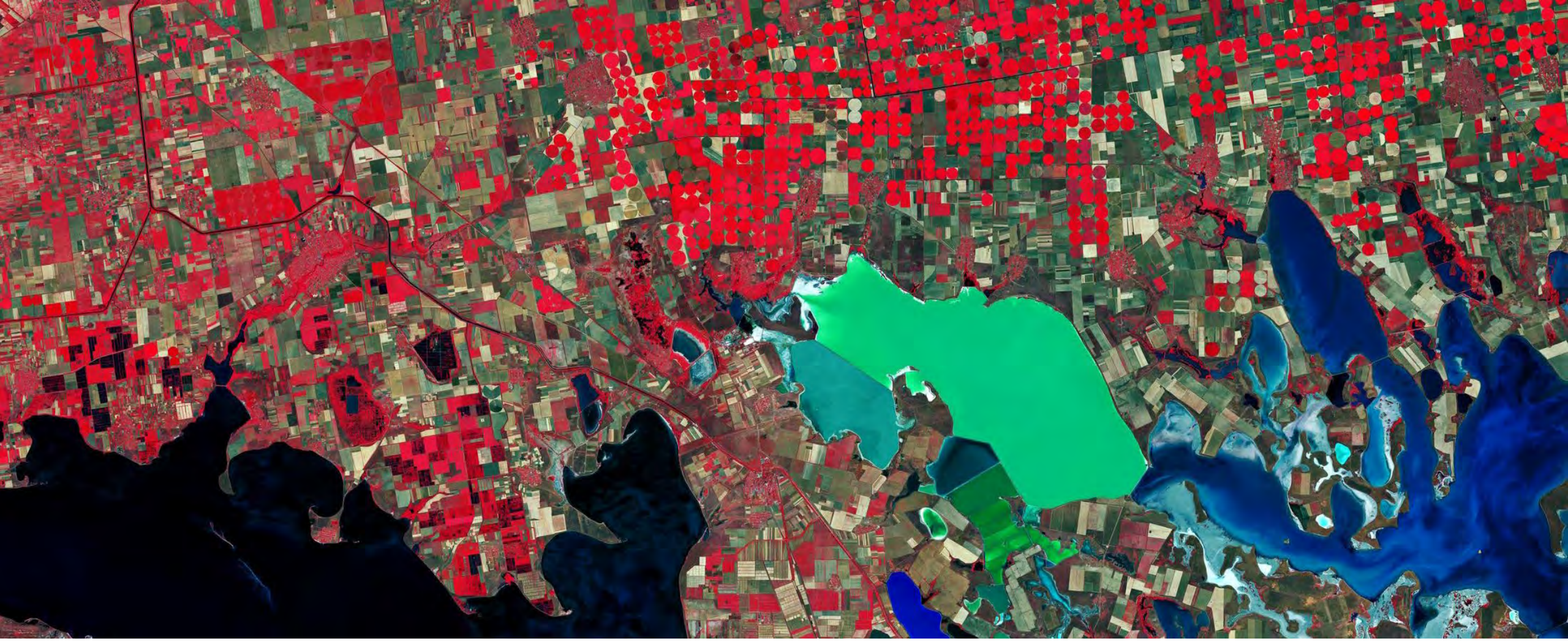


Optical Remote Sensing Refresher and pre-processing of optical time series using SNAP

Fabrizio Ramoino

Training Objectives

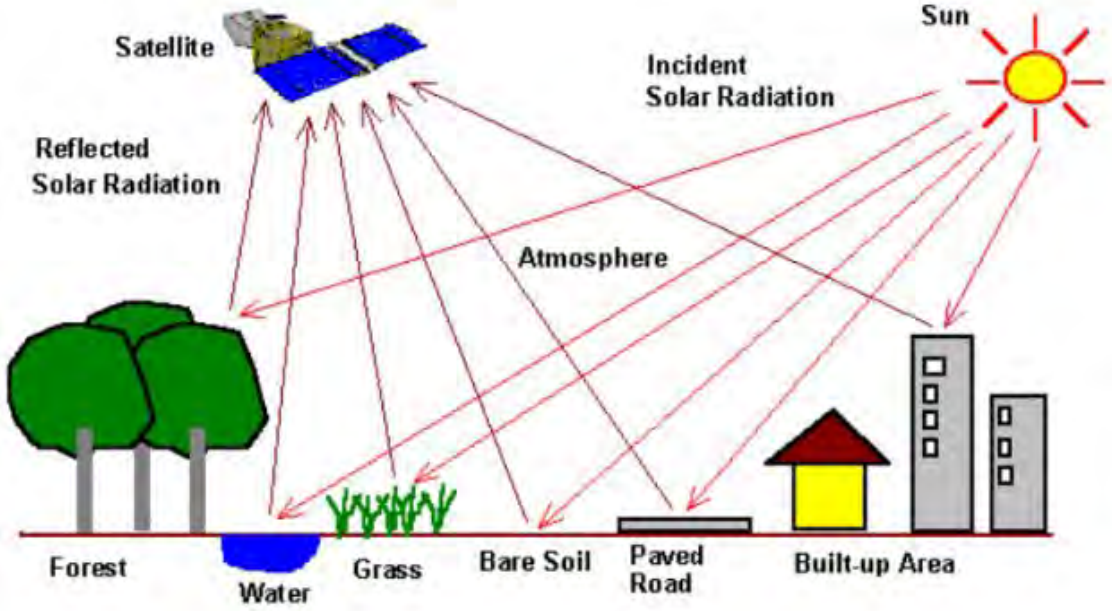
By the end of this training attendees will learn:

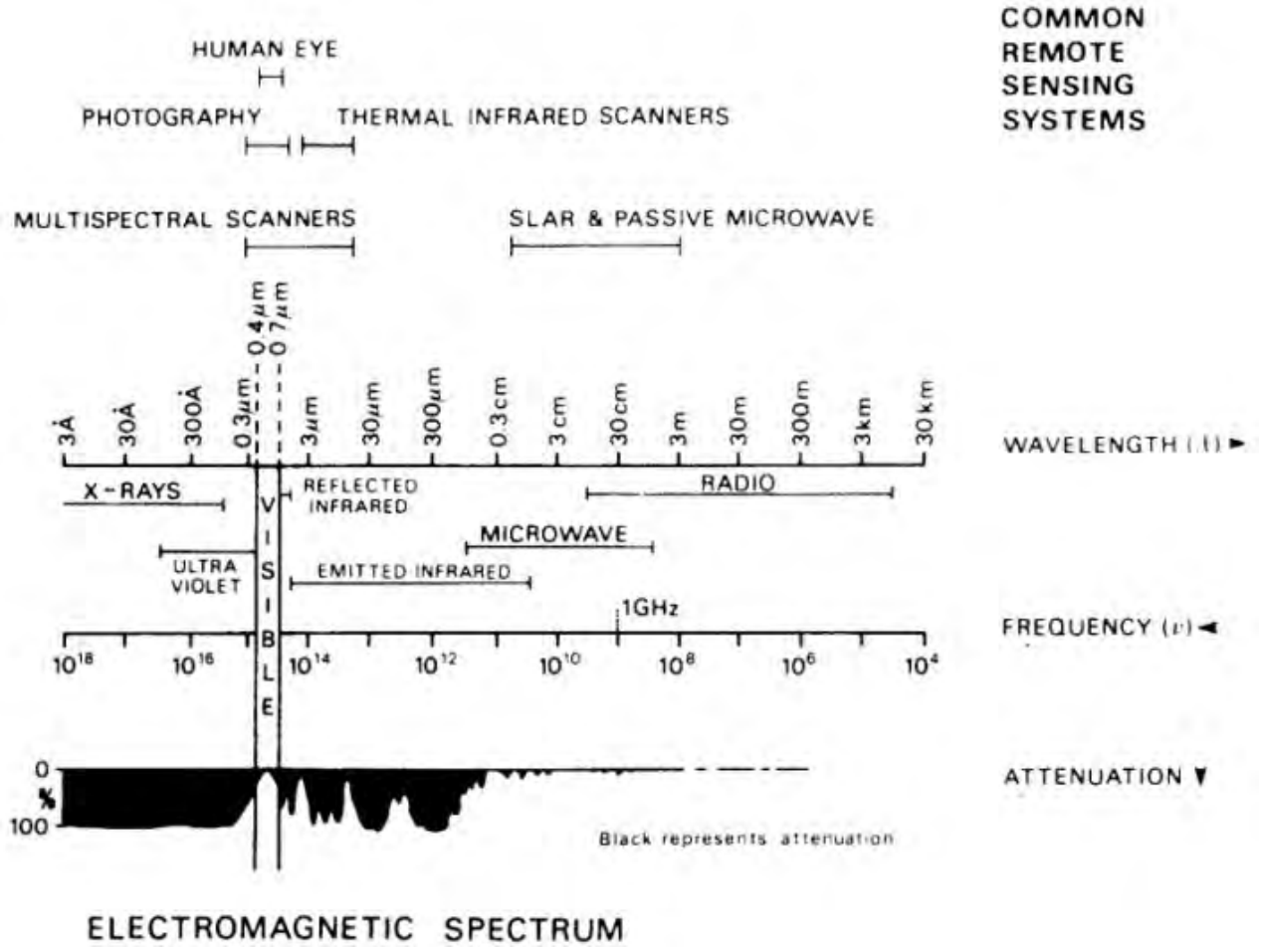
- *The basics of Optical Remote Sensing and the main characteristics of Sentinel-2 data*
- *Basics of radiometric indices and biophisical variables and its usage for agriculture*
- *How to prepare a reflectance time series and retrieve radiometric indices and biophysical variables using SNAP software*
- *How to control the quality of a crop-specific LAI time series*
- *How to detect the crop growth anomalies in a region*
- *How to assess the intra-parcel heterogeneity for different agricultural fields*

Optical Remote Sensing Refresher

Optical Remote Sensing Refresher

- Measure light from blue (~400 nm) to shortwave infrared (SWIR; ~2500 nm).
- Passive sensors where the energy source is the Sun.





