



EXERCISE 4 – TUTORIAL

Optical remote sensing using ESA Copernicus' data: image metadata, image resolution (spectral, spatial, temporal and radiometric resolution), color compositions and spectral indices, using SNAP software

1 | Exercise outline

In this exercise, we will:

- Gain understanding of image metadata and resolution concepts, including spectral, spatial, temporal, and radiometric resolution, and how these aspects influence data quality and usability
- Learn about optical remote sensing using data from the ESA's Copernicus program. Key focus areas include the types of sensors and platforms employed, from multi-spectral to hyper-spectral instruments
- Explore practical examples of using Copernicus data for environmental monitoring and management

2 | Background

The exercise involves exploring Sentinel data products, specifically focusing on optical Sentinel-2 imagery of the High Tatras, Slovakia, obtained from the Dataspace Copernicus Open Access Hub.

Sentinel data products are distributed in a Sentinel-specific variation of the Standard Archive Format for Europe (SAFE) format, containing essential information about the imagery. This includes metadata, which provides details such as acquisition time, sensor geometry, and geographic location. Utilizing SNAP software, users can access and browse this metadata.

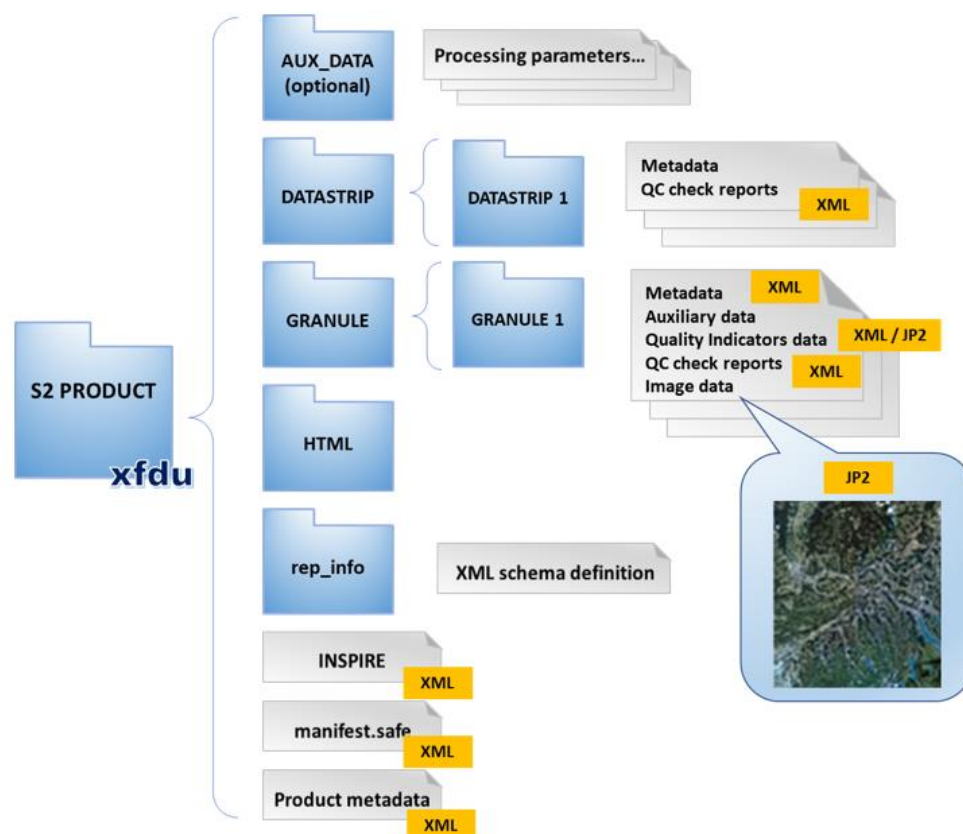
The spatial resolution of satellite imagery, crucial for discerning details on Earth's surface, varies across bands, with higher resolutions capturing finer details. Sentinel-2 bands offer different spatial resolutions tailored to specific features, enabling effective Earth observation. Spectral resolution refers to a sensor's ability to distinguish between wavelengths, with Sentinel-2's Multi-Spectral Instrument (MSI) capturing imagery across 13 spectral bands. Radiometric resolution, denoting the level of detail encoded in each pixel, is vital for discerning subtle variations in energy. Sentinel-2 boasts a radiometric resolution of 12 bits per pixel, enhancing its capacity for precise data capture. Temporal resolution, dictating how frequently a satellite revisits and captures images of the same area, is significant for monitoring environmental changes over time. Sentinel-2 satellites provide a combined revisit time of approximately 5 days, facilitating timely responses to dynamic environmental conditions.

Additionally, the exercise involves creating colour compositions and spectral indices like NDVI from the Sentinel-2 product to assess vegetation health. This comprehensive approach enables users to gain insights into Earth's dynamics and environmental parameters for various applications, including precision agriculture and disaster monitoring.

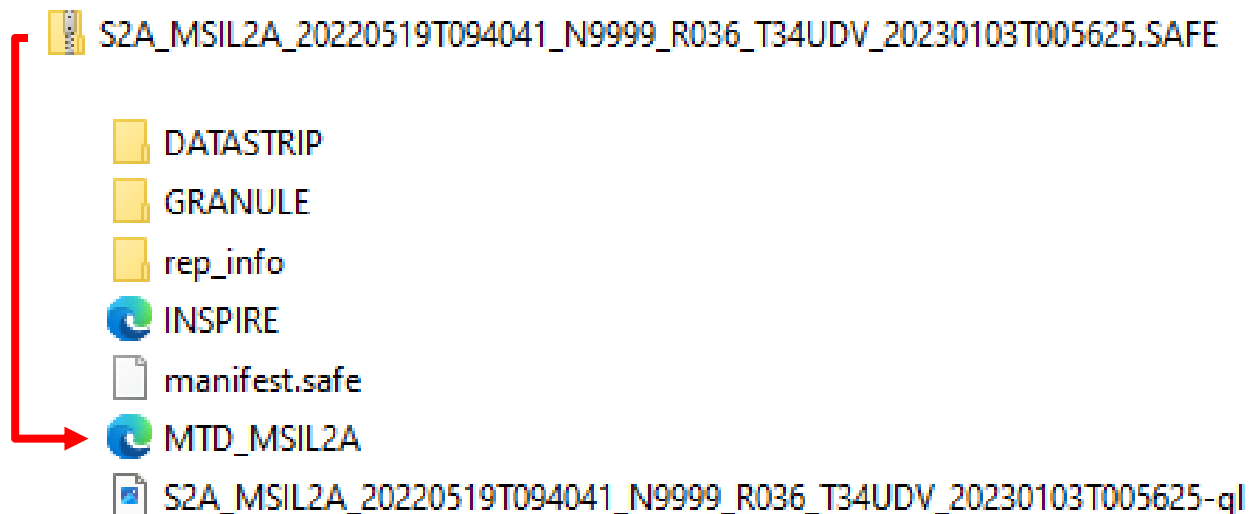
3 | Image metadata

Sentinel data products refer to a directory folders that contain a collection of information and are distributed using a Sentinel-specific variation of the Standard Archive Format for Europe (SAFE) format specification. It includes:

- A product metadata file in XML format, detailing the physical structure and content of the product (e.g. MTD_MSIL2A).
- A manifest.safe file, which contains general product information in XML format.
- A DATASTRIP subfolder containing information at the datastrip level.
- A GRANULE subfolder containing image data (granules/tiles) in JPEG2000 format, along with quality indicators such as quality masks and reports.
- An AUX_DATA subfolder containing auxiliary files that may be embedded in the product.
- A rep-info subfolder containing XSD schemas describing the product components.
- An INSPIRE XML file, which is a metadata file based on the INSPIRE Metadata regulation.
- An HTML subfolder containing a product presentation file for easy display of the main content of the product.



Navigate to the folder for this exercise and take a look at the structure of the Sentinel-2 product yourself.



Metadata, as commonly understood, refers to "data about the data." In the context of satellite imagery, metadata refers to the information describing these images, including details such as the time of acquisition, the geometry of the sensor at that time, the specific geographic location depicted in the image.

Double-click on „MTD_MSIL2A“ file inside Sentinel-2 product to open it

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3.1. SNAP - Open and explore product

We can also open the metadata using SNAP software and browse them. For this exercise, we will use Sentinel-2 L2A image of the High Tatras, Slovakia, downloaded from the Dataspace Copernicus Open Access Hub [https://dataspace.copernicus.eu/].

