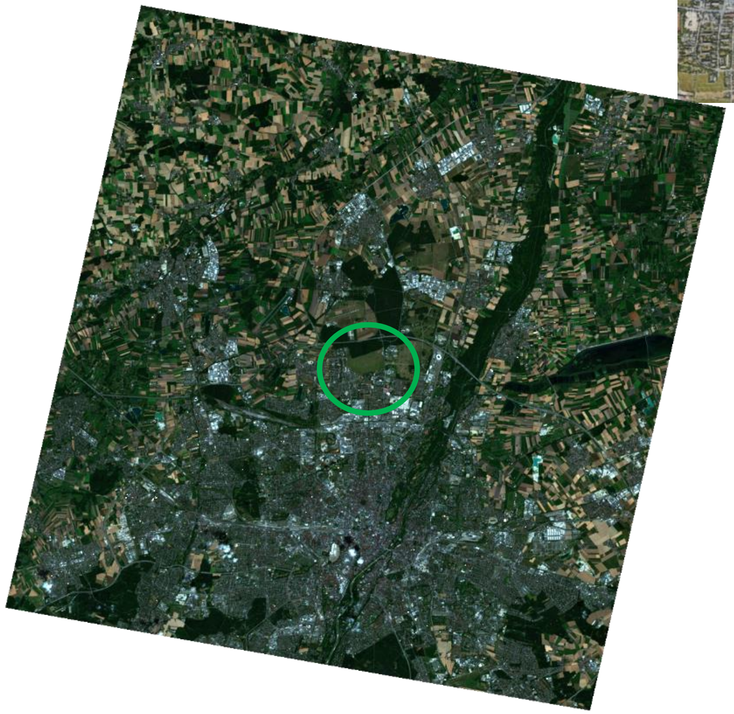
2022 Munich / Panzerwiese – EnMAP overpass

Pflug, B. et al, 2023, LVPE 2023

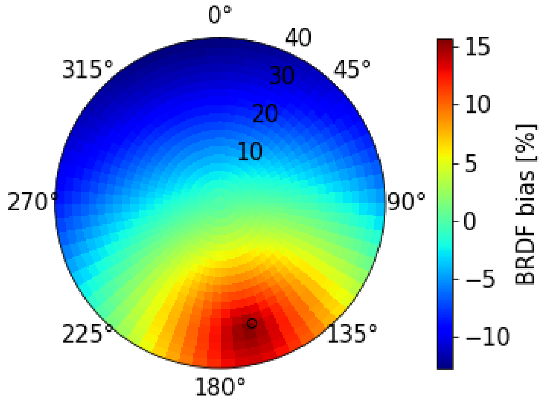
https://az659834.vo.msecnd.net/eventsairwesteuprod/production-nikal-public/cc11f67cb84c4c75a4d54cbf4602a7e4

28.07.2022	UTC	(θ_s, φ_s)	(θ_v, φ_v)	AOT_{550}	WV (cm)	$BRDF_{bias}$ [% @ 645 nm]
EnMAP	10:48	(29.9°, 165.6°)	(1.0°, 284.5°)	0.09±0.00	2.45±0.13	- 0.2
AERONET (> 9 km)	$10{:}48 \pm 1^h$	---	---	0.09±0.01	1.86±0.05	---





U_{ROI} unknown



UPV BRDF LUTs (Gorrono, J.)

CEOS ARD

Infrared and Visible Optical Sensors (IVOS) 35
CEOS, Working Group on Calibration and Validation (WGCV)
Oberpfaffenhofen, 27.09.2023

Federal Ministry for Economic Affairs and Climate Action

CEOS ARD – Status

- EnMAP L2A „Land“
  - Assessment completed in 2022
- EnMAP L2A „Water“
  - Discussion with CEOS & USGS, now internal evaluation if / how to provide all required metadata (esp. Masks)
- TIMELINE AVHRR „Land Surface Temperature“
  - Composite product, discussion with CEOS started if / how to include this
- … also Radar products in progress