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ENPT – AN ALTERNATIVE PRE-PROCESSING CHAIN FOR HYPERSPECTRAL ENMAP DATA

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ABSTRACT

The hyperspectral EnMAP (Environmental Mapping and Analysis Program) satellite was successfully launched in April 2022, passed its commissioning phase, and entered the nominal phase of operational data acquisition in November 2022. Since then, users may submit data acquisition proposals and download the data in three processing levels: Level-1B (radiometrically-corrected and spectrally-characterized top-of-atmosphere (TOA) radiance), Level-1C (geometrically-corrected L1B data), and Level-2A (atmospherically-corrected Level-1C data, i.e., bottom-of-atmosphere (BOA) reflectance). The official product generation is usually done by the ground segment processing chain. Alternatively, the EnMAP processing tool (EnPT) provides a highly customizable free and open-source pre-processing chain enabling additional functionalities and options to fulfill individual user requirements and quality expectations. Here, we provide an overview of the implemented pre-processing chain and its modular design with a specific focus on the additional functionalities of EnPT to obtain highly accurate and customizable hyperspectral EnMAP Level-2A data.

***Index Terms*—** EnPT, EnMAP, EnMAP-Box, FOSS, hyperspectral, pre-processing, Level-2

1. INTRODUCTION

1.1. EnMAP mission

EnMAP (Environmental Mapping and Analysis Program) is a German hyperspectral satellite mission launched in April 2022 from Cape Canaveral aboard a Falcon 9 rocket. The primary objective of the mission is to provide qualitative and quantitative on-demand-measurements of environmental processes and surface coverage dynamics at a global scale [1], [2]. The instrument is equipped with a prism-based push-broom dual-spectrometer with 30 m ground sampling distance (GSD), covering the spectral range between 418.2 nm and 2445.5 nm. EnMAP provides 224 spectral bands, in which the VNIR sensor covers 418.2 nm to 993 nm, and the SWIR sensor covers 902.2 nm to 2445.5 nm. With a swath width of 30 km and an off-nadir-pointing capability of ± 30 degrees, a target revisit time of up to four days is feasible [2].

After passing its commissioning phase, EnMAP entered the nominal phase of operational data acquisition in November 2022. Since then, users may submit data acquisition proposals and download the data in three processing levels: Level-1B (radiometrically-corrected and spectrally-characterized top-of-atmosphere (TOA) radiance), Level-1C (geometrically-corrected L1B data), and Level-2A (atmospherically-corrected Level-1C data, i.e., bottom-of-atmosphere (BOA) reflectance). The product generation is usually done by the Earth Observation Center (EOC) operating the ground segment processing chain at DLR in Oberpfaffenhofen, Germany [2].

1.2. EnPT – overview

Compared to the official processing of the ground segment, the EnMAP processing tool (EnPT) represents an alternative pre-processing chain that empowers users with advanced functionalities and customization options to precisely meet their unique requirements and quality expectations. The software [3] (available for download at https://git.gfz-potsdam.de/EnMAP/GFZ_Tools_EnMAP_BOX/EnPT) is a free and open-source (FOSS) solution developed at the German Research Centre for Geosciences (GFZ) Potsdam to process EnMAP Level-1B data according to the user's needs to spatially and spectrally optimized Level-2A BOA reflectance or normalized water leaving reflectance (water pixels only). Besides the standard procedures (radiometric conversion to TOA reflectance, dead pixel correction,

atmospheric correction, and orthorectification), the processing chain provides advanced co-registration of VNIR and SWIR detectors and/or to a user-provided spatial reference. The output format is similar to the Level-2A data format of the ground segment but can be configured to include additional output data according to the user´s needs. The software is developed in Python and features a graphical user interface (GUI) as well as a command line tool in addition to the Python API. The GUI is embedded into the EnMAP-Box [4] QGIS plugin. EnPT is a fully automated and highly customizable processing pipeline that can be easily implemented into existing workflows.
Figure 1 illustrates the principles of the Level-2-processing chain with the EnPT GUI as it is implemented within the EnMAP-Box. Since the input Level-1B TOA radiance data is provided in two separate arrays for the VNIR and SWIR detector, the geometric and spectral pre-processing is challenging and not a linear intuitive workflow. The data is geometrically projected and un-scaled (each spectral band needs to be un-scaled with individual gains and offsets) in the background within the EnPT processing. All processing steps can be adjusted to individual requirements via the GUI. The resulting output Level 2A BOA reflectance data represent a combined and highly accurate stacked VNIR/SWIR spectral cube projected to customizable map geometry, with a very high relative geometric accuracy to a user-defined geometric reference. The customization options are described in detail in the following chapter.