On the Copernicus dataspace website, metadata can be found next to each searched product. Clicking on the information icon displays a more detailed preview of each product

The screenshot shows the Copernicus Browser interface. The search results list three Sentinel-2 L2A products. The first product is highlighted with a red box:

- Product ID: S2A_MSIL2A_20220519T094041_N9999_R036_T34UEV_20221227T230336.SAFE
- Mission: SENTINEL-2
- Instrument: MSI
- Size: 1214MB
- Sensing time: 2022-05-19T09:40:41.024Z

A red arrow points from this product to a larger view of its metadata:

- Product ID: S2A_MSIL2A_20220519T094041_N9999_R036_T34UEV_20221227T230336.SAFE
- Mission: SENTINEL-2
- Instrument: MSI
- Size: 1214MB
- Sensing time: 2022-05-19T09:40:41.024Z

A box labeled "Metadata information" has arrows pointing to the information icon in the metadata view and the "PRODUCT INFO" panel below:

PRODUCT INFO

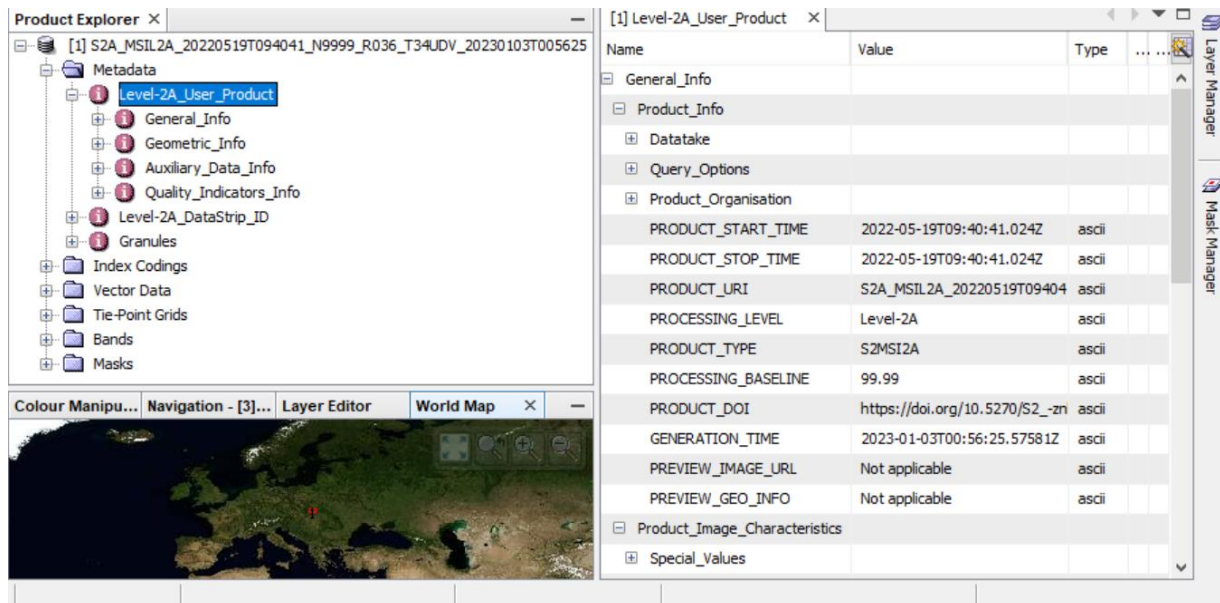
ATTRIBUTES	
Summary	
Name:	S2A_MSIL2A_20220519T094041_N9999_R036_T34UEV_20221227T230336.SAFE
Size:	1214MB
Sensing time:	2022-05-19T09:40:41.024Z
Platform short name:	SENTINEL-2
Instrument short name:	MSI
Product	
Instrument	

PREVIEW

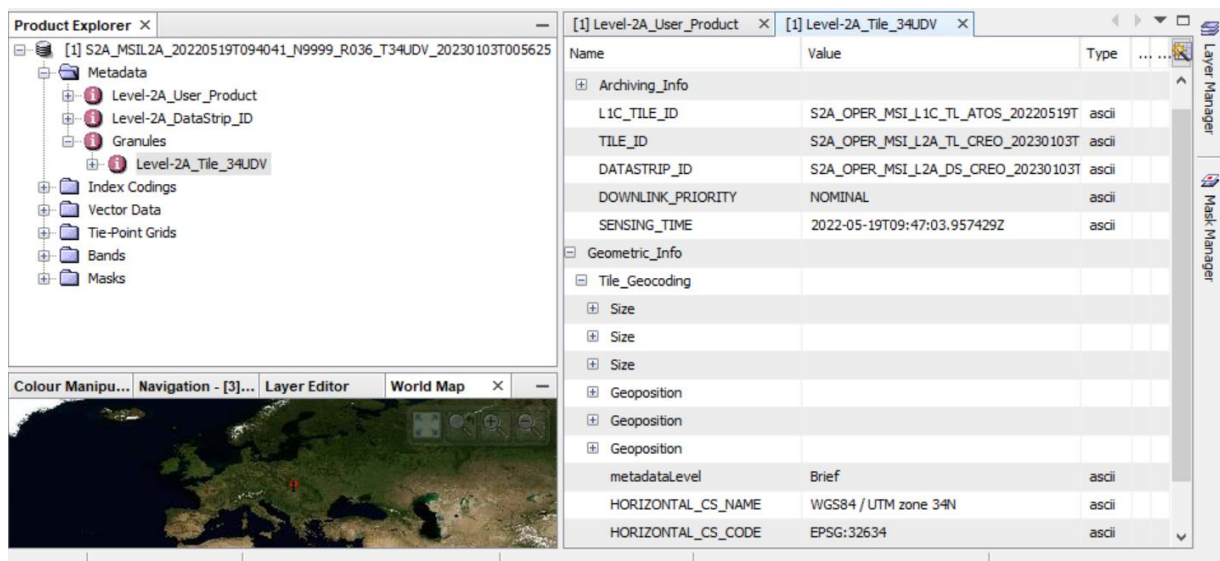
Open SNAP Desktop, click Open Product and open downloaded product (unzipped) by double click on the metadata „MTD_MSIL2A.xml“ inside the folder. The opened products will appear in Product Explorer window.

S2A_MSIL2A_20220519T094041_N9999_R036_T34UDV_20230103T005625.SAFE

To access the metadata information within the product, double-click on the product in the Product Explorer to reveal the directories – open Metadata directory – select Level-2 User Product by double click on it, so it opens in a new window. Explore the basic information on image product.



To obtain information on granules, e.g. sensing time, projection, coordinates, etc. Visualize also granules for the tile.



4 | Image resolution

Resolution influences the usability of data collected by a sensor, and it can differ based on factors such as the satellite's orbit and sensor configuration. When evaluating a dataset, it's important to consider four types of resolution: spatial, spectral, radiometric and temporal.

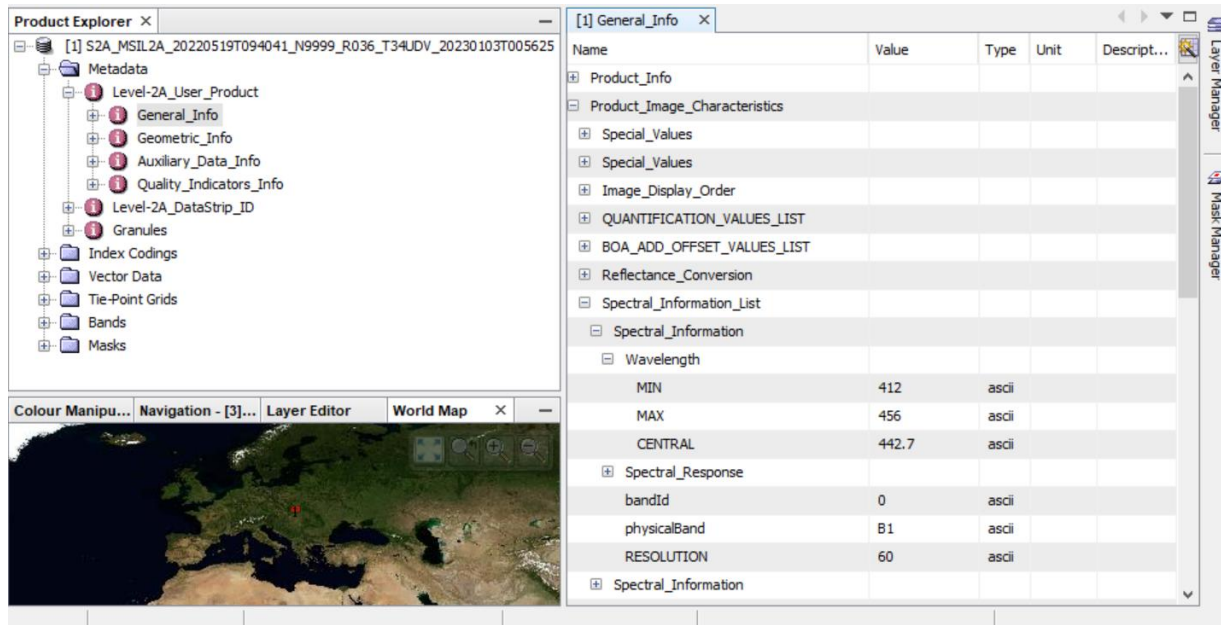
Spatial resolution

Spatial resolution is defined by the size of each pixel within a digital image and the area on Earth's surface represented by that pixel.