Pre-processing of Optical data

Pre-processing chain includes all the steps needed to generates cloud-free surface reflectance products taking as input Top Of Atmosphere data. For each of the module in the pre-processing chain different methods and algorithm can be applied.

- Cloud detection and removal
- Atmospheric correction
- Reprojection
- Resampling
- Co-registration

Cloud detection and removal

A large portion of the earth surface is covered by clouds, consequently, most earth observation images in the visible spectral domain include a significant amount of cloudy pixels.

An image pixel can be:

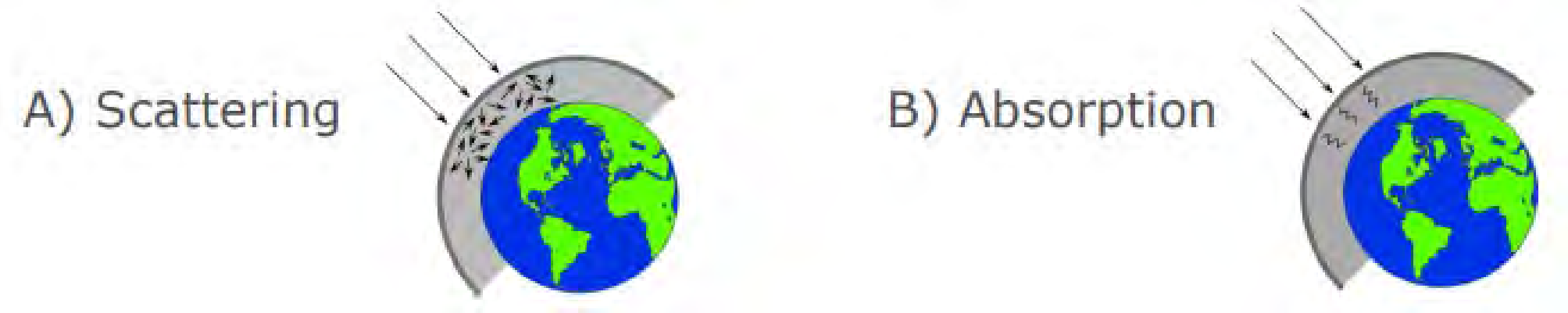
- cloud free (there are no water droplets or ice crystals in the atmosphere which change the surface reflectance)
- partly cloudy (comprises all intermediate situations where the measured reflectance is a mixture of a significant portion of the surface reflectance, but modified due to the presence of a cloud)
- totally cloudy (the optical thickness is so high that the portion of surface reflectance at the signal measured by the satellite is negligible)

Cloud detection methods can be categorized in the following classes [Brockmann et al., 2008]:

- Spectral threshold methods (spectral characteristics, such as temperature, brightness, whiteness or height of the scatterer are tested against a threshold value)
- Feature extraction and classification (the spectral data space, if transformed into a feature space, can be statically or dynamically separated into cloud or clear classes)
- Learning algorithms (cloud probability or cloudiness index values are generated after training the algorithm with simulated or measured data)
- Multi-temporal analysis (Pixels are not always cloud covered and a time series of data is used to separate cloudy from clear cases)
- Multi-sensor approach (where multiple sensors are on the same platform and perform simultaneous measurements, the synergetic algorithms can be used to better identify clouds)

Interactions with the Atmosphere

- Before radiation used for remote sensing reaches the Earth's surface it has to travel through some distance of the Earth's atmosphere
- Particles and gases in the atmosphere can affect the incoming light and radiation:



Scattering occurs when particles or large gas molecules present in the atmosphere interact with and cause the electromagnetic radiation to be redirected from its original path.

Absorption causes molecules in the atmosphere to absorb energy at various wavelengths.

Retrieval of Surface Reflectance

For further analysis we want to use a surface reflectance product

1) Allows comparison between images
2) Allows repeatable measurements (e.g., ground spectra comparison to satellite observations)
3) Represents a known physical unit.

To retrieve surface reflectance we need to ‘add back’ the component ‘lost’ in the atmosphere.

At Sensor Refl = Surface Refl + Atmospheric Refl

What is in the atmosphere?

Aerosols

E.g., fine dust, sea salt, water droplets, smoke, pollen, spores, bacteria.

Has a significant effect on the visible wavelengths (Blue, Green and Red).

Aerosol Optical Depth (AOD)

Aerosol Optical Thickness (AOT)

Water Vapour

Particularly, effects the SWIR bands

Reprojection, resampling and co-registration

Reprojection

If the input of the time series come from several sources with different CRS the reprojection to a common CRS is needed.

Resampling

Data coming from different sources could have different spatial resolution, therefore in this case before to analyse the time series a resampling is necessary.

Nearest Neighbour:

- Pros: Very simple and fast; No new values are calculated by interpolation
- Cons: Some pixels get lost and others are duplicated; Loss of sharpness

Bi-linear interpolation:

- Pros: Extremas are balanced; Image losses sharpness compared to Nearest Neighbour
- Cons: Less contrast compared to Nearest Neighbour; New values are calculated which are not present in the input product

Cubic convolution:

- Pros: Extremas are balanced; Image is sharper compared to Bi-linear Interpolation
- Cons: Slow and less contrast compared to NN; New values are calculated which are not present in the input product

Co-registration

In order to maximise the geolocation accuracy in time series analysis, even if the input data come from the same satellite/constellation, the co-registration is need especially if you work with VHR and HR data.

Why use time series

- A time series is defined as a set of satellite images taken over the same area of interest at different times

- It makes use of different satellite sources to obtain a larger data series with short time interval between two images

- Time Series of Satellite observations offer opportunities:
    - o for understanding how Earth is changing
    - o for determining the causes of these changes
    - o for predicting future changes

Remotely sensed data, combined with information from ecosystem models, offers an opportunity for predicting and understanding the behaviour of the Earth's ecosystem.

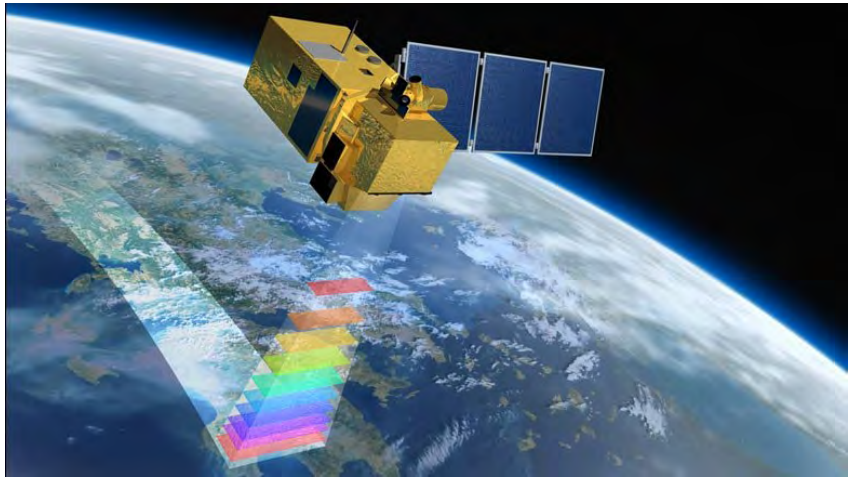
Temporal components integrated with spectral and spatial dimensions allows the identification of complex patterns concerning applications connected with environmental monitoring and analysis of land-cover dynamics.

