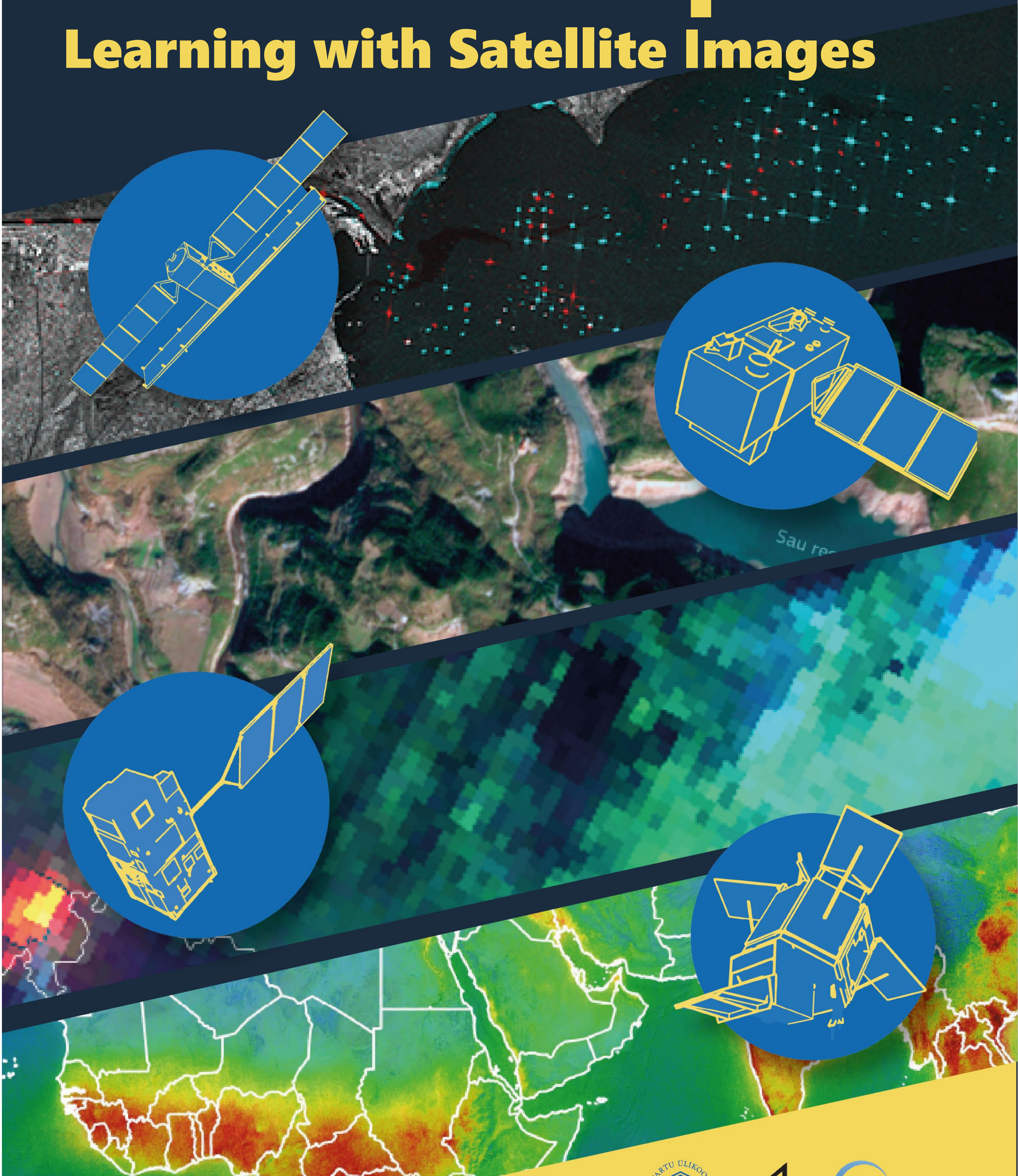
Sentinels in Space

Learning with Satellite Images



RUHR UNIVERSITÄT BOCHUM RUB
TARTU ÜLIKOOL UNIVERSITAS TARTUENSIS 1632
DLR
Copernicus Europe's eyes on Earth

Table of contents

1. Introduction Earth Observation and Copernicus

1.1 The Sentinel satellites

In cooperation with ESA, the EU Commission has developed a project that serves as the core component of the Copernicus program. This is the "Sentinel" satellite family. The Sentinel satellites are the backbone of the European Space Agency's Copernicus program and play a crucial role in monitoring the Earth from space. Each mission in the Sentinel family is designed to observe specific aspects of our planet and provide important environmental and climate data.

Almost every mission consists of several identical satellites, two of which are in orbit at the same time. By using two satellites, it is possible to record the same location more frequently. As a result, the Sentinel satellites together can be described as a powerful network of "sentinels" in space that continuously collects data about our planet and thus helps to better understand and manage important environmental and climate issues.

The Sentinel family consists of six missions, of which Sentinel-1, Sentinel-2, Sentinel-3, Sentinel-5P, and Sentinel-6 are independent missions. Sentinel-4 and Sentinel-5 are not satellites in the traditional sense, but rather measuring instruments that fly on Eumetsat satellites. This booklet describes the main features and objectives of the independent Sentinel missions.

1.1.1 Sentinel-1

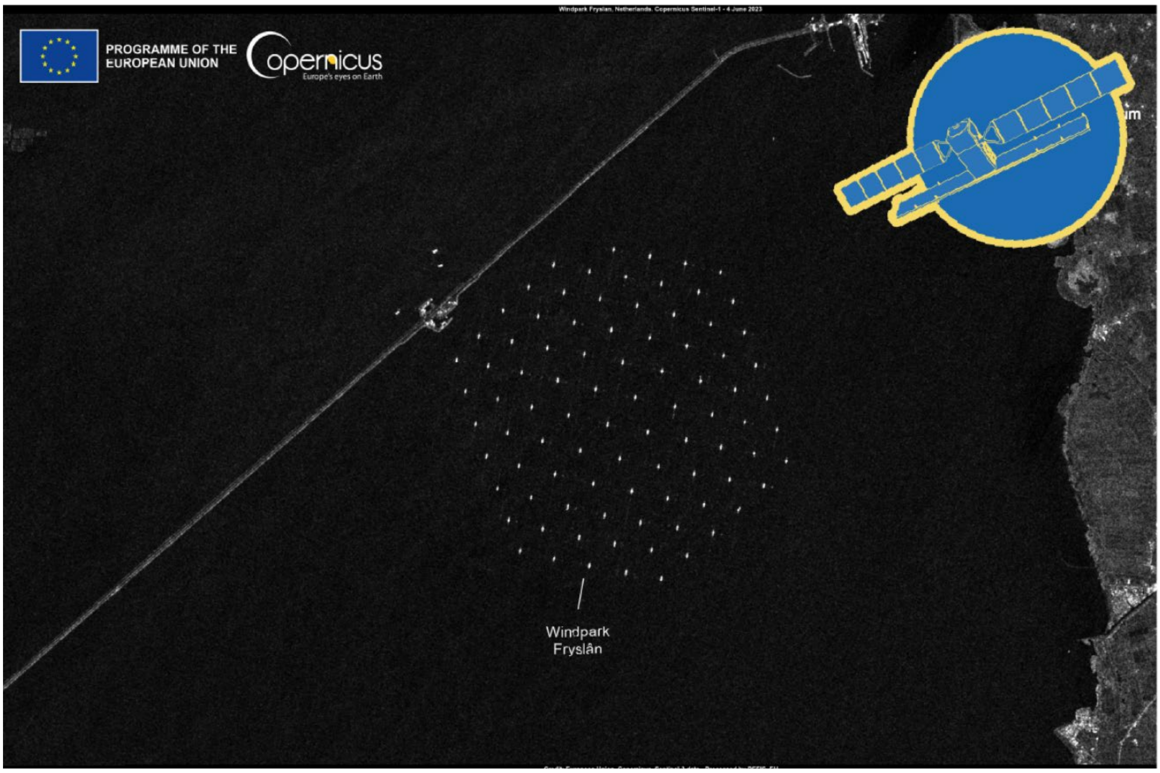


Fig. 1: Windpark Fryslân in Lake IJssel, Netherlands. (https://www.copernicus.eu/en/media/image-day-gallery/windpark-fryslan-lake-ijssel-netherlands)

Sentinel-1 is the first of six missions and has a broad range of tasks: Environment, traffic, economy and security. It provides data on land and water surfaces from an altitude of around 700 kilometres. The first satellite, Sentinel-1A, was launched in French Guiana on April 3, 2014, followed by Sentinel-1B on April 25, 2016. The last one will be replaced by Sentinel-1C on December 5, 2024.

The main instrument is an imaging high-resolution C-band radar of the SAR (Synthetic Aperture Radar) type. This ensures optimal data acquisition regardless of cloud cover and brightness. The sun-synchronous satellite can provide real-time images of flooding, oil spills, soil movements or vegetation density.

What is special about Sentinel-1 is that it is the only European satellite designed to provide support in the event of natural disasters. The data is used to record flooding and ground movements, monitor ice propagation and detect oil spills, among other things.

The image taken by the Sentinel-1A satellite shows the Fryslân wind farm, which is considered to be the largest freshwater wind farm in the world. The wind turbines were installed in the Ijsselmeer in the Netherlands and went into operation at the end of 2021.

1.1.2 Sentinel-2

Fig. 2: The Sau Reservoir at worrisome water levels. (https://www.copernicus.eu/en/media/image-day-gallery/sau-reservoir-worrisome-water-levels)

Sentinel-2 is the second of six missions in the Copernicus program. Unlike Sentinel-1, its areas of operation are specifically geared towards vegetation. The high resolution of the satellites enables optimal detection of changes in vegetation from an altitude of approximately 786 km. Waters are another area of operation.

The first Sentinel-2A satellite was launched on June 23, 2015. Two years later, on March 7, 2017, Sentinel-2B followed. Sentinel-2C, the successor to Sentinel-2A, was launched on September 5, 2024, and has been delivering images ever since. Two more satellites are scheduled to be launched into orbit in the future: Sentinel-2D in 2028 and the new generation in 2033. All satellites will be sent into orbit from French Guiana.

The satellites provide images in both the visible spectrum and the infrared spectrum. The main instrument is an MSI (Multi-Spectral Instrument) and provides high-resolution satellite images. The sun-synchronous satellites help to create harvest forecasts, map forest stands or determine the growth of wild and crop plants. Data is provided on surface changes, forests, agricultural areas, lakes and coasts. In this way, Sentinel-2 can also contribute to risk and disaster prevention. The satellites can also monitor biophysical parameters such as the chlorophyll content and water content of leaves.

The areas of application are diverse in terms of vegetation. These include inland waters, federal waterways, land monitoring, forestry and forestry, marine environment and coastal waters as well as weather and climate change. Security, geo-resources and geo-risks are also areas of application for Sentinel-2.

The image is from 17.01.2024 and was taken by a Sentinel-2 satellite. It shows a satellite image of a region of Spain. It shows a nature reserve in Catalonia. What is particularly striking is the drought that has caused the water level to be so low and the high vegetation-free banks that indicate where the water level should actually be.

1.1.3 Sentinel-3

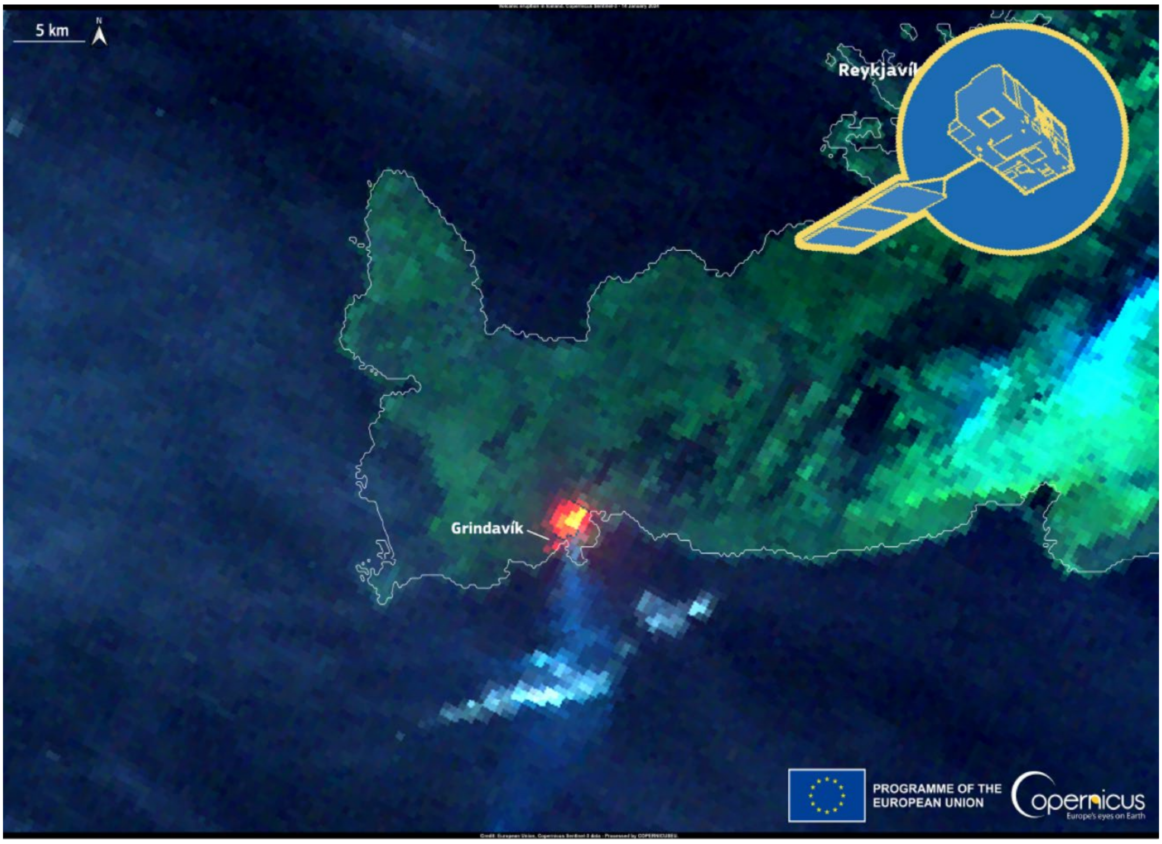


Fig. 3: Second volcanic eruption in Iceland's Reykjanes Peninsula in just a few weeks. (https://www.copernicus.eu/en/media/image-day-gallery/second-volcanic-eruption-icelands-reykjanes-peninsula-just-few-weeks)

Sentinel-3, ESA's third mission, plays a major role in environmental monitoring as another part of the Copernicus program.

Sentinel-3A was launched on February 16, 2016 and Sentinel-3B on April 25, 2018. Both satellites were launched from the Plessezk Cosmodrome, which is located in north-western Russia. The launch of Sentinel-3C is planned from 2024. Sentinel-3D will then be launched from 2025.

Sentinel-3 was initially developed to provide precise information about the oceans. By combining various instruments that can determine the color, temperature and level of the surface, it is possible to derive findings about ocean currents, wave heights and the distribution of nutrients in the oceans.

Sentinel-3 not only provides information about the oceans, but also provides important information about land. With the help of the SLSTR instrument (Sea and Land Surface Temperature Radiometer) on board Sentinel-3, the land surface temperature can be measured with impressive accuracy. The SLSTR instrument measures the thermal radiation emitted by the Earth's surface in nine different spectral bands. This radiation is then converted into temperature values that provide detailed temperature maps of the land mass.

In summary, Sentinel-3 contributes to the early detection of relevant environmental changes and provides information on land use, enabling a better understanding of the Earth from the data provided, on the basis of which measures to protect the Earth can be developed.

The satellite image was captured by a Sentinel-3 satellite and shows the hotspot of the volcanic eruption in Iceland on January 14, 2024, which began just a few hours earlier. Thus, the Sea and Land Surface Temperature Radiometer (SLSTR) carried by the Copernicus Sentinel-3 satellites can accurately monitor the land surface temperature.

1.1.4 Sentinel-5P

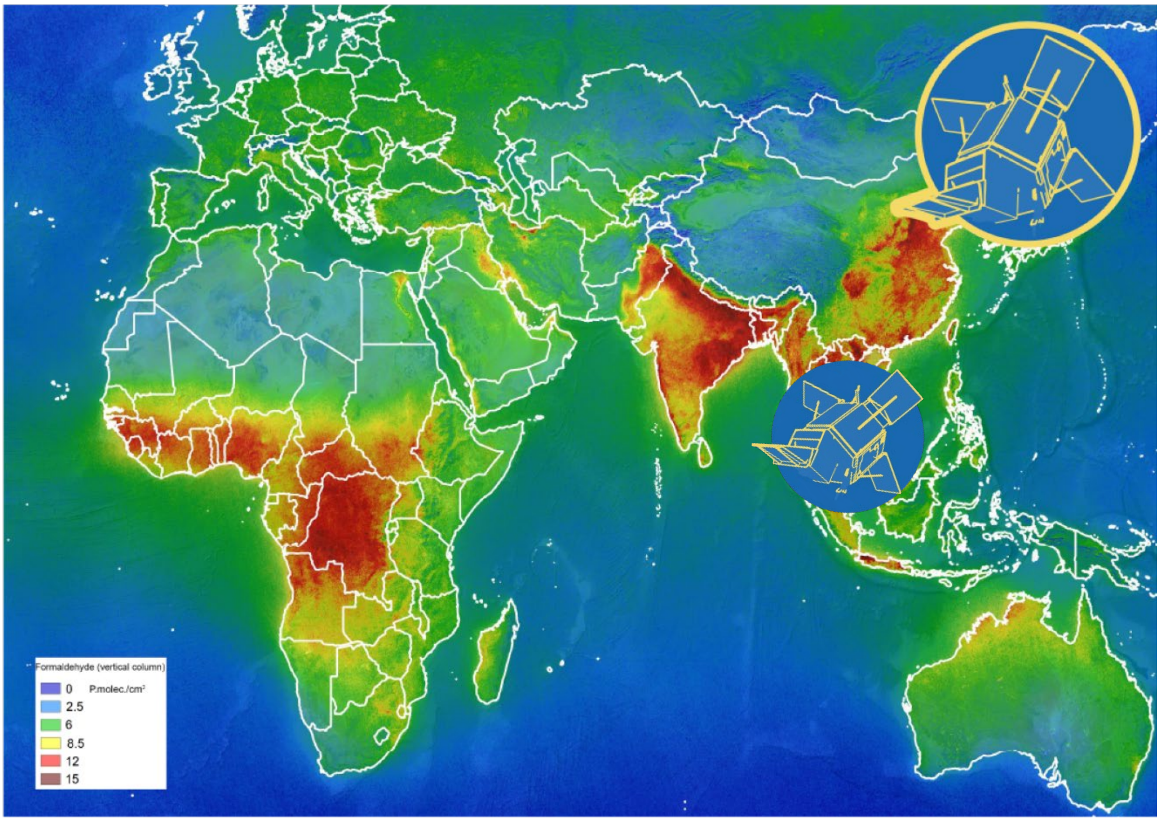


Fig. 4: Copernicus Sentinel-5P Formaldehyde 2018.
https://www.esa.int/Space_in_Member_States/Germany/Copernicus_Sentinel-5P_reveals_new_nasties

Sentinel-5P also belongs to the ESA missions and the Sentinel satellite family. The "P" stands for Precursor. While Sentinel-5P is an independent satellite, Sentinel-5, the follow-up mission, is a measuring instrument on board another satellite. Sentinel-5P was also launched from the Plessezk Cosmodrome on October 13, 2017.