For instance, most bands captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) possess a spatial resolution of 1 km, with each pixel representing a ground area of 1 km x 1 km. Additionally, MODIS includes bands with finer spatial resolutions of 250 m or 500 m. A lower number indicates a finer resolution, allowing for greater detail to be discerned. In the provided image, you can observe the variance in pixelation between a 30 m/pixel image (left), a 100 m/pixel image (center), and a 300 m/pixel image (right).



To check the spatial resolution of the Sentinel-2 bands, open Metadata directory – select General info under Level-2 User Product by double click on it, so it opens in a new window. Go to Product Image Characteristics – Spectral Information and have a look at spectral wavelenghts and resolutions of individual bands.



The spatial resolution of Sentinel-2 bands varies depending on the specific spectral band. Sentinel-2 offers a variety of spectral bands with different spatial resolutions:

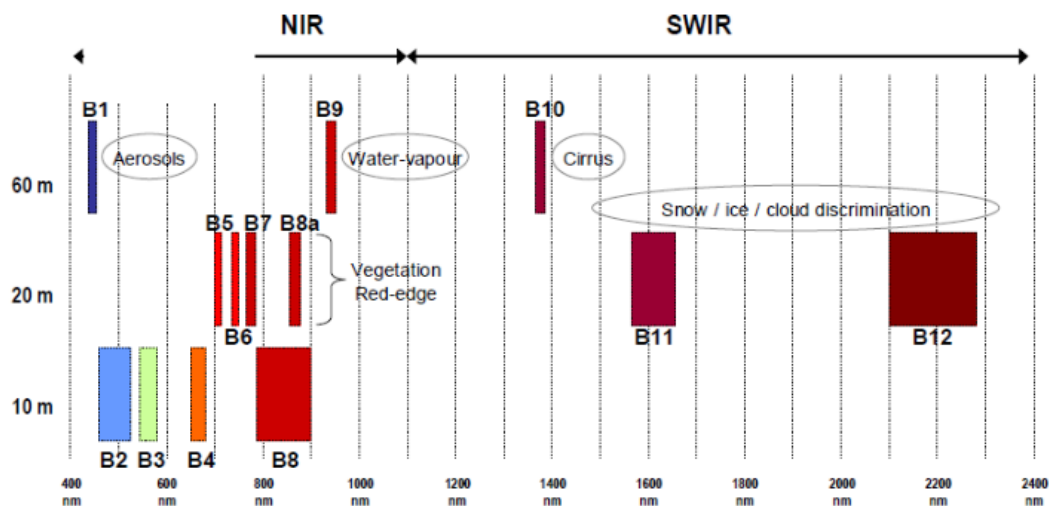
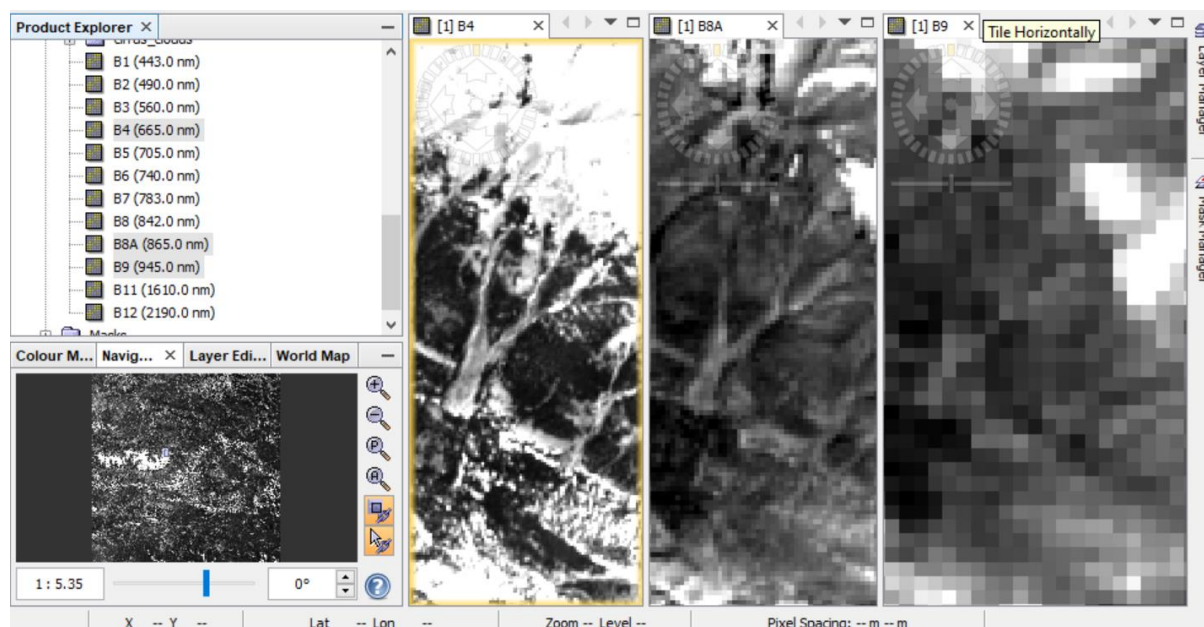


Figure 1: MSI Spectral-Bands versus Spatial Resolution

The different spatial resolutions of Sentinel-2 bands serve specific purposes and are determined based on the requirements of different applications and the characteristics of the Earth's surface.

To explore the spatial resolution of the Sentinel-2 bands, you can visualize individual bands – you can open e.g. B4 (10m spatial resolution), B8A (20m spatial resolution), B9 (60m spatial resolution) by double-click on each of these bands in Bands folder. Then, tile windows Horizontally and zoom into the image to see different spatial resolutions.

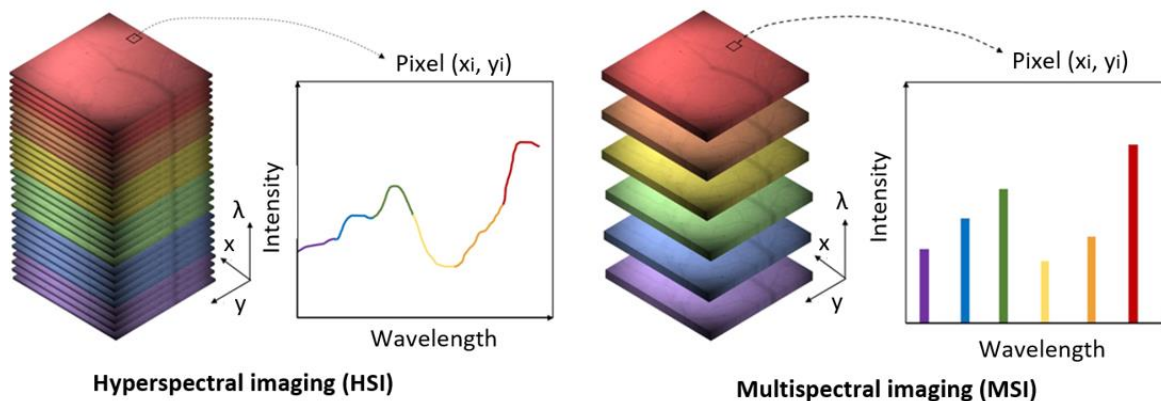


It's important to note that the spatial resolution of each band determines the level of detail captured in the imagery, with higher spatial resolutions providing finer details.

The spatial resolution of Sentinel-2 bands varies to optimize the sensor's ability to capture specific features on the Earth's surface, with higher resolutions (e.g., 10 meters per pixel) suited for detailed features like urban areas, and lower resolutions (e.g., 60 meters per pixel) for broader-scale observations. Trade-offs between spatial resolution and factors like spectral range and cost are necessary due to design limitations, balancing the sensor's capabilities to provide comprehensive Earth observation data. Despite the complexity and cost associated with higher resolutions, Sentinel-2's diverse spatial resolutions enable it to meet various Earth observation needs effectively.