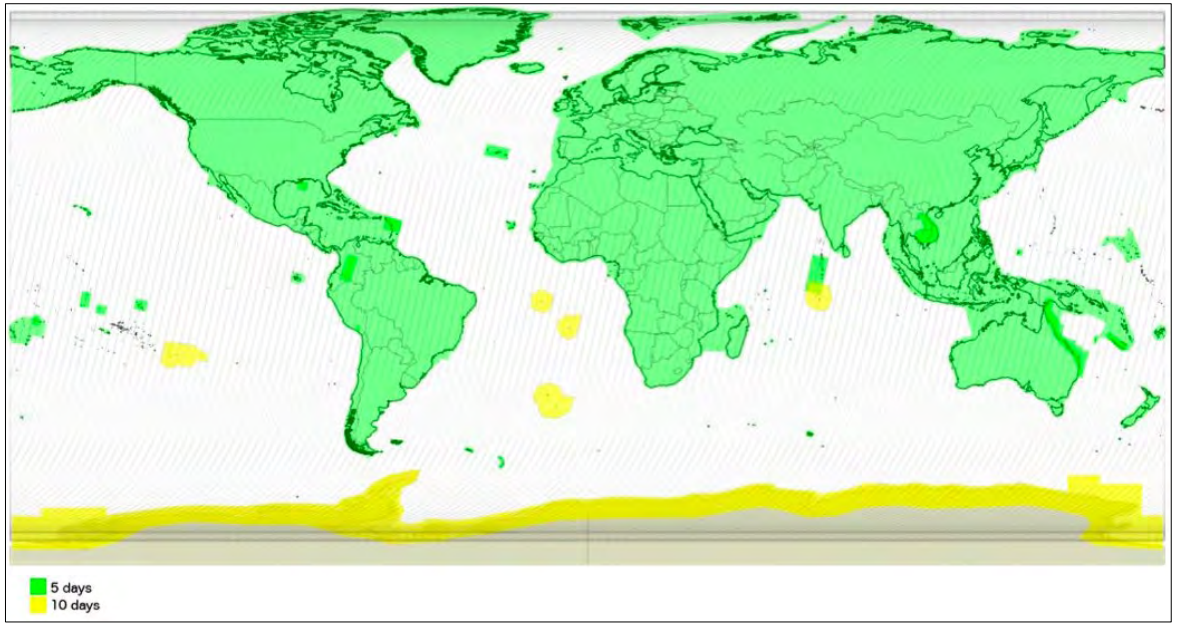
Sentinel-2 characteristics

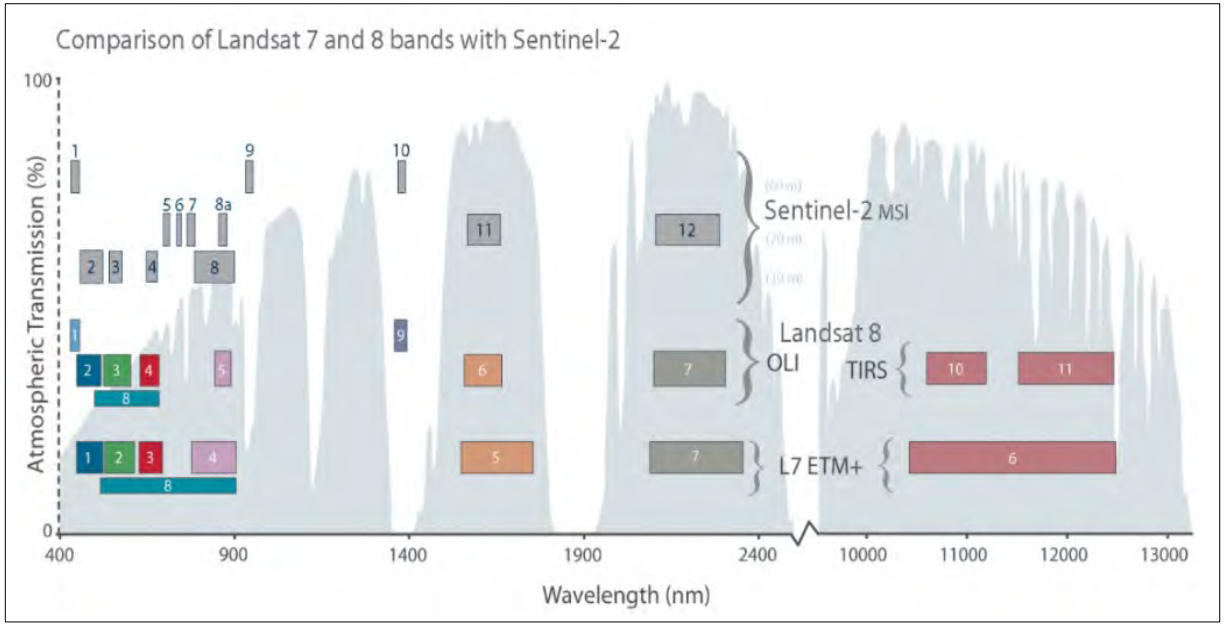
Optical mission for the monitoring of land and coastal regions

Main features:

→ *Constellation of two satellites (Sentinel-2A and Sentinel-2B)*
→ *Multi-Spectral Instrument (MSI)*
→ *Polar, sun-synchronous orbit at 786km and LTDN 10h30*
→ *10 days repeat cycle (5 days with both Sentinels 2A and 2B operational)*
→ *Swath of 290km*





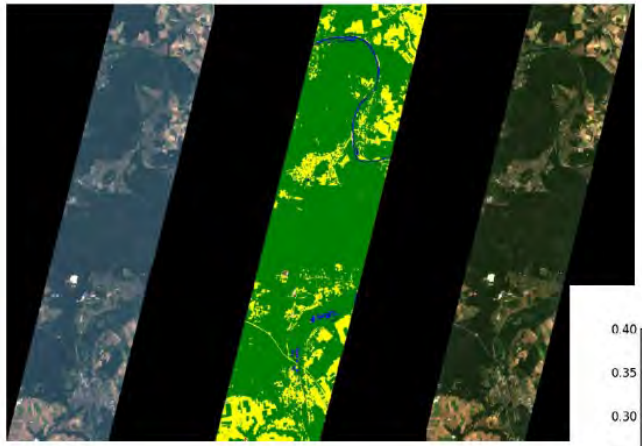


Sentinel-2 products

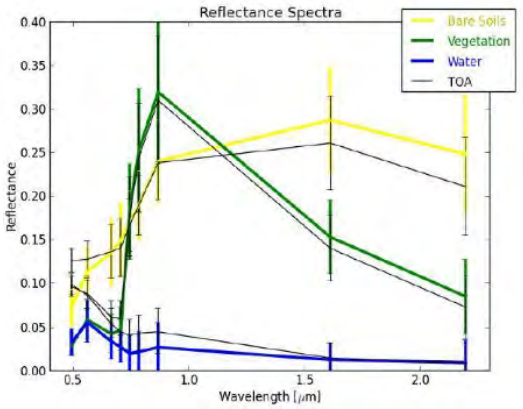
SENTINEL-2 products available for users (either generated by the ground segment or by the SNAP) are:

Level-1C
- *Top-Of-Atmosphere reflectances in cartographic geometry*
- *Systematic generation and online distribution*
- *~600MB (each 100km x 100km)*

Level-2A
- *Bottom-Of-Atmosphere reflectances in cartographic geometry*
- *Systematic and on-User side (using SNAP)*
- *~600MB (each 100km x 100km)*



Site: Fontainebleau, France



Products are a compilation of elementary granules of fixed size, along with a single orbit. A granule is the minimum indivisible partition of a product (containing all possible spectral bands).

For Level-1C and Level-2A, the granules, also called tiles, are 100x100 km^2 ortho-images in UTM/WGS84 projection.

Sentinel-2 L2A data overview

Sen2Cor is the Atmospheric Correction processor used in the ESA Payload Data Ground Segment to generate S2 L2A data and it is distributed via STEP to be used as SNAP plug-in or via command line.

- ✓ Bottom-of-atmosphere (BOA) reflectances in cartographic geometry (UTM/WGS84)
- ✓ Products additionally include:
  - Scene Classification Map
  - Water Vapor Map
  - Aerosols Optical Thickness Map
- ✓ Algorithm includes:
  - Cloud and cloud shadow detection
  - Cirrus detection and correction
  - Slope effect correction
  - BRDF effect correction

Beyond Sen2Cor, Sentinel-2 data can be atmospherically corrected using others processors depending from your application:

MAJA (developed jointly by CESBIO/CNES and DLR

LaSRC (developed by NASA GSFC/USA)

