ESA contract 4000140187/23/NL/SC/rp (ENEUM)

Deliverable 5.1

Earth Observation Applications

Practical Exercise Workbook

ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach
UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH
FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

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UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 1 – TUTORIAL

Introduction to ESA Earth Observation and evolution – ESA EO data on the web

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1 | Exercise outline

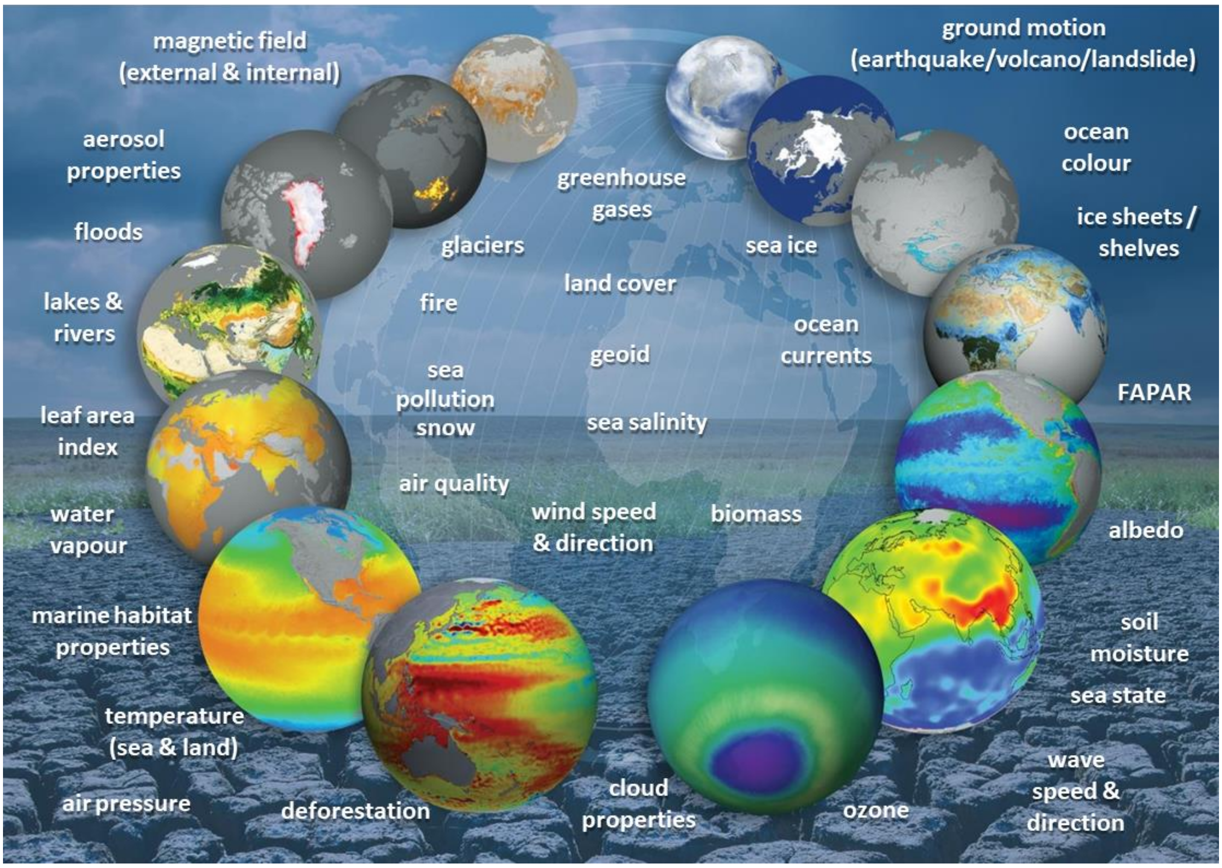
In this exercise, we will:

- acquire skills in retrieving satellite imagery from both ESA and third-party missions
- conduct specific analyses utilizing the EO Browser
- install ESA SNAP and execute fundamental image operations
- explore the spectral curve of various surface types

2 | Background

The European Space Agency (ESA) has several key mission programs covering various areas of space exploration, Earth observation, scientific research, and international collaboration. Some of the main mission programs include:

- Earth Observation (EO) Programs: ESA has a comprehensive portfolio of EO missions aimed at monitoring and understanding various aspects of the Earth's environment. Examples include the Copernicus program, which has developed Sentinel missions to manage the environment, understand and tackle the effects of climate change, and safeguard everyday lives, Earth Explorers designed to improve our understanding of Earth, and the Living Planet Program.
- ESA provides EO mission data addressing almost all parameters retrievable by EO satellites

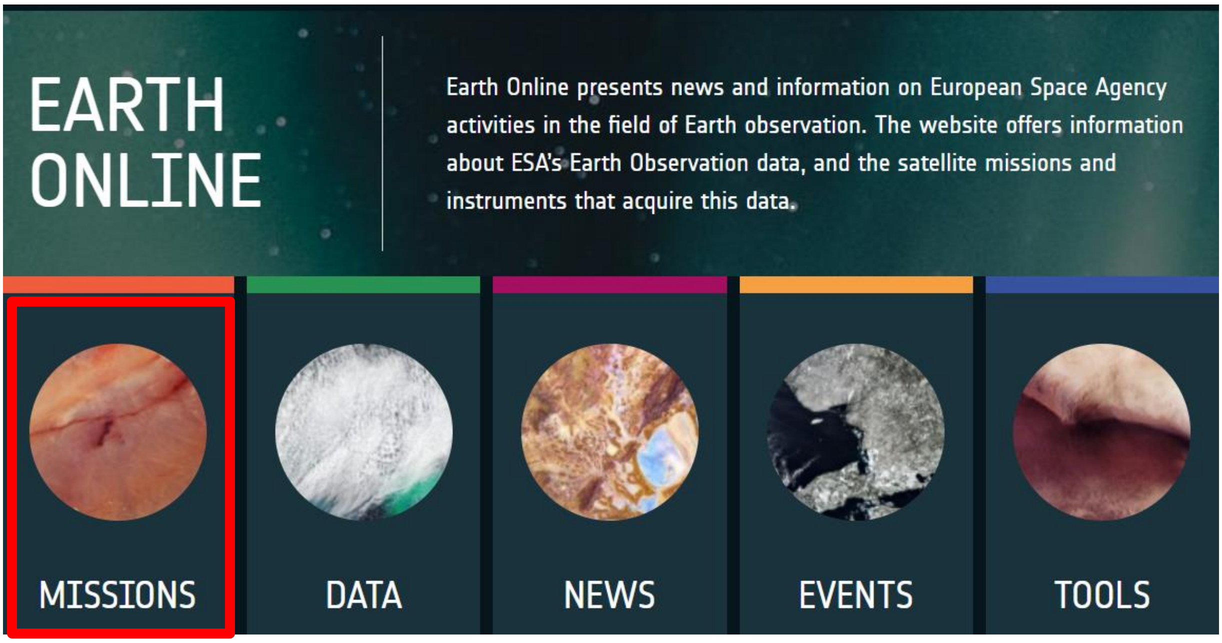


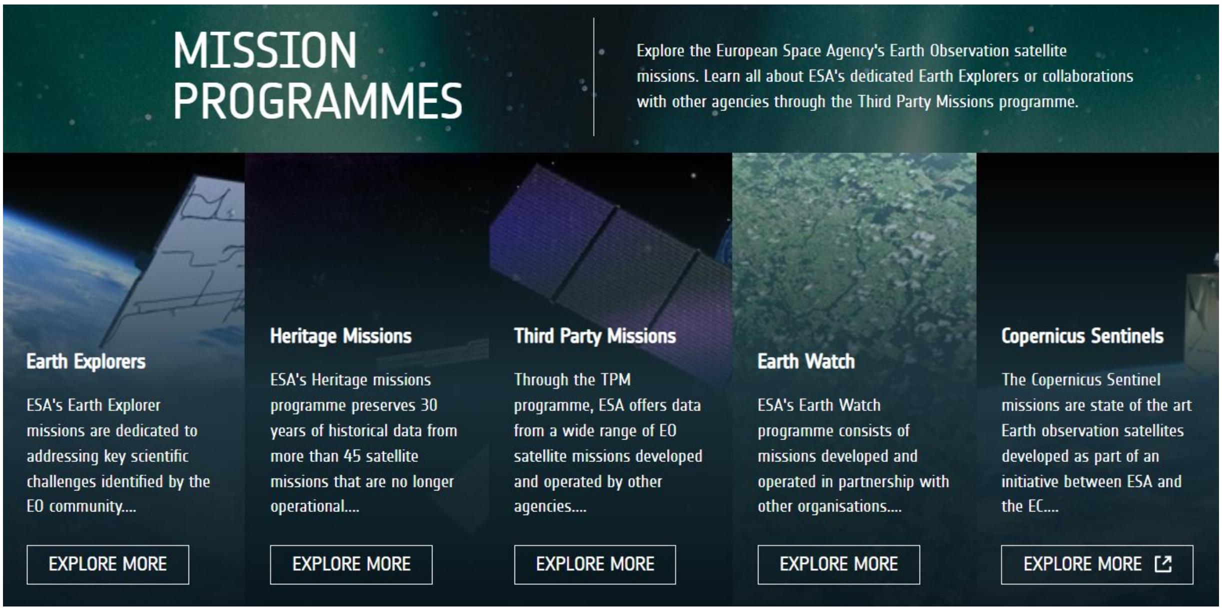
- Exploration Programs: ESA conducts various scientific missions to explore the cosmos and increase our understanding of the universe. This includes missions like the Hubble Space Telescope, the Gaia mission for astrometry, and the Planck mission for studying the cosmic microwave background. ESA is actively involved in space exploration initiatives, including the ExoMars program in collaboration with Roscosmos, which aims to search for signs of past or present life on Mars. Additionally, ESA contributes to lunar exploration efforts, robotic missions, international collaborations with agencies like NASA, human spaceflight missions in collaboration with the International Space Station (ISS). The agency contributes astronauts, research, and technology to advance human space exploration.
- Telecommunications and Integrated Applications: ESA focuses on developing advanced satellite communication technologies and applications. This includes programs such as the Advanced Research in Telecommunications Systems (ARTES) program.
- Navigation Programs: ESA is involved in satellite navigation programs, such as the Galileo program, which aims to provide Europe with its global navigation satellite system (GNSS).

It's important to note that the specifics of ESA's mission programs may evolve over time, and new programs may be initiated. Within this course, we will focus mainly on the field of EO Programs.

3 | EO Mission Programmes

https://earth.esa.int/eogateway





ESA's EO Mission Programme is dedicated to several ongoing and past Earth Observation satellite missions. Users can learn all about ESA's dedicated Earth Explorers, Copernicus Sentinels, Heritage Missions or collaborations with other agencies through the Third Party Missions programme by accessing the dedicated Earth Online website that presents news and information on ESA activities in the field of Earth observation. The website offers information about ESA's Earth Observation data, along with insights into the satellite missions and instruments that acquire this data.

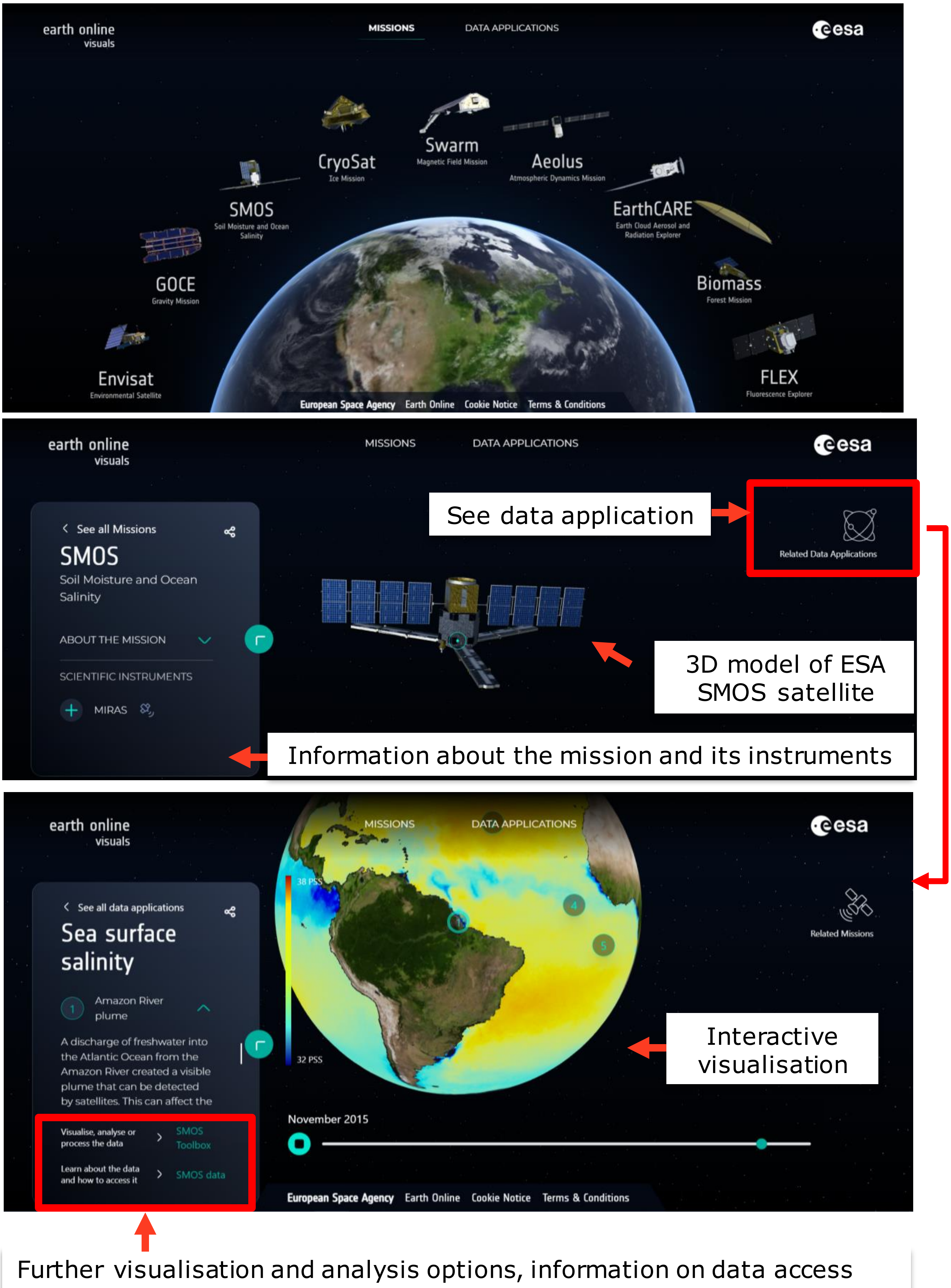
3.1 Earth Explorers

The Earth Explorers program comprises a set of satellites united in their mission to enhance Earth science by addressing fundamental scientific inquiries through the observation of crucial Earth systems.

Each Earth Explorer is specifically designed to monitor distinct facets of the Earth's system, including the Cryosphere, Hydrosphere, Atmosphere, Ionosphere, and the Earth's interior. The primary aim of these missions is to gain insight into the Earth as a geosphere and comprehend the intricate interactions among spheres and sub-spheres

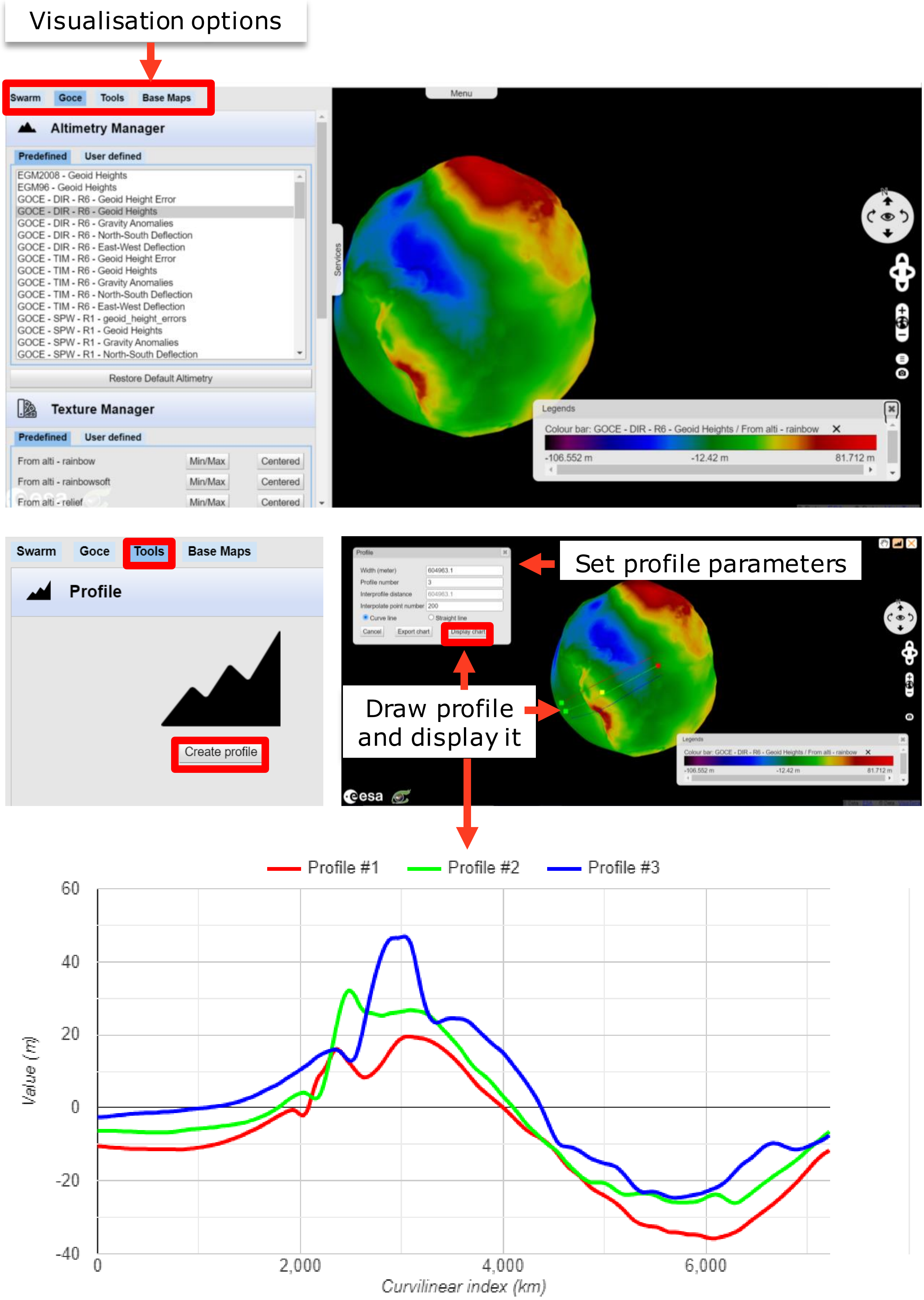
Current Earth Explorer missions include Aeolus, CryoSat, SMOS, and Swarm. Future expansions will introduce new missions like EarthCARE, Biomass, and FLEX.

Users have the ability to engage with three-dimensional representations of ESA satellites and payloads via the link: https://visuals.earth.esa.int/ Additionally, users can explore case studies that showcase practical applications of the satellite data.



VisioTerrra

VisioTerra is a French company that focuses on scientific consulting in the field of Earth observation as an independent entity. It enables access to online visualisation of GOCE altimetry and SWARM products.



3.2 Sentinel Online - Copernicus Sentinels

https://sentinels.copernicus.eu/web/sentinel

https://sentinel.esa.int/web/sentinel/home

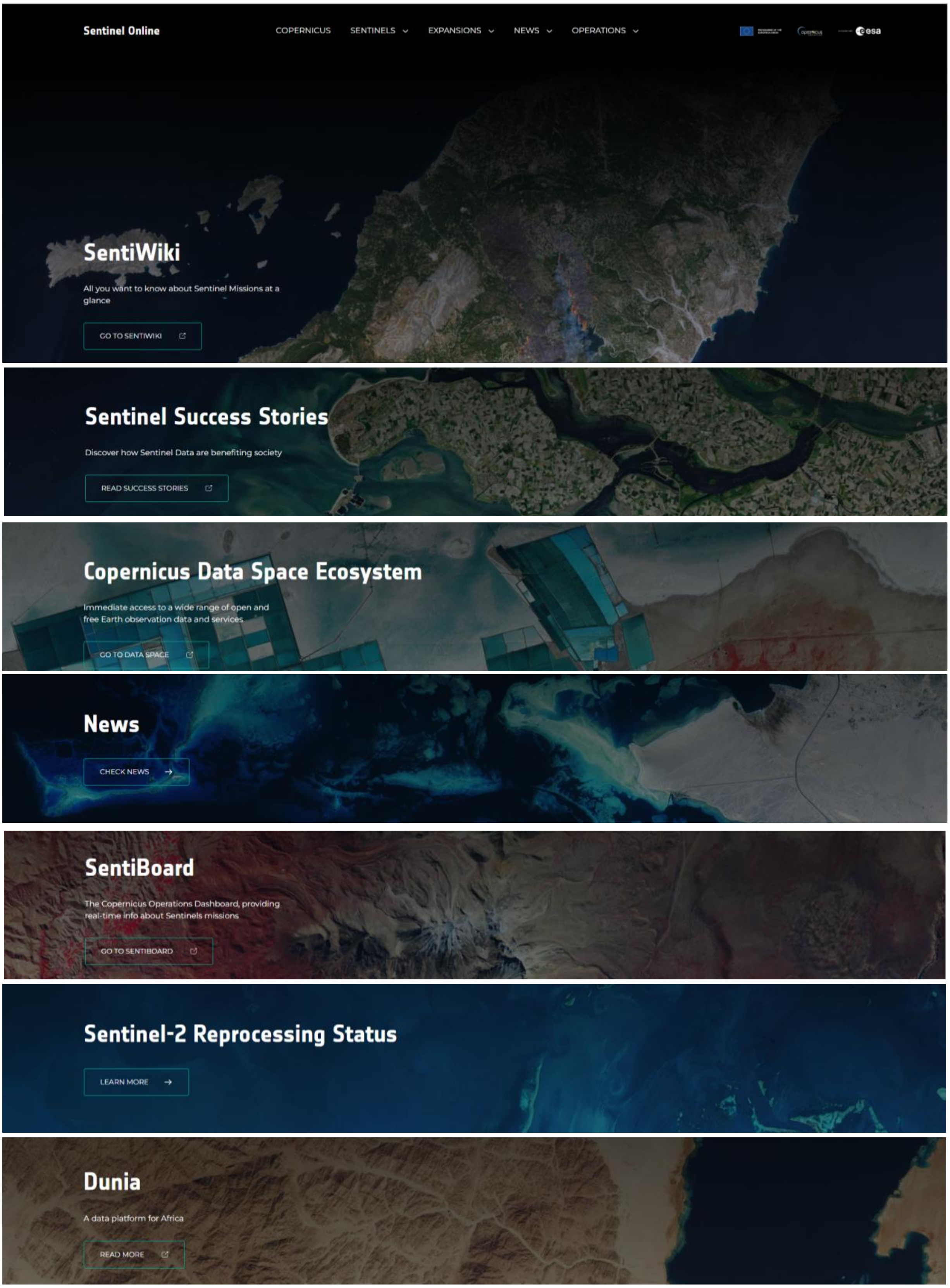
Copernicus stands as the most ambitious Earth observation program to date, aiming to deliver precise, timely, and readily available information to enhance environmental management, comprehend and alleviate the impacts of climate change, and ensure civil security.

ESA developed the Sentinel satellite family to meet Copernicus program needs. The Copernicus Ground Segment oversees operations, data acquisition, and distribution. Currently, three two-satellite constellations orbit, with two individual satellites, including Sentinel-5P. After Sentinel-1B, Sentinel-1C will restore the Sentinel-1 constellation.

Sentinels offer diverse observations, from Sentinel-1's all-weather radar images (2014, 2016) to Sentinel-2A's high-res optical images (2015). Sentinel-3 satellites (2016, 2018) provide ocean and land data, with Sentinel-3 marine operated by EUMETSAT and Sentinel-3 land by ESA. Sentinel-5P, launched on October 13, 2017, is the first Copernicus mission dedicated to atmospheric monitoring, reducing data gaps.

Sentinel Online aims to offer extensive information to prospective users regarding the Sentinel program, including its specific missions, operational priorities, and the Copernicus Thematic domains it caters to. The technical platform prioritizes in-depth explanations covering instruments, performance of data products, scientific applications, Ground Segment processing, and guidance on how to access Sentinel data.

Users can explore Copernicus Sentinel missions and instruments through SentiWiki, applications through Sentinel Success Stories, get an immediate access to a wide range of open and free EO data and services through Copernicus Data Space Ecosystem, check News, real-time info about Sentinels missions through SentiBoard, Sentinel-2 Reprocessing Status or explore Dunia – data platform for Africa.

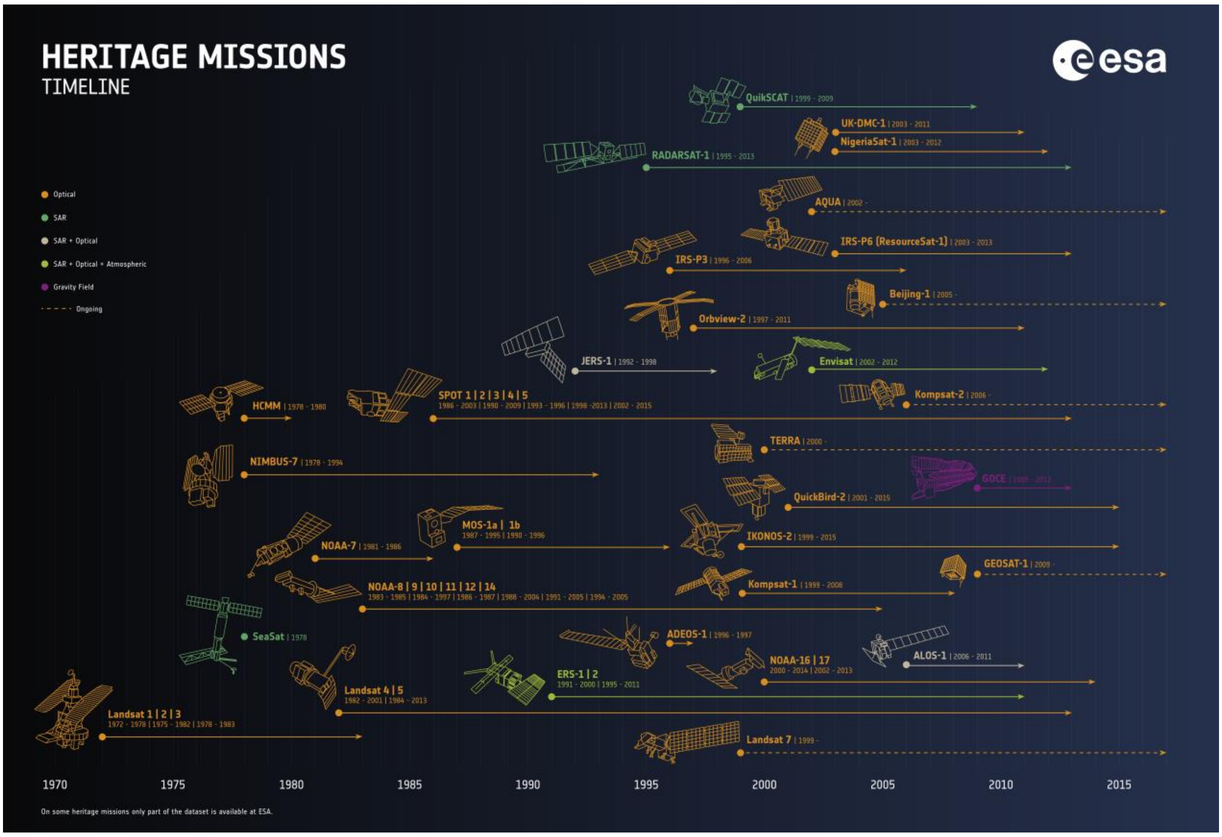


3.3 Heritage missions

https://earth.esa.int/eogateway/missions/heritage-missions

ESA's Heritage Space Programme is dedicated to safeguarding, ensuring accessibility to, and managing over four decades of Earth Observation heritage data. This extensive dataset originates from more than 45 satellite missions that are no longer in operation, as well as from dedicated Earth Observation campaigns conducted by ESA.

Included in the program are significant missions such as the European Remote Sensing satellites (ERS-1 and ERS-2), Envisat, and the Gravity Field and Ocean Circulation Explorer (GOCE).



The user can discover the instruments used in each of these featured missions, access mission data and explore A number of tools that are available for visualising, processing and analyzing.

4 | EO Training and Education

ESA is involved in a diverse array of initiatives related to education, training, and capacity building in the field of Earth Observation (EO). These efforts span from advanced training in state-of-the-art processing techniques for the upcoming generation of scientists to broader outreach activities and EO education for schools.

4.1 Earth Observation for Society (EO4Society)

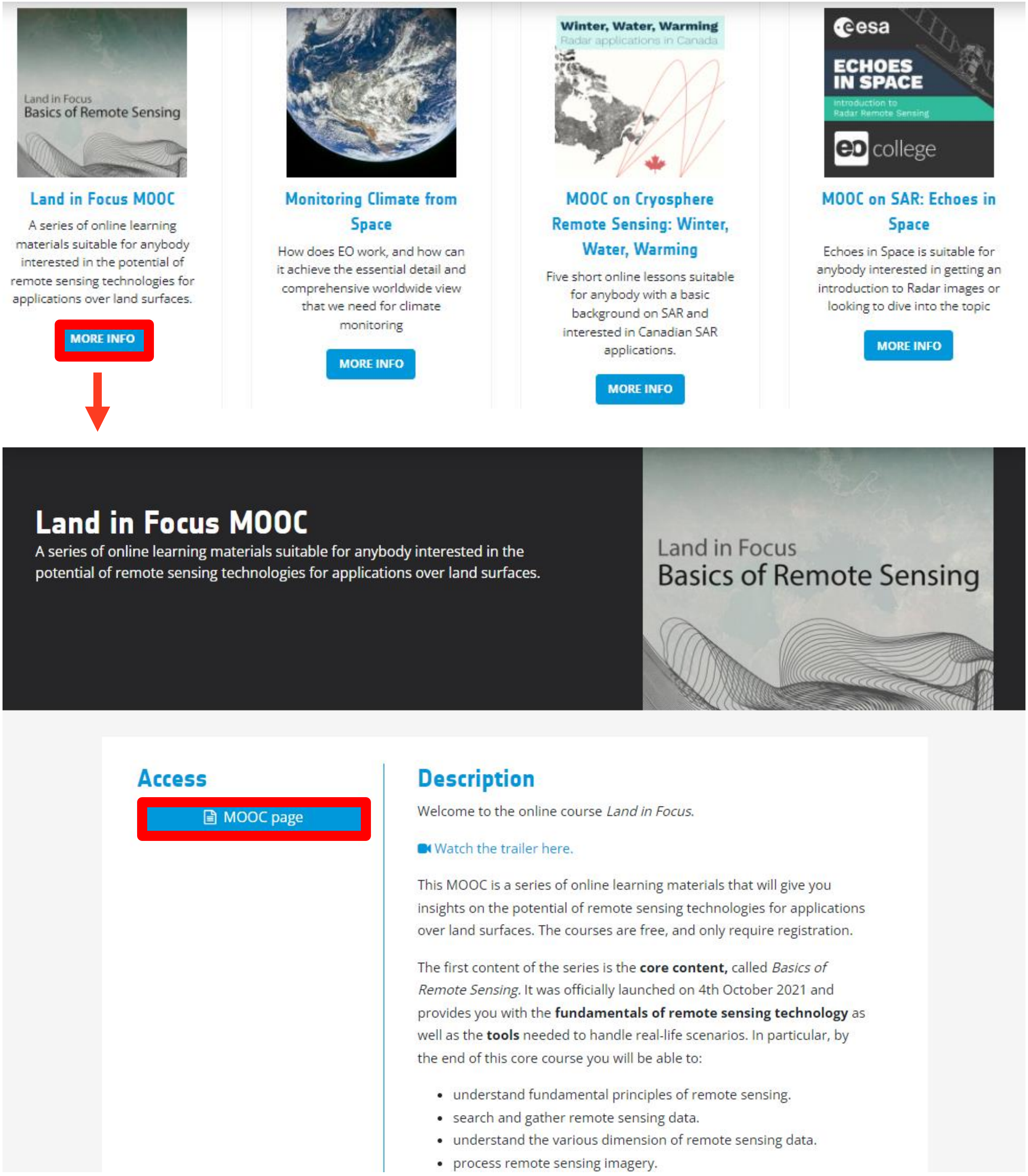
https://eo4society.esa.int/training-education/

EO4Society is a program that focuses on utilizing Earth observation data to address societal challenges. The EO4Society program aims to promote the use of Earth observation data for various societal benefits, including environmental monitoring, climate change studies, disaster management, agriculture, and urban planning, among others.

Within this platform ESA has developed Massive Open Online Courses (MOOCs) on various topics related to space exploration, science, and technology. These courses are inclusive, accommodating individuals from diverse backgrounds, such as scientists, policy-makers, educators, professionals, students at schools or universities, and casual learners. Each course lasts several weeks, challenging the traditional educational framework by integrating data, video content, applications, and online materials.

The educational journey can be tailored to individual preferences due to its social dimension, which includes online discussions and feedback from educators, along with the incorporation of optional materials. Each MOOC training course has its dedicated page with learning materials.

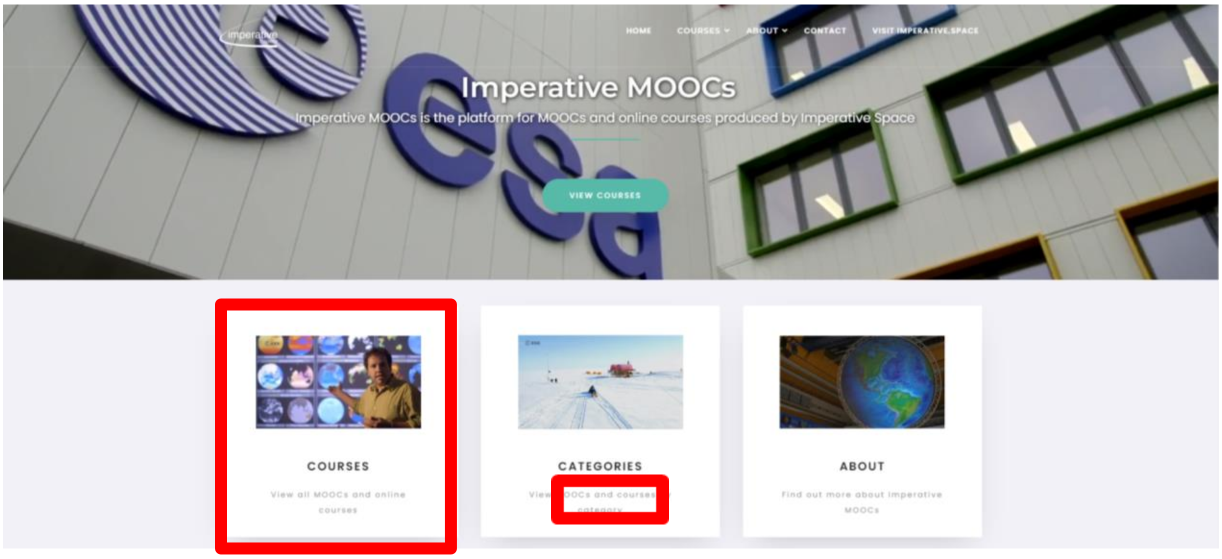
Link: https://eo4society.esa.int/training-education/massive-open-online-courses-moocs/



4.1.1 Imperative MOOCs

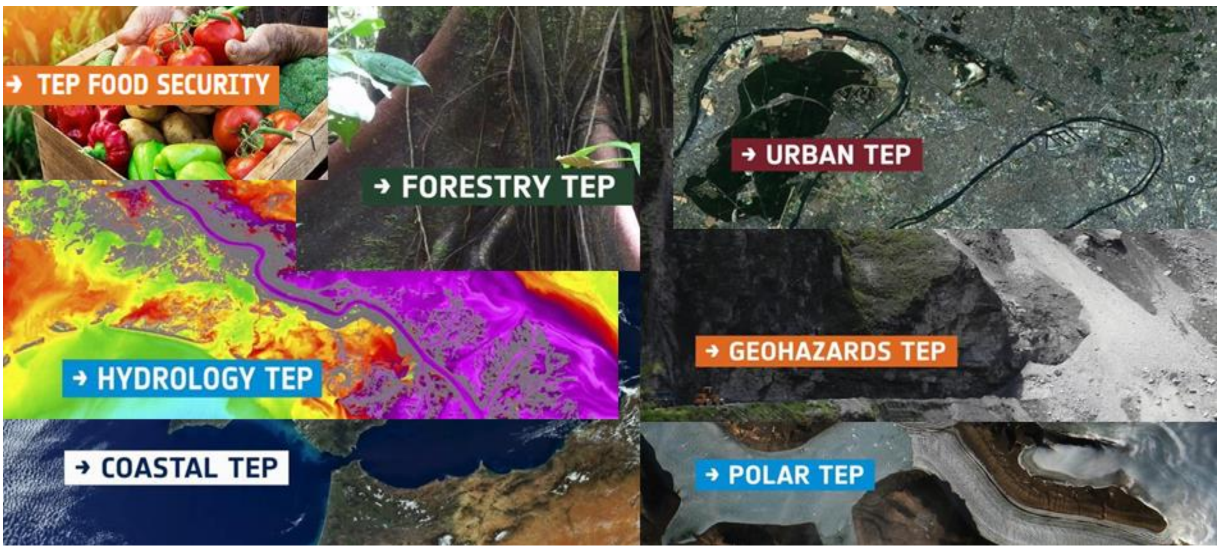
https://www.imperativemoocs.com/

Imperative MOOCs is the platform for MOOCs and online learning projects produced by Imperative Space whose one of the clients is also ESA. Its Earth Observation courses have created innovative new approaches to training and knowledge exchange in this field, and are supported by purpose-built data apps-

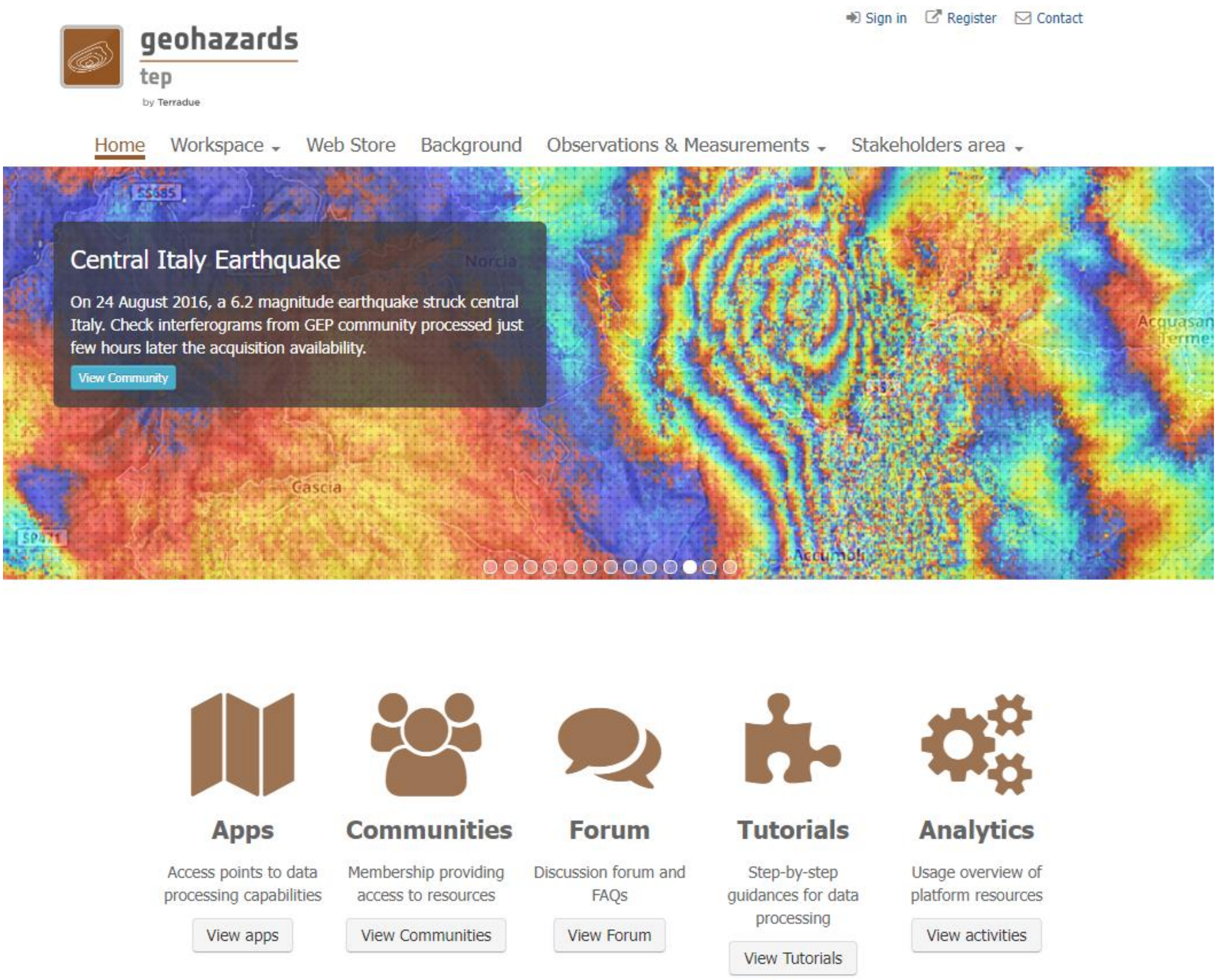


4.1.2 Thematic Exploitation Platforms (TEPs)

Another result of EO4SocietyTEPs are collaborative and virtual workspaces that grant access to Earth Observation (EO) data, along with the necessary tools, processors, and information and communication technology resources essential for effectively working with them. These resources are made accessible through a unified and cohesive interface. TEPs are adressing following topics: Coastal, Forestry, Hydrology, Geohazards, Polar, Urban themes, Food Security.



E.g. the Geohazards TEP (G-TEP) platform is built on the virtualization and federation of satellite EO data and methods. Its primary goal is to offer innovative solutions to the geohazards community's needs. By utilizing advanced services for both Optical and Synthetic Aperture Radar (SAR) data, it provides on-demand and systematic processing services tailored to the specific requirements of user communities. The platform seamlessly connects to extensive Copernicus Sentinels-1/2/3 repositories, High-Resolution Optical imagery, and over 70 terabytes of EO data from archives like ERS and ENVISAT. Additionally, it interfaces with specific data collections from missions such as JAXA's ALOS-2, ASI's Cosmo-Skymed, and DLR's TerraSAR-X, all made available through special arrangements within the framework of the CEOS WG Disaster and GSNL. This integration allows the platform to efficiently address the challenges of monitoring tectonic areas globally by tapping into significant compute power on multi-tenant Cloud Computing resources.



4.1.3 Copernicus RUS Training Materials

https://eo4society.esa.int/resources/copernicus-rus-training-materials/

Operating from 2017 until December 2021, the Copernicus Research and User Support (RUS) service sought to create an open-access online platform with the goal of fostering the utilization of Copernicus data and facilitating the expansion of educational and research and development (R&D) initiatives. The primary objective of the RUS Service was to encourage the utilization of Copernicus data and facilitate the expansion of research and development (R&D) endeavors, including the advancement of pre-commercial processing chains. This service is structured within a scalable cloud environment, allowing for the remote storage and processing of Earth Observation (EO) data.

Additionally, the RUS Service extended its support through on-site training sessions, webinars, and online resources. Notably, this service is accessible to a diverse user community and various types of institutions at no charge.

Nowadays, the training sessions of the Copernicus RUS service are available at EO4Society website.

4.2 ESA Learning Hub

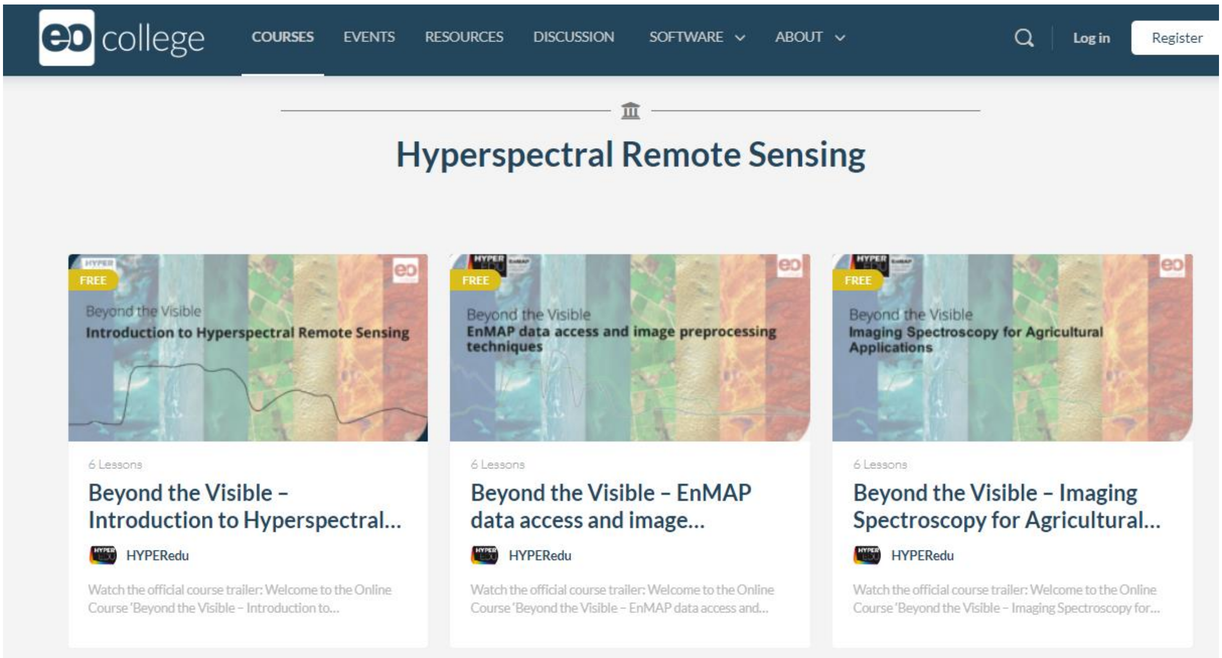
https://learninghub.esa.int/

The ESA Learning Hub, managed by the SME section in ESA's Directorate of Commercialisation, Industry, and Procurement, is an online platform providing industry stakeholders and delegations access to training courses and materials associated with ESA programs. As a central repository aligned with ESA activities, it aims to enhance European industry growth by supplementing core knowledge, competencies, and overall competitiveness.

4.3 EO College

https://eo-college.org/

The EO College serves as a central hub for digital learning content focused on Earth observation, remote sensing, and related subjects. This platform is specifically designed to function as a repository for open educational resources and online courses. In essence, it acts as a comprehensive source for individuals seeking to enhance their knowledge and skills in the field of EO through digital learning materials.

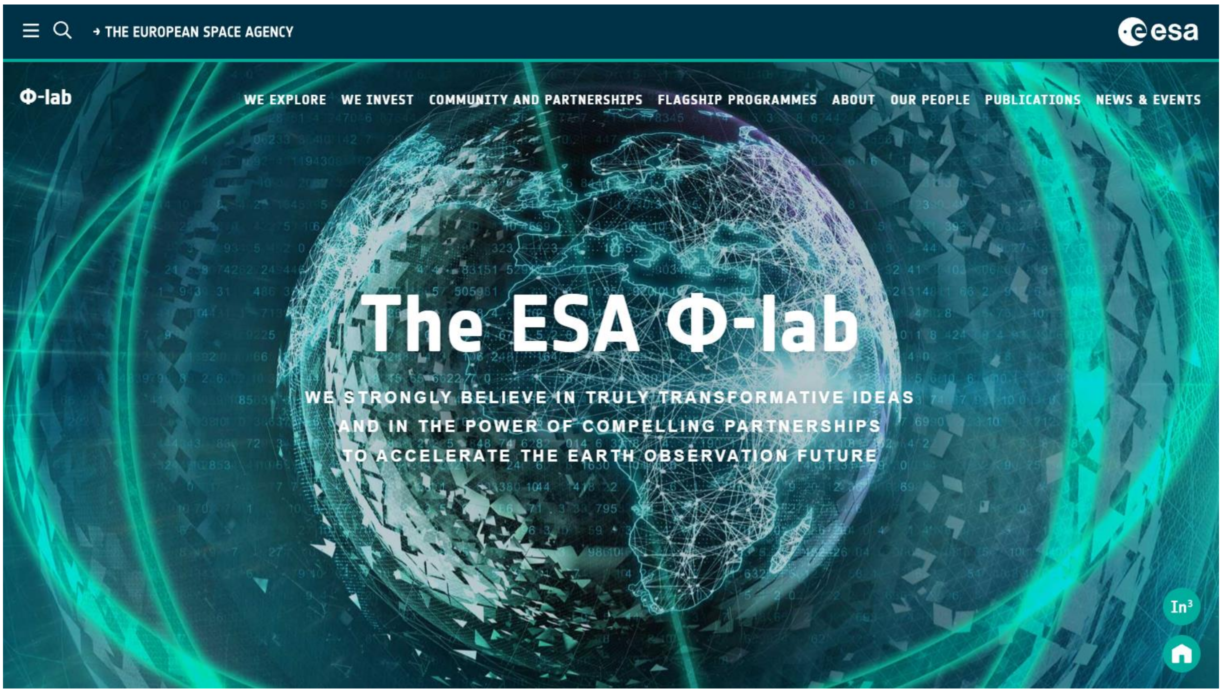


4.4 SEOM (Scientific Exploitation of Operational Missions)

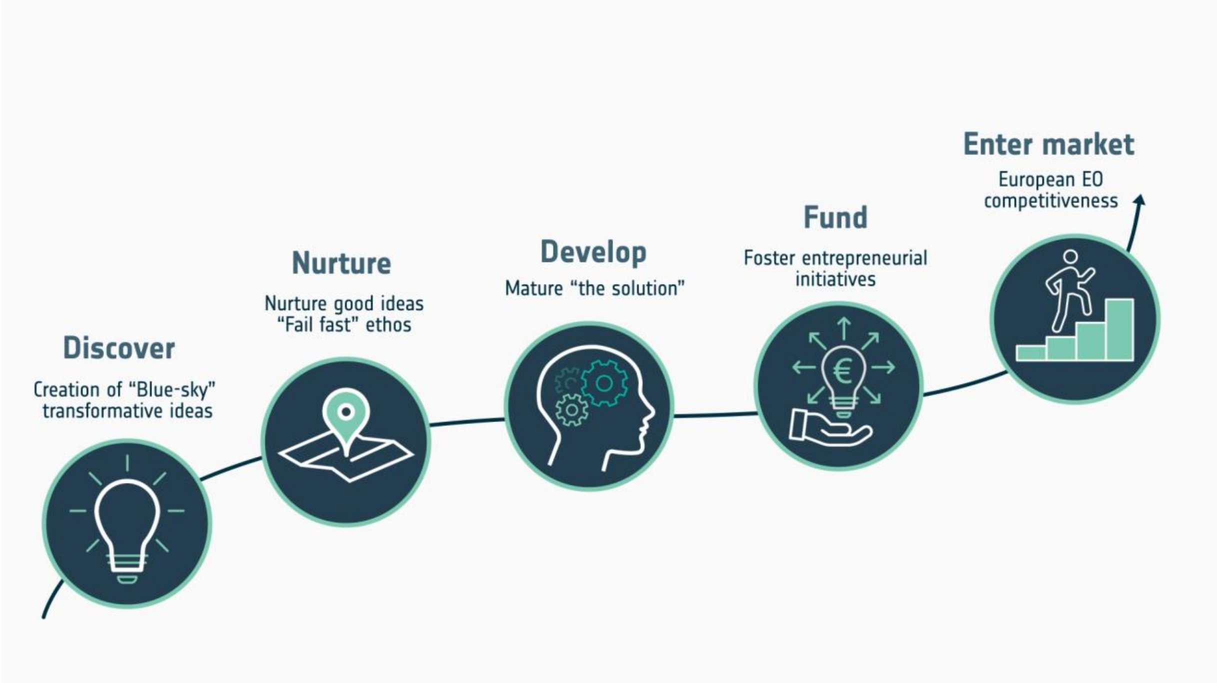
https://seom.esa.int/

The primary goal of the SEOM component within the Earth Observation Envelope Program 4 is to unite, assist, and extend the extensive international research community established through the ERS, ENVISAT, and Envelope programs over the past two decades. Its objective is to enhance the global leadership of the European Earth Observation research community by facilitating comprehensive utilization of observations from upcoming European operational EO missions. SEOM aims to empower the scientific community to explore numerous new avenues of research made possible by the free and open access to data from operational EO missions.

5 | Future of EO - ESA Φ-lab



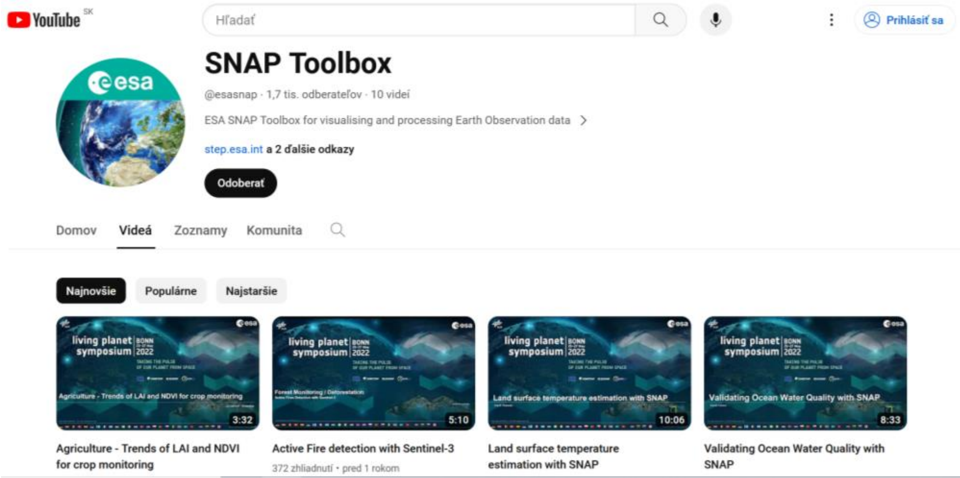
The primary objective of ESA's Φ-lab initiative is to accelerate the future of Earth Observation (EO) by fostering transformative innovations. These innovations have the potential to revolutionize or establish entire industries through novel technologies, ultimately enhancing the global competitiveness of the European EO industrial and research sectors.



6 | Video lectures and tutorials, Sentinel App

SNAP Toolbox

There are various tutorials and guides available on YouTube that cover the use of the SNAP (Sentinel Application Platform) toolbox, such as SNAP Toolbox. SNAP is developed by the European Space Agency (ESA) and is used for the analysis and processing of remote sensing data, particularly data from the Sentinel missions.



Sentinel App

The Sentinel App serves as a portal for gaining insights into the Copernicus Sentinel satellites. It enables users to monitor the satellites in real-time, access information on their essential features, stay updated with the latest news, and delve into details about their offerings. Among its features, users can explore intricate 3D representations of the satellites, observe the past and upcoming instances when the satellites will be visible from their location, etc.

For more information, see the lecture: [1. Introduction to ESA Earth Observation and evolution – current and next generation missions]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 2 – TUTORIAL

ESA EO Data Access and Selection,
applications of Copernicus Earth Observation data

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- acquire skills in retrieving satellite imagery from both ESA and third-party missions
- conduct specific analyses utilizing the EO Browser
- install ESA SNAP and execute fundamental image operations
- explore the spectral curve of various surface types

2 | Background

Most of the ESA's Earth observation datasets are easily accessible online, free of charge. Users can acquire access by completing a simple registration process.

The Copernicus Data Space Ecosystem provides full, free and open access to large amount of Earth observation data, along with scalable interfaces integrated with the Copernicus Sentinel satellites. This includes a range of both new and historical Sentinel images, commercial datasets, as well as Copernicus Contributing Missions.

Sentinel data is also accessible through Copernicus Data and Information Access Services (DIAS), which are platforms designed to facilitate the discovery, retrieval, and use of Copernicus satellite data, including data from the Sentinel missions. There are several DIAS platforms available, each offering a user-friendly interface and tools for working with the data.

The ESA Hub allows checking searches online by browsing and viewing product metadata and measurements without downloading them. Sentinel products are provided for download over HTTP in *.ZIP archive file format.

Sentinel Hub is a cloud-based platform that provides access to satellite data, particularly from the ESA Sentinel missions. The platform offers a variety of services and tools for the retrieval, processing, and analysis of satellite imagery. It is commonly used by researchers, developers, and businesses to access Earth observation data for various applications, including environmental monitoring, agriculture, urban planning, and more. EO Browser is an online platform developed by Sentinel Hub that allows users to visualize and explore satellite imagery, particularly from the Copernicus Sentinel missions. Sentinel Hub provides the backend infrastructure and access to the satellite data, while EO Browser serves as the user interface for interacting with that data.

ESA not only provides satellite data from its own Earth Observation (EO) satellite resources, but also facilitates access to Third Party Missions (TPMs), which are non-ESA EO missions. Integrating data from these diverse sources is crucial for enhancing the sustainability of satellite services, expanding the scope of monitored parameters, and promoting scientific development. Researchers and students alike can request third-party data, but it's important to be aware of licensing conditions, especially for users in certain countries, where national legislation on data access may apply.

3 | How to access ESA data

To access data from the European Space Agency (ESA), user can use various platforms and tools provided by ESA. Here are some key sources:

Earth Online Portal

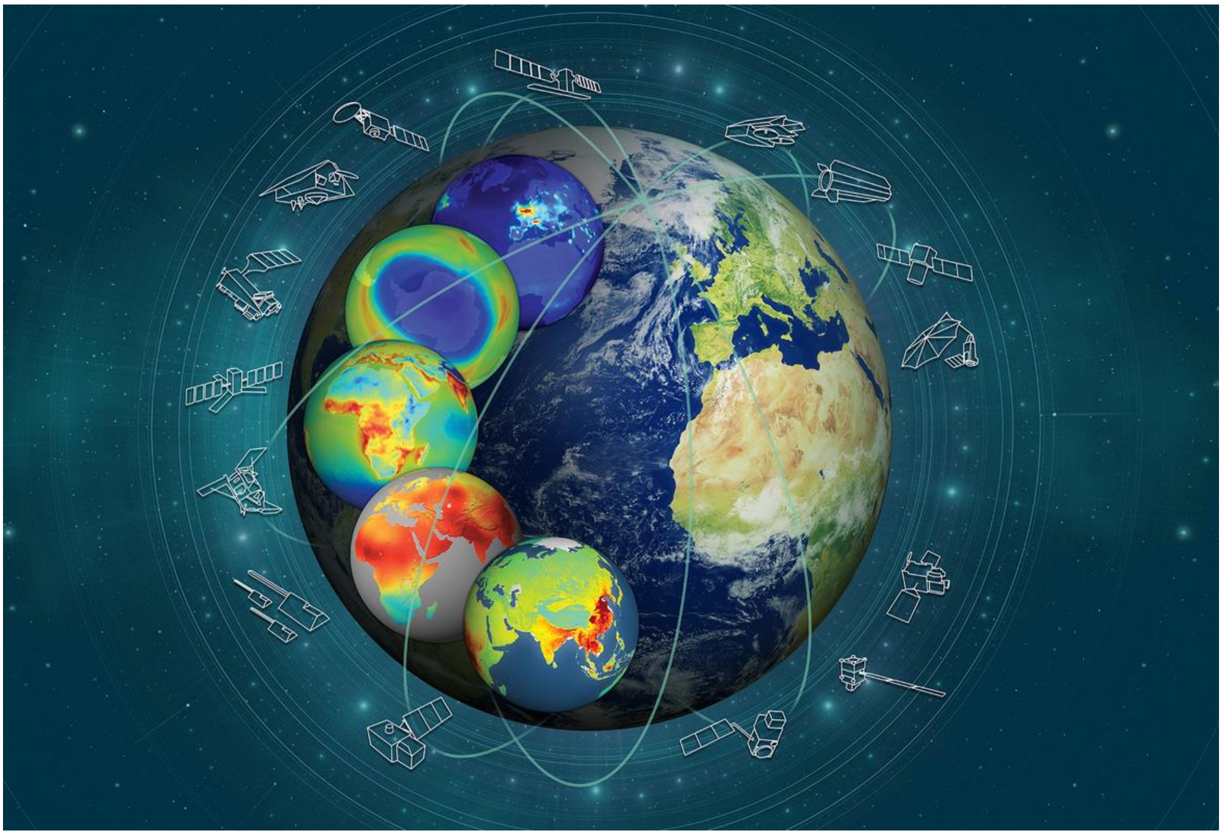
The Earth Online Portal serves as a gateway to a diverse range of Earth observation resources. It includes a directory for discovering missions and datasets, offering convenient access to satellite data, operational updates, events, and tools to enhance data utilization.

Sentinel Online

The Sentinel online platform offers technical details about the Copernicus Sentinel missions and allows systematic access to processed data, which is readily accessible on the website. User registration is required for access.

Copernicus Contributing Missions Online

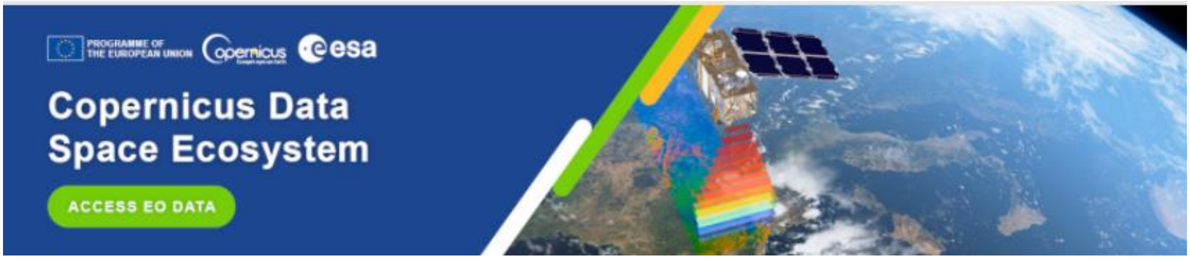
To obtain data with higher resolution, users can visit the Copernicus Contributing Missions website. This platform offers comprehensive information on all Contributing Missions that provide data complementing the Copernicus Sentinels, addressing the requirements of the Copernicus Services. Eligible users can access the data for free upon registration and confirmation of their user category.



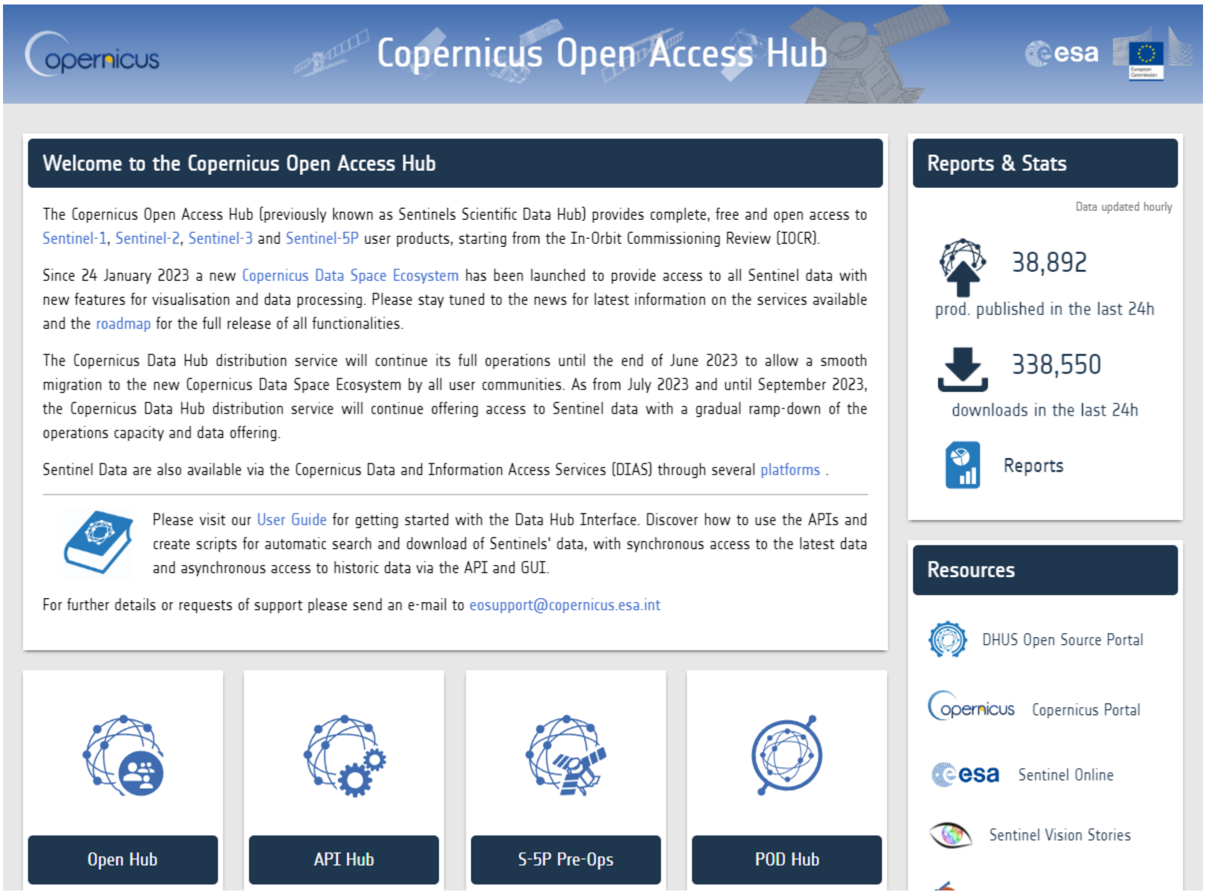
4 | Copernicus Data Space Ecosystem

https://dataspace.copernicus.eu/

- Since 24 January 2023 a new Copernicus Data Space Ecosystem has been launched to provide free and open access to Earth Observation data from all Sentinel satellites with new features for visualisation and data processing.

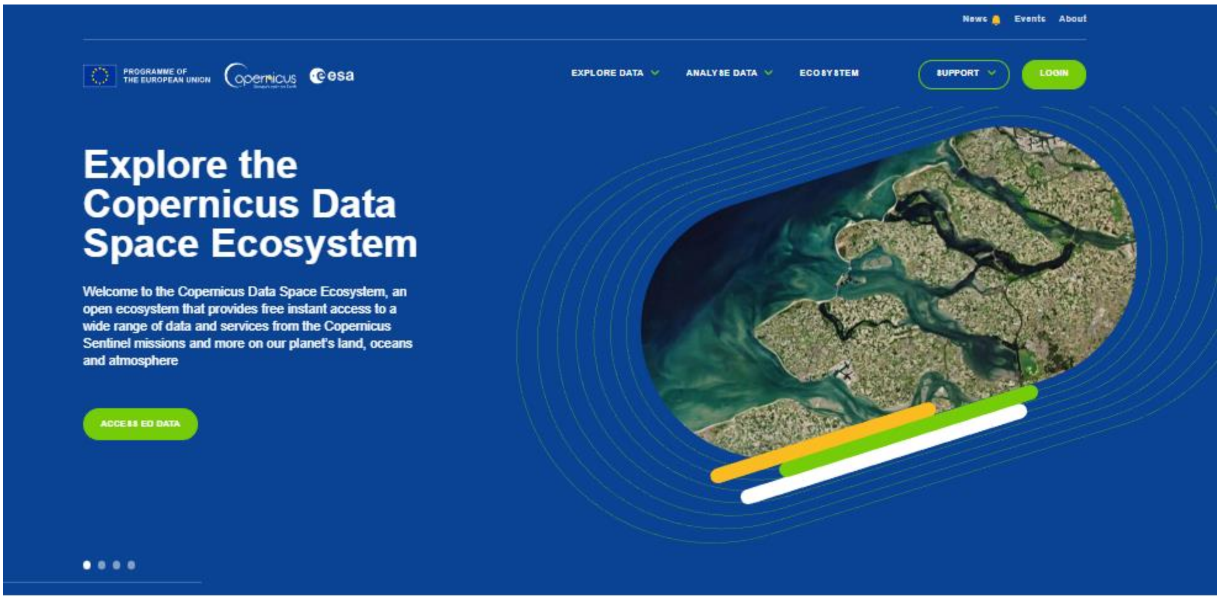


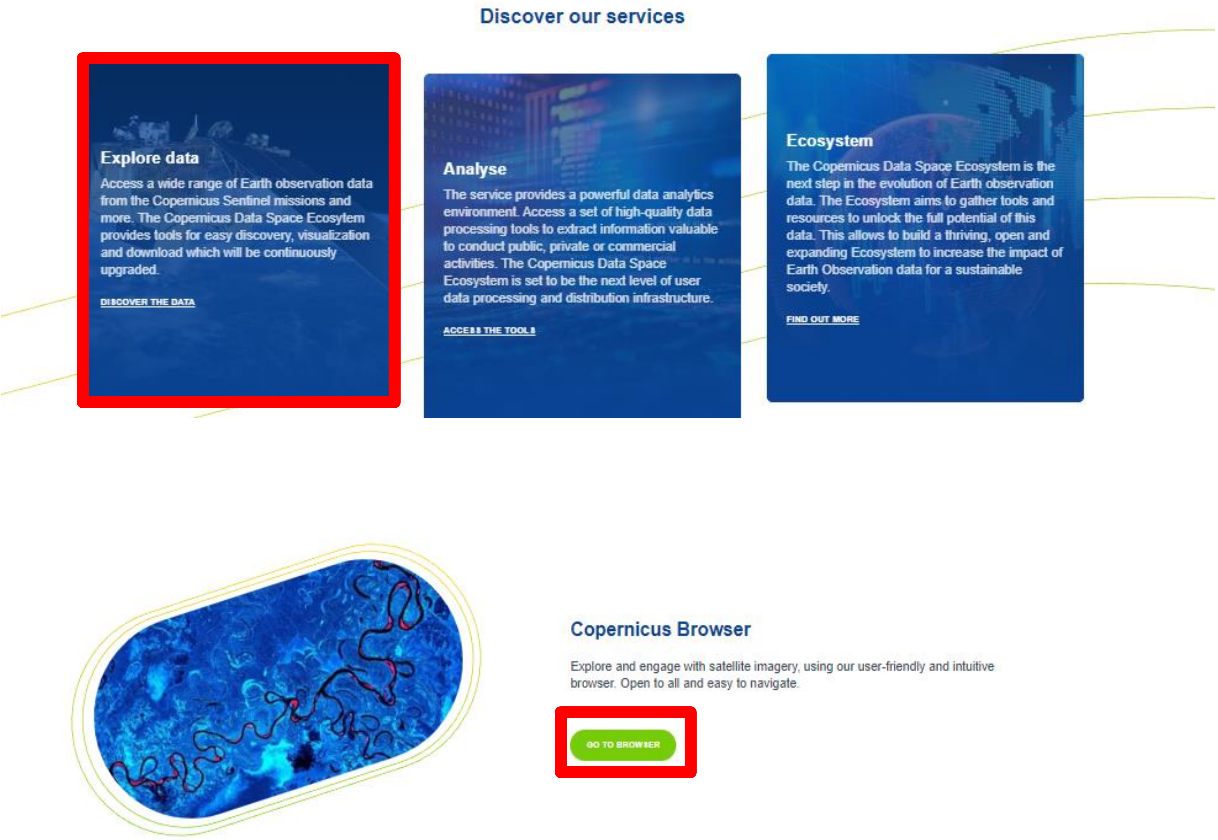
- The previous Copernicus Data Hub distribution service that has been providing access to Copernicus data is offering access to Sentinel data with a gradual ramp-down of the operations capacity and data offering.



- Sentinel Data are also available via the Copernicus Data and Information Access Services (DIAS) through several platforms.

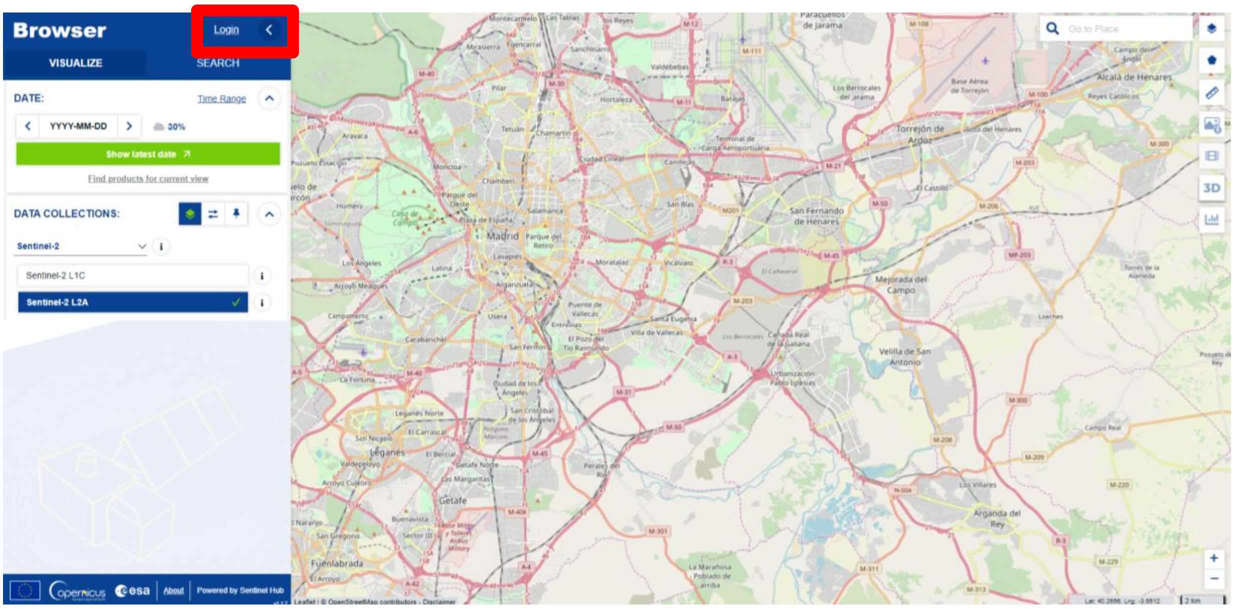
The Copernicus Data Space Ecosytem allows us to access a wide range of Earth observation data from the Copernicus Sentinel missions and more. The Copernicus Data Space Ecosytem provides tools for easy discovery, visualization and download which will be continuously upgraded.

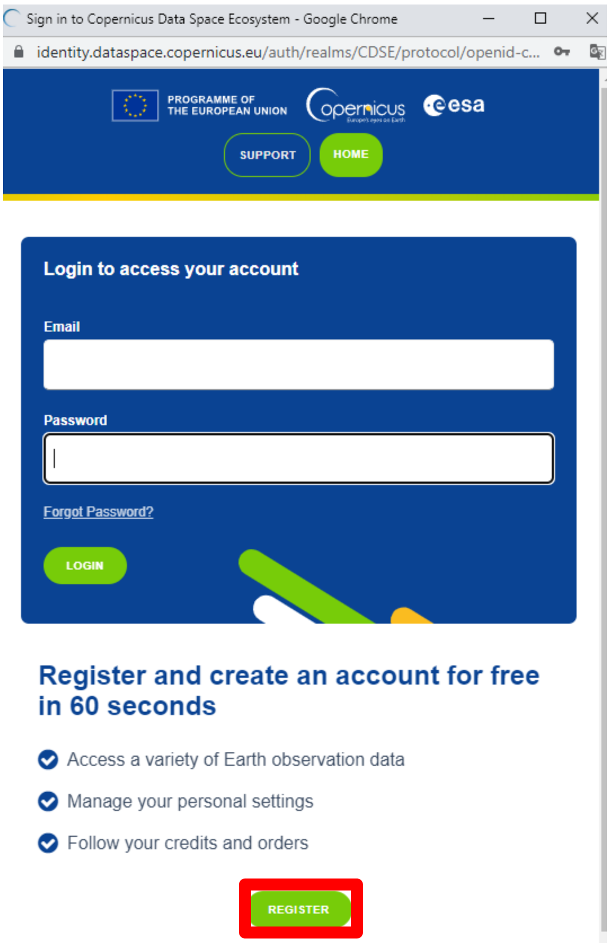


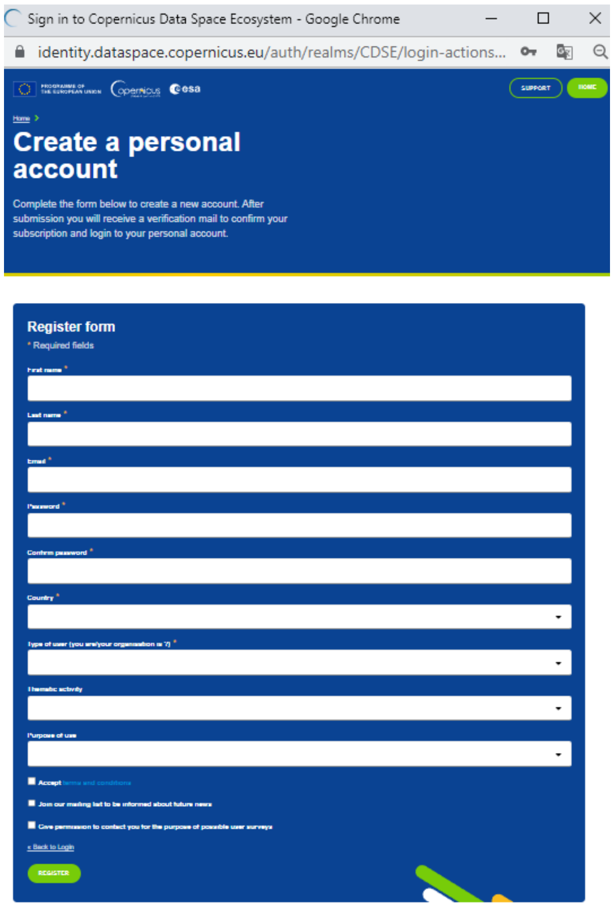


4.1. Registration and login

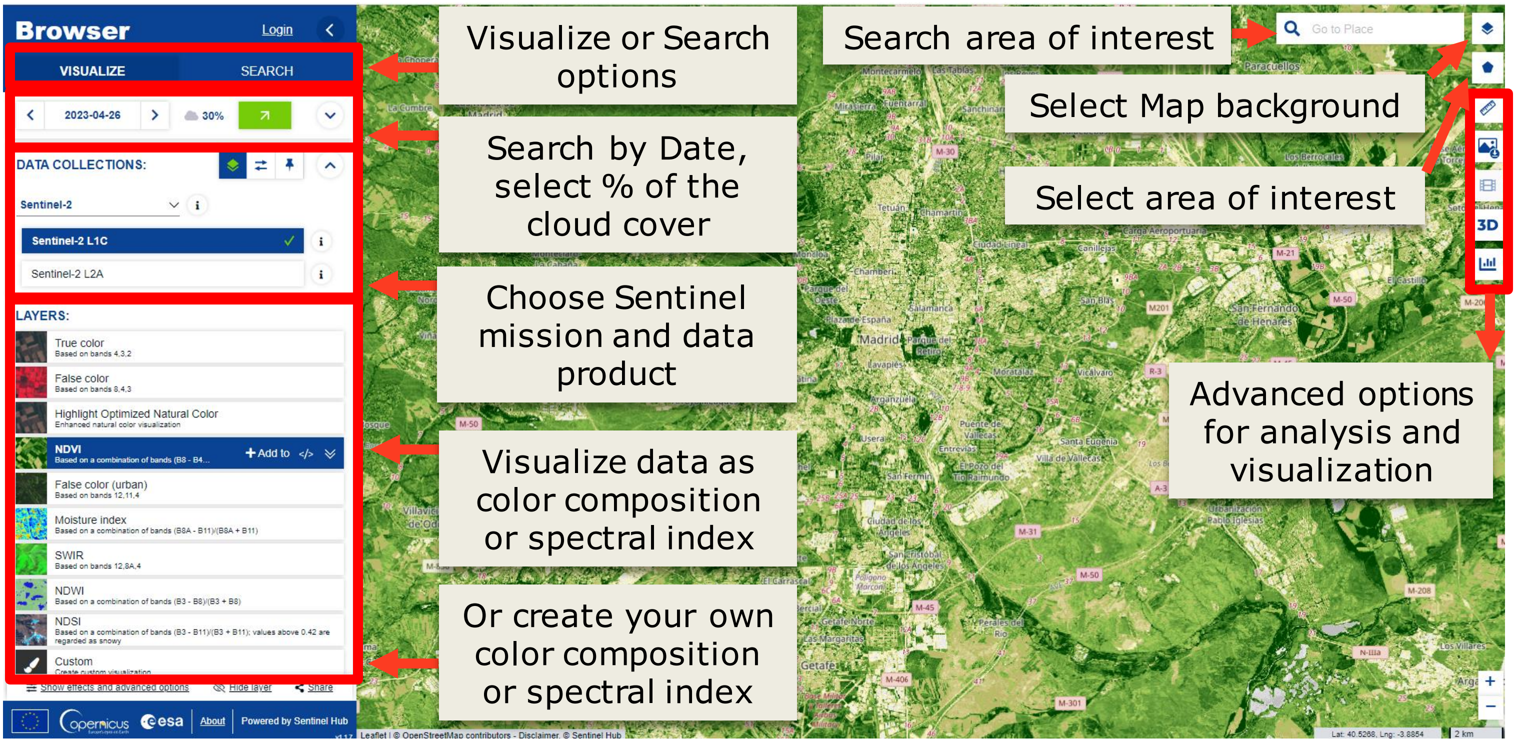
- We can register a new user or log in as an existing user to the portal.
- The Copernicus Data Space Ecosytem allows us to browse and visualize satellite images freely, but we need to register and create an account to be able to download them.

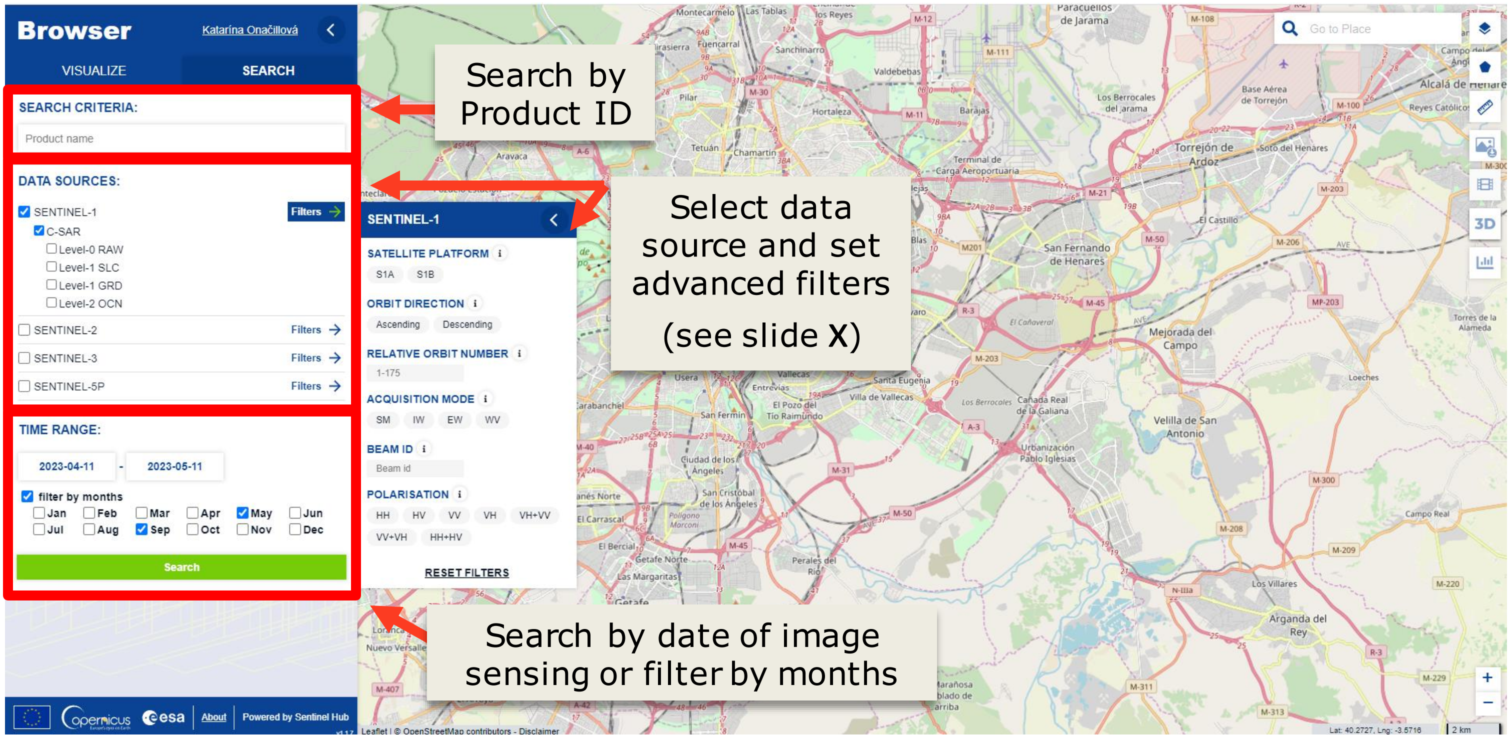




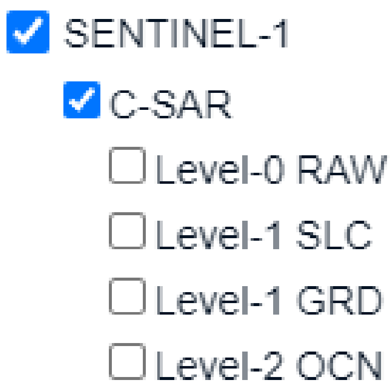


After registration and login, it is possible to visualize or search EO data products within portal. We can choose various satellite platforms, product types, polarizations, and sensing modes for individual satellites:



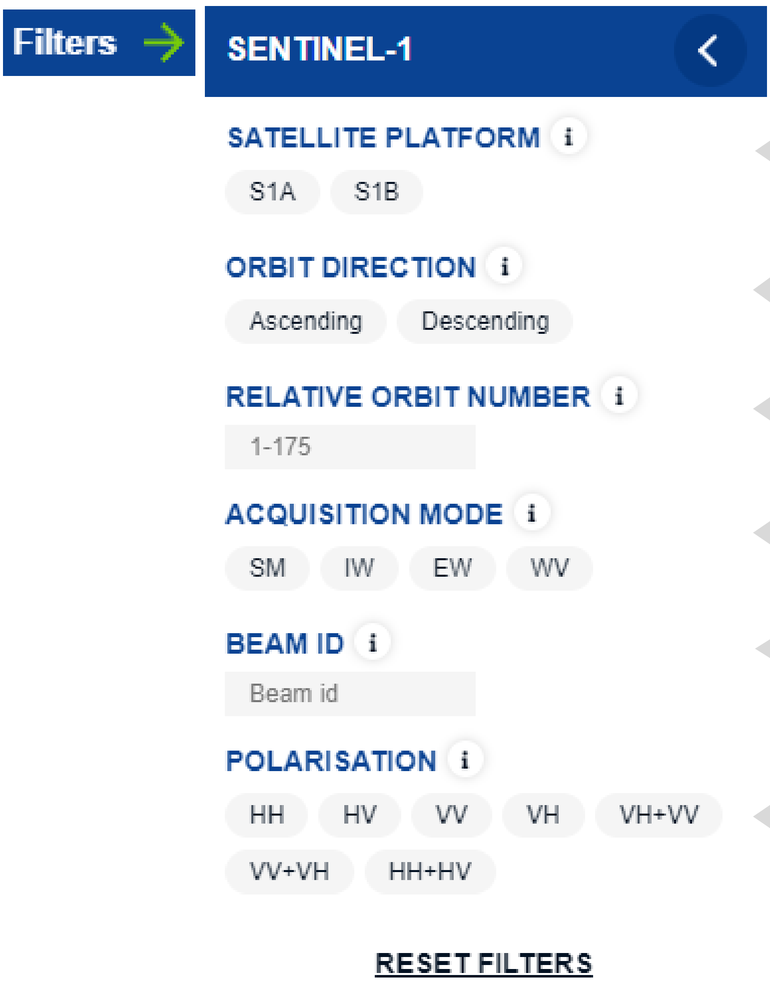


E.g. Sentinel-1 C-SAR - SAR Instrument that provides an all-weather, day and night imagery at C-band at high and medium resolutions for land, coastal zones and ice observations.



Levels of product types

- unprocessed raw data
- (Single Look Complex) contains complex images with amplitude and phase in the slant range by azimuth imaging plane, in the image plane of satellite data acquisition
- (Ground Range Detected) consists of focused SAR data that has been detected, multi-looked and projected to ground range using an Earth ellipsoid model
- (Ocean) provide geo-located geophysical products derived from Level-1 for wind, wave and currents applications



The available Sentinel-1 data includes products from the Sentinel-1 satellite constellation, including Sentinel-1A (operational since 2014) and Sentinel-1B (operational from 2016 to 2022)

Determines wheter the data was recorded during a descending orbit (flight direction: north-south) or an ascending orbit (flight direction: south-north)

The Relative Orbit Number is the number of full orbits since the relative orbit 1 to the end of a cycle

Sentinel-1 operates in 4 instrument acquisition modes: Stripmap (SM), Interferometric Wide Swath (IW), Extra-Wide Swath (EW), Wave (WV)

Depending on the acquisition mode, different swaths and identifiers are possible

Determines with which polarisation the data was acquired. The first letter indicates the polarisation when sending the signal, the second letter when receiving the signal. Data can be acquired in single polarisation HH or VV or in dual polarisation HHHV or VVVH depending on the instrument mode

4.2. Search results

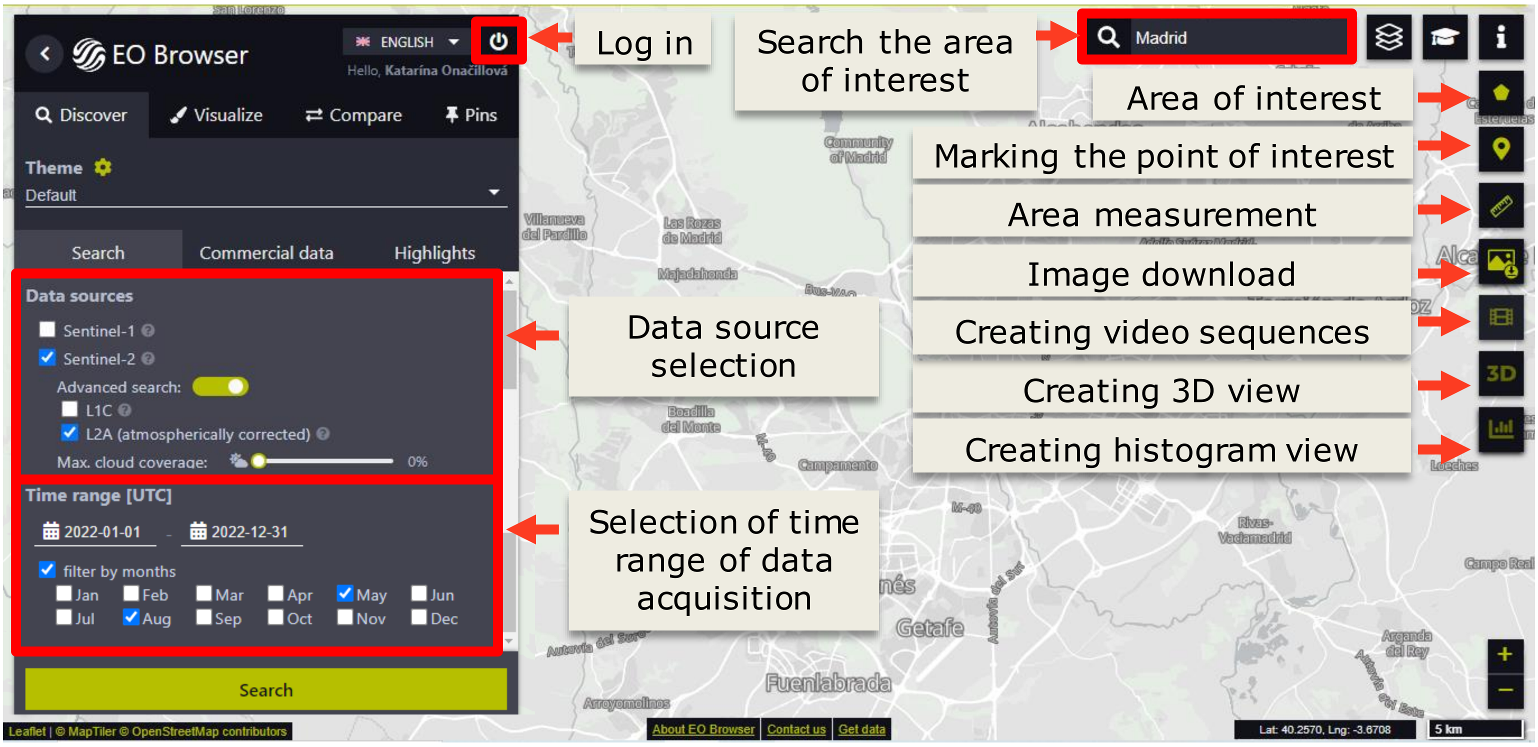
After defining the search criteria, we get the results that can be further viewed, analysed or downloaded.

5 | Sentinel Hub - EO Browser

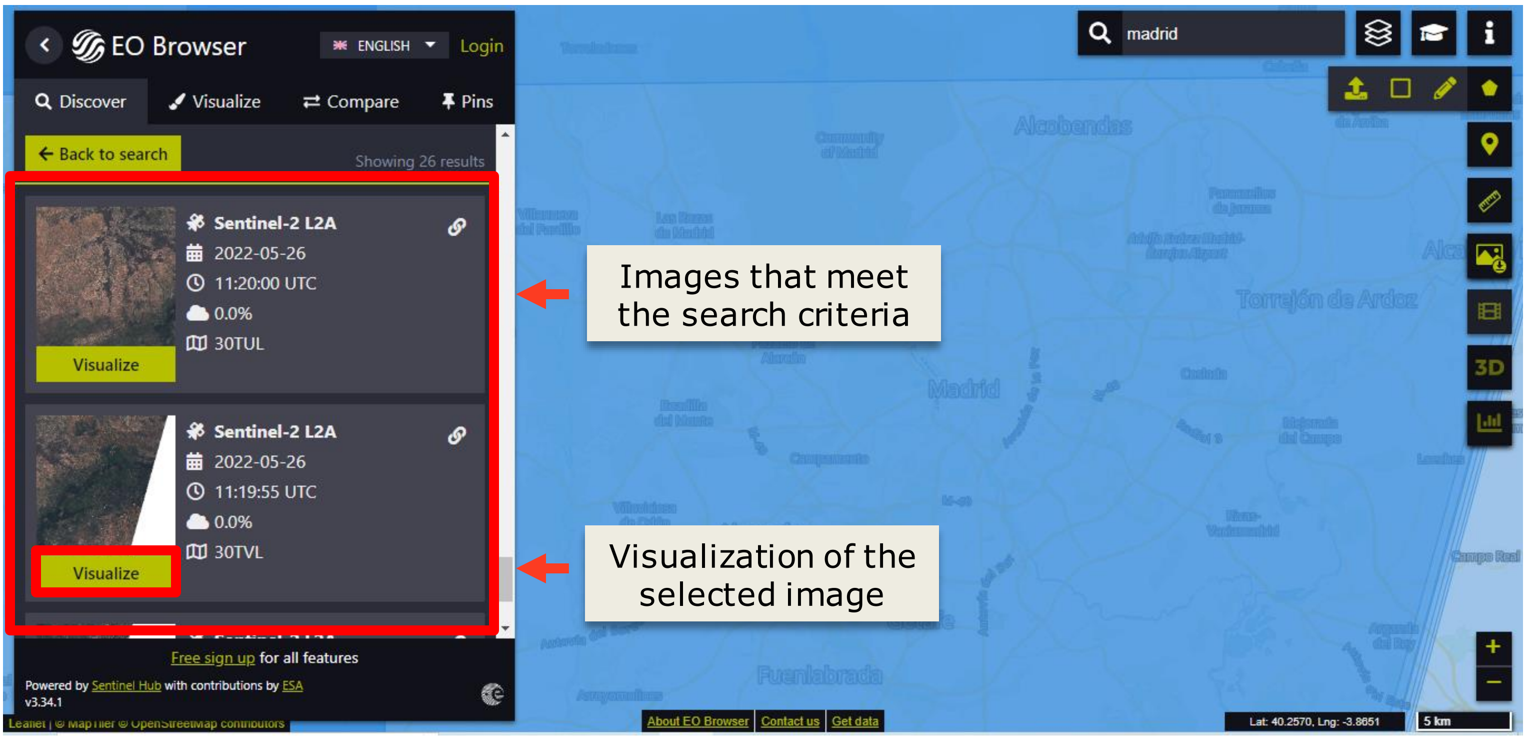
https://apps.sentinel-hub.com/eo-browser/

EO Browser, developed by Sentinel Hub, is an online platform that empowers users to explore and visualize satellite imagery from Earth observation (EO) missions, with a focus on the Copernicus program. Offering an intuitive and user-friendly interface, the platform is widely utilized for educational, research, and environmental monitoring purposes. Key features encompass direct access to Copernicus Sentinel data, enabling users to visualize and analyze imagery within the browser. Customization options allow users to tailor their view by adjusting parameters like date and cloud cover, catering to specific research needs. The platform's educational utility is evident in its use in educational settings, introducing students to Earth observation and remote sensing through its accessible interface. Additionally, EO Browser facilitates time-lapse creation for monitoring changes in the Earth's surface over time. EO Browser is a valuable tool for those interested in exploring and understanding satellite imagery for a wide range of applications, including environmental monitoring, agriculture, forestry, and urban planning.

