2nd DESIS User Workshop

13th Workshop on Hyperspectral Image and Signal Processing : Evolution in Remote Sensing

Operational Quality Control for Spaceborne Hyperspectral Sensors

On the Spectral and Radiometric Quality of Hyperspectral Data Products and the Related Influences on Higher-Level Processing

EnMAP

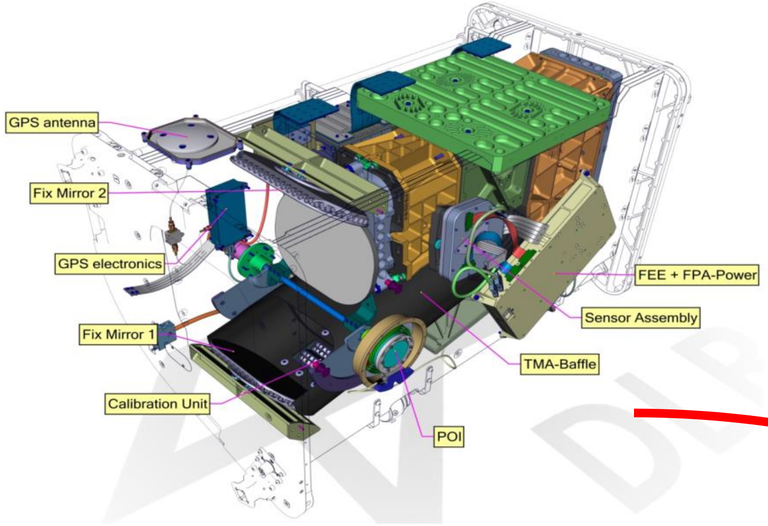
Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

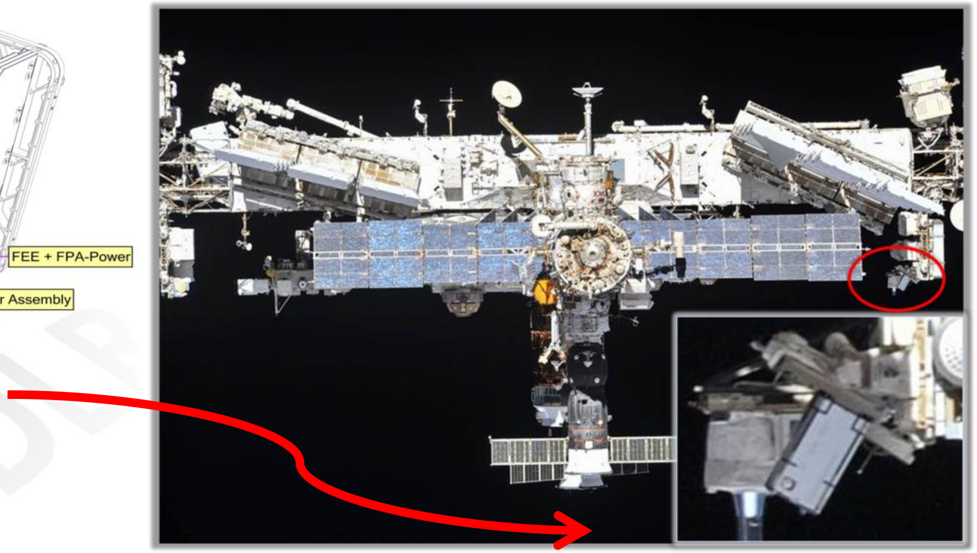
M. Bachmann, E. Carmona, U. Heiden, S. Holzwarth, M. Habermeyer, D. Marshall, M. Pato, T. Storch, R. de Los Reyes and R. Müller

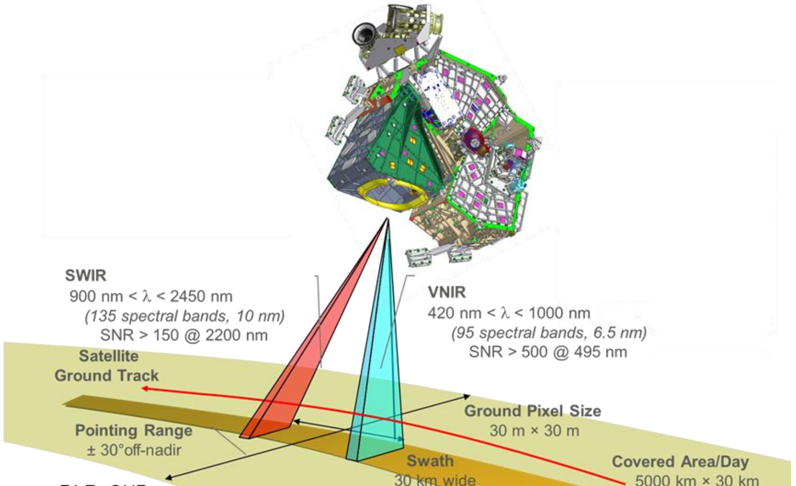
DLR-EOC Earth Observation Center

DLR Teledyne

Mission Instrument	ISS/MUSES DESIS	EnMAP HSI (2 instruments)
Off-nadir tilting (across-track, along-track)	-45° (backboard) to +5° (starboard), -40° to +40° (by MUSES and DESIS)	-30° to +30°, 0° (by EnMAP)
Spectral range	400 nm to 1000 nm	420 nm to 2450 nm
Spectral (res., acc.)	2.55 nm, (*)	6.5 nm, 0.5 nm (VNIR), 10.0 nm, 1.0 nm (SWIR)
Radiometry (res., acc.)	13 bits, (*)	14 bits, 5%
Spatial (res., swath)	30 m, 30 km (@ 400 km)	30 m, 30 km
SNR (signal-to-noise)	205 (no bin.)/406 (4 bin.) @ 550 nm	500 @ 495 nm, 150 @ 2200 nm
Instrument (mass)	93 kg	350 kg
Capacity (km, storage)	2360 km per day, 225 GBit	5000 km per day, 512 GBit







Source: DLR, OHB

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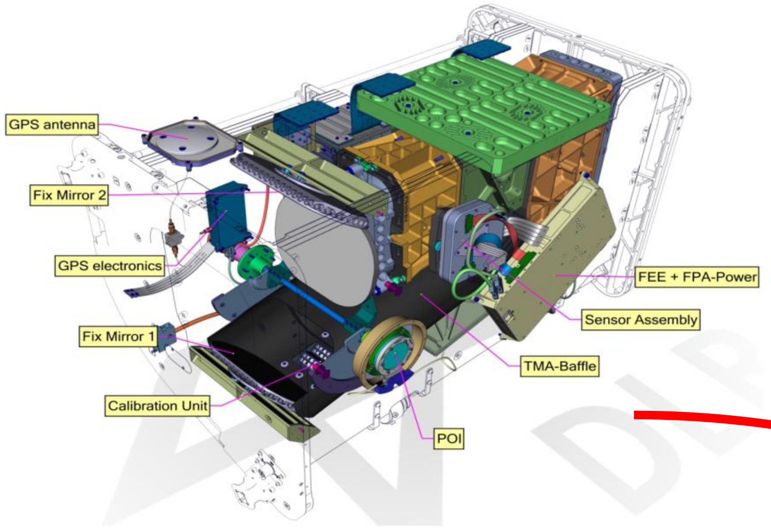

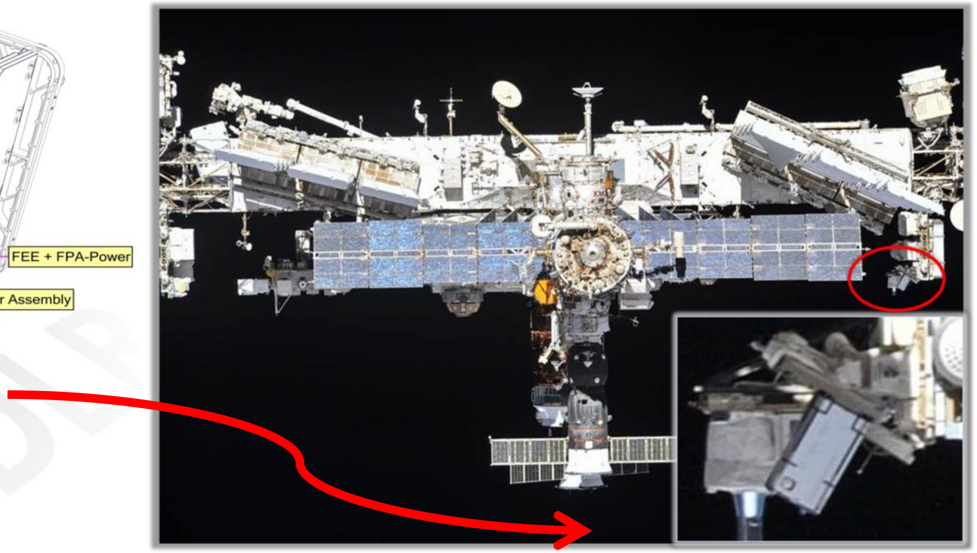

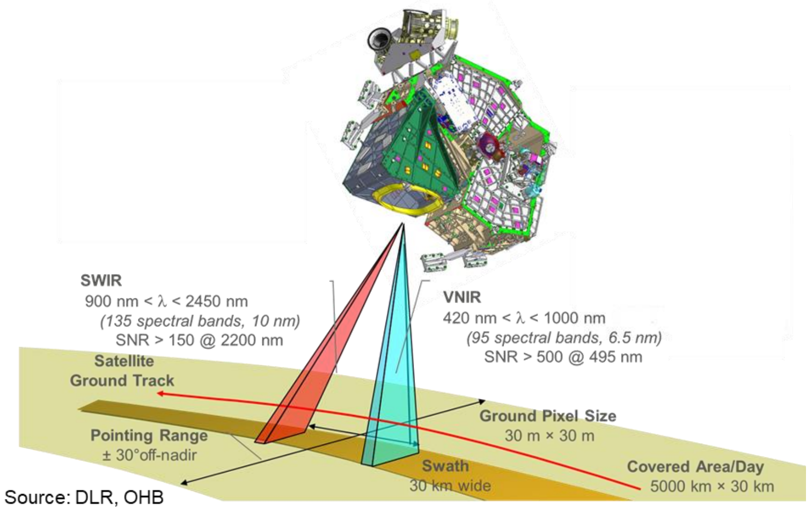

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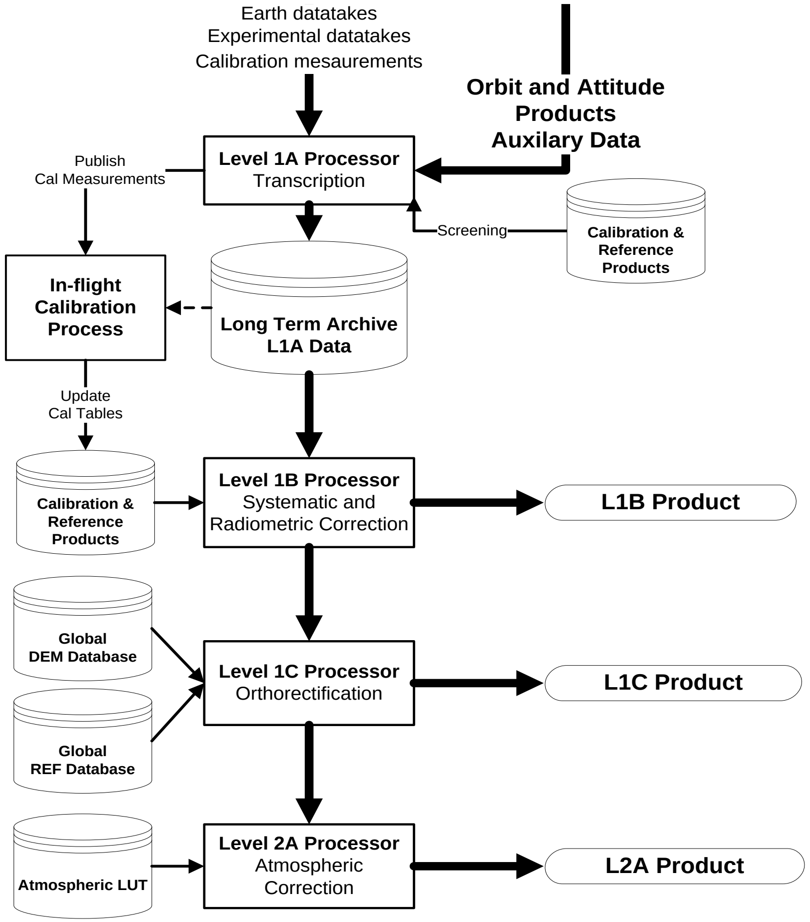
Mission Instrument	ISS/MUSES DESIS	EnMAP HSI (2 instruments)
Target lifetime	2018-2023+	2022-2027
Satellite (mass, dimension, usage)	455 t, 109.0×97.9×27.5 m^3 (multi-purpose)	1 t, 3.1×2.0×1.7 m^3 (single-purpose)
Orbit (type, local time at equator, inclination, height, repeat cycle)	not Sun-synchronous, various, 51.6°, 320 km to 430 km, no repeat cycle	Sun-synchronous, 11:00, 98.0°, 653 km, 398 revolutions in 27 days
Coverage	55° N to 52° S	74° N to 74° S
Revisit frequency	3 to 5 days (average)	≤ 4 days, ≤ 27 days (±5° tilting)