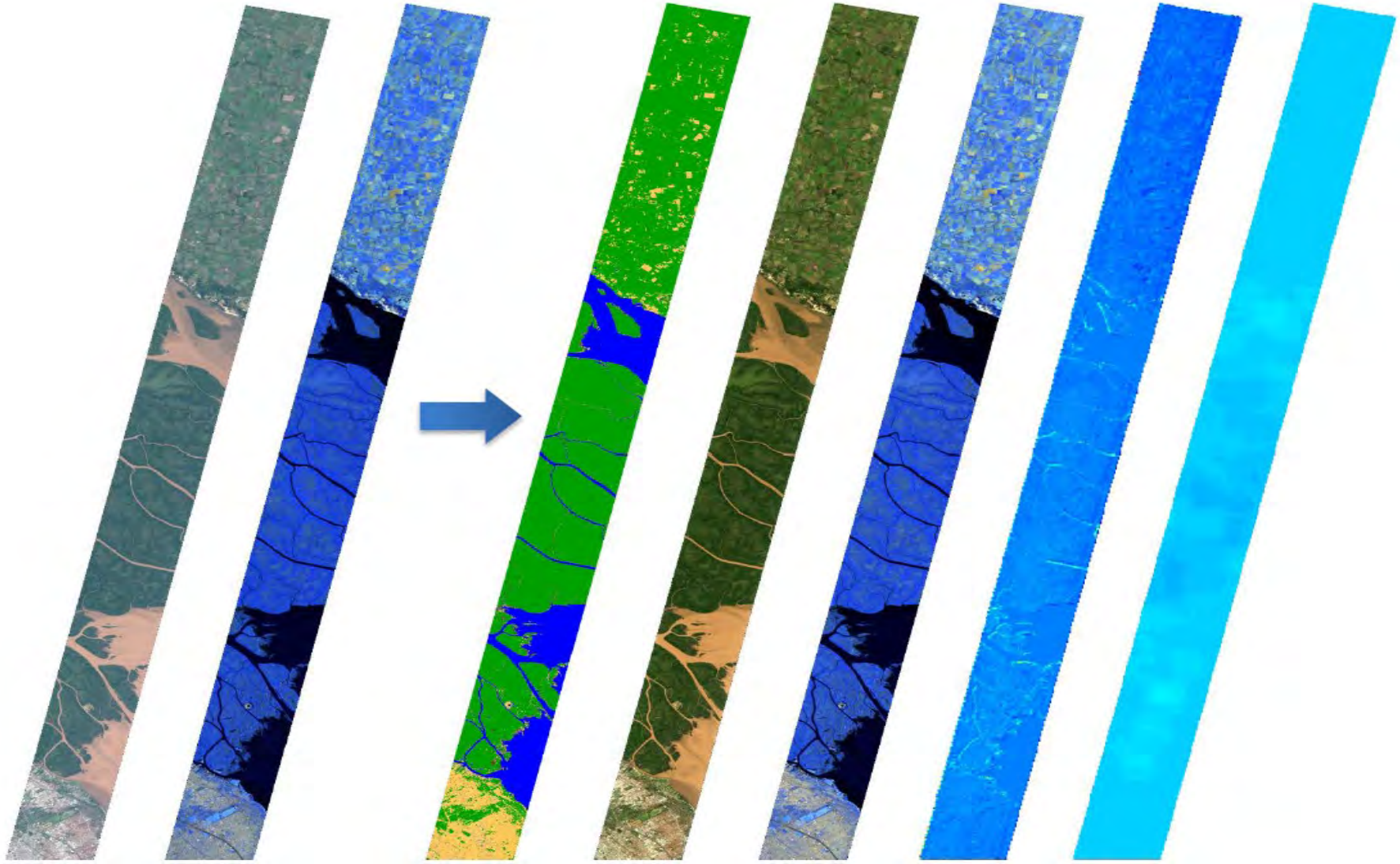
i-COR (developed by VITO)

CorA (developed by Brockmann Consult)

……

Sentinel-2 L2A data overview

From left to right:



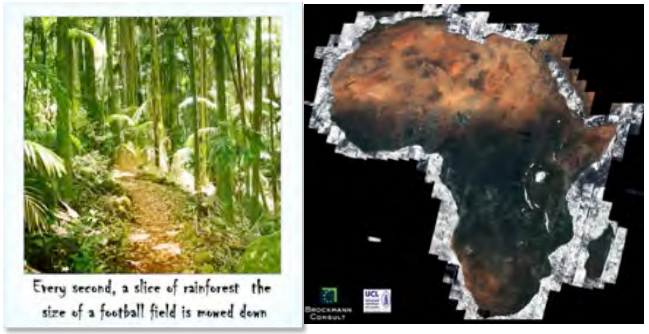
Level-1C [TOA]

- *[RGB] B4-B3-B2*
- *[RGB] B12-B11-B8a*

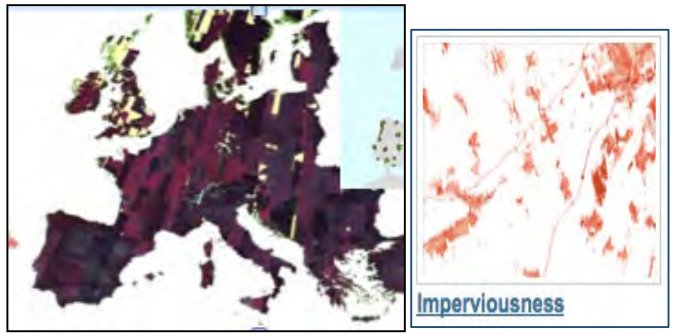
Level-2A [BOA]

- *Scene Classification*
- *[RGB] B4-B3-B2*
- *[RGB] B12-B11-B8a*
- *Water Vapour*
- *Aerosols Optical Thickness*

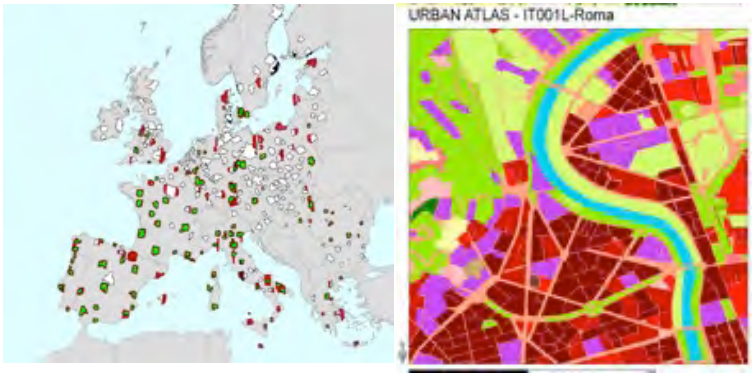
Sentinel-2 applications



Agriculture, Forests & Carbon, Vegetation monitoring

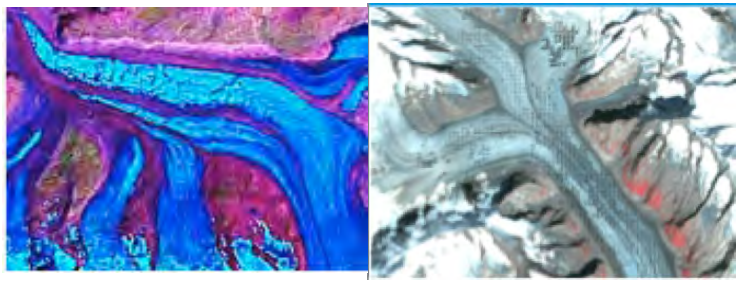


Land cover classification, high resolution layers & change.



