ENMAP OPERATIONS IN LIGHT OF DATA PRODUCT STATISTICS

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ABSTRACT

The hyperspectral mission EnMAP has been launched in April 2022 delivering data products with a quality exceeding the expectations. Still, there were challenges in the context of planning and processing the data, especially serving the demand over regions with many acquisition requests. The EnMAP Ground Segment (GS) provides the infrastructure responsible for the operation of the mission and it acts as the interface between the users and the satellite. In this contribution we present the up-to-date status of EnMAP mission operations when the system has been in operation for over two and a half years. The latest updates that have been introduced in the tasking of the instrument such as the background and the foreground missions accompanied by the enabling of back-to-back imaging are presented. The result of the incorporation of the additional ground station is shown as well as the status of the reprocessing.

Index Terms— Earth Observation, Hyperspectral, Spaceborne Mission, Ground Segment, Operations

1. INTRODUCTION

EnMAP (Environmental Mapping and Analysis Program, enmap.org) [1] is a scientific mission for measuring, deriving, and analyzing diagnostic parameters, which describe vital processes on the Earth's surface encompassing agriculture, forestry, soil and geological environments, as well as coastal zones and inland waters. It was designed with the aim of providing the scientific community with high-quality hyperspectral data from space.

EnMAP was successfully launched on April 1st, 2022, from Cape Canaveral aboard a Falcon 9 rocket. The two spectrometers (VNIR and SWIR) aboard can image the Earth with 224 bands in the wavelength range 420 − 2450 nm using a push-broom configuration with a dual-spectrometer. The satellite follows a Sun-synchronous orbit with a 27-day repetition cycle. It has a revisit capability of less than 4 days for any point on the Earth's surface due to a possible tilting angle of ±30 deg in the across-track direction. The spatial resolution of the instrument is 30m×30m, covering a swath width of 30 km and a swath length varying between 30 and 990 km. Each 30kmx30km portion is called tile in the following.

EnMAP data is publicly available and can be ordered after 3 different levels of processing and with different processing parameters selectable by the users when ordering a product. The three processing levels follow the ESA specification and are:

- Level 1B (L1B): radiometrically corrected Top-Of-Atmosphere (TOA) radiance in sensor geometry,
- Level 1C (L1C): L1B products orthorectified to a user selected map projection and resampling model,
- Level 2A (L2A): atmospherically corrected Bottom-Of-Atmosphere (BOA) reflectance. The users can select algorithms for processing land and water and two different water output products: water leaving reflectance and underwater irradiance reflectance. L2A land products are compliant with CEOS ARD [2].

After the commissioning phase (see [3] for a detailed review of the commissioning results), the mission was open to the users. Registered users can enter requests to perform new observations with the EnMAP instrument [4] or can download products from the mission catalogue [5]. More information on accessing data products or requesting observations is available in [6].

The Ground Segment (GS) provides all the infrastructure and operations that support and control the satellite and also allow to receive, process and distribute the data products, making available the access to the satellite and its data for scientists around the world. The following sections are structured as follows: section 2 provides an overview of the Ground Segment and its services. Section 3 shows the status of the Ground Segment taken on June 30th 2024), stressing the improvements that have been facilitated regarding the tasking of the instrument in form of the background and foreground