Ground Segment Processors



Processors at the Ground Segments

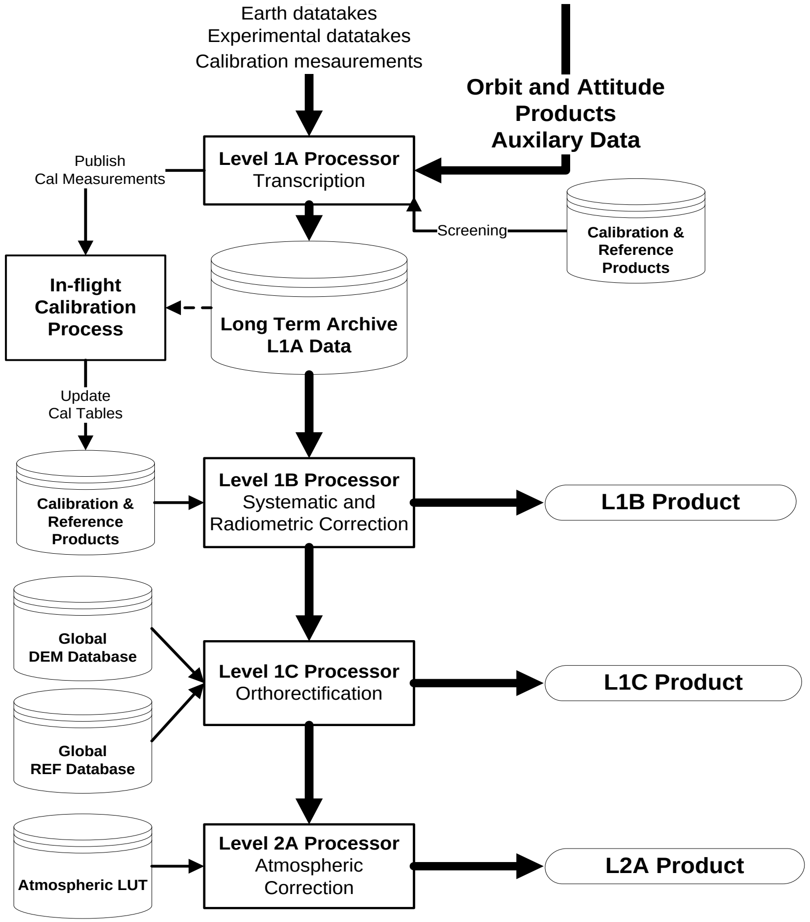
- Fully automated
- Run ‘on-request’ over archived data
- Two instances: one at Teledyne (Amazon Cloud), one at DLR

Products:

- **Level 0 (L0)**
  - Raw data
- **Level 1A (L1A)**
  - L0 data with correction and calibration computed and appended.
- **Level 1B (L1B)***
  - Top of Atmosphere (TOA) radiance (W.m-2.sr-1.µm-1)
  - Systematic and radiometric correction (rolling shutter, keystone, smile)
- **Level 1C (L1C)***
  - Level 1B data ortho-rectified, re-sampled to a specified grid
  - Global DEM, sensor model refinement using global reference image (Landsat-8 PAN with 12m CE90)
- **Level 2A (L2A)***
  - Ground surface reflectance (i.e. after atmospheric corrections)
  - Smile taken into account

* Delivery product

Ground Segment Processors



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DESIS

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DESIS

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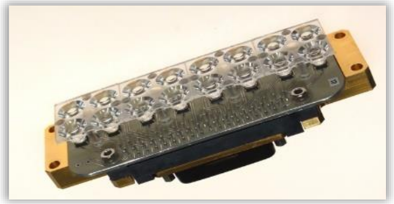
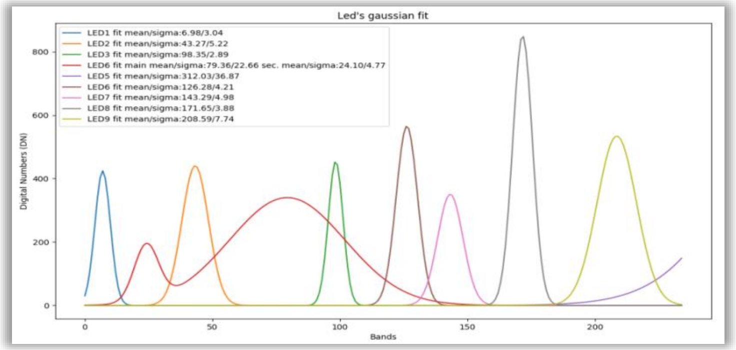
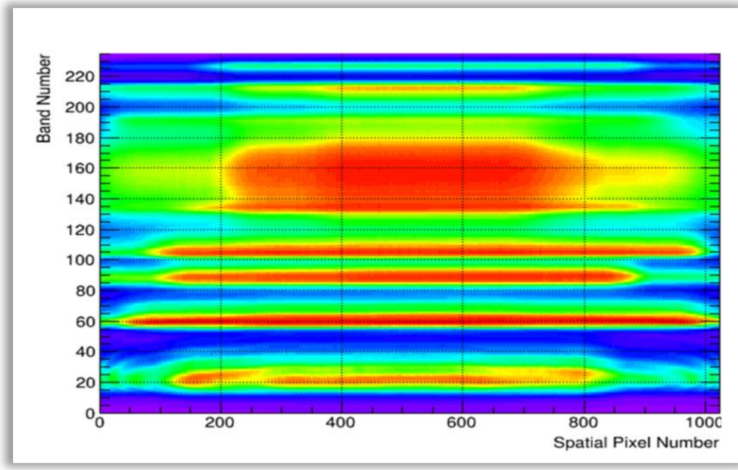
DESIS: In-Orbit Spectral Characterization

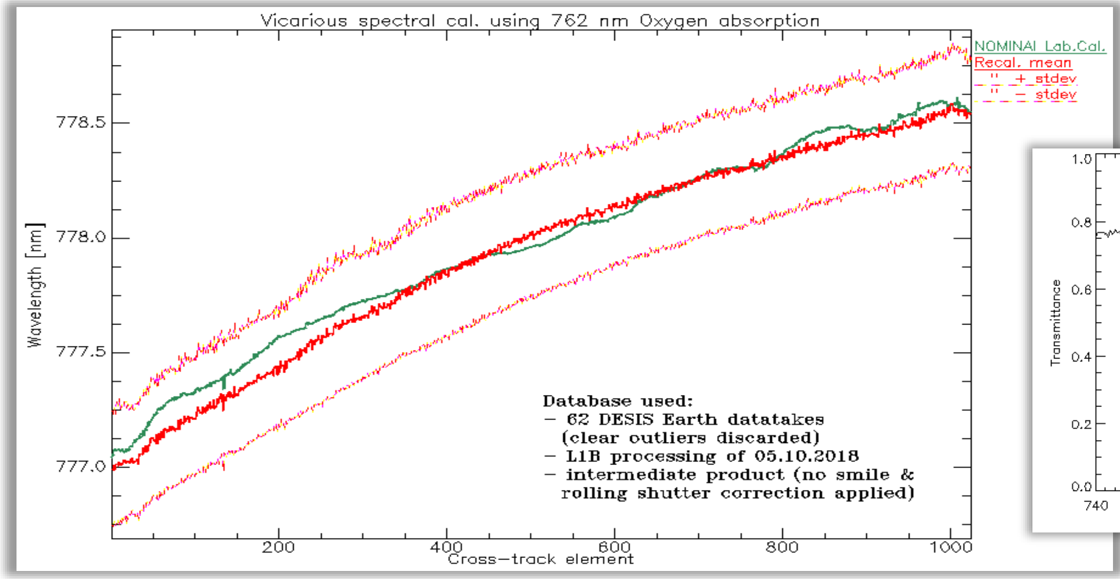


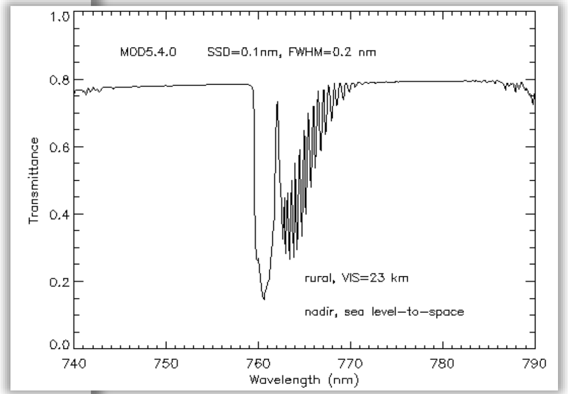
- Using on-board calibration sources (LEDs)
  - ✓ Pre- and post-launch characteristics
  - Incl. temperature stability & other HK / telemetry data





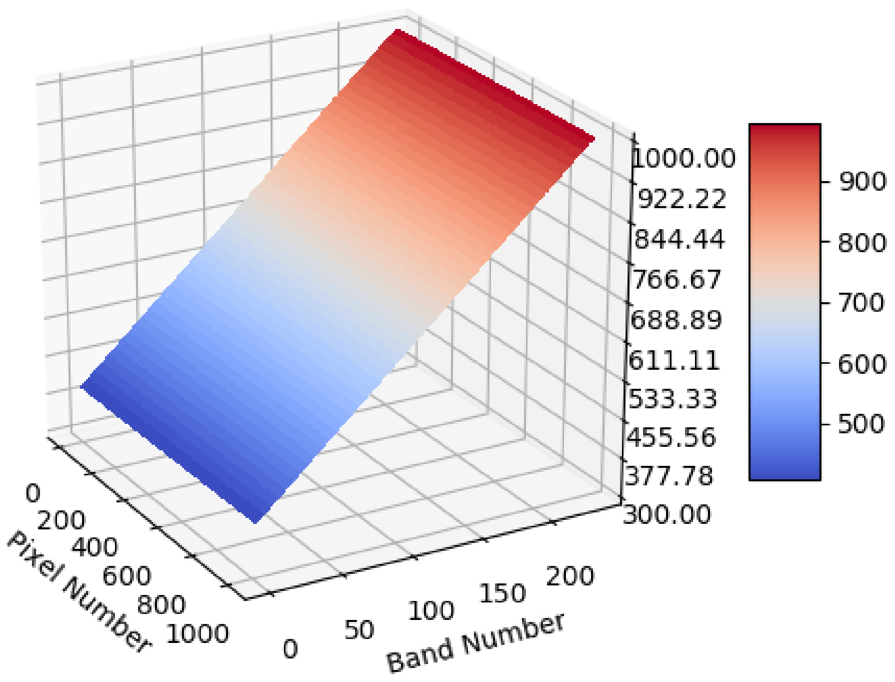
- Using atmospheric absorption features
  - ✓ Smile pre- and post-launch