Compared to the other Sentinel satellites, 5P focuses on monitoring the Earth's atmosphere. This enables it to obtain information on air quality, ozone and UV radiation and thus provide further information on various changes, particularly in terms of climate change. For example, the tropospheric concentration of gases such as NO2 (nitrogen dioxide), which is considered harmful to health, is measured.

The measurements collected by the Copernicus Sentinel-5P mission between January and August 2018 (Fig. 4) were used to detect formaldehyde in the atmosphere. This air pollutant is released into the atmosphere by forest fires and wood processing, for example. It is an important intermediate gas in the oxidation of methane and other hydrocarbons. While it is short-lived in the atmosphere, it reacts chemically and becomes a major source of carbon monoxide.

In addition, 5P transmits information on greenhouse gases such as CH4 (methane), which play a very central role in climate change. Following on from this, the ozone layer in the stratosphere and the associated UV radiation are also monitored.

A final example of data acquisition by Sentinel-5P is the observation of volcanic eruptions. For example, relevant conclusions can be drawn about the distribution and concentration of volcanic ash.

In summary, the task of the satellite is to provide climate-relevant data and to provide both weather and health institutions with information that can be used for warnings, for example regarding air quality.

1.2 What is earth observation and what do you do with it?

How do we know so much about climate, urban growth, vegetation or climate disasters? How can different land surfaces, such as deserts or rainforests, be mapped? We can do all this and much more with the help of satellites. Earth observation describes the exploration of the Earth's surface, its ecosystems and the atmosphere from space. It is the most important task of space travel. Remote sensing or earth observation satellites orbit the earth and regularly transmit images. Earth observation is used to obtain data, which is then analyzed. For example, the data can be used to create digital maps or predict the daily weather.

There are various areas of application. Among other things, changes in land and water surfaces can be detected, as well as changes in the atmosphere and climate. Based on the information obtained, the various data can be analyzed, providing us with regular new information about the conditions and changes to the earth's surface and allowing appropriate measures to be developed. For example, earth observation satellites provide a timely and precise overview of the extent of a disaster, allowing us to determine more precisely where help is urgently needed. Furthermore, urban growth and sea surface rise can also be investigated. The information obtained can help in decision-making, for example when drawing up a new (international) climate protection treaty or updating existing treaties.

Copernicus provides information based on satellite-based earth observation and in-situ data. This involves using satellites to cover the earth and collect data. The data can be used worldwide for research and development and also plays a key role in political decision-making in the EU. The EU program works closely with the European Space Agency (ESA). The special thing about Copernicus is that it is free and open to all.

In addition to the ESA, there are other cooperation partners. These include, for example, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT), the European Centre for Medium-Range Weather Forecasts (ECMWF), the EU agencies and Mercator Ocean.

1.2.1 History of earth observation

Earth observation dates back to the First World War, when aerial photographs were used for military purposes for the first time thanks to the recently developed aviation. The first remote sensing systems were used to observe enemy positions, troops and their strength.

Remote sensing systems were developed further during the Second World War and the technology was improved. With the help of satellites, for example, aerial photographs of the coast could be used to locate landing positions. The use of infrared film also made it possible to distinguish between vegetation and camouflage nets.

In the 1960s, films were developed for recording types of vegetation and shortly afterwards other remote sensing methods: Radar systems for mapping. These were attached to airplanes for the first time. In 1960, the first weather satellite was deployed in space: TIROS 1.

In 1972, the first reconnaissance satellite for mapping was deployed: Landsat 1. The satellite was equipped with a new type of sensor. It set new standards and demonstrated the already advanced development of earth observation systems.

The Copernicus program was launched in 1998. Today, Copernicus is one of the most important earth observation programs in the world.

1.2.2 List of application areas

areas of application
land use changes
data on land, sea and air
effects of global climate change
data for geodesy, meteorology, geoecology, environmental sciences, sustainable development, ...
climate and atmospheric research (including weather forecasting)
Ground movements
Civil protection
Security sector
Monitoring of marine and air pollution
Disaster prevention
Landscape planning and urban planning (land use, road traffic, noise mapping)
Resource management
Environmental protection and nature conservation
And much more...

1.2.3 History of the sensor via Landsat

In the 1960s, the subject of aerospace design was slowly being taken up and there were several scientists and companies working on it. Virgina T. Norwood was part of a group that worked for the Hughes Aircraft Company. One of her responsibilities was to monitor what new projects NASA was considering. So she knew that NASA was working on satellite-based multispectral images of the Earth. Norwood then raised research and development funds and put together a team of experts from various fields. Together they worked on multispectral images themselves.

NASA had a Return Beam Vidicon (RBV) as an instrument for the first Landsat satellite. This technology proved its worth on the TIROS weather satellites and the Surveyor missions on the moon. The RBV was similar to conventional cameras. However, some NASA engineers recognized the limitations of the RBV, and Norwood and her team were tasked with designing a spaceborn scanner.

Norwood went on to design the MSS scanner with Jack lansing, a Hughes engineer. The MSS builds an image line by line as the satellite moves forward. After some challenges and improvements, a working MSS scanner was created. The (digital) MSS data positively advanced satellite remote sensing and digital Earth observation.

On July 23, 1972, Landsat 1 was launched with the RBV and the MSS. When the first images arrived two days later, scientists, engineers and technicians were delighted with the image quality. The sensor showed stable performance both geometrically and radiometrically.

The Landsat program was the most important collaboration between NASA and USGS.

https://landsat.gsfc.nasa.gov/article/virginia-t-norwood-the-mother-of-landsat/

1.3 Earth observation in the classroom

1.3.1 Introduction

The integration of Earth observation into school lessons offers unique opportunities and is a great chance for students to further their education due to its relevance to the future. The integration of Earth observation content can be beneficial for teaching in various subjects. Geography and physics lessons in particular can be enriched. Earth observation also opens up exciting perspectives in other STEM subjects such as chemistry, mathematics and biology. Pupils can experience interdisciplinary connections and discover practical applications in various fields of knowledge, such as climate change.

1.3.2 Advantages of earth observation in the classroom

Teaching and learning...

... about earth observation	*... through earth observation*	*... with earth observation*
tools and methods	spatial thinking	explorative learning
research	data literacy	research-based learning
disciplines	critical thinking	problem-oriented learning
professional development	analytical thinking	technical skills
	Citizenship Formation	
What is possible with earth observation?	Which transferable skills are acquired when using earth observation?	How is earth observation used as a learning tool?

Teaching earth observation teaches more than just earth observation!

This table illustrates the numerous advantages that arise when Earth observation is integrated into school lessons.

Teaching about Earth observation not only teaches tools and methods, but also provides insights into various specialist areas and current research findings. This not only promotes students' skills, but also opens up the variety of possibilities associated with Earth observation. Learning through Earth observation develops essential skills such as spatial thinking, media literacy and critical and analytical thinking. The use of earth observation in the classroom enables explorative, research-based and problem-oriented learning. This not only teaches subject-specific content, but also teaches transferable skills that go far beyond the spectrum of earth observation. A closer look at the advantages of integrating earth observation into school lessons reveals further precise examples.

One outstanding benefit lies in the topicality of remote sensing data. This enables pupils to deal with current issues in a contemporary way. This makes lessons more relevant and practical, as pupils can interact with current developments in real time. Another significant advantage is the unique perspective offered by earth observation from a bird's eye view. This opens up a new dimension in the consideration of problems and provides learners with a particularly vivid representation of complex relationships. Pupils develop a deeper understanding of spatial relationships and learn to analyze phenomena from different perspectives. The motivating effect of Earth observation in the classroom should not be underestimated. The combination of fascinating satellite images with modern technology appeals to pupils emotionally and stimulates their curiosity. This motivating component plays a key role in arousing pupils' interest and getting them actively involved in the learning process.

The versatility of satellite images is also demonstrated in practical terms. These can be used in a problem-oriented way in the aforementioned subjects of geography, mathematics, physics and computer science. The interdisciplinary use promotes a holistic understanding and gives pupils the opportunity to apply their knowledge in different contexts. Last but not least, the use of earth observation in lessons promotes independent work. Pupils are encouraged to work independently with the information provided and develop important methodological skills in information processing. These skills are not only of great importance for everyday school life, but also for later academic and professional development.

In summary, it is clear that earth observation in the classroom goes far beyond the mere transfer of knowledge. The topicality of the data, the unique perspective, the motivating effect and the versatile applicability create a rich didactic added value. The use of Earth observation in the classroom thus enables a comprehensive and practical education that enriches pupils in a variety of ways.

1.4 Earth observation – education projects

1.4.1 Copernicus Academy

The Copernicus Academy was established by the European Commission and creates links between European universities, research institutions and business schools, both in the participating countries of the program and beyond. The overall aim is to create a link between scientific institutions and public authorities and service providers. The aim is to facilitate joint research activities and develop educational initiatives such as lectures, training courses, internships and educational materials. This will serve to equip the next generation of researchers, scientists and entrepreneurs with the necessary skills to make the best use of Copernicus data and information services.

The Copernicus Academy is also committed to intensifying the exchange of ideas and best practices across borders and disciplines. Thus, the Copernicus Academy's mission is to support a wide range of educational disciplines, including science, technology, engineering, mathematics, humanities and other fields. At the same time, it strives to promote the use of Earth observation data in general, and Copernicus data and information in particular, in various public or private institutions or industries. The Copernicus Academy actively promotes collaboration between educational institutions and established commercial operators or entrepreneurs to ensure that innovations can reach the market and thus benefit the citizens of Europe and the future of the Earth.

As an integral part of the European Space Strategy, the Copernicus Academy also strives to develop new tools, promote knowledge sharing and strengthen cooperation at different levels. This should help to unleash the immense potential of Copernicus Sentinel's data and information delivery.

Overall, the Copernicus Academy plays an important role in shaping the future of learning and society by creating dynamic learning environments that help students to develop their potential and become active shapers of their own future. In this way, the educational project helps to prepare learners for the various challenges of the modern world.

1.4.2 Cop4Schools

The Copernicus Academy is made up of a group of members from all over the world. The Interdisciplinary Geoinformation Sciences working group of the Institute of Geography at Ruhr-Universität Bochum is also a member of the program.

The working group carries out a variety of educational projects, one of which is called "Cop4Schools" and is supported by Copernicus. The core of this project is to establish Earth observation as an integral part of the school curriculum. Teaching and educational materials are being developed that link the topic of Earth observation with various relevant school subjects. The project is thematically located in the area of disaster prevention in connection with climate change. In view of the increasing frequency and intensity of various natural events due to climate change and the crucial role that earth observation plays in disaster prevention and disaster impact assessment, it is logical to establish this link in the teaching materials developed.

These materials are available on the “Remote Sensing in Schools” website (https://fis.rub.de/), which was set up by the working group. This platform also offers educational materials on a variety of topics from other projects dedicated to the subject of “Earth observation in the classroom”.

2. Basics of earth observation

2.1 What is earth observation? Far away and yet close.

Earth observation deals with the observation of objects from a distance, whereby the object usually refers to the surface of our planet Earth. How and with what means and methods this works is described below. Fig. 8 shows the procedure in simplified form.

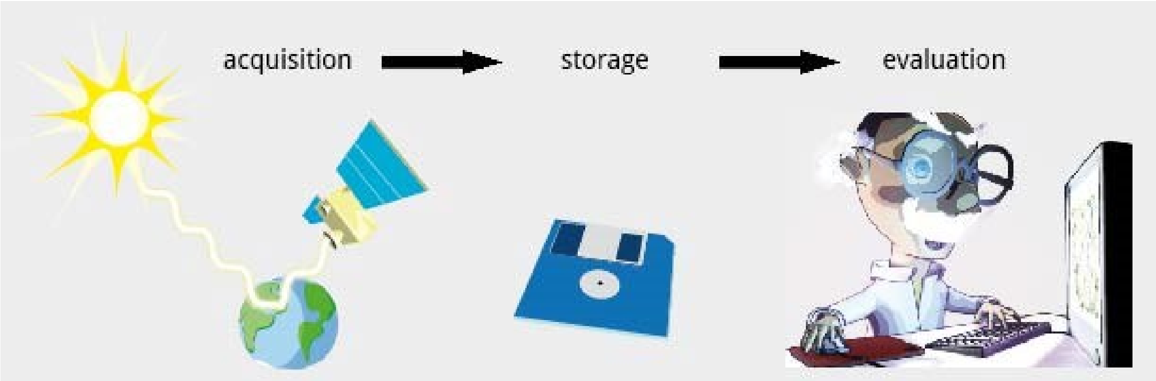


Fig. 5: How does earth observation work?

The rays of sunlight hit objects on the earth's surface in the form of electromagnetic radiation and are reflected by them. The reflected rays can be recorded and stored by satellites. The data is analyzed on a computer.

In astronomy, the universe with its planets, stars and other celestial bodies is observed and studied from Earth. Earth observation is similar: it also observes objects from a distance, i.e. without direct contact. However, in earth observation, the object of study is not outer space, but the earth itself!

In order to observe and examine the earth's surface, measuring devices (known as sensors) are attached to aircraft and satellites. They record electromagnetic waves and then store them as image data.

2.2 What does earth observation work with?

Earth observation works with sunlight that is reflected from the Earth's surface. Sensors pick up this light and store it. But how does this work? We often refer to the sun's light as "sunbeams". Actually, that's not quite right. Due to its special properties, we should rather refer to it as "solar waves".

2.2.1 Long and short waves

In principle, waves are vibrations that transport energy. A simple example of a stone thrown into water and making waves illustrates this. Sunlight is referred to as an electromagnetic wave. The difference to waves in water or sound waves is that the electromagnetic wave does not need a medium such as water or air to travel.

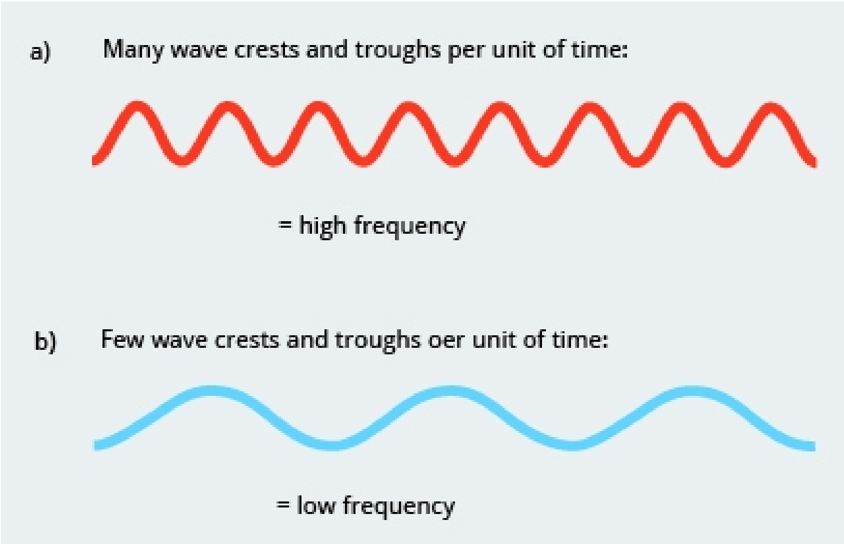


Fig. 6: Electromagnetic waves with high and low frequencies.

As can be seen in the illustration above, waves have a crest and a trough. The distance from one crest to the next is called the wavelength. The frequency of wave troughs and crests per time unit is called frequency. In general, the smaller the wavelength, the higher the frequency and energy of an electromagnetic wave.

Electromagnetic waves also have other properties. When they hit a surface, they are reflected (thrown back), absorbed (taken in) or transmitted (allowed to pass through).

2.2.2 The electromagnetic spectrum

Measuring devices, also known as sensors, are attached to aircraft and satellites for observation purposes. These record electromagnetic waves and process them into image data, which can later be analyzed. The following diagram shows the extent to which the electromagnetic waves differ from one another.

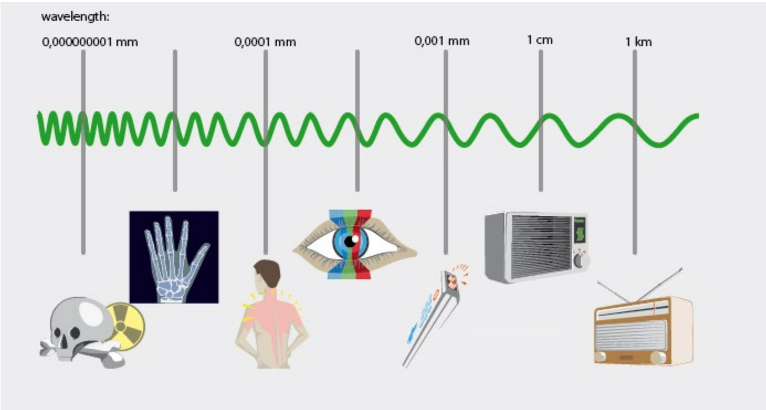


Fig. 7: The electromagnetic spectrum.

Electromagnetic waves such as sunlight can be reflected and absorbed. In the case of reflection, they are thrown back by a surface; in the case of absorption, they are taken up by a surface and converted into thermal energy.

2.2.3 What does reflection mean?

Reflection means that something is thrown back. For example, if a ball is thrown against a wall and it comes back, it is reflected. The same happens with sunlight when it hits the earth's surface. It is reflected and can be picked up by the satellite. If it hits a smooth surface, e.g. a mirror, the following applies: angle of incidence = angle of reflection. The angle of incidence is the angle between an incident light beam and a surface, the angle of reflection is the angle between the reflected light beam and a surface.

The principle of specular reflection is illustrated in the figure below. A distinction is generally made between three types of light reflection, whereby the roughness of the surface of the object is decisive for how the light beam is reflected:

1. Specular reflection: The light beam is reflected back at the angle at which it strikes a smooth surface.
2. Diffuse reflection: The light beam is reflected evenly in all directions by a roughened surface.
3. Mixed reflection: The light beam is reflected unevenly in all directions by a very rough surface. This type of reflection is normal in nature.