Spectral resolution

Spectral resolution refers to a sensor's capacity to distinguish between finer wavelengths, typically achieved by having more and narrower bands. Many sensors are classified as multispectral, featuring 3-10 bands, while others, known as hyperspectral sensors, offer hundreds to even thousands of bands. The narrower the wavelength range for a specific band, the higher the spectral resolution.

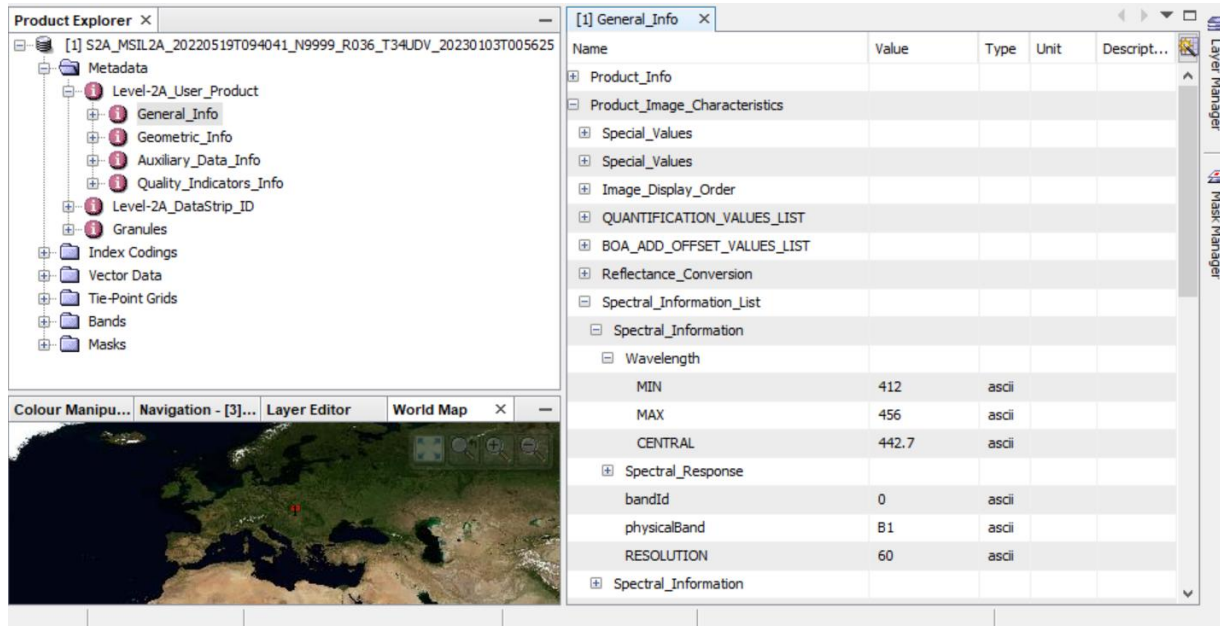


Sentinel-2 satellites have a multispectral instrument called the Multi-Spectral Instrument (MSI) that captures imagery in 13 spectral bands, ranging from visible to near-infrared and shortwave infrared wavelengths.

Sentinel-2 Bands	Central Wavelength (μm)	Resolution (m)
Band 1 - Coastal aerosol	0.443	60
Band 2 - Blue	0.490	10
Band 3 - Green	0.560	10
Band 4 - Red	0.665	10
Band 5 - Vegetation Red Edge	0.705	20
Band 6 - Vegetation Red Edge	0.740	20
Band 7 - Vegetation Red Edge	0.783	20
Band 8 - NIR	0.842	10
Band 8A - Vegetation Red Edge	0.865	20
Band 9 - Water vapour	0.945	60
Band 10 - SWIR - Cirrus	1.375	60
Band 11 - SWIR	1.610	20
Band 12 - SWIR	2.190	20

Spectral resolution

To check the spatial resolution of the Sentinel-2 bands, open Metadata directory – select General info under Level-2 User Product by double click on it, so it opens in a new window. Go to Product Image Characteristics – Spectral Information and have a look at spectral wavelengths of individual bands.



The screenshot shows the Sentinel-2 metadata viewer interface. On the left, the 'Product Explorer' tree shows the hierarchy: Metadata > Level-2A_User_Product > General_Info. The main window displays the 'General_Info' metadata in a table format. The 'Spectral_Information_List' section is expanded, showing the following data:

Name	Value	Type	Unit	Descript...
Product_Info				
Product_Image_Characteristics				
Special_Values				
Special_Values				
Image_Display_Order				
QUANTIFICATION_VALUES_LIST				
BOA_ADD_OFFSET_VALUES_LIST				
Reflectance_Conversion				
Spectral_Information_List				
Spectral_Information				
Wavelength				
MIN	412	ascii		
MAX	456	ascii		
CENTRAL	442.7	ascii		
Spectral_Response				
bandId	0	ascii		
physicalBand	B1	ascii		
RESOLUTION	60	ascii		
Spectral_Information				

The spectral resolution of these Sentinel-2 bands ranges from 10 to 60 meters. This means that the sensors can differentiate between different wavelengths of light within these ranges. This high spectral resolution allows for the characterization of various features on the Earth's surface, such as vegetation health, land use and land cover, water quality, and more. Additionally, the combination of high spectral and spatial resolution in Sentinel-2 data makes it valuable for a wide range of applications in agriculture, forestry, environmental monitoring, urban planning, and disaster management.

Right click on the Sentinel-2 product to open RGB Image Window – select Sentinel 2 MSI Natural Color composition. Double click on the individual bands to visualize it. Tile Windows Horizontally and zoom in to explore in detail.

Visualize the bands to understand their common applications – double-click on each individual band to View it in the new window:

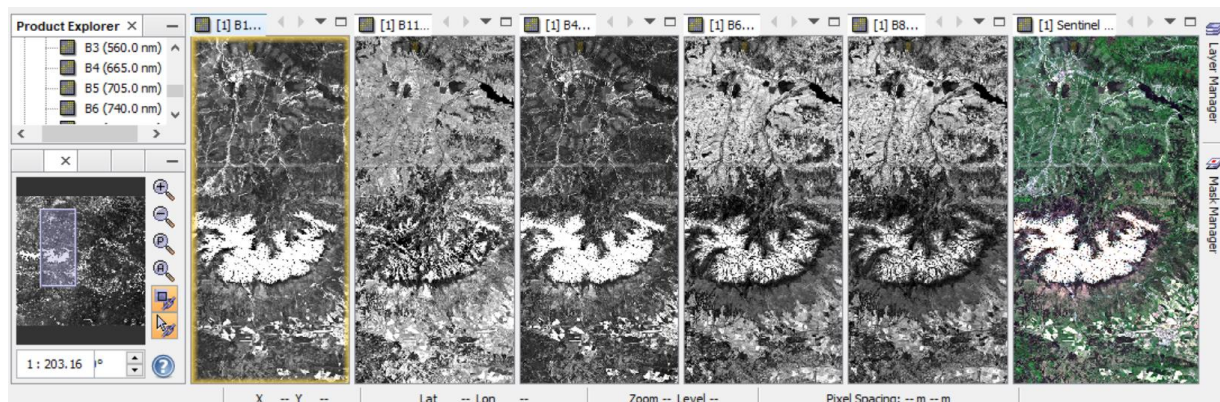
Near Infrared (NIR) band (Band 8) is highly sensitive to chlorophyll content in vegetation, making them useful for monitoring vegetation health, estimating biomass, and detecting changes in plant vigor. It can be also used to detect and analyze urban heat islands, as urban areas often have different thermal properties than surrounding natural environments.

Red, Green, and Blue bands (Bands 2, 3, and 4) are commonly used for traditional RGB (Red-Green-Blue) imaging, which allows for visual interpretation and classification of different land cover types.

Coastal Aerosol band (Band 1) is particularly sensitive to changes in water turbidity and sediment concentrations in coastal regions, making it useful for monitoring water quality.

Shortwave Infrared (SWIR) bands (Bands 11 and 12) along with NIR band are sensitive to changes in snow and ice reflectance and can be used to monitor snow cover extent, snow melt, and ice dynamics.

Red Edge bands (Bands 5, 6, and 7) are sensitive to changes in chlorophyll content and leaf structure, making them useful for detecting vegetation stress caused by factors such as disease, drought, or nutrient deficiency.

