THE ENMAP SATELLITE – DATA PRODUCT VALIDATION ACTIVITIES

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ABSTRACT

In preparation of the German spaceborne imaging spectroscopy mission EnMAP (The Environmental Mapping and Analysis Program) and its upcoming launch in early 2022, the data product validation activities have been intensified. As part of the science preparation and mission support project led by the German Research Center (GFZ) Potsdam, the overall quality of the official EnMAP products has to be accessed and evaluated independently from the data quality control activities performed by the Ground Segment at DLR EOC. Therefore, the radiometric, spectral, reflective, geometric and general quality of the three official EnMAP products (L1B, L1C and L2A) has to be validated during the commissioning and nominal phase.

This paper presents an update of the data product validation activities, an in-depth insight into the overall approach and into specifically designed methods described in the EnMAP Product Validation Plan.

Index Terms — Imaging spectroscopy, EnMAP, spaceborne, hyperspectral remote sensing, product validation

1. INTRODUCTION

The EnMAP imaging spectrometer covers a spectral range from 420 nm to 1000 nm (VNIR) and from 900 nm to 2450 nm (SWIR). Beside its high radiometric resolution and stability, the instrument is characterized by its high spatial resolution of 30 m x 30 m, a swath width of 30 km as well as an off-nadir (30°) pointing feature enabling a fast target revisit every four days [1], [2]. Due to its specific sensor design (pushbroom and curved prism) and its onboard calibration capabilities (sun diffuser, shutter, two calibration spheres with white and doped spectralon as well as focal plane LEDs) high quality is expected considering the spectral and spatial uniformity and radiometric characterization of the instrument. Nevertheless, the final quality of the data products is determined by the complex interaction of sensor specification, calibration, data acquisition, and preprocessing. The Ground Segment at DLR EOC [3], [4] is responsible for handling this complexity and to make the official products available to the users in compliance with the mission requirements. An independent quality validation of the L1B (radiometrically-corrected and spectrally-characterized TOA radiance data), the L1C (geometrically-corrected L1B data), and the L2A (atmospherically-corrected L1C data) products ensures that the various requirements are fulfilled. This product validation has to be performed during both commissioning and nominal mission phases according to the specifications of the EnMAP Product Validation Plan (PVP).

2. OVERALL VALIDATION APPROACH

The overarching objective of the EnMAP PVP is to access and evaluate the radiometric, spectral, reflective, geometric and the general quality of three official EnMAP products (L1B, L1C, L2A). For each data product various quality parameters (Tab. 1) have to be derived by using adequate and specially designed algorithms and modules.

For scene-based techniques, such as striping and keystone, the data product is sufficient in itself. However, most of the field-, image-, and model based validation methods require additional reference information. In-situ reflectance and atmospheric measurements are needed for the radiometric (L1B) and reflectance (L2A) validation, for example. Absolute geometric validation also needs high resolution and adequately georectified reference image data. Regarding the required additional reference information, we rely on the cooperation with experienced international partners, already established CAL/VAL sites and networks (e.g., CEOS, RadCalNet, AERONET, BOUSSOLE, and HYPERNETS), pseudo invariant calibration sites (PICS) as well as on image

Tab. 1: Overview of the required Field-, Image-, and Model based validation methods/parameters; bold marked validation procedures are presented in the next chapter

Data product	Field-, Image-, Model based validation			
	Radiance	Reflectance	Geometry	Quality
L1B	**L(TOA)**, Moon		**Keystone**	SRF/Smile, **Striping, MTF,** SNR, Anomalies
L1C	Cross-Calibra-tion		**Absolute**, Band-to-Band, VNIR-to-SWIR	Anomalies
L2A		**In-situ** (**ASD**, CEOS, **AERONET**)	Absolute, Band-to-Band, VNIR-to-SWIR	Anomalies