Registration or Log in



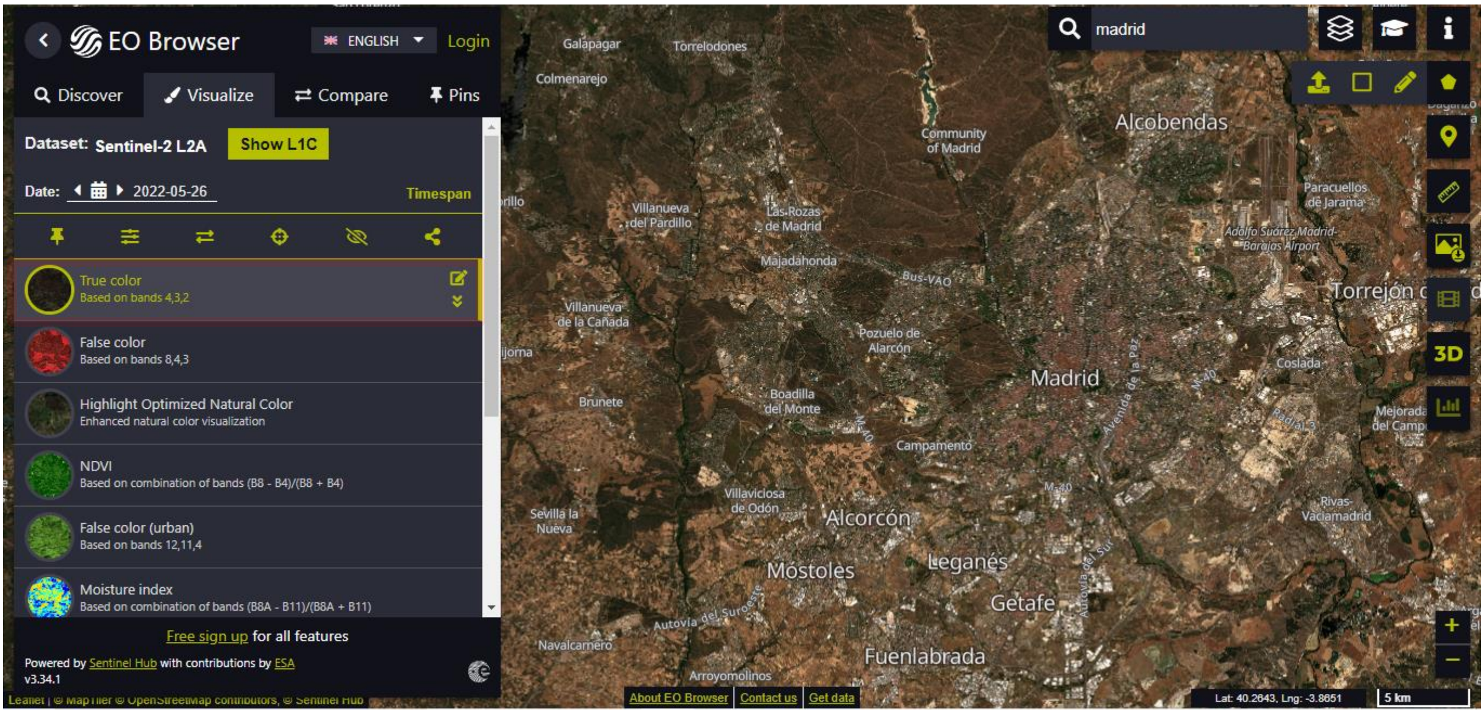
After the search, the selected image can be visualised in the browser.



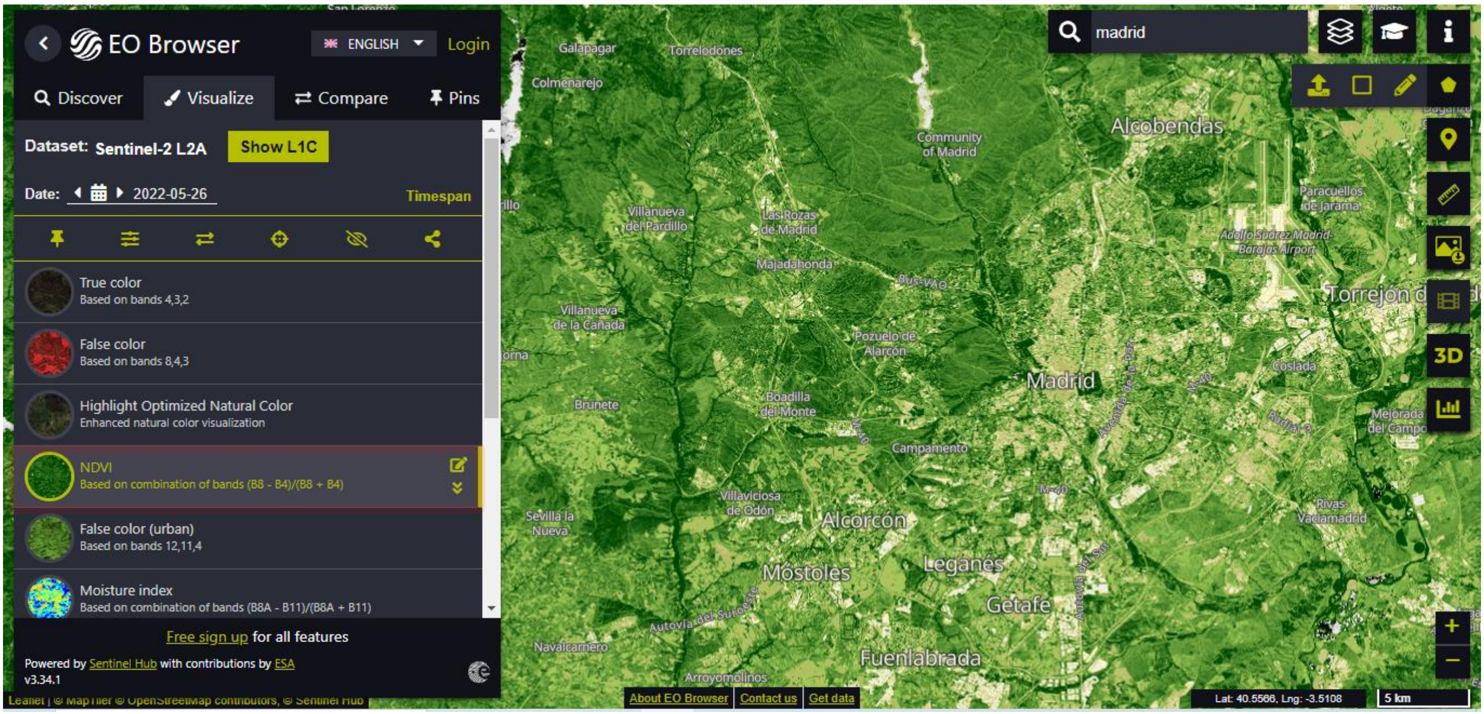
5.1 Optical data

In the visualisation tab, we can change the view mode (available are visualization options in the form of color compositions and spectral indices).

True color composition (R-G-B)



Normalised difference vegetation index (NDVI)



Other visualization options

Available color compositions:

- True colour (bands: Red-Green-Blue)
- False colour (bands: NIR-Red-Green)
- Highlight Optimized Natural Color
- False colour (urban) (bands: 12-11-4)
- SWIR (bands: 12-8A-4)

Available spectral indices:

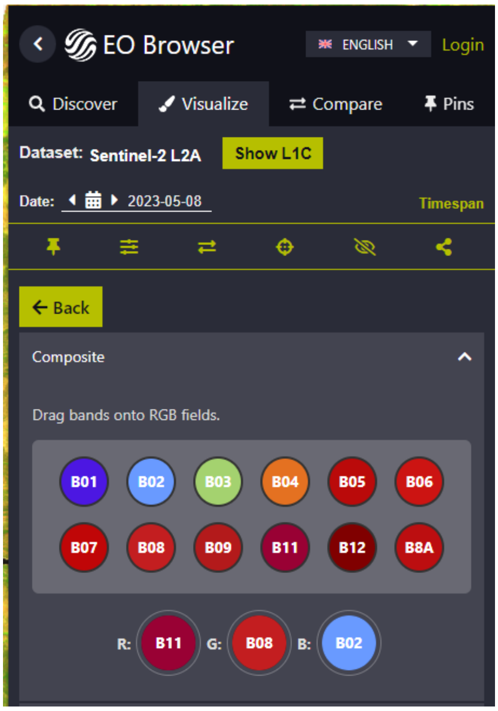
- NDVI - for vegetation monitoring
- NDWI - for water monitoring
- NDSI - for snow monitoring
- Moisture index - for moisture monitoring

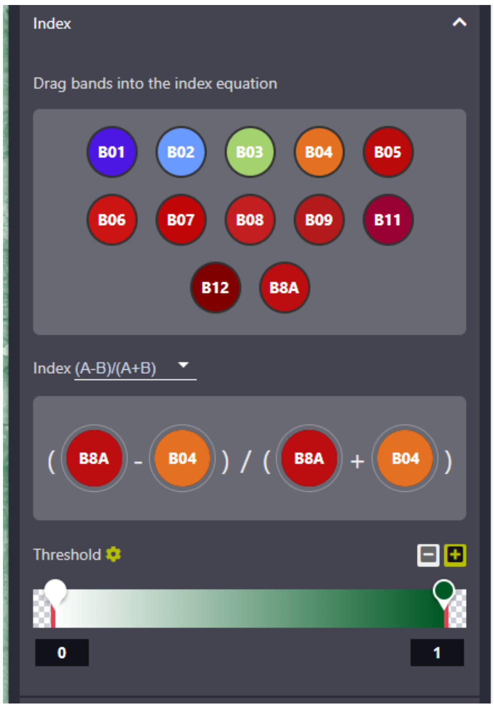
Available classifications:

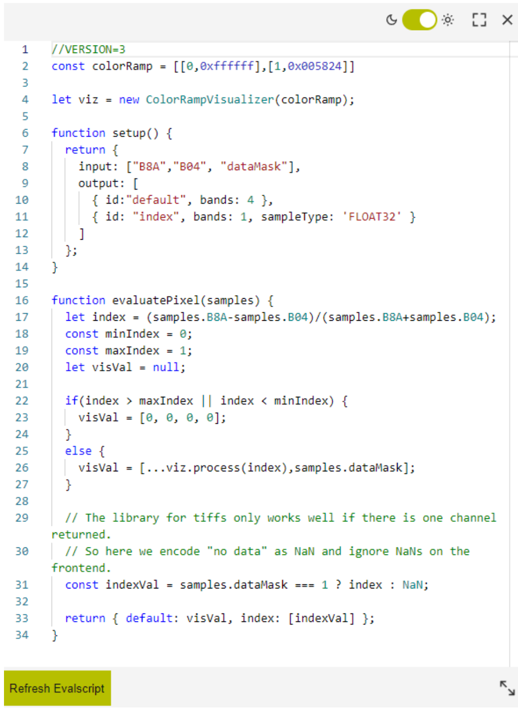
- Scene classification map - classification display based on ESA algorithms

+ Available custom visualization

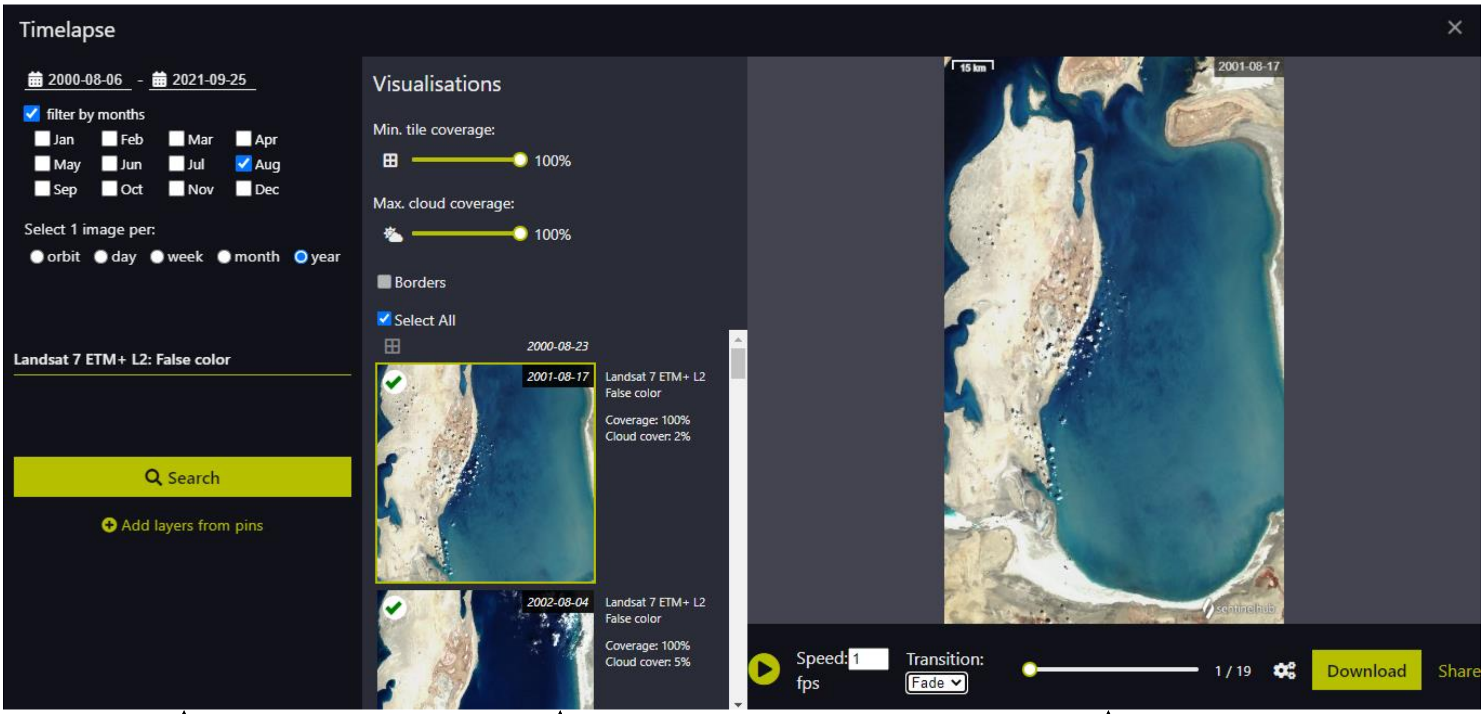
We can also use a visualisation for custom color combinations or spectral indices of default bands or the scripting tool and use additional datasets.







An important visualisation tool of EO Browser is the *Timelapse* function. We can choose multiple images filtered by date or month and select one image per orbit, day, week, month or year. We can set prefered tile coverage and % of cloud cover. Then we can select all or only some images and play, download or share the timelapse visualisation.

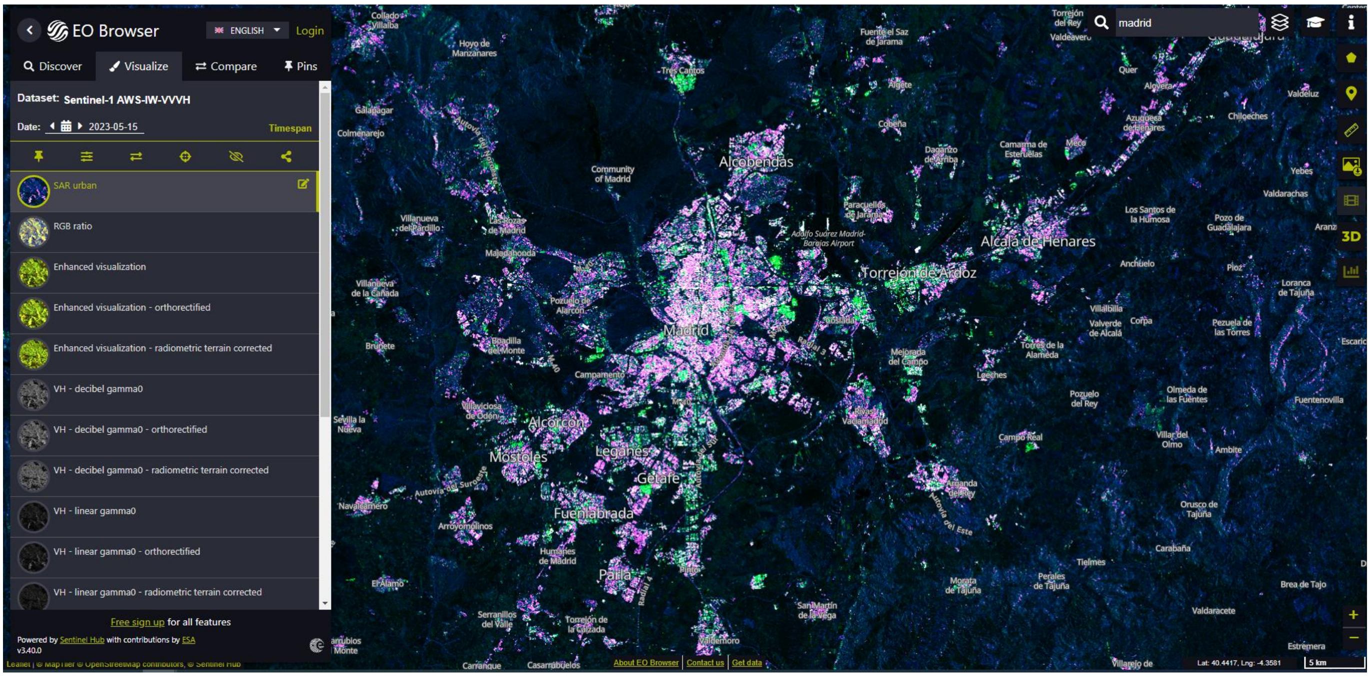


Select time range | Select/deselect image | Play a video, select transition mode, download or share your created timelapse

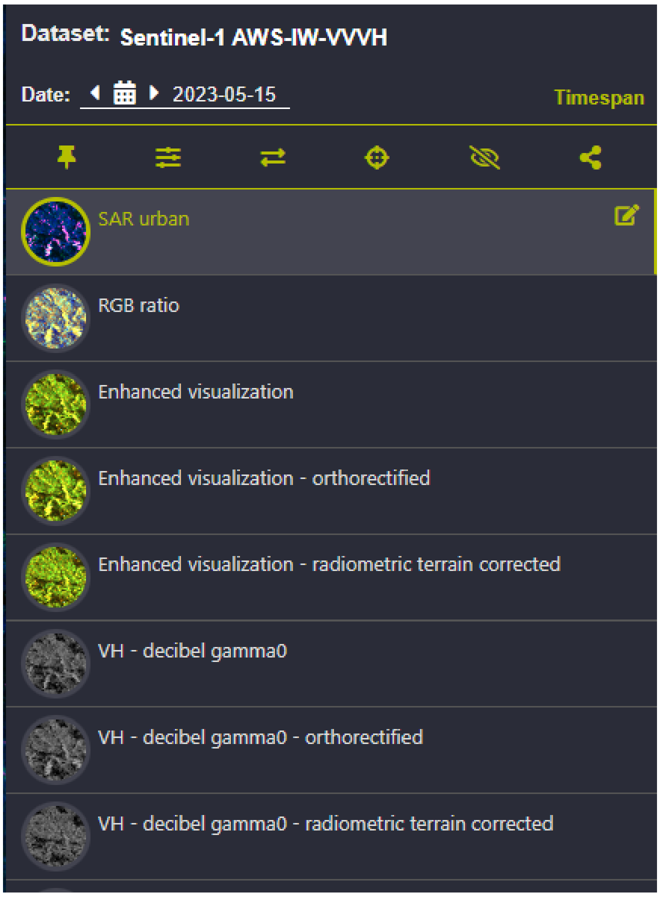
The resulting timelapse of images from the Landsat 7 satellite showing the disappearance of the Aral Sea by 2020

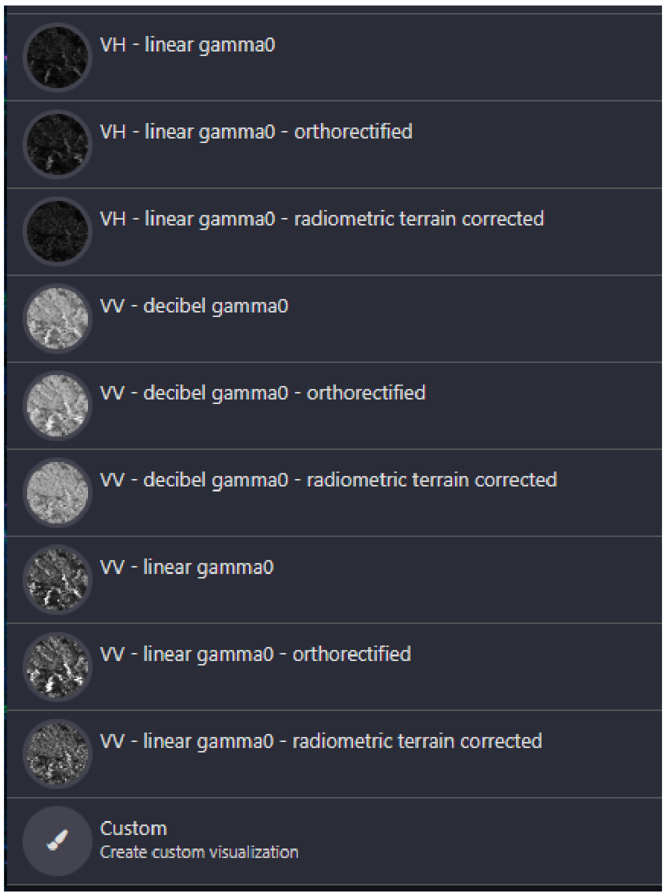
5.2. Radar data

When displaying radar data, we have the option to choose from various types of visualizations.



In accordance with specific requirements, the terrain can be displayed using different polarizations, cross- polarizations, and corrections.

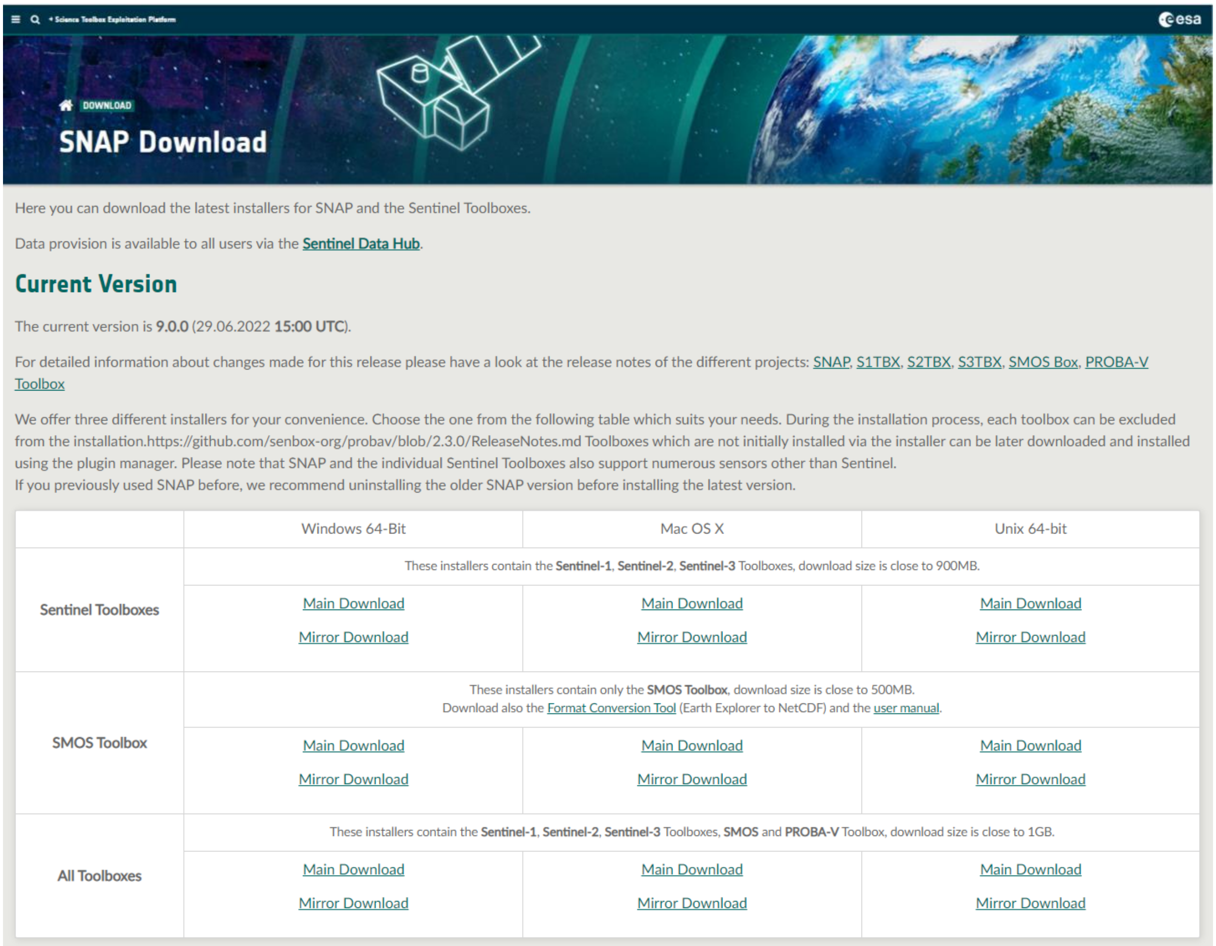




6 | Sentinel Application Platform (SNAP)

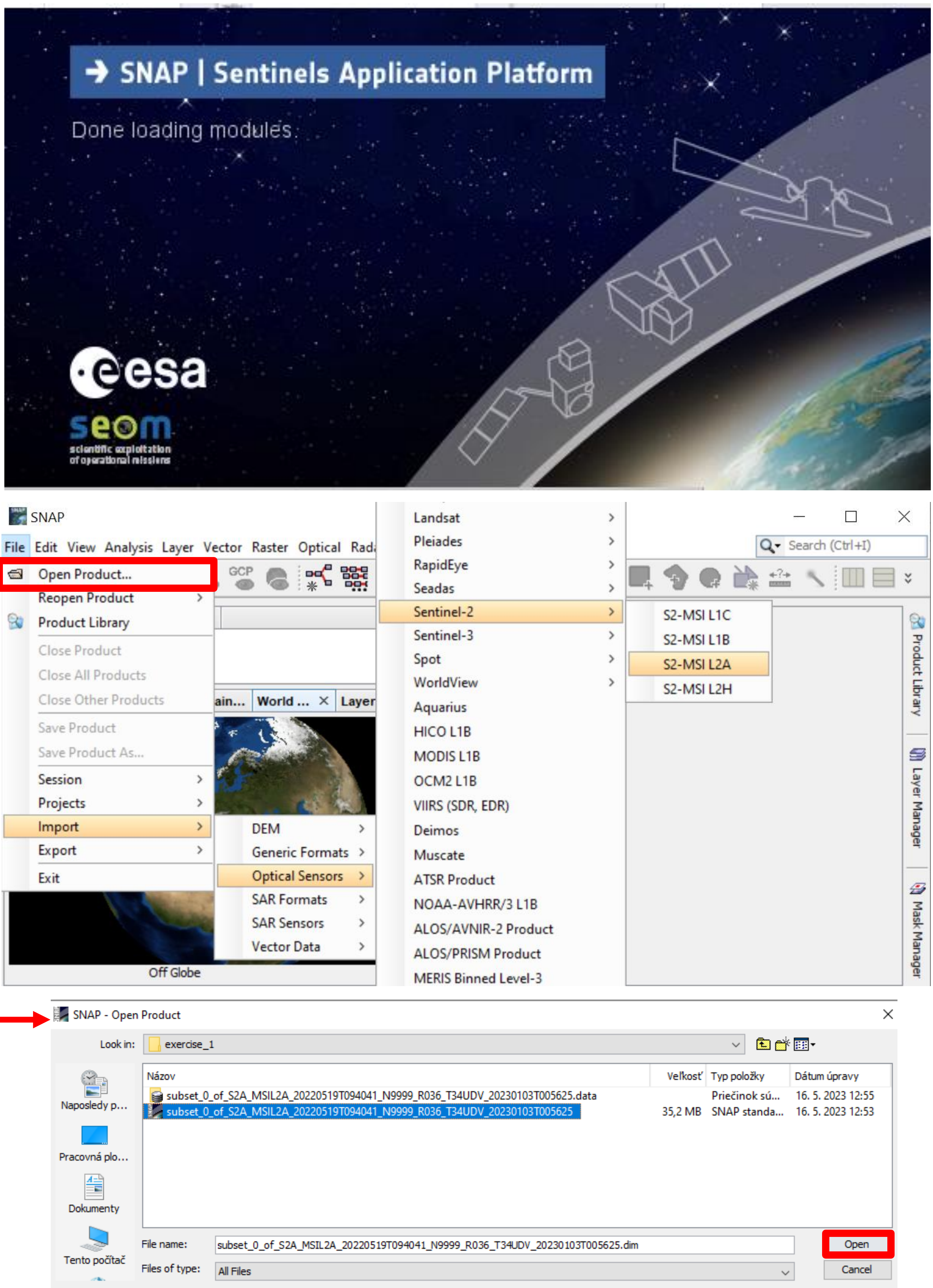
https://step.esa.int/main/download/snap-download/

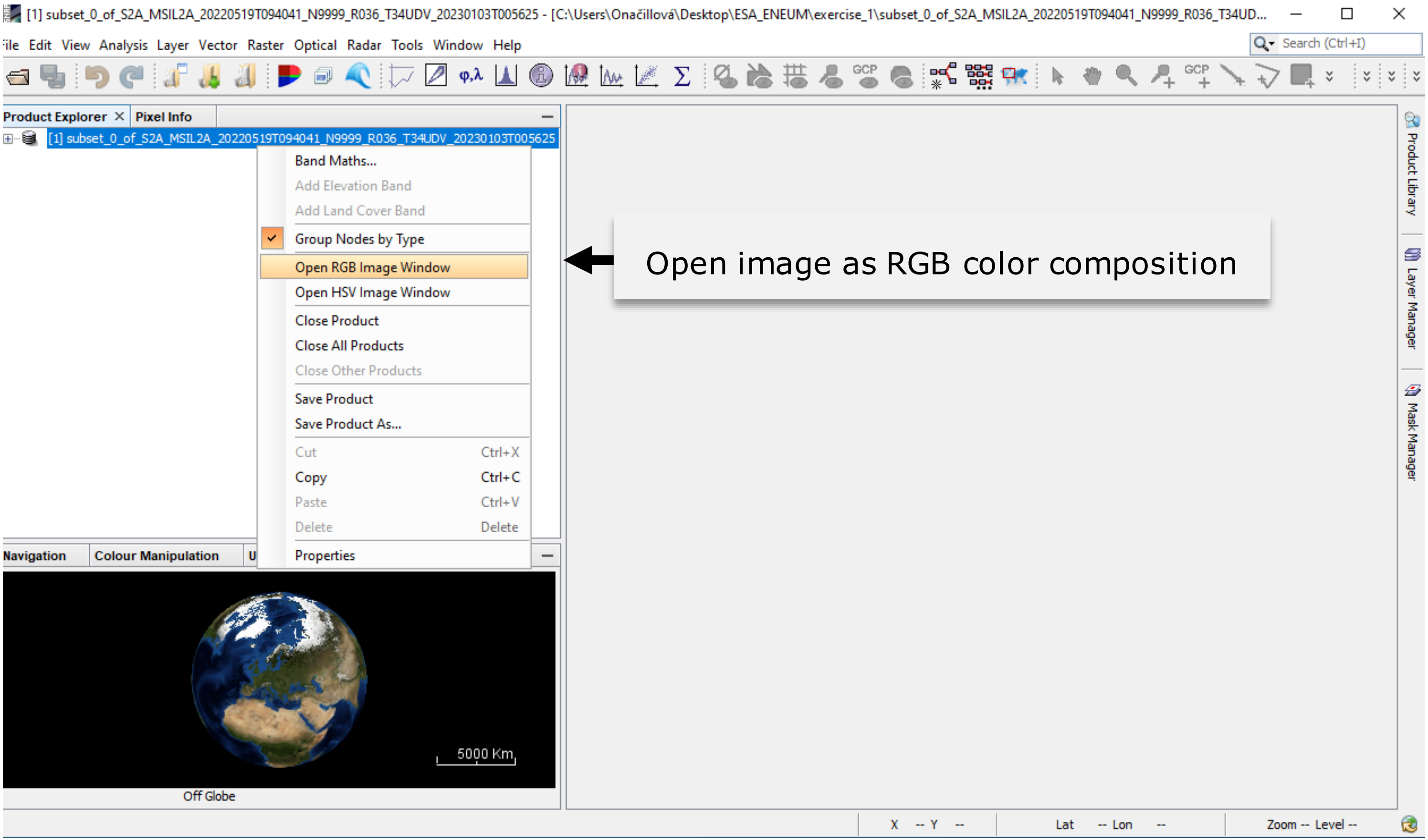
ESA Sentinel Application Platform (SNAP) is a software toolkit developed by the European Space Agency (ESA) for processing and analyzing Earth observation data, particularly data from the Sentinel satellites. SNAP is part of the Sentinel Toolbox and is freely available to the public. It provides a user-friendly interface and a comprehensive set of tools also for working with a variety of other remote sensing data.

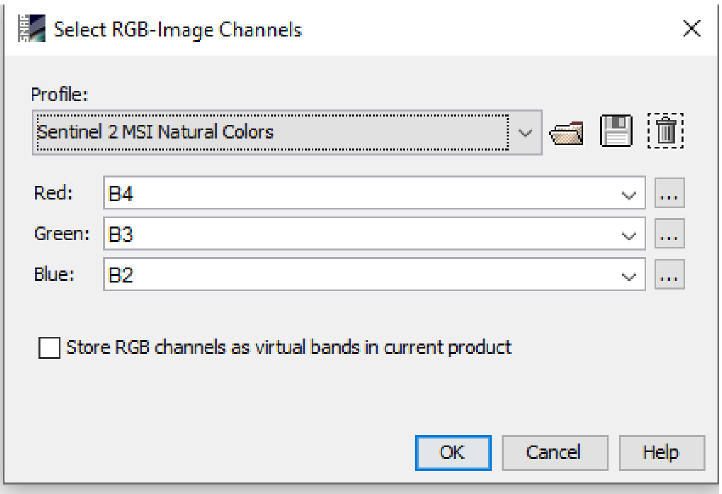


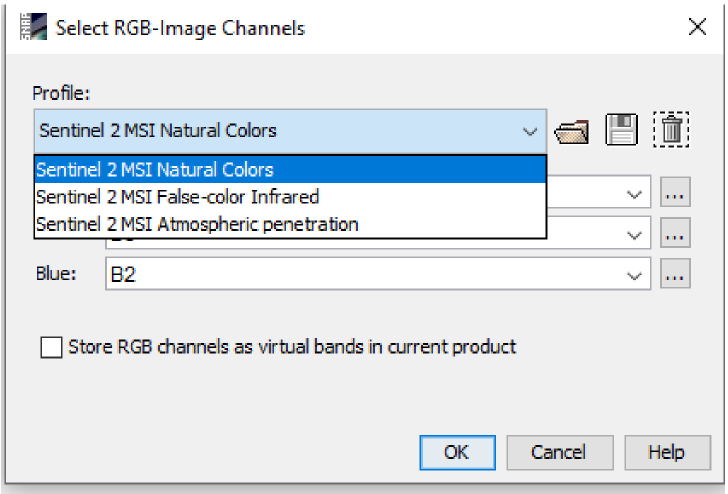
SNAP is widely used in the scientific community and by remote sensing professionals for a variety of applications, including land cover mapping, environmental monitoring, and disaster response. It is an open-source tool, and its modular architecture allows for the integration of plugins and additional functionalities.

After installing and starting the software, we can open an image using File – Open Image or by Import option:



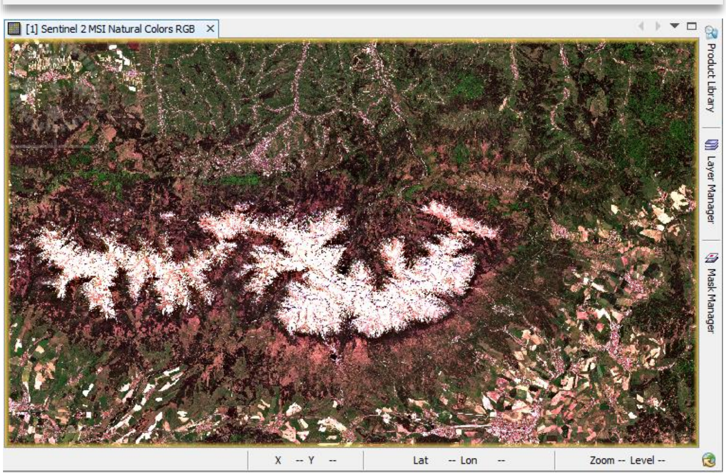


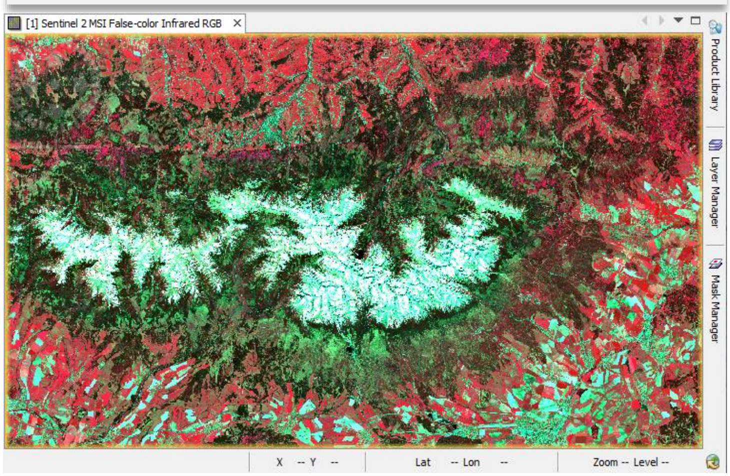




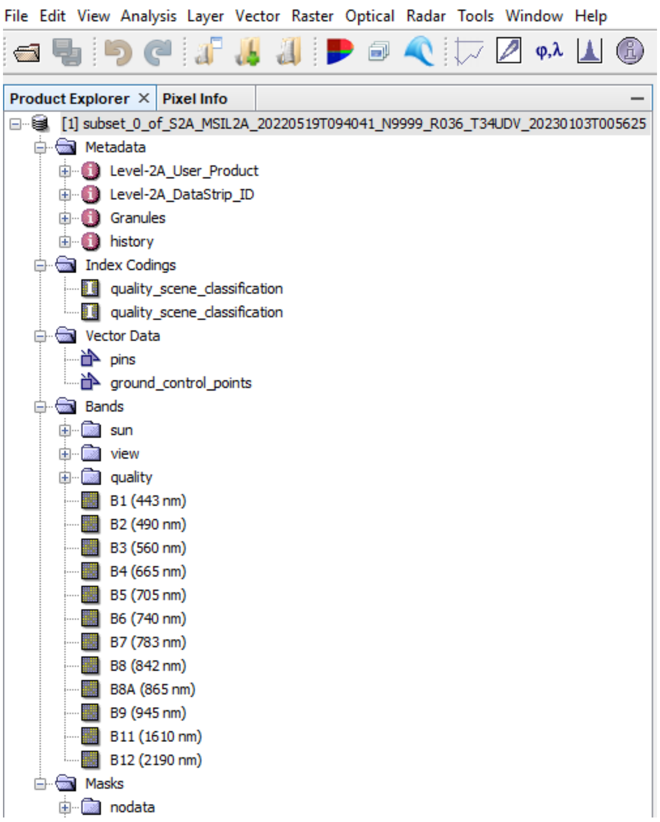
Display image in Natural Colors (as seen by human eye)

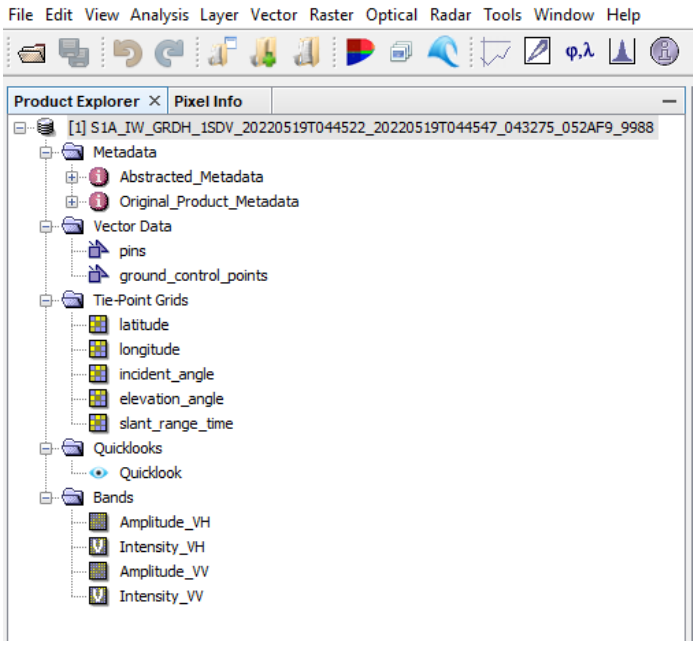
Open image in False Colors or open as an Atmpospheric penetration image





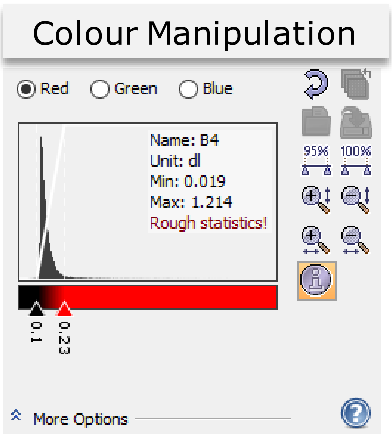
Upon opening an image, users can explore the image data through the Product Explorer window. This encompasses opening RGB composite images, navigating metadata, inspecting spectral bands, and reviewing image masks. In the case of radar images, amplitude or intensity can be visualized in various polarizations.





In the bottom-left Window Group, we can see 4 tools:

- *Navigation tool* – to navigate within the opened image
- *Colour Manipulation* – to view the histogram for the opened image and manipulate individual channels or assign new colours to the image
- *Uncertainty Visualisation* – to visualise the uncertainty information associated with a band shown in an image view
- *World View* – to see the position of our selected image

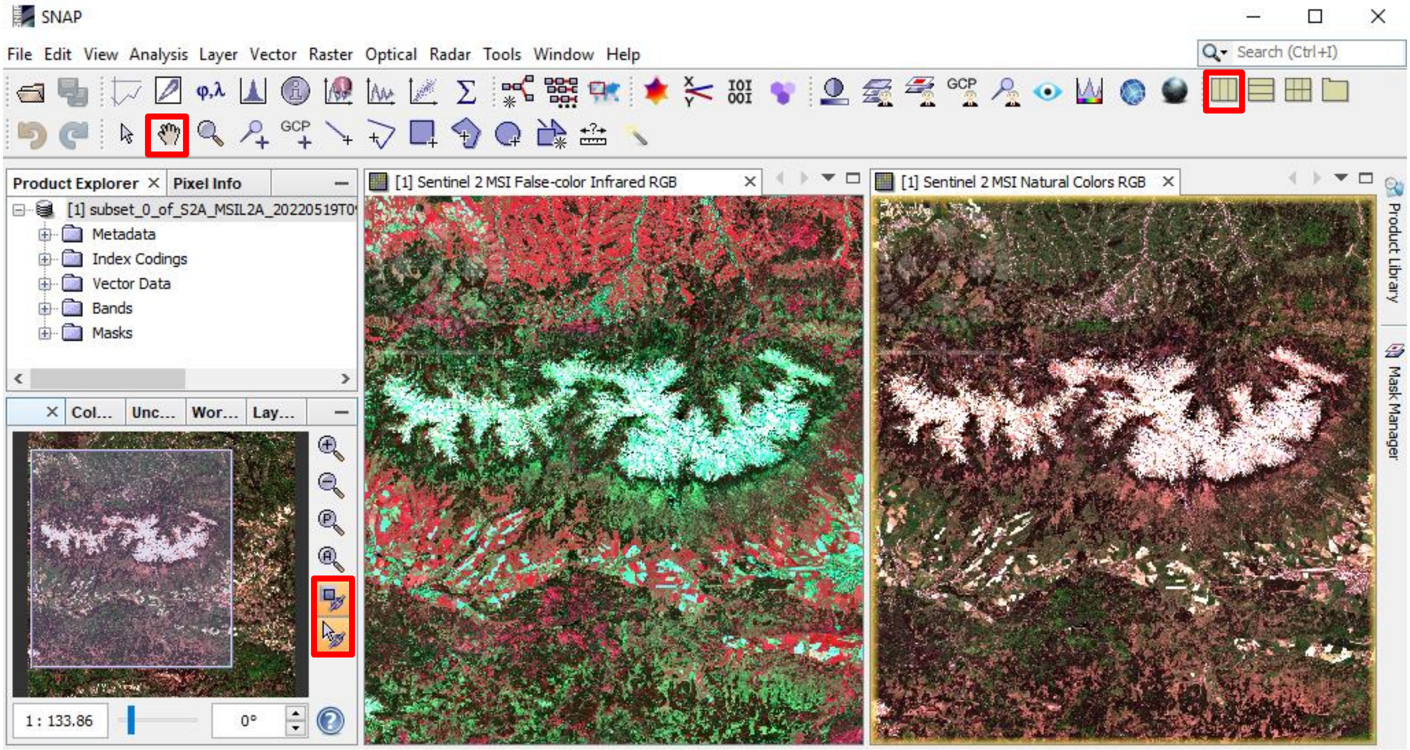


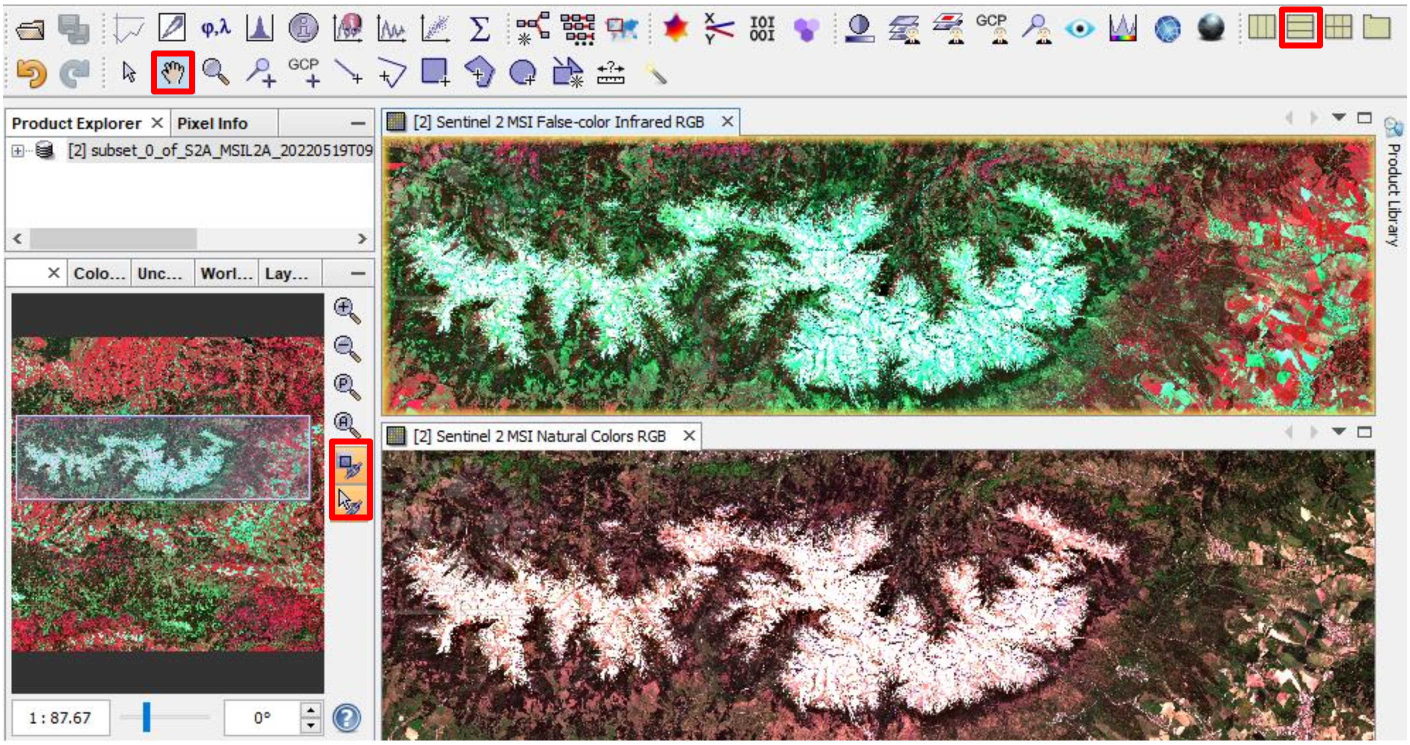
To simultaneously view and compare multiple opened images, utilize the *Tile* function (e.g. *"Tile Horizontally" or „Tile Vertically").*

Ensure that the cursor is visible and that simultaneous manipulation of all images is possible by navigating to the Navigation tab and verifying that the following is checked:

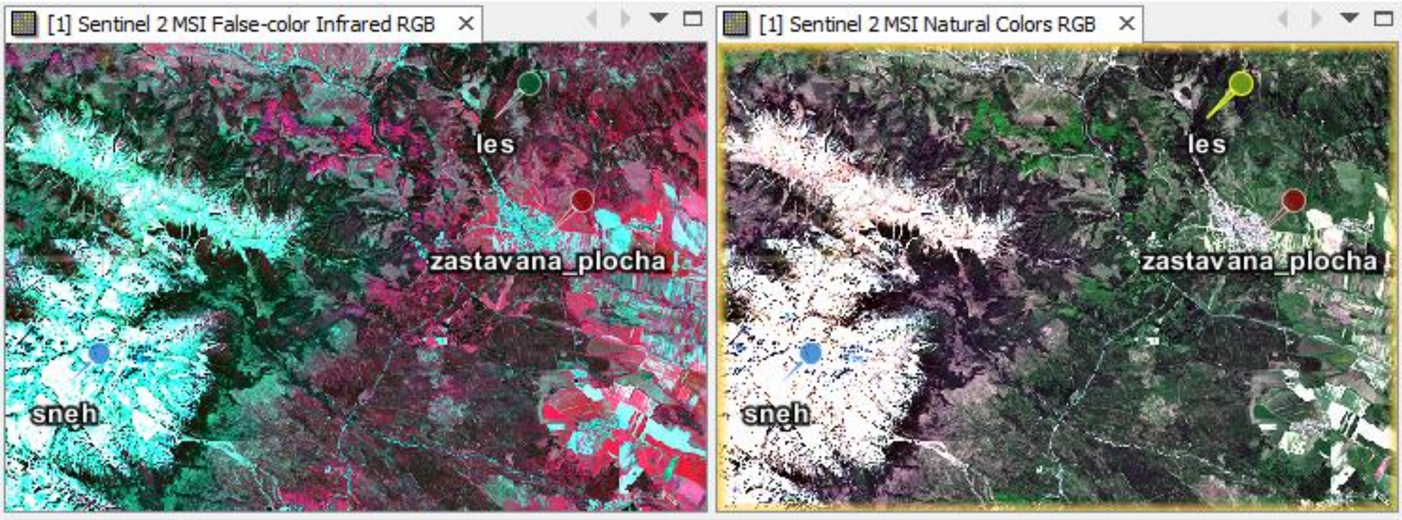
synchronises views across multiple image windows

synchronises cursor positions across multiple image windows





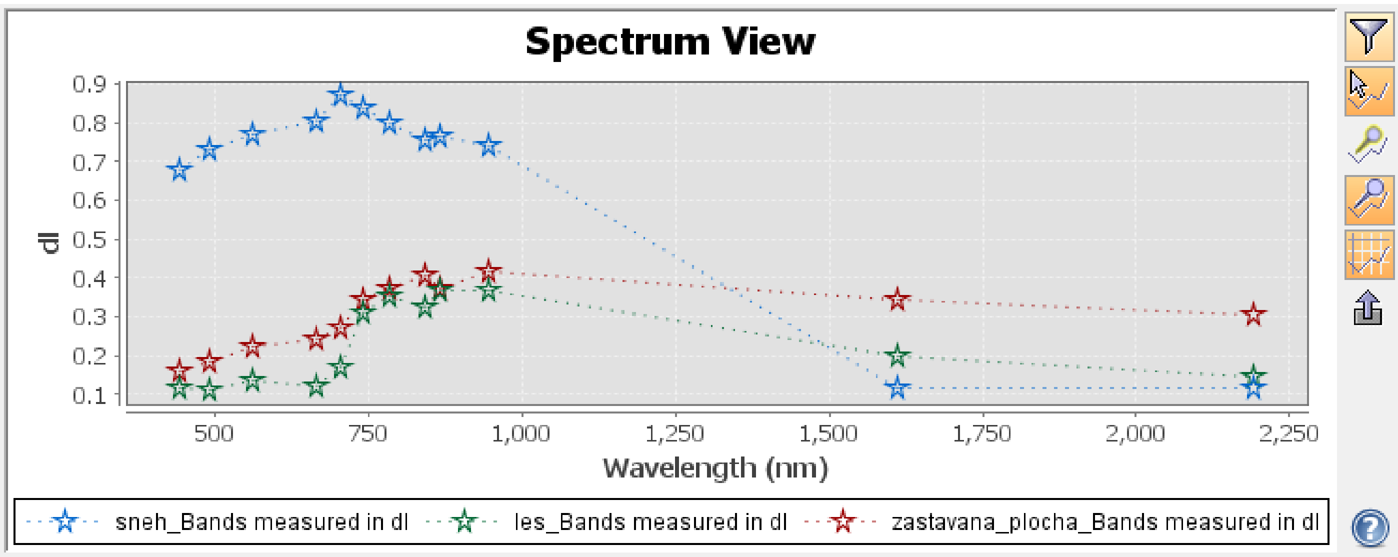
For localization purposes, we can add various pins to different pixels and add the description to them (*View – Tool Windows – Pin Manager* or by clicking on the icon of *Pin placing tool*



Pin Manager

X	Y	Lon	Lat	Color	Label
4126.500	5051.500	20.193265	49.195525		sneh
5235.500	4356.500	20.344647	49.259001		les
5371.500	4657.500	20.363685	49.232032		zastavana_plocha

To observe spectral information of these various pins, we can use the tool Spectrum View



7 | Third party missions

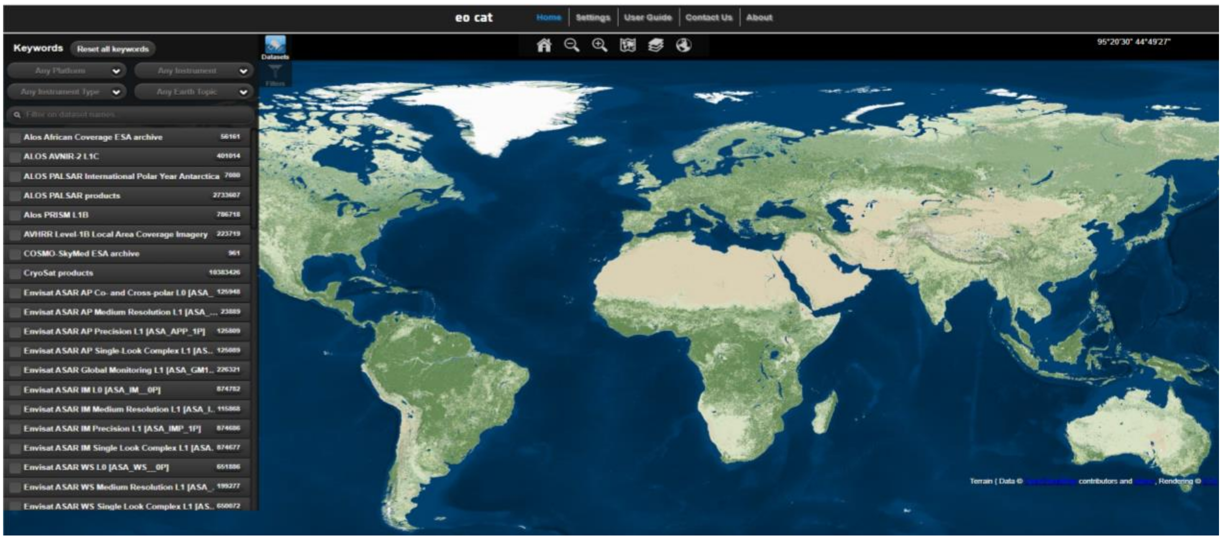
https://earth.esa.int/eogateway/missions/third-party-missions

In addition to providing users with data from its own Earth observing (EO) satellites, the European Space Agency (ESA) has played a significant role in providing access to Earth Observation missions not under ESA ownership or operation—referred to as Third Party Missions (TPM). With a history spanning over 45 years, the TPM program involves a series of Earth Observation-focused satellites owned by various commercial and public organizations worldwide. The TPM initiative currently includes over 50 missions, contributing data from more than 60 instruments to support users engaged in research and development endeavors.

7.1. Access to TPM data

Users have the ability to explore and download Earth Observation (EO) data from the extensive catalog of missions operated and supported by the European Space Agency through the ESA EO Catalogue (EO-CAT):

- https://eocat.esa.int/sec/#data-services-area



User can find here:

- mission, instrument and product news and descriptions;
- collection descriptions;
- data access links;
- information on selected Earth/environmental topics and applications of satellite data

Data are also accessible through the TPM L-OADS web interface:

- https://tpm-ds.eo.esa.int/collections/

For more information, see the lecture: 2. ESA EO Data Access and resources, including Third Party missions, applications of Copernicus Earth Observation data

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 3 – TUTORIAL

Key concepts of remote sensing data processing, converting DN values to radiance and reflectance, using SNAP software

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Convert Landsat 8 radiance to reflectance
- Calculate Land Surface Temperature at the Top of the Atmosphere (TOA)
- Explore TOA temperatures within the area of interest

2 | Background

2.1 HOW TO CONVERT DNs TO PHYSICAL UNITS

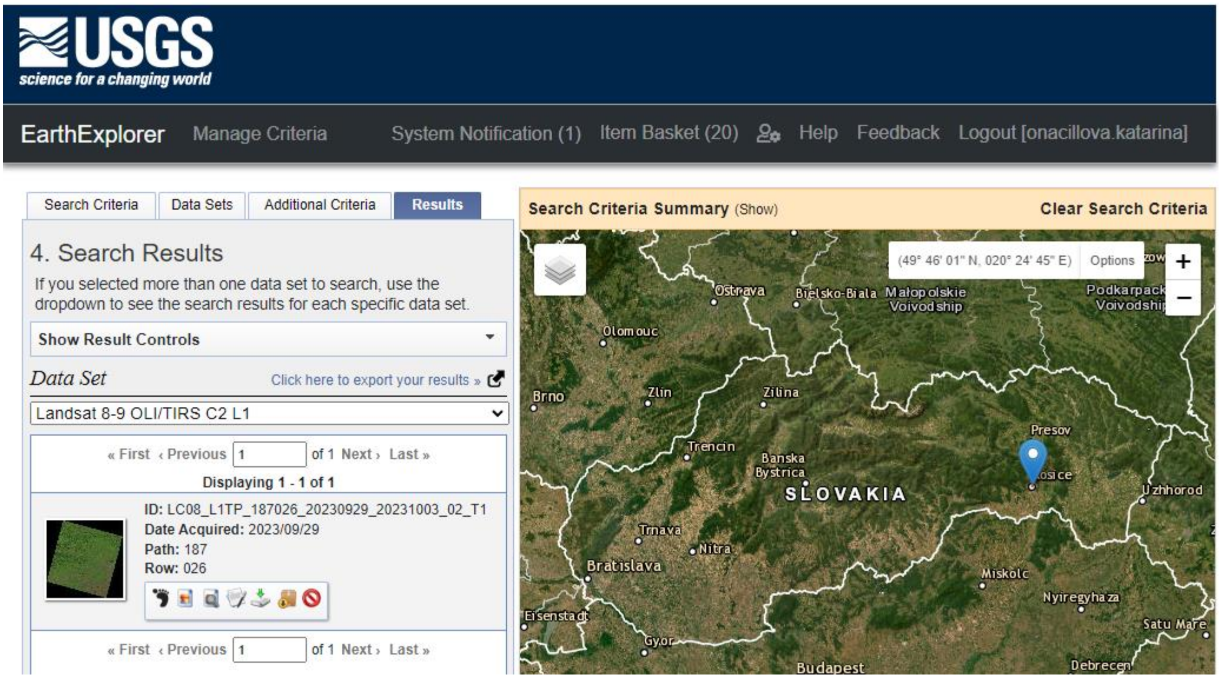
Multispectral sensors usually capture reflected solar energy and rescale this data into a digital number (DN) - a variable assigned to a pixel, usually in the form of a binary integer the range of which depends on the radiometric resolution; e.g. 0–255 (8-bit DNs) for Landsat ETM+. The Landsat 8 OLI sensor is more sensitive so these data are rescaled into 16-bit DNs with a range from 0 and 65536.

DNs can be used directly for spectral index calculation or land cover evaluation within a single scene. However, for comparing reflectance between two or more scenes, it is necessary to convert DNs to surface reflectance values. DNs do not directly express the values of a physical quantity. For radiance values, it is necessary to recalculate DN values.

There are a number of spaceborne multispectral sensors to date providing multispectral data in visible and thermal infrared spectrum simultaneously. For our purpose of this exercise, we opted for the Landsat-8 data that provide the highest possible spatial resolution of the thermal band among the deployed missions on the Earth's orbit. Also, there is a favorable temporal coincidence with Sentinel 2 acquisitions today that can be used for combined approach.

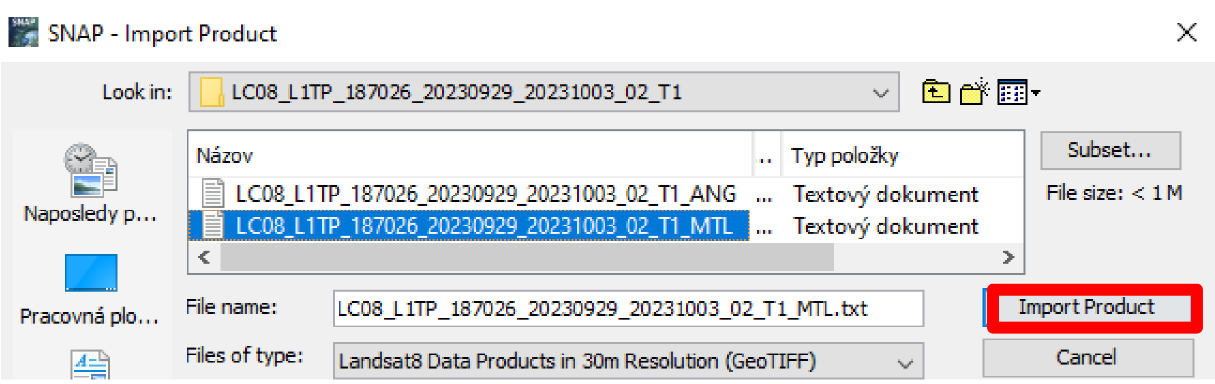
2.2 Study area and data used

For this exercise, we will use Landsat-8 L1 product (path 187, row 26, 29 September 2023, scene center time 9:26:47 GMT) for the study area of Košice City, Slovakia, which was downloaded from the USGS EarthExplorer website [@https://earthexplorer.usgs.gov/]. It contains data recorded by two instruments - the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) with a spatial resolution of 30 meters for visible, near infrared and short-wavelength infrared bands (bands 1-7, band 9), 15 meters for panchromatic band 8, and 100 by 30 meters for thermal bands 10 and 11. The data of thermal bands are resampled to 30 by 30 meter pixels in the L1T product.

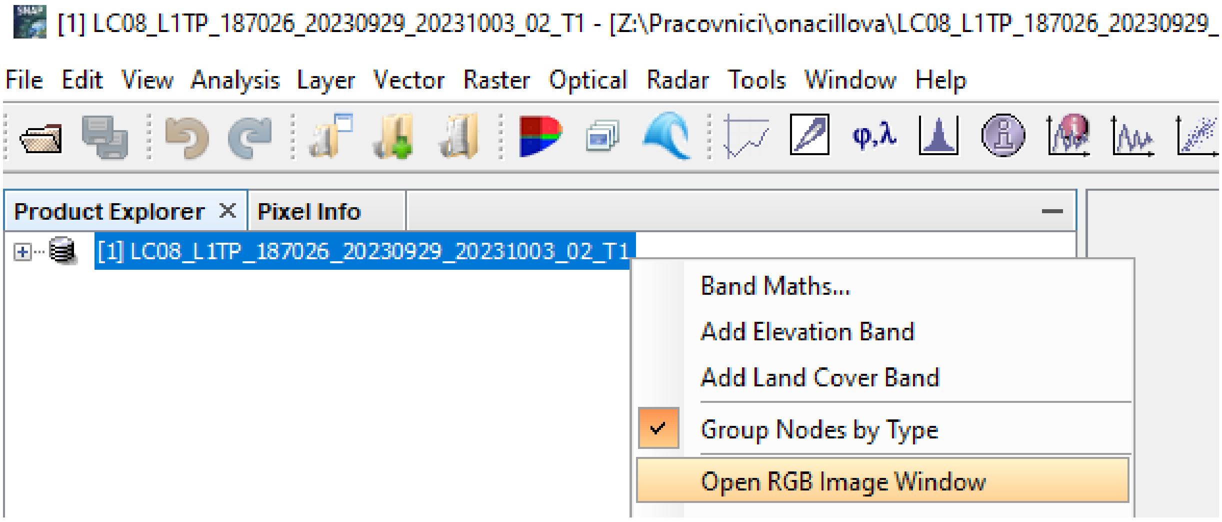


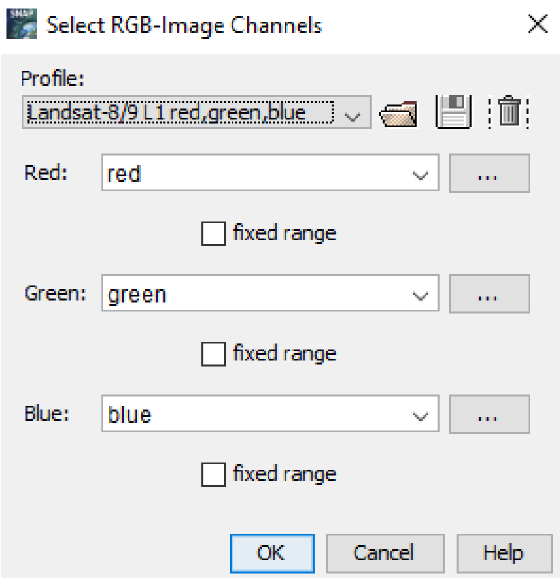
2.3 SNAP - Open and explore product

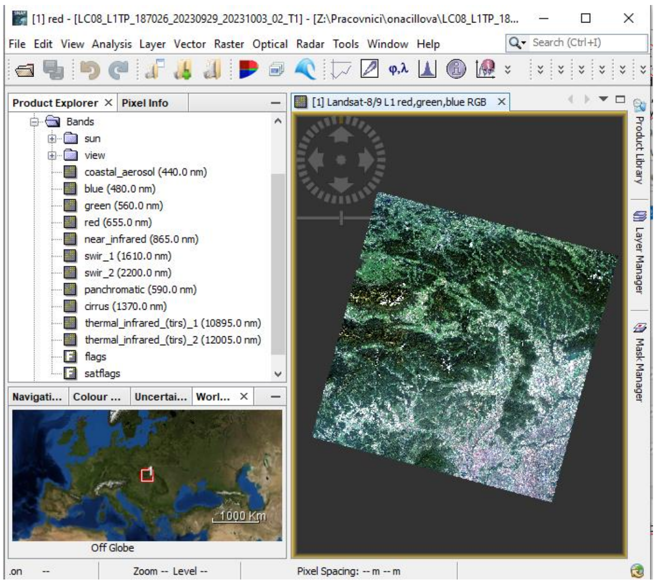
Open SNAP Desktop, click File – Import – Optical Sensors – Landsat – Landsat8 in 30m (GeoTIFF) and open downloaded product *„LC08_L1TP_187026_20230929_20231003_02_T1"* by double click on the metadata „LC08_L1TP_187026_20230929_20231003_02_T1_MTL .txt" inside the folder (or click on Import Product). The opened product will appear in Product Explorer window.

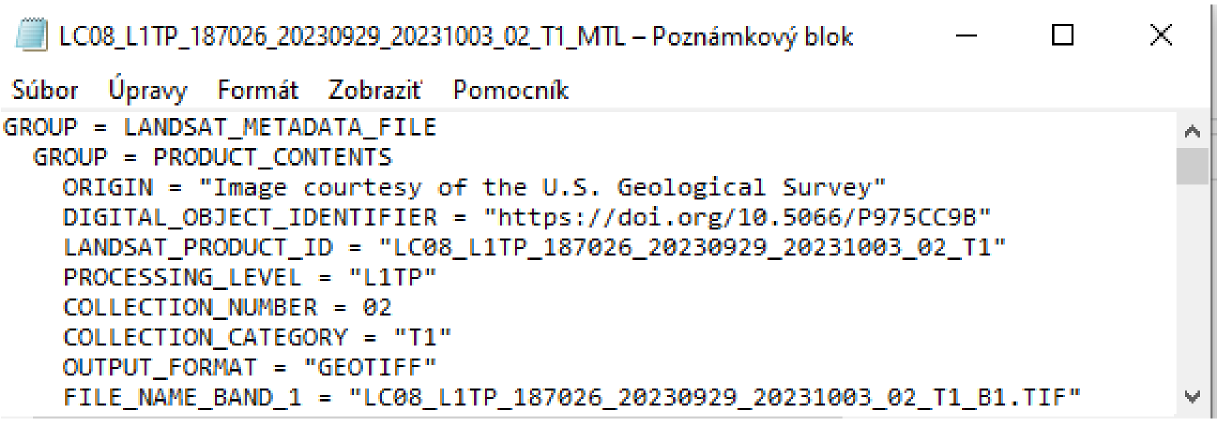


Display product using e.g. True color composition: Right click on the product – Open RGB Image Window – SNAP should automatically select Landsat-8/9 L1 red,green,blue profile (using Red, Green, Blue band in the corresponding red, green and blue color channels), resulting in a natural colored result,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








LC08_L1TP_187026_20230929_20231003_02_T1_MTL – Poznámkový blok

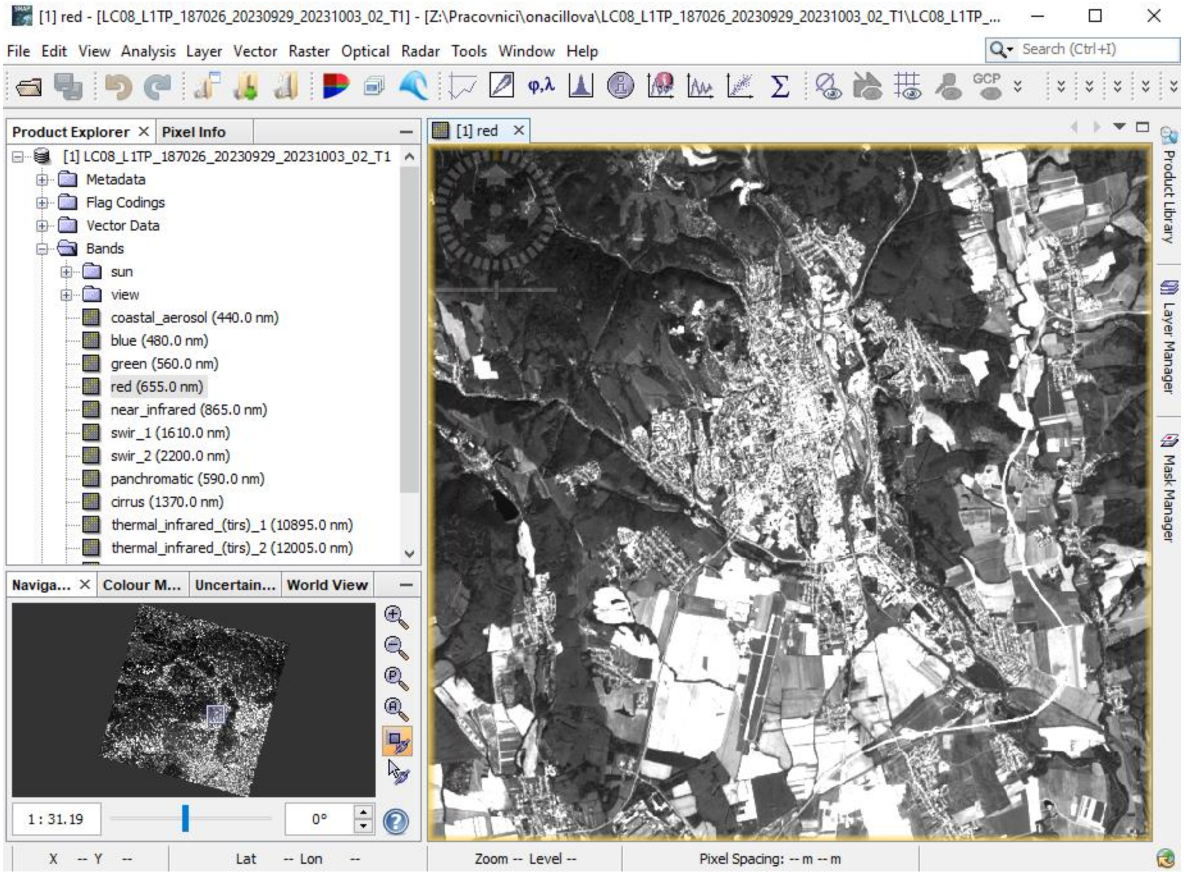
Súbor Úpravy Formát Zobraziť Pomocník

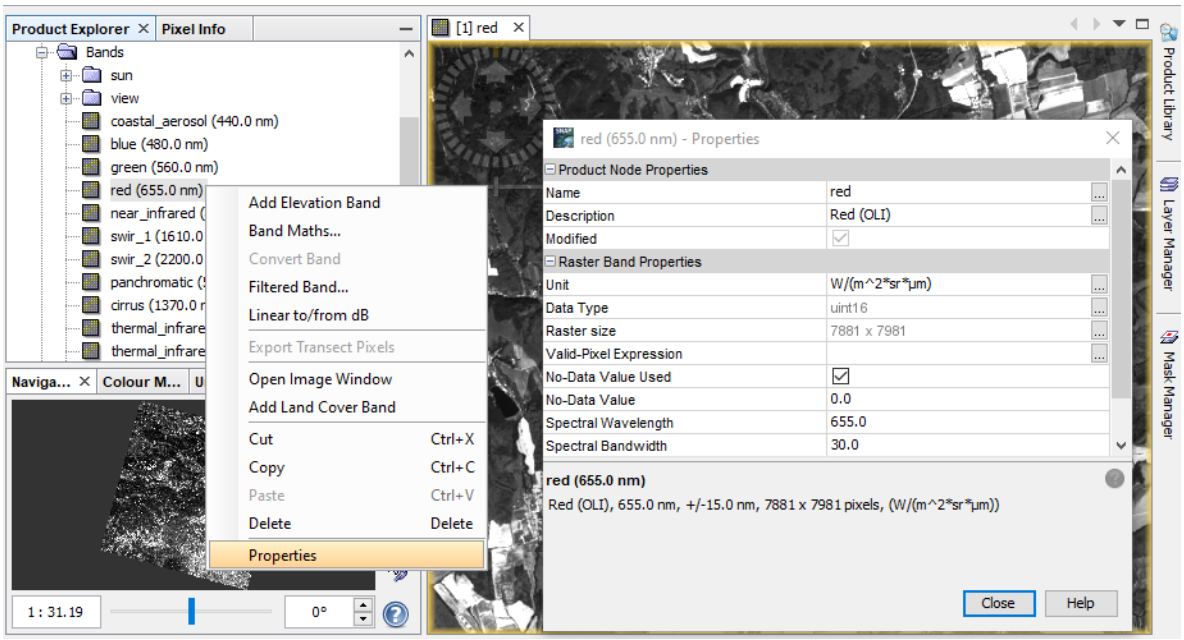
```
GROUP = LANDSAT_METADATA_FILE
  GROUP = PRODUCT_CONTENTS
    ORIGIN = "Image courtesy of the U.S. Geological Survey"
    DIGITAL_OBJECT_IDENTIFIER = "https://doi.org/10.5066/P975CC9B"
    LANDSAT_PRODUCT_ID = "LC08_L1TP_187026_20230929_20231003_02_T1"
    PROCESSING_LEVEL = "L1TP"
    COLLECTION_NUMBER = 02
    COLLECTION_CATEGORY = "T1"
    OUTPUT_FORMAT = "GEOTIFF"
    FILE_NAME_BAND_1 = "LC08_L1TP_187026_20230929_20231003_02_T1_B1.TIF"
```

3 | Top of Atmosphere Reflectance

3.1 Conversion of DN values to TOA reflectance (without sun angle correction)

First, in SNAP we can display the Landsat-8 OLI band (raster) that we want to convert to physical units, e.g. Band 4 (Red) „LC08_L1TP_187026_20230929_20231003_02_T1_B4". In Product Explorer window expand Bands within your imported Landsat-8 product – double click on „red" (Band 4) to display selected band. We can have also a look at the raster properties (right click on the raster – Properties).



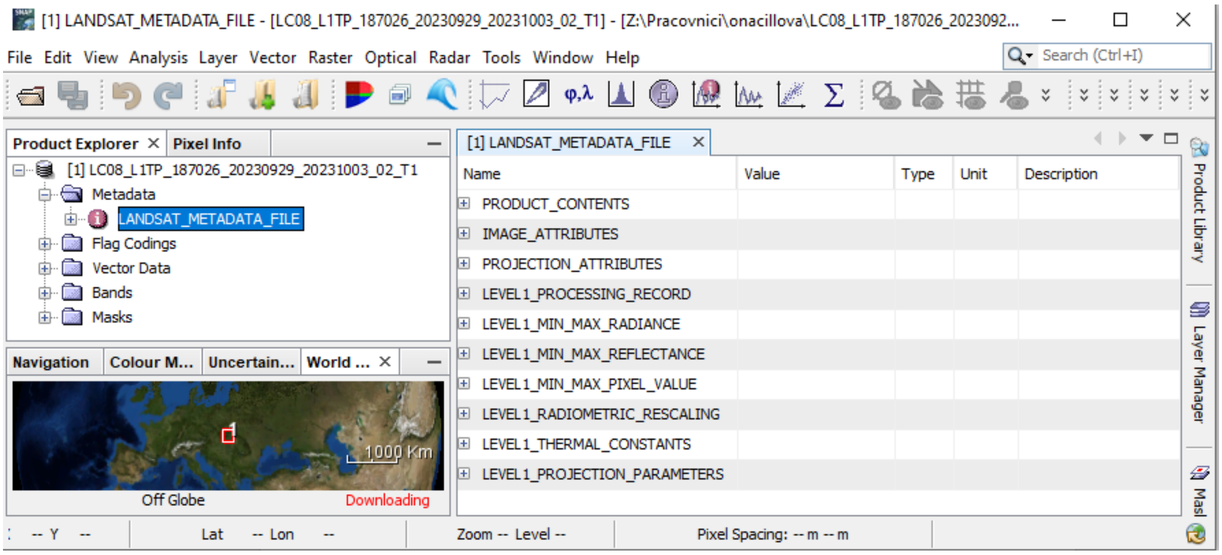


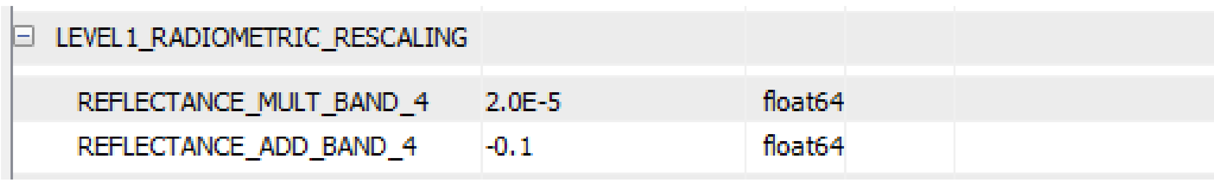
OLI sensor data (bands) can be converted to planetary reflectance at the TOA (Top Of Atmosphere = TOA) using reflectance scaling coefficients provided in the product metadata file (MTL file). The following equation is used to convert Level 1 DN values to TOA reflectance for OLI data without sun angle correction:

$$\rho\lambda' = M\rho * Qcal + A\rho$$

where:
ρλ' = TOA Planetary Spectral Reflectance, without correction for solar angle
Mρ = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x from the metadata).
Aρ = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x from the metadata).
Qcal = Quantized and calibrated standard product pixel value in DN

The needed values to perform the conversion can be found in the Landsat 8 metadata file (LC08_L1TP_187026_20230929_20231003_02_T1_MTL .txt) or by expanding and double click on Metadata information in SNAP.

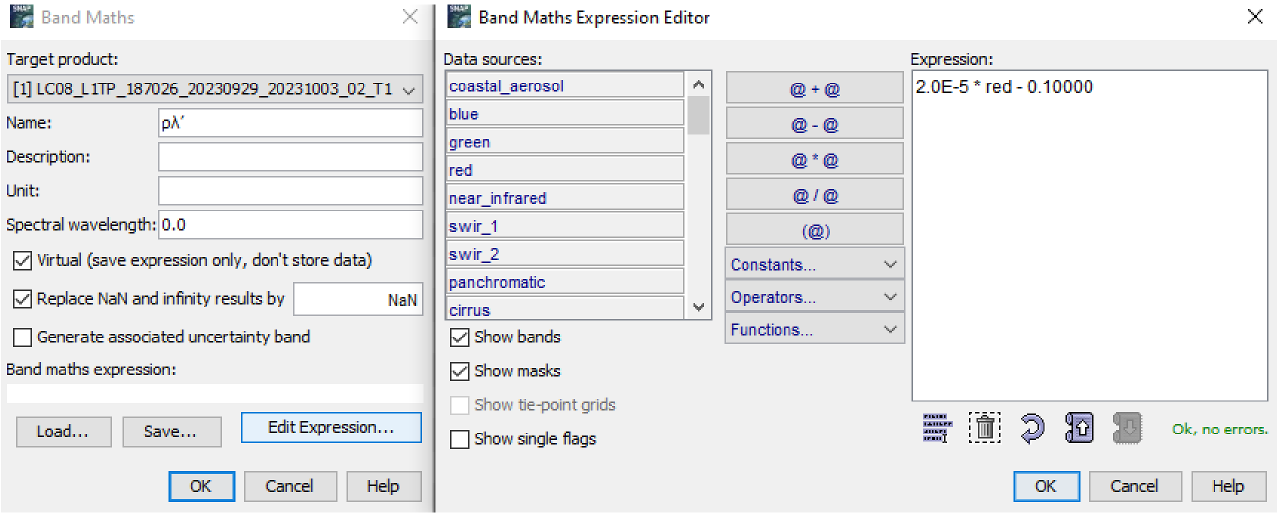




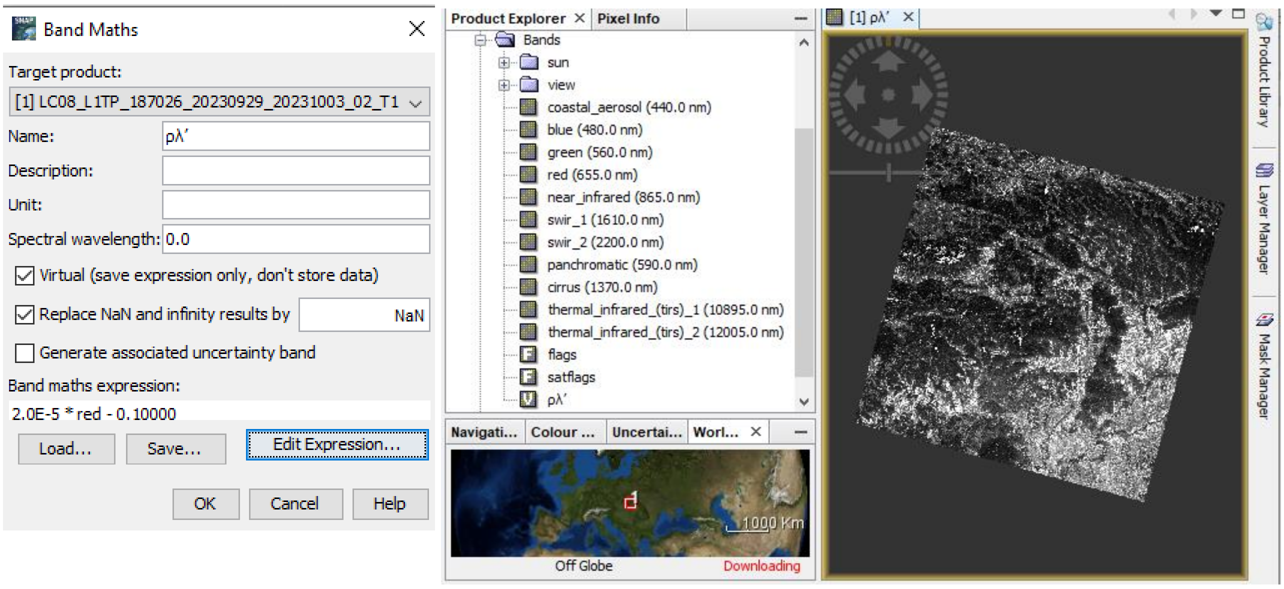
After substituting the reflectance scaling coefficients provided in the product metadata file, the equation to convert red band (Band 4) to planetary reflectance at the TOA will be as follows:

$$\boldsymbol{\rho\lambda' = 2.0E\text{-}5 * red - 0.10000}$$

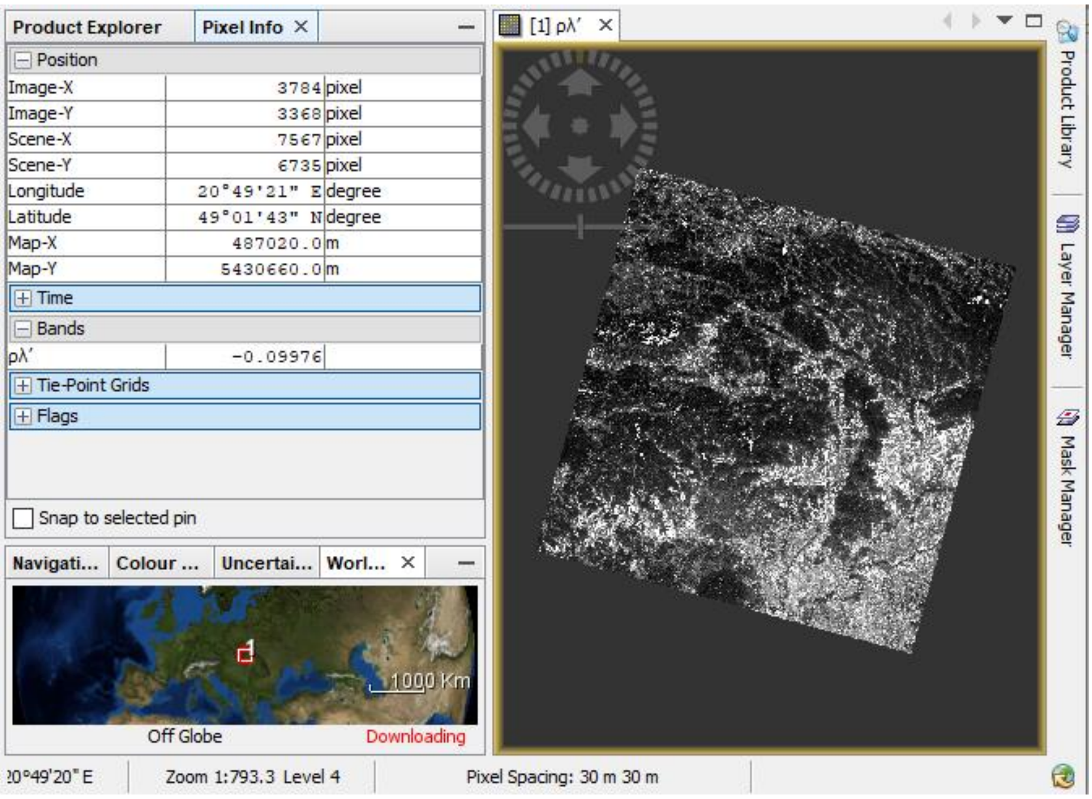
Now go to Raster – Band Math and enter this expression to Band Maths Expression Editor.



Band Maths
Target product:
[1] LC08_L1TP_187026_20230929_20231003_02_T1
Name: ρλ'
Description:
Unit:
Spectral wavelength: 0.0
Virtual (save expression only, don't store data)
Replace NaN and infinity results by NaN
Generate associated uncertainty band
Band maths expression:
Load... Save... Edit Expression...
OK Cancel Help
Band Maths Expression Editor
Data sources:
coastal_aerosol
blue
green
red
near_infrared
swir_1
swir_2
panchromatic
cirrus
Show bands
Show masks
Show tie-point grids
Show single flags
@ + @
@ - @
@ * @
@ / @
(@)
Constants...
Operators...
Functions...
Expression:
2.0E-5 * red - 0.10000
Ok, no errors.
OK Cancel Help



Band Maths
Target product:
[1] LC08_L1TP_187026_20230929_20231003_02_T1
Name: ρλ'
Description:
Unit:
Spectral wavelength: 0.0
Virtual (save expression only, don't store data)
Replace NaN and infinity results by NaN
Generate associated uncertainty band
Band maths expression:
2.0E-5 * red - 0.10000
Load... Save... Edit Expression...
OK Cancel Help
Product Explorer Pixel Info
Bands
sun
view
coastal_aerosol (440.0 nm)
blue (480.0 nm)
green (560.0 nm)
red (655.0 nm)
near_infrared (865.0 nm)
swir_1 (1610.0 nm)
swir_2 (2200.0 nm)
panchromatic (590.0 nm)
cirrus (1370.0 nm)
thermal_infrared_(tirs)_1 (10895.0 nm)
thermal_infrared_(tirs)_2 (12005.0 nm)
flags
satflags
ρλ'
Navigati... Colour ... Uncertai... Worl...
1000 Km
Off Globe
Downloading
[1] ρλ'
Product Library
Layer Manager
Mask Manager



Product Explorer
Pixel Info
Position
Image-X 3784 pixel
Image-Y 3368 pixel
Scene-X 7567 pixel
Scene-Y 6735 pixel
Longitude 20°49'21" E degree
Latitude 49°01'43" N degree
Map-X 487020.0 m
Map-Y 5430660.0 m
Time
Bands
ρλ' -0.09976
Tie-Point Grids
Flags
Snap to selected pin
Navigati... Colour ... Uncertai... Worl...
1000 Km
Off Globe
Downloading
20°49'20" E
Zoom 1:793.3 Level 4
Pixel Spacing: 30 m 30 m
[1] ρλ'
Product Library
Layer Manager
Mask Manager

Note that ρλ' is not true TOA Reflectance, because it does not contain a correction for the solar elevation angle that is left out of the Level 1 scaling at the users' request; some users are content with the scene-center solar elevation angle in the metadata, while others prefer to calculate their own per-pixel solar elevation angle across the entire scene.

Once a solar elevation angle is chosen, the conversion to true TOA Reflectance (with sun angle correction) is as follows:

$$\rho\lambda = \frac{\rho\lambda'}{cos(\theta_{SZ})} = \frac{\rho\lambda'}{sin(\theta_{SE})}$$

where:
ρλ = TOA planetary reflectance
θSE = Local sun elevation angle; the scene center sun elevation angle in degrees is provided in the metadata
θSZ = Local solar zenith angle; θSZ = 90° - θSE

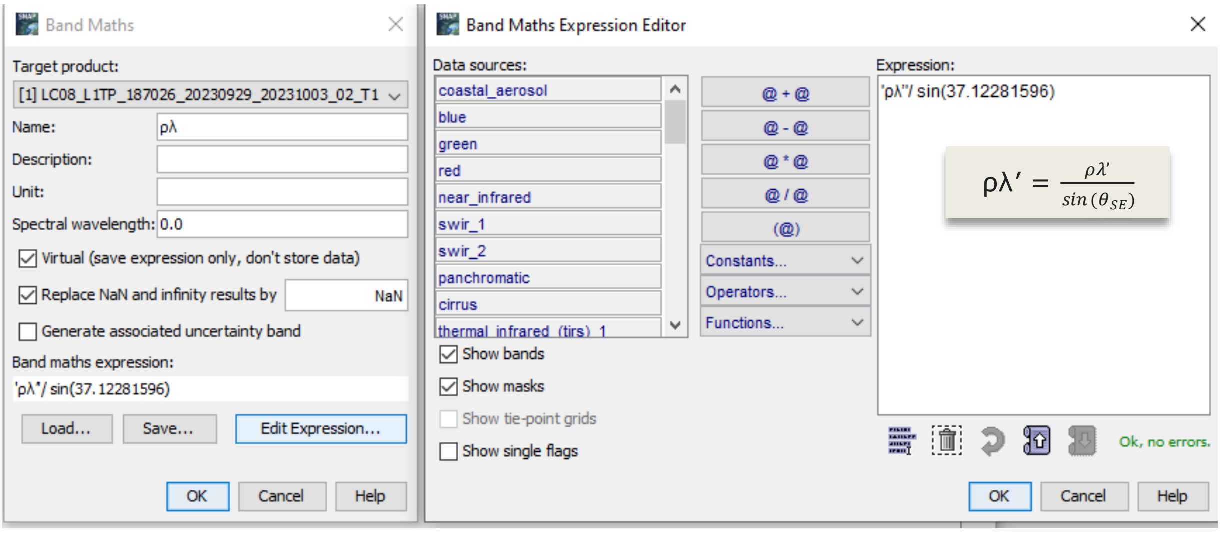
[1] LANDSAT_METADATA_FILE

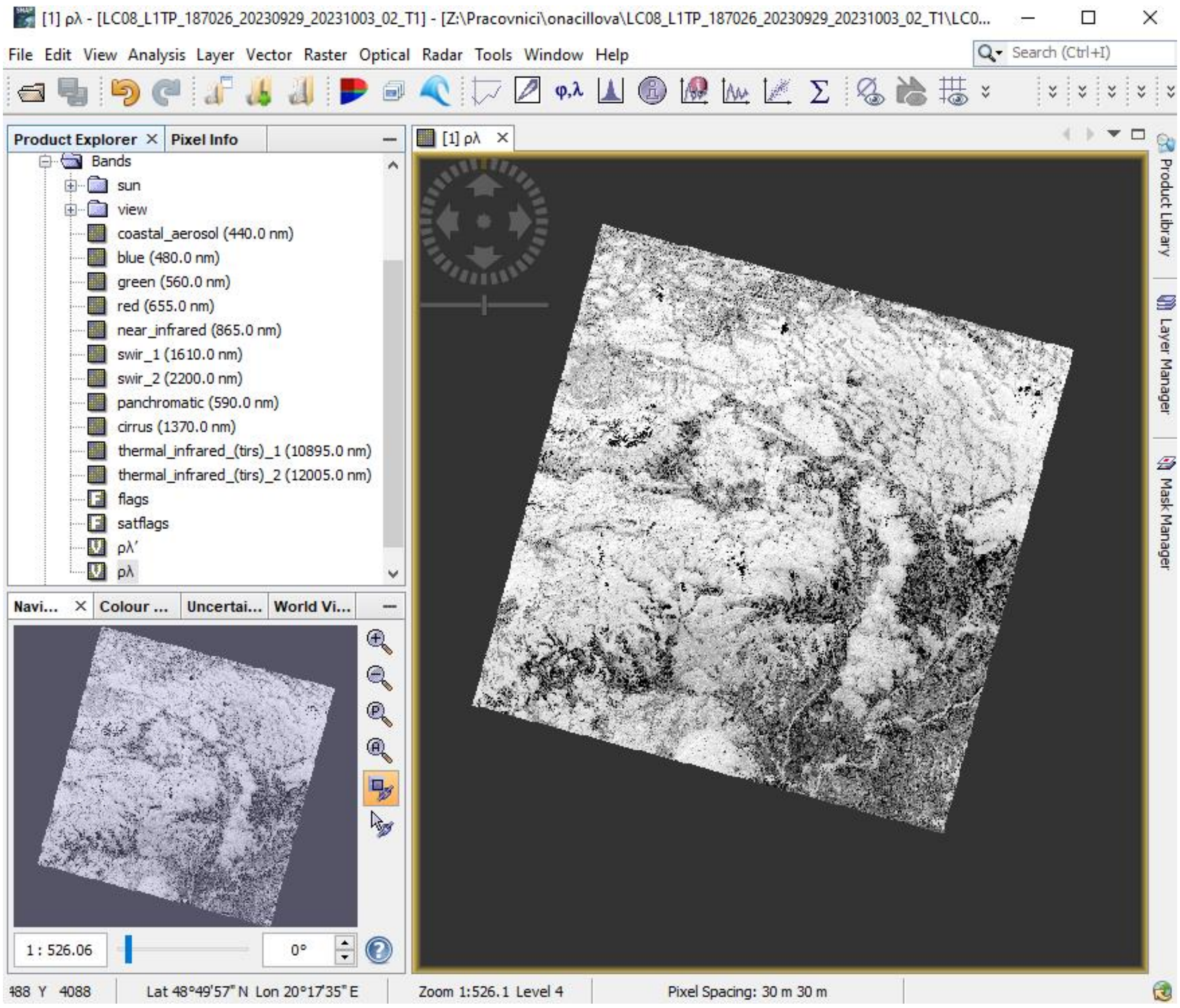
Name	Value	Type	Unit	Description
⊟ IMAGE_ATTRIBUTES				
SUN_ELEVATION	37.12281596	float64		

After substituting the local sun elevation angle provided in the product metadata file (or calculating local solar zenith angle), the equation to convert red band (Band 4) to true planetary reflectance at the TOA will be as follows:

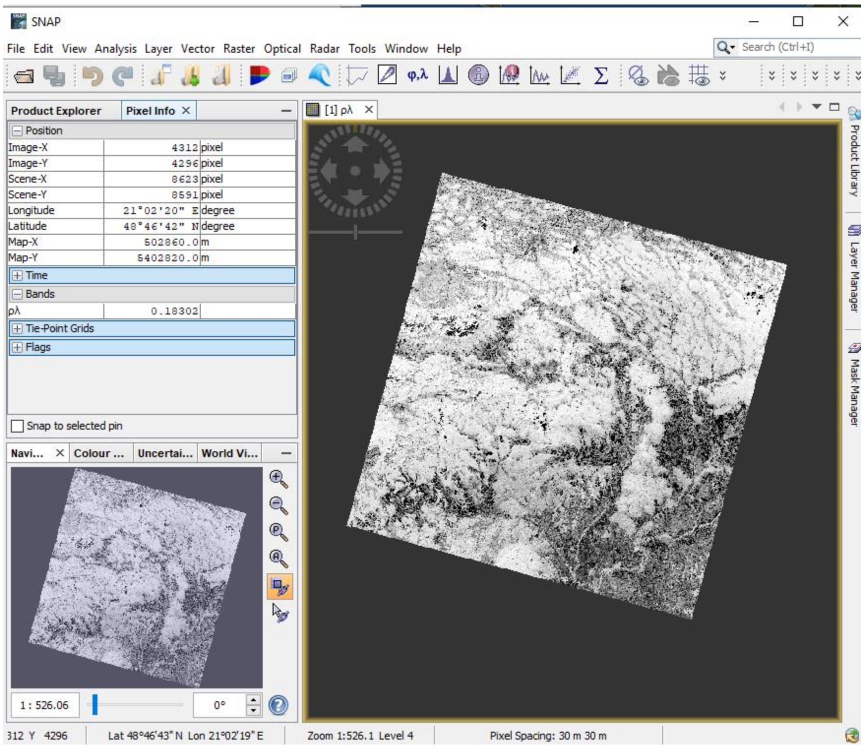
$$\boldsymbol{\rho\lambda = \rho\lambda'/sin(37.12281596)}$$

Now go to Raster – Band Math and enter this expression to Band Maths Expression Editor.