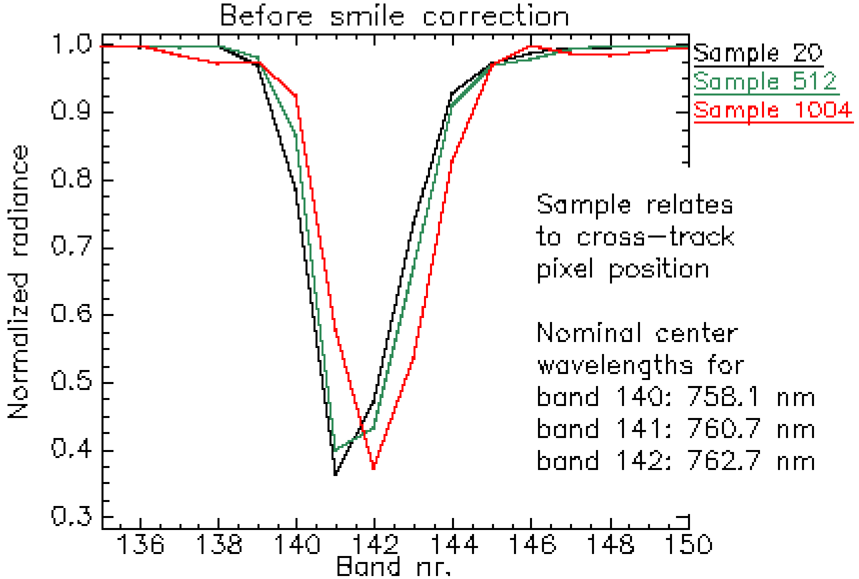


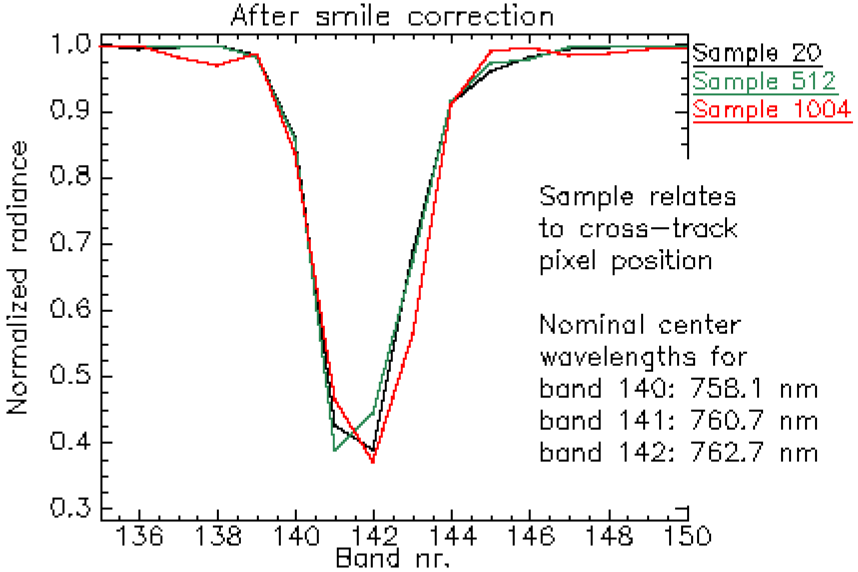


DESIS: Smile Correction / Spectral Monitoring

- Bicubic interpolation to the central pixel wavelength.
- Assessments, performed on DESIS data, around Oxygen absorption band.



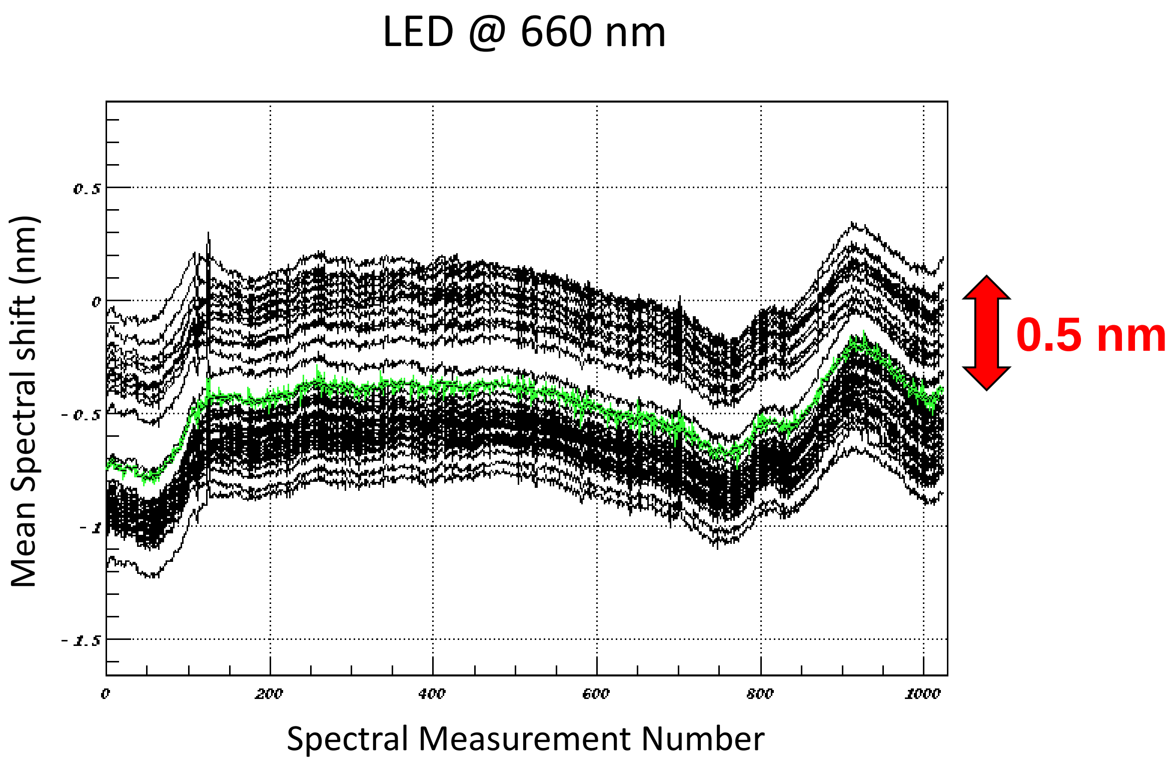




DESIS: Influences on Spectral Stability

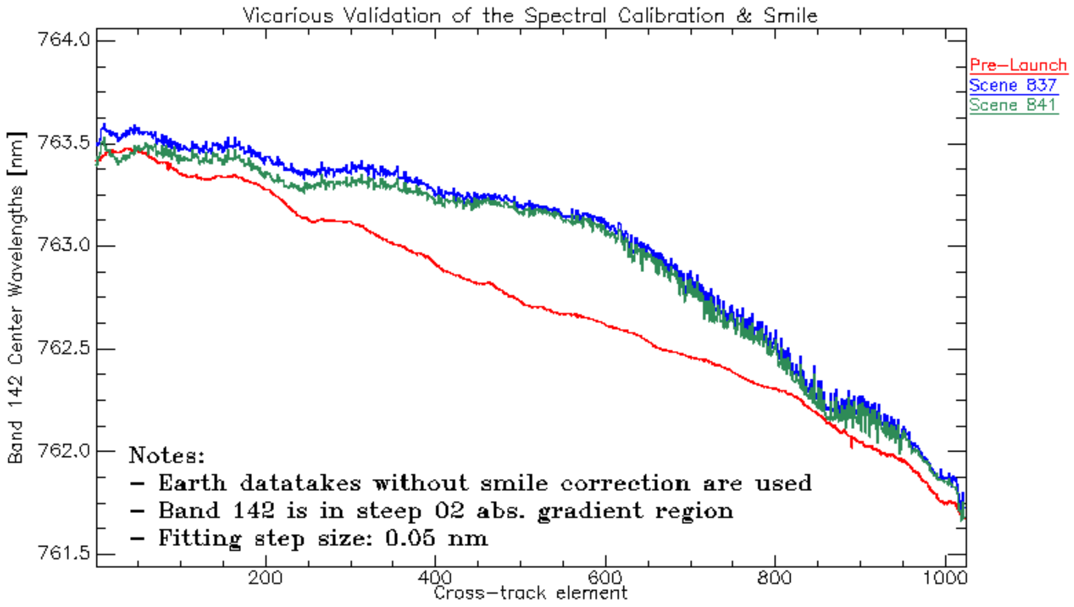
DESIS
Temperature gradient in housing
(see talk by E.Carmona)

Note: FPA stabilized to 0.1k

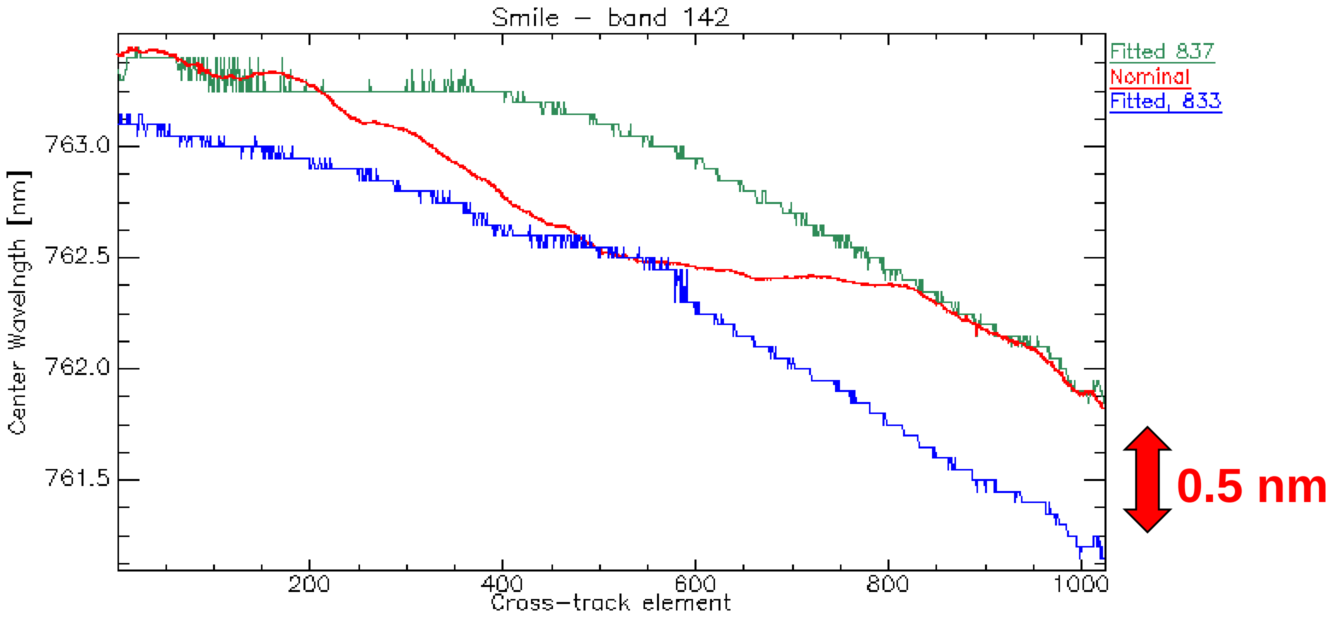


DESIS: Influences on Spectral Stability

- Vicariously performed on DESIS Earth datatakes, L1B processing, no smile correction applied
- Shift confirmed for Oxygen absorption region (762 nm) & other wavelengths (483, 524 & 819 nm)



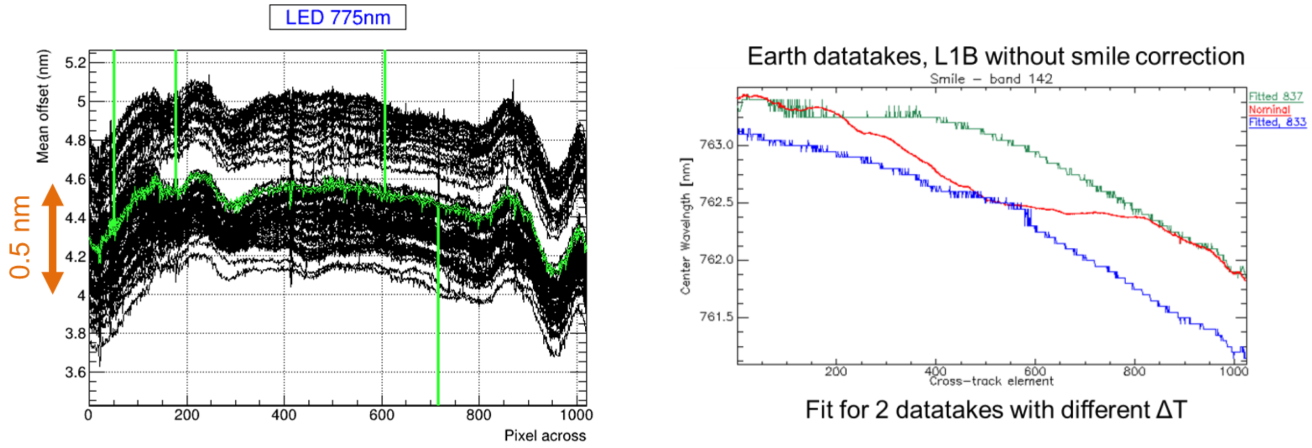
Left: fit for 2 datatakes with same ΔT



Right: fit for 2 datatakes with different ΔT

The L2A product… now adding spectral uncertainties @ L1B

Slight spectral shifting due to temperature gradient



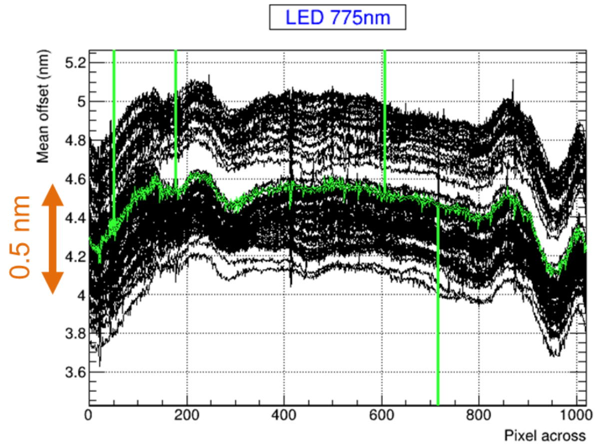
Fit for 2 datatakes with different ΔT

Corrected in L1B processor, remaining RMS ~0.1 nm (@ ~ 2.55 nm SSI)

