

MOOC Document

Beyond the Visible – EnMAP data access and image preprocessing

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List of Abbreviations

The list includes all terms that are introduced in the MOOC.

ACT: Across-track	water and land bidirectional reflectance
A/D: analog/digital	measurements for satellite validation
AERONET: Aerosol Robotic Network	IFOV: Instantaneous-field-of-view
AO: Announcement of Opportunity	ISOFIT: Imaging Spectrometer Optimal
AOI: Area of Interest	FITting
AOT: Aerosol optical thickness	MIR: Mid infrared
AROSICS: Automated and Robust	MODTRAN: MODerate resolution
Open-Source Image Co-Registration	atmospheric TRANsmission
Software	MOOC: Massive open online course
BOA: Bottom-of-Atmosphere	NIR: Near Infrared
CAL/VAL: Calibration/Validation	OE: Optimal Estimation
CEOS: Committee on Earth Observation	PICS: Pseudo invariant calibration sites
Satellites	PyPI: Python package index
DEM: Digital elevation model	PSF: Point spread function
DLR: German Aerospace Center	RadCalNet: Radiometric Calibration
DN: Digital number	Network
D-SDA: German Satellite Data Archive	RGB: Red Green Blue
EnMAP: Environmental Mapping and	RPC: Rational polynomial coefficients
Analysis Program	RTM: Radiative Transfer Model
EnPT: EnMAP Processing Tools	SICOR: Sensor independent
EnSAG: EnMAP Science Advisory Group	atmospheric correction
EOC (DLR): Earth Observation Center of	SLIC: Simple Linear Iterative Clustering
DLR	SNR: Signal-to-noise ratio
EOWEB: DLR multi-mission web portal	SRF: Spectral response function
for interactive access to long-term	SRTM: Shuttle Radar Topography
archived Earth Observation (EO) data	Mission
GFZ: German Research Centre for	SWIR: Short wave infrared
Geosciences	TIR: Thermal infrared
GUI: Graphical User Interface	TOA: Top-of-Atmosphere
HYGEOS: Company specialized in	UV: Ultraviolet
processing, analysis and validation of	VIS: Visible (light)
Earth Observation data	VNIR: Visible near-infrared
HYPERNETS: Hyperspectral radiometer	XML: Extensible Markup Language
integrated in automated networks of	

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1 Welcome

Hi there, welcome to the MOOC **‘Beyond the Visible’ on EnMAP data access and preprocessing techniques!**

Like our other courses, this MOOC is **structured in six lessons** that usually **contain several topics** and are accompanied and completed by a number of **short exercises** and **quizzes**.

However, this course differs a little from the other ‘Beyond the Visible’ MOOCs as it really focuses on the EnMAP satellite. In **the first lesson**, we’ll introduce the mission organization to you – there are many different responsibilities and the “organs” have to work closely together. And, if you haven’t yet already, there will be a chance to meet EnMAP, the German hyperspectral satellite mission that triggered the creation of this series of MOOCs!

Oh, and **the second lesson** differs, as **all quizzes in this MOOC, except for the final assessment, are optional**. We want to make EnMAP data access easy and comfortable for everyone! Still, we have decided to keep the format of the second lesson as a quiz on the basics of hyperspectral remote sensing to ensure you have sufficient background knowledge to enjoy this MOOC. There is no need to pass the test, but if your score is lower than 50 %, you may want to consider participating in our [Basic MOOC](#) first ...

The third to fifth lesson comprise the actual content and will introduce you to the (theoretical) background of hyperspectral image preprocessing and common EnMAP product (= preprocessing) levels, EnMAP data access via one of the two portals, including registration and ordering data from the archive as well as new acquisitions. In the final lesson, you’ll get the chance to participate in expert-led, hands-on training exercises.

The „core“ thematic lessons (3-5) contain a lot of interactive content and you are asked to complete a short final quiz at the end of each lesson (10 questions each). Though again, there is no need to pass in order to proceed to the next lesson. The course is completed by a **final assessment** which includes a total of 20 questions. Here, **you need at least 70 % to pass**. If you have successfully done this, you will receive a **certificate of completion** as well as a **diploma supplement document**. Don’t worry, you have unlimited attempts ;).

We use the **sixth lesson** to say goodbye – by then, you should have learned ...

- how a large satellite mission like EnMAP is organized
- the need for thorough preprocessing of imaging spectroscopy data
- the most important preprocessing steps (over LAND)
- the complexity of the preprocessing process
- how to assess data quality
- what the different EnMAP product levels include and what they are useful for
- how to register to the EnMAP portals, submit a new proposal, order new acquisitions and search for already existing data in the archive
- and finally, how to preprocess an imaging spectroscopy dataset yourself!



Advice – how to get through the course smoothly

To complete the course and get the certificate you still need to answer the quizzes in the online version of the course. This course was designed to be taken from a desktop PC or laptop, though most content should work on a tablet or even smartphone as well. For the best learning experience, we recommend participating using **Google Chrome, Microsoft Edge or Mozilla Firefox on a desktop PC or laptop**. During beta-testing, we observed some issues with Safari – if the content is not displayed properly, try re-loading.

Now... did you ever wonder how a large satellite mission is organized?

Of course, there is the very prominent **Space Segment**, consisting of Sensor and Platform. But there is also a **Ground Segment**, responsible, for example, for the Operation of the instrument as well as data *Processing*. As the EnMAP mission is accompanied by a major scientific (preparation) program, there is a **Scientific Principal Investigator** and an entire EnMAP Science Advisory Group (EnSAG). And, last but not least, the **Project Management**. Some of the names and faces behind these elements may be familiar to you if you've participated in a 'Beyond the Visible' MOOC before and you'll get to know even more people in this course. By the way, HYPERedu is also part of the elements described above – we belong to the scientific (preparation) program.

Learn more in the video below:

VIDEO: Preprocessing-02: Mission Overview



URL of the video: <https://youtu.be/4tyM4SwssNk>

Let's move on with the first topic **"Hyperspectral image preprocessing – what is it and why is it important?"** You can select the topic from the overview below!

1.1 Hyperspectral image preprocessing – what is it and why is it important?

If you are just a little familiar with remote sensing, you've probably heard of **preprocessing** before – it refers to all the processes applied to the data before any actual analyses can (or should be) performed. Preprocessing is necessary with any spaceborne dataset, however, with data as complex as hyperspectral imagery, **a comprehensive preprocessing routine is crucial. Why?**

First of all, the (spaceborne) sensor acquires only unitless digital numbers (DN) that are physically not interpretable!

Then, we want to ensure an accurate and precise geolocation of each measurement (pixel). Ideally, spatial resolution should be homogeneous across the scene, independent of topography.

Furthermore, each measurement should be independent of illumination and atmospheric state as well: The source of the electromagnetic energy recorded by optical sensors (passive) is the sun: Extraterrestrial radiation reaching the Earth is influenced by the atmosphere in various ways. Thereby, **the atmosphere significantly alters the signal measured by the sensor** and thus changes the actual signal of the target object. One reason for this is the composition of the atmosphere, but also the viewing geometry. In order to generate so called “surface reflectance” data without biases across a variety of sensor systems, surface types, atmospheric and imaging conditions requires consistent, accurate atmospheric correction.

All in all, preprocessing assumes a well-calibrated and stable sensor instrument and aims at generating a data source for deriving **quantitative surface properties** and **spatio-temporally comparable and transferable measurements**.

A typical (very simplified) **workflow** progresses from Digital numbers to radiance at the sensor level to geometrically and finally atmospherically corrected surface reflectance. Very generally, this procedure involves the steps of (1) radiometric correction, (2) geometric correction, and (3) atmospheric correction.

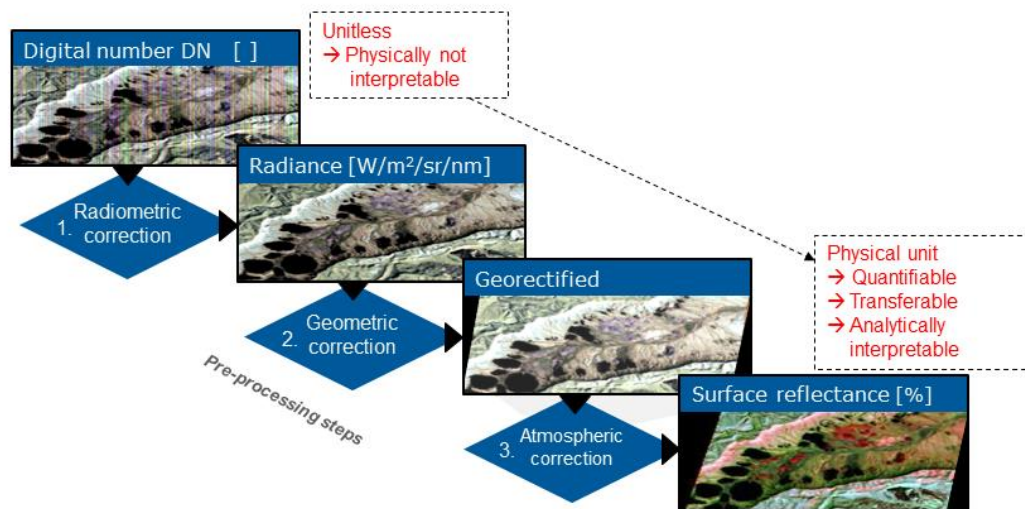


Figure 1 Simplified preprocessing workflow of optical remote sensing data. In courtesy of Maximilian Brell

Hyperspectral imagery is often available at **different preprocessing levels**, whereas the terminology might differ slightly depending on the sensor. **In this course, we will focus on EnMAP data** which can be obtained at product level 1B (at-sensor-radiance), 1C (orthorectified at-sensor-radiance), and 2A (orthorectified surface-reflectance data for land and water including several quality masks).

So, if you can get all data readily preprocessed for analyses, **why should you be familiar with preprocessing?** Well, we think that a basic knowledge of the preprocessing process will help you to better understand the nature and complexity of hyperspectral imagery: Despite careful preprocessing, some issues might persist and should be kept in mind during data analysis and interpretation. The information provided in the subsequent lessons will also guide you through the product level selection suitable for your application as well as data access and will provide a hand in case you want to try preprocessing yourself!

Preprocessing of hyperspectral vs. multispectral data

„Atmospheric transmittance and absorption correction and sensor calibration of hyperspectral imagery are more difficult than they are for multispectral imagery because of hyperspectral imagery’s substantially higher spectral resolution. The specific reasons for this extra difficulty include the following:

- Hyperspectral sensor bands coinciding with narrow atmospheric absorption features or the edges of broader spectral features will be affected by the atmosphere differently than the neighboring bands
- The band locations in imaging spectrometer systems are prone to small wavelength shifts under different operating conditions, particularly in airborne sensors
- Many analysis algorithms for hyperspectral data require precise absorption band-depth measurements exactly at the wavelength of maximum absorption
- From the computational standpoint alone, the calibration problem is much greater for hyperspectral systems.” Schowengerdt (2007)

Thanks to the high number of bands, hyperspectral data are a lot more sensitive to atmospheric influences than multispectral data and require rigorous atmospheric correction. For example, “water vapor can have pronounced effects on hyperspectral sensor data acquired near the 0.94, 1.14, 1.4 and 1.88 μm absorption bands. In addition to being a strong absorber, atmospheric water vapor can vary dramatically in its temporal and spatial distribution. Within a single scene, the distribution of water vapor can be very patchy and change on the time scale of minutes. Also, large variations in water vapor can result simply from changes in the atmospheric path length between the sensor and the ground due to changes in surface elevation.” Lillesand et al. (2015)



Let us and your fellow students know who you are, what question(s) you are interested in, and for which research question you would like to use hyperspectral data in the [discussion forum](#) of this topic. There is a separate discussion forum for each topic of this course in the discussion section at EO-College.

1.2 EnMAP – The German Spaceborne Imaging Spectroscopy Mission

The **Environmental Mapping and Analysis Program (EnMAP)** is a **German hyperspectral satellite mission** that aims at monitoring and characterizing Earth's environment utilizing its regional coverage on a global scale. EnMAP measures and models key ecosystem processes by extracting geochemical, biochemical and biophysical parameters that provide information on the status and evolution of various terrestrial and aquatic ecosystems. It is funded under the DLR Space Agency with resources from the German Federal Ministry for Economic Affairs and Climate Action and the mission is accompanied by an extensive scientific preparation program and educational initiative. In this context, we have developed an open source software (EnMAP-Box) and trained a number of experts in the past decade. Our MOOCs are the next step to share our knowledge with all potential users of hyperspectral data and encourage the growth of a global imaging spectroscopy community.

VIDEO: Basic-05: Sensor technologies & data acquisition techniques: EnMAP Mission



URL of the video: <https://youtu.be/LQZNtLp3RfM>

The sensor covers a **swath width of 30 km with a ground sampling distance of 30 m × 30 m**. The along-track dimension is given by the satellite movement. **Data length up to 5000 km** can be collected per day and downlinked via X-band with 320 Mbits/s in 31 minutes/day. The chosen sun-synchronous orbit combined with a **±30° off-**

nadir pointing feature allows each point on Earth to be revisited within 4 days, viewing nadir within 27 days.

EnMAP is a pushbroom-type imaging spectrometer with a prism-based dual-spectrometer instrument design covering the 420–2450-nm spectral range: a VNIR system (420–1000 nm) and a SWIR system (900–2450 nm). The threshold requirements for the Signal-to-noise ratio (SNR) are

- VNIR >500:1 (@495 nm)
- SWIR > 150:1 (@2200 nm)

and the spectral calibration uncertainty

- VNIR 0.5 nm
- SWIR 1 nm

The required radiometric calibration accuracy is 5 % and co-registration VNIR-SWIR < 20 % of a pixel.

You might have noticed the different number of bands of the EnMAP sensor mentioned in the video and the mission fact sheet. Indeed, a total of 246 bands are recorded at sensor. However, not all are provided to the users in the final data products, but are used for internal calibration and monitoring processes. **The standard configuration in the L2A product at the start of the nominal phase was 91 (VNIR) and 133 (SWIR) bands, which makes 224 in total.**



Let us and your fellow students know who you are, what question(s) you are interested in, and for which research question you would like to use hyperspectral data in the [discussion forum](#) of this topic. There is a separate discussion forum for each topic of this course in the discussion section at EO-College.

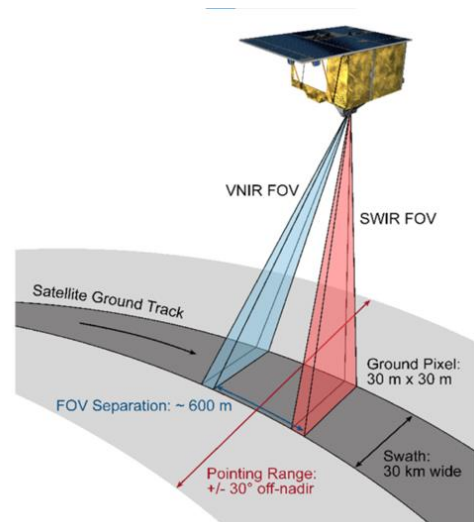


Figure 2 Schematic representation of an EnMAP overpass.

GFZ Potsdam, satellite illustration with permission from DLR Space Agency, figure taken from EnMAP Brochure available at enmap.org Copyright © 2012-2023 EnMAP at Earth Observation Center EOC of DLR

1.3 Resources section: 'Welcome'

In this section, we have assembled resources used for the creation of this lesson that we recommend for further reading as they provide a lot more detail. Please remember that this selection is not a complete overview of all resources – if you think an important resource is missing, let us and your fellow students know (e.g. in the discussion forum).



Sources and further reading

Hyperspectral image preprocessing – what is it and why is it important?