True planetary reflectance at the TOA



4| Top of Atmosphere Radiance

4.1 Conversion of DN values to TOA radiance

Images are processed in units of absolute radiance using 32-bit floating-point calculations. These values are converted to 16-bit integer values in the finished Level 1 product. They can then be converted to spectral radiance using the radiance scaling factors provided in the metadata file. The equation below is used to estimate TOA radiance:

$$L\lambda = ML * Qcal + AL$$

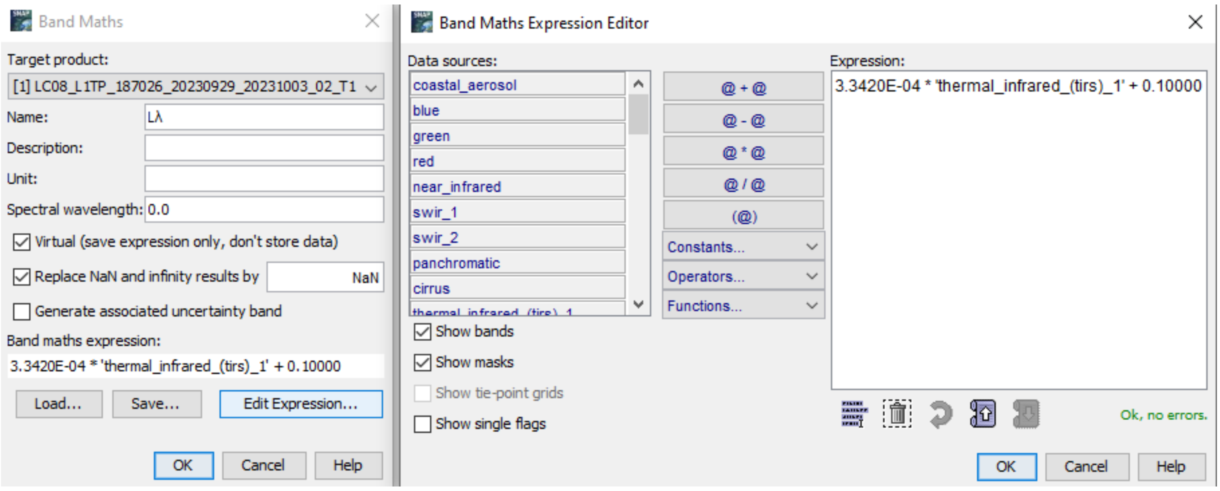
where:
Lλ = TOA Spectral radiance (Watts/(m2 * srad * μm))
ML = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x from the metadata, where x is the band number)
AL = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x from the metadata, where x is the band number)
Qcal = Quantized and calibrated standard product pixel value in DN

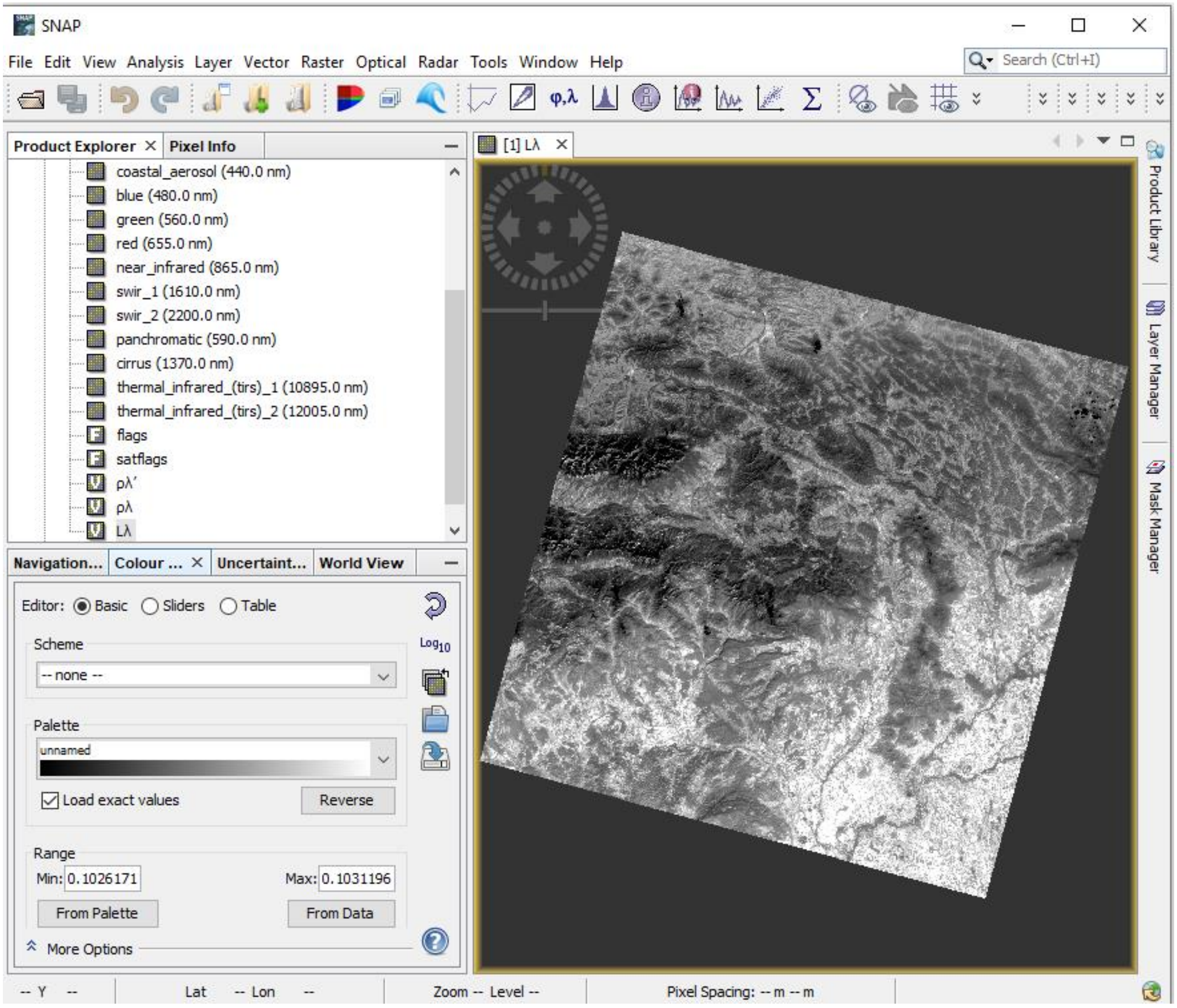
After substituting the variables in equation using provided metadata file, the equation to convert red band (Band 4) to radiance at the TOA will be as follows:

Lλ = 3.3420E-04 * thermal_infrared_tirs_(1) + 0.10000

By default, the S3TBX provides the TOA radiance of Landsat L1 data, but you can switch to TOA reflectance by specifying a property.

Now go to Raster – Band Math and enter this expression to Band Maths Expression Editor.





TOA spectral radiance (Watts/(m2 * srad * µm))

4.2 TIRS Top of Atmosphere Brightness Temperature

TIRS data can also be converted from spectral radiance (as described above) to brightness temperature, which is the effective temperature viewed by the satellite under an assumption of unity emissivity. The following conversion formula is used to convert TOA radiance to TOA brightness temperature:

$$T = \frac{K_2}{ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

where:

T = Top of atmosphere brightness temperature (K)

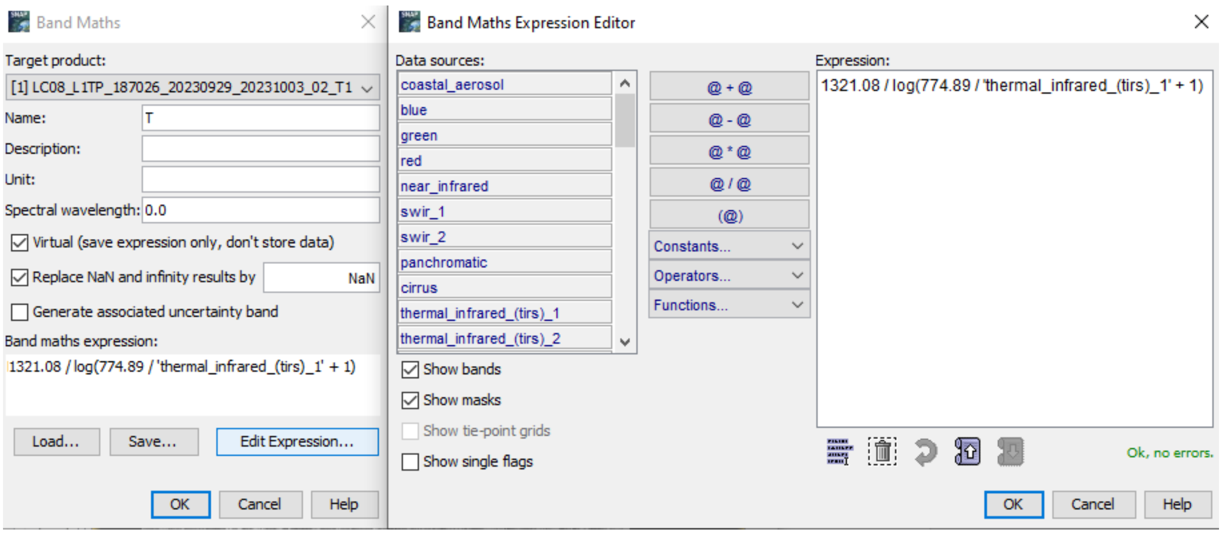
Lλ = TOA spectral radiance (Watts/(m2 * srad * μm))

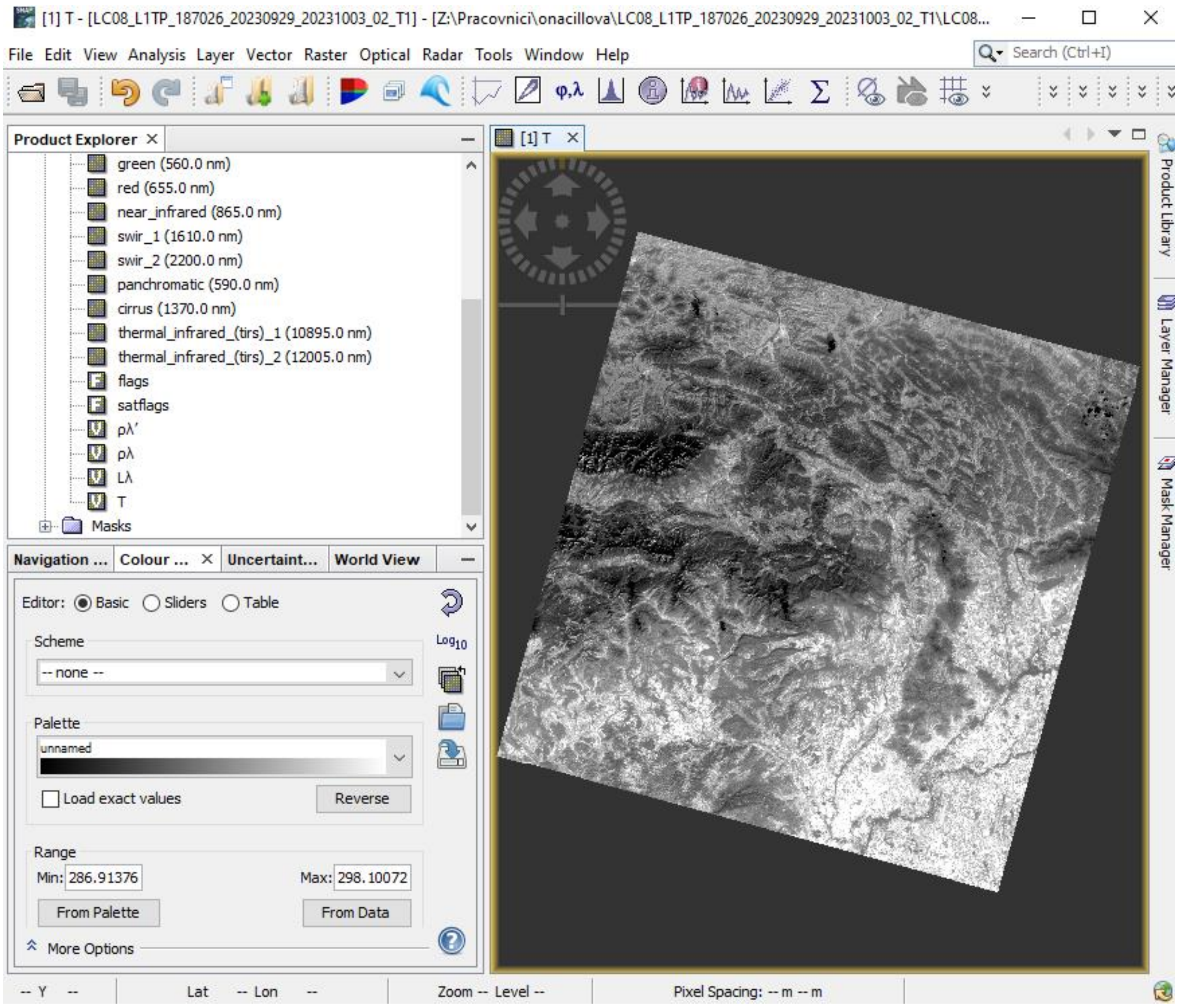
K1 = Band-specific thermal conversion constant from the metadata (K1_CONSTANT_BAND_x, where x is the thermal band number)

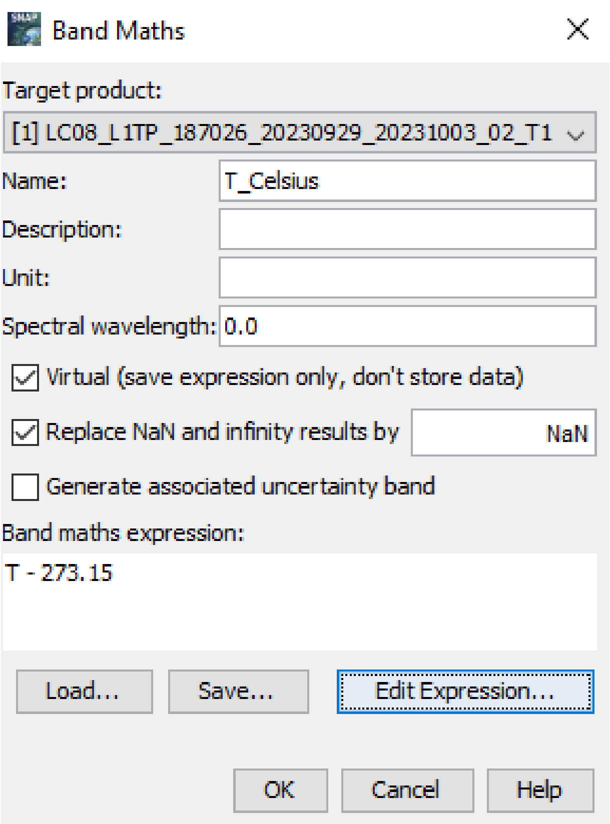
K2 = Band-specific thermal conversion constant from the metadata (K2_CONSTANT_BAND_x, where x is the thermal band number)

After substituting the variables in equation using provided metadata file, the equation to convert thermal band no. 10 (Band 10) to radiance at the TOA will be as follows:

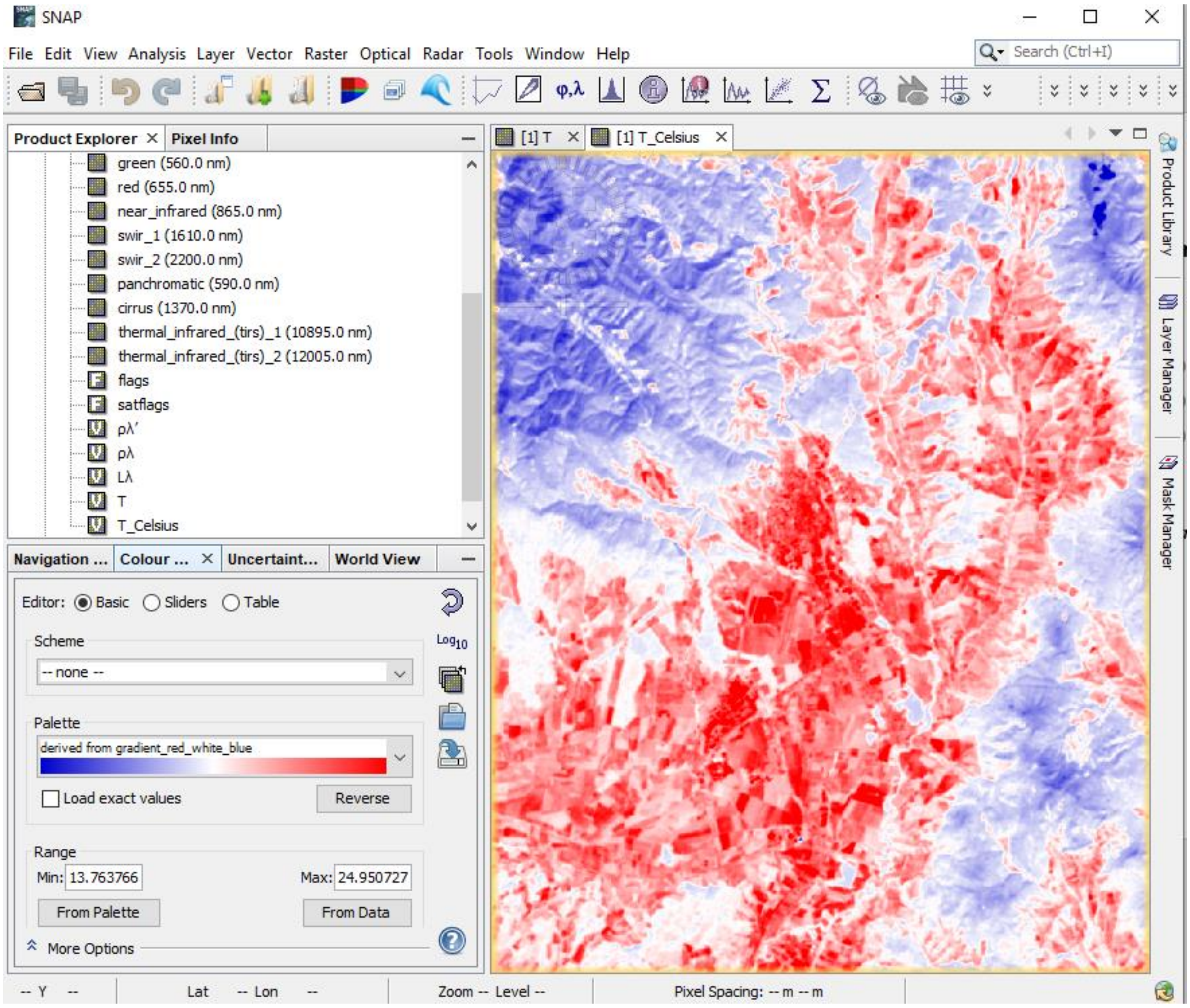
$$T = \frac{1321.08}{\ln\left(\frac{774.89}{L_\lambda} + 1\right)}$$







Now you have converted the T into degrees Kelvin. If you want to convert this into Celsius, you need to subtract 273.15 from the degrees kelvin. For Fahrenheit, multiply the degrees Celsius by 1.8 and then add 32. You can do this as one step within the Band Math function.



Visualize by double click the final Top of Atmosphere Brightness Temperature raster converted into Kelvin degrees. Change the colour ramp to see diferrences better.

Explore the distribution of TOA temperatures within the city of Košice. Compare it with, e.g. land cvoer map to see how different land cover/land use correlate with these temperatures.

For more information, see the lecture: [3. Key concepts and physical principles of remote sensing methods: electromagnetic energy, its properties, spectral behaviour and interaction with the environment]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

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

esa

ÚSTAV GEOGRAFIE
Prírodovedecká fakulta UPJŠ v Košiciach

UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

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.

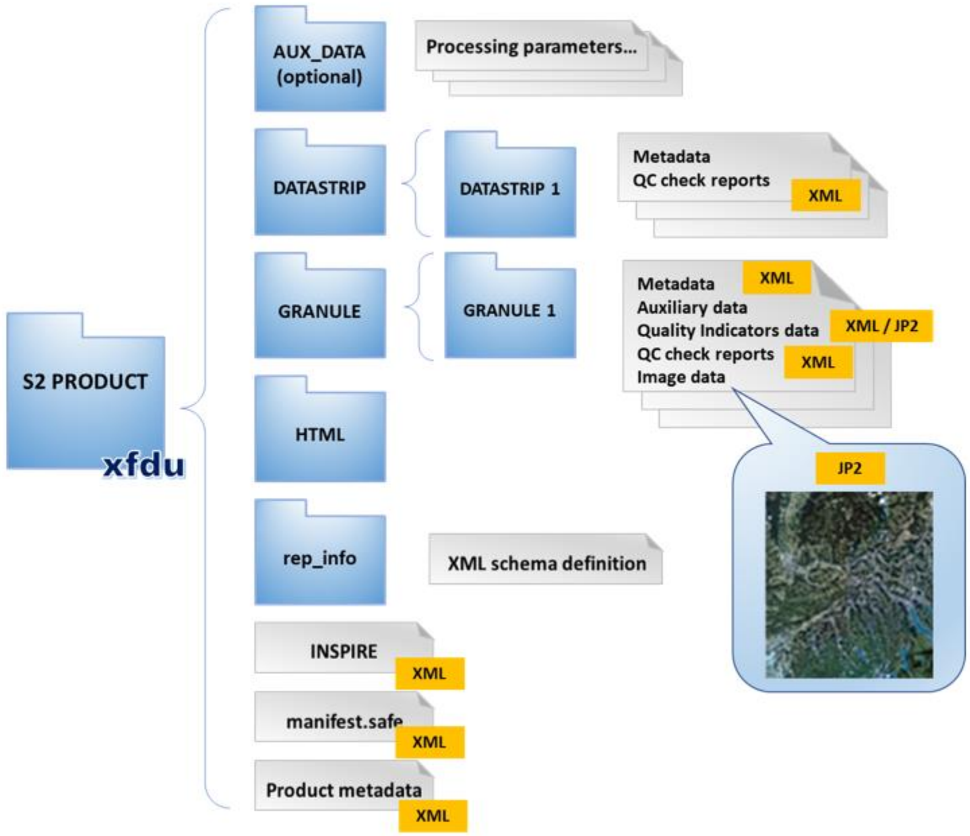
The spatial resolution of satellite imagery, crucial for discerning details on Earth's surface, varies across bands, with higher resolutions capturing finer details. Sentinel-2 bands offer different spatial resolutions tailored to specific features, enabling effective Earth observation. Spectral resolution 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.

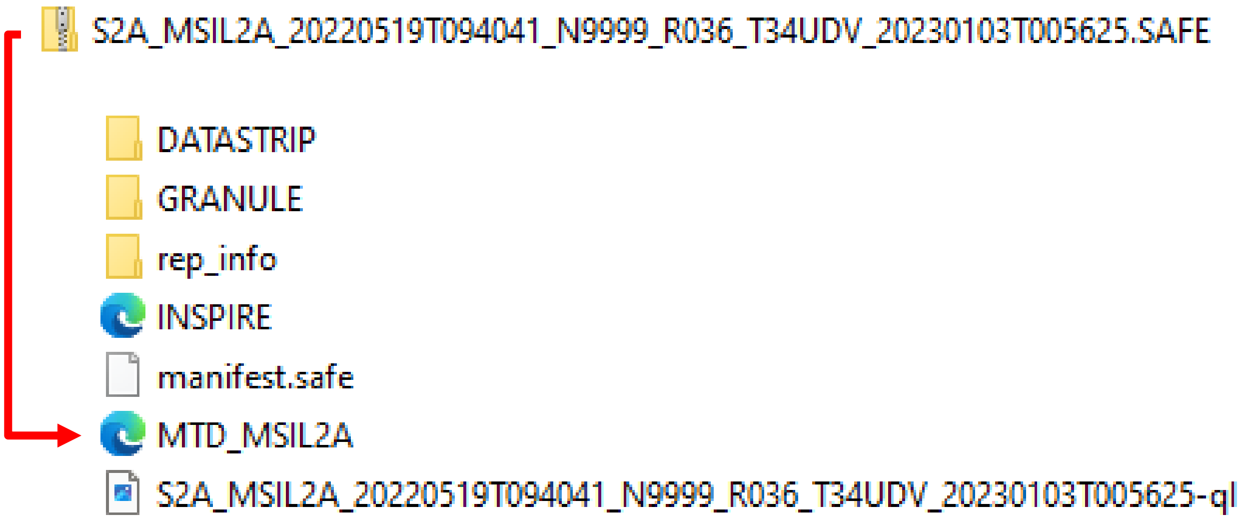
3 | Image metadata

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.

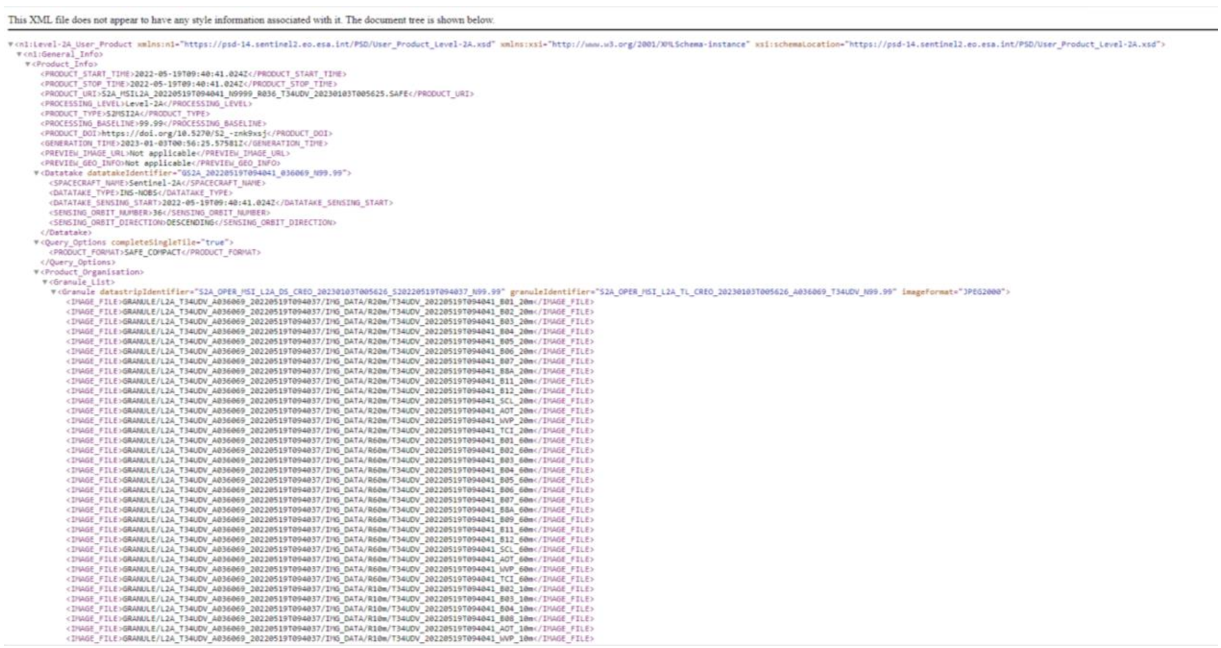


Navigate to the folder for this exercise and take a look at the structure of the Sentinel-2 product yourself.



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



3.1. SNAP - Open and explore product

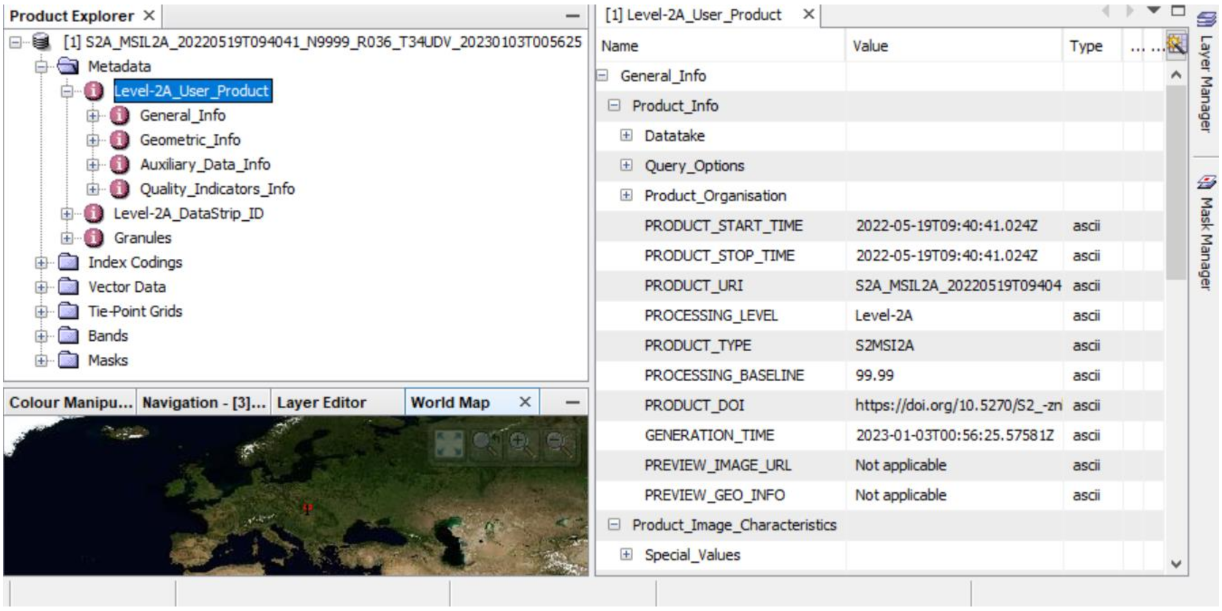
We can also open the metadata using SNAP software and browse them. For this exercise, we will use Sentinel-2 L2A image of the High Tatras, Slovakia, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

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

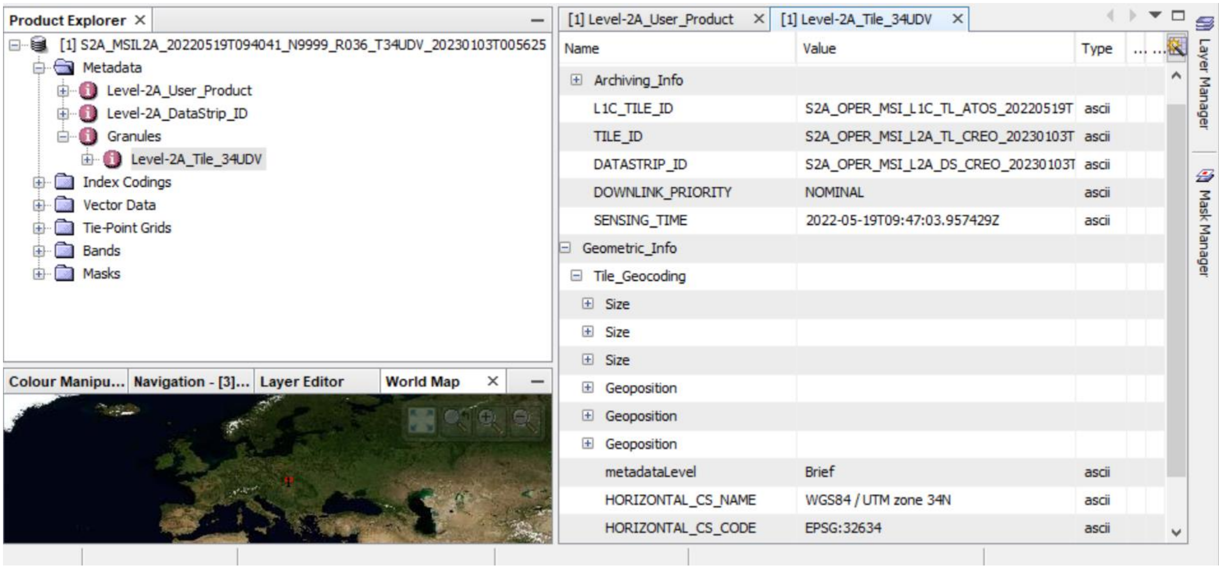
Open SNAP Desktop, click Open Product and open downloaded product (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window.

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 direcory – 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.



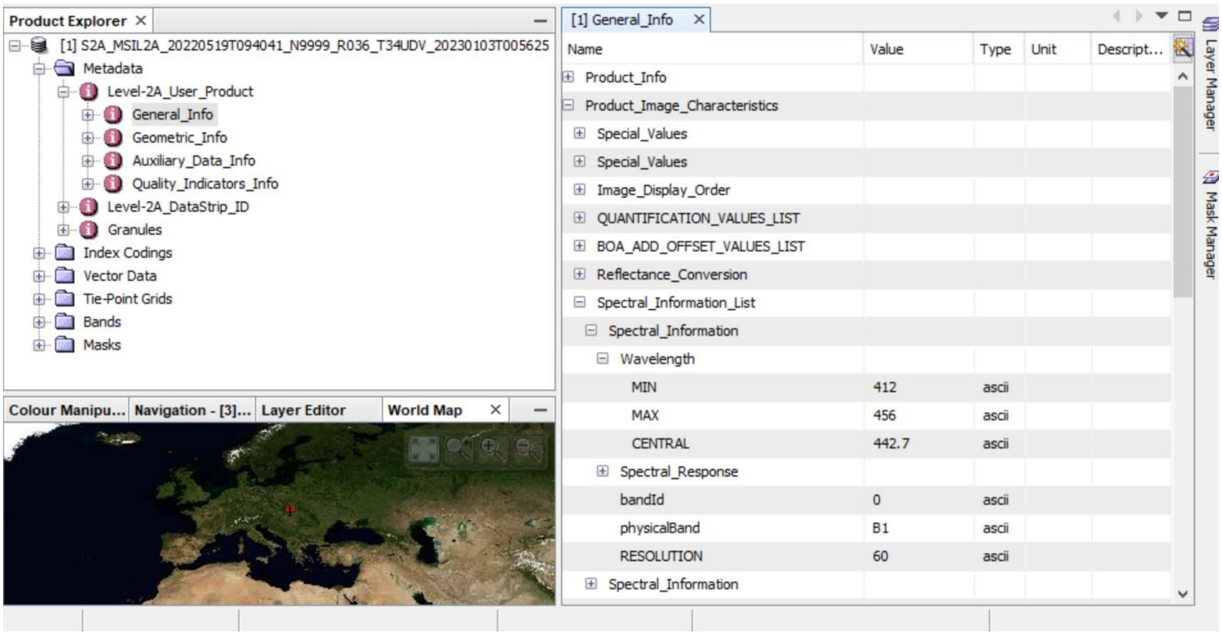
4 | Image resolution

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 direcory – 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:

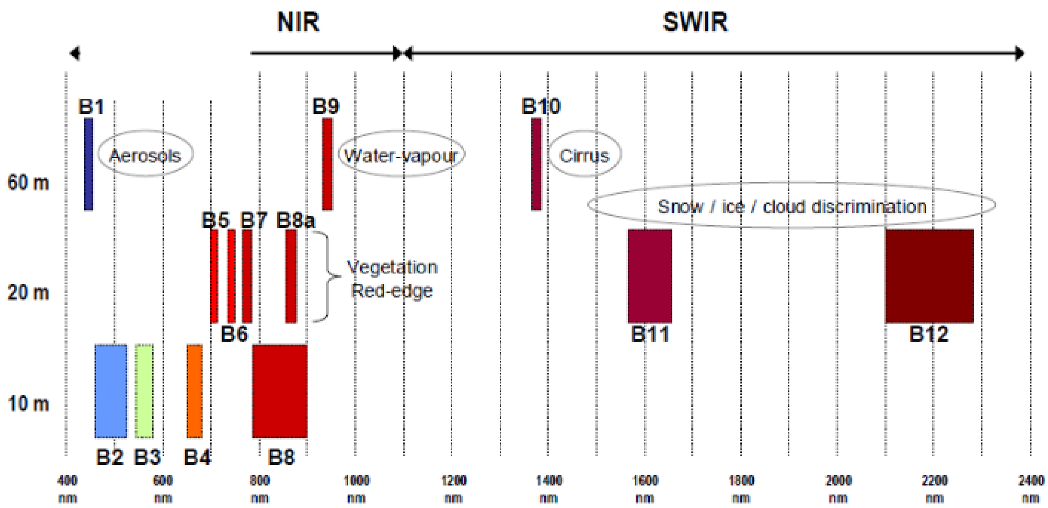
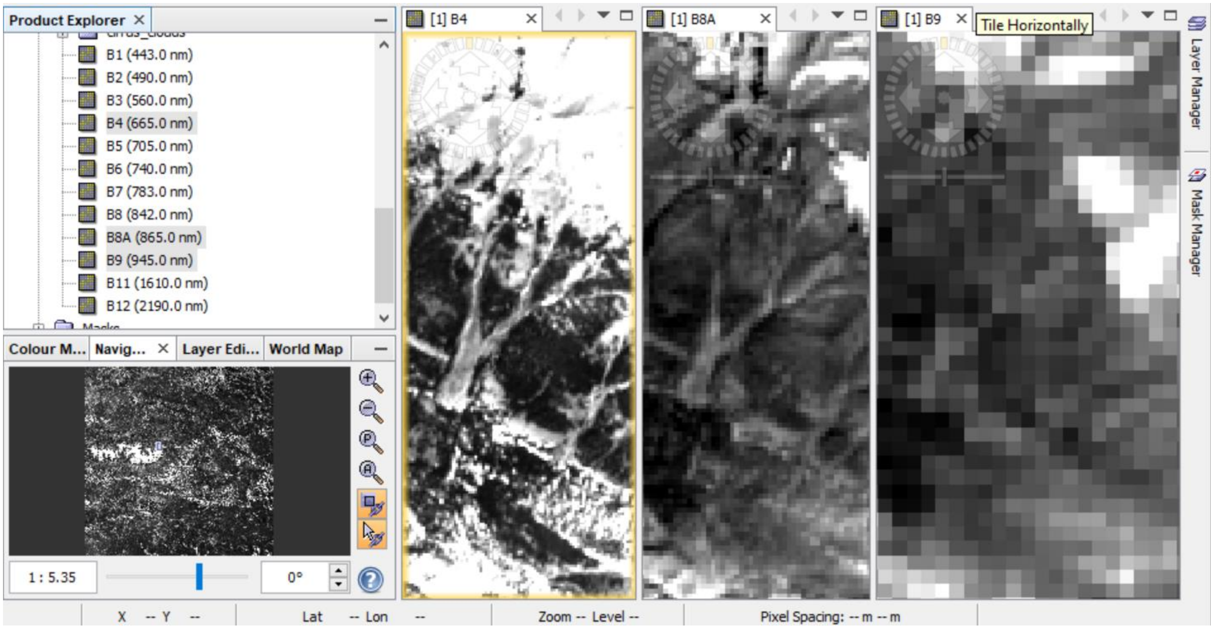


Figure 1: MSI Spectral-Bands versus Spatial Resolution

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.

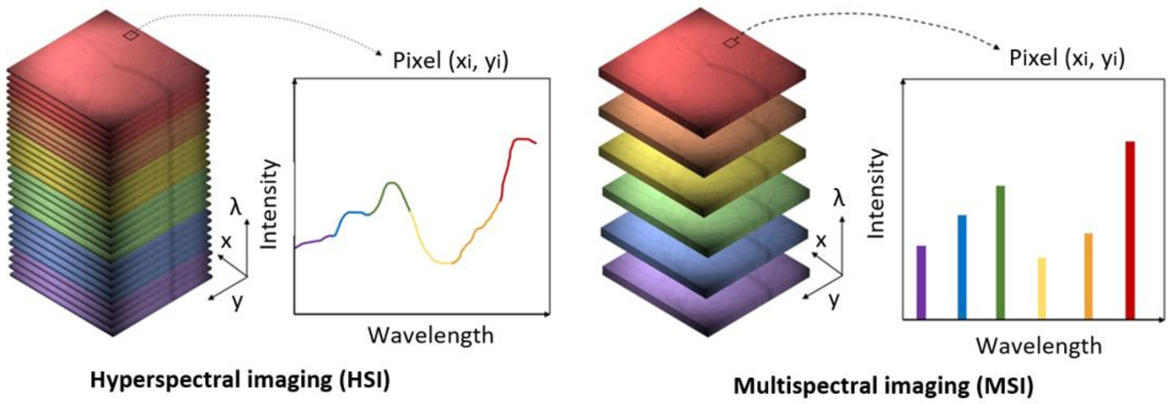
To explore the spatial resolution of the Sentinel-2 bands, you can visualize individual bands – you can open e.g. B4 (10m spatial resolution), B8A (20m spatial resolution), B9 (60m spatial resolution) by double-click on each of these bands in Bands folder. Then, tile windows Horizontally and zoom into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

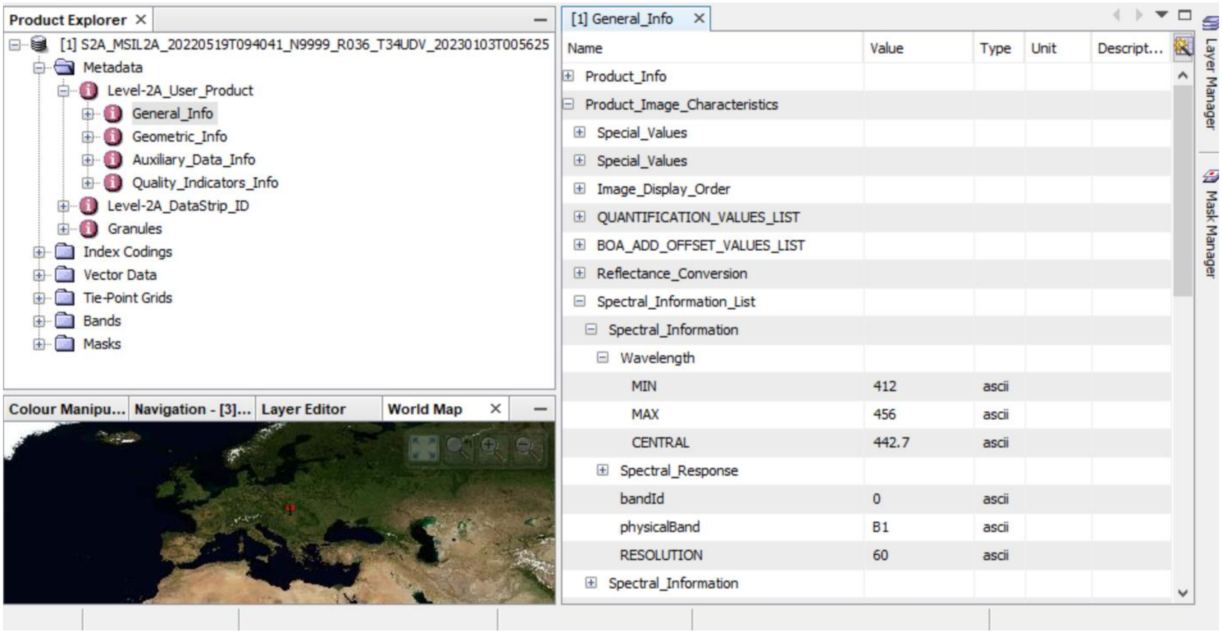


Sentinel-2 satellites have a multispectral instrument called the Multi-Spectral Instrument (MSI) that captures imagery in 13 spectral bands, ranging from visible to near-infrared and shortwave infrared wavelengths.

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 direcory – 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 of individual bands.



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.

Rigth 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:

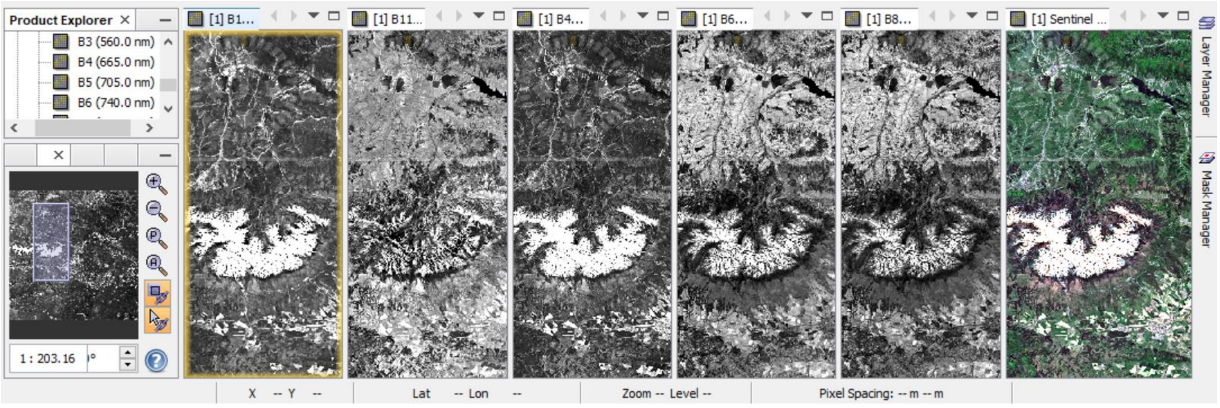
Near Infrared (NIR) band (Band 8) is highly sensitive to chlorophyll content in vegetation, making them useful for monitoring vegetation health, estimating biomass, and detecting changes in plant vigor. It can be also used to detect and analyze urban heat islands, as urban areas often have different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

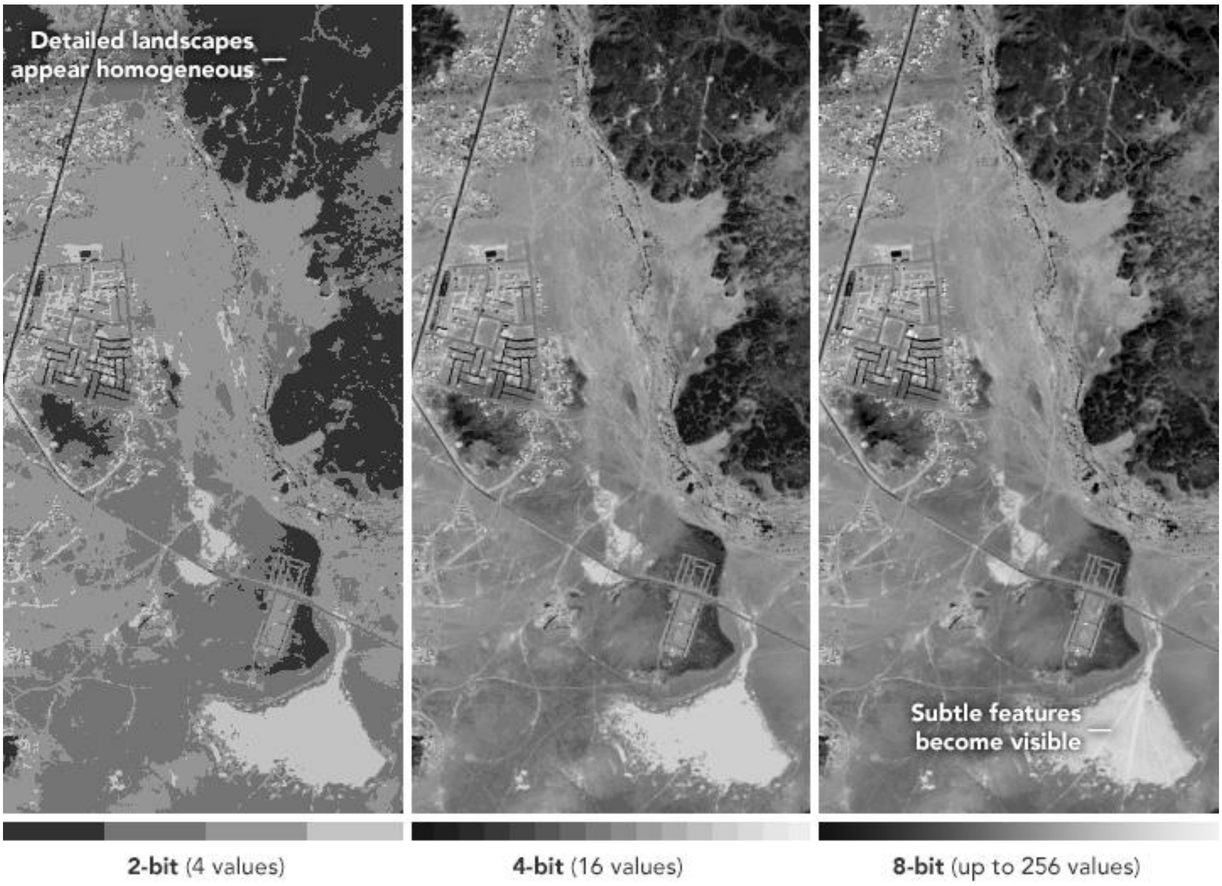


Radiometric resolution

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.

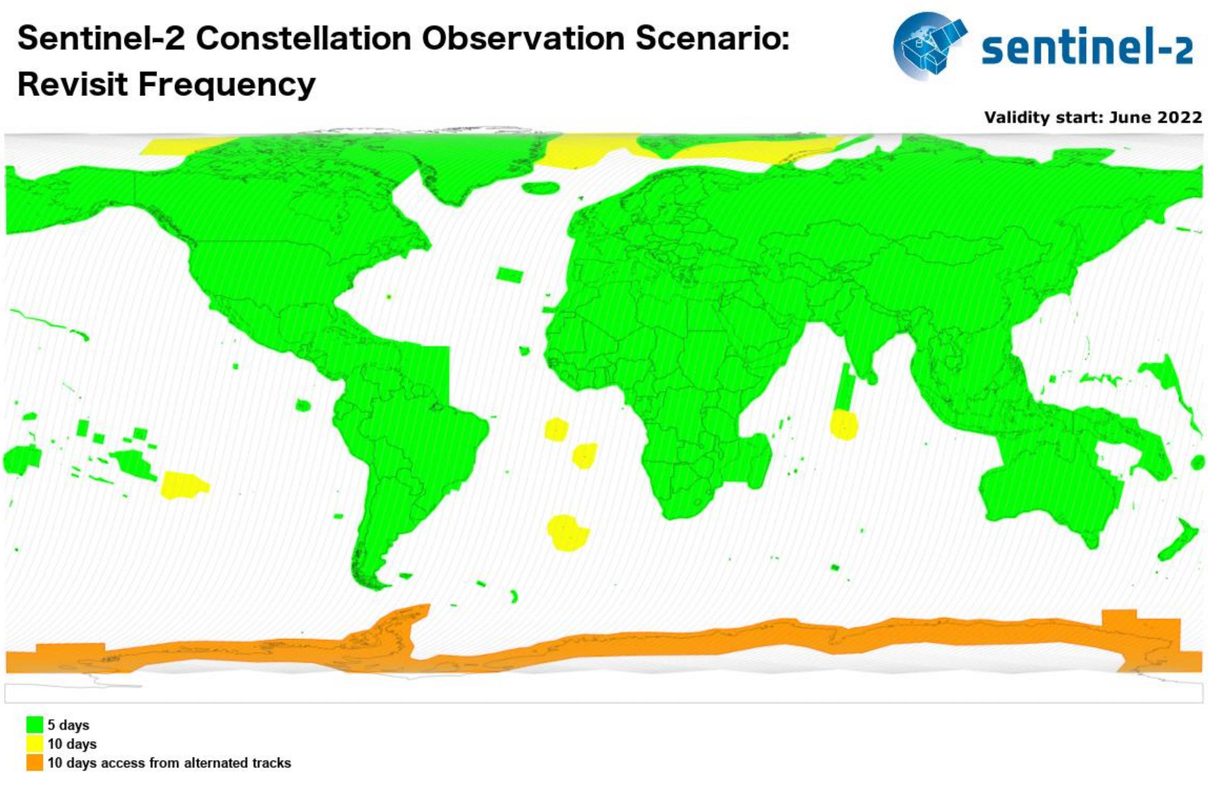
A 12-bit radiometric resolution means that each pixel in the imagery captured by Sentinel-2 can represent 2^12 (4096) different levels of brightness or intensity. This high radiometric resolution allows for the detection of subtle variations in reflectance across the Earth's surface, which is crucial 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.

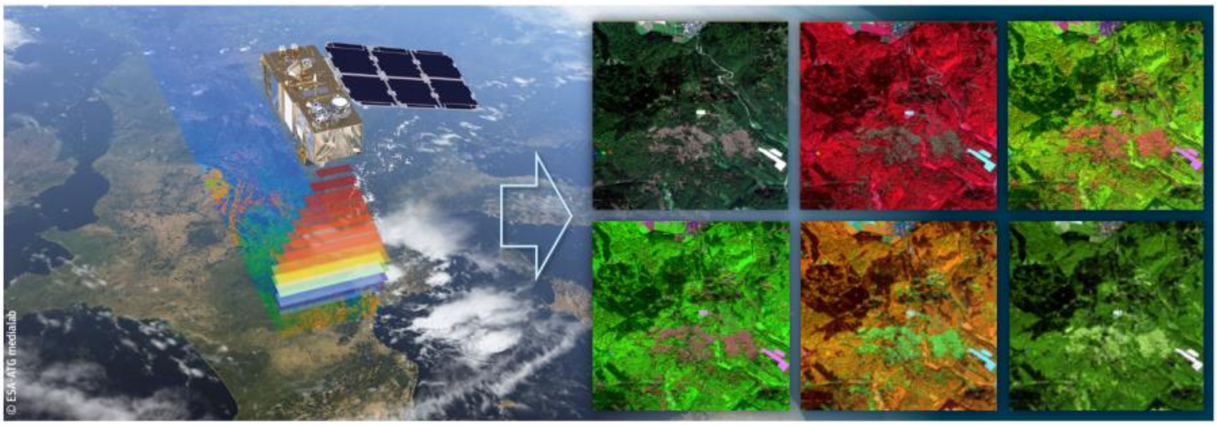


5 | Color compisitions and spectral indices

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.

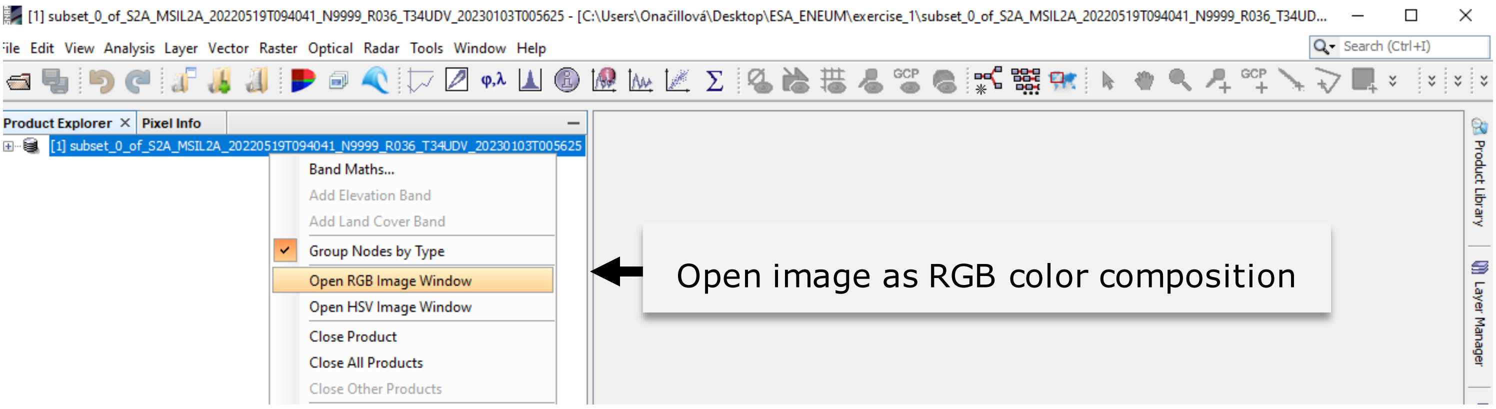
Multispectral images can be viewed either as single-band grayscale images or as color composite images, combining information from three bands at a time. These three bands correspond to the primary colors of light: red, green, and blue. Computer screens can display images by representing each band with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

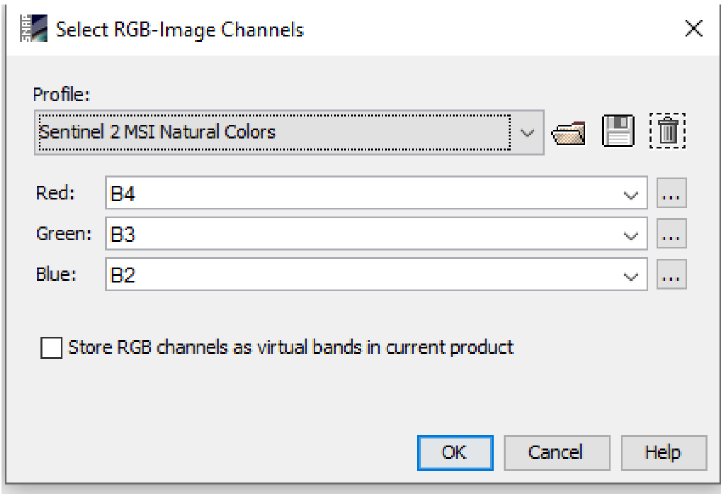


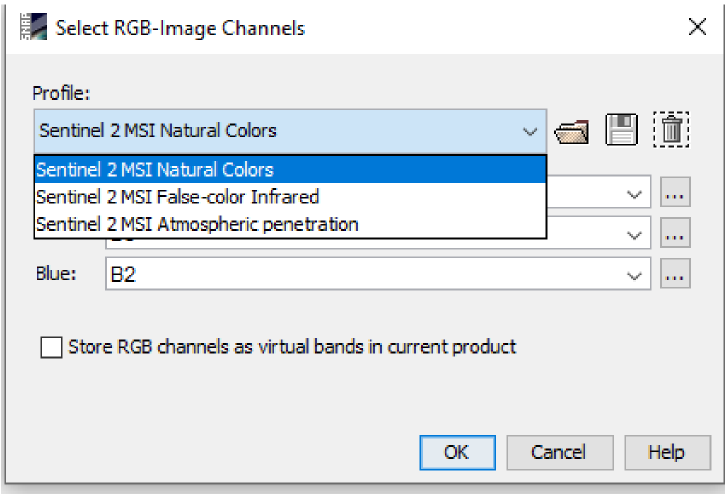
Natural or True Color Composites
A natural or true color composite combines visible red, green, and blue bands to resemble what would be observed naturally by the human eye. This composite replicates natural appearances, with vegetation appearing green, water as blue to black, and bare ground and surfaces 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.

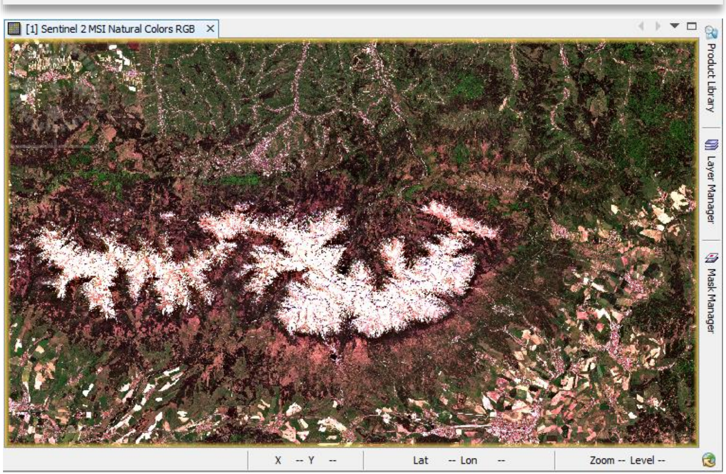


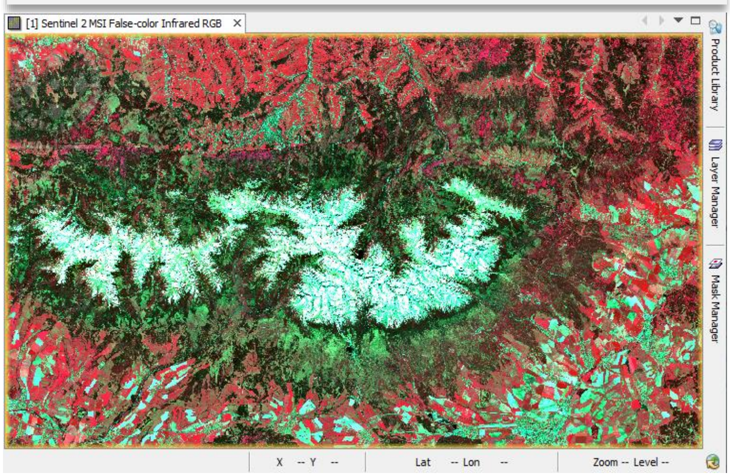




Display image in Natural Colors (as seen by human eye)

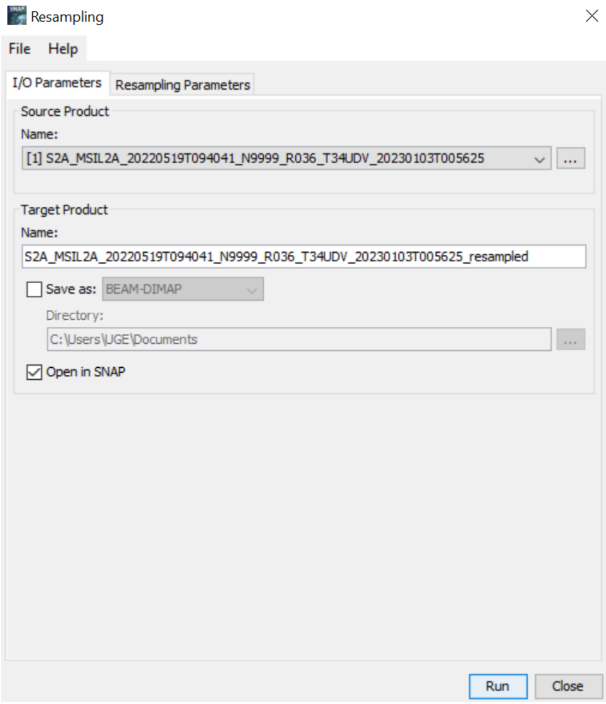
Open image in False Colors or open as an Atmpospheric penetration image

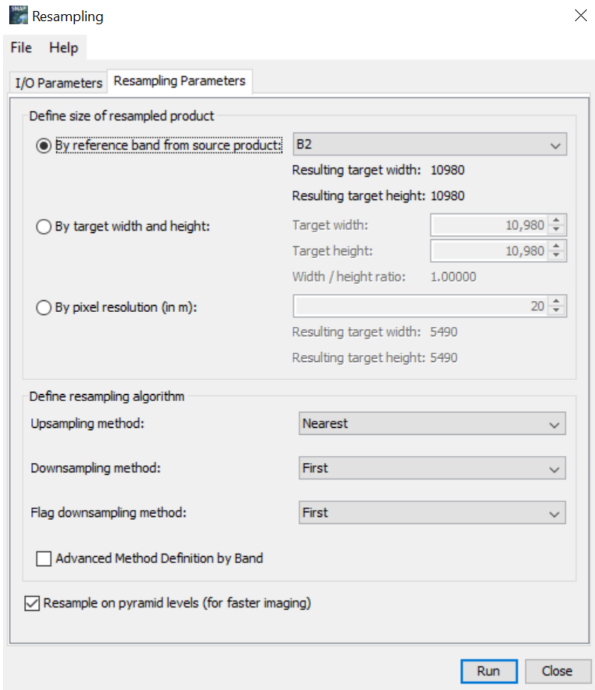




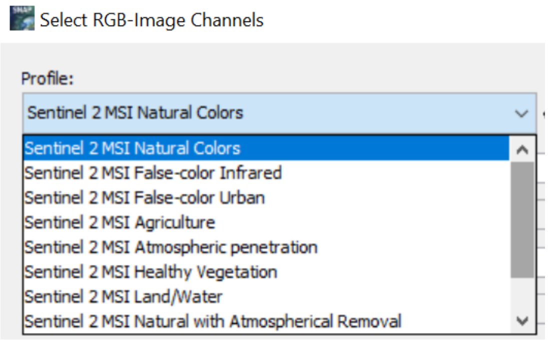
To display multiple options of color compositions, it is necessary to resample the data to the same spatial resolution.

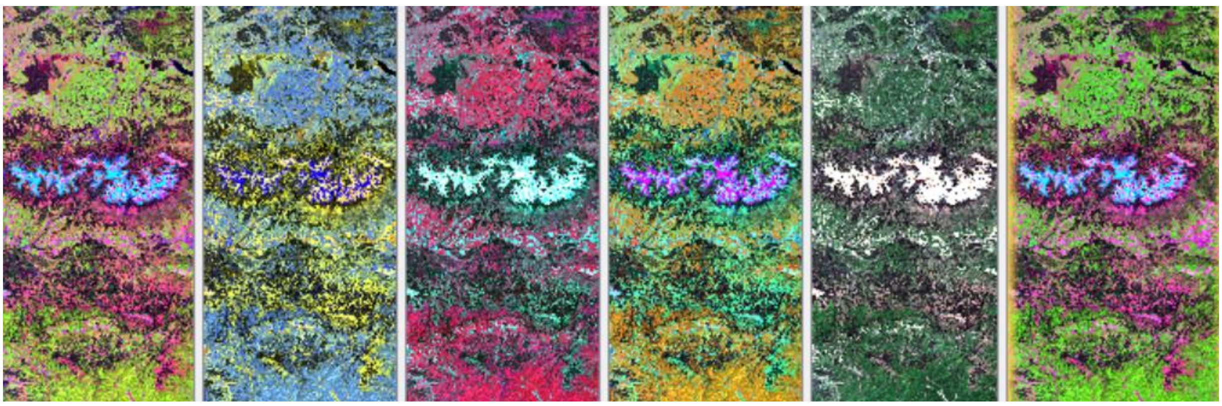
Navigate to the Main Menu: Raster – Geometric – Resampling
In the I/O Parameters tab select the source product and set the name for the target product
In the Resampling Parameters set B2 as the band used to resample all other bands of the product and click RUN.





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.

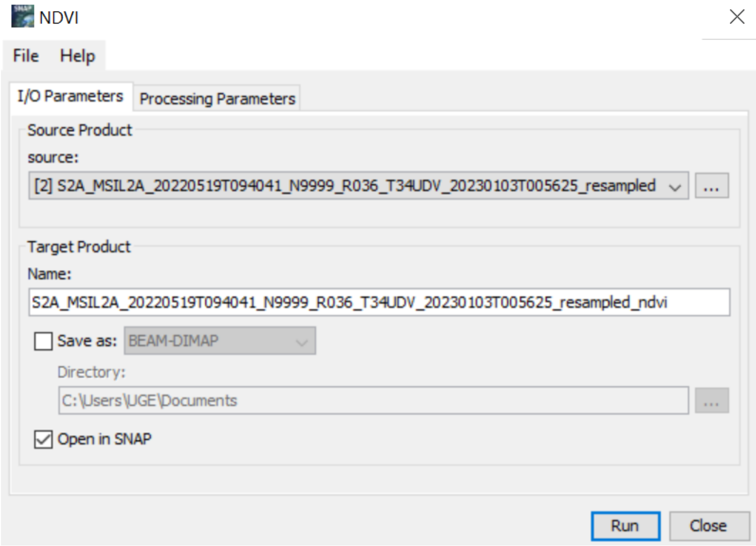
Let´s create, e.g. NDVI from our Sentinel-2 product:
The Normalized Difference Vegetation Index (NDVI) algorithm exploits the strength and the vitality of the vegetation on the earth's surface. It is calculated from the visible and near-infrared light reflected by vegetation.

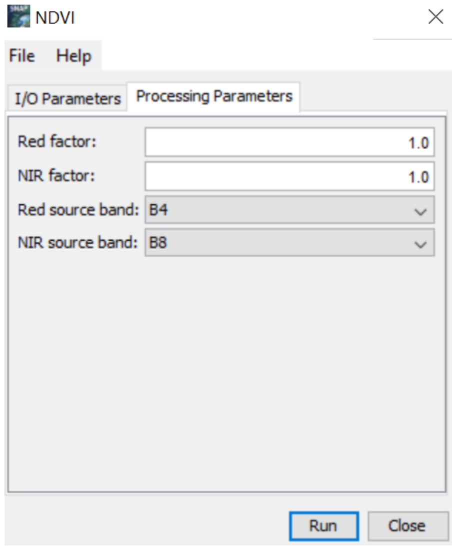
Even if it is an old and classic method it is still much used to estimate the health of green vegetation and post processed high definition images for precision agriculture.

- 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**





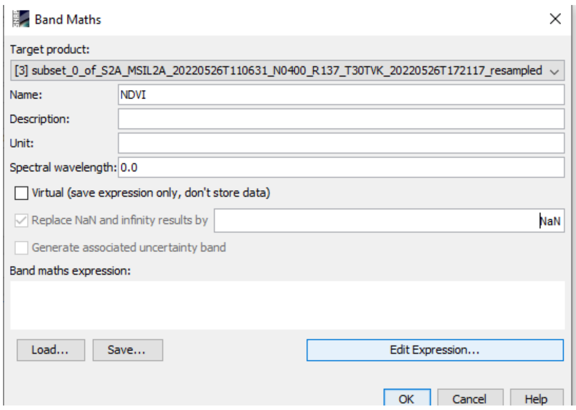
User can also use Band Maths option to create vegetation indices:

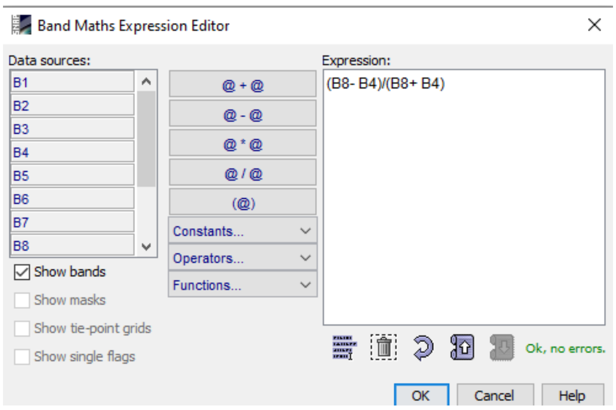
- Select the subset product in the Product Explorer window.
- Click on ‘Raster’ - ‘Band Maths…’

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…’

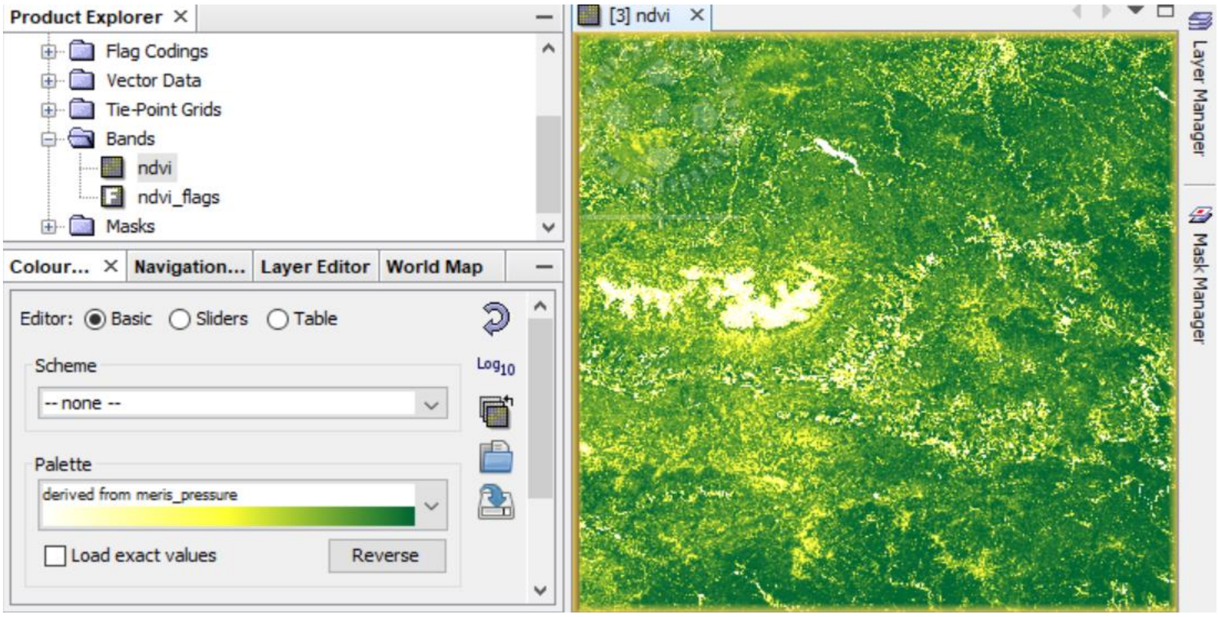
Create your expression using ‘@’ and after replace them with the bands
(@ - @) / (@ + @)
(B8 – B4) / (B8 + B4)

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.

For more information, see the lecture: 4. Optical remote sensing using ESA Copernicus´ data: sensors and platforms, image metadata, image resolution (spectral, spatial, temporal and radiometric resolution)

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 5 – TUTORIAL

Basics of Radar Remote Sensing - data processing, using SNAP software

esa
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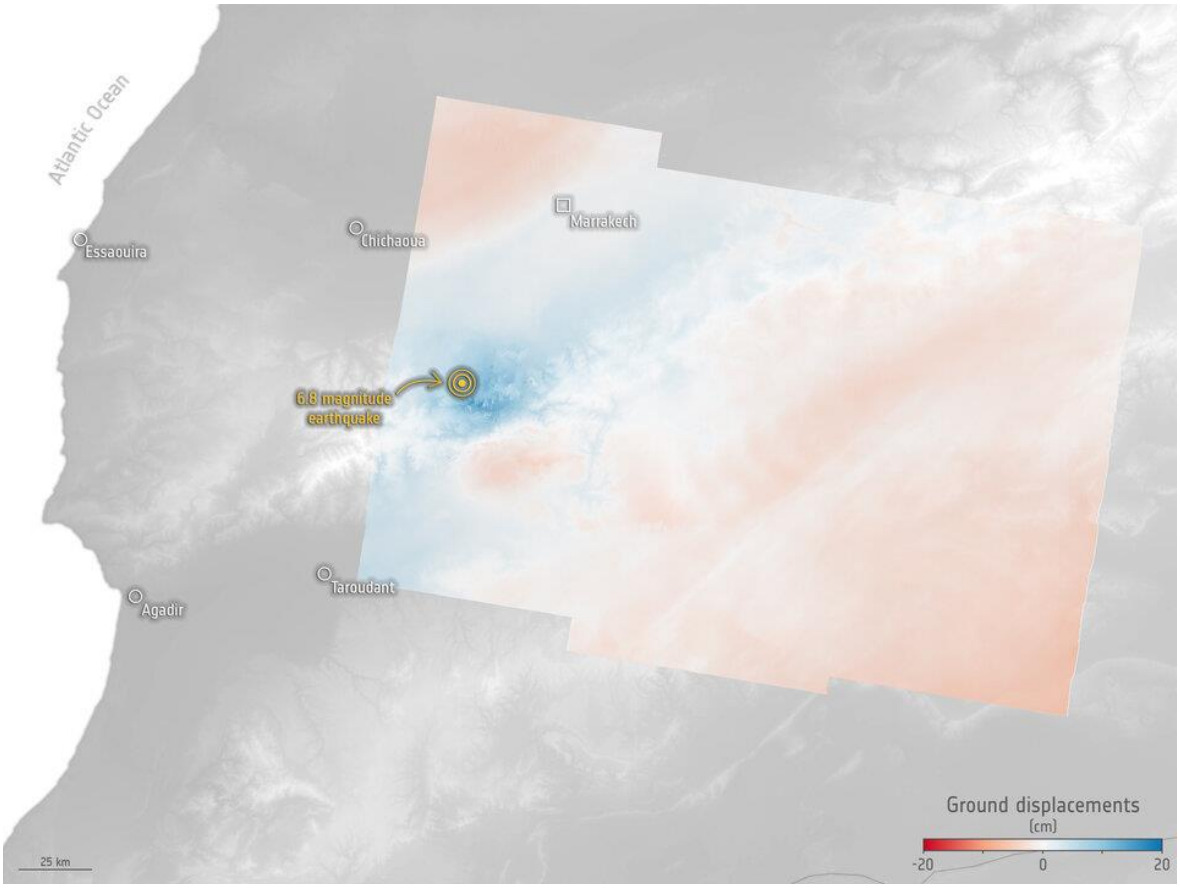
UNIVERZITA PAVLA JOZEFA ŠAFÁRIKA V KOŠICIACH

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Learn the basic physics of SAR interferometry
- Perform necessary data processing for making an interferogram
- Understand the information content in SAR interferometric images

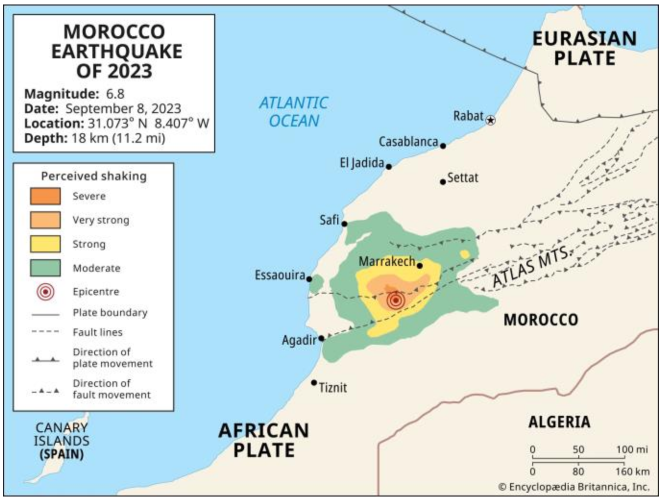


Morocco earthquake deformation
Source: contains modified Copernicus Sentinel data (2023), processed by Aristotle University of Thessaloniki and the DIAPASON InSAR service of CNES integrated by TRE Altamira on the Geohazard Exploitation Platform GEP/ESA.

2 | Background

Deformation Mapping and Change Detection using Sentinel-1 data

Satellites constantly monitor Earth from space, providing vital data essential for rapid damage assessment and disaster management. The radar on board the Copernicus Sentinel-1 mission can detect ground conditions and penetrate clouds, functioning day and night.



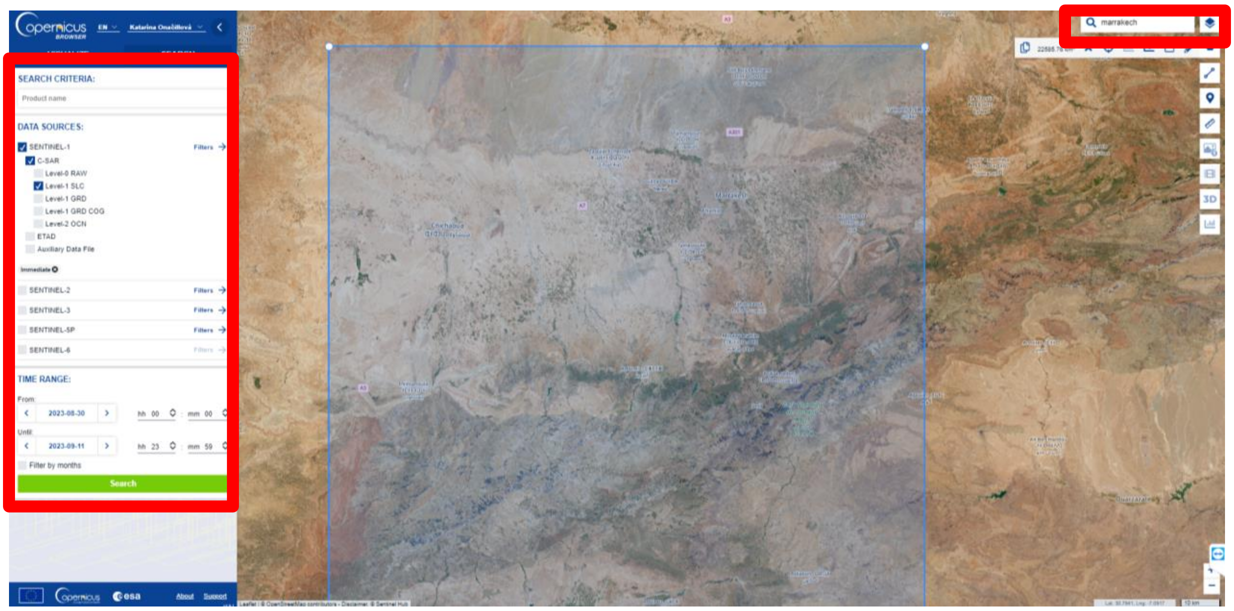
One of the mission's primary functions is to regularly monitor subtle alterations in the Earth's surface elevation. During an earthquake event, surface changes are notably more conspicuous compared to gradual movements such as subsidence or uplift. These radar images enable scientists to meticulously observe and analyze the specific impacts of earthquakes on the Earth's land surface.

On Friday 8 September 2023, the powerful 6.8 magnitude earthquake struck the Atlas Mountains, about 75 km from Marrakech. Tragically, the earthquake resulted in a significant loss of life, widespread building and home collapses, and the blockage of roads. Its impact extended to the extent that buildings even swayed on the country's northern coast.

In response to the Moroccan earthquake, the Copernicus Emergency Mapping Service was mobilized to facilitate the exchange of satellite data.

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 SLC images of the same area near Marrakech, Morocco, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products by double click on the zipped folders. The opened products will appear in Product Explorer window.

S1A_IW_SLC__1SDV_20230830T062919_20230830T062946_050101_06076B_20BE.SAFE.zip
S1A_IW_SLC__1SDV_20230911T062920_20230911T062947_050276_060D5E_D10D.SAFE.zip

To access the information within the product, double-click on it to reveal the directories, which include:

- Metadata: containing parameters pertaining to orbit and data.
- Tie Point Grids: providing interpolation data for latitude/longitude, incidence angle, etc.
- Quicklooks: presenting a visible image of the entire scene in radar coordinates.
- Bands: consisting of complex values for each subswath "i" and "q", along with intensity (where intensity represents the squared amplitude and functions as a virtual band).

Select intensity image for swath IW1 VV – double click on it to View it
Note: Each SAR image is flipped north—south it maintains the same orientation as its acquisition (in this case, ascending track).

3.2 Coregistration

Image coregistration is the process that involves aligning two or more images geometrically, ensuring that corresponding pixels depict the same area on the Earth's surface. While orbit state vectors alone can suffice to coregister images, for precise offset tracking, additional data from a digital elevation model (DEM) is necessary to enhance coregistration accuracy.

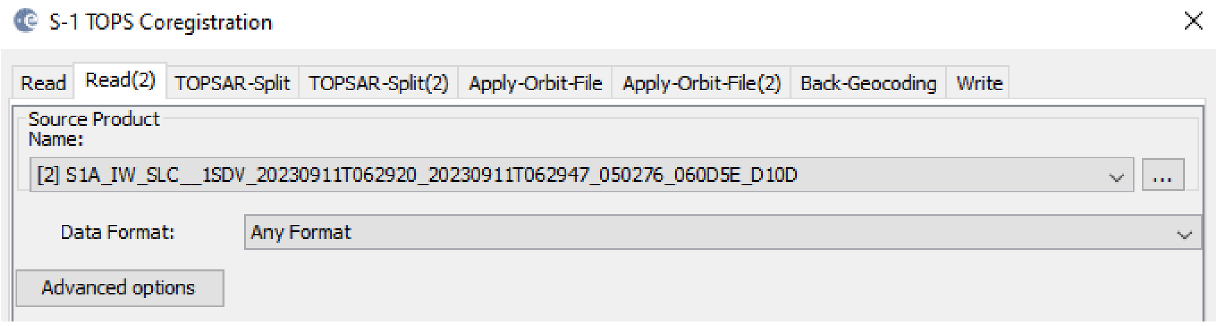
Navigate to Main Menu – Radar – Coregistration –S1 TOPS Coregistration – S1 TOPS Coregistration

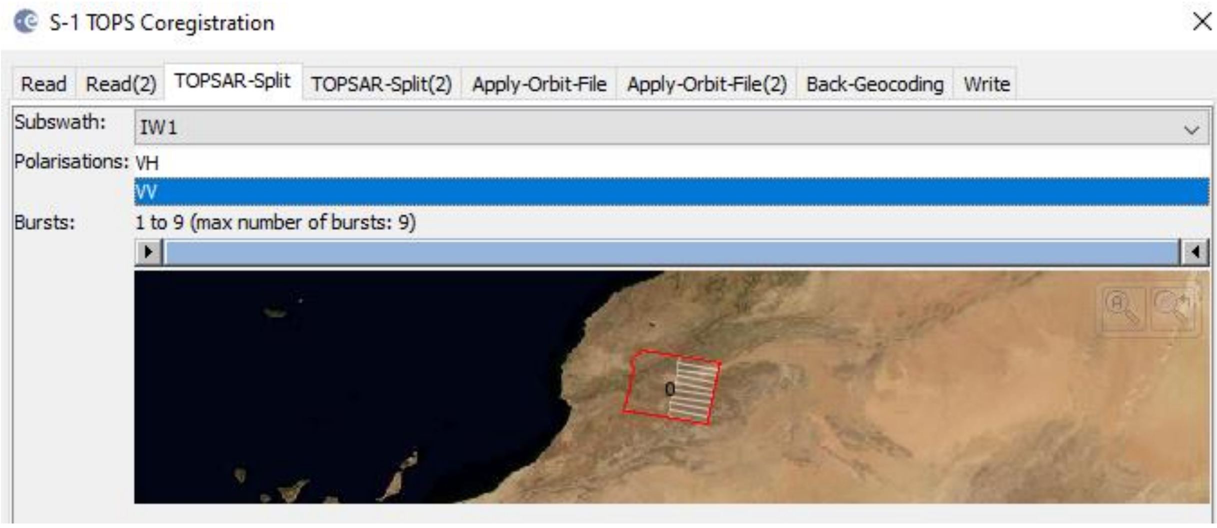
In the Read tab, select the 20230830 SLC product and in the Read(2) tab select the 20230911 SLC product

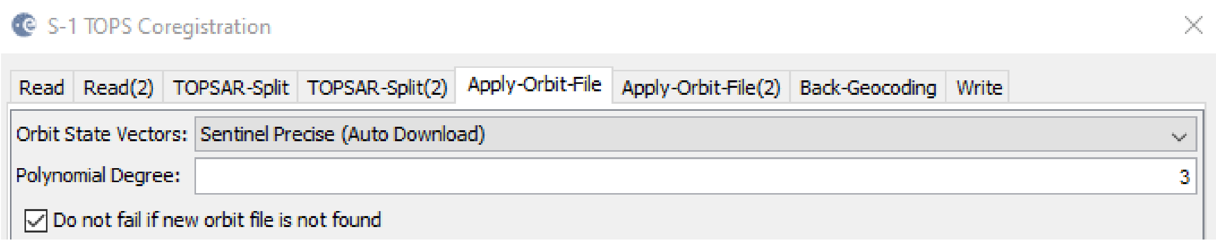
In TOPSAR-Split and TOPSAR-Split(2) tabs select Subswath: IW1 Polarizations:VV

In the Apply Orbit File tab select leave default parameters and uncheck „Do not fail if new orbit is not found" option

In the Write tab, select the directory to save your processing outputs



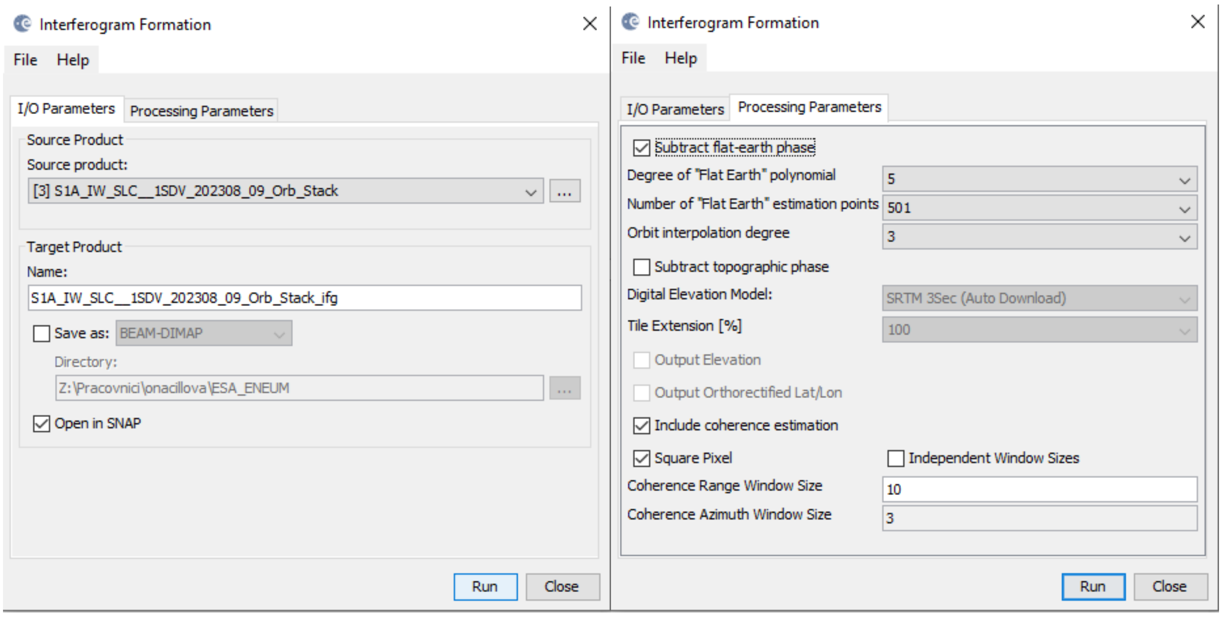




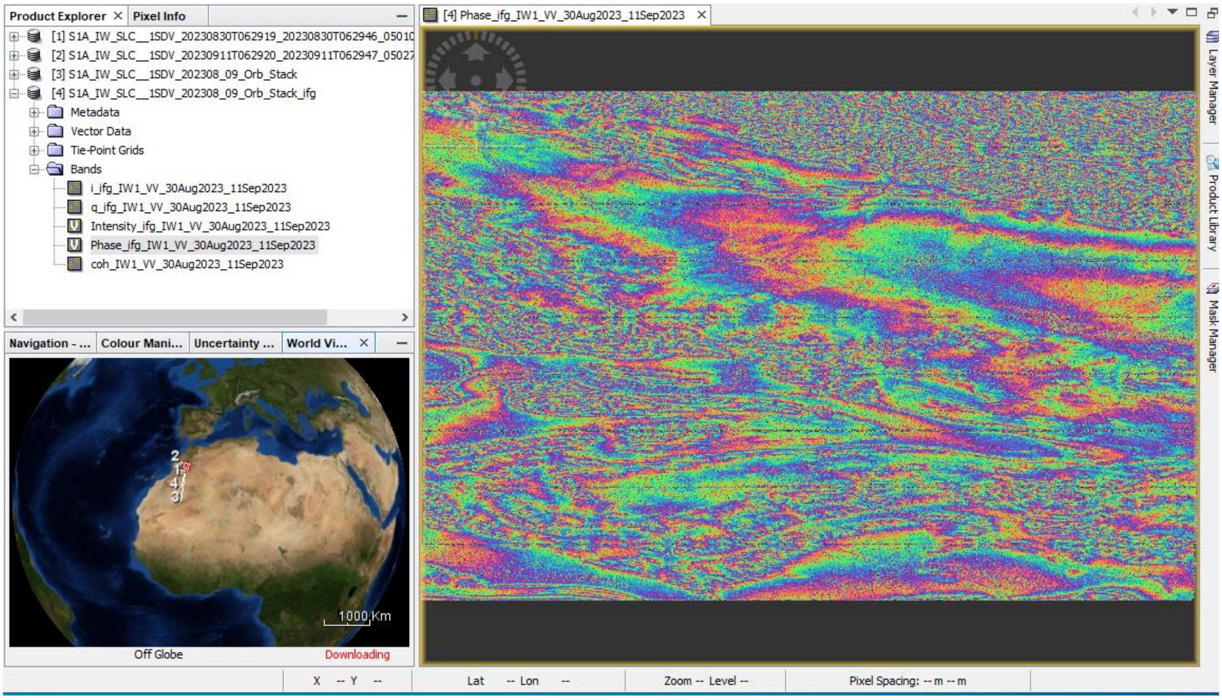
3.3 Forming a Raw Interferogram

The next phase of interferometry involves generating an interferogram using the coregistered SLC images. To do this, follow these steps:

From the main menu bar, go to Radar – Interferometric - Products and finally select Interferogram Formation.
In the I/O Parameters tab, choose the "Orb_Stack" product that was generated during the coregistration process.
By default, the output target is set to the same directory and appends "ifg" to the filename.
For standard processing, there's no need to modify the defaults in the Processing Parameters tab.



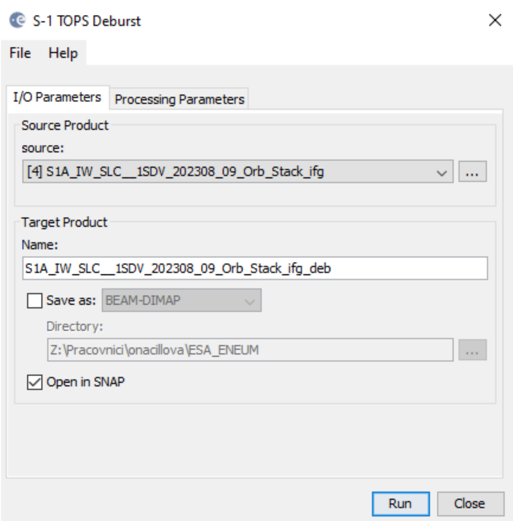
Raw Interferogram — Phase Image should appear int he View tab.

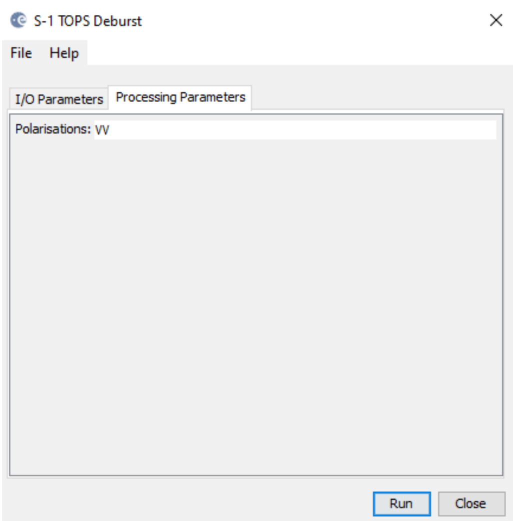


3.4 TOPS Debursting and Topographic Phase Removal

The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts, a step not required with Sentinel-1 or other stripmap SAR data.

To perform debursting, follow these steps:
From the main menu bar, navigate to Radar, then Sentinel-1 TOPS, and finally S-1 TOPS deburst.
In the I/O Parameters tab, choose the "Orb_Stack_ifg" product generated during the interferogram formation process. By default, the output appends "deb" to the filename.
There is no need to make changes in the Processing Parameters tab.