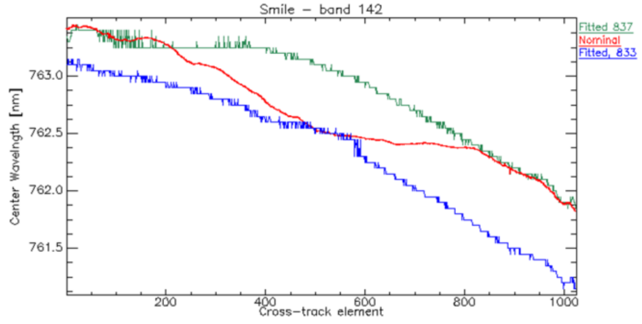
Correction possible based on housekeeping data, implemented in L1B processing

The L2A product… now adding spectral uncertainties @ L1B

Slight spectral shifting due to temperature gradient



Earth datatakes, L1B without smile correction



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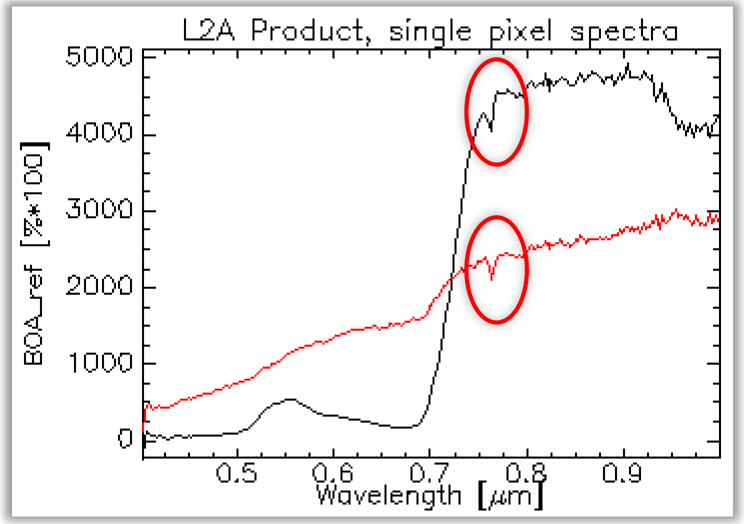
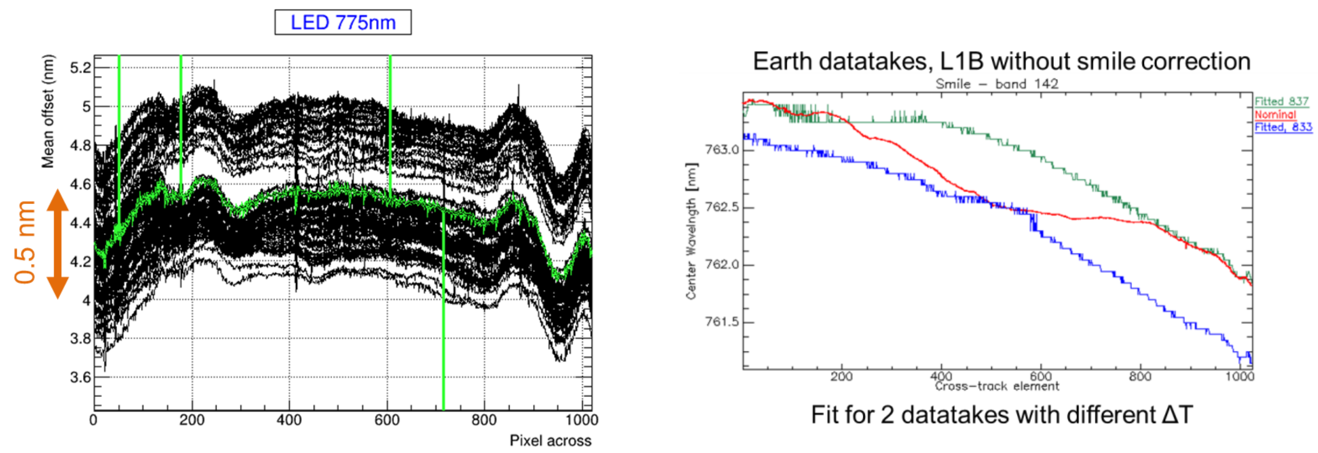
DESIS L2A Product



Oxygen absorption at 760 nm

The L2A product… now adding spectral uncertainties @ L1B

Slight spectral shifting due to temperature gradient



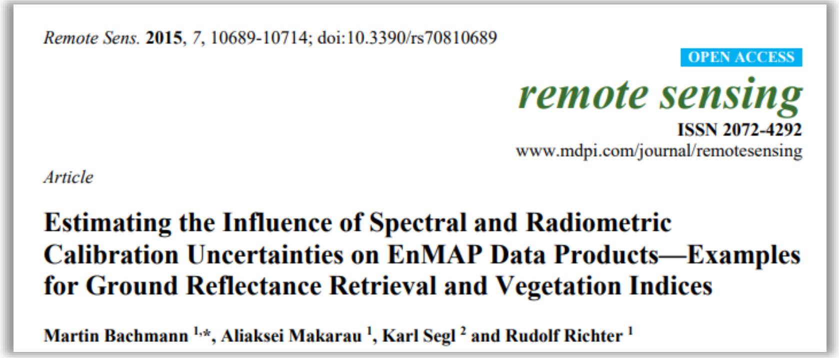
Fit for 2 datatakes with different ΔT

Corrected in L1B processor, remaining RMS ~0.1 nm (@ ~ 2.55 nm SSI)

Approach:

- Shifting the center wavelengths at TOA_RAD
  - by +/- 0.1 nm (nominal corrected case)
  - by +/- 0.5 nm (uncorrected case)

- Process to BOA_ref using ATCOR
  - Interactive, but using same settings as DESIS L2A (PACO)
  - No smoothing nor interpolation


Remote Sens. **2015**, *7*, 10689-10714; doi:10.3390/rs70810689

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Article

Estimating the Influence of Spectral and Radiometric Calibration Uncertainties on EnMAP Data Products—Examples for Ground Reflectance Retrieval and Vegetation Indices

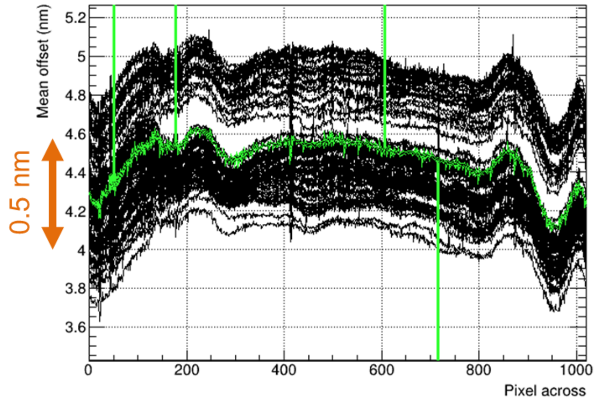
Martin Bachmann [1,*], Aliaksei Makarau [1], Karl Segl [2] and Rudolf Richter [1]

DLR

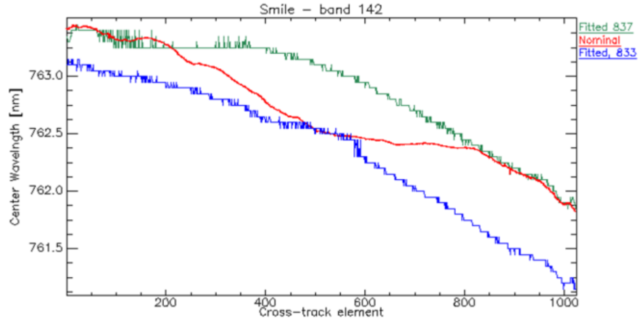
The L2A product… now adding spectral uncertainties @ L1B

Slight spectral shifting due to temperature gradient

LED 775nm



Earth datatakes, L1B without smile correction



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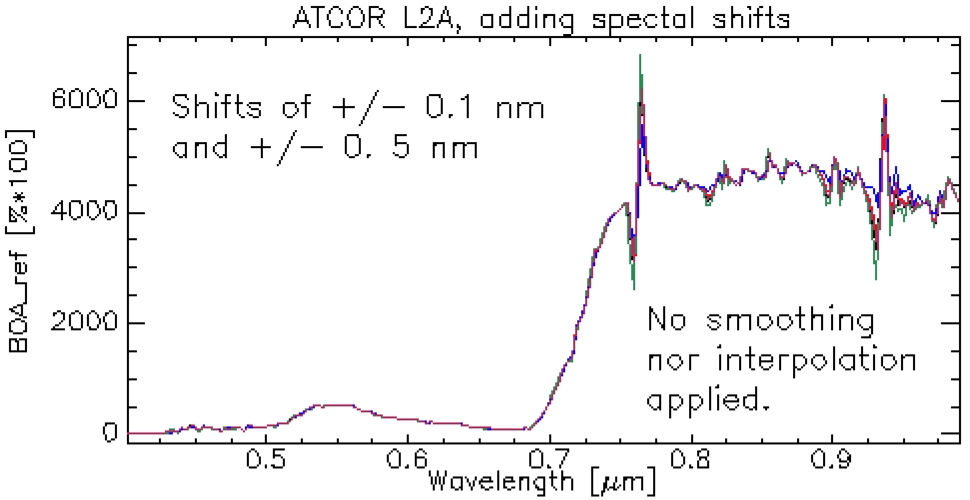

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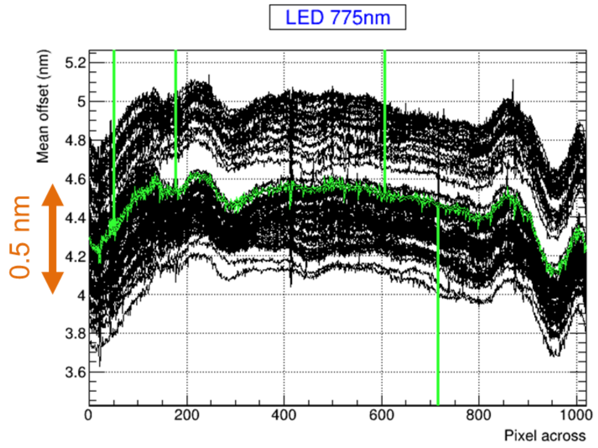

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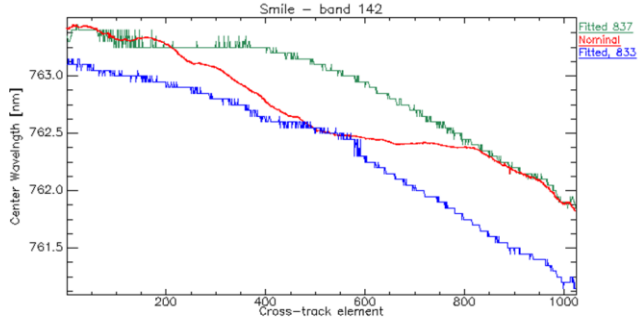