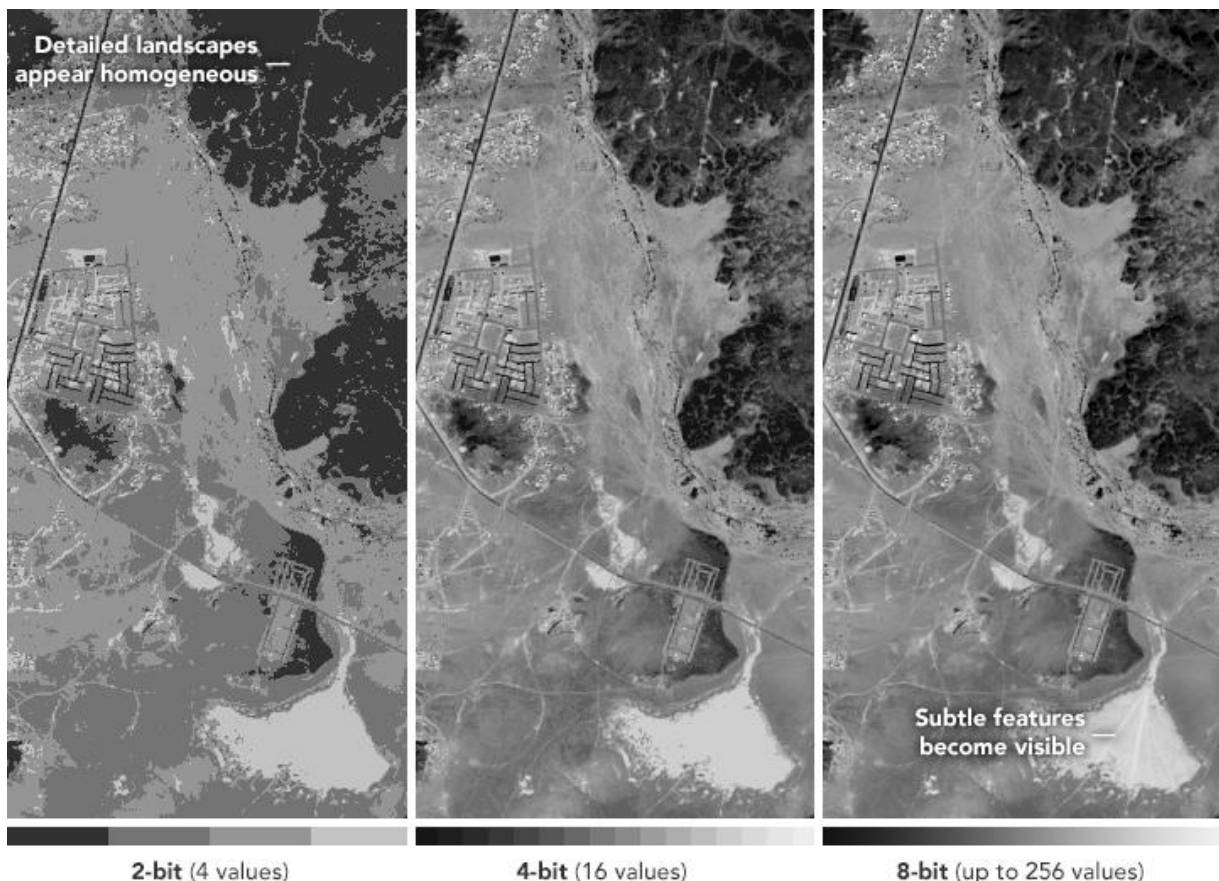


Radiometric resolution

Radiometric resolution refers to the level of detail encoded in each pixel, specifically, the number of bits used to represent the recorded energy. Each bit corresponds to an exponent of power 2. For instance, an 8-bit resolution equals 2^8 , offering 256 potential digital values (ranging from 0 to 255) to capture information. Consequently, higher radiometric resolution provides a greater range of values to store data, enhancing the ability to discern even minor differences in energy. For example, in assessing water quality, radiometric resolution is crucial for distinguishing subtle variations in ocean color.

The radiometric resolution of Sentinel-2 refers to the ability of its sensors to capture and represent the intensity of electromagnetic radiation (light) across its spectral bands. Sentinel-2 has a radiometric resolution of 12 bits per pixel.

A 12-bit radiometric resolution means that each pixel in the imagery captured by Sentinel-2 can represent 2^{12} (4096) different levels of brightness or intensity. This high radiometric resolution allows for the detection of subtle variations in reflectance across the Earth's surface, which is crucial for applications such as land cover classification, vegetation monitoring, and change detection.



Temporal resolution

The temporal resolution of satellite refers to how frequently the satellite revisits and captures images of the same area on the Earth's surface. Sentinel-2 satellites operate in a polar sun-synchronous orbit, which means they pass over the same area at approximately the same local solar time on each orbit.

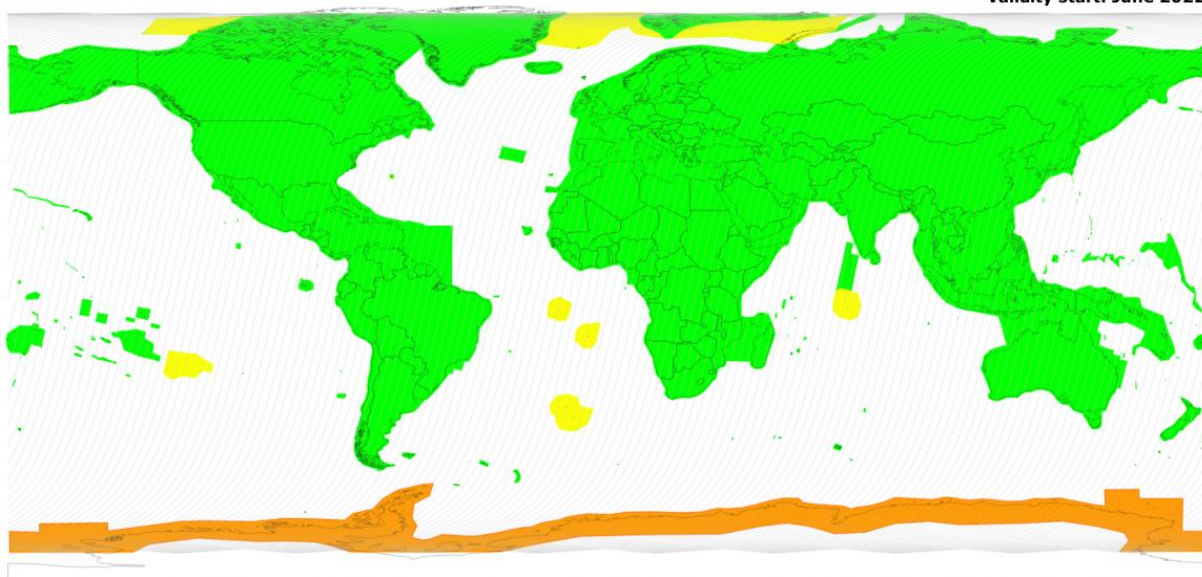
Polar orbiting satellites have a temporal resolution that can vary from 1 day to 16 days. For example, the MODIS sensor aboard NASA's Terra and Aqua satellites has a temporal resolution of 1-2 days, allowing the sensor to visualize Earth as it changes day by day. The Operational Land Imager (OLI) aboard the joint NASA/USGS Landsat 8 satellite, on the other hand, has a narrower swath width and a temporal resolution of 16 days; showing not daily changes but bi-monthly changes.

Today, Sentinel-2A and Sentinel-2B provide a combined revisit time of 5 days at the equator with a 10-day revisit time at higher latitudes. This means that for any given location on the Earth's surface, Sentinel-2 captures imagery approximately every 5 days, on average. However, frequent cloud cover or other atmospheric conditions may affect the availability of cloud-free imagery. The frequent revisit time of Sentinel-2 data is valuable for monitoring changes in land cover, vegetation dynamics, and other environmental parameters over time, allowing for timely responses to natural disasters, agricultural monitoring, and other applications that require up-to-date information about the Earth's surface.