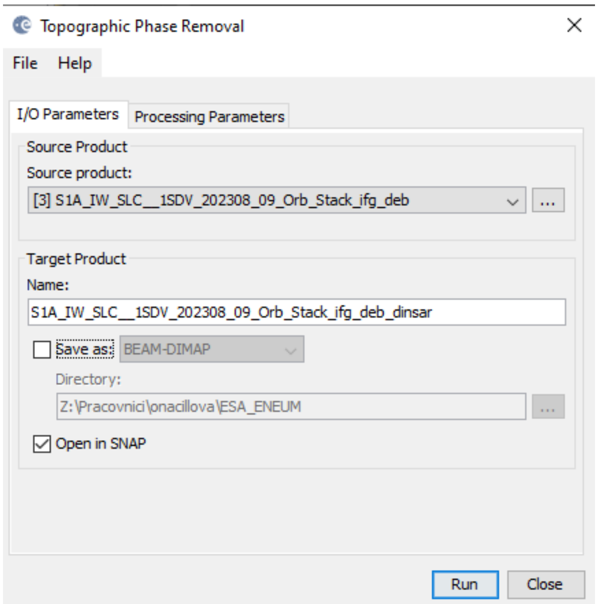


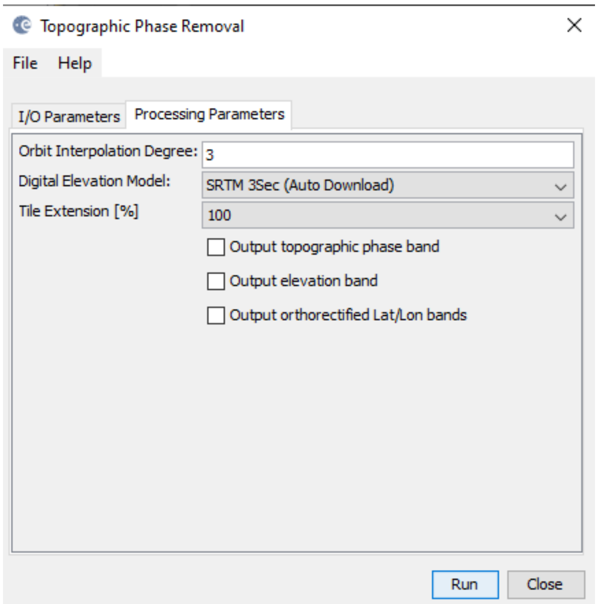


The subsequent stage in all interferometry processes involves eliminating the topographic phase using a Digital Elevation Model (DEM).

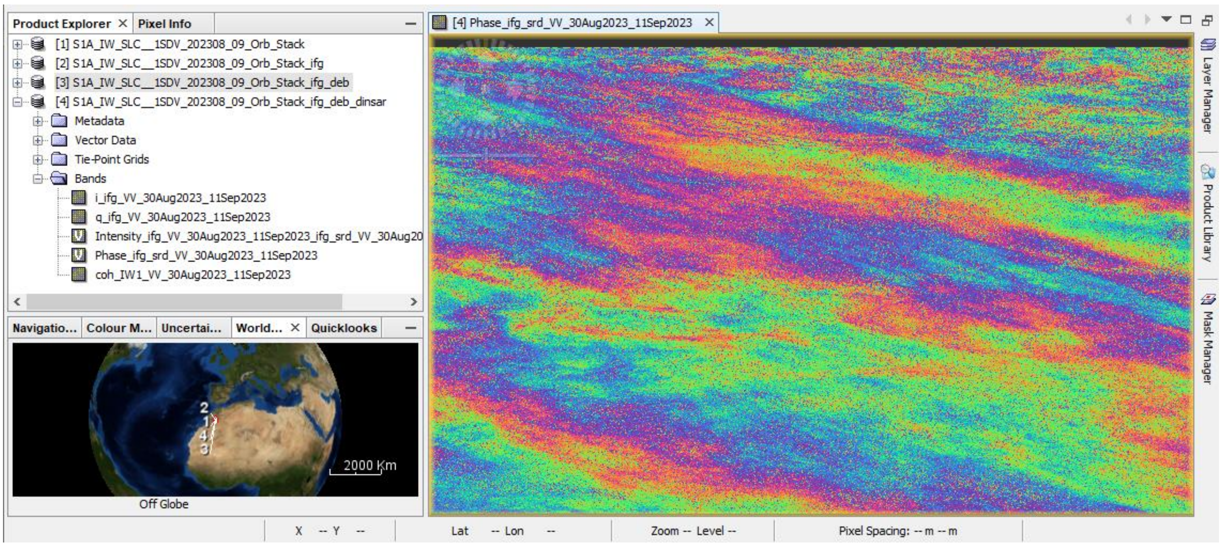
To proceed with topographic phase removal, follow these steps:

From the main menu bar, navigate to Radar, then Interferometric, then Products, and finally Topographic Phase Removal.
In the I/O Parameters tab, choose the "Orb_Stack_ifg_deb" product generated during the deburst step. If not using TOPS mode, select "Stack_ifg" instead.
By default, the output appends "dinsar" to the filename.
The Processing Parameters tab indicates that the default setting is to download the SRTM 3-arcsecond DEM, which is suitable for basic processing. However, in certain cases, you may require a different DEM.





Viewing Differential Interferogram — Phase Image



3.5 Filtering and Multi-Looking Interferogram

There are two methods to minimize noise in the interferogram: filtering and multi-looking. While our standard procedure involves applying filtering initially, it's also possible to opt for multi-looking first.

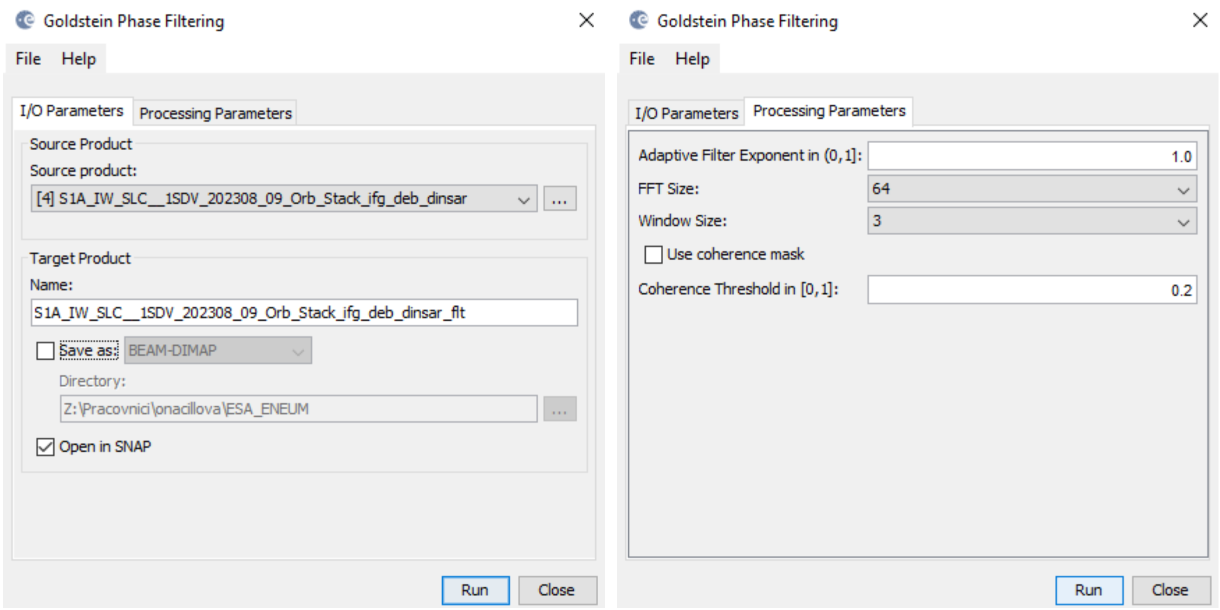
To begin filtering:

Go to Radar, then Interferometric, then Filtering, and select Goldstein Phase Filtering from the top main menu bar.

In the I/O Parameters tab, choose the "dinsar" product generated in the previous step.

By default, the output name includes "flt."

There's no necessity to adjust the default settings in the Processing Parameters tab for basic processing.



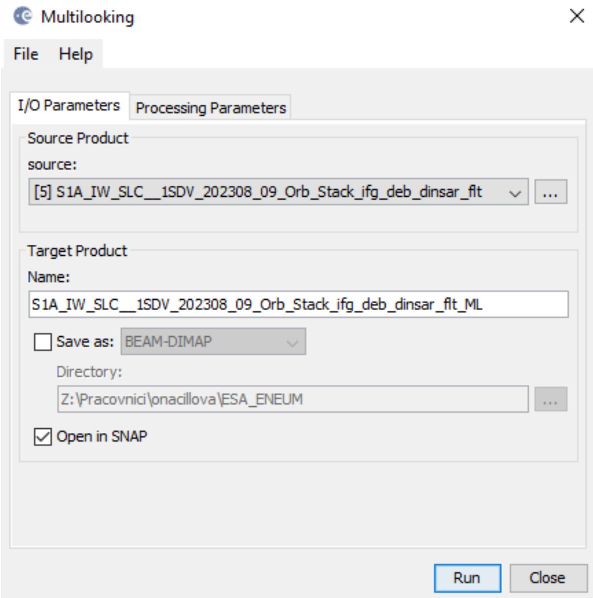
3.6 Multi-Looking Interferogram

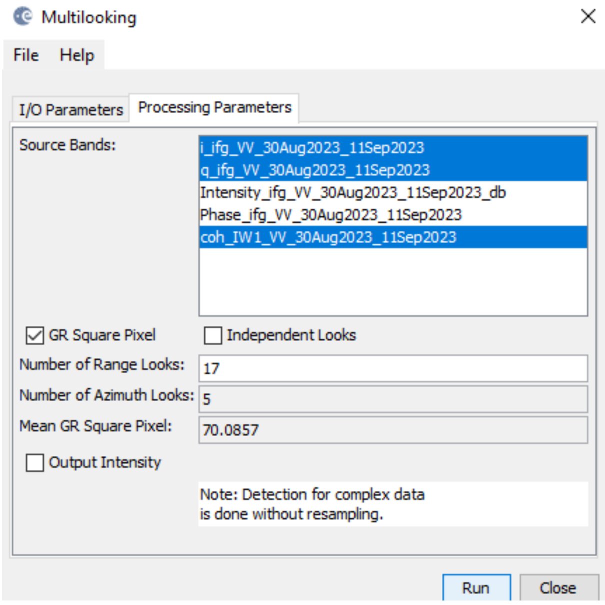
Multi-looking involves averaging several pixels in each direction, a process referred to by radar engineers as "taking multiple looks." This leads to larger pixels and has the potential to significantly diminish noise.

The extent of multi-looking required depends on the desired spatial resolution and the spacing of the fringes.

The Morocco earthquake, with a depth of approximately 18 km, exhibits widely spaced fringes. Additionally, there is no surface rupture, allowing for increased spatial averaging without sacrificing the earthquake signal.

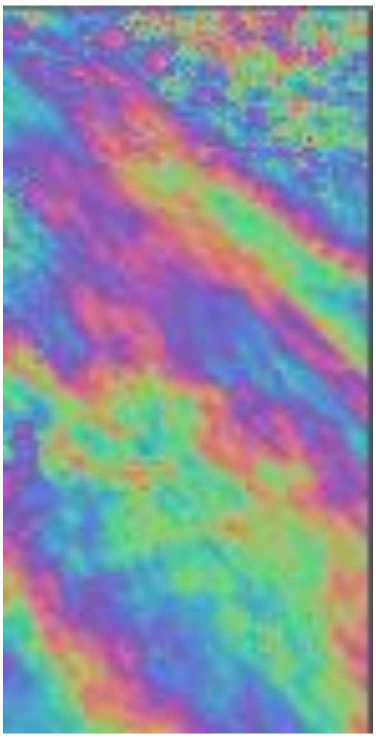
To initiate multi-looking:
From the top main menu bar, select Radar, then SAR Utilities, and finally Multilooking.
In the I/O Parameters tab, choose the "dinsar_flt" product generated by the filtering step. By default, "ML" is appended to the output name.
In the Processing Parameters tab, select the Source Bands "i_ifg", "q_ifg", and "coh". For this scene, 17 range looks are utilized, with the calculation of 5 azimuth looks resulting in approximately 70 m output pixels.
Do not select the "Phase" band.





Viewing Multi-Looked Interferograms
Initially, we must generate a new virtual phase band after multi-looking the complex interferogram.

To do this:
From the top main menu bar, navigate to Raster, then Data Conversion, and select Complex i and q to Phase.
Subsequently, you can display the newly created phase band.
As a result of this process, the fringes exhibit significantly reduced noise, and the aspect ratio has been modified, resulting in pixels that are approximately square on the ground. The new image now measures considerably smaller number of pixels than the original image.



3.7 Phase Unwrapping

Unwrapping in SNAP follows three distinct steps:

1. Export of the wrapped phase (and definition of the parameters)
2. Unwrapping of the phase (performed outside SNAP by snaphu)
3. Import of the unwrapped phase back into SNAP

Export of the wrapped phase

Export your interferogram or your subset interferogram from Sentinel-1 Toolbox to SNAPHU:

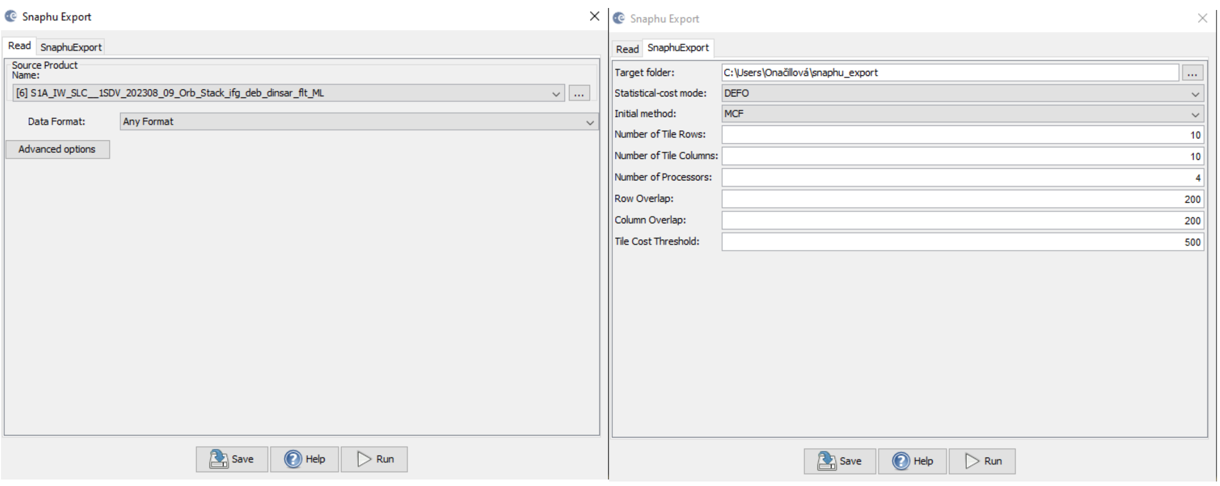
From the top main menu bar, navigate to Radar > Interferometric > Unwrapping > Snaphu Export.

In the Snaphu Export window:
In Read tab, select the "ML" product created by the multilooking step
In Snaphu Export tab, you also need to specify a target folder for exported files. Create a new target folder for this step by entering a path and new folder name (e.g. „snaphu_export). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field.

In Snaphu Export tab, select DEFO as Statistical-cost mode
Select MCF.

Note: You can also change the number of tile rows, columns and number of processors to e.g. "1" because we don't need multiple tiles after multilooking or select 200 pixels for Row Overlap and Column Overlap if you want to multilook. Depending on the number of processors of your computer, you can also increase the Number of Processors variable.

Click Run to create the SNAPHU_Export file
The folder now holds files used for phase unwrapping.



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Select MCF.

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Click Run to create the SNAPHU_Export file

The folder now holds files used for phase unwrapping:
▪ the coherence: image (*.img) and metadata (*.hdr)
▪ the wrapped phase: image (*.img) and metadata (*.hdr)
▪ the unwrapped phase: only the metadata (*.hdr), because the image (*.img) is first to be created
by snaphu in the next step.
▪ a configuration file (snaphu.conf) containing the parameters defined in the export operator

Unwrapping of the phase

You should see the wrapped interferogram phase "Phase_ifg*.img", coherence "coh_*.img", and a "snaphu.conf" file.

For the next step, you will need to instal SNAPHU in Windows. SNAPHU is a tool for phase unwrapping of interferometric information. To use it as an executable file (*.exe) in Windows it has to be compiled first so all required drivers (*.dll) are installed correctly. Follow the steps for installation here: file:///C:/Users/Ona%C4%8Dillov%C3%A1/Downloads/Installation_SNAPHU_English_ABraun.pdf

To start unwrapping, check the location of the interferogram exported from SNAP. If snaphu.exe is not in your system's PATH variable: Copy it in there as well. It is recommended to store the data and snaphu on the same disk. Open Command Window Here.

Type snaphu and hit Enter. The help menu should be displayed.

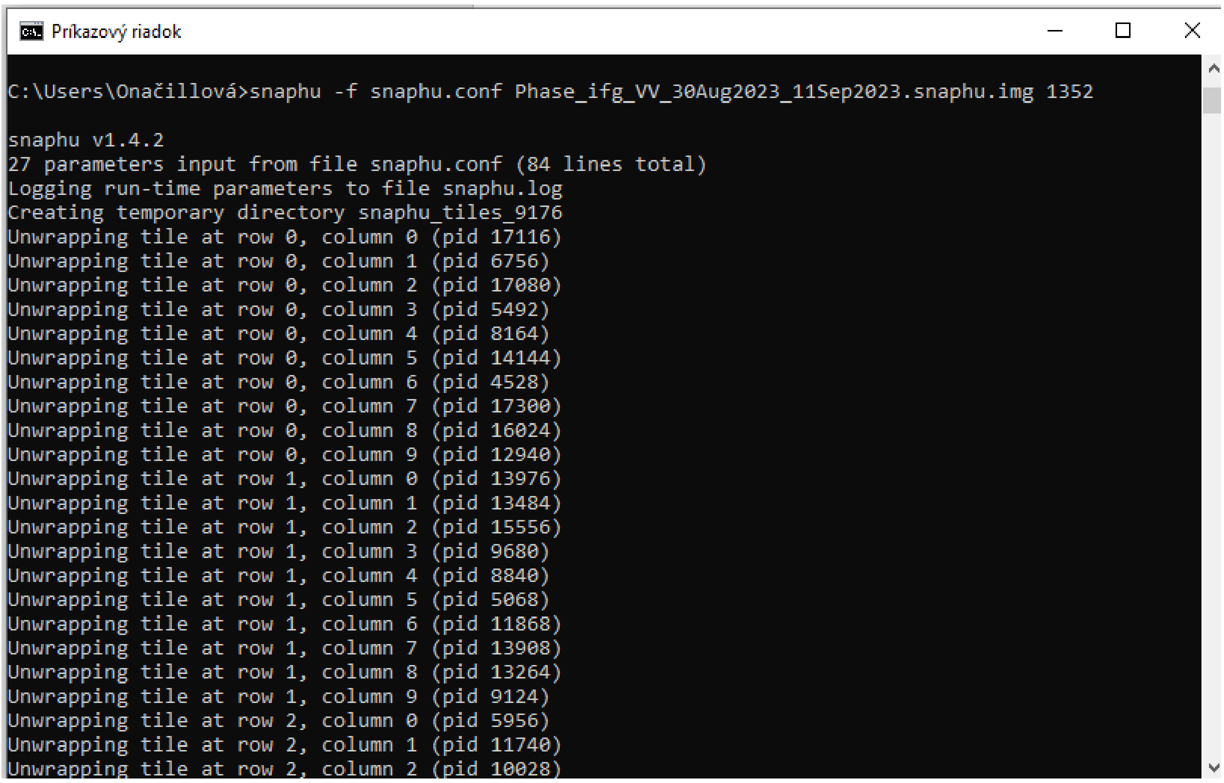
```
Príkazový riadok
C:\Users\Onačillová>snaphu

snaphu v1.4.2
usage:  snaphu [options] infile linelength [options]
most common options:
  -t                use topography mode costs (default)
  -d                use deformation mode costs
  -s                use smooth-solution mode costs
  -f <filename>     read configuration parameters from file
  -o <filename>     write output to file
  -a <filename>     read amplitude data from file
  -c <filename>     read correlation data from file
  -b <decimal>      perpendicular baseline (meters)
  -i                do initialization and exit
  -l <filename>     log runtime parameters to file
  -v                give verbose output
  --mst             use MST algorithm for initialization (default)
  --mcf             use MCF algorithm for initialization

type snaphu -h for a complete list of options
```

The command to start the unwrapping is shown in the file snaphu.conf. Open it with a text editor. The beginning of the "snaphu.conf" file shows the command to call Snaphu

```
snaphu – Poznámkový blok
Súbor  Úpravy  Formát  Zobraziť  Pomocník
# CONFIG FOR SNAPHU
# ---------------------------------------------------------------
# Created by SNAP software on: 09:50:02 14/02/2024
#
# Command to call snaphu:
#
#       snaphu -f snaphu.conf Phase_ifg_VV_30Aug2023_11Sep2023.snaphu.img 1352
```



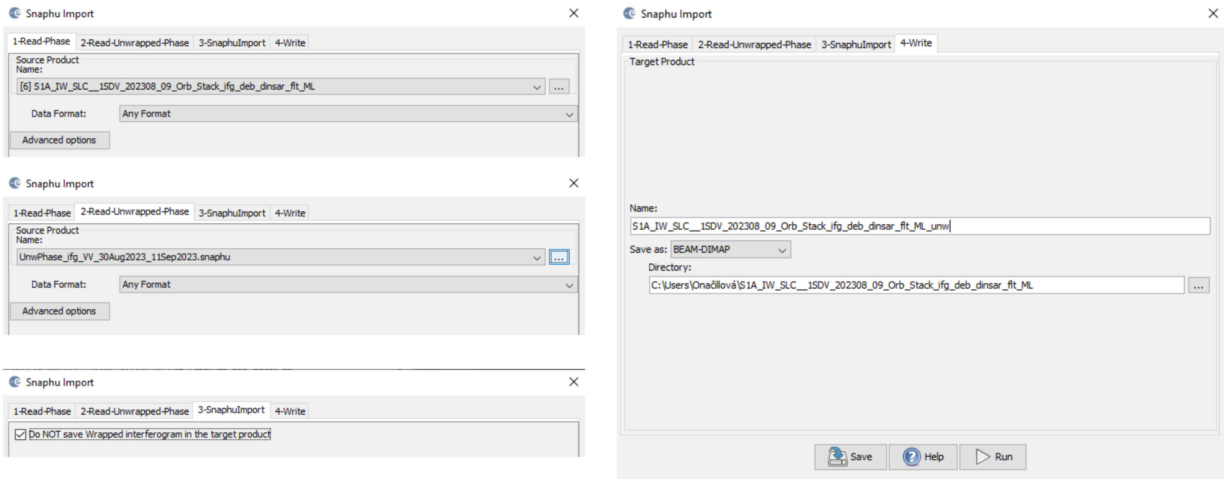
The Snaphu program can take a long time to run. At the end it writes **unwrapped phase to "Unw_ifg*.img" file**

Import of the unwrapped phase

Now, we import the unwrapped phase. From the top main menu bar, select Radar > Interferometric > Unwrapping, and then Snaphu Import that converts it back into the BEAM DIMAP format and adds the required.

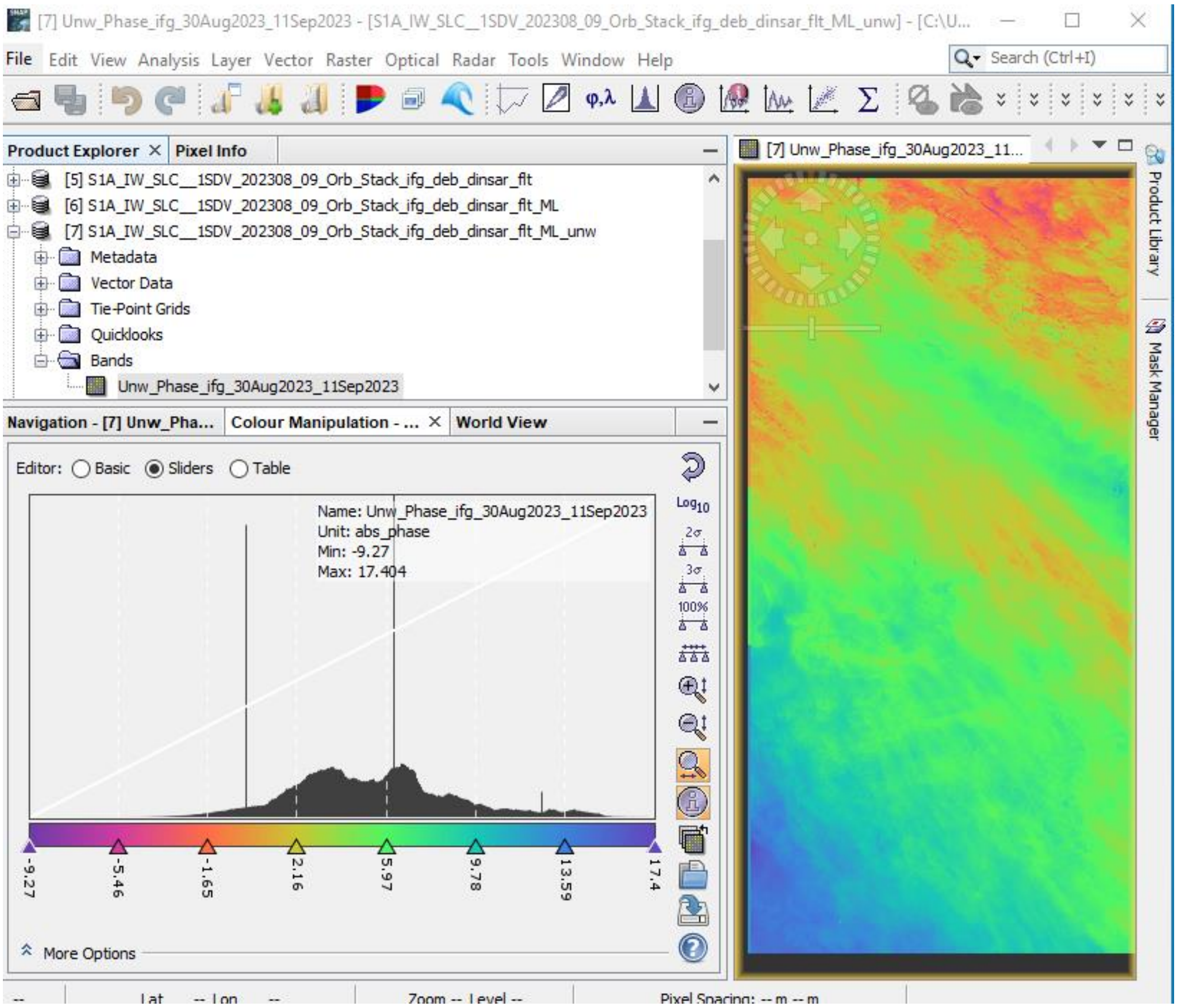
Read-Phase: should be set to the wrapped product that you exported(before the export)
Read-Unwrapped-Phase: select the unwrapped phase product: Navigate to folder where you exported for Snaphu. Select the "UnwPhase_ifg*.snaphu.hdr" file. Note: The error message will then vanish if you proceed to the next tab.
SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product"
unchecked, because it is required in the later step.
Write: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the end of the output name and click Run.

Finally, a new product is added to the Product Explorer which contains the the unwrapped phase that we can display.



Select the Unw_Phase_ifg band. Double click on this unwrapped phase to see if the unwrapping was successful. It should be a smooth raster with little variation except for the areas of expected deformation.

All fringe patterns are summarized to absolute changes. Go to the Colour Manipulation tab and select "100%" to stretch color scale to full range of unwrapped data. Unwrapped phase is still in radians. Phase is reference image minus coregistered image. If reference image is earlier, then negative phase is land moving toward satellite (negative range change)



3.8 Phase to displacement

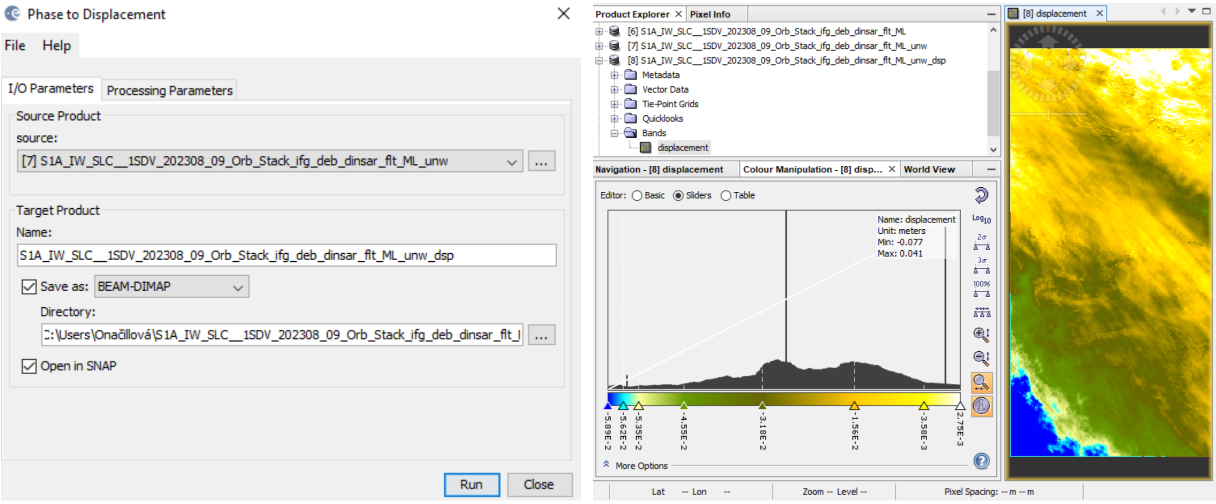
We can convert the unwrapped phase to displacements. From the top main menu bar, select Radar, then Interferometric, then Products, and then Phase to Displacement.

The I/O Parameters tab should be set to the unwrapped product that you imported.

Default for target product name is to add "_dsp" to the name

Now, we can display displacement band of result. Again, better to stretch colors. Displacements is now in meters.

Sign was changed so positive displacement is "up" towards satellite



3.9 Geocoding results—Terrain Correction

SNAP calls geocoding with topography "Terrain Correction." From the top main menu bar, select Radar, then Geometric, then Terrain Correction, and then Range-Doppler Terrain Correction.

The I/O Parameters tab should be set to the displacement product that you imported (or one of the other ML products).

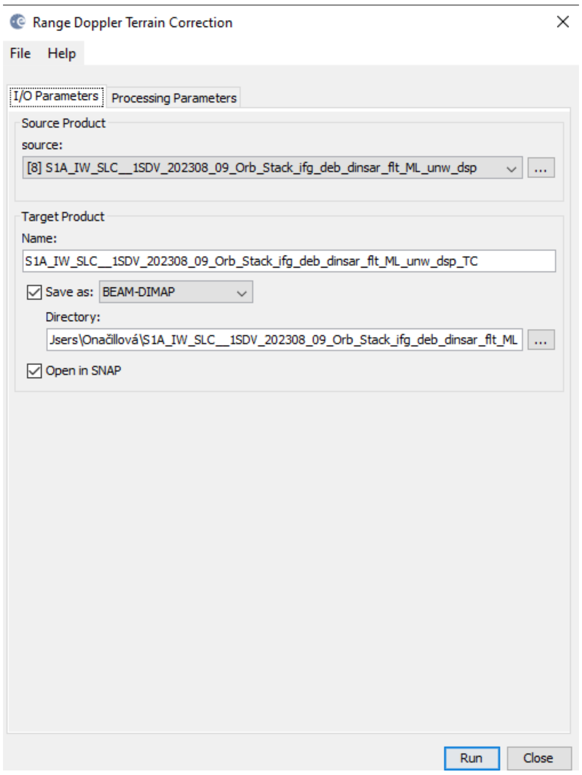
default for target product name is to add "_TC" to the name

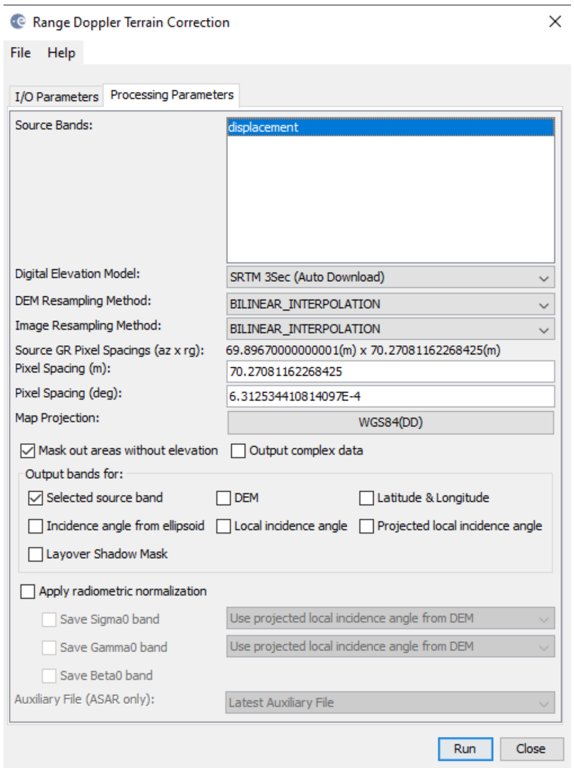
Under Processing Parameters tab, select the Source Bands and any additional Output Bands. You can also choose what DEM to use, output spacing, and map projection.

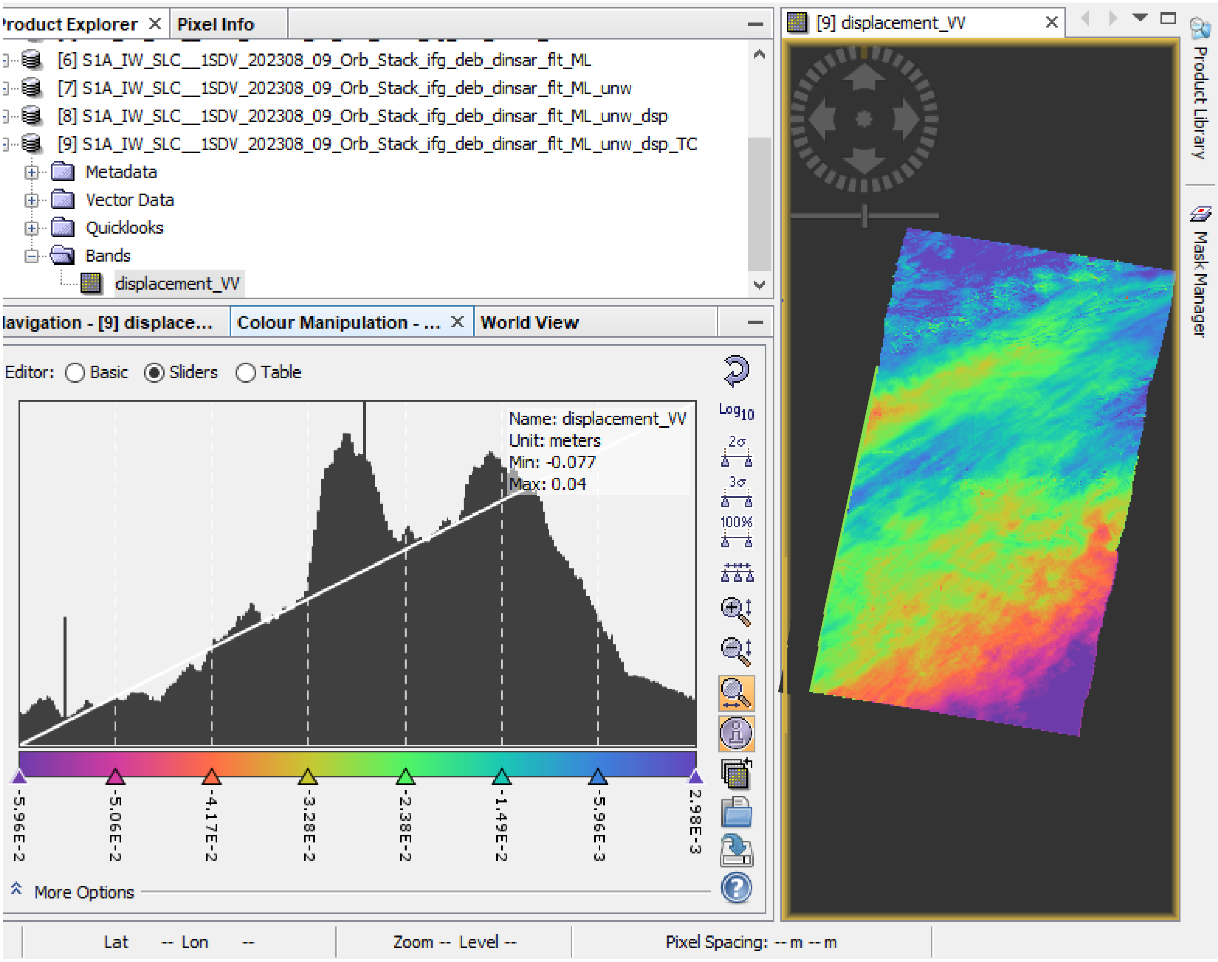
Now, we can display displacement_vv band of geocoded result. Again, better to stretch colors.

Displacements in meters with positive values "up" towards satellite in Line-of-Sight direction.

Product is now evenly spaced in latitude and longitude.


Range Doppler Terrain Correction
File Help
I/O Parameters
Processing Parameters
Source Product
source:
[8] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp
Target Product
Name:
S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp_TC
Save as: BEAM-DIMAP
Directory:
Jsers\Onačillová\S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML
Open in SNAP
Run
Close

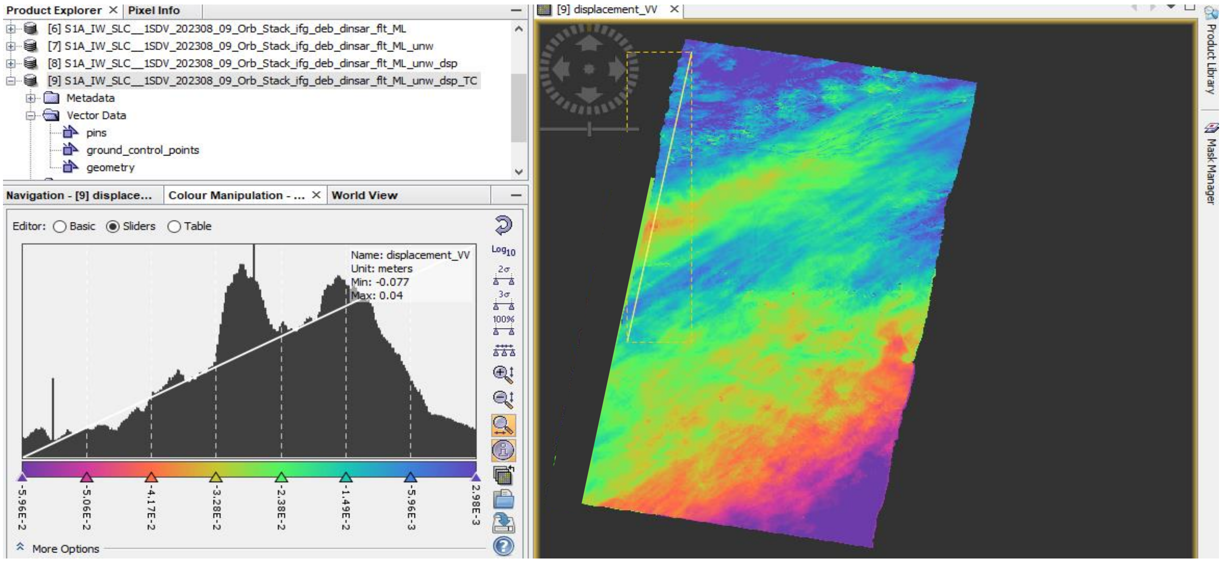

Range Doppler Terrain Correction
File Help
I/O Parameters
Processing Parameters
Source Bands:
displacement
Digital Elevation Model:
SRTM 3Sec (Auto Download)
DEM Resampling Method:
BILINEAR_INTERPOLATION
Image Resampling Method:
BILINEAR_INTERPOLATION
Source GR Pixel Spacings (az x rg):
69.89670000000001(m) x 70.27081162268425(m)
Pixel Spacing (m):
70.27081162268425
Pixel Spacing (deg):
6.312534410814097E-4
Map Projection:
WGS84(DD)
Mask out areas without elevation
Output complex data
Output bands for:
Selected source band
DEM
Latitude & Longitude
Incidence angle from ellipsoid
Local incidence angle
Projected local incidence angle
Layover Shadow Mask
Apply radiometric normalization
Save Sigma0 band
Use projected local incidence angle from DEM
Save Gamma0 band
Use projected local incidence angle from DEM
Save Beta0 band
Auxiliary File (ASAR only):
Latest Auxiliary File
Run
Close

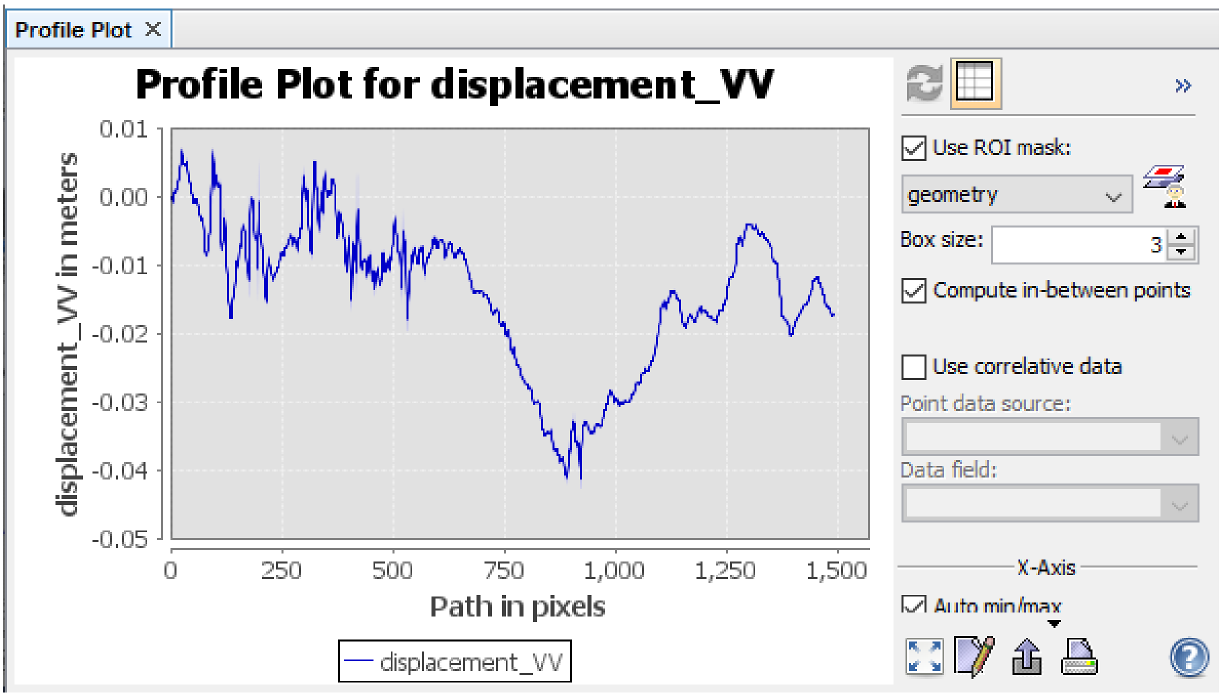

Product Explorer
Pixel Info
[6] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML
[7] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw
[8] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp
[9] S1A_IW_SLC__1SDV_202308_09_Orb_Stack_ifg_deb_dinsar_flt_ML_unw_dsp_TC
Metadata
Vector Data
Quicklooks
Bands
displacement_VV
[9] displacement_VV
Product Library
Mask Manager
Colour Manipulation - ...
World View
Editor: Basic Sliders Table
Name: displacement_VV
Unit: meters
Min: -0.077
Max: 0.04
-5.96E-2
-5.06E-2
-4.17E-2
-3.28E-2
-2.38E-2
-1.49E-2
-5.96E-3
2.98E-3
More Options
Lat -- Lon --
Zoom -- Level --
Pixel Spacing: -- m -- m

3.10 Displacement Profiles

Use the line drawing tool (top bar of SNAP window) to draw a line across the signal. Run Analysis>Profile Tool to see displacement along the profile

Remember that InSAR displacements are relative. In this case, displacement far from the signal is about -0.1 m, so that is probably the "true zero" offset. Maximum is about 0.24 m, but we need to subtract zero offset to get total displacement of about 0.35 m





For more information, see the lecture: [5. Basics of Radar Remote Sensing - principles and applications]

THANK YOU FOR FOLLOWING THE EXERCISE!

EXERCISE 6 – TUTORIAL

Precision agriculture mapping – digital image analyses using Sentinel-2 multispectral data, image classification, comparison with UAV multispectral data, using SNAP software

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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Delve into the use of Copernicus multispectral data in optimizing agriculture mapping
- Explain how to use Sentinel-2 data to monitor plant health and soil conditions
- Learn to process and interpret this data, using indicators like the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Moisture Index (NDMI)
- Compare Sentinel-2 outputs with high-resolution UAV multispectral data

2 | Background

Precise agriculture using Sentinel-2 data

Sentinel-2 satellites are instrumental in precision agriculture due to their ability to provide detailed and frequent multispectral imagery. These images offer valuable insights into crop health, soil moisture, and vegetation growth, enabling farmers to optimize their agricultural practices. In precision agriculture, commonly used indices derived from Sentinel-2 satellite imagery include:

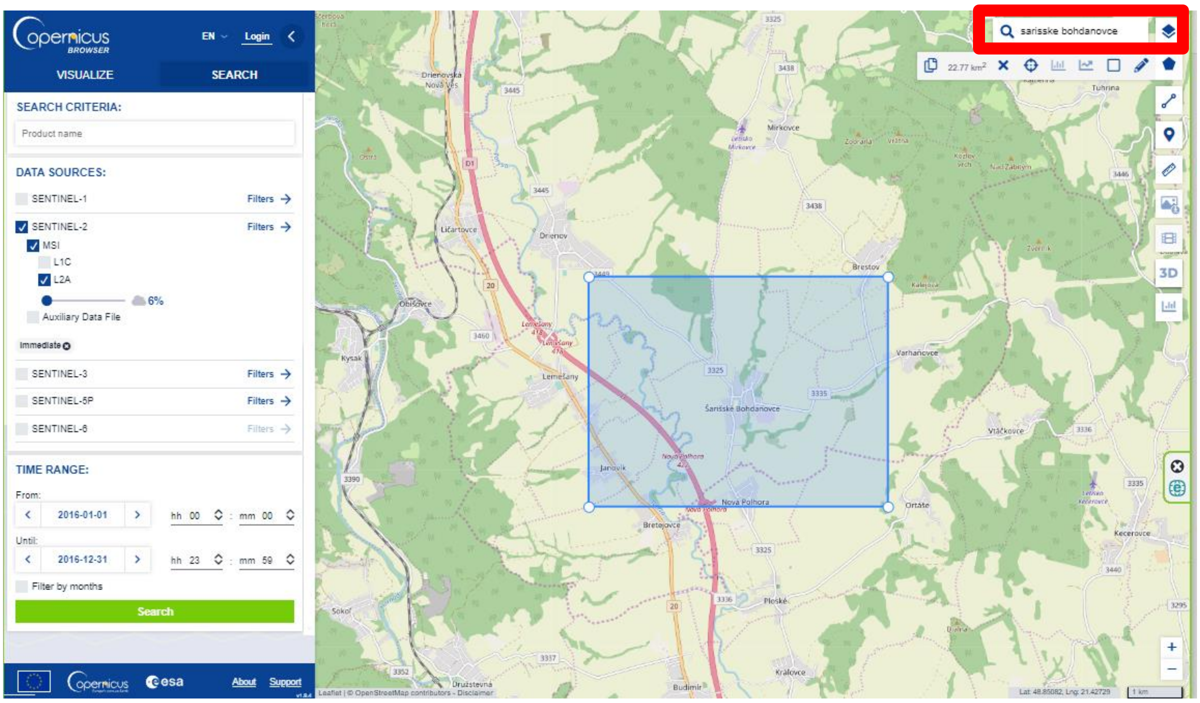
- NDVI: Measures vegetation health and vigor based on near-infrared and red light reflectance.
- EVI: An improved version of NDVI that corrects for atmospheric effects and provides better sensitivity to vegetation changes.
- SAVI: Adjusts NDVI to account for soil brightness, improving accuracy in areas with sparse vegetation.
- NDWI: Quantifies water content in vegetation and soil, aiding in soil moisture monitoring and water stress detection.
- LAI: Measures leaf area per unit ground area, providing insights into vegetation density and biomass accumulation.

These indices help farmers and land managers monitor crop health, predict yields, and make informed decisions for optimal agricultural practices.

Source: https://eos.com/blog/precision-agriculture/

2.1 Study area and data used

For this exercise, we will use three Sentinel-2 images of the same area in Šarišské Bohdanovce, Slovakiia, using the Tile Number *34UEV* downloaded for four time intervals in 2016 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/]. At the end of this exercise, we will compare these Sentinel-2 data with UAV data acquired in September 2016.



2.2. SNAP - Open and explore product

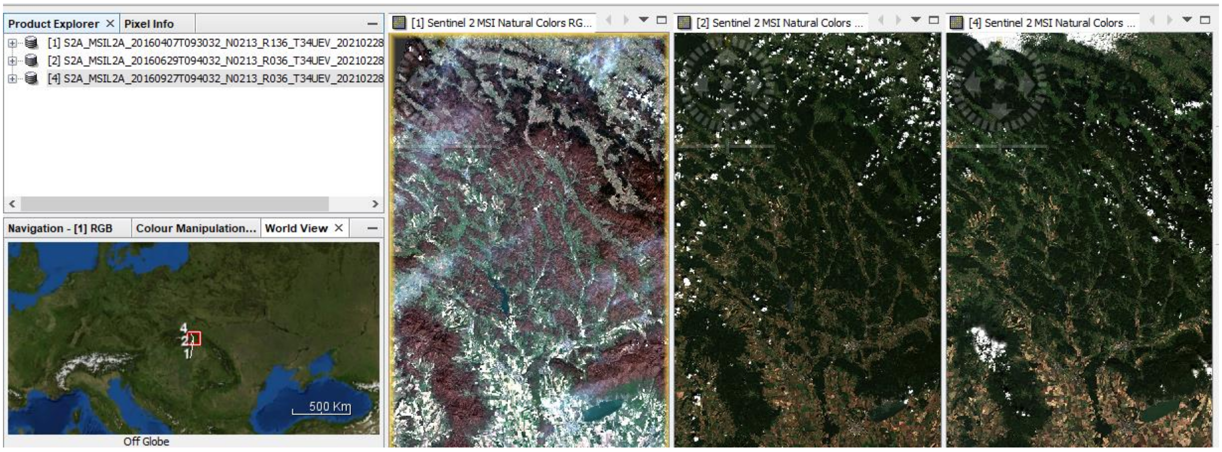
Open SNAP Desktop, click Open Product and open 4 downloaded products (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window.

S2A_MSIL2A_20160407T093032_N0213_R136_T34UEV_20210228T161314.SAFE
S2A_MSIL2A_20160629T094032_N0213_R036_T34UEV_20210228T170703.SAFE
S2A_MSIL2A_20160927T094032_N0213_R036_T34UEV_20210228T181146.SAFE

Display all products side by side using e.g. Atmospheric penetration band combination: Right click on the product – Open RGB Image Window – select Sentinel 2 MSI Natural colors. Repeat this step also for other two products.

Then, tile windows horizontally. By opening and displaying all 4 images at once, we can take a first visual interpretation of agriculture fields in 2016 - from the left.

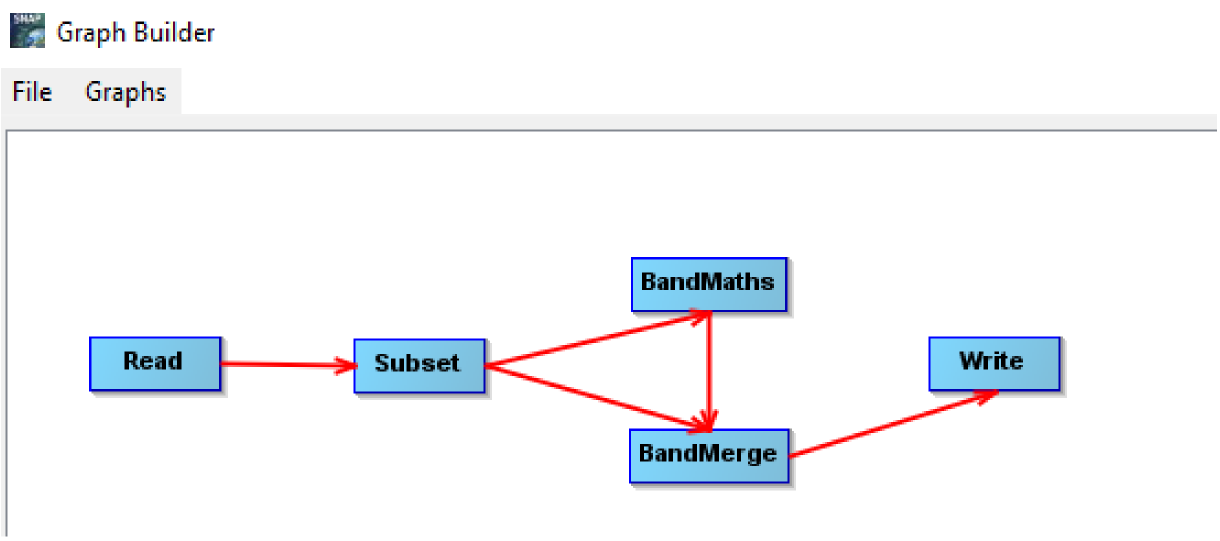
In Navigation tab – Synchronise views across multiple image windows – Zoom into the eastern part of the image to explore deforestation.



2.3 Create Processing Graph

Then, we need apply the same pre-processing steps for all our scenes. However, processing the data step by step and product by product could be time-consuming and impractical. Fortunately, the **Batch Processing** tool in SNAP allows us to apply all the steps to both images simultaneously, saving both time and disk space since only the final product is physically stored.

To use the tool, the initial step is to define the process we intend to apply along with all its corresponding steps. This can be accomplished by utilizing the GraphBuilder tool. Therefore, let's build our graph by navigating to **Tools** → **GraphBuilder**. Through the GraphBuilder function, we build a processing graph, outlining the specific order of processing steps:



At the beginning, the graph has only two operators: **Read** (to read the input) and **Write** (to write the output). To add the new operator right-click the white space between the existing operators and select the desired operators:

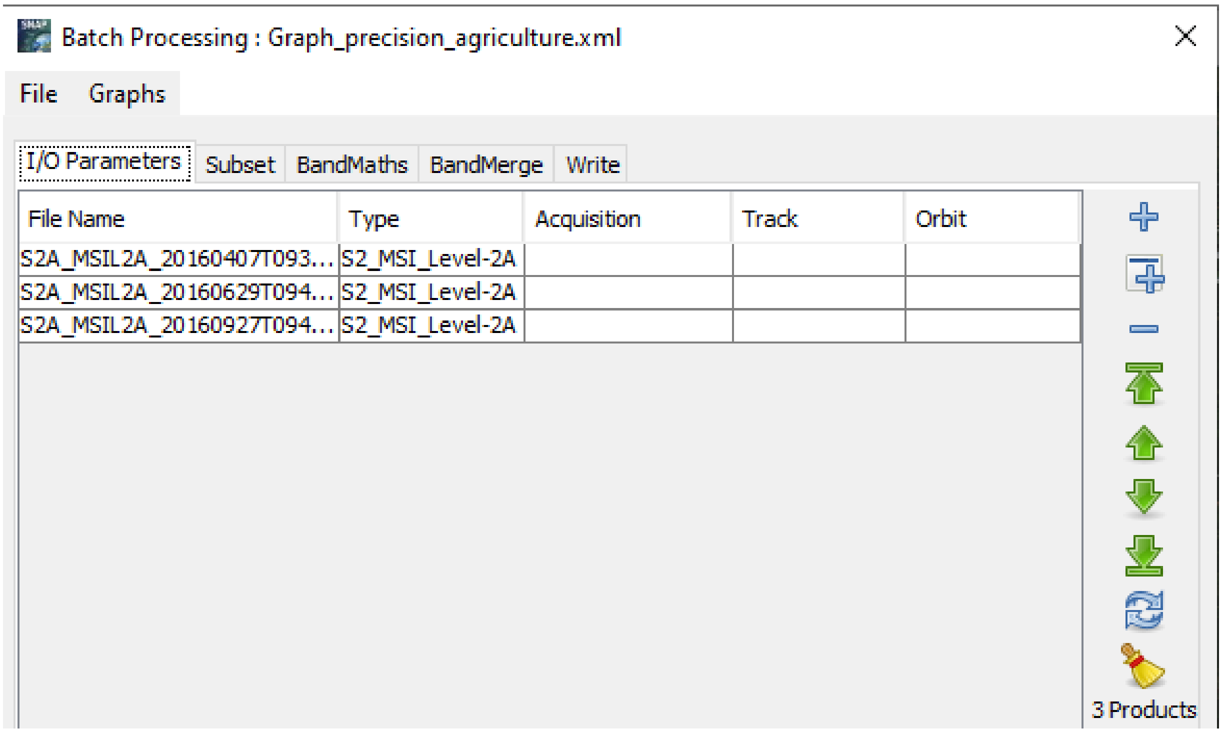
- **Subset** – export only bands that we will need for further analysis to calculate NDVI, GNDVI, GRVI – select only B3, B4 and B8
- **Band Maths –** to calculate NDVI, GNDVI, GRVI using slected bands
- **Band Merge** – to combine the resulting bands into the resulting file

For the moment, do not change anything in the parameter tabs and save the graph (File – Save Graph) as „Graph_precision_agriculture.xml" to your working folder. After you have saved it, close the GraphBuilder window.

2.4 Batch Processing

Open the **Batch Processing tool** (Tools → Batch Processing).

We will add all opened products by clicking Add Opened on the upper right (second icon from the top). Then, we delete original = not projected products by sleecting them and clicking Delete (third icon from the top left only reprojected products). Then, when we have only 4 reprojected products, we click File - **Load Graph** at the top of the window and navigate to our saved graph *„Graph_Deforestation"* and open it. We see that new tabs have appeared at the top of window corresponding to our operators with the exception of Read; this is correct as these parameters will be set in the I/O Parameters tab.

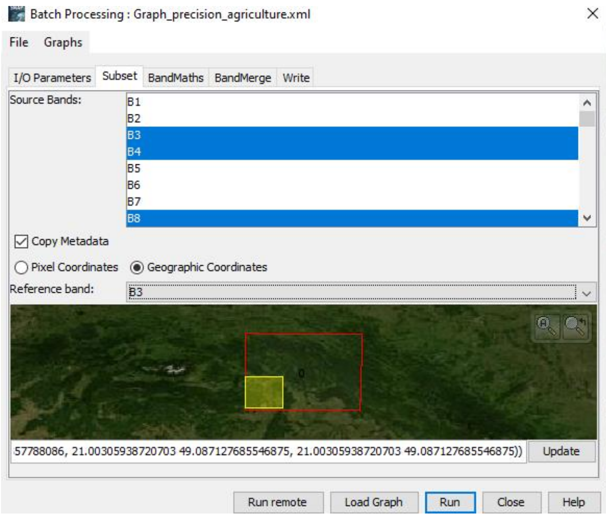


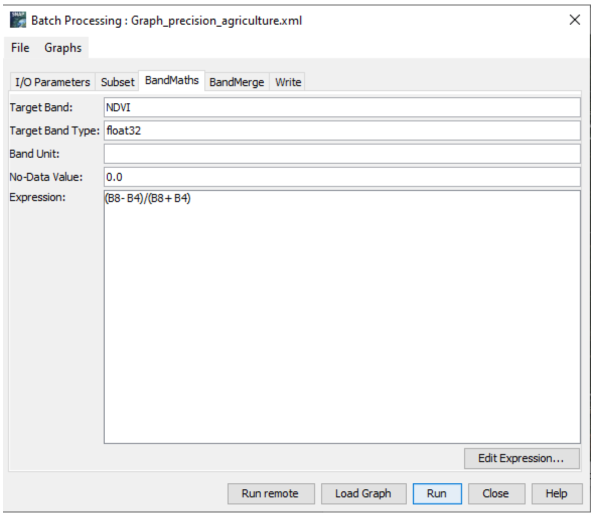
In the next step it is advisable to create **Subset** of these products for faster processing:

- **Source bands –** select only bands that we will need to calculate NDVI – B3, B4 and B8
- **Geographic Coordinates** – create the subset of the area also by clicking on zoom into the area of image (red rectangle) and draw smaller (yellow) polygon inside it that includes only eastern part of the images where we observed deforestation
- **Reference band** – select Reference band according which all the Source Bands will be resampled

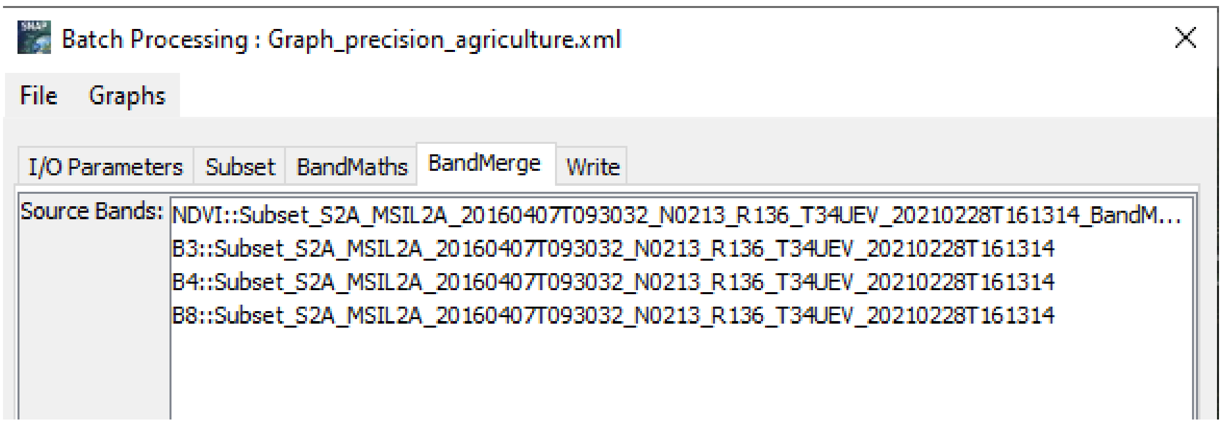
In BandMath, we firstly enter the formula for NDVI calculation. The NDVI is calculated as a normalized difference of visible infrared (B8) and visible red (B4) bands, using the following equation (Rouse et al. 1974):

(B8-B4)/(B8+B4)





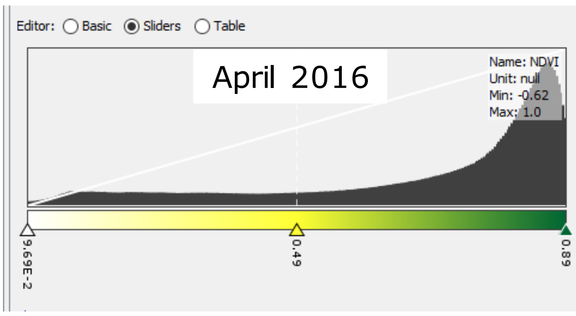
Then, in **BandMerge** tab we can combine the resulting bands into the resulting file and set the directory for the output file in **Write** tab. The common processing can be monitored. Writing target product may take some time.

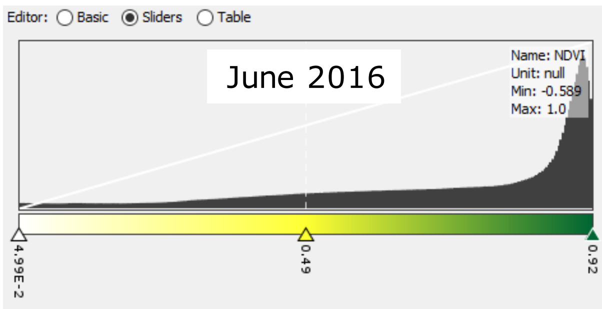


3.1. NDVI analysis

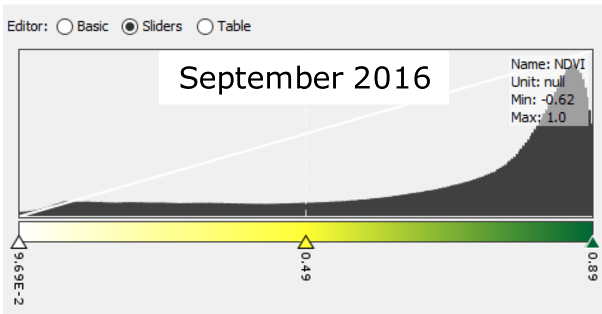
Open the output NDVI images side by side for all processed years – **Window – Tile Horizontally**. In Colour Manipulation select Colour ramp derived from meris pressure.

NDVI image - has values from < -1, 1 >, where forested areas are displayed in values higher than 0. The peaks of the histogram point to 2 extremes - forested and logged area.





The highest NDVI values occurs in the summer season – June - during periods of peak vegetation growth and vigor. NDVI values tend to increase as vegetation biomass and chlorophyll content rise, reaching their peak when vegetation is at its most lush and dense.



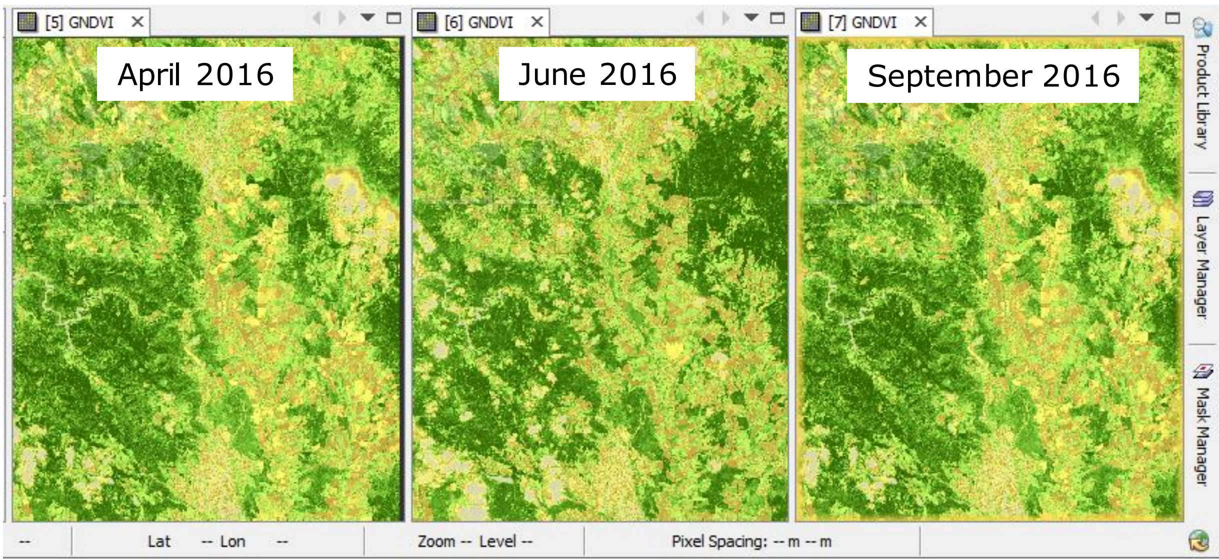
Lower Normalized Difference Vegetation Index (NDVI) values occur at the beginning of the growth season – April and during periods of reduced vegetation activity in September - a decline in NDVI values may exhibit also reduced chlorophyll content or structural damage, affecting its reflectance properties.

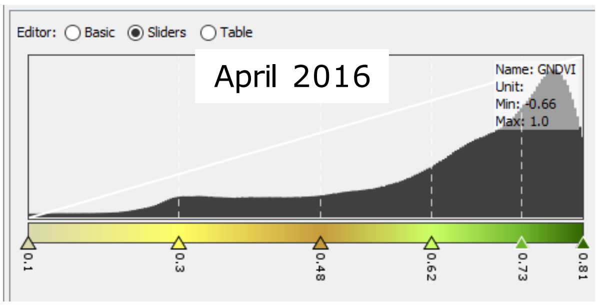
3.2 GNDVI analysis

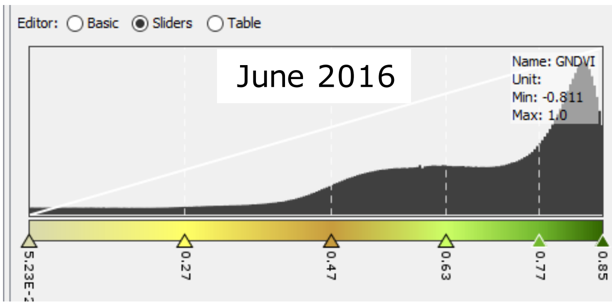
Create the GNDVI. Use the resulted subsets. Navigate to the Main menu – Raster - Band Maths and edit formula as following:

$$GNDVI = (NIR - Green) / (NIR + Green)$$

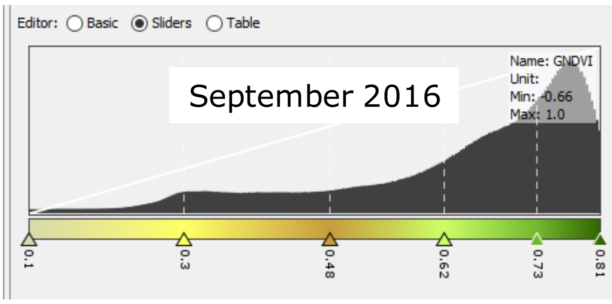
Click on RUN. Then, firstly open the output GNDVI images side by side for all processed years – **Window – Tile Horizontally**. In Colour Manipulation select Colour ramp derived from meris pressure.







GNDVI values typically range from -1 to 1, with higher values indicating healthier and more dense vegetation. Values close to 1 indicate strong vegetation presence, with dense and healthy vegetation exhibiting the highest values. Values close to 0 suggest sparse vegetation or non-vegetated areas. Negative values may occur in features such as water bodies or shadows.

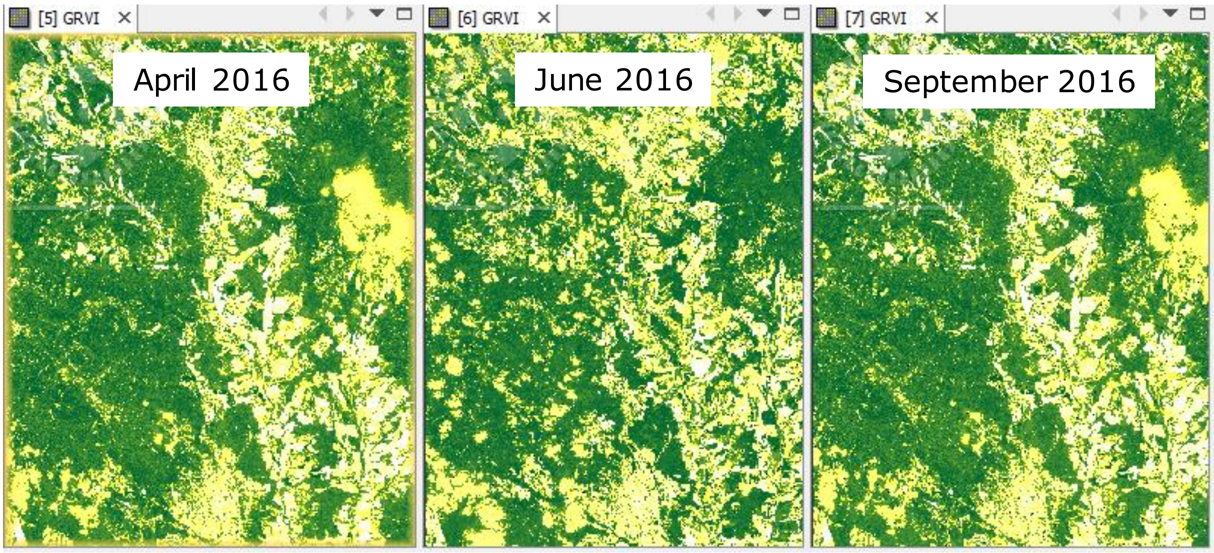


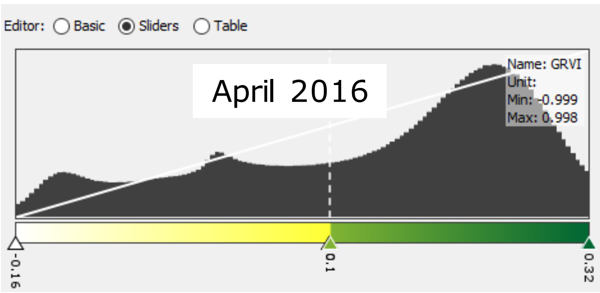
3.3 GRVI analysis

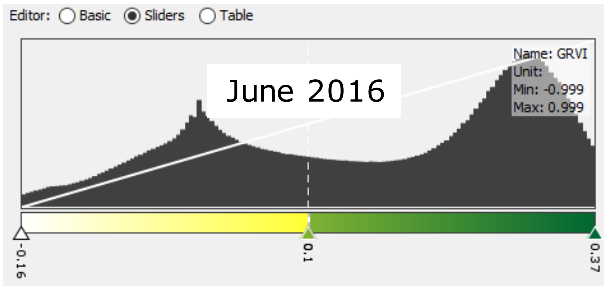
Create the GRVI. Use the resulted subsets. Navigate to the Main menu – Raster - Band Maths and edit formula as following:

$$GRVI = (Green - Red) / (Green + Red)$$

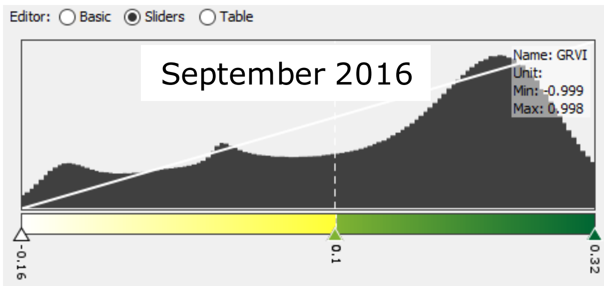
Click on RUN. Then, firstly open the output GRVI images side by side for all processed years – **Window – Tile Horizontally**. In Colour Manipulation select Colour ramp derived from meris pressure.







GRVI index can differentiate between green vegetation (index above 0), water and snow (index around 0), and soils (index below 0). Additionally, unlike the NDVI, the GRVI is sensitive to changes in leaf color, making it effective for detecting shifts in vegetation phenology.

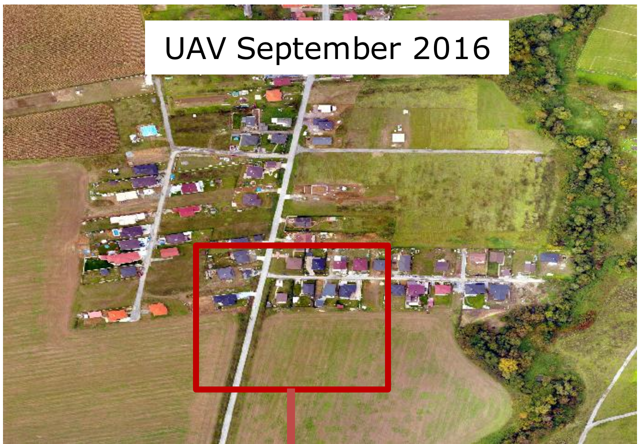


4. Comparison of UAV data with Sentinel-2

In QGIS open the sample data for the smaller area of interest within the locality of Šarišské Bohdanovce. Compare high spatial resolution of UAV data compared to Sentinel-2 multispectral data.

UAV data offer high spatial resolution and flexibility, making them suitable for detailed and targeted assessments of small areas. UAVs have revolutionized, e.g. precise agriculture by providing farmers and agronomists with timely, accurate, and actionable information for optimizing crop production, resource management, and decision-making processes. With their ability to collect high-resolution spatial data efficiently and cost-effectively, UAVs are increasingly becoming indispensable tools in modern agriculture.

On the other hand, Sentinel-2 satellite data provide consistent and systematic coverage over larger regions, offering valuable insights into broader landscape dynamics and long-term trends. The choice between UAV and Sentinel-2 data depends on the specific requirements of the application, considering factors such as spatial scale, temporal frequency, cost, and accessibility.



For more information, see the lecture: [6. Precision agriculture mapping using multispectral data]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 7 – TUTORIAL

Spatio-temporal mapping of deforestation using Sentinel-2 data using SNAP software

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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Learn the basic steps to calculate the deforestation area based on S2 images
- Download images of the same area of interest over a period of 4 years
- Perform preprocessing for the 4 images using SNAP software

2 | Background

Mapping deforestation using Sentinel-2 data

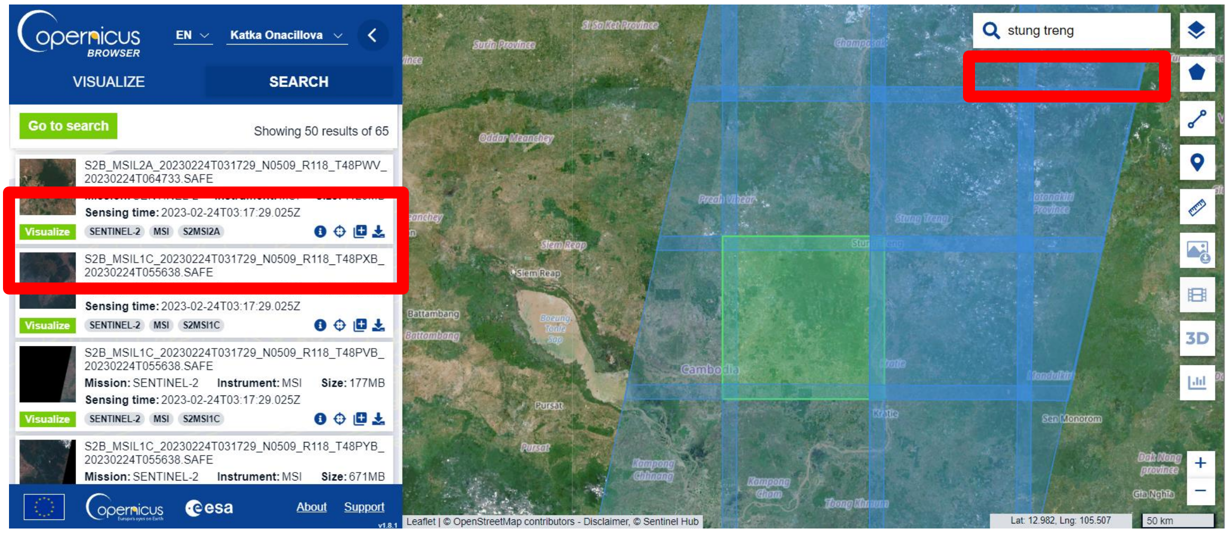
The presence of forests is crucial for preserving ecological balance, combating climate change, and ensuring a sustainable future for both the Earth and its inhabitants. Despite serving numerous essential functions, these ecosystems have faced significant threats to their condition, and overall quality in recent decades.

While various regions globally are undergoing deforestation, the reasons driving this phenomenon vary among countries. Data from Global Forest Watch's Dashboards reveals that, e.g. since 2001, Cambodia has seen a reduction of approximately 24 percent in its tree cover—an alarming percentage compared to more extensive, forested countries like Brazil and Indonesia. Protected Planet reports that around 26% of Cambodia's land is designated as protected areas for ecological or cultural conservation. However, GFW data from 2001 to 2018 indicates a loss of 557,000 hectares of tree cover in these areas, comprising 11.7% of Cambodia's total protected area. Many protected areas notably lost its protected status due to extensive deforestation for rubber and cashew plantations. This widespread forest loss contributes to increased flooding and erosion, impacting water storage, fishing, and agriculture during droughts.

Presently, the majority of countries regularly conduct forest inventory or remote sensing (RS) surveys every few years to observe alterations and assess the quality of forest cover. Over the last decade, the Sentinel-1 and Sentinel-2 satellite imagery from the European Space Agency's Copernicus program has offered substantial potential for examining forest stands. This technology can efficiently track changes, even in expansive forest areas, with a high temporal and spatial resolution.

2.1 Study area and data used

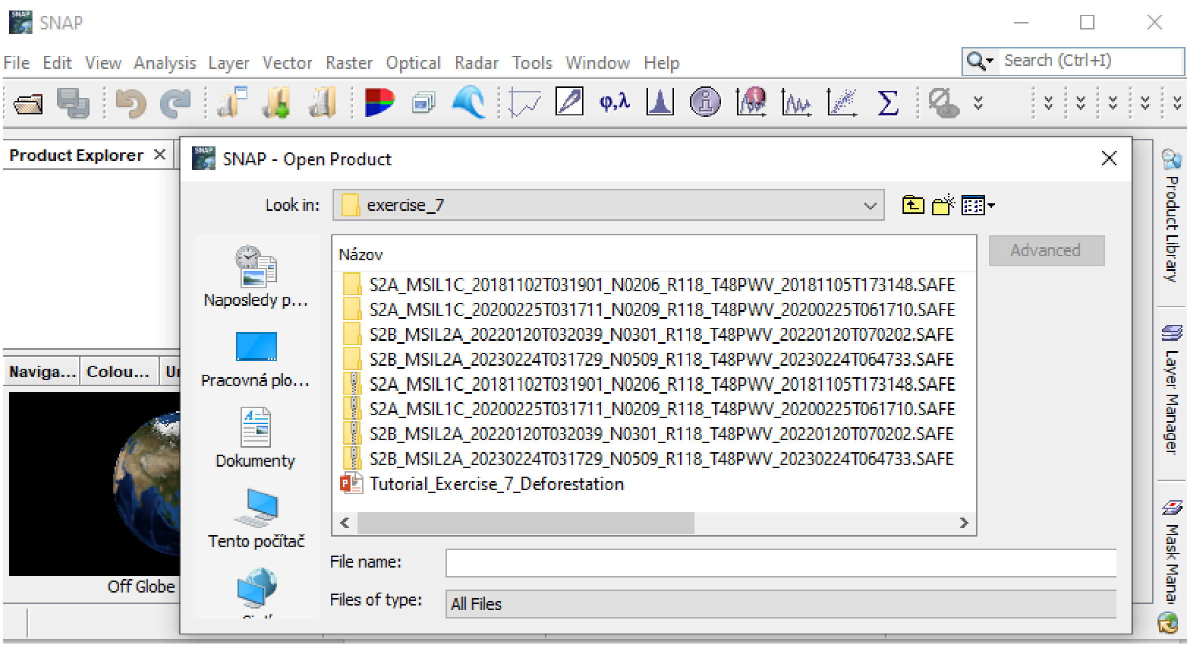
For this exercise, we will use three Sentinel-2 images of the same area in Stung Treng province, Cambodia, using the Tile Number *48PWV* downloaded for years 2018, 2020, 2022 and 2023 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



2.2. SNAP - Open and explore product

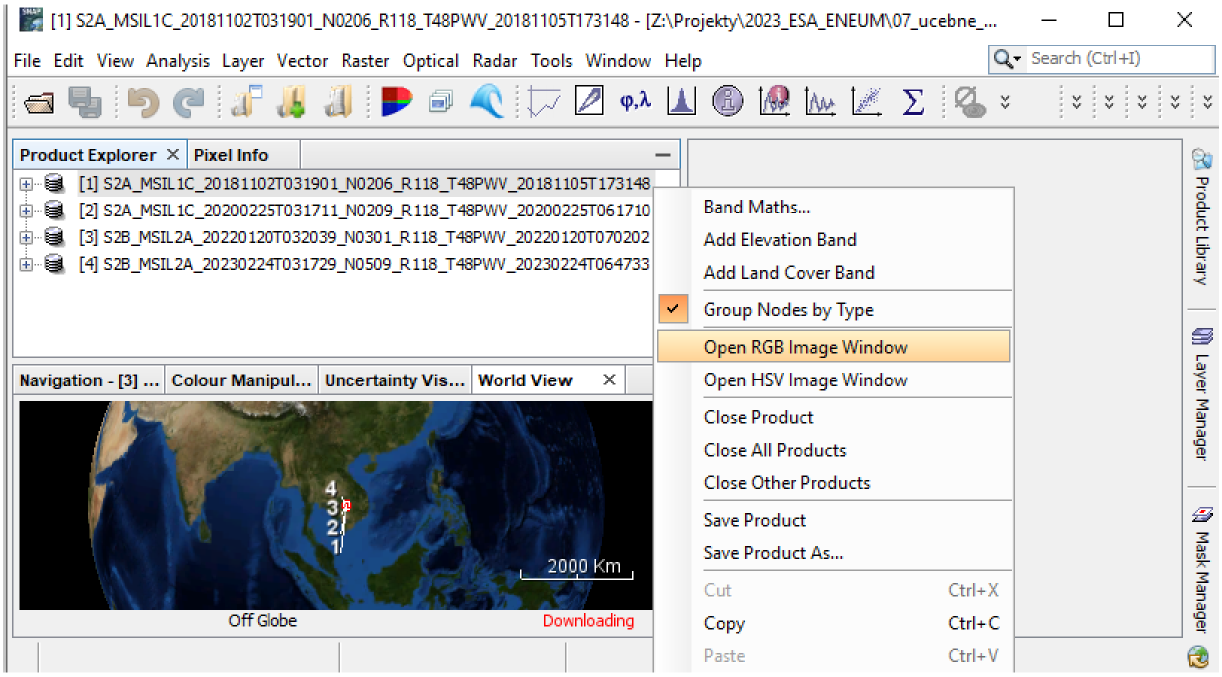
Open SNAP Desktop, click Open Product and open 4 downloaded products (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window.

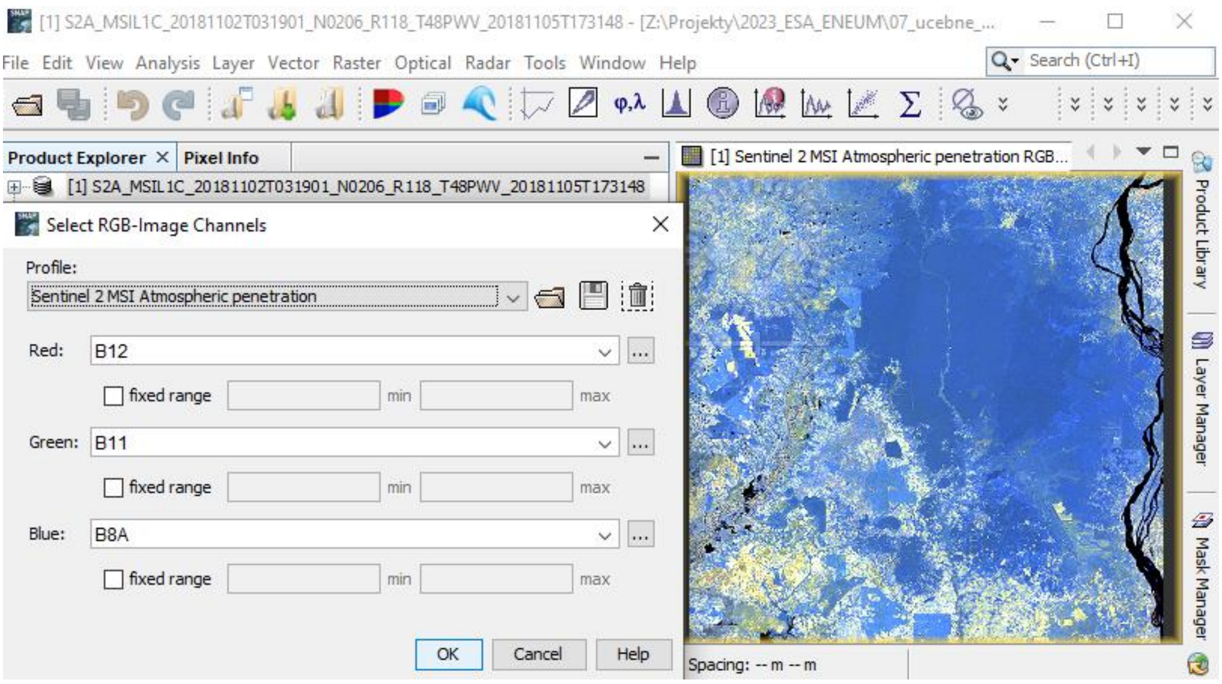
S2A_MSIL1C_20181102T031901_N0206_R118_T48PWV_20181105T173148.SAFE
S2A_MSIL1C_20200225T031711_N0209_R118_T48PWV_20200225T061710.SAFE
S2B_MSIL2A_20220120T032039_N0301_R118_T48PWV_20220120T070202.SAFE
S2B_MSIL2A_20230224T031729_N0509_R118_T48PWV_20230224T064733.SAFE



Display all products side by side using e.g. Atmospheric penetration band combination: Right click on the product – Open RGB Image Window – select Sentinel 2 MSI Atmospheric penetration. Repeat this step also for other three products.

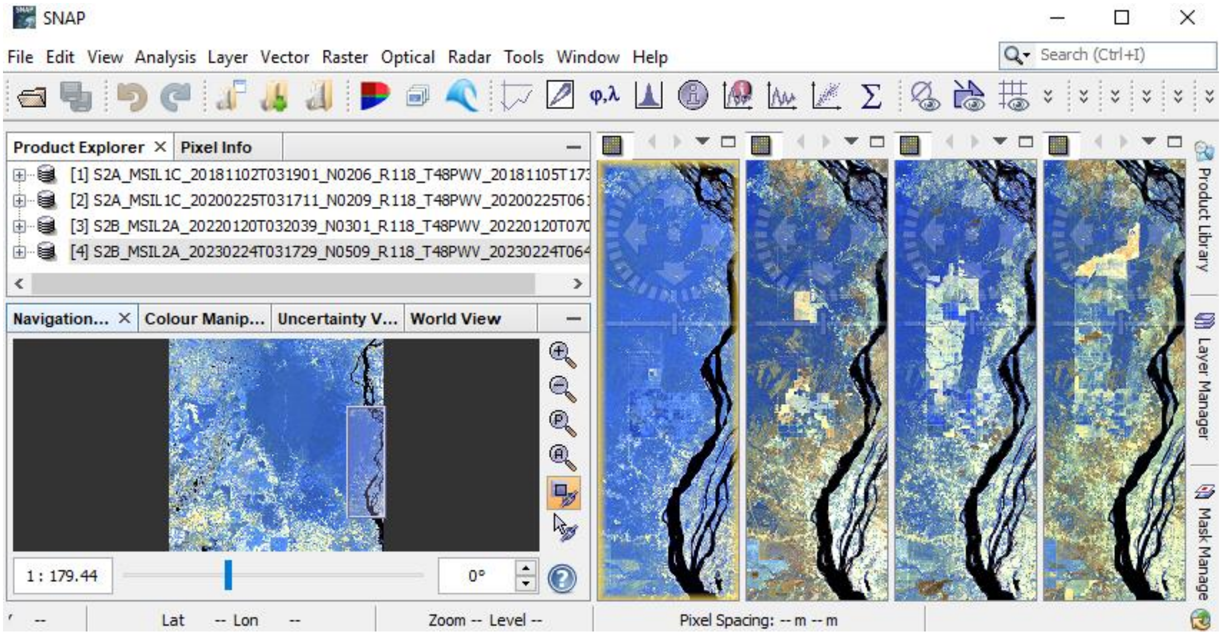
The Atmospheric Penetration band combination (SWIR 2, SWIR 1, NIR) shows results similar to traditional false-color infrared color composition but with exceptional clarity. This method excludes visible bands, effectively penetrating atmospheric particles, smoke, and haze, thereby minimizing their impact on the image.





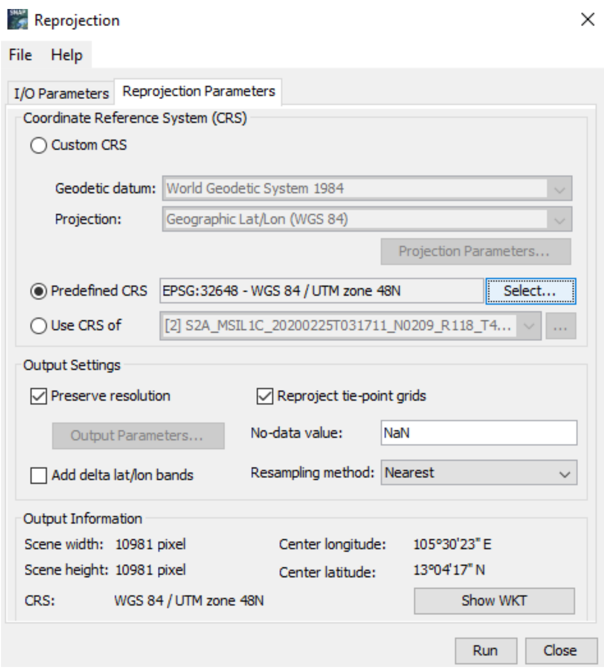
Then, tile windows horizontally. By opening and displaying all 4 images at once, we can take a first visual interpretation of deforestation in the years 2018, 2020, 2022 and 2023 - from the left.

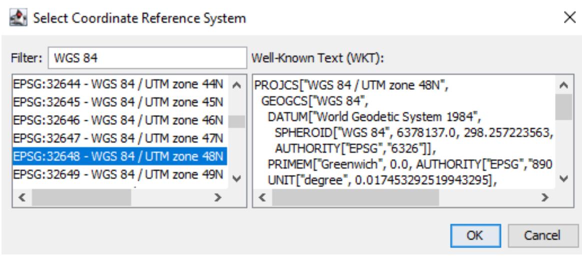
In Navigation tab – Synchronise views across multiple image windows – Zoom into the eastern part of the image to explore deforestation.

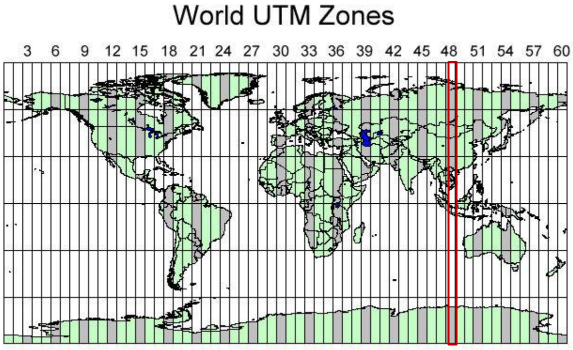


2.3 Pre-processing

Firstly, it is advisable to reproject subsets to the system that corresponds to the area of interest (Cambodia) - WGS 84, UTM zone 48 North. Go to **Raster – Geometric - Reprojection** and reproject them to the system WGS 84, UTM zone 48N. Writing target product may take some time. At the end, 4 new reprojected products will be in the Product Explorer.





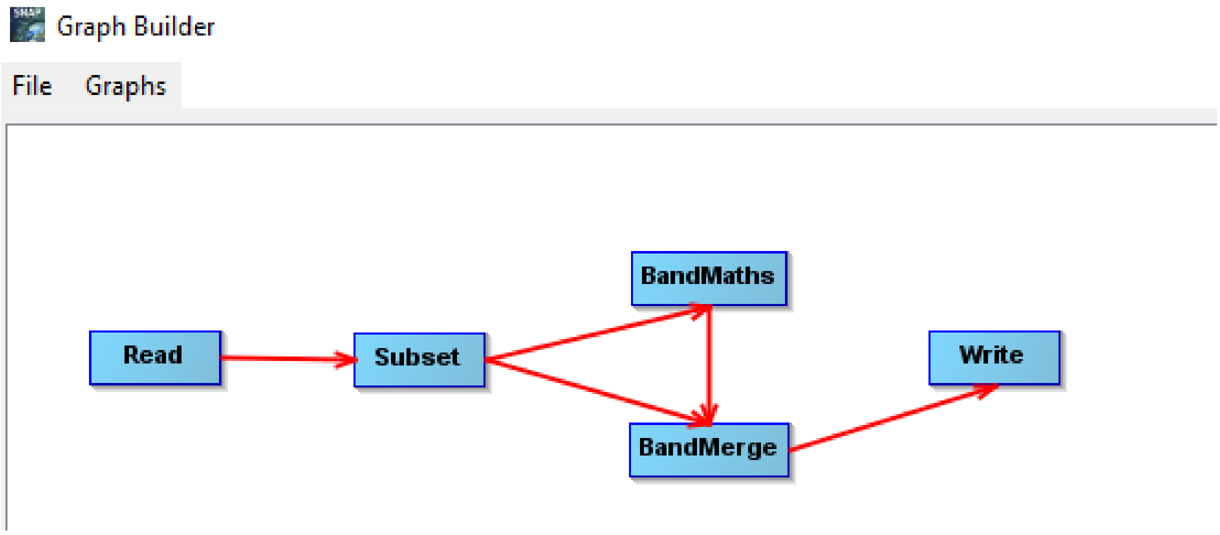


2.3.2 Create Processing Graph

Then, we need apply the same pre-processing steps for all our scenes. However, processing the data step by step and product by product could be time-consuming and impractical. Fortunately, the **Batch Processing** tool in SNAP allows us to apply all the steps to both images simultaneously, saving both time and disk space since only the final product is physically stored.

To use the tool, the initial step is to define the process we intend to apply along with all its corresponding steps. This can be accomplished by utilizing the GraphBuilder tool. Therefore, let's build our graph by navigating to **Tools** → **GraphBuilder**.