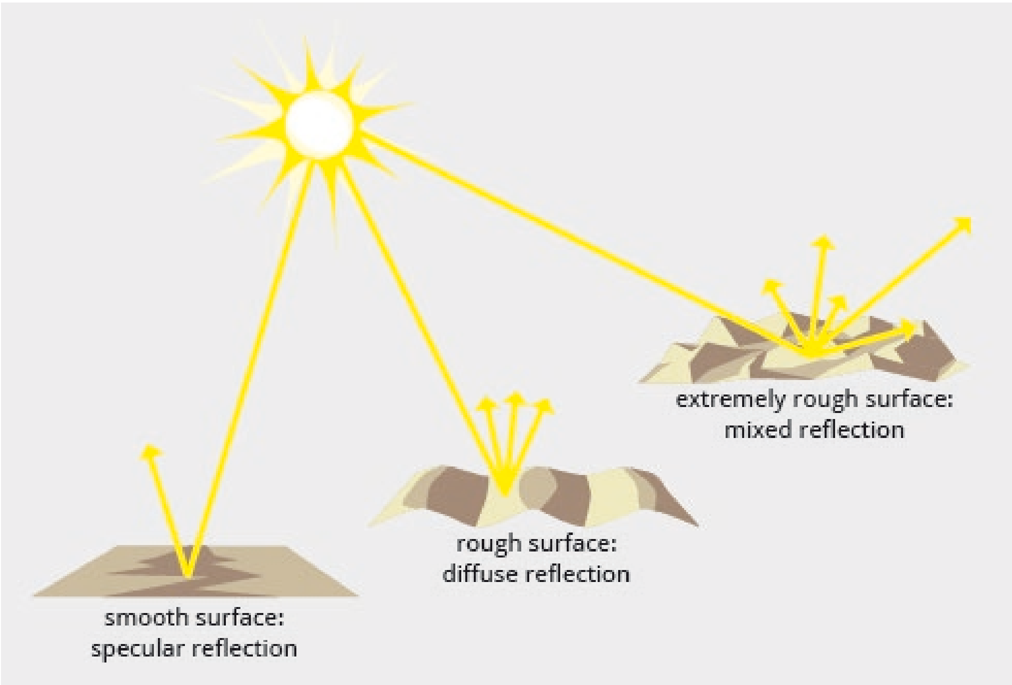


Fig. 8: Three types of light reflection. Mixed reflection (right) is the normal case in nature.

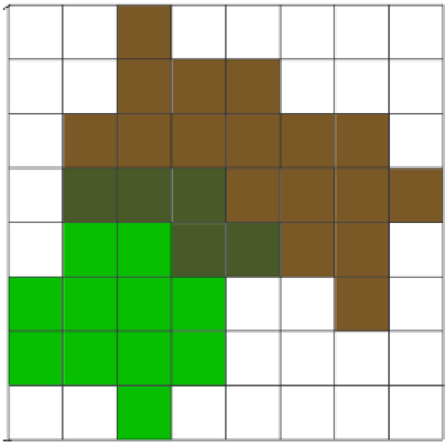
2.2.4 What does absorption mean?

Light is not only reflected by surfaces, but also absorbed. The absorbed energy of the light is stored and slowly released as heat. This type of energy conversion is called absorption.

This can also be applied to everyday life: A black T-shirt, for example, absorbs much more sunlight than a white one. This is the reason why you sweat more in a black T-shirt in summer than in a white T-shirt.

2.2.5 Images as number grids

The information is converted into image data, which consists of countless numbers arranged in rows and columns. This is also referred to as raster data.



=

		54					
		54	54	54			
	54	54	54	54	54	54	
	61	61	61	54	54	54	54
	68	68	61	61	54	54	
68	68	68	68			54	
68	68	68	68				
		68					

Fig. 9: Image data is stored by the sensor as numbers.

The numbers indicate the intensity with which the light is reflected. White surfaces generally reflect with high intensity and have a high numerical value, whereas dark surfaces absorb more light and therefore reflect less. They have a low value, which is zero for black objects.

2.2.6 Earth observation techniques

Earth observation sensors can be attached to satellites or aircraft. They work either passively with sunlight or with actively emitted microwaves.

Earth observation recording systems can be differentiated according to the type of electromagnetic radiation used. There are the systems already mentioned, which work with the sun's rays reflected from the earth's surface. These recording systems are referred to as passive recording systems (see Fig. 10, left).

Fig. 10: Passive and active recording systems for earth observation.

Active recording systems utilize a different approach. These actively emit microwaves in the direction of the earth's surface and then pick up the radiation that was reflected by the earth's surface (see Fig. 10, right).

Another distinguishing feature of earth observation recording systems is the transportation technology. In airborne earth observation, the recording system is attached to airplanes. These recording systems work very accurately and also have a very high spatial resolution due to the small distance to the earth's surface. However, they can only fly over a small part of the earth's surface, so they are mostly used for special investigations.

2.3 What is resolution?

2.3.1 Spatial resolution

The individual grid cells are called pixels. The size of the area that can be imaged in a pixel depends on the performance of the sensor. With a high spatial resolution, more details are visible. Fig. 11 illustrates this.

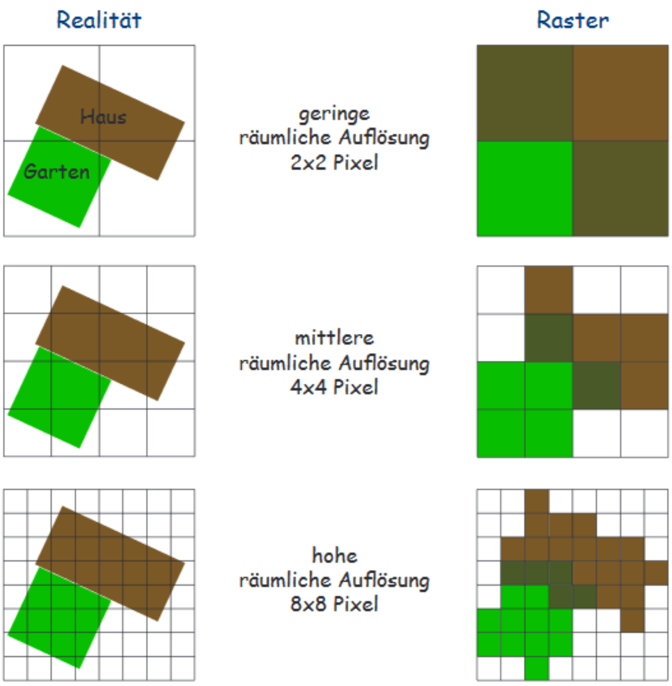


Fig. 11: Differences in spatial resolution.

It is almost unavoidable that several objects have to be depicted in one and the same area and therefore appear together in one pixel. Fig. 12 shows how the color components of the objects mix and a mixed pixel is created. The lower the spatial resolution, the more mixed pixels are created and the fewer objects can be distinguished from each other.

Fig. 12: Formation of mixed pixels.

2.3.2 Temporal resolution

In addition to spatial resolution, temporal resolution also plays an important role. It indicates the time interval between two images of the same area. Depending on how the orbit of the satellite is defined, this distance can be between 15 minutes and several weeks. This depends on the purpose of the satellite and also influences the spatial resolution. As the land surface can change quickly and over a wide area, e.g. due to natural disasters, a high temporal resolution is also important.

2.3.3 Spectral resolution

Satellite sensors work with the light reflected from the earth. But what color does light actually have? The answer can be found by looking through a prism. The light is then divided into three colors: red, green and blue. All other colors can be composed of these three so-called main colors. Yellow, for example, is made up of green and red.

2.4 Why do we perceive things in color?

When visible light hits color pigments (coloring components of surfaces), some wavelengths are absorbed and others are reflected. Pigments that absorb green and blue light and reflect red light are therefore responsible for the red color of a red apple. Green leaves, on the other hand, absorb red and blue light but reflect green light.

White pigments reflect all three wavelengths to the same extent, while black pigments absorb all three wavelengths completely. All other colors are created by the interaction of red, green and blue light. This is how the objects around us color what is actually white sunlight and make the world appear colorful.

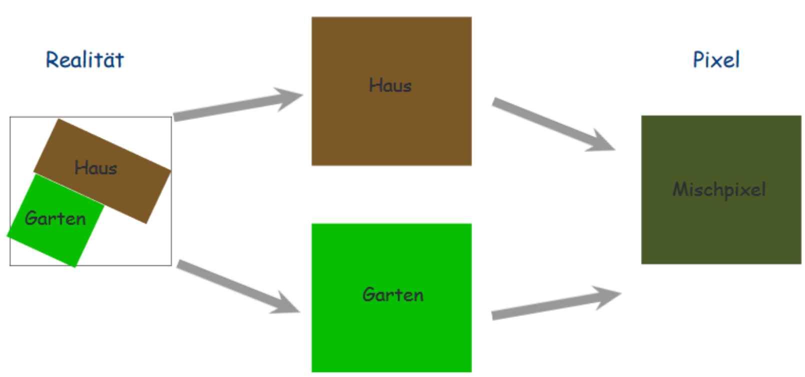


Fig. 13: Reflection and absorption.

Do satellites also perceive the earth's surface in color?

Satellite sensors see the earth in gray. This is because they record each wavelength range separately in so-called channels. In addition to the channels of visible light (red, green, blue), most satellites also have sensors in infrared light, which is invisible to humans, and some even in ultraviolet light.

The number of recording channels of a satellite is called spectral resolution. The more channels an earth observation sensor has, the higher the spectral resolution of a satellite.

The satellite creates an image in each channel that consists of different shades of gray, which is why it is also called a grayscale image. If a surface reflects a lot of red light, such as tennis courts, for example, this surface appears completely white on the gray-scale image of the red channel and black on the green channel.

2.5 What can an image tell us?

2.5.1 The NDVI

Due to the peculiarity of healthy plants that they reflect strongly in infrared light, but almost not at all in red light, they can be found in satellite images with a simple index and their condition examined. This index is called NDVI (Normalized Differentiated Vegetation Index) and is calculated as follows:

$$NDVI = \frac{Infraroter\ Wert - Roter\ Wert}{Infraroter\ Wert + Roter\ Wert}$$

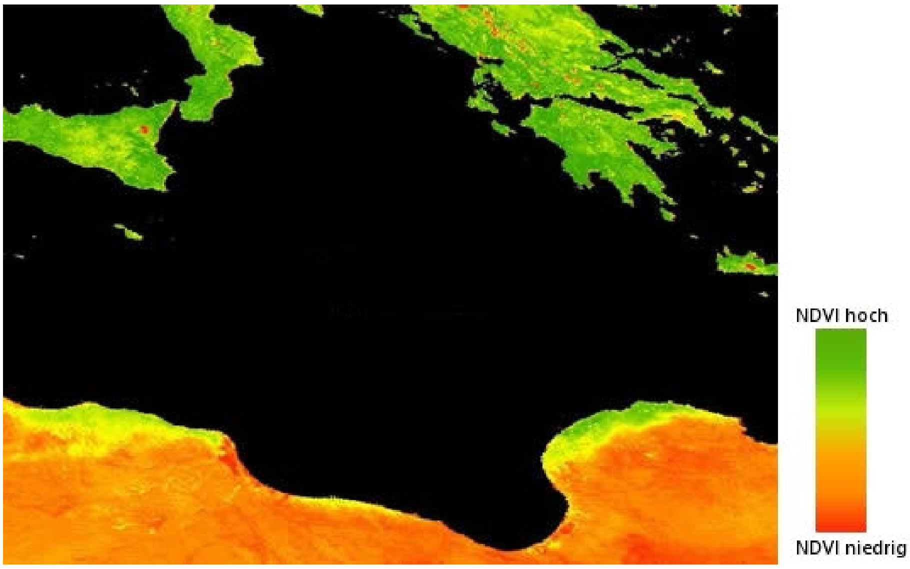


Abb. 14: NDVI image of the Mediterranean Sea.

2.5.2 Classification

If similarly colored pixels are grouped thematically into classes, this is referred to as classification. Fig. 18 shows how the assignment of blue color values to water and green to vegetation can simplify the interpretation of the images.

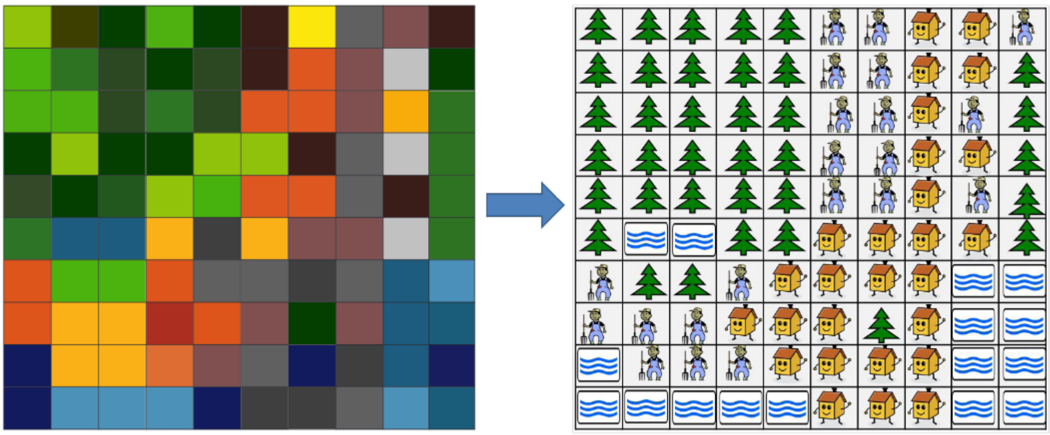


Fig. 15: Classification based on color values.

The earth observation method of classification makes it possible to represent the land surface in a simplified way by creating classes such as settlement, water or forest. This is now referred to as a thematic map.

2.5.3 Change analysis

With the change detection method (change analysis), not only the current state of the land surface is simplified, but also its change over time. The following figure shows two classified satellite images of the Bonn/Rhine Sieg region at two points in time. The third image shows where the change has taken place.

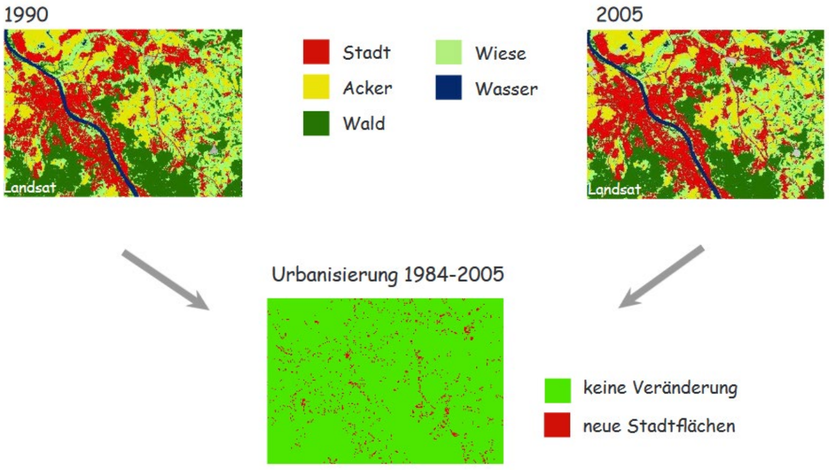


Fig. 16: The change detection method.

3. Copernicus – Earth observation for everyone!

Copernicus is a European Earth observation program that is building a powerful infrastructure for satellite-based observation of the Earth. The program is coordinated and managed by the European Commission to ensure that the political vision is always up to date and evolving and that all necessary elements are available. The European Space Agency (ESA) is responsible for technical coordination. The data collected and processed is freely accessible to all citizens around the world, allowing Copernicus to contribute to the development of new applications and services.

The core services of the program are land monitoring, marine environment monitoring, disaster and crisis management, atmospheric monitoring, climate change monitoring and security. The services are all based on the EU-owned Sentinel family of satellite imagery. "Contributing missions" provide additional information based on third party satellites. With the help of the services, the raw data can be processed and analysed in order to be useful for authorities, scientists, companies, organizations and citizens.

Copernicus can be used to address social problems that humanity faces today and in the future. The data from the Copernicus program supports the management of global challenges such as climate change, natural disasters and population growth. With the further processing of the data and the know-how for its use, the program also relies on a continuous expansion of the fields of application through research and industry.

The following links provide information on Copernicus:

Official brochure “Copernicus: Europe´s eyes on Earth”: https://www.copernicus.eu/sites/default/files/documents/Copernicus_brochure_EN_web_Oct2017_0.pdf

Copernicus in Germany: https://www.d-copernicus.de/

Sentinel-Online: https://sentinels.copernicus.eu/web/sentinel/home

Copernicus for enviromental monitoring:

https://www.d-copernicus.de/fileadmin/Content/pdf/Tutorial_Copernicus_online.pdf

3.1 Services

Atmosphere Monitoring Service: Since June 2015, this service has been providing regular data on the composition of the atmosphere. Greenhouse gases, reactive gases, ozone and aerosols are components of the atmosphere about which data is provided. Both the past, present and future situation are described. The Atmosphere Monitoring Service focuses on five main areas - air quality and atmospheric composition, ozone layer and ultraviolet radiation, emissions, solar radiation and climatic influences. An important cooperation partner is the European Center for Medium-Range Weather Forecast (ECMWF).

Catalog of the Atmosphere Monitoring Service:

https://www.copernicus.eu/sites/default/files/documents/Copernicus_AtmosphereMonitoring_Feb2017.pdf

Marine Environment Monitoring Service: This service has been providing regular data on the physical and biogeochemical state, variability and dynamics of the ocean and marine ecosystems since May 2015. The data obtained can contribute to safety at sea, for example by analyzing and predicting currents and winds. Other areas of application include the protection of living marine resources and applications in the coastal and marine environment. Annual ocean status reports can be used to forecast trends in ocean health due to climate change. The cooperation partner for this service is Mercator-Océan.

Catalog of the Marine Environment Monitoring Service:

https://www.copernicus.eu/sites/default/files/documents/Copernicus_MarineMonitoring_Feb2017.pdf

Land Monitoring Service: Since 2012, this service has been collecting data on, for example, land cover, land use, vegetation status and the water cycle. The data can help with spatial planning, but also support agriculture, water management and nature conservation. The land monitoring service consists of five main components: The systematic monitoring of biophysical parameters (e.g. soil moisture), land cover and land use mapping (e.g. urban vs. agricultural land), thematic hotspot mapping, imagery and reference data (e.g. on hydrography and elevation profiles). A further component is currently being developed, which is a new European ground movement activity (e.g. landslides). The component measures ground displacements and the deformation of infrastructure. An important cooperation partner is the European Environment Agency.

Catalog of the Land Monitoring Service:

https://www.copernicus.eu/sites/default/files/Copernicus%20Land%20Monitoring%20Service%20factsheet%20status%20October%202018.pdf

Copernicus Climate Change Service: The service collects information on the past, present and future climate. The aim is to support the EU's adaptation and mitigation policies. The data collected is used, for example, to assess the impact of climate change on biodiversity in certain regions, risk management for commodity trading or sustainable water management. The Climate Change Service is an important service for the Global Framework for Climate Services (GFCS). The climate data and other information are made available on the Climate Data Store (CDS) and made accessible to all users. The service is complementary to the EU's existing meteorological and environmental services.

