Agricultural Crop Classification with Synthetic Aperture Radar and Optical Remote Sensing

Part 2: Optical Remote Sensing Refresher and Introduction to SNAP

Fabrizio Ramoino & Magdalena Fitrzyk - October 7, 2021

Training Format

- Five 2.5-hour sessions including presentations and question and answer sessions
- The same content will be presented at two different times each day.
- Session A will be presented in **English.**
- Session B will be presented in **Spanish.**
  - Session A: 10:00-12:30 EST (UTC-4)
  - Session B: 13:00-15:30 EST (UTC-4)

- Training materials and recordings will be available from:

  https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and

Homework and Certificate

- Homework Assignment:
  - Answers must be submitted via Google Form
  - Due Date: November 2, 2021
- A certificate of completion will be awarded to those who:
  - Attend all live webinars
  - Complete the homework assignment by the deadline (access from website)
  - You will receive a certificate approximately two months after the completion of the course from: marines.martins@ssaihq.com

Training Outline

October 5, 2021

Synthetic Aperture Radar (SAR) Refresher

October 7, 2021

Optical Remote Sensing Refresher and Introduction to SNAP

October 12, 2021

Operational Crop Classification Roadmap using Optical and SAR Imagery (Part 1)

October 14, 2021

Operational Crop Classification Roadmap using Optical and SAR Imagery (Part 2)

October 19, 2021

Biophysical Variable Retrieval using Optical Imagery to Support Agricultural Monitoring Practices

Training Objectives

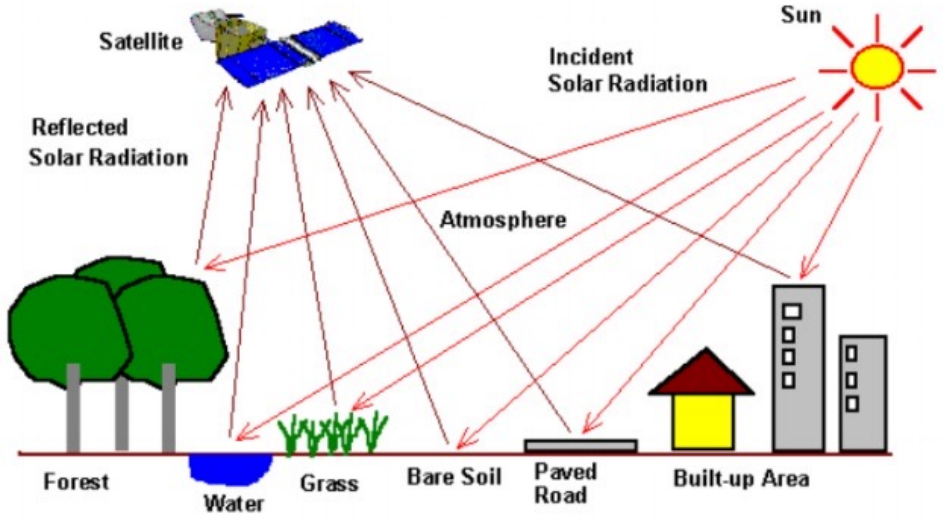
By the end of this training attendees will learn:

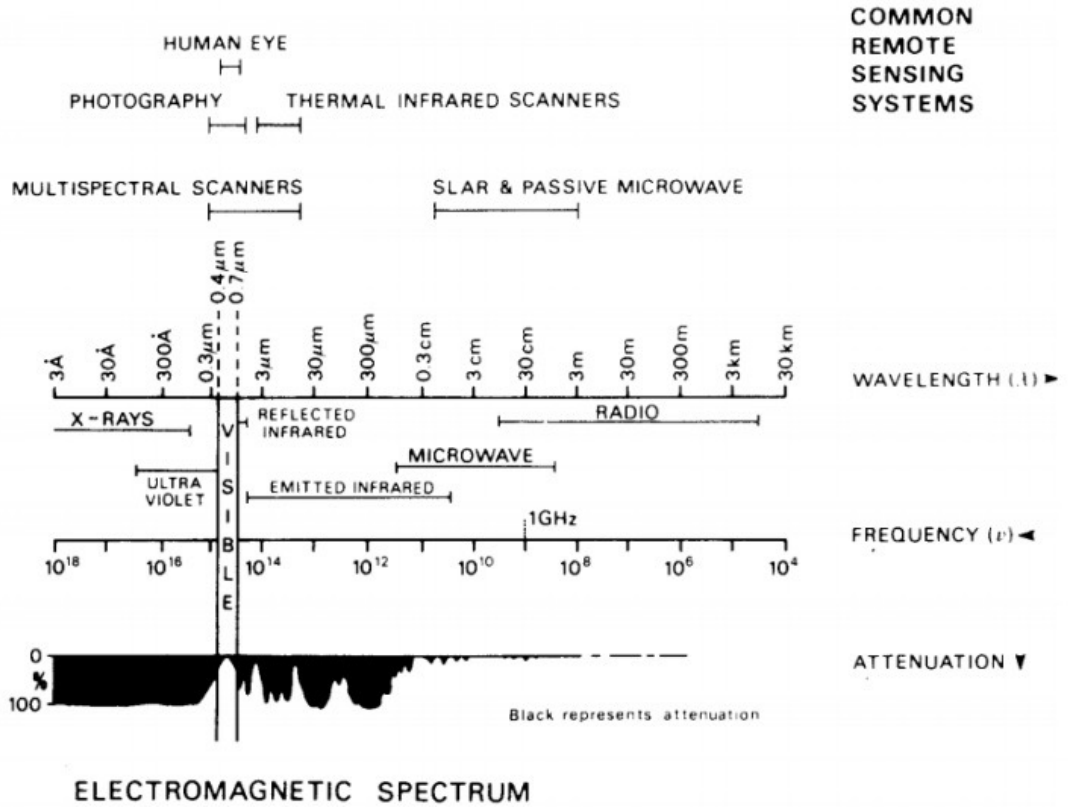
- The basics of Optical Remote Sensing
- The main characteristics of Sentinel-2 data
- The basics of radiometric indices and biophisical variables and their usage for agriculture
- Main features of SNAP software
- How to use SNAP to preprocess Sentinel-2 data and calculate radiometric indices

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

The pre-processing chain includes all the steps needed to generate cloud-free surface reflectance products taking Top Of Atmosphere data an input. For each of the modules in the pre-processing chain, different methods and algorithms can be applied.

- Cloud Detection and Removal
- Atmospheric Correction
- Reprojection
- Resampling
- Co-Registration

Cloud Detection and Removal

A large portion of the Earth's surface is covered by clouds. Consequently, most Earth observation images in the visible spectrum 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 and Removal

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

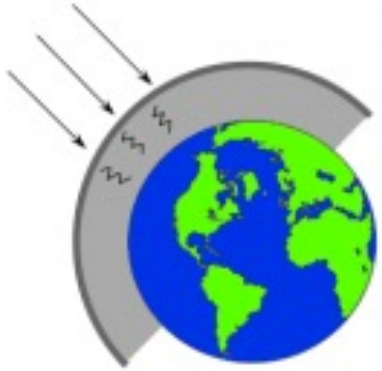
- **Spectral Threshold Methods:** Spectral characteristics, such as temperature, brightness, whiteness, or height of the scatterer are tested against a threshold value.
- **Feature Extraction and Classification:** The spectral data space, if transformed into a feature space, can be statically or dynamically 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 the 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:

A) Scattering

B) Absorption



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

Retrieval of Surface Reflectance

What's 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 inputs of the time series come from several sources with different coordinate reference systems (CRSs), the reprojection to a common CRS is needed.

Image Credit: Earth Lab

Reprojection, Resampling, and Co-Registration

Resampling:

Data coming from different sources could have different spatial resolutions. In these cases 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 loses 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.