- Lillesand, T., Kiefer, R.W., Chipman, J. (2015). **Remote Sensing and Image Interpretation**. 7th Edition, Wiley
- Schowengerdt, R. A. (2007). **Remote Sensing: Models and Methods for Image Processing**. 3rd Edition, Elsevier

EnMAP – The German Spaceborne Imaging Spectroscopy Mission

- www.enmap.org
- Guanter, L., Kaufmann, H., Segl, K.; Foerster, S., Rogass, C., Chabrillat, S., Kuester, T., Hollstein, A., Rossner, G., Chlebek, C., Straif, C., Fischer, S., Schrader, S., Storch, T., Heiden, U., Mueller, A., Bachmann, M., Mühle, H., Müller, R., Habermeyer, M., Ohndorf, A., Hill, J., Buddenbaum, H., Hostert, P., Van der Linden, S., Leitão, P.J., Rabe, A., Doerffer, R., Krasemann, H., Xi, H., Mauser, W., Hank, T., Locherer, M., Rast, M., Staenz, K., Sang, B. (2015). **The EnMAP Spaceborne Imaging Spectroscopy Mission for Earth Observation**. *Remote Sens.* 2015, 7, 8830-8857. <https://doi.org/10.3390/rs70708830>

2 Pre-assessment: Ready for imaging spectroscopy?

Are you ready for the preprocessing of imaging spectroscopy data? As mentioned before, in order to really enjoy this course, **you should have some basic understanding of hyperspectral remote sensing principles**. In this specific course, you cannot fail the quiz. However, if your score is low (< 50 % of correct answers) then we recommend that you look into some more basic resources before taking this course, e.g., our Basic MOOC '[Beyond the Visible: Introduction to Imaging Spectroscopy](#)'. Here we go and good luck!

Do the questions look (too) complicated to you? Then try our Basic MOOC '[Beyond the Visible: Introduction to Imaging Spectroscopy](#)' to get the most out of our introduction to preprocessing and EnMAP data access afterwards!

Quiz: The Pre-assessment Quiz

An object will appear red to the observer ... (single-choice)

- ... if it absorbs only red wavelengths
- ... if it transmits only red wavelengths
- ... if it reflects all visible wavelengths equally
- ... if it mostly reflects red wavelengths

Sort the wavelength ranges from short to long wavelengths

- MIR
- UV
- NIR
- SWIR
- VIS
- Microwaves
- TIR

Which parts of the electromagnetic spectrum can we see? (single-choice)

- Ultraviolet light
- Visible light
- Infrared light
- Microwaves

The spectral region where electromagnetic radiation passes through the atmosphere without much attenuation is known as ... (single-choice)

- ... ozone hole
- ... atmospheric window
- ... black hole
- ... skylight

Can you identify some advantages of imaging spectroscopy data? (multiple-choice)

- The data contains a high level of spectral detail
- The data allow for the retrieval of a range of different surface variables
- Analysis is much faster and easier compared to other types of remote sensing data

What is a radiometric correction and what does it do? (multiple-choice)

- It transforms digital numbers to radiance
- It transforms digital numbers to reflectance
- It involves data resampling using nearest neighbor, bilinear interpolation or cubic convolution methods
- It involves a linear transformation in which correction coefficients (gain and offset) are applied to every image pixel

Which surface material has usually the lowest reflectance in the SWIR? (single-choice)

- Clear water
- Green vegetation
- Dry vegetation
- Open soil

Which factors influence the reflectance of vegetation? (multiple-choice)

- Moisture content
- Species
- Phenology
- Health

Healthy vegetation strongly reflects light in which parts of the electromagnetic spectrum? (single-choice)

- Green and red
- Blue and green
- Green and near-infrared
- Blue and red

What is a Lambertian surface? (single-choice)

- An ideal specular reflector
- An ideal diffuse reflector
- A calibration target
- A perfect emitter

3 Hyperspectral Image Preprocessing over LAND

In this lesson, we want to introduce you to the **general principles of image preprocessing** and how they translate to the available EnMAP product levels – Charly will give you more details on the specific learning objectives in the video below.

VIDEO: Preprocessing-03: Intro Lesson 3



URL of the video: https://youtu.be/LDvSXc9_qS4

Let's move on with the first topic of this lesson!

3.1 General introduction to preprocessing (simplified workflow)

Most applications are based on surface reflectance data. As the title of this lesson indicates, we will focus on the **preprocessing of hyperspectral imagery over LAND surfaces** and you will learn about the procedure to process images from the raw measurement to surface reflectance. From an application perspective, it is always useful to have a basic understanding of this workflow, since there are some differences to consider depending on the surface cover and application at hand. This is especially true when your focus is on water, snow or atmosphere, or includes time series data.

To quickly cover the basics, solar irradiance reaches the Earth and first interacts with the atmosphere in various ways, whereas a part of it is reflected back into space. The other part travels through the atmosphere and is subject to further wavelength-dependent processes. For example, radiation is absorbed and scattered by gaseous and particulate components. For the target, the dominant energy source is direct illumination from the Sun (1, see figure below). In addition, there is diffuse sky irradiance (2,3) due to scattering and absorption in the atmosphere. Thereby, the part of the diffuse sky radiation that acts in the direction of the sensor without ever

reaching the surface is called path radiance (2). It is determined by the scattering processes within the atmosphere and is strongly wavelength-dependent. On its way to the sensor, all the reflected radiation from the target area (1,3,5) has to pass through the atmosphere AGAIN and is thereby attenuated (2,4). So ideally, the signal recorded by the sensor is a true function of the amount of radiance leaving the target within the instantaneous-field-of-view at a specific solid angle. However, in reality, other radiant energy may enter into the sensor’s field of view from various other paths and introduce confounding noise (Jensen, 2007). You can find detailed descriptions of light – atmosphere – surface interaction in our [Basic MOOC](#).

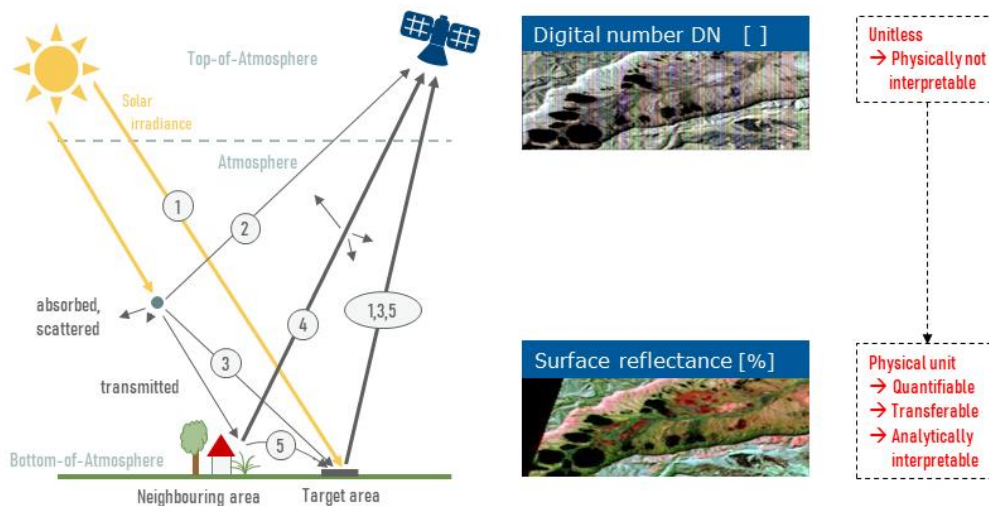


Figure 3 Interaction of electromagnetic radiation with atmosphere and Earth surface.
In courtesy of Maximilian Brell and Daniel Scheffler

Now, before we can use the signal recorded by the sensor (digital number; unitless), the data needs to be preprocessed into surface reflectance (in %; physical unit) to make it quantifiable, transferable, and analytically interpretable. The goal of any preprocessing is to extract only the signal reflected from the target area without any interfering effects from the atmosphere or the sensor itself. There is a lot to consider when attempting to **generate a**

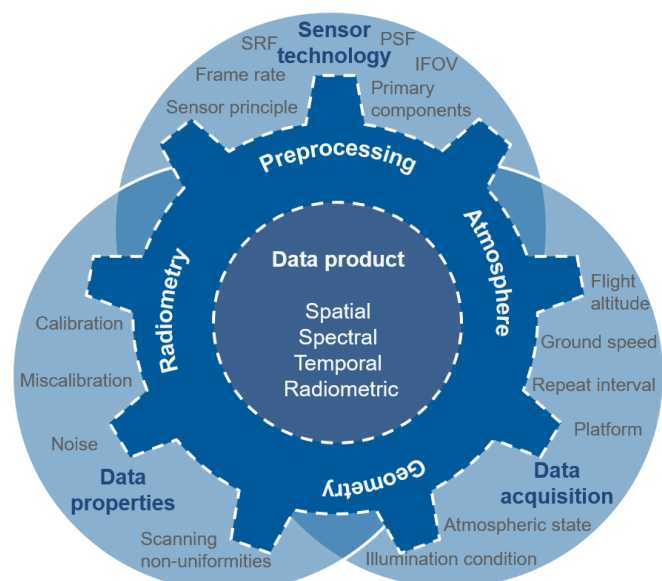


Figure 4 The data product is influenced by many aspects.
In courtesy of Maximilian Brell and Daniel Scheffler

consistent data product from the interaction between **sensor technology** (e.g. the sensor principle, instantaneous field of view (IFOV), spectral response function (SRF) or point spread function (PSF)), the kind of **data acquisition and parametrization** (e.g. ground speed, flight altitude but also illumination and atmospheric conditions), and the **data properties** (e.g. (mis)calibration, noise, or scanning non-uniformities). Imaging spectrometers are complex systems. For technical reasons, some – like EnMAP – are actually composed of two separate detector arrays and instruments, a **VNIR** and a **SWIR** sensor, that need to be aligned during preprocessing. If that sounds all very unfamiliar, you can find some input on sensor technology and data acquisition in our [Basic MOOC](#).

A typical (very simplified) **preprocessing workflow** progresses from digital numbers to radiance at sensor level to geometrically and finally atmospherically corrected surface reflectance. This procedure involves the steps of (1) radiometric correction, (2) geometric correction, and (3) atmospheric correction.

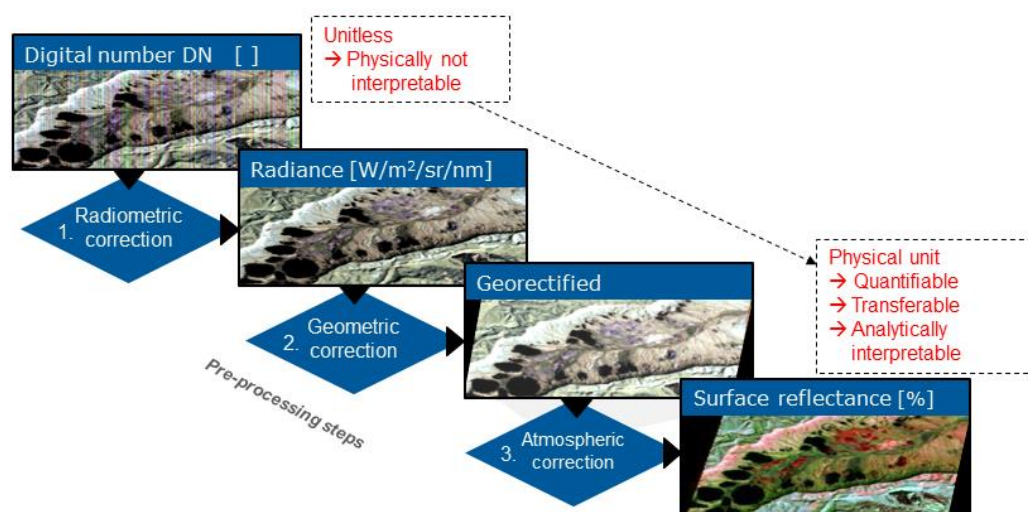


Figure 5 Simplified preprocessing workflow.
In courtesy of Maximilian Brell

Radiometric Correction

Raw data is recorded as discrete digital numbers (DNs), i.e. numbers without physical units. To create these DN, every sensor has its **specific gains and offsets** applied to the recorded signals. The **offset** includes digital offsets of the thermally induced dark current and the **gain** is determined by measuring the sensor's response to known radiance targets. Gain and offset are set to provide sufficient signal amplitude to the A/D converter and are different for each band because of different sensitivities and anticipated irradiance levels (low- and high-gain settings for imaging very bright and

dark targets, respectively). They are usually preset before and cannot be changed during flight and though they are often assumed constant over time, they usually change throughout a sensor’s life. Therefore, a **radiometric calibration** is done by sphere measurements in the lab and is repeated from time to time for airborne spectrometers. For spaceborne imaging spectrometers, post-launch radiometric calibration can be achieved e.g. by dark signal calibration (closed shutter, dark ocean, deep space), the repeated observations of well-calibrated ground targets (vicarious calibration) or onboard measurements that are highly desirable as they are independent from ground morphology and atmospheric effects and provide an indication of system degradation. Both correction coefficients are determined for each detector element separately.

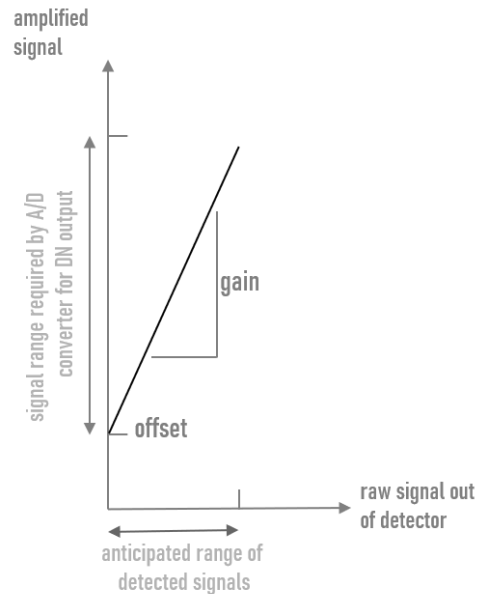
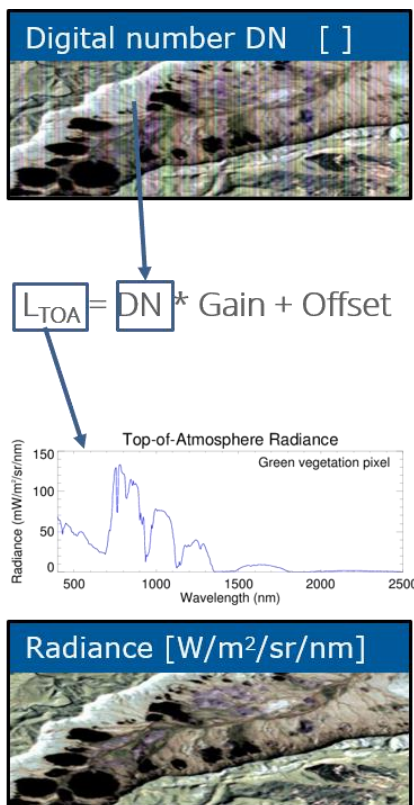


Figure 6 Sensor radiometric calibration: gain and offset.

Adapted from Schowengerdt (2007)



Okay, back to preprocessing: The first step is most commonly and **radiometric correction that transforms digital numbers to radiance**. This is a linear transformation, in which the **correction coefficients** – offset and gain – are applied to every band and every image pixel.

Figure 7 Radiometric correction.
In courtesy of Maximilian Brell and
Daniel Scheffler

Geometric Correction

The radiometric correction is usually followed by a **geometric correction, involving the transformation of image coordinates that were acquired in sensor geometry into object coordinates with a map projection.** The approach is parametric and based on the principles of direct georeferencing which incorporates a geometric sensor model and navigation data (such as altitude and trajectory data) to calculate the line-of-sight intersection with a digital elevation model for every pixel to **account for terrain distortions.**

The geometric correction further involves a compensation for spatial sensor distortions known as “keystone” effect (lateral chromatic aberration). The keystone is typically a simple curvature where the position of a pixel in across-track direction (ACT) varies by the wavelength. It is considered in the orthorectification process by applying higher resampling techniques.