The European Centre for Medium-Range Weather Forecasts (ECMWF) implements the C3S as a cooperation partner.

Climate Data Store (CDS): https://cds.climate.copernicus.eu/#!/home

Security (since 2015): Three areas characterize the Security Service. Border surveillance, maritime surveillance and support for EU foreign policy. Border surveillance works towards the goals of reducing the number of illegal undetected immigrants, reducing the death toll of illegal immigrants at sea, increasing the internal security of the EU and combating cross-border crime. The tasks of maritime surveillance consist of supporting European maritime safety. This concerns, among other things, the safety of shipping, but also support for fisheries control and the fight against marine pollution. The last area is foreign policy support, which aims to support third countries in crisis situations and prevent global and supra-regional threats.

Cooperation partners are the European Commission FRONTEX (European Coast Guard), the European Maritime Safety Agency (EMSA) and the European Union Satellite Centre (EU SAtCen).

Catalog of the Security Service:

https://www.copernicus.eu/sites/default/files/documents/Copernicus_Security_October2017.pdf

Emergency Management Service, EMS: Authorized users can use this service to request maps and analyses of crises. Data is available at all times of a crisis (before, during and after a crisis). This data is based on satellite images that are created after a disaster and contain information about the spatial extent, for example. The data can also be used to analyze vulnerability and risk. These can include disasters caused by floods, earthquakes, forest fires and humanitarian crises. The images can be used to better visualize the situation and support crisis management in decision-making. After a crisis, the progress of reconstruction measures can be tracked and analyzed. EMS products can be requested from the Joint Federal and State Reporting and Situation Center (GLMZ).

Catalog of the Emergency Management Service:

https://www.copernicuszeu/sites/default/files/documents/Copernicus_Security_October2017.pdf

https://emergency.copernicus.eu/

3.2 Dataspace

The Copernicus Dataspace Ecosystem is a freely accessible system that provides access to data from the Sentinel missions and more. The browser is easy to use. Satellite data can be searched, visualized and downloaded.

Services are "Explore Data", "Analysis" and "Ecosystem": Explore Data provides access to a large selection of Earth observation data from the Sentinel missions. The Analysis service provides a data analysis of the environment. It provides access to a range of high-quality data processing tools. For example, users have access to Earth observation datasets via web services such as openEO and SentinelHub. Product catalogs also make it possible to filter for specific data sets. The ecosystem combines tools and resources to exploit the full potential of this data. This can create a growing ecosystem that increases the impact of Earth observation data.

Official Site: https://dataspace.copernicus.eu/

Youtube video (from the official site): https://youtu.be/Am93Xi0PZ5o

3.3 SNAP

SNAP (ESA Sentinel Application Platform) is a program provided free of charge by Copernicus, which was developed by Brockmann Consult, Skywatch, Sensar and C-S. The program and toolboxes can be used to process and analyze earth observation data. SNAP can be downloaded and used by anyone free of charge.

ESA information page: https://earth.esa.int/eogateway/tools/snap

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

3.4 Data processing via Dataspace-Hub

3.4.1 Geography example – Change Detection

1. Go to https://dataspace.copernicus.eu/ and in the top mid, hover over "Explore data" and click "Copernicus Browser" in the pop-up menu.
2. Register or log in to the Copernicus Browser (it's free and no ads!).
3. In the top left corner, click on the SEARCH-Tab to reach the download menu.
4. In the top right corner, click into the "Go to Place" field and type "Zhoukou".
5. Click on "Zhoukou, China". The window should move to China now. Zoom close enough towards Zhoukou that the city is visible well.
6. To the left, in "data sources", activate "Sentinel-2" and in the submenu "MSI" (Multi-Spectral Instrument), activate "L2A" to receive atmospherically corrected imagery. Adjust the cloud cover slider to 10%.
7. For this kind of change detection, it makes sense to use a large gap between the time periods. Therefore, the two sensing periods must be search consecutively. The oldest usable data for Zhoukou was sensed in April 2017.Adjust the time range from 1st until 30th April, so *From 2017-04-01 Until 2017-04-30* and click "Search".

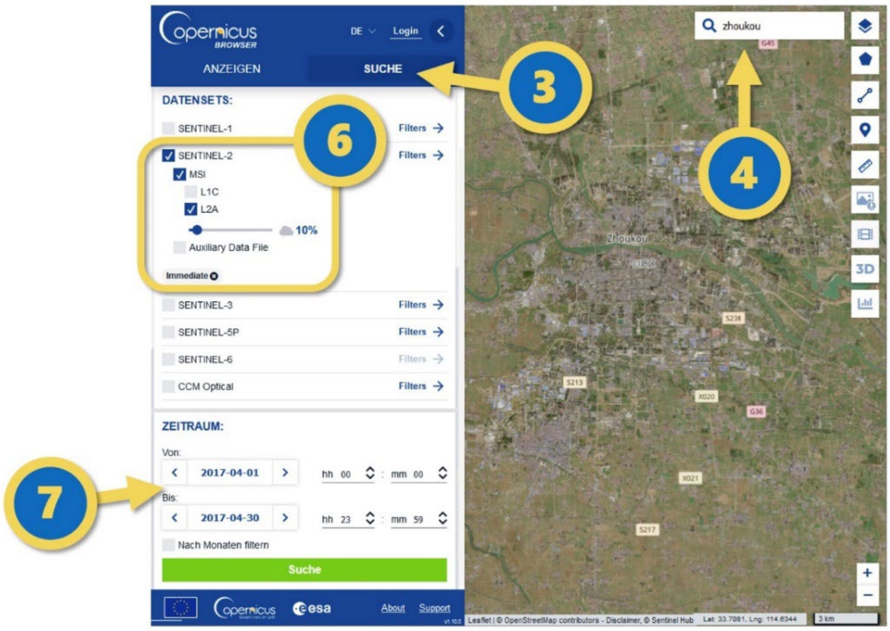


Fig. 17: Selecting the location to be examined.

8. A list of results should be shown that overlap near Zhoukou. Click on one of the scenes and inspect the details. The designations of the scenes differ only minimally as they come from the same recording strip. Download the scene: *S2A_MSIL2A_20170428T030541_N0500_R075_**T50SKC**_20231114T174920.SAFE*

9. Repeat the search for *From 2024-04-01 Until 2024-04-30*. Start with the Until date, as the From-date cannot be after the Until-date.

10. Download the cloudfree scene that overlaps with the previously downloaded scene: *S2B_MSIL2A_20240426T030519_N0510_R075_**T50SKC**_20240426T062656.SAFE*

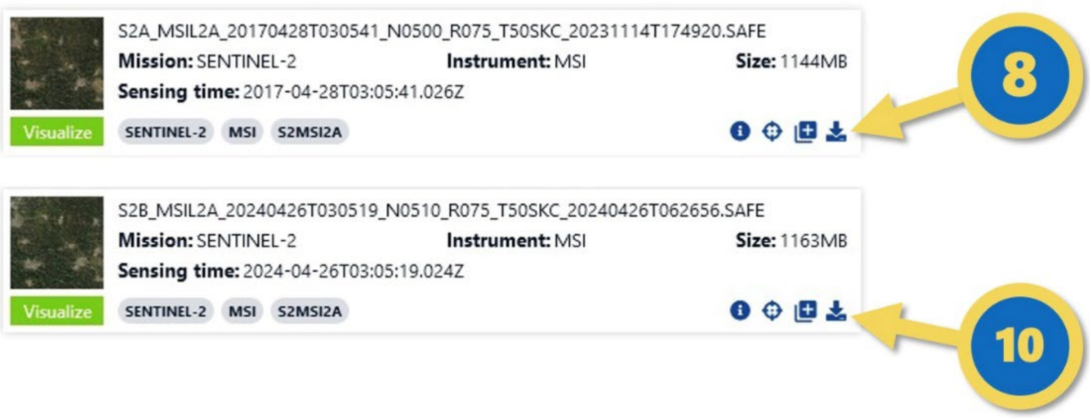


Fig. 18: Selecting the scenes.

11. Unzip the downloaded files into your preferred folder.

Inspect the scenes in SNAP and create subsets:

12. Open *SNAP*.
13. Click on the folder symbol to open the files. Navigate to the folder you saved the unzipped files in, into the .SAFE folders and open the *MTD_MSIL2A.xml*. of both files.

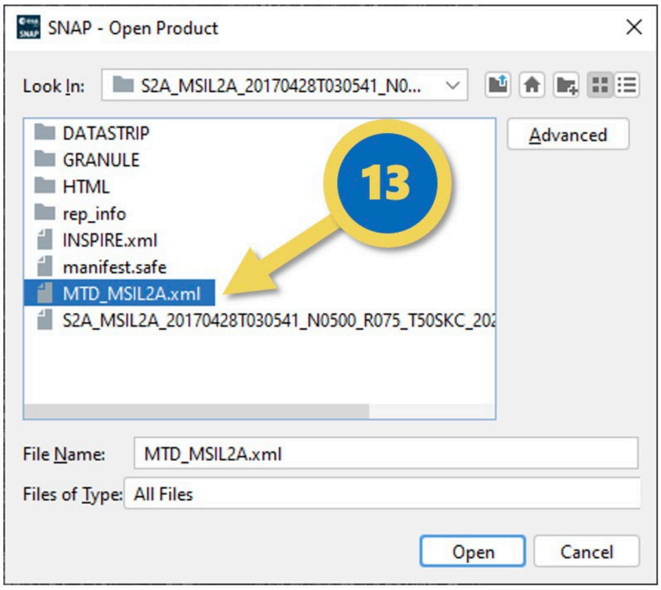


Fig. 19: Opening the files.

14. Right-click on each scene name and click on “Open RGB Image Window”. Make sure the selected profile is “Sentinel 2 MSI Natural Colors” and Red B4, Green B3, Blue B2 are set. Click on OK.

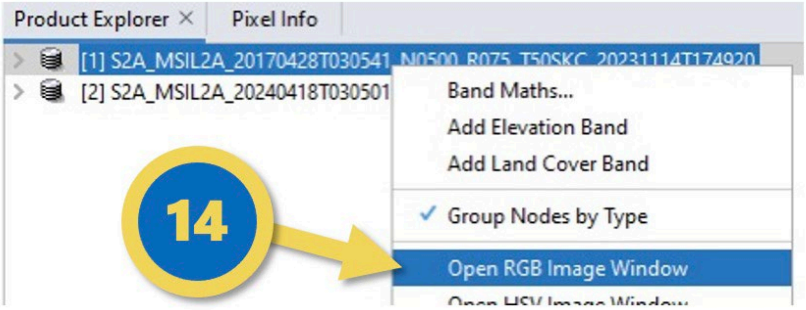


Fig. 20: Opening the files.

15. Explore the images parallel by clicking on “Tile horizontally” in the symbol bar at the top. → *symbols*
16. Since classifying the entire scene would take very long on most computers, a subset must be chosen. Click on “Raster” in the top Menu and then on “Subset”.
17. In the tab Spatial Subset, the limits of the subset can be set. Since both scenes have identical limits so far, the same new limits can be used for the respective subsets. With B1 as Reference Band, use the following settings for the pixel coordinates:

    Scene start X: 4490

    Scene start Y: 1000

    Scene end X: 5489

    Scene end Y: 1999

    This creates a small subset of a rural region that is administered by Zhoukou. Several towns have already grown together.

    At the 2010 census, the area had a population of about 340,000. (https://www.citypopulation.de/de/china/townships/zhoukou/411627__t%C3%A0ik%C4%81ng_xi%C3%A0n/)

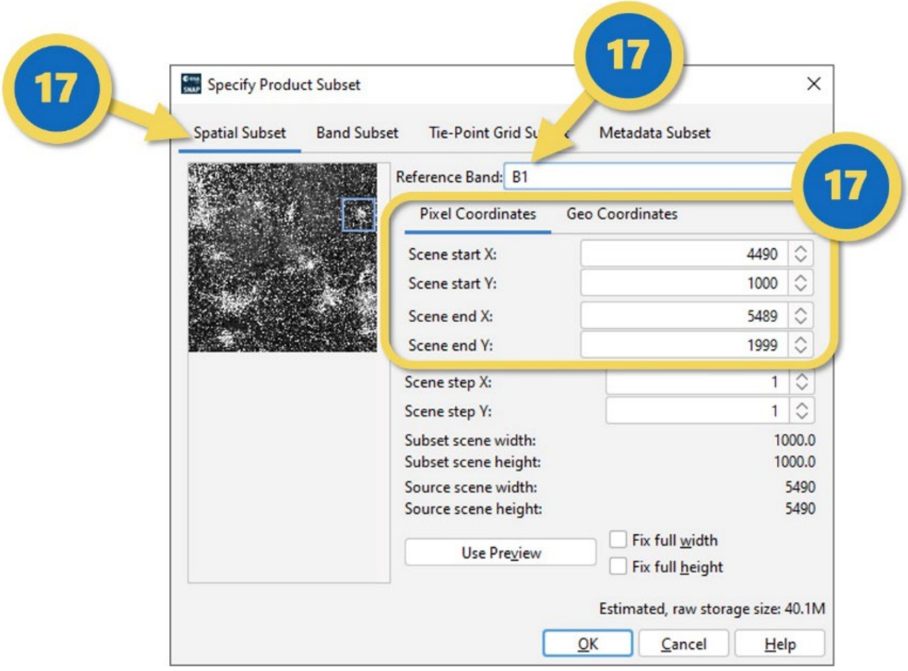


Fig. 21: Settings of the spatial subset.

18. In the tab Band Subset, the bands can be reduced to the ones needed for the classification. Only reflectances are needed this time, and only certain bands among them. Click "Select none" and then only the Bands 2-8 and 11-12, which are the bands with 10 or 20 m resolution in the visible and near infrared light.

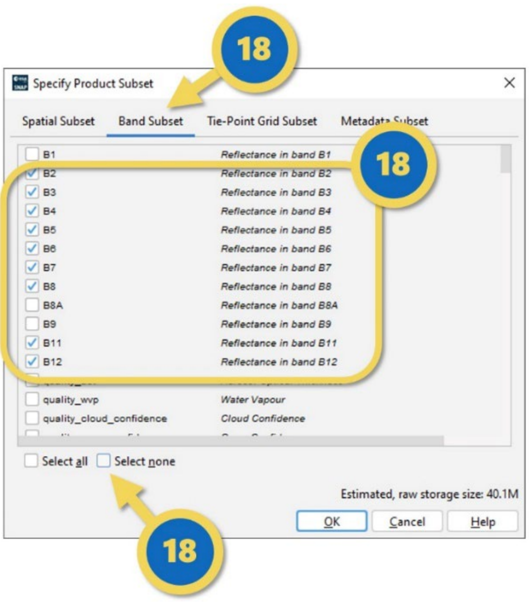


Fig. 22: Classification of the band subset

19. In the tab Tie-point Grid Subset, select none as none of them are needed for the classification, either. The Metadata Subset cannot be changed, so leave it

the way it is. Click OK. The subset will be opened in the Product Explorer. Repeat the Subset steps with the other scene.

20. Most classification algorithms require all bands to have the same resolution and extent. Since some bands of the subset have a 10 m and others a 20 m resolution, the 10 m bands must be resampled. Go to *Raster, Geometric, Resampling*.

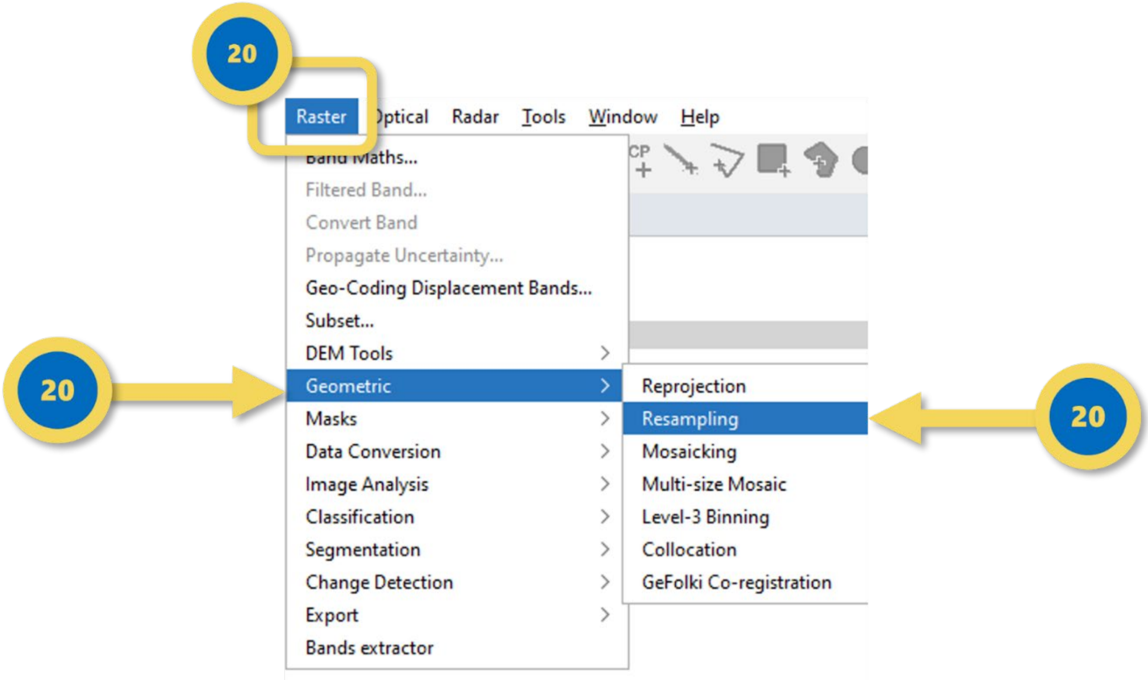


Fig. 23: Resampling.

21. In the I/O Parameters, pick the subset from 2017. The processing step is added to the file name, but you can shorten it, e.g. *S2A_MSIL2A_20170428T030541_Zhoukou_20m*
22. In the *Resampling Parameters* under *Define size of resampled product*, *choose By reference band B5.*
23. In Define resampling Algorithm, choose *Mean* as the *Downsampling Method*. Click *Run*. Repeat the Resampling for the subset from 2024.
24. Before Classification can commence, the subsets need to be reprojected. In the top menu band, click on *Raster, Geometric, Reprojection*. Illustration 23.
25. Under *I/O-Parameters*, chose the 2017 Subset. For the Target Product, the word reprojected is simply added to the existing name. Make sure it is written into the correct directory; the folder the other data is already in.
26. In the Tab Reprojection Parameters, make sure the Custom CRS is „Geographic Lat/Lon (WGS 84)“. All other settings can stay the way they are. Click Run. Repeat the steps for the 2024 resampled subset.
27. Open both as true color images in SNAP.