Reprojection, Resampling, and Co-Registration

Co-Registration:

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

→ **1 pixel shift can drastically affect your results!**

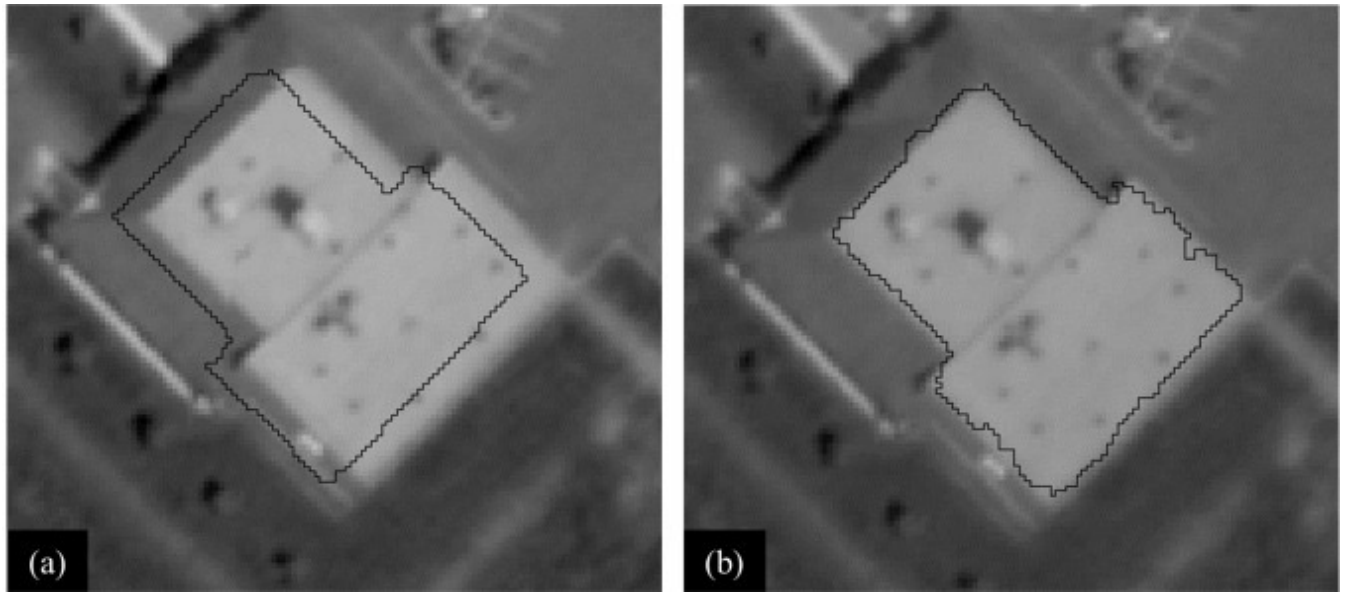


Image Credit: Jabari & Zhang

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 intervals between images.
- Time series of satellite observations offer opportunities:
  - For understanding how Earth is changing
  - For determining the causes of these changes
  - For predicting future changes

Why Use Time Series?

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 allow the identification of complex patterns concerning applications connected with environmental monitoring and analysis of land-cover dynamics.

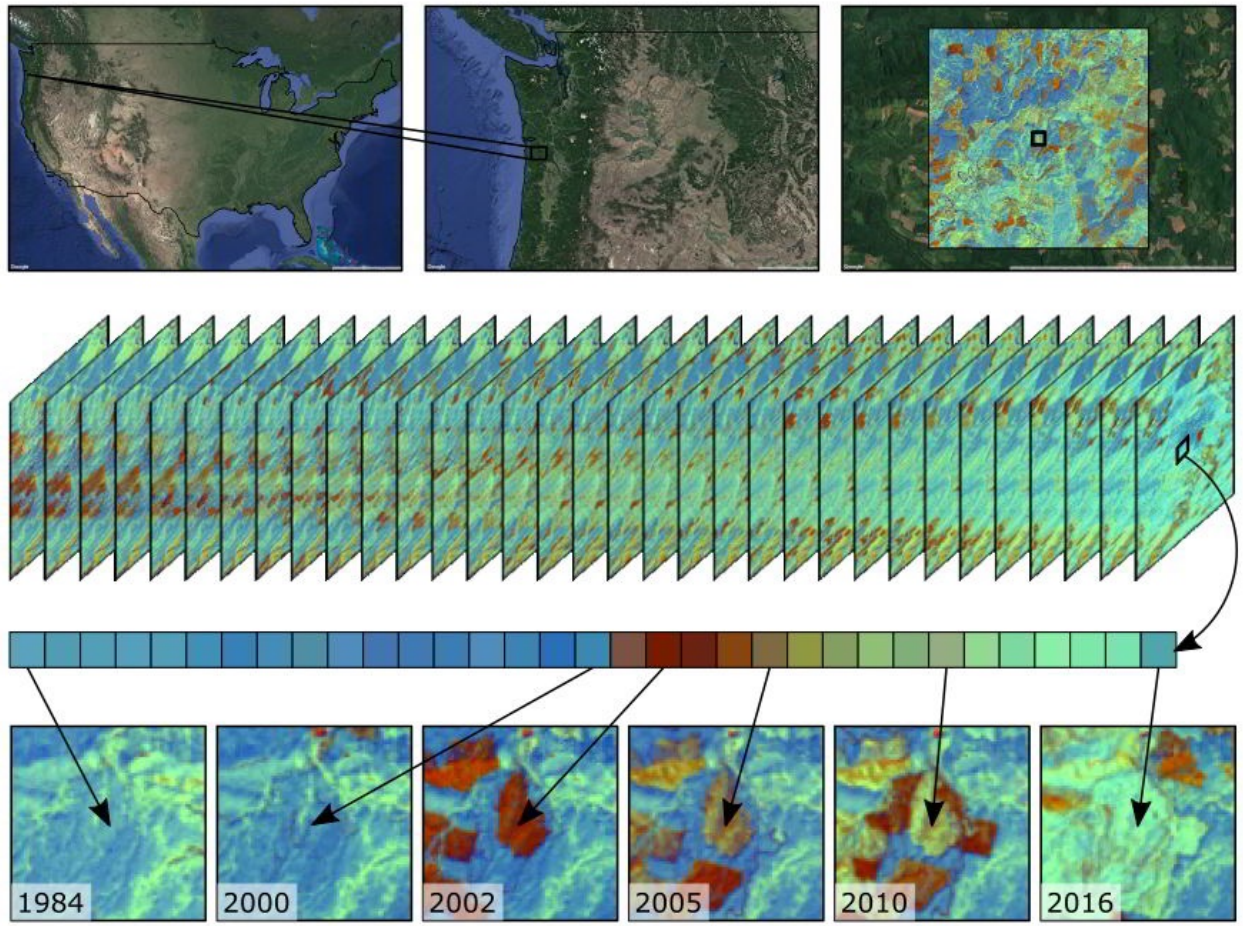


Image Credit: LandTrendr

Sentinel-2 Characteristics

Optical mission for the monitoring of land and coastal regions.

Main Features:

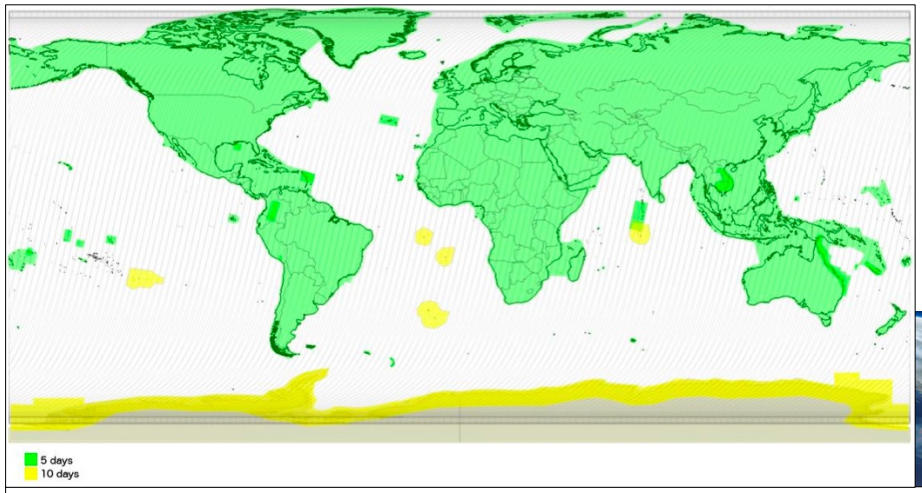
→ Constellation of two satellites (Sentinel-2A and Sentinel-2B)

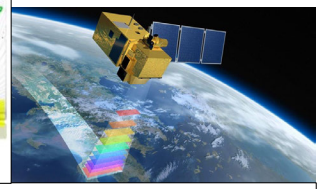
→ Multi-Spectral Instrument (MSI)