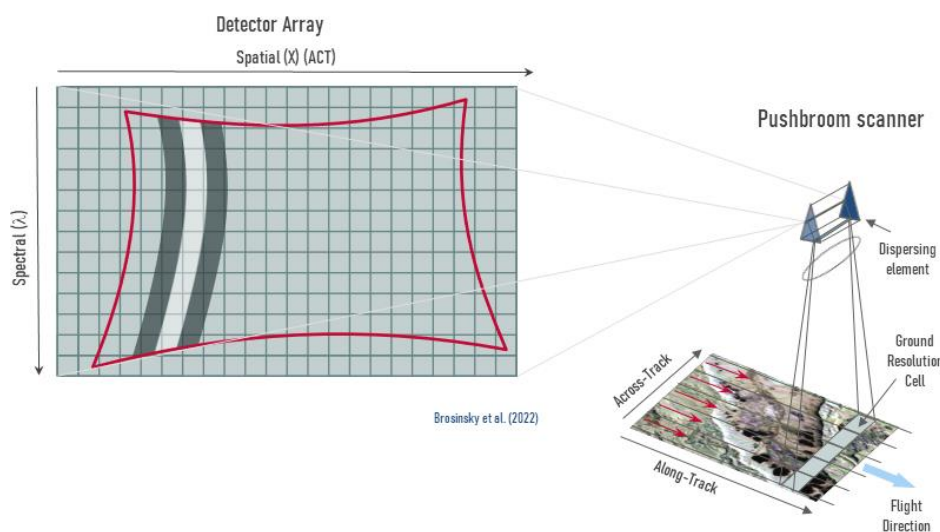
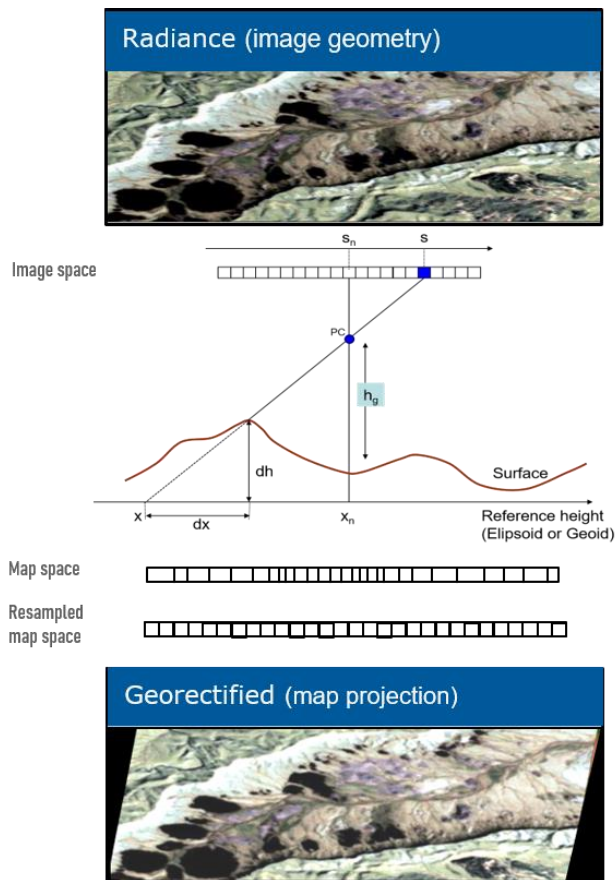


Figure 8 Spatial sensor non-uniformities – the “keystone” effect.
Brosinsky et al. 2022

Remember that EnMAP, among other hyperspectral instruments, is actually composed of two separate detector arrays and instruments: A **VNIR** and a **SWIR** sensor which have a slightly different line-of-sight that need to be geometrically co-registered. This **co-registration** is ideally a parametric procedure (based on mathematical models and navigation data to model the acquisition geometry) which incorporates image-matching techniques (between VNIR and SWIR) to optimize the interior- and exterior parametrization of the matched e.g. SWIR sensor.



In order to transform irregularly spaced measurements into regularly spaced pixels, the data is then resampled using nearest neighbor, bilinear interpolation or cubic convolution methods.

Figure 9 Geometric correction.
In courtesy of Maximilian Brell and Daniel Scheffler

Atmospheric Correction

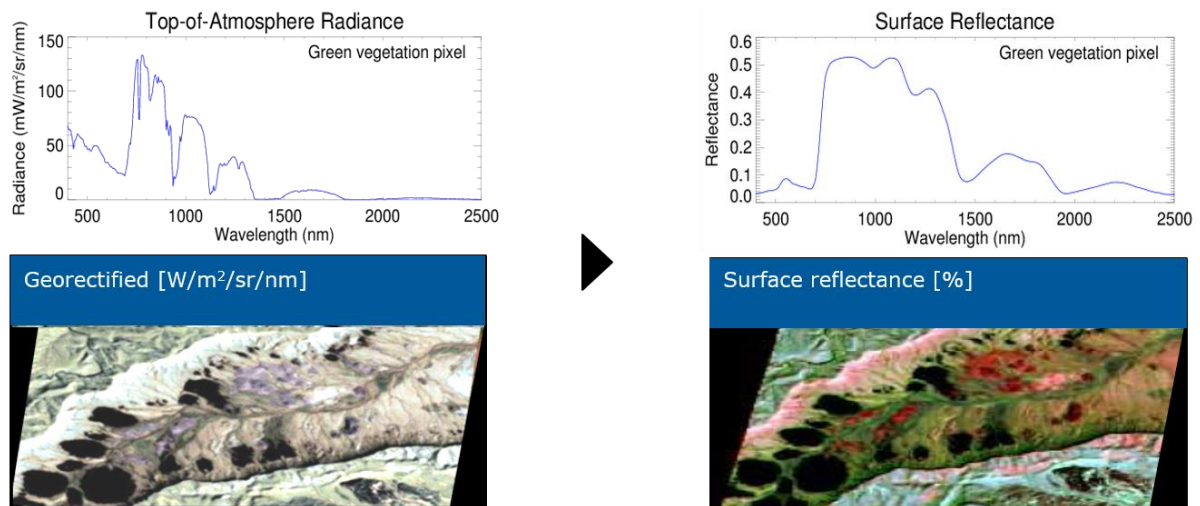


Figure 10 Atmospheric correction. In courtesy of Maximilian Brell and Daniel Scheffler

Therefore, to get from top-of-atmosphere radiance to bottom-of-atmosphere or at-surface reflectance, we apply an **atmospheric correction**. The atmospheric correction includes **corrections of atmospheric scattering as well as absorption effects such as adjacency and illumination effects caused by terrain and clouds**. Most transferable approaches are parametric ones that model the atmospheric absorption and scattering properties using a Radiative Transfer Model (RTM). An RTM describes how electromagnetic radiation propagates through the atmosphere based on the radiative transfer equation.

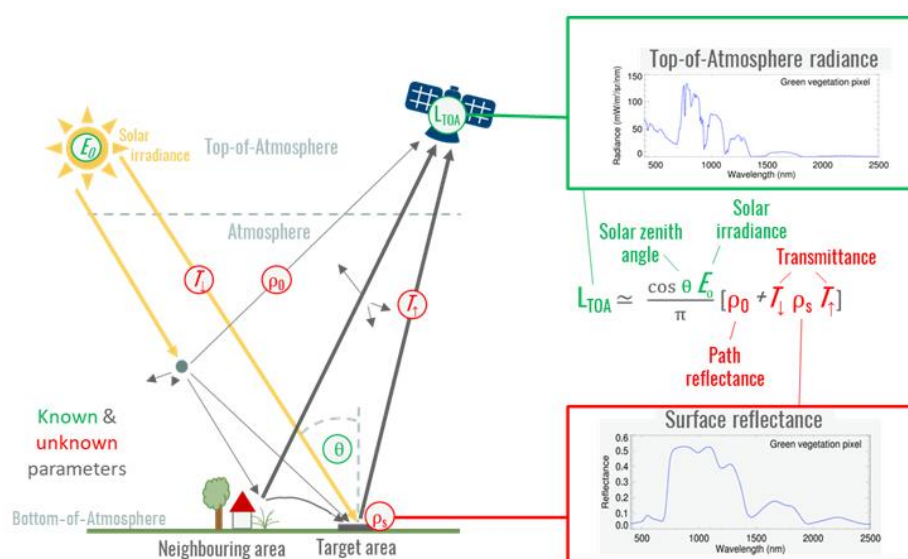


Figure 11 Radiative Transfer Modelling.

In courtesy of Maximilian Brell and Daniel Scheffler

It accounts for the processes of absorption, emission and scattering by the atmospheric constituents. The radiative transfer parameters are usually precomputed for different atmospheric properties (e.g. water vapor or aerosol content) and geometric conditions and are stored in lookup tables. This speeds up the atmospheric correction process by interpolating parameters for a given observation instead of performing costly radiative transfer calculations. Actual water vapor or aerosol influences are compensated by inverting the model to retrieve the unknown parameters by matching the simulated and observed spectra. The resulting bottom-of-atmosphere or at-surface reflectance provides spectra representing the underlying surface materials which are not influenced by the atmospheric or illumination state. This makes the derived information content of an acquisition transferable, quantifiable and analytically interpretable independent from temporally and spatially varying influences.

Atmospheric corrections over snow and ice come with their own challenges. Radiation penetrates the water and snow bodies and is dependent on **turbidity, floating objects, adjacency effects and anisotropy**. Accordingly, the atmospheric correction can only be solved by highly specialized approaches.

Atmospheric correction may also include the correction of spectral non-uniformities caused by the sensor(s): An important artifact for some imaging spectrometers is the spectral **“smile” effect**, also known as spectral non-uniformity or spectral aberration. Typically, this effect is a simple curvature of the monochrome images of the entrance slit, whereas the wavelength varies with the across-track pixel position. The effect can be estimated in-flight from atmospheric absorption features and must be considered in the atmospheric correction process, e.g. by spectrally interpolating the reflectance data.

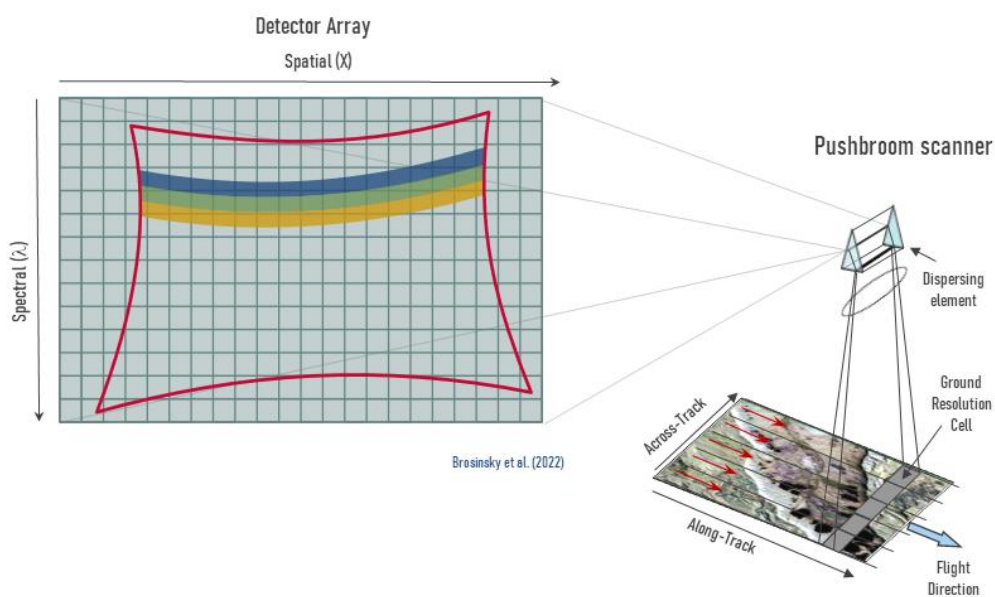


Figure 12 Spectral sensor non-uniformities – the “smile” effect.
Brosinsky et al. 2022

Thompson et al. (2018) provide a good overview on atmospheric retrieval focusing on imaging spectrometers.

This has been a lot of information! You might like to listen to Charly again summarizing the main preprocessing steps in the following video taken from our **Basic MOOC** (check out the section 1:23min – 3:37min):

VIDEO: Basic-20: Hands-on training: Data preprocessing



URL of the video: <https://youtu.be/drqFyMmyPI0>



Let us and your fellow students know who you are, what question(s) you are interested in, and for which research question you would like to use hyperspectral data in the [discussion forum](#) of this topic. There is a separate discussion forum for each topic of this course in the discussion section at EO-College.

Quiz: General introduction to preprocessing (simplified workflow)

Gain and offset are constant over time (single-choice)

- True
- False

Have a guess: The effect of geometric correction is usually more visible in ...

(single-choice)

- Airborne data
- Spaceborne data

What is considered in atmospheric correction? (multiple-choice)

- sun position
- keystone compensation
- atmospheric state
- terrain

Why is atmospheric correction important? (multiple-choice)

- Because it transforms digital numbers to top of atmosphere radiance
- Because it transforms surface reflectance to digital numbers
- Because it provides reflectance spectra representing the surface materials
- Because it generates surface reflectance that is transferable between scenes acquired at different dates or locations

3.2 The EnMAP product levels

In the previous chapter, we presented a rather simplified overview of a general preprocessing workflow. In reality, every sensor has its adopted workflow. Rigorous preprocessing can be a pretty complex process not as linear and simplified as presented. In this chapter, we want to provide you with a short definition of the official EnMAP data products and their **processing levels provided to the users. We describe how the different products reflect the preprocessing steps described above.** More detailed descriptions can be found in Storch et al. (2023). The Ground Segment at DLR EOC is responsible for handling the complex data preprocessing, ensuring data quality and to make the official products available to the users in compliance with the mission requirements. The following data products are available to the user community:

Level 1B (Systematic and Radiometric correction)

The Level 1B product represents top-of-atmosphere radiance (bandwise scaled with gain and offset provided in the metadata file). This product is radiometrically corrected, spectrally- and geometrically characterized, quality controlled, and annotated with preliminary pixel classification (usability mask). The auxiliary information (e.g., position and pointing values, interior orientation parameters) necessary for further processing is attached, but not applied. The Level 1B processor corrects the hyperspectral image for known effects, e.g., radiometric non-uniformities, and converts the system corrected data to physical at-sensor radiance values [mW/m²/sr/nm] based on the most up-to-date radiometric calibration values.

Level 1C (geometrically-corrected L1B data)

The Level 1C product represents georectified top-of-atmosphere radiance (bandwise scaled with gain and offset provided in the metadata file). This product is derived from the Level 1B product, which is subsequently geometrically corrected (orthorectified) and re-sampled to a specified grid. Auxiliary data for further processing are attached,

but not applied. The Level 1C processor creates orthoimages by direct georeferencing, utilizing an adequate digital elevation model. As far as possible/available, image-matching to reference images (Sentinel-2) improves the line-of-sight vectors and, therefore, increases the geometric accuracy of the orthoimages. The Level 1C processor orthorectifies image tiles from the VNIR and SWIR instrument independently.