Regional to Urban Applications

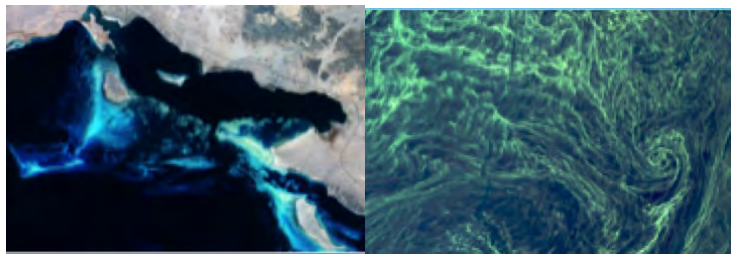
Emergency management



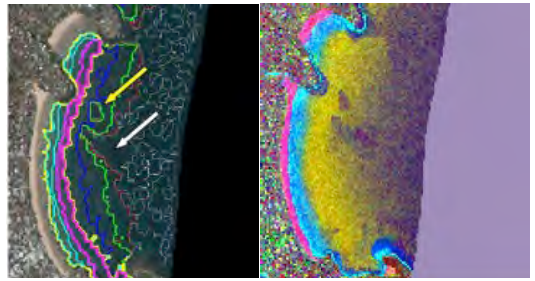
Glaciers & Ice

Global Land use & change

Geology



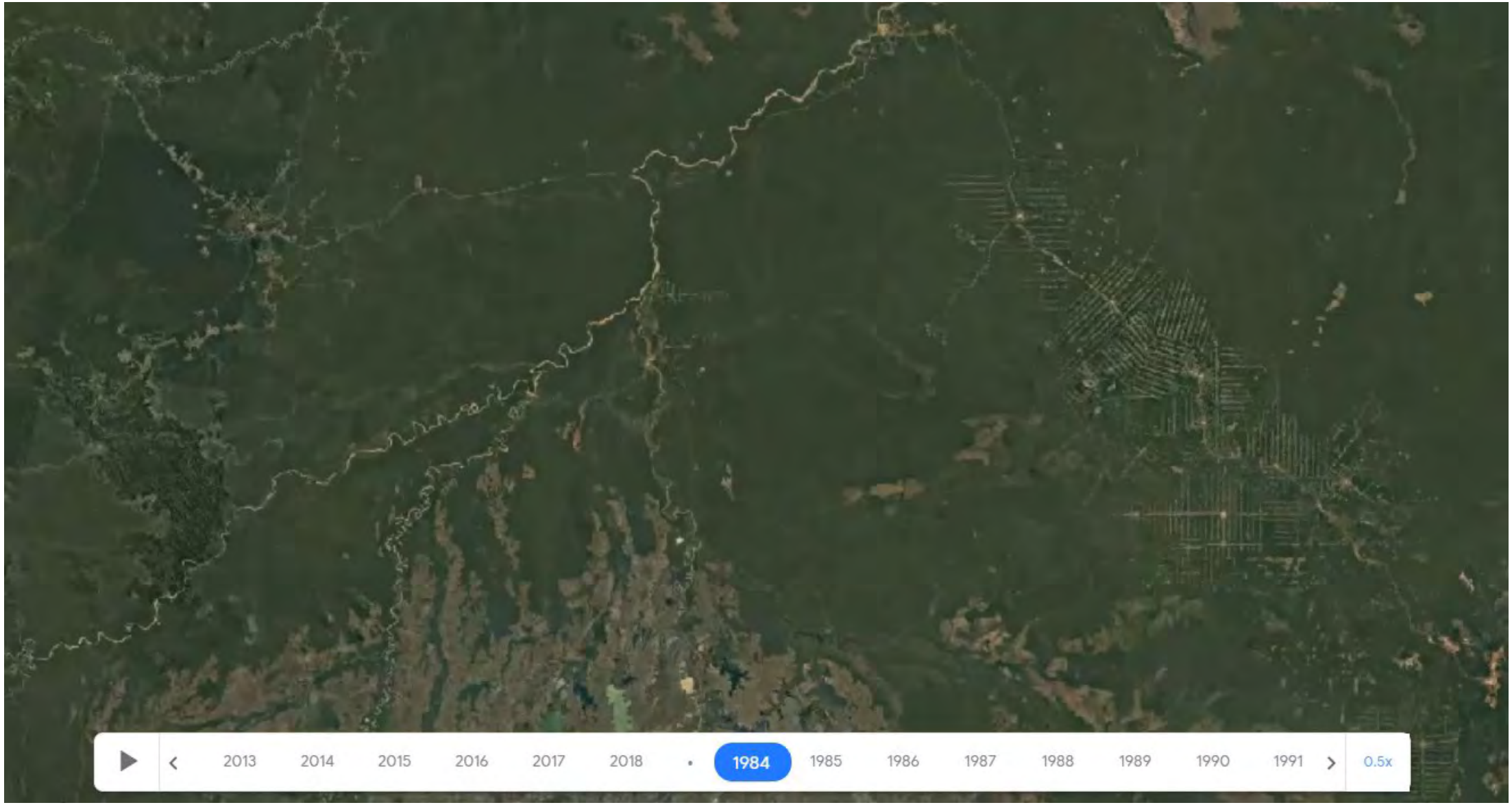
Water quality



Coastal zones/bathymetry

Theewaterskloof Dam change by S2 time series

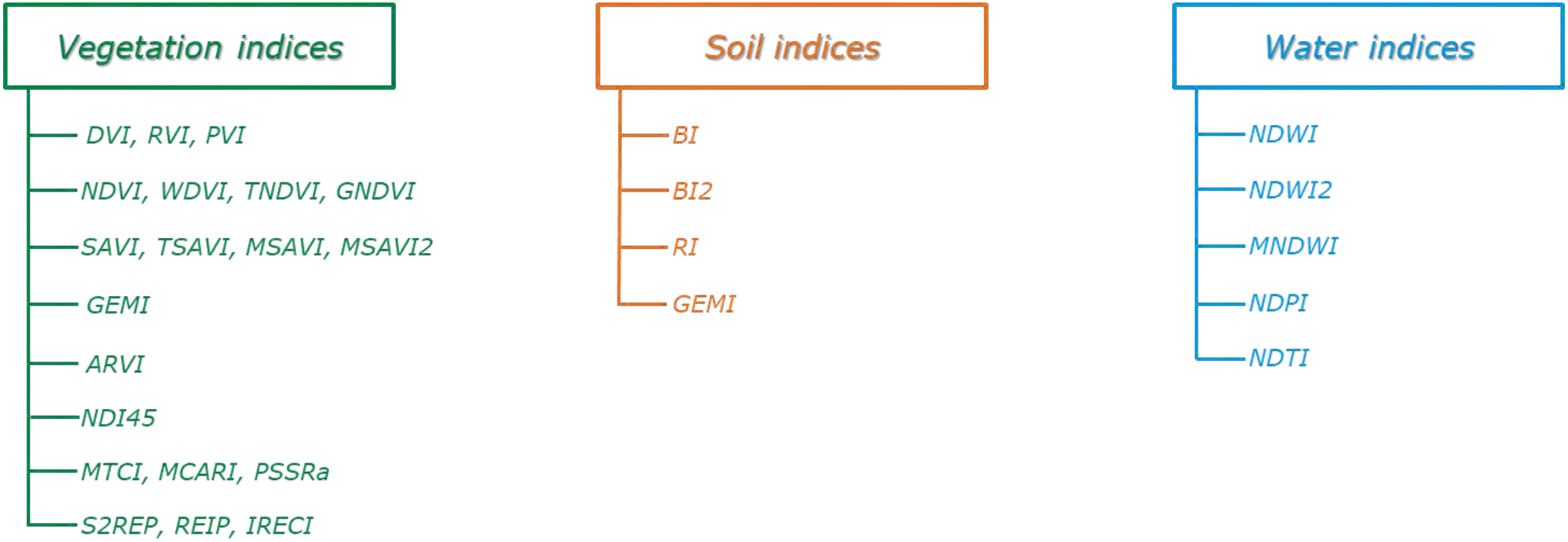
Rondônia deforestation by Landsat time series



Retrieval of crop specific LAI time series from Sentinel-2 using SNAP software

Radiometric Indices

Radiometric indices are quantitative measures of features that are obtained by combining several spectral bands

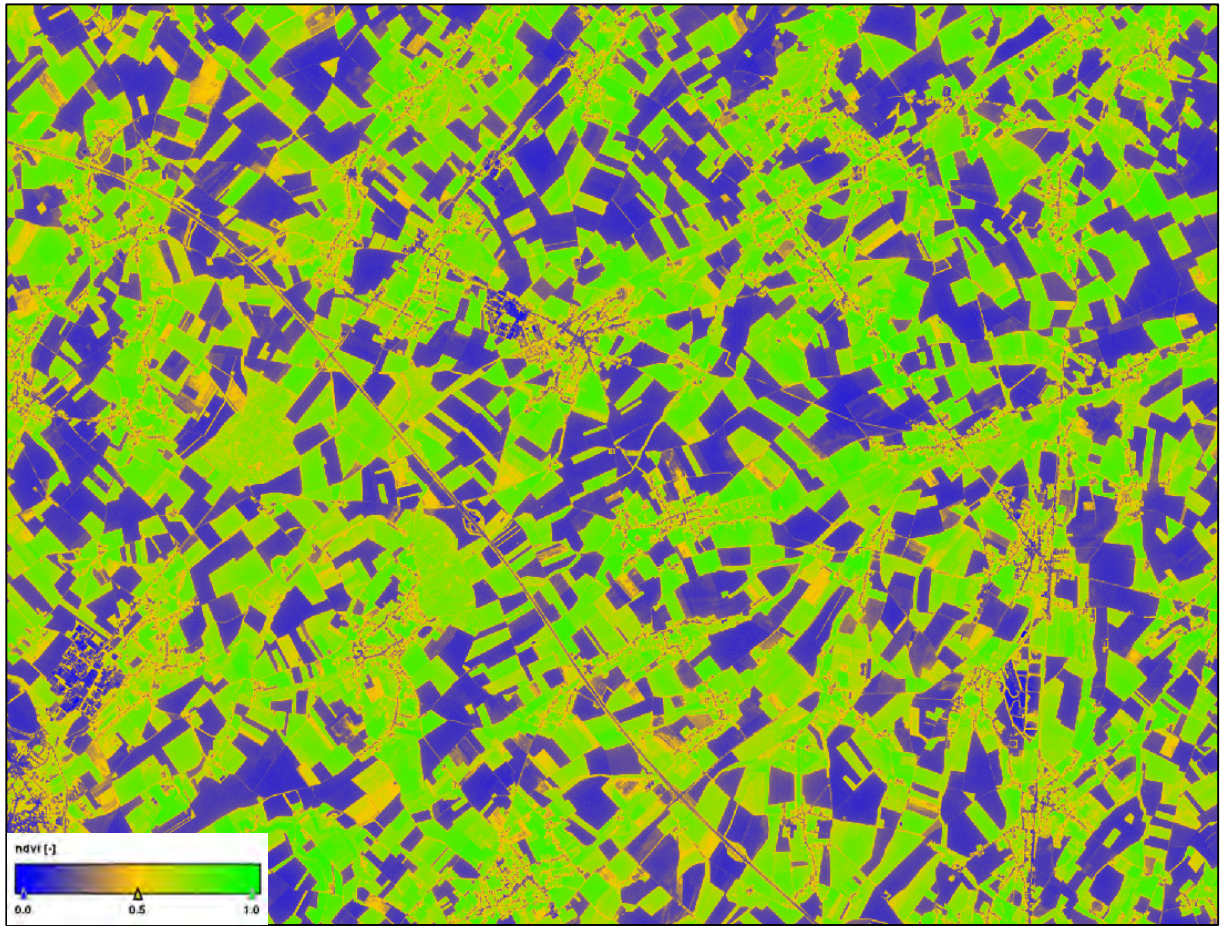


Radiometric Indices (e.g. NDVI)

