Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

EnMAP Ground Segment

Mission Quarterly Report #04

01.04.2023 to 30.06.2023

Restriction: public

Doc. ID	EN-GS-RPT-1104
Issue	1.0
Date	16.08.2023

Configuration Controlled: Yes

German Remote Sensing Data Center (DFD)

Remote Sensing Technology Institute (IMF)

German Space Operations Center (GSOC)

German Research Centre for Geosciences (GFZ-Potsdam)

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DISTRIBUTION LIST

The document is publicly available via www.enmap.org.

CHANGE RECORD

Version	Date	Chapter	Comment
1.0	16.08.2023	All	First issue of Mission Quarterly Report #04

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1 Introduction

1.1 Purpose

This mission quarterly report (MQR) states information on the EnMAP mission status with regard to the registered user community, announcements-of-opportunities and observations as well as the status of the user interfaces, satellite (platform and payload), ground stations (S-band and X-band), processor (Archive, Level 1B, Level 1C, Level 2A (land and water)), calibration (spectral, radiometric, geometric), data quality control and validation of EnMAP.

Please visit www.enmap.org for further information on EnMAP.

1.2 Scope

This fourth Mission Quarterly Report (MQR) applies to the operations of EnMAP in the reporting period of Routine Phase (RP) from **01.04.2023 to 30.06.2023 (Q2/2023)**.

2 References

Reference Identifier	Document Identifier and Title
[1]	L. Guanter et al. (2015) The EnMAP Spaceborne Imaging Spectroscopy Mission for Earth Observation. Remote Sensing, Issue 7, pp. 8830-8857.
[2]	EN-GS-UM-6020 Portals User Manual, Version 1.0
[3]	EN-PCV-ICD-2009 Product Specification, Version 1.8
[4]	EN-PCV-TN-4006 Level 1B ATBD, Version 1.7
[5]	EN-PCV-TN-5006 Level 1C ATBD, Version 1.6
[6]	EN-PCV-TN-6007 Level 2A (land) ATBD, Version 2.2
[7]	EN-PCV-TN-6008 Level 2A (water) ATBD, Version 3.1
[8]	Chabrillat, S. et al. (2022) EnMAP Science Plan. EnMAP Technical Report, DOI: 10.48440/enmap.2022.001
[9]	Lachérade, S. et al. (2014) Introduction to the Sentinel-2 radiometric calibration activities during commissioning phase. Proc. SPIE, Vol. 9241, DOI: 10.1117/12.2067123

Table 2-1 References

3 Terms, Definitions and Abbreviations

Terms, definitions and abbreviations for EnMAP are collected in a database which is publicly accessible via Internet on www.enmap.org.

An Earth observation of swath length $n \times 30$ km (and swath width 30 km) is separated into n tiles of size 30 km × 30 km.

4 Mission

4.1 Mission Objectives

The primary goal of EnMAP (Environmental Mapping and Analysis Program) is to measure, derive and analyze quantitative diagnostic parameters describing key processes on the Earth's surface [1].

During the mission operations, with the successful launch on 1st of April 2022 and an expected operational mission lifetime of at least 5 years, EnMAP will provide valuable information for various application fields comprising soil and geology, agriculture, forestry, urban areas, aquatic systems, ecosystem transitions.

4.2 Mission Description

The major elements of the EnMAP mission are the EnMAP Space Segment, built by OHB System AG and owned by the German Space Agency at DLR, the EnMAP Ground Segment built and operated by DLR institutes DFD, MF, RB, and the EnMAP User and Science Segment represented by GFZ. The project management of the EnMAP mission is responsibility of the German Space Agency at DLR.

The EnMAP Space Segment is composed of

- the platform providing power and thermal stability, orbit and attitude control, memory, S-band uplink/downlink for TM/TC data transmission/reception, X-band downlink for payload data transmission, and
- the payload realized as a pushbroom imaging dual-spectrometer covering the wavelength range between 420 nm and 2450 nm with a nominal spectral resolution ≤ 10 nm and allows in combination with a high radiometric resolution and stability to measure subtle reflectance changes.

The EnMAP satellite is operated on a sun-synchronous repeat orbit to observe any location on the globe with comparable illumination conditions. This allows a maximum reflected solar input radiance at the sensor with an acceptable risk for cloud coverage.

The EnMAP Ground Segment is the interface between Space Segment and User and Science Segment. It comprises functionalities to

- perform planning of imaging, communication and orbit maneuver operations, provision of orbit and attitude data, command and control of the satellite, ground station networks (in particular: Weilheim, Germany, for S-band and Neustrelitz, Germany, for X-Band), receive satellite data, perform long-term archiving and delivery of products, and
- perform processing chain (for systematic and radiometric correction, orthorectification, atmospheric compensation), instrument calibration operations, and the data quality control of the products.

The EnMAP mission interfaces to the international science and user community through the EnMAP Portal www.enmap.org with official information related to EnMAP by DLR and GFZ-Potsdam (as the document in hand) and links for ordering observations and products.

The EnMAP Science Segment is represented by the EnMAP Science Advisory Group chaired by the mission principal investigator at the GFZ-Potsdam. The Science Segment addresses aspects such as

- supporting and performing validation activities to improve sensor performance and product quality
- developing scientific and application research to fully exploit the scientific potential of EnMAP [8] including provision of software tools for EnMAP data processing and analyses (EnMAP-Box) and provision of teaching and education materials (HYPERedu)
- Organizing workshops, summer schools and in general information, training and networking activities for the user community

The EnMAP User Segment is the community of German and international users ordering acquisitions and accessing products of EnMAP.

4.3 Mission Status Summary

The mission entered its routine phase (RP) on 02.11.2022. Between the 13.12.2022 and the 13.02.2023 the instrument suffered an outage that was fixed with a software patch, recovering operations with no limitations of functionality and not requiring the use of redundancies. In the reporting period between 01.04.2023 and 30.06.2023 there have been no major issues affecting the instrument or the satellite.

In this period, 1340 Earth observations of 30 km swath width and up to 990 km swath length were successfully performed which resulted in 6434 archived Earth observation tiles of 30 km × 30 km. In total, 4803 Earth observations were performed until 30.06.2023 by the EnMAP team (mostly during commissioning phase) and the 805 registered Science users which resulted in 28615 archived Earth observation tiles and 29753 Earth observation tiles delivered to users. Details are presented in Sections 5 and 5.1.

The following limitations are applicable at 30.06.2023:

- Some striping effects in SWIR data in the along-track direction more visible in uniform areas with a strong spectral gradient.
- Limitations on user interfaces are expected to be solved by the end of Q3 and Q4 2023.
- Performance issues in the generation of VC-AUX (relevant for data quality assessment) products for L0 data prevent to incorporate them to the operational processing chain for the moment.
- An error in L2A processing in some snow spectra below 750 nm when snow is confused with clouds.
- Error in coordinates of the acquired image in the along-track direction. Error depends on the off-nadir view angle and, in some cases, off-nadir values larger than 20 degrees could lead to the center coordinate being outside a 1-tile image acquisition. It is recommended to the users to order at least 2 tiles in each of their acquisitions (see Portals User Manual document [2]).
- Integration of Inuvik station for additional X-Band data reception is not completed yet due to pending license from Canadian authorities.

The following changes where implemented in the reporting period:

- Improved geometric accuracy in the along-track direction was introduced in processor version 01.03.00 (release date 02.05.2023).
- Fixed errors concerning update of quality masks during processing, determination of land processing atmospheric quality and rare crash during total AOT calculation.
- Preparatory work for the update of the SWIR band configuration.
- Improved evaluation of HSI status parameter during data screening.
- Fixed the background color in HDR files for BSQ/BIP/BIL products.
- Implementation of auxiliary instrument data (VC-AUX), relevant for data quality assessment, in archived L0 data for the re-processing chain. VC-AUX can improve the quality flagging of L0 products in the archive.
- Start re-processing of archived products: first re-processed products with archived version ≥ 01.03.01 stored in archive, previous products also available in the archive.
- Several improvements on user interfaces introduced during Q2/2023 (see section 7.1).

The following changes are expected to be performed in the next quarters:

- Update of SWIR band configuration. Total number of bands in the SWIR spectrometer will be kept constant, but 3 wavelengths are going to be changed. The 3 bands located (approximately) at wavelengths 1939 nm, 1949 nm and 1958 nm will be removed from the SWIR data and replaced by bands at (approximately) wavelengths at 1450 nm, 1770 nm and 1780 nm.
- Further improvements on archived products, e.g. on VNIR-SWIR co-registration, quicklooks and quality attributes, are expected by a re-processing started in June 2023.

- For changes concerning the User Interfaces see chapter 7.1
- Correction of radiometric striping in the along-track direction
- Fix snow spectra / cloud mask to solve issue with snow spectra
- Change provider of temperature and ozone values for L2A processing when automatic estimation is selected.

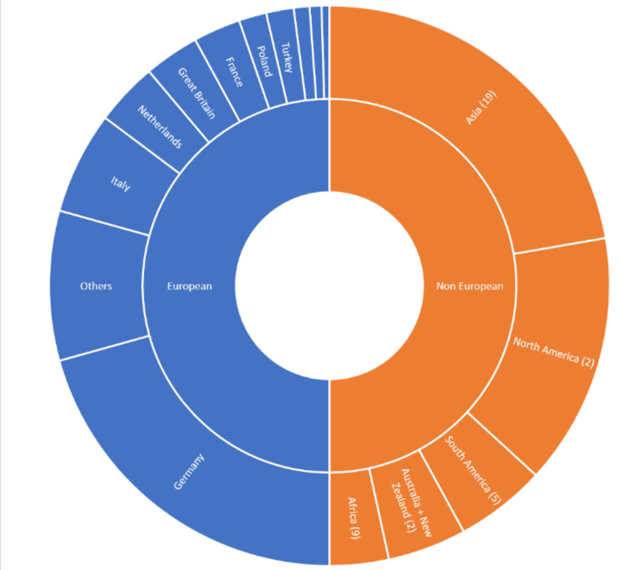
5 Users and Announcements-of-Opportunities

5.1 Users

	Country/*Continent (No of Countries)*	Reporting Period 01.04.2023 to 30.06.2023	Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period)
Total European Users	*Europe (31)*	220	910
European	• Germany	91	429
	• Italy	26	84
	• France	12	52
	• Great Britain	14	51
	• Spain	4	36
	• Netherlands	16	37
	• Portugal	0	17
	• Turkey	7	27
	• Greece	3	20
	• Belgium	2	15
	• Poland	7	22
	• Austria	7	9
	• Others (10)	37	120
Non European	*North America (2)*	64	*198*
	South America (13)	23	*97*
	Asia (19)	98	*228*
	Africa (16)	15	*85*
	Australia + New Zealand (2)	20	*54*
	Total (83)	440	1584
	*Rejected**	3	*5*

Table 5-1 Number of registered users per continent

*Users are rejected because of, e.g. EU sanction list checks, data policy or license violations.



Reporting Period 01.04.2023 to 30.06.2023 with a total of 440 Users of 58 different countries.

Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period) with total of 1584 Users of 83 different countries.

Figure 5-1 Number of registered users per country

Registered users belong to different categories, therefore e.g. All/World ≠ Science/World + Others/World.

User per Category		Reporting Period 01.04.2023 to 30.06.2023	Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period)
Cat-1 Science	Total	445	1250
	AO Process 00001	226	785
	AO Process 00002	195	620
	AO Process 00003	95	95
Cat-1 Distributor	Total	245	791

Table 5-2 Number of registered users per category (Cat-1 Science and Cat-1 Distributor)

5.2 Announcements-of-Opportunities

Announcement-of-Opportunity	Reporting Period 01.04.2023 to 30.06.2023			Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period)		
	Proposals	Total tiles requested	Total tiles released	Proposals	Total tiles requested	Total tiles released
AO#1	65	4481	2423	177	13014	9505
AO#2	38	2032	1190	111	17739	8304
AO#3	1	72	54	1	72	54
Total	104	6585	3667	289	30825	17863

Table 5-3 Number of released science proposals per Announcement-of-Opportunity (AO#) and total number of requested and released tiles per AO#.

Icon	Topic	Reporting Period 01.04.2023 to 30.06.2023			Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period)		
		Proposal	Total tiles requested	Total tiles released	Proposal	Total tiles requested	Total tiles released
	VEGETATION	46	2813	1565	125	16595	8504
	GEO/SOIL	31	796	812	84	3529	2536
	WATER	13	614	346	38	2130	2240
	SNOW/ICE	2	561	161	6	1751	648
	URBAN	1	200	100	3	456	196
	ATMOSPHERE	5	1070	342	9	2088	1017
	HAZARD/RISK	1	100	100	4	219	189
	METHODS	2	158	158	7	744	429
	CAL/VAL	3	273	83	13	3313	2104
	Total	**104**	**6585**	**3667**	**289**	**30825**	**17863**

Table 5-4 Number of accepted science proposals and total number of requested and released tiles per topic

6 Archived and Delivered Observations

The following table shows the number of archived Earth Observation and Calibration products and their sizes within the specified time frames. Reason for “Archived = No” is that datatakes were commanded but no data arrived at the Processing System HSI.

Type	Archived		Reporting Period 01.04.2023 to 30.06.2023		Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period)	
			Number Tiles / Observations	Size (in GB)	Number Tiles / Observations	Size (in GB)
Earth Observation (EO)	Yes	Total	6434/1340	2993.5	28615/4803	13340.1
		Average / Day	70.7/14.7	32.9	62.8/10.5	29.3
	No	Total	19		835	
		Average / Day	0.2		1.8	
Calibration (CAL)	Yes	Total	24	110.4	112	489.6
		Average / Day	0.3	1.2	0.2	1.1
	No	Total	0		1	

		Average / Day	0		0.002	

Table 6-1 Number and size of archived and not archived products

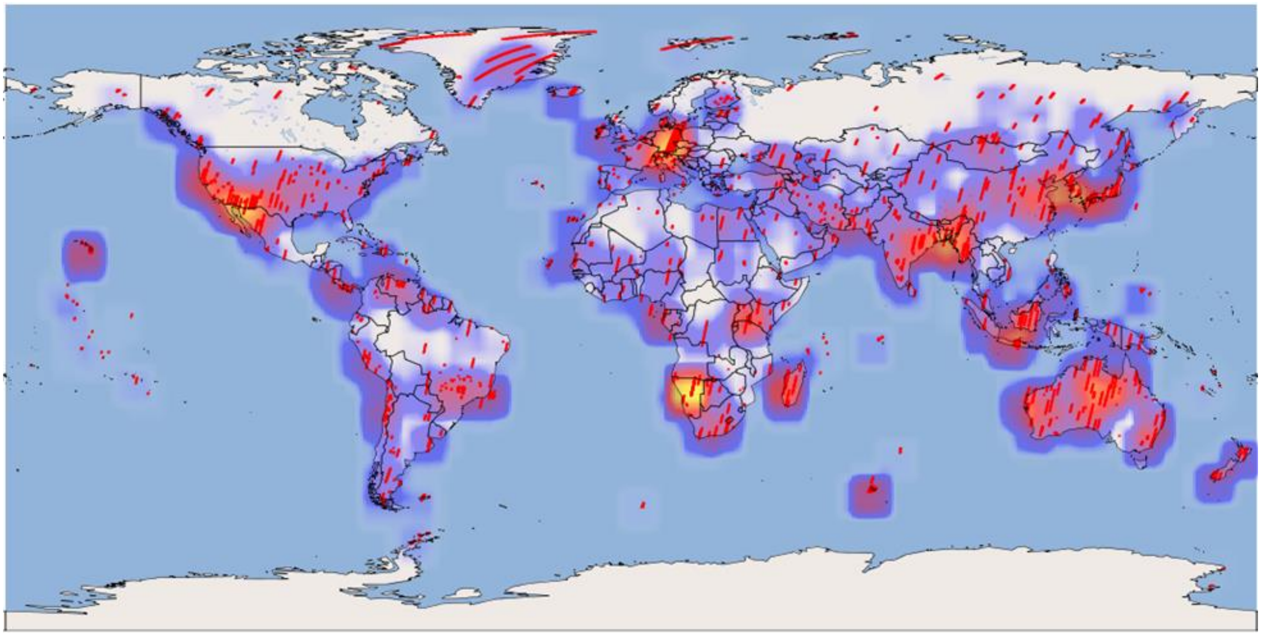
The following table shows the number of delivered products and their sizes within the specified time frames. Product deliveries result either directly from acquisition orders ("Observation") or catalog orders ("Archive").

Type	Delivered		Reporting Period 01.04.2023 to 30.06.2023		Since beginning of Commissioning Phase until 30.06.2023 (end of reporting period)	
			Number Tiles / Observations	Size (in GB)	Number Tiles / Observations	Size (in GB)
Earth Observation (EO)	Observation	Total	9521/1112	4009.5	29654/3996	8687.7
		Average / Day	104.6/12.2	44.1	65.0/8.8	27.8
	Archive	Total	11701	69065	21488	117314.2
		Average / Day	128.6	759.0	47.1	257.3
Calibration (CAL)	Observation	Total	24	110.4	90	417.9
		Average / Day	0.3	1.2	0.2	0.9
	Archive	Total	5	422.3	73	3524.2
		Average / Day	0.1	0.0	0.2	7.7

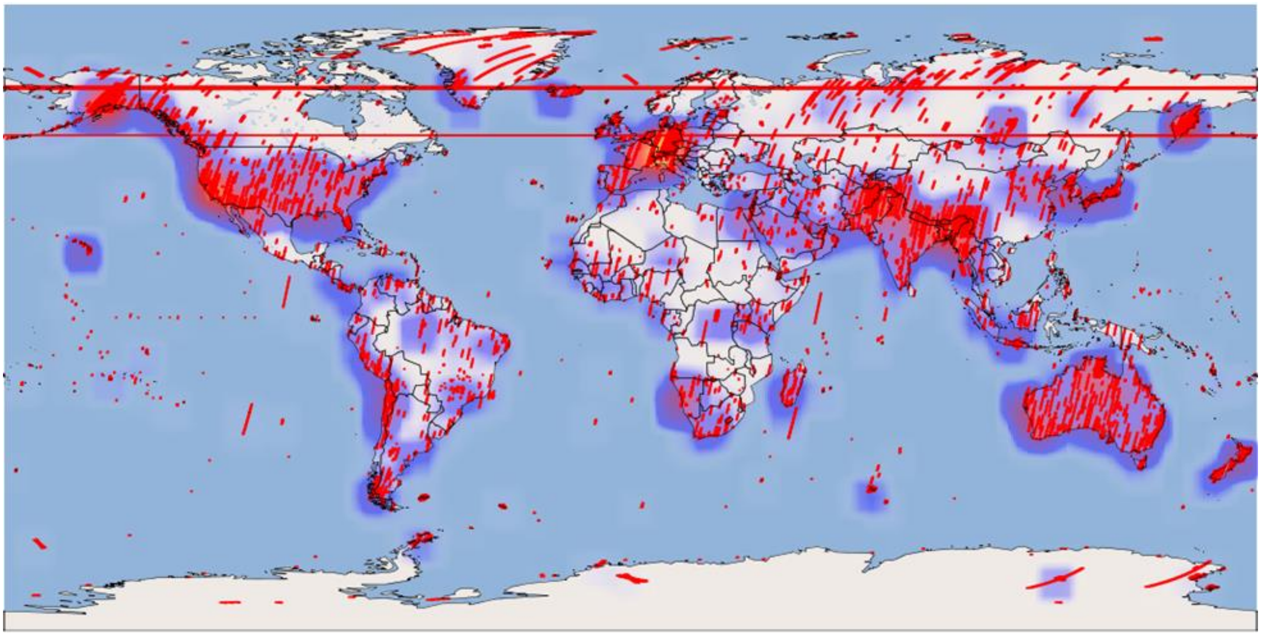
Table 6-2 Number and size of delivered products

6.1 Archived Observations

The following figures show the heatmaps for the whole world and for Europe within the specified time frames. The heatmaps represent the frequencies of products at a geographic location, where the number of products increases from blue over red to yellow.

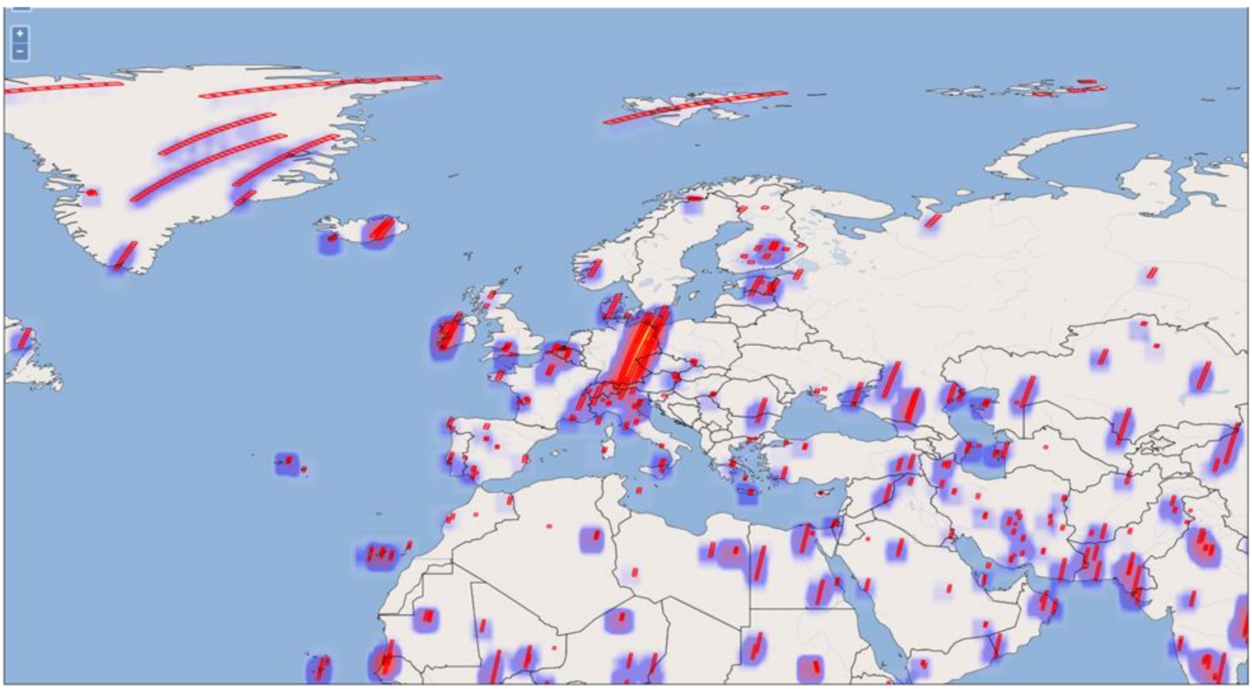


01.04.2023 to 30.06.2023 with 6434 tiles

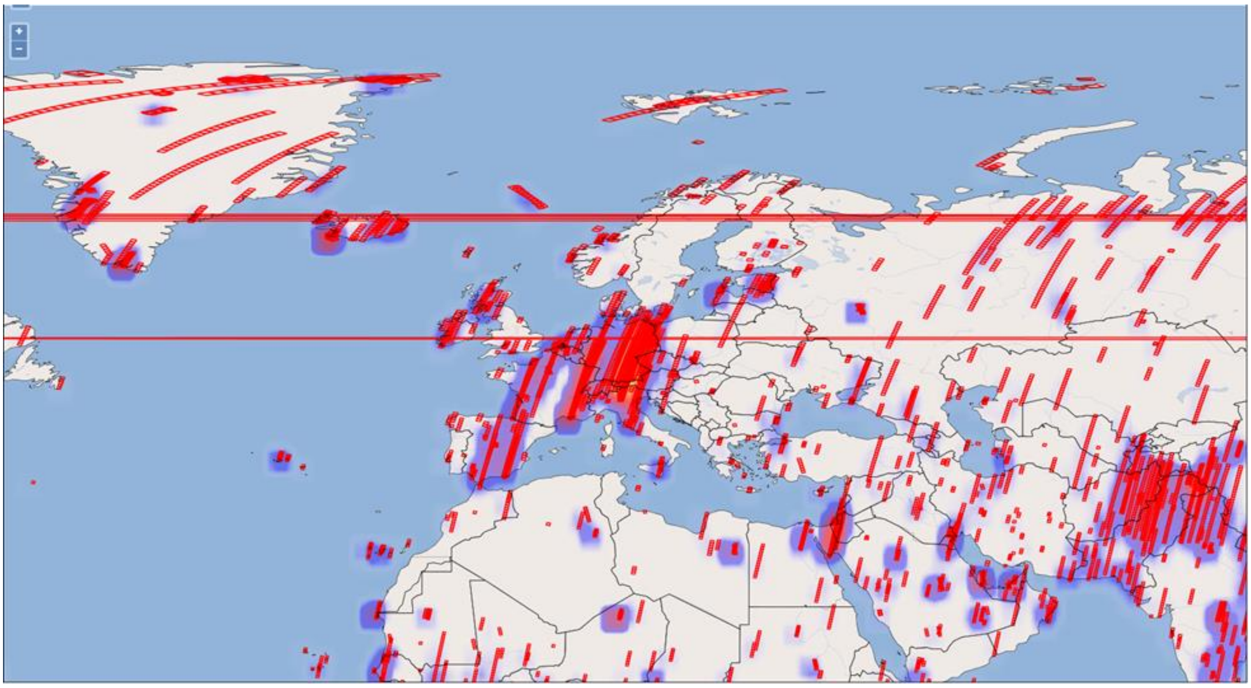


until 30.06.2023 with 28615 tiles (includes commissioning phase acquisitions) (The red lines are caused by two datatake crossing the antimeridian. For these the footprints are not displayed correctly)

Figure 6-1 Geographic location of all Earth observation tiles archived, World



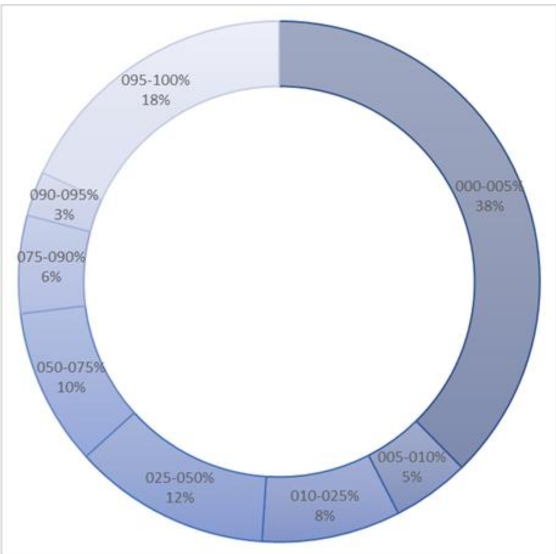
01.04.2023 to 30.06.2023 with 552 tiles



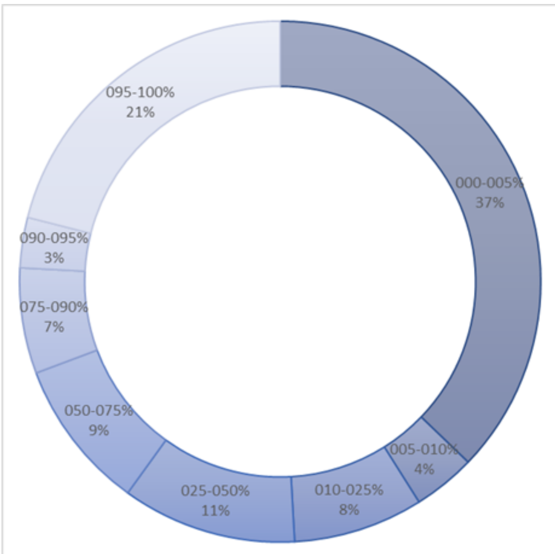
until 30.06.2023 with 3158 tiles (includes commissioning phase acquisitions) (The red lines are caused by two datatake crossing the antimeridian. For these the footprints are not displayed correctly)

Figure 6-2 Geographic location of all Earth observation tiles archived, Europe

The following figures show the distribution of cloud coverage for the archived products.