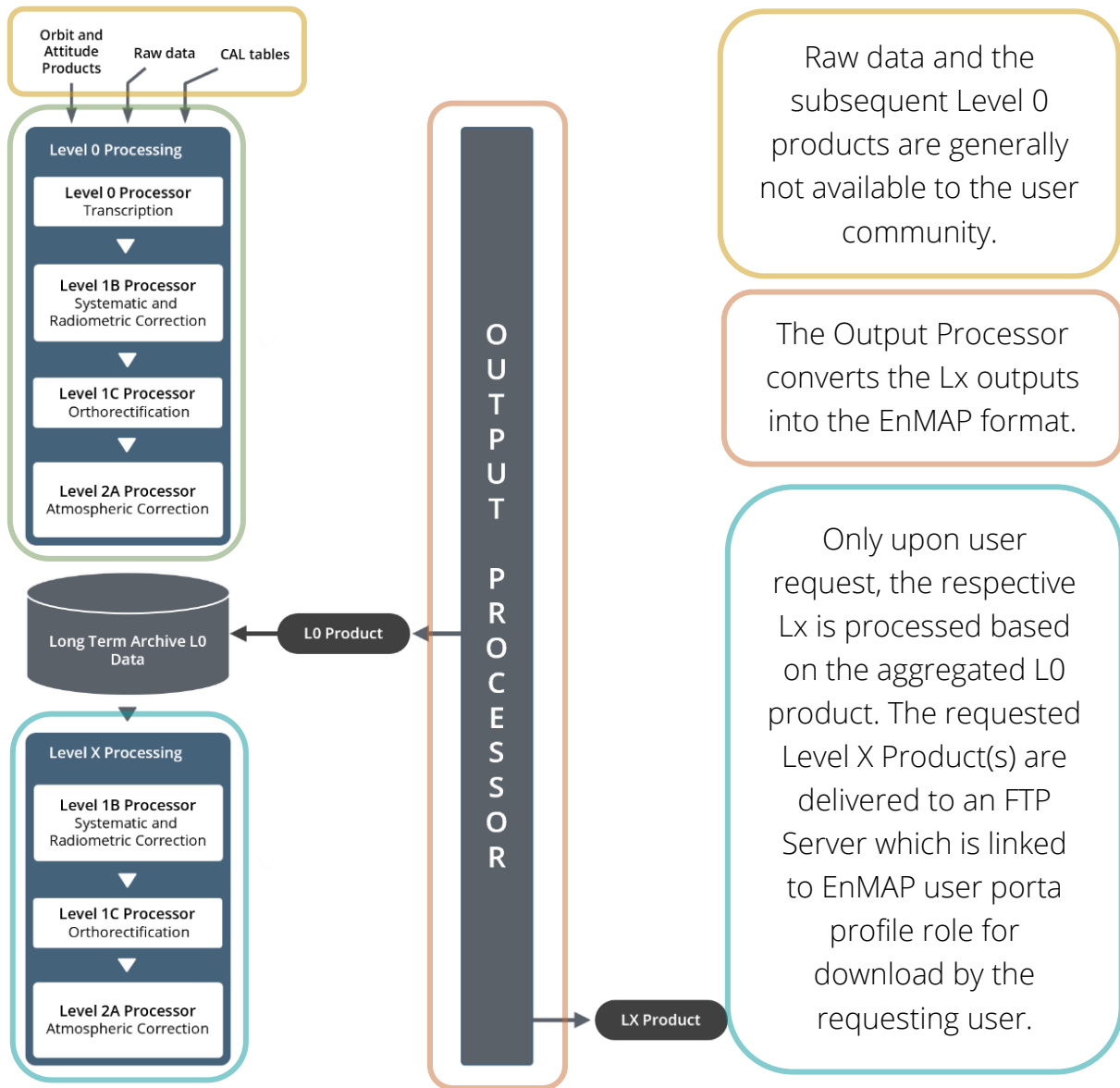
Level 2A (atmospherically-corrected L1C data)

The Level 2A processor converts the Level 1C products to surface reflectance [0-1]. For land and water applications a split procedure gives the user the possibility to select the best result according to the area of interest (land or water or combined). The atmospheric correction involves the detection (and correction) of haze and cirrus, estimation of aerosol optical thickness and columnar water vapor, and retrieval of surface reflectance after adjacency and terrain correction. For water surfaces, it involves in addition the generation of sun glint maps by identification of specular reflections. Auxiliary data for further processing is attached, but not applied. **Most applications are envisioned to use the Level 2A product for further analysis.**

Processing and delivery of Level 1B, Level 1C and Level 2A products are to be conducted by the EnMAP Ground Segment within a maximum of 6 days after completion of the corresponding downlink. The user can choose the image format (BSQ, BIL BIP, JPEG2000 or GeoTIFF), the atmospheric correction mode and the product level as well as several map projections (UTM, LAEA and WGS84). The metadata is always in Extensible Markup Language (XML) format. In addition to the data cube and metadata.xml, a quicklook and several quality masks (pixel, cloud, cirrus, haze, snow, classes) are delivered.

Okay, that still looked pretty linear and simple ... below, you can see a – still simplified – overview of EnMAP image preprocessing in reality. Basically, all raw data acquired by the sensor plus orbit and attitude information as well as calibration tables are used to process Level 0 to Level 2A data (Level 0 Processing, the top box of the graph below). This process is necessary to generate parameters that are not acquired but need to be generated or estimated from the data products themselves (e.g. quality masks, accurate and optimized trajectories and pointing, bad pixel interpolation, incorporate calibration tables). These parameters are then aggregated in the internal Level 0 product (not available to the public) and saved in the Long-Term Archive. Only upon user request, the respective Lx product (L1B, L1C or L2A) is processed based on the aggregated L0 product.

Interactive graph on EnMAP product levels. Available under this [LINK](#).



After the acquisition and transfer of the RAW data, a complete Level 0 – L2A Processing is conducted and auxiliary data to aggregate and derive all parameters necessary for rigorous preprocessing – some are known a priori but others are estimated from the data itself. All the aggregated information is stored in the L0 product which is stored in the Long Term Archive together with the auxiliary data attached.

The Level 0 product is not available to the user community.



Let us and your fellow students know who you are, what question(s) you are interested in, and for which research question you would like to use hyperspectral data in the [discussion forum](#) of this topic. There is a separate discussion forum for each topic of this course in the discussion section at EO-College.

Quiz: The EnMAP product levels

Which EnMAP product levels are available to the user community? (multiple-choice)

- Level 1B (Systematic and Radiometric correction)
- Level 0 (raw data)
- Level 1C (geometrically-corrected data)
- Level 2A (atmospherically-corrected data)

3.3 Data Quality

EnMAP product validation activities

Due to EnMAPs specific sensor design and its onboard calibration capabilities, the spectral and spatial uniformity and radiometric characterization of the instrument are of high quality. Nevertheless, the final quality of the data products is determined by the complex interaction of sensor specification, calibration, data acquisition, and preprocessing. An independent quality validation of the available data products ensures that the various requirements are fulfilled (Brell et al., 2021).

Radiometry	
Absolute	5%
Multitemporal	2.5 %
Inter-band/cross-sensor	no requirement
Geometry	
Absolute	+ - 1 pixel in case matching is possible or 1 +- 3 pixel
Multitemporal	not specified
Detector co-registration	20 % of a spatial pixel
Keystone	20 % of a spatial pixel
Image quality	
VNIR	SNR: > 500:1 @ 495 nm / 10 nm FWHM [@ Lref = 16.956 mW cm ⁻² sr ⁻¹ μm ⁻¹]
SWIR	SNR > 150:1 @ 2200 nm / 10 nm FWHM [@ Lref = 0.548 mW cm ⁻² sr ⁻¹ μm ⁻¹]
Spectral calibration	
CWL/FWHM	+ - 1 nm
Spectral stability	0.5 nm
Smile	< 20 % of a spectral pixel

Figure 13 Overview of the required Field-, Image-, and Model based validation methods/ parameters. Brell et al. (2021)

The product validation is performed during both commissioning and nominal mission phases to track the changes in data quality over time. All products and quality parameters are analyzed on a regular basis. After being intensively checked during the commissioning phase, validation activities will be performed at least twice a year for image-based tests of instrument parameters, and at least once a year for activities requiring field-based data, as long as no incidence in the mission performance or product quality is detected (Chabrillat et al., 2021). The validation activities are performed from an end-user perspective and independent from calibration and data quality control activities of the Ground Segment. Additionally, to validate the quality of EnMAP thematic mapping in the field of inland and coastal waters, agricultural, and bare Earth applications (top soils and mineral mapping) validation activities of derived bio- and geophysical products in a selection of “core test sites” take place (Chabrillat et al., 2021).

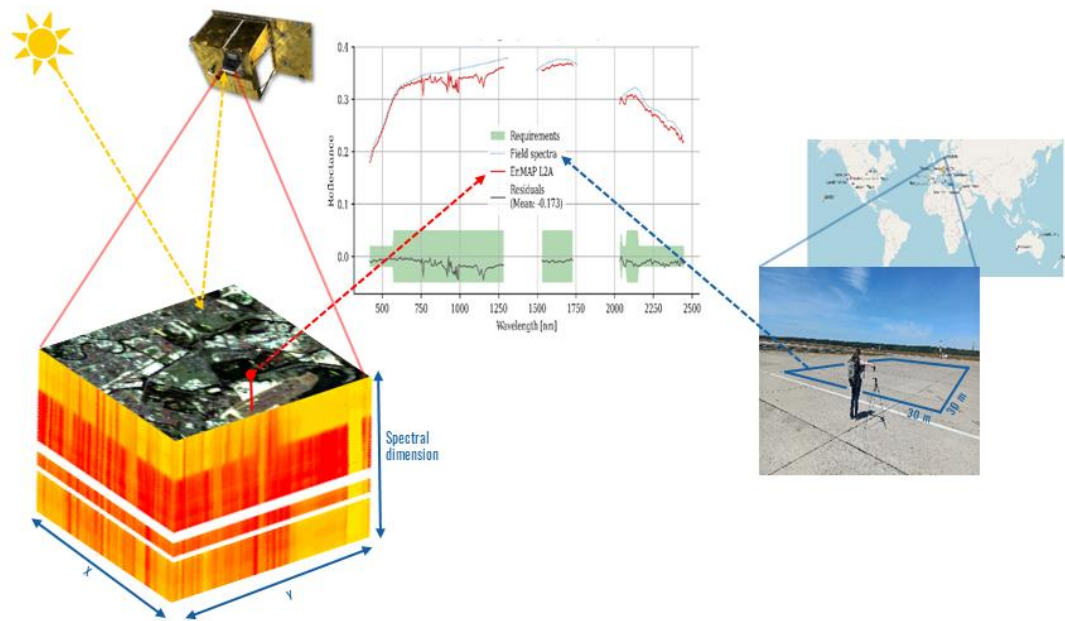


Figure 14 Validation of EnMAP surface reflectance spectra with in-situ reflectance spectra collected at Tegel airport, Berlin, Germany. Foto courtesy of R. Milewski and K. Ward, figure courtesy of M. Brell. EnMAP satellite with permission of DLR Space Agency



Some details on the EnMAP product validation

As described by Chabrillat et al. (2021) based on Brell et al. (2021):

“The focus of the **validation of the Level L1B Product lies on radiometric parameters** (e.g. absolute and relative radiometric accuracy, signal-to-noise ratio (SNR), spatially-coherent artifacts (striping), bad and dead pixels), **spectral parameters** (e.g. spectral response function, spectral channel position, smile) **and spatial parameters** (keystone and modulation transfer function). Different methods that use image based analysis techniques as well as in situ reference measurements are applied, whereas we rely on the cooperation with experienced international collaborators, established calibration/ validation (CAL/VAL) sites and networks (e.g. CEOS, RadCalNet, AERONET, HYPERNETS), pseudo invariant calibration sites (PICS), image data from other missions and own hyperspectral airborne campaigns. In addition, we are attempting to measure the moon.

The **validation of the L1C Product** (geometric performance) includes the **analysis of the absolute and relative spatial accuracy**, the detector co-registration and the band-to-band co-registration. This is achieved by using image-based techniques that compare information from reference images of higher spatial accuracy, data from other optical satellite missions and EnMAP data.

The **validation of the L2A Product** includes the analysis of the reflectance accuracy, the analysis of the L2A quality mask layers as well as atmospheric aerosol and water vapor contents derived by the atmospheric correction processor. In-situ reference measurements from extensive science-oriented field- and airborne campaigns as well as from selected core test sites in Germany and from international collaborators over different targets of interest are used. In contrast to L1B radiometric sites the validation will be performed under normal EnMAP acquisition conditions.”

Even more details can be found in **Storch et al. (2023)**.



Let us and your fellow students know who you are, what question(s) you are interested in, and for which research question you would like to use hyperspectral data in the [discussion forum](#) of this topic. There is a separate discussion forum for each topic of this course in the discussion section at EO-College.

Quiz: Data Quality

During the EnMAP product validation, which product levels require field-based in-situ reference measurements? (multiple-choice)

- Validation of the Level 1B Product (systematic and radiometric correction)
- Validation of the Level 1C Product (geometric correction)
- Validation of the Level 2A Product (atmospheric correction)

3.4 Resources section: 'Hyperspectral Image Preprocessing over LAND'

In this section, we have assembled resources used for the creation of this lesson that we recommend for further reading as they provide a lot more detail. Please remember that this selection is not a complete overview of all resources – if you think an important resource is missing, let us and your fellow students know (e.g. in the discussion forum).



Sources and further reading

EnMAP mission and operations

- Chabrillat, S., Brell, M., Segl, K., Foerster, S., Guanter, L., Schickling, A., Storch, T., Honold, H.-P., Fischer S. (2021). **The EnMAP satellite – Mission status and science preparatory activities.** Proceedings, 2021 IEEE International Geoscience and Remote Sensing Symposium (IGARSS). <https://doi.org/10.1109/IGARSS47720.2021.9553627>
- Storch, T., Honold, H. P., Chabrillat, S., Habermeyer, M., Tucker, P., Brell, M., Ohndorf, A., Wirth, K., Betz, M., Kuchler, M., Mühle, H., Carmona, E., Baur, S., Mücke, M., Löw, S., Schulze, D., Zimmermann, S., Lenzen, C., Wiesner, S., Aida, S., Kahle, R., Willburger, P., Hartung, S., Dietrich, D., Plesia, N., Tegler, M., Schork, K., Alonso, K., Marshall, D., Gerasch, B., Schwind, P., Pato, M., Schneider, M., de los Reyes, R., Langheinrich, M., Wenzel, J., Bachmann, M., Holzwarth, S., Pinnel, N., Guanter, L., Segl, K., Scheffler, D., Foerster, S., Bohn, N., Bracher, A., Soppa, M. A., Gascon, F., Green, R., Kokaly, R., Moreno, J., Ong, C., Sornig, M., Wernitz, R., Bagschik, K., Reintsema, D., La Porta, L., Schickling, A. Fischer, S. (2023). **The EnMAP imaging spectroscopy mission towards operations.** Remote Sensing of Environment, Volume 294, 2023, 113632, ISSN 0034-4257, <https://doi.org/10.1016/j.rse.2023.113632>.

Product validation and preprocessing procedures

- Brell, M., Guanter, L., Segl, K., Scheffler, D., Bohn, N., Bracher, A., Altenburg Soppa, M., Foerster, S., Storch, T., Bachmann, M., Chabrillat, S. (2021). **The EnMAP Satellite –Data Product Validation Activities.** Proceedings, 11th Workshop on Hyperspectral Imaging and Signal Processing: Evolution in Remote Sensing (WHISPERS), Amsterdam, Netherlands. <https://doi.org/10.1109/WHISPERS52202.2021.9484000>
- Brosinsky, A., Brell, M., Livens, S., Segl, K., Kuester, T., Kaufmann, H., Guanter, L., Foerster, S. (2022). **Imaging spectroscopy sensor technologies – How imaging systems are defined and how they acquire data.** HYPERedu, EnMAP education initiative, German Centre for Geosciences GFZ; originally published March 2022, 2nd revision February 2023.
- Jensen, J. R. (2007). **Remote Sensing Of The Environment: An Earth Resource Perspective.** 2nd Edition, Pearson.