Sentinel-2 Constellation Observation Scenario: Revisit Frequency



Validity start: June 2022



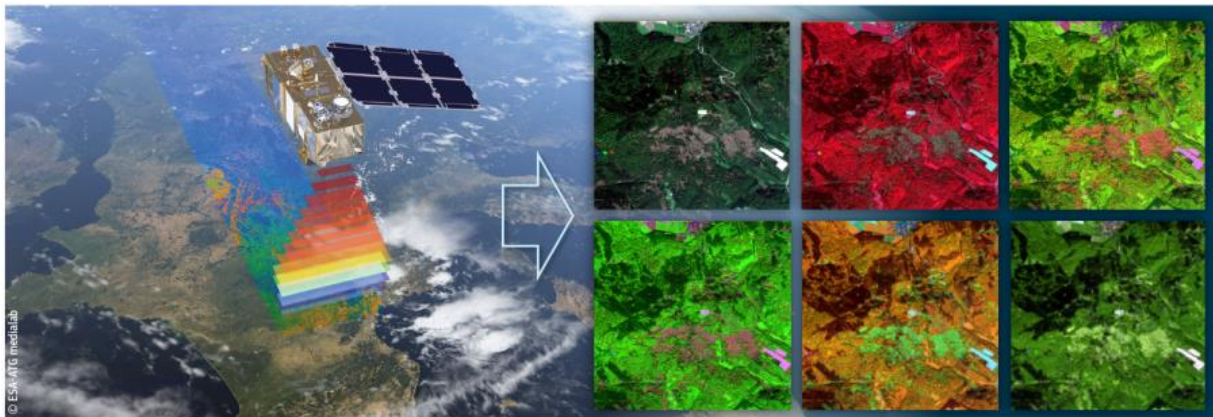
5 days
10 days
10 days access from alternated tracks

5 | Color compositions and spectral indices

5.1 Color compositions

Satellites equipped with sensors observe Earth's surface by measuring the electromagnetic radiation reflected or emitted from it. These sensors, known as multispectral sensors, capture data across various regions of the electromagnetic spectrum simultaneously, including visible light, near-infrared, and short-wave infrared. Each portion of the spectrum measured by a sensor is referred to as a band, typically defined by its wavelength.

Multispectral images can be viewed either as single-band grayscale images or as color composite images, combining information from three bands at a time. These three bands correspond to the primary colors of light: red, green, and blue. Computer screens can display images by representing each band with a different primary color, enabling the creation of color composite images by combining these three separate images.



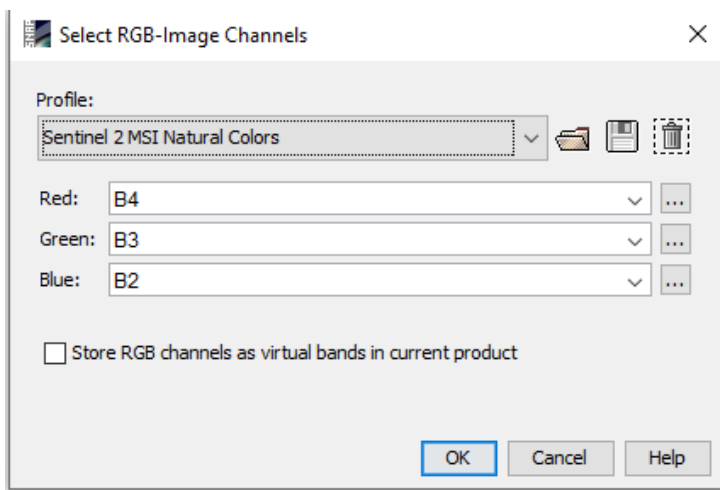
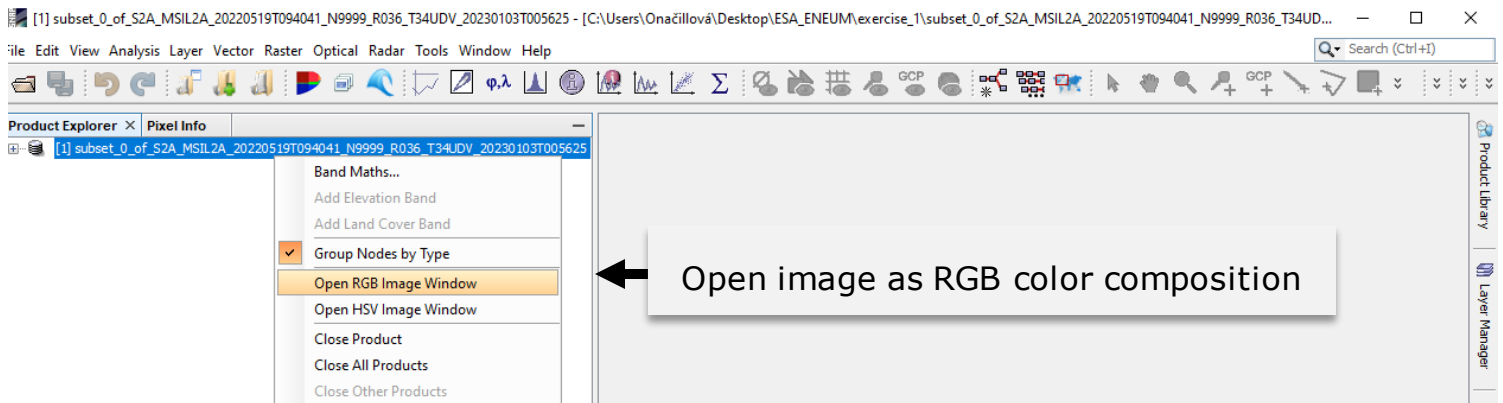
Natural or True Color Composites

A natural or true color composite combines visible red, green, and blue bands to resemble what would be observed naturally by the human eye. This composite replicates natural appearances, with vegetation appearing green, water as blue to black, and bare ground and surfaces in light grey or brown tones. While favored for their natural color representation, true color compositions may lack contrast and clarity due to atmospheric blue light scattering, making subtle features challenging to discern.

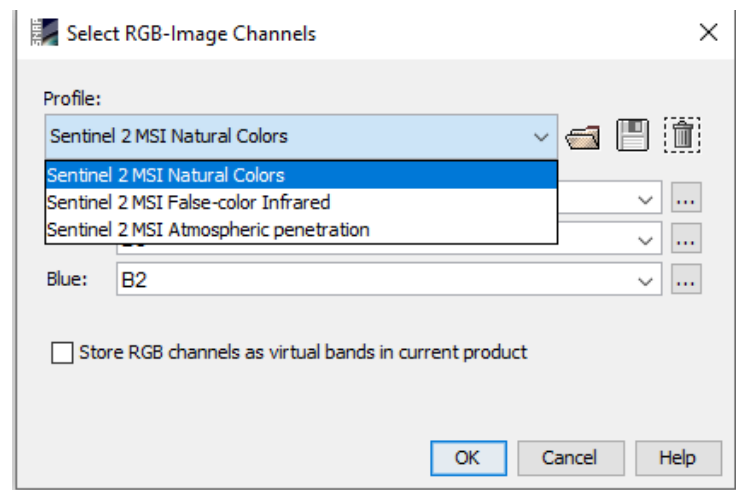
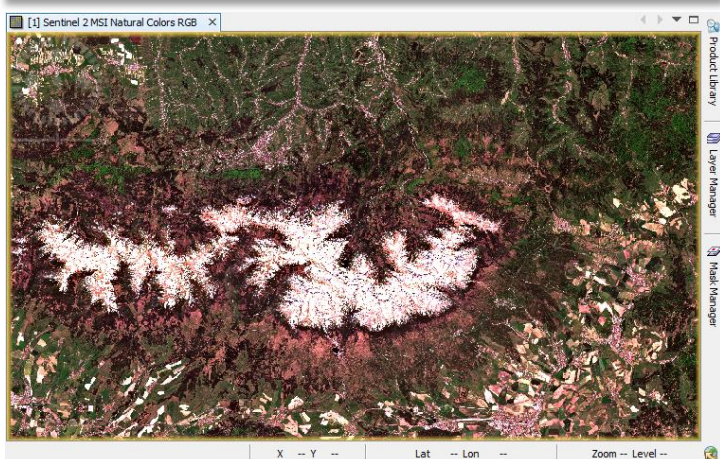
False Color Composites

False color images are a representation of a multi-spectral image produced using bands other than visible red, green and blue as the red, green and blue components of an image display. False color composites allow us to visualize wavelengths that the human eye can not see. Using bands such as near infra-red increases the spectral separation and interpretability of the data. There are many different false colored composites which can highlight many different features. See the heading below for more information about common band combinations for false color composites.