data from other missions (e.g., PRISMA; DESIS, OLCI/S3, MSI/S2). In addition, the potential of lunar measurements for radiometric calibration will be investigated. Since our goal is to ensure outstanding surface reflectance information (L2A), we will use additional in-situ reference measurements from extensive science-oriented, field- and airborne campaigns [5]–[8] as well as from selected core sites (DEMMIN - agriculture, soils; Lake Constance – water; Munich North Isar – agriculture; Makhtesh Ramon – geology; Mammoth Mountain (Sierra Nevada, US) - snow).
In order to cope with the limited data availability for special test areas and the required additional reference information, the validation algorithms and methods have to be designed as robust and flexible as possible.
All quality parameters will be analyzed on a regular basis but also on demand and will be confronted with mission requirements in semi-automatically generated product validation reports. The product validation is performed during both commissioning and nominal mission phases to track the changes in data quality over time. The frequency of validation activities will ultimately depend on the stability of the instrument. In order to fulfill the EnMAP PVP, the activities have to be performed from an end-user perspective and independent from calibration and data quality control activities of the Ground Segment.

3. SELECTED L1B, L1C, L2A VALIDATION METHODS

In the following, some selected methods, which are described in the EnMAP PVP, are introduced in more detail. Overall, far more validation procedures are involved which are indicated in *Tab. 1*.

3.1. L1B Product validation

The L1B product is validated mainly in terms of its radiometrical but also its spectral and spatial quality and characteristic. The following image and in-situ reference measurements based analysis will be used for this task.

3.1.1. Top of Atmosphere Radiance

According to the PVP, the Top of Atmosphere (TOA) Radiance (L(TOA)) measured by the EnMAP satellite is validated by a reflectance based approach (Fig. 1). Based on ground-based reference spectra, which are measured concurrently to the EnMAP overpass, and additional atmospheric measurements, reference TOA radiance spectra are calculated. This is realized by using a combined radiative transfer and instrument model. The modeled TOA radiance spectra can then be compared and statistically analyzed with the L(TOA) measured by EnMAP. The in-situ reference spectra are contributed by international collaborators and established CAL/VAL sites and networks (e.g. CEOS, RadCalNet, AERONET, HYPERNETS).

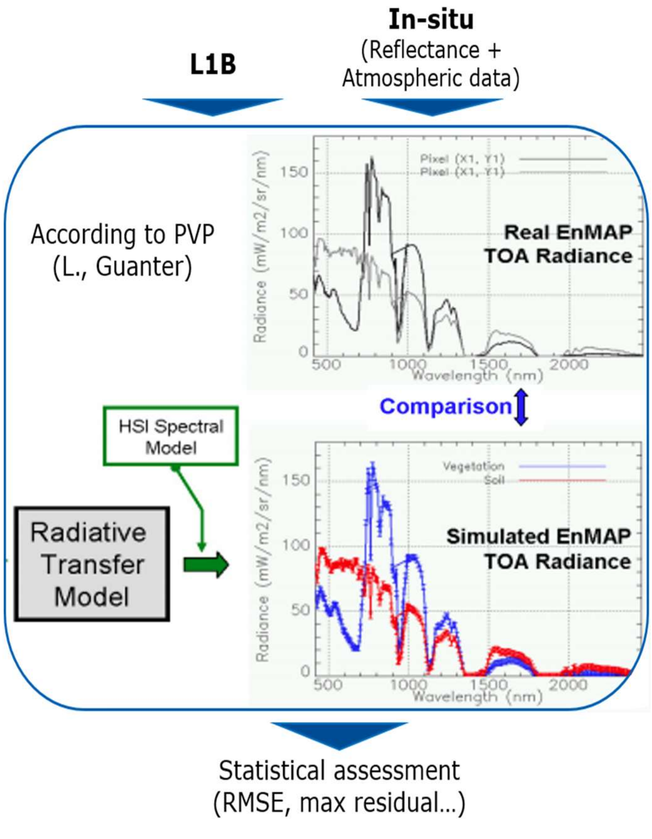


Fig. 1: L1B TOA Radiance (L(TOA)) validation based on reference reflectance spectra

3.1.2. Spatially-coherent artifacts (Striping)

Another performed validation, which aims at the general radiometric quality, is the detection and quantification of spatially-coherent artifacts that cause striping patterns inside the L1B product (Fig. 2). The validation gives the opportunity to calculate a potential band/column wise radiometric miscalibration. The used algorithm is based on the destriping algorithm of [9].