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- Muller, R., Lehner, M., Muller, R., Reinartz, P., Schroeder, M., Vollmer, B. (2002). **A program for direct georeferencing of airborne and spaceborne line scanner images.** International Archives of Photogrammetry Remote Sensing and Spatial Information Sciences 34, 148–153.
 - Richter, R., Schläpfer, D. (2002). **Geo-atmospheric processing of airborne imaging spectrometry data.** Part 2: atmospheric/topographic correction. International Journal of Remote Sensing 23, 2631–2649.
 - Schläpfer, D., Richter, R. (2002). **Geo-atmospheric processing of airborne imaging spectrometry data.** Part 1: Parametric orthorectification. International Journal of Remote Sensing 23, 2609–2630. <https://doi.org/10.1080/01431160110115825>
 - Thompson, D.R., Guanter, L., Berk, A., Gao, B.-C., Richter, R., Schläpfer, D., Thome, K.J. (2018). **Retrieval of Atmospheric Parameters and Surface Reflectance from Visible and Shortwave Infrared Imaging Spectroscopy Data.** Surveys in Geophysics. <https://doi.org/10.1007/s10712-018-9488-9>
 - Atmospheric / Topographic Correction for Airborne Imagery (ATCOR-4 User Guide, Version 7.4.0, September 2021)

Final Quiz Lesson 3

Which instruments are carried by EnMAP? (multiple-choice)

- TIR
- SWIR
- VNIR

Which radiance terms do actually exist? (multiple-choice)

- Top-of-Atmosphere-Radiance
- Top-of-Bottom-Radiance/ at-surface reflectance
- Bottom-of-Atmosphere-Radiance

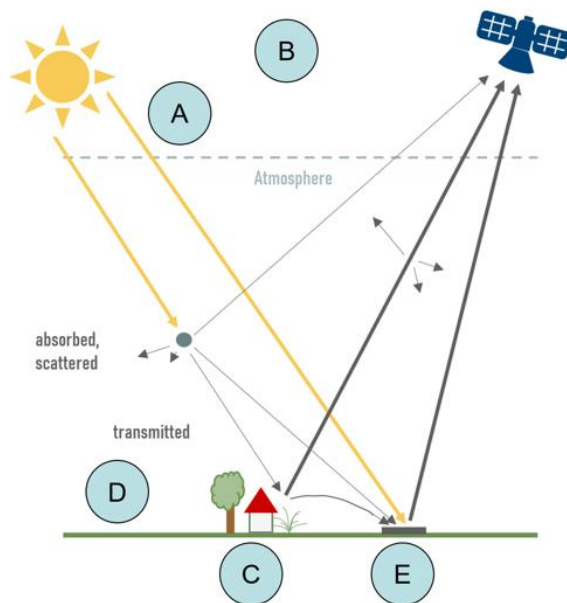
Place the steps of a very simplified preprocessing workflow in the correct order (as described in this lesson).

- Radiometric correction Assign the number
- Atmospheric correction Assign the number
- Geometric correction Assign the number

Which data products are available to the user community? (multiple-choice)

- Level-1B: Systematic and Radiometric Correction
- Level-1C: Geometrically corrected Level-1B data
- Level-2A: Atmospherically corrected Level-1C data
- Level-3D: Raw data

Assign the terms.



- A Choose an element
- B Choose an element
- C Choose an element
- D Choose an element
- E Choose an element

Why is atmospheric correction important? (multiple-choice)

- Because it transforms digital numbers to top of atmosphere radiance
- Because it transforms surface reflectance to digital numbers
- Because it provides reflectance spectra representing the surface materials
- Because it generates surface reflectance that is transferable between scenes acquired at different dates or locations

The analysis of the reflectance accuracy, the analysis of quality mask layers as well as atmospheric aerosol and water vapor contents derived by the atmospheric correction processor are part of which validation? (single choice)

- The validation of the L1B Product
- The validation of the L1C Product
- The validation of the L2A Product

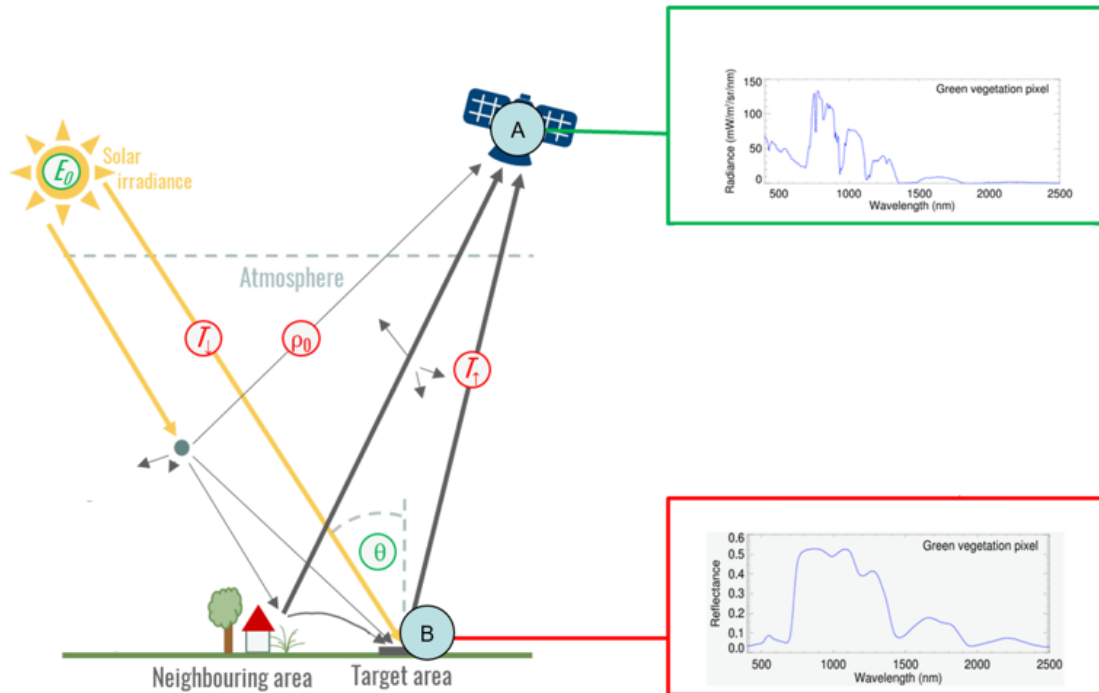
What is considered in atmospheric correction? (multiple-choice)

- sun position (CORRECT)
- keystone compensation
- atmospheric state (CORRECT)
- terrain (CORRECT)

Gain and offset are constant over time (single choice)

- True
- False (CORRECT)

Which spectrum depicts Top-of-Atmosphere radiance and which one Bottom-of-Atmosphere/ Surface Reflectance? Assign the terms.



- A Choose an element
- B Choose an element

4 EnMAP Data Access

Welcome to this lesson on EnMAP data access! Now that you have gained insights on the standard steps for preprocessing satellite images, the different available EnMAP product levels and data quality in the previous lesson, we want to introduce you to the [EnMAP Data Access Portal](#) and how to acquire EnMAP imaging spectroscopy data yourself! But first, Charly will explain the learning objectives of this lesson in the video below.

VIDEO: Preprocessing-04: Intro Lesson 4



URL of the video: <https://youtu.be/-8KrVnxMf9U>

Let's move on with the first topic of this lesson!

4.1 The EnMAP Data Access Portal & User Registration and User Role Assignment

As you have seen in the previous lesson, preprocessing is applied, as well as required, for all satellite data. Before you get to actively preprocess imaging spectroscopy data yourself in our hands-on tutorial in the next lesson – **how do we actually acquire this data?** – we have prepared a step-by-step instruction, through which Charly will guide you.

The EnMAP Mission

After **years of preparation**, **EnMAP** finally launched into space on April 1st 2022! Approximately 3 weeks later, on April 27th, the first light image was captured. A strip of ~ 30 kilometres in width and 180 kilometres in length was recorded over the Bosphorus in Turkey. The data was then downlinked and processed. Already this first image gave a glimpse of the high quality to be expected.



Figure 15 First light image, displaying the high-quality acquisition of typical spectral profiles.
DLR (CC BY-NC-ND 3.0)

True colour image of a subset of about 30 km x 54 km (red: 637 nm, green: 547 nm, blue: 461 nm) on the left side and a false-colour composite of the same subset (red: 2340 nm, green: 1570 nm, blue: 1210 nm) on the right side.

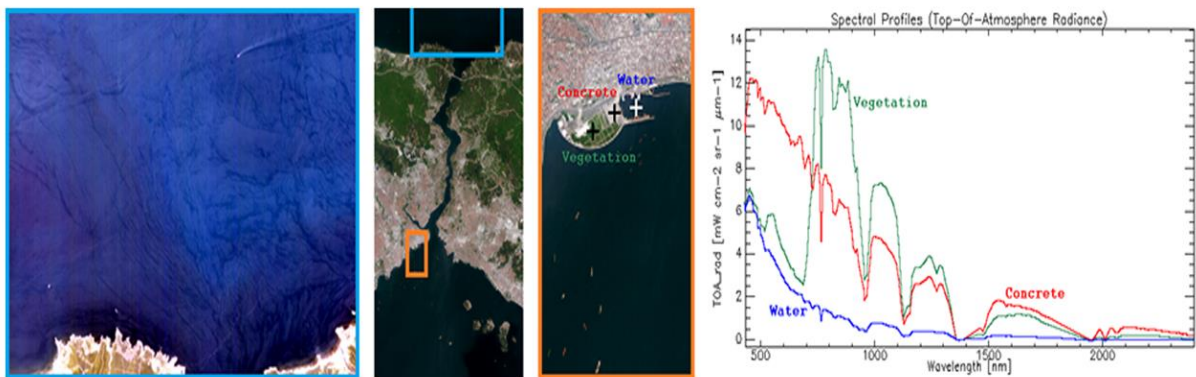


Figure 16 Low noise and disturbing image fringes in the extensive dynamic range and the acquisition of typical spectral profiles. DLR (CC BY-NC-ND 3.0)

After about seven months of the commissioning phase, during which data was calibrated and validated, EnMAP started the Operational Phase on November 2nd 2022 and the EnMAP Data Access Portal was opened.

The EnMAP Data Access Portal

The **EnMAP Data Access Portal** includes two main entry points: the **EnMAP Instrument Planning Portal** and the **EOWEB® GeoPortal**. On the EnMAP Instrument Planning Portal users can register, submit proposals, and plan and request future orders. The EOWEB® GeoPortal contains the full EnMAP Data archive.

Users can access EnMAP data using two different options:

- Users can request acquisitions through the **EnMAP Instrument Planning Portal (IPP)**. The portal includes the Proposal Portal for proposal submission by all scientific users responding to an Announcement of Opportunity (AO) and the Observation Request Portal providing planning support of observation requests and submission of future orders.
- Users can search, process, and order data from the archive catalogue from the German Satellite Data Archive (D-SDA) through the **EOWEB® GeoPortal**.

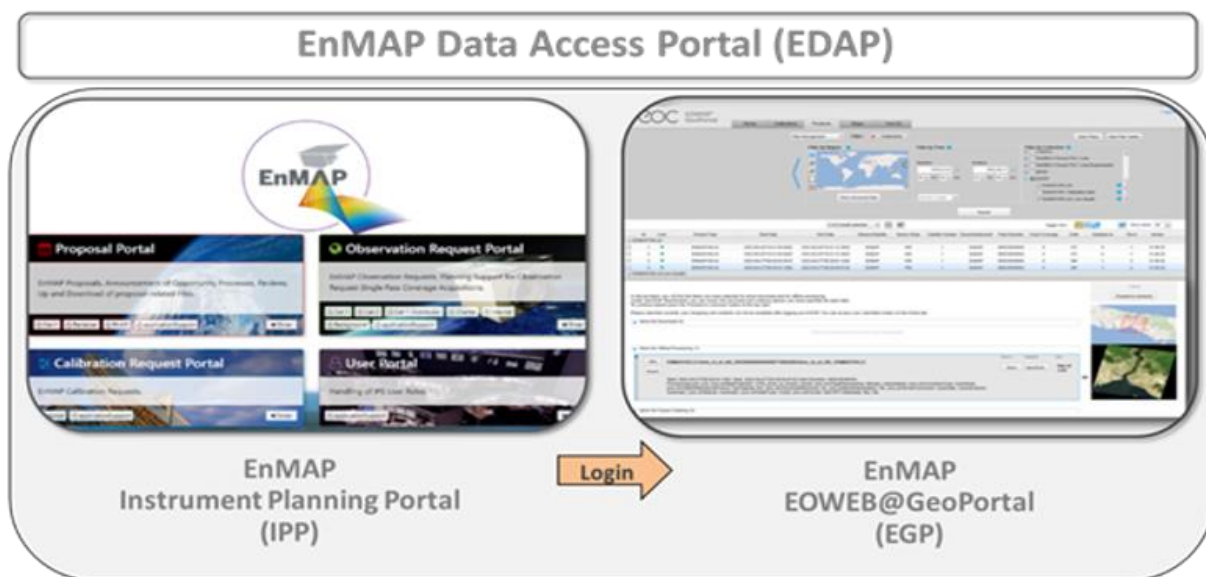
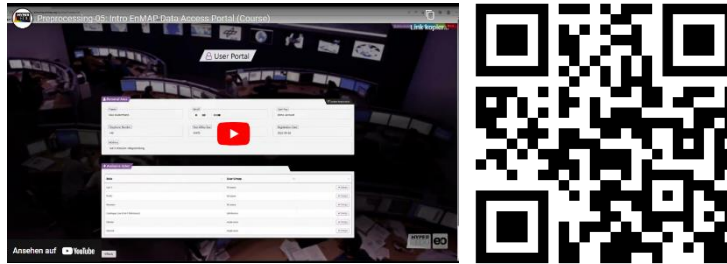


Figure 17 EnMAP Data Access Portal.

Copyright © 2012-2023 EnMAP at Earth Observation Center EOC of DLR

In the first video you will get a short overview of the EnMAP mission and learn step by step how to register for the EnMAP Data Access Portal. You will get to know the four different sub-portals of the **Instrument Planning Portal** – namely the **Proposal Portal**, the **Calibration Request Portal**, the **Observation Request Portal** and the **User Portal** – and how to assign to certain user roles.

VIDEO: Preprocessing-05: Intro EnMAP Data Access Portal (Course)

URL of the video: <https://youtu.be/d3Xq6KL8fol>**Quiz: The EnMAP Data Access Portal & User Registration and User Role Assignment****Which data products are available to the user community?** (multiple-choice)

- The scientific Cat-1 User
- The Reviewer
- The commercial Cat-2 User
- The Catalogue (Cat-1 distributor) User

What cannot be done within the Instrument Planning Portal? (single-choice)

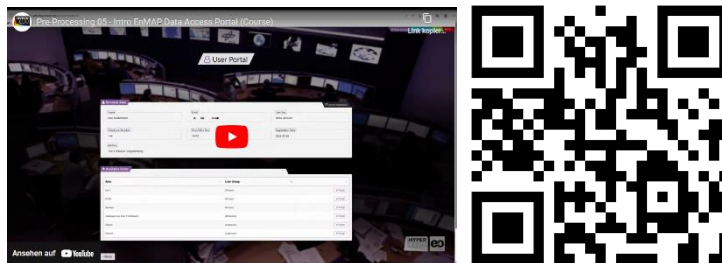
- The submission of new proposals
- The submission of future observation requests
- The ordering of archive data
- The search for similar proposals

4.2 The Proposal Portal

Now that you have gained an overview of the Instrument Planning Portal, the different portals and the user role assignment, we are one step closer to acquire new EnMAP data!

The second video will introduce you to the different sections of the **Proposal Portal**, where you create and submit new proposals. Here, you can additionally find information on how to search for other submitted proposals, browse for users requesting data in similar regions or check the statuses of your own proposals.