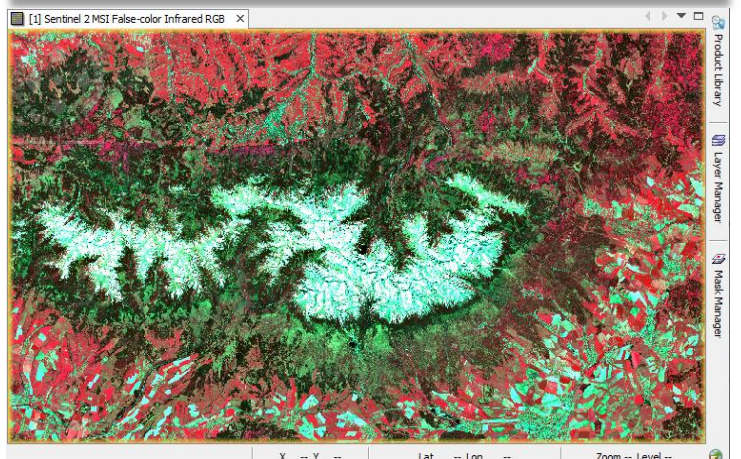
To display product using e.g. True color composition: Right click on the product – Open RGB Image Window – SNAP should automatically select Landsat-8/9 L1 red,green,blue profile (using Red, Green, Blue band in the corresponding red, green and blue color channels), resulting in a natural colored result, that is a good representation of the Earth as perceived by human eye. User can also explore Landsat-8 bands and metadata.



↑
 Display image in Natural Colors
 (as seen by human eye)



↑
 Open image in False Colors or open as
 an Atmospheric penetration image

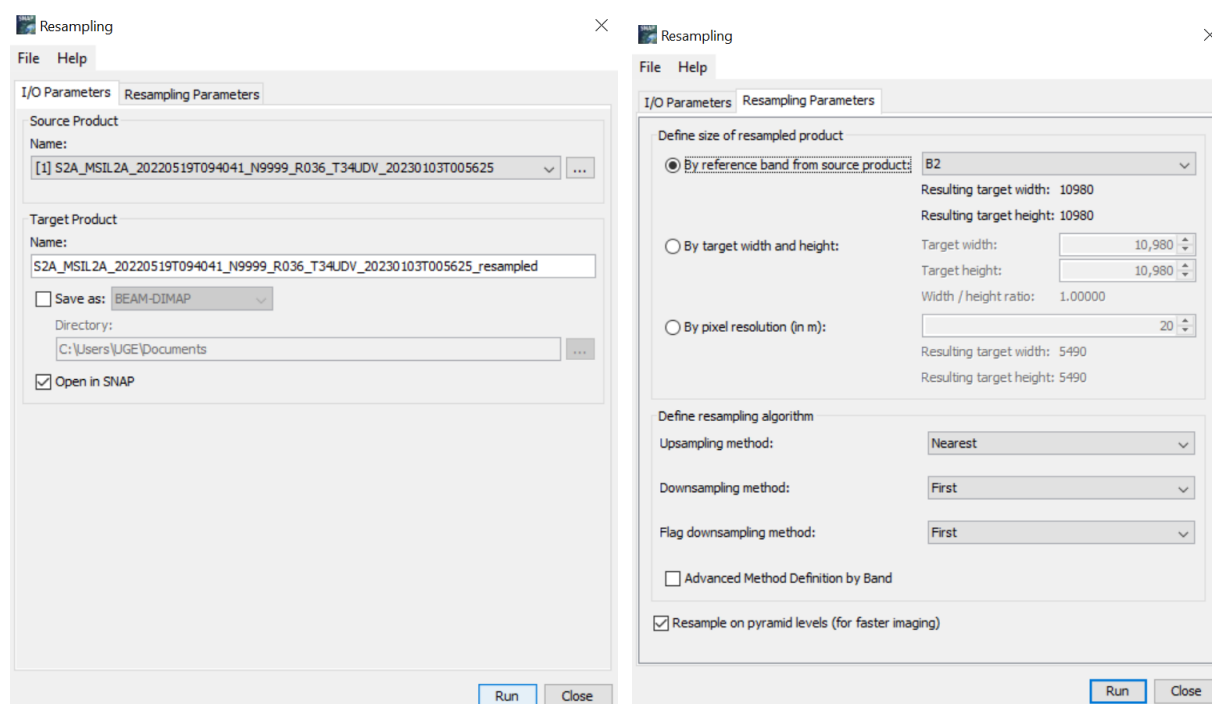


To display multiple options of color compositions, it is necessary to resample the data to the same spatial resolution.

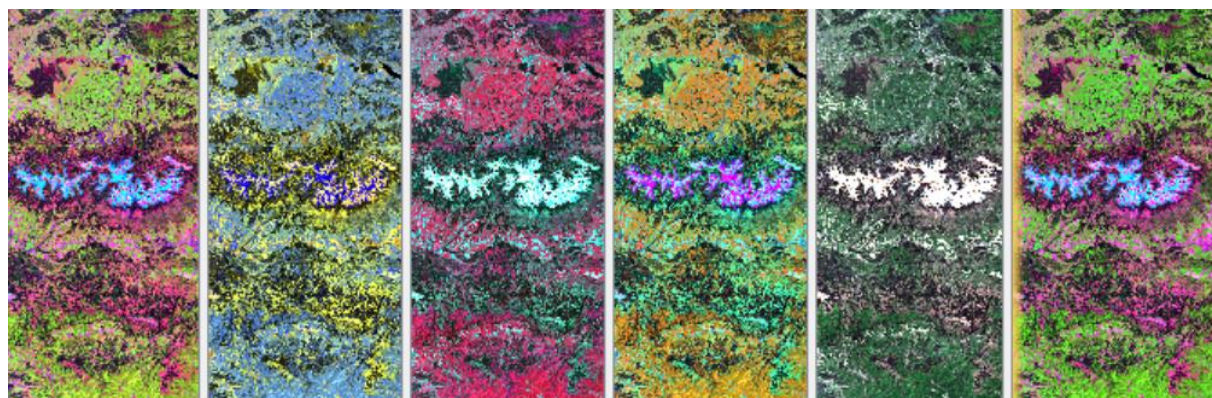
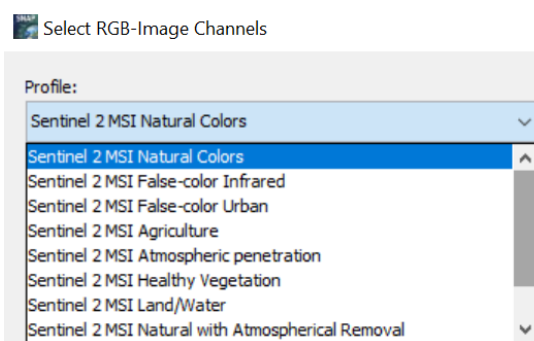
Navigate to the Main Menu: Raster – Geometric – Resampling

In the I/O Parameters tab select the source product and set the name for the target product

In the Resampling Parameters set B2 as the band used to resample all other bands of the product and click RUN.



Right click on the resulted product in the Product Explorer tab – Open RGB Image Window. Now that we have resampled all bands to the same spatial resolution, it is possible to create many more color compositions.



4.2 Spectral indices

Radiometric spectral indices are quantitative measures of features that are obtained by combining several spectral bands, features that are not otherwise obvious if using only one band. There are many others developed for specific applications and environmental parameters. The indices provided with Sentinel-2 Toolbox, detailed below, are grouped into three categories:

- Vegetation indices
- Soil indices
- Water indices

These are commonly used spectral indices:

- **Normalized Difference Vegetation Index (NDVI)** is calculated from the red and near-infrared bands of satellite imagery and is widely used to assess vegetation health, biomass, and photosynthetic activity.
- **Normalized Difference Water Index (NDWI)** is calculated using the green and near-infrared bands and is used to detect the presence of water bodies and monitor changes in water content in vegetation.
- **Normalized Burn Ratio (NBR)** is used to detect and assess the severity of burned areas after wildfires by comparing near-infrared and shortwave infrared bands.