The Normalized Difference Vegetation Index (NDVI) algorithm exploits the strength and the vitality of the vegetation on the earth's surface.
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.

$$\frac{(NIR - Red)}{(NIR + Red)}$$

$$\frac{(B8 - B4)}{(B8 + B4)}$$

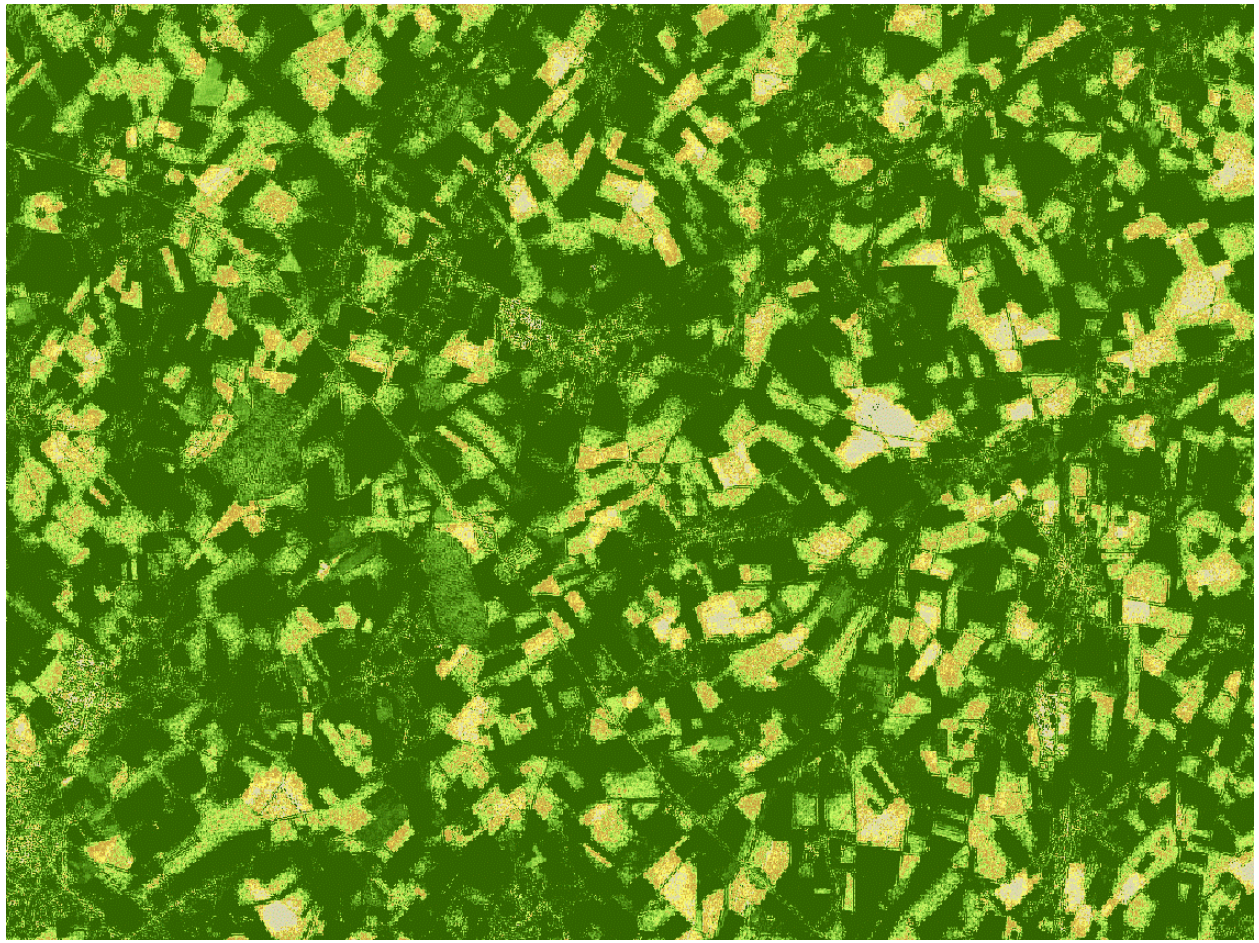


Radiometric Indices (e.g. S2REP)

The **S**entinel-**2** **R**ed-**E**dge **P**osition Index algorithm is based on linear interpolation, as presented by Guyot and Baret (1988).
S2REP is sensitive to both crop (chlorophyll content) nitrogen content and growth status. Generally, the higher the S2REP value, the higher is the chlorophyll content.

$$705 + 35 \times \frac{\frac{(Red + NIR)}{2} - Red_2}{(Red_3 - Red_2)}$$

$$705 + 35 \times \frac{\frac{(B4 + B7)}{2} - B5}{(B6 - B5)}$$



Biophysical Variables

More physical variables of the canopy like the leaf area index, the fraction of vegetation cover, and the fraction of radiation absorbed for the photosynthesis, respectively quantify the density, the extent and the health of the vegetation. These biophysical products are useful for a wide range of thematic areas such as the global crop monitoring and the food security applications; forest, water, and natural resources management; land carbon modelling, and weather and climate forecasting.

- **LAI** - Leaf Area Index

  The Leaf Area Index is defined as half the total area of green elements of the canopy per unit horizontal ground area. The satellite-derived value corresponds to the total green LAI of all the canopy layers, including the understory which may represent a very significant contribution, particularly for forests. Practically, the LAI quantifies the thickness of the vegetation cover.

- **FAPAR** - Fraction of Absorbed Photosynthetically Active Radiation

  The FAPAR quantifies the fraction of the solar radiation absorbed by live leaves for the photosynthesis activity. Then, it refers only to the green and alive elements of the canopy. The FAPAR depends on the canopy structure, vegetation element optical properties, atmospheric conditions, and angular configuration.

- **FVC** - Fraction of Vegetation Cover

  The Fraction of Vegetation Cover (FCover) corresponds to the fraction of ground covered by green vegetation. Practically, it quantifies the spatial extent of the vegetation. Because it is independent from the illumination direction and it is sensitive to the vegetation amount, FCover is a very good candidate for the replacement of classical vegetation indices for the monitoring of ecosystems.

- **Cab** - Chlorophyll content in the leaf

  The chlorophyll content is a very good indicator of stresses including nitrogen deficiencies. It is strongly related to leaf nitrogen content (Houlès et al. 2001). This quantity can be calculated both at the leaf level and at the canopy level by multiplication of the leaf level chlorophyll content by the leaf area index.

- **CWC** - Canopy Water Content

  CWC is defined as the mass of water per unit ground area (g.m-2). One of the difficulties in retrieving this variable is the possible confusion with soil moisture effects.

Biophysical Variables of interest for agriculture

Crop processes	LAI	FAPAR	FCOVER	Albedo	Chlorophyll	Water-content	SLA	soil brightness	Temperature
Photosynthesis	+++	+++			+++		++		
Evapotranspiration	++	+++	+++	++		++			+++
Respiration	++								
Nitrogen	+++				+++				
Phenology	+++	++	++						
Lodging									
Impact of pests	+++								
Soil permanent charac.								+++	
Residues									