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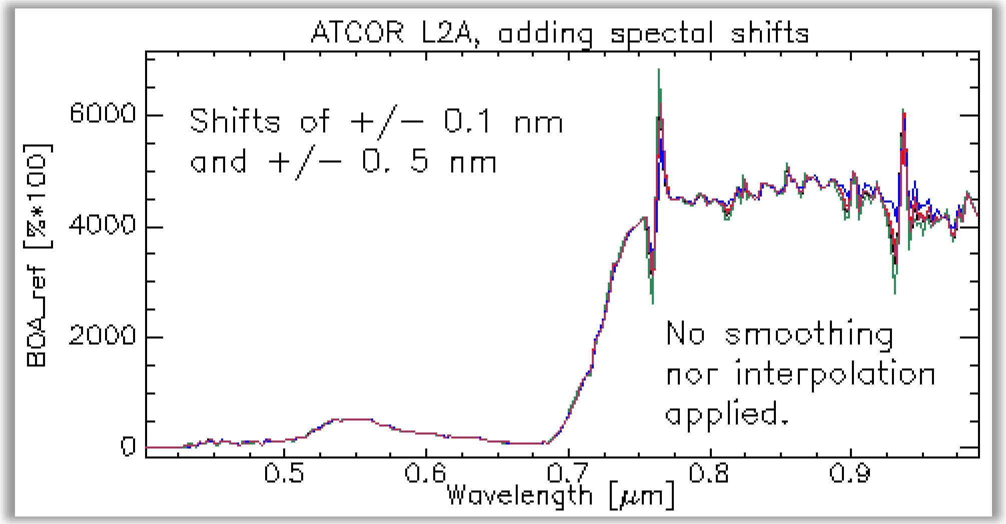

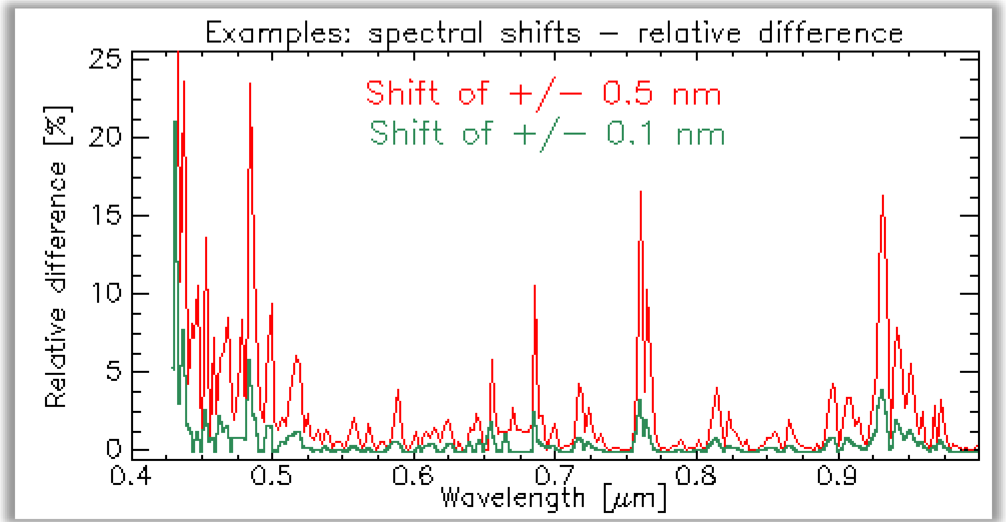

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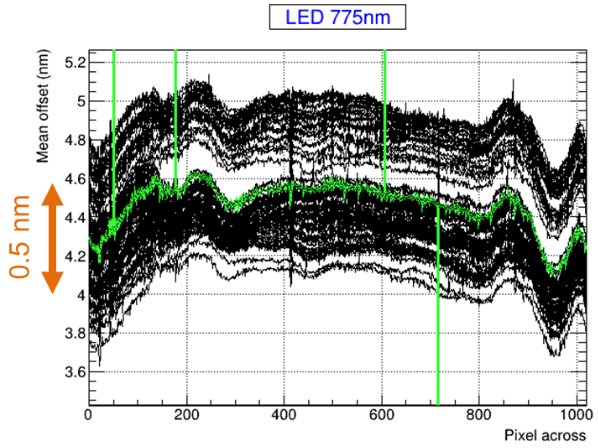

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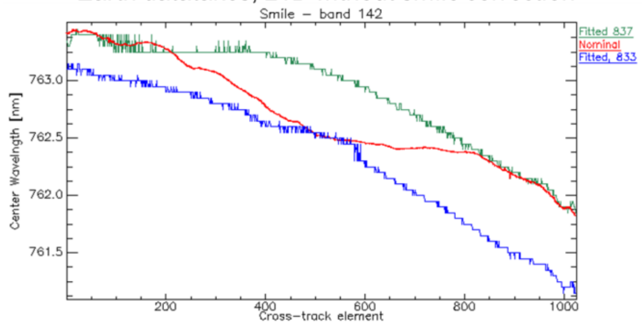

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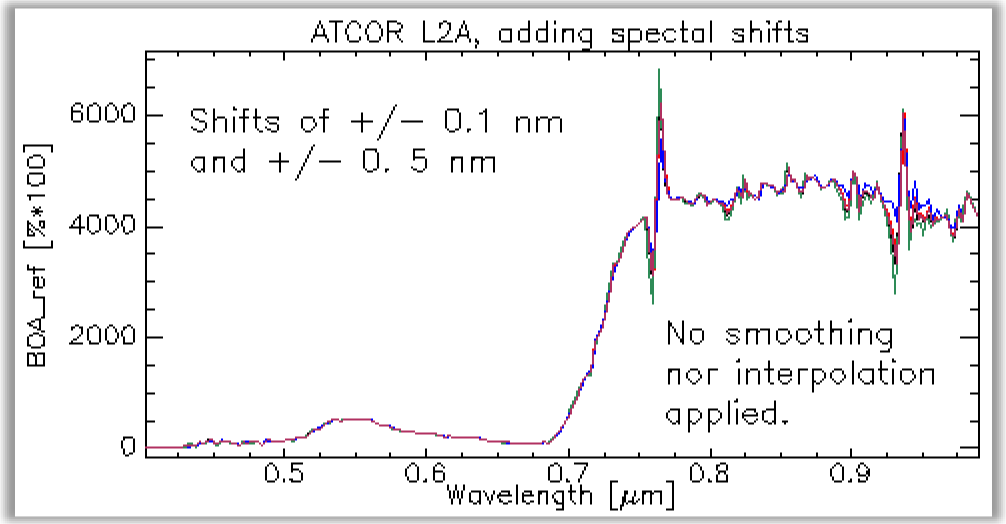
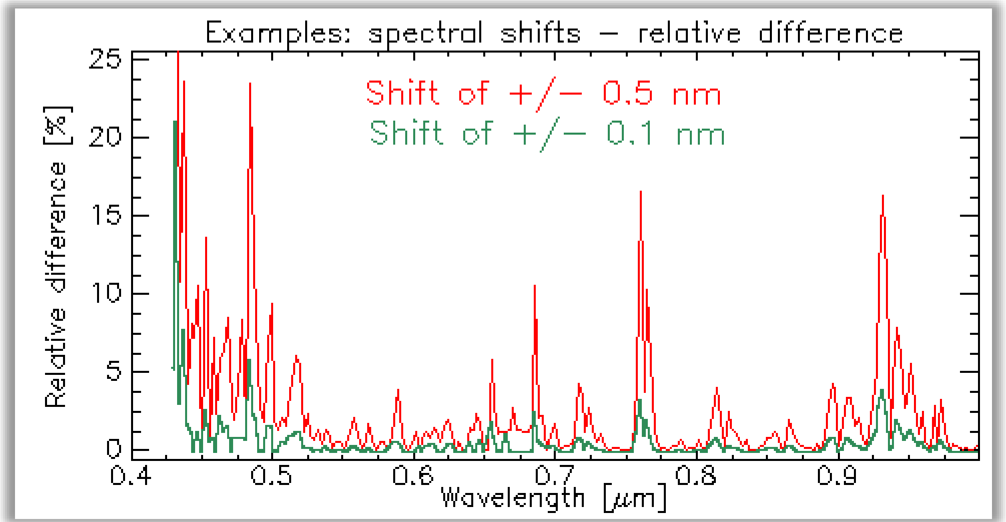
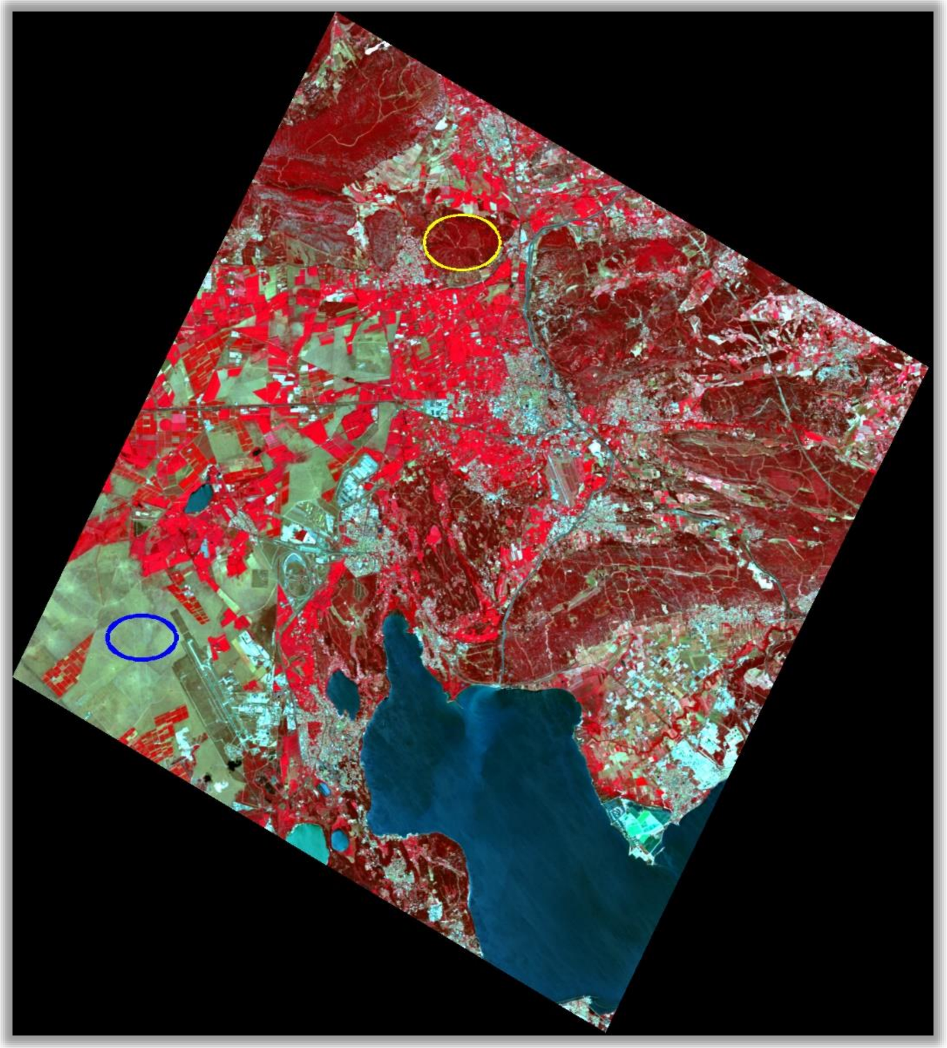




Sidenote:
WV retrieval influenced by 2% (±0.1nm) resp. 7% (±0.5nm)
AOT retrieval not significantly influenced in this example.