Through the GraphBuilder function, we build a processing graph, outlining the specific order of processing steps:



At the beginning, the graph has only two operators: **Read** (to read the input) and **Write** (to write the output). To add the new operator right-click the white space between the existing operators and select the desired operators:

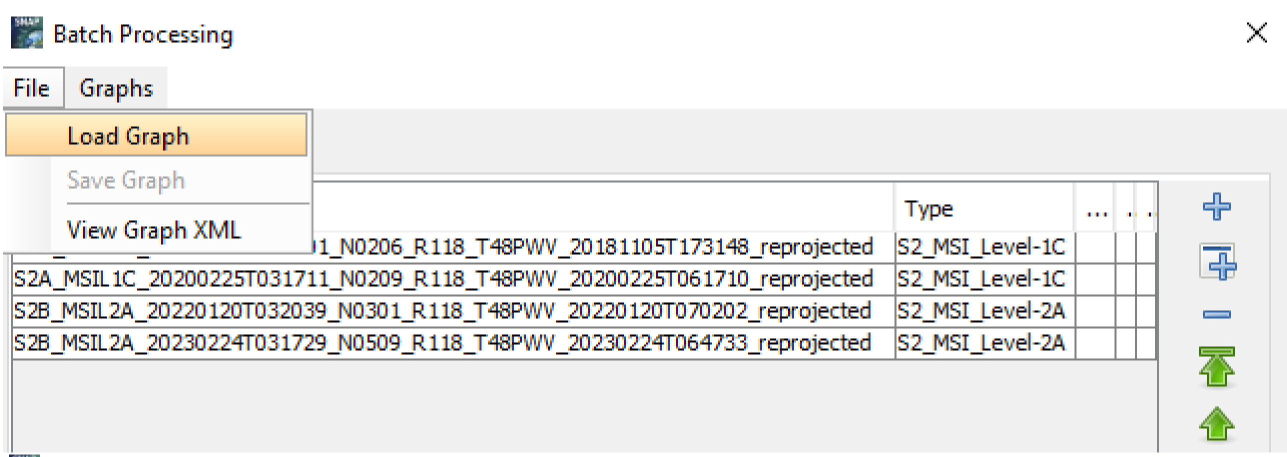
- **Subset** – export only bands that we will need for further analysis to calculate NDVI – select only B4 and B8
- **Band Maths –** to calculate NDVI using slected bands B4 and B8
- **Band Merge** – to combine the resulting bands into the resulting file

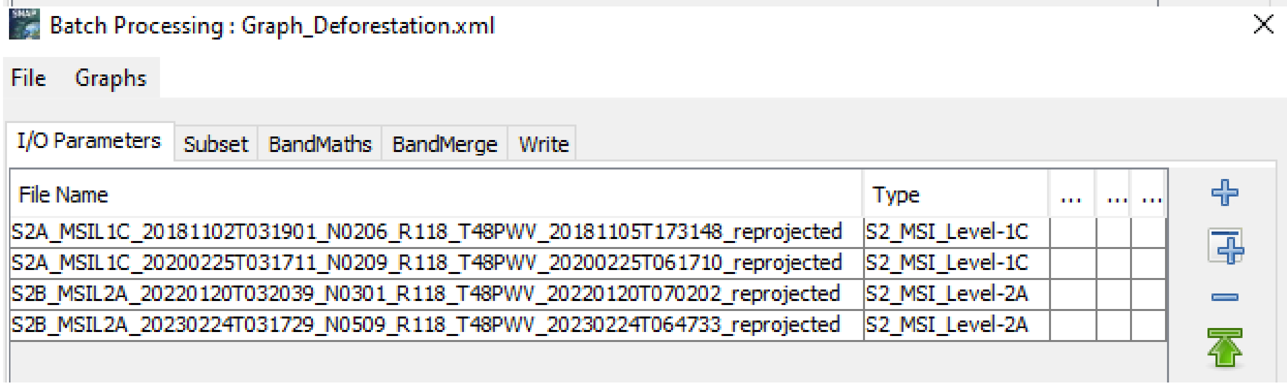
For the moment, do not change anything in the parameter tabs and save the graph (File – Save Graph) as „Graph_Deforestation.xml to your working folder. After you have saved it, close the GraphBuilder window.

2.3.3 Batch Processing

Open the **Batch Processing tool** (Tools → Batch Processing).

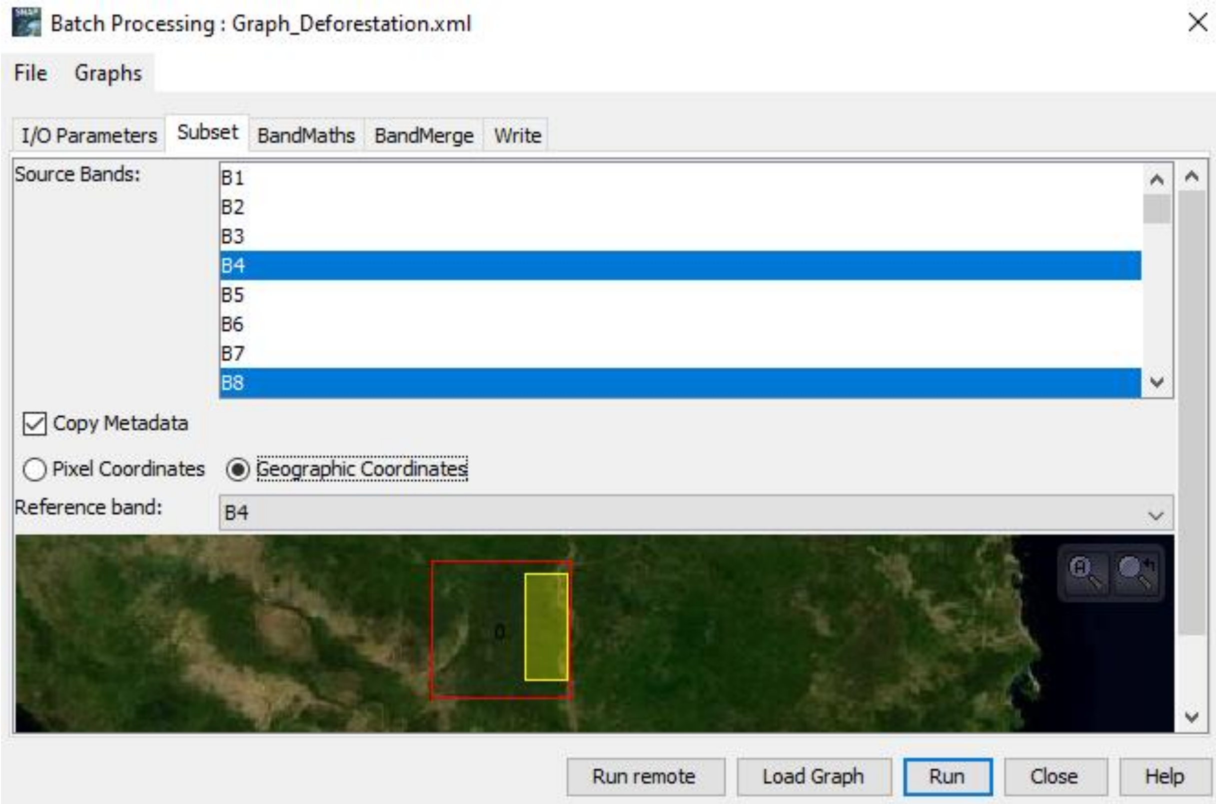
We will add all opened products by clicking Add Opened on the upper right (second icon from the top). Then, we delete original = not projected products by sleecting them and clicking Delete (third icon from the top left only reprojected products). Then, when we have only 4 reprojected products, we click File - **Load Graph** at the top of the window and navigate to our saved graph „*Graph_Deforestation*" and open it. We see that new tabs have appeared at the top of window corresponding to our operators with the exception of Read; this is correct as these parameters will be set in the I/O Parameters tab.





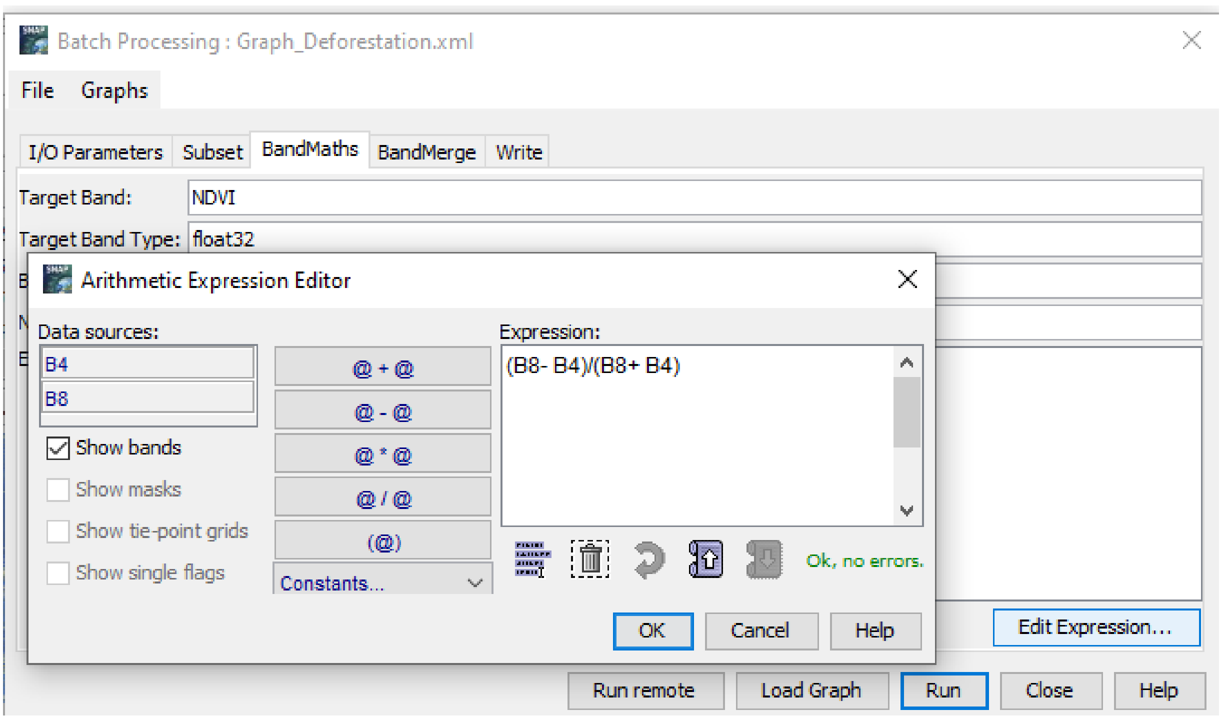
In the next step it is advisable to create **Subset** of these products for faster processing:

- **Source bands –** select only bands that we will need to calculate NDVI - B4 and B8
- **Geographic Coordinates** – create the subset of the area also by clicking on zoom into the area of image (red rectangle) and draw smaller (yellow) polygon inside it that includes only eastern part of the images where we observed deforestation
- **Reference band** – select Reference band according which all the Source Bands will be resampled

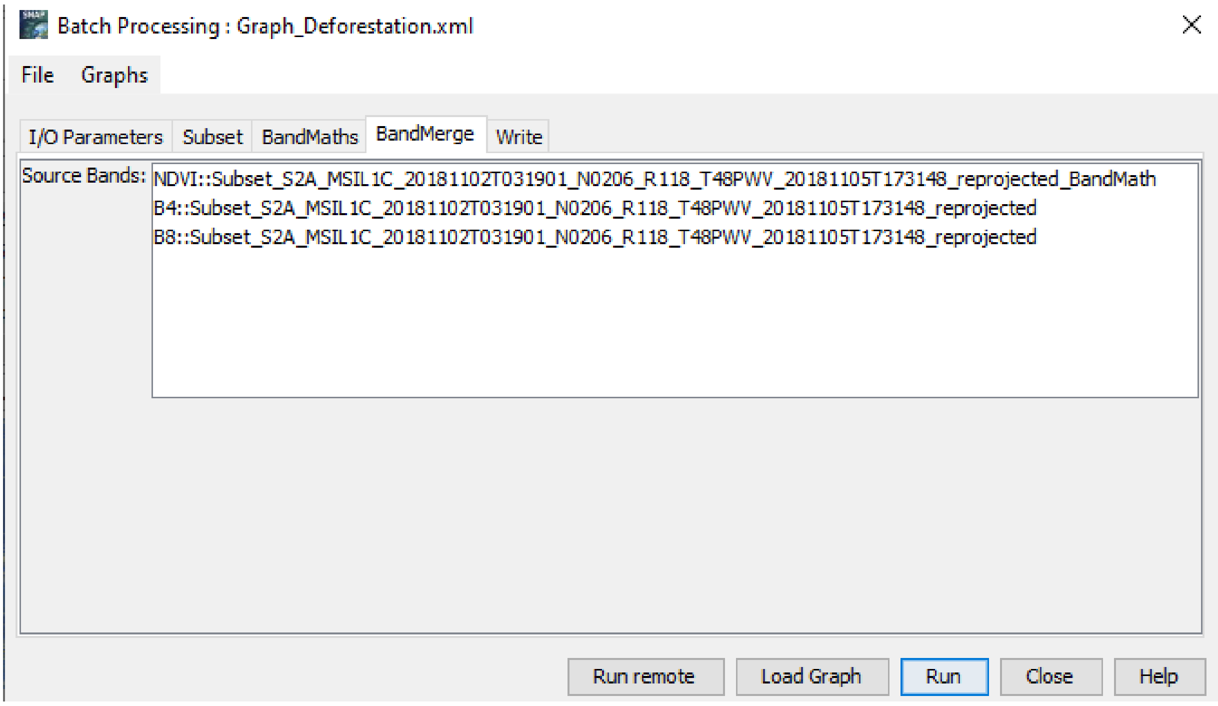


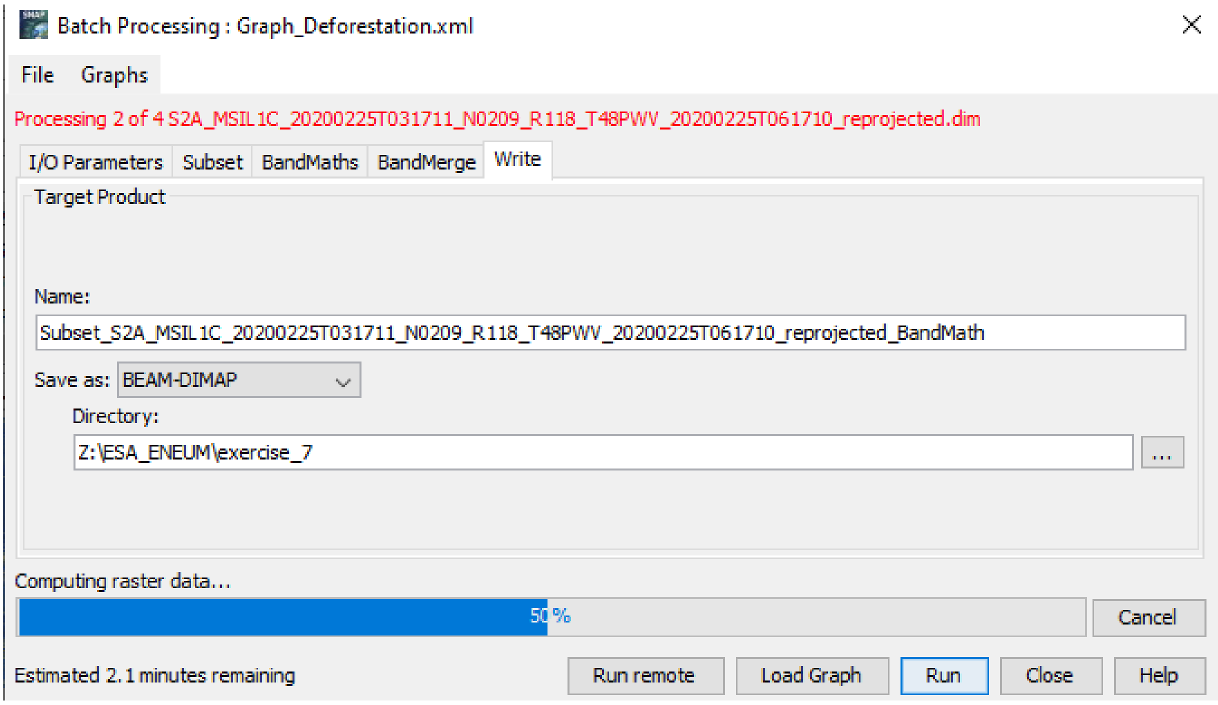
In BandMath, we enter the formula for NDVI calculation. The NDVI is calculated as a normalized difference of visible infrared (B8) and visible red (B4) bands, using the following equation (Rouse et al. 1974):

(B8-B4)/(B8+B4)



Then, in **BandMerge** tab we can combine the resulting bands into the resulting file and set the directory for the output file in **Write** tab. The common processing can be monitored. Writing target product may take some time.

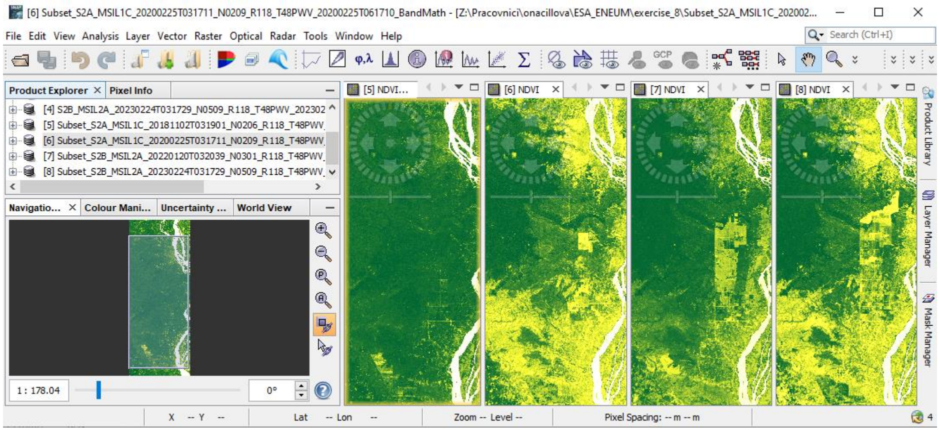


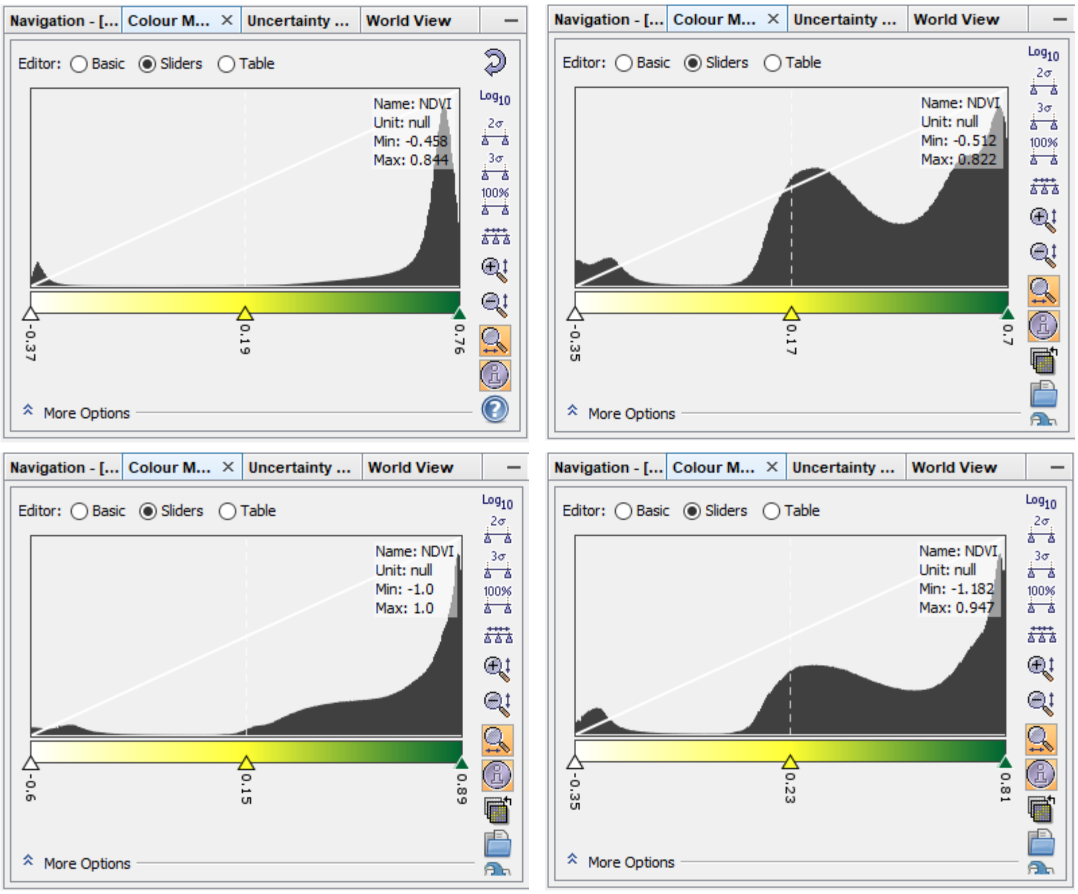


3. Image analysis

Open the output NDVI images side by side for all processed years – **Window – Tile Horizontally**. In Colour Manipulation select Colour ramp derived from meris pressure.

NDVI image - have values from < -1, 1 >, where forested areas are displayed in values higher than 0. The peaks of the histogram point to 2 extremes - forested and logged area.





For more information, see the lecture: [7. Spatio-temporal mapping of deforestation using multispectral data]()

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 8 – TUTORIAL

Mapping wildfires and burn severity using Sentinel-2 data, using SNAP software

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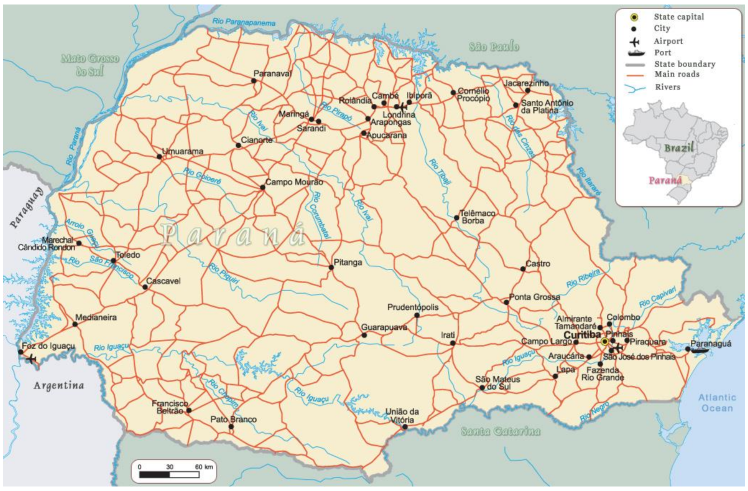
FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Detect wildfires on Sentinel-2 image
- Export subset as image to perform another analysis in QGIS
- Map burned areas and quantify burn severity using Normalised Burn Ratio index
- Develop a graph for automated processing using Batch processing

2 | Background



Fires in the grasslands close to a vital South American river delta present serious threats to both nearby wetland ecosystems and human well-being, caution environmental experts.

The wildfires around the important riverside port of Rosario, essential for transporting Argentina's extensive grain harvest, have raised concerns among local residents and activists.

Fires in the grasslands close to a vital South American river delta present serious threats to both nearby wetland ecosystems and human well-being, caution environmental experts. The wildfires around the important riverside port of Rosario, essential for transporting Argentina's extensive grain harvest, have raised concerns among local residents and activists.

The Parana River, South America's second-longest river after the Amazon, experienced its lowest water levels since 1944 in 2021 as reported by official data. This decline is attributed to multiple cycles of drought and reduced rainfall in upstream Brazil. In August 2022, the water level remained exceptionally low. The wildfires, many intentionally set by farmers preparing the land for new crops, generated a thick haze that reached Buenos Aires, located approximately 190 miles (300 km) south of Rosario. Residents were displeased with the presence of soot in the air, leading popular weather apps to issue forecasts simply describing the conditions as "smoke."

Wildfires burning in the wetlands of the Paraná River Delta, Argentina, 19 August, 2022

2.1 Study area and data used

For this exercise, we will use two Sentinel-2 images of the same area in Paraná River Delta, Argentina, using the Tile Number *20HQJ* downloaded for two days of summer 2022 (before and after the wildfires) from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

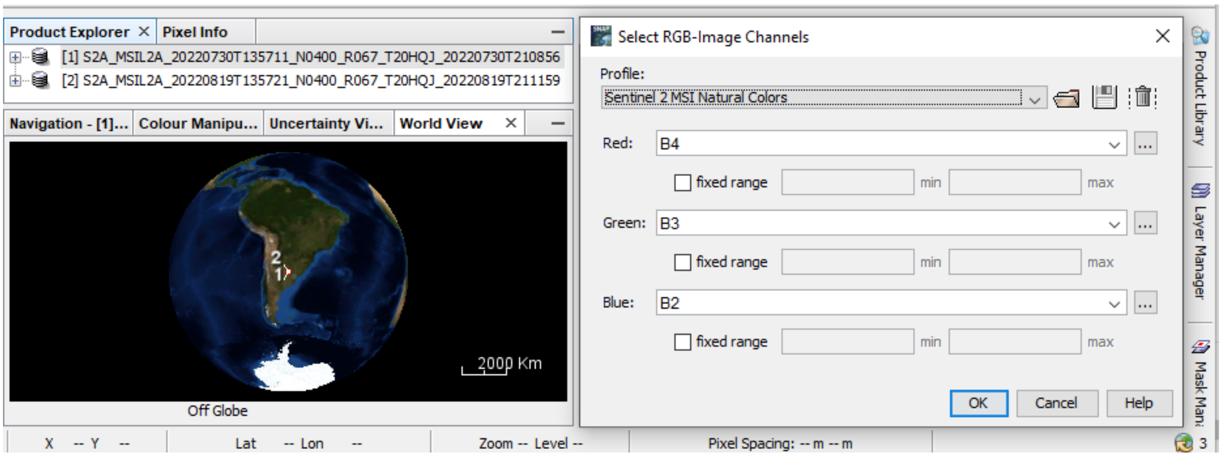
2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window.

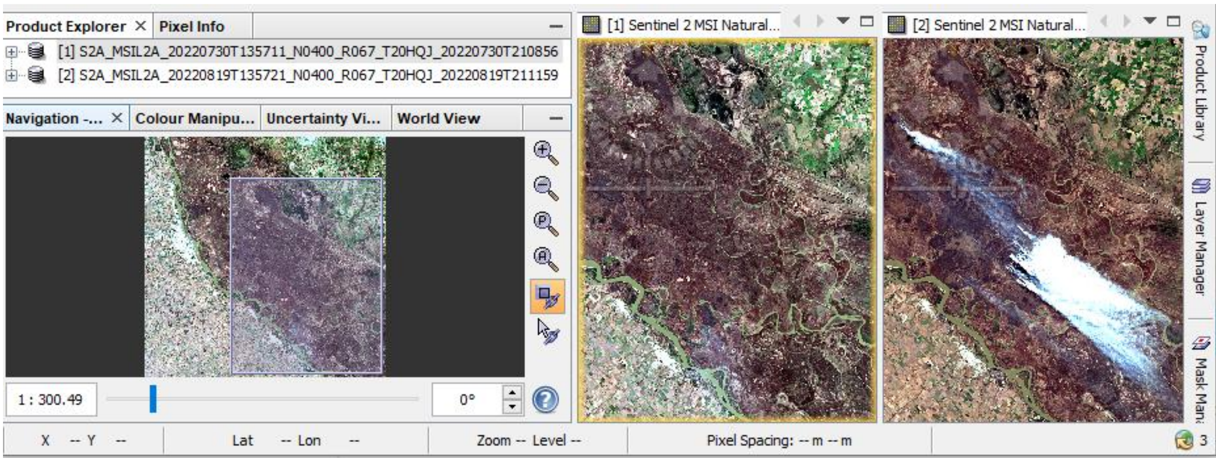
S2A_MSIL2A_20220730T135711_N0400_R067_T20HQJ_20220730T210856.SAFE.zip
S2A_MSIL2A_20220819T135721_N0400_R067_T20HQJ_20220819T211159.SAFE.zip

A: Detecting wildfires on Sentinel-2 image

1. Select the first product in the Product Explorer window.
2. Right click on the product.
3. Open RGB Image Window.
4. In the pop-up window select 'Sentinel 2 MSI Natural colors (Red: B4; Green: B3; Blue: B2)'.

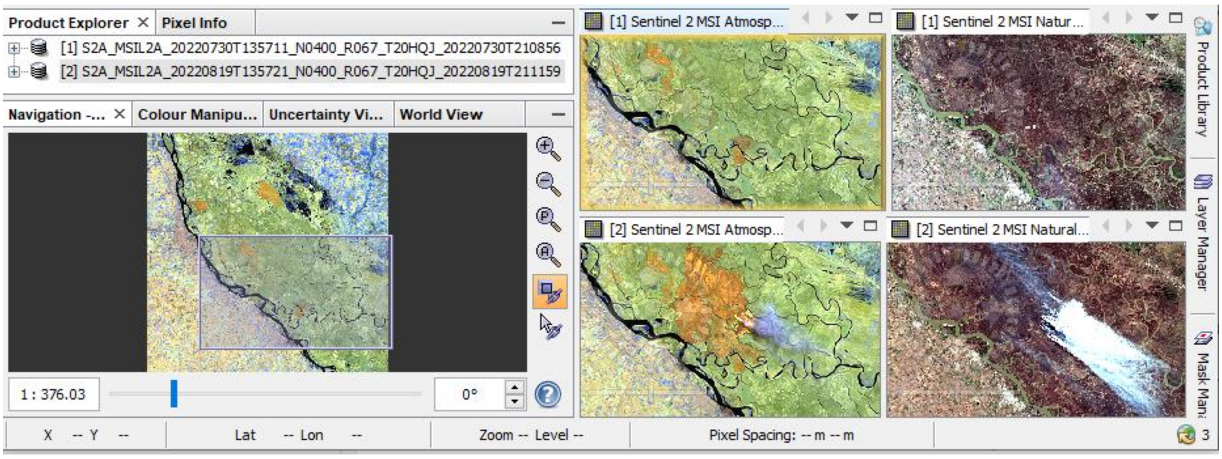


5. Repeat the process for the second product.
6. Tile two opened RGB Windows, e.g. horizontally
7. In the Navigation window, zoom in to the wildfire region and syhnchronise views to see the same area before and after wildfires



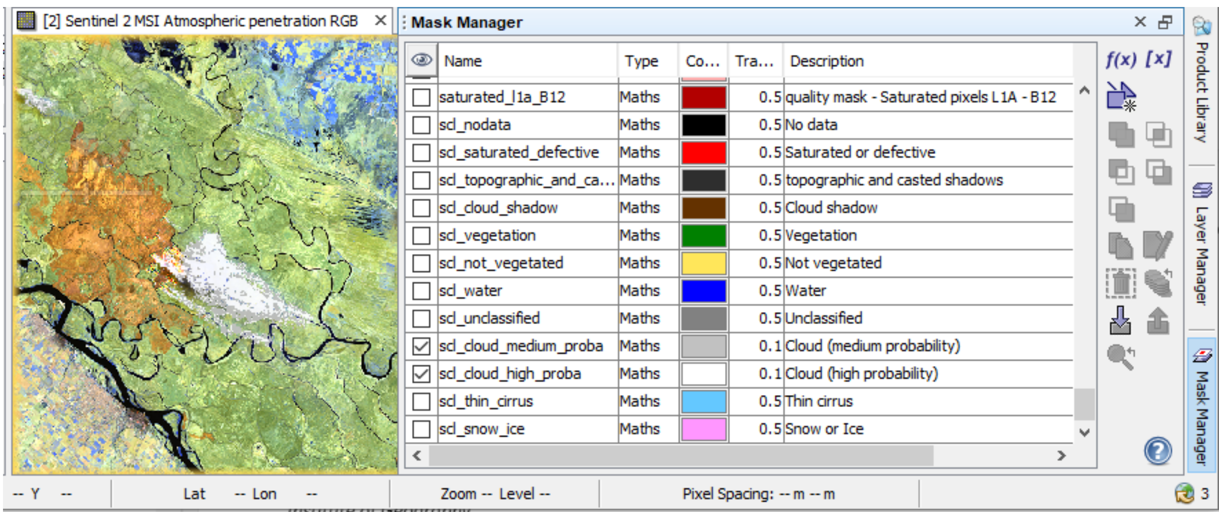
Do the same process for obtaining the color composition in false colors:

1. Select the first product in the Product Explorer window.
2. Right click on the product.
3. Open RGB Image Window.
4. In the pop-up window select 'Sentinel 2 MSI Atmospheric penetration (Red: B12; Green: B11; Blue: B8A)'.
5. Apply color manipulation (stretching) for RGB
6. Repeat the process for the second product.
7. Tile opened RGB Windows, e.g. evenly
8. If necessary, in the Navigation window, zoom in again to the wildfire region and syhnchronise views to see area before and after wildfires



Now let's detect the smoke plume:

1. Keep only the Sentinel 2 MSI Atmospheric penetration composition with visible smoke plume from 19 August open
2. Go to Mask Manager, and scroll down to the Maths masks
3. Select: "scl_cloud_medium_prob" and "scl_cloud_high_proba"
4. To visualize the masked areas better, lower the transparency(e.g. 0.1)

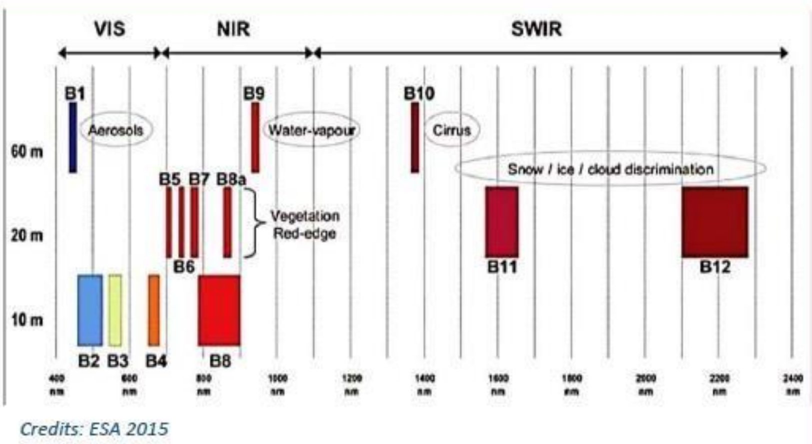


Fire + cloud plume map

Let’s export this View as an image and safe as a GeoTIFF:

Because of multiple S2 spatial sizes, we first have to resample the data. Resample to highest spatial resolution: 10 m (e.g. B2).

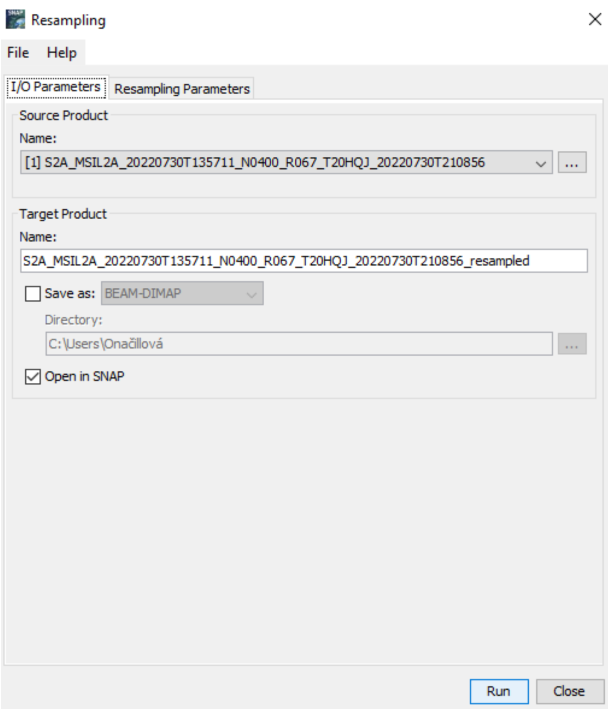
NOTE 1: The input product contains 13 spectral bands in 3 different spatial resolutions (The surface area measured on the ground and represented by an individual pixel). When we open the RGB view all our input bands have 20 m resolution, however, the view is displayed in the full 10 m resolution.

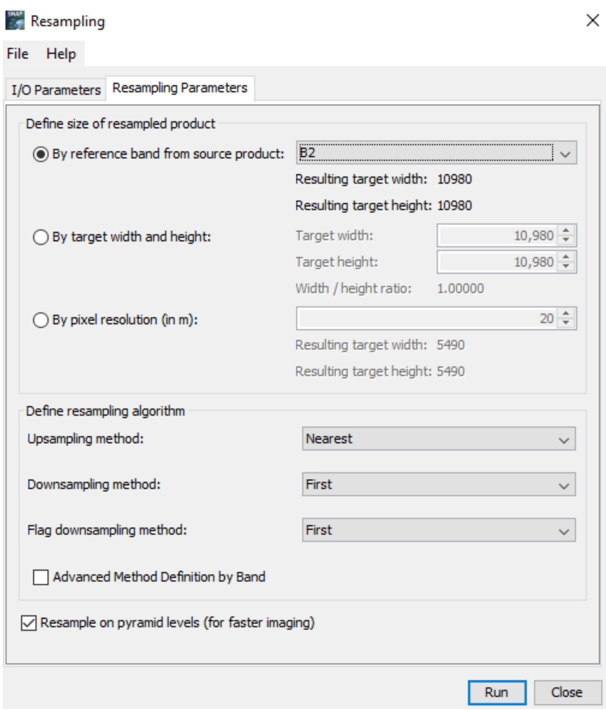


Credits: ESA 2015

Raster->Geometric->Resampling:

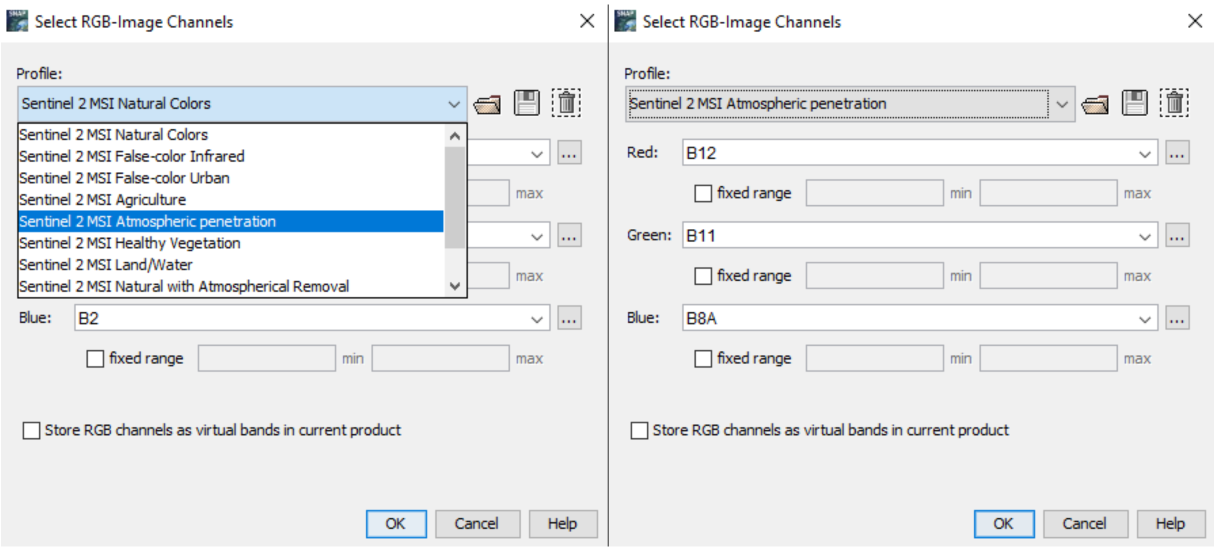
- Keep I/O names
- In Resampling Parameters, select B2 (10 m)



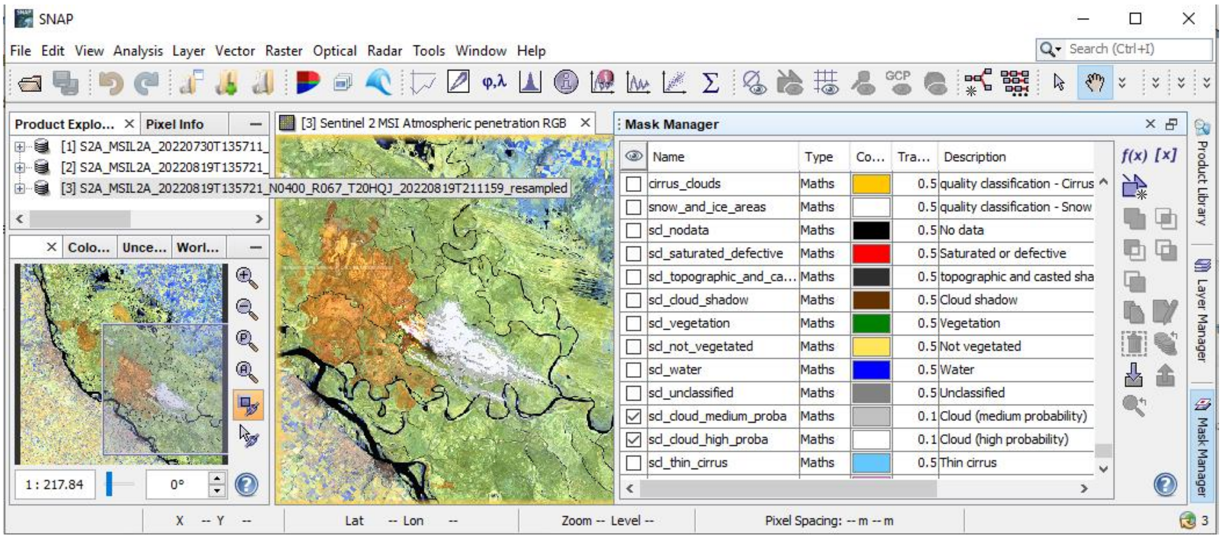


Let’s create a subset based on the current view

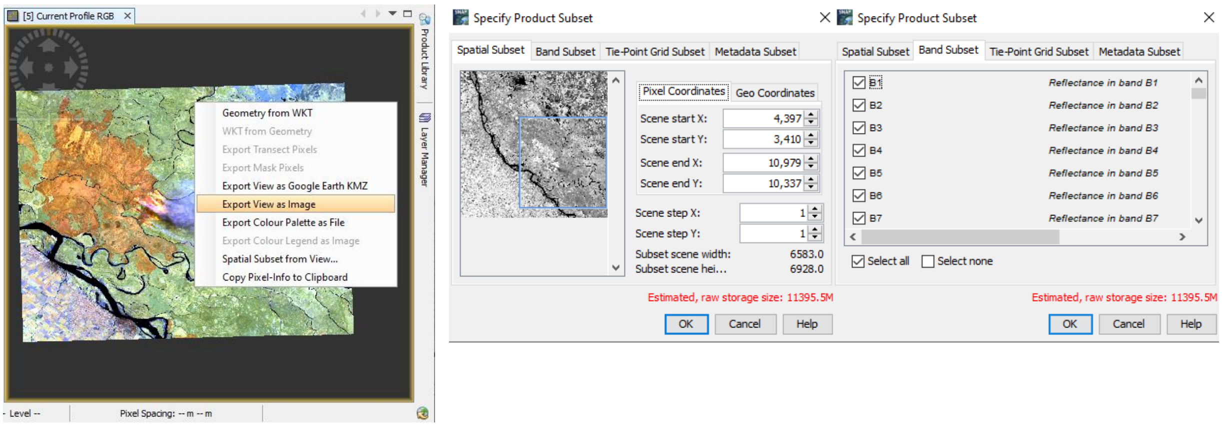
- Display the image. Note that now many more color options are available. Select MSI Atmospheric penetration



- Make a zoom and add the cloud masks again

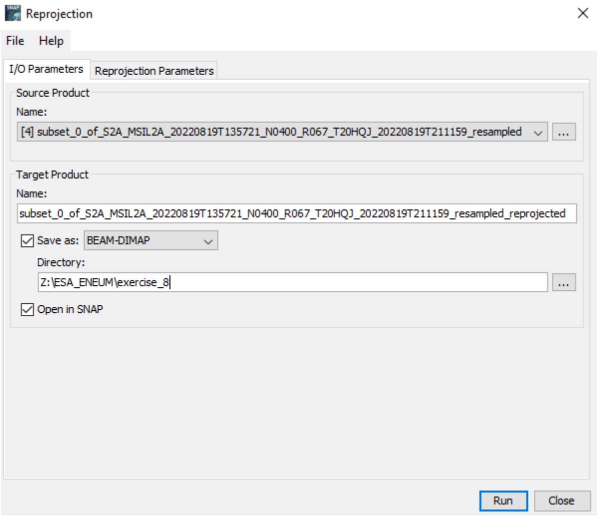


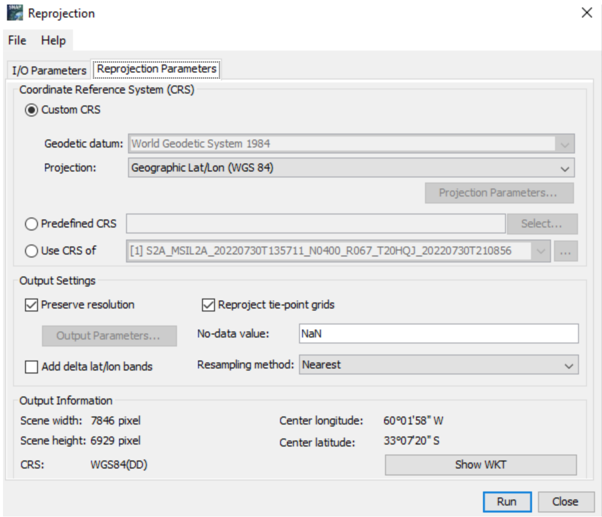
- Right-mouse button -> Spatial Subset from View – in the Band Subset you can select all or only few bands to be exported



Let’s reproject the image in Latitude & Longitude coordinates

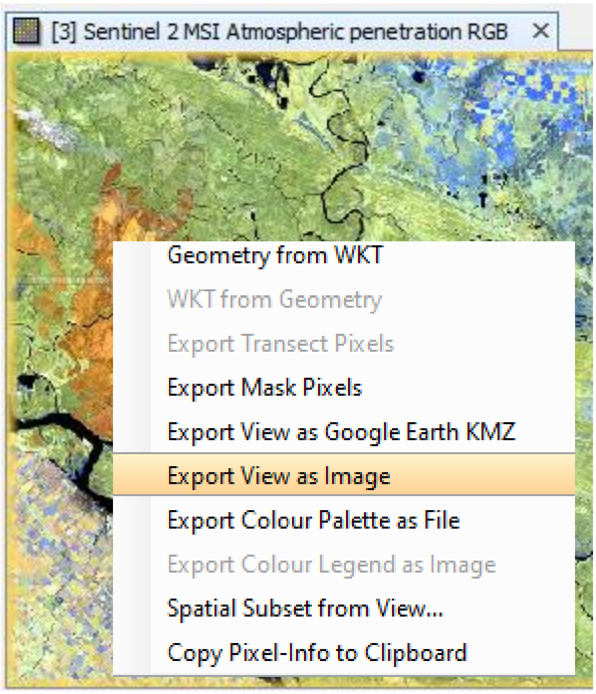
- Raster->Geometric Operations->Reprojection
- Select the default: Geographic Lat/lon (WGS 84)
- Run (writing might take some time)

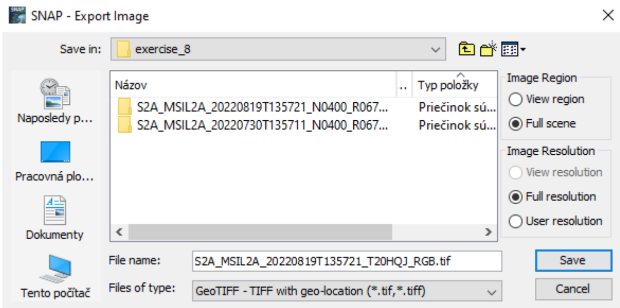




Now we can export View as GeoTiff

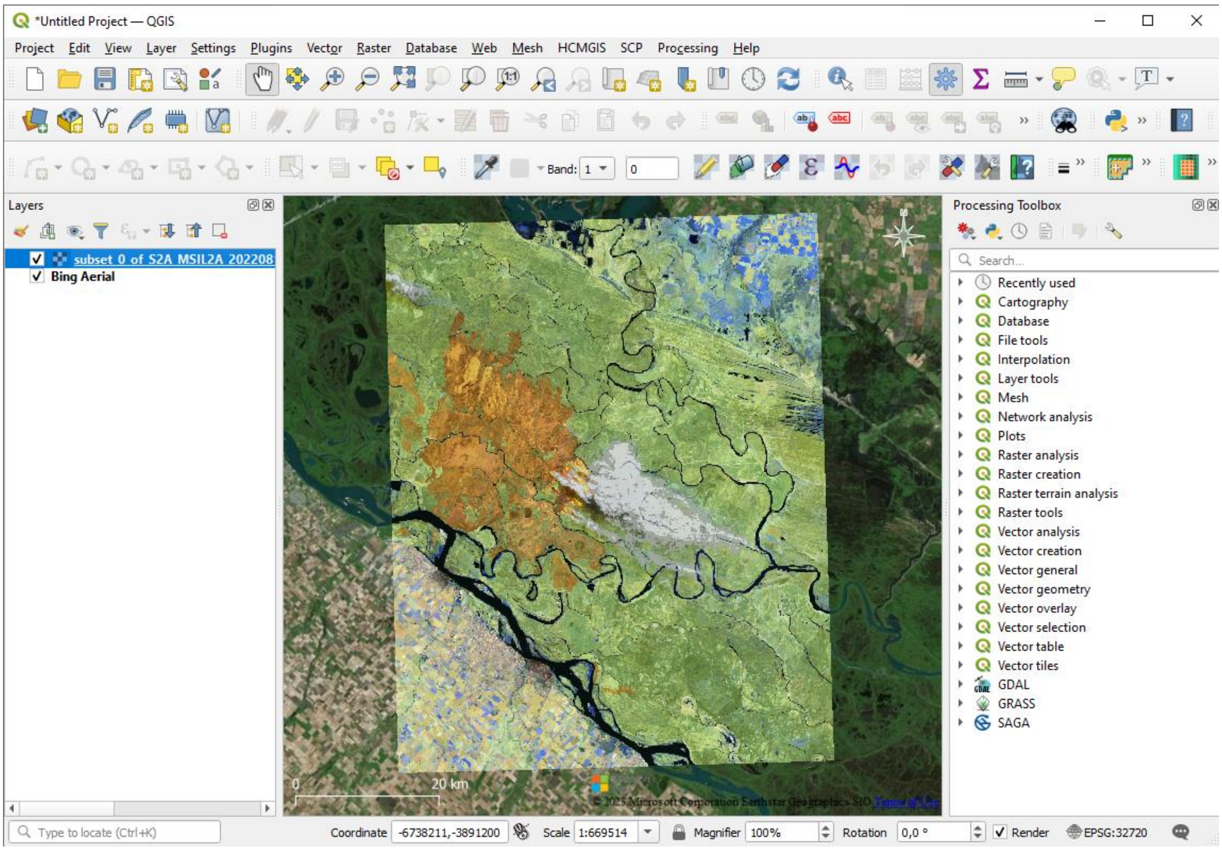
- Right mouse button: Export View as Image
- Select: Full scene, Full resolution, GeoTIFF





Now we open the output image in QGIS

- We can overlay it to e.g. Google Satellite or Bing aerial image:
- Web->OpenLayers plugin->Google Maps->Google Satellite
- Move the Subset above the satellite
- Play with Transparency: Properties->Transparency (e.g. 80%)

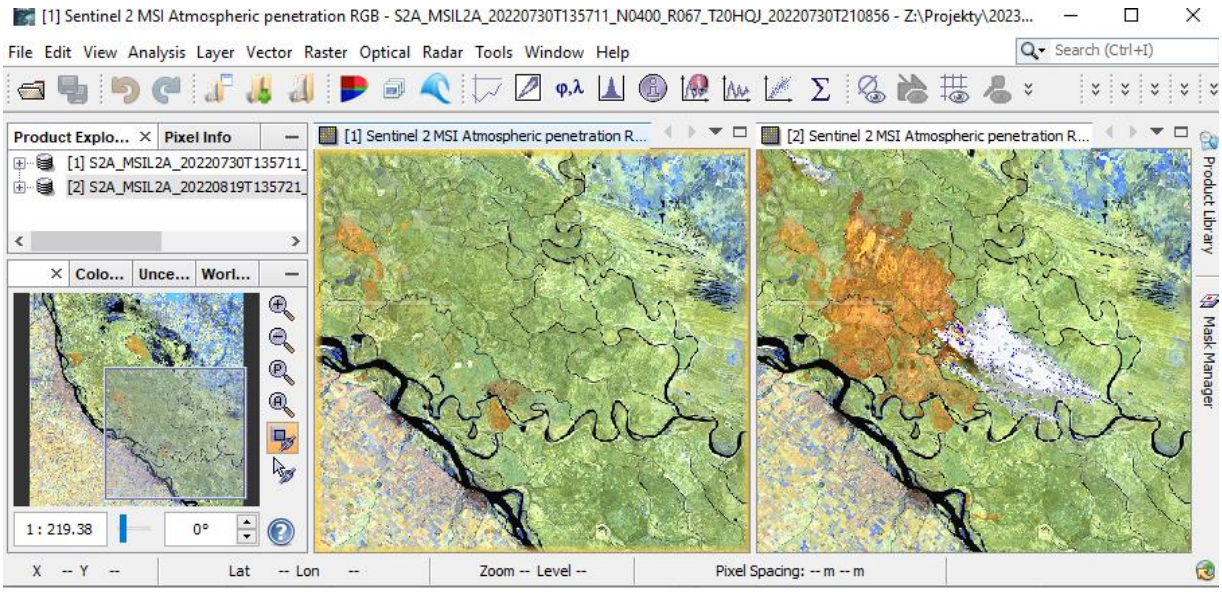


B: Burned area mapping with Sentinel-2

How to quantify the impact of the Paraná wildfire?

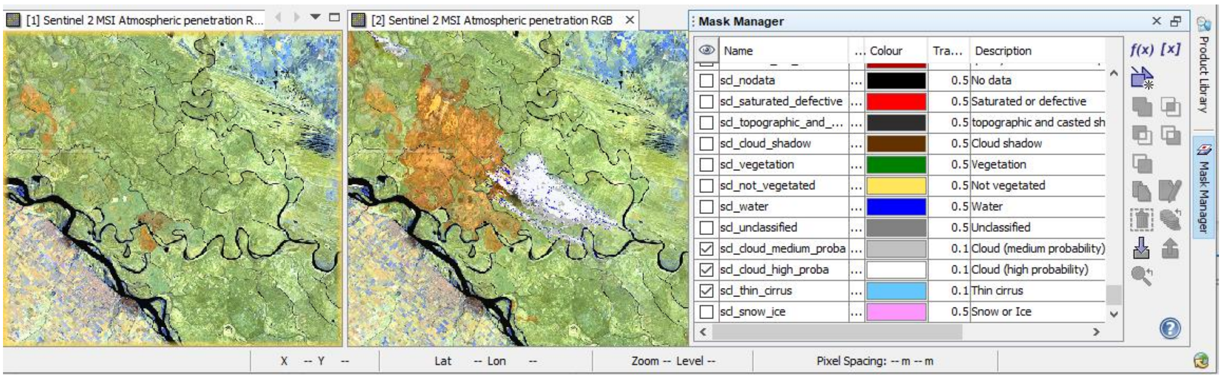
Let's have look to the before & after images:

- Open RGB Image Window:
- Select: MSI Atmospheric penetration
- Window-> Tile horizontally, zoom in



Let's create a cloud mask:

- Go to Mask Manager, and scroll down to the Maths masks
- Select: cloud medium & cloud high probability & Thin cirrus
- To visualize them better, lower the transparency (e.g. 0.1)

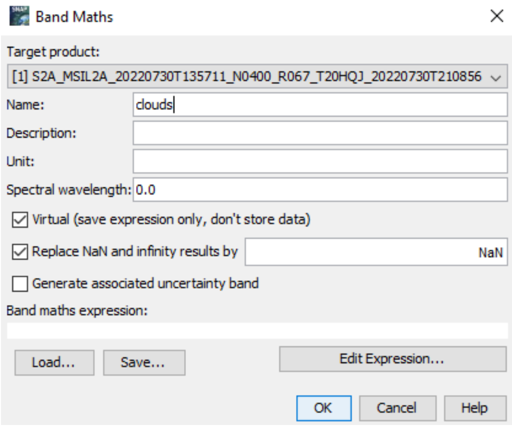


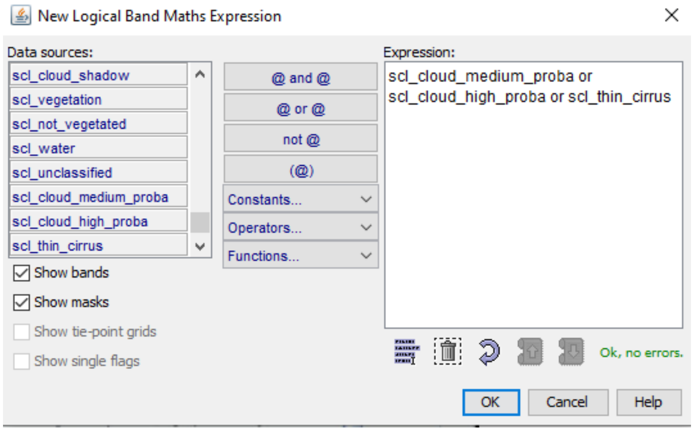
Now we make a cloud band based on the selected mask

- Band math expression

We make a cloud band based on the selected mask

- Navigate to Raster - Band Maths
- Name the new mask: ***clouds***

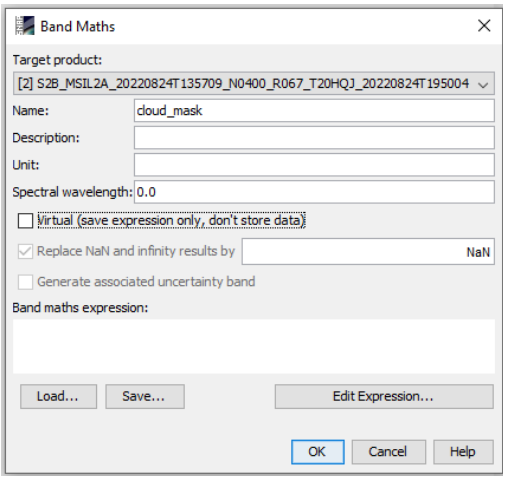


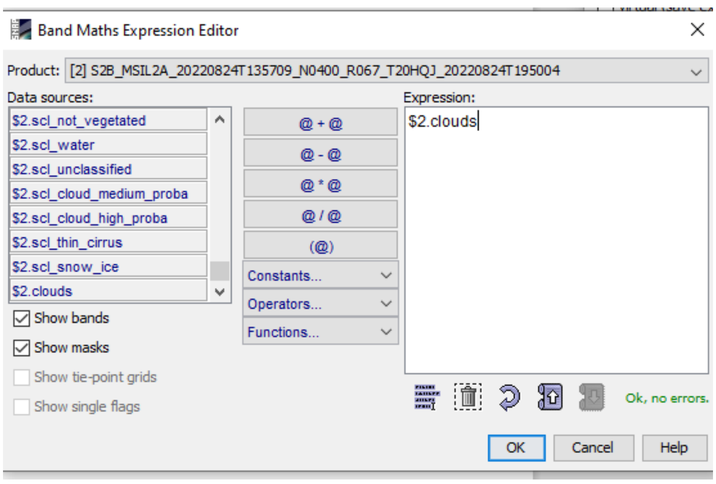


Adding the cloud mask as a band

- On the image, right click-> Band Maths
- Make sure to deactivate "Virtual". We want to store the data!
- Go to "Edit Expression"
- Select Clouds

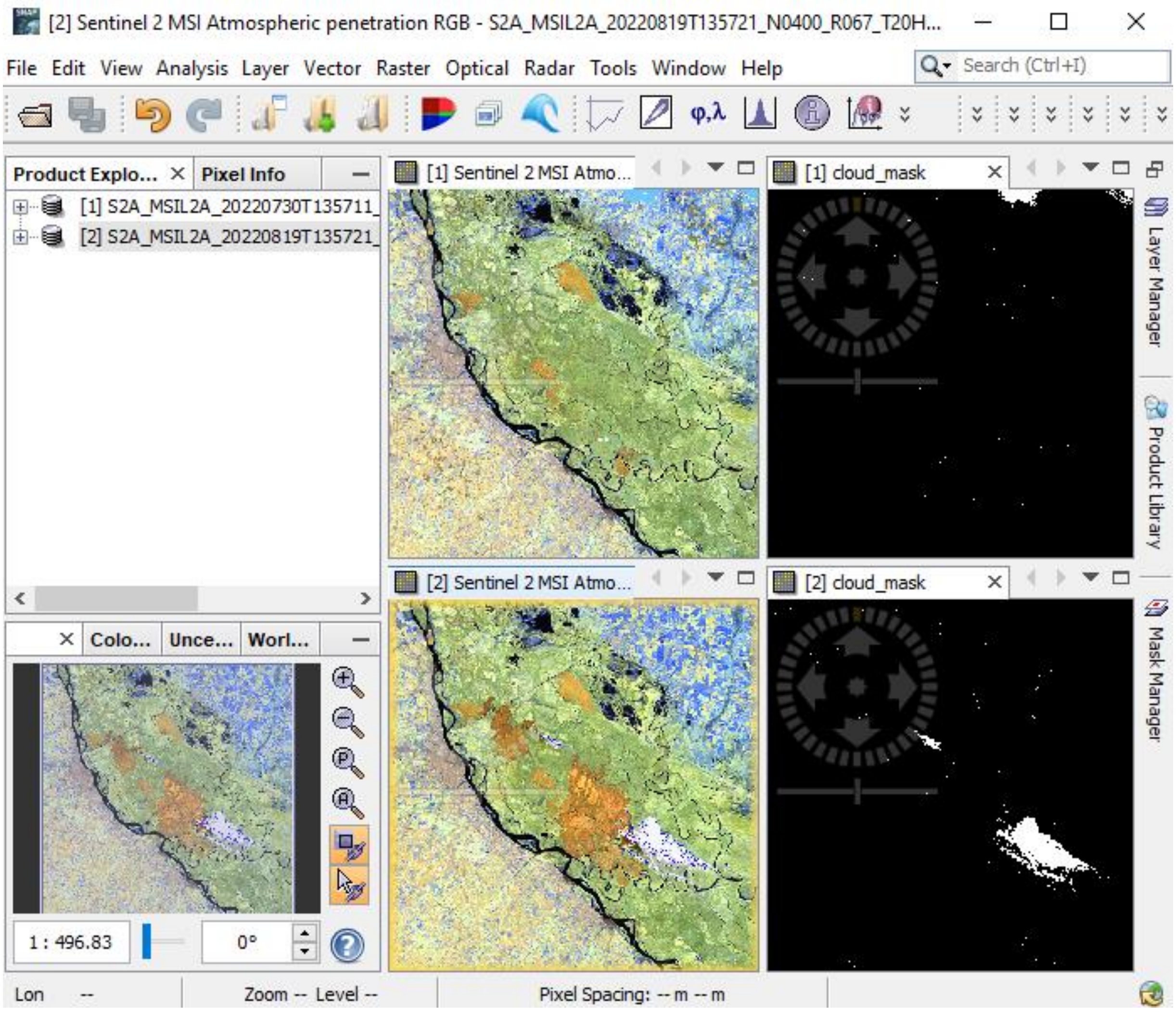
Repeat for the second image



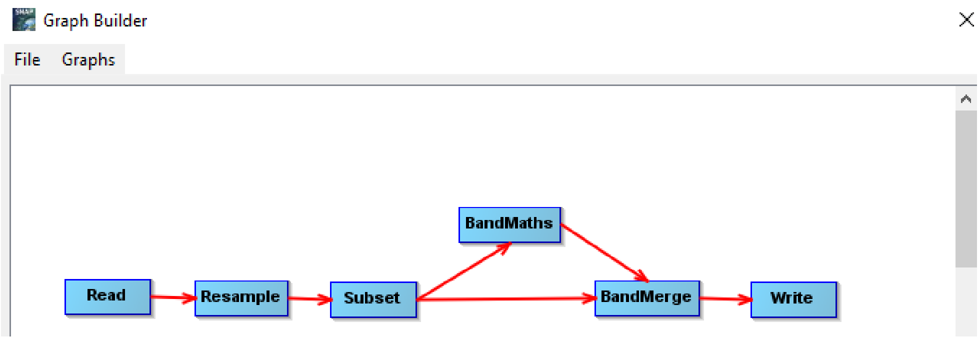


Vizualize all products

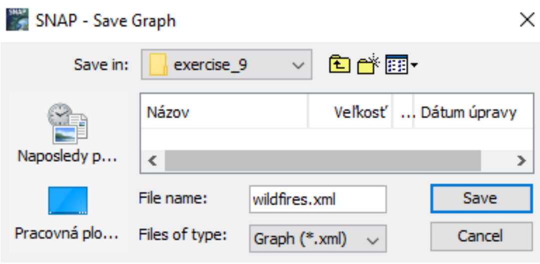
- Windows: Tile evenly
- Navigation: zoom all



Tools – Graph Builder



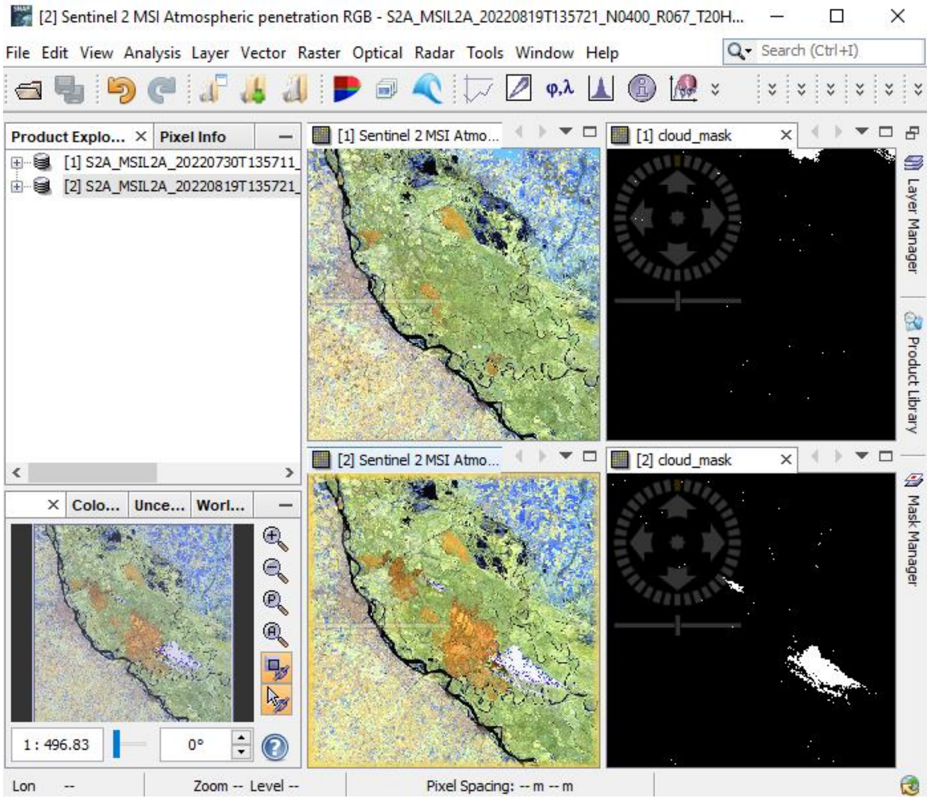
- Add->Raster->Geometric->Resample
- Add->Raster->Geometric->Subset
- Add->Raster->BandMaths
- Add->Raster->BandMerge
- Save your created graph

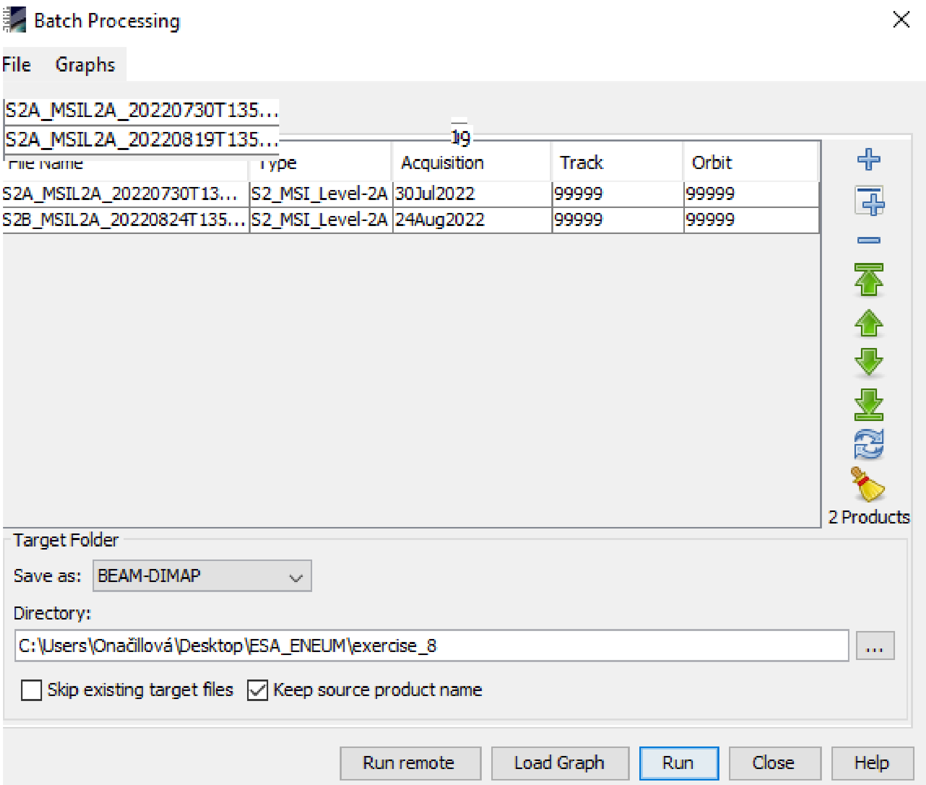


Tools – Batch processing

This allows to process both images at the same time.

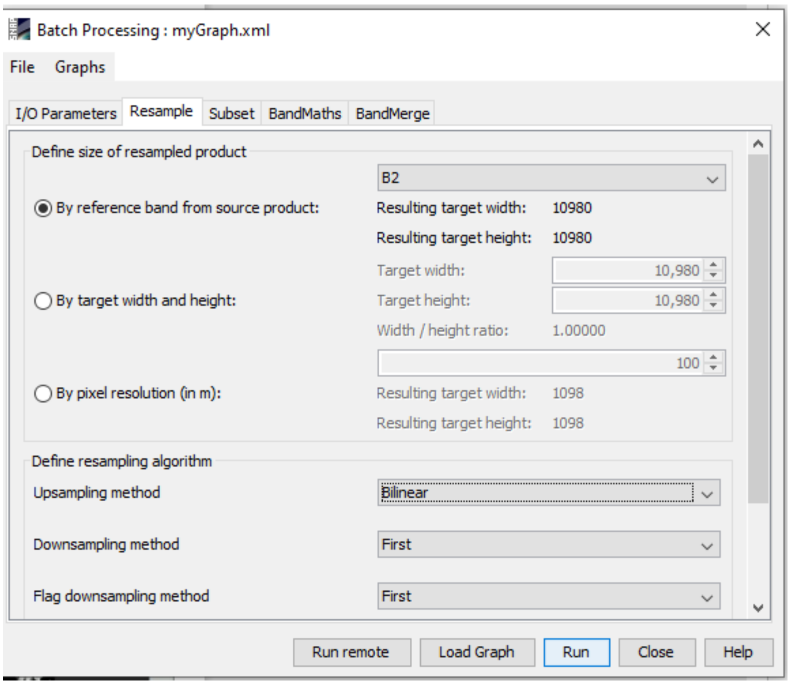
- Click on Add opened
- Load your graph
- Make sure to refresh





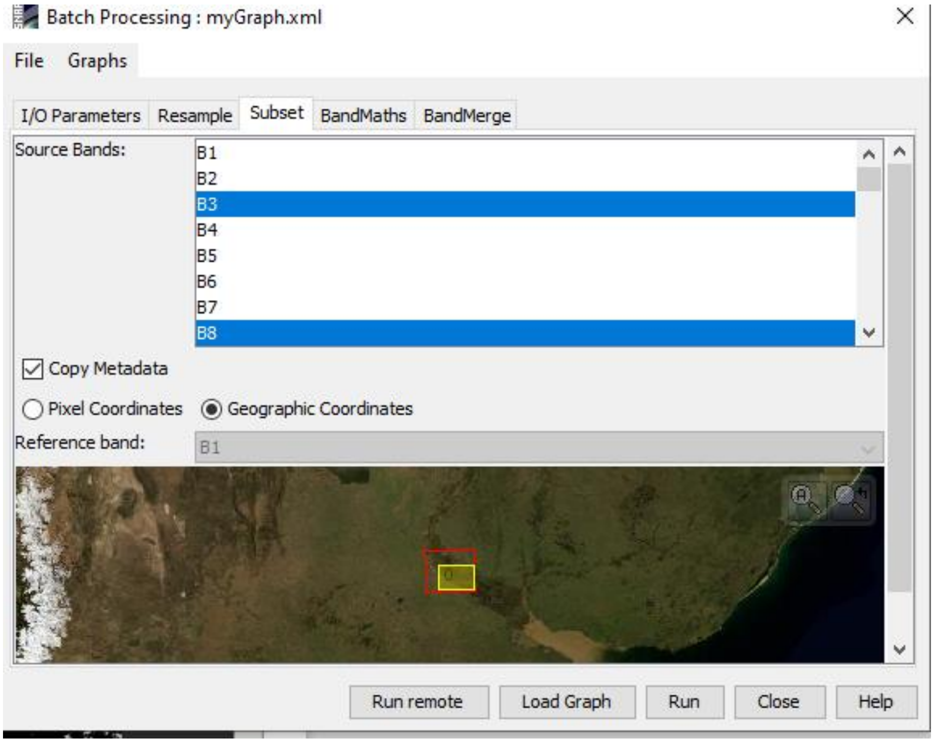
Resample

- Select a reference band: B2 at 10 m.
- Resampling method: Bilinear



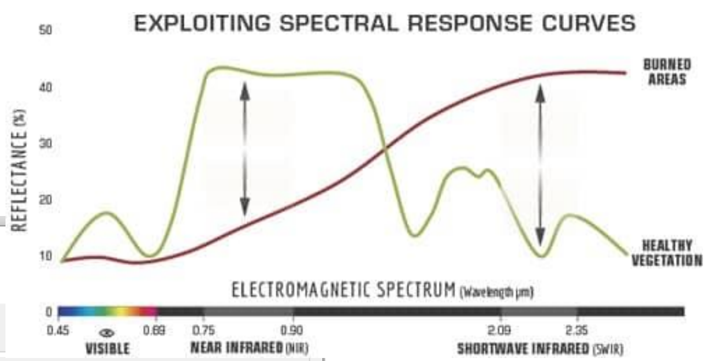
Subset

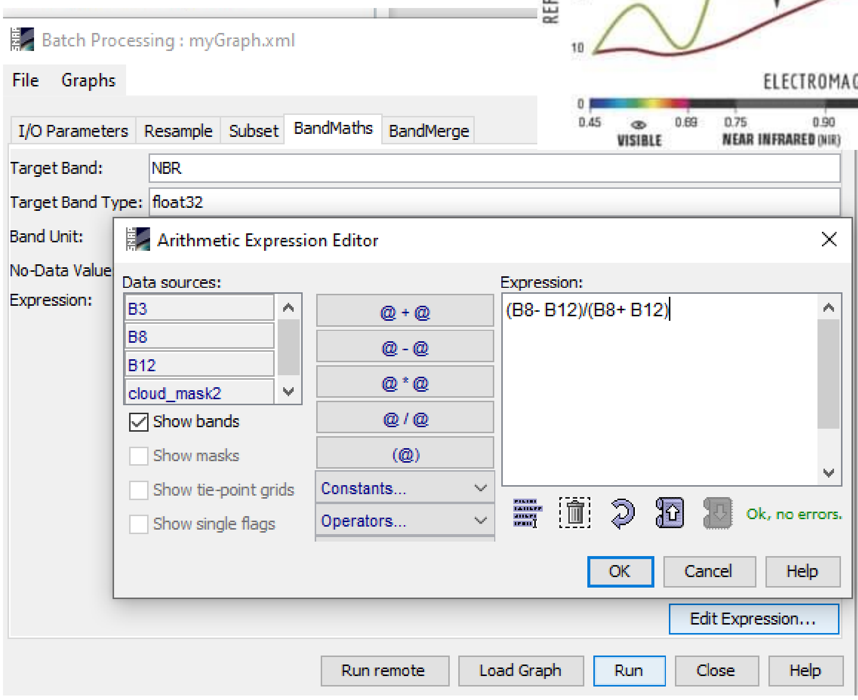
- Select bands: B3, B8, B12, Cloud_mask
- Select Geographic coordination
- Click on A, zoom in to the area of interest
- Select a yellow box within the red square



Band Math

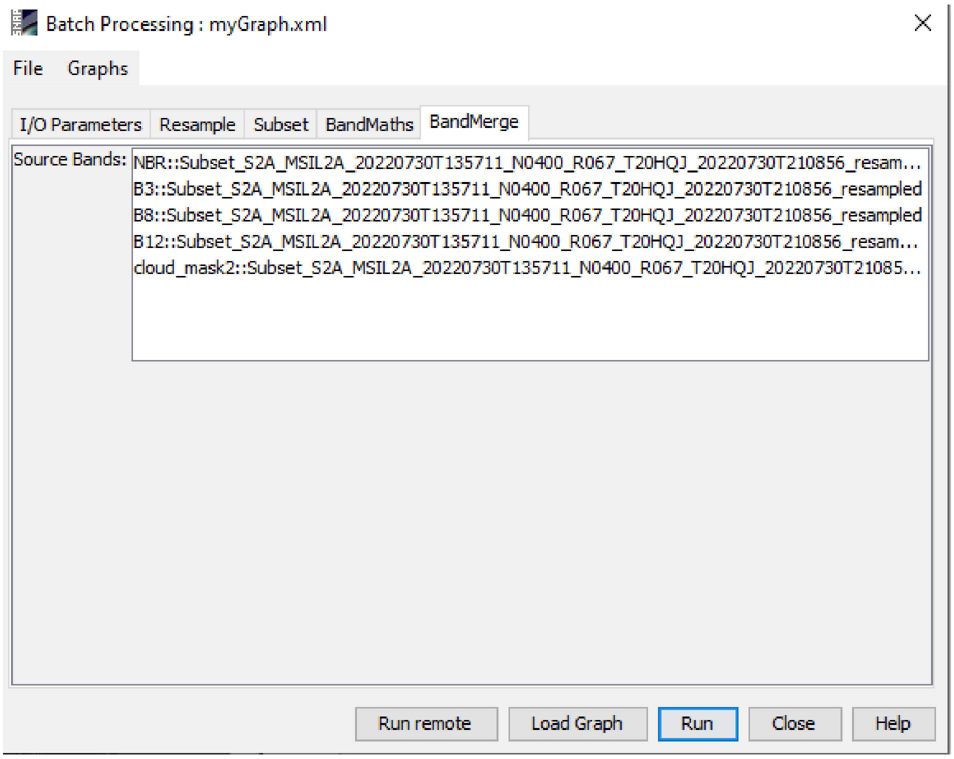
- Go to “Edit Expression”
- NBR: Normalized Burn Ratio: (B8-B12)/(B8+B12)





Band merge

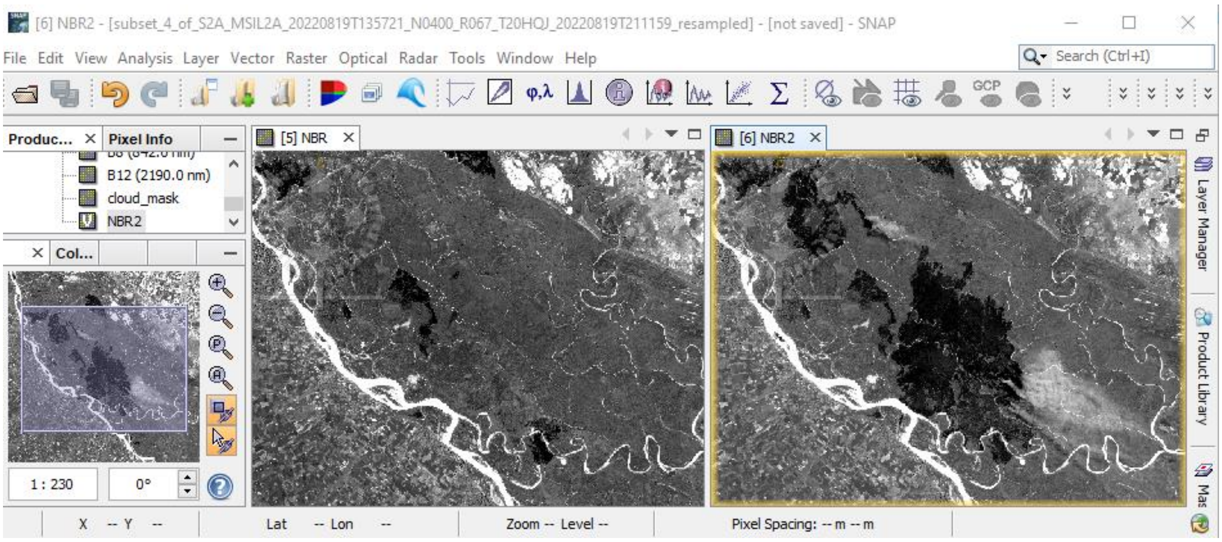
- Keep the source bands: **NBR, B3, B8, B12, cloud_mask**

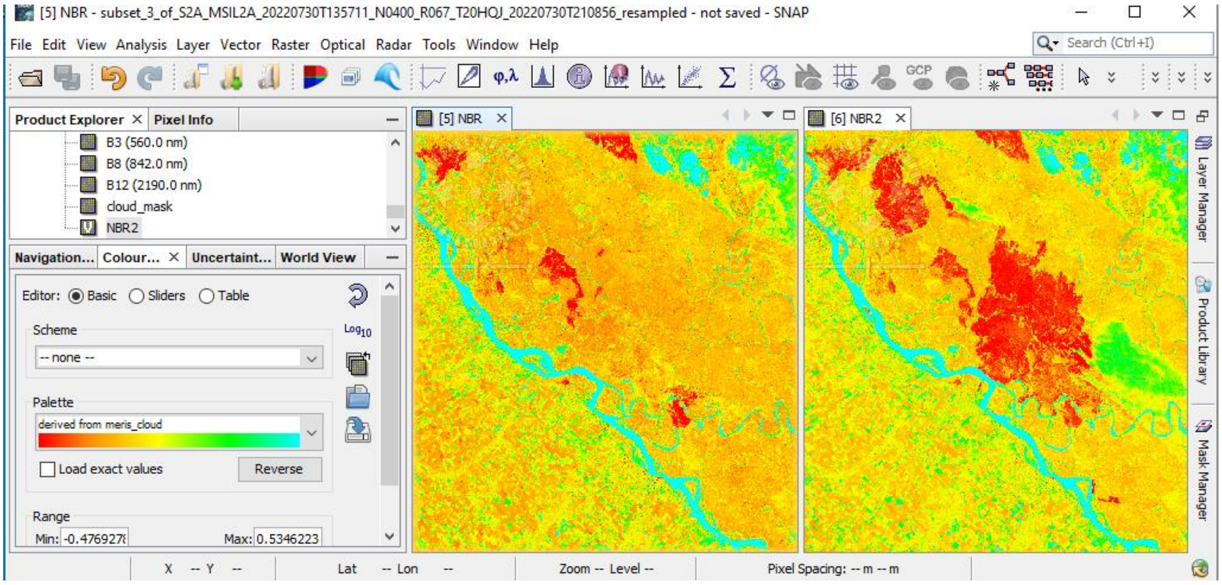


Running and visualizing the NBR band

Try a color table:

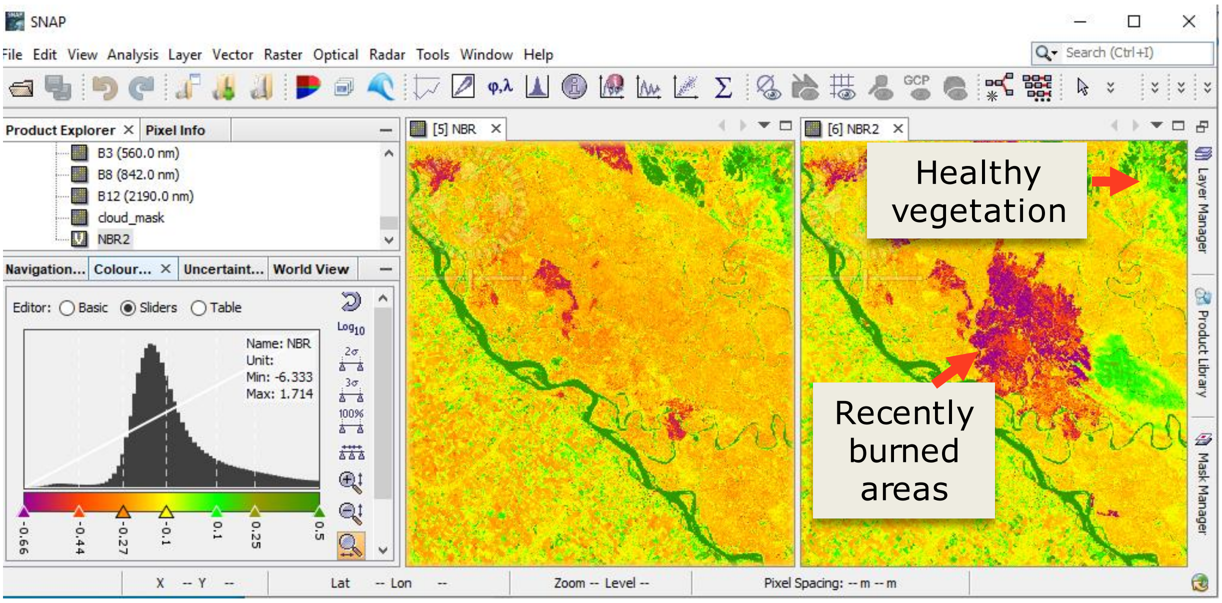
• Colour manipulation: Open color table, choose a color gradient, e.g. „derived from meris_cloud"





You can also set the position of sliders and color them for better visualization or change ranges of values in the Table tab.

NBR ranges between -1 and 1. A high NBR value indicates healthy vegetation. A low value indicates bare ground and recently burnt areas. Non-burnt areas usually have values close to zero.

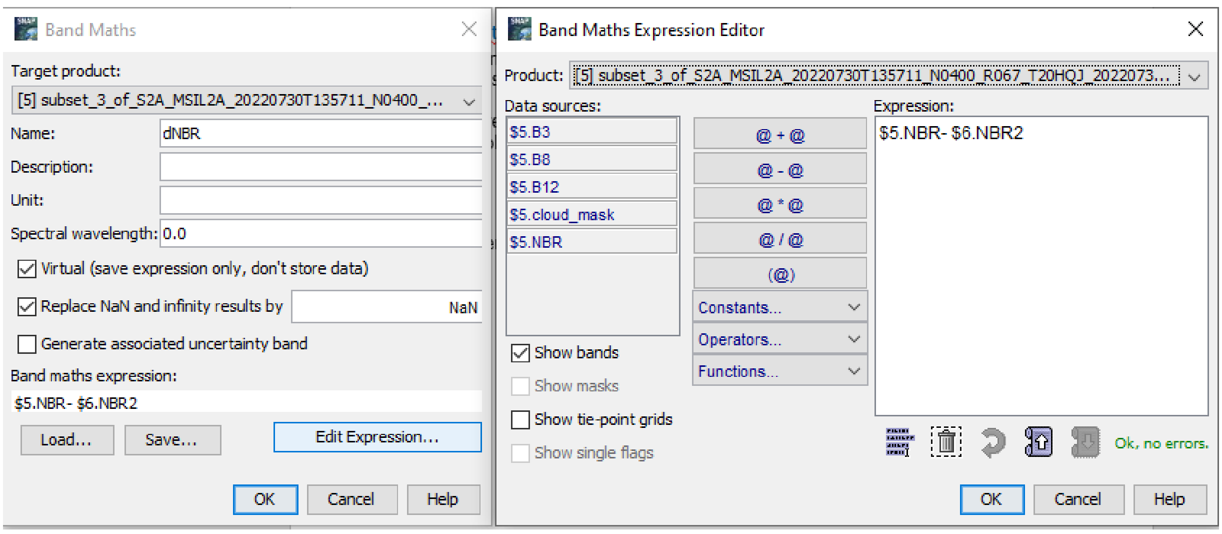


Burn severity - dNBR

The difference between the pre-fire and post-fire NBR obtained from the images is used to calculate the delta NBR (dNBR or ΔNBR), which then can be used to estimate the burn severity. A higher value of dNBR indicates more severe damage, while areas with negative dNBR values may indicate regrowth following a fire. The formula used to calculate dNBR is illustrated below:

$$dNBR \text{ or } \Delta NBR = PrefireNBR - PostfireNBR$$

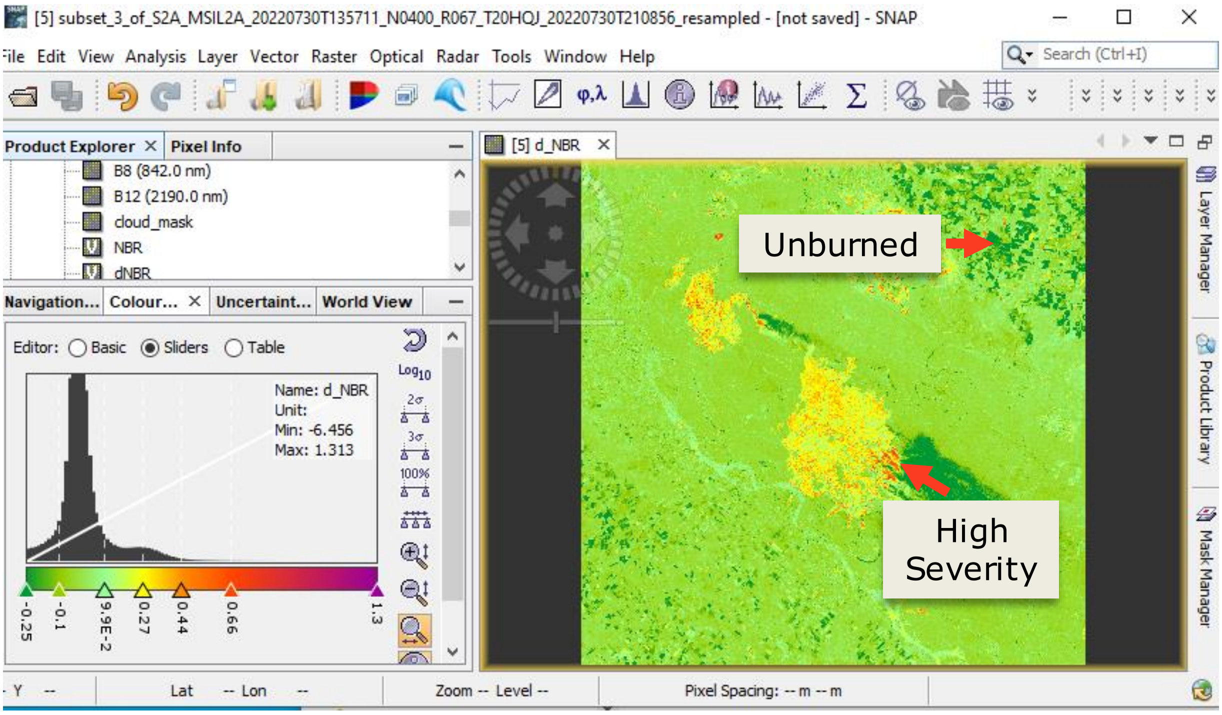
Go to Raster – Band Maths and Edit Expression



Set the position of sliders and color them for better visualization or change ranges of values in the Table tab.

NBR ranges between -1 and 1. A high NBR value indicates healthy vegetation. A low value indicates bare ground and recently burnt areas. Non-burnt areas usually have values close to zero.

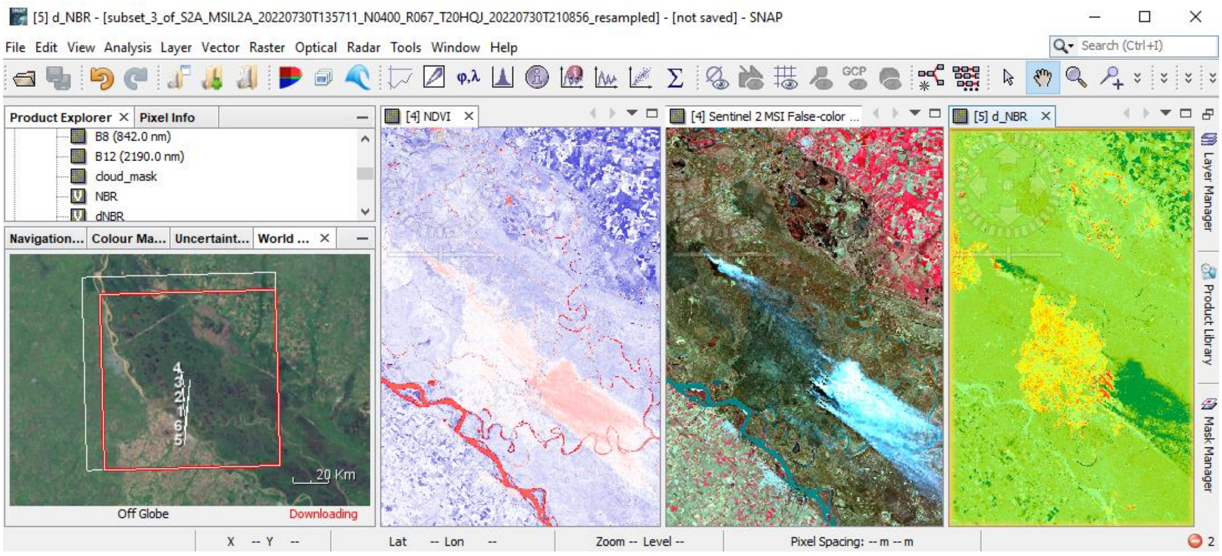
dNBR values can vary from case to case, and so, if possible, interpretation in specific instances should also be carried out through field assessment; in order to obtain the best results. However, the United States Geological Survey (USGS) proposed a classification table to interpret the burn severity, which can be seen below in the table.



Severity Level	dNBR Range (scaled by 10^3)	dNBR Range (not scaled)
Enhanced Regrowth, high (post-fire)	-500 to -251	-0.500 to -0.251
Enhanced Regrowth, low (post-fire)	-250 to -101	-0.250 to -0.101
Unburned	-100 to +99	-0.100 to +0.99
Low Severity	+100 to +269	+0.100 to +0.269
Moderate-low Severity	+270 to +439	+0.270 to +0.439
Miderate-high Severity	+440 to +659	+0.440 to +0.659
High Severity	+660 to +1300	+0.660 to +1.300

Comparison: Severity map, NDVI and false color composition

To compare different views of the same area and explore it more in detail, create also NDVI and false color composition. You can observe, that areas with high NDVI values correspond to the barren areas affected by wildfires. False color composition also depicts areas affected by fire – these areas are shown in dark pixels. False color composite B8-B4-B3 of the Sentinel 2 image (during fire), with superimposed ongoing wildfire sites, note that the smoke direction is corresponding to the wind direction.



For more information, see the lecture: [8. Mapping wildfires and burn severity using multispectral data]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 9 – TUTORIAL

Air quality monitoring using Sentinel-5 data – practicals, using SNAP software

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

- Define suitable search criteria (time range, area, satellite, satellite product, visualization type) and compare images from different sensors in EO Browser for a case study in air pollution
- Explore impact of Covid-19 on different cities in Europe
- Interpret Sentinel-5P NO2 maps in SNAP
- Context information with Sentinel-2
- Monitor volcanic emissions with Sentinel-5P

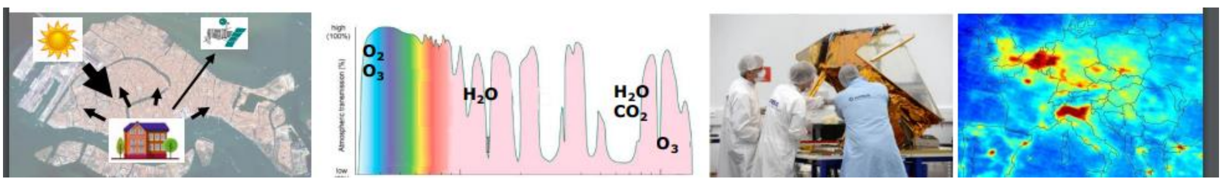
2 | Background

Nitrogen dioxide (NO2) is a common air pollutant that plays a big role in the formation of smog and acid precipitation. Over 90% of the overall nitrogen oxide emissions are released into the air during the combustion of diverse fuel types.

There has been a notable increase in the amount of satellite data specifically related to air pollution. In particular, satellite instruments for observing the lower troposphere have significantly improved. Space radiometers, like MODIS, GOES, AVHRR and TOMS have proven very useful in measuring aerosols and air pollutants across large areas. The latest generation spectrometers, such as TROPOMI, are capable of detecting NO2 and other pollutants in urban areas.