28. Due to the reprojection, the scenes are now distorted. The empty corners would be classified and distort the results as well, so they must be cut off. Repeat the subset process again with both resampled, reprojected subset and the pixel coordinates:
    Scene start X: 50
    Scene start Y: 50
    Scene end X: 1149
    Scene end Y: 949
    Bands and Metadata stay the same this time.
29. When you have successfully trimmed, resampled, reprojected and trimmed both scenes again, save both scenes. Open both scenes as True Color RGB. Select all other versions of the scenes in the Product Explorer, right-click on them and Close [X] products. They do not need to be saved. This will free up memory that will be needed in the following steps.

Classification:

SNAP has various classification methods to choose from. There is unsupervised classification, where the software itself decides what belongs together, or supervised classification, where users specify what belongs together. The disadvantage of unsupervised classification is that it is not comparable. This can lead to very different classification results between the two scenes. A supervised classification is therefore usually required to compare two time periods.

30. For the supervised classification, the software needs examples of what belongs in which surface class, e.g. urban area, barren land, vegetation and water. In true color, these can be hard to distinguish. Alternatively, you can make use of the other spectral colors by using a different profile in the RGB Image, e.g Healthy Vegetation in which plants glow red.

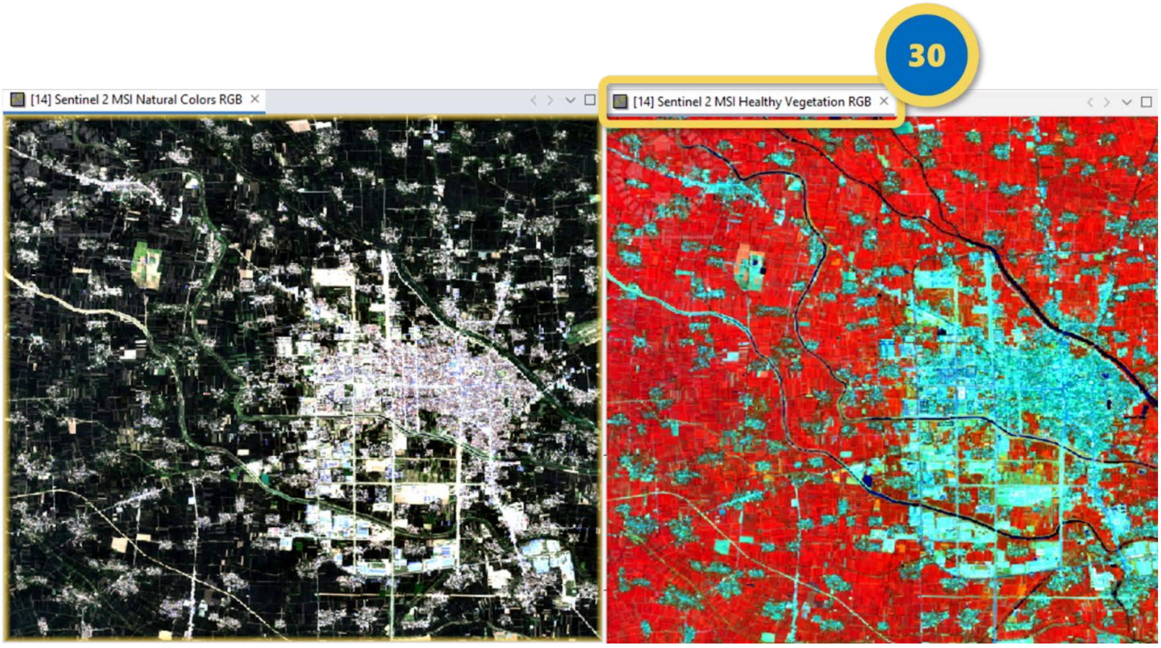


Fig. 24: Spectral color image.

31. The examples should not contain any pixels from another class. These example areas are created as vectors. To do this, click on "New Vector Data Container" in the toolbar at the top and give it a name.
32. Use the polygon buttons  to mark small sample areas for each class in turn. A few hundred pixels per class is enough. Only start a new class when you are satisfied with your selection for the previous class, because switching between classes is complicated in SNAP.
33. For each class, make sure that you only use example areas that you are absolutely sure are correct. Also make sure that the areas remain “pure”, i.e. that you do not include any trees in the neighborhood, no roads in the fields, no boats in the water, and no green areas in the fallow land.

    Every pixel counts!
    Hints:

    In China, red and blue roofs are considered lucky. Include them in your city class, but make sure there are no trees in between. Large industrial areas are also well suited for city areas.

34. When you’re happy with your reference areas of all four classes (5-6 small polygons are sufficient!), save the respective scene by right-clicking on it and then “Save Product”.
35. Create new example areas in the other scene. Make sure to use the same classes in the same order as before. The polygons can be more or less where

they were in the first scene, as long as the areas are still of the same type. Make sure to save the scene in the end.

36. When both scenes are saved with their example areas click on *Raster, Classification, Supervised Classification, Random Forest Classifier*.

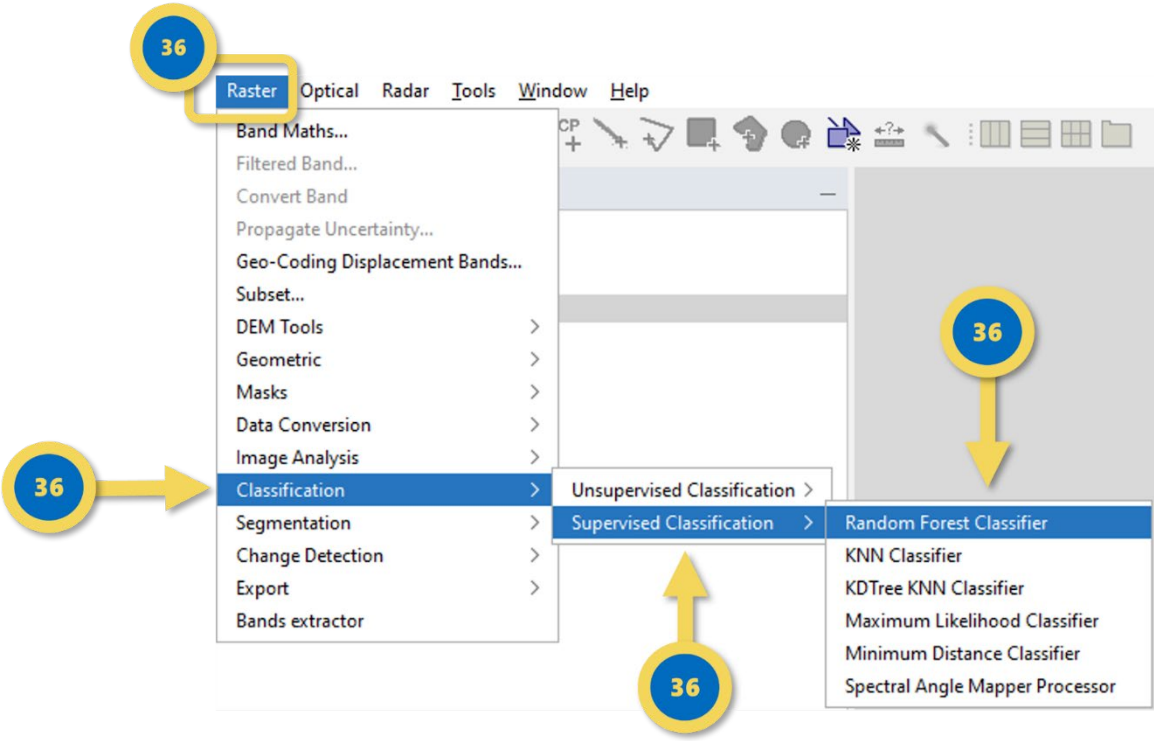


Fig. 25: Find classification.

37. In the window that opens, click on the big plus sign and navigate to the 2017 file with the classes of polygons you just made.
38. In the tab Random Forest Classifier, in the Classifier area, put the Number of training samples down to 1000.
39. In the Vector Training, select all classes by clicking on the first one and then clicking on the last one while holding down Shift. Do the same for the bands 2-12 a bit lower.

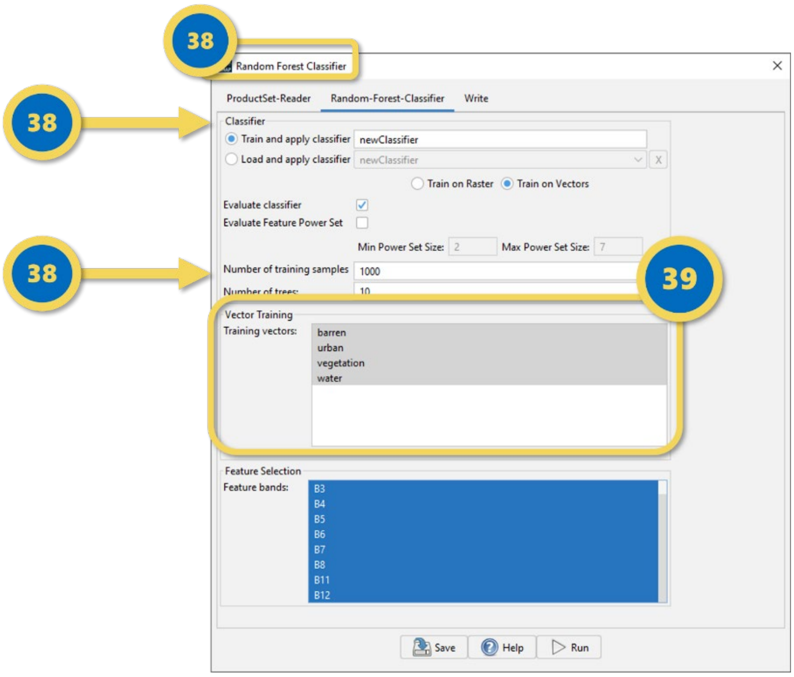


Fig. 26: Random Forest Classifier.

40. Go to the Write tab and make sure the Target Product has a good name and is written into the correct directory, the one everything else is in. Then click *Run*.
41. Repeat the process for the 2024 file with the classes. Afterwards, open the *Labeled Classes* from both products with a double click in the *Product explorer*.
42. There should be a Color Manipulation window below the Product Explorer. If not, activate it in the top menu → View → Tool windows → Color Manipulation
43. In the Color Manipulation field, you can adjust the classes' colors. You can use predefined ones by clicking on the color fields, or you can click on More and choose your own colors, e.g. in the RGB tab a darker green like 00B400 for vegetation.

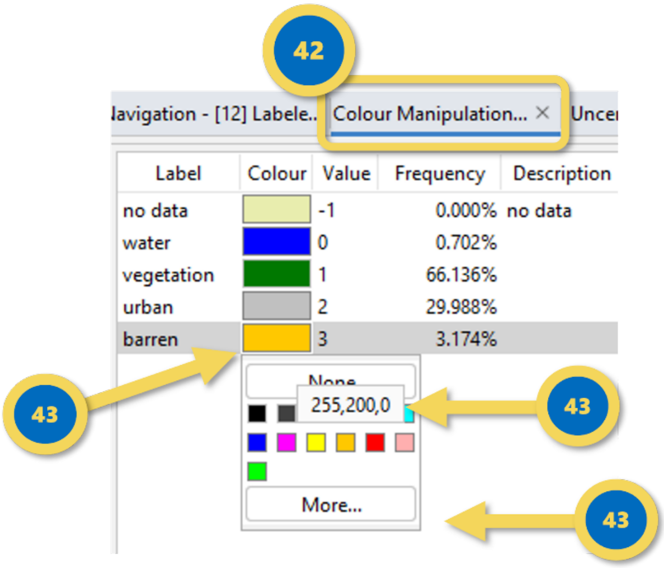


Fig. 27: Colour Manipulation.

44. Give the classes the same colors across both classification results.
45. Compare the Frequency of the classes between the two classification results. How has the amount changed in 7 years?
46. Compare the urban area between 2017 and 2024.

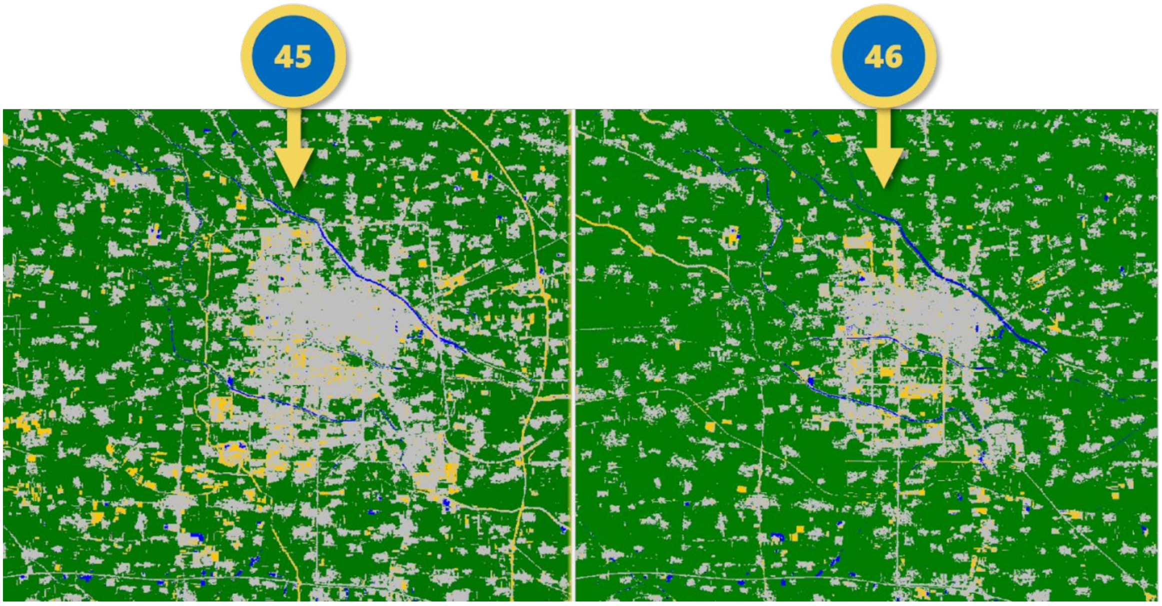


Fig. 28: Results.

Classification results from our example:

Class	Colour	Frequency 2017	Frequency 2024
Water		0,75%	0,7%
Vegetation		77,7%	66,1%
Urban		19,9%	30%
Barren		1,7%	3,2%

Between April 2017 and 2024, around 10% of the analysed area was built on. The built-up area thus increased by a factor of one and a half. At the same time, the area covered by vegetation took up 11.5% less space in the study area. The proportion of barren land almost doubled from 1.7 to 3.2%. A closer look reveals that in 2024, there are also numerous vacant fields in the south-west of the scene that were probably just harvested or freshly planted, in contrast to the vacant areas in the urban area or along long, thin stretches that are presumably construction sites. The proportion and distribution of water areas has changed only marginally and is probably due to different water levels in the watercourses.

In total, around 10% of the study area was converted from planted to built-up areas between 2017 and 2024.

Note: For an exact scientific analysis, further statistical analyses would be necessary here, but these would require a separate tutorial.

3.4.2 Biology example – soccer – artificial turf vs. natural turf

The NDVI gives us information about how healthy plants are in an area. These properties not only provide information about whether plants are healthy or not, but also whether there are actually real plants in the area of interest. This is not always very clear - some soccer pitches are not made of natural grass but of artificial turf, a hard-wearing substitute material made of plastic. In a true color satellite image, however, the difference can hardly be seen, as the artificial turf is also colored green - and often it is even significantly greener than the real grass. However, if you use the NDVI vegetation index, it becomes clear that natural turf reflects light in the near infrared range more strongly than its substitute product.

Data acquisition:

Sentinel-2 records the visible, near-infrared and infrared spectrum with 13 bands. The NDVI can be calculated using data from the Sentinel-2 satellite and, more precisely, its red and near-infrared bands.

This comparison of true colors and NDVI can be performed directly in the Dataspace Copernicus Browser. For this purpose, we use the data query and the internal analysis of the online software.

Fig. 29: True color vs. NDVI image.

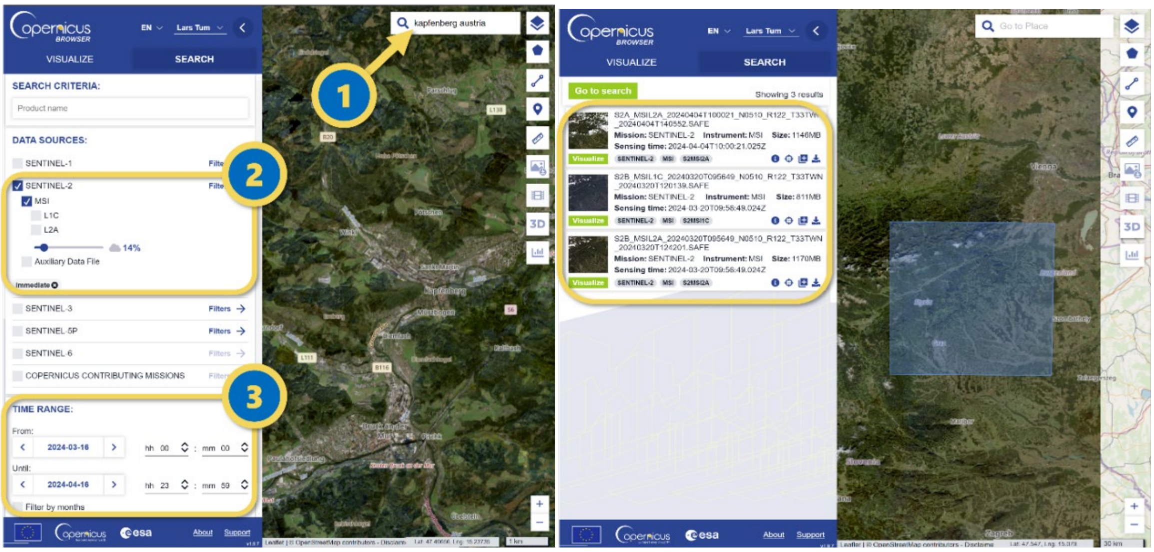


Fig. 30: Dataspace Copernicus Browser satellite image query.

1. Navigate to browser.dataspace.copernicus.eu and log in or register for free on the site to be able to use all functions.
2. Click on the search field at the top right and enter “Kapfenberg Austria”.
3. Click SEARCH to specify the satellite query.
4. Select Sentinel-2 and a low cloud coverage (approx. 15%). Select a reasonably long time range to have enough days/satellite images with low cloud cover available (ill. 30).
5. Click on search.
6. Select one of the results by clicking on “Visualize” or adjust your search criteria if necessary.
7. Once the satellite image has been visualized (this may take some time), select NDVI under “Layers”.
8. Click on “Add to” and finally on “Add to Compare”
9. Carry out steps 7 and 8 for the “True Color” layer as well.