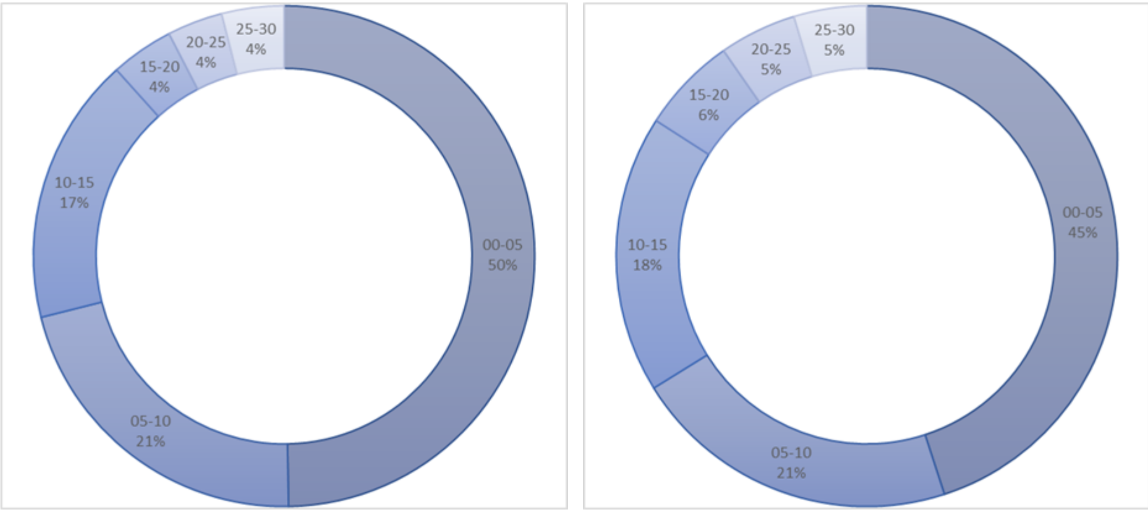
01.04.2023 to 30.06.2023 with 6434 tiles



until 30.06.2023 with 29753 tiles (includes commissioning)

Figure 6-3 Cloud coverage in [%] of archived Earth observation tiles

The following figures show the distribution of observation angles for the archived products.

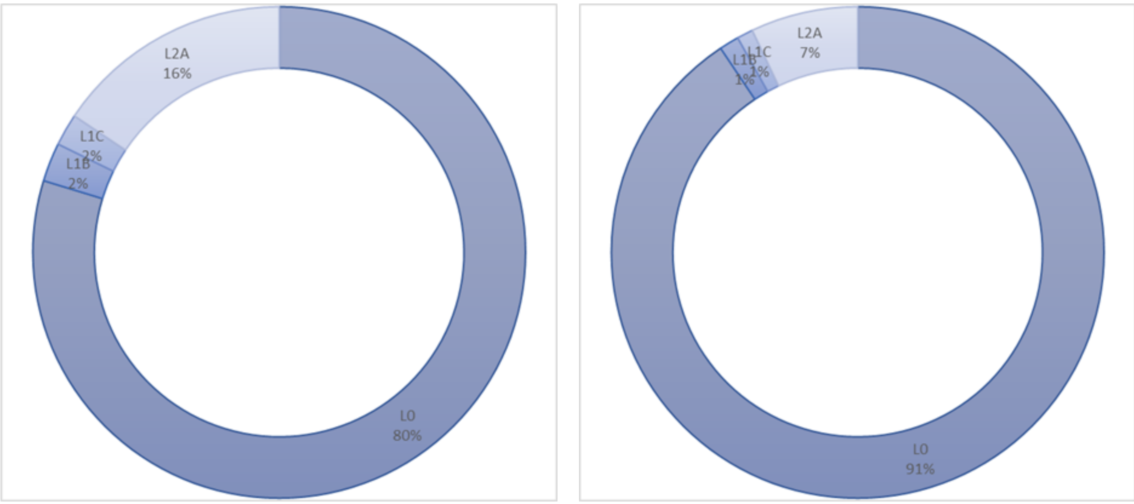


01.04.2023 to 30.06.2023 with 6434 tiles until 30.06.2023 with 29753 tiles (includes commissioning)

Figure 6-4 Observation angle of archived Earth observation tiles

6.2 Delivered Observations

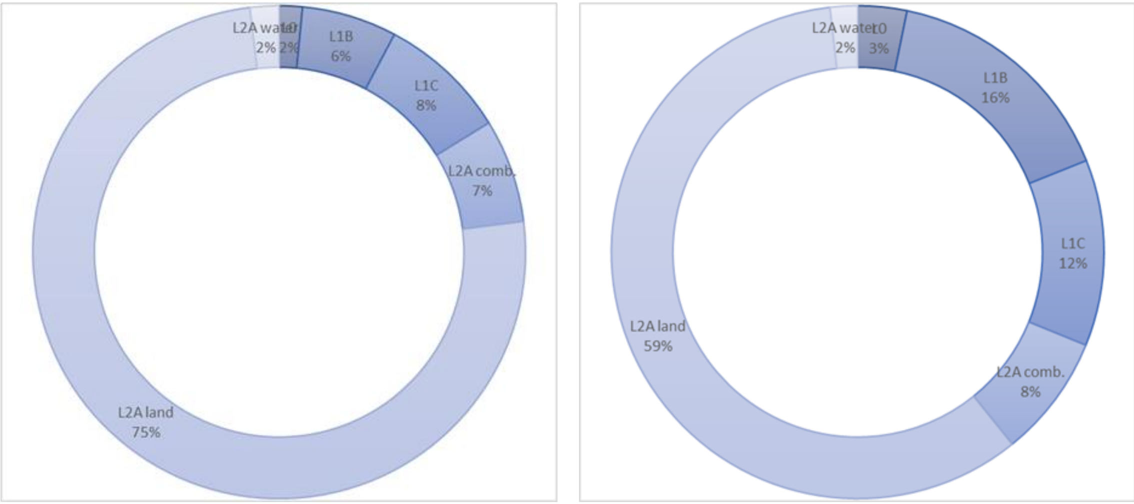
The following figures show the distribution of processing level of the delivered products from acquisition orders.



01.04.2023 to 30.06.2023 with 9521 tiles until 30.06.2023 with 29654 tiles (includes commissioning)

Figure 6-5 Levels of delivered Earth observation tiles from acquisition orders

The following figures show the distribution of processing level and correction type (for L2A) of the delivered products from catalog orders.



01.04.2023 to 30.06.2023 with 11701 tiles until 30.06.2023 with 21484 tiles (includes commissioning)

Figure 6-6 Levels of delivered Earth observation tiles from catalog orders

7 Detailed Status

7.1 User Interfaces

Based on feedback from the users the following improvements of the IPP User Interface were implemented and made available in Q2/2023:

- Instrument Planning Support Tool: The option to submit coordinate values to support the users in ordering datatakes for precisely pre-defined geographical areas of interest is released. This option was made available to the users during Q2/2023.

Further improvements to the user interfaces are continuously on-going and will be reported in this section.

7.2 Satellite

No major satellite issues have been observed in the reporting period. Some DSHA issues caused sporadic loss of acquisitions. The tests performed in May 2023 in the context of the preparation for the SWIR band updated (completed in July 2023) required one week of planned instrument outage.

7.2.1 Orbit

The reference orbit is a Sun-synchronous polar orbit with a mean local time of descending node of 11:00 hrs and a repeat cycle of 398 revolutions in 27 days at an altitude of 643 km (lateral deviation of at most 22 km at equator and altitude deviation of at most 6 km).

During 2023 Q2, a total of 1579 ACS Precise Modes were commanded, compared to 886 during the previous quarter. This increase is related to the major instrument anomaly that occurred on Dec 12th 2022 and prevented the execution of Image Acquisitions until the end of the recovery on DOY043 during 2023 Q1. One ACS Precise Mode on DOY094 was aborted and therefore not executed successfully due to the execution of an Orbit Propagator update which was performed in parallel Mitigation solutions for this problem are currently implemented. No special ACS Precise Modes were commanded in 2023 Q2.

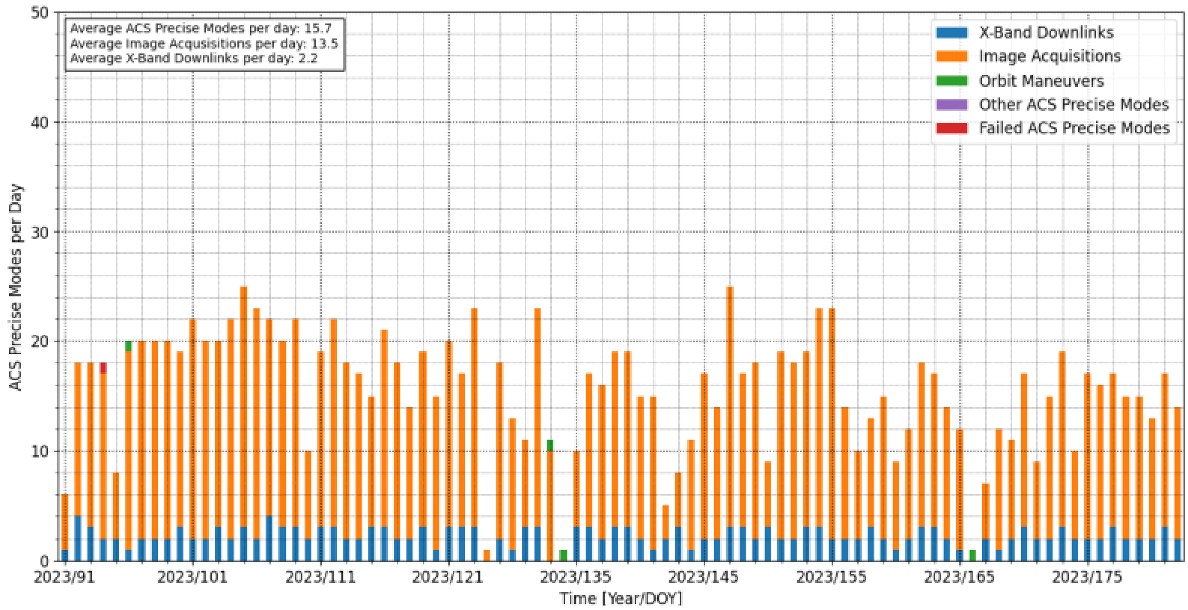


Figure 7-1 Number of ACS Precise Modes per day during 2023 Q2

7.2.2 Life Limited Items

Life-Limited Item	01.04.2023 to 30.06.2023	until 30.06.2023	until end-of-life
Fuel	+0.3 kg	4.2 kg	>15 years
Battery and Solar Cells	nominal	nominal	nominal
Shutter Usage	+1,56%	5,47%	22,8 years (@ daily use)
FAD movements	+2,00%	13%	8,5 years (@ monthly use)
Diffuser exposure time based on sole measurement time	+3,33%	21,67%	5,2 years (@ monthly use)
Diffuser exposure time based on real cyclogram duration	+3,92%	25,49%	4,4 years (@ monthly use)
On-Board Calibration Equipment Usage	On-board calibration equipment:		
- OBCA SPC lamp 1	+1,41%	5,62%	19,3 years (@ biweekly use)
- OBCA RAD lamp 1/LED 1	+2,09%	9,39%	7,9 years (@ weekly use)
- FPA LEDs 1	+0,75%	3,19%	44,3 years (@ monthly use)

Table 7-1 Status of life-limited items

7.2.3 Redundancies

To date, the SWIR wavelength range is covered by SWIR-A (SWIR-B can be activated using a one-time switch mechanism).

All satellite subsystems are using nominal configurations.

7.3 Ground Stations

7.3.1 S-Band

S-Band Ground Stations	01.04.2023 to 30.06.2023		
	Total Passes	Non-Routine Passes (e.g. Anomaly Handling/SW Updates)	Failed Passes
Weilheim, Germany Neustrelitz, Germany Inuvik, Canada O'Higgins, Antarctica Svalbard, Norway	399	5	3

Table 7-2 S-Band Ground Station Passes

7.3.2 X-Band

X-Band Ground Stations	01.04.2023 to 30.06.2023	
	Executed Passes	Successful Passes
Neustrelitz, Germany	221	221

Table 7-3 X-Band Ground Station Passes

Work is ongoing to integrate Inuvik, Canada, as an additional X-Band ground station in Q2/2023. As a result, more data and more flexibility in X-band data reception are expected, especially concerning image acquisitions over Europe. At the end of Q2/2023 Inuvik is still not operational for EnMAP data reception as the project is waiting for license approval by the Canadian authorities.

7.4 Processors

[3] provides the product specification and [4], [5], [6], [7] the algorithm theoretical basis for Level 1B, Level 1C and Level 2A (land / water).

In the reporting period (01.04.2023-30.06.2023) there were three processor updates:

1. **Version 01.03.00 (02.05.2023, replaced by 01.03.01 before available to users)**

   This version includes the following changes:

   - Improved geometric accuracy in along-track direction (fix within speed of light correction).
   - Fixed an error concerning update of quality masks.
   - Fixed an error during determination of land atmospheric correction quality (division by zero).
   - Deleting temporary files if debug flag in processor configuration is turned off. This significantly reduces file size of the working directories.
   - Updated quality control configuration for planned band swap (also works with old band configuration).
   - Fixed the background color in HDR files for BSQ/BIP/BIL products.

2. **Version 01.03.01 (03.05.2023, available to users on 04.05.2023)**

   This version includes the following changes:

   - The deletion of temporary files introduced in V01.03.00 was creating problems when processing on an NFS mount. This issue was fixed in this version.

3. **Version 01.03.02 (13.06.2023, available to users on 16.06.2023)**
   - Added new JobOrder option "product_type LX", to produce all 3 LX outputs in one job
   - Improved Evaluation of HSI status parameter for screening.
   - Fixed a rare crash occurring in the calculation of the total AOT.
   - Changed the substitution region at 1400 nm absorption region for the planned band swap.

The following limitations are applicable as of 30.06.2023:

- The SWIR-A compressor cooler produces a micro-vibration pattern of horizontal stripes on SWIR bands with strong spectral gradients. Still, all spectral and radiometric requirements are within the specification of the mission. An improvement of the processor is planned for mitigating that effect by middle of 2023.
- Defective snow spectrum below 750 nm when snow is confused with clouds by the atmospheric correction processor

The following changes are expected to be performed by 30.09.2023:

- Switch from MODIS database (Ozone, Land Surface Temperature) to Copernicus service database
- Fix snow spectra / cloud mask to solve issue with snow spectra
- Correction for SWIR along-track striping

7.5 Calibrations

Table 7-4 summarises the radiometric calibration observations acquired in this quarter and which will be described in the rest of this section. The calibration acquisitions were generally acquired according to routine operations. However, due to a few technical issues, fewer Relative Radiometric calibration datatakes were acquired than anticipated. Some DSHA issues led to cancelled datatakes as well as planned outages due to the change of transmitted SWIR bands. Nevertheless, there appear to be no significant problems with tasking calibration datatakes from EnMAP.

Category	01.04.2023 to 30.06.2023	
	Number of Archived Observations	Size (in GB)
Total	25	112.9
Deep Space	3	3.9
Rel. Radiometric	8	31.2
Abs. Radiometric	2	2.6
Linearity	4	68
Spectral Calibration	8	7.2

Table 7-4 Number and size of archived radiometric and spectral calibration observations

The continuous degradation of the VNIR sensor was monitored and quantified. The rate of degradation is constantly decreasing as illustrated in Figure 7-2 and by the end of March 2023 it has reached the point where it is practically negligible and has been kept that way during the reporting period.

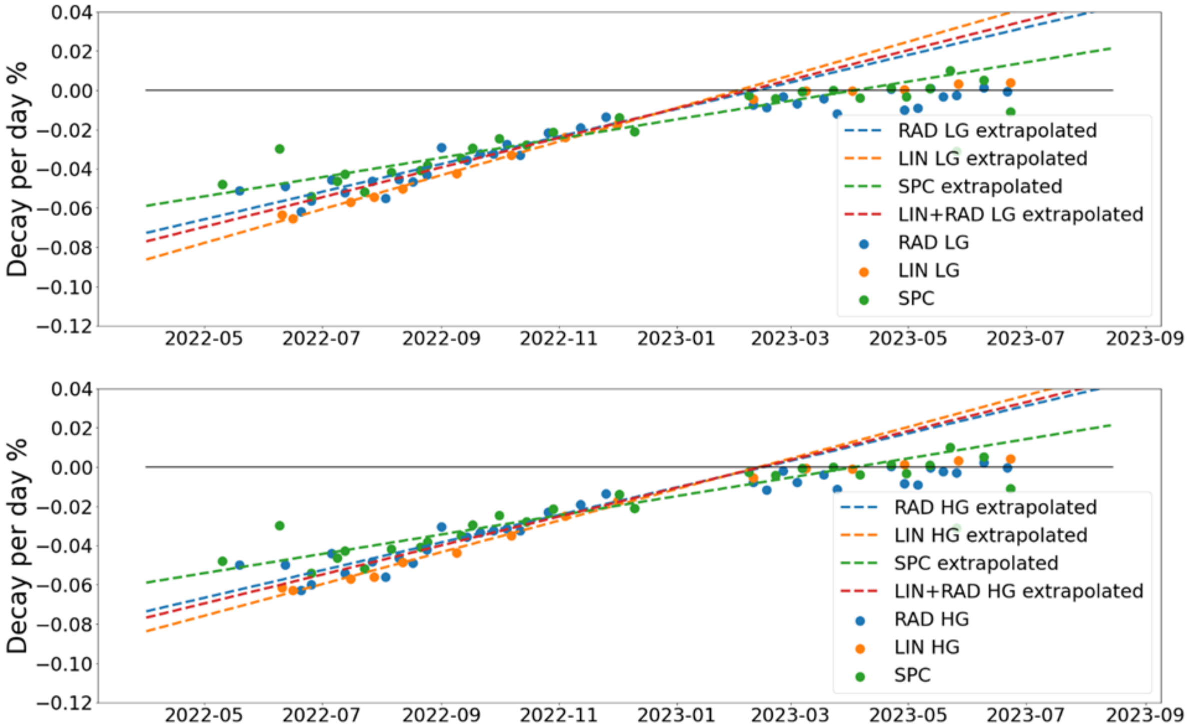


Figure 7-2 **Daily degradation of the VNIR sensor for low gain (top) and high gain (bottom). Estimations based on relative radiometric (RAD), spectral (SPC) and linearity (LIN) calibration measurements for low gain (LG) and high gain (HG). The long-term behavior is linearly extrapolated**

The computed radiometric coefficients are illustrated in Figure 7-3 for five selected spectral bands in VNIR. From one Sun calibration to the next, the coefficients are seen to jump, increasing in value over time. It is most pronounced in the edge bands, see e.g. bands 5 and 85. This effect is reducing over time and by the end of March 2023 is negligible.

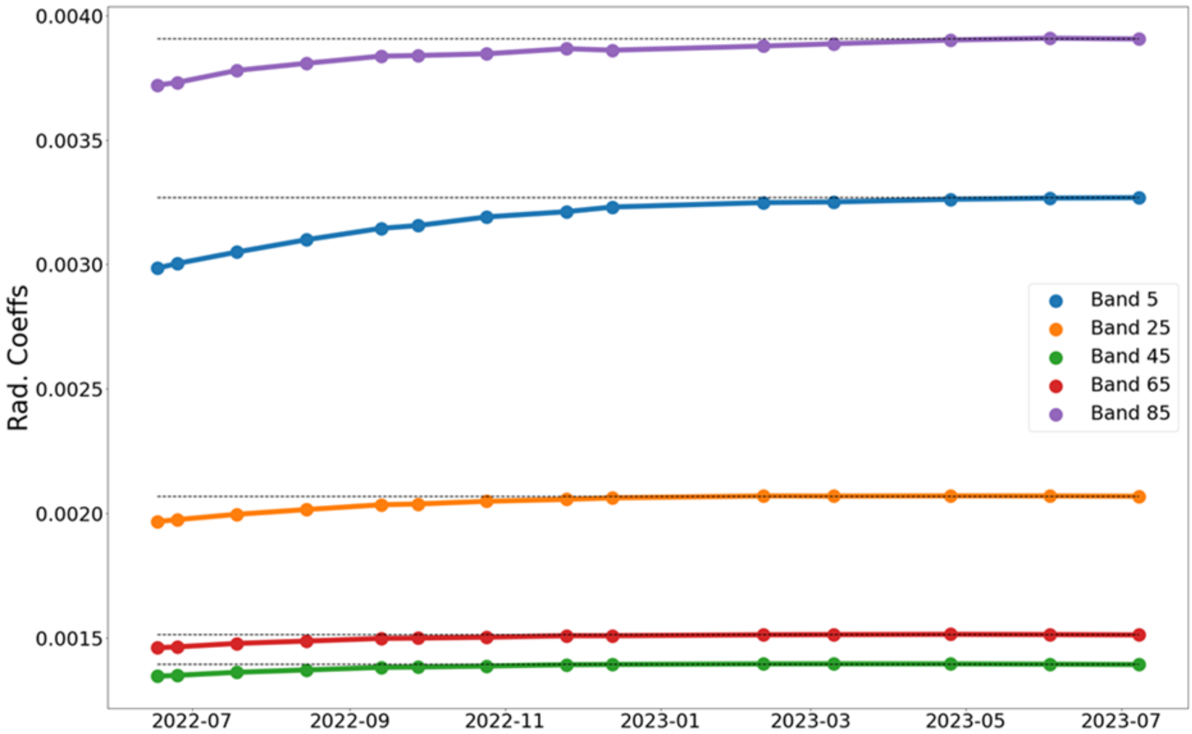


Figure 7-3 **Radiometric coefficients over time for five selected bands. The dashed lines denote the most recent value.**

Figure 7-4 shows the cumulative change in performance as a function of time for VNIR and SWIR sensors, obtained from the linearity calibration measurements.

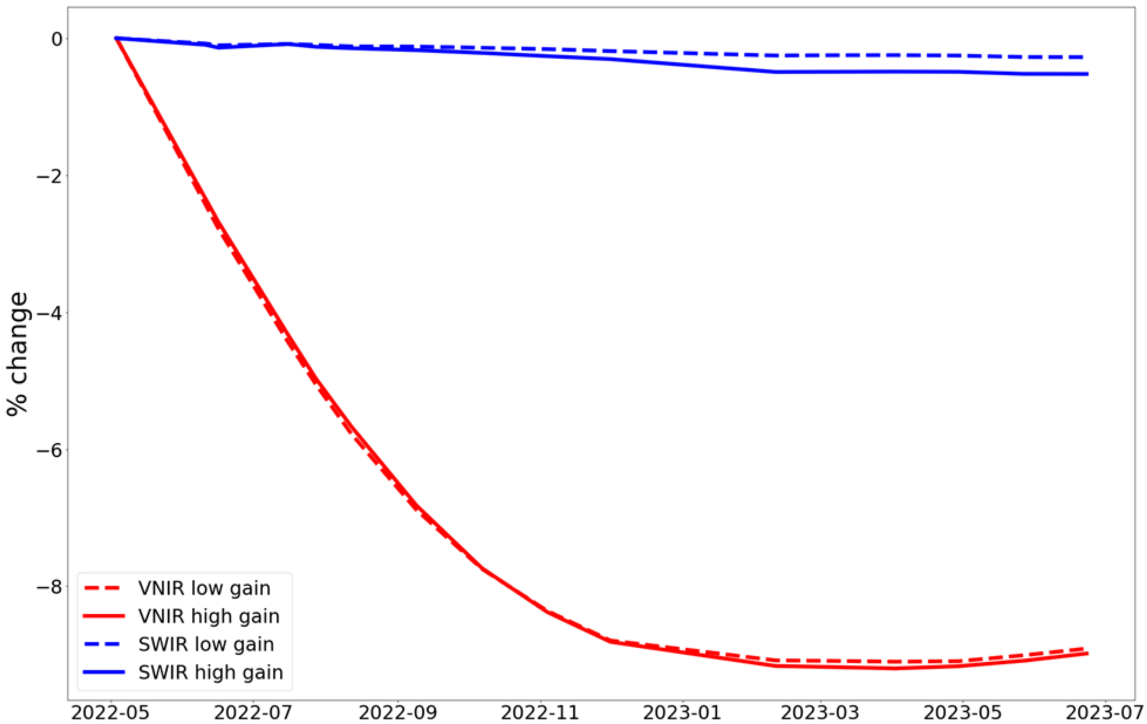


Figure 7-4 **Average percentage change in the linearity reference measurements since launch for VNIR and SWIR in high and low gains**

7.5.1 Dead Pixels

The following table shows the number and percentage of dead pixels. Figure 7-5 and Figure 7-6 show the position of the dead pixels in the focal plane of VNIR and SWIR sensors respectively.