Influence on vegetation products



Examples using

- Heterogene vital green forest / shrub area (yellow circle)

	Shift of +/- 0.1 nm	Shift of +/- 0.5 nm
Broadband (NDVI, SAVI, EVI)	<1%	~1%
RedEdge (Vogelmann)	<1%	~1.5%
Photochem. index (PRI)	~2%	**up to 60%**
Carotenoid index	<1%	~3%
Anthocyanin index	~1%	**~5%**

- Homogene dry grassland area (blue circle)

	Shift of +/- 0.1 nm	Shift of +/- 0.5 nm
Broadband (NDVI, SAVI, EVI)	<1%	~2%
RedEdge (Vogelmann)	<1%	~1.7%
Photochem. index (PRI)	~2%	**~10%**
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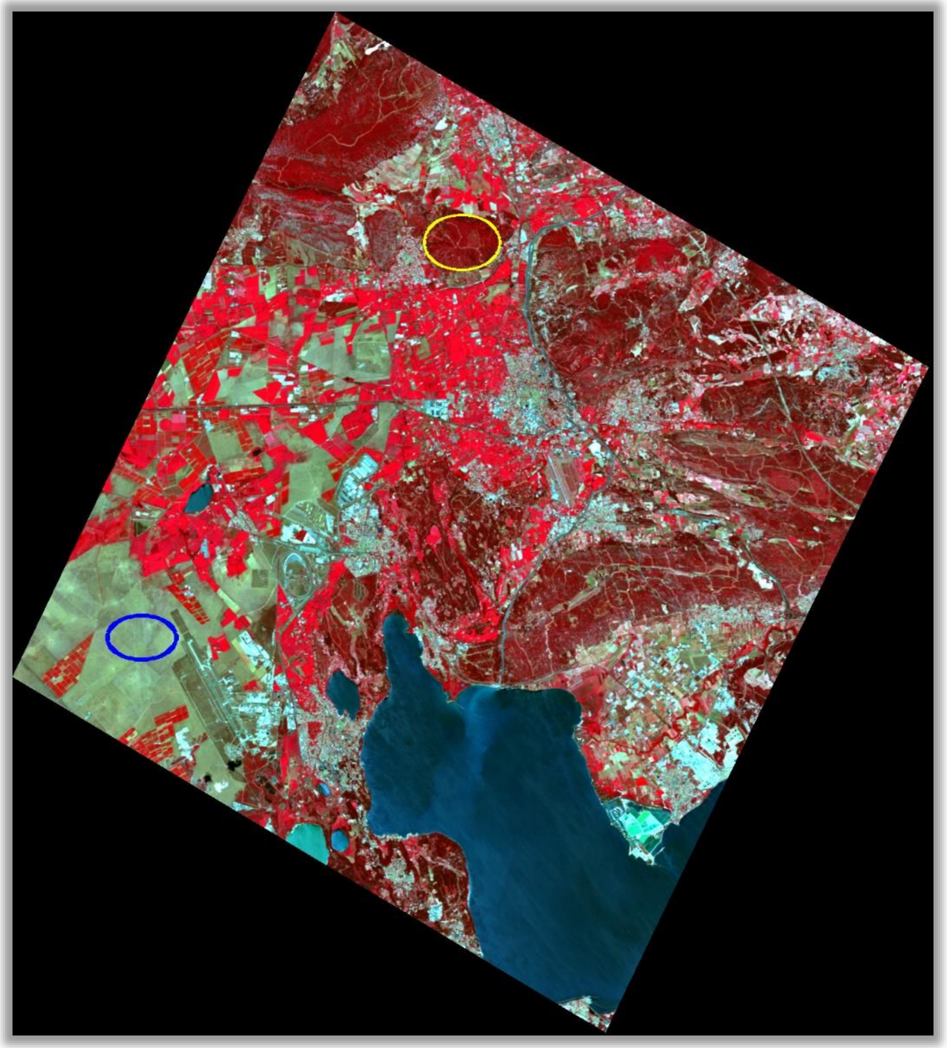
Influence on vegetation products



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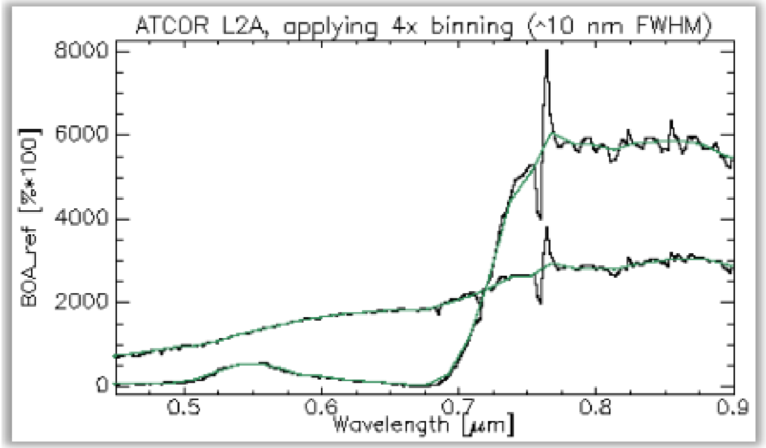
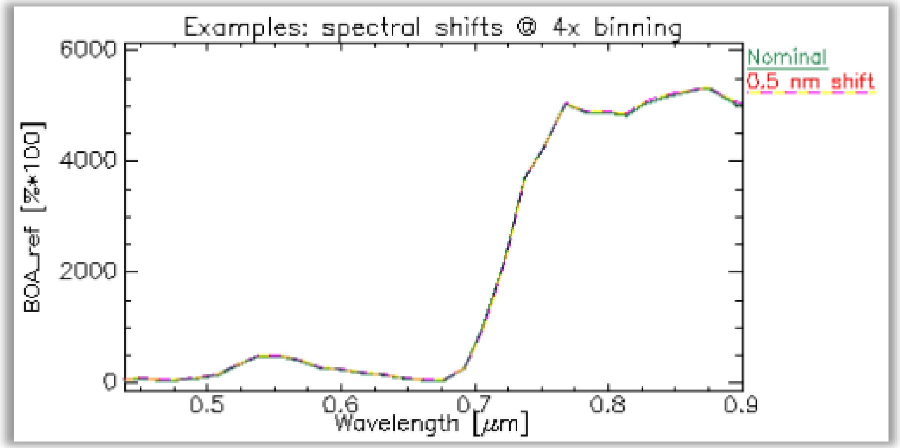
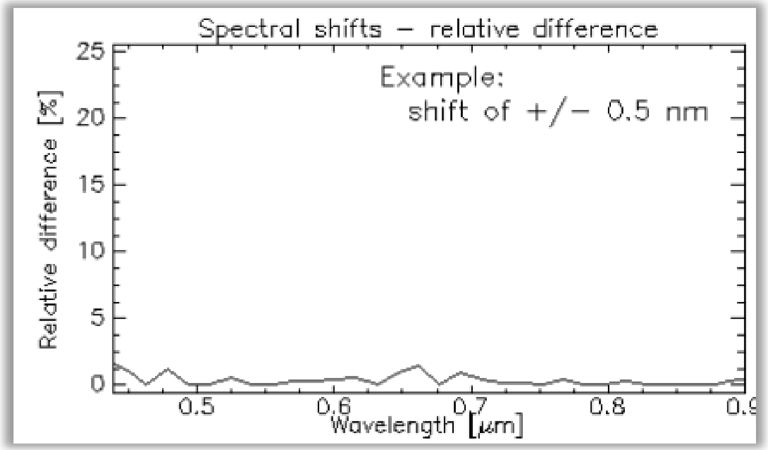
… and now for 4x binning (~10 nm FWHM):





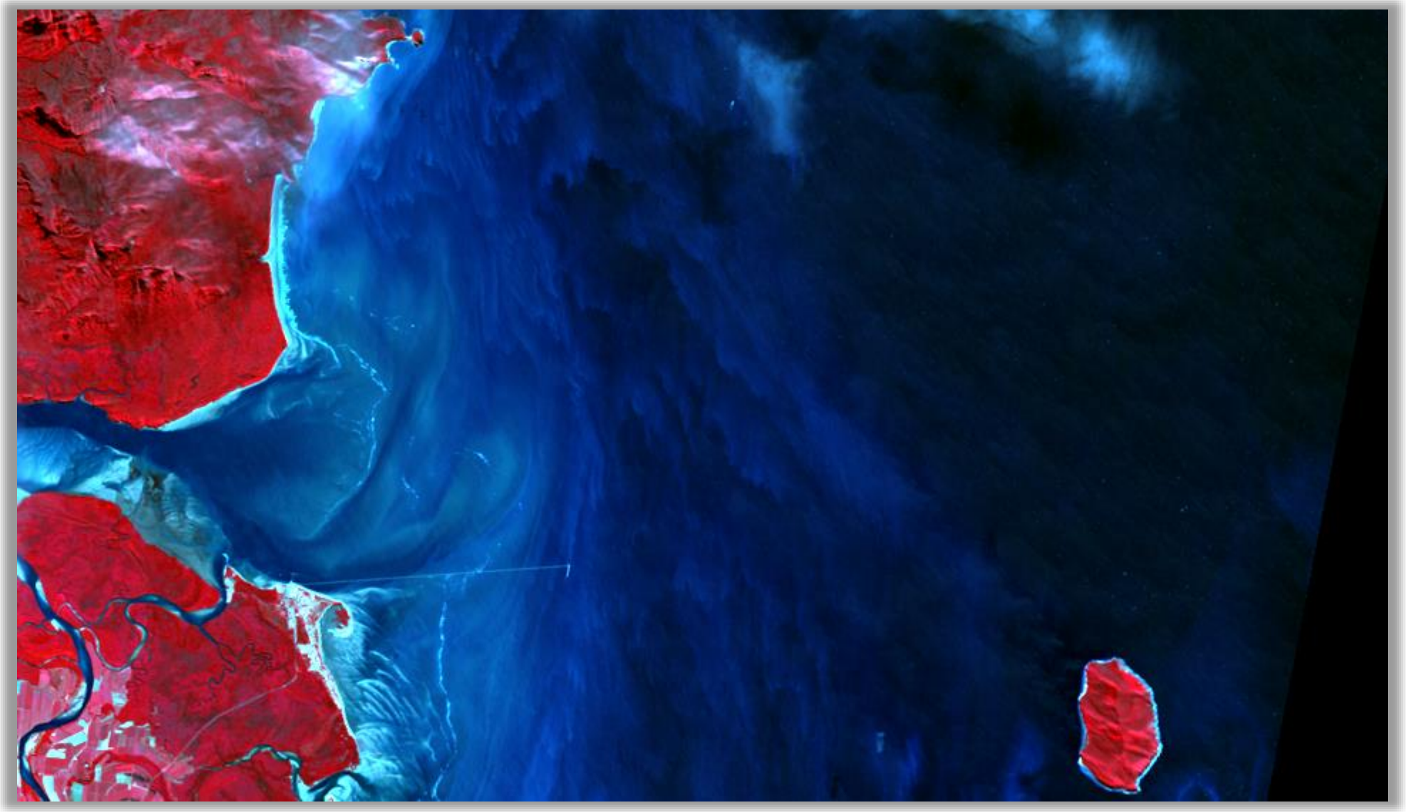


… and the typical relative difference (at max. 0.5 nm shifts):

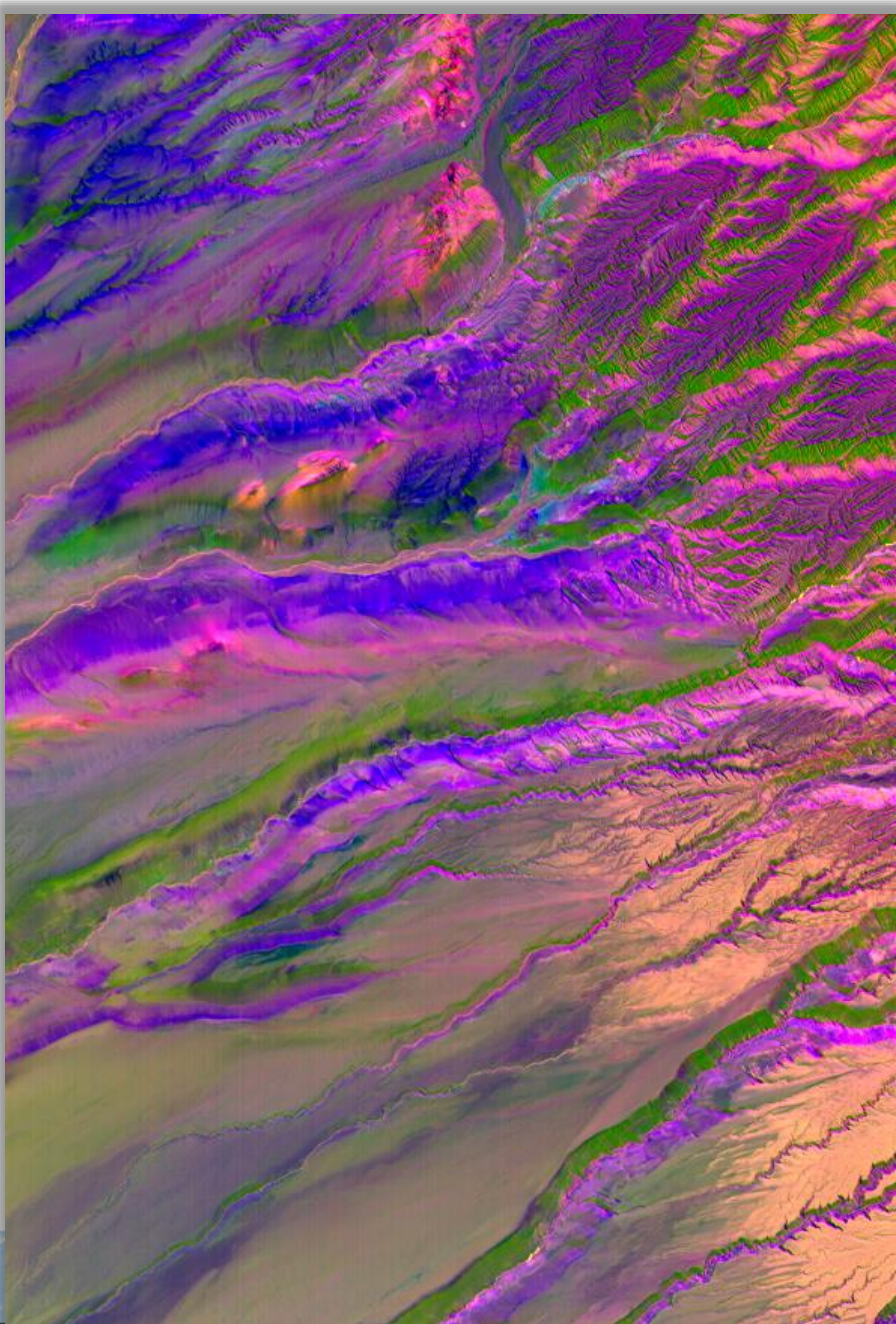
	Shift of +/- 0.5 nm
Broadband (NDVI, SAVI, EVI)	<< 1%
RedEdge (Vogelmann)	<< 1%
Photochem. index (PRI)	~4%
Carotenoid index	<< 1%
Anthocyanin index	~ 1%

… even for large shifts minimal influence!