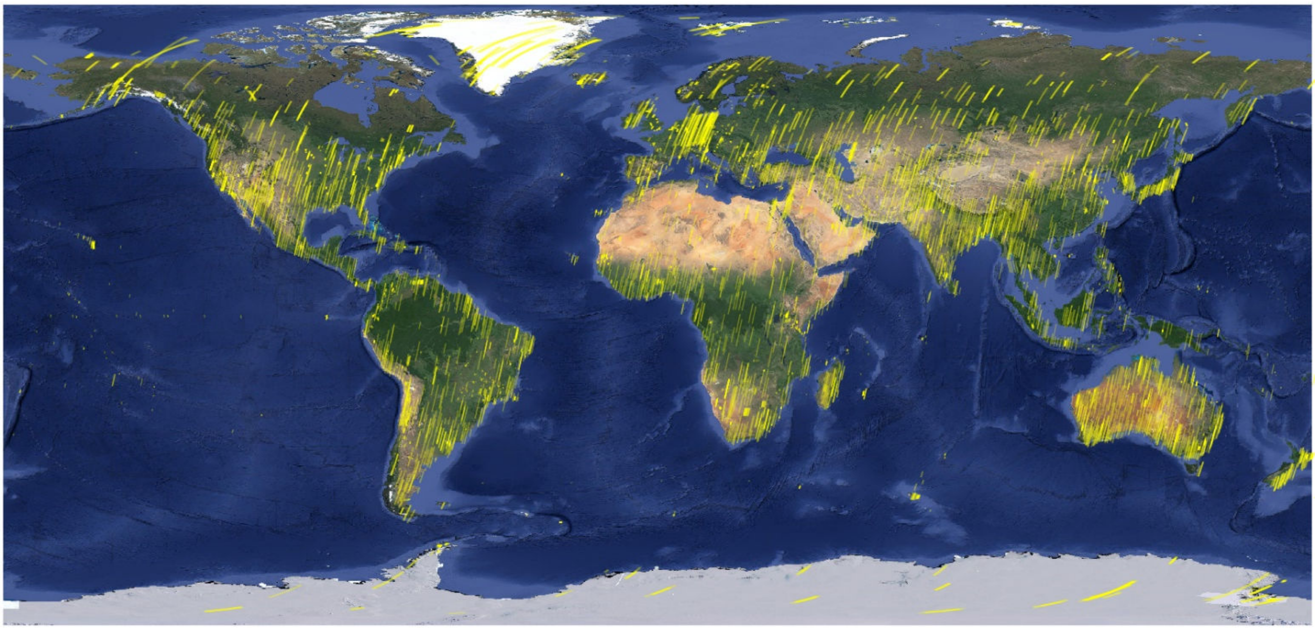

Fig. 1: Footprint of EnMAP Acquisitions plotted over Google Maps since launch until 30th of June 2024.

missions and the back-to-back-imaging. The successful incorporation of an additional ground station and the status of the reprocessing that is accomplished in order to provide the user with more precise information is discussed in section 4.

2. THE ENMAP GROUND SEGMENT

The Ground Segment of the EnMAP mission provides all the infrastructure and operations that support and control the satellite and allow to receive, process and distribute the data products. EnMAP's Ground Segment is the responsibility of the German Aerospace Centre (DLR). It is designed to operate for 5 years and provides access to EnMAP data for another 10 years. The GS is composed of 3 systems:

- The Mission Operation System (MOS) is responsible for controlling the satellite and the instrument. It is in charge of receiving telemetry data and sending telecommands, controlling the satellite's orbit, executing the necessary satellite maneuvers and planning the satellite's daily operations (imaging acquisitions, contacts with ground stations, etc.). The Mission Planning System (MPS) is part of MOS and implemented back-to-back imaging.

- The Payload Ground System (PGS) is responsible for receiving, processing and archiving data, as well as providing the user interfaces for user registration, submission of proposals, instrument tasking and processing and downloading of the user's EnMAP products. The Product Library is located in this system which serves as a data source for deriving the properties of the products described in section 3.

- The Processor and Calibration/Validation System (PCV) is responsible for developing and maintaining the processing chain that transforms the instrument raw data into the ordered products, by performing data calibration, orthorectification and atmospheric correction. It monitors and updates the radiometric, spectral and geometric calibration, performs quality control of the data and monitors the instrument to guarantee the quality of the delivered data.

The GS also provides the interfaces that the users can use for registering and accessing the EnMAP data. Users can register using the EnMAP Instrument Planning Portal (IPP) [5] that provides the following services:

- Proposal handling: users can submit the observation request proposals using this tool (a necessary condition to submit tasking orders to EnMAP).
- Instrument Planning: users with approved proposals can enter EnMAP tasking orders and check the status of their requests. The system allows to task priority observations based on the assigned proposal quota providing an observation window and selecting the geographical area of interest.