Defect Pixels	01.04.2023 to 30.06.2023	
	Number of Pixels	Percent
Total	1921	0.8
VNIR	137	0.2
SWIR	1784	1.2

Table 7-5 Number and percent of dead pixels

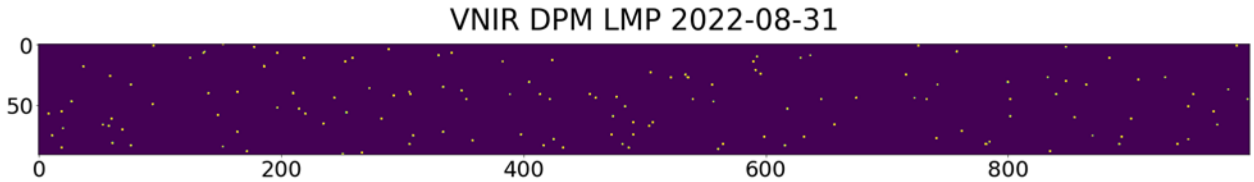


Figure 7-5 VNIR Dead Pixel Mask

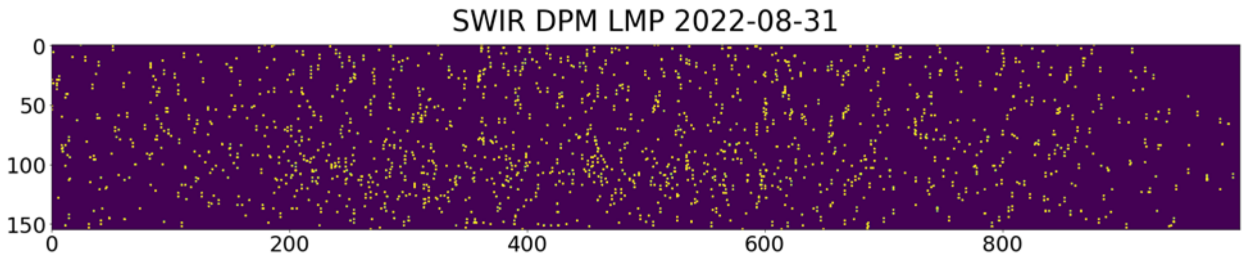


Figure 7-6 SWIR Dead Pixel Mask

There are no clusters of more than three spectrally or spatially adjacent dead pixels.

7.5.2 Spectral Calibration

Remark: In the following figures, OBCA is abbreviation for On-Board Calibration Assembly for spectral and radiometric calibrations.

Category	01.04.2023 to 30.06.2023	
	Number of Archived Observations	Size (in GB)
Total	8	7.2
Spectral Calibration	8	7.2

Table 7-6 Number and size of archived spectral calibration observations

The spectral properties – in particular center wavelength (CW) (see Figure 7-7 and Figure 7-8) and full width at half maximum (FWHM) (see Figure 7-9) for each band (spectral coordinate) and pixel (spatial coordinate) – have been characterized, considering all bands and pixels provided in Level 1B, Level 1C and Level 2A products.

The major conclusions of the monitoring of the spectral performance is summarized as follows:

- During the reporting period, 8 spectral calibration measurements were made. These took place on: 05.04.2023, 21.04.2023, 29.04.2023, 11.05.2023, 22.05.2023, 26.05.2023, 09.06.2023 and 23.06.2023. The measurement obtained on the 22.05.2023 was taken in the scope of preparations for the SWIR band change which is scheduled for July 2023. Acquisitions were acquired optimally and in accordance with the fortnightly scheduling.

- The VNIR spectral range in this reporting period was found to be 418.4 – 993.3 nm over 91 bands. The average spectral sampling distance was 6.4 nm with a total range of 4.7 – 8.2 nm. This meets the requirement for overall wavelength coverage [HSI-POSS-0210], average spectral sampling distance [HSI-POSS-0310 and spectral sampling distance range [HSI-POSS-0320].
- The SWIR spectral range in this reporting period was found to be 902.0 – 2445.3 nm over 155 bands. The average spectral sampling distance was 10.0 nm with a total range of 7.5 – 12.0 nm. This meets the requirement for overall wavelength coverage [HSI-POSS-0210], average spectral sampling distance [HSI-POSS-0310] and spectral sampling distance range [HSI-POSS-0320].
- The spectral calibration measurements from this quarter show good temporal stability – measurements showed a <0.2 nm change from the VNIR sensor and <0.3 nm change in SWIR. All changes were below the 0.69 nm requirement between measurements for VNIR and below the 0.86 nm requirement between measurements for SWIR. This meets the requirement for consecutive spectral stability [HSI-POSS-0510] and overall spectral stability [HSI-POSS-0520].
- FWHM for VNIR and SWIR are shown below but are not recalculated inflight.
- No new calibration and reference tables were generated in this reporting period.
- The VNIR degradation is visible in the spectral reference calibration measurements acquired in this period, totaling -0.14% across all pixels from 22.03.2023 to 23.06.2023. This is lower than the value of -0.2% reported in the previous quarter.

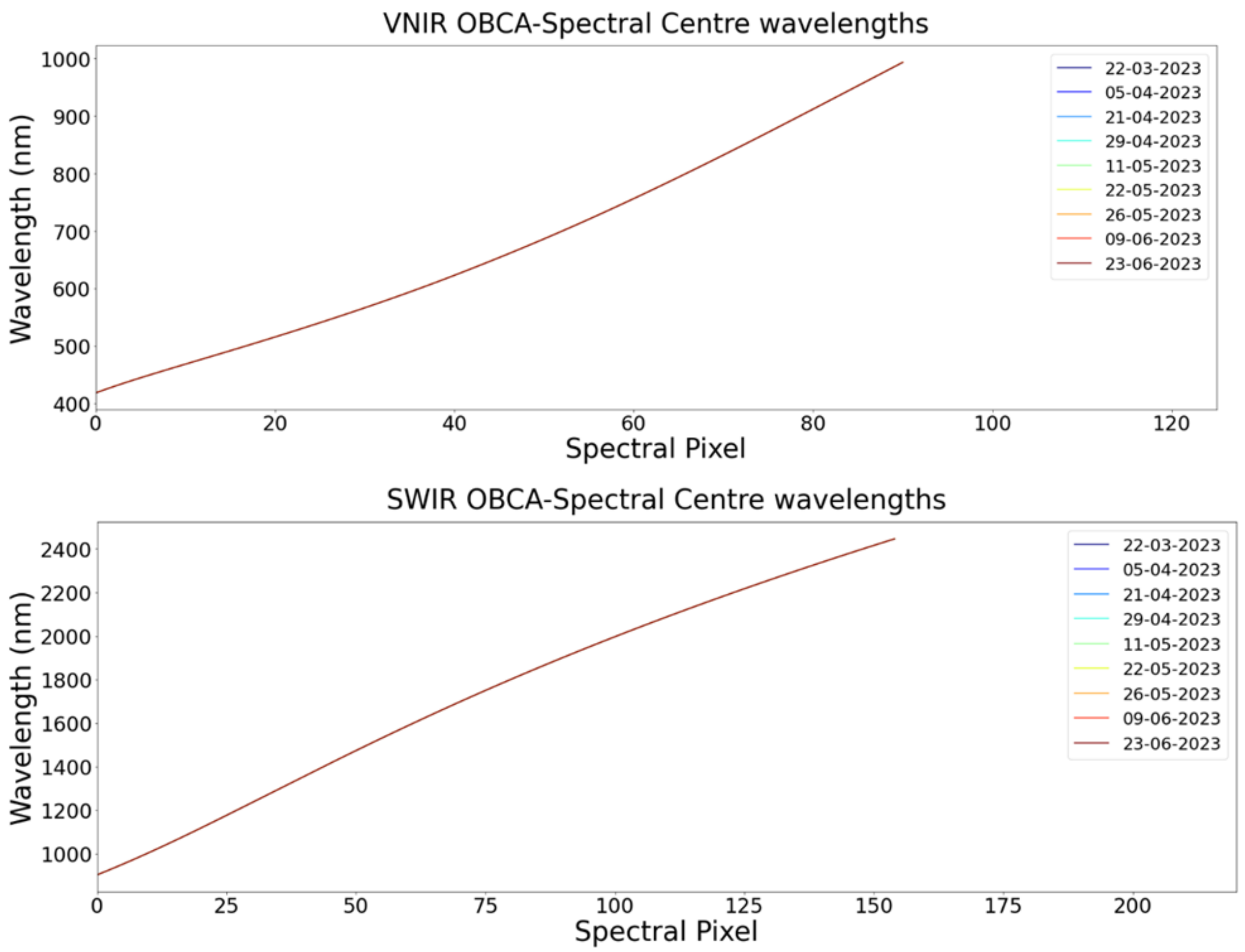


Figure 7-7 VNIR (top) and SWIR (bottom) center wavelength in nm

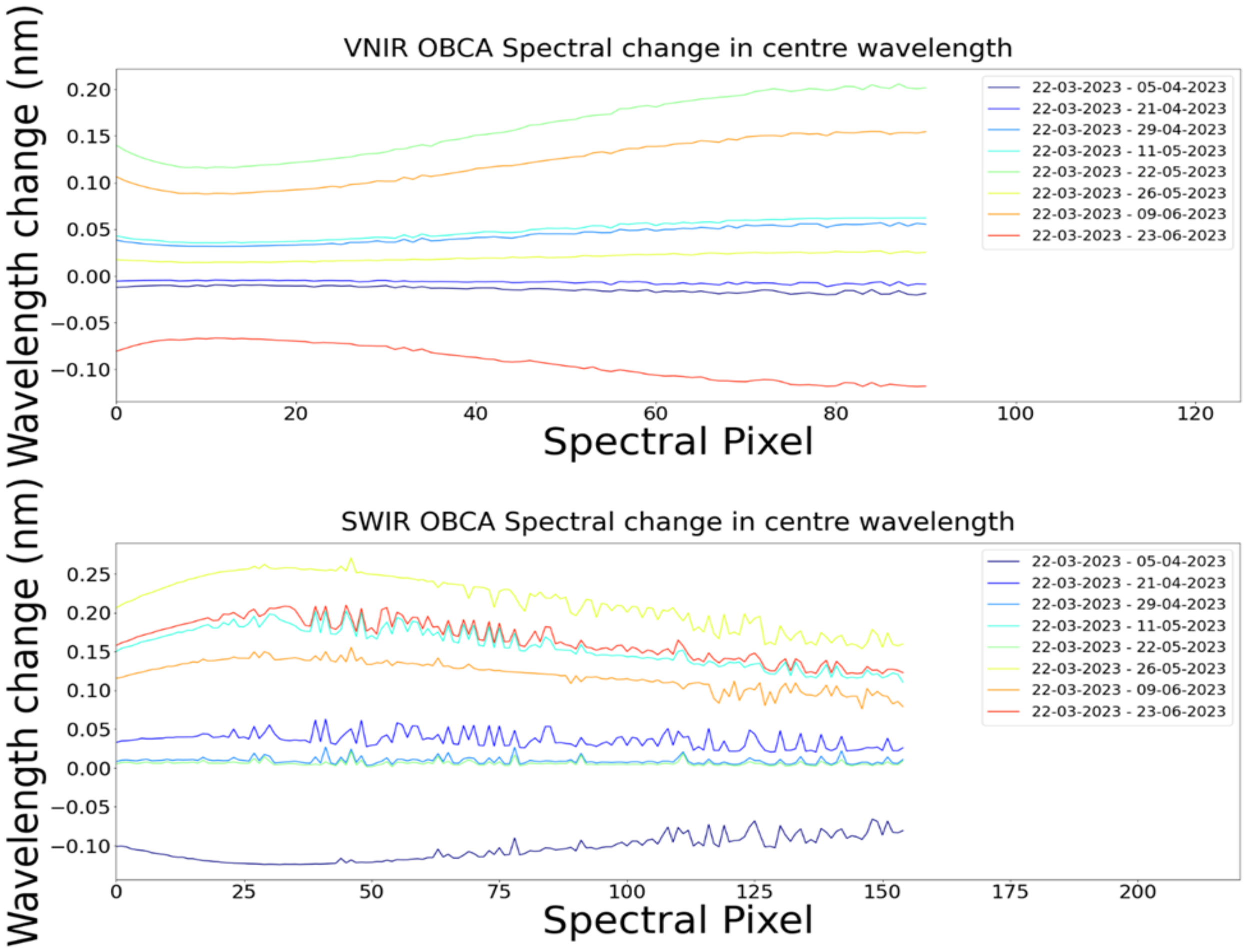
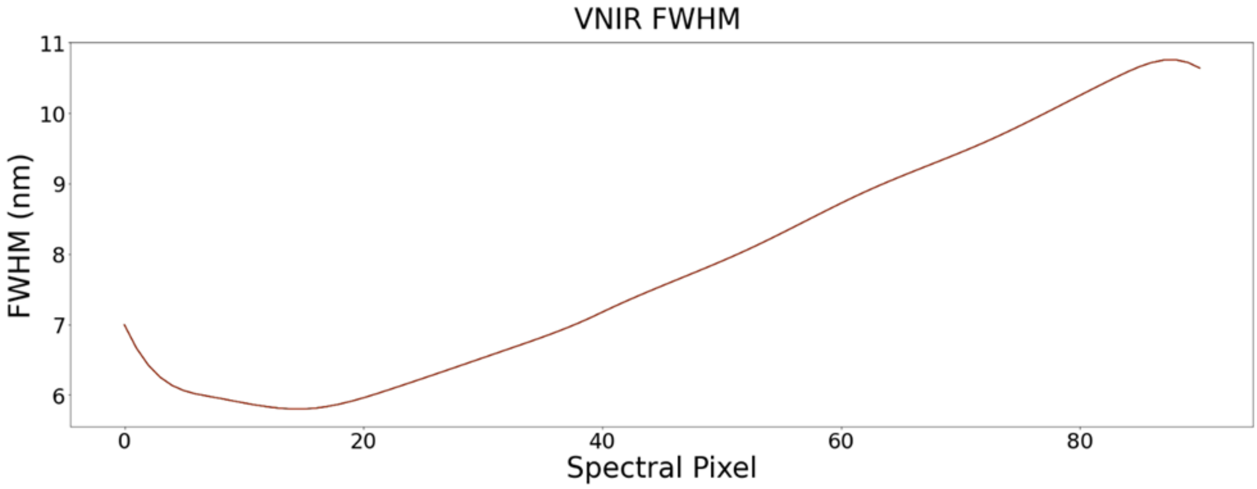


Figure 7-8 **Change in center wavelength per spectral pixel for VNIR (top) and SWIR (bottom)**



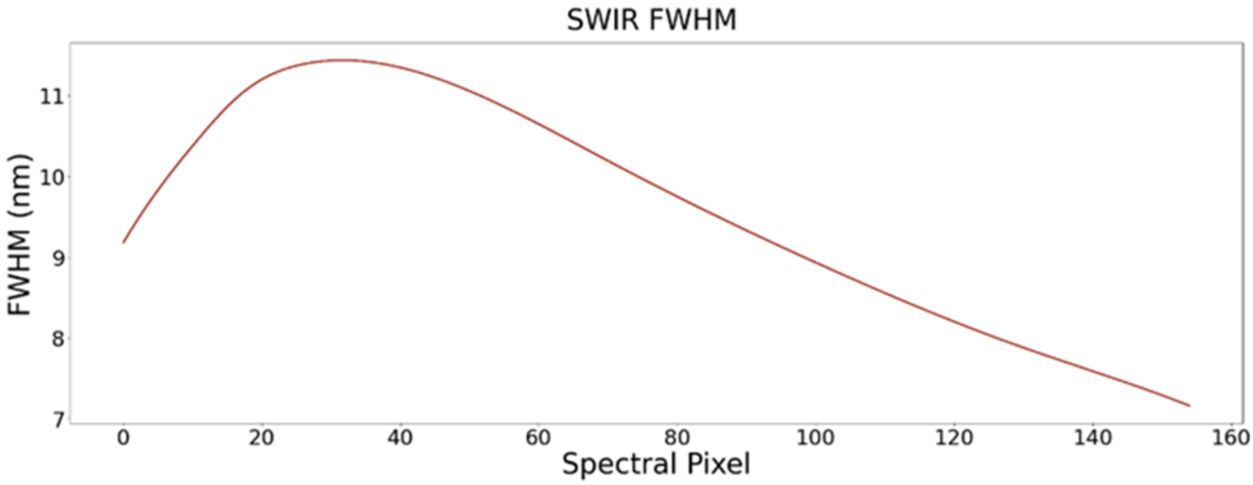


Figure 7-9 VNIR (top) and SWIR (bottom) FWHM in nm

CW and FWHM are available in the spectral calibration tables (see Table 7-7) and System Response Functions (SRF) per band are modelled by a Gaussian shape using those parameters. No new spectral calibration tables have been generated during the reporting period.

Product	Type	Date of Generation	Date of Validity Start	Date of Validity End	Delivered to
None					

Table 7-7 Generated spectral calibration tables

7.5.3 Radiometric Calibration

Category	01.04.2023 to 30.06.2023	
	Number of Archived Observations	Size (in GB)
Total	17	105.7
Deep Space	3	3.9
Rel. Radiometric	8	31.2
Abs. Radiometric	2	2.6
Linearity	4	68

Table 7-8 Number and size of archived radiometric calibration observations

The radiometric properties – characterized in particular by the calibration coefficient for each band (spectral coordinate) and pixel (spatial coordinate) and radiance – during this reporting period are investigated, considering all bands and pixels and radiances provided in Level 1B, Level 1C and Level 2A products.

Both sensors feature two gain settings each. VNIR applies a quantization of 13 bits using a pixel-individual automatic gain switching, where the low gain value is automatically selected, if the signal exceeds a defined threshold. SWIR applies a fixed gain setting, where bands below 1980 nm take the low gain value and bands above 1980 nm take the high gain value.

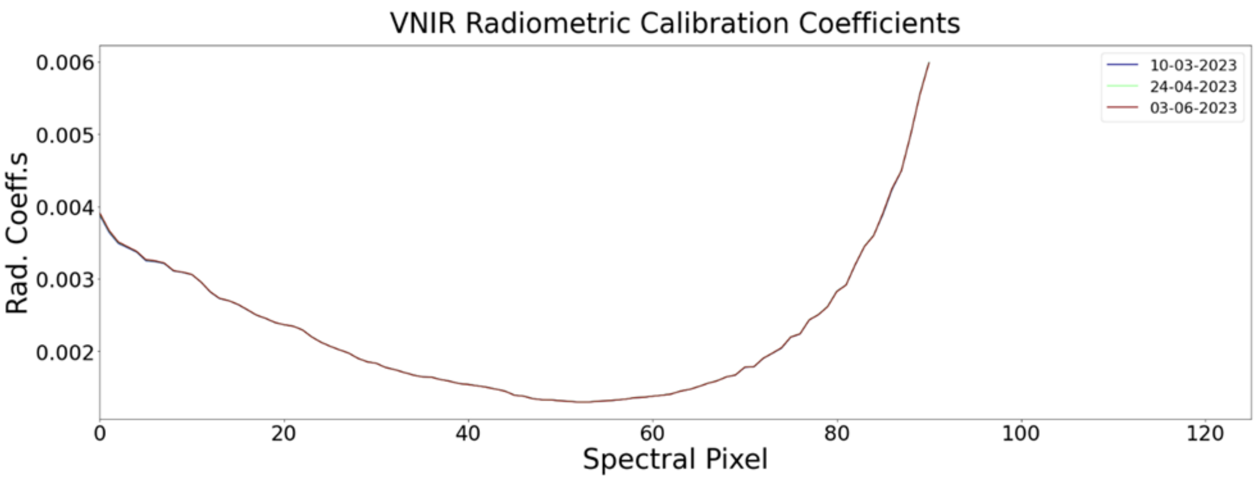
Radiometric calibration coefficients (see Figure 7-10, Figure 7-11 and Table 7-9) and VNIR RNU (response non-uniformity) (see Figure 7-13) are affected by the degradation of the VNIR sensor and the (expected) change after launch of the SWIR sensor. In-flight, the gain matching coefficients (see Figure 7-12), the SWIR calibration coefficients, and the SWIR RNU (response non-uniformity) (see Figure 7-13) have been stable.

During the reporting period, 2 Absolute Radiometric calibration measurements were obtained. These took place on: 24.04.2023 and 03.06.2023. Owing to the degradation in the VNIR sensor, new calibration and reference tables were created for each new absolute radiometric measurement. Although the VNIR degradation has almost stopped, the overall effects are visible in the reference measurements of the sun. However geometric conditions (sun-earth distance, pointing angle) also play a role in the absolute magnitude so the degradation cannot be quantified with these reference measurements.

The major conclusions of the monitoring of the absolute performance is summarized as follows:

- The VNIR degradation has affected the absolute Radiometric calibration coefficients but as the size of the degradation is now reaching zero, the coefficients appear to be reaching a stable state. In this reporting period, the calibration coefficients only increased by a small amount to offset the decrease in absolute signal, averaging 0.05% relative to the sun calibration on 13.12.2023. Regarding RNU, the degradation features are visible in the focal plane. Looking at the average along across track pixels, the RNU correction does not appear to have changed much in this reporting period. Lastly, the Gain Matching correction has been relatively stable during this reporting period.
- The SWIR sensor has shown good stability during this reporting period, with no significant changes in the gain matching, RNU or radiometric calibration coefficients.
- Regarding the total change in calibration corrections as a result of the VNIR degradation, almost all pixels experienced a change of less than 2.5% between consecutive measurements as set in requirement [HSI-POSR-0410]. Only two pixels exceeded this value and these pixels were already marked as dead during preflight assessment. No SWIR pixels experienced a change of more than 2.5% between consecutive absolute calibration measurements.
- Due to the degradation in the VNIR sensor, new calibration and reference tables were created for each new absolute radiometric measurement. The size of the degradation has been decreasing during this reporting period and it is almost zero. As a result, the calculation of the dynamic coefficients has been turned off and calibration coefficients are taken directly from the most recent calibration table as envisioned at the beginning of the mission. Monthly updates to the radiometric calibration table may not be necessary if the coefficients are now in a steady state.

The VNIR degradation, although coming to a stop, has directly affected the radiometry. Even though the EnMAP radiometric quality was well within the requirements, the absolute calibration measurements were taken at monthly intervals. Changes between measurements are comparable to the SWIR sensor. It is planned to perform calibration acquisitions at longer time intervals in the future.