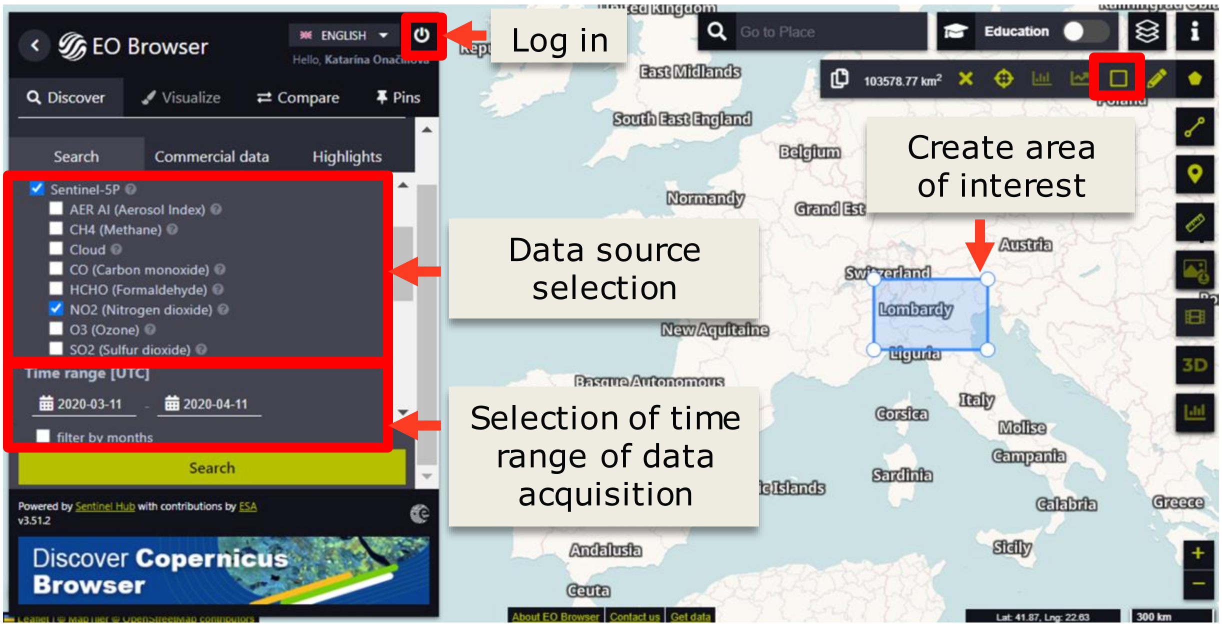
TROPOMI (Tropospheric Monitoring Instrument) is part of the payload on the ESA Sentinel-5 Precursor (Sentinel-5P) satellite, designed for the monitoring of Earth's atmosphere. It is an imaging spectrometer utilizing passive sun backscatter technology, allowing for the capture of imagery across eight bands, ranging from ultraviolet (UV) and visible to near-infrared (NIR) and shortwave infrared (SWIR) spectral domains. This instrument boasts a spatial resolution of 7 × 3.5 km² in both along-track and across-track dimensions. S5–P promptly delivers data on various trace gases, including O3, SO2, NO2, CO, and CH4).

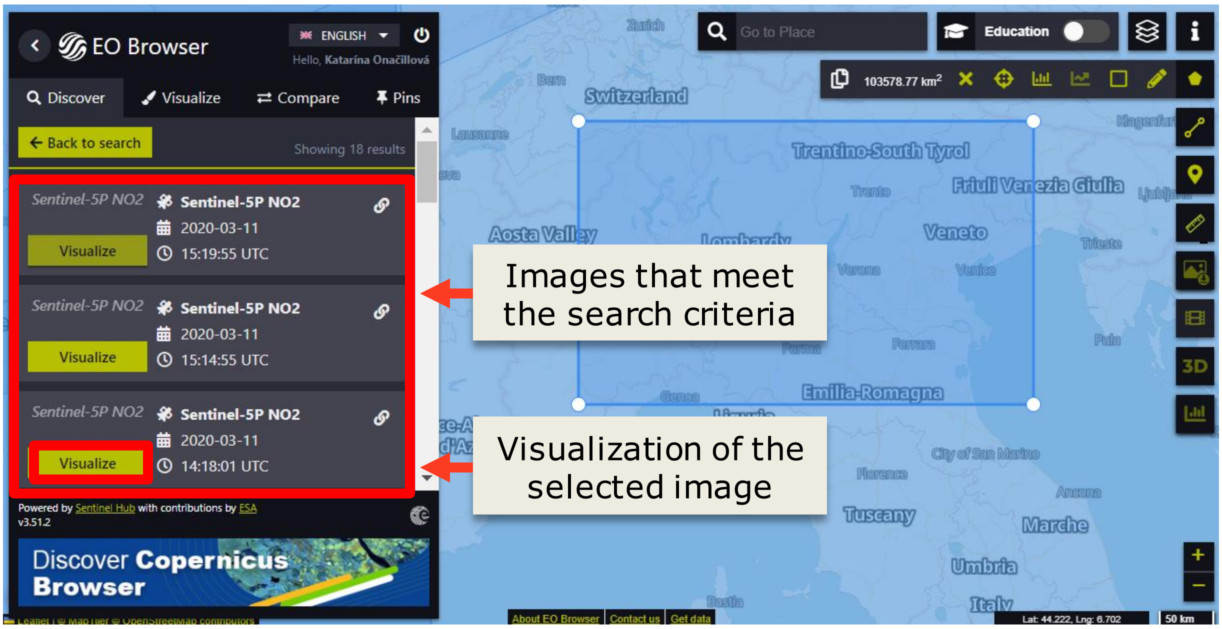
Sentinel-5P played a crucial role also in monitoring changes in air quality during the COVID-19 pandemic. By capturing data on NO2 levels from space, Sentinel-5P helped scientists and authorities assess the impact of lockdown measures on air pollution. The satellite data provided valuable insights into how NO2 concentrations fluctuated in response to changes in human activities and mobility restrictions.



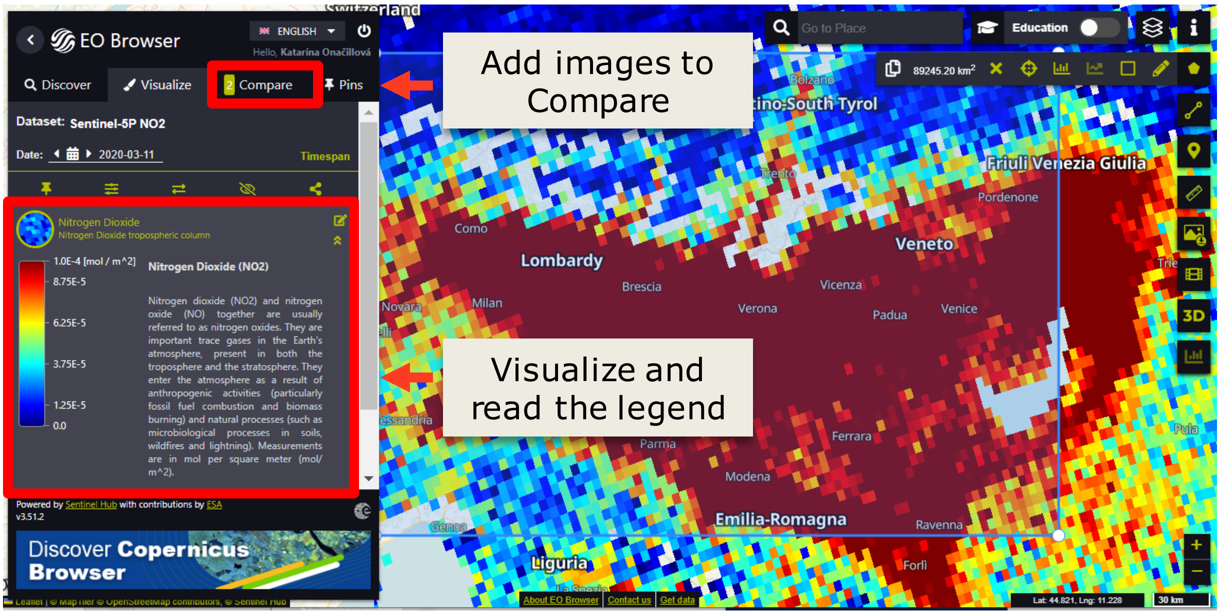
2.1 NO2 mapping with EO Browser

1. Login (register for free) to have full access to all the tools in EO Browser: https://apps.sentinel-hub.com/eo-browser
2. Navigate to the area of northern Italy
3. Create an area of interest using polygon – draw e.g. rectangular shape
4. Select Sentinel-5P sensor and NO2 (Nitrogen dioxide)
5. Define Time range: 2020-03-11 to 2020-04-11
6. Click Search.
7. Search for the first image from 2020-03-11 and visualise it

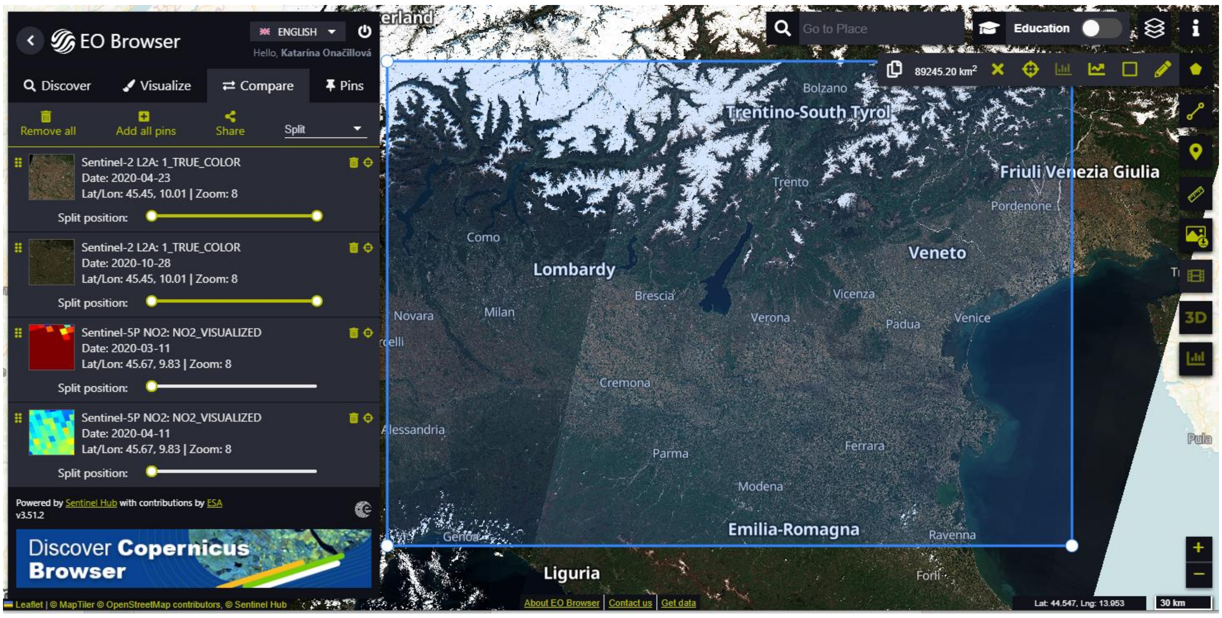




8. Visualize the legend too
9. Add to Compare the Sentinel-5P NO2 image from 2020-03-11 by using Add to Compare function.
10. Repeat the process with the second image - last search result (2020-04-11), visualize it and Add it to Compare

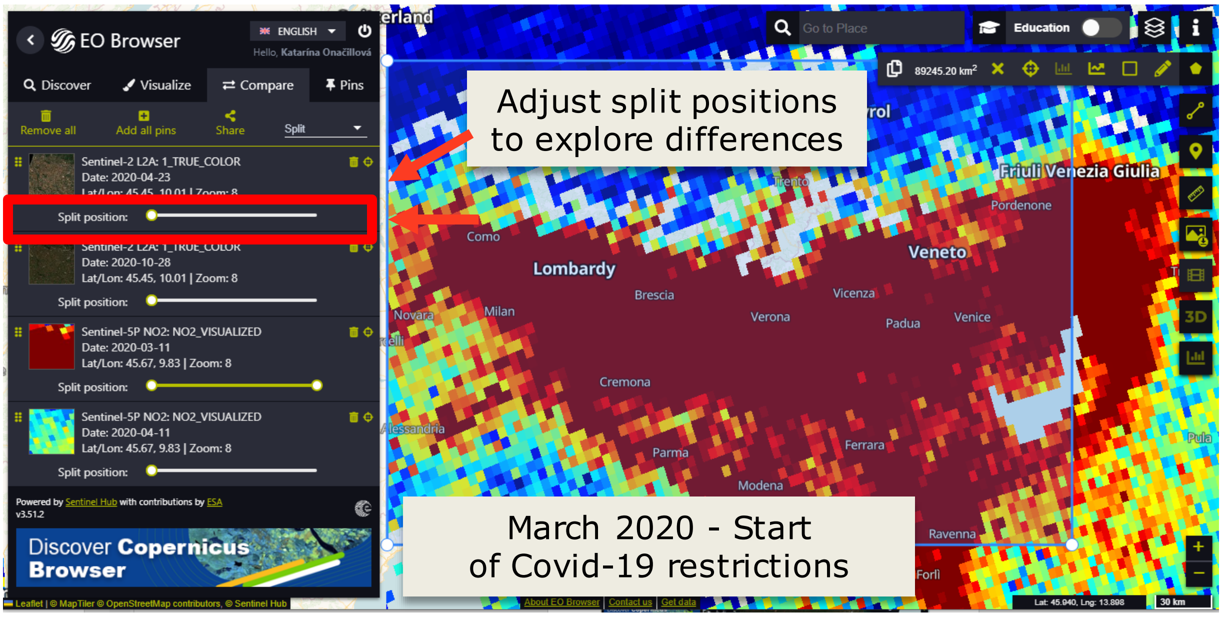


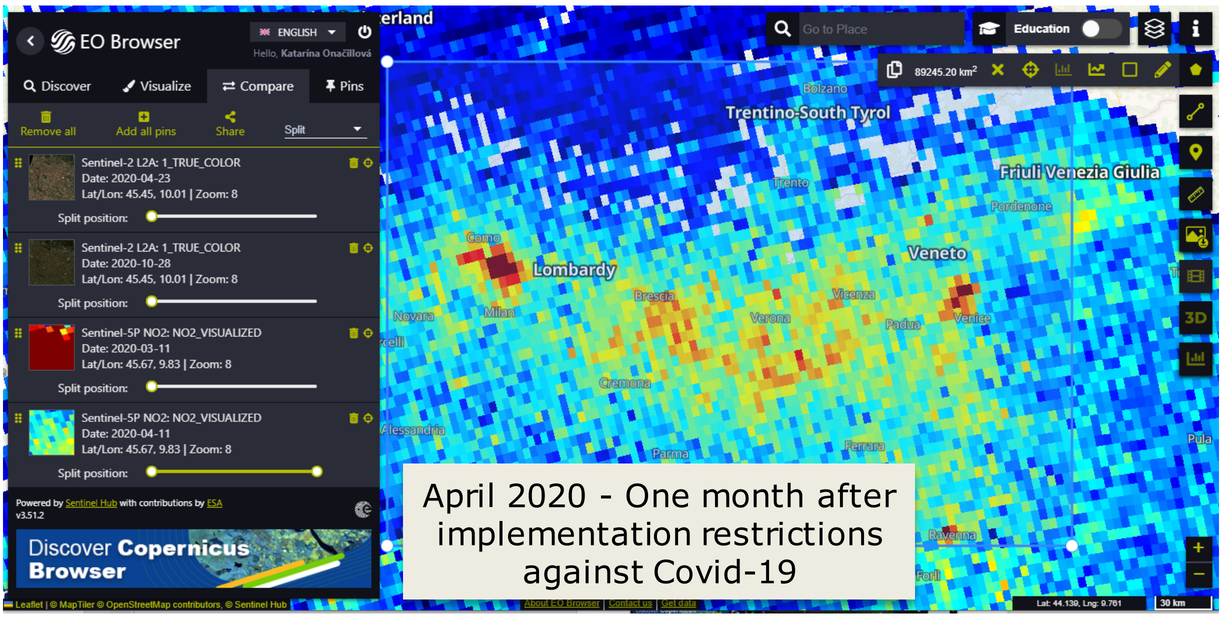
11. Now go back to Search tab and search for suitable cloud-free Sentinel-2 images for the same area of interest (Note: In this case it may be necessary to use two Sentinel-2 images from two different days with overlap – e.g. from 2020-04-23 and 2020-10-28) – Add them to Compare)
12. Open the Compare tab and explore images – NO2 emissions before and during the restrictions against Covid-19 and Sentinel-2 true color compositions



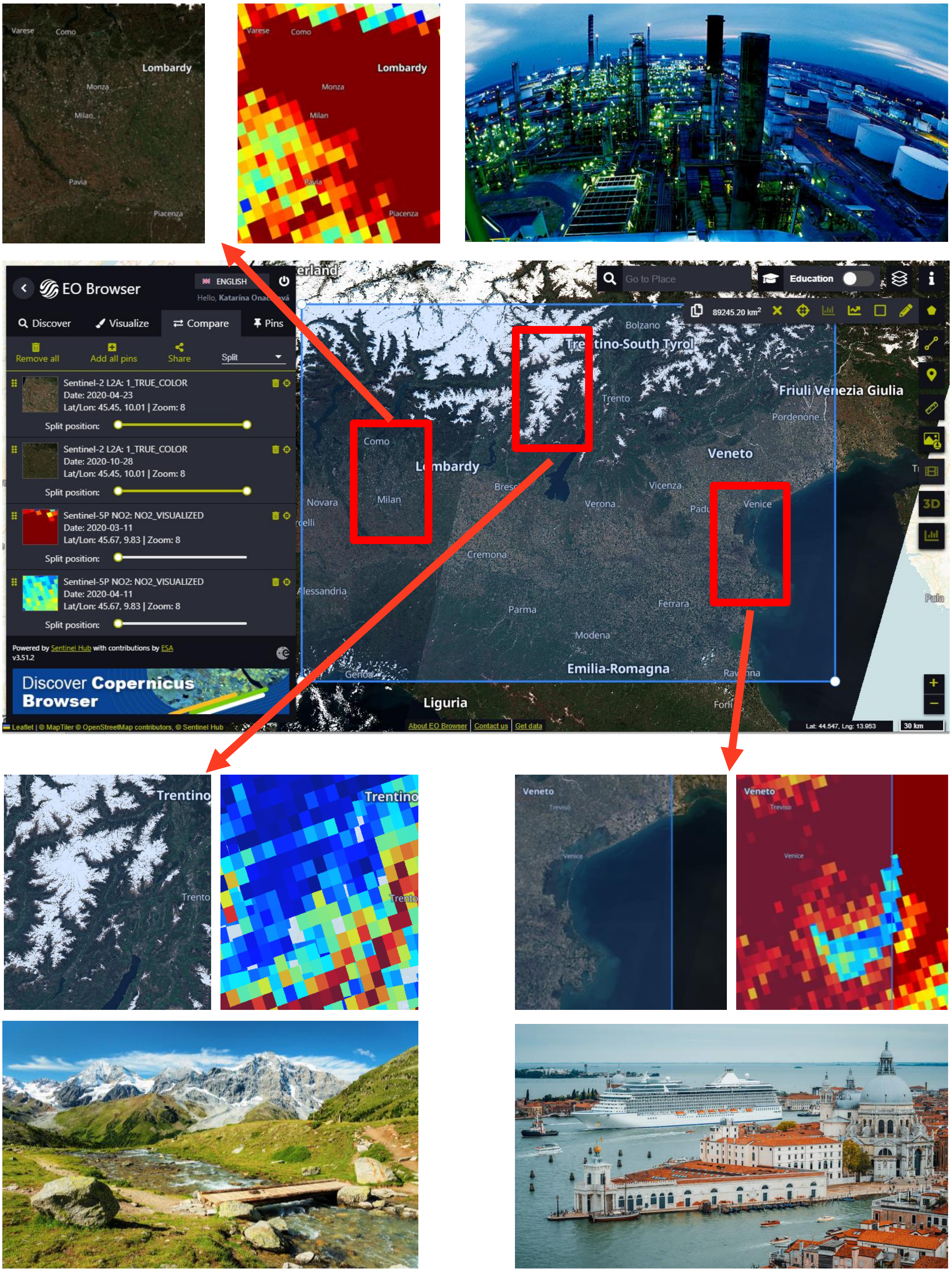
What you are seeing are the NO2 concentrations over Europe as mapped by the satellite Sentinel-5P on March (begging of Covid-19 restrictions) and April (after 1 month with Covid-19 restrictions). NO2 concentrations in clean air are close to 0 (shades of blue) and they only rise when an emission source is present. For example, large amounts of NO2 are released by the burning of fossil fuels so industry and vehicle traffic contribute to high levels of NO2 (shades of orange, red). As you can see in the image, high concentrations can be found mostly in urban areas, e.g. Milan, Treviso, Brescia, Verona. Milan is usually ranked as the worst Italian city in terms of NO2 pollution that often exceeds the mean annual concentration European limit value.

As we can see, one month after the restrictions hold against Covid-19 made an impact visible on concentrations of NO2. The satellite data provided valuable insights into how NO2 concentrations fluctuated in response to changes in human activities and mobility restrictions.

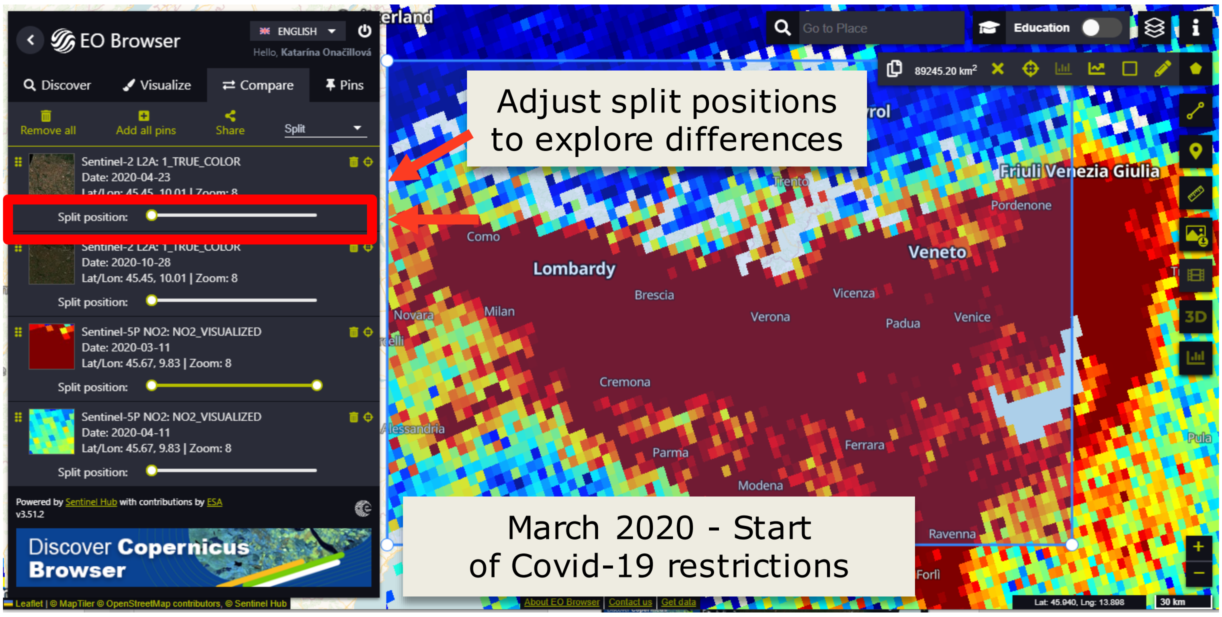




Now let’s explore also data from Sentinel-2 for better understanding of the scene. The Sentinel-5P image covers a larger area than the Sentinel-2 image. Therefore we use two Sentinel-2 images, which loverlap only a bit with each other, and which allow us to cover a larger part of Italy when we put them together. In this way we have more areas of comparison between the two satellites.



Note: Observe also that many pixels in the image are empty. That is because these pixels couldn't be retrieved for example due to clouds. Since the pixels are also quite large (one S-5P pixel covers an area of 7km*7km) it gets difficult to interpret this image. Let's use data from Sentinel-2 for better understanding of the scene.



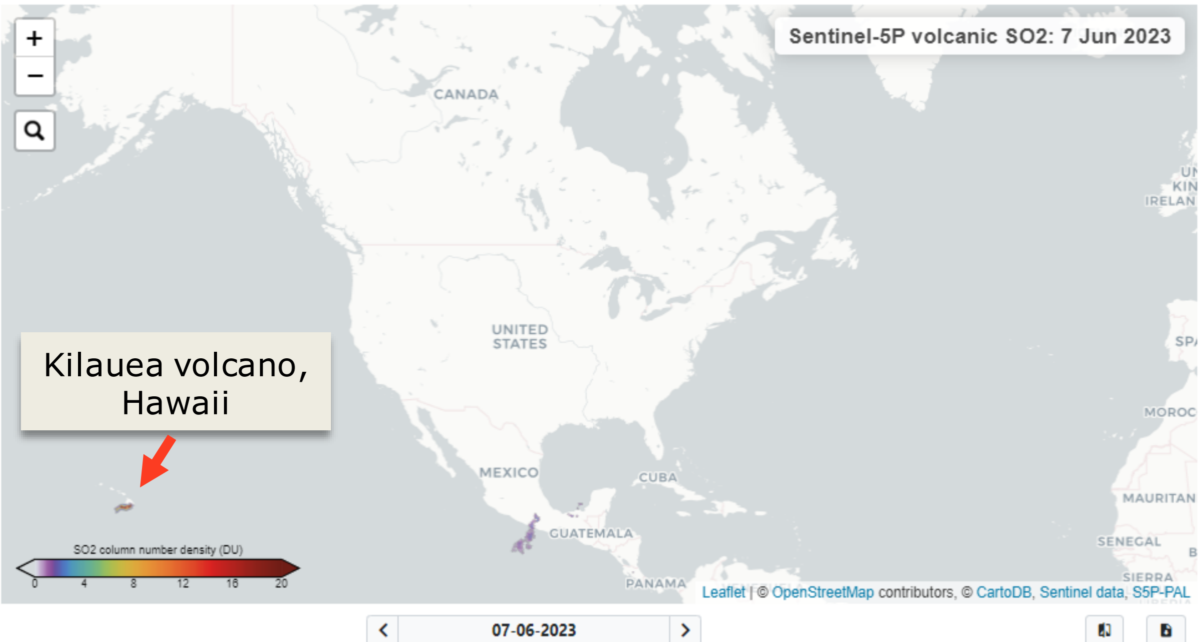
2.2 Monitoring volcanic emissions with Sentinel-5P

Volcanic eruptions are potent agents of change, impacting nearby landscapes and water. They can temporarily alter the Earth's climate by releasing sulfuric acid droplets into the stratosphere. Proximity to volcanoes may necessitate permanent evacuations, and even distant areas may experience damage to cities, crops, etc.

Ninety-nine percent of the gas molecules released during a volcanic eruption consist of water vapor (H2O), carbon dioxide (CO2), and sulfur dioxide (SO2). The remaining one percent comprises small quantities of hydrogen sulfide, carbon monoxide, hydrogen chloride, hydrogen fluoride, and other minor gas species, as noted by the US Geological Survey (USGS).

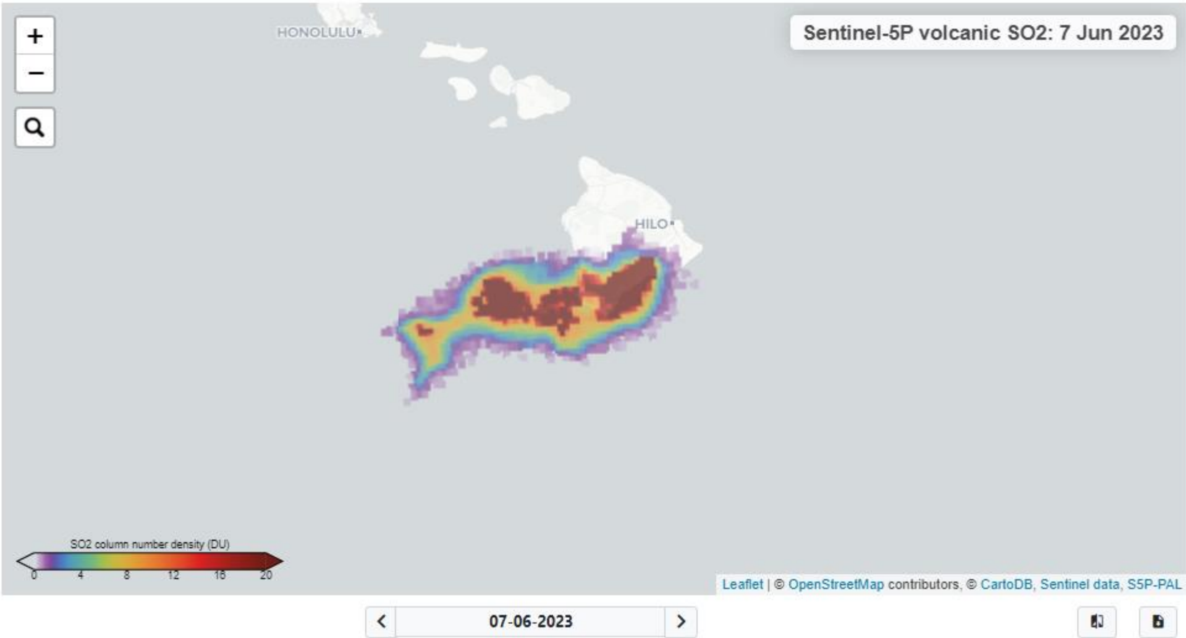
Copernicus Sentinel-5P Volcanic Sulfur Dioxide

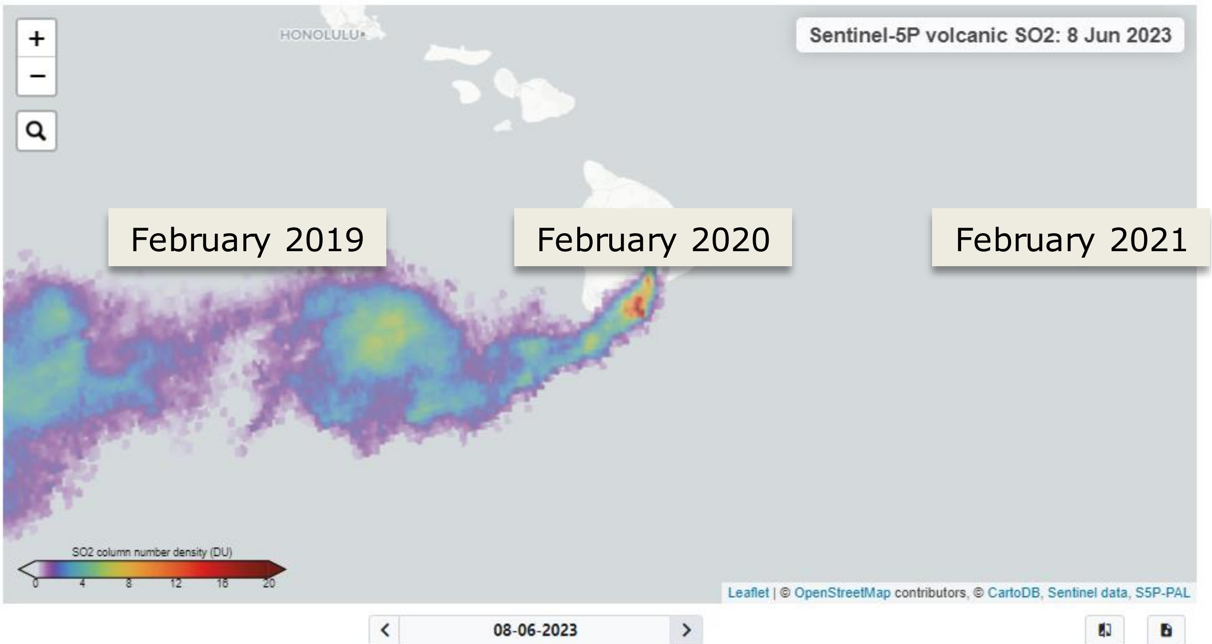
Maps of volcanic SO2 concentrations



This online platform uses data from the Copernicus Sentinel-5P satellite and shows the daily sulfur dioxide concentrations coming primarily from volcanic sources.

Lava flows in the Halema'uma'u crater among several active vent sources as the Kilauea volcano erupts in Hawaii on June 7, 2023.

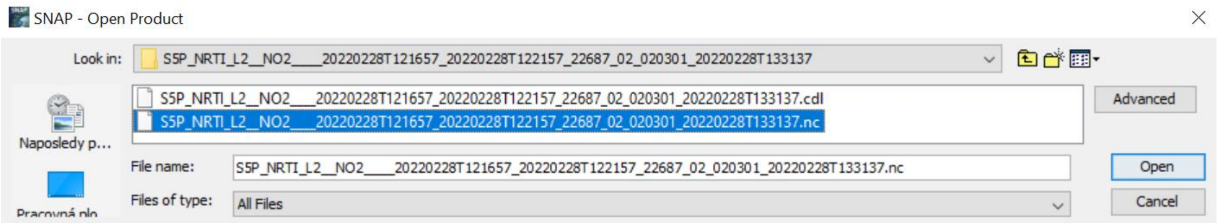




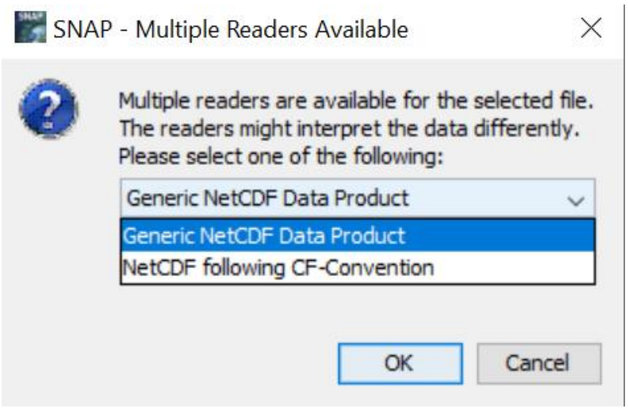
2.3 NO2 mapping in SNAP

Let´s explore NO2 concentrations over Europe in SNAP:

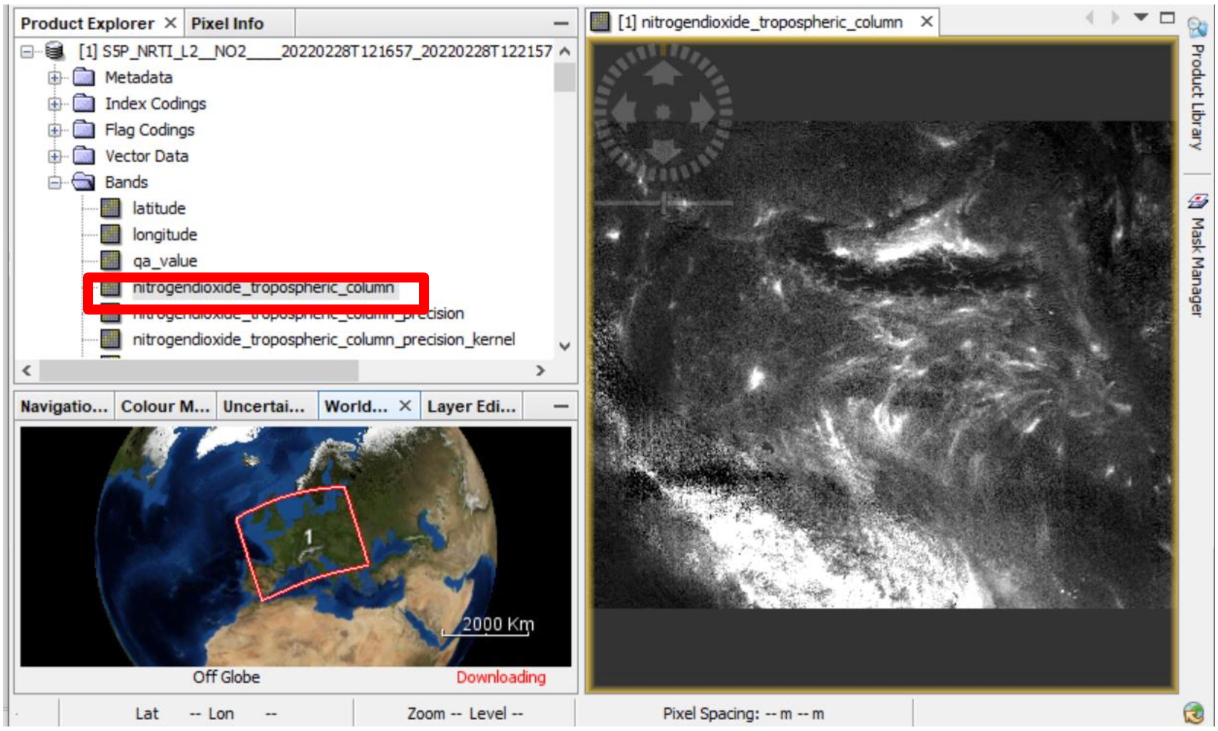
We can open a Sentinel-5P image navigating to File – Open Product – open the product with the .nc extension:



Select one of the following readers for the selected sile to open it.

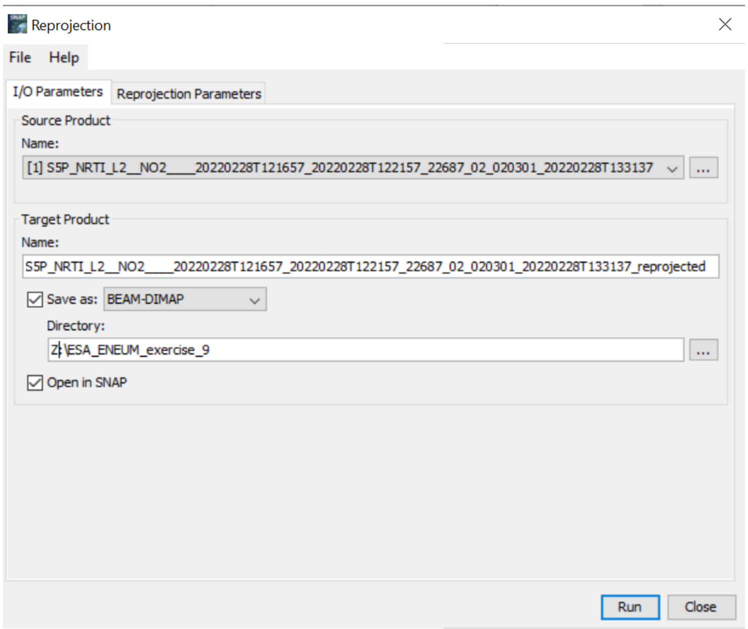


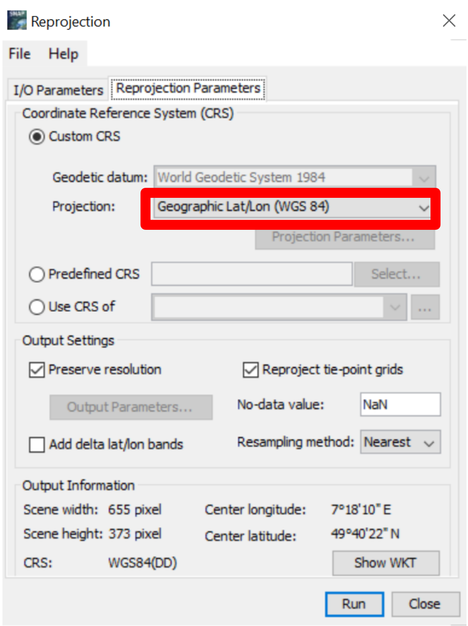
Double click on selected layer that we want to visualise



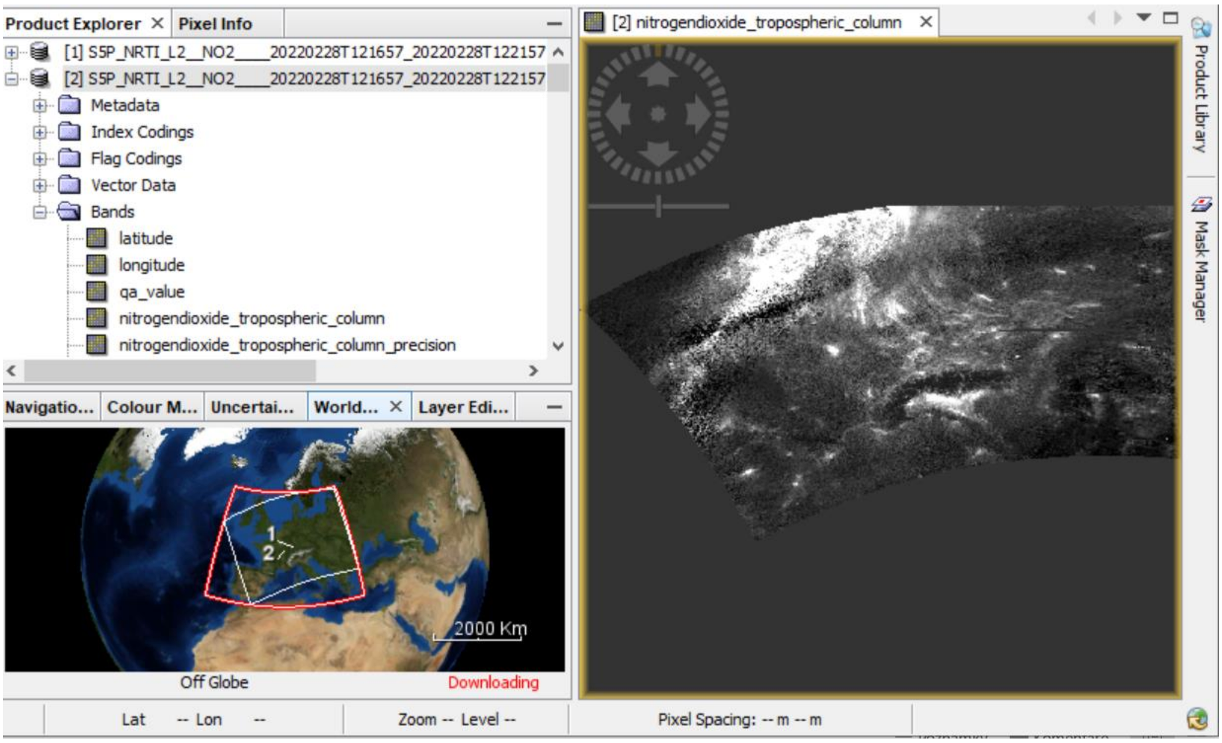
Raster – Geometric – Reprojection

Select Custom CRS – WGS84:



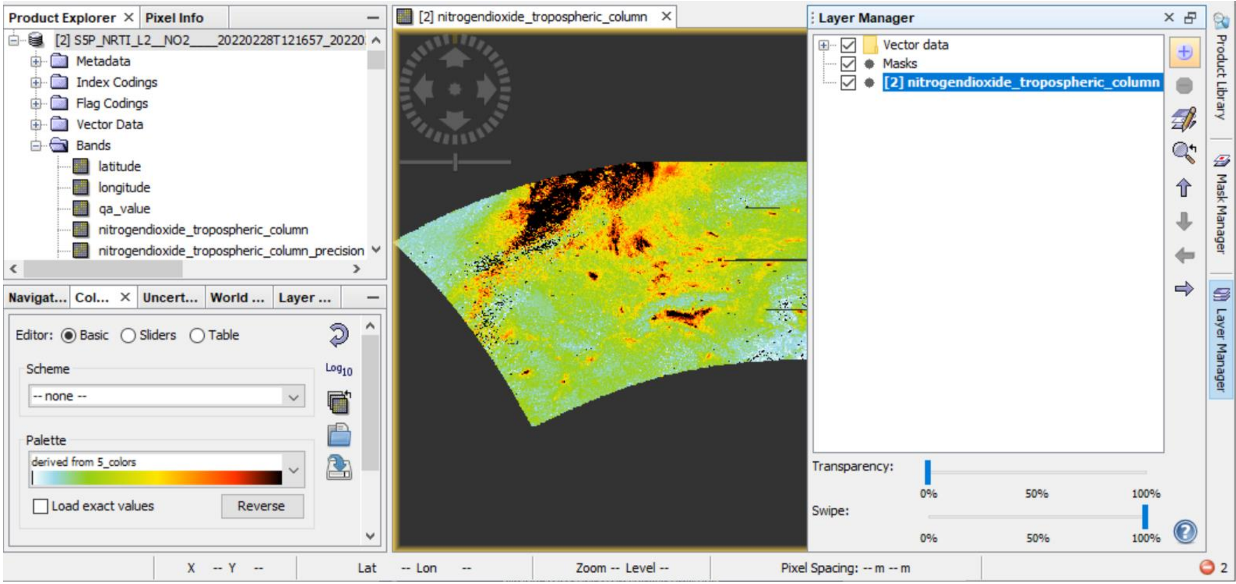


Let´s open new reprojected product

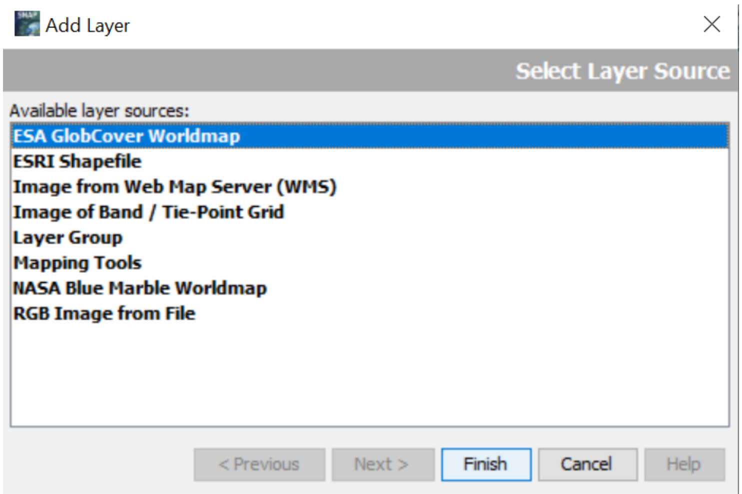


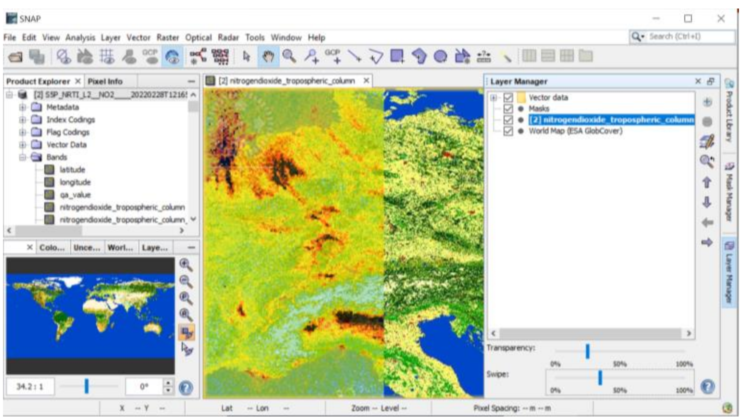
Raster – Geometric – Reprojection

Select Custom CRS – WGS84:



Let´s open new reprojected product. View the final NO2 raster in QGIS. Compare it with e.g. land cover mask.

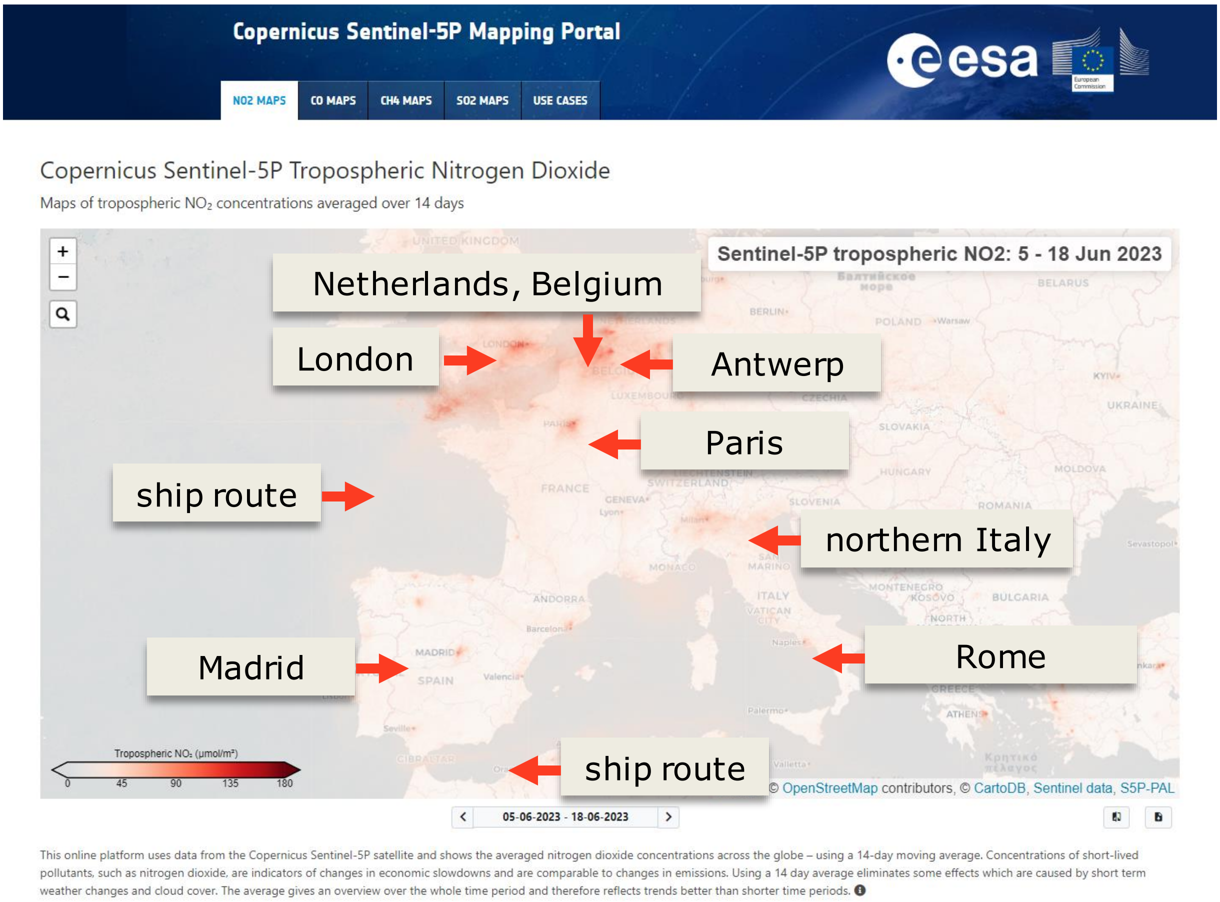




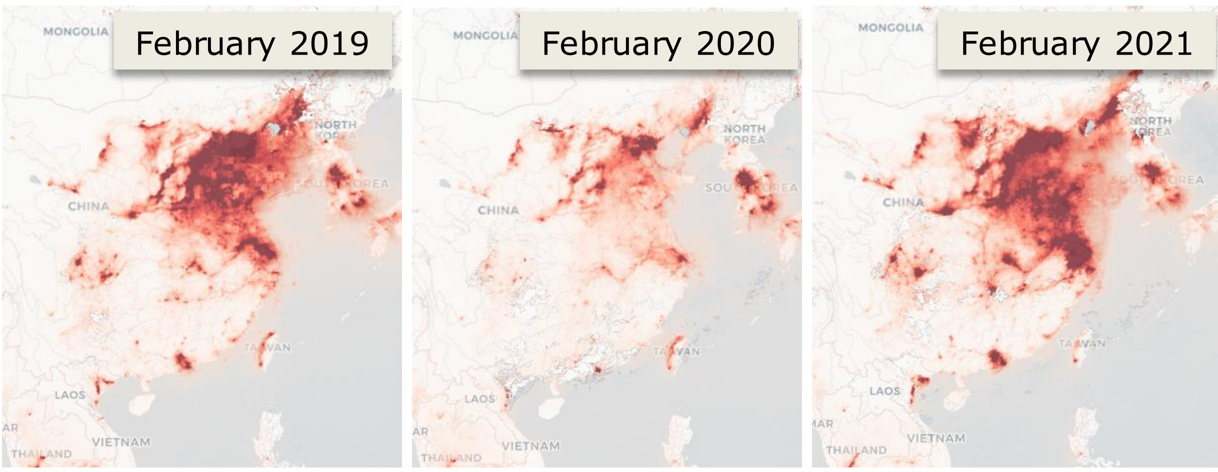
2.4 NO2 mapping with Copernicus Sentinel-5P Mapping Portal

Let´s explore NO2 concentrations over Europe using Copernicus Sentinel-5P Mapping Portal:

Try to identify cities, regions with high concentrations of NO2 and ship routes according NO2 concentrations on the map.



Let´s explore NO2 concentrations over China using Copernicus Sentinel-5P Mapping Portal:



For more information, see the lecture: [9. Air quality monitoring using Sentinel-5 data]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 10 – TUTORIAL

Land surface temperature mapping using Sentinel-3 data using SNAP software

FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

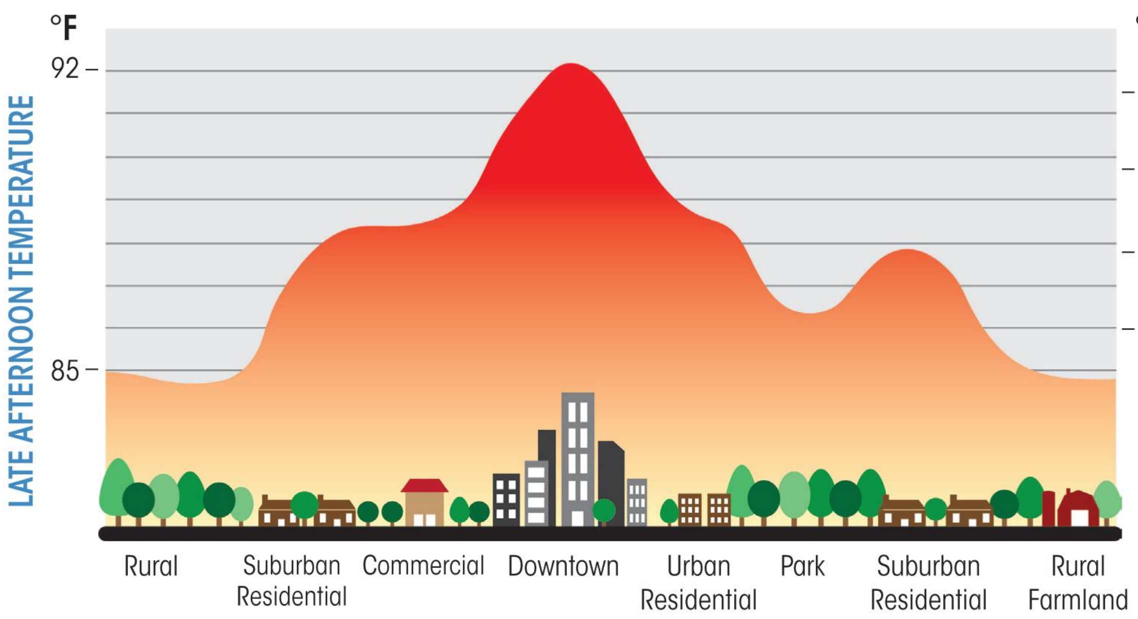
- learn about the phenomenon Urban Heat Island
- use Sentinel-3 LST product to analyse and classify surface temperature
- use land cover / land use band for extraction of land temperature
- extract the mean temperature by Pin placing tool and SNAP Statistics tool
- visualize the resulting Urban Heat Island map clipped on an interesting area

2 | Background

Urban heat islands are regions within cities that encounter higher temperatures compared to their surrounding areas. The presence of structures like buildings and roads, along with limited greenery, causes urbanized zones to absorb and release solar heat more efficiently than natural landscapes. This concentration of structures in urban areas leads to the formation of "islands" with higher temperatures, where daytime temperatures can be 1-7°F higher and nighttime temperatures approximately 2-5°F higher than those in the adjacent areas.

Urban areas, marked by high population and construction density, face challenges related to waste heat and Urban Heat Islands (UHIs). As cities expand vertically with skyscrapers, trapped heat from construction accumulates within UHIs. During nighttime, UHIs retain higher temperatures due to obstruction of upward heat movement by buildings and infrastructure, creating a warmer environment.

Furthermore, UHIs exhibit worse air and water quality compared to rural areas. The dense concentration of pollutants, originating from vehicles, industry, and human activities, results in lower air quality.

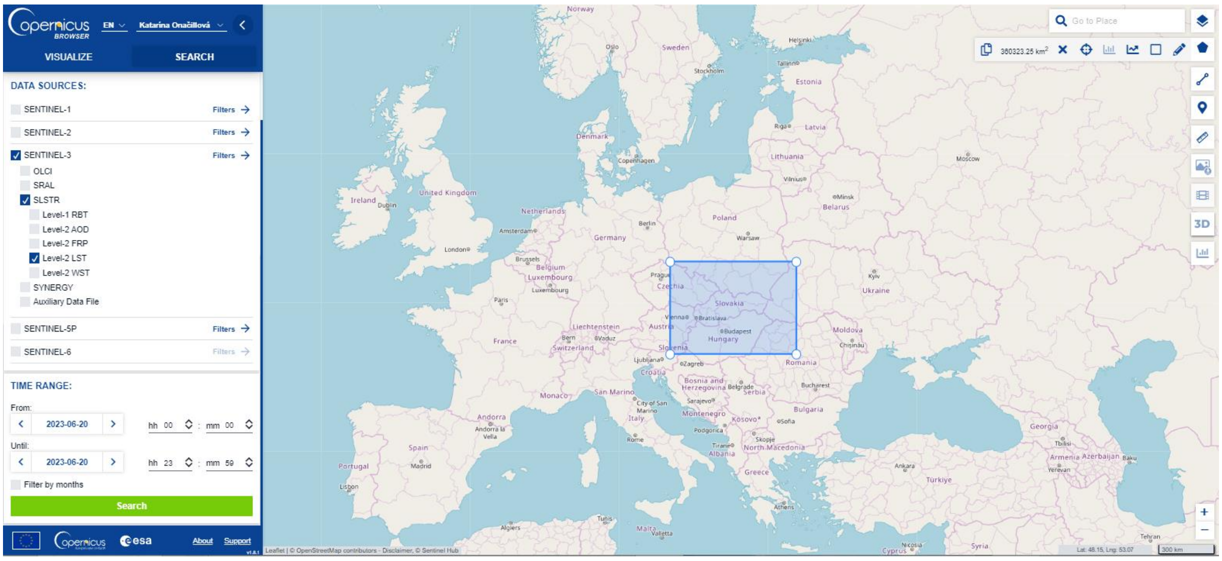


2.1 Study area and data used

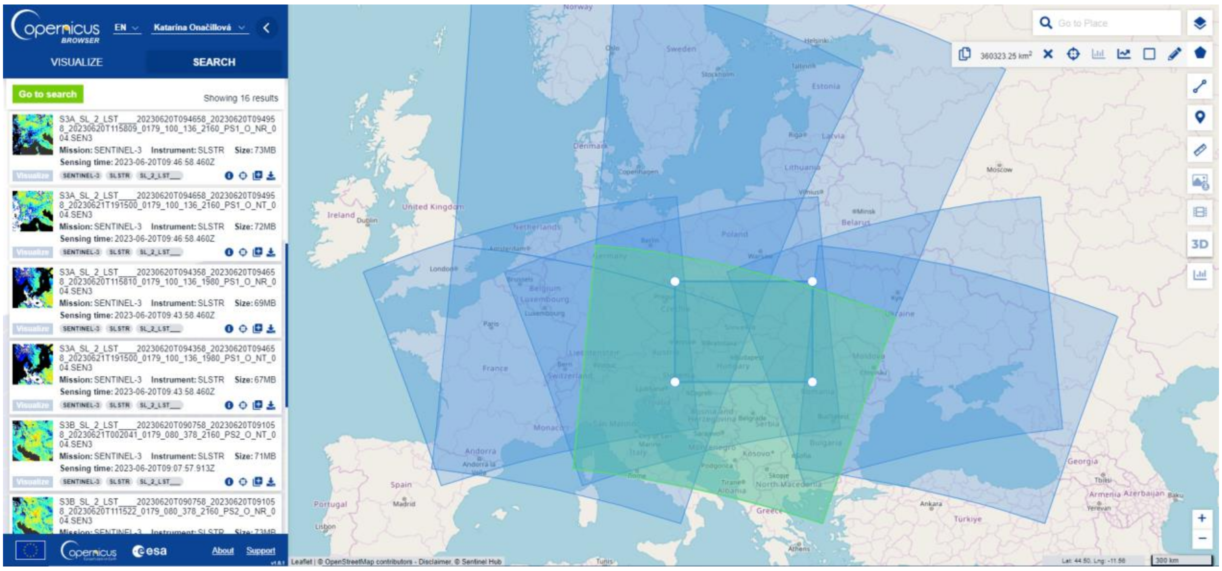
In this exercise, we will analyse Sentinel-3B image acquired during June 2023 and downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].

Navigate to the area of Slovak republic, create an area of interest by clicking on the icon in the upper right corner of the map and draw a rectangle as indicated below.

In the search menu on the left specify the following parameters and press the search button:
Data source: Sentinel-3 – SLSTR – Level-2 LST
Sensing period: From 2023/06/20 to 2023/06/20



In our case, the search returns 16 results (day and night acquisitions). Search for those that cover the entire area of the Slovakia and download them (if needed).



Download the day product by clicking on the arrow icon. Note the different sensing times of the images:

S3B_SL_2_LST____20230620T090758_20230620T091058_20230621T002041_0179_080_378_2160_PS2_O_NT_004.SEN3 (day acquisiton)

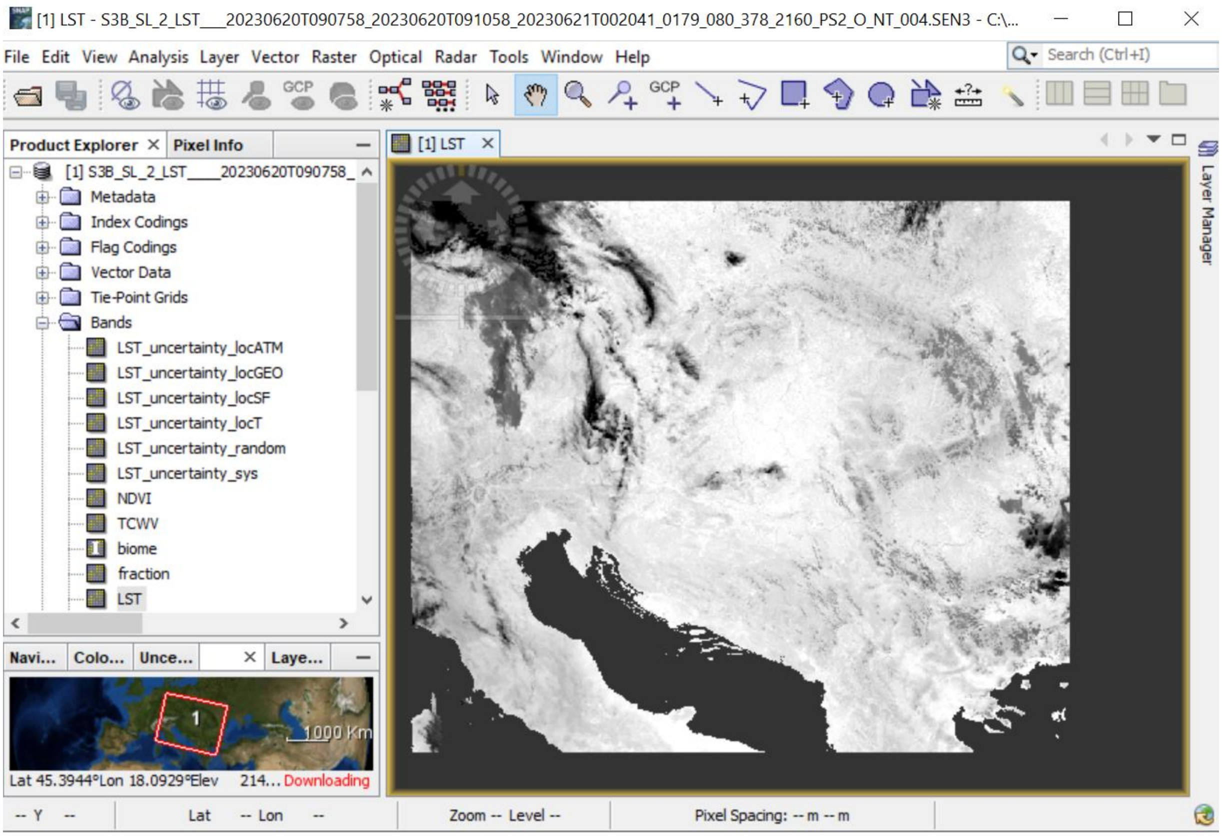
Once downloaded, move it to your folder for this exercise and unzip it.

2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and navigate to the folder where you saved your downloaded products and open the day-time Sentinel-3 product from 2023-06-20:
S3B_SL_2_LST____20230620T090758_20230620T091058_20230621T002041_0179_080_378_2160_PS2_O_NT_004.SEN3

Open the folder and select the file xfdumanifest.xml. Then, click OK.

In the Product Explorer, expand the product by clicking in the left arrow. Expand now the Bands folder and double click on the band LST to visualize it.

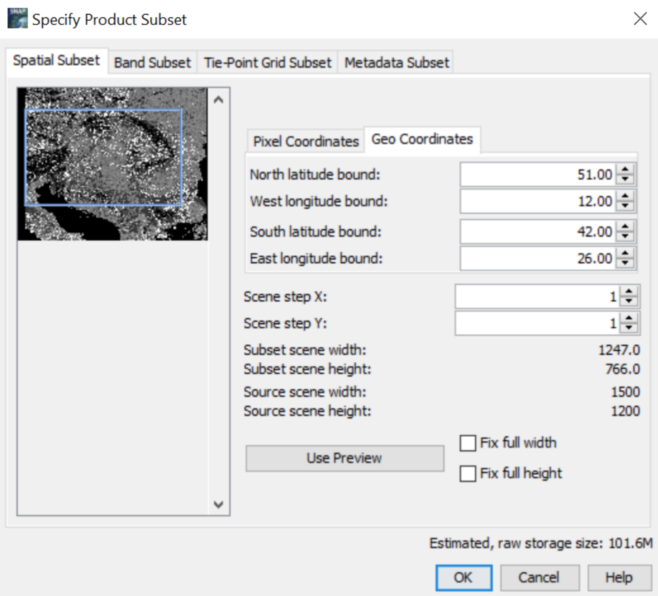


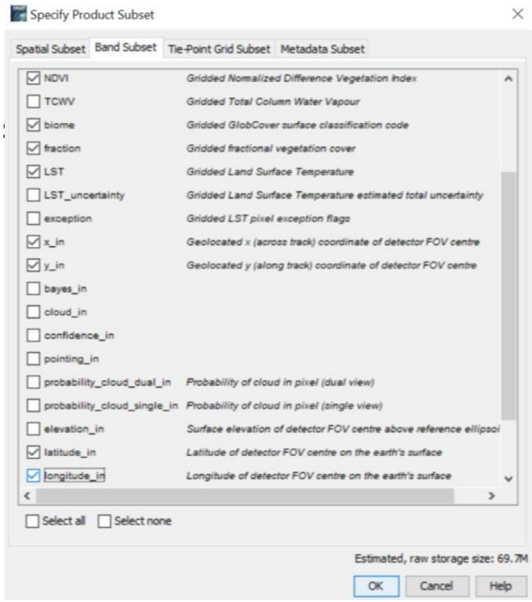
2.3. Subset

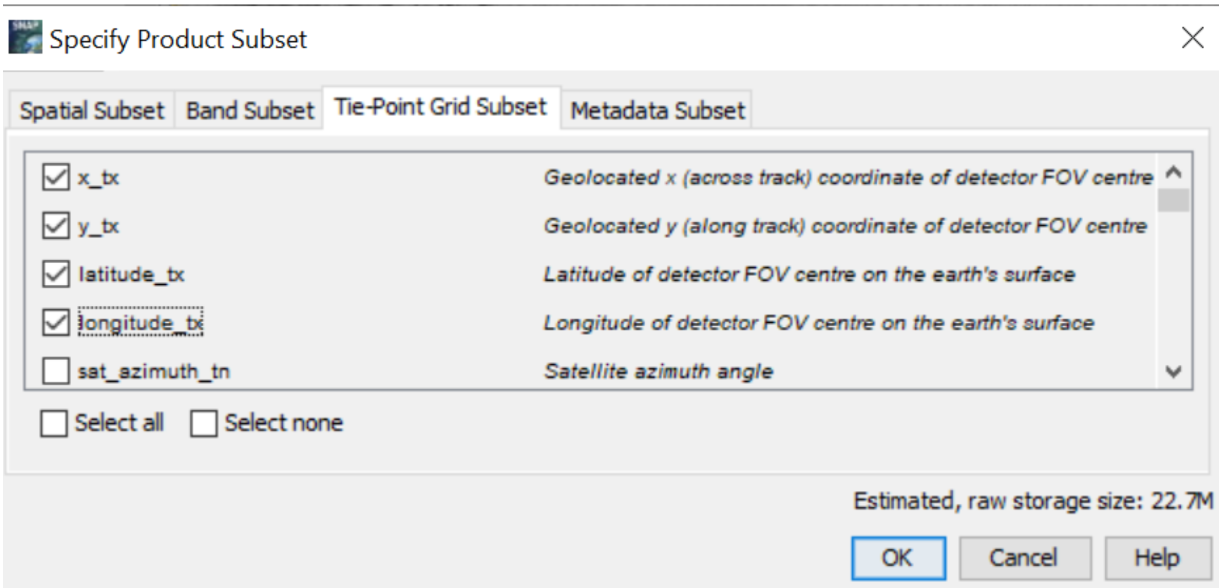
The initial phase of the methodology involves reducing the original size and number of bands in the image. To accomplish this, choose the Sentinel-3 SLSTR product in the Product Explorer, then proceed to Raster -> Subset. Within the Spatial Subset tab, select Geo Coordinates and input the specified values:

North latitude bound: 51.00
West longitude bound: 12.00
South latitude bound: 42.00
East longitude bound: 26.00

In the Band Subset tab, opt for the bands NDVI, biome, fraction, LST, x_in, y_in, latitude_in, and longitude_in. In the Tie-Point Grid Subset tab, choose only the bands x_tx, y_tx, latitude_tx, and longitude_tx. Then, click OK (responding with No to the pop-up flag dataset window).



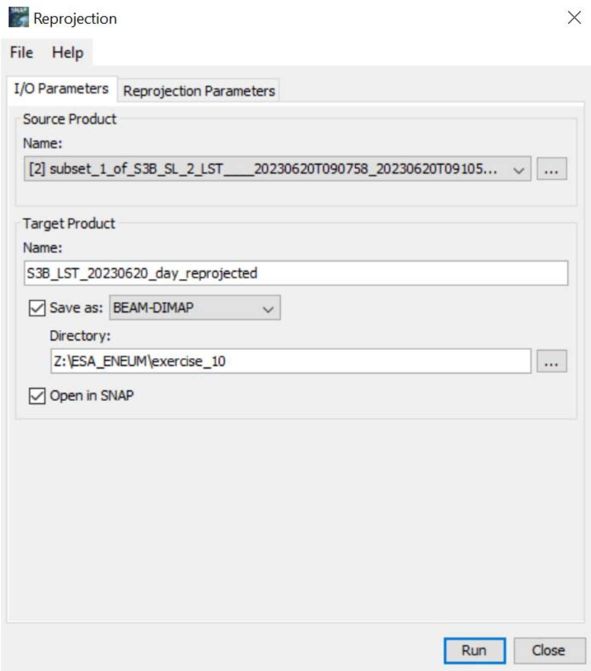


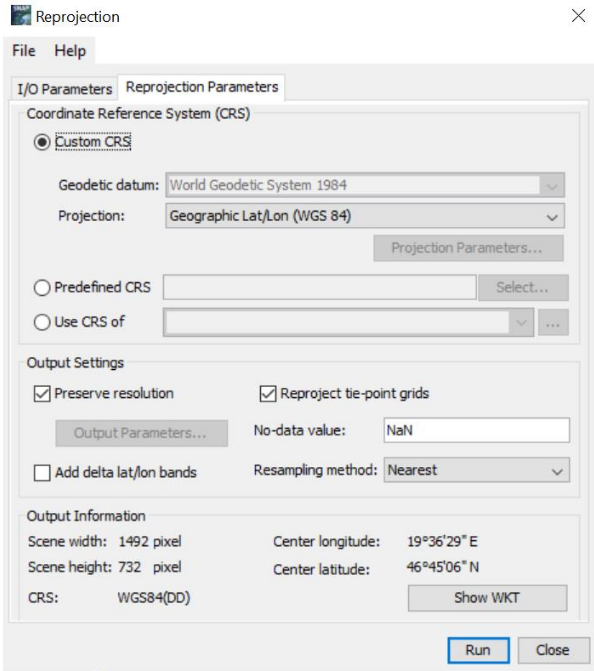


Upon completion, the subset product will be visible in the Product Explorer. It is essential to save it by right-clicking on it and selecting Save Product. Confirm the saving process by clicking YES in the ensuing pop-up window.

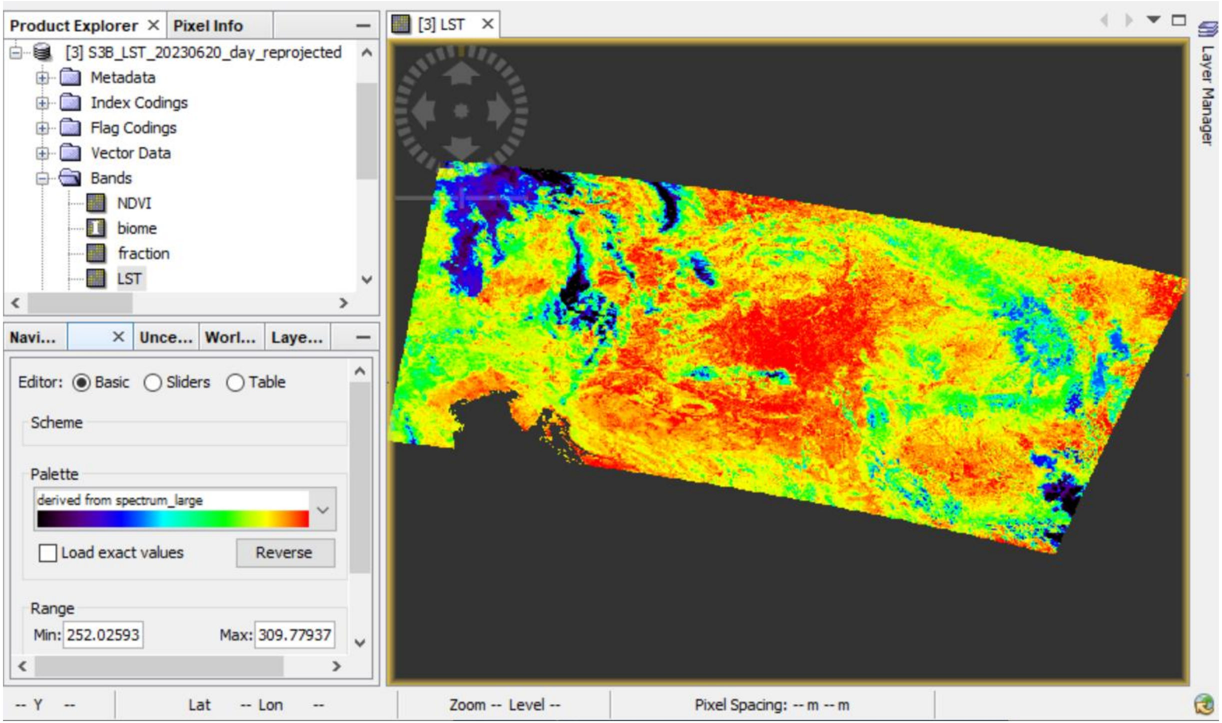
2.4 Reprojection

Proceed to reproject the Sentinel-3 SLSTR product using an appropriate map projection. Navigate to Raster -> Geometric -> Reprojection.
In the I/O Parameters tab, ensure that you choose the subset product as the input. Modify the output name to e.g. "S3B_LST_20230620_day_reprojected" and set/confirm that the output directory.
Within the Reprojection Parameters tab, access the Projection drop-down menu, and opt for UTM/WGS 84 (Automatic). Subsequently, click on Run.



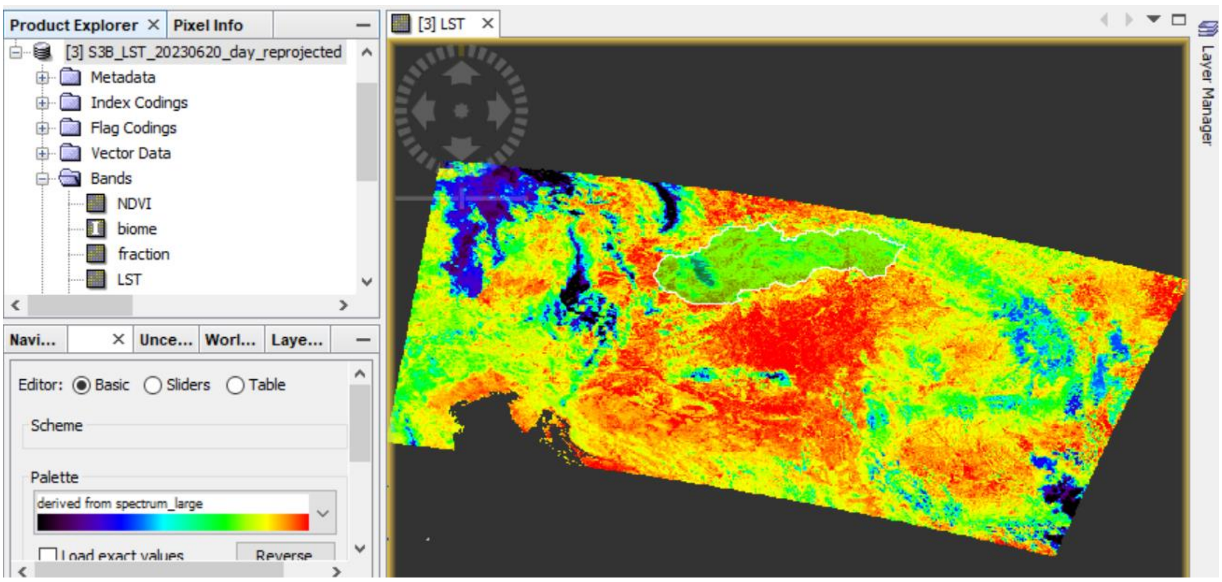


Within the Product Explorer, expand the reprojected product by selecting the left arrow. Expand the Bands folder, and double-click on the LST band to view it.
Access the Colour Manipulation tab, choose Basic as the Editor, and click on the e.g. „derived from spectrum_large" color ramp

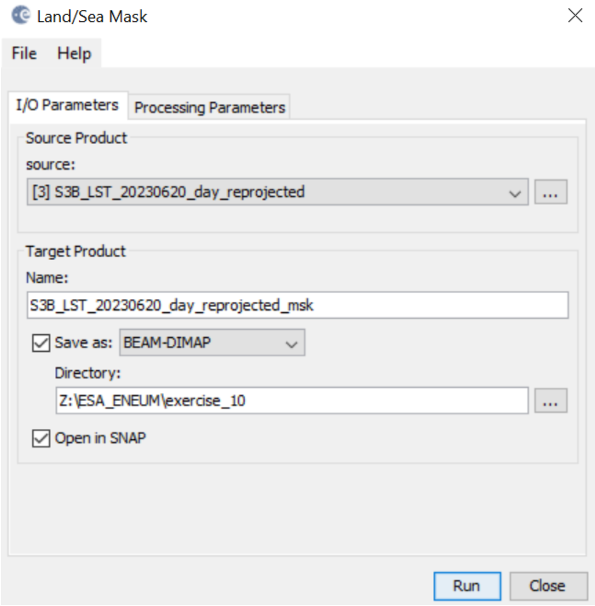


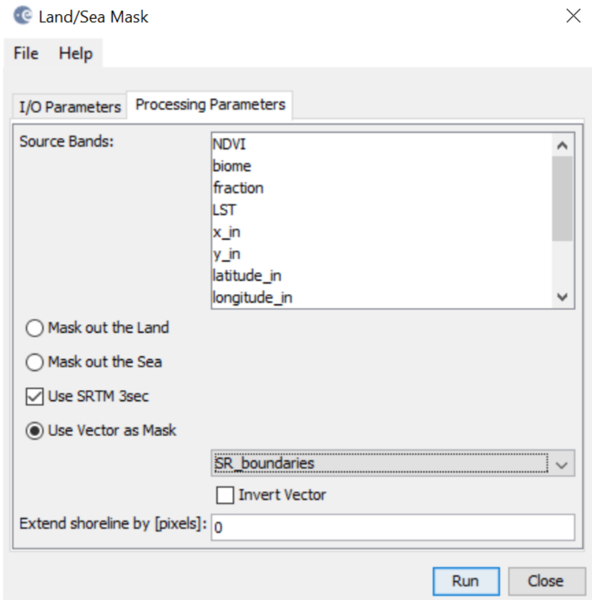
2.5 Clip by mask

Now let´s focus on the smaller area of interest, e.g. territory of the Slovak Republic. Choose the last Sentinel-3 reprojected product in the Product Explorer, then proceed to File – Import – Vector data – ESRI shapefile and open „SR_boundaries.shp" file that you have in the folder for this exercise. Once imported, this layer should appear within the product Vector data and also on the visualized LST image.

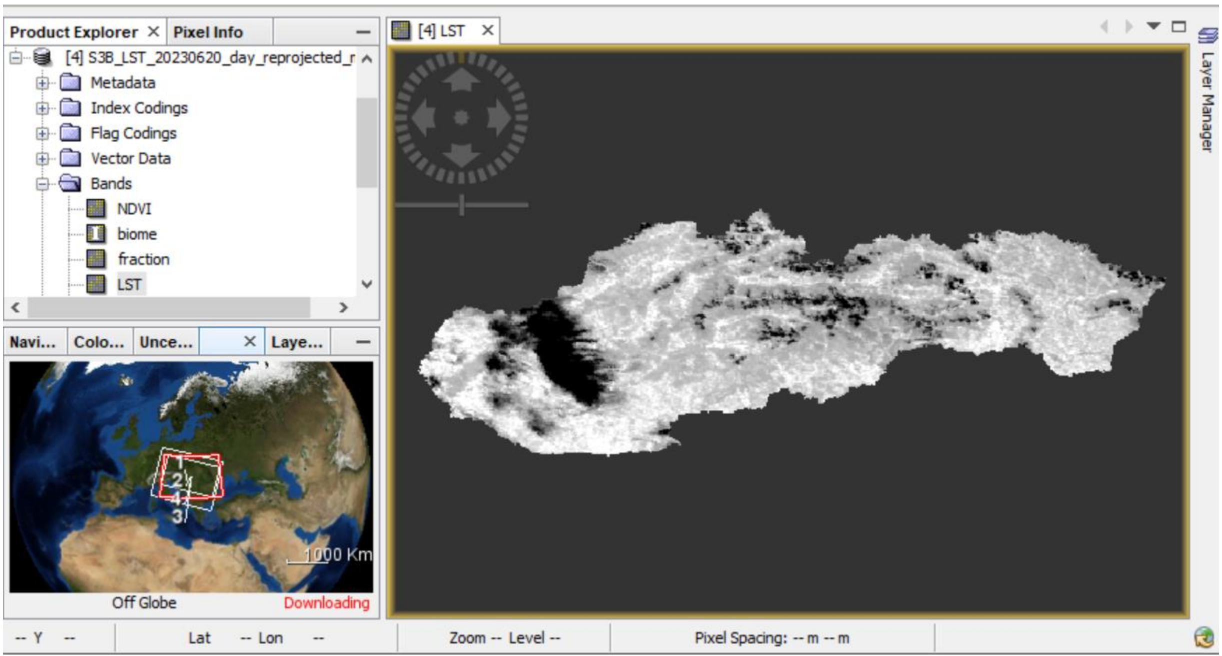


Now navigate to Raster – Masks – Land/Sea Mask. In the I/O Parameters tab you can rename the output target product to e.g. "S3B_LST_20230620_day_reprojected_msk" and set the output directory. In the Processing Parameters select the option „Use Vector as Mask“ and „SR_boundaries“ layer according to which the product will be clipped.

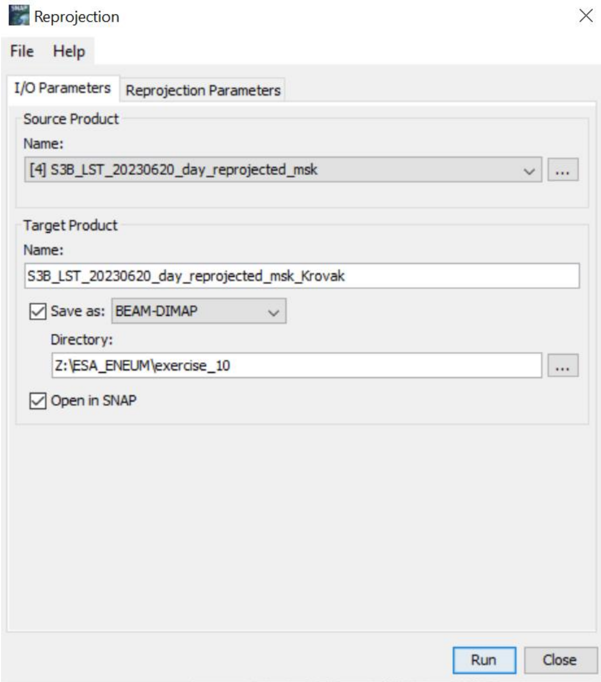


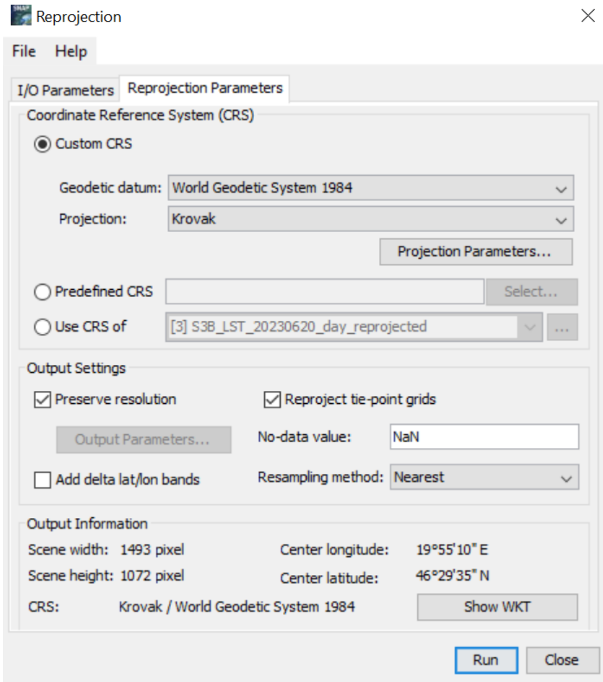


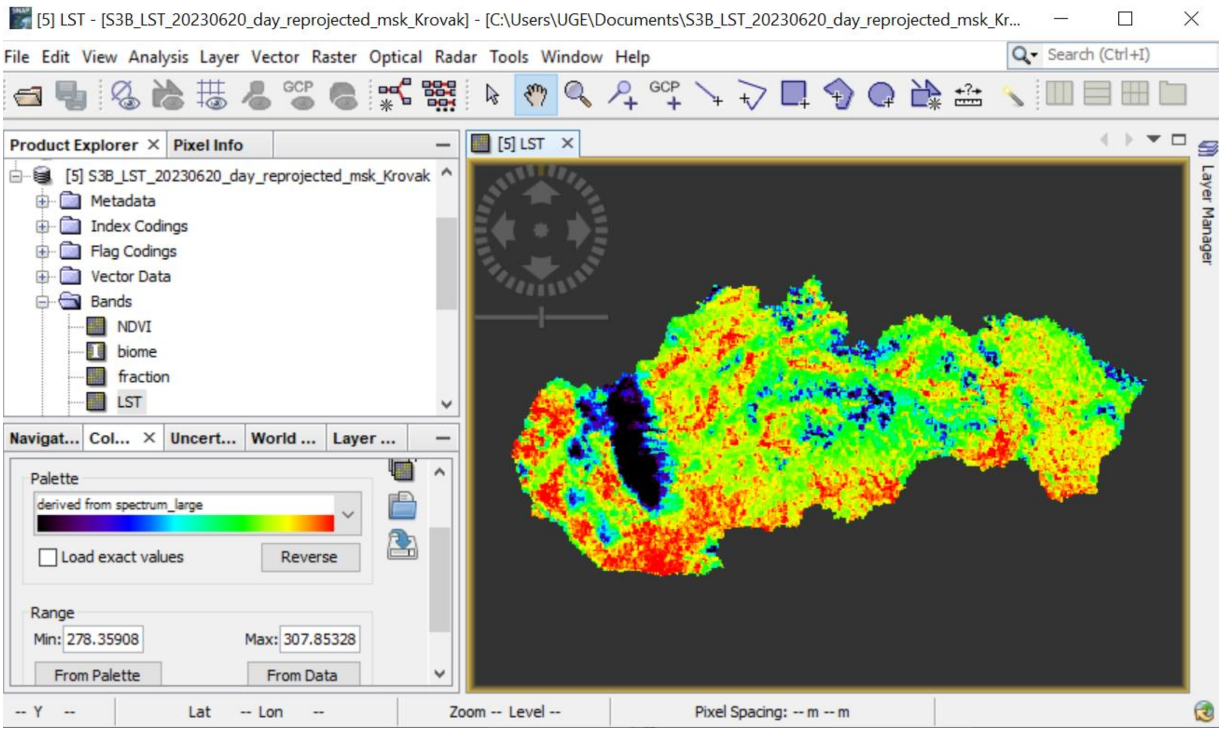
The resulted clipped product of the area of the Slovak Republic can be reprojected to lacal coordinate system using an appropriate map projection. Navigate to Raster -> Geometric -> Reprojection.



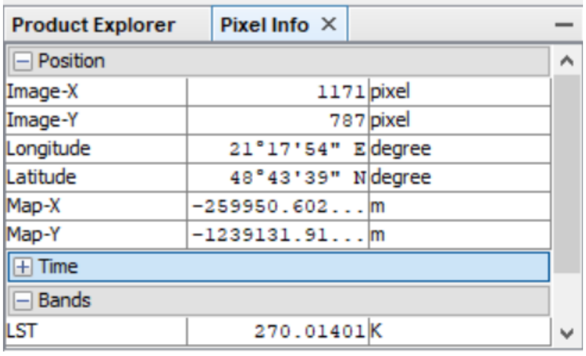
- In the I/O Parameters tab, ensure that you choose the last clipped product as the input. Modify the output name to e.g. "S3B_LST_20230620_day_reprojected_msk_Krovak" and set/confirm that the output directory.
- Within the Reprojection Parameters, access the Projection drop-down menu, and opt for Custom CRS - Krovak. Subsequently, click on Run.
- Within the Product Explorer, expand the final reprojected product by selecting the left arrow. Expand the Bands folder, and double-click on the LST band to view it. Access the Colour Manipulation tab, and choose e.g. „derived from spectrum_large" color ramp







Explore the temperatures (in Kelvins). Click on the Pixel info tab and move the mouse over the images to analyse pixel values.

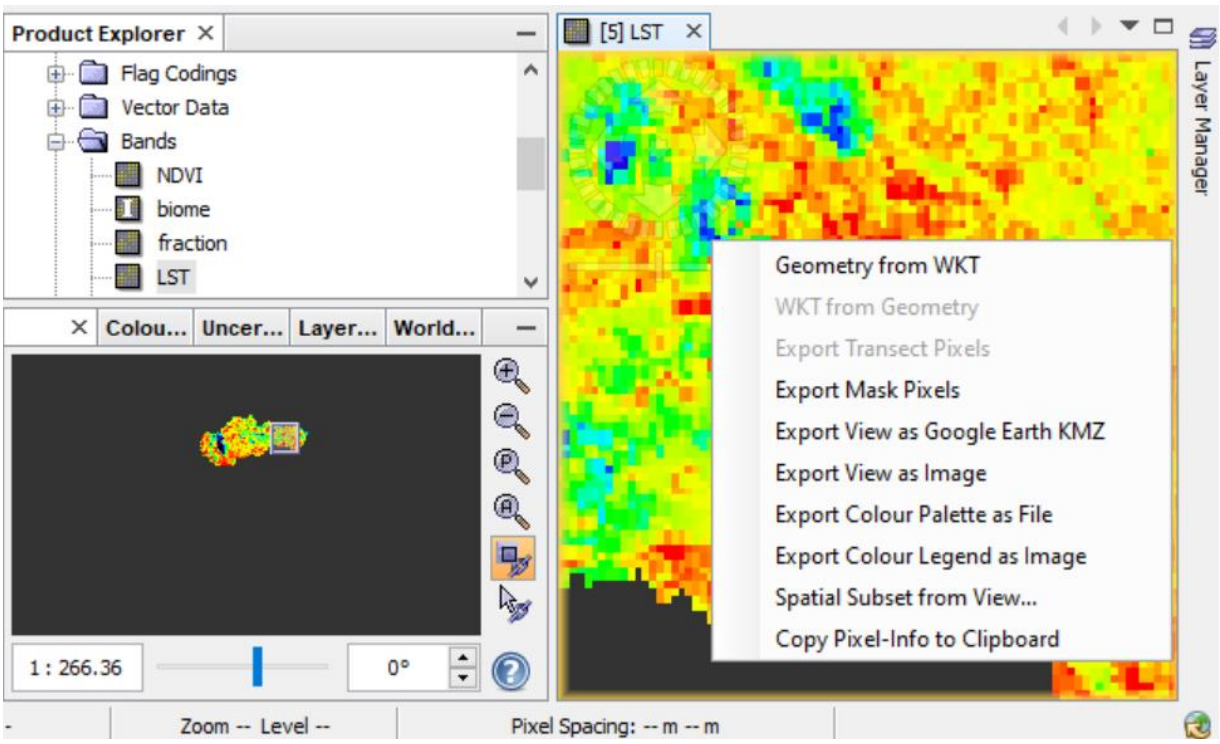


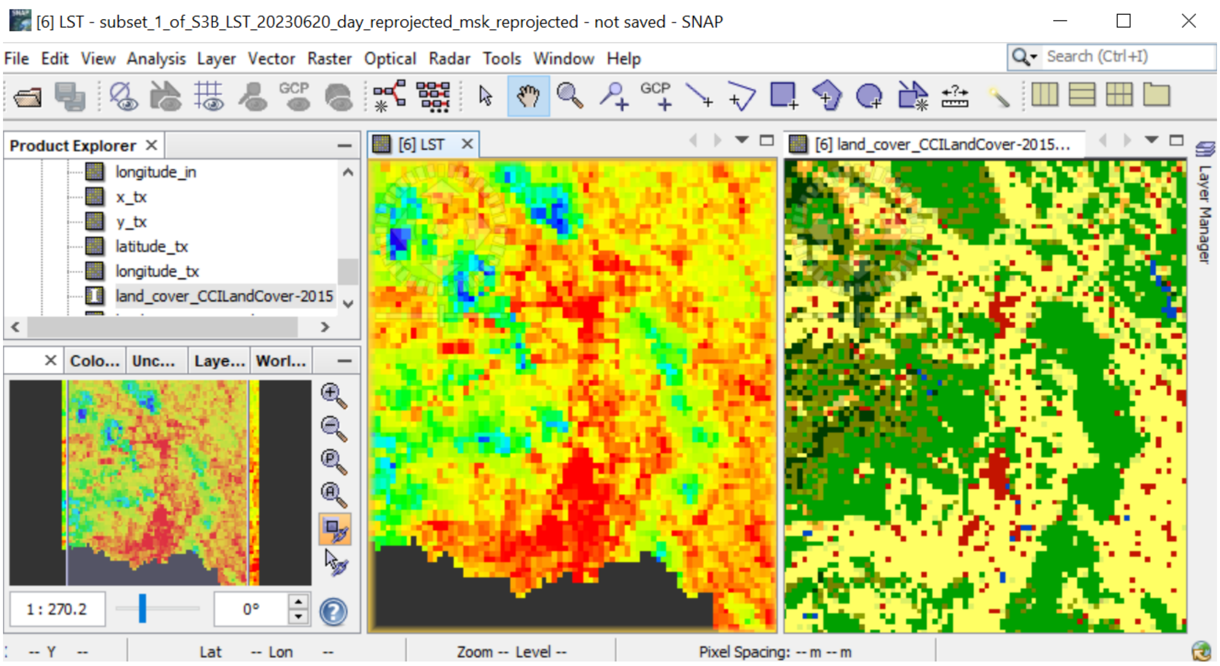
2.6 Add Land Cover Band

After comparing the temperature values (in Kelvin) during the day and night acquisitions, proceed to close the day product. In order to better identify the influence of urbanised areas on temperature, subtract the average temperature of non-urban areas near Košice.

To facilitate this, create smaller subset of day image – zoom into the vicinity of the Košice city, estern Slovakia – right click on the view – Spatial Subset from View... OK.

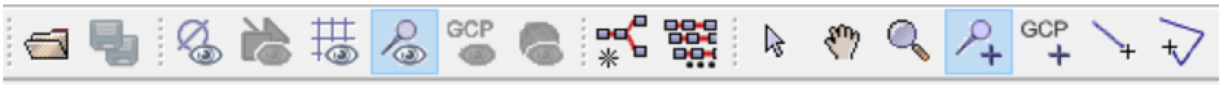
Then, open the LST layer from Bands of newly created subset and add a land cover band to distinguish various land cover and land use types. To do this, right-click on the day product, choose "Add Land Cover Band," navigate to CCILandCover-2015 in the menu, and click OK.