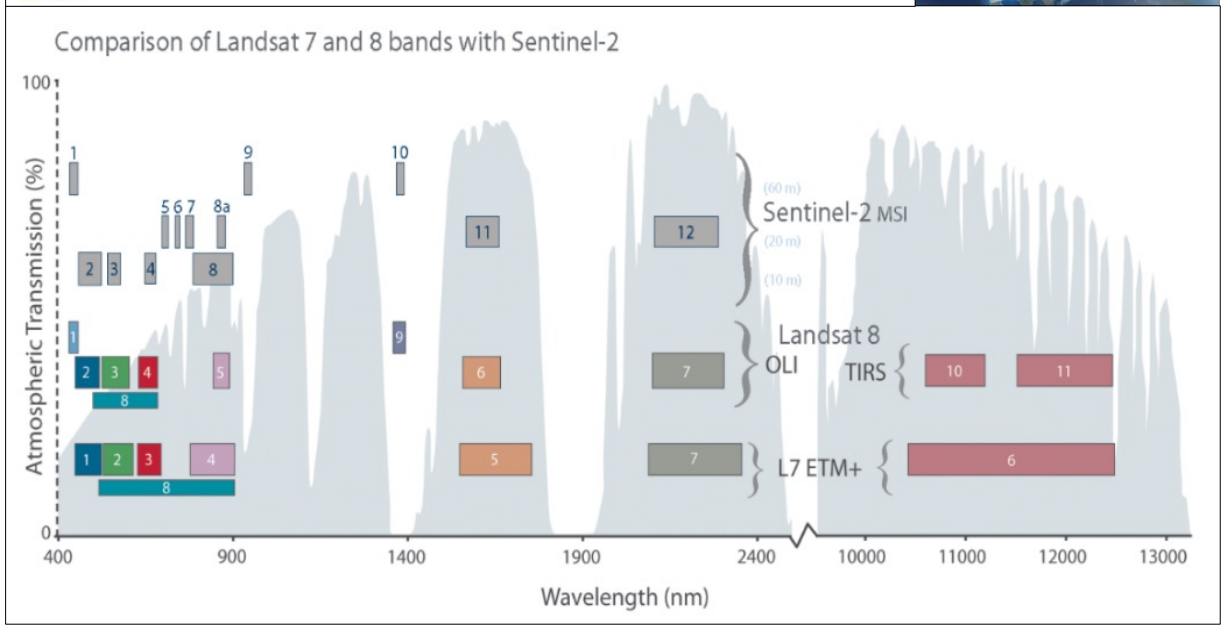
→ Polar, sun-synchronous orbit at 786km and LTDN 10h30

→ 10 days repeat cycle (5 days with both Sentinels 2A and 2B operational)

→ Swath of 290km





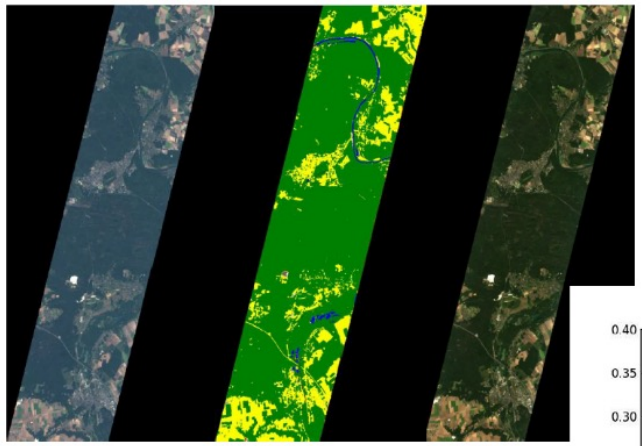


Sentinel-2 Products

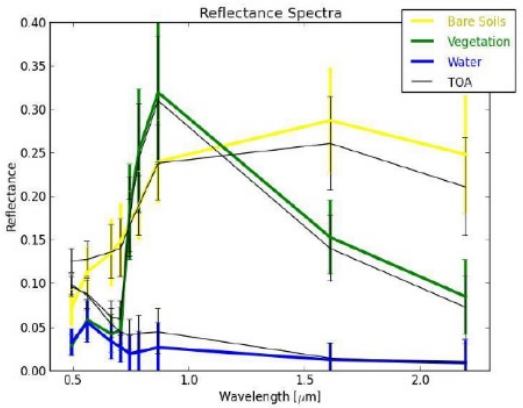
Sentinel-2 products available for users (either generated by the ground segment or by the SNAP) are:

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 other processors depending on 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

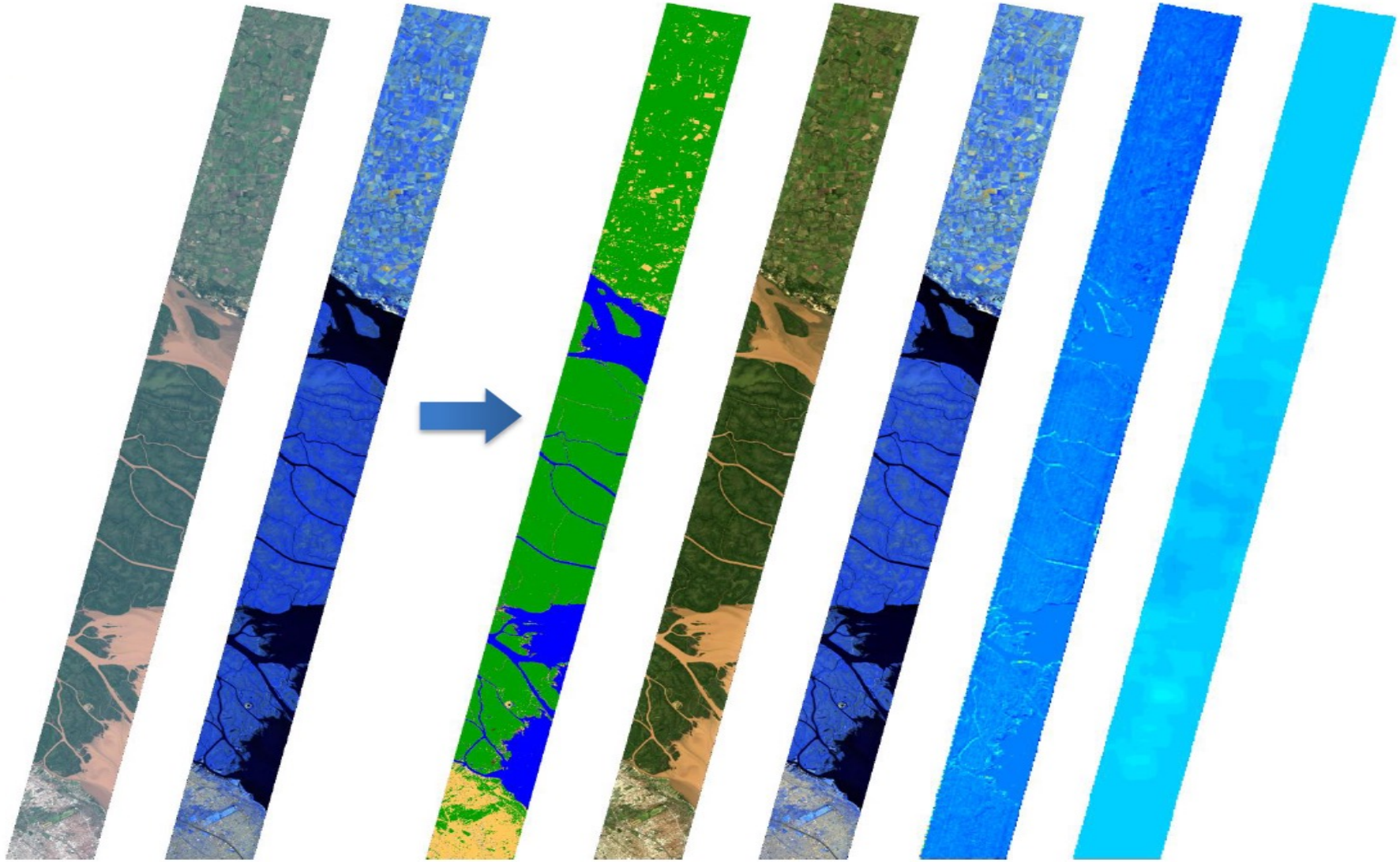
From left to right:

Level-1C [TOA]

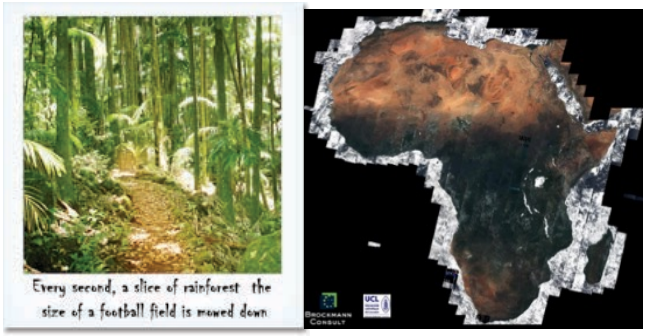
- *[RGB] B4-B3-B2*
- *[RGB] B12-B11-B8a*

Level-2A [BOA]