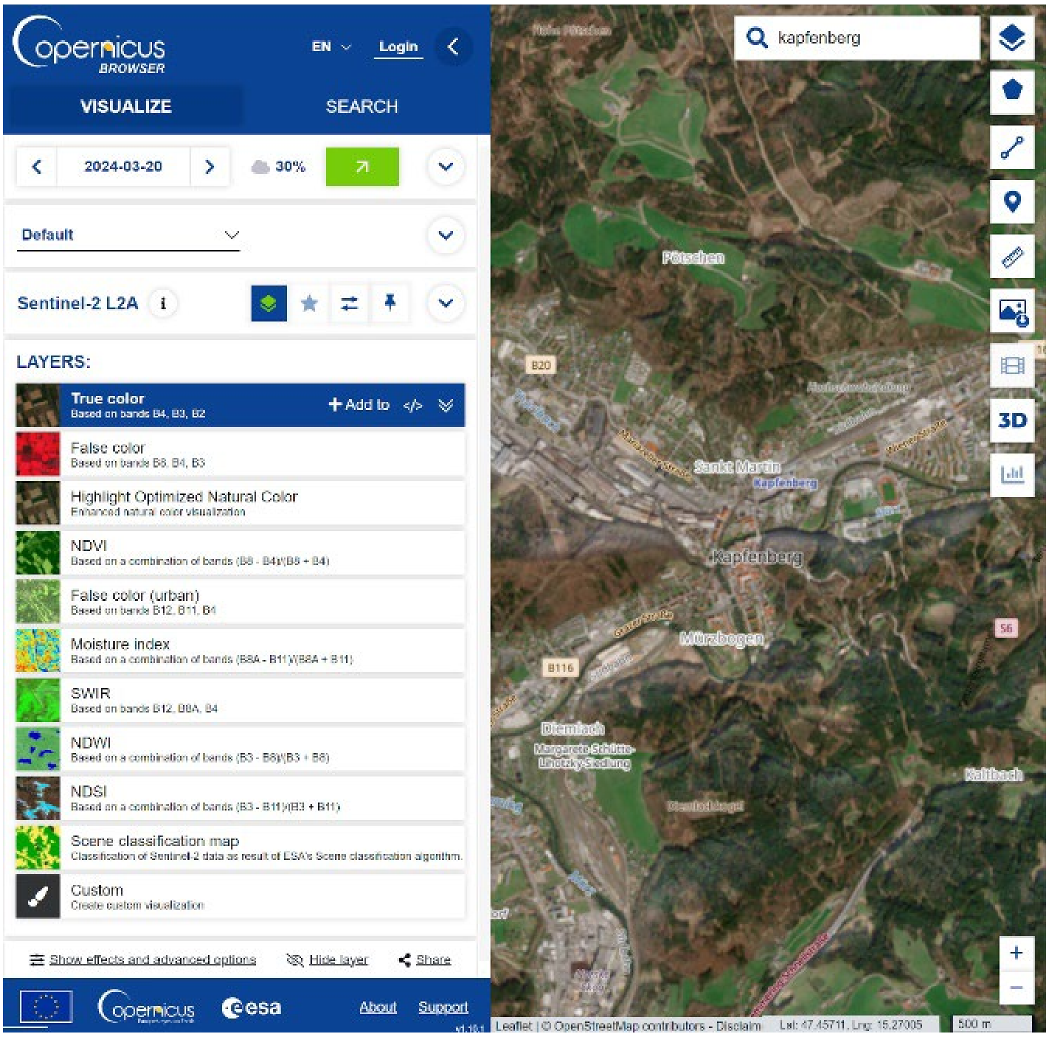


Fig. 31: Layer selection Dataspace Copernicus Browser.

10. Now click on the “Compare Panel”, the button with two horizontal arrows.
11. Now you can use the sliders to adjust the view so that you can view the NDVI directly in comparison to the True Color Image.

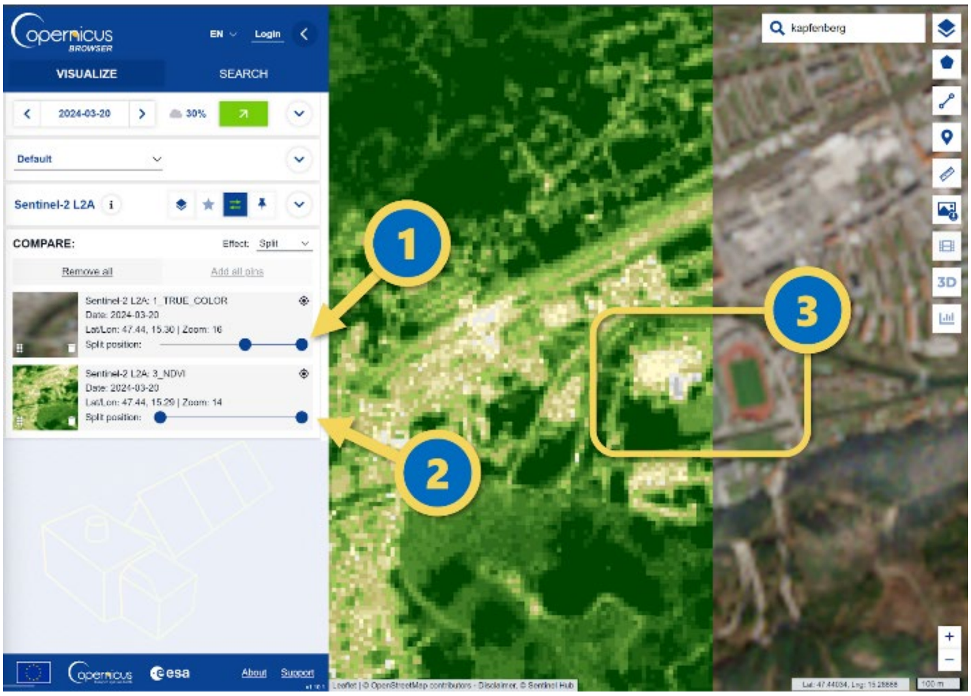


Fig. 32: Comparison view Dataspace Copernicus Browser.

12. Click on the symbol with the image and the arrow to download the displayed image

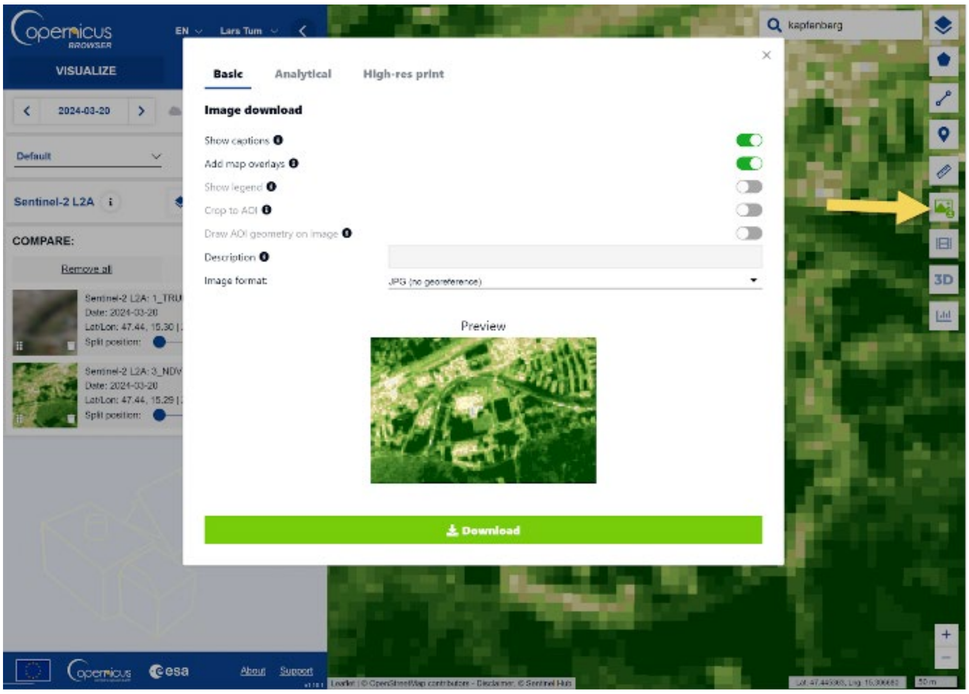


Fig. 33: Download function Dataspace Copernicus Browser.

3.4.3 Geography example – Heat in Spain

Download the data from the Copernicus Browser:

1. Go to https://dataspace.copernicus.eu/ and in the top mid, hover over *Explore data* and click *Copernicus Browser* in the pop-up menu.
2. Register or log in to the Copernicus Browser (it's free and no ads!).
3. In the top left corner, click on the *SEARCH* tab to reach the download menu.
4. In the top right corner, click into the *Go to Place* field and type *Madrid*.
5. Click on one of the options of Madrid in Spain. Your window should now move to Spain. Zoom further into the country until Madrid roughly fills your screen.
6. To the left, in *data sources*, activate *Sentinel-3* and in the submenu, activate *SLSTR* (this is the thermal infrared sensor) and then *Level-2 LST* for the Land Surface Temperature product.
7. To further narrow down the search, click on *Filters* next to Sentinel-3, and activate *Non Time Critical* and *Descending* to only get day time imagery.

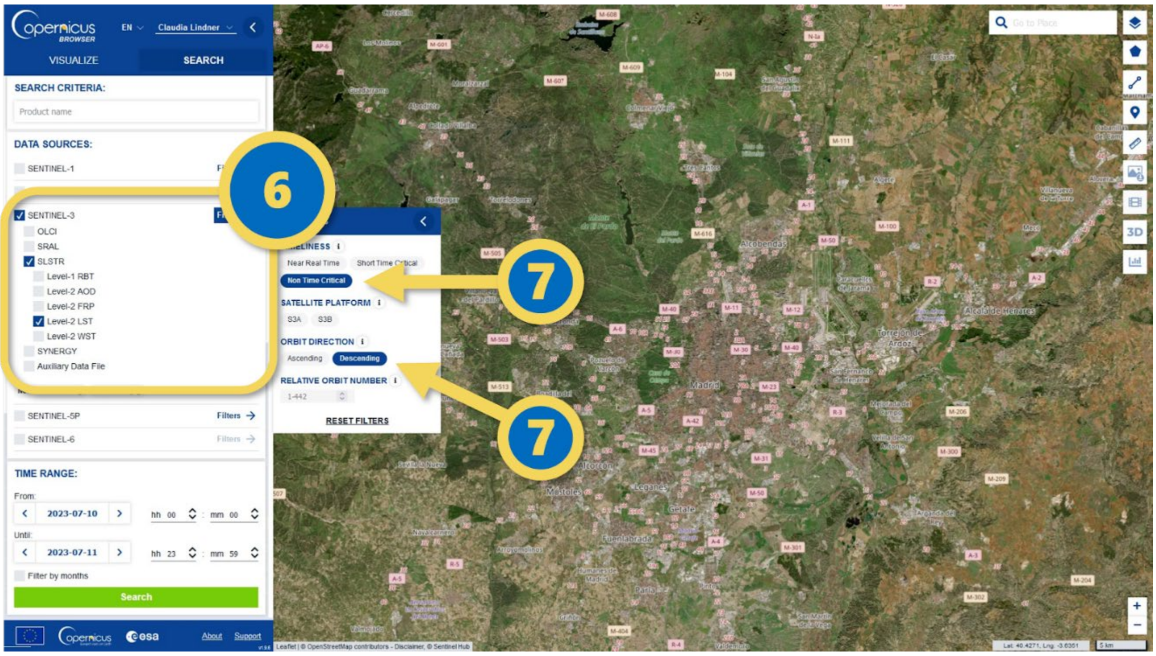


Fig. 34: Selection of data records and filter day images.

8. Adjust the time range from 10th till 11th July 2023, so *From 2023-07-10 Until 2023-07-11* and click *Search*.

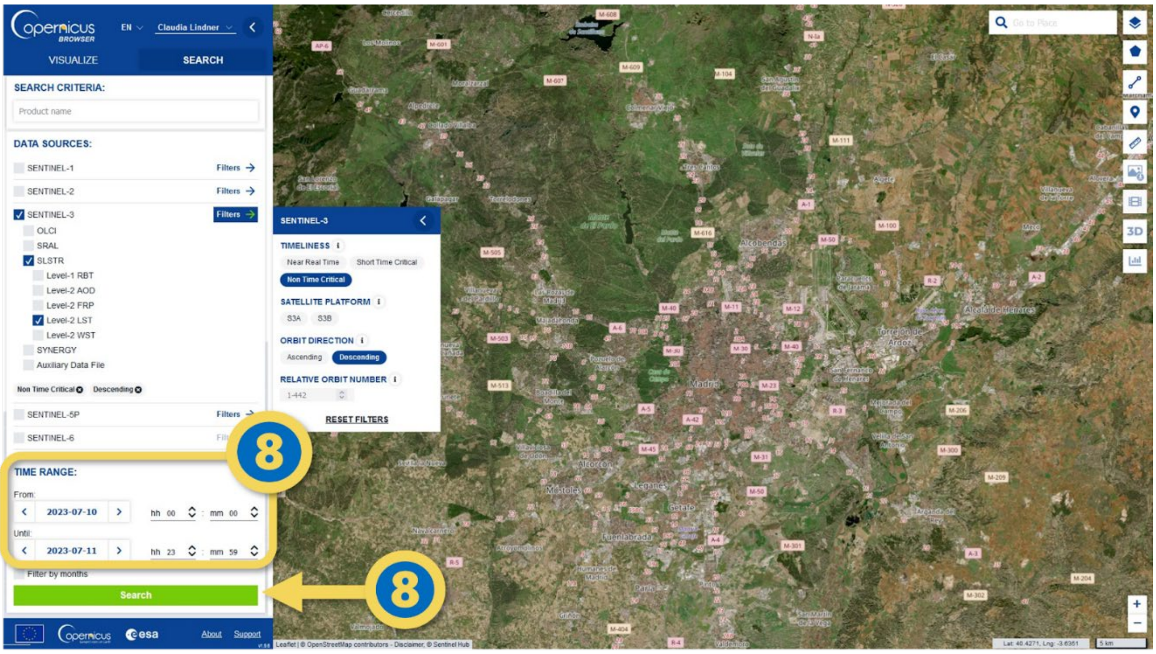


Fig. 35: Selection of the time period.

9. A list of results should be shown that overlap with the location you zoomed into. You can now zoom out to look at their coverage. You will notice that some overlap Spain better than others, but the country is always cut in half by the borders between scenes. If you don't see the overlapping scenes like in Fig. 36, zoom a little bit North or South and repeat the search.
10. Click on a tile where it doesn't overlap and look at the thumbnail. Try to figure out what is shown and what the colours mean. If you look closely, you can see some clouds in the imagery of the 11th July.
11. Download two scenes: *S3B_SL_2_LST____20230710T**103317*** … und *S3B_SL_2_LST____20230710T**103017***…

Fig. 36: Downloading the scenes.

12. Unzip the downloaded files into your preferred folder.

Inspect the scenes in SNAP

13. Open *SNAP*.
14. Click on the folder symbol to open the files. Navigate to the folder you saved the unzipped files in, into the *.SEN3 folders* and open the *xfdumanifest.xml* of both files.

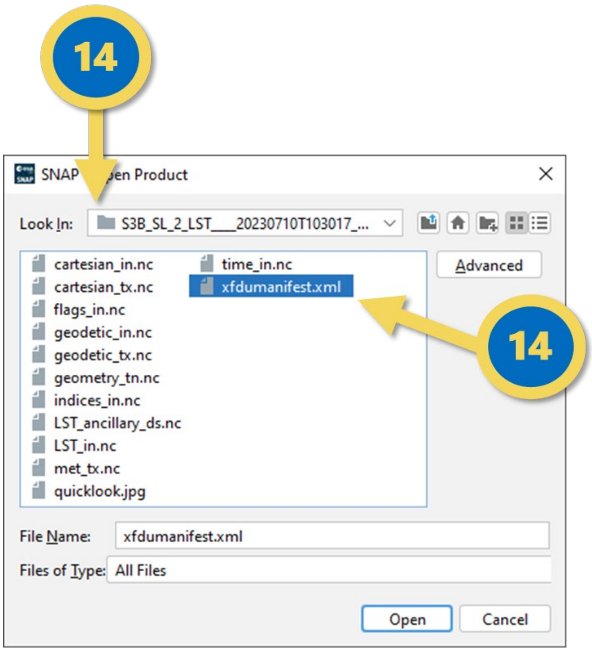


Fig. 37: Open the files.

15. Click on the little + next to the file name of either scene in the Product Explorer to open its contents, and then click on the little + next to Bands. Double Click on LST to open it.

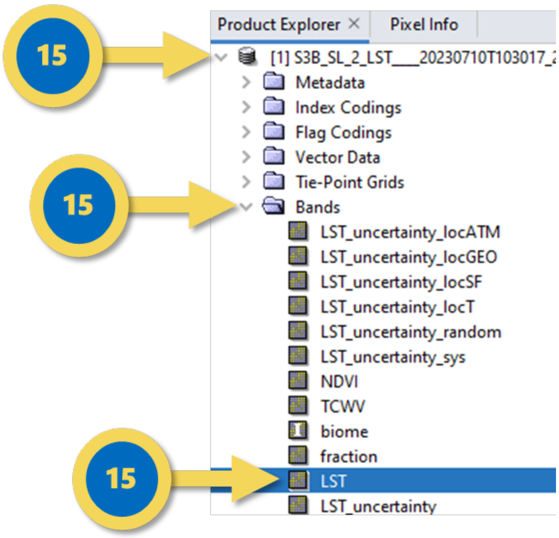


Fig. 38: Opening the image.

16. The image open in a greyscale, and of course, it is only half of our area of interest. This will be adjusted later.
17. Below the *Product Explorer*, one of the tabs should be *Color Manipulation*. If not, you can activate it in the *View* tab at the top. Click on *Color Manipulation* and then on the Palette. You'll see many different colour Palettes. Pick one that fits the purpose, e.g. *5_colors*.
18. If you look at the range of numbers, you will notice that they are around 300. This is due to the degrees being in Kelvin, which is basically °C but counted from absolute zero, which is -273.15°C. This will be adjusted in the next steps.