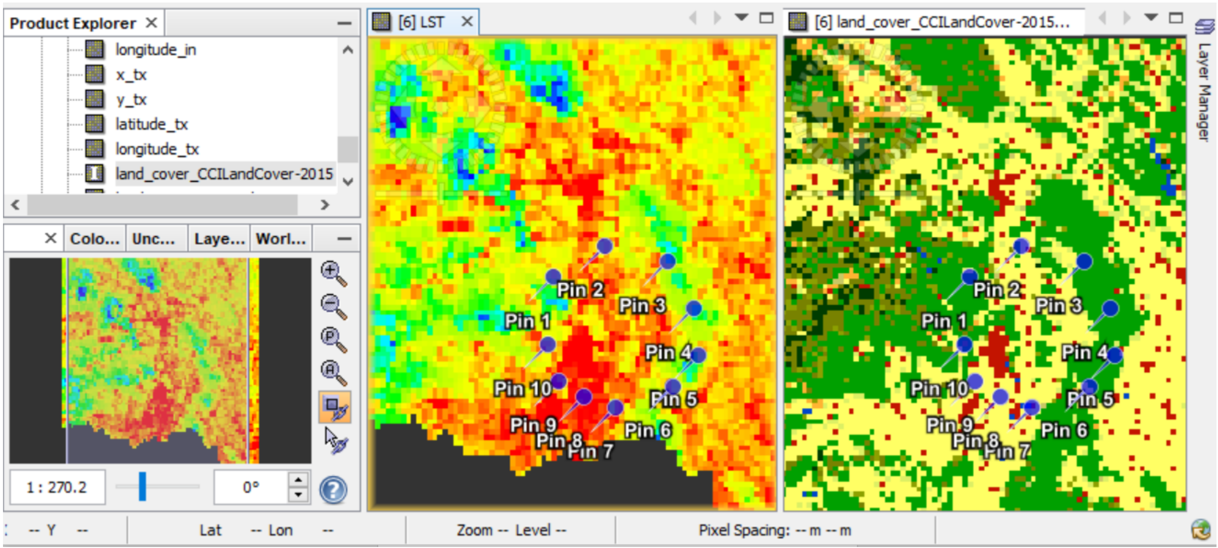


2.7 Mean temperature

After adding the land cover band, the subsequent action involves calculating the average temperature in the vicinity of Košice city by utilizing specific pixel values pinpointed with the Pin tool in SNAP. The ideal quantity is around 10 control points. Using these control points, it becomes feasible to calculate an average temperature value.

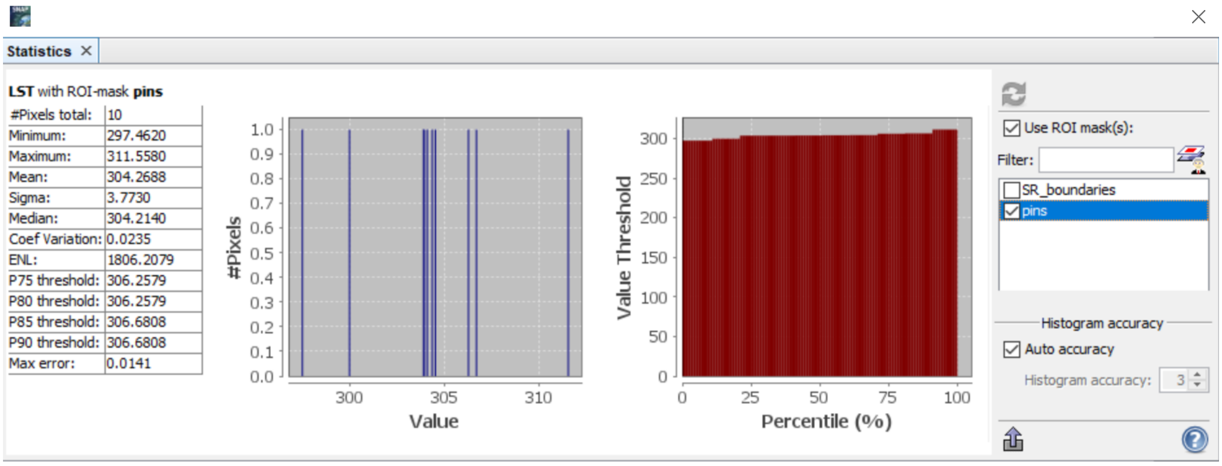


After creating the pins in the image, we can calculate the average value for the pixels identified by these pins using the Statistics tool in SNAP.

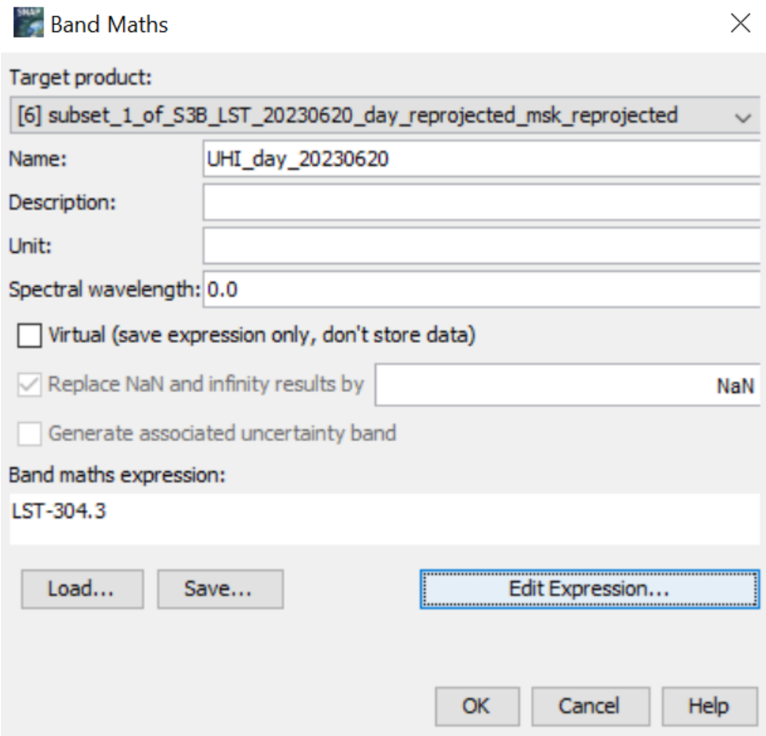


Close the land cover visualization and navigate to the Analysis -> Statistics. Choose the option „Use ROI Mask(s)" and select "pins." Lastly, click the refresh button.

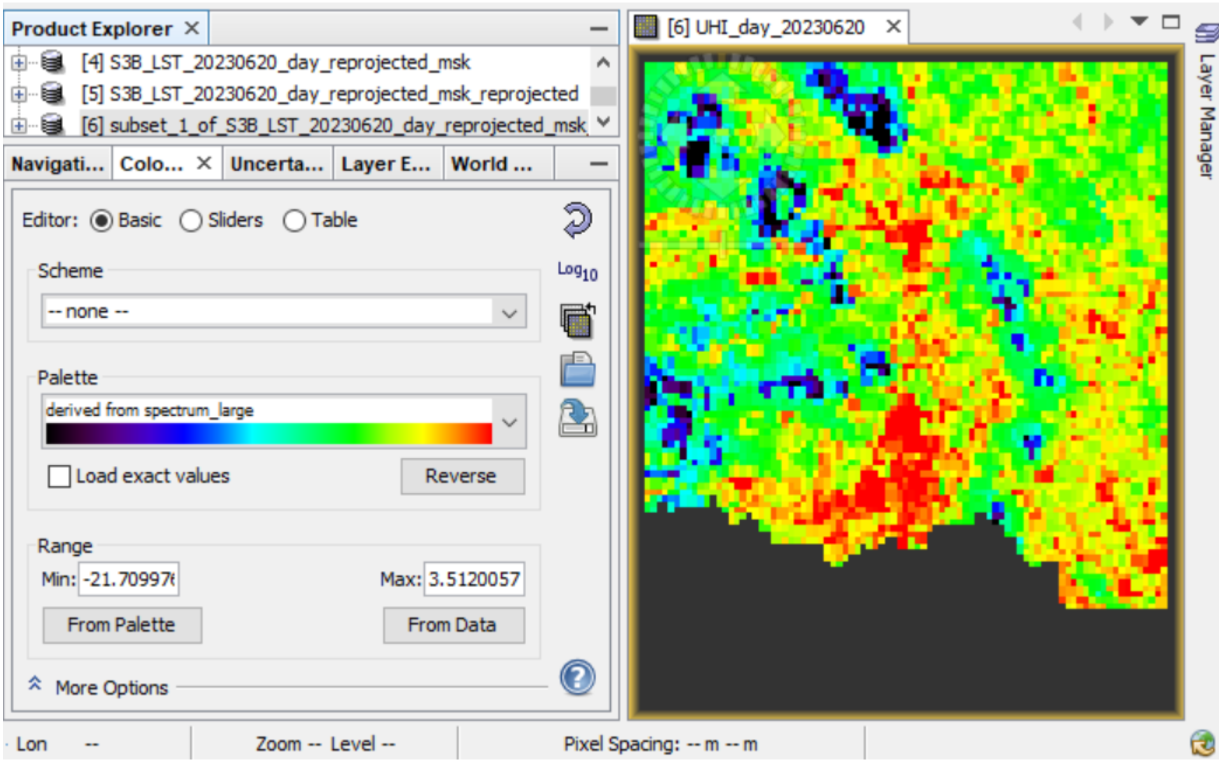
From the panel on the right side, we can obtain the mean temperature value (304.2688) for day image by referencing the pins recently inserted into our image.

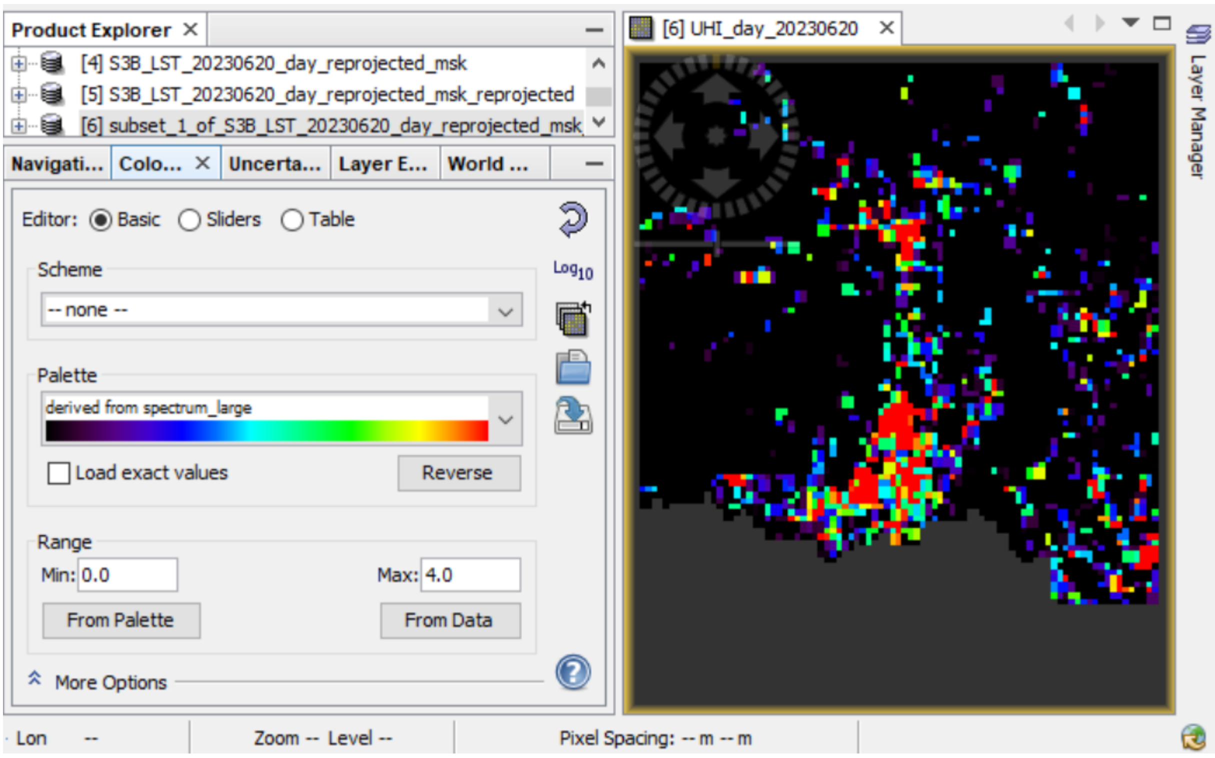


We can proceed to utilize the Band Math operator to subtract this value from the LST measurements. Right-click on the LST_20180802_night product, choose Band Math, modify the name to UHI_night, uncheck Virtual, and click the Edit Expression button. Copy and paste the provided expression, then click OK:



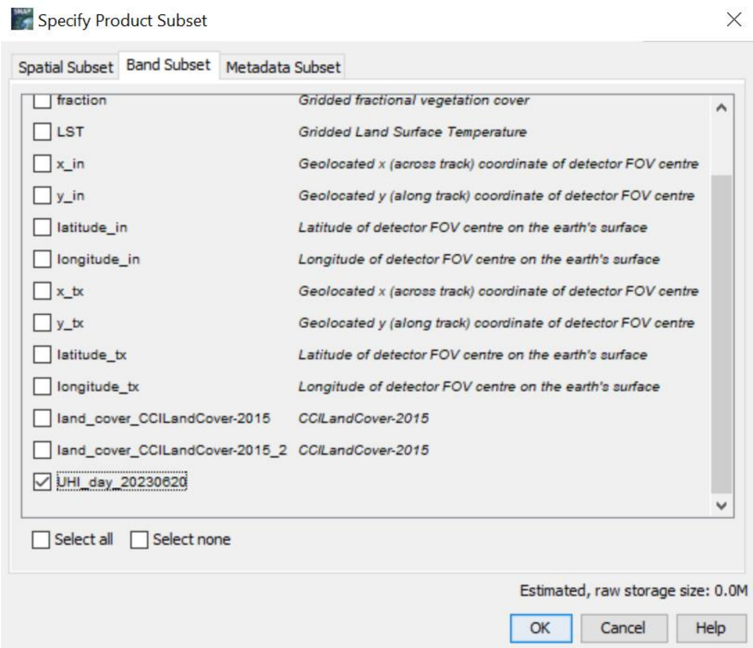
Close all previous visualizations except for the recently generated UHI_day_20230620band. Navigate to the Colour Manipulation tab, choose Basic as the editor, and select the palette. Then, click on the tab From Data to see the range of the final night UHI. Adjust the Min and Max values to ranges from 0 to the last value of the dataset (in this case 12.0).





2.8 Data export to QGIS

Once the result is ready, we will export it as GeoTIFF and open it in QGIS. For that, data must be again reprojected to Geographic Lat/Lon. Then, go to File -> Export -> GeoTIFF. Click on the Subset tab, and in the Band Subset menu select only the band UHI_day_20230620. Save the file with the name UHI_night_20230620.tif in the following path and click Export Product:

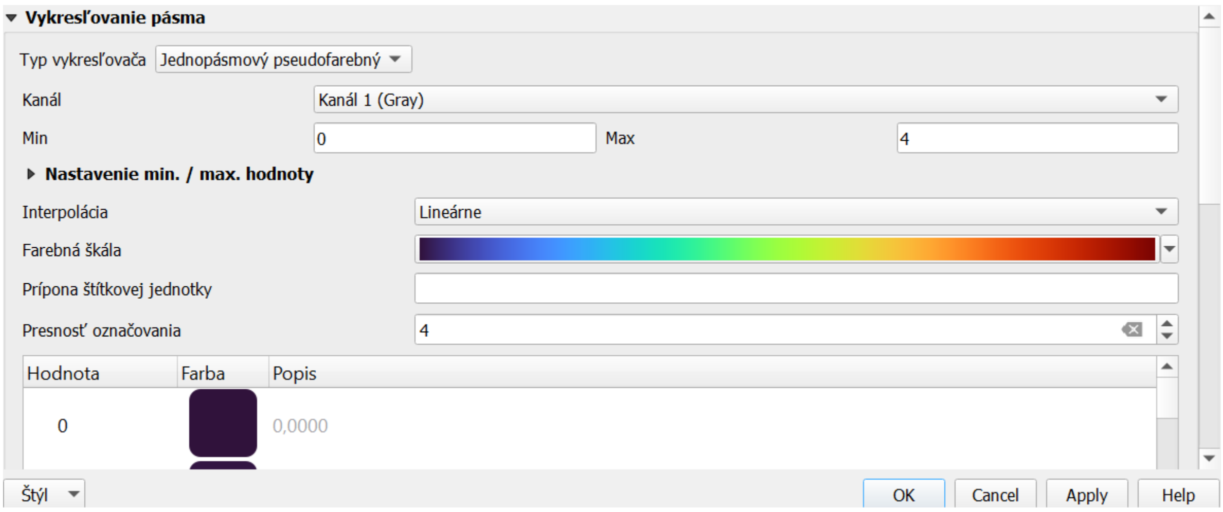


Data import to QGIS

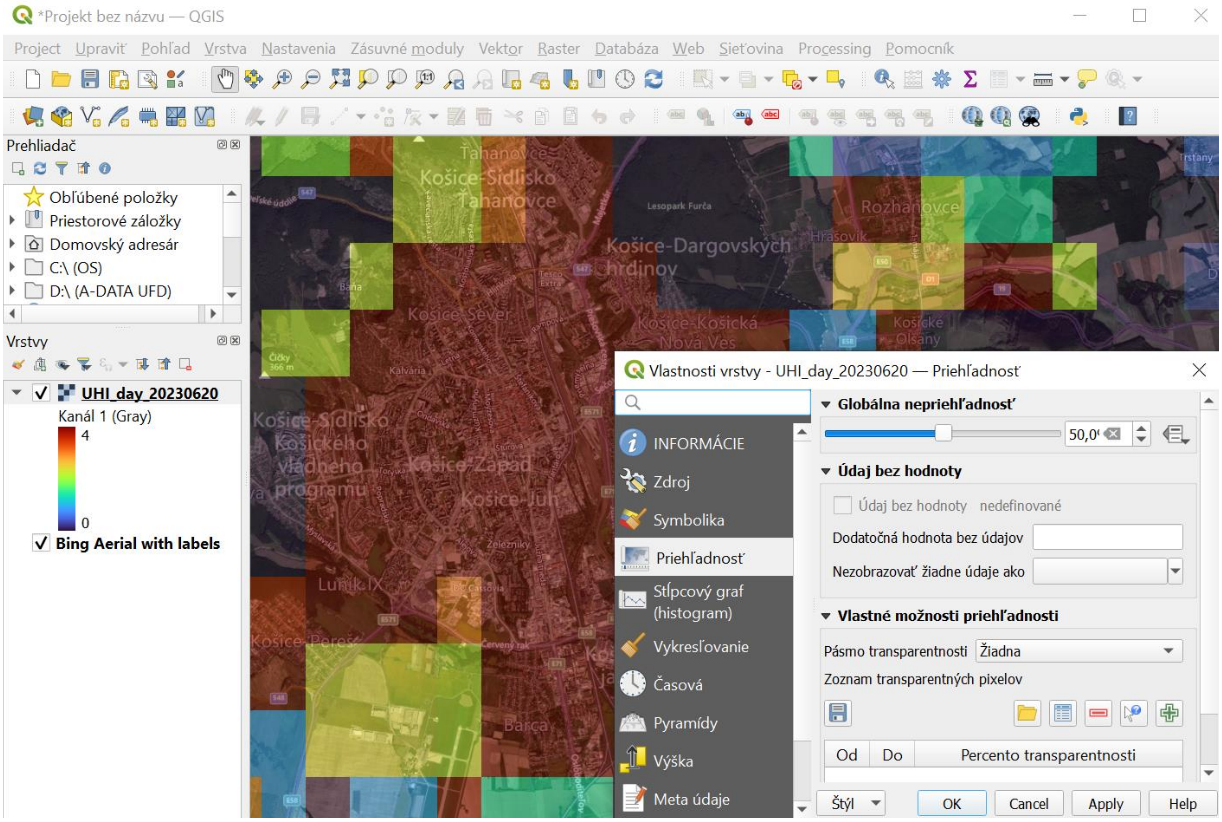
Once the images are processed in SNAP, we will visualize the results in QGIS. Minimize SNAP and open QGIS.

Import the subset_UHI_day_202306 into the panel Layers

Edit image parameters of subset_UHI_night_202306 – Navigate to Properties of this image and change the color palette. Set the Min/Max values for the night UHI similar like in the SNAP (0-12).



Now navigate to Web – OpenLayers plugin – Bing maps and add e.g. Bing aerial with labels. Place the layer UHI_day_20230620 above the layer of Bing map. Set transparency to the UHI_day_20230620 layer (Properties – Transparency).
Finally, explore the Urban Heat Island in the vicinity of Košice city and land use/cover that affects it.



For more information, see the lecture: [10. Land surface temperature mapping/urban heat island mapping using ESA EO data]

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 11 – TUTORIAL

Generating high resolution binary and fractional snow maps from Sentinel-2 data using SNAP software

esa
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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

In this exercise, we will:

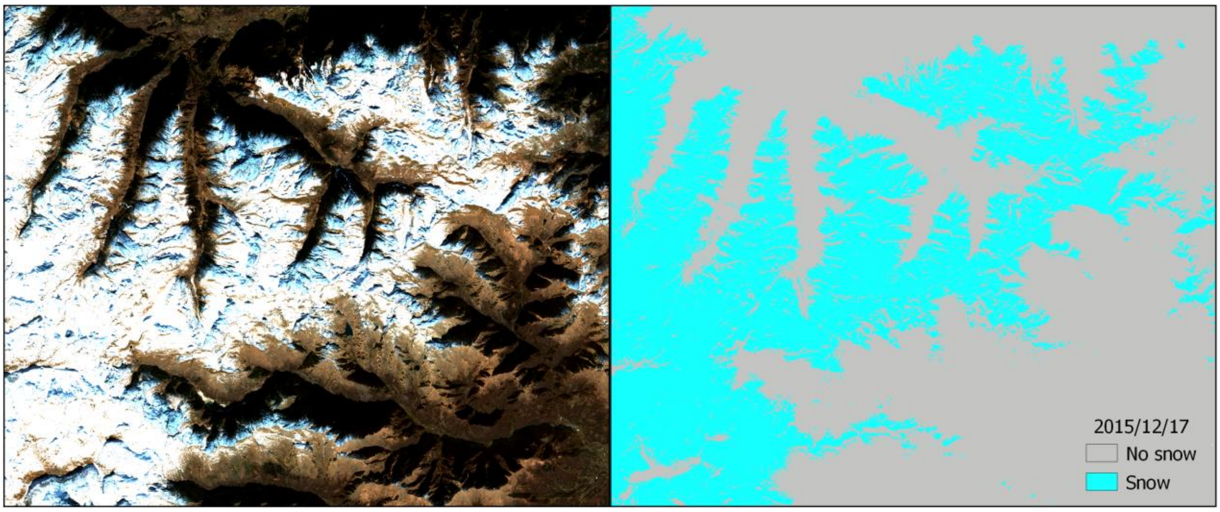
- Explore how data from Sentinel-2 multispectral data are used to detect and measure snow extent
- Larn how to generate and interpret high resolution binary and fractional snow cover products
- Demonstrate real-world examples and applications of these techniques in cryospheric research

2 | Background

Mapping snow and ice using Sentinel-2 data

The routine creation of hemispheric or global snow cover extent data typically relies on medium-resolution optical satellite data, such as Sentinel-3 SLSTR/OLCI, Terra/Aqua MODIS, or NPP VIIRS. To evaluate the accuracy of these products, snow maps derived from high-resolution optical satellite data, such as Sentinel-2 MSI or Landsat 8 OLI, can be utilized.

In this task, you'll produce binary and fractional snow cover datasets using a Sentinel-2 scene captured over the Alps on April 29, 2016. Two approaches, both centered on the Normalized Difference Snow Index (NDSI), will be tested.



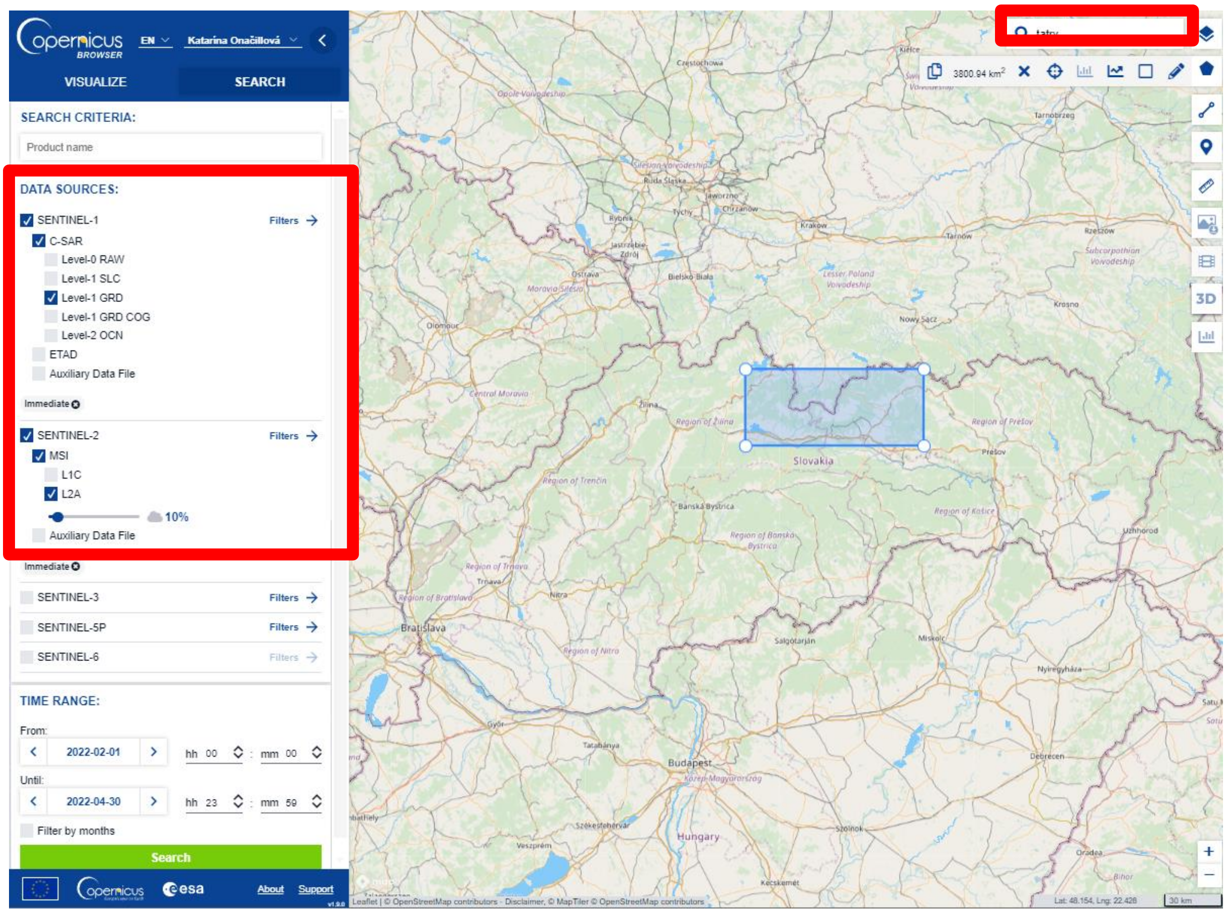
Snow cover extent map

In this Copernicus Sentinel-2 image of 17 December 2015, we can see an example of a snow cover extent map from Sentinel-2 tile T32TLR during the winter season.

Source: Contains modified Copernicus Sentinel data (2015)/processed by e-shape

2.1 Study area and data used

For this exercise, we will use Senetinel-1 and Sentinel-2B images of the Hight Tatras area in Slovakia, with its expanse of national parks with its typical flora and rocky mountains covered, especially in winter season with snow and ice. For the first part of the exercise, we will use the Tile Number *34UDV* downloaded for 25 March 2022 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



S2B_MSIL2A_20220325T094029_N0400_R036_T34UDV_20220325T132010.SAFE

2.2 Part A: Generate high resolution binary and fractional snow maps from Sentinel-2 data over the Alps

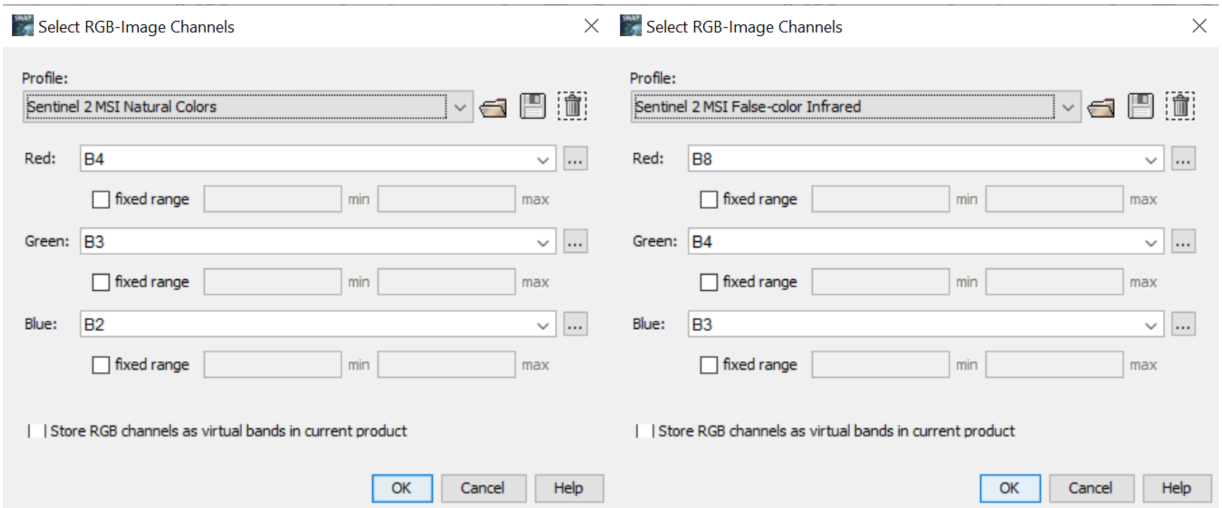
SNAP - Open and explore product

Open SNAP Desktop and import the Sentinel-2 data set Sentinel-2: File Import Optical Sensors Sentinel-2 S2 MSI L2A. Navigate to the S2 directory in the input data directory and select the XML file. The opened products will appear in Product Explorer window.

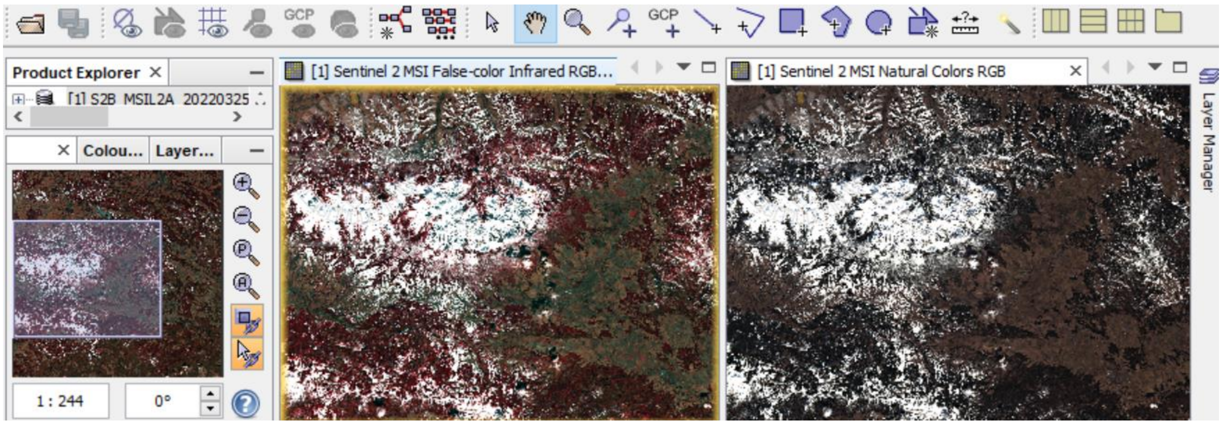
S2B_MSIL2A_20220325T094029_N0400_R036_T34UDV_20220325T132010.SAFE.zip

Get a first overview of the snow and cloud conditions on the 25 March 2022 over Tatra´s region using true- and false colour composite previews:

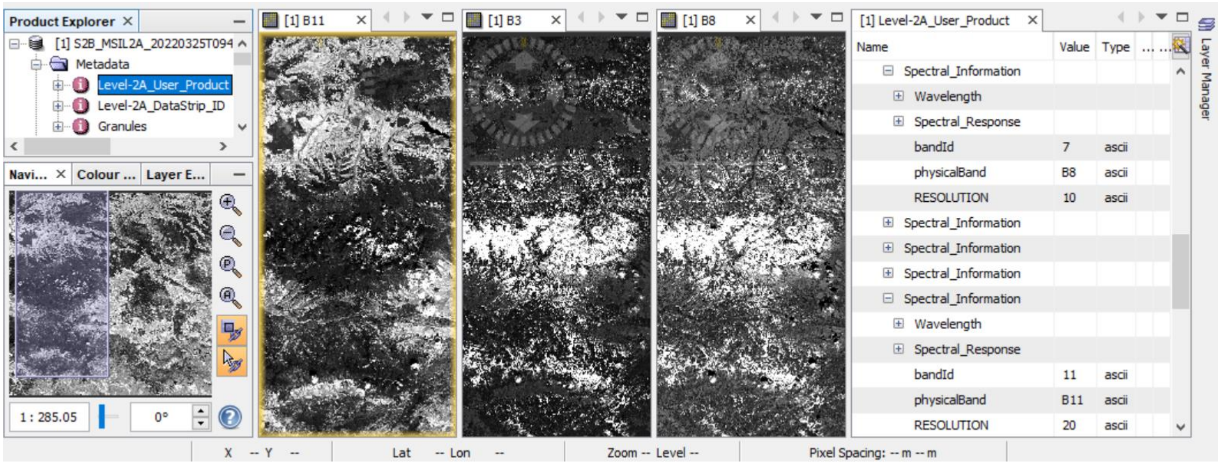
1. Select the product in the Product Explorer window.
2. Display product using e.g. True and False color composition: Right click on the product - Open RGB Image Window.
3. In the pop-up window select 'Sentinel 2 MSI Natural colors (Red: B4; Green: B3; Blue: B2)'.
4. Then, choose another color composition, e.g. 'Sentinel 2 MSI False-color Infrared (Red: B8; Green: B4; Blue: B3)'.



5. In the Navigation window, zoom in to the snow region
6. Tile Windows, e.g. Horizontally
7. Get an impression on the overall snow conditions on 25 March 2022

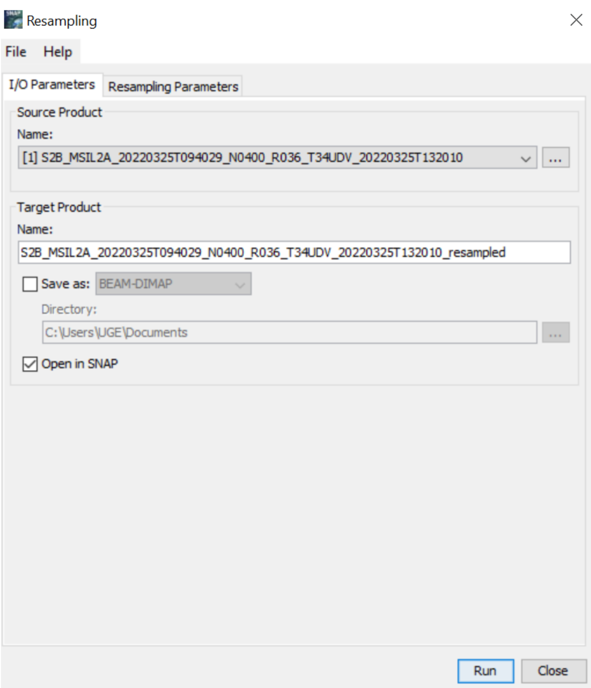


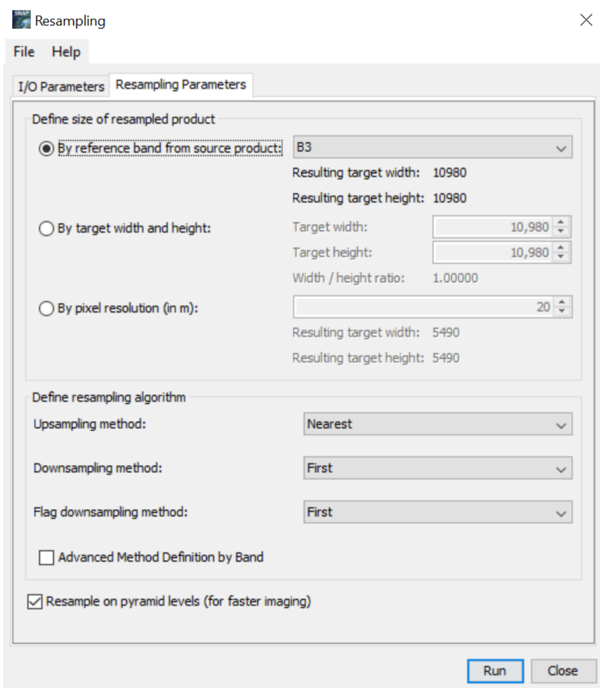
Get familiar also with the basic information associated to the Sentinel-2 data set:
Open the file structure of the Sentinel-2 scene by double left click on the product (or click on the +). Click on the menu Metadata, double click on Level-2A_User_Product and find the spectral information for the bands needed for the snow mapping approaches (B3, B8, B11): band numbers, resolution (pixel size).



Resample

Resample the bands to the pixel size of the VIS bands:
In the main SNAP menu, select Raster - Geometric - Resampling
In the I/O Parameters tab, the source product is set to our only product in the SNAP, change the name of the target resampled product if needed
Do not save the output product - disable the box "Save as:" (if selected).
In the Processing Parameters tab, use e.g. B3 with 10 m resolution to resample all the bands to 10 m as output spatial resolution.





Create subset

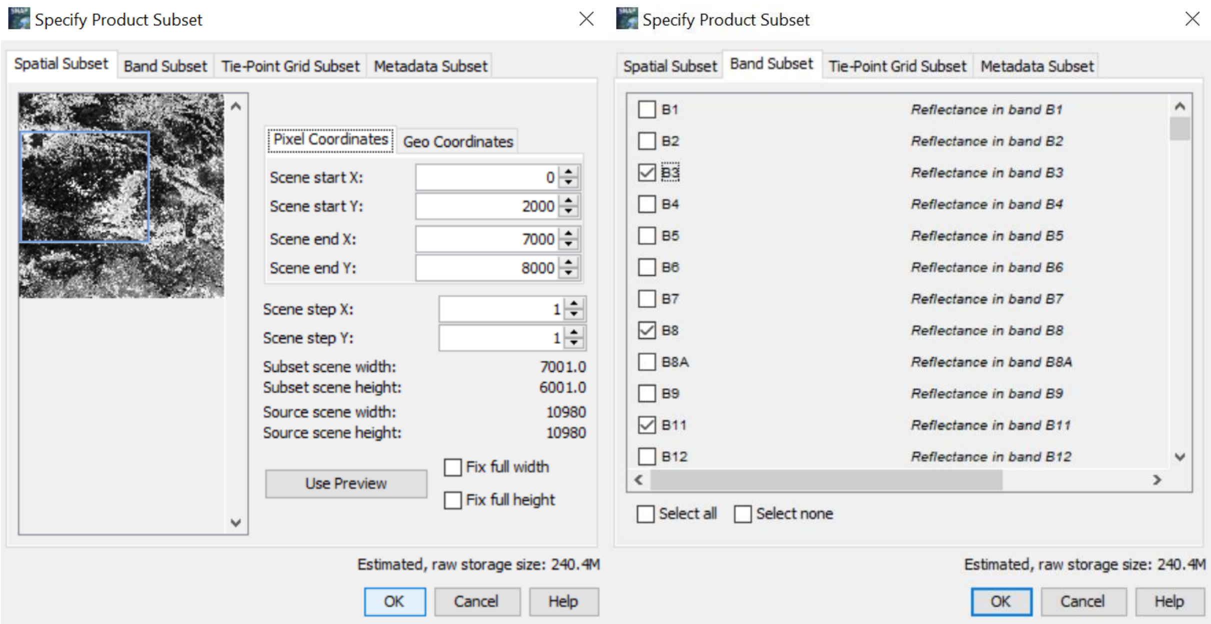
Click on the resampled product in the Product Explorer, go to the main SNAP menu and select Raster - Subset…:

Create a subset with the following settings:

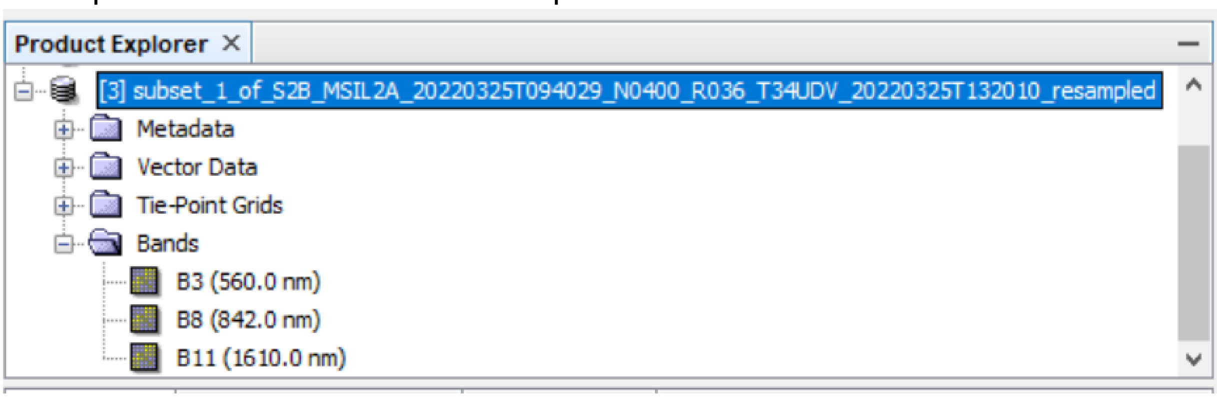
Spatial subset:
Scene start X: 0,
Scene start Y: 2000,
Scene end X: 7000,
Scene end Y: 8000

Band subset: B3, B8, B11

And click OK



In the main SNAP menu, select Raster - Band Maths (unlock the box "Virtual")
From the created subsets, calculate the NDSI using the 1.6 μm and the 0.56 μm bands and save the output.



Normalized Difference Snow Index

Next, we will calculate Normalized Difference Snow Index (NDSI) in SNAP.

The Sentinel-2 NDSI is a ratio of two bands: one in the VIR (Band 3) and one in the SWIR (Band 11). Values above 0.42 are usually snow. The Sentinel-2 NSDI can be used to differentiate between cloud and snow cover as snow absorbs in the short-wave infrared light, but reflects the visible light, whereas cloud is generally reflective in both wavelengths. Most potential cloudy pixels have NDSI values in a range between -0.1 and +0.2.

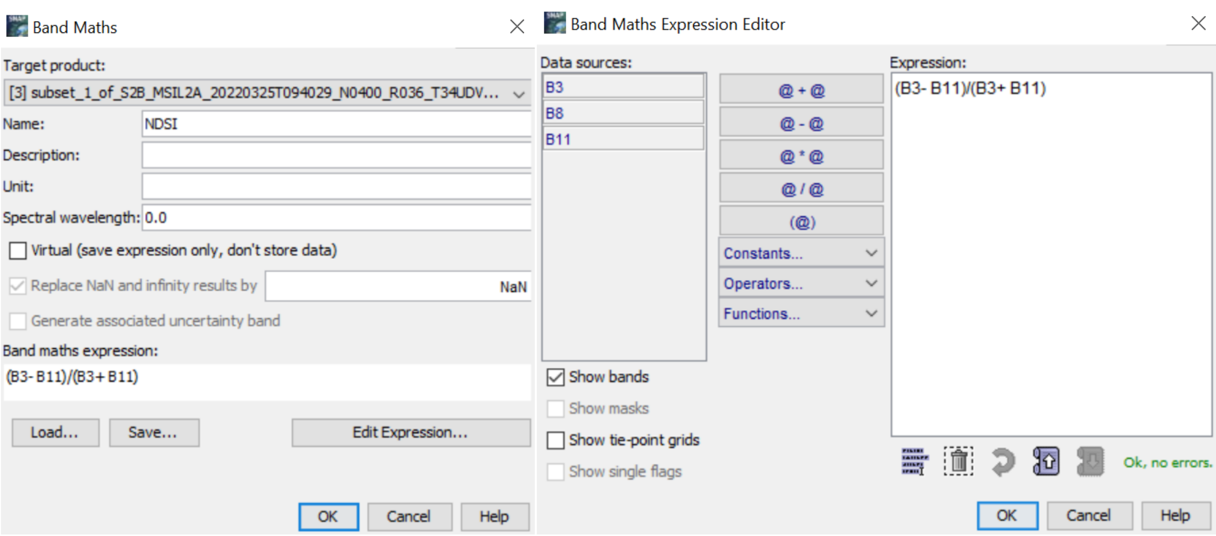
To calculate NDSI, select the last subset product, navigate to the main SNAP menu and select Raster - Band Maths (deselect the box “Virtual”). Click on Edit Expression to calculate the NDSI using the equation below and click OK:

$$\rho(VIS) - \rho(SWIR) / \rho(VIS) + \rho(SWIR)$$

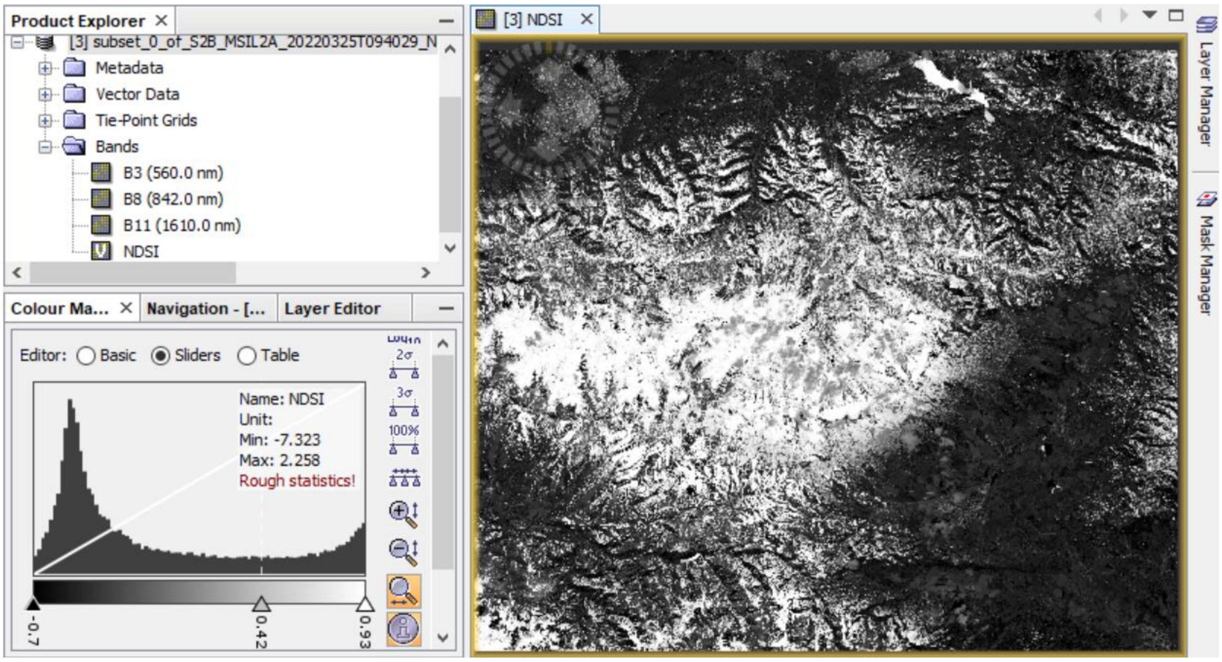
ρ = Top of atmosphere reflectance
VIS = Visible band (0.56 μm)
SWIR = Short-Wave Infrared Band (1.6 μm)

Replace the bands in the equation with the corresponding bands for Sentinel 2:

$$\rho(B3) - \rho(B11) / \rho(B3) + \rho(B11)$$

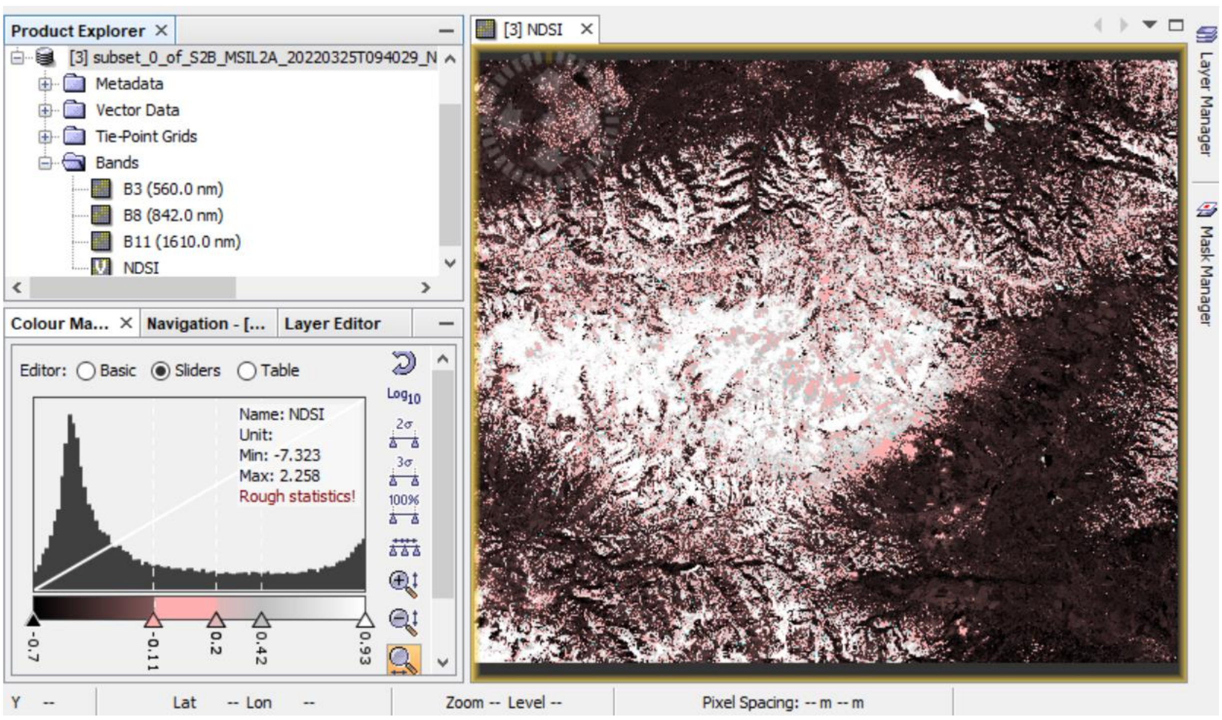


Open the output product in the Product Explorer by double click on the new raster NDSI within Bands folder.
Go to Color Manipulation tab and go to Table – set the thresholds of slider to three values – minimum value, up to 0.42 (usually pixels with no snow), higher than 0.42 (usually snow pixels) and maximum value.



Explore the image: values above 0.42 are usually snow pixels (shades of grey for the lowest probability of snow and shades of white for the highest probability of snow). The Sentinel-2 NSDI can be also used to differentiate between cloud and snow cover as snow absorbs in the short-wave infrared light, but reflects the visible light, whereas cloud is generally reflective in both wavelengths.

Most potential cloudy pixels have NDSI values in a range between -0.1 and +0.2. Add 4 new sliders and change their colour to e.g. red to highlight these values of potentially cloudy pixels.



Binary snow classification (snow / no snow)

Applying thresholds on the NDSI and a Near Infrared band (NIR, e.g. 0.842 µm) it is possible to derive binary snow classification.

The method utilized in this task has been adjusted and made simpler based on the approach employed in the Theia Snow collection (Gascoin et al. 2019). We apply a cautious threshold to NDSI. Certain murky waters may exhibit comparably high NDSI values, thus, we incorporate an extra condition concerning red reflectance to prevent erroneous snow identification in such regions. A pixel free from clouds is classified as snow under these conditions:

$$(NDSI < n1)\ AND\ (\rho red < r1)$$

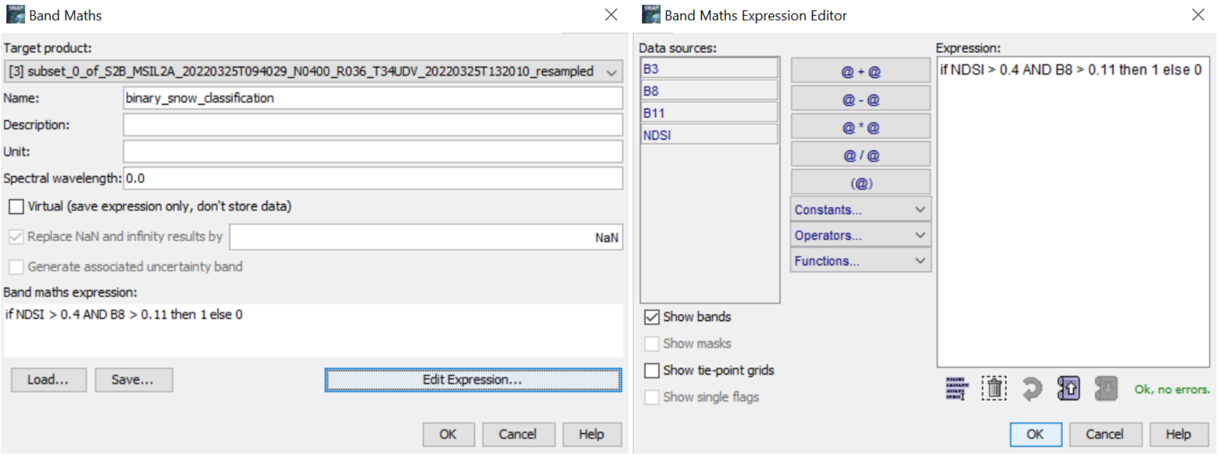
Where n1 and r1 are the selected thresholds, during the first pass they are set conservatively high to avoid false detections. If the above expression is not fulfilled, then the pixel is marked as "no snow"

Minimum value of NDSI for the pass 1 snow test - n1 0.4
Minimum value of the red band (B8) for the pass 1 snow test - r1 0.11

After subsititution with corresponding Sentinel-2 bands, the equation is:

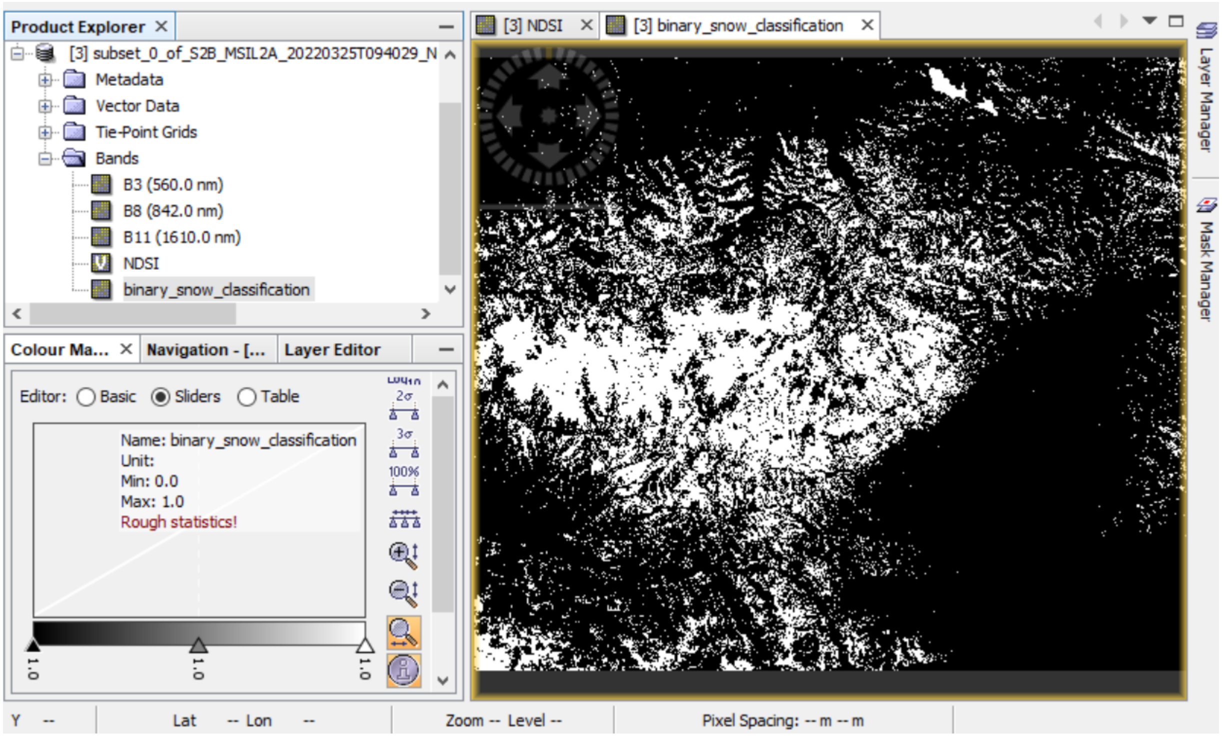
Expression: if NDSI > 0.4 AND B8 > 0.11 then 1 else 0

Now, navigate to Main Menu: Raster – Band Maths
Unlock the band "Virtual",
Define output layer name: binary_snow_classification
and Edit Expression: if NDSI > 0.4 AND B8 > 0.11 then 1 else 0



Open the output product in the Product Explorer by double click on the new raster „binary_snow_classification" within Bands folder.
Go to Color Manipulation tab and go to Table – set the thresholds of slider to three values – minimum value, up to 0.42 (usually pixels with no snow), higher than 0.42 (usually snow pixels) and maximum value.

We can observe that pixels have been divided into two cathegories: with snow (white pixels) and without snow (black pixels)

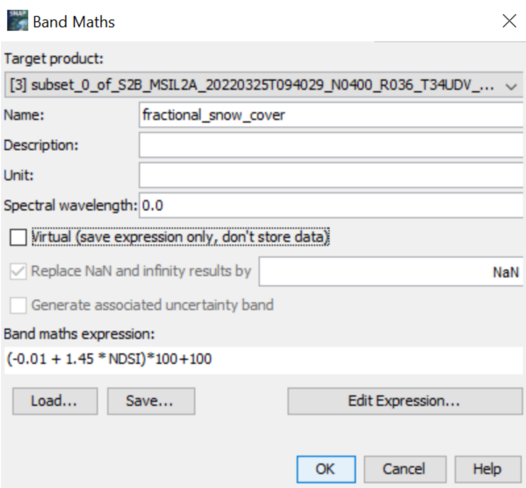


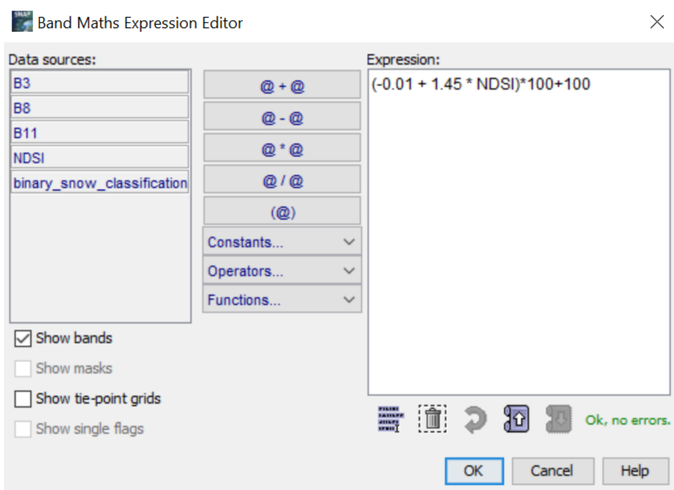
Fractional snow cover

In the second part of the task, we will try to detect fractional snow cover (FSC, 0 % - 100% snow) according to the approach of Salomonson and Appel (2004, 2006), which was originally developed for MODIS data:

$$FSC = (-0.01 + 1.45 * NDSI)*100+100$$

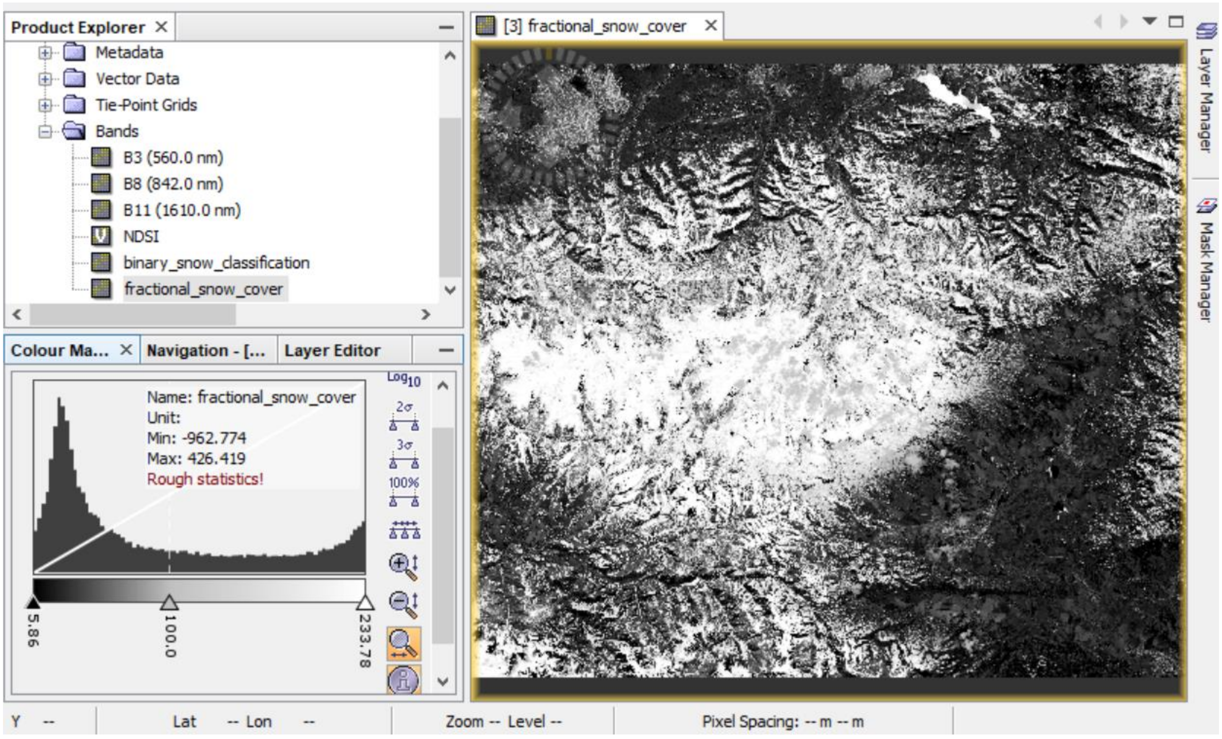
Now, navigate again to Main Menu: Raster – Band Maths
Unlock the band "Virtual",
Define output layer name: fractional_snow_cover
and Edit Expression: *(−0.01 + 1.45 * NDSI)*100+100*





In forested areas, this approach aims on detecting the viewable snow, i.e. the snow on top of the forest canopy. Let´s check the results.

Open the output product in the Product Explorer by double click on the new raster „fractional_snow_cover" within Bands folder.
Go to Color Manipulation tab and set value range between 100 (snow free) and 200 (100 % snow covered):



For more information, see the lecture: [11. Snow and ice cover mapping using ESA Sentinel-1 and Sentinel-2 data]

THANK YOU FOR FOLLOWING THE EXERCISE!

EXERCISE 12 – TUTORIAL

Retrieval of digital elevation model (DEM) from Sentinel-1/DEM generation with Sentinel-1, comparison with LiDAR outputs, using SNAP software

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FUNDED BY EUROPEAN SPACE AGENCY UNDER THE PLAN FOR EUROPEAN COOPERATING STATES, 7TH CALL FOR SLOVAKIA

1 | Exercise outline

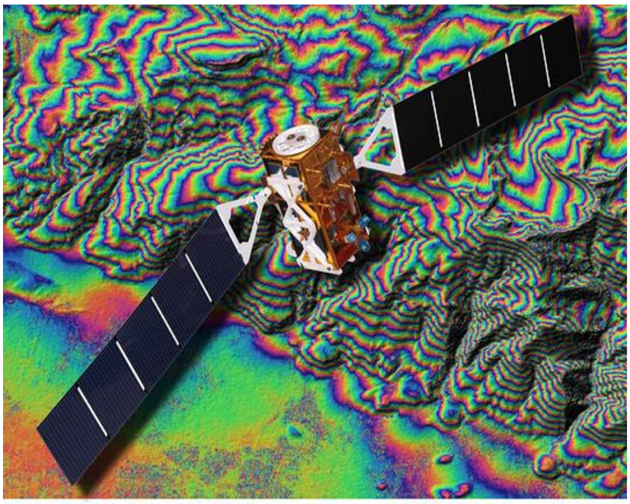
In this exercise, we will:

- Learn how to retrieve Digital elevation model (DEM)
- Perform necessary data processing for making an interferogram
- Understand the information content in SAR interferometric images
- Compare Sentinel-1 derived DEM with LiDAR outputs

2 | Background

Deformation Mapping and Change Detection using Sentinel-1 data

Satellites constantly monitor Earth from space, providing vital data essential for rapid land cover change assessment and disaster management. The radar on board the Copernicus Sentinel-1 mission can detect ground conditions and penetrate clouds, functioning day and night.



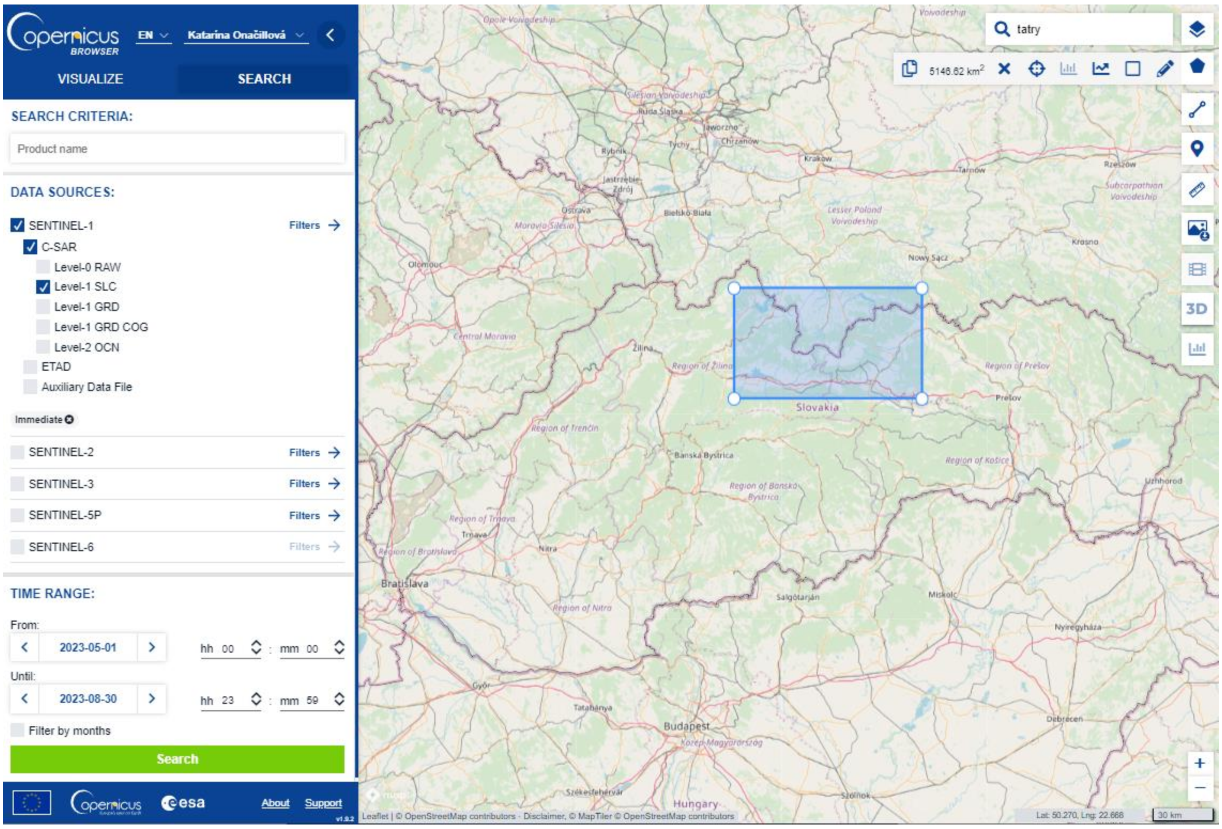
DEM generation with Sentinel-1 data offers a powerful method for deriving accurate and detailed elevation information over large areas, especially in regions with limited ground survey data or challenging terrain conditions.

DEM generation with Sentinel-1 data involves acquiring pairs of SAR images, processing them into interferograms, unwrapping the interferometric phase to obtain absolute phase values, removing the topographic phase contribution, converting the corrected phase into elevation values using appropriate algorithms, assessing the quality of the generated DEM, refining it if necessary, validating the accuracy, and utilizing the DEM for visualization and various applications such as terrain analysis and environmental monitoring.

Sentinel-1 derived DEMs find applications in topographic mapping, hydrological modeling for water flow and flood risk assessment, environmental monitoring for changes like erosion and landslides, natural resource management for agriculture and forestry, disaster management for assessing terrain accessibility and planning evacuation routes, infrastructure planning for designing roads and bridges, climate change studies for analyzing impacts on coastal erosion and glacier retreat, and remote sensing applications including orthorectification and 3D visualization.

2.1 Study area and data used

For this exercise, we will use two Sentinel-1 SLC images of the same area for High Tatras, Slovakia, downloaded from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



To ensure successful DEM generation, selecting image pairs with specific properties is crucial. These include:

- A short **temporal baseline**, minimizing the time between acquisitions to reduce temporal decorrelation risks, particularly over changing surfaces like vegetation or water areas. Sentinel-1 radar (C-band) is susceptible to decorrelation, especially over vegetation, so image pairs with minimal vegetation cover are preferable.
- A suitable **perpendicular baseline**, ideally between 150 and 300 meters, to capture topographic variations effectively through parallax-like effects. Smaller baselines may not produce pronounced topographic effects, while larger ones can lead to decorrelation.
- Consideration of the primary mission focus of Sentinel-1 for deformation retrieval rather than DEM generation, resulting in predominantly short baselines below 30 meters. Finding image pairs with short temporal and large perpendicular baselines can be challenging.
- Ensuring **suitable atmospheric conditions**, avoiding images acquired during rainy periods or with high water vapor content in the atmosphere to minimize phase delays and maintain measurement quality.

2.2. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open 2 downloaded products by double click on the zipped folders. The opened products will appear in Product Explorer window.

S1A_IW_SLC__1SDV_20230721T162703_20230721T162731_049524_05F481_08D0.SAFE.zip
S1A_IW_SLC__1SDV_20230802T162703_20230802T162731_049699_05F9EC_E68C.SAFE.zip

To access the information within the product, double-click on it to reveal the directories, which include:

- Metadata: containing parameters pertaining to orbit and data.
- Tie Point Grids: providing interpolation data for latitude/longitude, incidence angle, etc.
- Quicklooks: presenting a visible image of the entire scene in radar coordinates.
- Bands: consisting of complex values for each subswath "i" and "q", along with intensity

Select intensity image for swath IW1 VV – double click on it to View it

Note: Each SAR image is flipped north—south it maintains the same orientation as its acquisition (in this case, ascending track).

Check baseline information

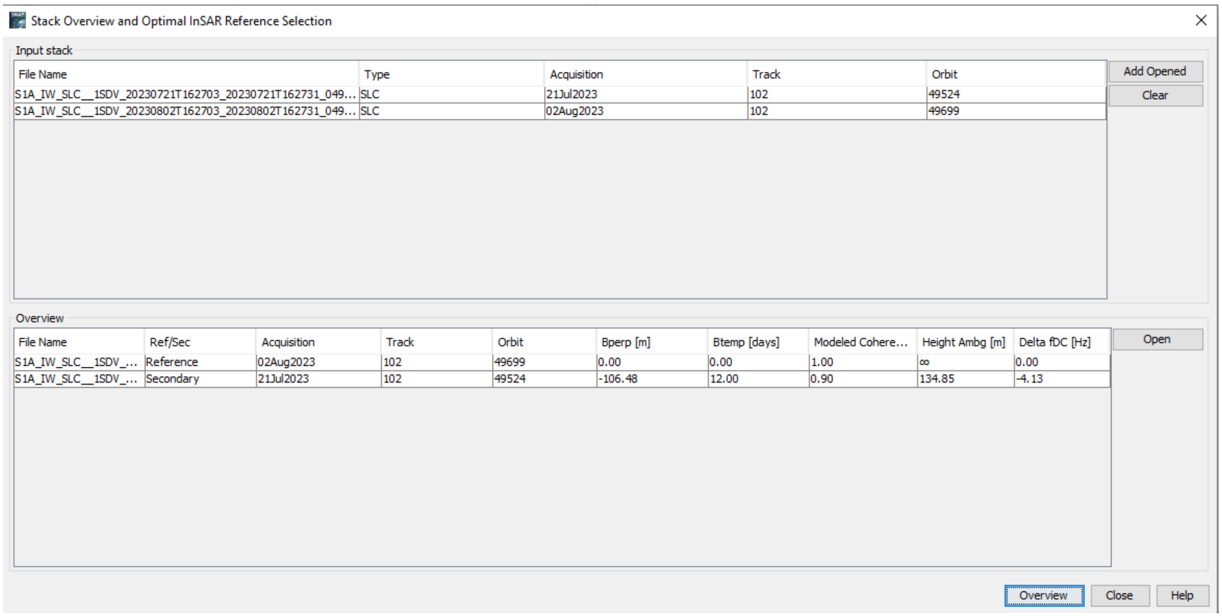
As previously mentioned, the quality of DEM generation relies heavily on the characteristics of the satellite images, particularly the spatial arrangement of the satellites during acquisition, termed the perpendicular baseline. A larger perpendicular baseline yields more detailed interferograms, enhancing the representation of elevation changes. For instance, a perpendicular baseline of 151 meters, as illustrated in Figure 8, produces denser fringe patterns, facilitating better terrain change description compared to baselines of 67 meters or 27 meters.

The time interval between the first and second images, known as the temporal baseline, also significantly impacts interferogram quality. Shorter temporal baselines, ideally around 6 or 12 days for Sentinel-1 data, minimize phase decorrelation issues, particularly over natural surfaces. As illustrated in Figure 9, longer temporal baselines result in poorer interferogram quality, particularly over areas with natural surfaces, where reliable height information cannot be extracted. If such areas dominate the interferogram, DEM extraction becomes unfeasible.

To examine the baseline details of your image pair, navigate to Radar > Interferometric > InSAR Stack Overview.

Initially, select "Add Opened" to import the two Sentinel-1 products into the list above, where their acquisition date, track, and orbit information should appear.
Next, click on "Overview" to access their metadata.
In the lower list, you'll find details such as:

- the perpendicular baseline (Bperp) in meters,
- the temporal baseline (Btemp) in days,
- the modelled coherence ranging from 0 to 1,
- the height ambiguity indicating the height difference represented by one color cycle in the interferogram,
- the mean Doppler centroid frequency difference.



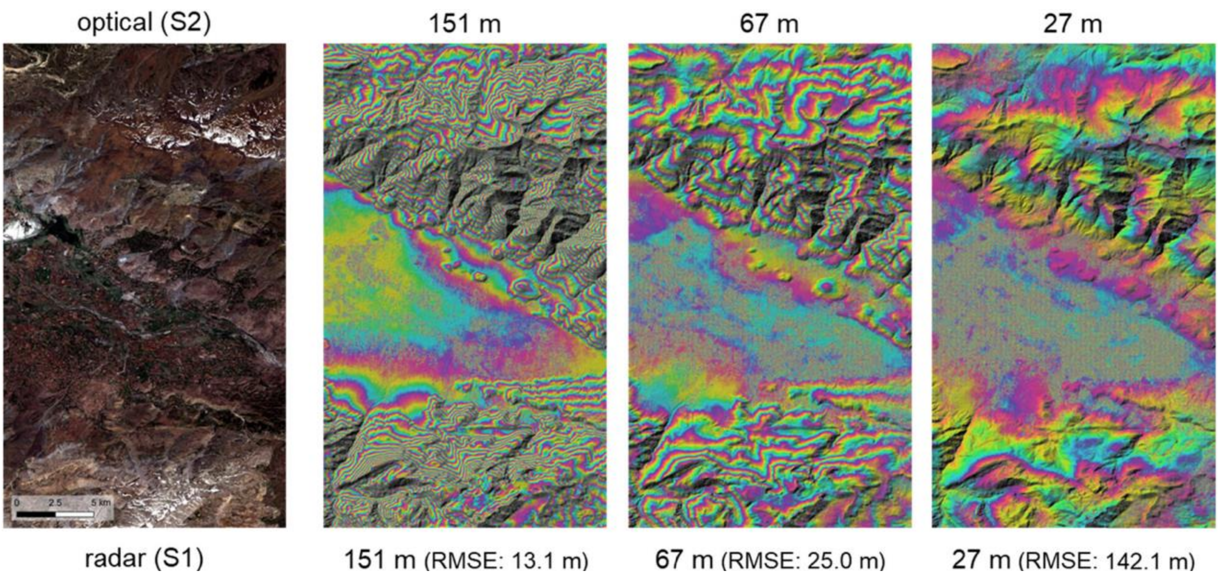
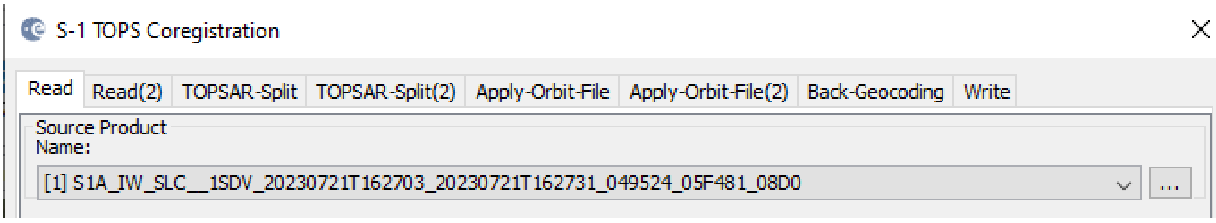


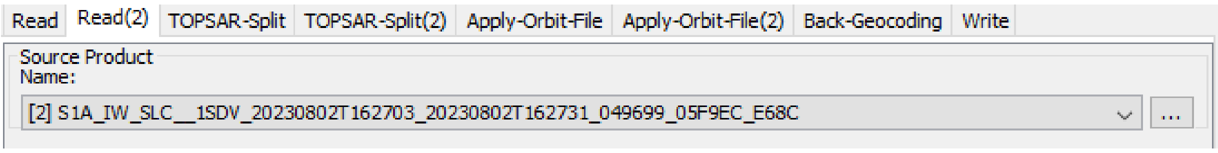
Figure: Effect of the perpendicular baseline on the interferogram (Braun 2021)

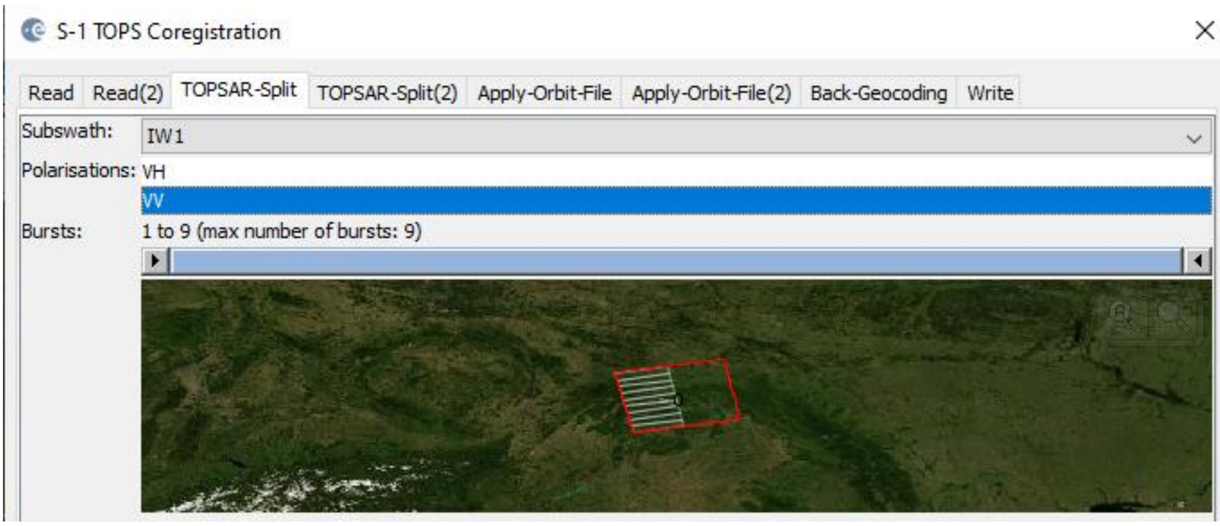
2.3 Coregistration

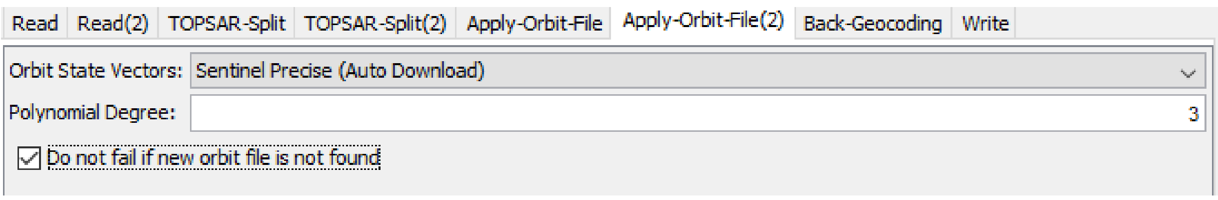
To utilize the phase difference between the acquisitions, it is necessary to initially construct a stack comprising both products. Image coregistration makes use of image statistics to align both products at sub-pixel accuracy. While orbit state vectors alone can suffice to coregister images, for precise offset tracking, additional data from a digital elevation model (DEM) is necessary to enhance coregistration accuracy.

Navigate to Main Menu – Radar – Coregistration – S1 TOPS Coregistration –S1 TOPS Coregistration
In the Read tab, select the 20230721 SLC product and in the Read(2) tab select the 20230802 SLC product
In TOPSAR-Split and TOPSAR-Split(2) tabs select Subswath: IW1 Polarizations:VV
In the Apply Orbit File and Apply Orbit File(2) tabs select leave default parameters and uncheck „Do not fail if new orbit is not found" option



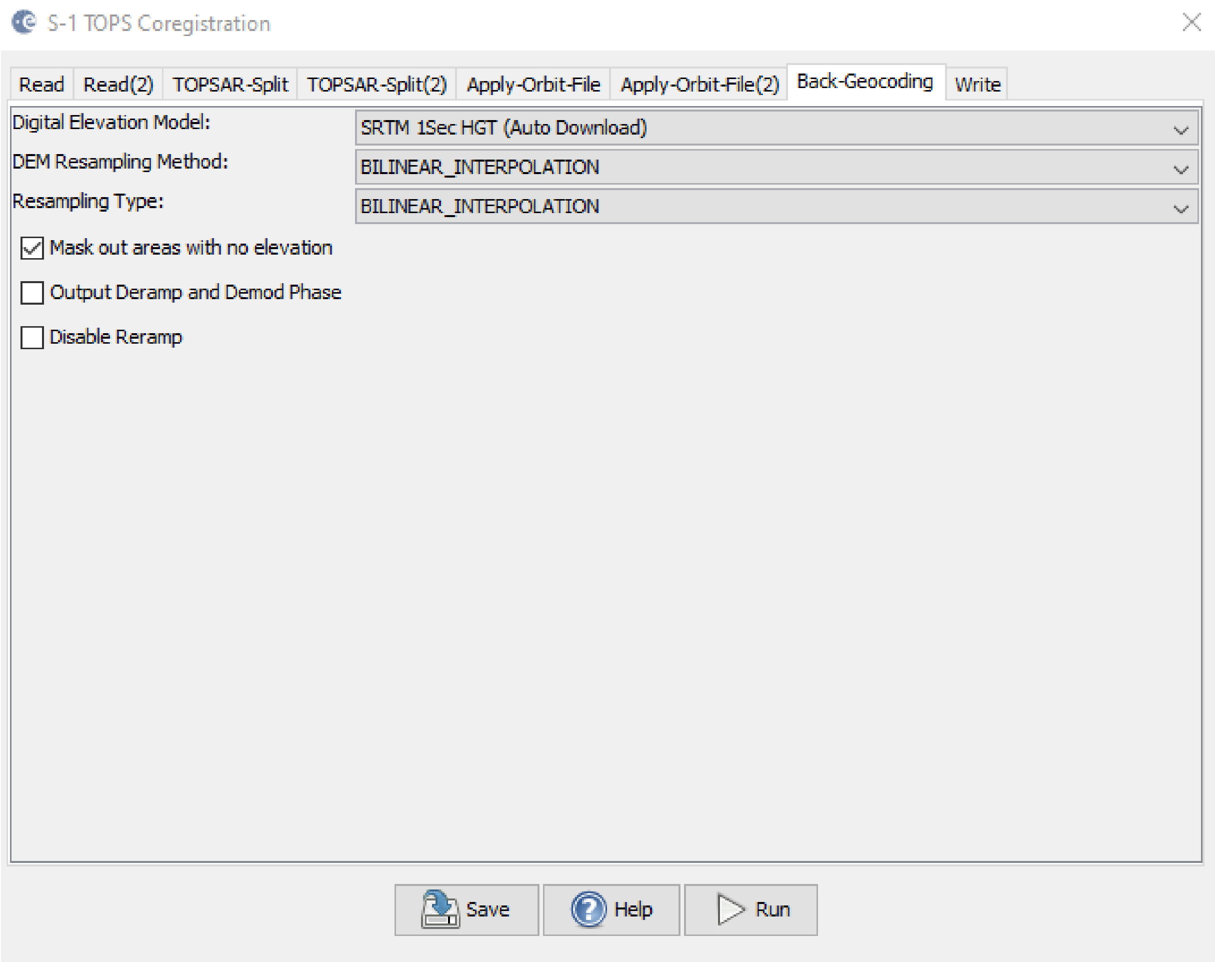






In the Back-Geocoding select SRTM 1Sec HGT (AutoDownload)
In the Write tab, select the directory to save your processing outputs

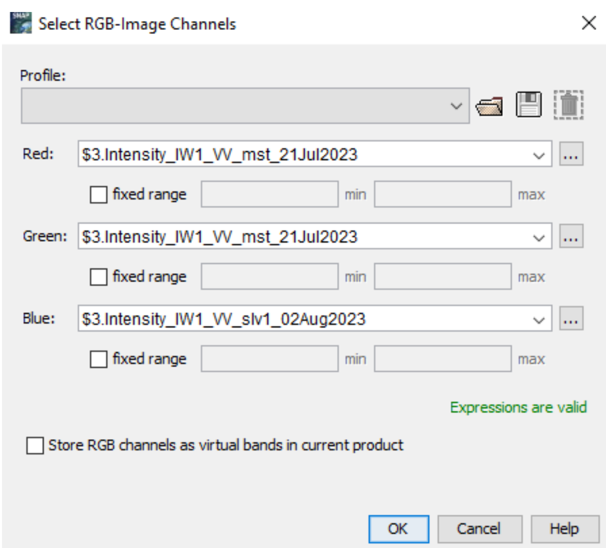
Note: SRTM data is accessible only within the latitudinal range of 60° North to 54° South. If your area falls outside this coverage, alternative DEMs with AutoDownload functionality can be utilized, or an external DEM stored as a GeoTiff and projected in geographic coordinates/WGS84 can be employed.



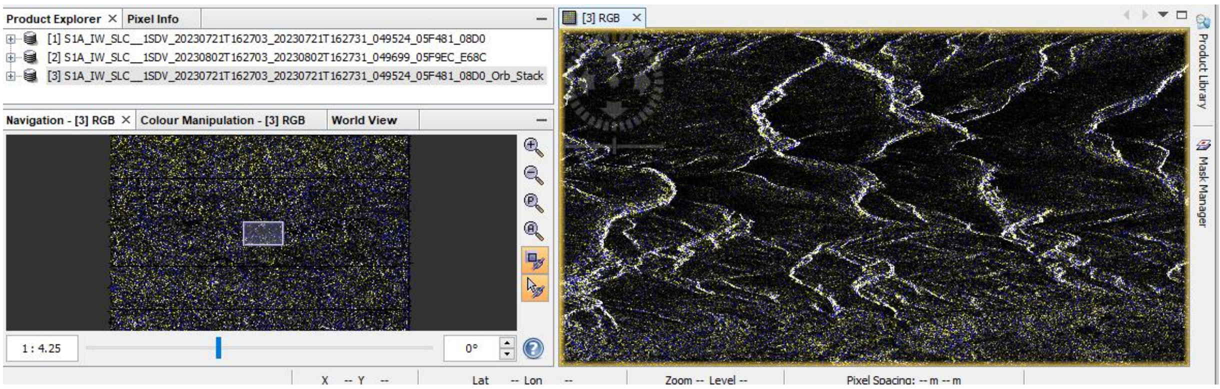
Once coregistration is finalized, it is recommended to visually inspect the stack's quality. This can be achieved through an RGB representation of the reference and secondary products, indicating if the images are appropriately aligned:

Right-click on the output coregistrated product – Open RGB Image Window

Choose the reference for red and green channels, and the secondary image for the blue channel.Click OK.



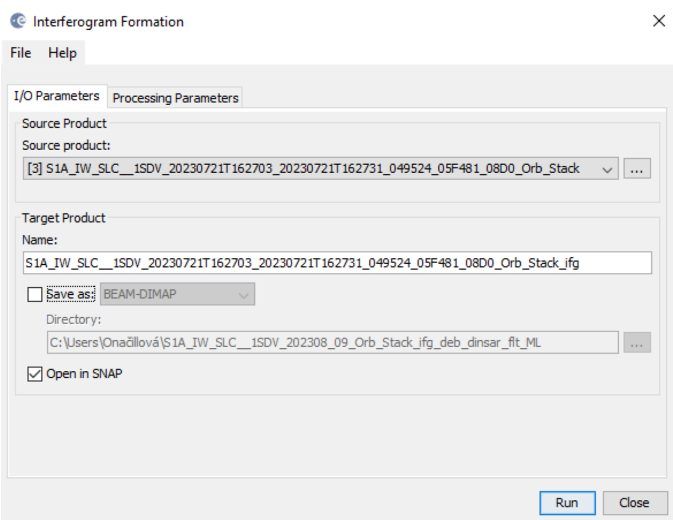
Zoom into a region with contrasting surfaces, such as the boundary between land and water. The RGB image should be clear and sharp, without being overly influenced by one of the images (e.g., appearing yellow for the reference or blue for the secondary image). The only acceptable exceptions are changes in land cover or scattering mechanisms which occurred in the time between the image acquisitions.

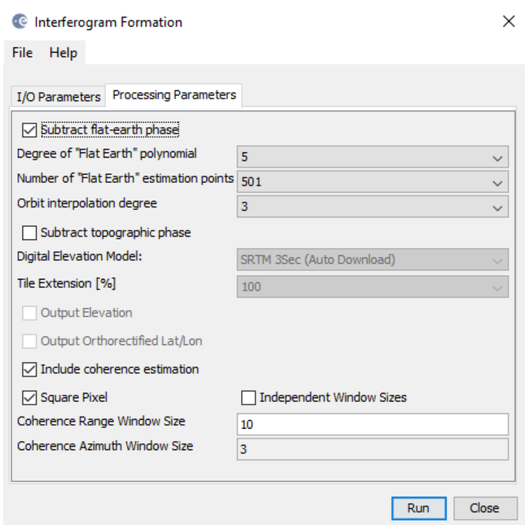


2.4 Forming a Raw Interferogram

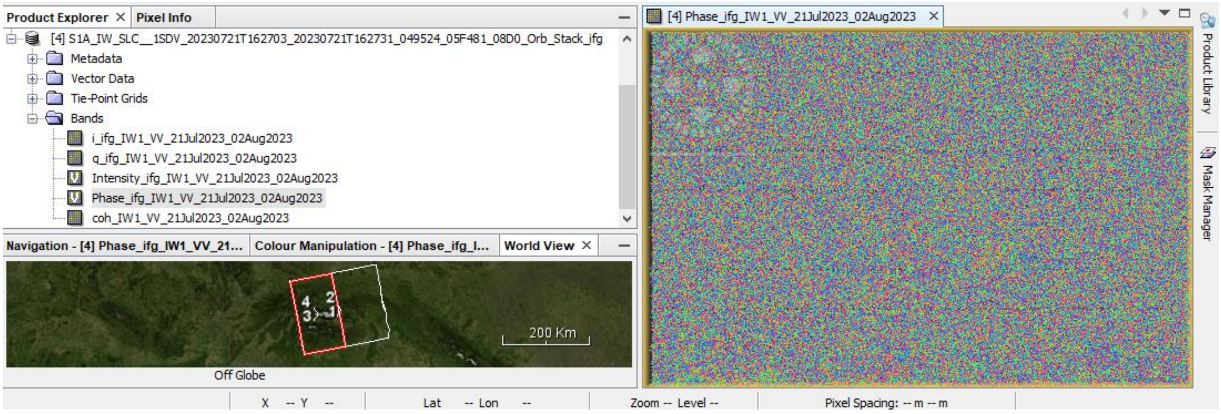
The next phase of interferometry involves generating an interferogram using the coregistered SLC images. To do this, follow these steps:

From the main menu bar, go to **Radar – Interferometric - Products** and finally select **Interferogram Formation**.
In the I/O Parameters tab, choose the "Orb_Stack" product that was generated during the coregistration process.
By default, the output target is set to the same directory and appends "ifg" to the filename.
For standard processing, there's no need to modify the defaults in the Processing Parameters tab.





Raw Interferogram — Phase Image should appear int he View tab.

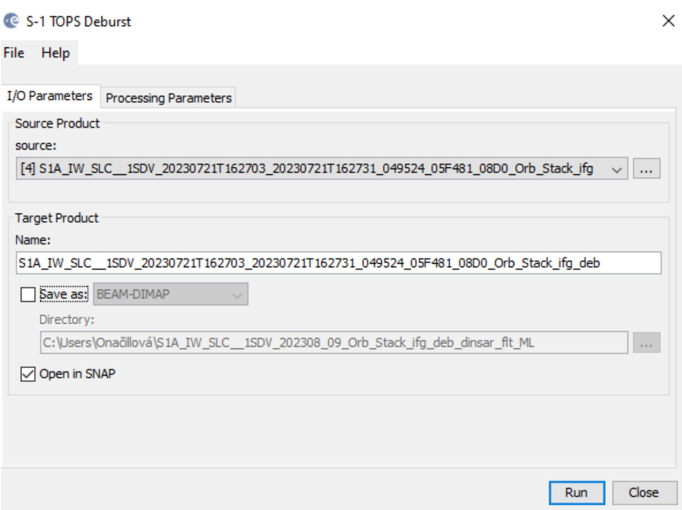


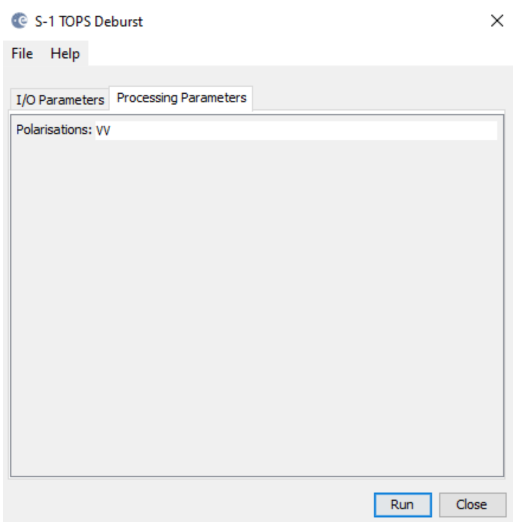
The interferogram is displayed in a rainbow color scale ranging from -topography, atmosphere and potential surface deformation (considered zero). The patterns, also called fringes appear in an interferogram as cycles of arbitrary colors, with each cycle representing half the sensor's wavelength.

2.5 TOPS Debursting

The next stage in interferometry using Sentinel-1 TOPS mode (IWS) data involves "debursting" or merging the bursts to remove the seamlines, a step not required with Sentinel-1 or other stripmap SAR data.

To perform debursting, follow these steps:
From the main menu bar, navigate to Radar, then Sentinel-1 TOPS, and finally S-1 TOPS deburst.
In the I/O Parameters tab, choose the "Orb_Stack_ifg" product generated during the interferogram formation process. By default, the output appends "deb" to the filename.
There is no need to make changes in the Processing Parameters tab.

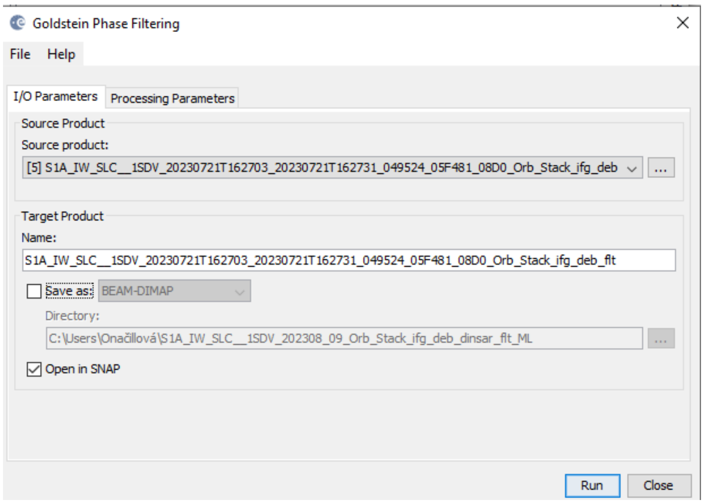


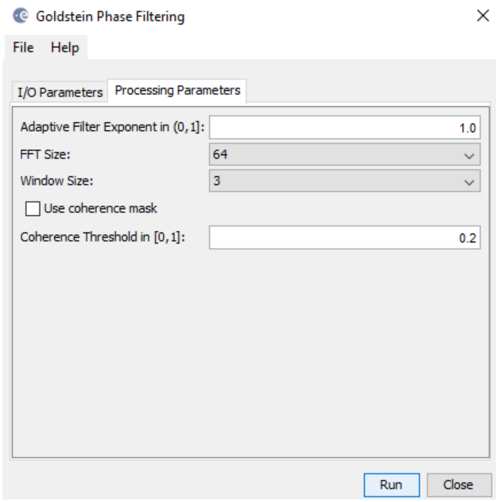


2.6 Goldstein Phase Filtering

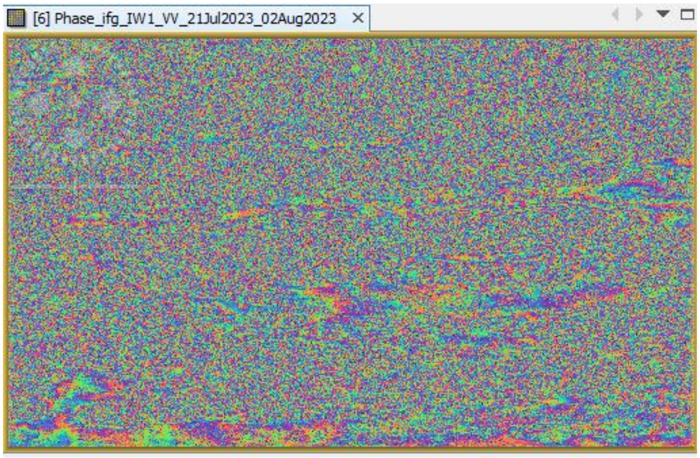
There are two methods to minimize noise in the interferogram: filtering and multi-looking. While our standard procedure involves applying filtering initially, it's also possible to opt for multi-looking first.