VIDEO: Preprocessing-06: The Proposal Portal (Course)



URL of the video: https://youtu.be/zaboH_zUaql

Quiz: The Proposal Portal

Within the proposal submission process – which topics can a user select from?
(multiple-choice)

- Vegetation
- Hazards/ Risks
- Geology /Soil
- Snow/Ice
- Energy/ Industry
- Atmosphere
- Methods
- Water
- Calibration /Validation

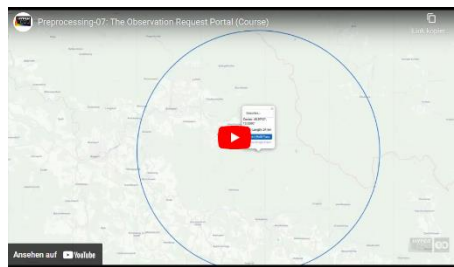
4.3 The Observation Request Portal

Congratulations – you have now submitted your first proposal! Depending on the current number of requests, the EnMAP review team will check your proposal within 2-10 days. You will be informed by e-mail on the status of your submitted proposal.

As we are using a demo proposal in our step-by-step instruction, the EnMAP review team has kindly accepted it – we can thus continue with the next step: the submission of future observation requests.

The third video shows how to submit future observation requests in order to acquire new EnMAP data in the **Observation Request Portal**. Furthermore, you will be introduced to the basic concept and the different steps of the Planning Support & Ordering, as well as different ordering strategies. Afterwards you will be well prepared to adjust search parameters based on your use case and order data for your own observation site!

VIDEO: Preprocessing-07: The Observation Request Portal (Course)



URL of the video: <https://youtu.be/9fNf-okqv54>

Quiz: The Observation Request Portal

Which are the global parameters that need to be set prior to selecting an AOI?
(multiple-choice)

- Product Type
- Product Format
- Processing Mode
- Proposal Title

Choose the two parameters that need to be defined by the users prior to ordering. (multiple-choice)

- Cloud Coverage
- Water Reflection Intensity
- Sunlint

Which product types can users choose from? (multiple-choice)

- Level 1B
- Level 1C
- Level 1D
- Level 2A

What kind of status can your proposal have following the review process?
(multiple-choice)

- Accepted
- Accepted with Modifications
- Rejected

4.4 EnMAP Data Archive at EOWEB® GeoPortal

Depending on the use case, some users might not require data above specific observation sites, or they are lucky and data was already acquired based on another's request – those, as well as all other interested users can browse the data archive for suitable EnMAP imagery.

The fourth video will demonstrate how to access the EOWEB GeoPortal, where you can search, process, and order data from the German Satellite Data Archive (D-SDA).

You will learn which search parameters and filters are available and how to select, order, and finally download data products. In addition, you will learn where to find your own ordering history. For the purpose of our hands-on training in the following lesson, we will search and download a dataset specifically provided for this purpose!

VIDEO: Preprocessing-08: The EOWEB GeoPortal (Course)



URL of the video: <https://youtu.be/C-OBORVp1L8>

Quiz: EnMAP Data Archive at EOWEB® GeoPortal

Which filters can be applied by the users when browsing the EOWEB® GeoPortal? (multiple-choice)

- Filter by Sensor
- Filter by Region
- Filter by Time
- Filter by Resolution

Data from which other sensors, inter alia, can be accessed through the EOWEB® GeoPortal? (multiple-choice)

- DESIS
- Landsat-8
- Sentinel-1
- TANDEM-X

Where can users find further information on the ordering of EnMAP data or get help? (multiple-choice)

- The User Manual
- The documents provided at the EnMAP Data Access Portal
- The EnMAP help desk at email
- The EnMAP Data Access Portal screencasts, available at enmap.org

4.5 Resources section: 'EnMAP Data Access'

In this section, we have assembled resources used for the creation of this lesson that we recommend for further reading as they provide a lot more detail on the different topics. Please remember that this selection is not a complete overview of all resources – if you think an important resource is missing, let us and your fellow students know (e.g. in the discussion forum).



Sources and further reading

EnMAP Data Access Portal

- planning.enmap.org

EnMAP mission

- www.enmap.org
- Recording of Launch Event at DLR Space Agency on 1 April 2022 (in German):
<https://www.youtube.com/watch?v=OuusSryduns>

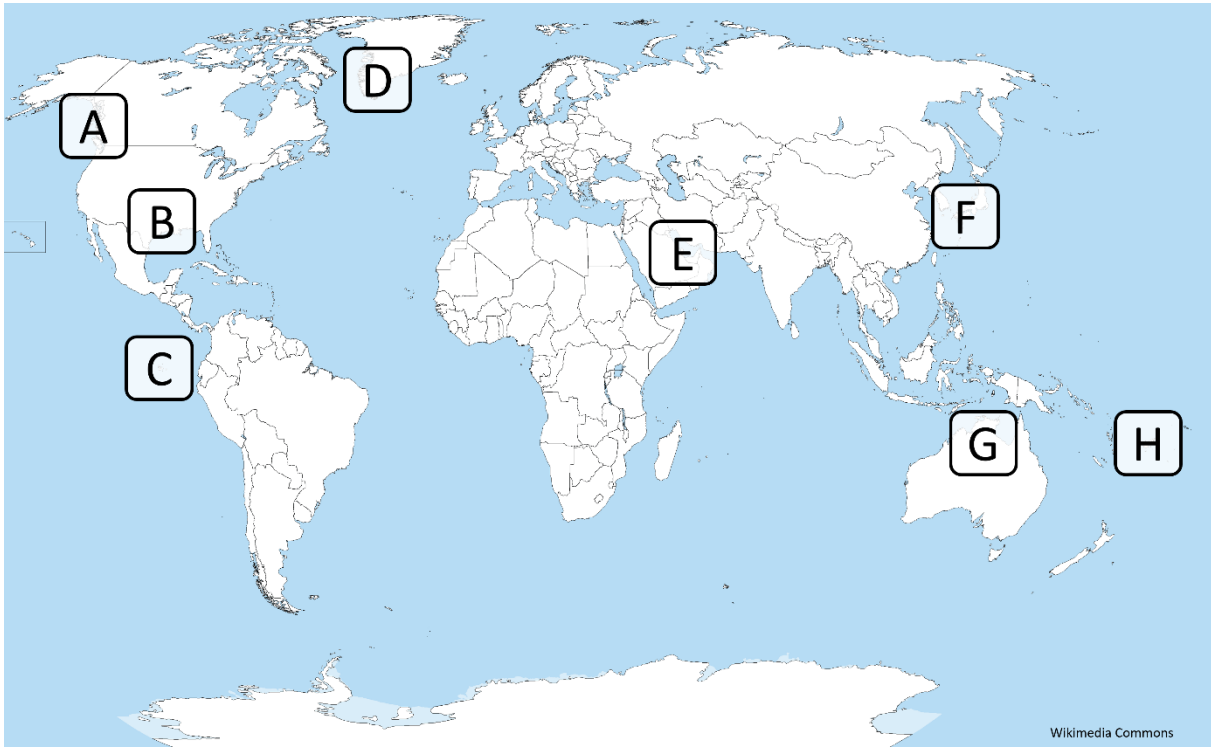
Additional data

- World Map: Wikimedia Commons
https://commons.wikimedia.org/wiki/File:A_large_blank_world_map_with_oceans_marked_in_blue.PNG

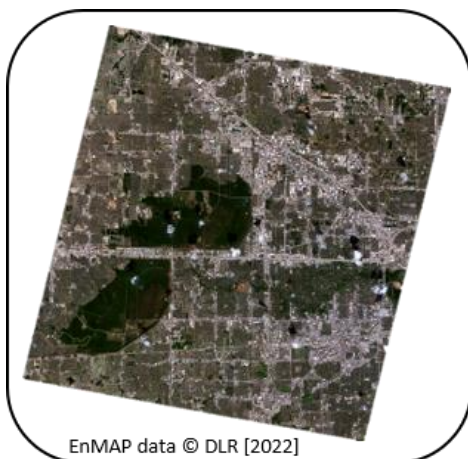
Final Quiz: Lesson 4

Before you start with the Final Quiz of this lesson, we have prepared a little game for you. Do you recognize the targets of these EnMAP scenes?

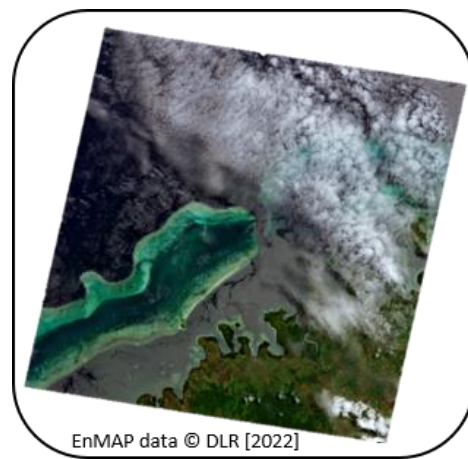
Choose the letter of the respective location of the EnMAP scene.



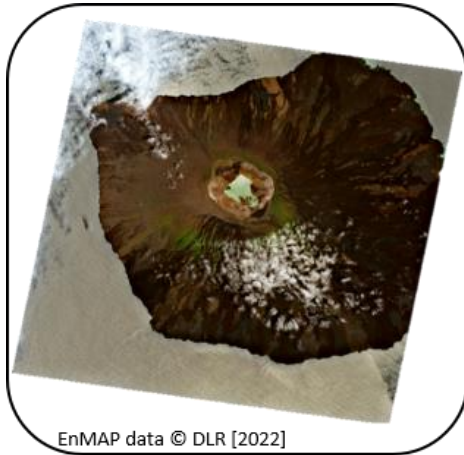
Choose a letter



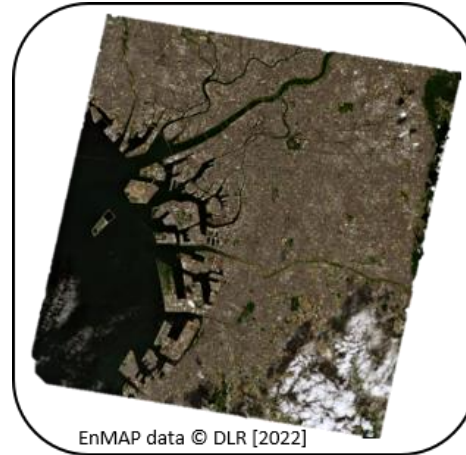
Choose a letter



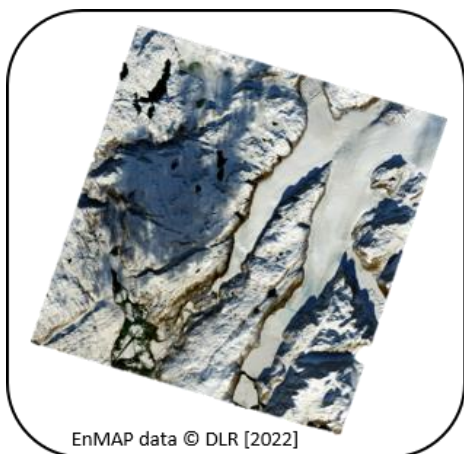
Choose a letter



Choose a letter



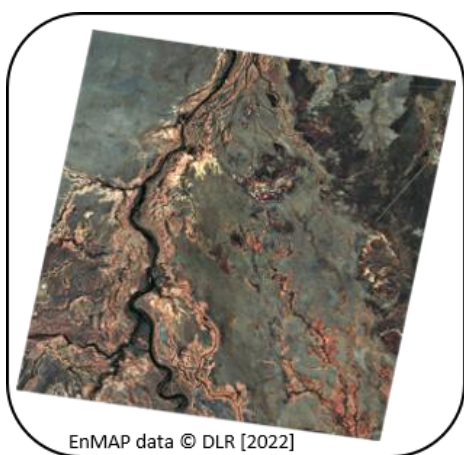
Choose a letter



Choose a letter



Choose a letter



Choose a letter



Which user roles are available for external users? (multiple-choice)

- The scientific Cat-1 User
- The Reviewer
- The commercial Cat-2 User
- The Catalogue (Cat-1 distributor) User

Which area was covered by EnMAPs' first light image? (single-choice)

- The area Berlin-Brandenburg, Germany
- The Bosphorus, Turkey
- The Provence, France
- The Great Lakes, USA

How many portals are part of the Instrument Planning Portal? (single-choice)

- 1
- 2
- 3
- 4

Data from which other sensors, inter alia, can be accessed through the EOWEB® GeoPortal? (multiple-choice)

- DESIS
- Landsat-8
- Sentinel-1
- TANDEM-X

What cannot be done within the Instrument Planning Portal? (single-choice)

- The submission of new proposals
- The submission of future observation requests
- The ordering of archive data
- The search for similar proposals

Which area of interest (AOI) was exemplarily used for the demo proposal?

(single-choice)

- The Machu Picchu National Park, Peru
- The Yosemite National Park, USA
- The National Park Bayerischer Wald, Germany
- The Serengeti National Park, Tanzania

Where can users find further information on the ordering of EnMAP data or get help? (multiple-choice)

- The User Manual
- The documents provided at the [EnMAP Data Access Portal](#)
- The EnMAP help desk at email
- The EnMAP Data Access Portal screencasts, available at [enmap.org](#)

In the Observation Request Portal: which parameters can be defined by the users prior to ordering? (multiple-choice)

- Cloud Coverage
- Water Reflection Intensity
- Sunlint

What is the pixel size of EnMAP data? (single-choice)

- 10 m x 10 m
- 20 m x 20 m
- 30 m x 30 m
- 40 m x 40 m

How many sensors does EnMAP carry? (single-choice)

- 2
- 3
- 5

5 Hands-On training

Hey, welcome to this lesson! As usual, it contains an expert-led **hands-on training exercise**, meaning you can actively participate in the exercises as in the [Mini-MOOC for Agricultural Applications](#), we will be working with the EnMAP-Box and for the very first time, we'll be working with **real EnMAP data!** The software and data can be downloaded for free and we will guide you step by step. Installation of the EnMAP-Box and active participation in any tutorial are not compulsory to pass this MOOC, however, for the best learning result we strongly encourage you to use this opportunity to “get your hands dirty”! As before, Charly will give you more details on the specific learning objectives in the video below.

VIDEO: Preprocessing-09: Intro Lesson 5



URL of the video: <https://youtu.be/BbW3CKT8xfU>

Let's move on with the first topic of this lesson!

5.1 Introduction to the EnMAP-Box

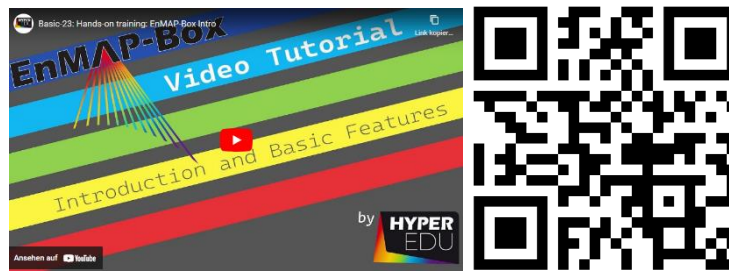
As Charly just explained, we will be using the “EnPT tool” within the EnMAP Box to learn how to process Level 1B EnMAP data to be ready for analyses. For active participation in the following exercises, you need to install the EnPT tool environment to your EnMAP box. This is a little different from the EnMAP Box installation you might be familiar with from previous MOOCs ... Detailed installation instructions can be found [here](#).

In case you have the EnMAP Box already installed and are familiar with the visualization tools, you can skip the rest of this topic and continue with Topic 5.2. For everyone else, we have produced the **following screencast to provide an introduction to working with the EnMAP-Box** and explain the **different visualization tools**. For detailed and up-to-date information on the EnMAP-Box

please visit the [documentation website](#), where you can also find a user manual as well as several application tutorials. Please refer to the installation website for information on the [latest supported QGIS version](#).