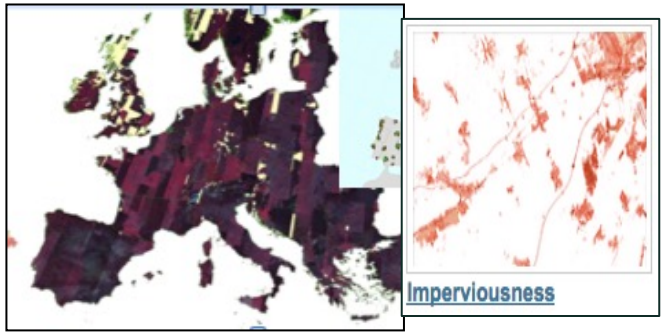
- *Scene Classification*
- *[RGB] B4-B3-B2*
- *[RGB] B12-B11-B8a*
- *Water Vapour*
- *Aerosols Optical Thickness*



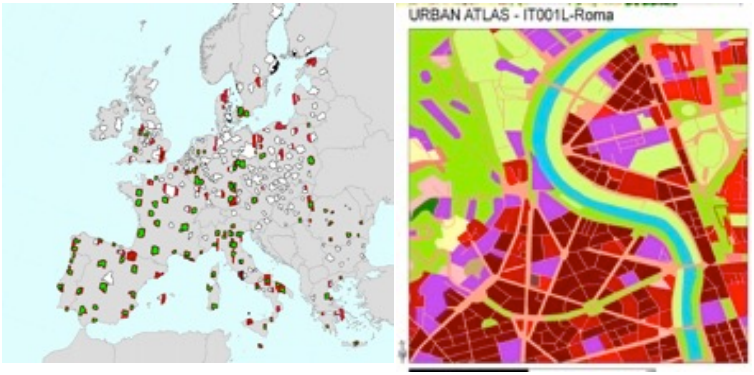
Sentinel-2 Applications



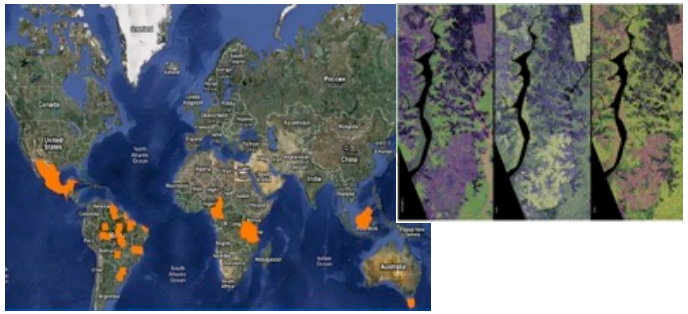
Agriculture, Forests & Carbon, Vegetation Monitoring



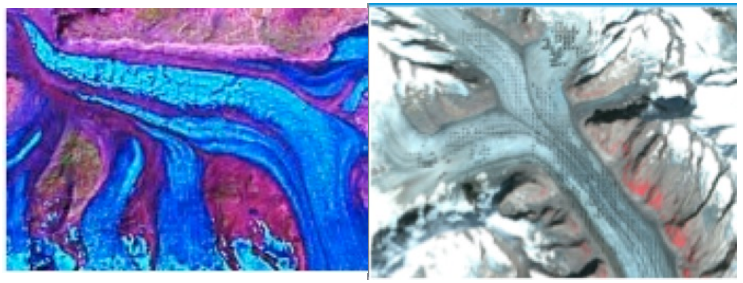
Land Cover Classification, High Resolution Layers, & Change