EnMAP – Focus on Vicarious Validation using Earth Datatakes



Lucinda Jetty, Australia (CIR)

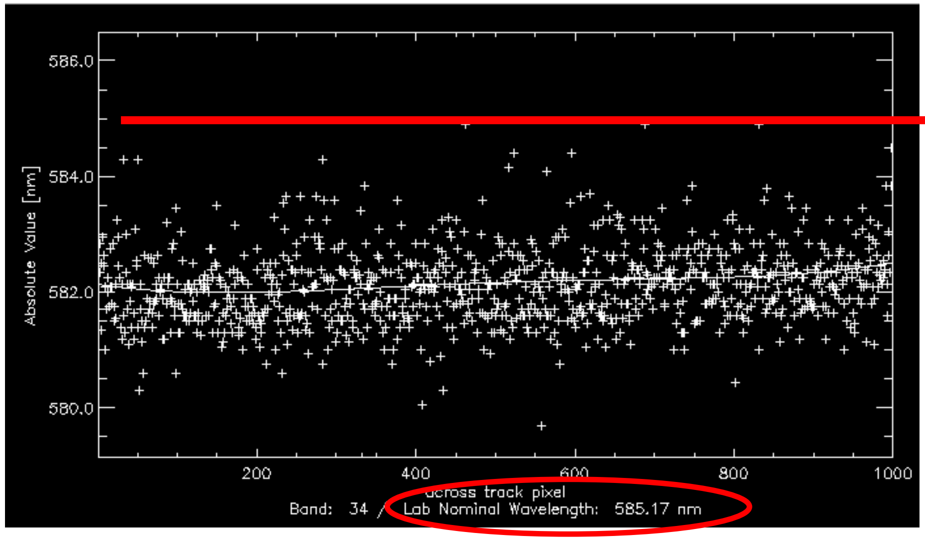


Desert Playa, Peru (SWIR, PC-Transfo.)

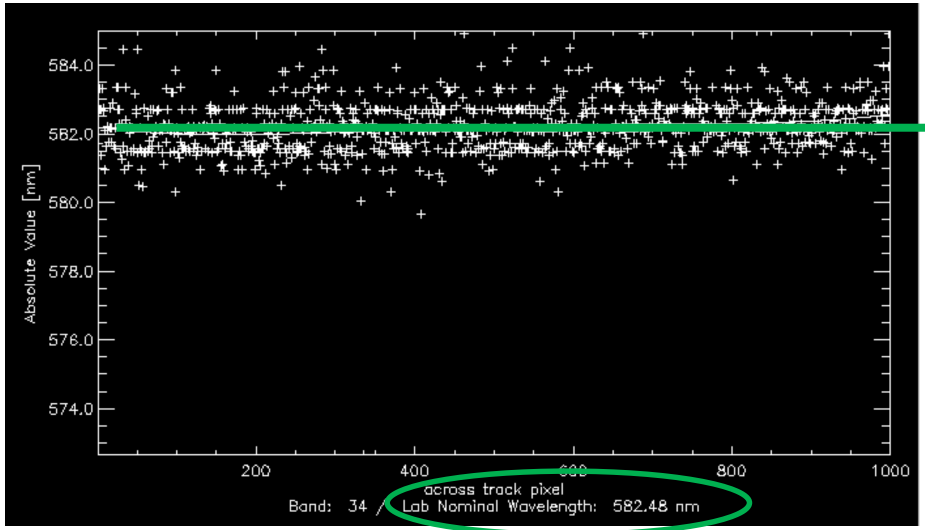
DLR

EnMAP – Pre- to Post-Launch Changes

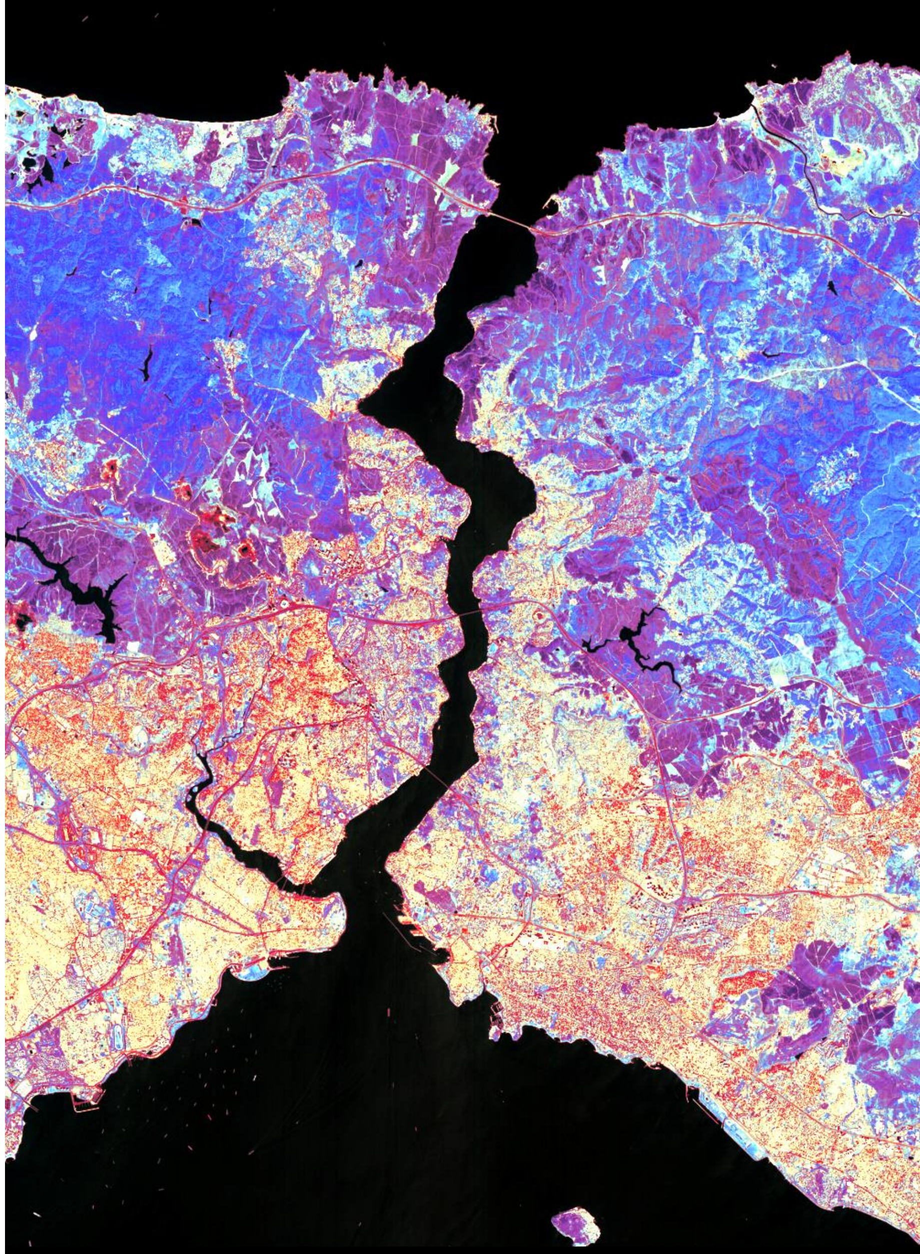
Results from spectral validation for pre- to 1st post-launch calibration tables



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

ENMAP – Spectral Stability Estimation using all Earth Datatakes

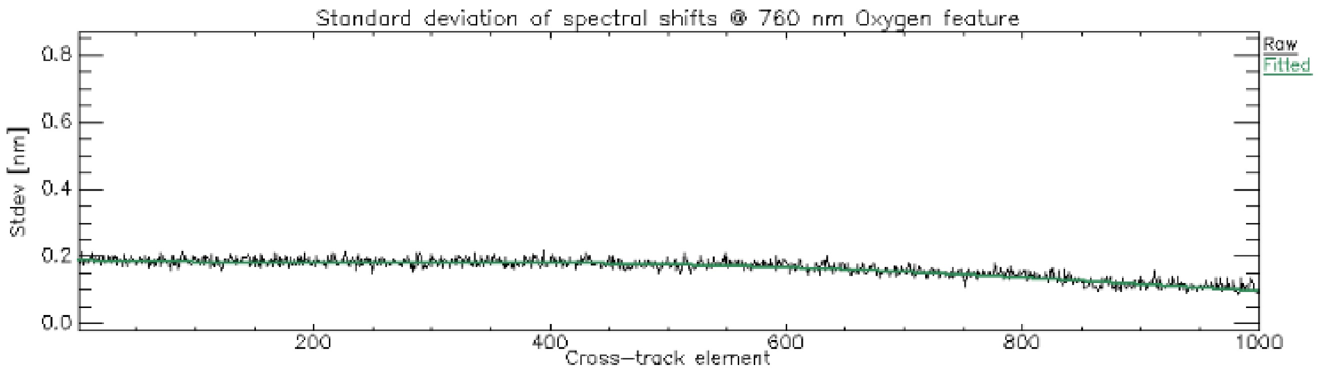
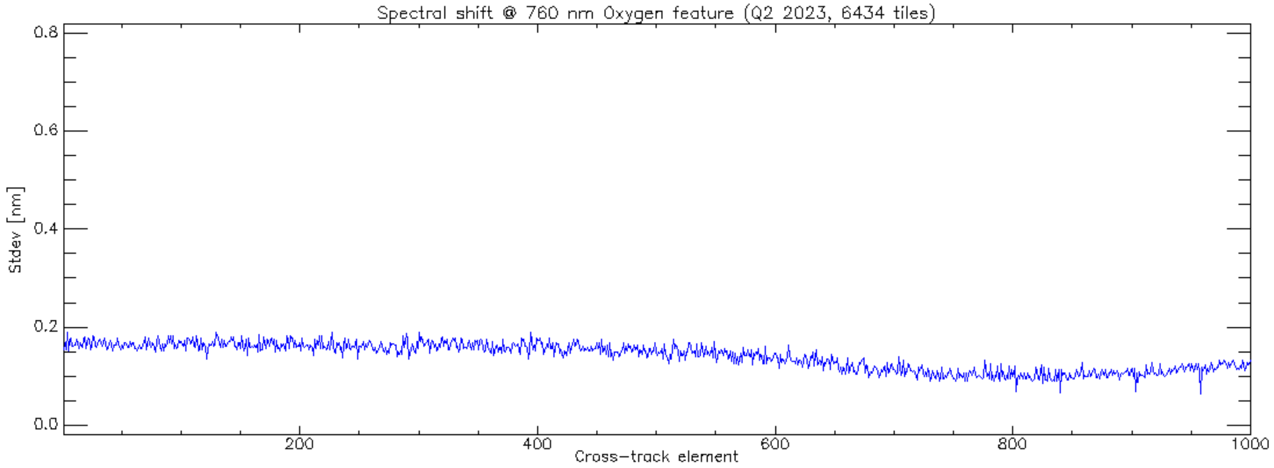