Data visualization

VIDEO: Basic-23: Hands-on training: EnMAP-Box Intro



URL of the video: <https://youtu.be/31FQ5zXl2Rw>



Let us and your fellow students know who you are and what question(s) you are interested in, in the [discussion forum](#) of this topic.

Quiz: Introduction to the EnMAP-Box

In the EnMAP-Box, you can visualize the following data types (multiple-choice)

- Raster data
- Vector data
- Spectral libraries

The EnMAP-Box is a great tool for hyperspectral data visualization and analyses ... (multiple-choice)

- ... as you can easily select which bands to combine in an RGB view of an image
- ... as image and vector data can be displayed together in the same “map view” panel
- ... as several “map view” panels can be spatially linked in side-by-side representations
- ... as spectral pixel information can be displayed as spectral profiles in a separate “spectral library” window

5.2 EnPT – the EnMAP processing tool

Okay, here we go. In the following screencast we will show you step by step how to explore EnMAP Level 1B data, run the EnPT tool to generate Level 2A data and observe the major differences between the two product levels.

If you haven't yet, you can install the EnPT tool environment for active participation. Detailed instructions can be found [here](#).

The required data can be downloaded from [here](#). Alternatively, if you participated actively in the previous lesson and already downloaded a L1B EnMAP scene from the portal, you could use that now! However, in addition to the EnMAP scene, EnPT benefits from a digital elevation model (DEM, freely available, e.g., from [SRTM](#), [Copernicus GLO-30](#) or [Terra-SAR-X](#)) as well as a reference image for image co-registration (e.g., Sentinel-2).

Get acquainted with Level 1B scene and produce Level 2A data with EnPT

VIDEO: Basic-23: Hands-on training: EnMAP-Box Intro



URL of the video: <https://youtu.be/WLw4xdBr3K0>



Let us and your fellow students know who you are and what question(s) you are interested in, in the [discussion forum](#) of this topic.

Quiz: EnPT – the EnMAP processing tool

Why is EnMAP Level 1B data not suitable for downstream remote sensing analyses? (multiple-choice)

- Actually, Level 1B is the most suitable product for downstream remote sensing analyses, especially for analysts with little experience
- Because the images are provided in sensor geometry, i.e., without coordinate reference system (CRS)
- Because the spectral information represents top-of-atmosphere radiance, separately scaled for each band (CORRECT)
- Because VNIR and SWIR images do not show the same spatial extent (offsets in along- and across-track direction)
- Because the spectral information is affected by various spatio-temporal effects, e.g., originating from the atmospheric state
- Due to some sensor-induced effects that are not directly visible (spectral smile, keystone, ...)

Which major differences between Level 1B and Level 2A data could be observed? (multiple-choice)

- The images have now different dimensions due to the geometric correction/orthorectification
- The VNIR and SWIR detector images have been merged so that their spectral information can now be used together
- Spatio-temporal varying interferences on the spectra have been corrected as far as possible, meaning they contain surface reflectance instead of top-of-atmosphere radiance information now
- Spatio-temporal varying interferences on the spectra have been corrected as far as possible, meaning they contain top-of-atmosphere reflectance instead of top-of-atmosphere radiance information now

5.3 Discussion of accuracy and limitations

EnPT represents an open-source alternative to the processing chain of the EnMAP Ground Segment and was developed at the GFZ Potsdam within the scientific preparation of the EnMAP mission. It is available as a standalone Python package or accessible via a graphical user interface as a plugin of the EnMAP-Box, as presented in the hands-on exercise. EnPT relies completely on open-source algorithms such as AROSICS (**A**utomated and **R**obust **O**pen-**S**ource **I**mage **C**o-**R**egistration **S**oftware, Scheffler et al., 2017; 2020), SICOR (Bohn et al., 2021), and POLYMER (HYGEOS; Steinmetz et al., 2011).



Interactive graph on EnMAP product levels. Available under this [LINK](#).

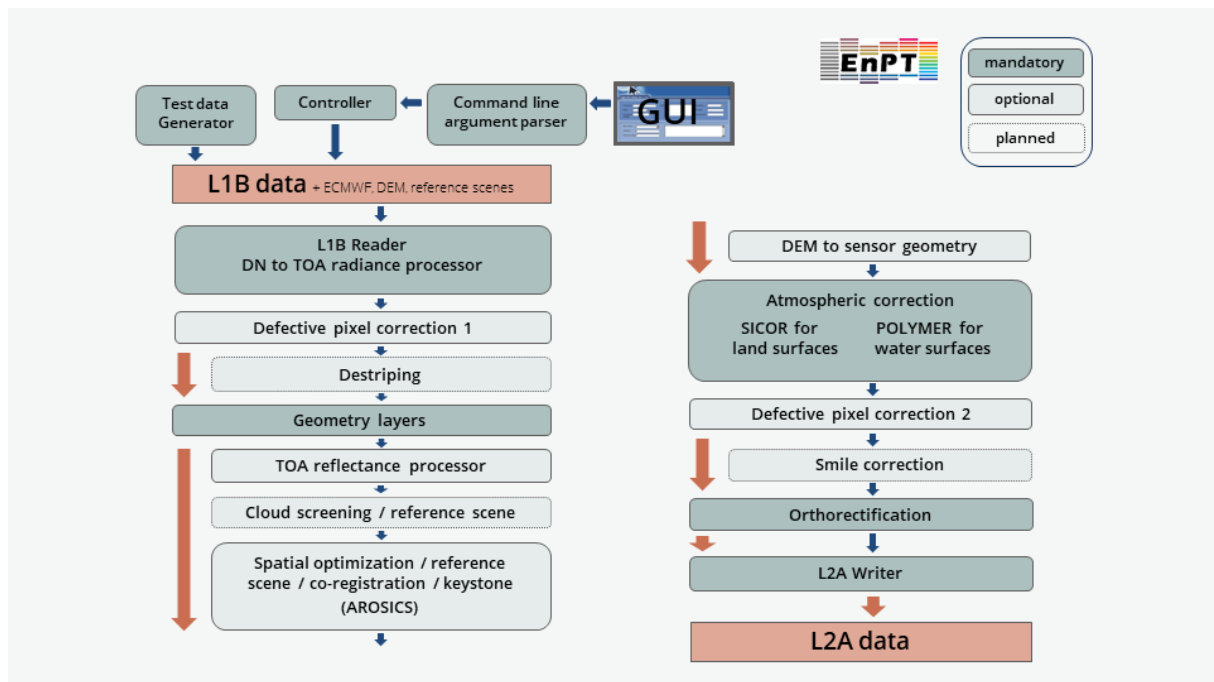


Figure 18 Processing workflow implemented in the EnMAP Processing Tool (EnPT). In courtesy of Daniel Scheffler

The transformation from sensor to map geometry is based on rational polynomial coefficients (RPC) and a user-provided digital elevation model. As an intermediate result for this, EnPT computes geometry layers for the VNIR and SWIR detectors, which are later used for orthorectification. EnPT offers an automatic detection and correction of spatial mis-registrations based on AROSICS (Scheffler et al., 2017). A dense grid of tie points is automatically generated with regard to a user-provided reference image. These tie points are then used to refine the previously computed geometry layers. Additionally, AROSICS is also used to refine the co-registration

between the VNIR and SWIR spectral cubes. The atmospheric correction based on SICOR and ACwater/POLYMER can be executed in three modes:

- Land mode: SICOR algorithm (Bohn et al., 2021) applied to all surfaces
- Water mode: ACwater/POLYMER (Soppa et al., 2021) applied to water only
- Combined mode: SICOR applied to land and ACwater/ POLYMER to water surfaces

SICOR (**S**ensor **I**ndependent atmospheric **COR**rection of optical Earth Observation data; Bohn et al., 2021) uses an Optimal Estimation (OE) approach based on the MODTRAN® Radiative Transfer Code and is available as a Python package on the Python package index (PyPI) and conda-forge. It features a simultaneous retrieval of atmospheric water vapor, surface liquid water, and ice path lengths by fitting absorption features at 940 and 1140 nm (Green et al., 2006; Bohn et al., 2020) as well as a SLIC Segmentation and an Empirical Line Solution (Thompson et al., 2022). The final product is a surface reflectance file. The output of water vapor, liquid water, and ice retrieval maps for the different processing modes is planned for the near future.

Alternatively, users can choose ACwater, a wrapper to run the POLYMER atmospheric correction algorithm for water pixels only. POLYMER is a spectral matching algorithm that obtains atmospheric and water signals simultaneously based on the complete available spectrum. Normalized water-leaving reflectance is retrieved for the spectral region of the VNIR, while the SWIR of water pixels is set to zero. In addition, POLYMER provides several products such as chlorophyll-a concentration.

EnPT is a very powerful tool. Thanks to the graphical user interface, the preprocessing is really easy to apply and allows a high level of customization enabling users to optimize the output exactly to their needs and study area requirements. In addition, its open source character offers the option to participate actively in code development and algorithm improvement. Planned future features and improvements include:

- the implementation of De-Striping
- the addition of SICOR retrieval maps to the EnPT Level 2A output (water vapor, liquid water, and ice)
- the implementation of an aerosol optical thickness (AOT) retrieval approach into atmospheric correction
- the implementation of the ISOFIT algorithm as an alternative atmospheric correction approach providing high-quality surface reflectance data as wells as additional accuracy information

- the improvement and fine-tuning of the co-registration module
- improvements of the water mask
- potentially the inclusion of cloud masks

However, please keep in mind that EnPT especially targets more experienced users who want to be able to customize the EnMAP Level-2 processing exactly to their needs or to produce parameter retrieval maps, which are not available from the standard preprocessing chain of the EnMAP ground segment. Other users, for whom it is sufficient to use the official EnMAP Level 2A product, are still encouraged to do so. Nevertheless, EnPT is a great tool, also in the didactic sense, which helps to understand what happens during preprocessing!



Let us and your fellow students know who you are and what question(s) you are interested in, in the [discussion forum](#) of this topic.

Quiz: Discussion of accuracy and limitations

What modes of atmospheric correction are available in EnPT? (multiple-choice)

- Land
- Water
- Combined Land and Water

What does the acronym AROSICS stand for? (single-choice)

- Advanced Rectification of Satellite Image Catalogues
- Automated and Robust Open-Source Image Co-Registration Software
- A really cool optical smart Image Correction System

5.4 Resources section: 'Hands-On training'

In this section, we have assembled resources used for the creation of this lesson that we recommend for further reading as they provide a lot more detail on the different topics. Please remember that this selection is not a complete overview of all resources – if you think an important resource is missing, let us and your fellow students know (e.g. in the discussion forum).



Sources and further reading

Introduction to the EnMAP-Box

- General information on the EnMAP-Box, a free and open source python plugin for QGIS: https://www.enmap.org/data_tools/enmapbox/
- Download, documentation and tutorials of and with the EnMAP-Box: <https://enmap-box.readthedocs.io/>

EnPT – the EnMAP processing tool

- EnPT – The EnMAP Processing Tool – **Code Repository**: https://git.gfz-potsdam.de/EnMAP/GFZ_Tools_EnMAP_BOX/EnPT
- EnPT – The EnMAP Processing Tool – **Documentation**: https://enmap.git-pages.gfz-potsdam.de/GFZ_Tools_EnMAP_BOX/EnPT/doc/

Software

- General information on the EnMAP-Box, a free and open source python plugin for QGIS: https://www.enmap.org/data_tools/enmapbox/
Download, documentation and tutorials of and with the EnMAP-Box: <https://enmap-box.readthedocs.io/> ; <https://artmtoolbox.com/>

Discussion of accuracy and limitations

- Bohn, N., Guanter, L., Kuester, T., Preusker, R., Segl, K. (2020). **Coupled Retrieval of the Three Phases of Water from spaceborne Imaging Spectroscopy Measurements**. Remote Sens. Environ., 242, 111708. <https://doi.org/10.1016/j.rse.2020.111708>
- Bohn, N., Scheffler, D., Brell, M., Segl, K. (2021). **SICOR – Sensor Independent Atmospheric Correction** (0.18.0). Zenodo. <https://doi.org/10.5281/zenodo.5973187>

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- Green, R. O., T. H. Painter, D. A. Roberts, and J. Dozier (2006). **Measuring the expressed abundance of the three phases of water with an imaging spectrometer over melting snow.** Water Resour. Res., 42, W10402. <https://doi.org/10.1029/2005WR004509>
 - Scheffler, D., Hollstein, A., Diedrich, H., Segl, K., Hostert, P. (2017). **AROSICS: An Automated and Robust Open-Source Image Co-Registration Software for Multi-Sensor Satellite Data.** Remote Sensing. 2017; 9(7): 676. <https://doi.org/10.3390/rs9070676>
 - Scheffler, D. (2020). **AROSICS: An Automated and Robust Open-Source Image Co-Registration Software for Multi-Sensor Satellite Data.** Zenodo. Jan. 31, 2020. doi: [10.5281/zenodo.3742909](https://doi.org/10.5281/zenodo.3742909).
 - Soppa, M. A., Silva, B., Steinmetz, F., Keith, D., Scheffler, D., Bohn, N., & Bracher, A. (2021). **Assessment of polymer atmospheric correction algorithm for hyperspectral remote sensing imagery over coastal waters.** Sensors, 21(12), 4125. <https://doi.org/10.3390/s21124125>
 - Steinmetz, F., Deschamps, P.-Y., Ramon, D. (2011). **Atmospheric correction in presence of sun glint: application to MERIS.** Optics Express, vol. 19, no. 10, pp. 9783–9800, May 2011, <https://doi.org/10.1364/oe.19.009783>
 - Thompson, D. R., Bohn, N., Brodrick, P. G., Carmon, N., Eastwood, M. L., Eckert, R., Fichot, C. G., Harringmeyer, J. P., Nguyen, H. M., Simard, M., Thorpe, A. K. (2022). **Atmospheric Lengthscales for Global VSWIR Imaging Spectroscopy.** J. Geophys. Res. - Biogeo., 127, 6, e2021JG006711. <https://doi.org/10.1029/2021JG006711>.

Final Quiz: Lesson 5

In the EnMAP-Box, you can visualize the following data types (multiple-choice)

- Exclusively EnMAP data but in all levels (L1B, L1C, L2A)
- Spectral libraries
- Raster data
- Vector data

The EnMAP-Box is a great tool for hyperspectral data visualization and analyses ... (multiple-choice)

- ... as you can easily select which bands to combine in an RGB view of an image
- ... as image and vector data can be displayed together in the same “map view” panel
- ... as several “map view” panels can be spatially linked in side-by-side representations
- ... as spectral pixel information can be displayed as spectral profiles in a separate “spectral library” window

Which EnMAP Processing Levels are available? (multiple-choice)

- L1B (systematically and radiometrically corrected)
- L1C (geometrically corrected)
- L2A (atmospherically corrected)
- L2B (additional maps, e.g. cloud and snow cover maps)

What are differences between L1B and L2A data? (multiple-choice)

- While L1B images are provided in sensor geometry, L2A are in map geometry with coordinate reference system (CRS)
- While the spectral information of L1B represents top-of-atmosphere radiance, L2A data represent bottom of atmosphere reflectance
- While in L1B they are separate files that do not show the same spatial extent, in L2A data, VNIR and SWIR images are geometrically aligned
- Unlike L1B, L2A is affected by sensor-induced effects that are not directly visible (spectral smile, keystone, ...)