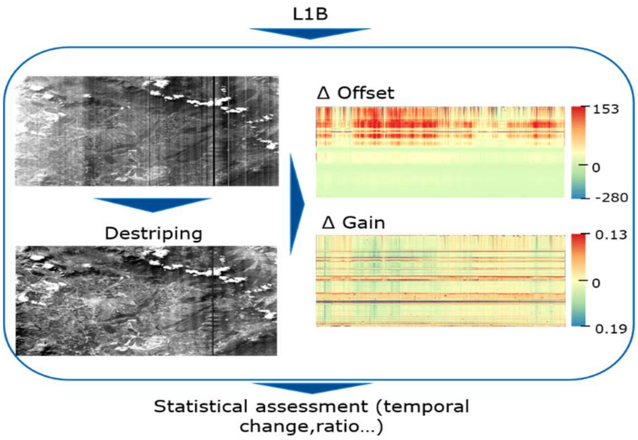


Fig. 2: detection and quantification of striping artifacts inside the L1B product.

3.1.3. Modulation transfer function (MTF)

The modulation transfer function (MTF) and the keystone are parameters related to spatial product quality that also have to be validated based on the L1B product.

The MTF validation determines how much contrast in the original object is maintained by the detector. On the basis of sharp-edges in the L1B product, the Edge Spread Function (ESF) is derived. Based on the intermediate step of the Line Spread Function (derivative of ESF), the MTF (absolute value of the LSF Fourier transform) is derived (Fig. 3). CEOS WGCV MTF-sites are used for MTF derivation.

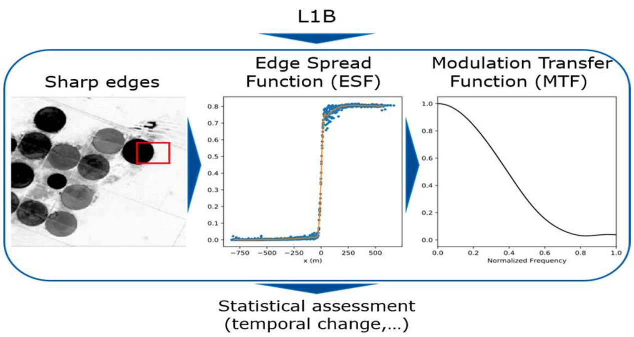


Fig. 3: MTF validation indicates how much contrast in the original object is maintained by the detector

3.1.4. Keystone

The Keystone validation indicates the band to band spatial misregistration caused by non-uniformity projection to the sensor array. The algorithm is based on Fourier shift detection of different across-track regions of the image and is expected to require the analyses of several suitable acquisitions (Fig. 4). Since this misregistrations are in the subpixel scale the keystone is challenging to detect with standard matching methods.

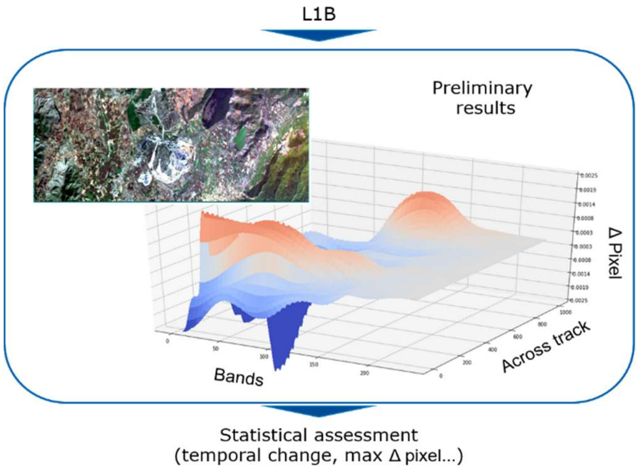


Fig. 4: Initial Keystone determination

Beside the introduced validation efforts for the L1C product, signal-to-noise ratio (SNR), bad and dead pixels, spectral response function (SRF), and spectral channel position (Smile) are also validated by specially adopted procedures.