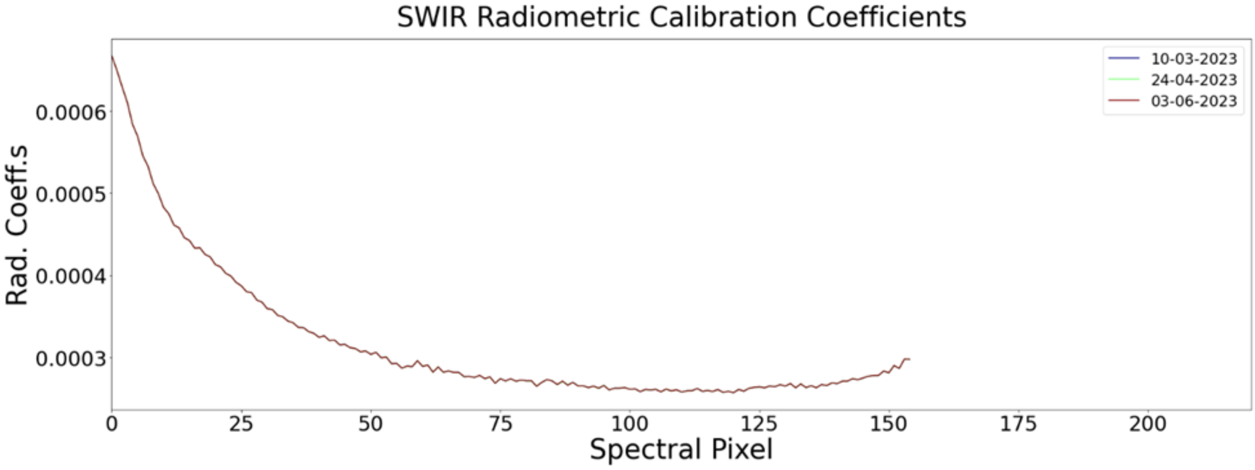


Figure 7-10 **VNIR (top) and SWIR (bottom) calibration coefficient in mW/cm²/sr/µm**

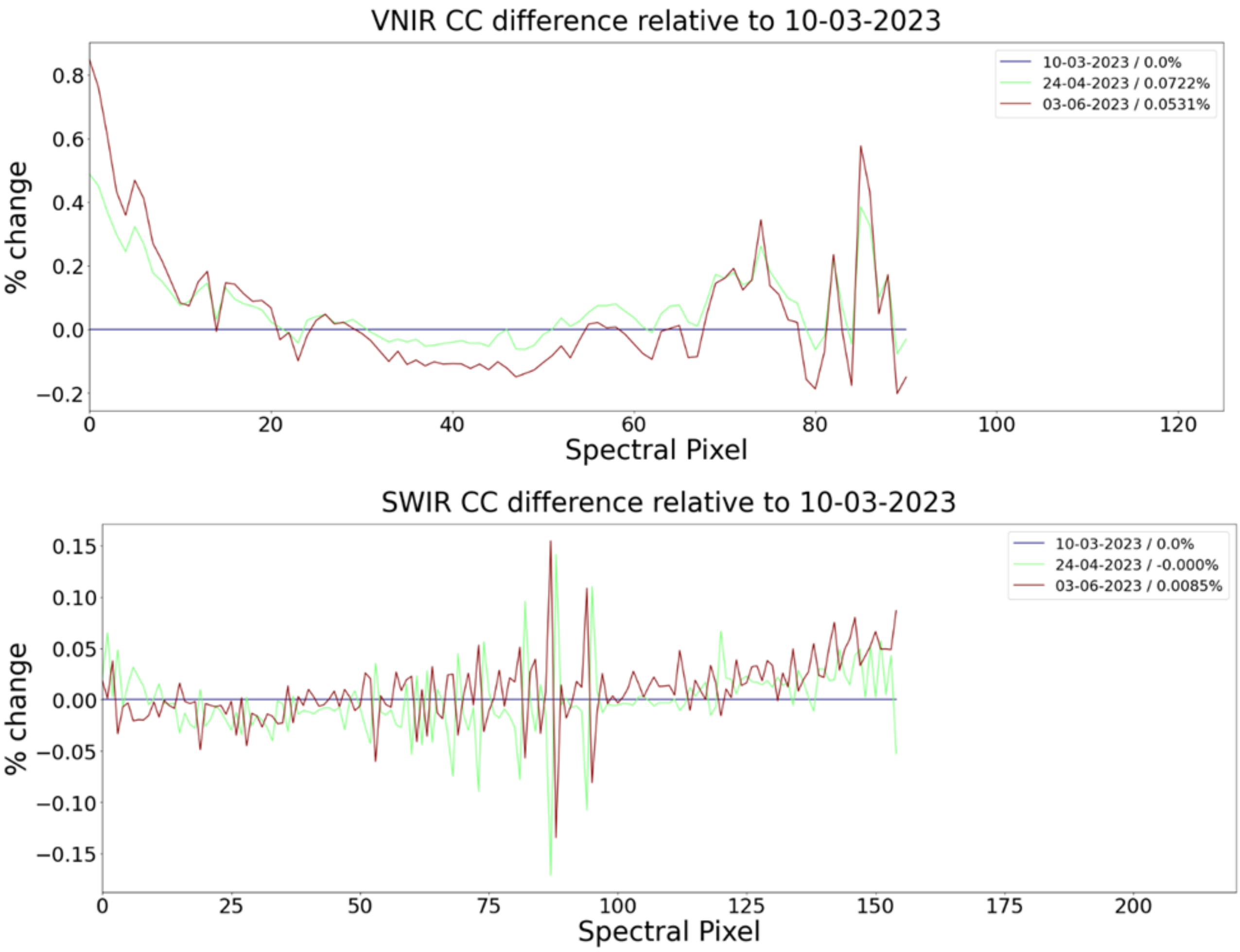


Figure 7-11 **Percentage change in VNIR Calibration Coefficients (top) and SWIR Calibration Coefficients (bottom)**

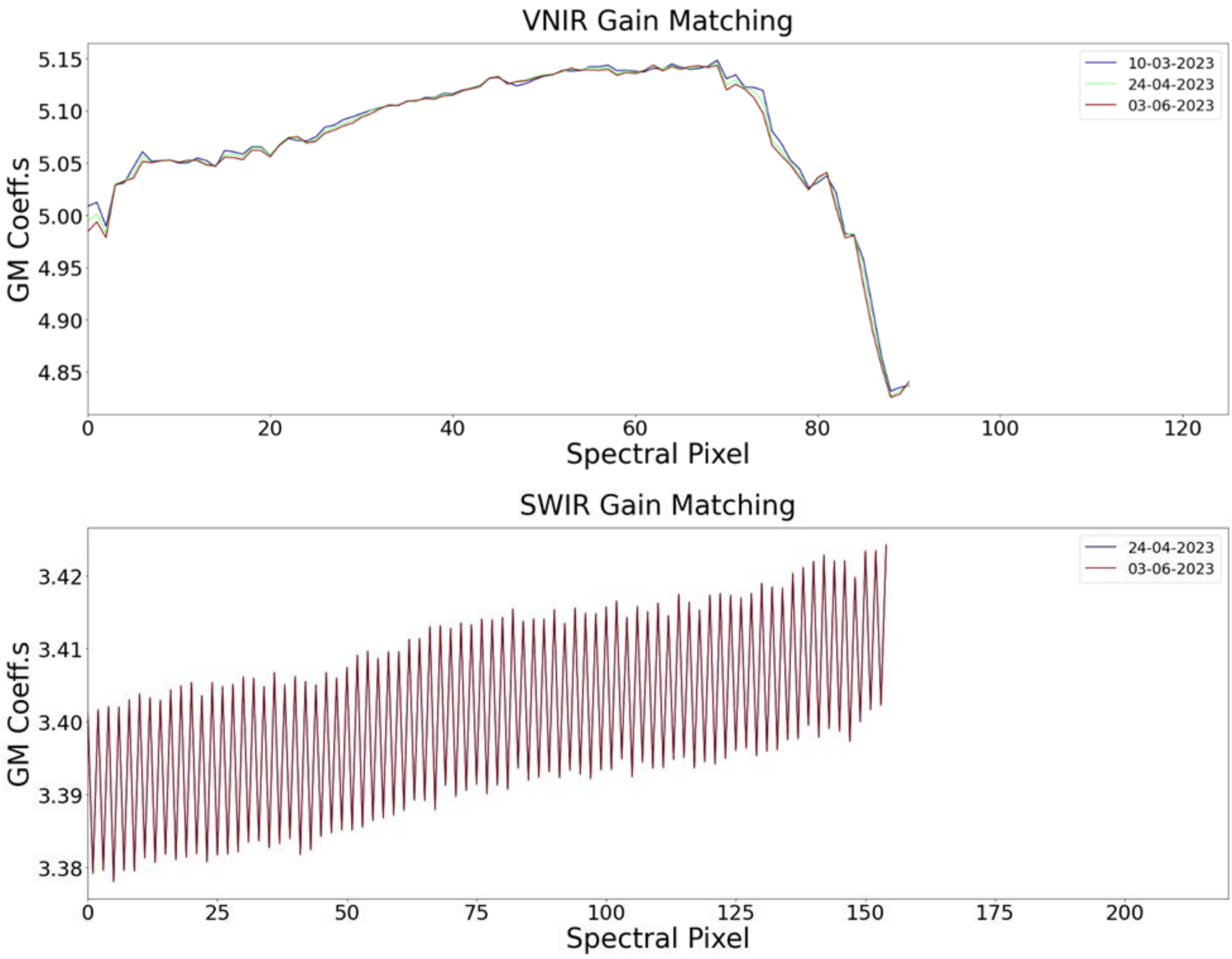
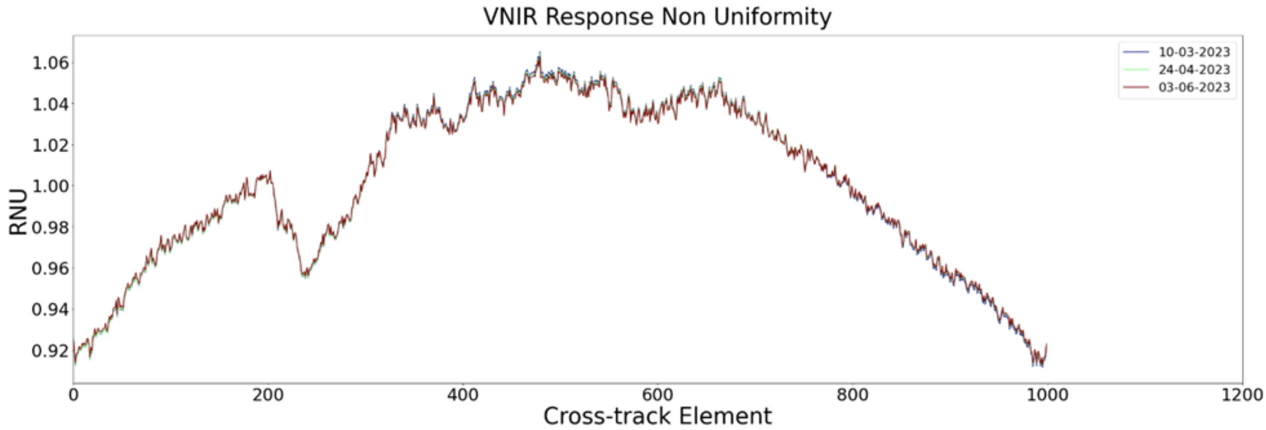


Figure 7-12 VNIR (top) and SWIR (bottom) gain matching calibration coefficients



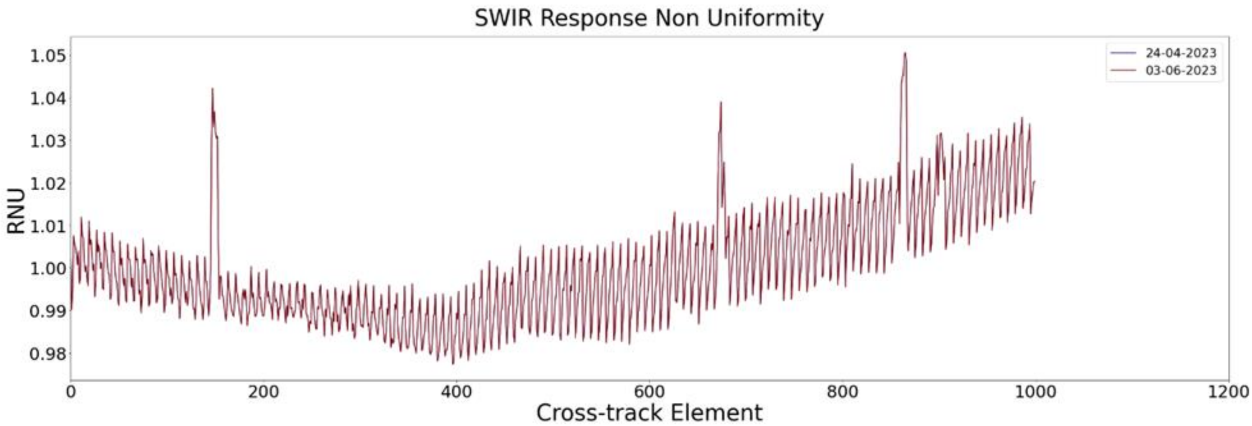


Figure 7-13 VNIR (top) and SWIR (bottom) response non-uniformity coefficients

The Signal-to-Noise Ratio (SNR) is derived from the Linearity reference measurements. This is not a perfect set-up for the assessment of the SNR as the linearity measurements only cover a single wavelength and light level at increasing integration times. However, it is well constrained, covering a wide range of radiances including the levels of the solar reference spectrum (30% reflectance, 30° sun incidence angle, 21 km visibility, target 500 m above sea level). The lamp reference measurements are not used, as the reference spectrum is not well covered at the radiances of the lamp and extrapolation would be required to test the performance at the SNR requirements: SNR greater than 500 at 495 nm in VNIR for the solar reference spectrum value; and SNR greater than 150 at 2200 nm in SWIR for the reference spectrum.

For the VNIR sensor, the Signal-to-Noise Ratio has changed during commissioning phase as a result of the ongoing degradation. Nevertheless, the high gain and low gain measurements imply that the SNR in each gain are above the requirement of the reference spectrum at 495 nm. In the case of VNIR low gain, the SNR was found to be 620 for the measurement on 22.06.2023. This value is the practically the same as the one reported in previous quarterly report and indicates how this VNIR degradation is reducing over time.

For the SWIR sensor, both gains are above the requirement at 2200 nm, giving an SNR value of 350 in high gain mode from 22.06.2023. Figure 7-14, Figure 7-15, Figure 7-16 and Figure 7-17 show SNR contour maps for each sensor and gain, based on observed linearity measurements from 22.06.2023, and the solar reference spectrum is plotted to show how the SNR is derived in each case.

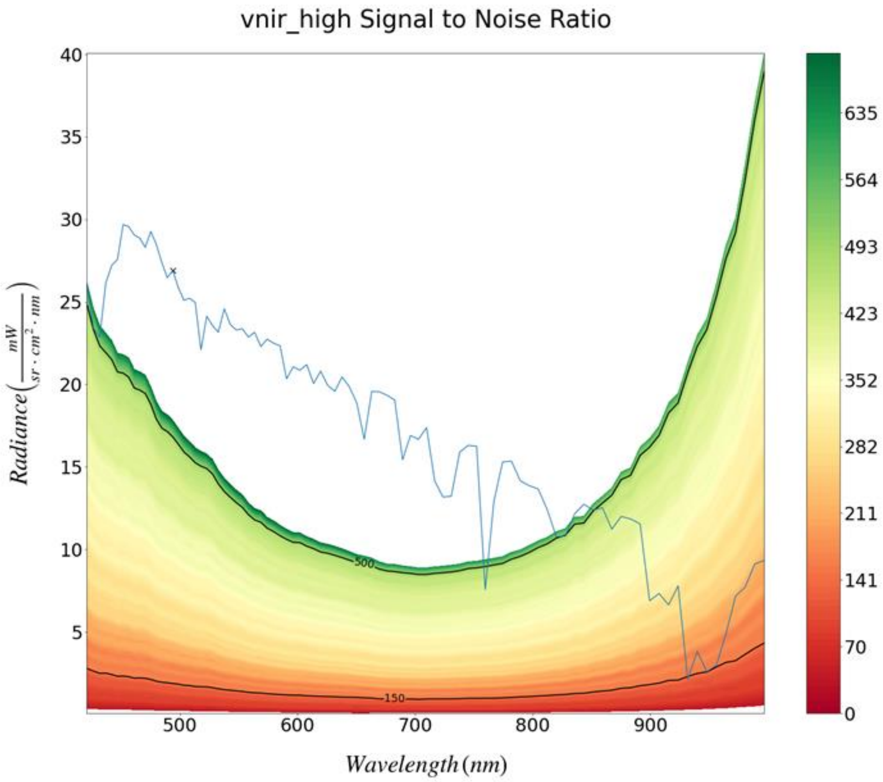


Figure 7-14 **SNR contour map for VNIR high gain from the LED linearity observations observed on 22.06.2023. The solar reference spectrum is shown with a blue line and the position of the requirement is marked on the reference spectrum with a black cross. Contour lines with SNR values of 150 and 500 are also shown in black.**

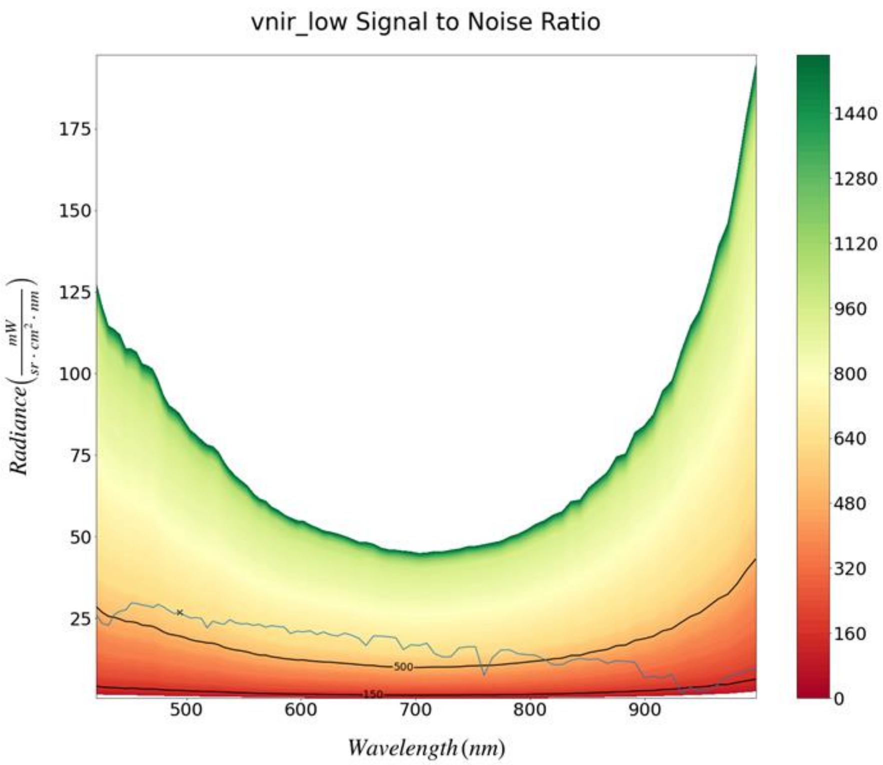


Figure 7-15 **SNR contour map for VNIR low gain from the LED linearity observations observed on 22.06.2023. The solar reference spectrum is shown with a blue line and the position of the requirement is marked on the reference spectrum with a black cross. Contour lines with SNR values of 150 and 500 are also shown in black.**

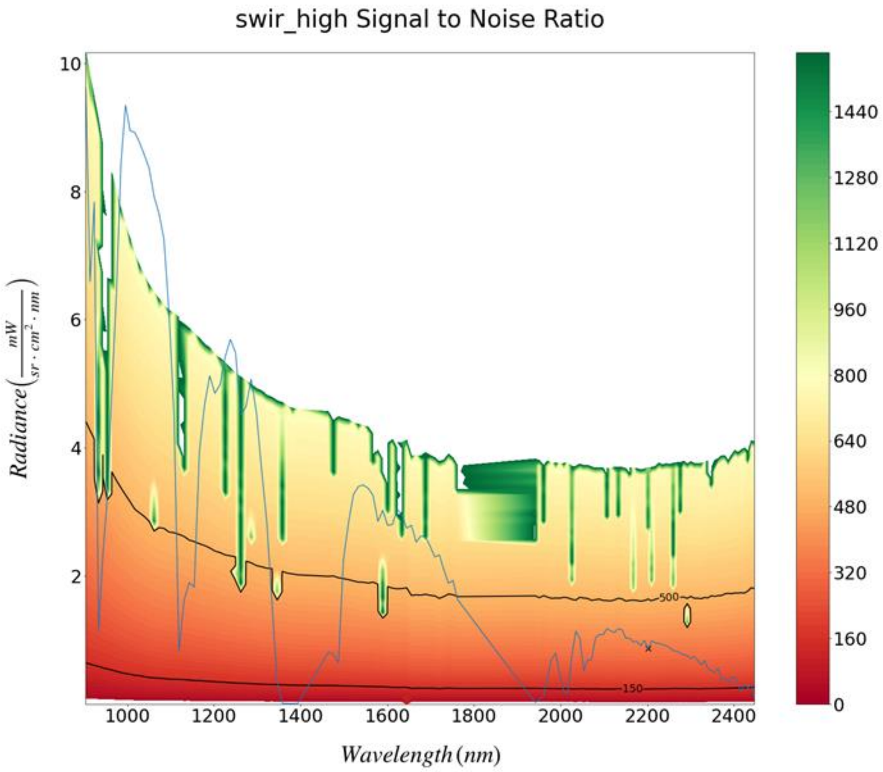


Figure 7-16 SNR contour map for SWIR high gain from the LED linearity observations observed on 22.06.2023. The solar reference spectrum is shown with a blue line and the position of the requirement is marked on the reference spectrum with a black cross. Contour lines with SNR values of 150 and 500 are also shown in black.

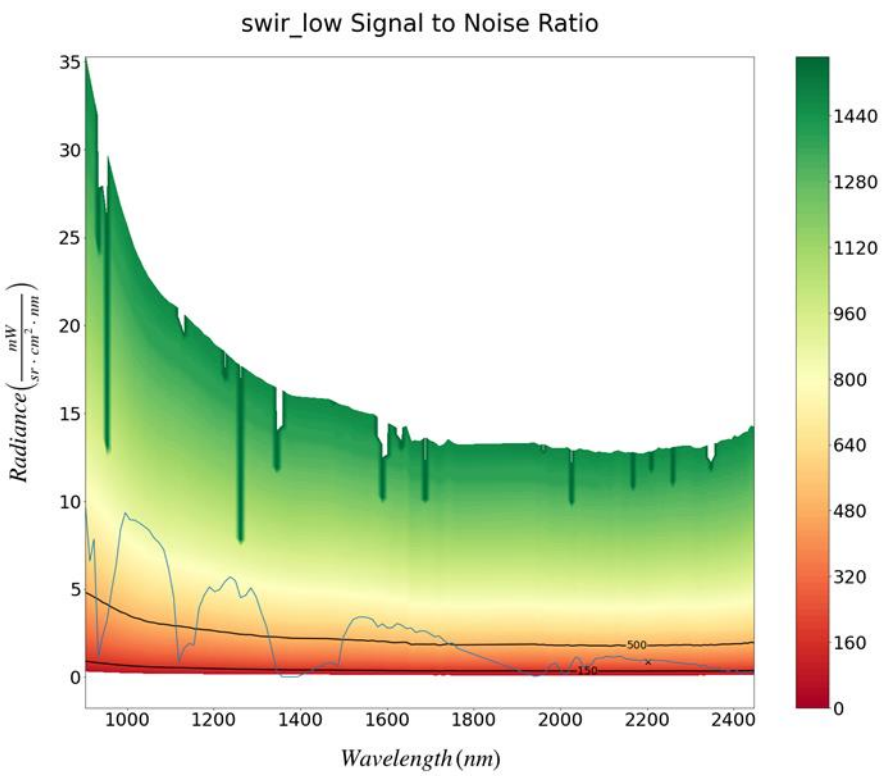


Figure 7-17 SNR contour map for SWIR low gain from the LED linearity observations observed on 22.06.2023. The solar reference spectrum is shown with a blue line and the position of the requirement is marked on the reference spectrum with a black cross. Contour lines with SNR values of 150 and 500 are also shown in black.

The following calibration products were generated and delivered.

Product	Type	Date of Generation	Date of Validity Start	Date of Validity End	Delivered to
ENMAP01-CTB_RAD-20230425T000000Z_V040002_20230426T063546Z	CTB_RAD	26.04.2023	25.04.2023*	21.06.2023	DIMS
ENMAP01-CTB_RAD-20230621T000000Z_V040002_20230615T131334Z	CTB_RAD	15.06.2023	21.06.2023	-	DIMS
ENMAP01-REF_SUN-20230425T000000Z_V040002_20230426T063546Z	REF_SUN	26.04.2023	25.04.2023	21.06.2023	DIMS
ENMAP01-REF_SUN-20230621T000000Z_V040002_20230615T131334Z	REF_SUN	15.06.2023	21.06.2023	-	DIMS

Table 7-9 Generated radiometric calibration tables

7.5.4 Geometric Calibration

There have been no new geometric calibration tables generated in the reporting period.

Type of Calibration Table	ID of Calibration Table	Date of Generation	Date of Validity Start	Date of Validity End
None				

Table 7-10 Generated new geometric calibration tables

The performance of the geometric calibration table is assessed in chapter 7.6.3.

7.6 Internal Quality Control

7.6.1 Archive

Within the given time period (01.04.2023 – 30.06.2023), 1340 datatakes with a total of 6434 tiles were acquired and archived (remark: additional datatakes were acquired during this period but for which the archiving is pending might be missing in the statistics).

The overall quality rating statistics are listed inTable 7-11, and in relation to the Solar Zenith Angle (SZA) in Table 7-12. Also these ratings are further detailed for the VNIR and SWIR detector in Table 7-13, showing a nominal performance rating for the given quality thresholds.

In addition, the rating for the atmospheric conditions for the scenes are depicted in Table 7-14. When setting the atmospheric quality rating in relation to the illumination conditions (i.e., large SZA) during data acquisition (Table 7-15), 9% of the “reduced quality” ratings and over 8% of the “low quality” ratings can be related to high Solar zenith angles / night time acquisitions.

In addition, the “low qualityAtmosphere” rating can be further related to high cloud cover (53% of the low qualityAtmosphere tiles) and the unavailability of enough DDV pixels (75%) (see Table 7-15). Consequently, the rating is absolutely reasonable and can be explained.