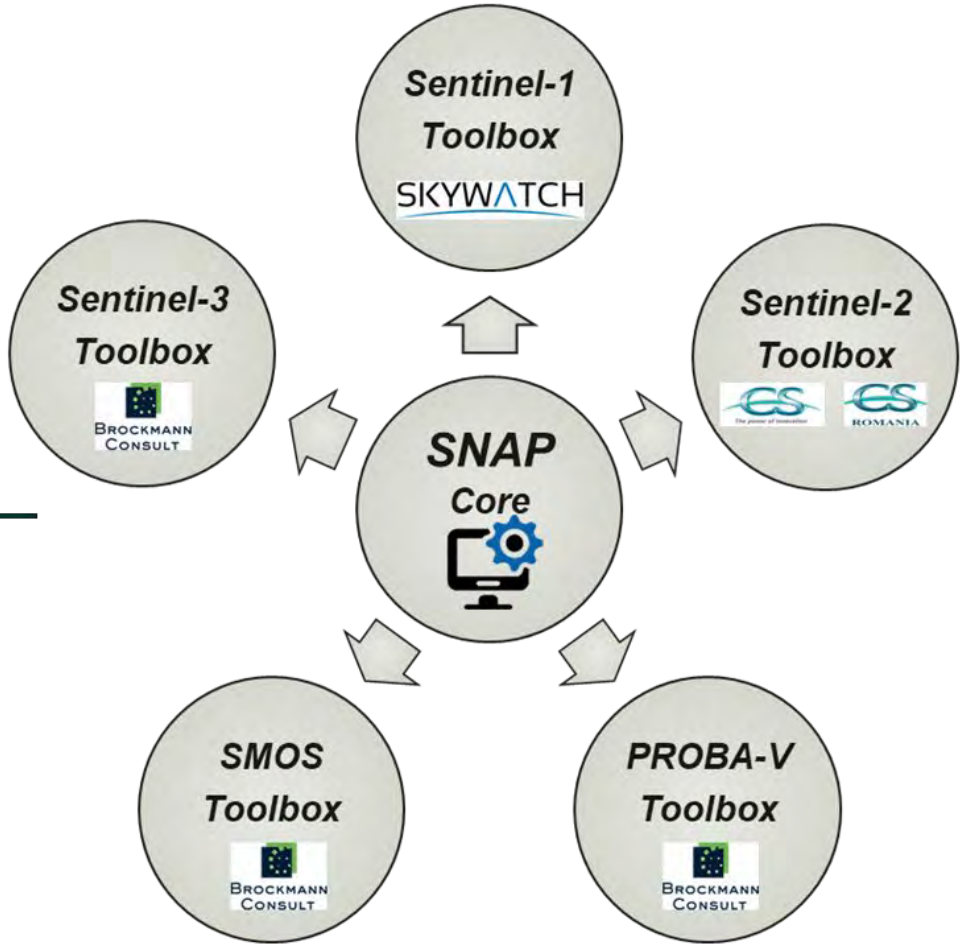
'Concepts and methods for LAI/fCover/fAPAR/Chlorophyll retrieval' – Marie Weiss [INRA]

Introduction to data processing with SNAP

SNAP – SentiNel Application Platform

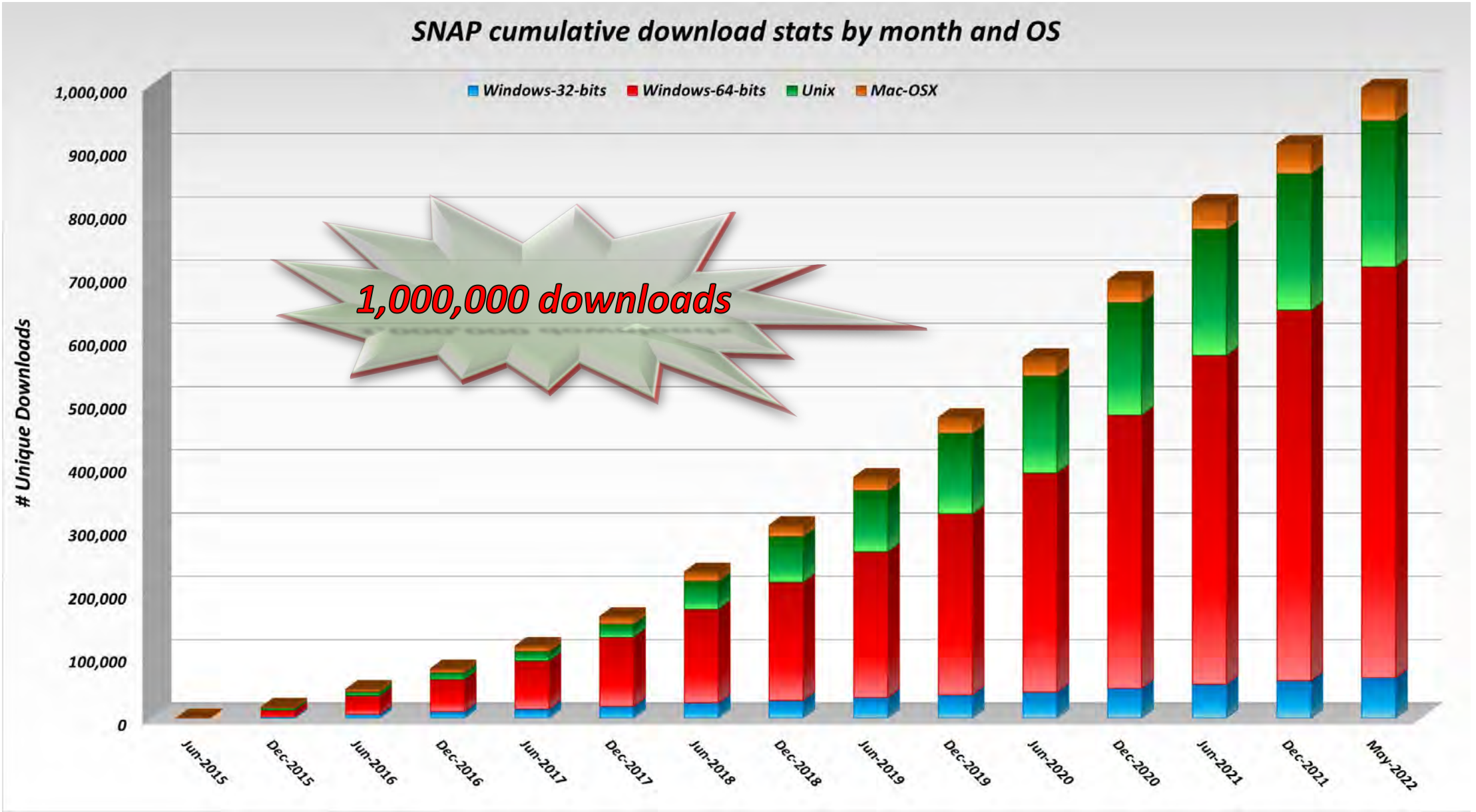
Download it at

step.esa.int



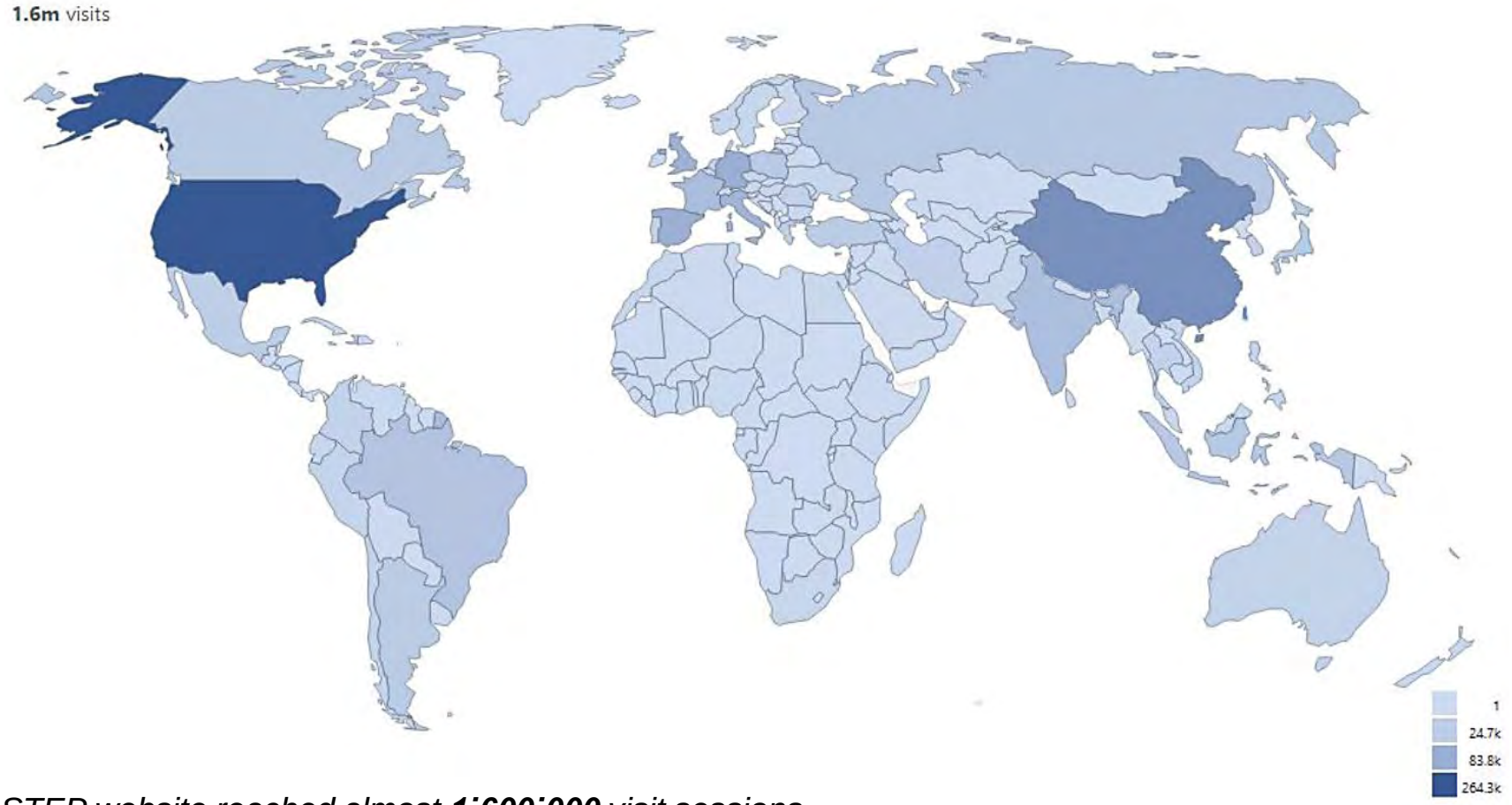
- *Free and open source software*
- *Common Java core framework*
- *Joint development of SNAP platform for Sentinel and other toolboxes*
- *Interchangeable Java/Python plugins*
- *Portable engine to Cloud infrastructure*
- *User friendly: single installation, intuitive GUI, online help, tutorials*
- *Active user forum to communicate with the developers and within the science community*