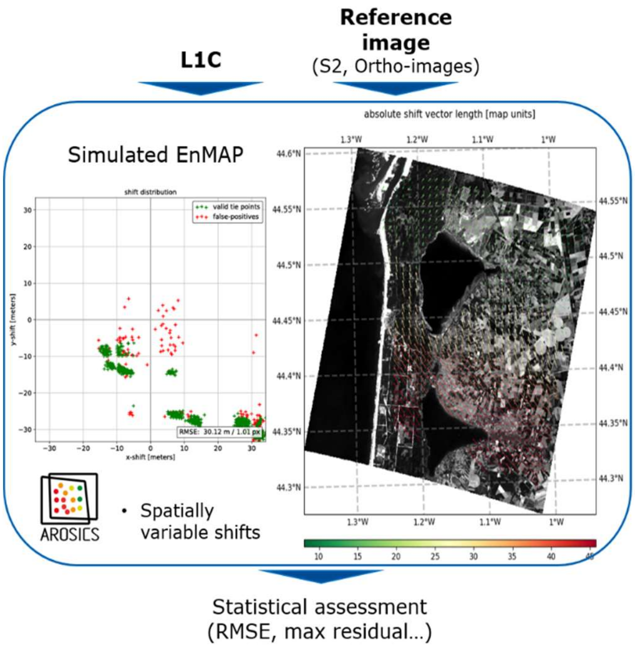
3.2. L1C product validation

The L1C product validation is focused on the geometric performance. It includes the analysis of the absolute and relative spatial accuracy as well as detector and band-to-band co-registration. All methods rely on image based matching techniques that compare EnMAP L1C data internally (band to band) or to reference images for which higher spatial accuracy is given.

3.2.1. Absolute geometric accuracy

For the validation of absolute geometric accuracy, spatially variable shifts between the L1C product and a reference image (e.g. Sentinel2, digital orthoimage) of higher accuracy are detected. This is realized with the existing software AROSICS [10], [11], which is based on cross-correlation in the Fourier space. The algorithm delivers misregistration maps, shift distribution scatterplots, and a text report per EnMAP scene (Fig. 5).

The algorithm should be applicable to any EnMAP scene that contains sufficient spatial contrast. However, there are particularly well fitted geometrical test sites for the validation which we will use.



Arcachon	RMSE [EnMAP pixels]
Tile 2	0.51
Tile 3	1.01

Fig. 5: Absolute geometric accuracy validation of a simulated EnMAP [8], [12] scene in comparison to a S2 scene.

3.3. L2A product validation

The overall accuracy of the Bottom of Atmosphere (BOA) reflectance, the quality mask layers as well as the atmospheric aerosol and water vapor content derived by the atmospheric correction processor are validated for the L2A product.

3.3.1. BOA reflectance

The main focus of the L2A validation is the at-surface reflectance information. In-situ spectral reference measurements, which are acquired close in time or concurrently to an EnMAP overpass, are required for validation. They are generated during extensive science-oriented field and airborne campaigns as well as from international collaborators and selected core sites in Germany and different targets of interest. The reference measurements have to fulfill certain standards regarding the measurement procedure and protocol as well as certain surface properties (homogeneity, reflectivity, less BRDF effects). In contrast to test sites used for the L1B radiometric validation, that require special conditions (homogeneous, high albedo, high elevation) the validation of L2A product will be performed under conventional EnMAP acquisition conditions.