Parameter	Value	Percentage	Number of tiles
overallQuality	Nominal	97%	6295
	Reduced	<1%	8
	Low	2%	131

Table 7-11 Overall quality rating statistics

Parameter	Number of tiles	Sub-Parameter	Number of tiles
overallQuality = Low	131		
		Thereof with SZA > 70°	131

Table 7-12 Overall quality rating in relation to Sun Zenith Angle (SZA)

Parameter	Number of tiles	Sub-Parameter	Number of tiles
overallQuality = Reduced	8		
		Thereof with qualityVNIR nominal	0
		Thereof with qualitySWIR nominal	8
overallQuality = Low	131		
		Thereof with qualityVNIR nominal or reduced	0
		Thereof with qualitySWIR nominal or reduced	0

Table 7-13 Reduced and low quality rating statistics

Parameter	Value	Percentage
QualityAtmosphere	Nominal	31 %
	Reduced	13%
	Low	56%

Table 7-14 QualityAtmosphere rating statistics

Parameter	Number of tiles	Sub-Parameter	Number of tiles
overallAtmosphere = Reduced	819		
		Thereof with SZA > 60°	75
		Thereof with SZA > 70°	38
		Thereof with SZA > 80°	27
overallAtmosphere = Low	3598		
		Thereof with SZA > 60°	308
		Thereof with SZA > 70°	172
		Thereof with SZA > 80°	109

Table 7-15 QualityAtmosphere rating in realtion to Sun Zenith Angle (SZA)

Parameter	Number of tiles	Sub-Parameter	Number of tiles

overallAtmosphere = Low	3598		
		Thereof with Cloud Cover > 66%	1934
		Thereof with DDV warnings	2724

Table 7-16 QualityAtmosphere rating in relation to Cloud Cover and DDV availability

7.6.2 Level 1B

7.6.2.1 Radiometric Performance

Indications for defective / de-calibrated detector elements

Using the Detector Map components, an offline check of possibly defective or de-calibrated detector elements is conducted. In particular, if a detector element is identified as "possibly defective" in at least 75% of the useful tiles. Within the given reporting period, the following indications for defective pixels are found for the VNIR and the SWIR camera:

VNIR (total of 6434 tiles, with 6303 suitable for analysis):

Newly found suspicious pixels in green, no longer present ones in ~~red~~.

Band	Cross-track element
~~19~~	~~187~~
~~77~~	~~600~~
85	14
89	395

SWIR (total of 6434 tiles, with 6280 suitable for analysis):

Newly found suspicious pixels in green, no longer present ones in ~~red~~.

Band	Cross-track element
2	235, 286, 593, 673
4	362, 363, 418
5	687
7	910
8	801
11	715
14	29, 684
16	535
~~19~~	~~84~~
~~20~~	~~84~~
~~28~~	~~104~~
29	855, 928
30	360
31	360
33	560
38	241
47	511
48	218

Band	Cross-track element
49	311, 344, 395
50	154, 155
52	97, 98
53	602, 941
55	221, 965
57	632, 922
58	89, 90
60	312
62	123
65	93
71	801, 844, 845
85	525
89	285
91	973
92	677, 973
96	341, 819
100	513
101	318
102	925

106	107
107	~~265,~~ 764
108	886
111	315
118	837

Indications for increasing dead detector elements

Within the given reporting period, the statistics for dead pixels are provided in the following tables. When comparing these numbers to the estimates in the EN-GS-RPT-1702 Radiometric Calibration Report, one must bear in mind that the latter is based on the full detector readout configuration, while the numbers provided in the following are related to the standard readout configuration as provided in the user product. Because of the smaller readout area, these following dead pixel numbers are lower in comparison.

Parameter	Value (number of pix)	Percentage of tiles
DeadPixelsVNIR	137	100%

Table 7-17 Dead pixel statistics, VNIR

Parameter	Value (number of pix)	Percentage of tiles
DeadPixelsVNIR	1531	100%

Table 7-18 Dead pixel statistics, SWIR

Saturation and radiance levels outside nominal range

Within the given reporting period, no indications for increased saturation defects are found for the VNIR and the SWIR camera (see Table 7-19 and Table 7-20).

Parameter	Value (per mille of scene)	Percentage of tiles
SaturationCrosstalkVNIR	0	88%
	> 0 per mille	12%
	> 10 per mille	2.5%

Table 7-19 Saturation statistics, VNIR

Parameter	Value (per mille of scene)	Percentage of tiles
SaturationCrosstalkSWIR	0	90.2%
	> 0 per mille	9.8%
	> 10 per mille	<<1%

Table 7-20 Saturation statistics, SWIR

Other radiometric artifacts

Within the given reporting period, the striping performance is similar to the one encountered during the Commissioning Phase. Within PCV, different de-striping approaches were tested, and the selected one by M. Brell (GFZ) is implemented in processor version V010200 (07.03.2023).

Apart from this, no indications for an increase in general radiometric artifacts are found for the VNIR and the SWIR camera (see following tables).

Parameter	Value (number of pix)	Percentage of tiles
generalArtifactsVNIR	0	0%
	> 0	100%
	> 10	7%
	> 100	2%
	> 1000	0%

Table 7-21 Artifacts statistics (without striping), VNIR

Parameter	Value (number of pix)	Percentage of tiles
generalArtifactsSWIR	0	0%
	> 10	100%
	> 25	13%
	> 100	2%
	> 1000	0%

Table 7-22 Artifact statistics (without striping), SWIR

7.6.2.2 Spectral Performance

For the analysis of the spectral stability, the Detector Maps of all Earth datatakes acquired in the reporting period were used. Note that no smile correction was applied, so the analysis shows only on the instrument characteristics. At the wavelengths of stable atmospheric features (760 nm Oxygen absorption and CO2 absorption at ~2050 nm), simulations of spectral shifts were carried out by resampling the absorption in the interval of +/- 3.0 nm with steps of 0.05 nm. Then the signal of the Detector Maps and the simulated shifted absorptions were normalized, and a least-square fit was used where the sensed absorption matches the simulations. Also an additional polynomial fitting was applied, as especially the CO2 absorption band region has low signal an is thus significantly influenced by noise.

When repeating this analysis for many Detector Maps, then the spectral behavior over time can be addressed (see Figure 7-18 and Figure 7-19). More important is the standard deviation of the shift, as this represents the spectral stability within the given period. As shown Figure 7-18 and Figure 7-19, the standard deviation (1σ) at 760 nm is better than 0.20 nm for all cross-track elements, and better than 0.60 nm at 2060 nm. Also the cross-track shape shows little variation; in case of the VNIR, the stability is equally good for all cross-track elements, while for the SWIR the shape is similar to the detected center wavelengths deviation.

In summary, these findings agree well with the instrument performance estimated during the Commissioning Phase and Q2 2023.

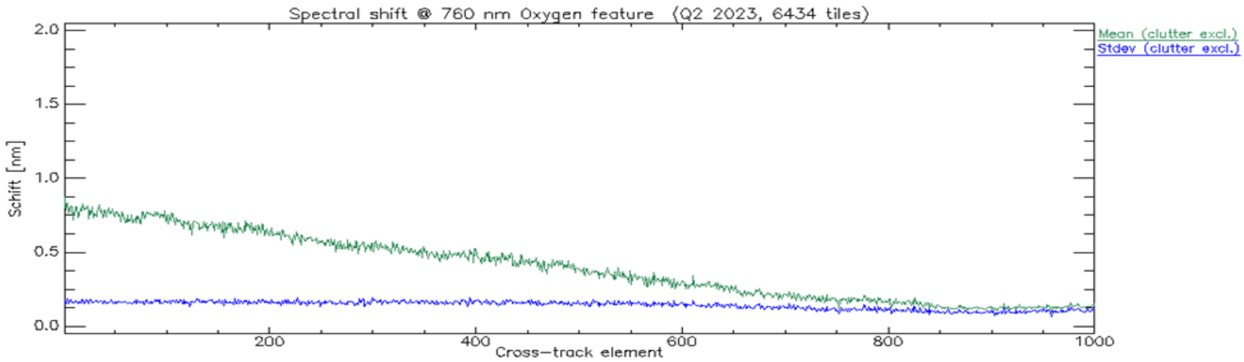


Figure 7-18 **VNIR estimated spectral shift at 760 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles**

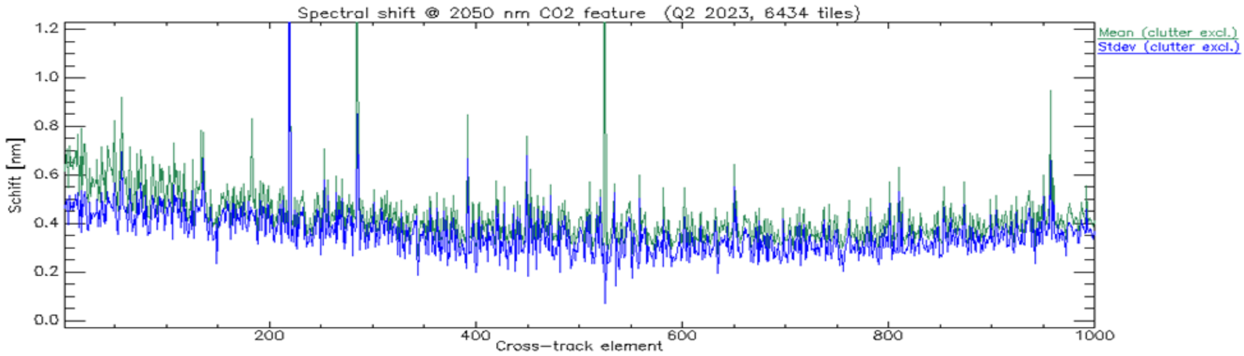


Figure 7-19 **SWIR estimated spectral shift at 2050 nm w.r.t the nominal band center, and relative spectral stability expressed at 1 sigma (Q2 2023, 6434 tiles)**

7.6.2.3 In-depth analysis of scenes

Apart from the known radiometric artefacts, no indications for an increase in general radiometric/spectral problems are found for the VNIR and the SWIR cameras. The known artefacts are indicated below. In addition, it has been studied the validity of the destriping algorithm included in processor version 01.02.00.

7.6.2.4 SWIR band swap test in May

In order to investigate the impact of the SWIR band swap, a test was conducted May 22 for a temporal band swap. As a baseline scene with the old SWIR configuration, the DT0000014109_20230424T172403Z_004 was used (Figure 7-20), as for this datatake the center wavelengths were interactively checked before during CTB_SPC updates.

The scene with the temporary new band configuration („Band Swap“) is the DT0000005483_20230522T203543_003 (Figure 7-21). This desert scene has a low scene water vapor content, so that the newly introduced bands (which are strongly affected by WV) do have a sufficient signal level.

It is important to mention that as different scenes are used, thus radiance spectra as well as DMs are not identical!

In order to check that the band swap is correct, the following 3 checks are applied:

1. TOA_RAD data, check in band space and in wavelengths space
2. Dead pixels per band
3. Check that dead pixel interpolation in L1B_int is correct

Figure 7-20 CIR for DT0000014109 with old SWIR configuration

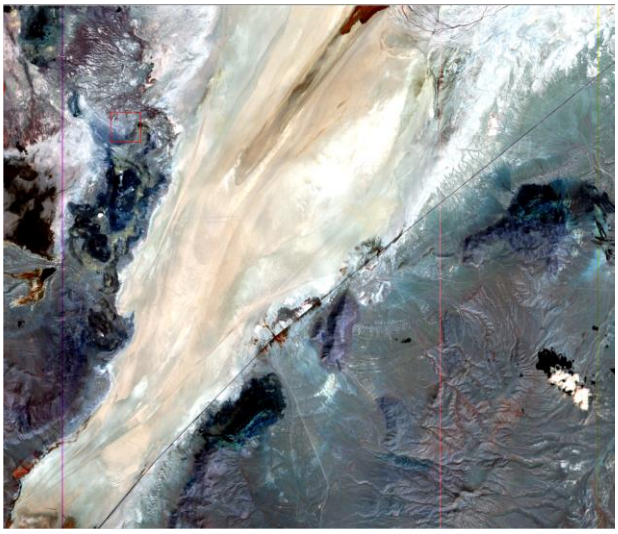


Figure 7-21 CIR of desert scene DT0000005483 with temporary band swap

Check of radiance data, by band and by wavelengths

For this the internal L1B_RAD products are used with

- Radiometric calibration applied
- No dead pixel interpolation
- No destriping applied

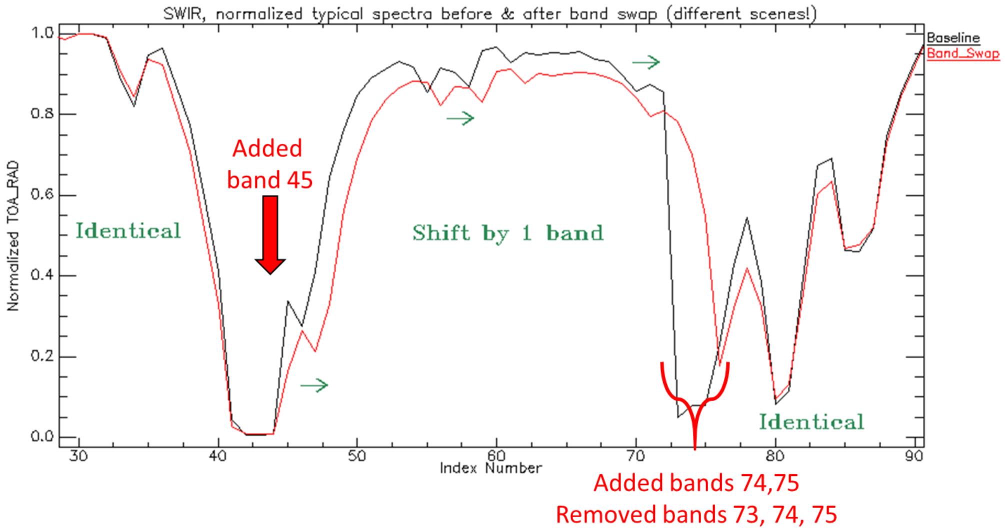


Figure 7-22 Comparison of baseline SWIR configuration with temporary band swap, ordered by bands

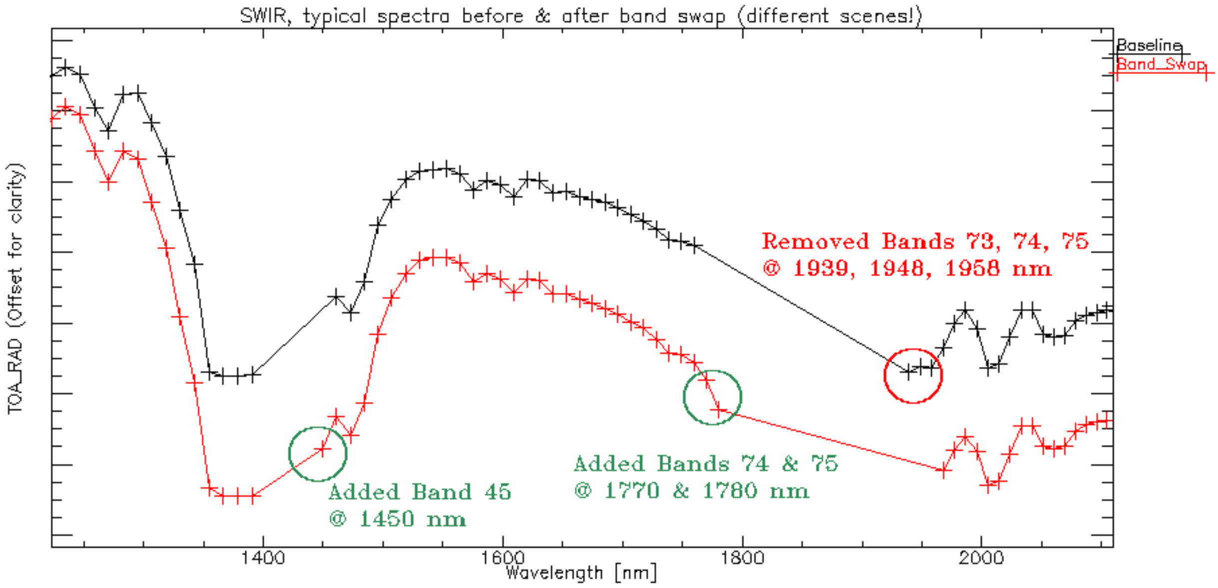
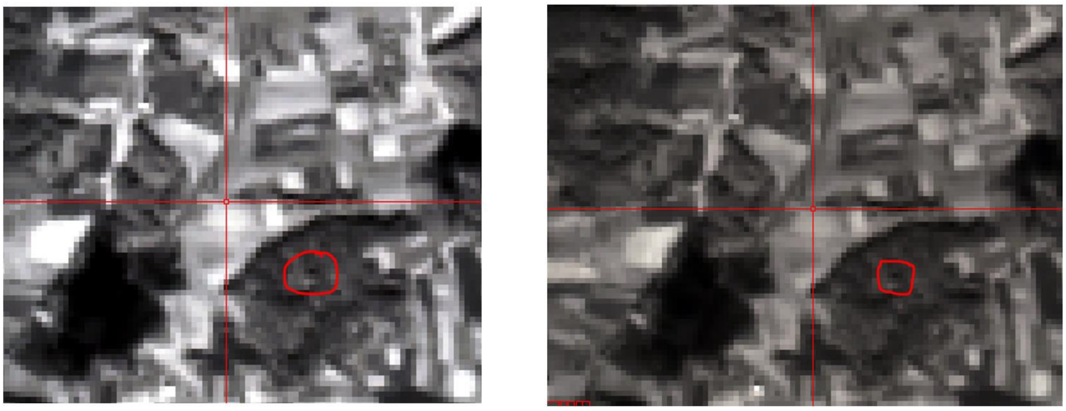


Figure 7-23 Comparison of baseline SWIR configuration with temporary band swap, ordered by wavelengths

As shown in Figure 7-22and Figure 7-23, no change exist up to SWIR band 44 and then after band 76, which is as expected. Next, it is very likely that the newly added band 45 is introduced in the right band position (high probability that this is correct) as the following bands are shifted by 1 index to higher bands (Figure 7-22). Also the newly added bands 74 & 75 are plausible regarding the band position. Consequently, the removed bands 73, 74, 75 are likely the correct ones. Also the center wavelength attached are plausible, but it is hard to verify the absolute CW for these bands as no narrow atmospheric absorption feature exists in this wavelength range. Further checks to confirm that the band positions where the correct ones were performed by comparing defective pixels in the new bands. The result of the L1B band swap test shows that the L1B processor is ready for the SWIR band update in Q3 2023.

7.6.2.4.1 Offset of VNIR-SWIR-overlap for dark targets

For a L1C product (Tile 22 of DT0000004720_20221025T105539Z), a mismatch in radiance levels was reported (see ticket #377), resulting in a band-to-band offset (“jump) in the overlapping region, especially a strong effect for a single pixel. The single pixel is a dark target in a forested are (Figure 7-24, Figure 7-25), where also the geometric offset between VNIR and SWIR possibly has a strong effect. Analysis of all product levels revealed that, as the offset is already included in L1B data (Figure 7-26), the geometric offset is not the root cause.



Nonlin. Stretch (84-82-79 color composite !)

Lin. stretch

Figure 7-24 Location of the reported single dark pixel with large VNIR-SWIR offsets (pix. 440/840 in L1C), red circle.

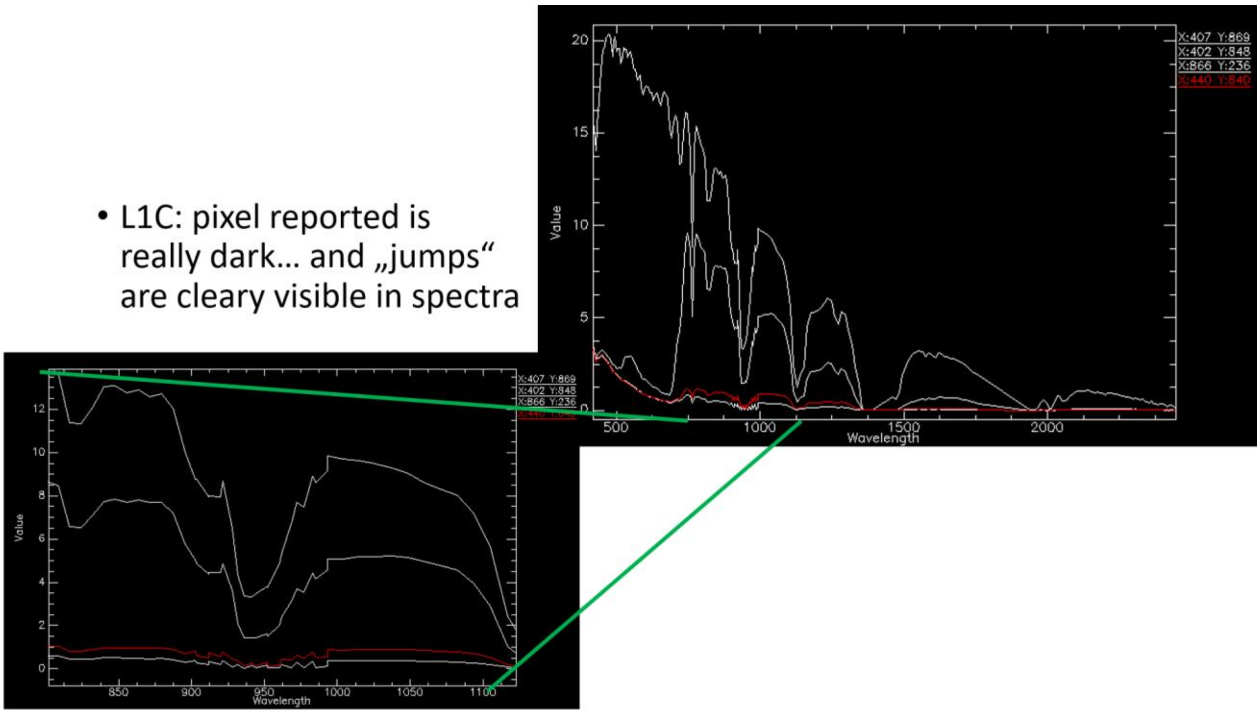


Figure 7-25 L1C radiance spectra of the reported pixel in comparison to spectra of other image locations.

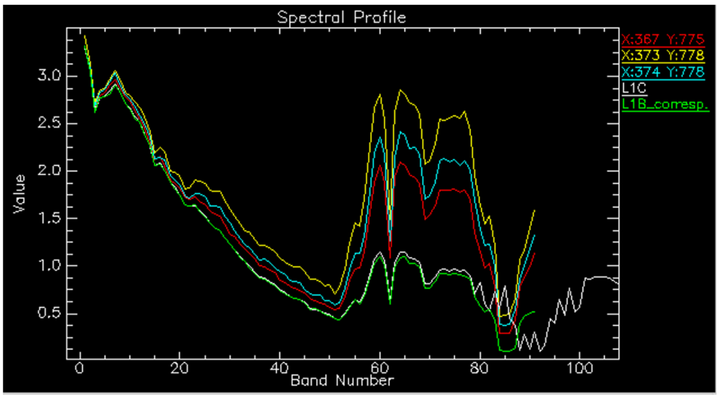


Figure 7-26 Comparison of different processing levels for the given location and surrounding pixels, s howing that the reported "jumps" are already present in L1B and for additional locations.

Next, the spatially-resolved differences of a VNIR band to a SWIR band (with similar center wavelengths) in the spectral overlap region (Figure 7-27) were analyzed, as shown in for band 84 of VNIR and band 85 of SWIR (Figure 7-28).

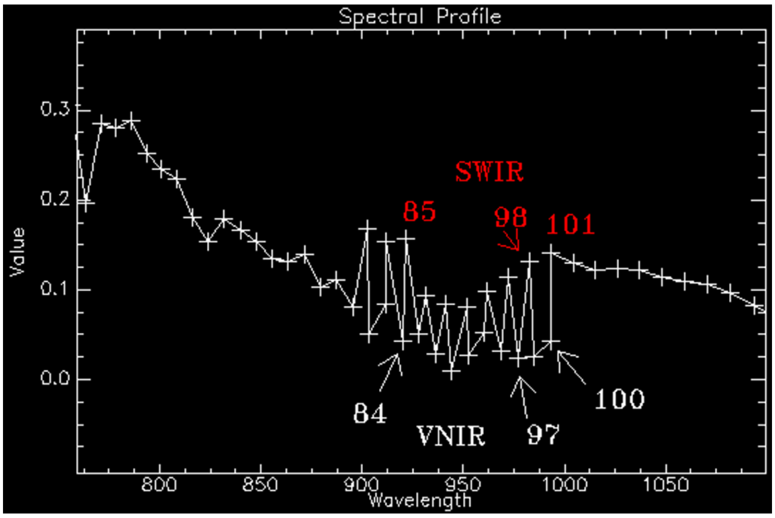


Figure 7-27 Illustration of VNIR-SWIR overlapping region using L1C data.

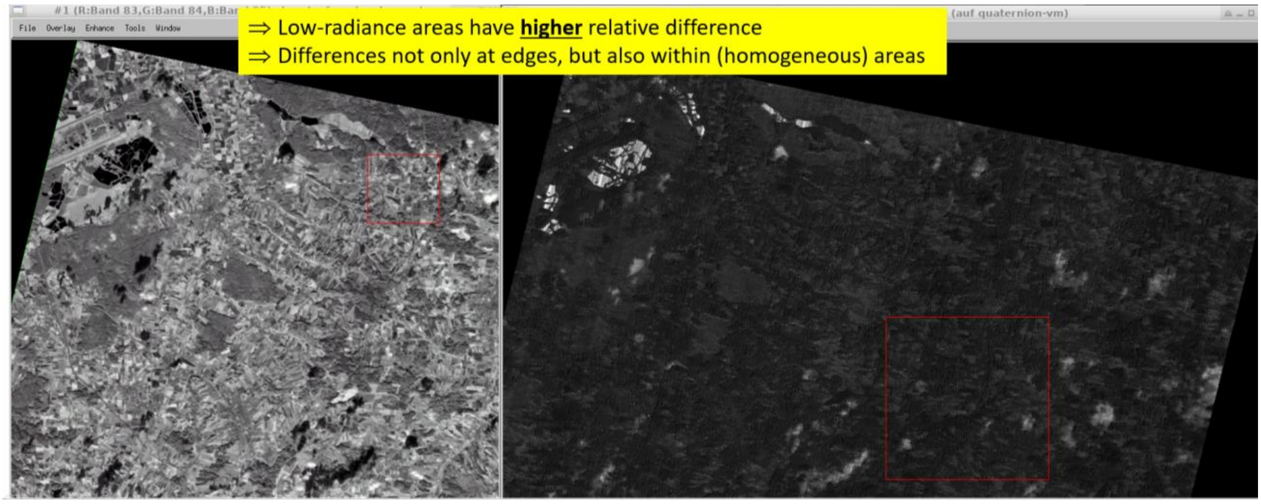


Figure 7-28 Relative difference of VNIR band 84 and SWIR band 85.