Creating and adjusting the mosaic:

19. In the *Raster* tab, hover your mouse over *Geometric* and then click on *Mosaicking* in the sub-menu.

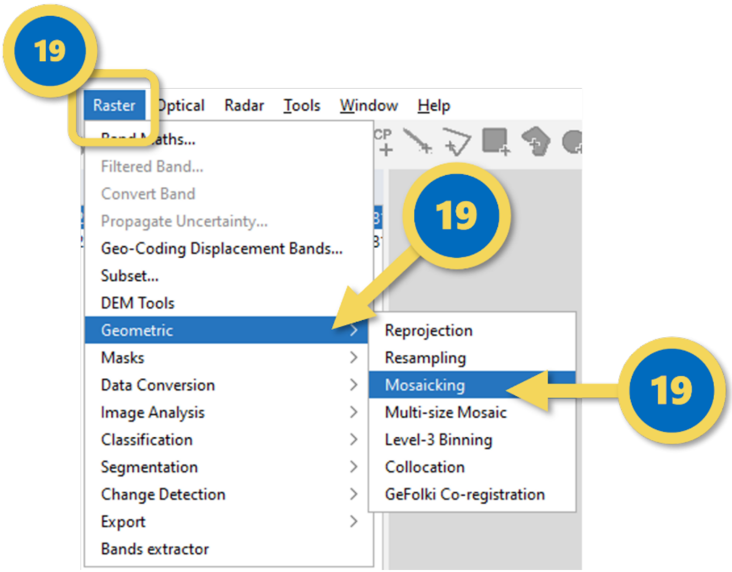


Abb. 39: Selection of the Raster.

20. In the *I/O Parameters* tab, click the plus button and add the two scenes the same way you opened them.
21. Make sure *Update target product* is unchecked. Give your mosaic a new name that will later tell you about its content, e.g. *IberianPeninsula_S3_LST_20230710T2023103317* which contains the location, the satellite, the product name, and the date and time.
22. For the directory, click on the three dots to the right and navigate to the folder the SEN3 files are in. Then click Select.
23. Open the *Map Projection Definition* tab. In the *Coordinate Reference System (CRS)*, change the Projection to *UTM / WGS 84* (Automatic).
24. Go further down to the *Mosaic Bounds*. The area of interest is only the Iberian Peninsula, so create a subset of the mosaic that is needed. Zoom to selected

product with the button in the map that has an arrow pointed at a *search* symbol.

25. Adjust the red bounding box or type in the boxes so it only covers the area of interest: The Iberian peninsula. The boundaries should be approx.:
    West: -10° East: 3.5°
    North: 44.5° South: 35.5°
    The Pixel size of 1000 m can stay the same.

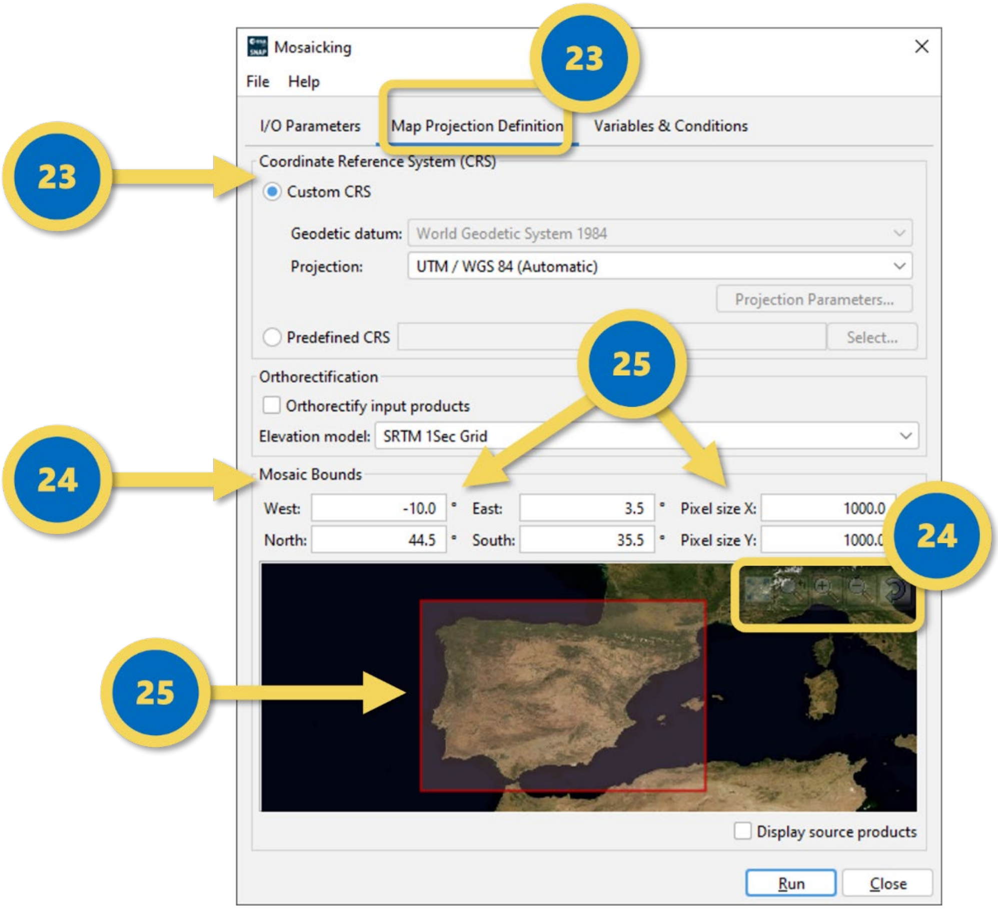


Fig. 40: Mosaicking.

26. In the *Variables & Conditions* tab, open the *Variables* Band chooser by clicking on the symbol with two sheets.
27. Only the LST and the NDVI are needed for this exercise, but also need the LST adjusted to degrees Celcius. Check only the NDVI for now and click OK.
28. Add a new processing variable by clicking the little plus under *Variables*.
29. A new variable appears. Double-Click into the field with the name and rename it into *LSTinCelsius*..
30. Double-click on the empty Expression field. A new window appears. In the expression field, type *LST - 273.15* and click *OK*.

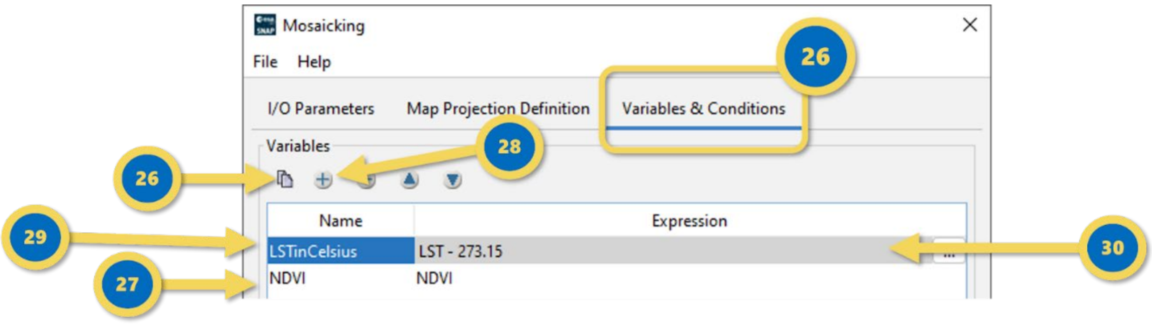


Fig. 41: Mosaicking.

31. Click *Run*.
32. Since a smaller subset was chosen and only two bands, the processing should be done within seconds. A window should appear to inform you that the file was written successfully and opened in SNAP. You may click *OK*. You may also close the Mosaicking window.

Visualisise the results:

33. Open the LST image in the new mosaic file. It should appear as a greyscale image. Pick a color palette that fits the purpose, e.g. 5_colors.
34. There is no dedicated temperature profile, but you can adjust the colors as necessary. Switch to the *Sliders* option.
35. You can click on the triangles to change colors or move them, or click into the numbers to adjust manually. You can add and removemore of these brackets with right-clicks on the color scheme and make as many adjustments as you like, e.g. as in the following image:

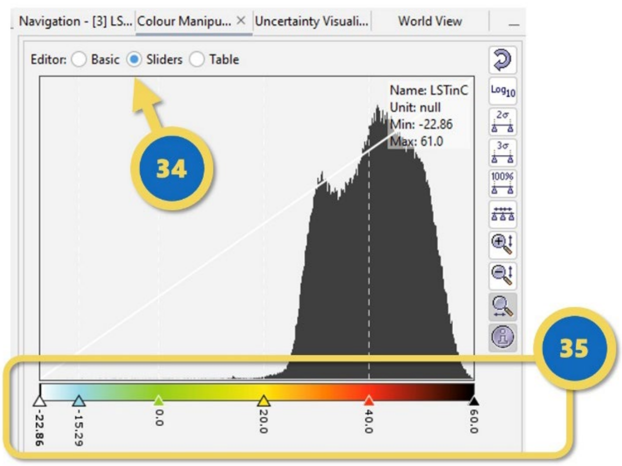


Fig. 42: Adaptation of the schemes.

36. Open the NDVI image in the mosaic file. It should appear as a greyscale image. A good representation for what the NDVI stands for is the *meris_veg_index*

palette. Pick it from the *Basic* Palette, then switch back to *Sliders* to make adjustments.

37. High Values (0.6-0.8) of NDVI indicate dense forests, moderate values (0.2 - 0,3) grass or shrubland or low plant vigor. Very low values (0.1 and below) correspond to barren areas of rock, sand, or snow. Negative values (< 0) indicate water boadies.
    Make the respective adjustments to the veg index colours by moving the slider values, e.g. as in the following image:

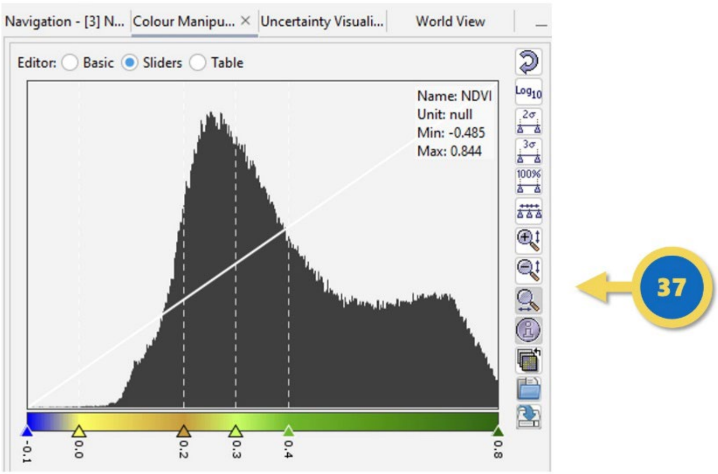


Fig. 43: NDVI values.

38. In the top bar, click on the *Tile Horizontally* button:

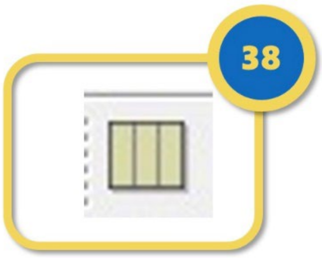


Fig. 44: Symbol 'Tile horizontally'.

You can now compare the LST and the NDVI image side by side and see the difference vegetation makes on the surface temperature for yourself.

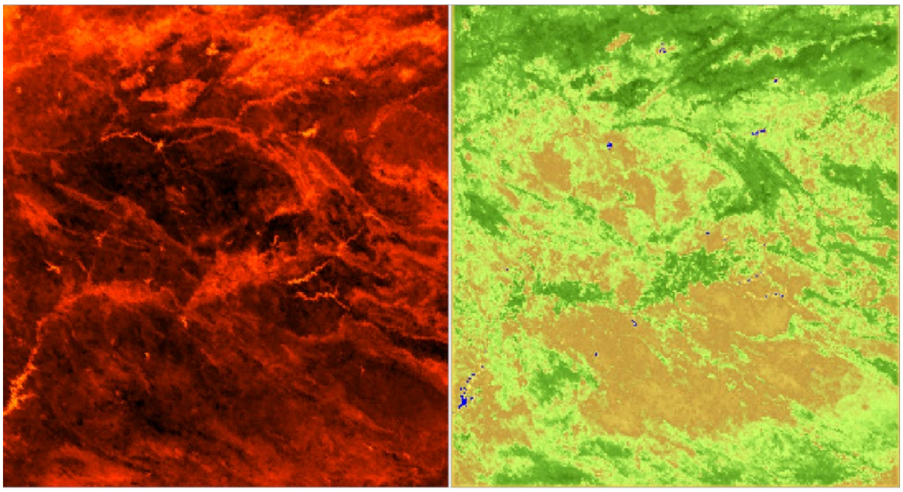


Fig. 45: Satellite images, vegetation and soil temperature in comparison.

39. Find or activate the *Navigation* tab near the *Colour Manipulation* tab. You can synchronise the images and the cursor positions.

3.4.4. Physics example – Suez Canal

1. Go to https://dataspace.copernicus.eu/ and in the top mid, hover over "Explore data" and click "Copernicus Browser" in the pop-up menu.
2. Register or log in to the Copernicus Browser (it's free and no ads!).
3. In the top right corner, click into the "*Go to Place*" field and type "Suez".
4. Click on "Suez, Egypt". Your window should now move to Egypt.

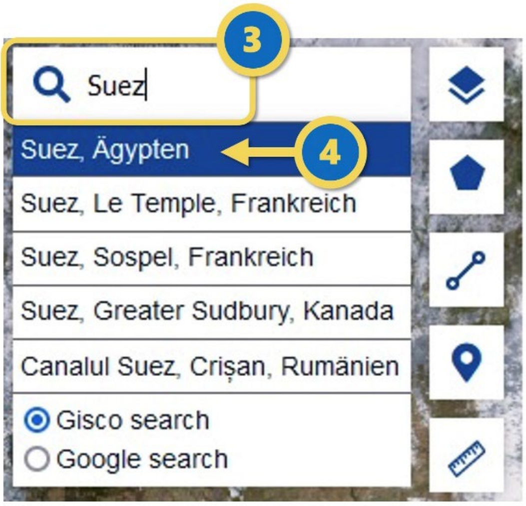


Fig. 46: Selection of the area of interest Suez, Egypt.

5. To the left, in "data sources", activate Sentinel-1 and in the submenu C-SAR, activate "Level-1 GRD".

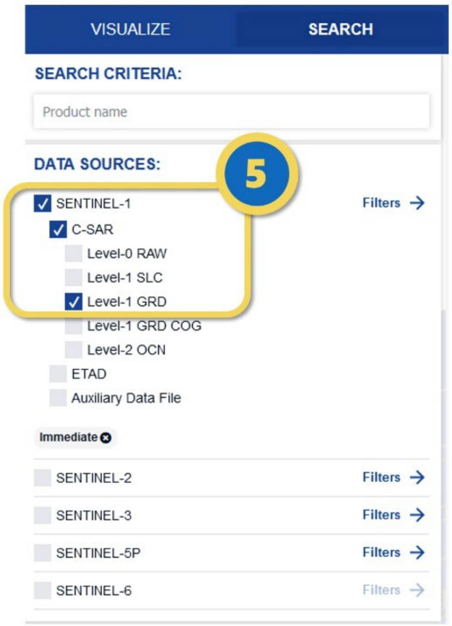


Fig. 47: Activate the data sets.

6. Adjust the time range from 21st til 27th March 2021, so “From 2021-03-21 Until 2021-03-27” and click “Search”.

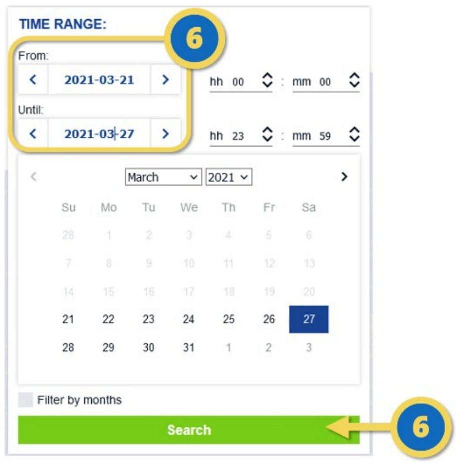


Fig. 48: Selection of the time period.

7. 5 results should be shown. Download only the ones with the Sensing times 2021-03-27T03:44:10.127Z and 2021-03-21T03:44:49.598Z (first and last in line)

Fig. 49: Downloading the recording times.

8. Unzip the downloaded files into your preferred folder.
9. Open *SNAP*.
10. Click on the folder symbol to open the files. Navigate to the folder you saved the unzipped files in, into the files and open the “manifest.safe” of both files.

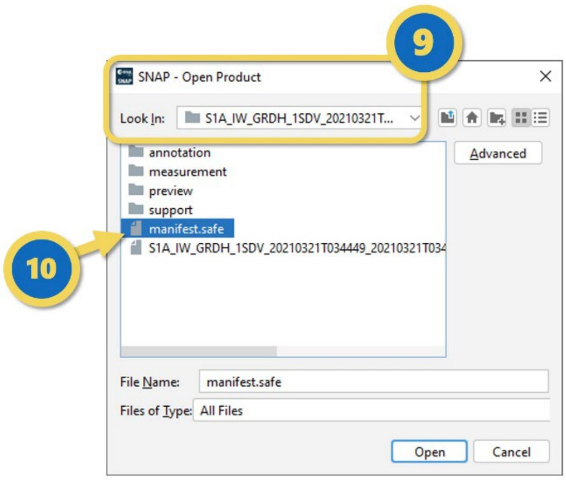


Fig. 50: Open the file on SNAP.

11. In the collocation settings, pick the file of the 21st March as Master, and chose the 27th March as Slave.

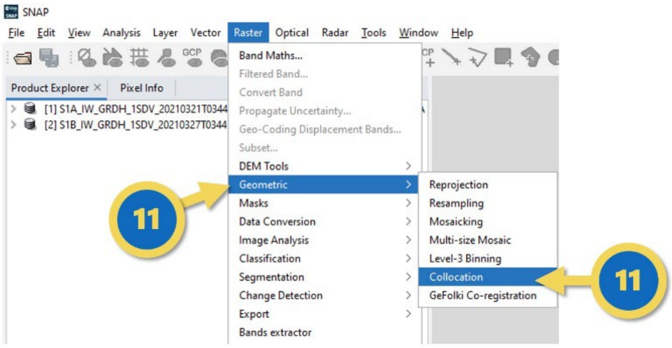


Fig. 51: Selecting the file.

12. Name your target product, for example "S1_EgyptMarch2021_comparison".
13. Chose a directory to save the product in, for example the directory with the unzipped files.
14. Adjust the renaming of the Source Product Components, for example by replacing everything after §{ORIGINAL_NAME}_ with the date and "before" and "after".
15. Leave all other settings as they are and click "*Run*".

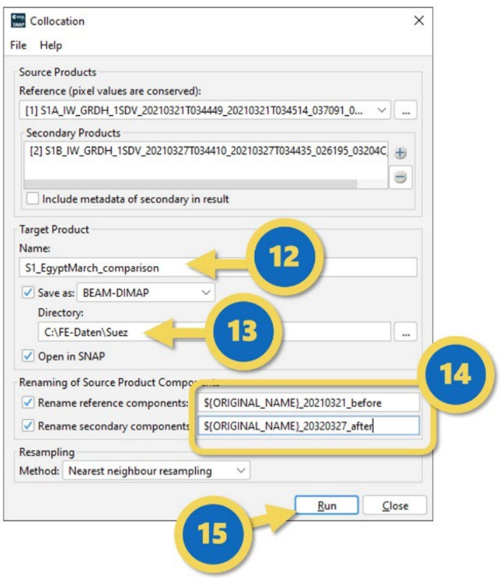


Fig. 52: Settings for collocation.