The reference surface reflectance measurements are directly compared with the EnMAP L2A BOA reflectance (Fig. 6) and Water Leaving Reflectance over water sites. The calculated residuals and statistical standard measures will indicate and validate the quality of the atmospherically corrected EnMAP L2A data.

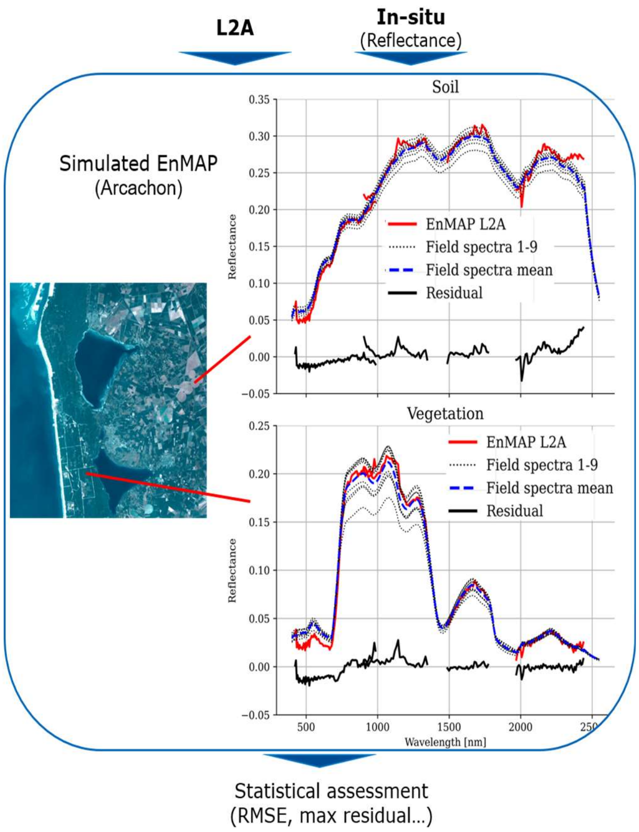


Fig. 6: BOA surface reflectance (L2A) validation based on a simulated EnMAP [8], [12] scene (Arcachon, tile 3).

3.3.2. Aerosol optical thickness and water vapor

Also, the L2A byproducts, i.e., aerosol optical thickness (AOT) and columnar water vapor (CWV), are compared to in-situ data measured by AERONET stations (Fig. 7).

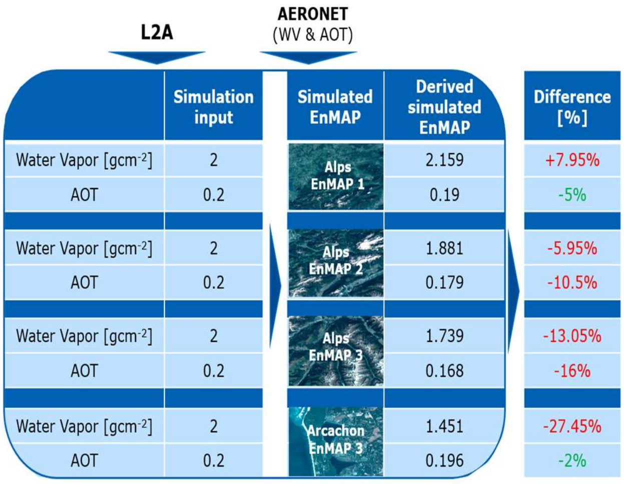


Fig. 7: AOT and CWV validation.

In this example, we derived AOT and CWV from simulated EnMAP data (Alpine and Arcachon scene [8], [12]). The EnMAP data was simulated with 2 [gcm^{-2}] water vapor and 0.2 for AOT. In a real validation scenario, these values are obtained for the EnMAP overpass from the AERONET stations.
The differences in percentage indicate that due to differences between the simulation and the retrieval methods and uncertainties in the parameter derivation the product requirements are not always fulfilled in the shown examples. In the future, spatial distribution maps of the parameters will help us to interpret these deviations correctly.