SNAP – SentiNel Application Platform



STEP – Scientific Toolbox Exploitation Platform

STEP is the ESA community platform for accessing the software and its documentation, communicating with the developers, dialoguing within the science community, promoting results and achievements as well as providing tutorials and material for training scientists using the Toolboxes.



STEP Forum

- ✓ *Since June 2015 STEP website reached almost **1˙600˙000** visit sessions*
- ✓ ***11˙632** discussion topics have been created, with a total of **79˙893** posts since 15/06/2015*

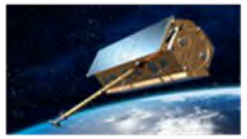
SNAP & SAR

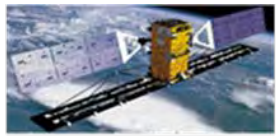
(Sentinel-1 Toolbox)

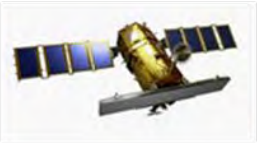

Sentinel-1


ENVISAT


ERS-1

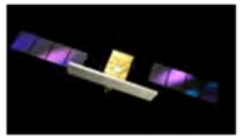

TerraSAR-X


RADARSAT


KOMPSAT-5


ALOS 1&2


ICEYE

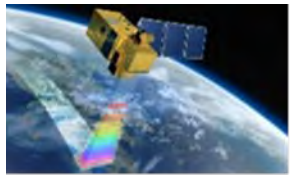

COSMO-SkyMed

Main features

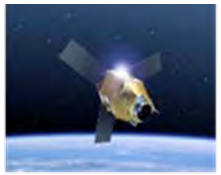
- *Absolute calibration, Multilooking, Speckle filtering, Precise orbits handling*
- *Coregistration of detected and complex products*
- *Full support of Sentinel-1 TOPS interferometry, debursting, slice assembly*
- *Terrain Correction*
- *SAR simulation and Layover and shadow masks*
- *Applications: oil spill detection, ship detection, wind field estimation etc.*
- *Fully integrated and featured InSAR tools for Stripmap and Zero-Doppler focused data*
- *Compatibility with PolSARpro Toolbox (Reader, Writer)*
- *Integrated Export to SNAPHU (interferometric phase unwrapping) and STAMPS (PS InSAR)*

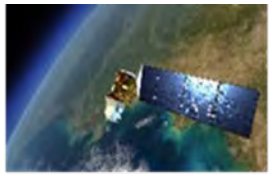
SNAP & Optical HR

(Sentinel-2 Toolbox)


Sentinel-2


SPOT


Pleiades


Landsat


ALOS AVNIR


RapidEye


Kompsat


Ikonos


Worldview

.....

Main features

Sen2Cor and i-Cor for Atmospheric Correction

L2B biophysical processor (LAI, fAPAR, …)

Reflectance to Radiance Processor

Radiometric Indices

Vegetation indices: DVI, RVI, PVI, IPVI, WDVI, TNDVI, GNDVI, GEMI, ARVI, NDI45, MTCI, MCARI, REIP, S2REP, IRECI, PSSRa

Soil indices: SAVI, TSAVI, MSAVI, MSAVI2, BI, BI2, RI, CI

Water indices: NDWI, NDWI2, MNDWI, NDPI, NDTI

IdePix Processor: pixel classification

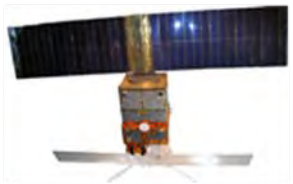
OTB tools: Pansharpening, Rasterization, Segmentation, …

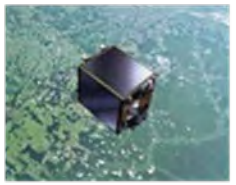
SNAP & Optical/Thermal MR

(Sentinel-3 Toolbox)

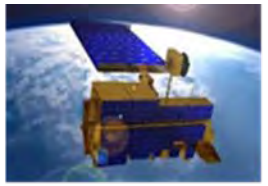

Sentinel-3


ENVISAT


ERS


Proba-V


SPOT VGT


MODIS


AVHRR


VIIRS

.....

Main features	
	Visualizing spectrum of pixels
	Uncertainty visualization and propagation of uncertainty in BandMaths
	Pixel extraction tool
	Specific sensor processors: *S3 OLCI Radiometry, S3 SLSTR PDU stitching* *AATSR/SLSTR Regridding* *Performs radiometric corrections on MERIS*
	Optical water type classification based on atmospherically corrected reflectances
	FU (Forel-Ule) Classification used to derive the hue angle and FU value
	IdePix Processor: pixel classification
	FLH (Fluorescence Line Height) / MCI (Maximum Chlorophyll Index) retrieval
	Case-2 C2RCC water processor
	MERIS FUB-CSIRO Coastal Water Processor

SNAP 9

New Features

SNAP features	*Introducing new ZNAP data format* *Smaller footprint on disk, faster writing, and it uses a single file or directory; It is Zarr based and can easily be read with Python/Xarray*
	Support for the high-resolution Copernicus DEM
	Improved Colour Manipulation Tool, e.g., auto-applied colour schemes based on band-name
S1TBX features	*S1 ARD functionality enhanced with the addition of a Noise Power Image and Gamma-to-Sigma ratio image*
	Support for SAR missions Cosmo-Skymed SG, Gaofen-3 and Spacety
S2TBX features	*Added new plugins adapter for MAJA and Sen2Cor tools*
	Support for Landsat processed by ESA and Landsat L2
	Added windowed reading of products in Graph Builder
S3TBX features	*New pre-processing operators for Sentinel-3 data. The OLCI Anomaly Detection operator, and operator for harmonising OLCI A and B data*
	OLCI L2 Land and Water products contain masks recommended by the QWG

Useful links

- **SNAP download**
  http://step.esa.int/main/download/snap-download/
- **STEP website**
  http://step.esa.int/main/
- **SNAP user forum**
  https://forum.step.esa.int/
- **Copernicus Open Access Hub (download Sentinel data)**
  https://scihub.copernicus.eu/
- **‘Advanced training course on Land remote sensing with the focus on Agriculture’ held in Louvain-la-Neuve, Belgium, on 16-20 September 2019**
  https://eo4society.esa.int/resources/advanced-training-course-on-land-remote-sensing-with-the-focus-on-agriculture/
- **‘Concepts and methods for LAI/fCover/fAPAR/Chlorophyll retrieval’ – Marie Weiss [INRA]**
  http://landtraining2019.esa.int/files/06_9thLTC2019__BioVarRetrieval_Weiss.pdf

Sentinel-2 practical summary

Resampling

The S2 products are multi-size

- *B2, B3, B4 and B8 @ 10m*
- *B5, B6, B7, B8A, B11 and B12 @ 20m*
- *B1, B9 and B10 @ 60m*

Needed if the user wants to combine bands with different spatial resolution

Reprojection

If the input of the time series come from several sources with different CRS or if the user wants to export the product in KMZ the reprojection to a common CRS is needed

Subset (spatially/spectrally)

The S2 data are distributed in tiles 100x100 km^2 ortho-images in UTM/WGS84 projection.

Needed if the AOI covers a portion of the S2 scene or if only a subset of bands are useful in the next step (this will reduce the computation time)

How to retrieve Radiometric Indices and Biophysical Variables using ESA SNAP software

GraphBuilder

The Graph Builder allows the user to assemble graphs from a list of available operators and connect operator nodes to their sources.

Batch processing

The Batch Processing tool allows you to execute a single reader/writer graph for a set of products.


Thank You!