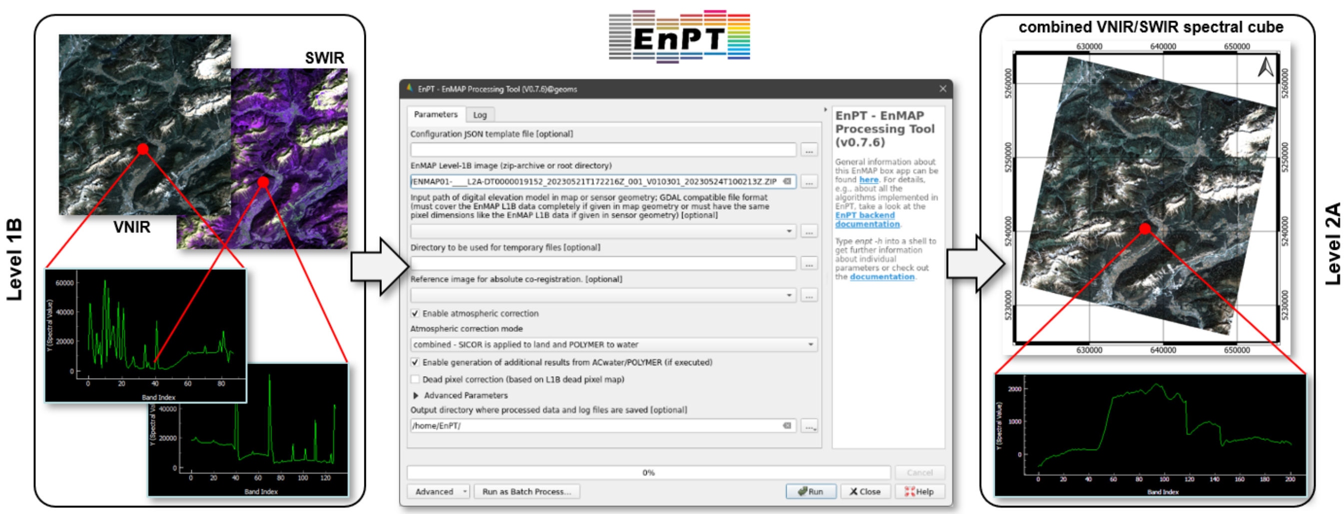

Fig 1: Visualization of the EnMAP pre-processing from Level-1B to Level-2A with the EnMAP Processing Tool (EnPT)

2. PROCESSING CHAIN

The EnPT pre-processing chain follows a modular design. Each processing step is highly configurable, allowing the user to easily customize the output according to individual needs.

2.1 Co-registration

The spatial co-registration approach is based on AROSICS [5], [6] and automatically computes a dense grid of tie points between selected EnMAP VNIR and SWIR bands and a geometric reference image if provided by the user. This allows the user to align optimal between EnMAP and existing data sources. The underlying algorithm relies on phase correlation in the frequency domain. It provides a high level of robustness, e.g., against different ground resolutions, spatial coverages, cloud occlusions, and surface coverage changes.

2.2 Orthorectification

The orthorectification is based on rational polynomial coefficients (RPC) contained in the Level-1B image metadata and considers a digital elevation model, which may optionally be provided by the user offering additional accuracy potential. Various resampling techniques are available, providing a high level of flexibility.

2.3 Atmospheric correction

The atmospheric correction uses two algorithms, SICOR [7] and ACwater, developed at GFZ and AWI, respectively. SICOR calculates BOA reflectance for land surfaces and uses an Optimal Estimation based inversion scheme that relies on simulations obtained from the MODTRAN radiative transfer code [8]. The algorithm includes retrieval of the three phases of water [9] and provides various measures of uncertainties as an optional output. ACwater is a wrapper to run the POLYMER atmospheric correction algorithm for water surfaces [10] (https://www.hygeos.com) within EnPT. POLYMER is a spectral matching algorithm in which atmospheric and water signals are obtained simultaneously using the complete available spectrum; it retrieves normalized water-leaving reflectance for the spectral region of the VNIR (SWIR of water pixels is set to zero) and several additional products such as chlorophyll-a concentration.

2.4 Custom handling of the VNIR/SWIR spectral overlap

EnPT offers multiple options to handle the spectral overlap of the VNIR and SWIR detector between 902.2 nm and 993.0 nm. Users may choose between using all available bands, only VNIR or SWIR bands, or averaging the spectral information, which prevents spectral peaks due to unequal VNIR/SWIR reflectance levels.

2.5 Level-2A outputs

The Level-2A output can be generated in different file formats, data interleaving types, and projections. Moreover, water absorption bands can be optionally excluded, and additional atmospheric parameter retrieval results (so far only from ACwater) can be added. If intended, the user can also choose to produce TOA reflectance by turning off the atmospheric correction completely.

3. OUTLOOK

EnPT is subject to continuous development and improvement. Besides usual code maintenance, bug fixes, or processing speed improvements, several new features are planned for future implementation. This includes additional atmospheric parameter retrieval maps generated by SICOR, which will be added as optional outputs to the EnPT Level-2A product. Moreover, the orthorectification module will be revised to speed up further and enhance the co-registration accuracy. Apart from that, we will also implement a de-striping approach based on a novel algorithm developed at GFZ, which effectively reduces along-track and across-track image striping artifacts to a minimum. In 2024, it is also planned to implement ISOFIT [11] as an alternative atmospheric correction approach to improve the overall performance of the atmospheric correction and to provide BOA reflectance uncertainties for EnMAP data.

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