Figure 6-13 Spectral stability VNIR at 760 nm, expressed at 1 sigma; 2770 tiles



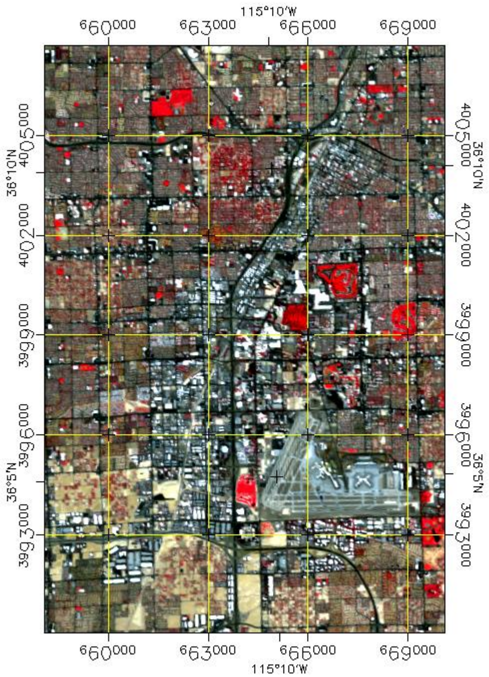
Approach:
fit of normalized TOA_rad to range of simulated spectrally shifted atm. absorption features of O_2 @760 nm, CO_2 @ 2060 nm

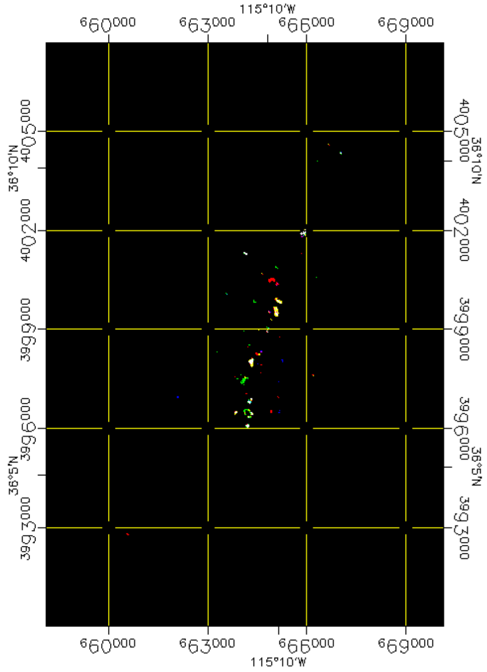
Result:
Overall good agreement with OBCA and interactive analysis

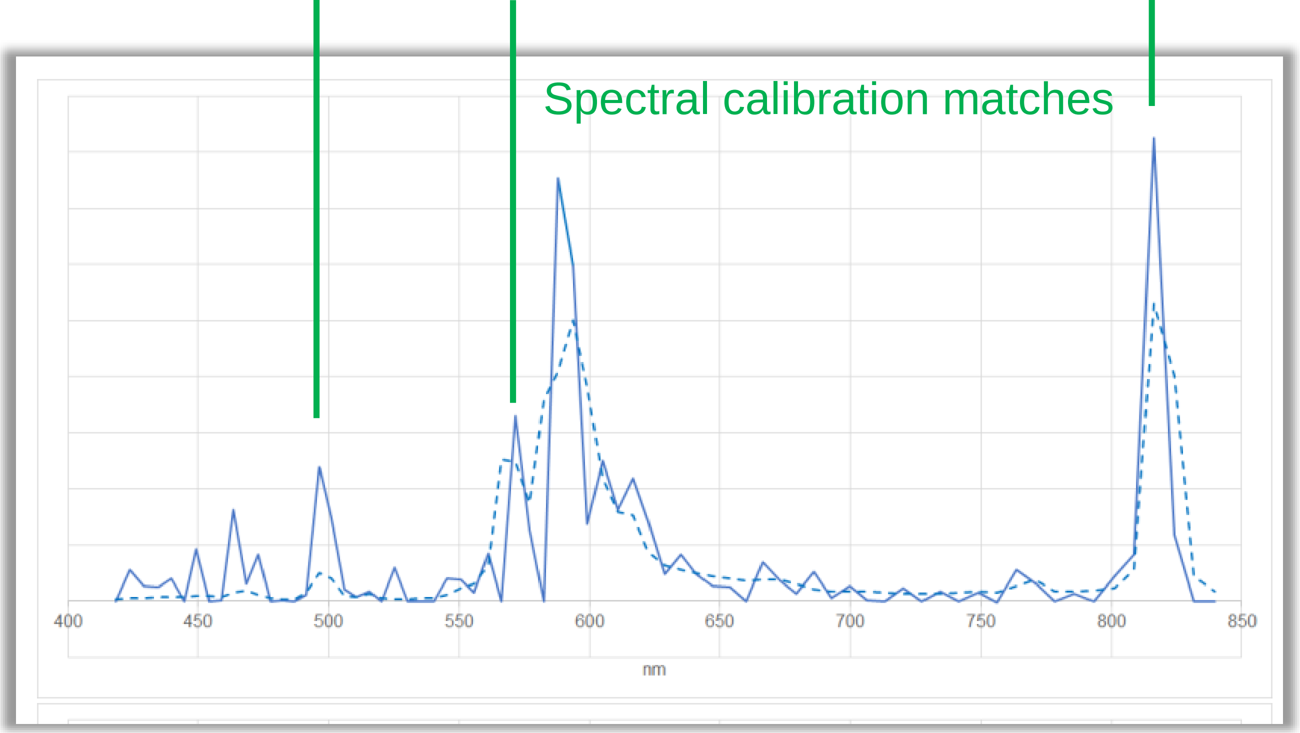
Figures:
Examples for EnMAP VNIR @ 760 nm expressed as stdev @ 1 sigma
Top: Q4 2022, 2770 image tiles
Bottom: Q2 2023, 6434 image tiles

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

EnMAP – Las Vegas Lights at Night

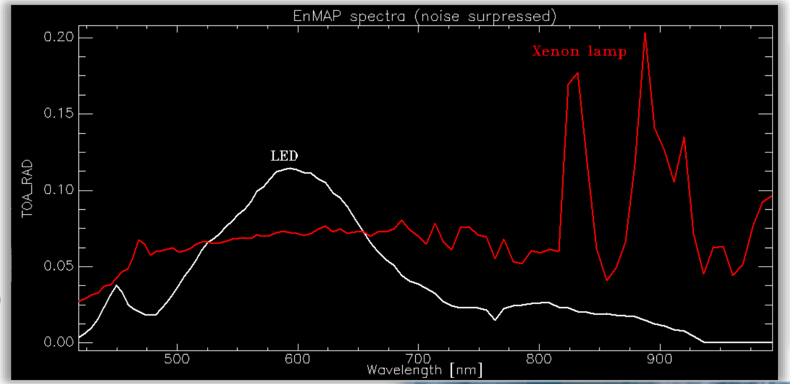






Actual TOA_rad EnMAP (solid) Vs. SpecLib by C. Elvidge
Example: HPS – high pressure sodium lamp

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.

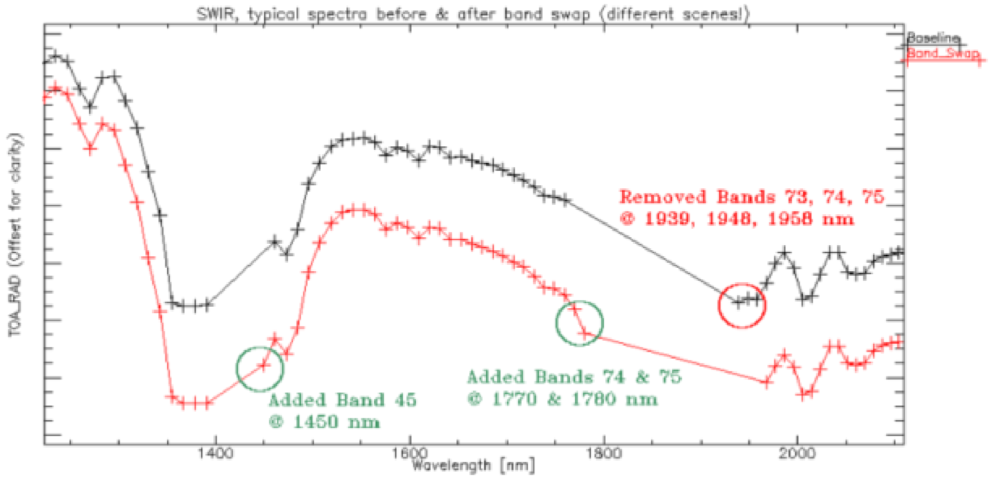
Remote Sens. **2023**, *15*(16), 4025; **https://doi.org/10.3390/rs15164025**

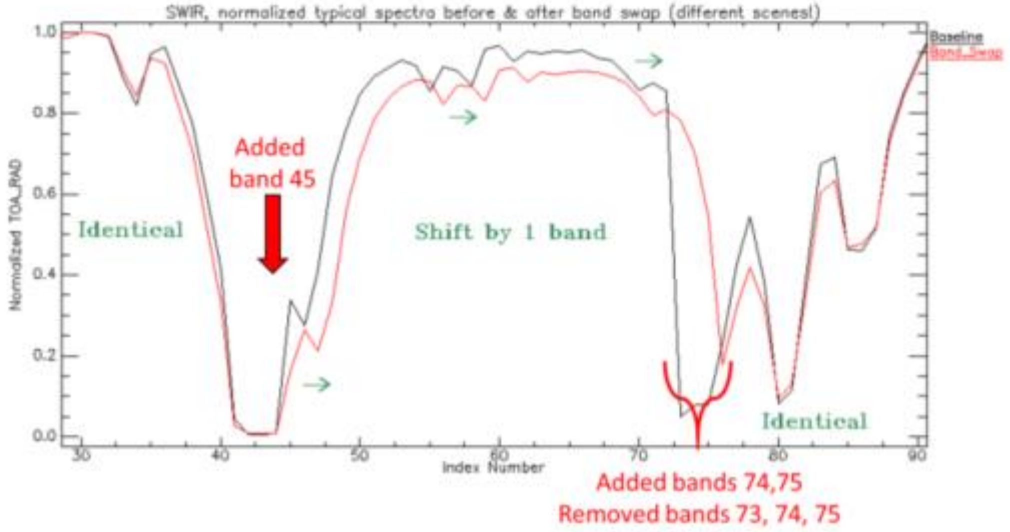
DLR

EnMAP – 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





Conclusions

- DESIS is well-calibrated to RadCalNet (for most bands < 5% @ TOA) and cross-checked to S2 / 8
  - **Aging** is tracked within calibration updates, less accurate for shorter wavelengths (< 450 nm)
  - **Fringing** remains a problem to some degree (> 850 nm)
  - **Spectral shifts** are handled within processor
  - Be cautious when analyzing the **first 10 bands**, as these contain **defects**

- Data products (L1B, L1C, L2A) are validated (internally and externally)
  - **Striping**, spectral **smile** and rolling shutter corrections in place
  - **Geolocation** is typically in subpixel range (RMSE with respect to Landsat 8 OLI: x and y << 25m; N=177 scenes)
  - But: if no GCPs found, could be off by 15-30 pixels => check metadata entry!

- Remaining **uncertainty of radiometric and spectral calibration** is relatively small
  - Further **improves when binning / spectral resampling** is applied


sensors

MDPI

Article

Data Products, Quality and Validation of the DLR Earth Sensing Imaging Spectrometer (DESIS)

Kevin Alonso [1], Martin Bachmann [2], Kara Burch [3], Emiliano Carmona [1], Daniele Cerra [1], Raquel de los Reyes [1], Daniele Dietrich [2], Uta Heiden [2], Andreas Hölderlin [4], Jack Ickes [5], Uwe Knodt [6], David Krutz [7], Heath Lester [5], Rupert Müller [1,*], Mary Pagnutti [3], Peter Reinartz [1], Rudolf Richter [1], Robert Ryan [3], Ilse Sebastian [7] and Mirco Tegler [2]

Earth Resources Observation and Science (EROS) Cal/Val Center of Excellence (ECCOE)

System Characterization Report

DLR Earth Sensing Imaging Spectrometer (DESIS)

Remote Sensing of Environment 294 (2023) 113632

Contents lists available at ScienceDirect

Remote Sensing of Environment

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

ELSEVIER

The EnMAP imaging spectroscopy mission towards operations

Tobias Storch [a,*], Hans-Peter Honold [e], Sabine Chabrillat [g,h], Martin Habermeyer [a], Paul Tucker [e],

For updates, please check:

https://www.enmap.org/mission/

https://www.dlr.de/eoc/desktopdefault.aspx/tabid-13614/

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Federal Ministry for Economic Affairs and Climate Action

on the basis of a decision by the German Bundestag

DLR