Regional to Urban Applications



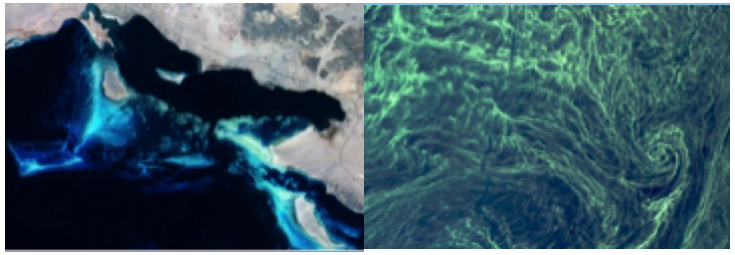
Emergency Management



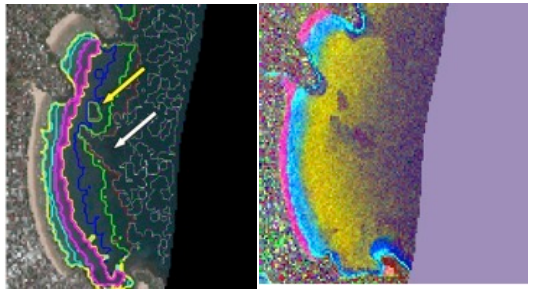
Glaciers & Ice

Global Land Use & Change

Geology



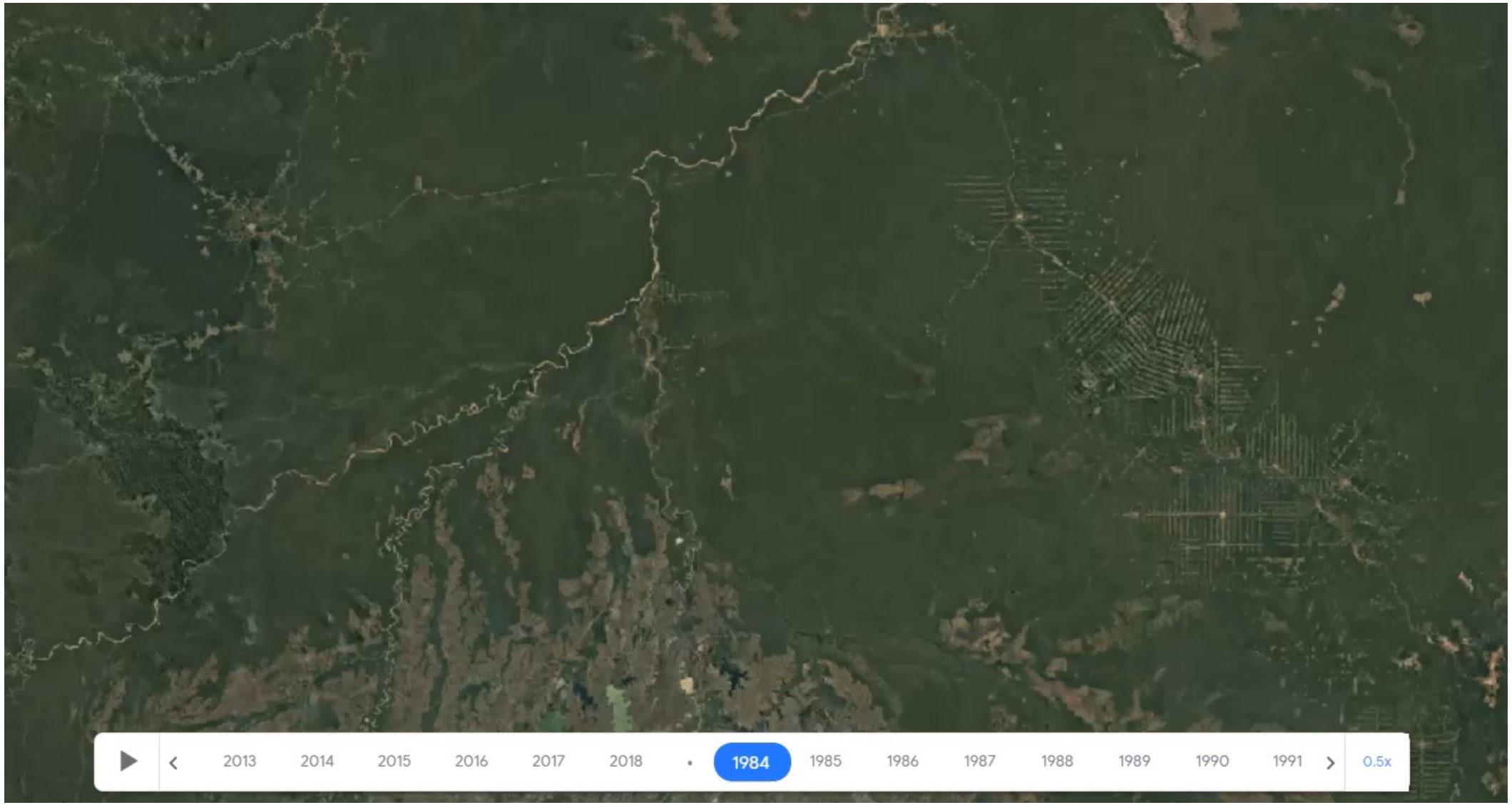
Water Quality



Coastal Zones/Bathymetry

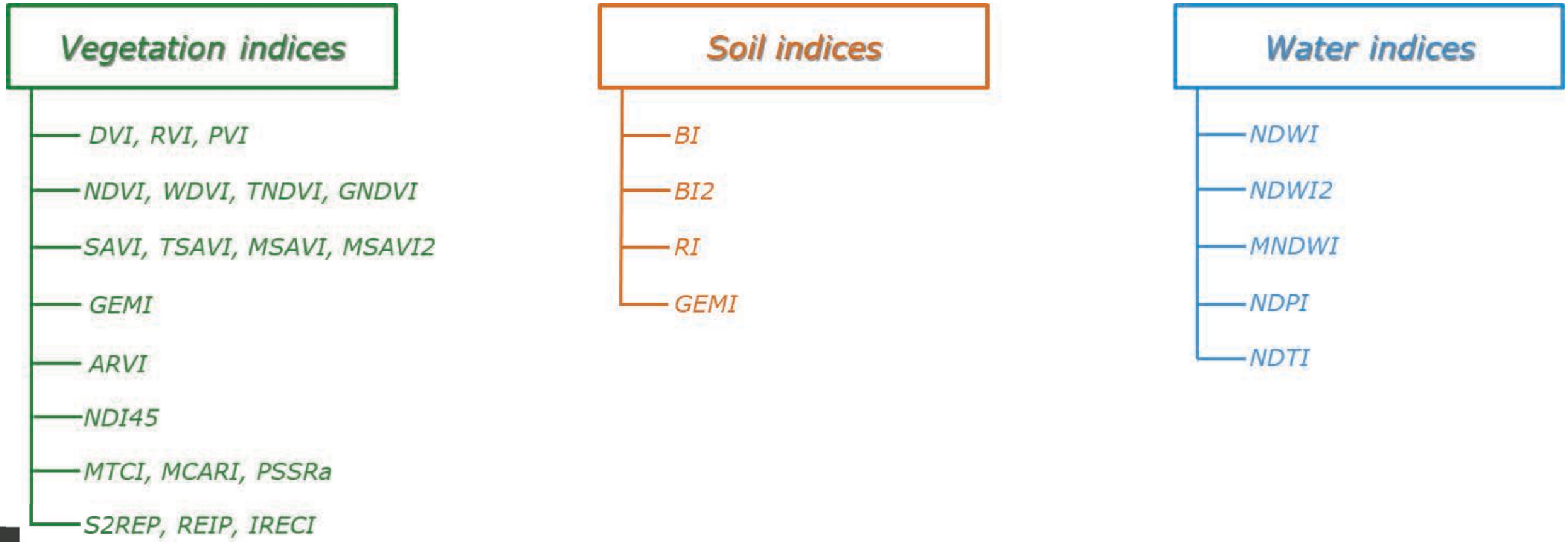
Theewaterskloof Dam Change by S2 Time Series

Rondônia Deforestation by Landsat Time Series



Radiometric Indices

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

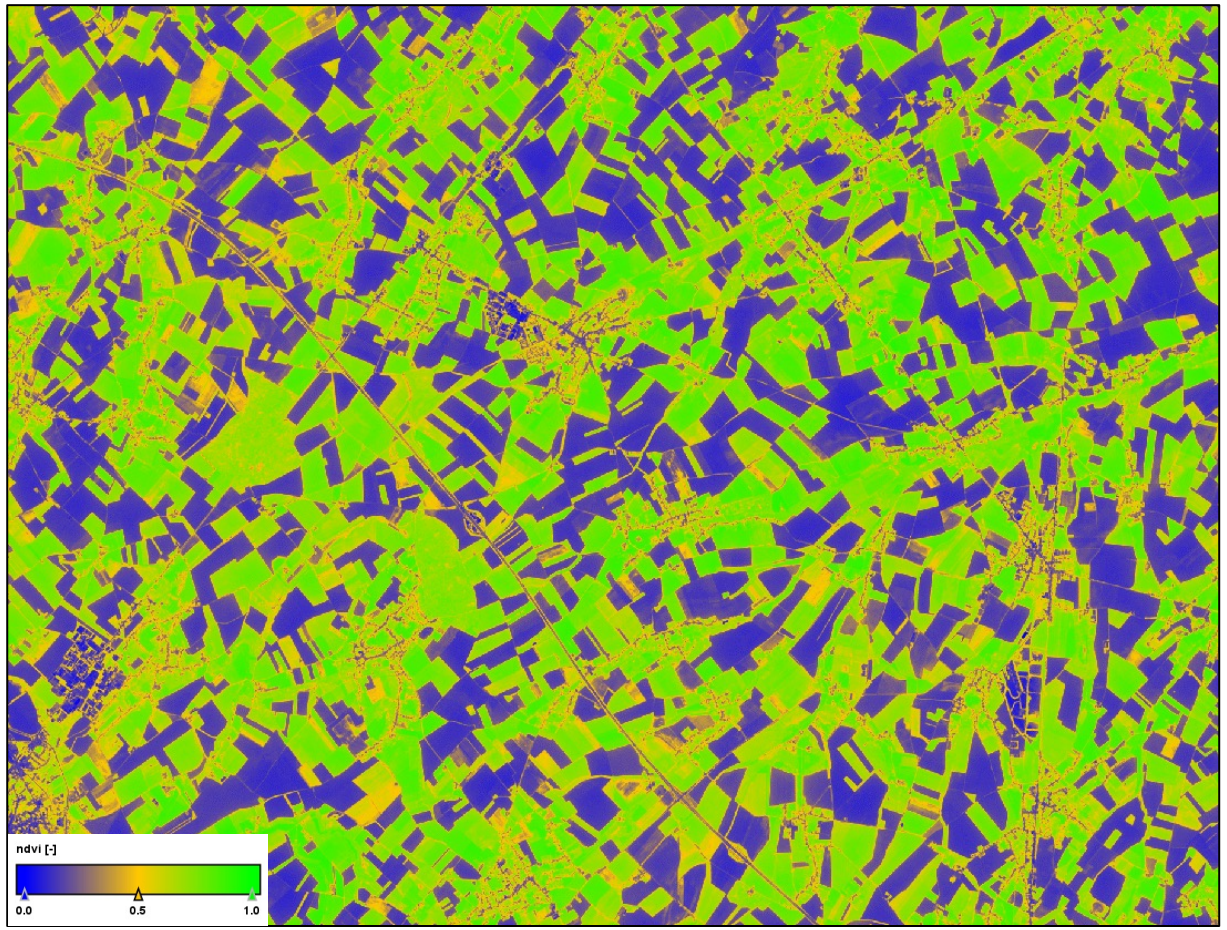


Radiometric Indices (e.g., NDVI)

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 heavily used to estimate the health of green vegetation and post-processed, high-definition images for precision agriculture.