The catalogue access to the EnMAP data is done through the EOWEB portal [6] that gives access to the German Satellite Data Archive where EnMAP L0 are long-term archived.

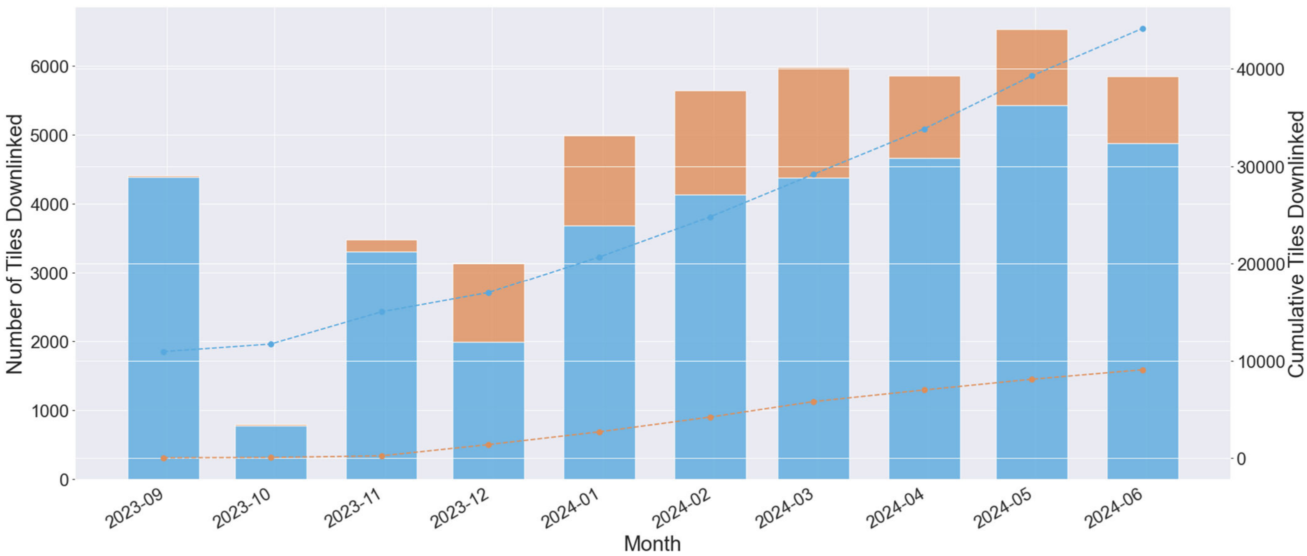

Fig. 2: Tiles received by Ground Station Inuvik (orange) and Neustrelitz (blue).

EnMAP products can be searched and selected in this service using the search interface with different selection filters available. The L1B/L1C/L2A products that can be downloaded from EOWEB do not exist prior to being ordered.
These data are generated on demand based on the user's request and the processing parameters that the user can specify. This allows to offer products tailored to the specific needs of the different applications. Product format can be selected for all products while other options like resampling method and geographic projection are only available on L1C and L2A products. The L2A product contains further specific options for the atmospheric correction that include correction over land or over water (with two different options for the type of output water products) and the possibility to adjust other parameters of the atmospheric correction like the season, ozone column value or the possibility to apply specific correction for cirrus and haze in the image.

The GS also maintains the EnMAP web portal [6] on which information updates about the status of the mission are announced and the mission quarterly reports are published. These reports offer many details on different aspects of the mission, calibration and quality of the data products. At the EnMAP web portal users can also find all the information about the GS services, data product formats and algorithms used during data processing.

By June 30th 2024 a total of 2700 users from 90 countries around the world have registered. A total of 571 reviewed and released proposals show the interest to get EnMAP data. The proposals indicate that the main areas of interest are vegetation, geology/soil and water applications.