4. FUTURE WORK

To ensure a consistent product validation workflow, concerted efforts are currently being done on the further implementation, translation, and a consolidation of the modules into a workflow with semi-automatic reporting of the validation results. Currently, in-depth and practice-oriented tests of the algorithms and modules are in focus. In particular, we have started to generate further test data to improve the robustness of the methods and algorithms and to meet the requirements of the validation modules.

4. ACKNOWLEDGMENTS

The EnMAP scientific preparation and mission support program is funded under the DLR Space Administration with resources from the German Federal Ministry for Economic Affairs and Energy. We would like to thank our partners in the EnMAP science P.I. project: HU Berlin, LMU München and AWI Bremerhaven.

6. REFERENCES

[1] S. Chabrillat *u. a.*, „THE ENMAP GERMAN SPACEBORNE IMAGING SPECTROSCOPY MISSION: UPDATE AND HIGHLIGHTS OF RECENT PREPARATORY ACTIVITIES“, S. 4.

[2] L. Guanter *u. a.*, „The EnMAP Spaceborne Imaging Spectroscopy Mission for Earth Observation“, *Remote Sensing*, Bd. 7, Nr. 7, S. 8830–8857, Juli 2015, doi: 10.3390/rs70708830.

[3] T. Storch *u. a.*, „STATUS OF THE IMAGING SPECTROSCOPY MISSION ENMAP WITH RADIOMETRIC CALIBRATION AND CORRECTION“, *ISPRS Annals of Photogrammetry, Remote Sensing and Spatial Information Sciences*, Bd. V-1–2020, S. 41–47, Aug. 2020, doi: 10.5194/isprs-annals-V-1-2020-41-2020.

[4] M. Bachmann *u. a.*, „The Calibration, Monitoring and DataQC Procedures within the EnMAP Ground Segment“, Imaging Spectroscopy - Cooperation in Space, ESA-ESRIN, Juli 09-11, 2019.

[5] M. Brell *u. a.*, „Demmin, Germany (October 2015) - An EnMAP Preparatory Flight Campaign“, 2020, doi: 10.2312/enmap.2020.004.

[6] S. Chabrillat *u. a.*, „EnMAP airborne soil Greece campaign 2019“, Bd. 22, S. 8988, Mai 2020.

[7] M. Robert, H. Eichstaedt, M. Brell, R. Behling, und S. Chabrillat, „Omongwa Salt Pan, Namibia - An EnMAP Preparatory Flight Campaign“, 2020, doi: 10.2312/enmap.2020.005.

[8] „Data & Tools - EnMAP“. https://www.enmap.org/data_tools/ (zugegriffen Feb. 12, 2021).

[9] C. Rogass *u. a.*, „Reduction of Uncorrelated Striping Noise—Applications for Hyperspectral Pushbroom Acquisitions“, *Remote Sensing*, Bd. 6, Nr. 11, S. 11082–11106, Nov. 2014, doi: 10.3390/rs61111082.

[10] D. Scheffler, A. Hollstein, H. Diedrich, K. Segl, und P. Hostert, „AROSICS: An Automated and Robust Open-Source Image Co-Registration Software for Multi-Sensor Satellite Data“, *Remote Sensing*, Bd. 9, Nr. 7, S. 676, Juli 2017, doi: 10.3390/rs9070676.

[11] D. Scheffler, *AROSICS: An Automated and Robust Open-Source Image Co-Registration Software for Multi-Sensor Satellite Data*. Zenodo, 2021.

[12] K. Segl *u. a.*, „EeteS - The EnMAP End-to-End Simulation Tool“, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, Bd. 5, Nr. 2, S. 522–530, Apr. 2012, doi: 10.1109/JSTARS.2012.2188994.