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

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

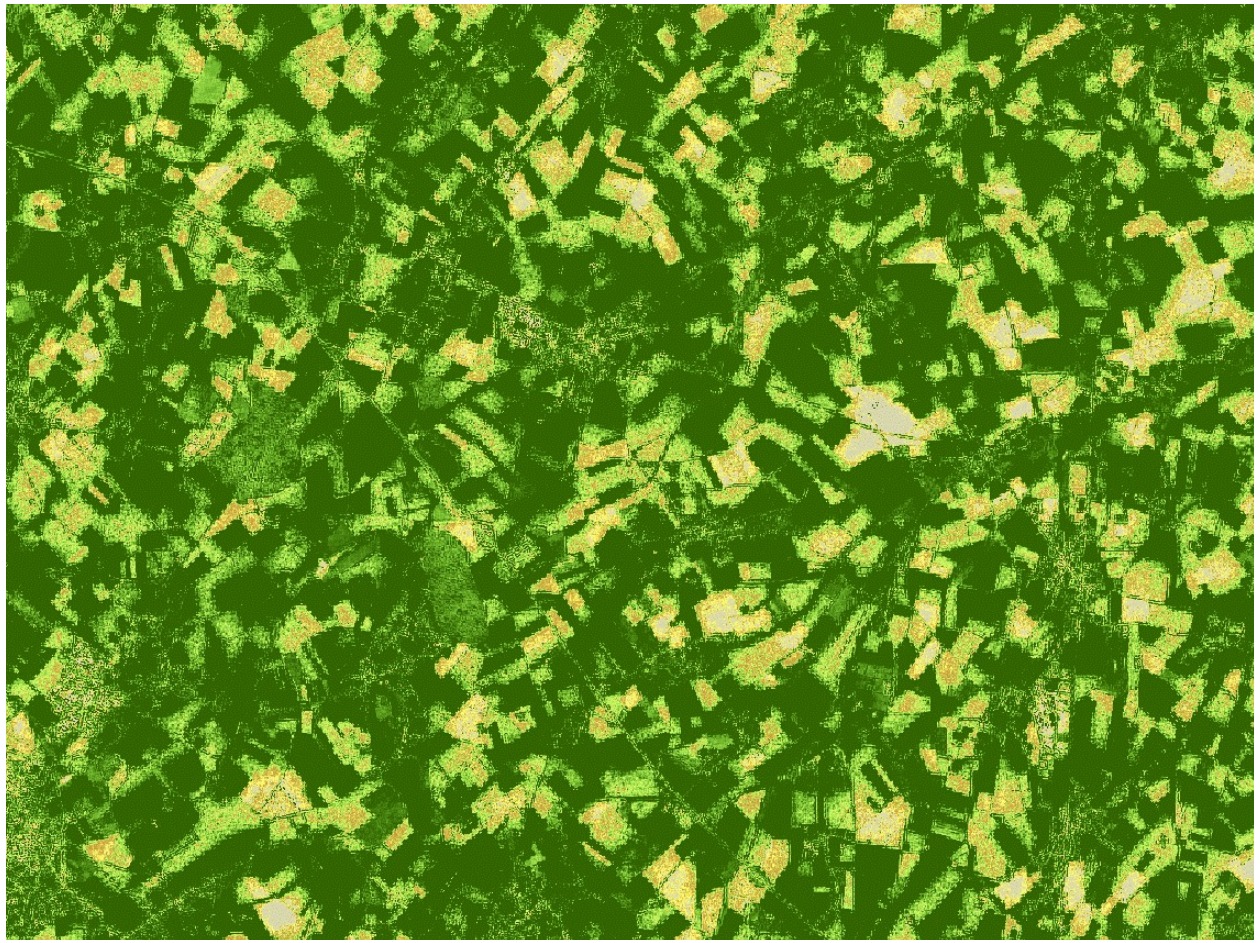


Radiometric Indices (e.g., S2REP)

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 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 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 global crop monitoring and food security applications; forest, water, and natural resources management; land carbon modelling; and weather and climate forecasting.

- **LAI** - Leaf Area Index

  Leaf Area Index is defined as half the total area of the green elements of the canopy per unit of 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

  FAPAR quantifies the fraction of solar radiation absorbed by living leaves for photosynthetic activity. Then, it refers only to the green and living 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 the ground covered by green vegetation. Practically, it quantifies the spatial extent of the vegetation. Because it is independent from the illumination direction and 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

  Chlorophyll content is a very good indicator of stress, 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 of 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]

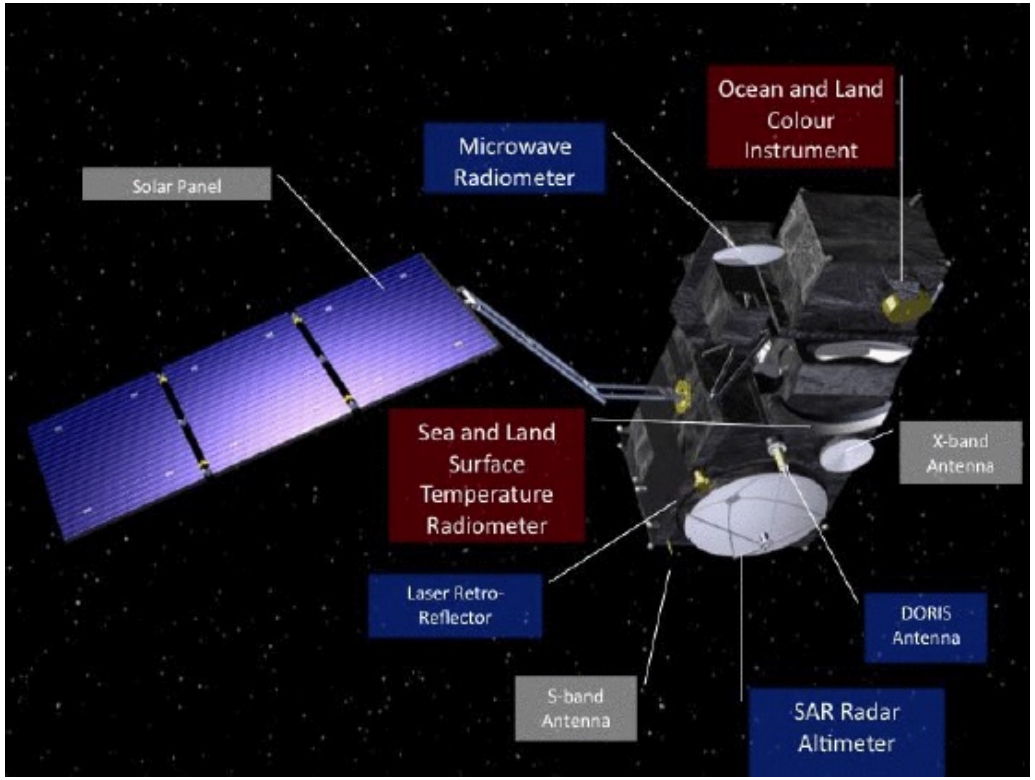
Sentinel-3 Characteristics

SENTINEL-3 is an ocean and land mission composed of two identical polar orbiting satellites, separated by 180 deg. The mission provides data continuity for the ERS, ENVISAT, and SPOT satellites.

The SENTINEL-3 mission is jointly operated by ESA and EUMETSAT to deliver operational land and ocean observation services.

The spacecraft carries four main instruments:

- **OLCI:** Ocean and Land Colour Instrument
- **SLSTR:** Sea and Land Surface Temperature Instrument
- **SRAL:** SAR Radar Altimeter
- **MWR:** Microwave Radiometer.



Main Features:

- Constellation of two satellites (Sentinel-3A and Sentinel-3B)
- Resolution and Swath Width:

OLCI – 1270km (FR: 300m; RR: 1.2km)

SLSTR – Dual view swath (1420km for nadir view and 740km width for oblique view defined at 55°) (VIS/NIR/SWIR 500m; TIR: 1km)

- Polar, sun-synchronous orbit at 814.5km and LTDN 10h00

Sentinel-3 OLCI Level 2 Land Products

The OLCI (Ocean and Land Colour Instrument) Level-2 Land Reduced (OL_2_LRR) or Full (OL_2_LFR) Resolution products are outputs from the OLCI Level-2 processor and contain land and atmospheric geophysical products at Full and Reduced resolutions.

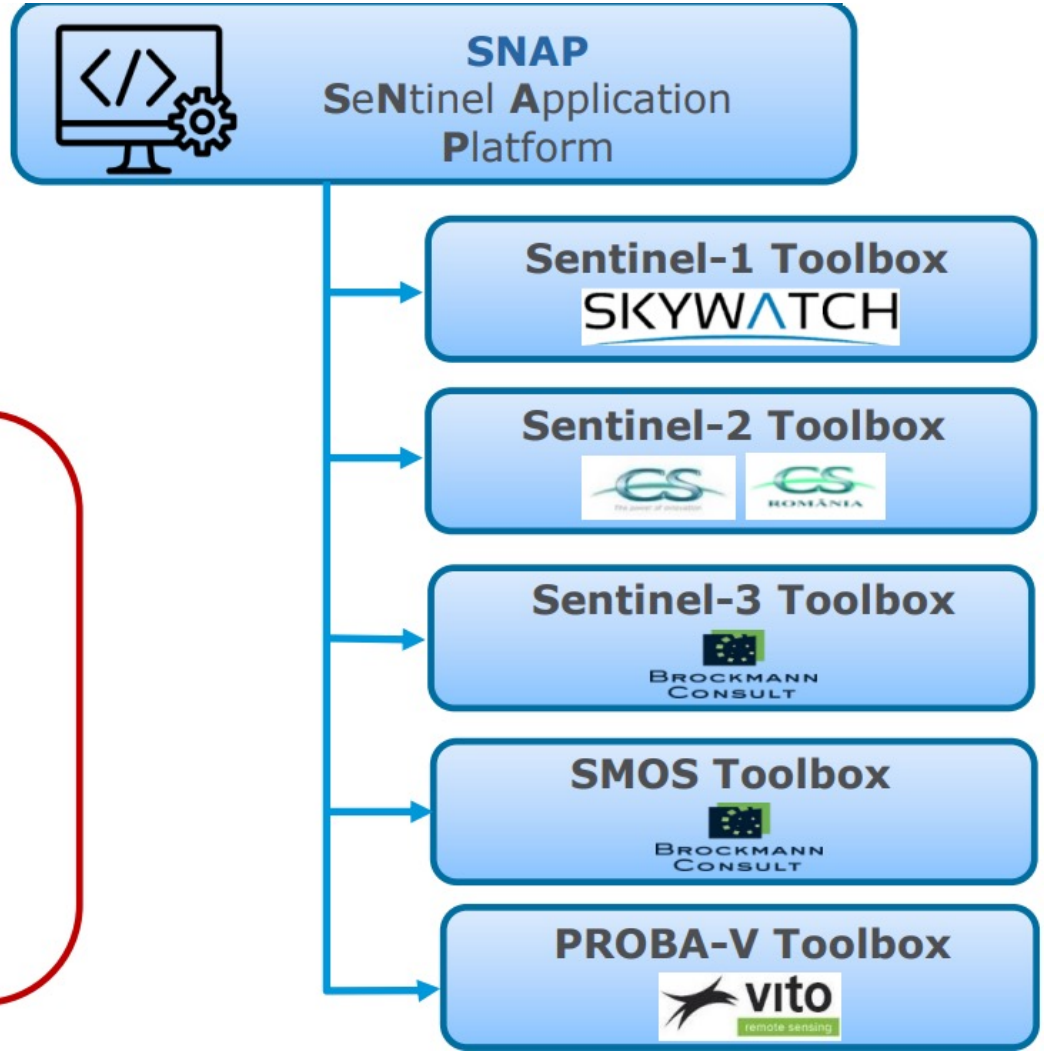
Variables	Description	Units	Input Bands
OLCI Global Vegetation Index (OGVI)	Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) in the plant canopy	Dimensionless	Oa03, Oa10, Oa17
OLCI Terrestrial Chlorophyll Index (OTCI)	Estimates of the Chlorophyll content in terrestrial vegetation, aims at monitoring vegetation condition and health	Dimensionless	Oa10, Oa11, Oa12
Integrated Water Vapour (IWV)	Total amount of water vapour integrated over an atmospheric column	$kg.m^{-2}$	Oa18, Oa19
RC681 and RC865	By-products of the OGVI, the so-called red and NIR rectified reflectances are virtual reflectance largely decontaminated from atmospheric and angular effects, and good proxy to Top of Canopy reflectances.	Dimensionless	Oa10, Oa17