3. ADAPTIONS IN THE GROUND SEGMENT

It has been shown that the goal of providing high quality hyperspectral data (see e.g. [7] [8]) has been reached. This partly is due to regular processor and calibration updates by the GS. Furthermore, actions were taken to identify problems and minimize their impact on the mission. These are discussed in this section.

Until June 30th 2024 the EnMAP Mission collected over 82009 30km x 30km tiles of the Earth's surface, spread out over 10769 datatakes, covering all parts of the world as shown in Fig. 1. If we look at the availability, it is worth to take a look at Table 1, where the number of acquisition days, number of acquisitions, tiles per year, the average per day, and the number of datatakes are displayed.

Year	#days	#acq.	#tiles	∅tiles/acq.	∅tiles/day
2022	181	2841	16926	5.95	93.51
2023	296	4621	30249	6.54	102.19
2024	180	3307	34834	10.53	193.52
Total	657	10769	82009	7.62	124.82

Tab. 1: Number of days, acquisitions, tiles, tiles/acquisition and tiles/day.

When interpreting the above table one should consider that the mission has experienced three outages caused by technical difficulties, where no observations could be performed. The longest one was an eight-week outage between December 2022 and February 2023, while two shorter ones (2 weeks) took place in October and December

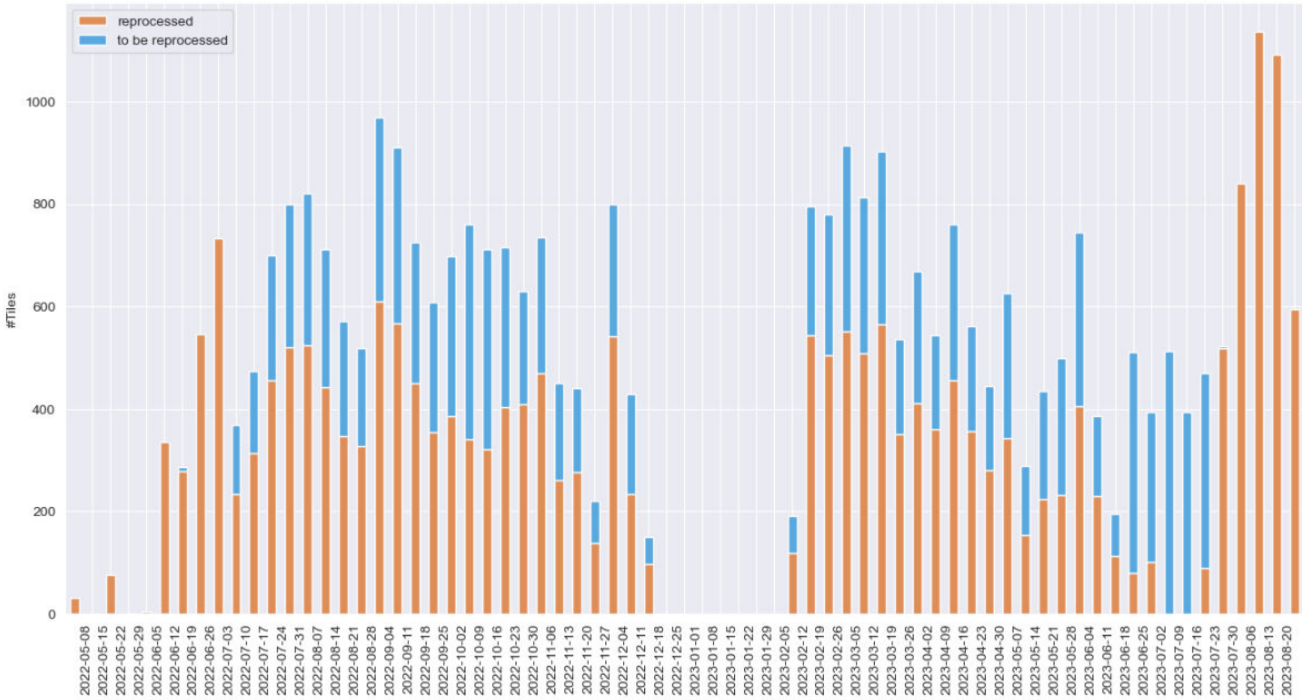

Fig. 3: Status of Reprocessing: Tiles reprocessed (orange) vs. tiles to be processed (blue).