In short, the results of S-330 can be summarized as follows:

- The “jumps” are similar for all bands in the overlapping region, so not an effect of a single band.
- If it would be „just“ geometry, then differences (both absolute and relative) should be highest over small targets, edges etc., and decrease over large & homogeneous areas
  => this is not the case, as also differences within such homogeneous objects are large
- Differences in VNIR-SWIR overlap are way larger over dark areas

=> Thus there is a strong indication that the origin are mostly non-linearity effects at low radiance levels

- For the reported pixel 440/840:
  - It‘s a single dark pixel, thus geometry and linearity problems at low radiances do add up

7.6.2.4.2 Analysis of data after DSHA issues

Validity of generated data after DSHA issue on 11. / 12.05.2023

Reference	Datatake ID	Processor Version	Comment
[L2A-3]	DT0000017275_20230512T053055Z_001 DT0000017275_20230512T053055Z_002 DT0000017397_20230511T162421Z_001 DT0000017397_20230511T162421Z_002 DT0000017397_20230511T162421Z_003 DT0000017397_20230511T162421Z_004 DT0000017397_20230511T162421Z_005 DT0000017397_20230511T162421Z_006 DT0000017397_20230511T162421Z_007 DT0000017712_20230511T002824Z_001 DT0000017712_20230511T002824Z_002 DT0000017712_20230511T002824Z_003 DT0000017741_20230512T152042Z_001 DT0000017741_20230512T152042Z_002	V01.03.01;	Processing up to L2A possible. Spectral and radiometric properties of VNIR and SWIR are **nominal** @ L1B - L1B processing complete, no errors encountered - QC-related metadata entries all nominal, no defects - DetectorMaps VNIR & SWIR nominal w.r.t. defective pixels, radiance spectrum shape & magnitude, spectral positions of atm. absorption features, cross-track homogeneity

	DT0000017741_20230512T152042Z_003		
	DT0000017741_20230512T152042Z_004		
	DT0000017784_20230512T152922Z_001		
	DT0000017784_20230512T152922Z_002		
	DT0000017784_20230512T152922Z_003		

Table 7-23 Datatake ID of generated data after DSHA issue

Validity of generated data after DSHA “stuck” issue on 14.06.2023

Table 7-24 - Datatake ID of generated data after DSHA “stuck” issue

Reference	Datatake ID	Processor Version	Comment
[L2A-6]	DT0000022379_20230616T183751Z_001 DT0000022379_20230616T183751Z_002 DT0000022383_20230616T135937Z_001 DT0000024664_20230616T165211Z_001	V01.03.01;	Processing up to L2A possible. Based on logs, quicklooks and Detector Maps: VNIR: spectral and radiometric properties of are **nominal** @ L1B and L2A. SWIR: spectral and radiometric properties of are **nominal** @ L1B and L2A.

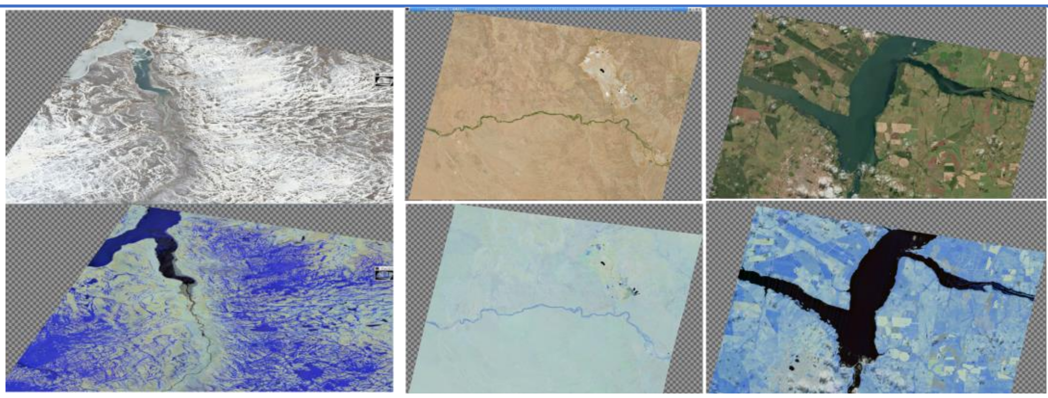


Figure 7-29 Visual inspection of quicklooks (examples), showing no defects.

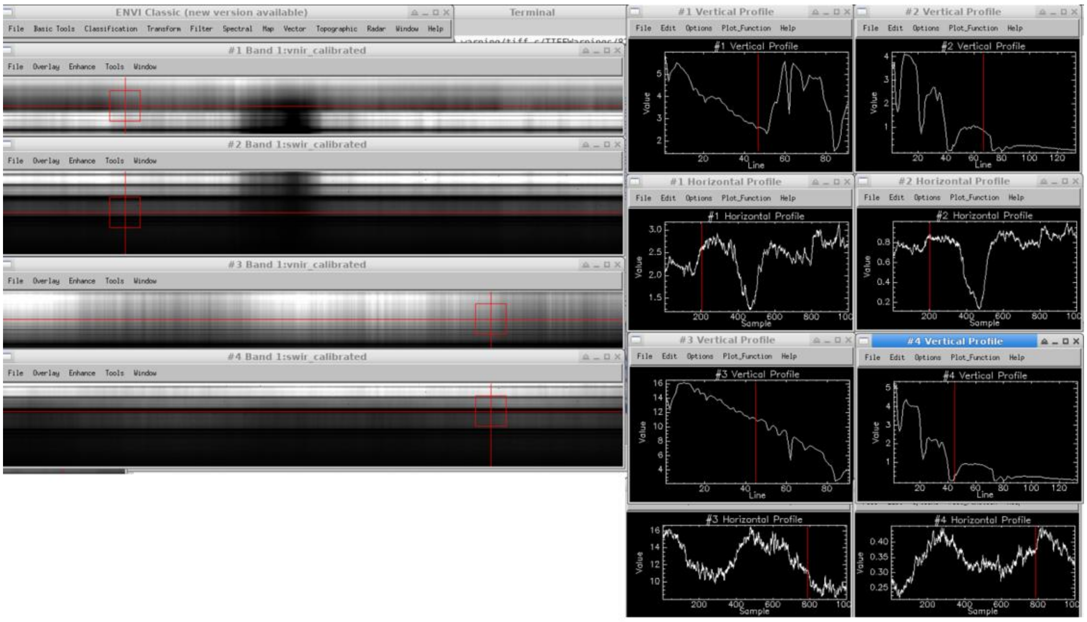


Figure 7-30 Examples of the analysis of Detector Maps, corresponding radiance spectra and cross-track profiles showing nominal properties w.r.t. spectral feature location and radiance levels.

7.6.2.5 Image artifacts

Apart from the three known radiometric artefacts, no indications for an increase in general radiometric/spectral problems are found for the VNIR and the SWIR cameras. The known artefacts are indicated below.

1. **Image Artefacts: VNIR Fringing / Etaloning**

   Fringing (also known as etaloning) is an expected effect of the VNIR CMOS detector. Fringing is a mixed spectral and radiometric effect. The Level 1B product shows an along-track low frequency variation which is constant across all frames (see Figure 7-31 and Figure 7-32) and does not appear in the lower bands nor in the SWIR (Figure 7-33). These fluctuations also appear in the across-track profiles shown in Figure 7-34, causing a wave pattern towards the edges of the image for the VNIR bands at longer wavelengths. Note that due to the very homogeneous observation site and the stacked plots in Figure 7-34 the fringing is highlighted, and usually shows less impact on observations. Based on results from the DESIS mission which features a VNIR CMOS detector from the same waver (but with differences regarding shutter and read-out wavelengths), the stability and the magnitude of the fringing strongly depends on the observation, not allowing for a generally valid estimation of the magnitude.

Figure 7-31 Fringing of the VNIR, illustrated by non-linear image stretch over homogeneous PICS

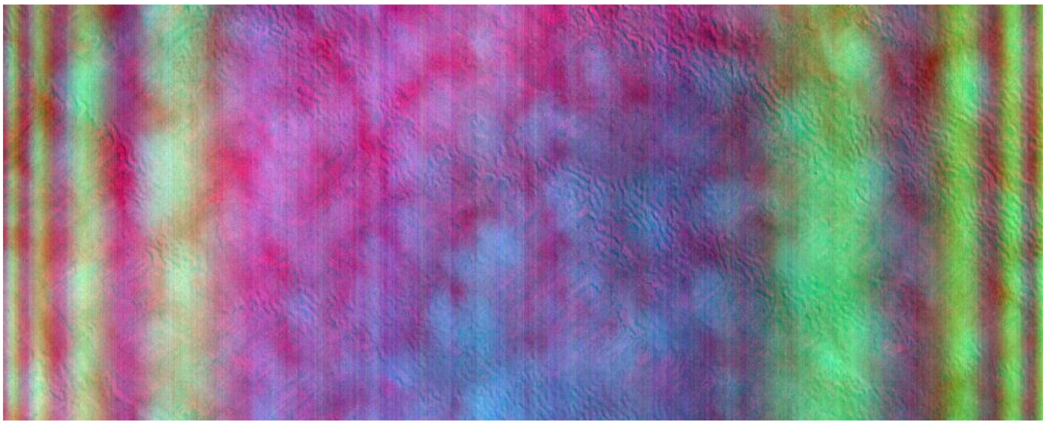


Figure 7-32 Fringing of the VNIR, Principal Component-transformed data

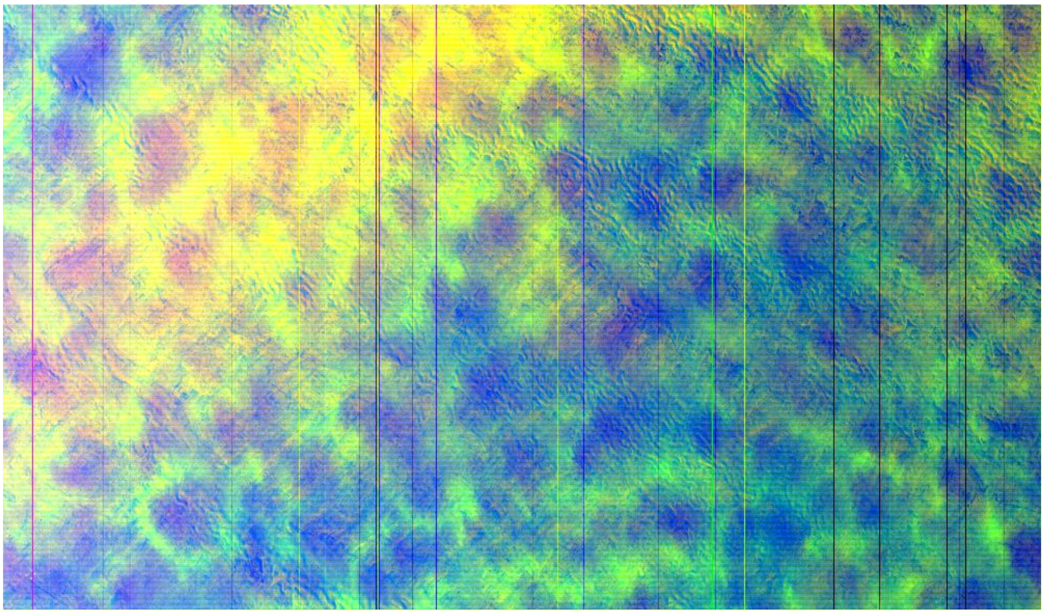


Figure 7-33 Principal Component-transformed data of the SWIR (no fringing) for comparison

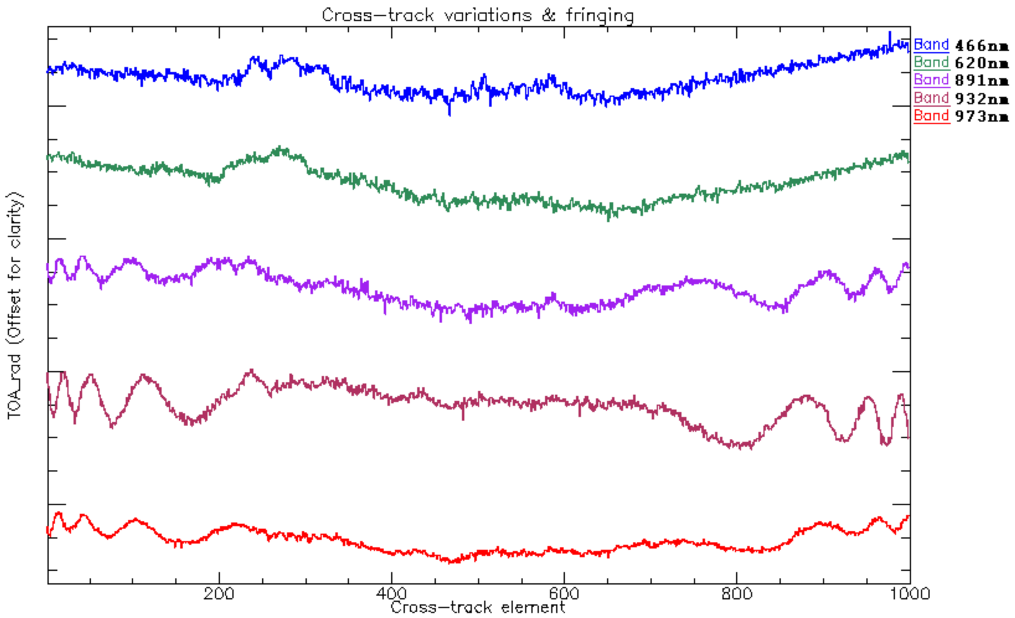


Figure 7-34 Across-track profiles for various VNIR bands, fringing influence increases towards bands at longer wavelengths

2. Image Artefacts: Micro-Vibration Effects on the SWIR

An additional effect on the SWIR is along-track striping due to SWIR-A compressor micro-vibration harmonics, resulting in a regular striping pattern in along-track direction, as highlighted by a principal component transformation shown in Figure 7-35. As shown in Figure 7-36, the magnitude of the along-track striping is relatively small and cyclic, with a relative magnitude below approx. 1% (which also includes the influence of the natural heterogeneity of the site).

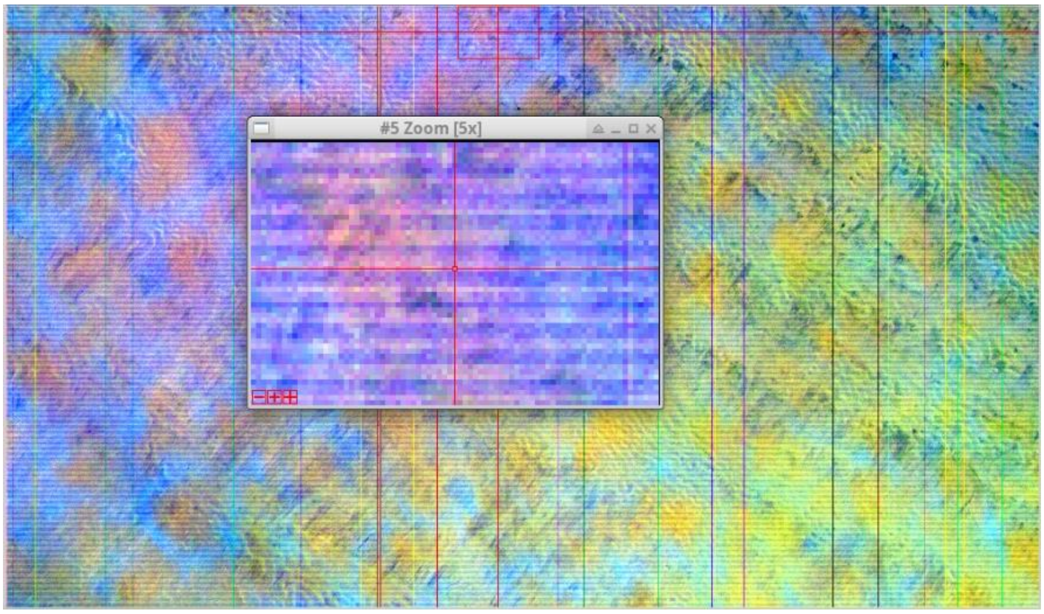
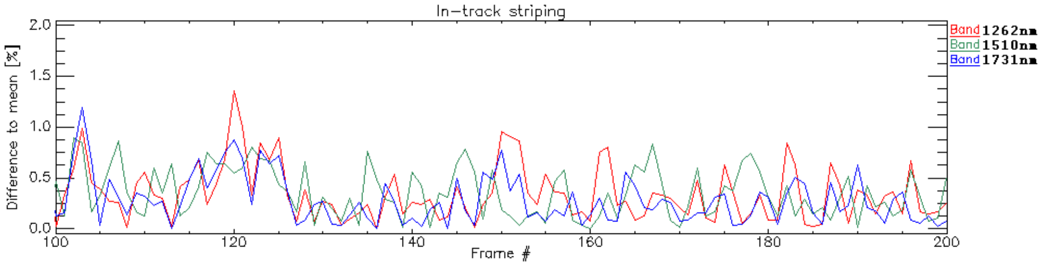


Figure 7-35 Principal Component Analysis (PCA) highlighting along-track striping



Values in [%] relative to the average.

Figure 7-36 Along-track profiles in Level 1B TOA radiances for 100 frames

To summarize, concerning Level 1B:

- Spectral stability and smile are within the requirements of the mission
- Absolute and relative radiometric calibrations are within the requirements of the mission
- Striping and other image artefacts are within the requirements of the mission
- The three identified anomalies, i.e. striping and fixed pattern noise, VNIR fringing / etaloning, SWIR micro-vibration effects, and methods for their correction are under further investigation

7.6.3 Level 1C

This report covers the timeframe between 01.04.2023 and 30.06.2023. No geometric calibration was performed during this period.

In the timeframe of this report, 1339 datatakes have been acquired. In 820 of those datatakes (~61%), enough GCPs and ICPs were found to perform a geometric accuracy assessment. The datatakes without enough GCPs were not assessed quantitatively, but a random subset of them was inspected visually. The vast majority of those datatakes was either almost fully covered with clouds or showing only water, desert or rain forest. The behavior is thus as expected.

The assessment of the RMSE values in the metadata is shown below in Figure 7-37.

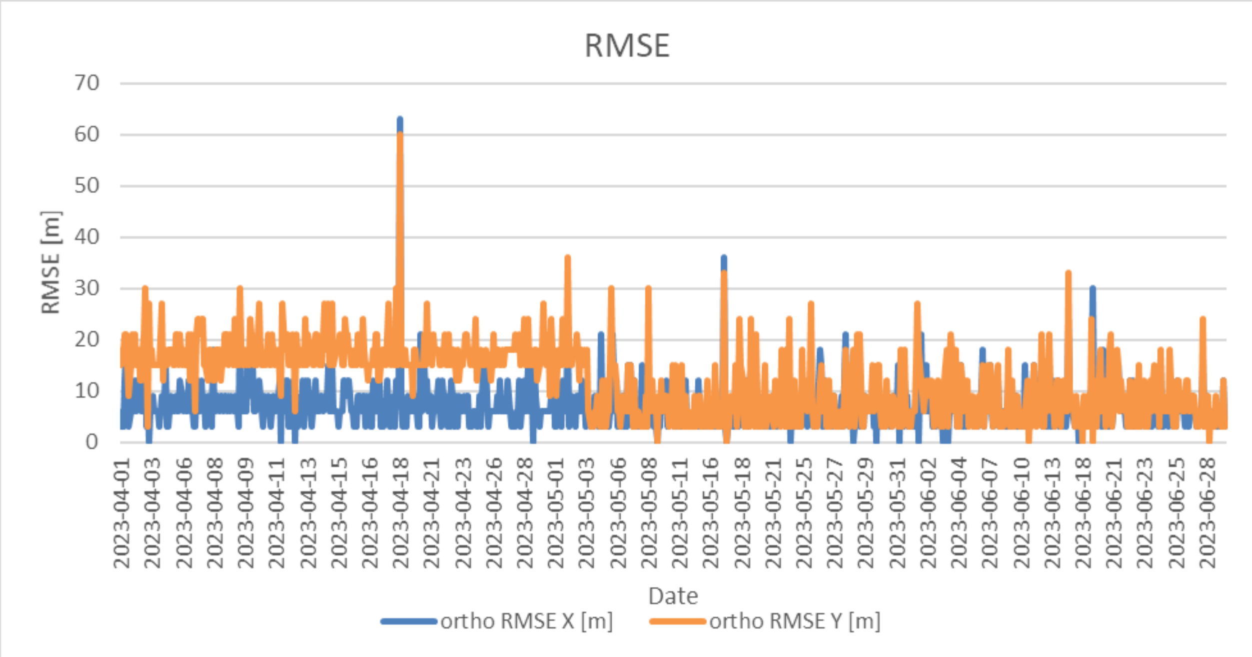


Figure 7-37 Assessment of RMSE values, calculated based on found ICPs, for all datatakes

In x-direction, two datatakes (~0.2%) have an RMSE value above 30 m (1 GSD), whereas in y-direction, 4 datatakes (~0.5%) are above this threshold. For most of those datatakes, only very few GCP and ICP could be found during processing, making the results less reliable. The mean values are 6.91 m in x-direction and 12.05 m in y direction. This shows a very high geolocation accuracy for the datatakes where matching was possible. The requirement GRD-PCV-0155 is thus fulfilled.

However, it is obvious that the RMSE values at the beginning of this period in y-direction are approximately twice as large as in x-direction, as already mentioned in the last report. After a very thorough investigation, the reason for this was identified: The speed of light correction is turned on during orthorectification. However, it is already implicitly included in the estimated boresight angles and is thus applied twice. After the update of the processor to version 01.03.01 on 05.05.2023, this change is incorporated in the processor. The mean RMSE values before this update (V01.02.02) are 7.56 m in x direction and 17.53 m in y direction, while after the update (>=V01.03.01), the mean RMSE values are 6.43 m in x-direction and 8.02 m in y direction. The values from data processed before the update of the processor are similar to the ones from the previous reports while the values obtained from data processed after the processor update match the prediction from the previous report based on tests with a small number of datatakes.

L1C/L2A products processed with V01.03.01 or higher will already include this change, however for data where the L0 processing was performed with processor version 01.02.02 or lower (see tag archivedVersion in metadata), in the metadata the RMSE values will remain the same until a L0 reprocessing is done (started in June 2023).

The average boresight angles, which can be interpreted as the correction and thus the error of the scene if no GCPs could have been found, corresponds to approximately 5 m in x direction with a standard deviation of approximately 24 m and -42 m in y direction with a standard deviation of approximately 46 m on ground. It is reasonable to assume that the scenes where no GCPs could be found are in the same accuracy range and thus well within the requirement of 100 m (GRD-PCV-0150). Note that the x and y direction mentioned in this report are not in the image coordinate system but in UTM, as the evaluation is done on L1C products.

7.6.3.1 **Geometric accuracy**

EnMAP L1C products are matched against a reference image (Sentinel-2 data, if not stated otherwise) by using image matching techniques to assess the geometric accuracy. At the obtained checkpoints, statistics are calculated to provide mean and RMSE values for each scene.

The requirement GRD-PCV-0155 shall be fulfilled:

The geolocation accuracy at nadir look direction of level 1C and 2A products shall be better than 1 GSD (1 sigma) in each direction with respect to reference images provided that reference images are available and sufficient similarity.

Note that the obtained accuracy in the analysis is always w.r.t. the reference image.

This report covers EnMAP data from 01.04.2023 to 30.06.2023.A random sample of 208 L1C tiles was selected based on visual inspection of the catalogue quicklooks (e.g. to avoid cloudy images).

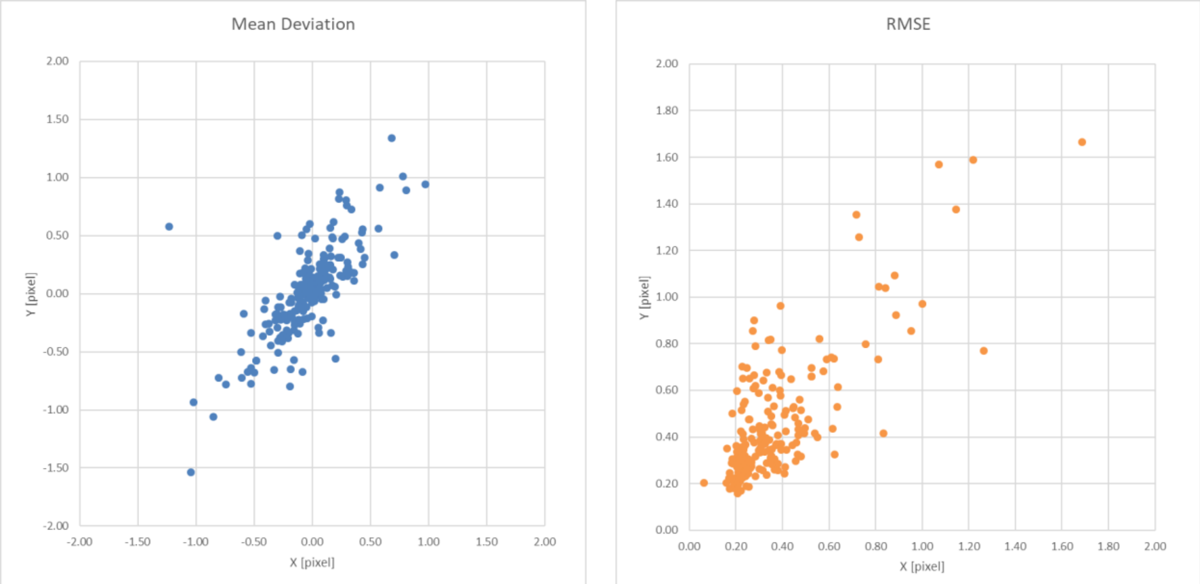


Figure 7-38 Mean deviation of EnMAP L1C products in pixel (left). RMSE value for EnMAP L1C products in pixel (right)

Note, that during processing the boresight angles and the geometric accuracy related quality flags are calculated on datatake level while in the figures and tables above, the accuracy is assessed per tile. The mean values over all 208 L1C tiles are -0.03 and 0.02 pixel in mean deviation with a standard deviation of 0.30 and 0.39 pixel while the mean RMSE values are 0.40 and 0.47 pixel, all in x and y direction respectively. The data show, that for the vast majority of scenes the accuracy wrt. reference image is better than one pixel and thus the requirements are fulfilled.