Introduction to Data Processing with SNAP

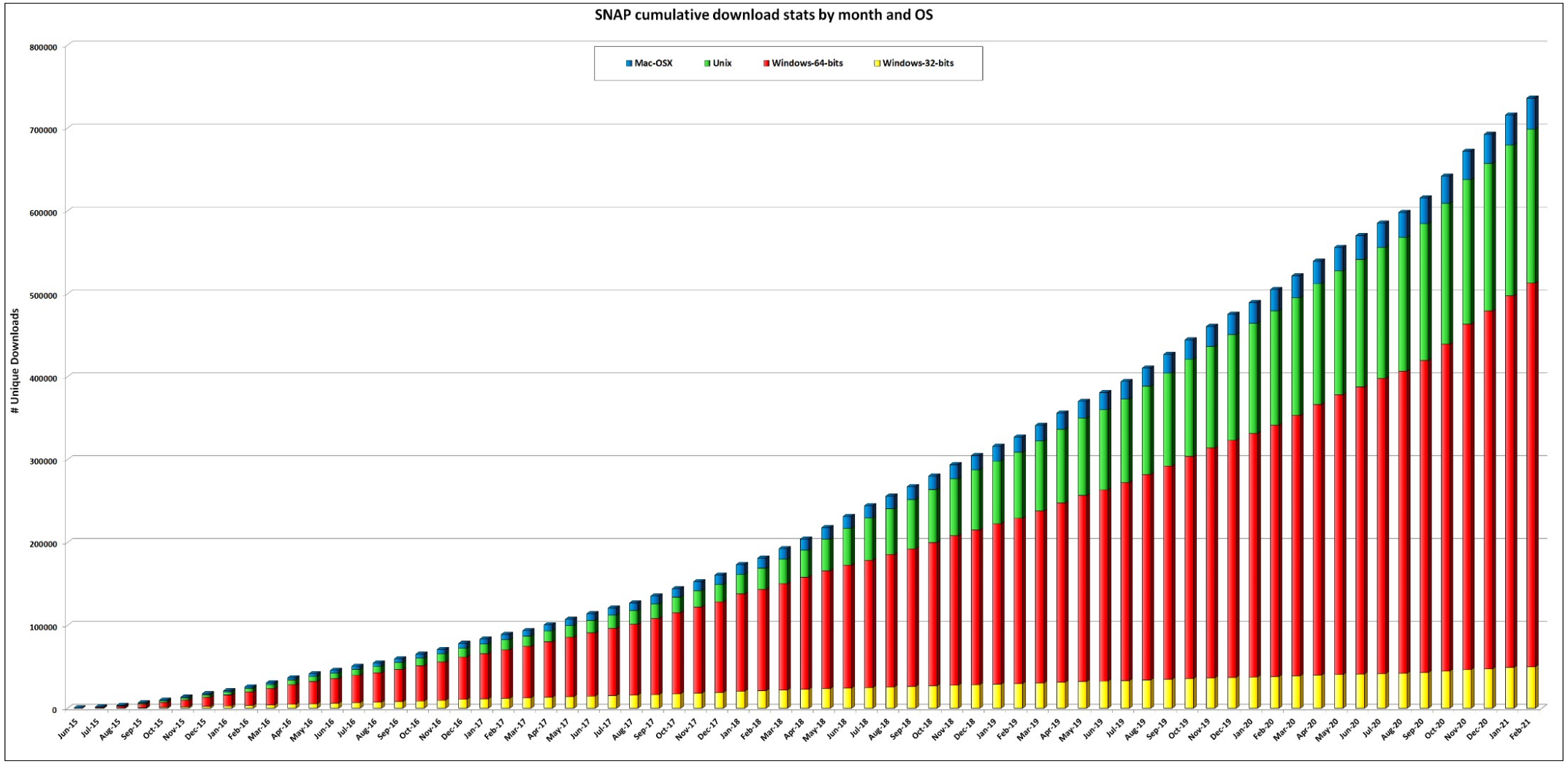
SNAP – SeNtinel Applications Platform

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



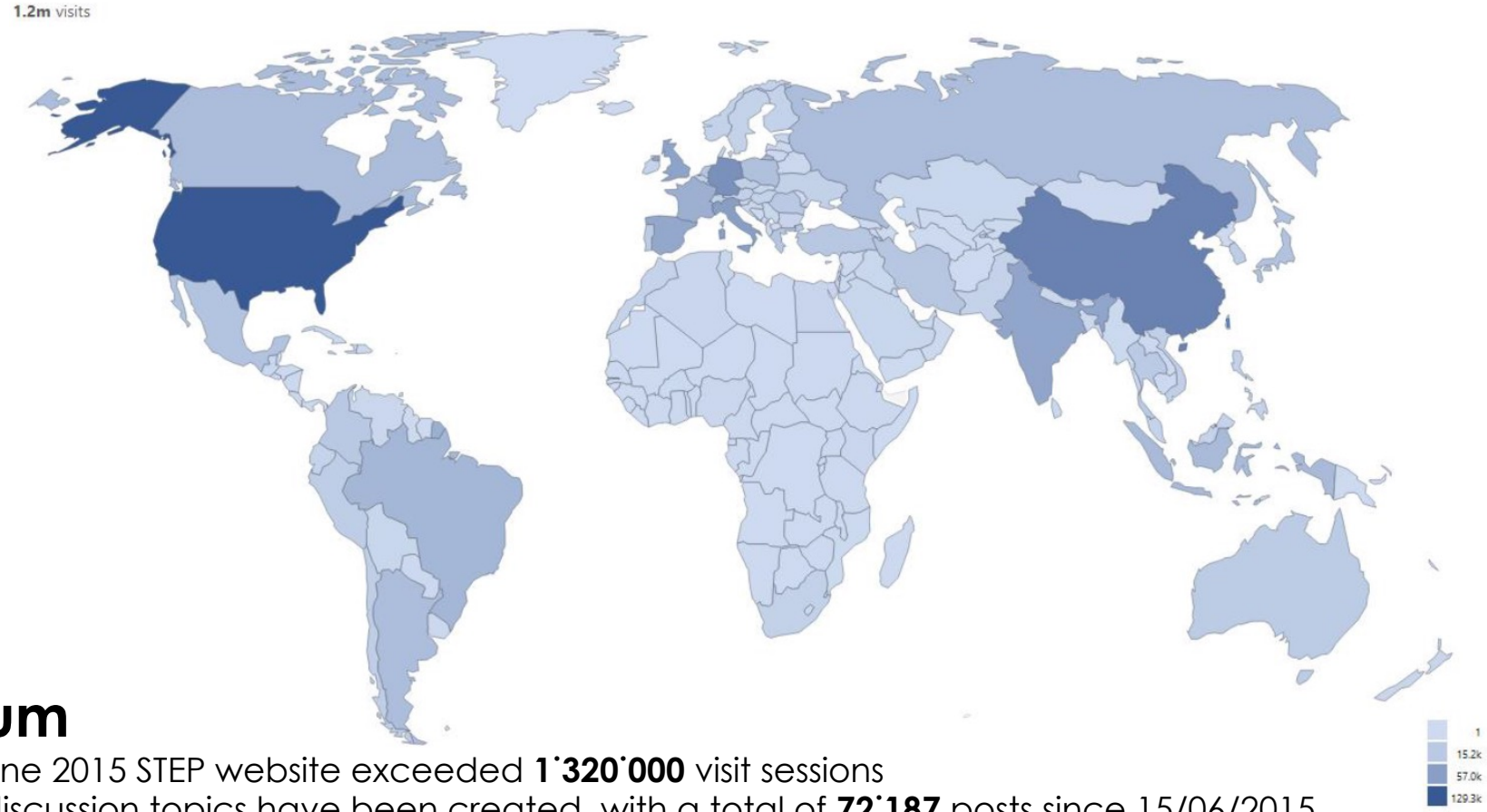
SNAP – SeNtinel Applications Platform



SNAP download exceeded 820'000 from June 2015 until today

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, and providing tutorials and material for training scientists using the Toolboxes.