16. When the new file appears in the Product Explorer, right-click on it and then click on "*Open RGB Image Window*".

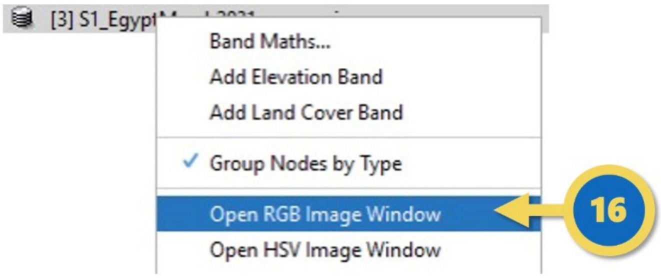


Fig. 53: Opening the file.

17. In the RGB window, pick "Intensity_VH" once for the "before" date (red), and twice! (green and blue) For the "after" date.

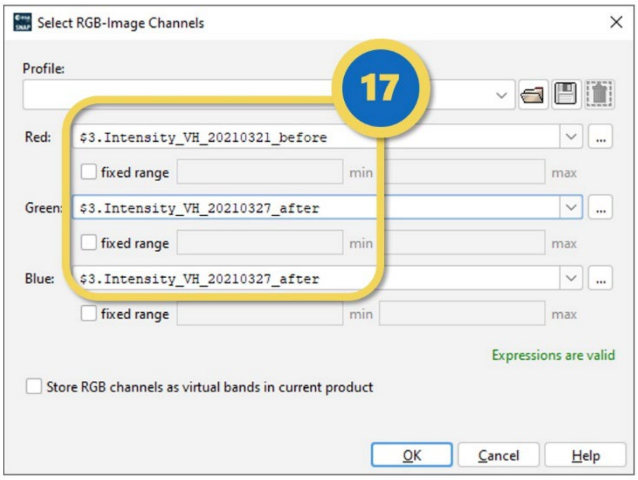


Fig. 54: Intensity_VH settings.

18. Click *OK*.
19. Zoom into the image towards the black area to the right.
20. In the black areas (the Red Sea), you can now see vessels present on 21^{st} March in red, and vessels present on 27^{th} March in light blue. A light blue vessel is blocking the Suez canal on the 27^{th}, where on the 21^{st} chips were going through regularly. Due to the blockage, on the 27^{th}, there is a large line of ships waiting to pass through.

3.5 Sentinel data in computer science lessons

In the course of globalization, earth observation is becoming increasingly important. Satellites collect immense amounts of data every day in order to gather information for a wide range of applications. The Copernicus program alone produces around 12 TB of data every day. This makes the Copernicus program the third largest data provider in the world. In order to manage and process this amount of data, computer scientists from a wide range of specializations are needed.

This chapter serves as a guideline for teaching various theoretical and practical basics from the field of programming. For example, students are taught the meaning of the terms Integrated Development Environment (IDE), interface and Application Programming Interface (API). Pupils generate GeoJSON files and visualize their function and structure. In addition, they learn how to program a Python API using an IDE to query and download satellite data from the Copernicus servers.

The user segment in particular requires the most automated data processing of the data masses possible. To make this possible, so-called APIs are used, among other things. An API is a programming interface with which it is possible to exchange data between programs or entire modules in a standardized way. IDEs are used to simplify the programming of such APIs. They are characterized by a user interface that contains all the necessary tools and functions for programming in various languages. These functions and tools include, for example, source code formatting or a debugger.

Further teaching materials for computer science can also be found on the websites http://www.esero.de/ and http://fis.rub.de/. Among other things, FIS offers an interactive learning module on the subject of columns and rows in raster data, binary code and the bit depth of an image.

ESERO Germany offers a variety of different teaching materials for computer science lessons. The target group ranges from ages 8 to 20 and the content ranges from computerless concept teaching for navigating a robot to programming a measuring station based on an ARDUINO with C++. The QR codes will take you directly to the teaching materials.

3.5.1 Using a Python API

Python version 2.7 or 3.4 and higher must be installed on the PC for the Python API programming to work. The option to use the package management program “pip” must be activated during installation. Furthermore, “Sentinelsat” must be installed using “pip” via the command prompt (cmd.exe). More information on Sentinelsat, installation and further syntax can be found at https://sentinelsat.readthedocs.io/ .

Fig. 55: Command prompt for programming.

1. Open the command prompt.
2. Use "pip" to install "Sentinelsat" within the command prompt. The command is:
   pip install sentinelsat
   Press Enter after the input.
   Then check whether the module has been successfully installed.

GeoJSON files can be used to specify an investigation area. This is a format with which it is possible to record geographical location and area data using JavaScript Object Notation (JSON). The website www.geojson.io offers a way to avoid having to write the code yourself.

3. Visit the website www.geojson.io
4. Select one of the drawing tools and draw a polygon over your area of interest. In this case, the Sundarbans in Bangladesh have been chosen.
5. Select the entire code that was created in the right-hand window.
6. Paste the text into any editor and save the file with the file extension *.geojson*

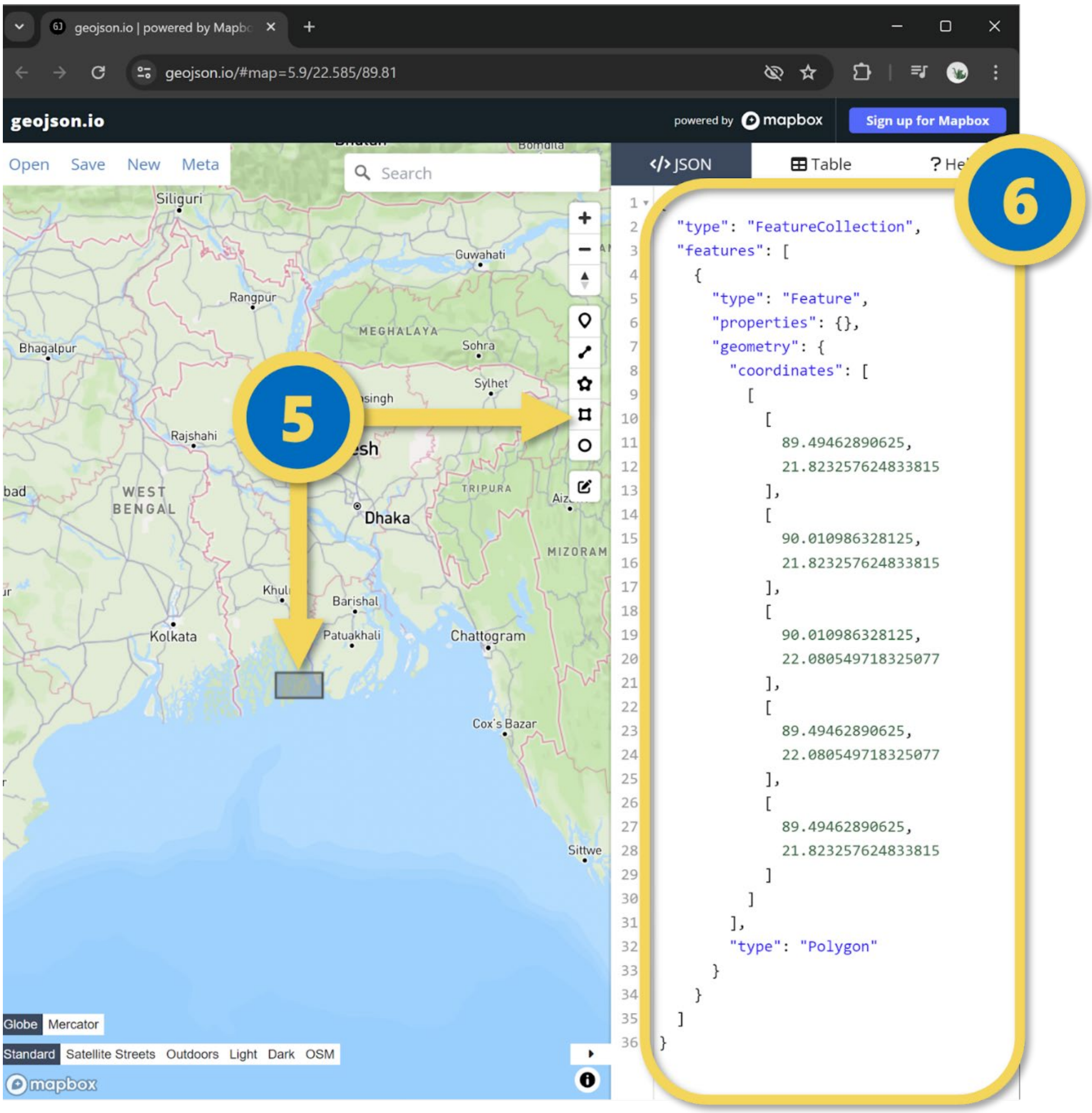


Fig. 56: Selecting the area of interest at www.geojson.io.

All subsequent steps now take place within the IDE. In this case, PyCharm Community was used. Visual Studio Code also works well, but requires the installation of the Python interpreter.

7. Open a suitable IDE and create a new project.

PyCharm automatically creates all relevant Python files in the project folder. If there are still problems with the interpreter, the Python path can be adjusted under File è *Settings è Project è Project Interpreter.*

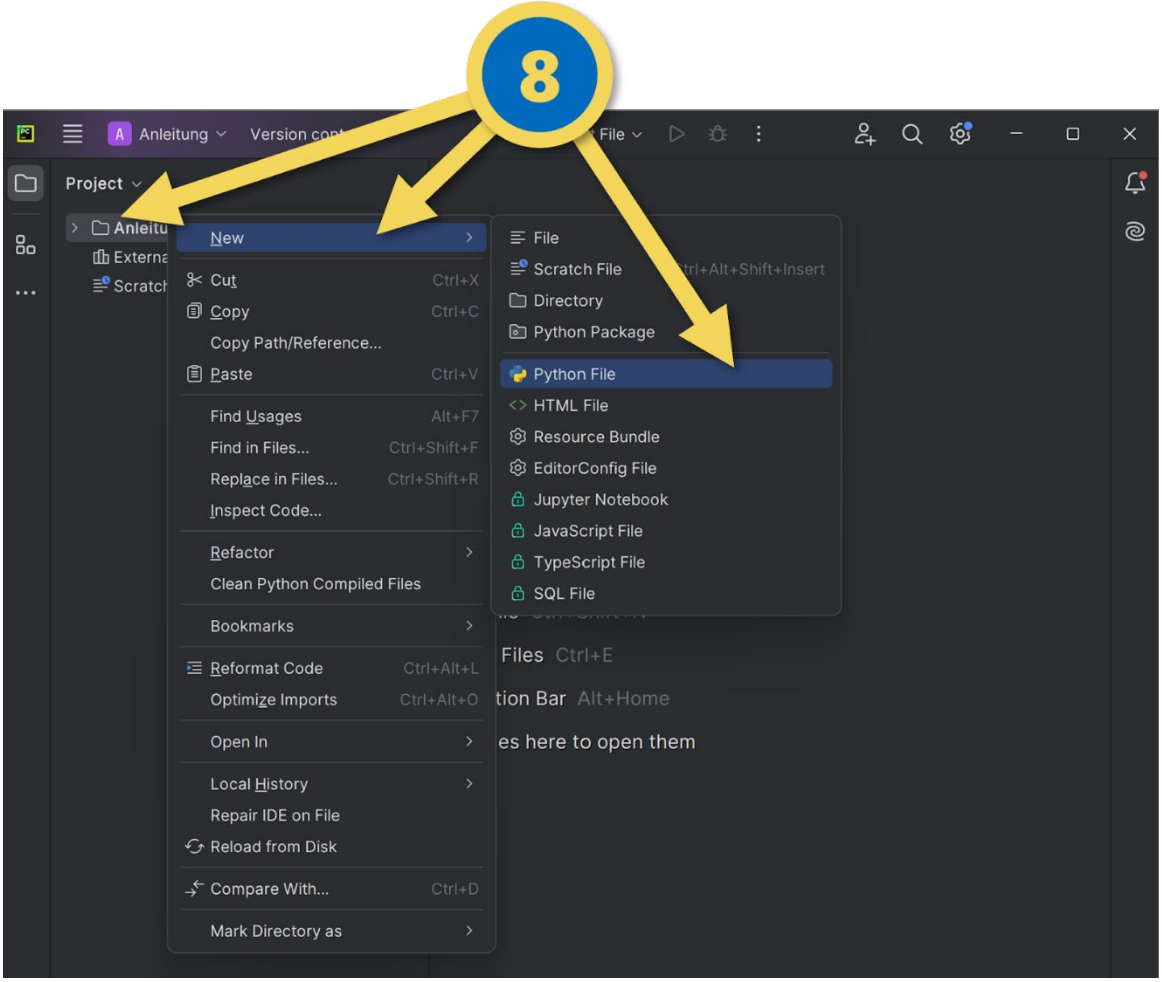


Fig. 57: Creating the Python files in PyCharm Community.

8. Add a new script to your project. You can do this by right-clicking on the *New Python File* project. Assign a name and save the project.
9. Import all necessary libraries:

```
from sentinelsat.sentinel import SentinelAPI, read_geojson, geojson_to_wkt
 from datetime import date
```

10. Connect to the Copernicus server by entering your access data:

```
api=SentinelAPI('Username','Password','https://scihub.copernicus.eu/dhus')
```

In order to be able to refer to the access data later, it makes sense to work with variables. As the passwords are visible within this script, it is advisable to prepare a certain number of accounts for the pupils.

11. Copy the GeoJSON file you have just created to the level in the folder path where the Python script is located.
12. Now refer to the GeoJSON file in the script:

```
footprint = geojson_to_wkt(read_geojson('Sunderban.geojson'))
```

In the following, a filter is to be written that filters out only those satellite images that fulfill certain criteria. These criteria include the area of investigation (footprint), the date of acquisition, the satellite, the degree of cloud cover and the processing stage. We would like to concentrate on data from the Sentinel-2 satellite, which has already been pre-processed. This means that atmospheric corrections have already been made to the image.

13. The code for the query to be used to filter the data can then look like this, for example:

```
products = api.query(footprint,
                     date=("20191101", date(2019, 11, 15)),
                     platformname='Sentinel-2',
                     processinglevel='Level-2A',
                     cloudcoverpercentage=(0, 5))
```

14. If the number of products found is to be displayed in the console, this filter can also be used. The code for this looks as follows:

```
print('Gefundene Produkte: ' + str(api.count(footprint,
                              date=("20191113", date(2019, 11, 15)),
                              platformname='Sentinel-2',
                              processinglevel='Level-2A',
                              cloudcoverpercentage=(0, 5))))
```

15. Furthermore, the size of all products found or their metadata can be output in the form of a GeoJSON. The code for this is as follows:

```
# getting information about product size
 print(str(api.get_products_size(products)) + ' GB')
 # getting geometric metadata from results
 print(api.to_geojson(products))
```

16. If all the products found are then to be downloaded to a specific storage location, the following command can be used with the appropriate modifications:

```
api.download_all(products, directory_path='C:/Users/Public/Downloads')
```

17. If only a specific product is to be downloaded, its UUID can be found within the geometric metadata. The command to download exactly this product is, for example:

```
api.download('b063bb06-1b64-4dc5-9e0f-af5838725d29')
```

18. Run your script with the desired download type.

The entire script then looks like this:

```python
from sentinelsat.sentinel import SentinelAPI, read_geojson, geojson_to_wkt
 from datetime import date


 #connect to the API
 api=SentinelAPI('Username', 'Password','https://scihub.copernicus.eu/dhus')


 #define Area of Interest (AOI)

footprint = geojson_to_wkt(read_geojson('Sunderban.geojson'))


 #set up query to filter data
 products = api.query(footprint,
                      date=("20191101", date(2019, 11, 15)),
                      platformname='Sentinel-2',
                      processinglevel='Level-2A',
                      cloudcoverpercentage=(0, 5))


#getting information about the results
 #getting number of results
 print('Gefundene Produkte: ' + str(api.count(footprint,
                                date=("20191113", date(2019, 11, 15)),
                                platformname='Sentinel-2',
                                processinglevel='Level-2A',
                                cloudcoverpercentage=(0, 5))))


# getting information about product size
 print(str(api.get_products_size(products)) + ' GB')
 # getting geometric metadata from results
 print(api.to_geojson(products))


 #Download
 api.download_all(products, directory_path='C:/Users/Public/Downloads')
 #Download via UUID
 api.download('b063bb06-1b64-4dc5-9e0f-af5838725d29')
```

3.5.2 Opening the data records in SNAP

SNAP is the Sentinel Applications Platform from Copernicus, which can be downloaded and installed free of charge at https://step.esa.int/main/download/snap-download/.

As soon as you have downloaded one or more products, the data can be viewed and processed in the "SNAP" software. In the following, the satellite image will be viewed within SNAP. Further processing steps can be found on the website: https://step.esa.int/main/doc/tutorials/ or in the previous chapters.

1. Open the software SNAP.
2. Select *File è Open Product...* and open the ZIP directory of the data set.
3. Right-click on the data set within the *Product Explorer* and select *Open RGB Image Window*.

Bibliography

Copernicus (Hg.): Copernicus Academy. https://www.copernicus.eu/en/opportunities/education/copernicus-academy

Copernicus (Hg.): Copernicus Programme. https://sentiwiki.copernicus.eu/web/copernicus-programme

Copernicus (Hg.): Die Sentinel-Satellitenfamilie. https://www.d-copernicus.de/daten/satelliten/daten-sentinels/

Geographisches Institut (Hg.): Copernicus4Schools - The great disaster challenge. https://www.geographie.ruhr-uni-bochum.de/izgw/projekte.html.de

NASA (Hg.): Virginia T. Norwood: The Mother of Landsat. https://landsat.gsfc.nasa.gov/article/virginia-t-norwood-the-mother-of-landsat/

Table of figures

Imprint

Authors:
Isabella Holovaciuc, Dr.Henryk Hodam, Claudia Lindner, Lars Tum, Franziska Tuschen

Faculty of Geosciences

Institute of Geography Ruhr-Universität Bochum

Working Group Interdisciplinary Geoinformation Sciences

Universitätsstraße 150

44801 Bochum

Contact

Jun.-Prof. Dr. Andreas Rienow

Telephone: +49 234 32-24791

E-Mail: andreas.rienow@ruhr-uni-bochum.de

Dr. Henryk Hodam

Telephone: +49 (0)234 32-23415

E-Mail: henryk.hodam@ruhr-uni-bochum.de