7.6.3.2 **Co-registration accuracy**

In this chapter, the co-registration accuracy is checked against the Space Segment requirement SRDS-PIM-0050 and later waivers on this requirement (EN-KT-RFW-003).

For the assessment of co-registration accuracy, the SWIR data of EnMAP L1C products are matched against the corresponding VNIR data.

This report covers EnMAP data from 01.04.2023 to 30.06.2023. A random sample of 208 L1C tiles was selected based on visual inspection of the catalogue quicklooks (e.g. to avoid cloudy images).

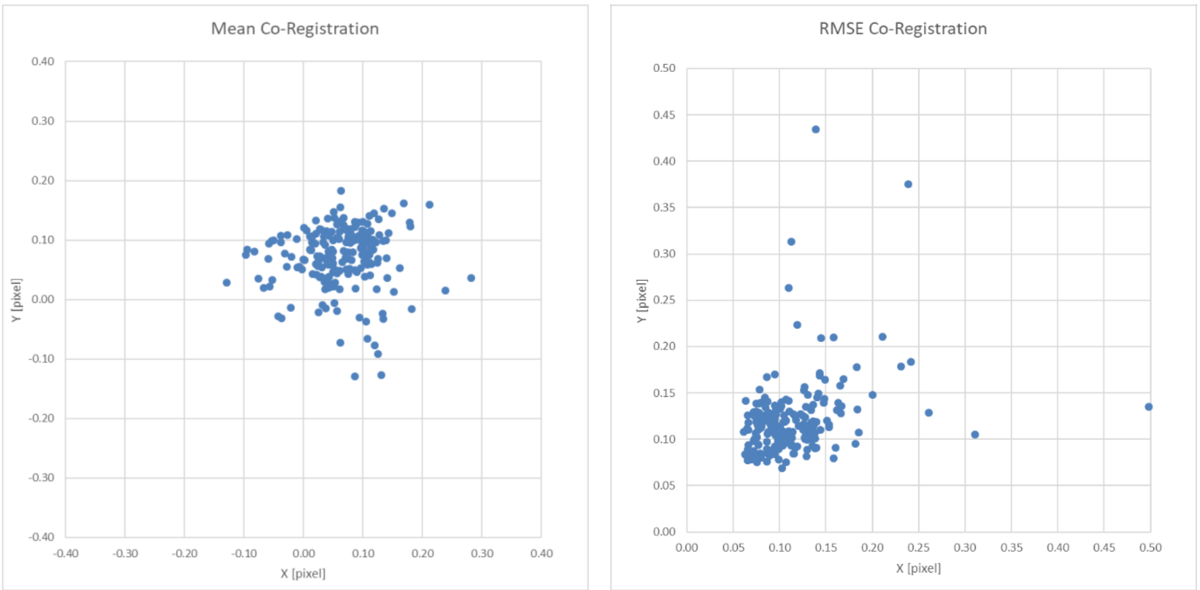


Figure 7-39 Mean deviation in pixel between VNIR and SWIR data of EnMAP L1C products (left). RMSE in pixel between VNIR and SWIR data of EnMAP L1C Products (right)

The data show, that the co-registration is in the order of 0.06 pixel in both in x and y direction which is well within the requirement. Note that the theoretical accuracy of the used matching algorithm is 0.1 pixel, and as can be seen in the RMSE values, still some mismatches were not removed by the blunder detection techniques that were applied. The mean deviation over all analyzed tiles are 0.06 pixel in x-direction with a standard deviation of 0.06 pixel and 0.07 pixel in y direction with a standard deviation of 0.05 pixel. After the update of the processor to V01.02.01 on 27.03.2023 and the corresponding update of the geometric calibration table, in the last report only very few tiles could be analyzed. In this report three months after the update, it is confirmed that the co-registration has been significantly improved and is now well within the space segment requirement.

7.6.4 Level 2A

7.6.4.1 In-depth analysis of atmospheric correction over land

For L2A quality check the following scenes acquired within the period of 2023-04-01 and 2023-06-30 were considered (Table 7-25):

datatakeID	tileId	date	location	L2A option	cirrus and haze removal	overall Quality	processor version
13489	3	09.04.2023	Ghana	Land_Mode	Cirrus_and_Haze	0	V010201
13489	3	09.04.2023	Ghana	Land_Mode	No	0	V010201
13489	3	09.04.2023	Ghana	Land_Mode	Cirrus	0	V010201
13144	1	10.04.2023	boarder of Hungary/Romania	Land_Mode	No	0	V010201
13144	1	10.04.2023	boarder of Hungary/Romania	Combined	No	0	V010201
15418	1	01.05.2023	Bighorn National Forest, USA	Land_Mode	No	0	V010301
16458	1	10.05.2023	Avignon, France	Land_Mode	No	0	V010301

16458	2	10.05.2023	La Crau, France	Land_Mode	No	0	V010301
16493	3	10.05.2023	Cachuma Lake, USA	Combined	No	0	V010301
21985	1	31.05.2023	Auburn, USA	Combined	No	0	V010302
20709	4	01.06.2023	Madagascar	Combined	Cirrus_and_Haze	0	V010302
22148	2	02.06.2023	Rügen, Germany	Water_Mode	Cirrus	0	V010302
22148	4	02.06.2023	Demmin, Germany	Land_Mode	No	0	V010302
21363	2	10.06.2023	Isfahan, Iran	Land_Mode	No	0	V010302
23659	1	24.06.2023	Challhuahuacho, Peru	Combined	No	2	V010302

Table 7-25 Inspected L2A scenes

For the selection of L2a data, care was taken to ensure a high degree of variety with respect to the geographical location of the data, external conditions (cloud cover) during the data take and processing parameters.

In addition, DT 6848 (2022-12-12) has been investigated due to ticket #358.

1. Difference between two processing options “Cirrus_and_Haze” removal and “Cirrus” removal (DT0000013489_20230409T111236Z_003)

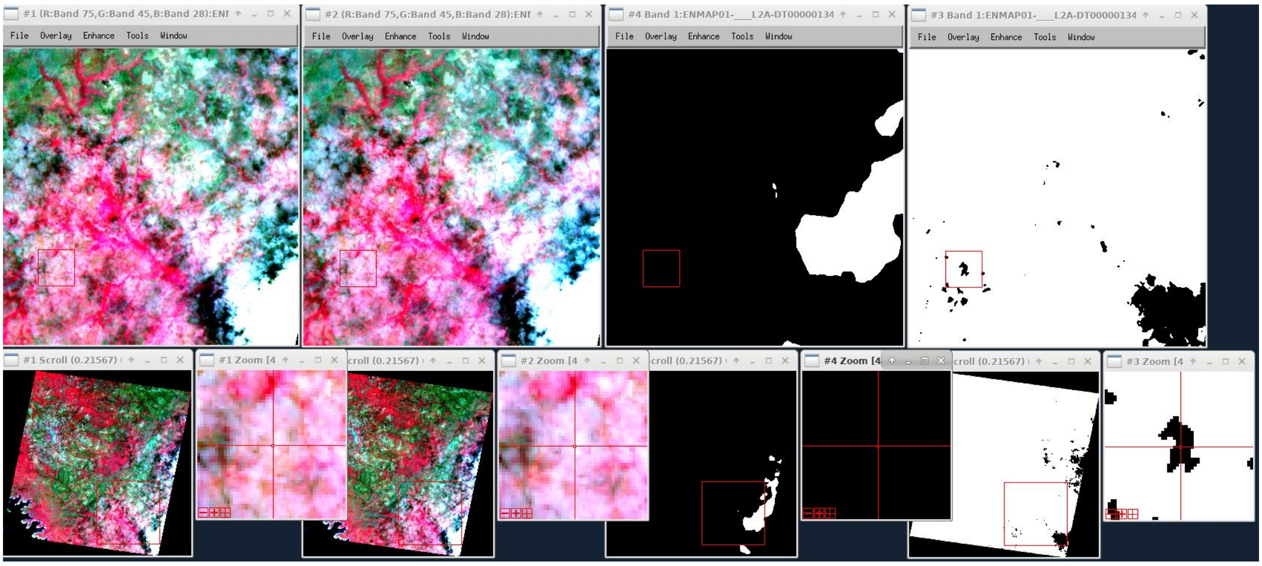


Figure 7-40 From left to right: cirrus and haze, cirrus only, cirrus mask, haze mask

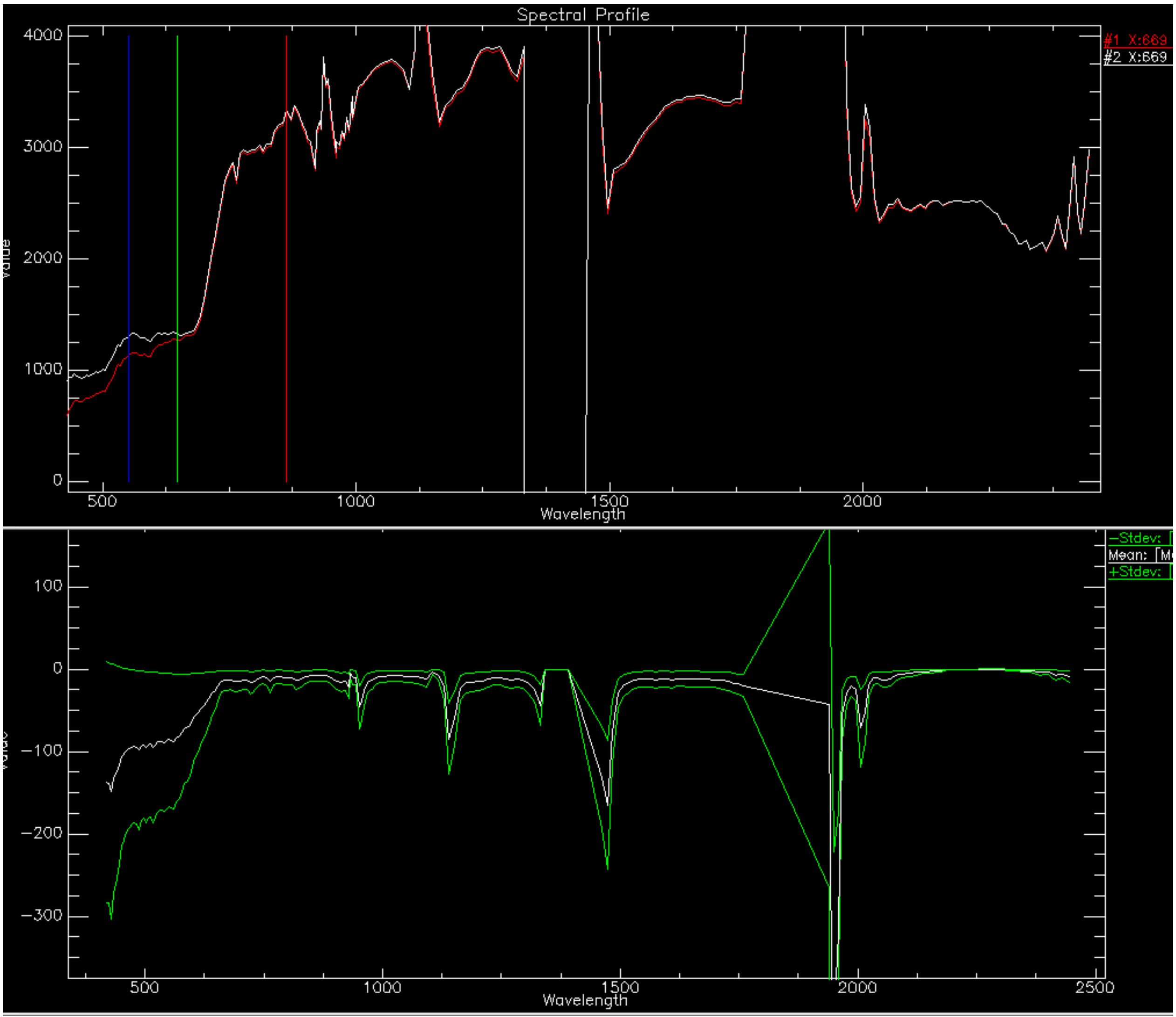


Figure 7-41 Difference in spectra (red = cirrus and haze), white = cirrus) and statistics of difference image (white= mean difference, green = Stdev)

Results as expected. No visible anomalies.

2. Checking the water mask and the correct application in combined mode

Check DT 13144 → processor version V010201

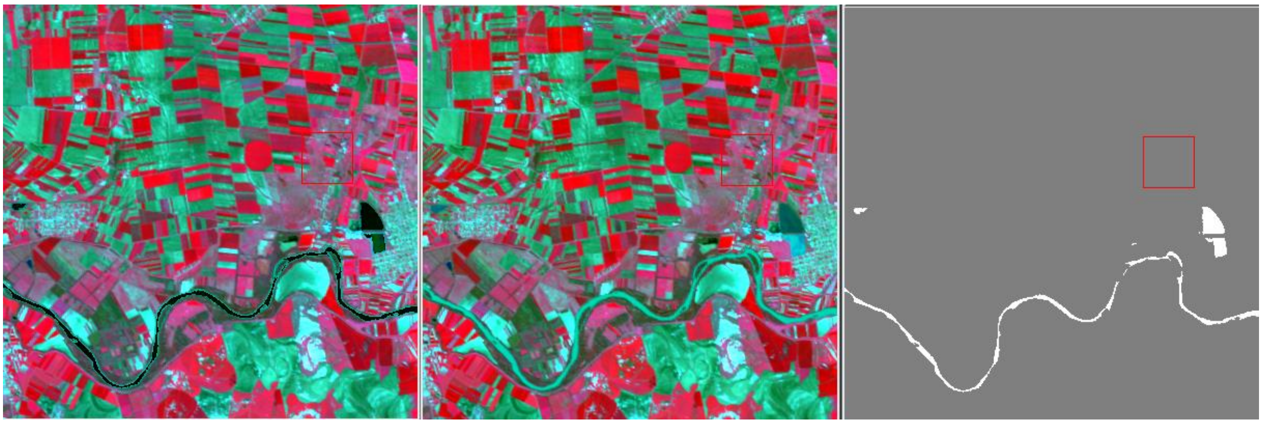


Figure 7-42 Left: Combined mode, Middle: Land mode, Right: Water mask

Check DT 16493 (Lake Cachuma) → processor version V010301

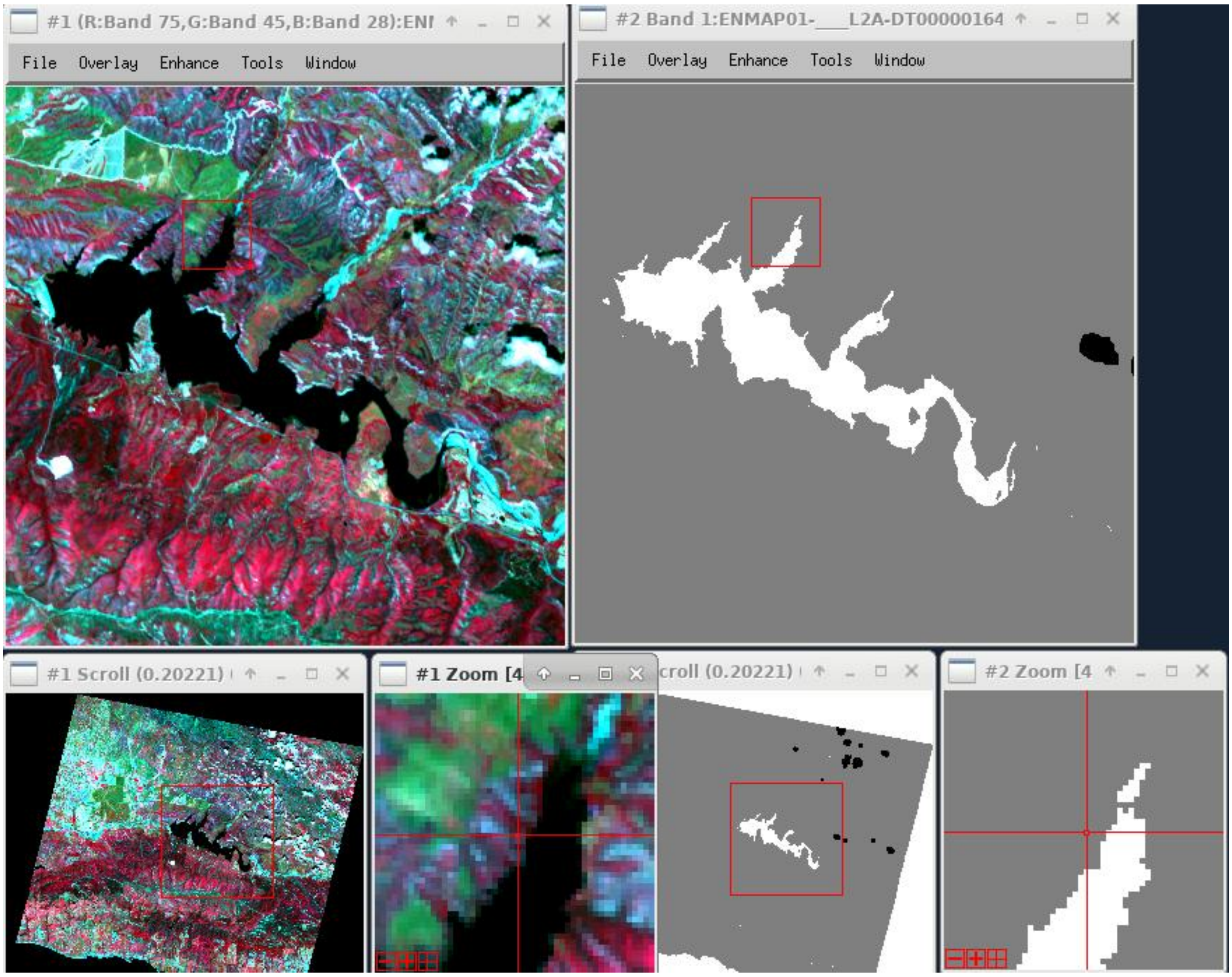


Figure 7-43 Image, QL classes

With processor version V010301 there are no more artifacts at the transition zone between land and water

3. Examination of the scene DT0000023659_20230624T154242Z_001 after user feedback on faulty water mask (see ticket #392: Water mask issue).

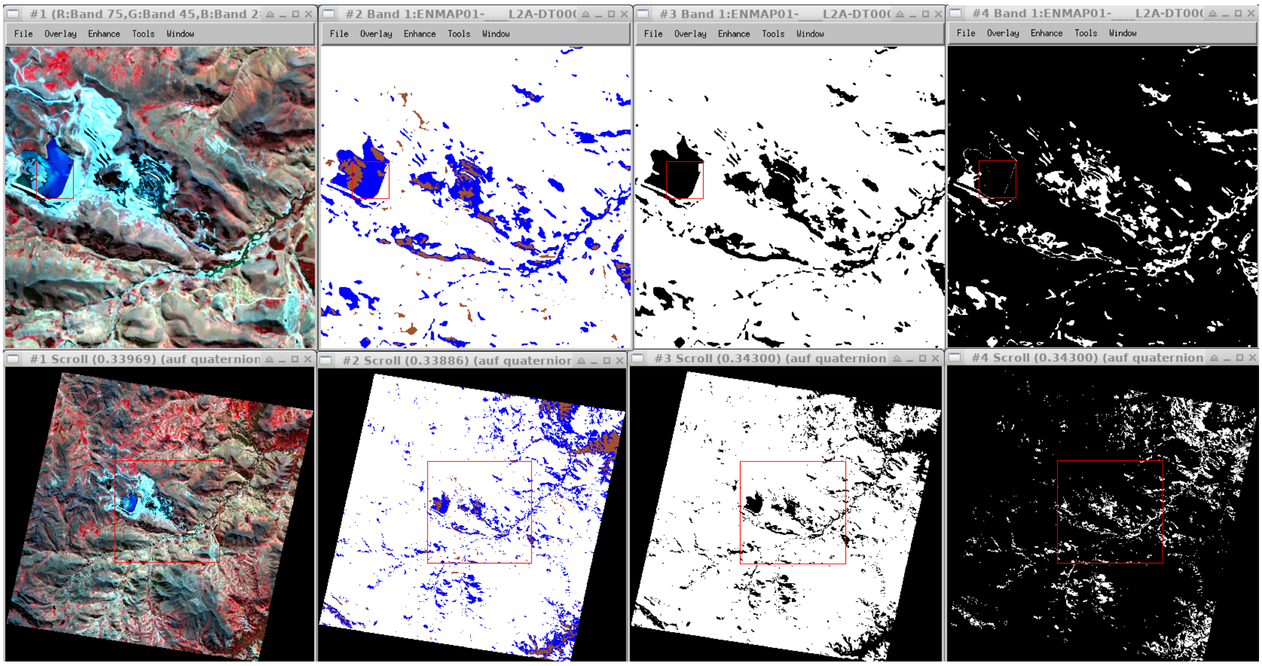


Figure 7-44 L2A products: #1 = EnMAP image (CIR), #2 = QUALITY_CLASSES (blue=water), #3 = CLOUD, #4 = CIRRUS

In addition to the incorrect water mask, it is noticeable that the cloud mask is also affected by errors. This has resulted in a downgrading of the scene's quality (overallQuality = 2), even though it is actually cloud-free.