STEP Forum

- ✓ Since June 2015 STEP website exceeded **1˙320˙000** visit sessions
- ✓ **10˙538** discussion topics have been created, with a total of **72˙187** posts since 15/06/2015
- ✓ During July 2021, **154** new users on the forum, with **577** "active/reading users" and **206** "posting users"

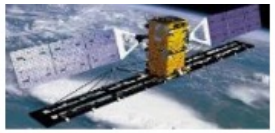
SNAP & SAR (Sentinel-1 Toolbox)

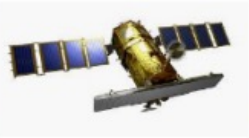

Sentinel-1


ENVISAT

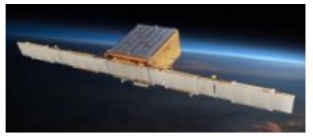

ERS-1

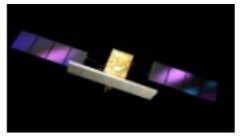

TerraSAR-X


RADARSAT


KOMPSAT-5


ALOS 1&2


ICEYE


COSMO-SkyMed

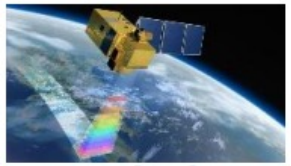
Main Features:

- Absolute calibration, Speckle filtering, Precise orbits handling
- Coregistration of detected and complex products
- Full support of Sentinel-1 TOPS interferometry, debursting, slice assembly
- Terrain Correction

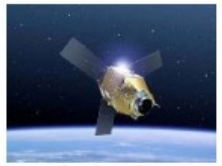
Compatibility with PolSARpro Toolbox (Reader, Writer)
Integrated Export to SNAPHU (interferometric phase unwrapping) and STAMPS (PS InSAR)

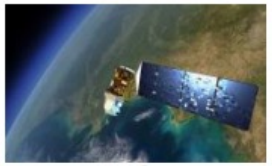
Applications:
Agriculture monitoring, ice and marine/land monitoring, mapping in support of humanitarian aid in crisis situations, oil spill detection, ship detection, wind field estimation, etc.

SNAP & Optical HR (Sentinel-2 Toolbox)


Sentinel-2


SPOT


Pleiades


Landsat


ALOS AVNIR


RapidEye


Kompsat


Ikonos


Worldview

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Main Features:

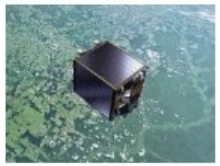
- Sen2Cor and i-Cor for Atmospheric Correction
- L2B biophysical processor (LAI, fAPAR, …)
- Reflectance to Radiance Processor
- Radiometric Indices
  - Vegetation Indices: DVI, RVI, PVI, IPVI, WDVI, TNDVI, GNDVI, GEMI, ARVI, NDI45, MTCI, MCARI, REIP, S2REP, IRECI, PSSRa
  - Soil Indices: SAVI, TSAVI, MSAVI, MSAVI2, BI, BI2, RI, CI
  - Water Indices: NDWI, NDWI2, MNDWI, NDPI, NDTI
- IdePix Processor: Pixel Classification

SNAP & Optical/Thermal MR (Sentinel-3 Toolbox)

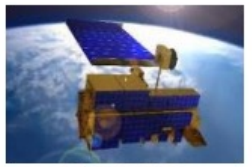

Sentinel-3


ENVISAT

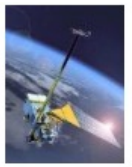

ERS


Proba-V


SPOT VGT


MODIS


AVHRR


VIIRS

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Main Features:

- Visualizing spectrum of pixels
- Pixel extraction tool
- Specific S3 and Envisat sensor processors
- 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

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

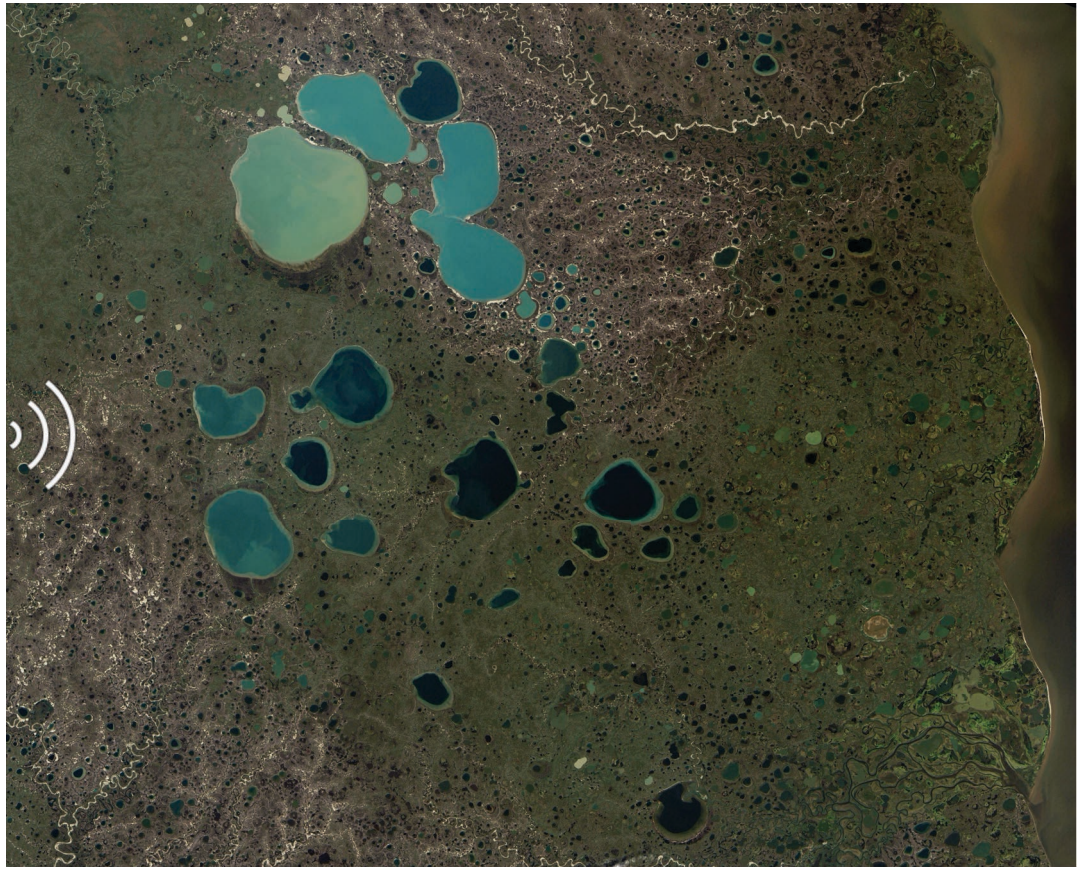
The Batch Processing tool allows you to execute a single reader/writer graph for a set of products.

Time Series Analysis

The Time series tool allows the user to analyse the trend of the retrieved biophysical variables or radiometric indices for a stack of data

Questions?

- Please enter your questions in the Q&A box. We will answer them in the order they were received.
- We will post the Q&A to the training website following the conclusion of the webinar.



https://earthobservatory.nasa.gov/images/6034/pothole-lakes-in-siberia

Contacts

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- Training Webpage:
  - https://appliedsciences.nasa.gov/join-mission/training/english/arset-agricultural-crop-classification-synthetic-aperture-radar-and
- ESA's EO4Society Website:
  - https://eo4society.esa.int/training-education/
- Twitter: @EOOpenScience


Thank You!