2023. All outages have been solved with no impact on mission requirements, lifetime or redundancies.

In order to discuss the improvements, the acquisition strategy has to be understood: the acquisition requests posted in the IPP are prioritized and there is no guarantee for an execution. The orders are integrated in a timeline by MPS, which arranges observation requests, data downlinks, and other planned activities in a conflict-free timeline that does not violate any resource constraints. The time elapsing between two observations used to be ~400s, which resulted in a distance of two subsequent targets of ~2750 km on ground. This restriction is now overcome by the introduction of back-to-back imaging. This mode allows two consecutive image acquisitions without leaving the precise mode, allowing the distance between consecutive acquisitions to be reduced to 105 seconds (~790 km on ground).

Furthermore, it turned out that the average user requested observations only covering 2.4 tiles (~72km), so that other user requests could not be respected in the same orbit, leading to a blocking situation over areas with high demand.
As a consequence, the foreground mission was introduced. It consists of high priority observations, originally over Germany, recently extended over Spain resulting in long stripes of acquired data. An online map with the status of (planned and new) acquisitions is available at [6].

Another concept making better use of the full acquisition capacity of the satellite is the background mission which uses input from the science team and acquires data over dedicated sites if these can be respected for acquisitions regarding the above parameters.

The introduction of back-to-back imaging, foreground mission, and the adaption of the background mission allowed the acquisition of an average of around 194 products per day in 2024, which even exceeds the mission's requirements of ~167 products per day, and shows the success of these measurements compared to the ~102 products/day in 2023.

The need to re-submit the proposals that exhaust their quota was also implemented as a measure to promote fair access to EnMAP data.

To improve the situation further, more changes are planned for the future. It is foreseen that the minimum swath length will change from 30 km (1 tile) to 90 km (3 tiles) for new observation requests. This change is expected to increase the total data volume, especially in the areas that are currently more in demand by the users and requests with only a few tiles are very frequent.

In addition, other changes like the introduction of an expiration date for proposals will be foreseen. The goal for the coming years is to provide more users with more of the high-quality hyperspectral data that the EnMAP mission can deliver.

The successful integration of Inuvik ground station can also be depicted from Fig. 2, which shows the number of tiles received in 2024 (for Inuvik in orange, and the number of tiles received in Neustrelitz in blue). The tiles brought down in Inuvik account for ~22 percent of the 34834 tiles operationally received in this period. This results in a reduction of the signal response time, an increase of acquisition possibilities, higher-frequent health-monitoring of the satellite and more flexible up- and downlink.

Besides the measurements taken to improve the availability of acquisitions to scientists, the GS is also reprocessing all datasets acquired since launch until the 20th of August 2023. This procedure is based on an improvement of the co-registration performance of the two instruments on-board. By end of June 2024, about 65 percent of the 34470 datasets have been reprocessed at a recent speed of 139 tiles/day, which allows an expectation of the end of re-processing by end of November 2024 (see Fig. 3).

4. SUMMARY AND OUTLOOK

In this contribution the up-to-date status of EnMAP mission operations has been shown. Starting out by a brief overview of the mission and the Ground Segment, the latest updates have been presented such as the relaxation of problems introduced by the concentration of requests over certain areas. This has been accomplished by an update of the background and an extension of the foreground mission accompanied by the enabling of back-to-back imaging. Furthermore, the successful integration of an additional ground station has been shown and the status of the reprocessing for a dedicated period has been presented. The presented further adaptions will hopefully let the EnMAP user community grow. A further analysis of the acquisitions' metadata will improve the knowledge of the data acquired and is in preparation.

5. ACKNOWLEDGEMENTS

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