4. Closely investigate for correct differentiation between snow and cirrus and correct snow spectra (ticket #358)

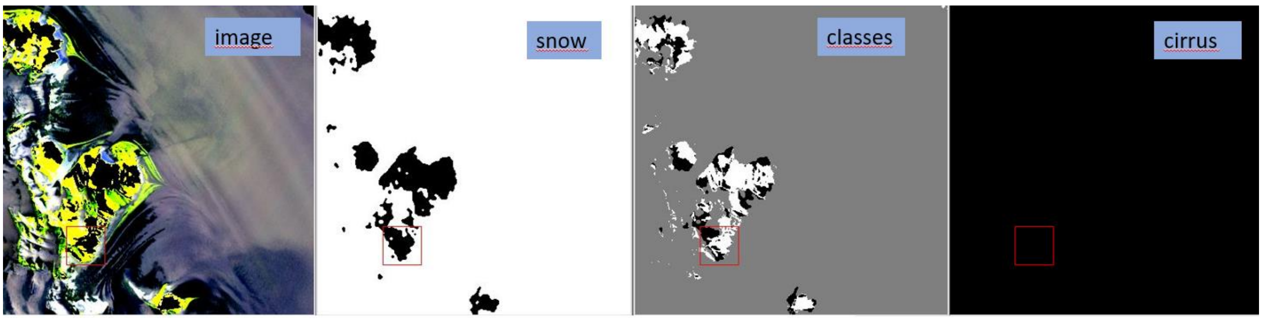


Figure 7-45 Image, QL snow, QL classes, QL cirrus

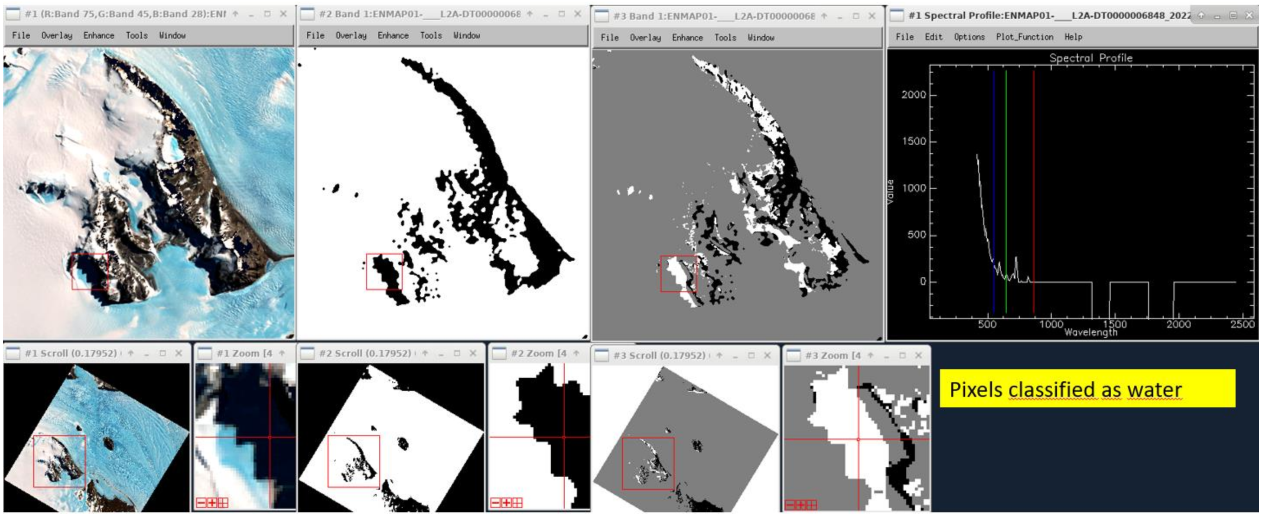


Figure 7-46 Image, QL snow, QL classes, spectra

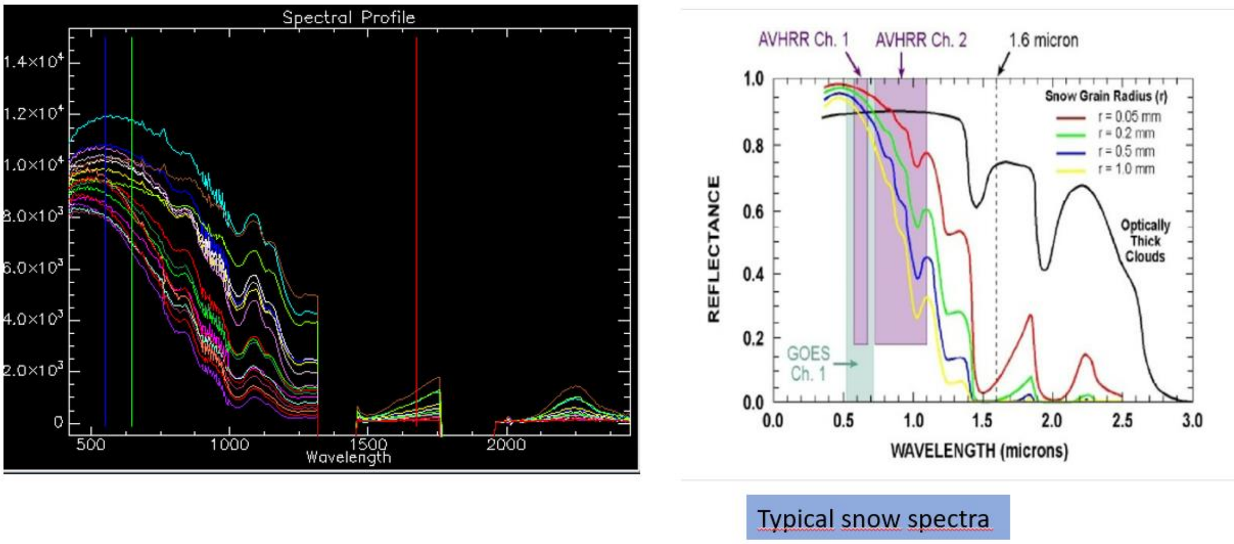


Figure 7-47 spectra extracted over pixels classified as snow

- Snow correctly identified in snow scenes (no misclassification with cirrus)
- Snow spectra looks correct
- Scenes with snow on steep slopes (mountains) still over 100% reflectance
- Some misclassifications observed (class 2 = water) on the shady slopes

Cross-check snow spectra within scene 15418

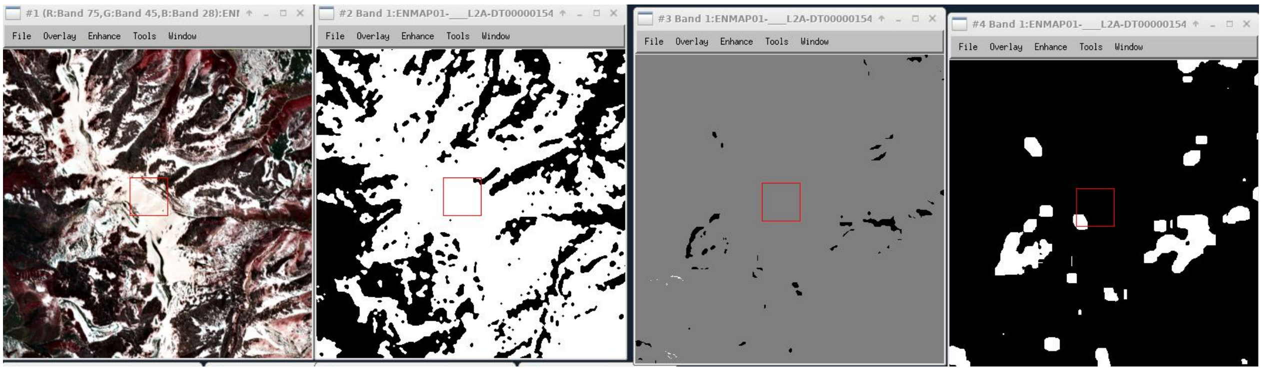


Figure 7-48 Image, QL snow, QL classes, QL cloud

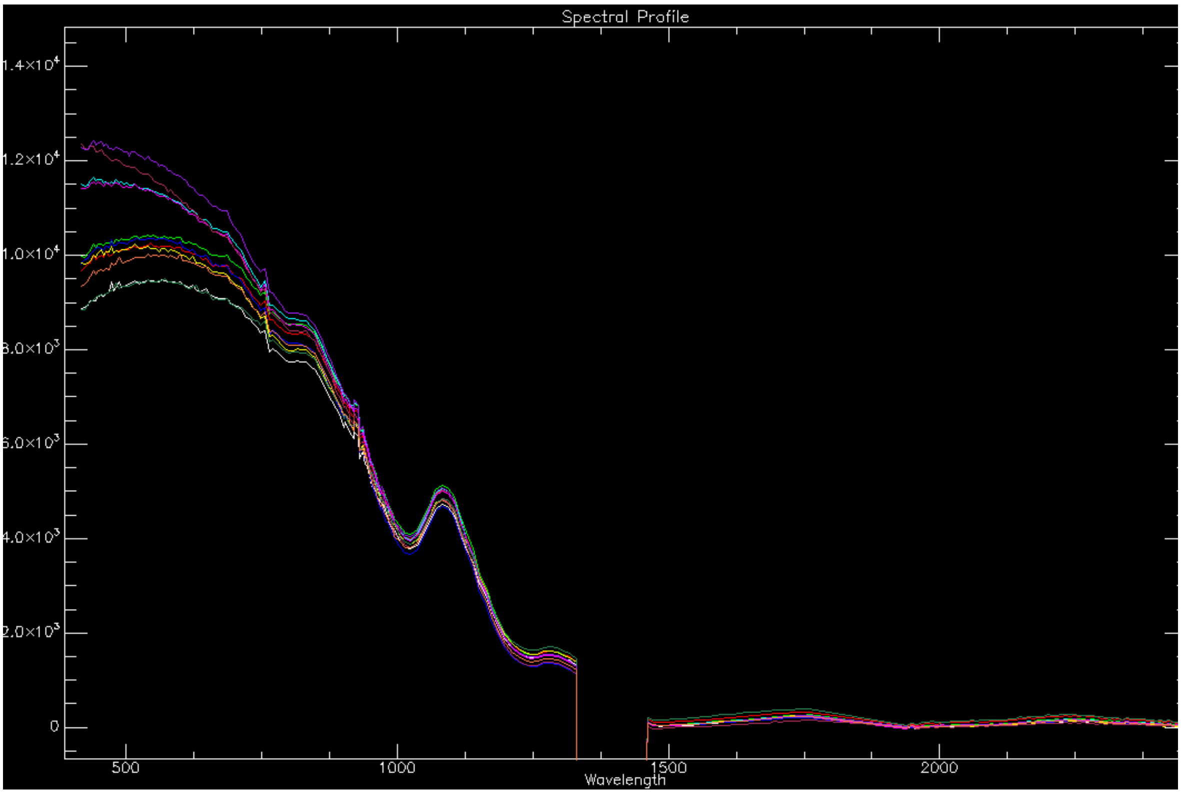


Figure 7-49 spectra extracted over pixels classified as snow

Same observations as before: Still spectra over 100% reflectance. But almost no misclassification of water within this scene.

5. Check adjacent tiles and their overlapping

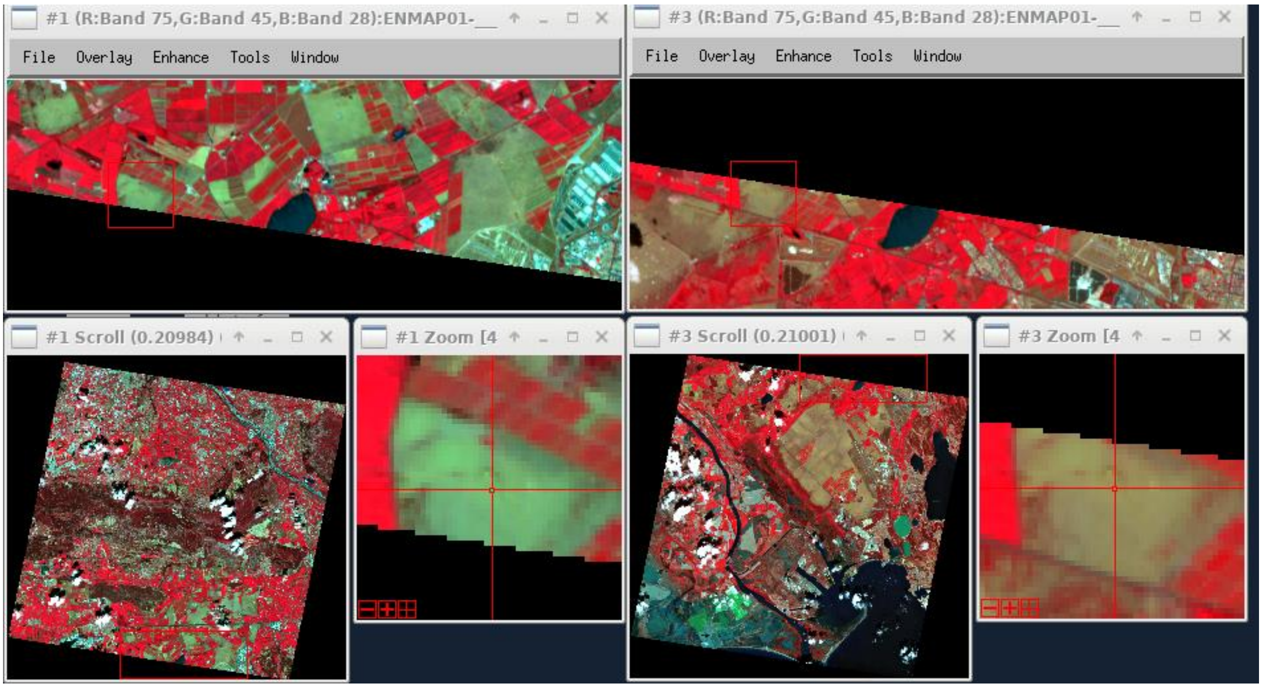


Figure 7-50 The two neighboring tiles 1 and 2 of DT 16458

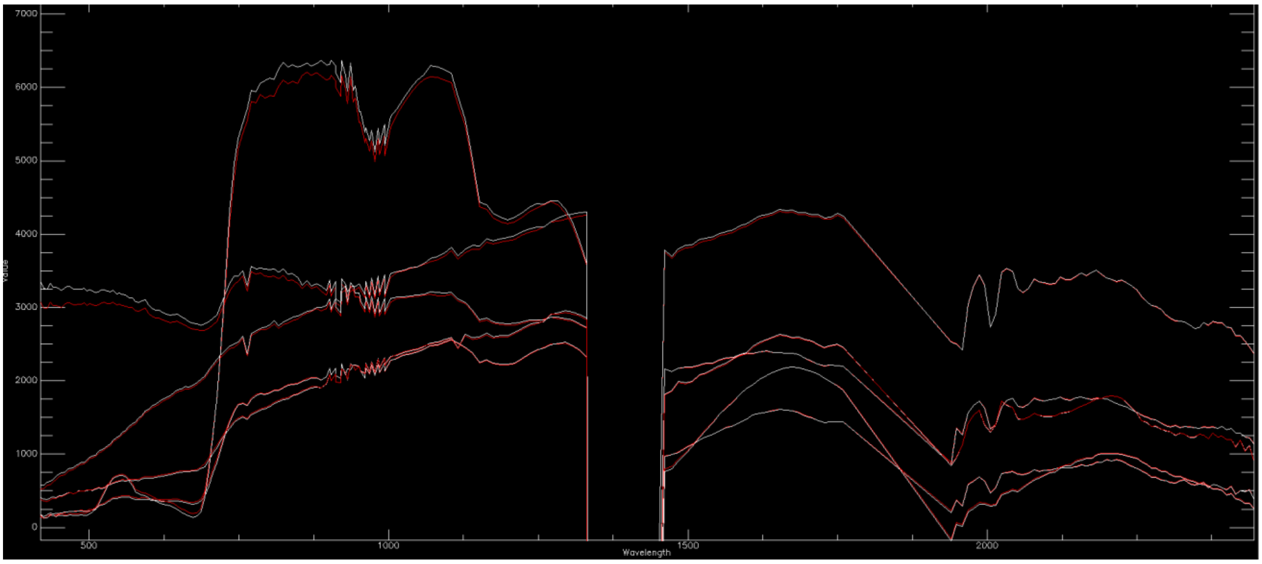


Figure 7-51 spectra of the same pixel in the overlapping area extracted from the two neighboring tiles (in red and white)

Good conformity. No anomalies.

7.6.4.2 In-depth analysis of atmospheric correction over water

Analyzed scenes

As part of the evaluation of water products done by EOMAP, the following scenes were taken into consideration and checked by EOMAP:

Table 26 - Datatake ID of analyzed water products

Datatake ID	Processor Version	Comment	
16630	V01.03.03(*)	Checked parameters for all datatakes:	
16707		Masking (Land, Water, Clouds, etc.):	No issues found.
19550		Adjacency correction:	No issues found.
25338		Retrieval of atmospheric properties:	No issues found.
25364		Cirrus – correction:	No issues found.
		Retrieval of water leaving reflectance:	No issues found.

(*): the upcoming L2A Water processor version was also tested.

Conclusion:

The atmospheric correction over water works as expected. No need for further action.

Reactivation of the adjacency correction

The adjacency processor of the ENMAP atmospheric correction over water was unintentionally deactivated after a recent processor update. Users that requested related products in the time period since November 2022 should note that the adjacency correction over water impacts the accuracy of reflectance products for targets that are close to or surrounded by land, such as inland waters. Enabling the adjacency correction will be fixed in the upcoming processor version.

The magnitude of the adjacency effect, where the radiance from a nearby bright land surface is scattered in the atmosphere and increases the apparent brightness of water, depends on various conditions. Almost immeasurable impact can be assumed for targets far (e.g. 20km) from the land, while specific recording geometries, aerosol properties, shapes, distance, and albedo of the surrounding land altogether can result in significant local impact that should be accounted for.

The ENMAP processor implements highly elaborated physics-based algorithms to account for all of these impacts. To illustrate the complexity of the adjacency effect, its local dependency, and the correction capability of the processor, we visualized the strength of the effect and the impact on the reflectance in the graph below. For further information see the ENMAP Water ATDB and Kiselev et al. 2013 (https://doi.org/10.1016/j.rse.2014.07.025).

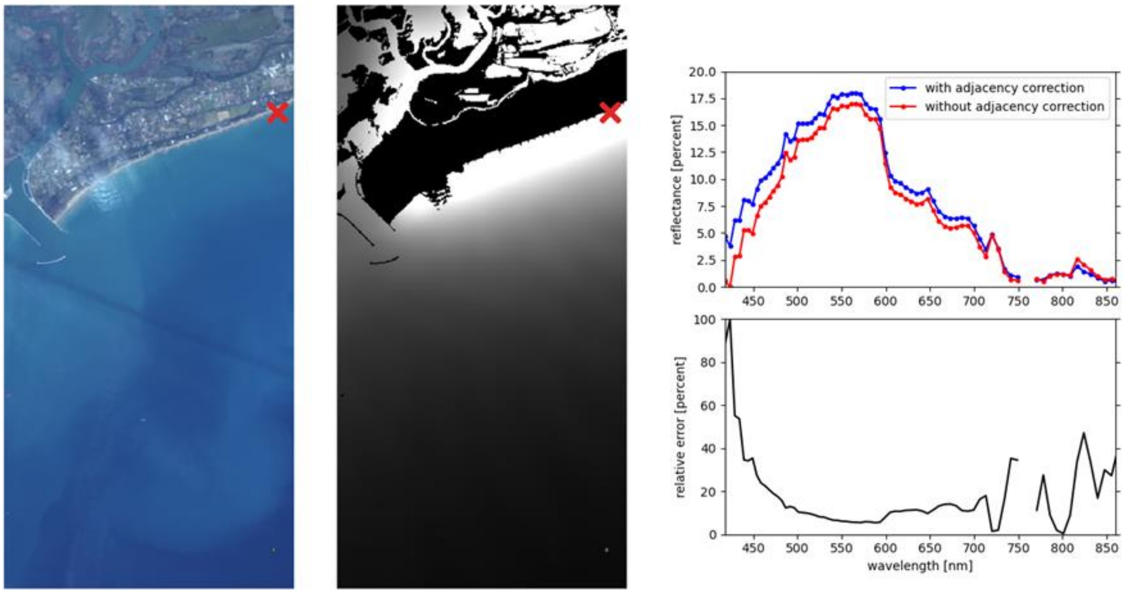


Figure 7-52 Impact of the adjacency correction. See text for discussion

The impact of the adjacency correction is depicted in Figure 7-52. Left: Radiance image of scene 1023 close to Venice on 2023-03-16. Center: The magnitude of the adjacency impact increases close to land (shown in black), with significant dependency on geometry and land albedo. The adjacency radiance is shown for band 10 at 463nm. Top right: reflectances for the point indicated by the red cross, calculated with and without adjacency correction, respectively. Bottom right: Relative error introduced by neglecting adjacency correction. Ignoring adjacency effects results in significant errors of up to 100% for the retrieved water-leaving reflectance in the blue spectral region. The error is introduced by erroneous spectral compensation of increased aerosol optical thickness.

7.6.4.3 Check of L2A data for correct handling of SWIR band swap

Also for L2A products, the newly added bands @ 1450 nm, 1769 nm & 1780 nm are now available and are correctly processed by L2A (Figure 7-53). The previously transferred bands @ 1939 nm, 1767 nm & 1782 nm are no longer included. The quality of these bands -which are within the WV absorption region- is good for this desert scene having low WV content (Figure 7-54). But for typical scenes having higher WV, the quality will likely be degraded: due to WV absorption, very low radiance / reflectance levels and predominantly noise are expected.

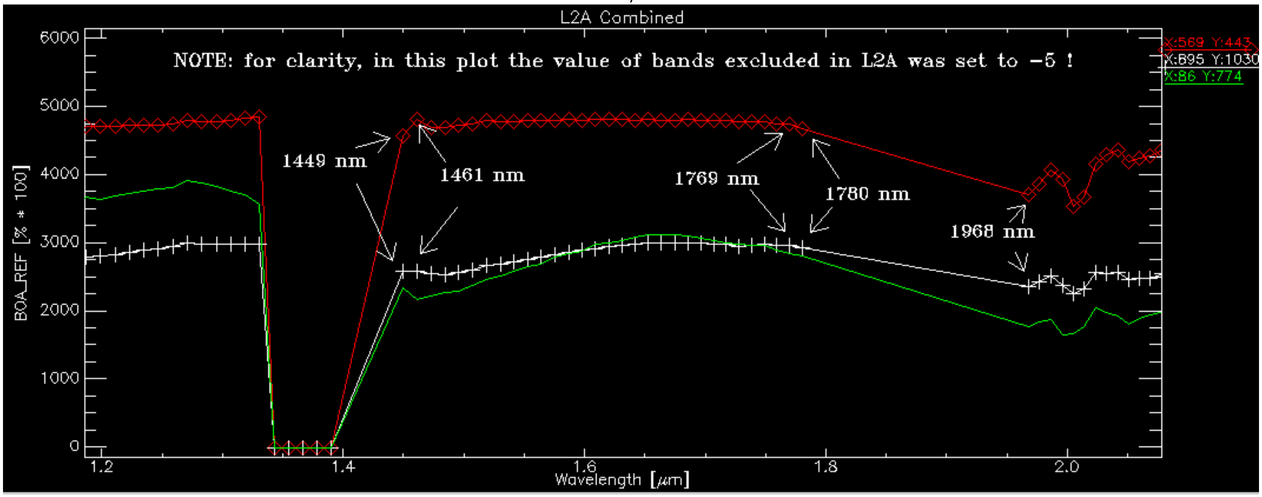


Figure 7-53 Typical spectra @ L2A (BOA_REF) for the dataset with band swap applied

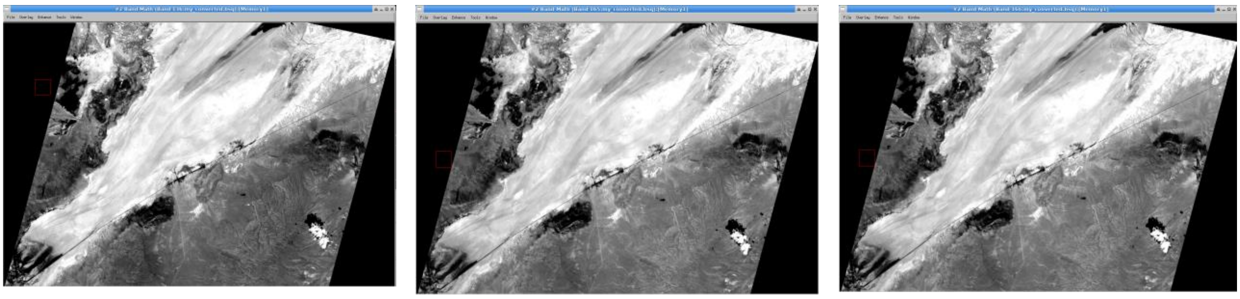


Figure 7-54 L2A images of newly added bands at 1.45 µm (left), 1.76 µm (center) and 1.78 µm (nonlinear stretch). For this desert scene all bands have a good quality as water vapor influence is low.

Therefore, the additional bands 45, 74 ,75 are very likely introduced correctly, and the previous bands 73, 74, 75 are very likely correctly removed. As mentioned before, the limitation is that center wavelengths of newly added bands can‘t be specified vicariously as no narrow atm. absorption feature are available in this wavelength range. The result of the L2A band swap test shows that the L2A processor is ready for the SWIR band update in Q3 2023.

7.6.4.4 L2A snow spectra discrepancy

It has been observed that in some circumstances the L2A spectra over snow is overestimated at wavelengths below 750 nm. This issue is caused by a confusion of the cloud and snow masks and it will be fixed in a future processor release.

8 External Product Validation

The data product quality monitoring activities during the reporting period validated the standard quality parameters. Unfortunately, due to the high demand for acquisitions from the user side, only a few successful EnMAP validation acquisitions could be realized. Therefore only a few in-situ matchups could be generated during the reporting period.

8.1 Level 1B

Several Level 1B products were validated during the reporting period:

- TOA Radiance
- Spatially coherent radiometric miscalibration (striping artifacts)
- Signal-to-Noise Ratio (SNR)
- Keystone

No valid matchups for TOA Radiance validation were available at the end of the reporting period. Several potential matchups were generated for which the in-situ data (RadCalNet, Hypernets, or synchronous field campaigns) were not available. Therefore, several acquisitions of sites that can be expected as reflectively stable were validated with in-situ data not from the same day but close in time to identify abnormalities during this period. This validation scenarios cannot count as valid, but work for rough abnormally indication. No abnormalities or changes were detected based on these scenarios. The generated potential validation matchups will be integrated in the next MQR period.

Spatially-coherent radiometric high frequent striping artifacts and undulations in the VNIR and SWIR across-track direction were not detected. The residual low-frequent across-track undulations are still inherent to the data cubes but do not violate the mission requirements of <5% misregistration. This issue is in the process of being solved. The same is true for the along-track artifacts detected in SWIR wavelength domains with a vital gradient/feature. Although the radiometric misregistrations are very small and thus far below the requirements of < 5 %, a correction is under investigation.

Regarding the SNR, no significant changes have been detected and the mission requirements (VNIR > 343:1 (@495 nm & SSD 4.7 nm) and SWIR > 137:1 (@2200 nm & SSD 8.4 nm) for L(TOA) reference of 30% reflective target) are still fulfilled.

No significant changes were found in the VNIR and SWIR Keystone either.

8.2 Level 1C

Level 1C products have been validated regarding:

- VNIR-to-SWIR spatial co-registration
- Absolute spatial accuracy

The VNIR-to-SWIR spatial co-registration improved slightly to an RMSE ~4.9. Thus they are well inside the mission requirements of < 30 % of a pixel, and the initial problems with the VNIR-to-SWIR co-registration can be seen as solved. Acquisitions acquired before 03.11.2022 will also significantly improve VNIR-to-SWIR spatial co-registration after finalizing the L0 reprocessing.

No significant changes have been recognized for the absolute spatial accuracy validation, and the mission requirements are still fulfilled.

8.3 Level 2A

During the reporting period, several L2A land and water products were investigated. Only a few valid in-situ matchups could be generated due to unsuccessful campaign matchups. For several potential matchups, the in-situ data was not available before the end of the report period.

Land

The few available matchups confirmed the fulfillment of mission requirements for BOA reflectance. The issue with the misclassification of cirrus clouds and their correction identified for tiles with snow surfaces during the last MQR is not solved yet.

Water

The L2A normalized water leaving reflectance was also investigated and was still well inside the mission requirements for several matchups.

8.4 Summary of External Product Monitoring

During the reporting period, several important validation scenarios and tasks could be fulfilled. Anomalies or non-compliance with the mission requirements has not been indicated for the reporting period. All validated parameters are still inside the mission requirements.

9 Others

EnMAP Publications:

- Tobias Storch, Hans-Peter Honold, Sabine Chabrillat, et al. “The EnMAP imaging spectroscopy mission towards operations”, Remote Sensing of Environment Volume 294, 15 August 2023, 113632. https://doi.org/10.1016/j.rse.2023.113632

EnMAP Presentations:

- Pinnel, N.: Cooperative lecture on ‘Sustainability’: Environmental Monitoring from Space – the EnMAP Satellite Mission, DLR Women Scientists and RRD WoMen's Network, 23.05.2023, Munich.