Let's create, e.g. NDVI from our Sentinel-2 product:

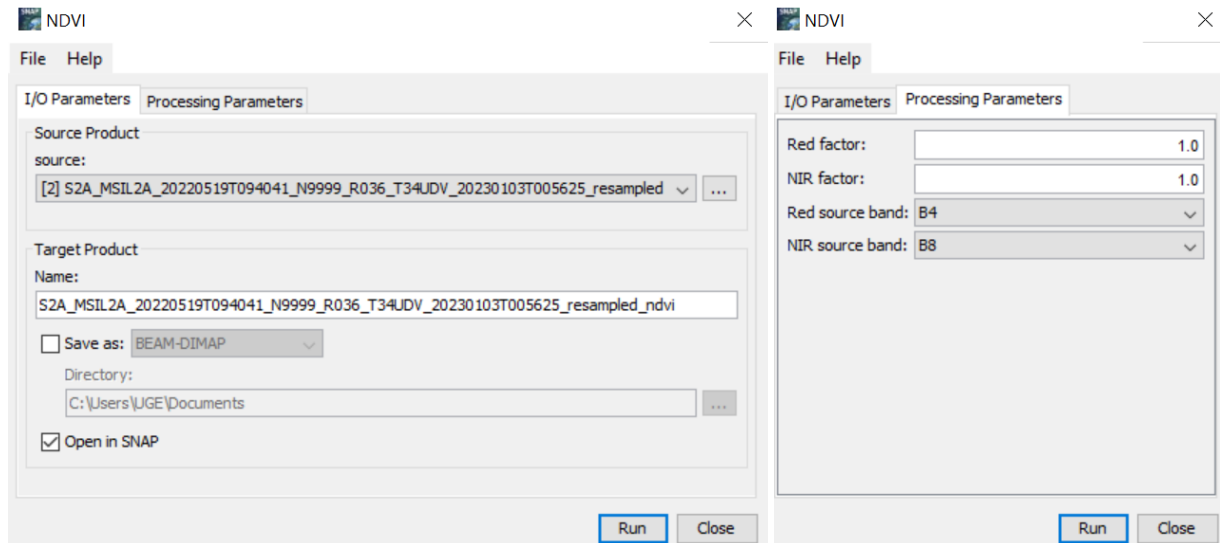
The Normalized Difference Vegetation Index (NDVI) algorithm exploits the strength and the vitality of the vegetation on the earth's surface. It is calculated from the visible and near-infrared light reflected by vegetation. Even if it is an old and classic method it is still much used to estimate the health of green vegetation and post-processed high definition images for precision agriculture.

- Vegetation has high NIR and low Red reflectance
- Other land cover have NIR and Red which are much close together
- vegetation from 0.3 to 0.8, depending on health/intensity
- water (sea, lakes, rivers) low positive or even negative
- bare soil low positive values from 0.1 to 0.2



$$NDVI = \frac{(NIR - Red)}{(NIR + Red)} = \frac{(B_8 - B_4)}{(B_8 + B_4)}$$

Navigate to the Main menu – **Optical – Thematic Land Processing – Vegetation Radiometric Indices – NDVI Processor**



User can also use Band Maths option to create vegetation indices:

- Select the subset product in the Product Explorer window.
- Click on 'Raster' - 'Band Maths...'

In the pop-up window set up the parameters as shown in the Figures:

Change the Name: 'NDVI'

Unselect 'Virtual' box

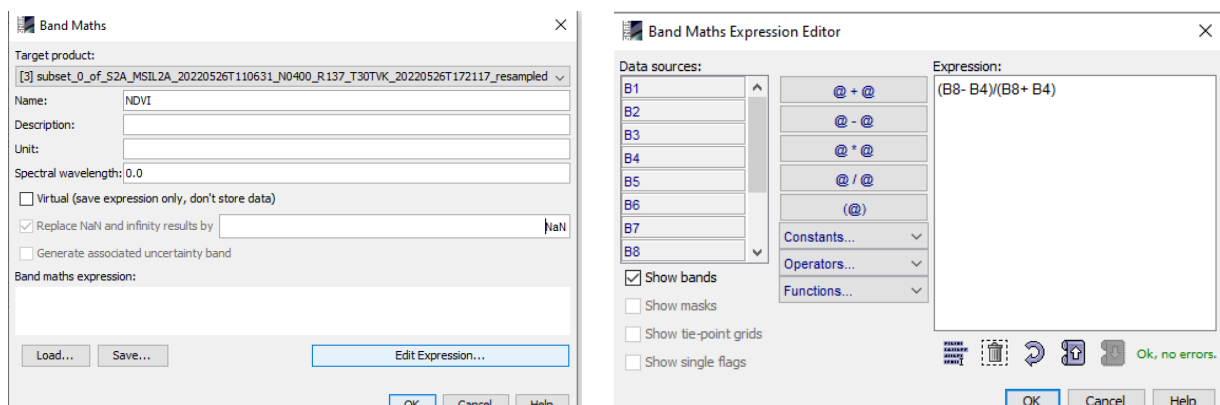
Click on 'Edit Expression...'

Create your expression using '@' and after replace them with the bands

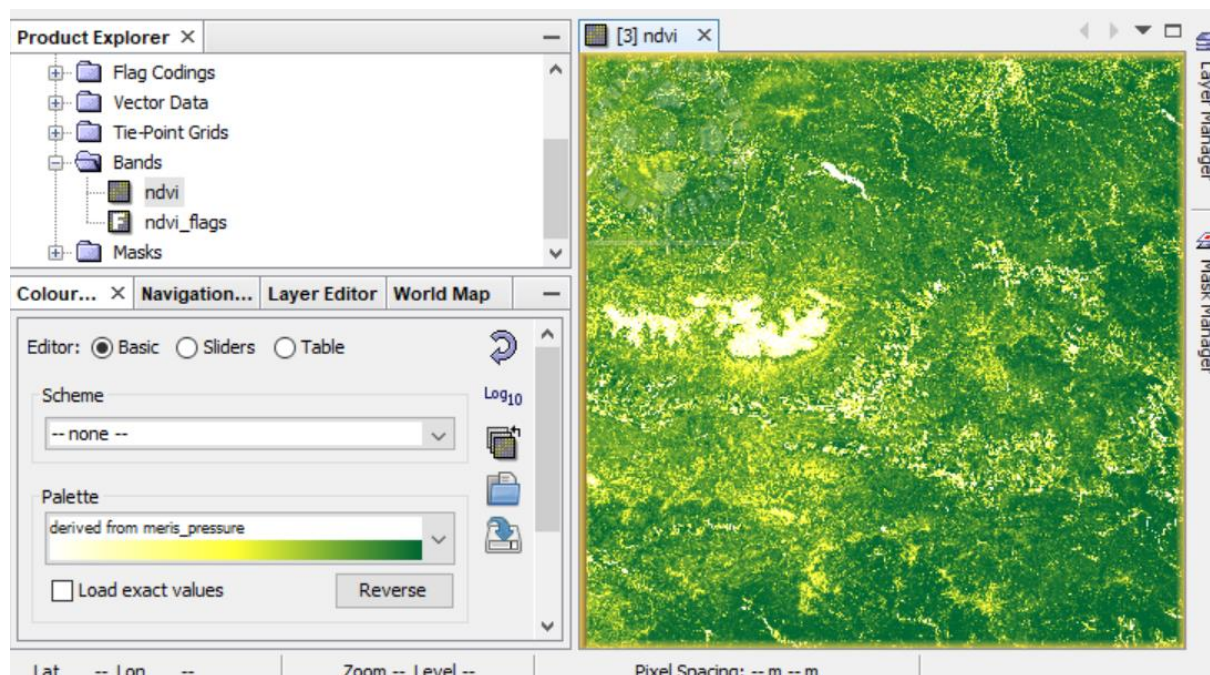
$(@ - @) / (@ + @)$

$(B8 - B4) / (B8 + B4)$

Click on 'OK' and 'Run'



To explore the final NDVI layer values of the Sentinel-2 product: double-click on the NDVI layer in Bands folder. Then, you can select in the Colour manipulation tab one of the palettes to visualize the resulted raster better.



Explore the NDVI values on the image:

NDVI values typically range from -1 to 1, although in practice, they often fall within a narrower range, typically from -0.1 to 0.9. Here's what these values generally represent:

Negative Values (-1 to 0): usually indicate non-vegetated surfaces such as water bodies, barren land, or built-up areas. These surfaces absorb more visible light and reflect less near-infrared light.

Values Around Zero (0 to 0.1): Values close to zero represent surfaces such as bare soil, rocks, or urban areas with sparse vegetation cover. They reflect similar amounts of visible and near-infrared light.

Low Values (0.1 to 0.3): Low positive values indicate areas with sparse or stressed vegetation cover, such as shrublands, savannas, or recently harvested fields.

Moderate Values (0.3 to 0.6): Moderate positive values typically represent healthy vegetation, including grasslands, forests, and croplands with good vegetation cover.

High Values (0.6 to 0.9): High positive values correspond to dense and vigorous vegetation cover, such as dense tropical rainforests or highly productive agricultural fields.

THANK YOU FOR FOLLOWING THE EXERCISE!