EnPT is available ... (multiple-choice)

- As a standalone Python package
- As part of the commercial image processing software ENVI
- via a graphical user interface as a plugin of the EnMAP-Box
- as default in QGIS, no additional installations are required

What modes of atmospheric correction are available in EnPT? (multiple-choice)

- Land
- Water
- Combined Land and Water

What does the acronym SICOR stand for? (single-choice)

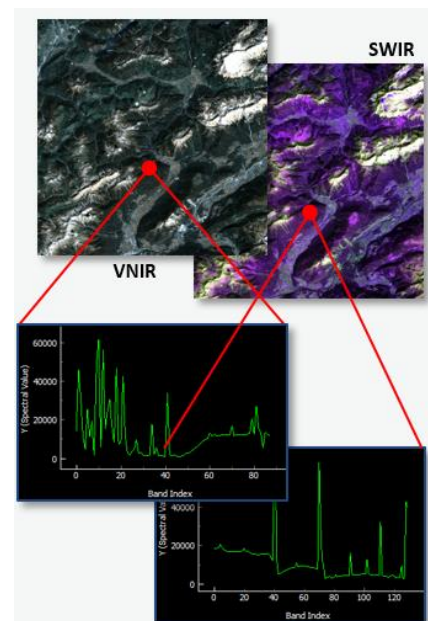
- Sensor Independent geometric CORrection
- Super-fast Image CORrection System
- Sensor Independent atmospheric CORrection of optical Earth Observation data

After preprocessing with EnPT, the EnMAP L2A products ... (single choice. Tip: The answer is in the video)

- ... contains 134 bands from both the VNIR and SWIR sensor
- ... contains 155 bands from both the VNIR and SWIR sensor
- ... contains 206 bands from both the VNIR and SWIR sensor
- ... contains 222 bands from both the VNIR and SWIR sensor

The following image shows ... (single-choice)

- An EnMAP scene in L1B
- An EnMAP scene in L1C
- An EnMAP scene in L2A



Who is the use of EnPT recommended for? (multiple-choice)

- All users, as the official L2A product is not very good (WRONG)
- Experienced users who want to be able to customize the EnMAP Level-2 processing exactly to their needs or to produce parameter retrieval maps not available from the ground segment (CORRECT)
- Inexperienced users who want to understand what happens during preprocessing (CORRECT)

6 Goodbye!

Well done! You've learned a lot about EnMAP data access and image preprocessing techniques in the past lessons. **Let's move on with the final survey!** The survey helps us to improve this course as well as future ones and will take you about 2 minutes. Afterwards it will get serious...we want to test your knowledge with the Final Quiz!

6.1 Final User Survey

Thank you for taking the time to answer our final survey! The feedback provided by earlier participants really helped to provide additional information where requested and to improve the entire course. We are aiming to regularly review your answers and update the course accordingly. You can access the [Link](#) to this course once you have enrolled to it.

6.2 Final Exam

Here we go, below you find the final quiz. If you've payed close attention in the previous lessons, you should be able to answer them easily. But even if you don't (answer easily), you have unlimited attempts to pass so don't get nervous. Unlike our other MOOCs, you did not need to pass any quiz to continue the lessons until here. However, **if you want** to complete this course and **receive a certificate and diploma supplement**, you need to pass this final quiz.

In this final quiz we have prepared 20 questions for you. Remember, you have unlimited attempts to pass the quiz. Once you've completed the quiz with more than 70 % of answers correct you'll get your certificate of completion along with a diploma supplement document describing the course contents!! Fingers crossed!

Oh ... and don't forget to say goodbye!

Final Quiz

Gain and offset are constant over time (single-choice)

- True
- False

What is considered in atmospheric correction? (multiple-choice)

- Sun position
- Keystone compensation
- Atmospheric state
- Terrain

Why is atmospheric correction important? (multiple-choice)

- Because it transforms digital numbers to top of atmosphere radiance
- Because it transforms surface reflectance to digital numbers
- Because it provides reflectance spectra representing the surface materials
- Because it generates surface reflectance that is transferable between
- Scenes acquired at different dates or locations

Which EnMAP product levels are available to the user community? (multiple-choice)

- Level 1B (Systematic and Radiometric correction)
- Level 0 (raw data)
- Level 1C (geometrically-corrected data)
- Level 2A (atmospherically-corrected data)

Which user roles are available for external users? (multiple-choice)

- The scientific Cat-1 User
- The Reviewer
- The commercial Cat-2 User
- The Catalogue (Cat-1 distributor) User

What cannot be done within the Instrument Planning Portal? (single-choice)

- The submission of new proposals
- The submission of future observation requests
- The ordering of archive data
- The search for similar proposals

Which area was covered by EnMAPs' first light image? (single-choice)

- The area Berlin-Brandenburg, Germany
- The Bosphorus, Turkey
- The Provence, France
- The Great Lakes, USA

How many portals are part of the Instrument Planning Portal? (single-choice)

- 1
- 2
- 3
- 4

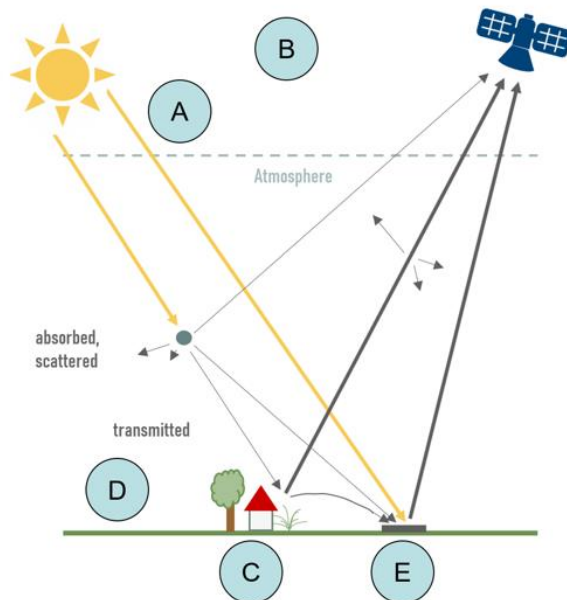
Which instruments are carried by EnMAP? (multiple-choice)

- TIR
- SWIR
- VNIR

Order the steps of a very simplified preprocessing workflow.

- | | |
|------------------------|-------------------|
| Radiometric correction | Assign the number |
| Atmospheric correction | Assign the number |
| Geometric correction | Assign the number |

Assign the terms.



- A Choose an element
- B Choose an element
- C Choose an element
- D Choose an element
- E Choose an element

The EnMAP-Box is a great tool for hyperspectral data visualization and analyses ... (multiple-choice)

- ... as several "map view" panels can be spatially linked in side-by-side representations
- ... as image and vector data can be displayed together in the same "map view" panel
- ... as you can easily select which bands to combine in an RGB view of an image
- ... as spectral pixel information can be displayed as spectral profiles in a separate "spectral library" window

What modes of atmospheric correction are available in EnPT? (multiple-choice)

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- Water
- Combined Land and Water

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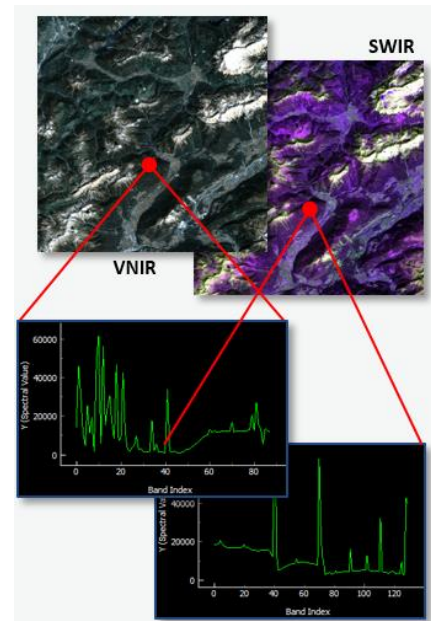
After preprocessing with EnPT, the EnMAP L2A products ... (single-choice. Tip:

The answer is in the video)

- ... contains 134 bands from both the VNIR and SWIR sensor
- ... contains 155 bands from both the VNIR and SWIR sensor
- ... contains 206 bands from both the VNIR and SWIR sensor
- ... contains 222 bands from both the VNIR and SWIR sensor

The following image shows ... (single-choice)

- An EnMAP scene in L1B
- An EnMAP scene in L1C
- An EnMAP scene in L2A



Who is the use of EnPT recommended for? (multiple-choice)

- All users, as the official L2A product is not very good
- Experienced users who want to be able to customize the EnMAP Level-2 processing exactly to their needs or to produce parameter retrieval maps not available from the ground segment
- Inexperienced users who want to understand what happens during preprocessing

Which city is visible in the hands-on exercise? (single-choice)

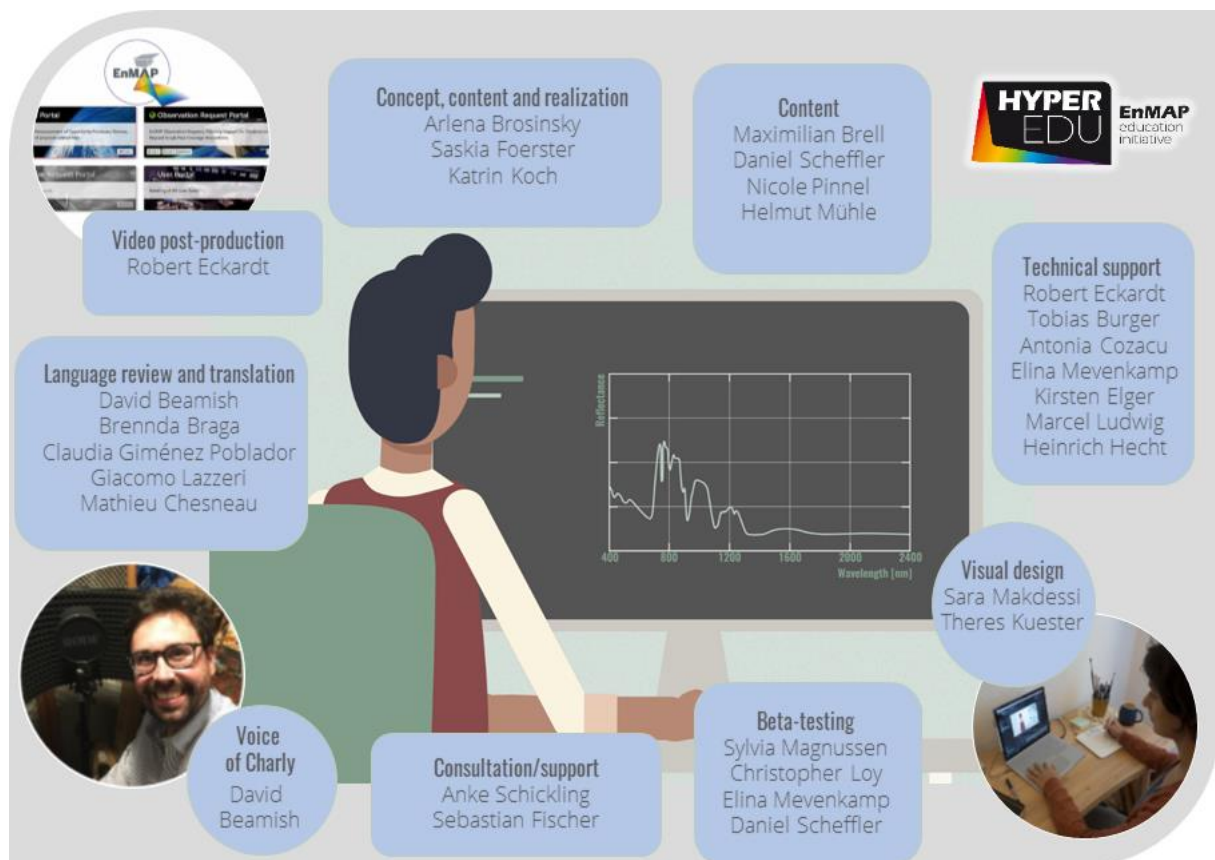
- Bamako, Mali
- Berlin, Germany
- Warsaw, Poland
- Brisbane, Australia

What kind of spatial resolution does one EnMAP tile have? (single-choice)

- 10 m x 10 m
- 20 m x 20 m
- 30 m x 30 m
- 40 m x 40 m

6.3 Goodbye

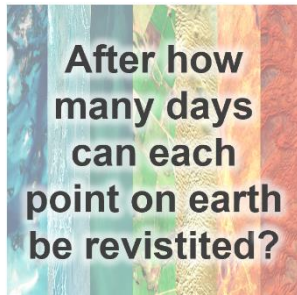
Thank you for completing the entire MOOC on EnMAP data access and image preprocessing techniques! We hope you had as much fun participating as we did creating this course (and a comparably steep learning curve) and that you will become an active member of the hyperspectral community! You know, the data is complex and we need a lot of experts ...



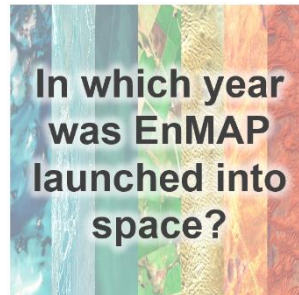
We have prepared a little game for you – check out **The EnMAP Memory Game!**

Below you get an adapted version of the EnMAP Memory Game for this Offline version of the course. You can access the interactive Memory Game on EnMAP product levels under this [LINK](#).

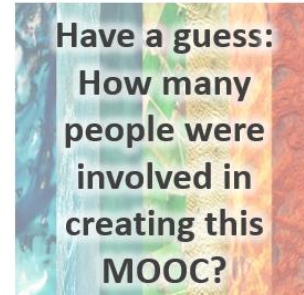
A



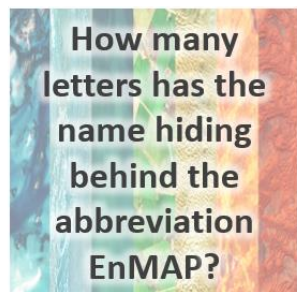
B



C



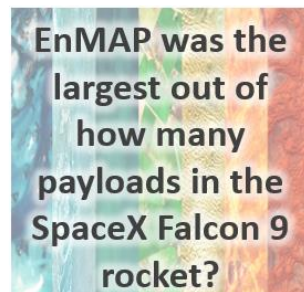
D



E



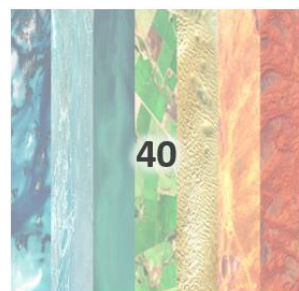
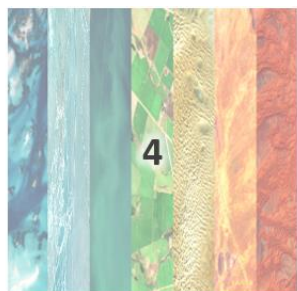
F



Choose the letter

Choose the letter

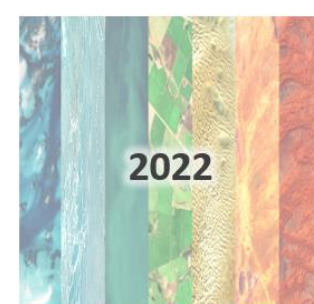
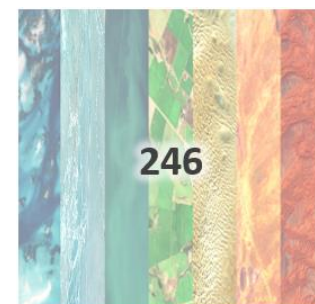
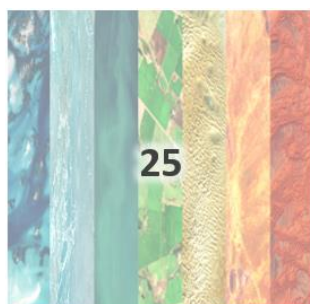
Choose the letter



Choose the letter

Choose the letter

Choose the letter



If you still want to learn more, check out the resource sections of the lessons where we have tried to link a lot of extra material and further reading. If you want to practice, download EnMAP data, install the EnMAP-Box (if you haven't done so yet) and check out the other tutorials. Also, stay tuned for our follow-up MOOCs.