To begin filtering:
Go to Radar, then Interferometric, then Filtering, and select Goldstein Phase Filtering from the top main menu bar.
In the I/O Parameters tab, choose the "deb" product generated in the previous step.
By default, the output name includes "flt."
There's no necessity to adjust the default settings in the Processing Parameters tab for basic processing.





Double-click on the output raster in the Bands folder of the new product to see the result.



Create subset (optional)

In the earlier stages of processing, empty pixels along the interferogram's perimeter may have been created, particularly in regions not overlapped by both input images. To remove these sections, employ the Subset function found under Raster. This approach will also decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.

2.7 Phase Unwrapping

Unwrapping in SNAP follows three distinct steps:

1. Export of the wrapped phase (and definition of the parameters)
2. Unwrapping of the phase (performed outside SNAP by snaphu)
3. Import of the unwrapped phase back into SNAP

Export of the wrapped phase

Export your interferogram or your subset interferogram from Sentinel-1 Toolbox to SNAPHU:

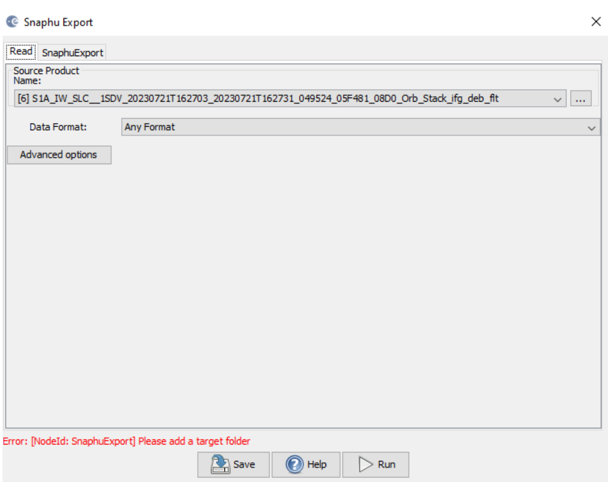
From the top main menu bar, navigate to **Radar > Interferometric > Unwrapping > Snaphu Export:**

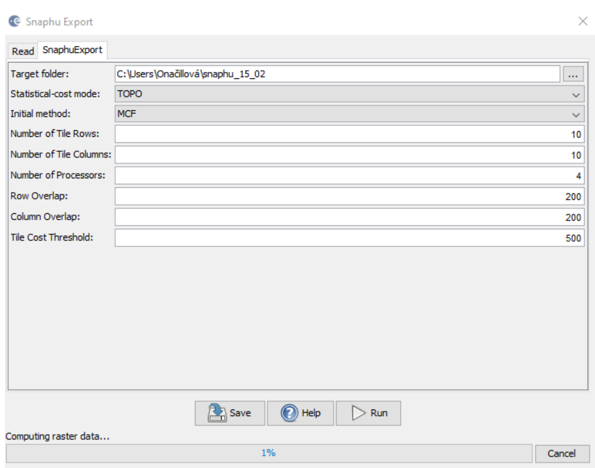
In the Snaphu Export window:
In Read tab, select the product created in the previous step
In Snaphu Export tab, you also need to specify a target folder for exported files. Create a new target folder for this step by entering a path and new folder name (e.g. „snaphu_export). If the selection of the directory does not work, simply copy and paste the path of your working directory into the text field.

In Snaphu Export tab, select TOPO as Statistical-cost mode and select 200 pixels for Row Overlap and Column Overlap if you want to multilook. Depending on the number of processors of your computer, you can also increase the Number of Processors variable.

Select MCF.

Click Run to create the SNAPHU_Export file
The folder now holds files used for phase unwrapping: the coherence image (*.img) and metadata (*.hdr), the wrapped phase: image (*.img) and metadata (*.hdr), the unwrapped phase: only the metadata (*.hdr), because the image (*.img) is first to be created by snaphu in the next step, a configuration file (snaphu.conf) containing the parameters defined in the export operator





Unwrapping of the phase

You should see the wrapped interferogram phase "Phase_ifg*.img", coherence "coh_*.img", and a "snaphu.conf" file.

For the next step, you will need to instal SNAPHU in Windows. SNAPHU is a tool for phase unwrapping of interferometric information. To use it as an executable file (*.exe) in Windows it has to be compiled first so all required drivers (*.dll) are installed correctly. Follow the steps for installation here: file:///C:/Users/Ona%C4%8Dillov%C3%A1/Downloads/Installation_SNAPHU_English_ABraun.pdf

To start unwrapping, check the location of the interferogram exported from SNAP. If snaphu.exe is not in your system's PATH variable: Copy it in there as well. It is recommended to store the data and snaphu on the same disk. Open Command Window Here.

Type snaphu and hit Enter. The help menu should be displayed.

Príkazový riadok

```
C:\Users\Onačillová>snaphu

snaphu v1.4.2
usage:  snaphu [options] infile linelength [options]
most common options:
  -t               use topography mode costs (default)
  -d               use deformation mode costs
  -s               use smooth-solution mode costs
  -f <filename>    read configuration parameters from file
  -o <filename>    write output to file
  -a <filename>    read amplitude data from file
  -c <filename>    read correlation data from file
  -b <decimal>     perpendicular baseline (meters)
  -i               do initialization and exit
  -l <filename>    log runtime parameters to file
  -v               give verbose output
  --mst            use MST algorithm for initialization (default)
  --mcf            use MCF algorithm for initialization

type snaphu -h for a complete list of options
```

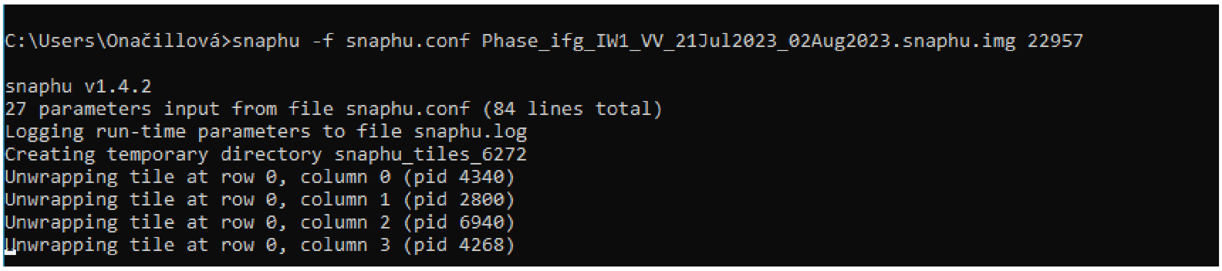
The command to start the unwrapping is shown in the file snaphu.conf. Open it with a text editor. The beginning of the "snaphu.conf" file shows the command to call Snaphu

snaphu – Poznámkový blok

Súbor Úpravy Formát Zobraziť Pomocník

```
# CONFIG FOR SNAPHU
# ----------------------------------------------------------------
# Created by SNAP software on: 12:23:26 15/02/2024
#
# Command to call snaphu:
#
#       snaphu -f snaphu.conf Phase_ifg_IW1_VV_21Jul2023_02Aug2023.snaphu.img 22957

#########################
# Unwrapping parameters #
#########################
```



The Snaphu program can take a long time to run. At the end it writes **unwrapped phase to "Unw_ifg*.img" file**

Import of the unwrapped phase

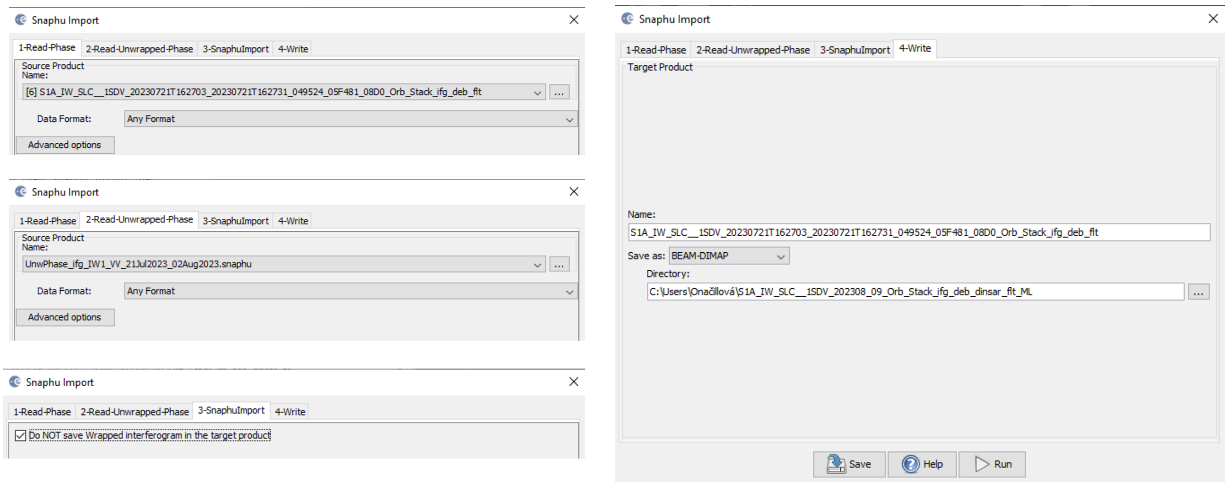
Now, we import the unwrapped phase. From the top main menu bar, select Radar > Interferometric > Unwrapping, and then Snaphu Import that converts it back into the BEAM DIMAP format and adds the required.

Read-Phase: should be set to the wrapped product that you exported(before the export)

Read-Unwrapped-Phase: select the unwrapped phase product: Navigate to folder where you exported for Snaphu. Select the "UnwPhase_ifg*.snaphu.hdr" file. Note: The error message will then vanish if you proceed to the next tab.

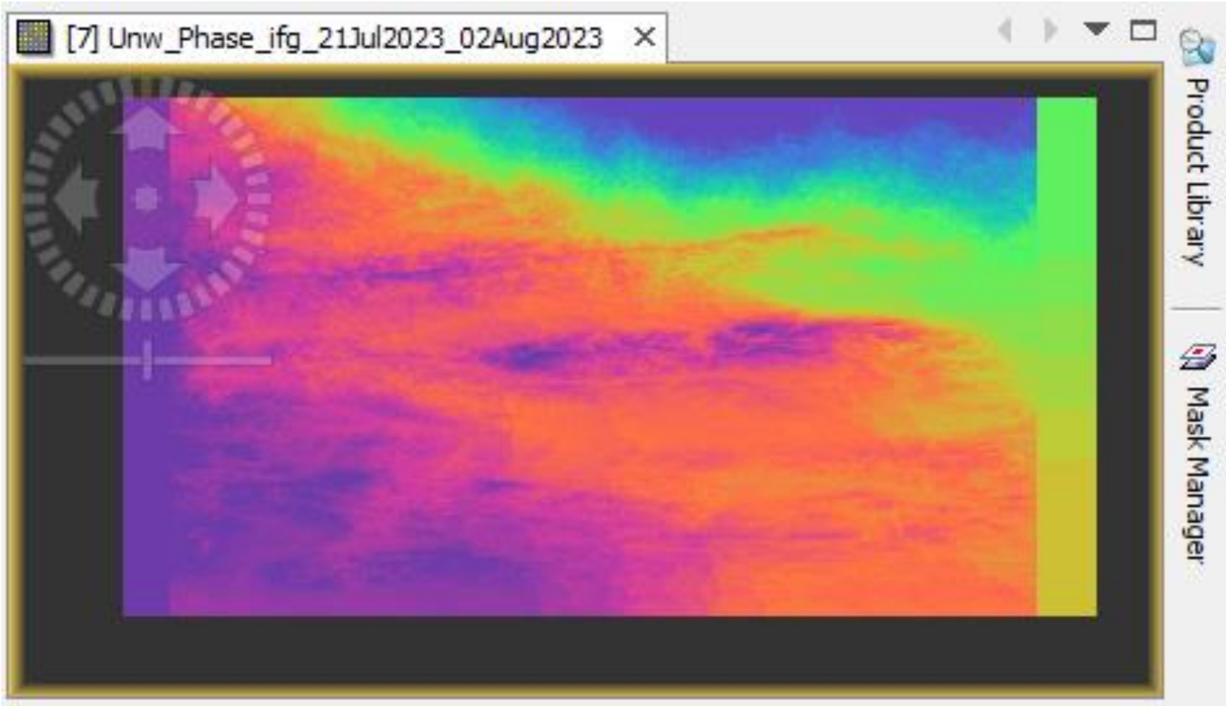
SnaphuImport: Leave the option "Do NOT save Wrapped interferogram in the target product"
unchecked, because it is required in the later step.

Write: To store the imported unwrapped band in a separate product (recommended), add '_unw' to the end of the output name and click Run.



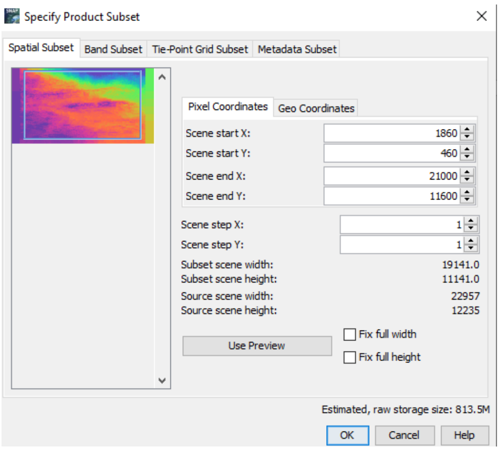
Finally, a new product is added to the Product Explorer which contains the the unwrapped phase that we can display.

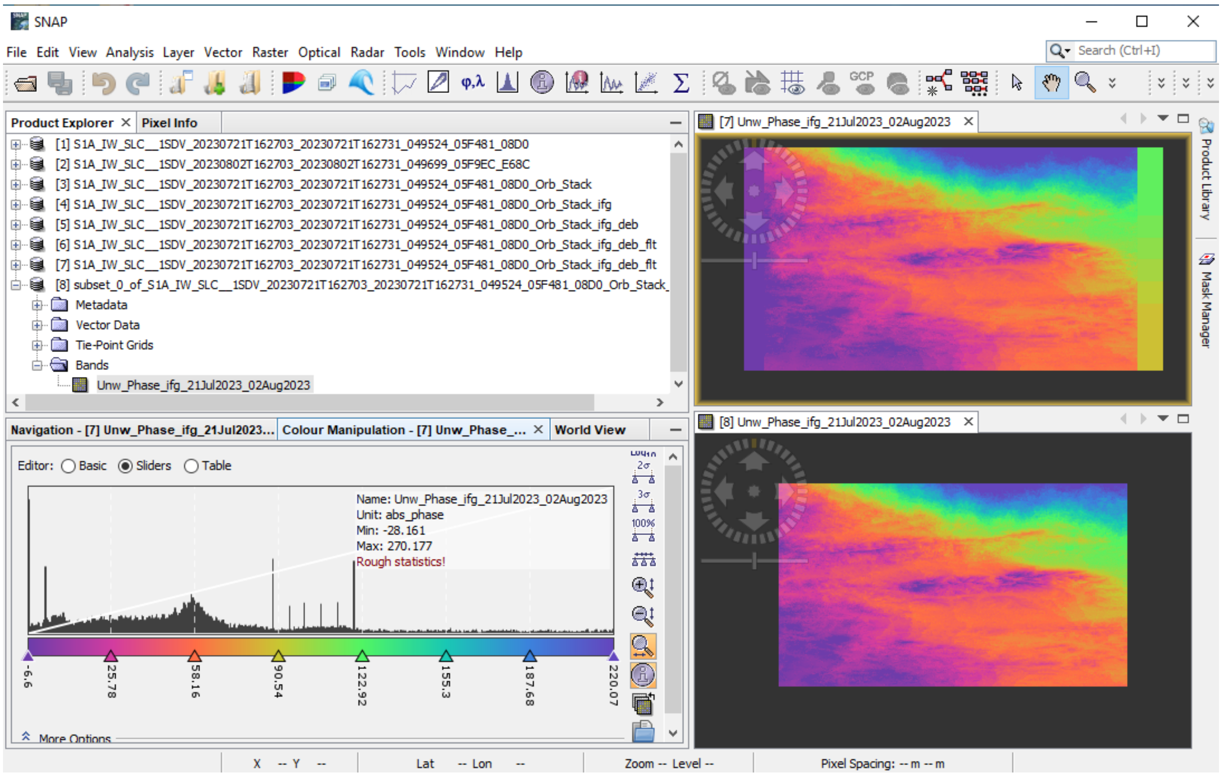
Select the Unw_Phase_ifg band. Double click on this unwrapped phase to see if the unwrapping was successful. It should be a smooth raster with little variation except for the areas of expected deformation.
All fringe patterns are summarized to absolute changes. Go to the Colour Manipulation tab and select "100%" to stretch color scale to full range of unwrapped data. Unwrapped phase is still in radians. Phase is reference image minus coregistered image. If reference image is earlier, then negative phase is land moving toward satellite (negative range change)



Create subset (optional)

In the earlier stages of processing, empty pixels along the interferogram's perimeter may have been created, particularly in regions not overlapped by both input images. To remove these sections, employ the Subset function found under Raster. This approach will also decrease processing time in subsequent stages, especially when the analysis is concentrated on a specific area rather than the entire scene.





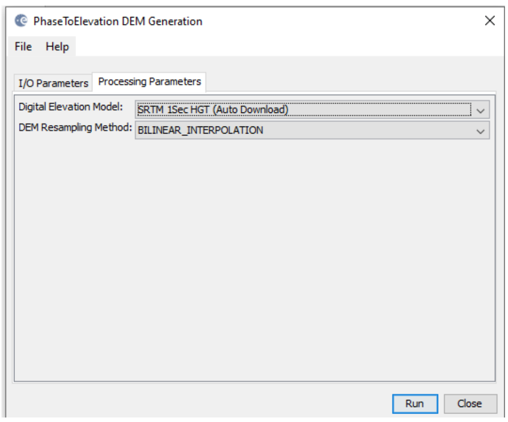
2.8 Phase to elevation

The unwrapped phase data is now a continuous raster, but it has not yet been converted into a metric measure. To achieve this conversion from radian units to absolute heights, the Phase to Elevation operator, found under **Radar > Interferometric > Products**, is employed. This operator translates the phase values into surface elevations along the line-of-sight (LOS) in meters. The LOS represents the direct line between the sensor and a specific pixel. To ensure accuracy, a Digital Elevation Model (DEM) is utilized to align the elevation values correctly.

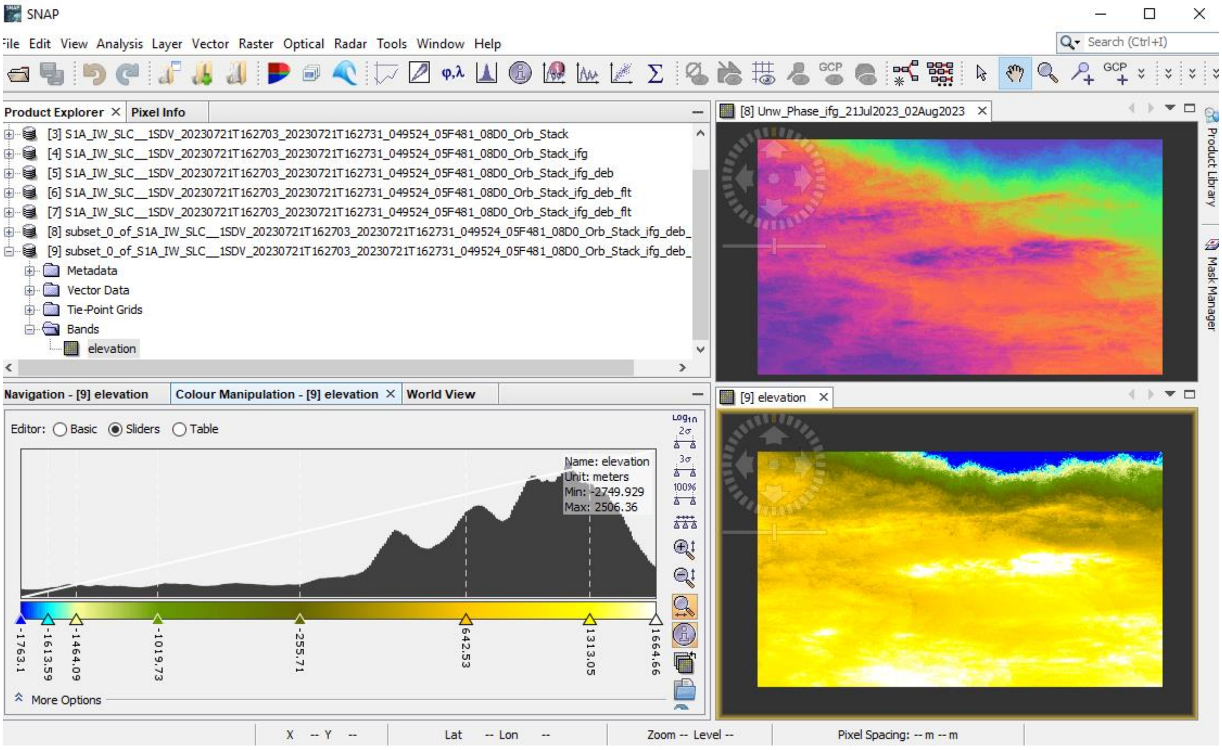
The I/O Parameters tab should be set to the last subset unwrapped product

Default for target product name is to add "_dem" to the name

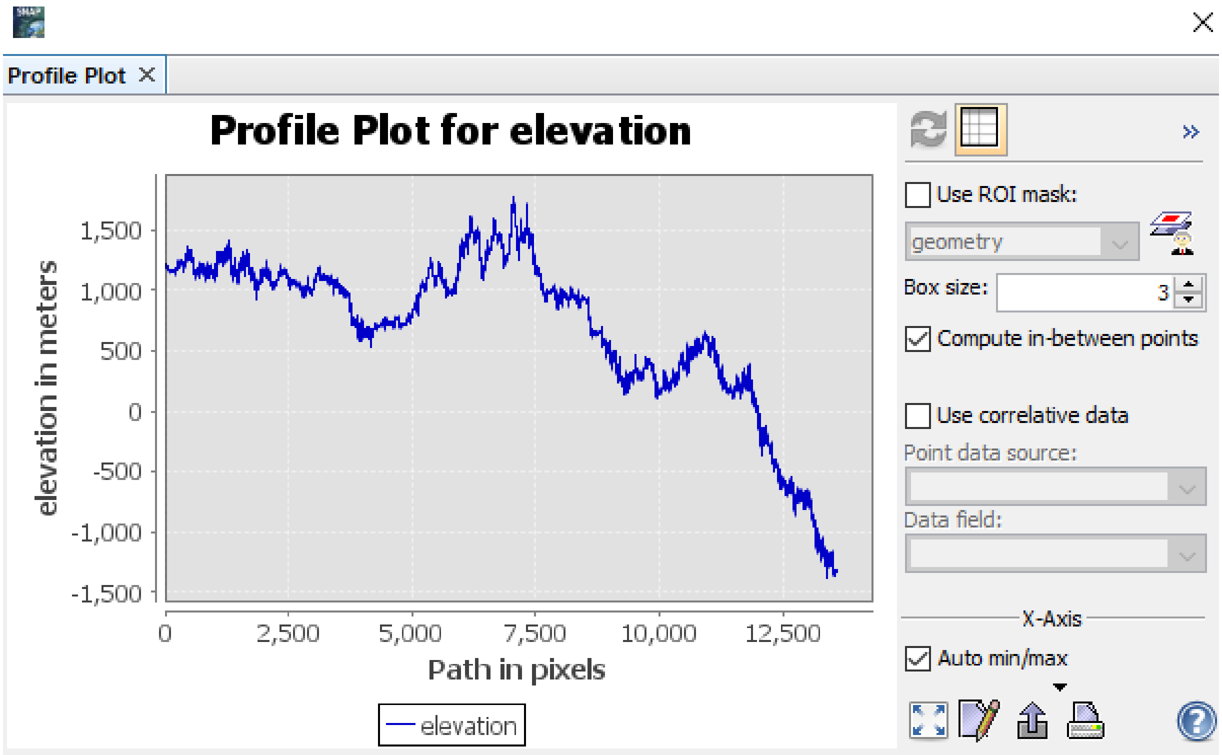
Navigate to the Processing Parameters tab and select SRTM 1Sec HGT (AutoDownload) as the input DEM.



Now, we can display elevation result. Again, better to stretch colors. Displacements is now in meters.
Sign was changed so positive displacement is "up" towards satellite



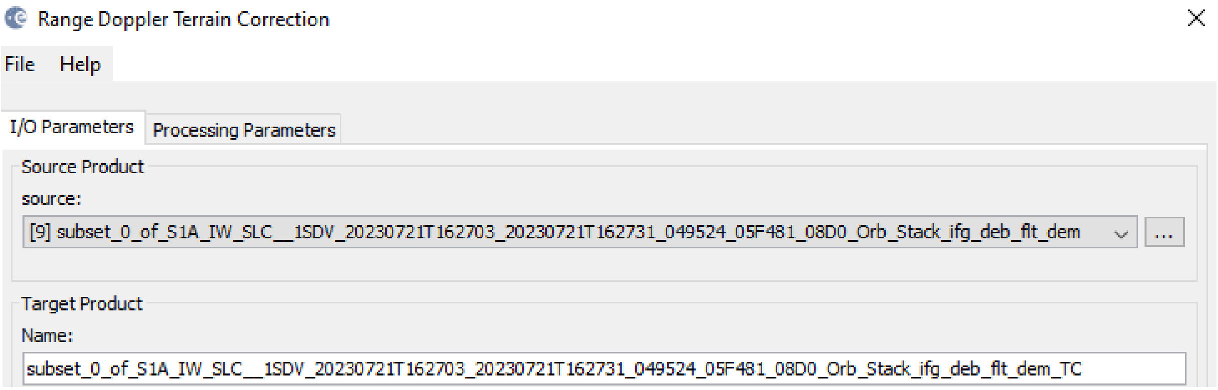
Profile plot



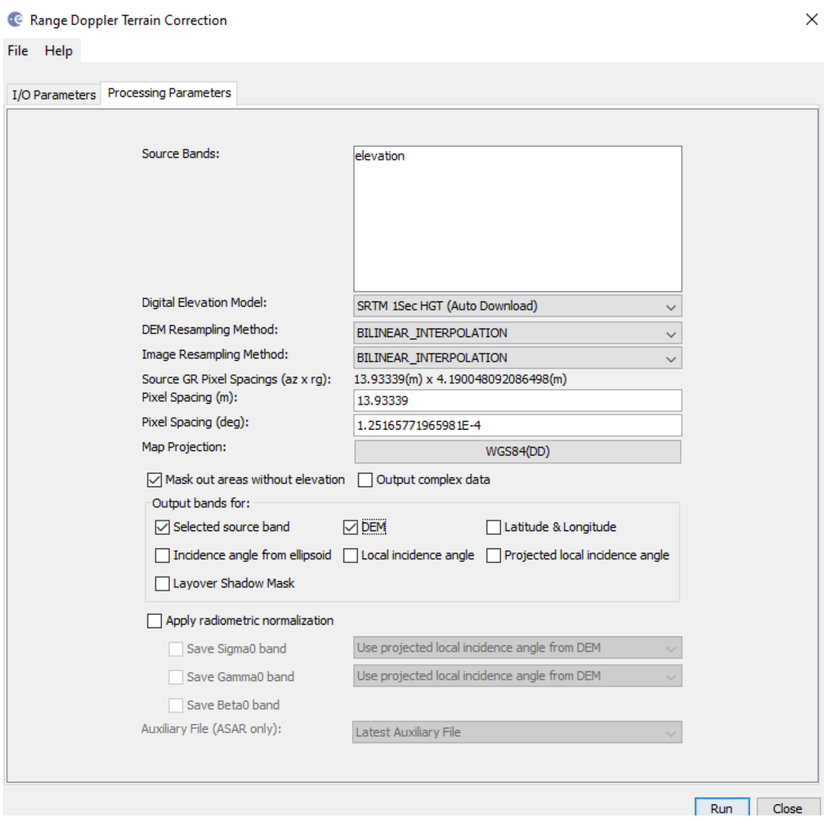
2.9 Terrain Correction

SNAP calls geocoding with topography "Terrain Correction." From the top main menu bar, select Radar, then Geometric, then Terrain Correction, and then Range-Doppler Terrain Correction.

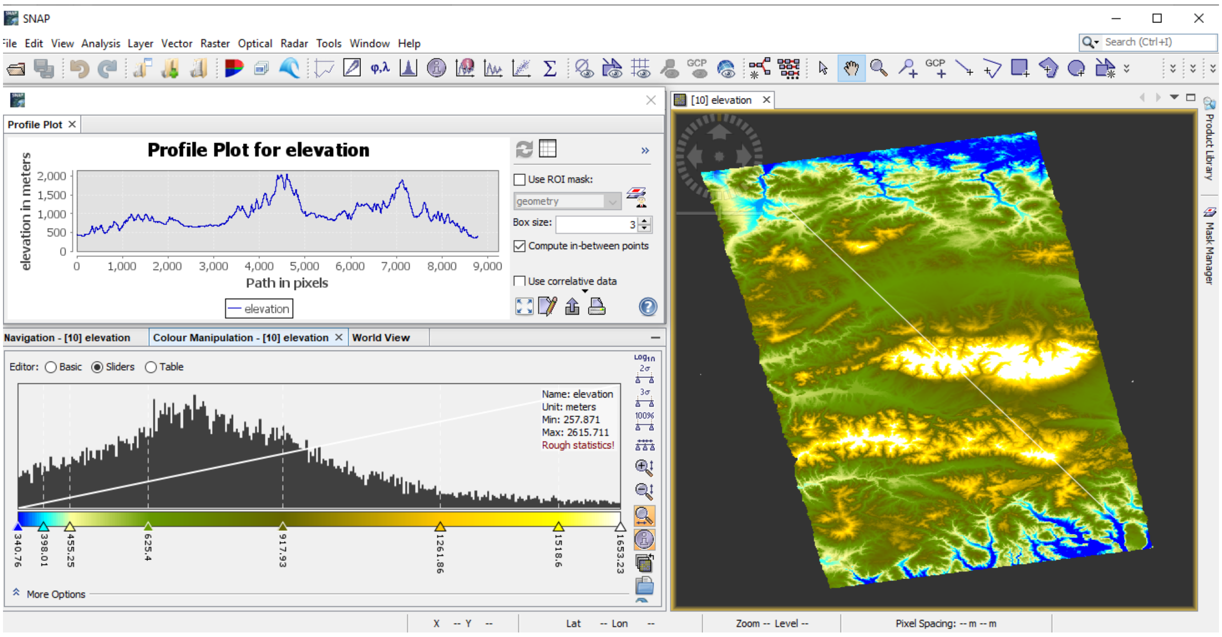
The I/O Parameters tab should be set to the last elevation product
Default for target product name is to add "_TC" to the name



Under Processing Parameters tab, select the elevation band as the input
Select SRTM 1Sec HGT (AutoDownload) as input DEM.
If you want to export the data as a KMZ file to view it in Google Earth, WGS84 must be selected as Map Projection (latitude and longitude).
If you want to compare the quality of the InSAR DEM, you can select DEM as a further output.



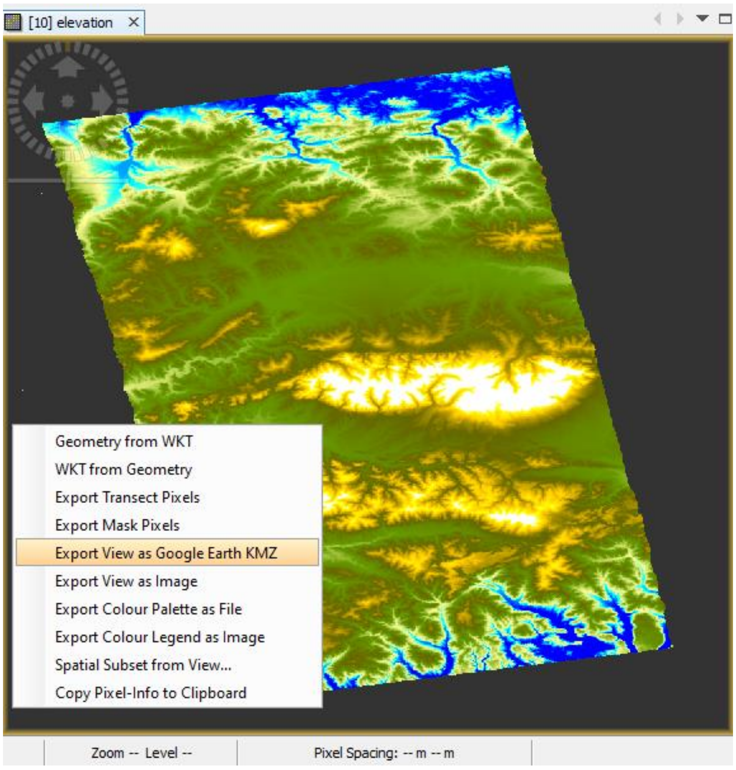
Now, double-click on the „elevation" raster to display the geocoded elevation raster output. Product is now evenly spaced in latitude and longitude and shows the elevation for the study area. You can create profile to see the elevation diversity.



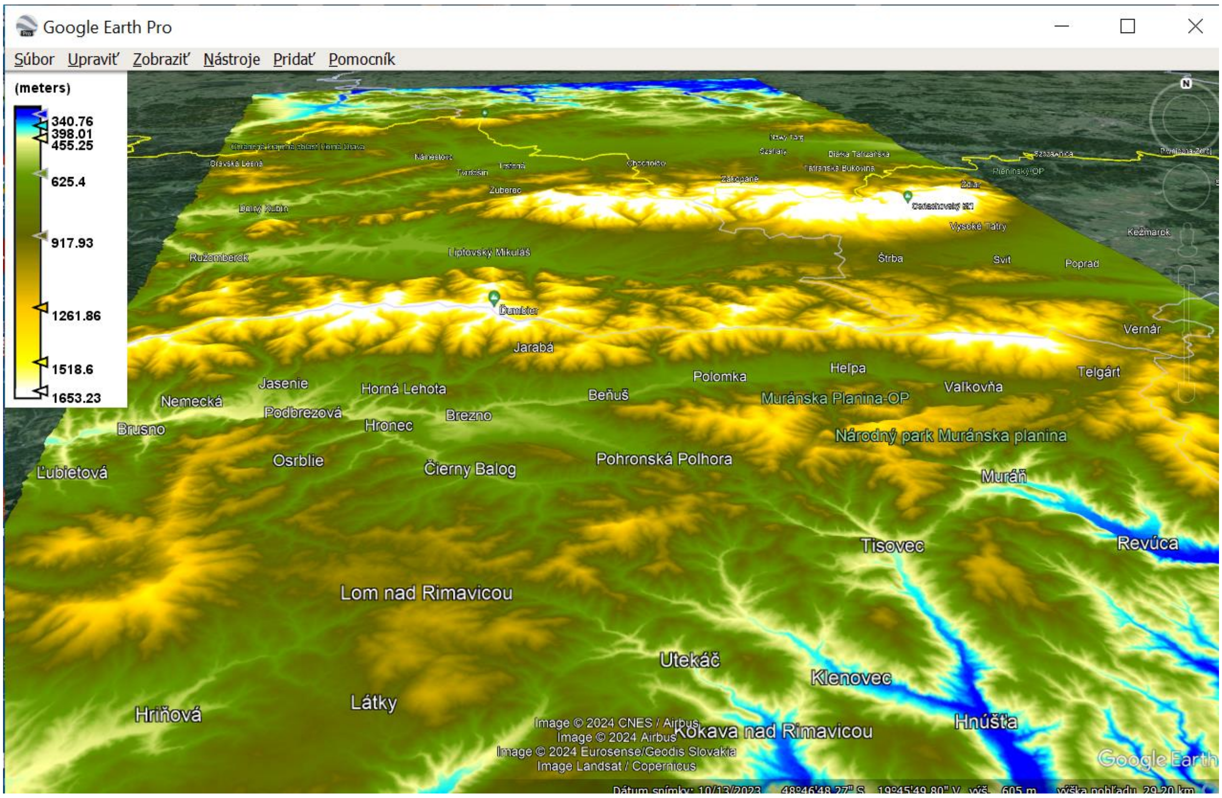
2.10 Export .kmz to Google Earth

Geocoded products (projected to WGS84) can be exported as a KMZ file to view in Google Earth (Pro):

Select an appropriate color scale and color ramp from the Color Manipulation tab.
Right click on the elevation raster in the View tab (or navigate to File > Export > Other > View As Google Earth KMZ)
Choose a directory to save the output .kmz and provide a fitting filename, then confirm with Save.



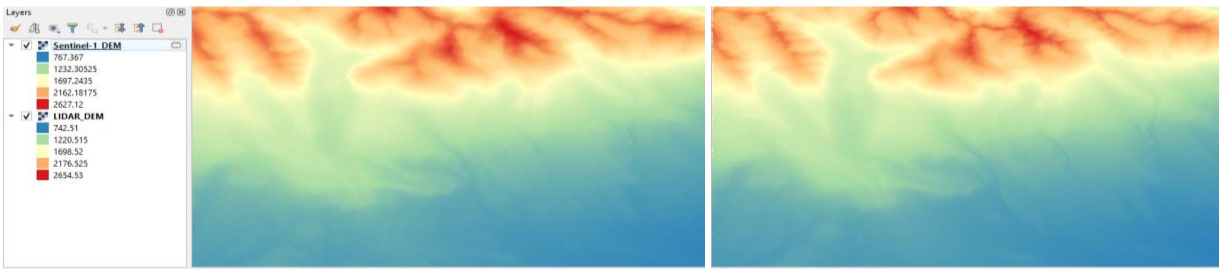
Open the resulting KMZ file in Google Earth to observe the elevation patterns overlaid on the satellite image base map.



Compare with LiDAR-derived DEM

Compare your Sentinel-1 derived DEM with Digital Elevation Model (DEM 5.0) with a resolution of 1 meter per pixel created from airborne laser scanning data by ÚGKK SR. „Source of ALS data: ÚGKK SR".

Open QGIS and comapre small LiDAR-derived DEM sample with our resulted DEM derived using Sentinel-1 data. We can observe that there are small differences in the elevation.



Comparing Sentinel-1 derived DEMs and LiDAR derived DEMs, LiDAR typically offers higher precision. This is because LiDAR directly measures the distance between the sensor and the Earth's surface using laser pulses, resulting in highly accurate elevation data. On the other hand, Sentinel-1 derived DEMs are generated using synthetic aperture radar (SAR) data, which can be affected by factors such as vegetation cover and terrain roughness, potentially leading to less precise elevation measurements compared to LiDAR. Therefore, in terms of precision, LiDAR derived DEMs are generally considered more accurate and reliable.

However, Sentinel-1 derived DEMs may be more cost-effective compared to LiDAR due to the lower cost associated with satellite data acquisition and processing. In this case, Sentinel-1 data are free of charge, available for everyone after the registration. Also, for large-scale mapping, monitoring, or areas with limited budget or accessibility, Sentinel-1 derived DEMs may be preferable.

For more information, see the lecture: 12. Retrieval of digital elevation model (DEM) from ESA EO data and comparison with LiDAR outputs

THANK YOU FOR FOLLOWING THE EXERCISE!

UNIVERSITY COURSE EARTH OBSERVATION APPLICATIONS

EXERCISE 13 – TUTORIAL

Marine applications: deriving nearshore bathymetric model with Sentinel 2 data using SNAP software

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1 | Exercise outline

In this exercise, we will:

- Learn the basic steps to derive near-shore bathymetry based on S2 images
- Preprocess the image to correct for atmospheric effects
- Identify and select appropriate bands for bathymetric analysis, particularly focusing on near-infrared (NIR) and shortwave infrared (SWIR) bands which penetrate water more effectively.
- Utilize empirical relationships to estimate water depth based on reflectance values in selected bands.
- Visualize the derived bathymetry map to interpret and analyze water depth variations across the coastal area.

2 | Background

Deriving bathymetry using Sentinel-2 data

Deriving bathymetry, or the measurement of water depth, using Sentinel-2 data involves leveraging the satellite's multispectral capabilities, particularly in the near-infrared (NIR) and shortwave infrared (SWIR) bands, to penetrate water and assess bottom reflectance. While Sentinel-2 imagery is primarily designed for land observation, it can still provide valuable information for coastal and shallow water applications.

Our approach to derive bathymetry from Sentinel-2 data involves exploiting the attenuation of light with depth in water. Water absorbs and scatters light as it penetrates deeper, with longer wavelengths like NIR and SWIR being less affected. By analyzing the reflectance values of these bands in shallow coastal areas, researchers can estimate water depth based on the relationship between reflectance and depth.

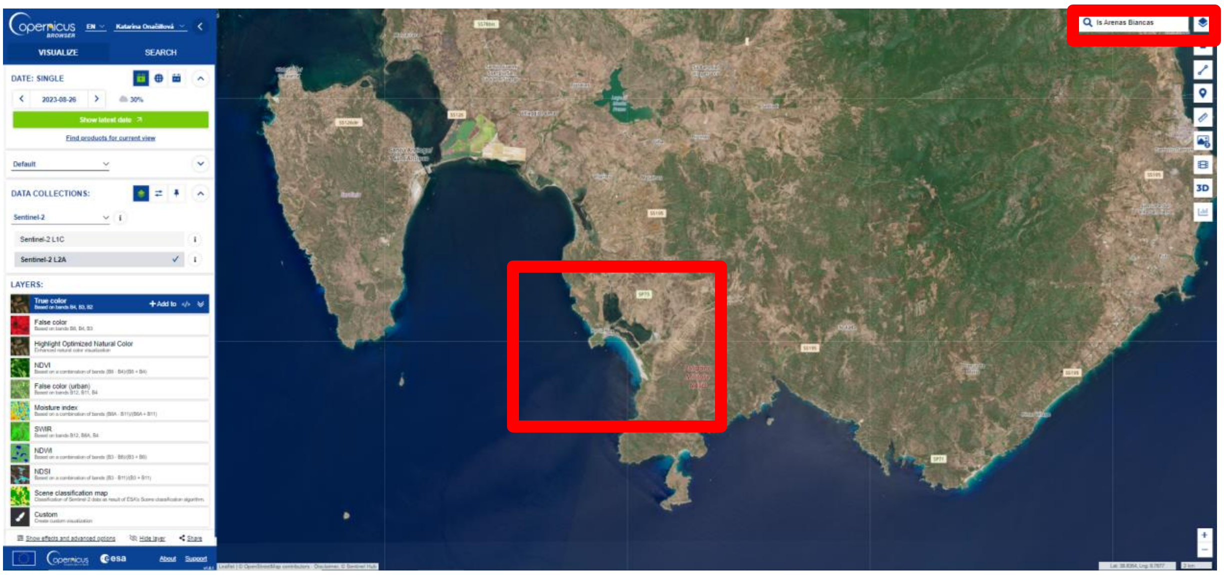
For bathymetric estimation in this exercise we use satellite imagery and empirical models that establish relationships between satellite-derived reflectance values and measured water depths from field surveys. By calibrating the model with ground truth data, researchers can predict water depth from reflectance values in Sentinel-2 bands.

Challenges in deriving bathymetry from Sentinel-2 data include atmospheric effects, water surface roughness, and bottom substrate variability. Additionally, accurate ground truth data for calibration and validation are essential for ensuring the reliability of bathymetric estimates.

Despite these challenges, Sentinel-2's frequent revisits and high spatial resolution make it a valuable tool for coastal and shallow water bathymetry mapping, aiding in coastal zone management, environmental monitoring, and habitat mapping. Ongoing research continues to refine and improve bathymetric estimation techniques using Sentinel-2 data.

2.1 Study area and data used

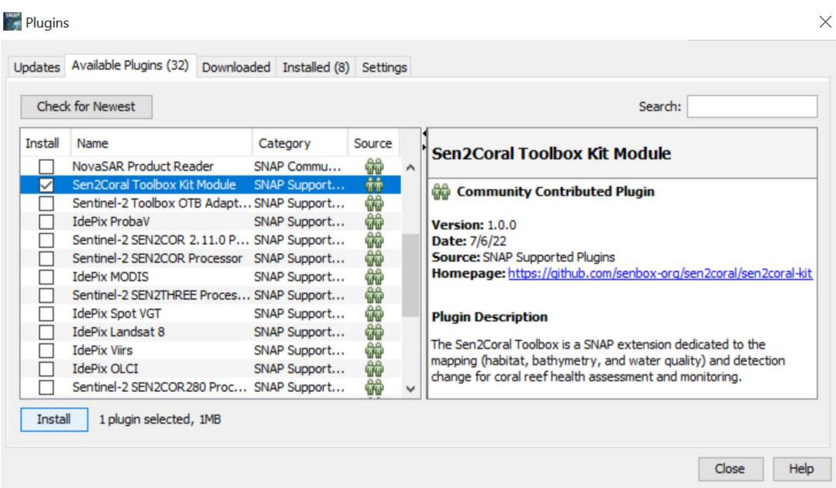
For this exercise, we will use Sentinel-2B image of the area Is Arenas Biancas, south of Cagliari, with its expanse of white sand, a vivid blue seabed and dunes covered in greenery behind it, using the Tile Number *32SMJ* downloaded for 26 August 2023 from the Dataspace Copernicus Open Access Hub [@https://dataspace.copernicus.eu/].



2.2. SNAP – Sen2Coral

Open SNAP Desktop and check if the Sen2Coral Toolbox that we will need for this exercise is installed. The Sen2Coral Toolbox is a SNAP extension dedicated to the mapping (habitat, bathymetry, and water quality) and detection change for coral reef health assessment and monitoring.

Navigate to Tools – Plugins and check whether the Sen2Coral Toolbox is Installed in the Installed tab. If it doesn´t appear there, go to Available plugins and install it. To complete the installation process, restart of the application is needed. After that, you can check if it was installed succesfully – Navigate to Optical – Thematic Water Processing – Sen2Coral plugin should be there.

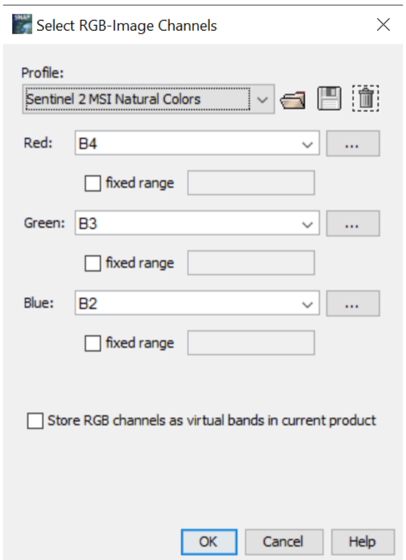


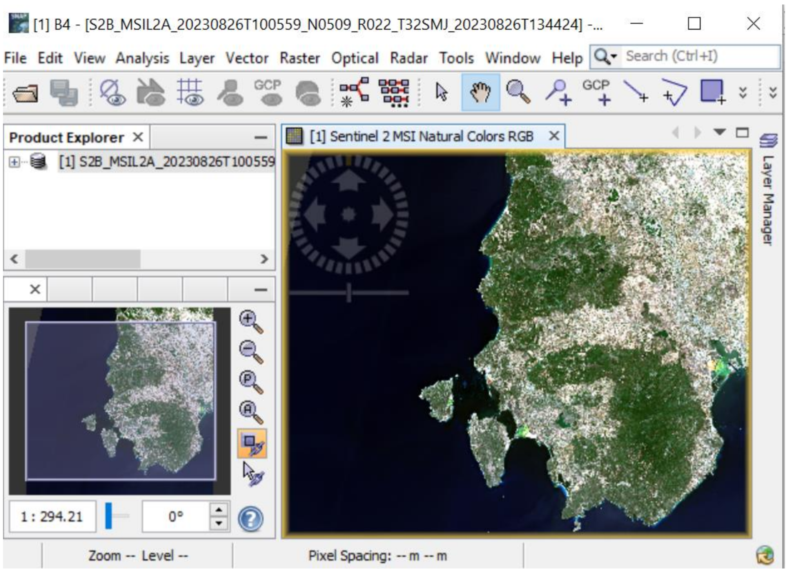
2.3. SNAP - Open and explore product

Open SNAP Desktop, click Open Product and open downloaded Sentinel-2 product (unzipped) by double click on the metadata „MTD_MSIL2A.xml" inside the folder. The opened products will appear in Product Explorer window.

S2B_MSIL2A_20230826T100559_N0509_R022_T32SMJ_20230826T134424.SAFE

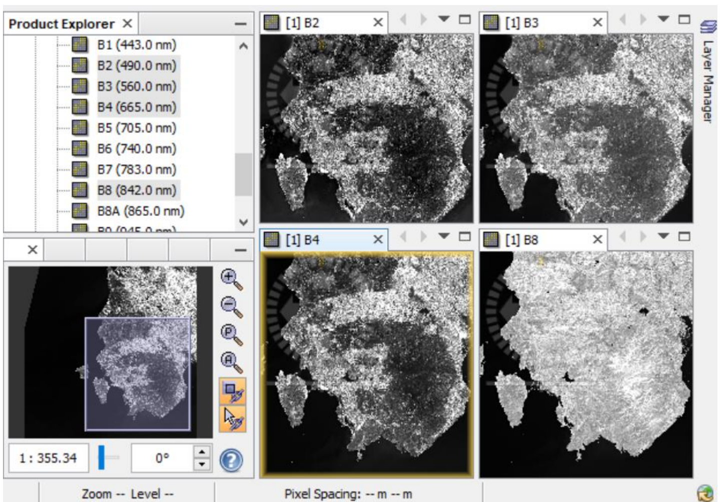
Display the product using e.g. True color composition:
Right click on the product – Open RGB Image Window – select Sentinel 2 MSI Natural Colors.





For this exercise, only bands with a spatial resolution of 10 meters will be employed: the Visible Blue (B2), Green (B3), Red (B4), and Near Infrared band (B8) due to their strong linear correlation with water depth. The NIR band is utilized for land masking.

To view these four bands in the View Window, navigate to the Bands folder of the image and double-click on them (B2, B3, B4, B8). Ensure synchronization of views by going to the Navigation tab in the lower left (red arrow) and confirming that the cursor and views are linked.



2.4 Resample

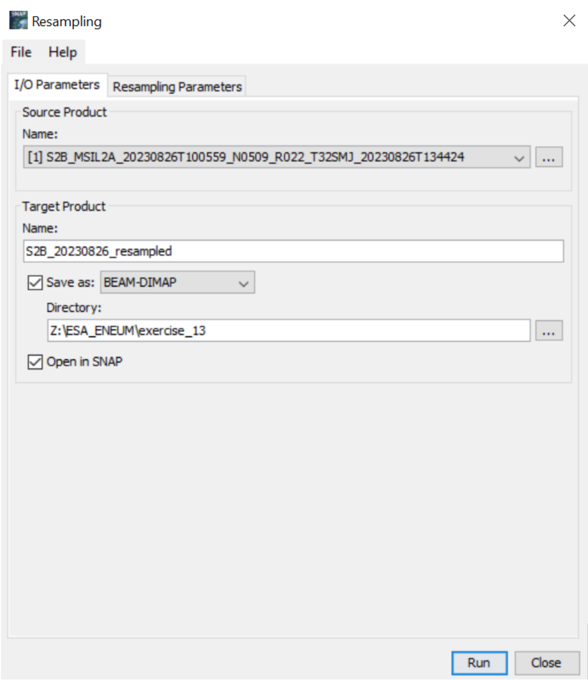
The Sentinel-2 products consist of 13 bands with varying resolutions, impacting their sizes. Since several operators in the SNAP toolbox cannot handle products with bands of different sizes, it is necessary to initially resample the bands to ensure uniform resolution.

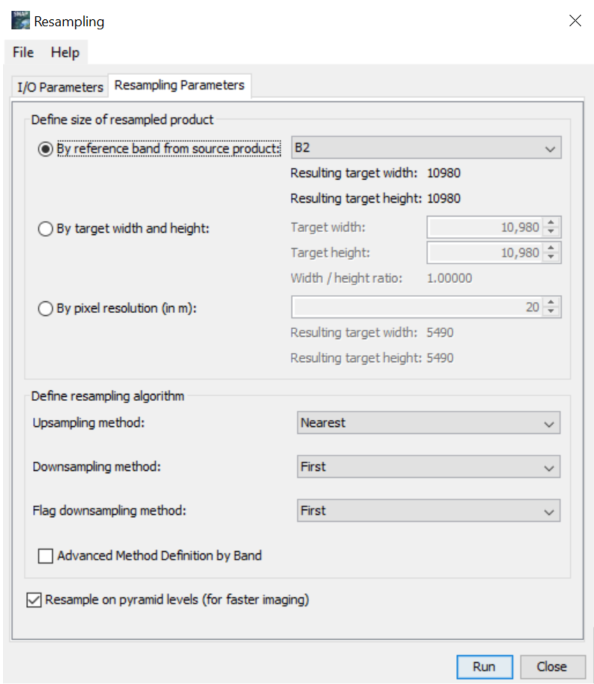
Navigate to Raster → Geometric → Resampling.

In the I/O Parameters tab, set the name for the "Target Product," as S2B_20230826_resampled and set the Directory where the resampled product will be saved.

In the Resampling Parameters tab, under "Define size of resampled product," select: By reference band from source product: B2.

Click **Run**. After the process is completed, if a window appears, click **OK**. Close the Resampling Window.
A new product [2], named **S2B_20230826_resampled** appeared in the **Product Explorer** Window.





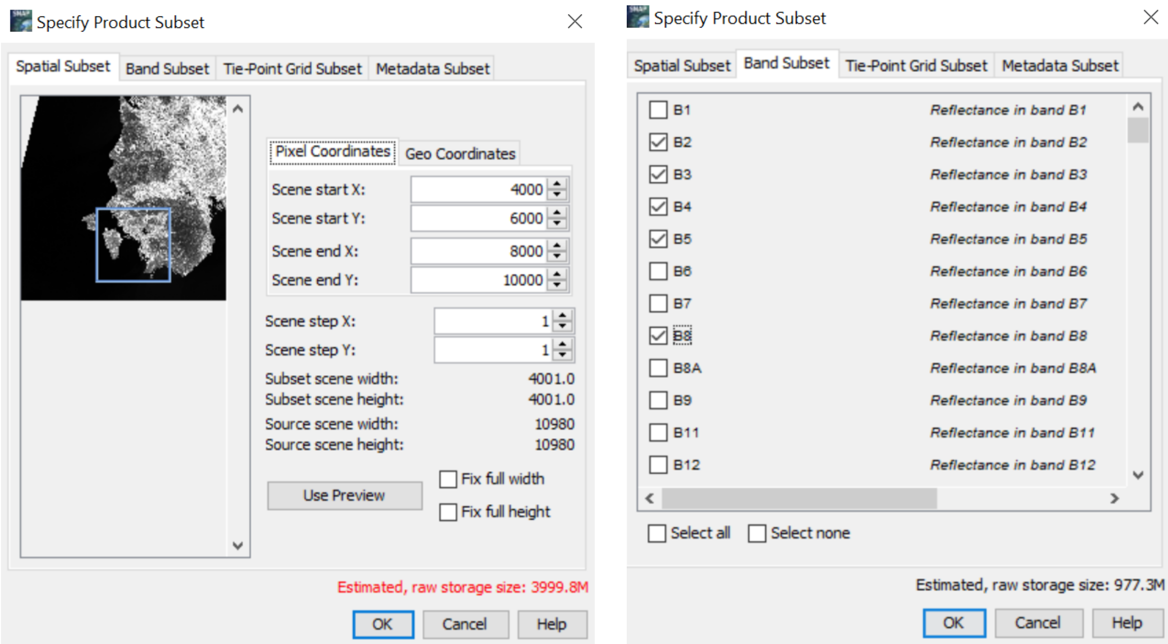
2.5 Subset

The initial phase of the methodology involves reducing the original size and number of bands in the image. To accomplish this, choose the Sentinel-2 resampled product in the Product Explorer, then proceed to **Raster -> Subset**.

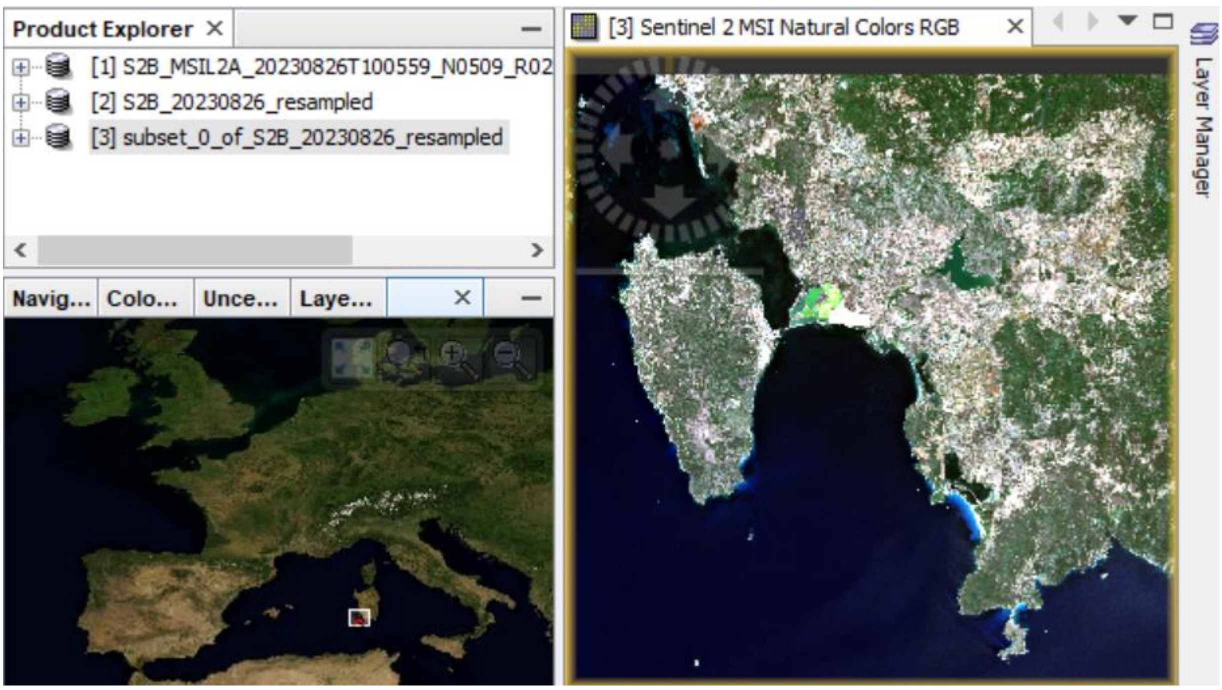
In the **Spatial Subset** tab select the Pixel Coordinates tab, set the following parameters:

Scene start X: 4000
Scene start Y: 6000
Scene end X: 8000
Scene end Y: 10000

In the **Band Subset** tab, choose only the bands that we will need: B2, B3, B4, B5, B8 and click OK:



Right-click on the subset product that will appear at the Product Explorer and click **Open RGB image window** and from the dropdown menu select **Profile: Sentinel 2 MSI Natural Colors** (B4, B3, B2) and click **OK**. Now we can see it contains only the area we selected to create subset.



2.6 Sun Glint Correction

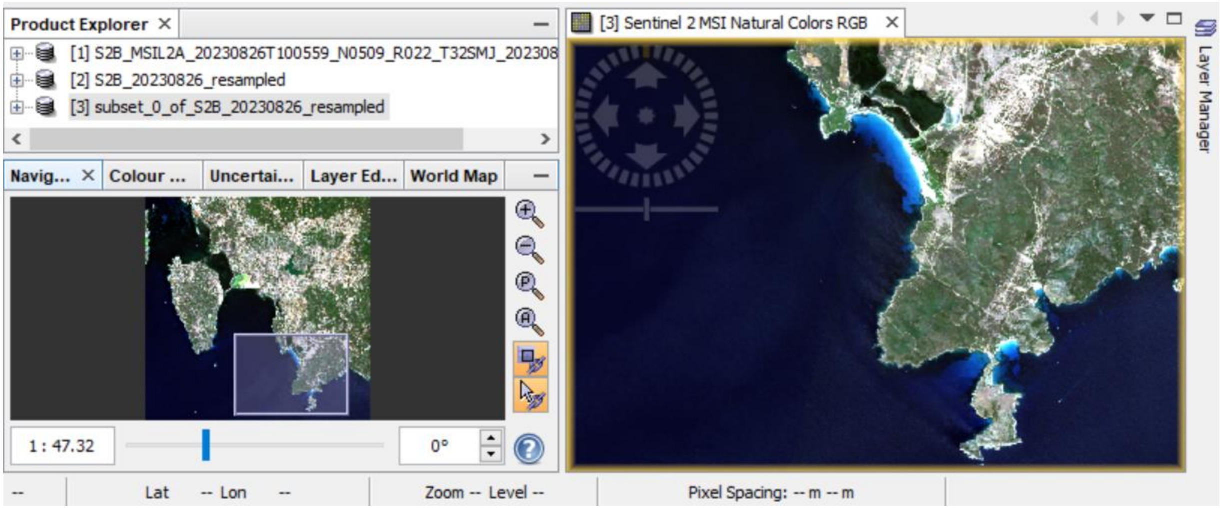
Sun glint is a common phenomenon in satellite images and it essentially refers to the specular reflection of the sun on water surfaces. The water-leaving reflectance can be difficult to observe due to the reflection of direct sunlight on the air-water interface (sunglint) in the direction of the satellite. The viewing geometry of Sentinel-2 satellite makes it vulnerable to sunglint contamination. Sun glint removal is a pre-processing step of multispectral images which is necessary when the amount of sun glint prevents the visibility of the sea bottom, usually in cases of marine habitat mapping.

There are several available sun glint removal methods for high resolution images and coastal applications. In this exercise we will apply the deglint methodology using SNAP plugin Sen2Coral.

To apply the correction we have to use one or more image samples of sun glinted regions to scale the relationship between the NIR signal and sun glint.

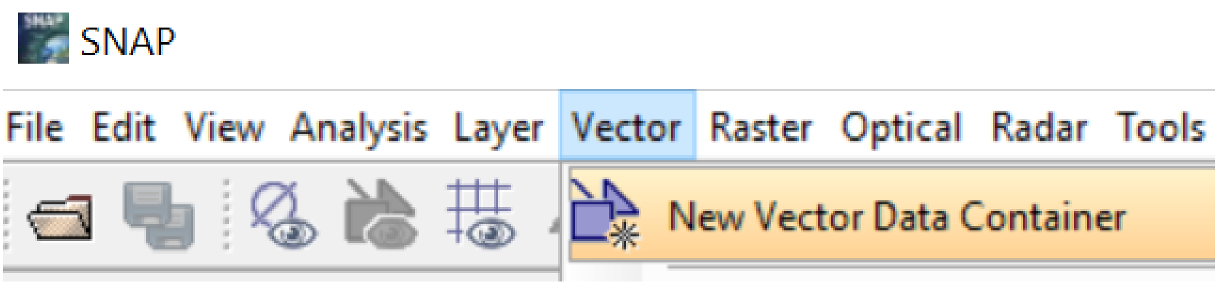
Right-click on the last subset product and click Open RGB image window and from the dropdown menu select Profile: Sentinel 2 MSI Natural Colors (B4, B3, B2) and click OK.

As you can see in the image, there are bright areas on the deep water – sunglint

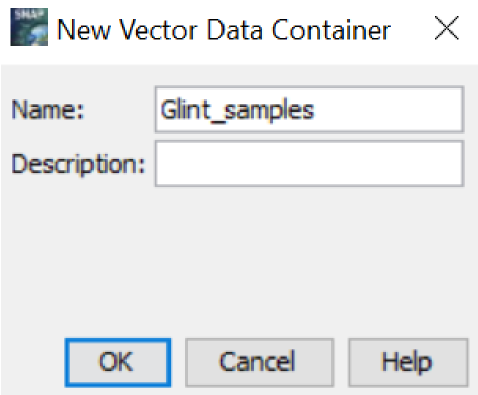


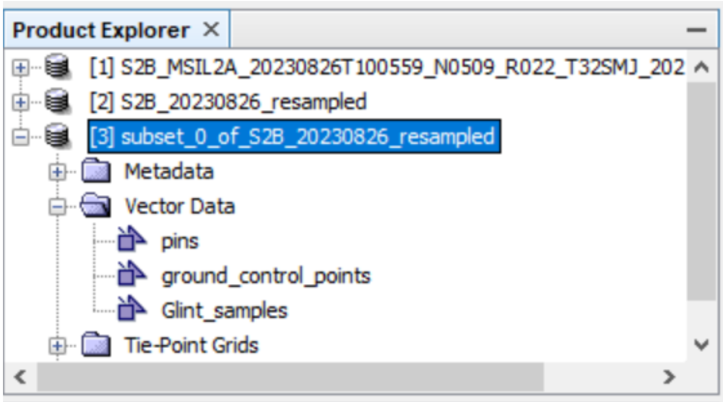
Now, we will create samples from those pixels as well as glint-free pixels.

Go to Vector – New Vector Data Container



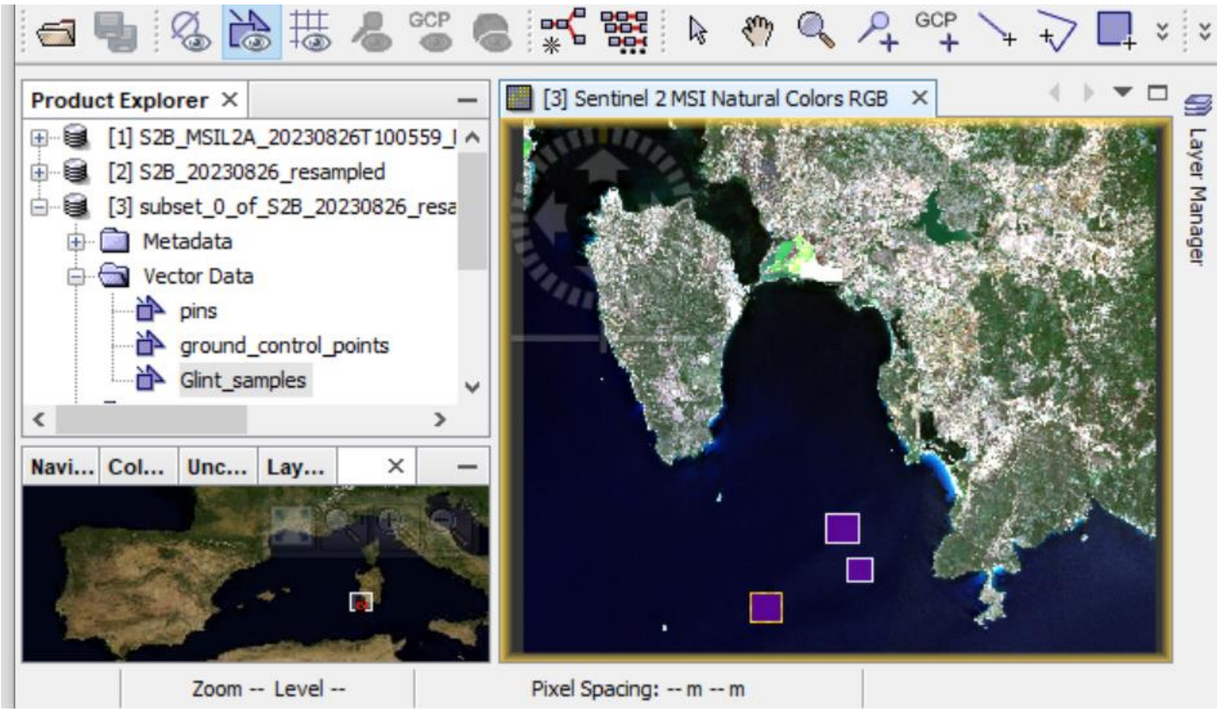
Set the parameters for new vector layer:
Name: Glint samples
And click OK.





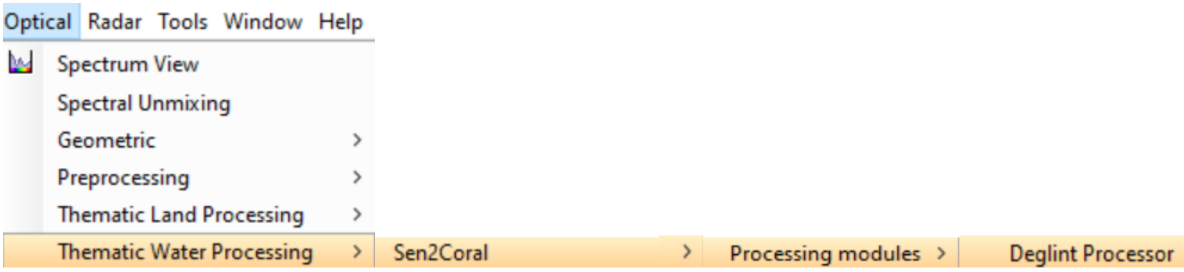
The new vector data container layer „Glint_samples" has been added in the Vectors folder of our subset product in the Product Explorer Window.

Let´s create some glint samples. For that, you can use RGB composition as well as one of the bands, e.g. band 8 (try to play with histogram to better see the sunglint ares)aClick on the Rectangle drawing tool icon int he Menu bar and draw the samples (at least 4) that includes sunglint and also glint-free pixels.



After that, we will use Deglint processor tool. (Note: if the product involves Tie-pont grids folder with some data, delete it first)

Navigate to Optical – Thematic Water Processing – Sen2Coral – Processing modules – Deglint processor



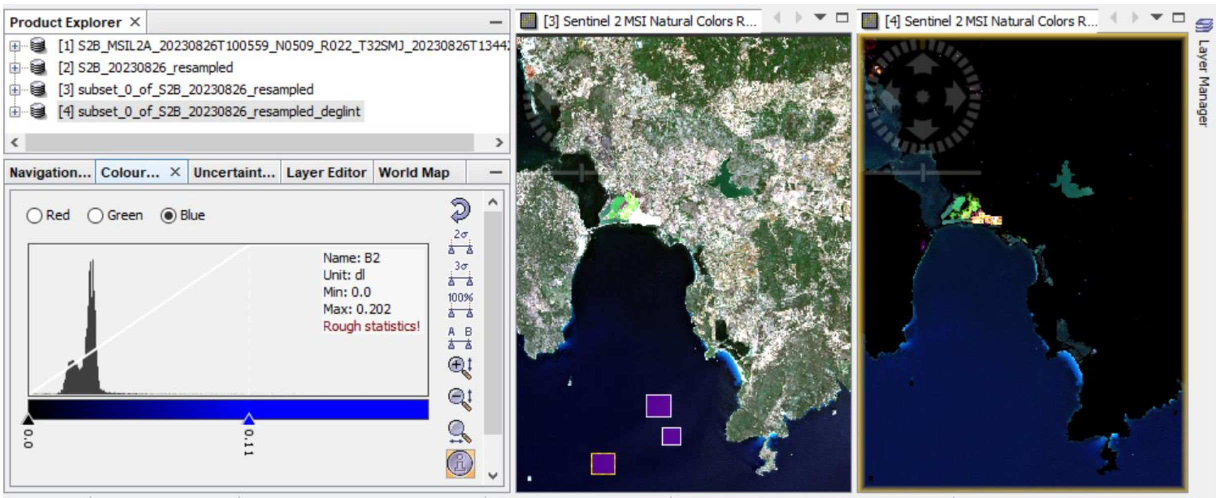
In the I/O Parameters tab, select the last subset product. In the Processing Parameters set the following parameters:

Sun Glint Areas: Glint_samples

Source Bands: select B2, B3, B4, B5

Reference Bands: select B8

After that, new product with „deglint" at the end is created in which land areas are also masked automatically. You can open an RGB image if you want before and after applying the sunglint correction and compare them.

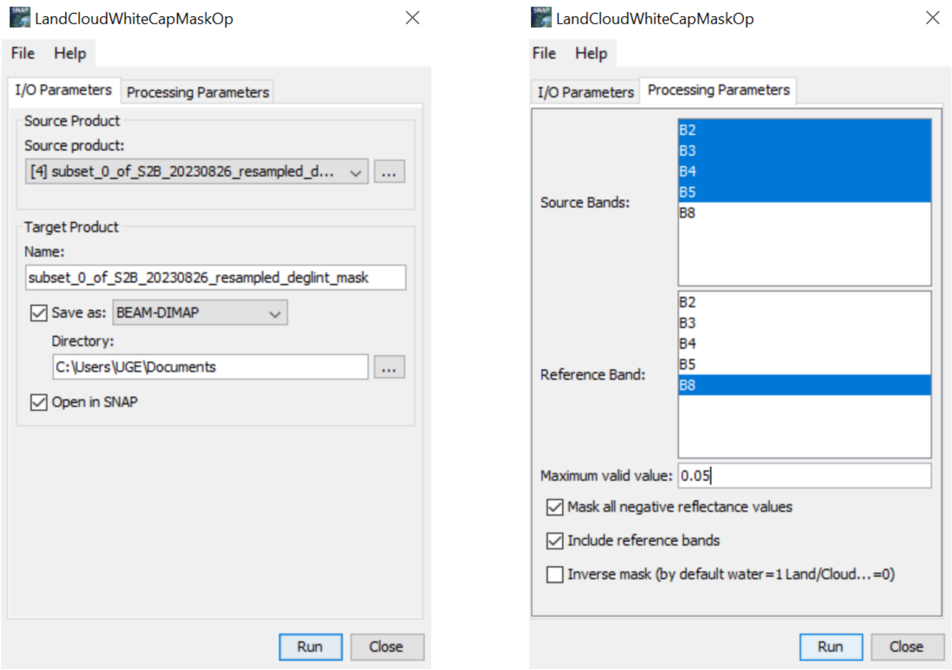


2.7 Dark-Object Atmospheric Correction

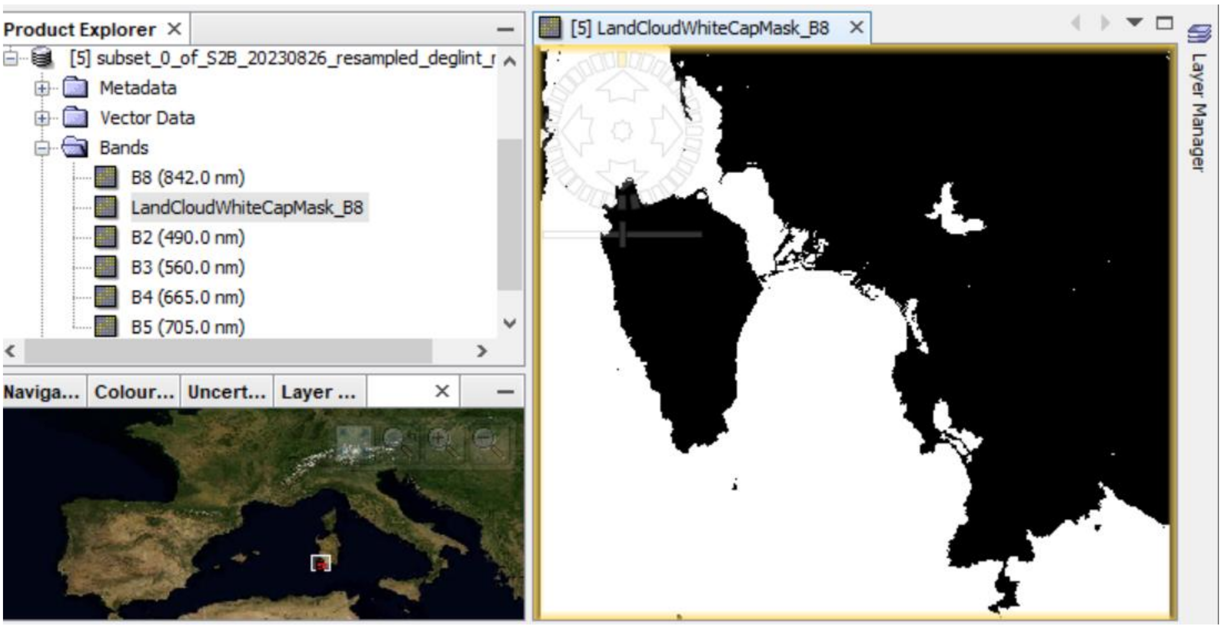
Dark Object Subtraction (DOS) is a practical method for atmospheric correction, assuming that dark objects reflect atmospheric scattering. By subtracting the atmospheric offset, calculated as the histogram's cut-off point at the lower end, from each pixel in a band, this method effectively corrects for atmospheric interference. Optically-deep water, with an anticipated zero reflectance, is considered the most suitable dark target for this purpose (Chavez, 1998).

Now, let´s mask the clouds.

Navigate to Optical – Thematic Water Processing – Sen2Coral – Processing modules – LandCloudWhiteCapMaskOpt

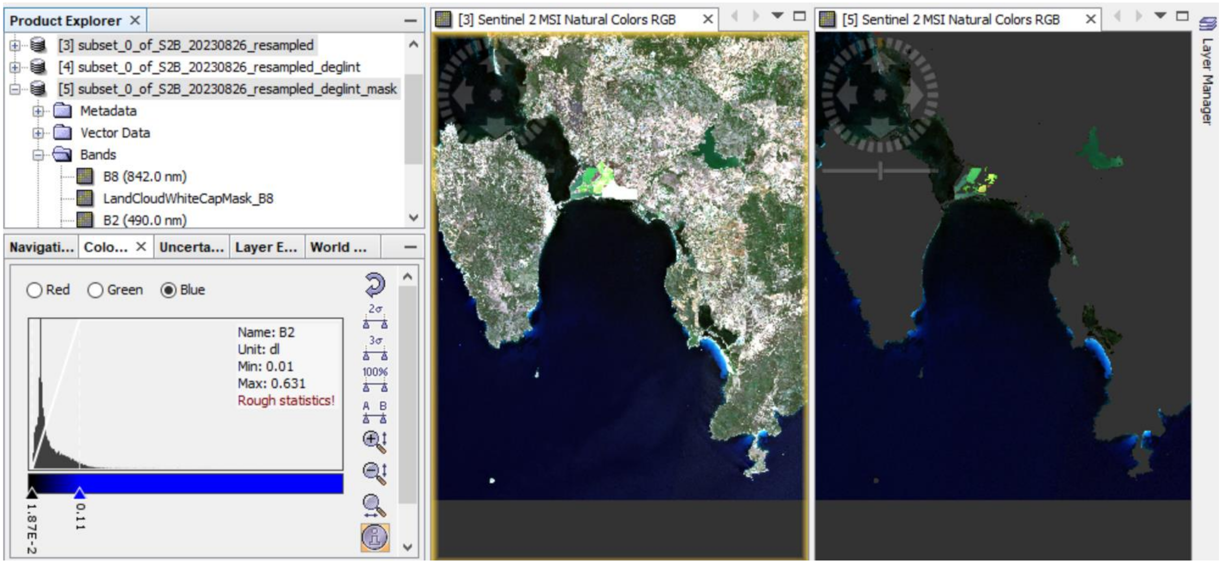


Now, we have create the new product. If we open the folder Bands for this new product in the Product Explorer, we will see that new layer was created. Double click to see it.



Now, open the RGB composition for the last product and RGB composition of the original resmapled product without any correction. Tile Windows Horizontally and set the histogram for RGB of the last product similar to the histogram of the original resampled product without any correction.

We can see that residuals (clouds, sunglint) have been corrected correctly.

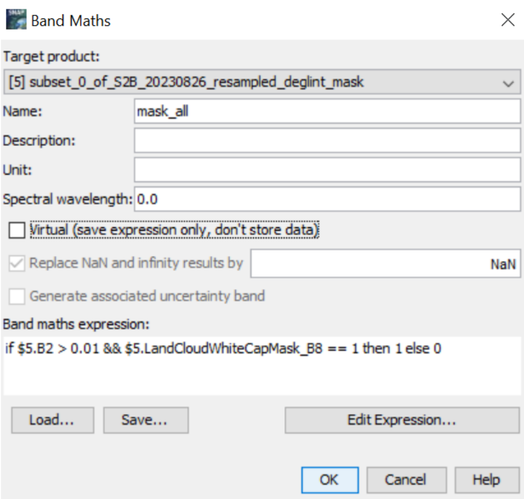


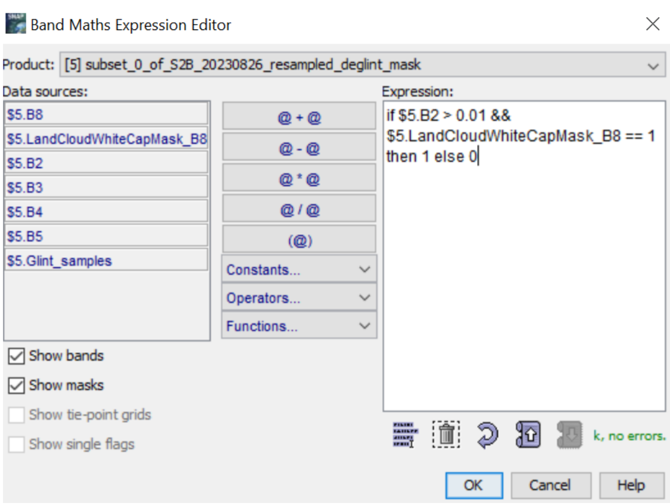
However, if we visualise e.g. B2, we can see that there are still some couds that need to be removed. We will create the final mask which will contain all the invalid features.

Right click on the product – Band Maths:

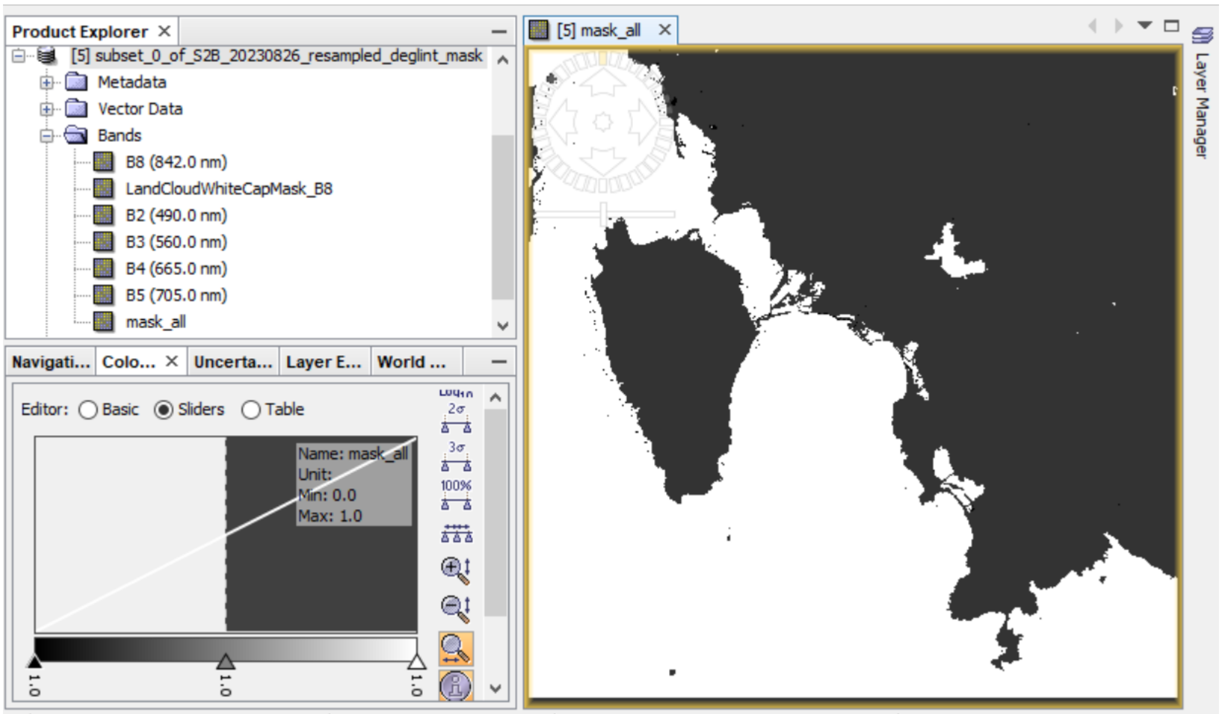
Name: mask_all

Deselect Virtual and click on Edit Expression





The final mask will appear in the new Window.



2.8 Empirical Bathymetry

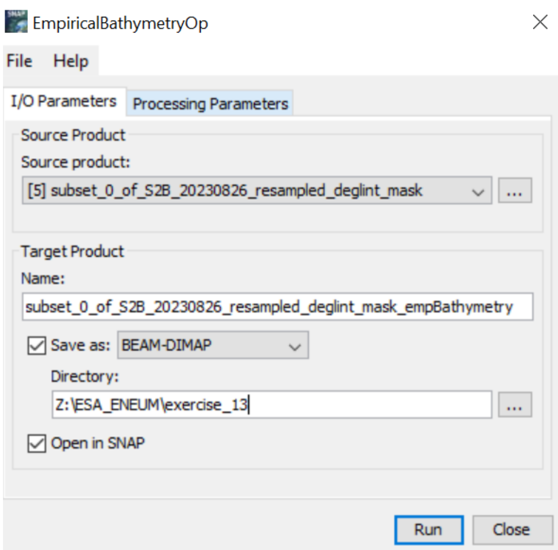
Navigate to Optical – Thematic Water Processing – Sen2Coral – Processing modules – EmpiricalBathymetry processor

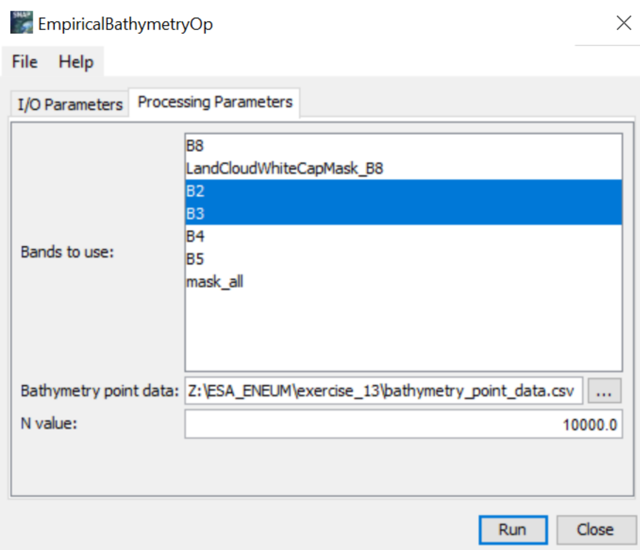
In the I/O Parameters tab select the resampled and sun-glinted mask

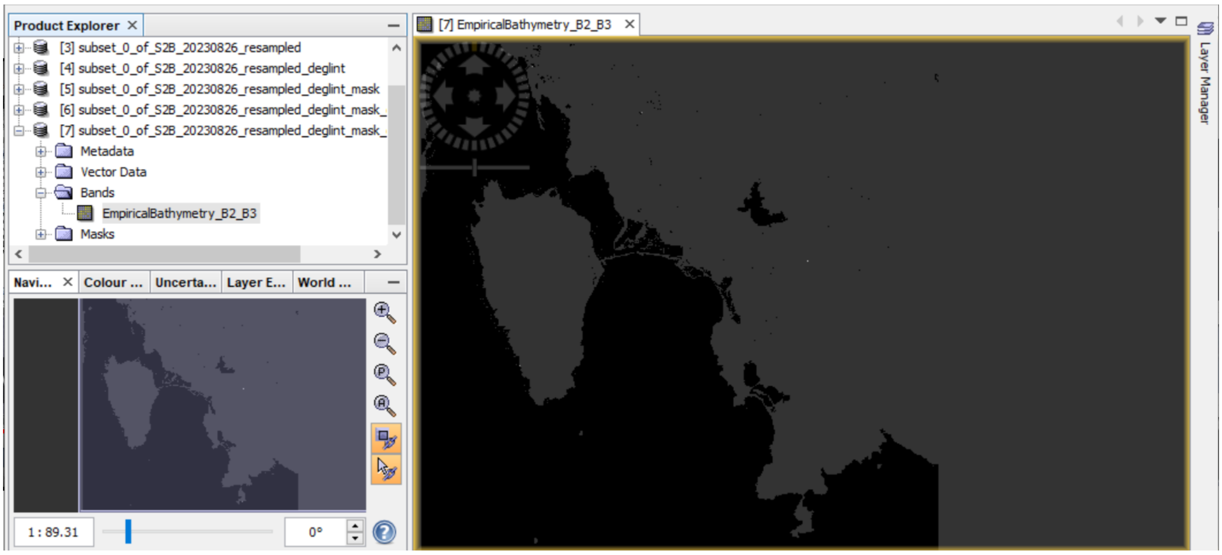
In the Processing Parameters choose bands B2 and B3 to estimate the bathymetry that give us the best trade-off between the water penetration depth and the spatial resolution

Then, choose the .csv file containing the set of bathymetry point data (latitude, logitude, depth) – these data have been derived using Coastal Relief Model Mosaic from https://www.ncei.noaa.gov/maps/grid-extract/

N value: 10000.0 (default)





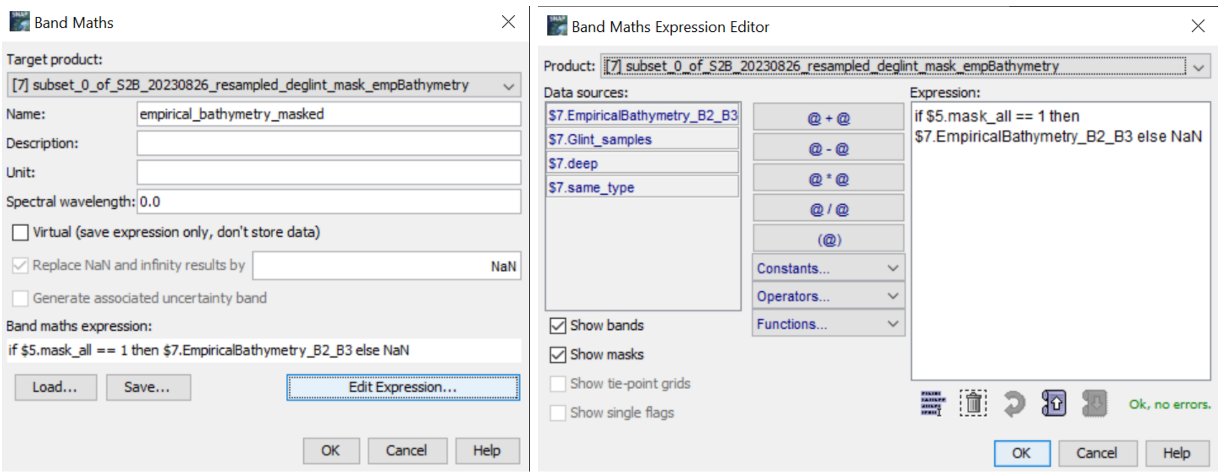


Now, we will mask the bathymetric product with the final mask

Right click on the bathymetric product – go to Band Math

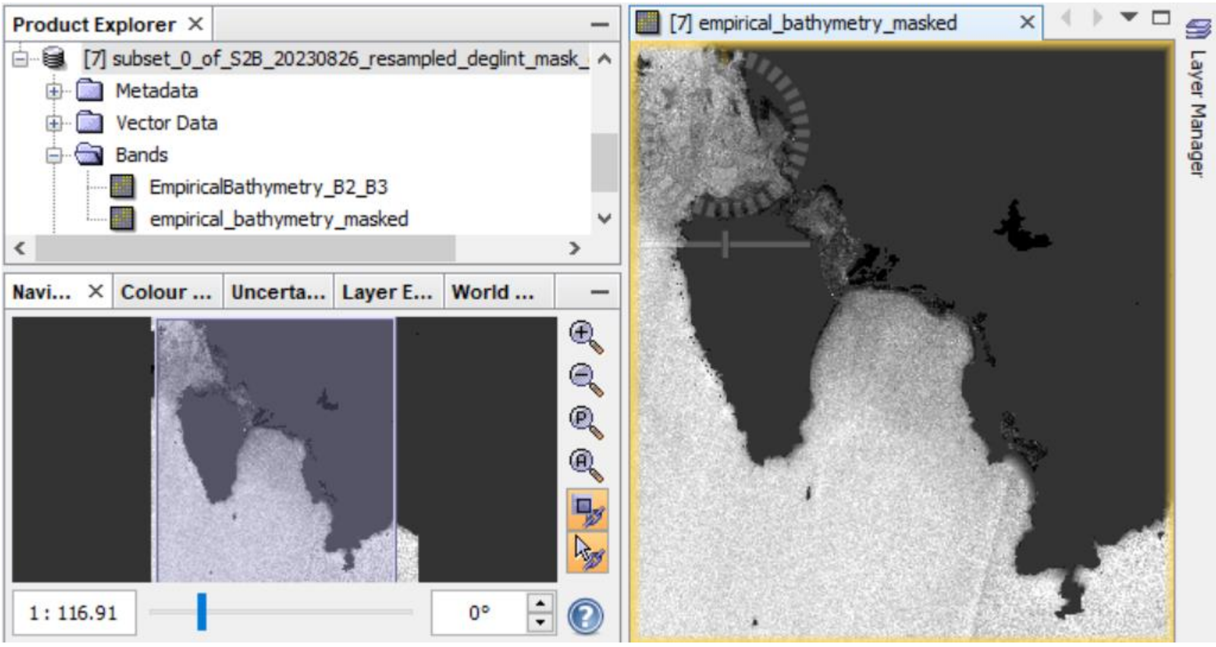
Unselect virtual raster

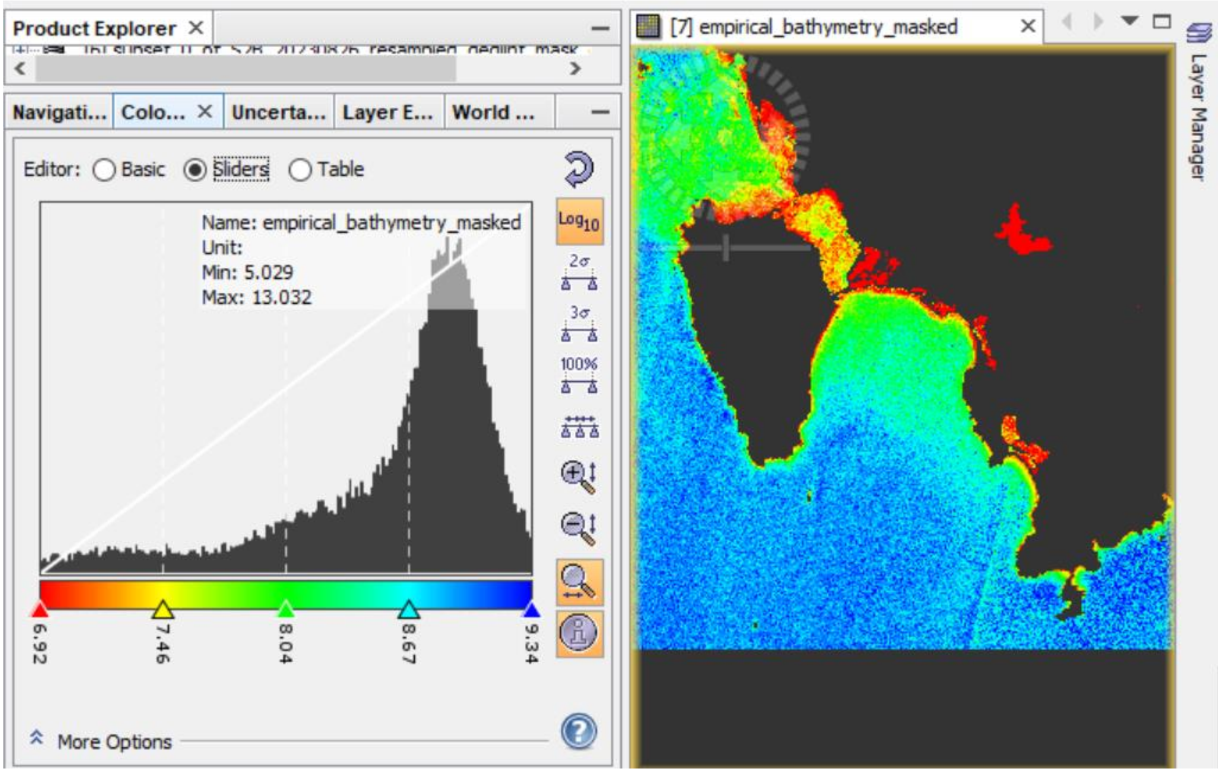
Go to Edit Expression and type in the following expression like in the image



In the Product Explorer Window, the new product is created. Double click on its band to visualize it.

Go to the Colour Manipulation tab and select the colour palette. Set the range according the data. Explore the values of the final output on bathymetry in this area





For more information, see the lecture: [13. Marine applications: nearshore bathymetry, sea surface monitoring]()

THANK YOU FOR FOLLOWING THE EXERCISE!

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